TN Blount County QL2 LiDAR

Report Produced for U.S. Geological Survey

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Executive Summary

The primary purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the Blount County Tennessee 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 7000ft by 4000ft. A total of 526 tiles were produced for the project encompassing an area of approximately 435 sq. miles.

THE PROJECT TEAM

Dewberry served as the prime contractor for the project. The Atlantic Group was contracted and responsible for the acquisition, survey, LAS classification, all LiDAR products, breakline production, and Digital Elevation Model (DEM) production. Dewberry then performed a Macro QC on the finished Data.

The Atlantic Group completed ground surveying for the project and delivered surveyed checkpoints. Their task was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. They also verified the GPS base station coordinates used during LiDAR data acquisition to ensure that the base station coordinates were accurate. Please see Appendix A to view the separate Survey Report that was created for this portion of the project.

SURVEY AREA

The project area addressed by this report falls within the project area encompassing Blount County, Tennessee.

DATE OF SURVEY

The LiDAR aerial acquisition was conducted between March 22, 2015 and March 29, 2015.

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: Tennessee State Plane (FIPS 4100)
Units: Horizontal units are in U.S. Survey Feet, Vertical units are in U.S. Survey feet.
Geoid Model: Geoid12A (Geoid 12A was used to convert ellipsoid heights to orthometric heights).

LIDAR VERTICAL ACCURACY

For the Blount County TN LiDAR Project, the tested $RMSE_z$ of the classified LiDAR data for checkpoints in non-vegetated terrain equaled **0.28 ft** compared with the 0.33 ft specification; and the NVA of the classified LiDAR data computed using $RMSE_z$ x 1.9600 was equal to **0.55 ft**, compared with the 0.64 ft specification.

For the Blount County TN LiDAR Project, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to **0.63 ft,** compared with the 0.96 ft specification.

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

PROJECT DELIVERABLES

The deliverables for the project are listed below.

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

PROJECT TILING FOOTPRINT

Five hundred twenty six (526) tiles were delivered for the project. Each tile's extent is 7,000 feet by 4,000 feet (see Appendix B for a complete listing of delivered tiles).

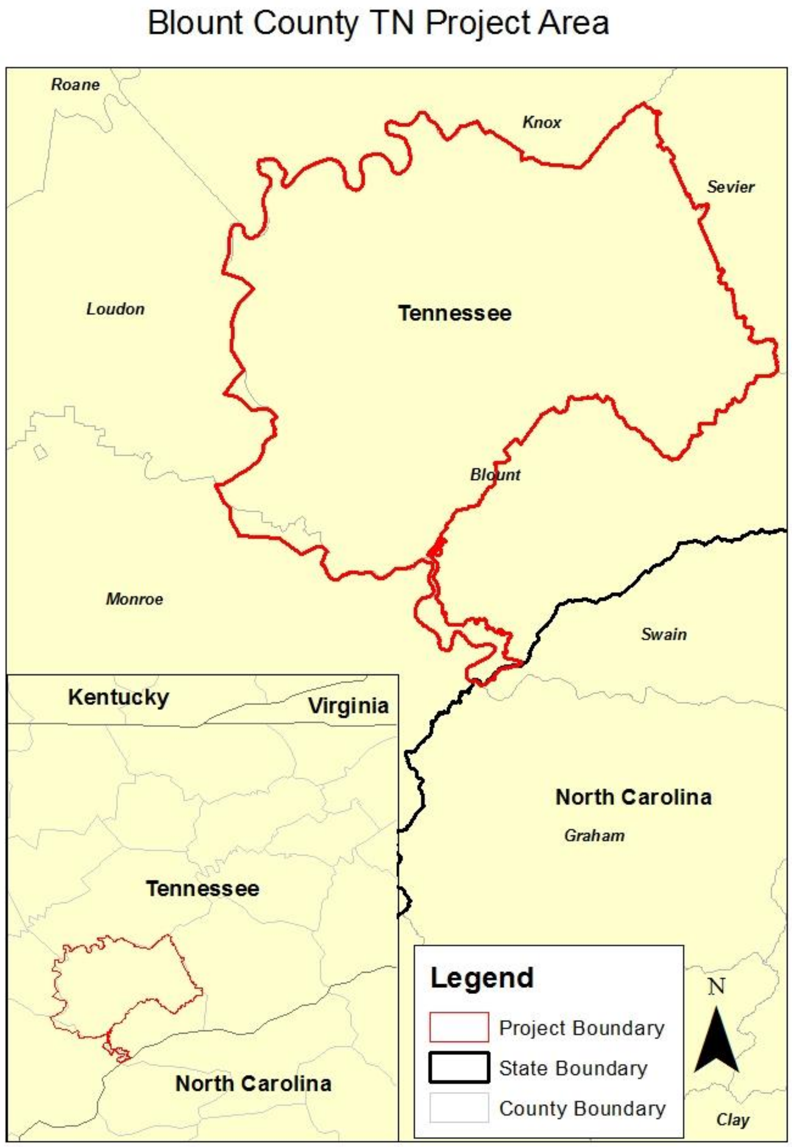

Figure 1 - Project Map

LiDAR Acquisition Report

Dewberry elected to subcontract the LiDAR Acquisition and Calibration activities to The Atlantic Group. The Atlantic Group was responsible for providing LiDAR acquisition, calibration and all deliverables to Dewberry.

Dewberry received calibrated swath data from The Atlantic Group on June 9, 2015

LIDAR ACQUISITION DETAILS

Atlantic acquired forty eight (48) passes of the AOI as a series of perpendicular and/or adjacent flight lines. The flight plan included zigzag flight line collection as a result of the inherent IMU drift associated with all IMU systems. At least two (2) GPS reference station(s) were in operation during all missions, sampling positions at 1 Hz or higher frequently. Differential GPS baseline lengths did not exceed 40 km, unless otherwise approved. Differential GPS unit in aircraft recorded sample positions at 2 Hz or more frequently. LiDAR data was only acquired when GPS PDOP was ≤ 4 and at least 6 satellites were in view.

Atlantic monitored weather and atmospheric conditions and conducted LiDAR missions only when conditions existed that would not degrade sensor ability in the collection of data. These conditions included no snow, rain, fog, smoke, mist and/or 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. Atlantic 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, Atlantic 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. Atlantic LiDAR sensors are calibrated at a designated site located at the Fayetteville Municipal Airport (FYM) in Fayetteville, TN and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Atlantic operated a Partenavia S.P.A. P 68 C/TC (N775MW) outfitted with a Leica ALS70-HP LiDAR system during the collection of the study area. Table 1 illustrates The Atlantic Group system parameters for LiDAR acquisition on this project.

Lidar System Acquisition Parameters	
Item	**Parameter**
System	Leica ALS-70 HP
Nominal Pulse Spacing (m)	0.6
Nominal Pulse Density (pls/m²)	2.5
Nominal Flight Height (AGL meters)	1144
Nominal Flight Speed (kts)	125

Pass Heading (degree)	90
Sensor Scan Angle (degree)	45
Scan Frequency (Hz)	34.5
Pulse Rate of Scanner (kHz)	265.6
Line Spacing (m)	884
Pulse Duration of Scanner (ns)	4
Pulse Width of Scanner (m)	0.46
Central Wavelength of Sensor Laser (nm)	1064
Sensor Operated with Multiple Pulses	Yes
Beam Divergence (mrad)	0.15
Nominal Swath With (m)	1657
Nominal Swath Overlap (%)	20
Scan Pattern	Triangle

Table 1: The Atlantic Group 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 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.

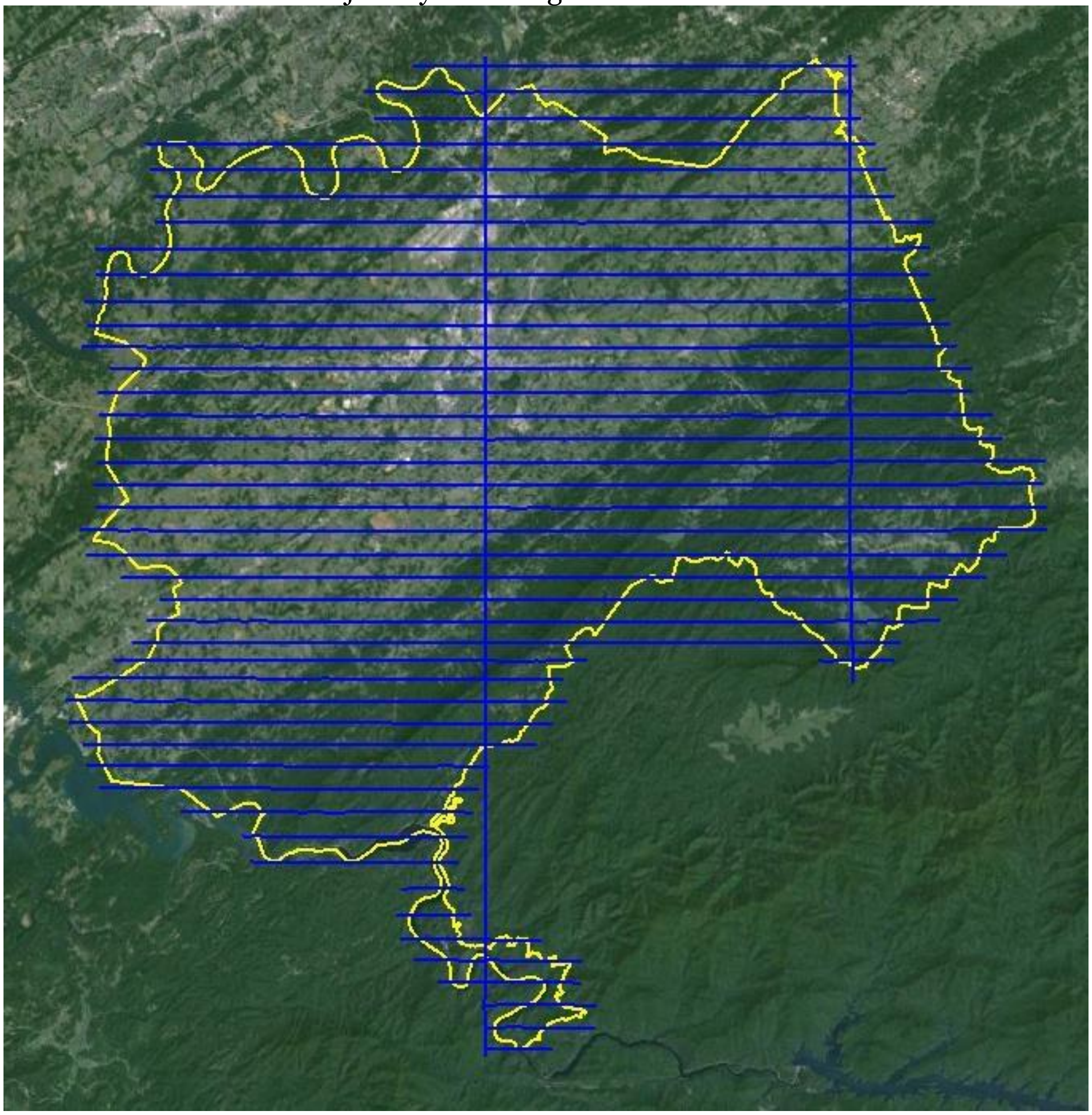

Figure 2: Trajectories as flown by The Atlantic Group

LIDAR CONTROL

Twenty three (23) checkpoints were used by Atlantic to control the lidar acquisition for the Tennessee LiDAR project area. The coordinates of all used base stations are provided in the table below. All control and calibration points are also provided in shapefile format as part of the final deliverables.

GPS Reference Station Coordinates			
Designation	**Easting**	**Northing**	**Height (Ellipsoid Meters)**
CP02	2569395.5	551637.8125	964.4320068
CP03	2531378.5	549101.25	818.1920166
CP04	2532422.75	522438.5313	889.6140137
CP05	2524416	476995.9375	938.7299805
CP06	2616548	516012.0938	932.8150024
CP07	2630807.5	497405.5	1028.514038
CP08	2580369.75	523890.25	1048.215942
CP09	2565529.25	439864.9375	892.1380005
CP10	2540614	468746.0313	978.6209717
CP11	2554916.5	508009.5	1035.623047
CP12	2612510.5	542933	1038.729981
CP13	2557989.25	536402.125	928.4630127
CP14	2537833.75	505017.4688	949.4609985
CP15	2553561.25	486702.4063	979.5200195
CP16	2599276.25	543585.0625	899.8220215
CP17	2582487.75	498521.7813	1052.719971
CP18	2575184	470420.9375	1270.154053
CP19	2532524.25	490262.4688	872.367981
CP20	2566807.5	484660	1012.064026
D295	2535919.5	471039.75	904.8619995
GPS34V292	2565288.75	518326.875	1030.833984
LHT682	2592821.5	557256.125	1074.078003
SETPOINT	2565307.25	544380.5	953.492981

Table 2 – Base Stations used to control LiDAR acquisition

AIRBORN GPS KINEMATIC

Differential GPS unit in aircraft collected positions at 2 Hz. Airborne GPS data was processed using the Inertial Explorer (version 8.5.4320) software. Flights were flown with a minimum of 6 satellites in view (10° above the horizon) and with a PDOP of ≤4 when laser online. Distances from base station to aircraft were kept to a maximum of 40 km.

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

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

GPS processing results for each lift are included in Appendix C.

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

The initial step of calibration is to verify availability and status of all needed GPS and Laser data against field notes and compile any data if not complete. Subsequently, the mission points are output using Leica's CloudPro post processor with the most recent boresight values. The initial point generation for each mission calibration is verified within TerraScan using distance colored points to identify errors. If a calibration error greater than specification is observed within the mission, the roll, pitch and scanner scale corrections that need to be applied are calculated. Once validated each output mission is imported into the GeoCue software package. Here a project level supplementary coverage check is carried out to ensure no data voids unreported by Field Operations are present.

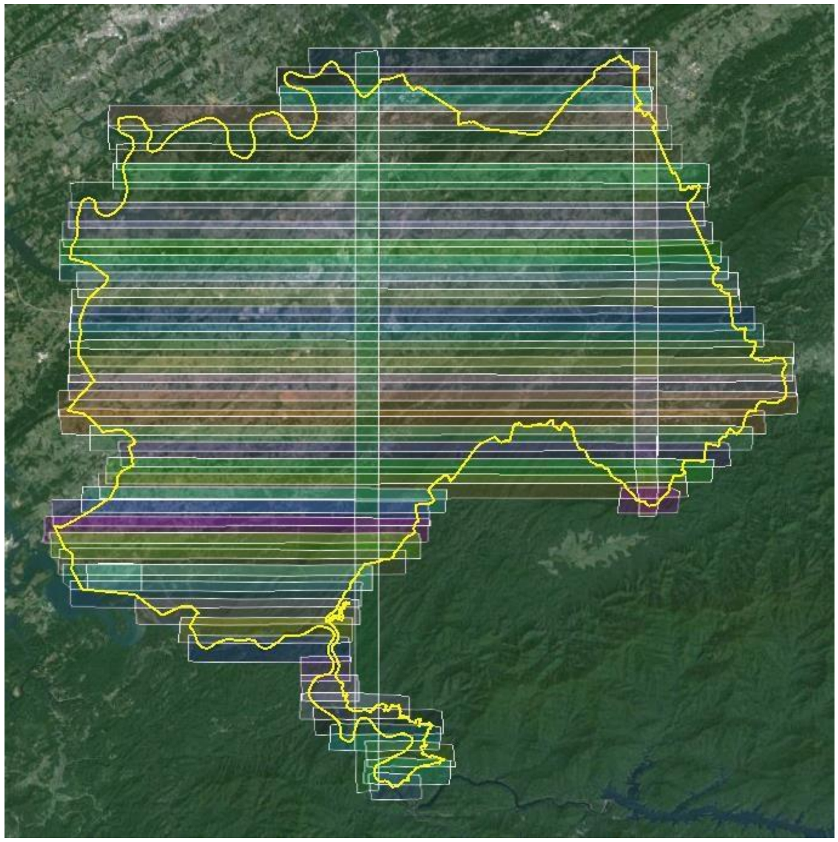

Figure 3 – LiDAR Swath output showing complete coverage.

BORESIGHT AND RELATIVE ACCURACY

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

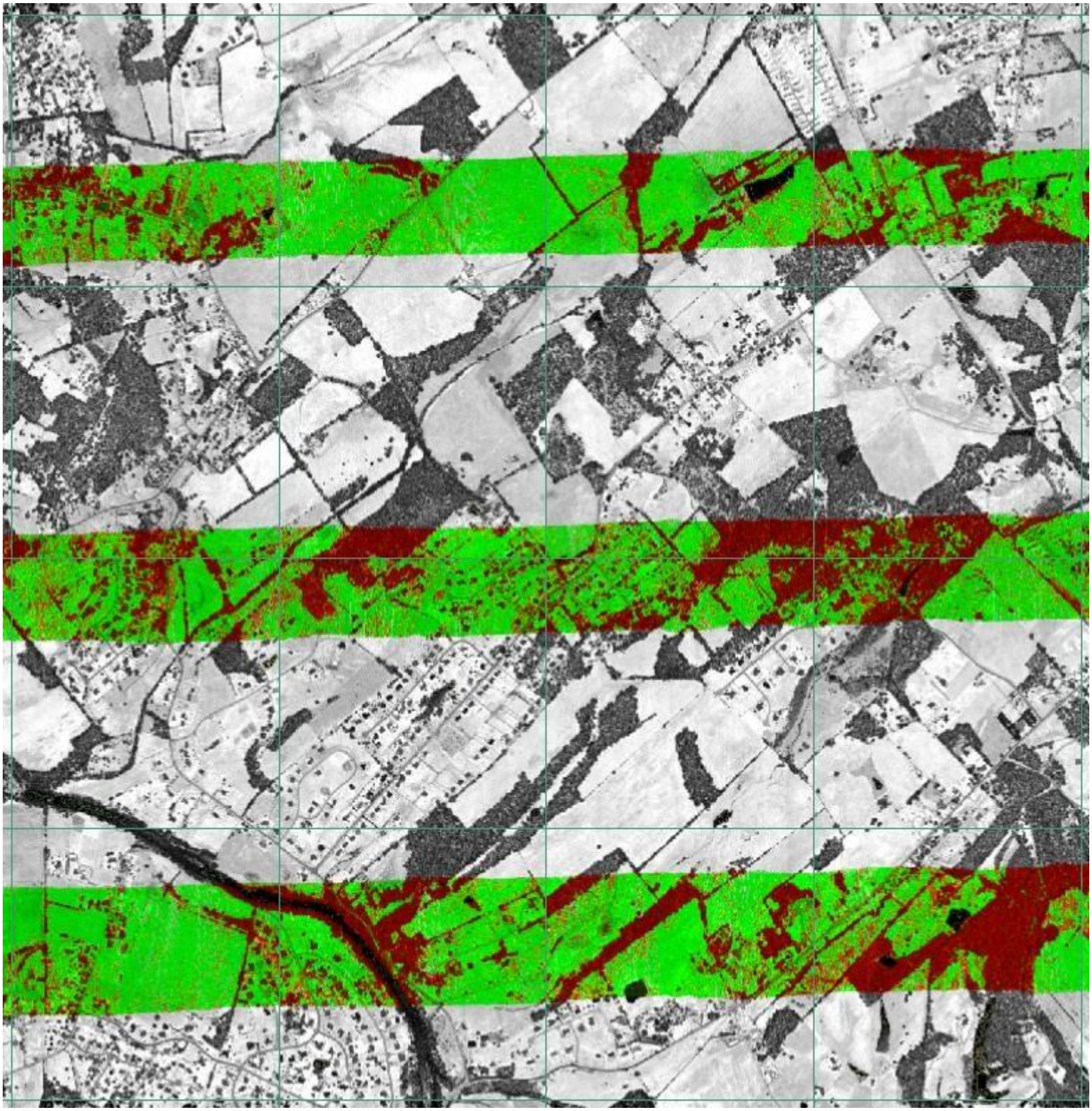

Figure 4 – Delta Z ortho sub-sample

LiDAR Processing & Qualitative Assessment

INITIAL PROCESSING

Once Dewberry receives the calibrated swath data from the acquisition provider, Dewberry performs several validations on the dataset. These validations include vertical accuracy of the swath data, 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.

Final Swath Vertical Accuracy Assessment

Once Dewberry received the calibrated swath data from The Atlantic Group, Dewberry tested the vertical accuracy of the non-vegetated terrain swath data prior to additional processing. Dewberry tested the vertical accuracy of the swath data using the thirty non-vegetated (open terrain and urban) independent survey check points. The vertical accuracy is tested by comparing survey checkpoints in non-vegetated terrain to a triangulated irregular network (TIN) that is created from the raw swath points. Only checkpoints in non-vegetated terrain can be tested against raw swath data because the data has not undergone classification techniques to remove vegetation, buildings, and other artifacts from the ground surface. Checkpoints are always compared to interpolated surfaces created from the LiDAR point cloud because it is unlikely that a survey checkpoint will be located at the location of a discrete LiDAR point. Project specifications require a NVA of (19.6 cm) 0.64 ft based on the $RMSE_z$ (10 cm or 0.33 ft) x 1.96. The dataset for the Blount County TN Project satisfies this criteria. This raw LiDAR swath data set was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm $RMSE_z$ Vertical Accuracy Class. Actual NVA accuracy was found to be $RMSE_z$ = 0.28 ft (8.53 cm), equating to +/- 0.54 ft (16.46 cm) at 95% confidence level. The table below shows all calculated statistics for the raw swath data.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) Spec=0.64 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Min (ft)	Max (ft)	Kurtosis
NVA	30	0.28	0.54	-0.07	-0.09	0.86	0.27	-0.50	0.58	0.44

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

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 QL2 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 -12 cm are colored yellow, and areas in the dataset where overlapping flight lines have elevation differences in each pixel greater than 12 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 12 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 Blount County are shown in the figure below; this project meets inter-swath relative accuracy specifications.

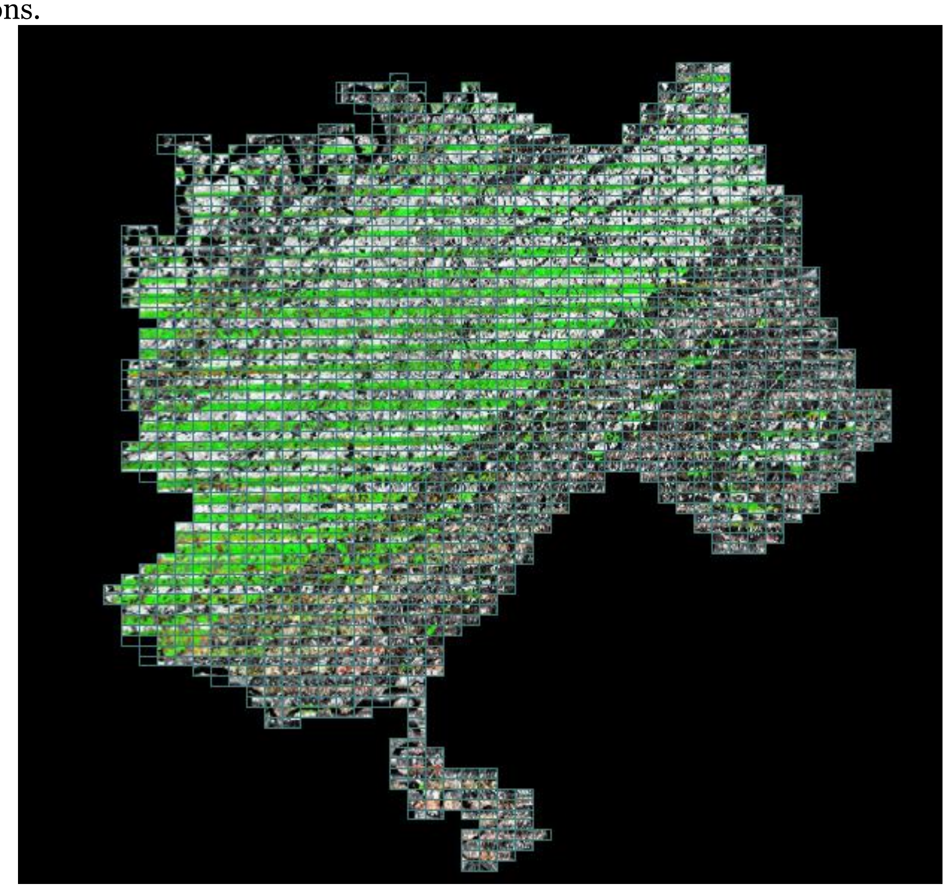

Figure 5- Single return DZ Orthos for the Blount County TN LiDAR Project. Inter-swath relative accuracy passes specifications.

Intra-Swath (Within a Single Swath) Relative Accuracy

Dewberry verifies the intra-swath or within swath relative accuracy by using Quick Terrain Modeler (QTM) scripting and visual reviews. QTM scripting is used to calculate the $RMSD_z$ of all points within each 1-meter pixel/cell size of each swath. Dewberry analysts then identify planar surfaces acceptable for repeatability testing and analysts review the QTM results in those areas. 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 QL2 data must meet intra-swath relative accuracy of 6 cm RMSDz or less. The image below shows examples of the intra-swath relative accuracy of Blount County TN LiDAR; this project meets intra-swath relative accuracy specifications.

Figure 6–Intra-swath relative accuracy. The top left image shows the full project area; areas where the RMSDz is ≤6 cm per pixel within each swath are colored green and areas exceeding 6 cm RMSDz are colored red. The top right image shows a large portion of the dataset; flat, open areas are colored green as they are within 6 cm RMSDz whereas sloped terrain is colored red because it exceeds 6 cm RMSDz, as expected, due to actual slope/terrain change. The bottom image is a close-up of a flat area. With the exception of few trees and a building (shown in red as the RMSDz in vegetated areas and high slopes/terrain angles will exceed 6 cm) this open flat area is acceptable for repeatability testing. Intra-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 Blount County, TN; no horizontal alignment issues were identified.

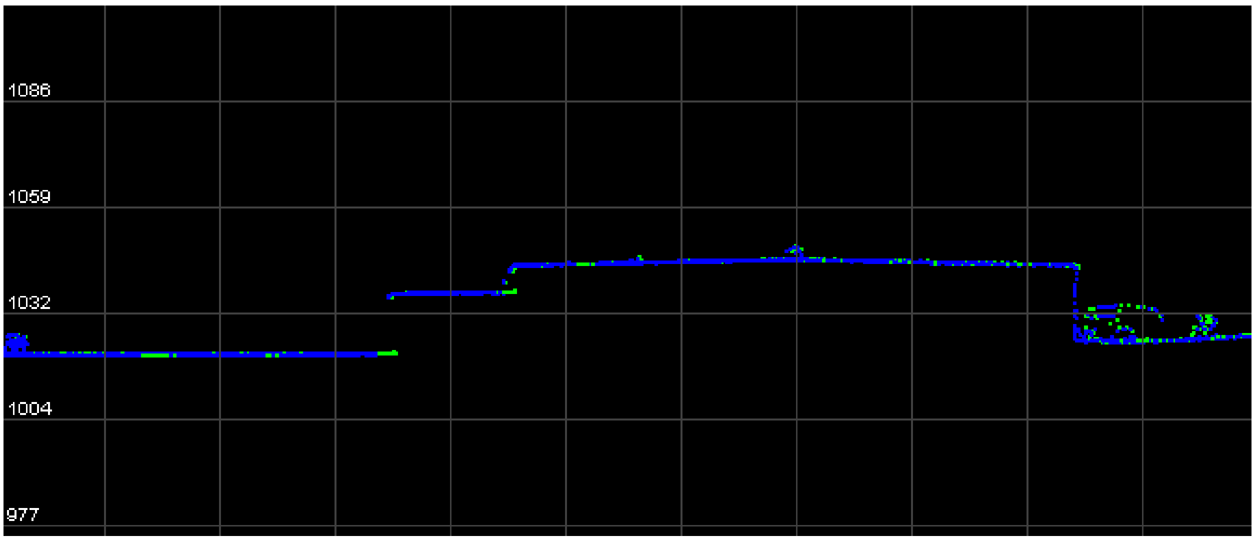

Figure 7– Horizontal Alignment. Two separate flight lines differentiated by color (Blue/Green) are shown in this profile. There is no visible offset between these two flight lines. No horizontal alignment issues were identified.

Point Density and Spatial Distribution

The required Aggregate Nominal Point Spacing (ANPS) for this project is no greater than 0.71 meters, which equates to an Aggregate Nominal Point Density (ANPD) of 2 points per square meter or greater. Density calculations were performed using first return data only located in the geometrically usable center portion (typically ~90%) of each swath. By utilizing statistics, the project area was determined to have an ANPS of 0.59 meters or an ANPD of 2.86 points per square meter which satisfies the project requirements.

The spatial distribution of points must be uniform and free of clustering. This specification is tested by creating a grid with cell sizes equal to the design NPS*2. QTM scripting is then used to calculate the number of first return points of each swath within each grid cell. At least 90% of the cells must contain 1 LiDAR point, excluding acceptable void areas such as water or low NIR reflectivity features, i.e. some asphalt and roof composition materials. This project passes spatial distribution requirements, as shown in the image below.

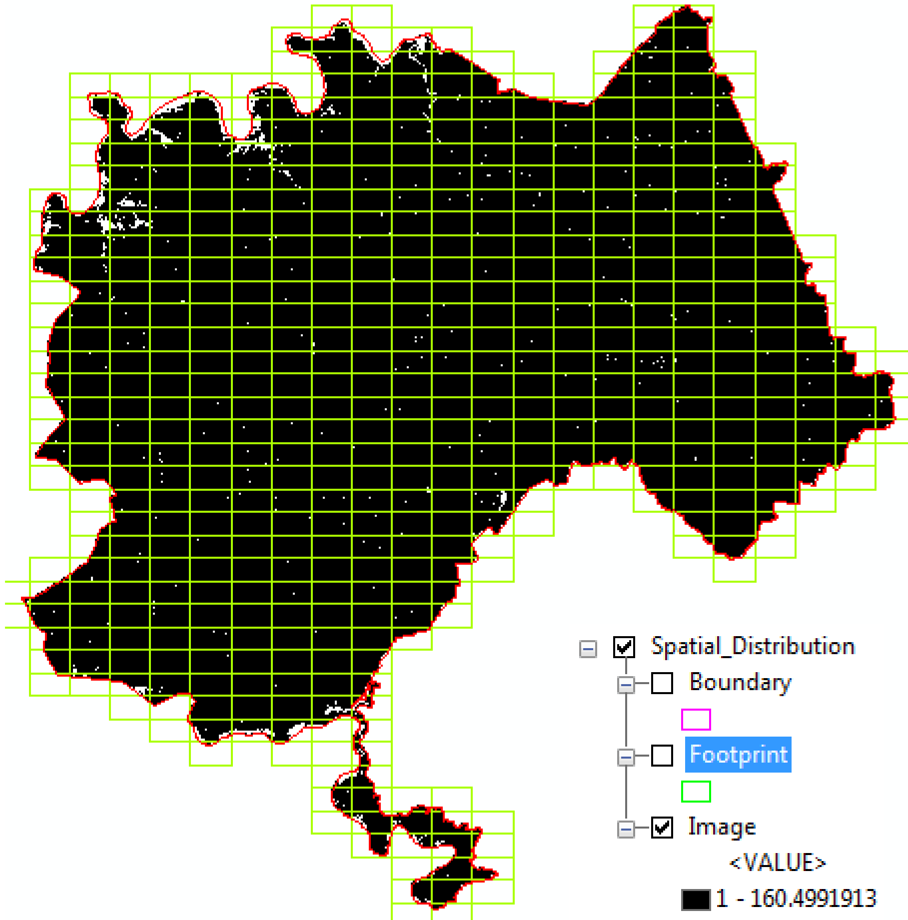

Figure 8– Spatial Distribution. The 2*NPS tile grid is shown in green and all tiles containing at least one LiDAR point are colored black.

LIDAR QUANTITATIVE REVIEW

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 also tests the horizontal accuracy of LiDAR datasets when checkpoints are photo-identifiable in the intensity imagery. 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. As not all projects contain photo-identifiable checkpoints, the horizontal accuracy of the LiDAR cannot always be tested.

SURVEY VERTICAL ACCURACY CHECKPOINTS

For the vertical accuracy assessment, fifty (50) check points were surveyed for the project and are located within bare earth/open terrain, brush, high grass, urban terrain, and low trees land cover categories. Please see appendix A to view The Atlantic Group's 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	NAD 83(2011)Tennessee State Plane FIPS 4100		NAVD88 (Geoid 12A)
	Easting X (ft)	Northing Y (ft)	Elevation (ft)
BARE01	2547542.33	530375.14	996.70
BARE02	2539192.56	555474.00	863.93
BARE03	2556010.57	497937.09	1038.76
BARE04	2603377.97	548719.39	1009.55
BARE05	2532017.39	480072.43	991.15
BARE06	2565288.53	518326.95	1030.69
OT01	2564931.75	540411.76	940.56
OT02	2516417.14	528143.43	963.53
OT03	2556292.82	516139.20	946.46
OT04	2567317.12	509461.75	1030.74
OT05	2550670.16	522053.63	962.09
OT06	2619745.92	555142.39	998.21
OT07	2578027.26	542532.97	877.22
OT08	2523310.37	544761.69	862.71
OT09	2587996.64	536253.36	984.87
UB01	2562725.52	557314.53	916.70
UB02	2565037.37	528083.85	877.68
UB03	2540432.86	549327.48	868.77
UB04	2536091.35	524892.60	956.24
UB05	2534177.52	499804.96	936.90
UB06	2564155.96	516669.08	1033.44
UB07	2575265.08	504562.73	1074.98

UB08	2611786.41	553411.68	1025.02
UB09	2574033.86	560460.38	934.66
UB10	2557340.35	532541.88	907.97
UB11	2530024.58	485693.66	995.05
UB12	2535536.38	460570.72	848.47
UB13	2544036.57	490397.12	965.75
UB14	2555822.49	488465.97	1032.60
UB15	2637431.92	496995.08	1080.59
HG01	2554726.88	547801.87	869.79
HG02	2530043.16	537457.54	876.13
HG03	2543544.03	513505.29	1113.22
HG04	2642545.15	499179.51	1074.45
HG05	2602644.39	537673.57	929.40
HG06	2578959.41	532707.79	986.80
HG07	2524378.77	476909.60	935.80
BR01	2580852.25	553425.93	991.60
BR02	2522462.05	554063.91	823.35
BR03	2528431.30	515836.08	877.22
BR04	2527165.62	493686.95	889.41
BR05	2564504.34	502416.32	1050.97
BR06	2579882.70	512496.54	1025.92
BR07	2534235.37	473080.88	927.25
LT01	2543658.25	537694.23	862.12
LT02	2515725.58	514650.59	835.09
LT03	2545918.07	501977.01	974.64
LT04	2569884.39	494626.94	1025.81
LT05	2572596.73	521043.82	991.20
LT06	2535590.47	470737.15	917.05

Table 4: Blount County TN surveyed accuracy checkpoints

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

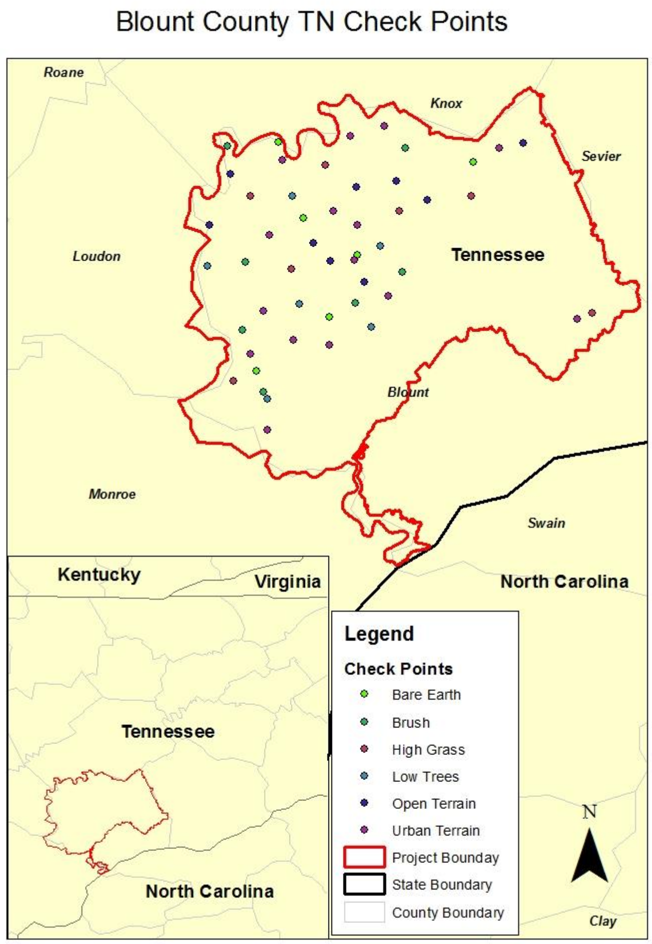

Figure 9 – Location of QA/QC Checkpoints

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in non-vegetated terrain, including open terrain (grass, dirt, sand, and/or rocks) 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 (RMSEz) of the checkpoints x 1.9600. For the Blount County, TN project, vertical accuracy must be 0.64 ft (19.6 cm) or less based on an RMSEz of 0.33 ft (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 Blount County TN, LiDAR Project VVA standard is 0.96 ft (29.4 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, Accuracyz differs from VVA because Accuracyz 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	0.64 ft (based on $RMSE_z$ (0.33 ft) * 1.9600)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined at the 95% confidence level	0.96 ft (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. The Atlantic Group'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.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSE$_z$ x 1.9600) Spec=0.64 ft	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft
NVA	30.00	0.55	
VVA	20.00		0.63

Table 6 – Tested NVA and VVA

This LiDAR dataset was tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 0.33 ft (10 cm) RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSE$_z$ =0.28 ft (8.53 cm), equating to +/- 0.55 ft (16.76 cm) at 95% confidence level. Actual VVA accuracy was found to be +/- 0.63 ft (19.2 cm) at the 95th percentile.

The figure below illustrates the magnitude of the differences between the QA/QC checkpoints and LiDAR data. This shows that the majority of LiDAR elevations were within +/- 0.4 ft of the checkpoints elevations, but there were some outliers where LiDAR and checkpoint elevations differed by up to -0.72 ft.

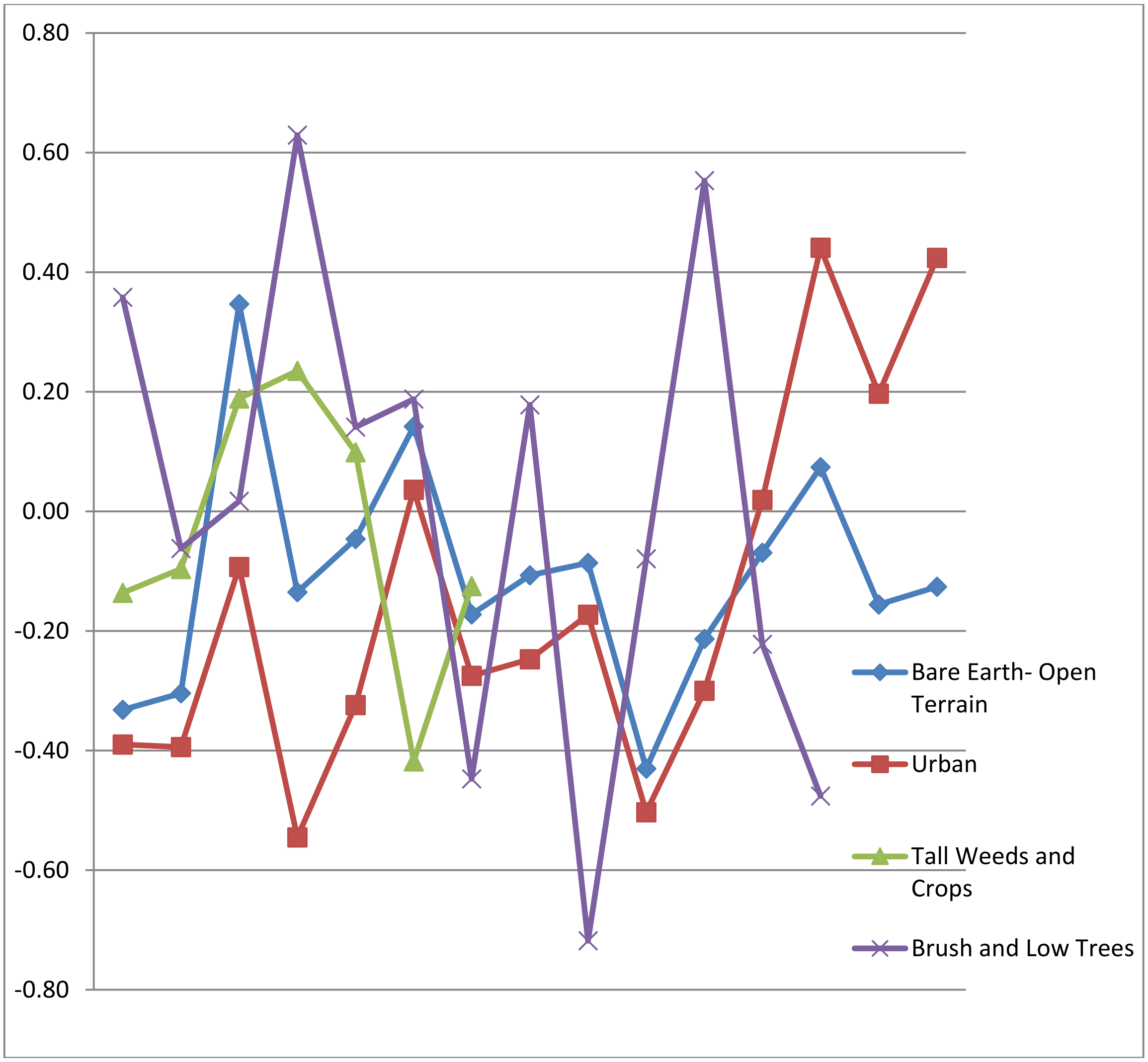

Figure 10 – Magnitude of elevation discrepancies per land cover category in feet

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

Point ID	NAD 83(2011)Tennessee State Plane FIPS 4100		NAVD88	LiDAR Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
LT02	2515725.58	514650.59	835.09	834.38	-0.72	0.72

Table 7 – 5% Outliers

Table 8 provides overall descriptive statistics.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
Open Terrain	15	0.21	-0.11	-0.13	0.71	0.12	-0.29	-0.43	0.35
Urban	15	0.33	-0.14	-0.25	0.75	0.31	-0.34	-0.54	0.44
NVA	**30.00**	**0.28**	**-0.12**	**-0.15**	**0.65**	**0.25**	**0.11**	**-0.54**	**0.44**
Tall Weeds and Crops	7	N/A	-0.04	-0.10	-0.48	0.23	-0.19	-0.42	0.23
Brush Lands and Trees	13	N/A	0.00	0.02	-0.20	0.40	-0.52	-0.72	0.63
VVA	**20.00**	**N/A**	**-0.01**	**-0.02**	**-0.14**	**0.34**	**-0.10**	**-0.72**	**0.63**

Table 8 — Overall Descriptive Statistics

The figure below illustrates a histogram of the associated elevation discrepancies between the QA/QC checkpoints and elevations interpolated from the LiDAR triangulated irregular network (TIN). The frequency shows the number of discrepancies within each band of elevation differences. Although the discrepancies vary between a low of -0.72 feet and a high of +0.63 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 -0.375 feet to +0.375 feet.

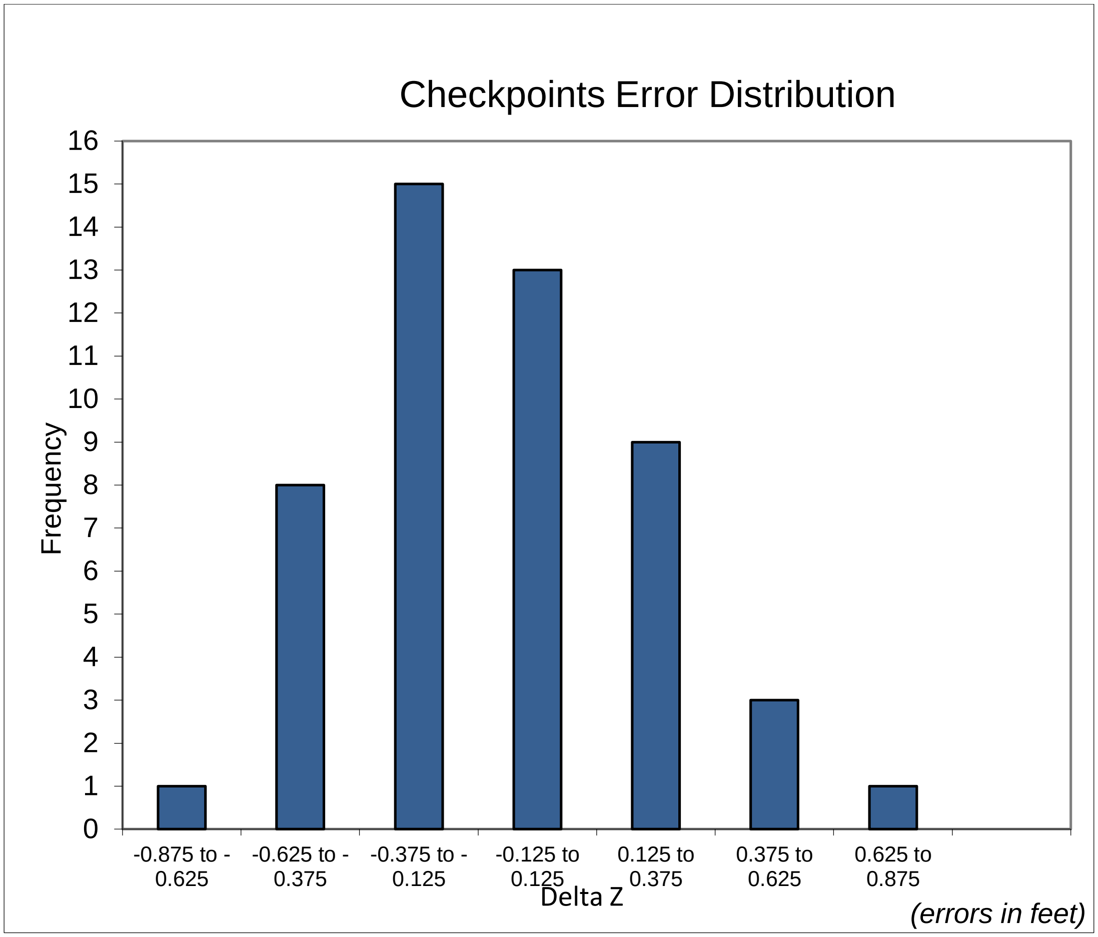

Figure 11 — Histogram of Elevation Discrepancies with errors in feet

Based on the vertical accuracy testing conducted by Dewberry, the LiDAR dataset for the USGS Blount County TN 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. Elevation datasets, including LiDAR datasets, do not always contain well-defined checkpoints suitable for horizontal accuracy assessment. However, the ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) recommends at least half of the NVA vertical check points 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 reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. This subset of checkpoints are then used for horizontal accuracy testing.

The primary QA/QC horizontal 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 and tried to locate half of the NVA checkpoints on features photo-identifiable in the intensity imagery.
2. Next, Dewberry identified the well-defined features in the intensity imagery.
3. Dewberry then computed the associated xy-value differences between the coordinates of the well-defined feature in the LiDAR intensity imagery and the ground truth survey checkpoints.
4. The data were analyzed by Dewberry to assess the accuracy of the data. Horizontal accuracy was assessed using NSSDA methodology where horizontal accuracy is calculated at the 95% confidence level. This report provides the results of the horizontal accuracy testing.

HORIZONTAL ACCURACY RESULTS

No checkpoints were photo-identifiable in the intensity imagery; horizontal accuracy could not be tested on this dataset.

LIDAR COMPLETENESS REVIEW

Dewberry received 526 LiDAR tiles for the project area. The LiDAR was delivered in LAS format 1.4, point data format 6 is used, and all data have intensity values. The LAS tiles are named appropriately according to the State of Tennessee's naming convention and have correct extents (7000 ft x 4000 ft).

All spatial projection information was correct and is as follows:

- Horizontal Datum: NAD83 (2011)
- Vertical Datum: NAVD88, Geoid 12A
- Projection: State Plane Tennessee (FIPS 4100)
- Horizontal and Vertical Units: U.S. Survey Feet

Each record includes the following fields (among others):

- X, Y, Z coordinates
- Intensity value
- Return number
- Number of returns
- Classification flags
- Scanner channel
- Scan direction flag
- Edge of flight line
- Scan angle
- User data
- Point source ID
- Classification
- GPS time

The LiDAR data has been classified to contain the following classes:

Required Classes

- Class 1 (Unclassified)
- Class 2 (Bare Earth)

- Class 7 (Low Points)
- Class 9 (Water)
- Class 10 (Ignored Ground)
- Class 17 (Bridges)
- Class 18 (High Noise)

Both withheld and overlap flags have been used correctly.

LIDAR QUALITATIVE REVIEW

The goal of Dewberry's qualitative review is to assess the continuity and the level of cleanliness of the bare earth product. Each LiDAR tile is expected to meet the following acceptance criteria:

- The point density is homogenous and sufficient to meet the user's needs;
- The ground point have been correctly classified (no man-made structures or vegetation remains, no gaps except over water bodies);
- The ground surface model exhibits a correct definition (no aggressive classification, no over-smoothing, no inconsistency in the post-processing);
- No obvious anomalies due to sensor malfunction or systematic processing artifacts are present (data voids, spikes, divots, ridges between flight lines or tiles, cornrows, etc);
- Residual artifacts <5%

Dewberry analysts performed a visual inspection of 100% of the bare earth data digital terrain model (DTM) at a macro level. The DTMs are built by first creating a fishnet grid of the LiDAR mass points with a grid distance equal to or better than the final DEM deliverables. Then a triangulated irregular network is built based on this gridded DTM and displayed as a 3D surface. A shaded relief effect was applied which enhances 3D rendering.

Quick Terrain Modeler, the software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies. Models can also be viewed by point density, in which areas meeting the specified point density threshold are displayed green and areas not meeting the point density threshold are displayed red. This can help to identify void areas and areas that are misclassified. As the surface model is created from ground only points, sparse or red areas are expected over buildings, water, and dense vegetation where there is poor LiDAR penetration. The table below shows a breakdown of the calls made during the first review of the project data.

Issue	Number of Occurrences	Delivery 2
Aggressive Misclassification	6	0
Artifacts	2	0
Total	**8**	**0**

Table 9 – Breakdown of LiDAR qualitative edit calls.

Aggressive Misclassification

Aggressive misclassification calls in this document imply that LiDAR points are unclassified in the delivered dataset when they should be classified to ground. This call indicates areas where some class 1 points could be reclassified to class 2, ground, to improve detail in the surface model and to more correctly model surface features. There were six (6) instances of aggressive misclassification identified in this project area. An example of aggressive misclassification edit calls is found below.

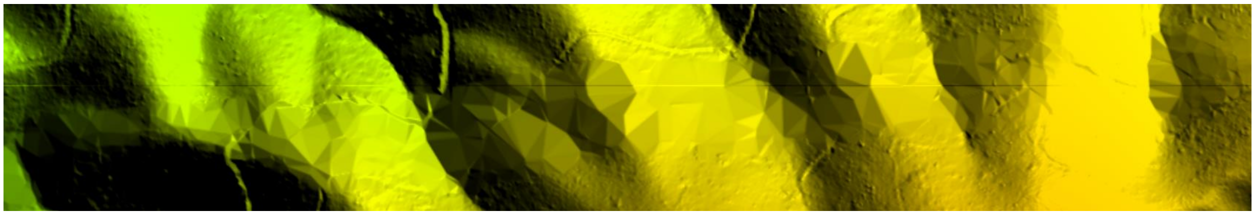

Figure 12– Tile 2570413NE, first delivery. The majority of the points are classified as unclassified but valid unclassified and overlap points should be reclassified to ground to improve the definition of the bare-earth surface. The image is a bird's eye view of the DEM.

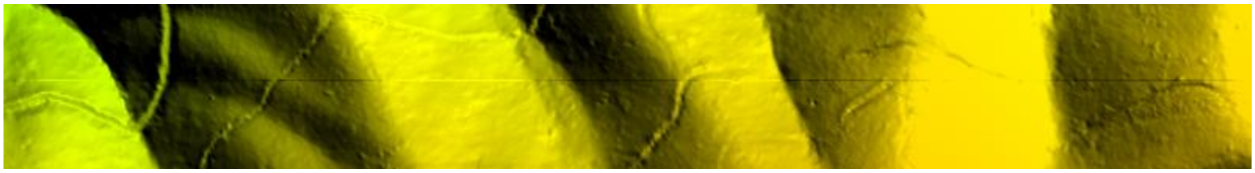

Figure 11 – Tile 2570413NE, second delivery. The majority of the points have been reclassified to ground to improve the definition of the bare-earth surface. The image is a bird's eye view of the DEM.

Artifacts

Artifacts are features that are left in the ground model that should be removed. There were two (2) artifacts identified in the project area and include vegetation, bridges and structures. These should be removed in order to improve the bare-earth surface model and classed to their appropriate class. Examples of the artifact edit calls can be found below.

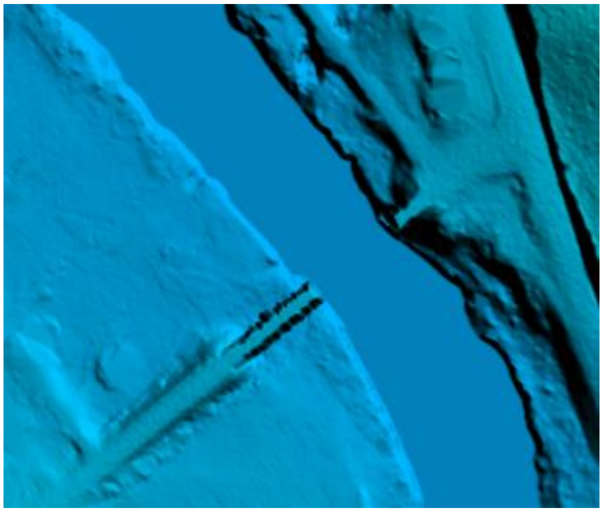

Figure 14 – Tile 2570549SE, first delivery. The structure can be seen protruding from the ground and should be reclassified to the specified bridge deck class (class 17).

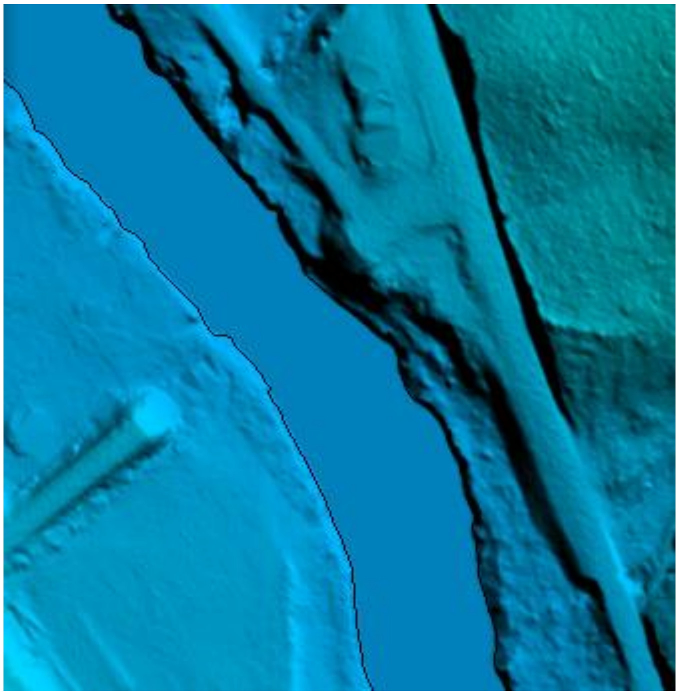

Figure 12 – Tile 2570549SE, second delivery. Bare-earth DEM colored by elevation is shown. The feature has been reclassified to the specified bridge deck class (class 17).

LIDAR RECOMMENDATION

Dewberry recommends the LiDAR be accepted. All previous issues have been correctly addressed.

Derivative LiDAR Products

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

1-FT CONTOURS

One-foot contours have been created for the full project area. The contour attributes include labeling as either Index or Intermediate and an elevation value. The contours are also 3D, storing the elevation value within its internal geometry. Some smoothing has been applied to the contours to enhance their aesthetic quality. Due to the large number of contours present and their file size, the contours have been tiled to the project tiles. Keeping all contours in one large contour file rendered the contours un-usable. The contour tiles are all located within one file GDB and are named according to the final project tile grid. The final version of contours has not yet been delivered and verified for correct topological behavior.

Breakline Analysis

A qualitative/quantitative review was completed on the project area breaklines. The comprehensive review consisted of a visual review of the breaklines for completeness in compilation and horizontal placement as well as proper feature coding. This visual analysis was followed by several automated tests for hydro-flattening and topology using ESRI Data Reviewer tools and proprietary tools developed by Dewberry.

BREAKLINE DATA OVERVIEW

The Breakline qualitative review starts with an overview. First, the ESRI geodatabase is reviewed in ArcCatalog for correct spatial projections, data organization, and to ensure all necessary feature classes are present and are properly populated.

The breaklines were delivered in a geodatabase, containing two separate feature classes. The delivered geodatabase contained the correct feature classes, shown below:

- Blount_Ponds_Lakes
- Blount_Rivers_Streams

The coordinate system of the delivered breaklines is correct and is as defined below:

- Horizontal Datum: NAD83 (2011)
- Vertical Datum: NAVD88
- Projection: Tennessee State Plane (FIPS 4100)
- Horizontal Units: US Survey Feet
- Vertical Units: US Survey Feet

BREAKLINE QUALITATIVE REVIEW

The breakline qualitative review includes reviewing data for completeness, validating the horizontal placement of breaklines, and verifying the coding and attribution of breaklines.

The breaklines were reviewed against intensity imagery Dewberry creates for its QC process. A macro review was performed on 100% of the data in an ESRI environment to validate data collection consistency and to validate all necessary features were collected. A breakdown of the edit calls made during the review can be seen in the table below.

Issue	Number of Occurrences	Delivery 2
Break in Continuity	2	0
General Call - Clip Breaklines	1	0
Total	**3**	**0**

Table 10 – Breakdown of breakline qualitative edit calls

Break in Continuity

Two (2) issues were identified where hydrographic breaklines were stopped or closed, but should have continued or connected through a feature. An example is shown below

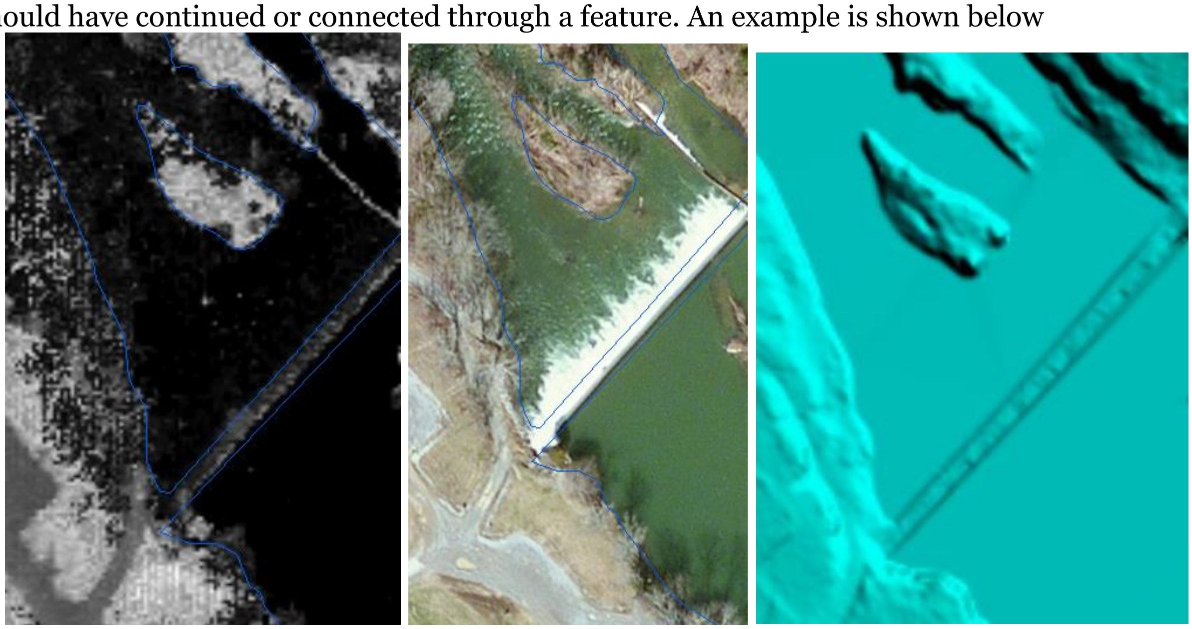

Figure 16 – Tile 2598517NE, first delivery. Full point cloud intensity, left, displays where the breaklines are stopped and started again mid-stream. The Bing imagery, middle, shows a spillway that inhibits the water but does not fully retain. The right image shows the effect on the DEM.

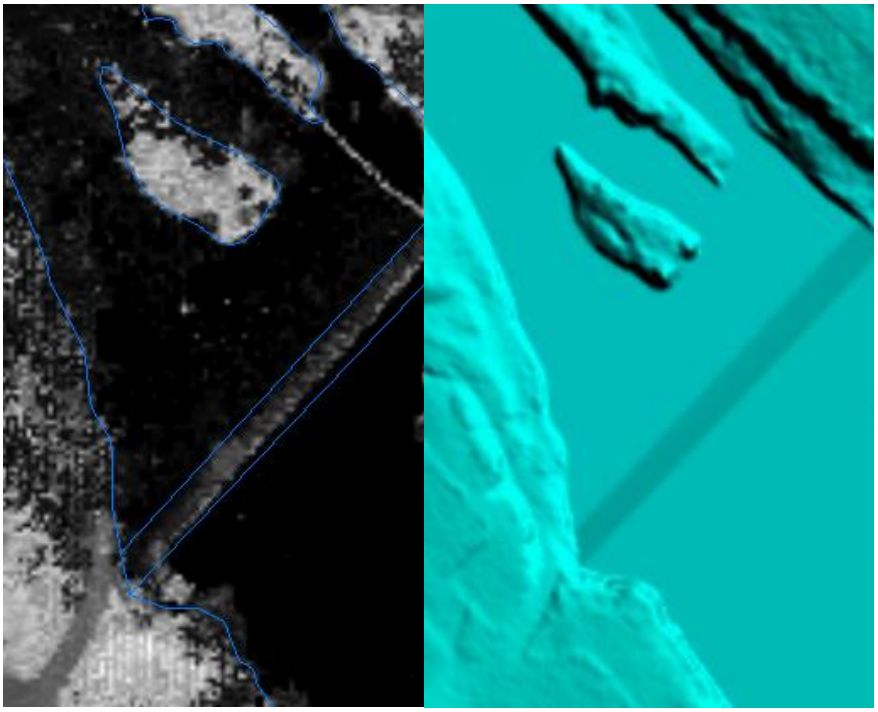

Figure 17- Tile 2598517NE, second delivery. Full point cloud intensity, left, displays where the breaklines have been connected enforcing the elevation difference. The right image shows the effect on the DEM.

Clipped Breaklines

One (1) general call was made to clip the breaklines to the boundary. The breaklines were clipped to the boundary creating a “finished” look. An example is shown below.

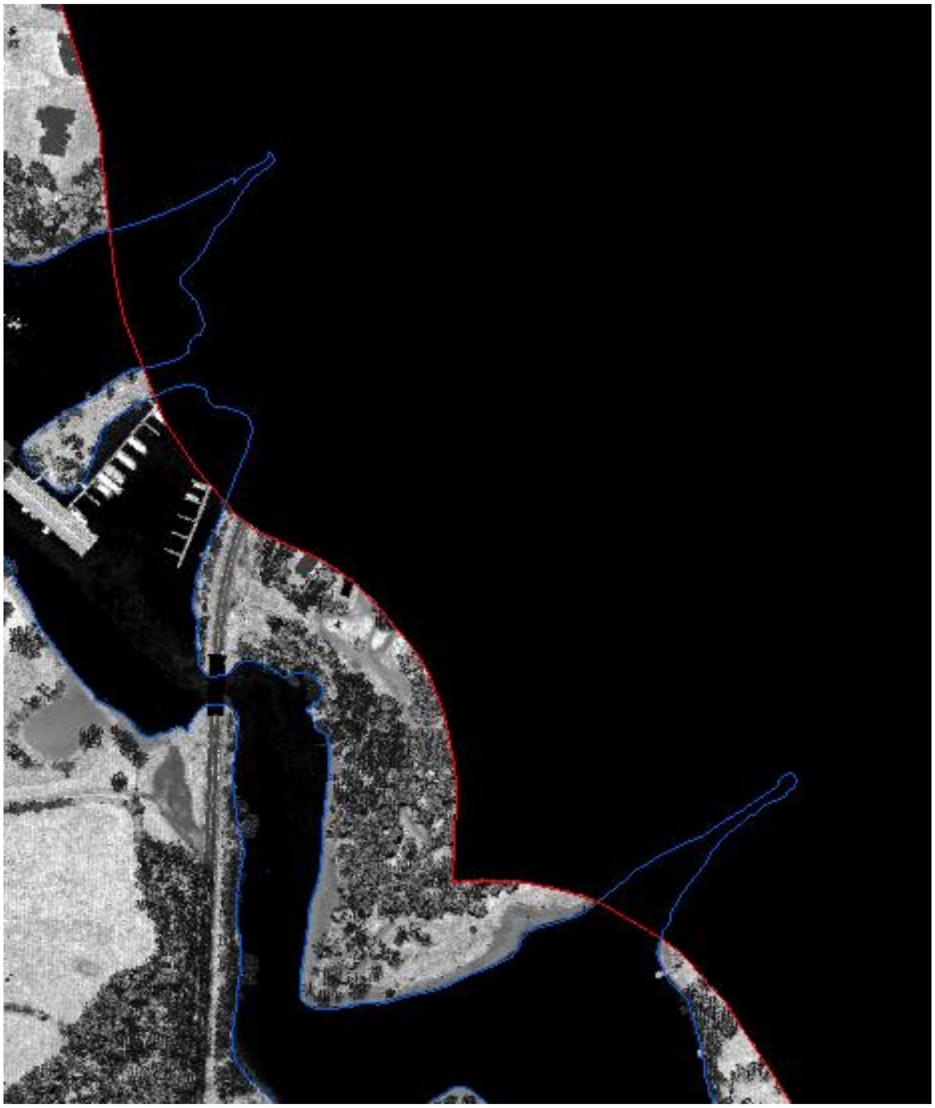

Figure 38 – Tile 2570565SE, first delivery. The breaklines (blue) extend past the project boundary (red) and should be clipped to the boundary.

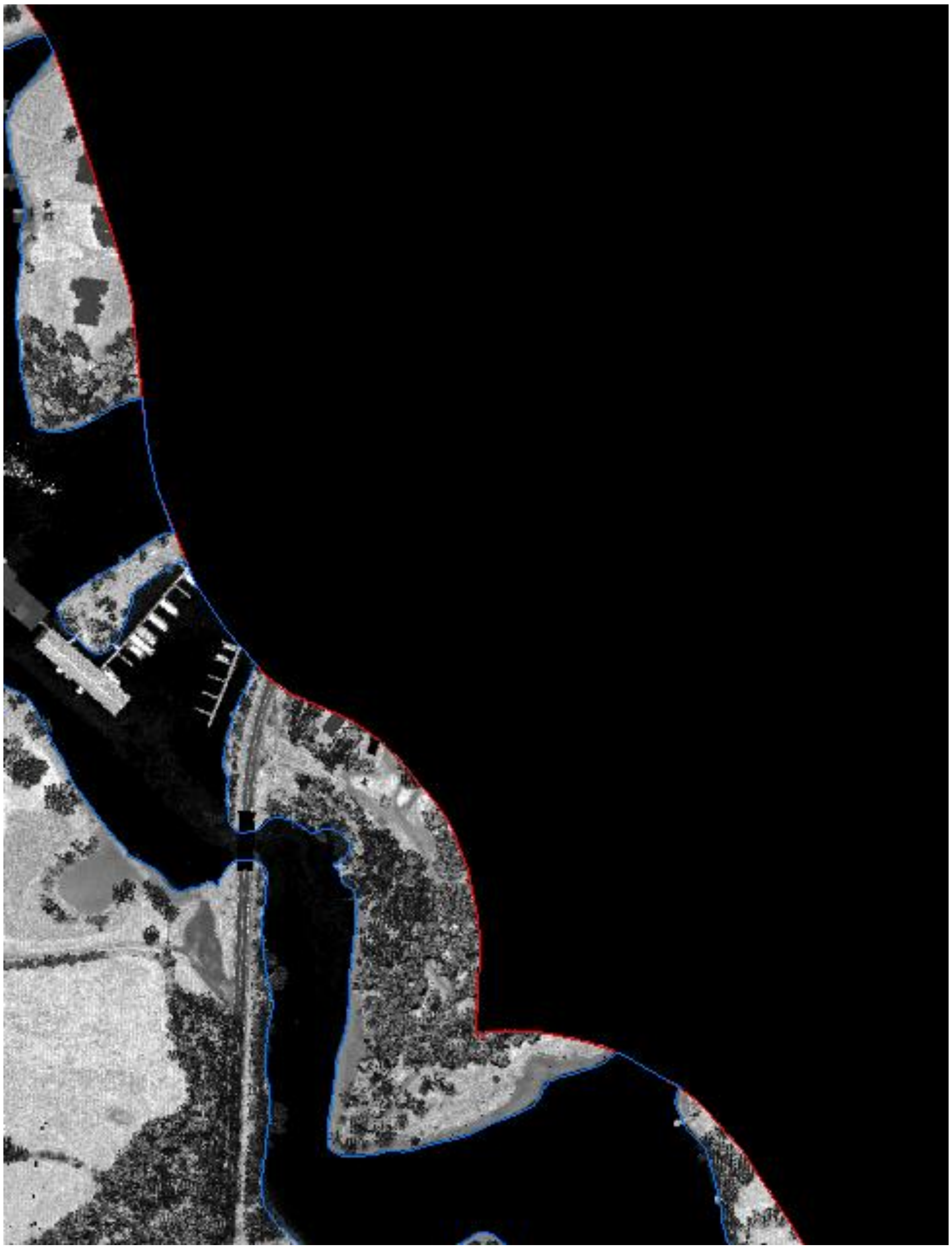

Figure 49 – Tile 2570565SE, second delivery. The breaklines (blue) have been clipped to the project boundary (red).

BREAKLINE QUANTITATIVE REVIEW

The Quantitative Vertical Analysis compares the breakline vertices against the bare-earth LiDAR data. Dewberry begins this process by converting all breakline vertices to points. At the same time an ESRI Terrain is created from the LiDAR using ground and water points. The LiDAR elevation, extracted from the terrain, is recorded for every breakline vertex. An analysis of the differences in elevation between the breakline vertices and LiDAR is conducted to determine the vertical accuracy of the breakline collection.

Dewberry found no issues in this portion of the review.

BREAKLINE RECOMMENDATION

Dewberry recommends accepting the breaklines; all identified issues have been resolved.

Hydro-flattened Digital Elevation Model Analysis

Dewberry received 526 hydro-flattened bare earth DEMs as part of the deliverables for the project area. Dewberry used proprietary scripts and tools to ensure all DEMs have the correct formatting, cell size, projection, and extents. Dewberry used ESRI ArcMap and Global Mapper software to review all DEMs for completeness and qualitative analysis.

OVERVIEW

Dewberry ran proprietary tools on all delivered DEMs to verify formatting, cell size, extents, and projection information.

All DEMs were correctly formatted:

- DEM type: IMG
- Cell Size: 2.5 foot
- Extents: 7,000 ft x 4,000 ft tiles

The coordinate system of the delivered DEMs is correct and is as defined below:

- Horizontal Datum: NAD83 (2011)
- Projection: Tennessee State Plane (FIPS 4100)
- Horizontal and Vertical Units: US Survey Feet

DEM QUANTITATIVE REVIEW

The same checkpoints used to test the vertical accuracy of the LiDAR data were also used to test the vertical accuracy of the DEMs. Table 11 outlines the calculated $RMSE_z$ and associated statistics, in feet, while **Error! Reference source not found.**12 outlines vertical accuracy as omputed by the different methods, in feet.

100 % of Totals	# of Points	RMSEz (ft) NVA Spec=0.33 ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	Kurtosis	Min (ft)	Max (ft)
Open Terrain	15	0.22	-0.10	-0.10	0.72	0.20	0.76	-0.41	0.37
Urban	15	0. 33	-0.14	-0.24	0.86	031	-0.22	-0.52	0.45
NVA	**30.00**	**0.28**	**-0.12**	**-0.14**	**0.71**	**0.26**	**0.00**	**-0.52**	**0.45**
Tall Weeds and Crops	7	N/A	-0.03	-0.06	-0.80	0.22	0.38	-0.43	0.22
Brush Lands and Trees	13	N/A	0.05	0.13	-0.42	0.43	-0.68	-0.76	0.65
VVA	**20.00**	**N/A**	**0.02**	**0.10**	**-0.28**	**0.37**	**-0.22**	**-0.76**	**0.65**

Table 11 - The table shows the calculated $RMSE_z$ values, in feet, as well as associated statistics of the errors for the Blount County, TN DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=0.64 ft	VVA – Vegetated Vertical Accuracy (95th Percentile) Spec=0.96 ft
NVA	30.00	0.55	
VVA	20.00		0.65

Table 12 - The table shows the calculated NVA and VVA, in feet, at the 95% confidence level for Blount County DEMs.

Table 13 lists the 5% outliers that are larger than the 95th percentile, or 0.65 feet.

Point ID	NAD83 (2011) Tennessee State Plane (FIPS 4100)		NAVD88	LiDAR Z (ft)	Delta Z	AbsDeltaZ
	Easting X (ft)	Northing Y (ft)	Survey Z (ft)			
LT02	2515725.58	514650.59	835.09	834.33	-0.76	0.76

Table 13 – 5% Outliers

The Blount County, Tennessee DEMs pass vertical accuracy specifications.

QUALITATIVE REVIEW

Dewberry performed a visual analysis on 100% of the delivered DEMs. The DEMs were reviewed in Global Mapper or ESRI ArcMap software. The DEMs were reviewed with hillshades, which allow the viewer to see the DEMs as if in 3D. This helps with the identification of issues and anomalies. The DEM is required to be free of artifacts, gaps, and artificial smoothing. A breakdown of the edit calls made during the review can be seen in the table below.

Issue	Number of Occurrences	Delivery 2
Water Artifact	1	0
Total	**1**	**0**

Table 14 – Breakdown of DEM qualitative edit calls

Water Artifacts

One (1) water artifact example was marked in the DEMs and has been addressed.

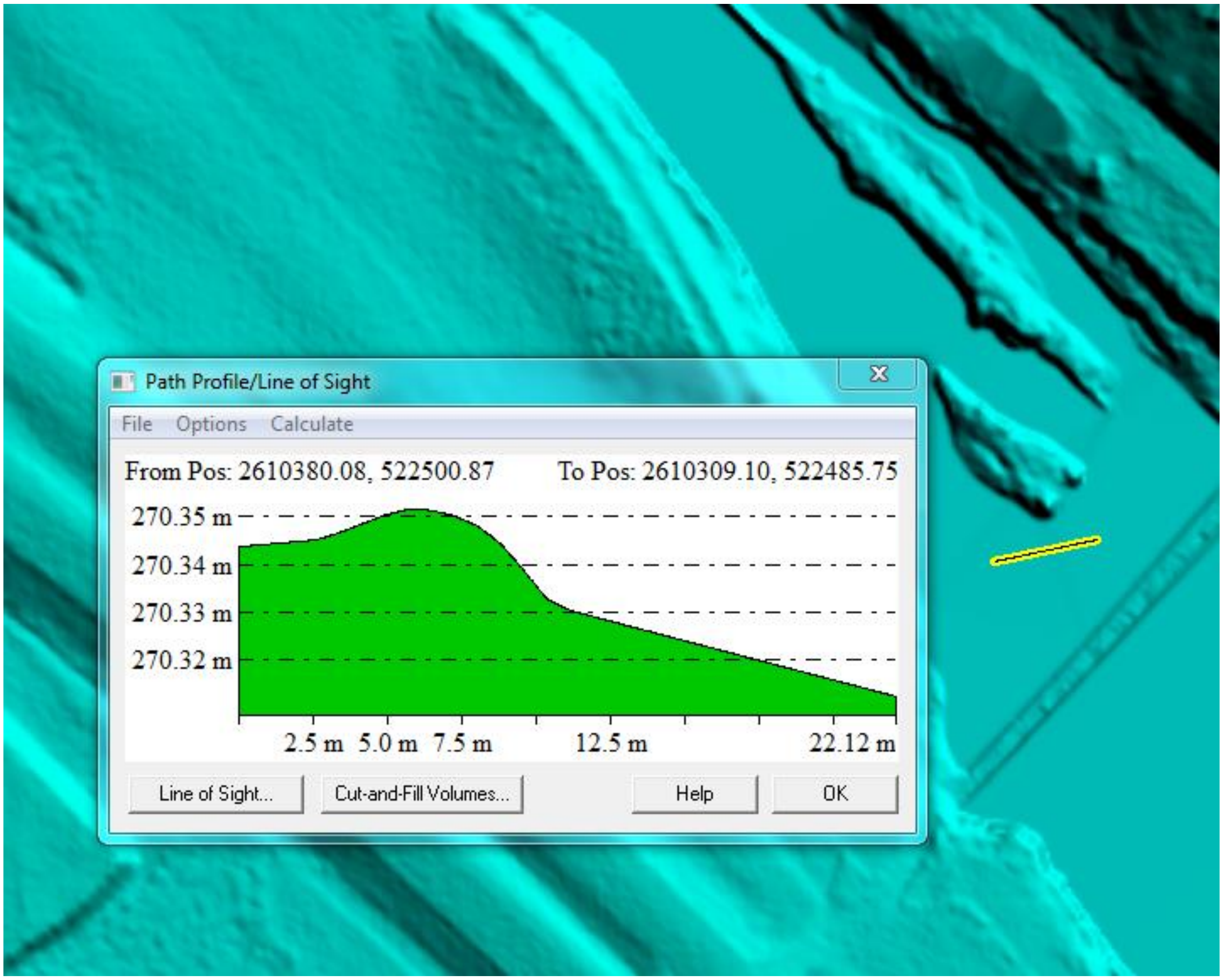

Figure 20 - DEM tile 259851NE, first delivery. Water Artifact found in the DEM.

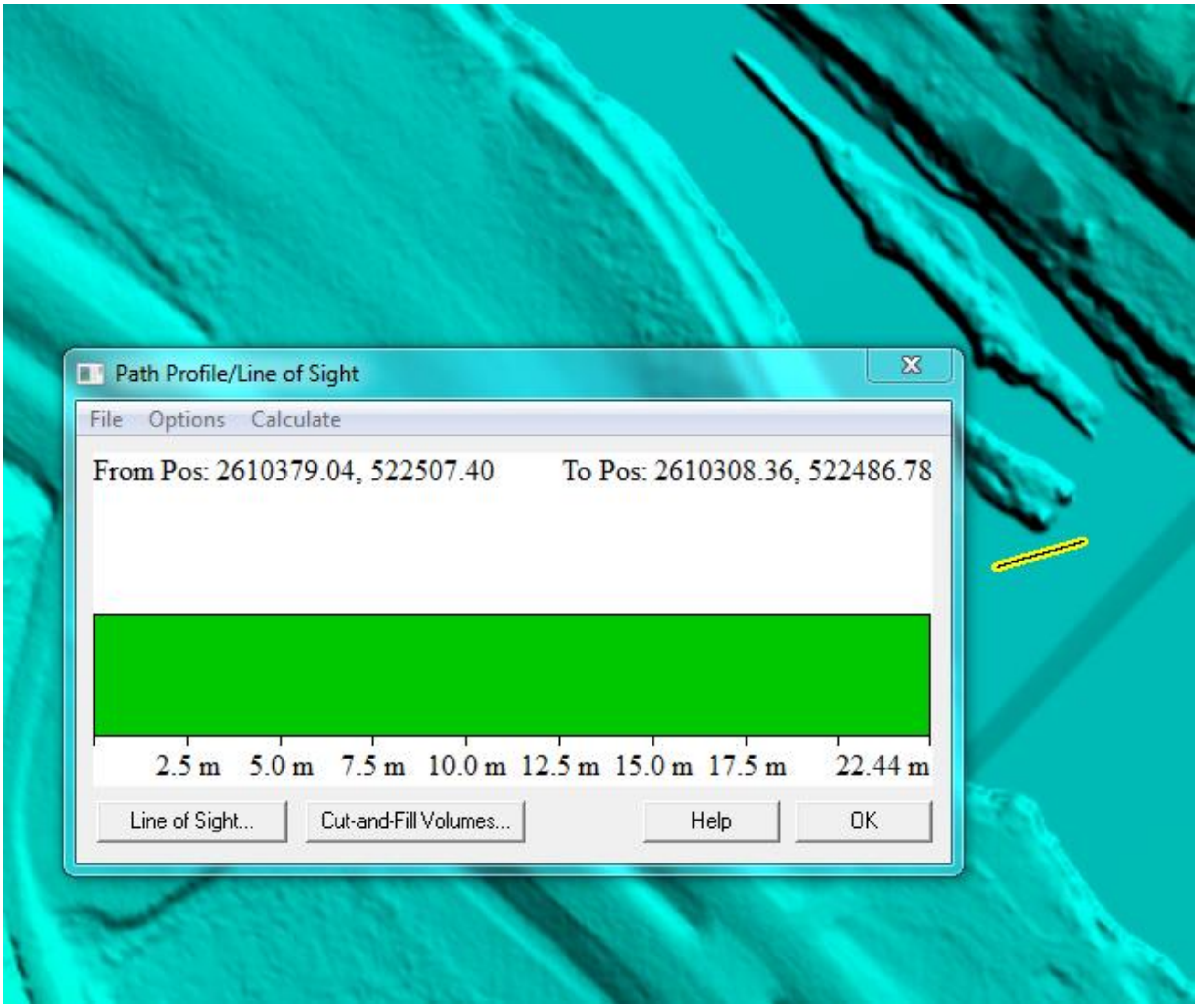

Figure 21 - DEM tile 2598517NE, second delivery. Water Artifact has been removed from the DEM.

DEM RECOMMENDATION

It is Dewberry's recommendation that the DEMs be accepted. All issues have been addressed appropriately.

Metadata

Atlantic delivered 14 metadata files, in XML format, for the classified LAS, breaklines, DEMs, Raw Flight Lines, and project level metadata. Dewberry reviewed the metadata files for correct formatting and for sufficient content. All metadata files meet FGDC standards and were deemed error free by the MetaParser (MP) tool developed by the United States Geological Survey. All of the fields that are discarded or ignored by the USGS MetaParser were expected from the new LiDAR tags.

After reviewing the delivered metadata files there were several fields that needed a few adjustments, which Dewberry performed.

METADATA RECOMMENDATION

Dewberry recommends accepting all metadata.

Appendix A: Survey Report

Final Survey Report

Blount, TN

15121

Dewberry®

atlantic

2223 Drake Ave SW
Suite 200
Huntsville, AL 35805
(256) 971-9991
(256) 971-1154 – Fax

June 2015

Table of Contents

Section 1: Narrative

1.1 Introduction

A survey was performed to support the acquisition of Light Detection and Ranging (LiDAR) data for the Dewberry, Blount, TN area of interest.

1.2 Applicable Standards

This Geodetic Control GPS Survey was conducted to support LiDAR data in accordance with the current USGS guidelines.

Section 2: Ground Control Geodetic Network Survey

2.1 Ground Control Points

A GPS control network was performed for the purpose of establishing three-dimensional coordinates on each of the base station locations. The control network included a combination of a National Geodetic Survey (NGS) Control Monument ***D 295, GPS 34 V2 92, and LHT 682)*** and Atlantic Temporary Control Points ***(CP02, CP03, CP04, CP05, CP06, CP07, CP08, CP09, CP10, CP11, CP12, CP13, CP14, CP15, CP16, CP17, CP18, CP19, CP20, and SETPOINT)***.

A graphical representation of all the ground control points is provided in figure 1:

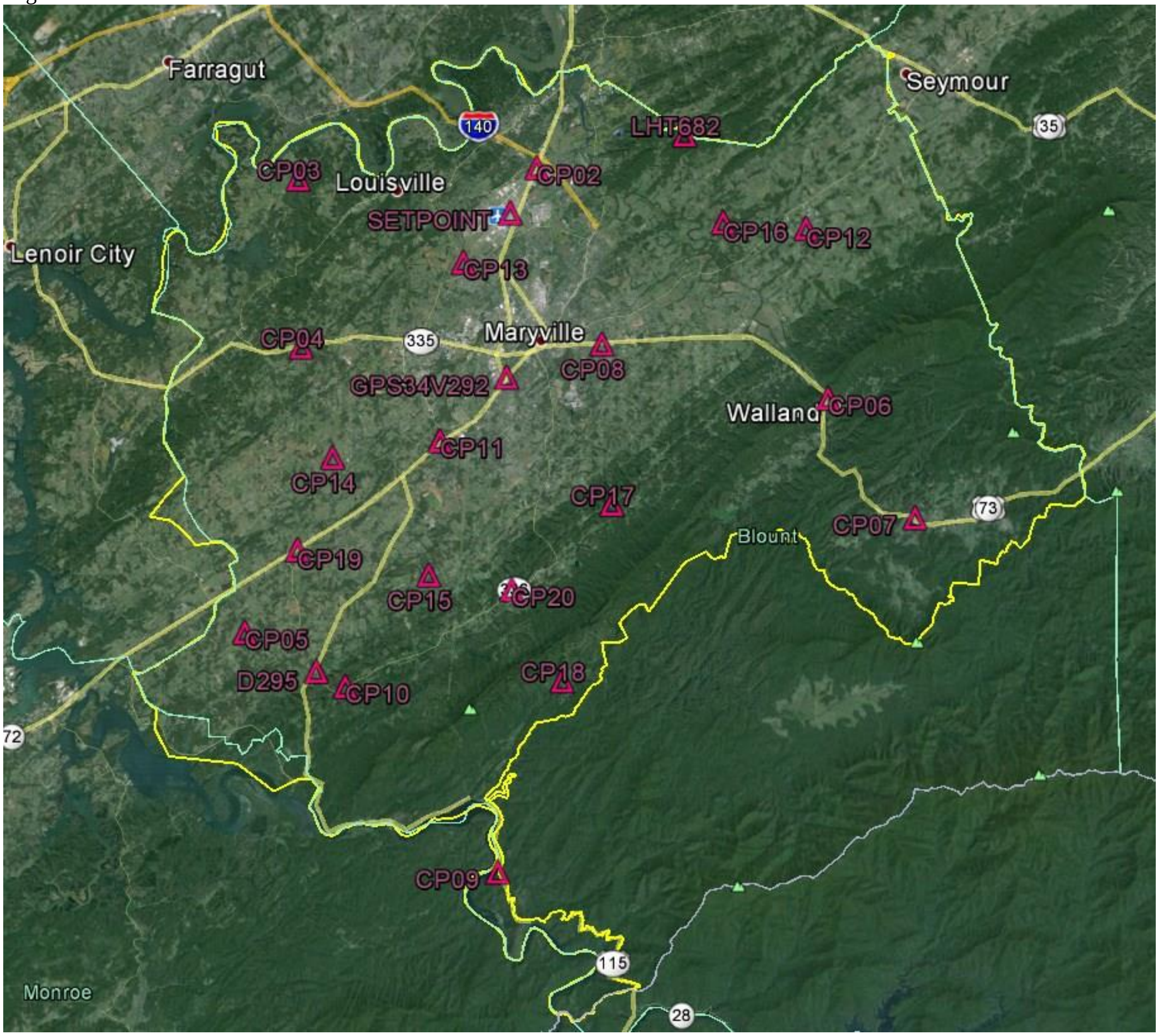

Figure 1: Ground Control Geodetic Network Points

2.2 Ground Control Station Collection

GPS observations at all ground control points in the network were made with Leica System 500 dual-frequency GPSreceivers with a Leica AT502 antenna and a Topcon HiPER V with a Topcon TPSHIPERV antenna between March 2015 and May 2015. Both GPS receivers were configured to log data at 1 Hz, and at a 10 degree mask. Session lengths were based upon the distance between points and were set for a minimum of one hour per every 10 km.

2.3 Ground Control Data Processing and Analysis

Data collected during each GPS session was processed using GrafNet 8.50.4320 with their respective GPS antenna type, and antenna height reading. A network was processed in order to establish coordinates and height values for all points. The RMS values for the latitude, longitude and ellipsoid heights for all results were reviewed to ensure that they are within acceptable limits. Two adjustments were made during each network's development. Each adjustment reports baseline RMSE and residual values at the control points.

2.3.1 GROUND CONTROL NETWORK PROCESSING

The network development involved performing a minimally constrained network adjustment, holding NGS monuments **(GPS 34 V2 94, LHT 682 and d 295)** as a horizontal and vertical control point. This minimally constrained adjustment allowed for blunders and errors to appear within the network. These blunders were analyzed and the baselines were rejected if they had high residuals against other redundant baselines.

Twenty three (23) control points within the network were then fully constrained for a final network adjustment, holding NGS monuments **(GPS 34 V2 94, LHT 682 and d 295)** as a horizontal and vertical control point. Geoid12A was utilized during GPS processing. In all, sixty (60) baselines were kept in the fully constrained adjustment after the final network analyses. Final network control values were then assigned to Atlantic Temporary Control Points ***(CP02, CP03, CP04, CP05, CP06, CP07, CP08, CP09, CP10, CP11, CP12, CP13, CP14, CP15, CP16, CP17, CP18, CP19, CP20, and SETPOINT)***. A tabulated summary of the final coordinates resulting from the network survey are listed in section 2.4.1

2.4 Network Survey Final Coordinates

After analyzing all fully constrained final network adjustments, a tabulated summary of the final coordinates were established for all ground control points. These summaries are listed below.

2.4.1 STATE PLANE COORDINATES

NAD83 (2011), State Plane Tennessee, NAVD88, Geoid12A, U.S. Survey Feet.

Ground Control Points			
Point ID	Easting (ft)	Northing (ft)	Elevation (ft)
CP02	2569395	551637.8	964.432
CP03	2531378	549101.3	818.192
CP04	2532423	522438.5	889.614
CP05	2524416	476995.9	938.73
CP06	2616548	516012.1	932.815
CP07	2630808	497405.5	1028.514

CP08	2580370	523890.3	1048.216
CP09	2565529	439865	892.138
CP10	2540614	468746	978.621
CP11	2554917	508009.5	1035.623
Point ID	Easting (ft)	Northing (ft)	Elevation (ft)
CP12	2612511	542933	1038.73
CP13	2557989	536402.1	928.463
CP14	2537834	505017.5	949.461
CP15	2553561	486702.4	979.52
CP16	2599276	543585	899.822
CP17	2582488	498521.8	1052.72
CP18	2575184	470420.9	1270.154
CP19	2532524	490262.5	872.368
CP20	2566808	484660	1012.064
D295	2535919	471039.7	904.862
GPS34V292	2565289	518326.9	1030.834
LHT682	2592822	557256.1	1074.078
SETPOINT	2565307	544380.5	953.493

Section 3: Ground Cover Classification Survey

3.1 Ground Cover Classification Check Point Collection

GPS observations were conducted at each ground control point (except OT04, HG07 and LT06) in order to conduct a Virtual Reference Station (VRS) survey. GPS observations at each VRS ground control point were made with a Topcon GRS1 GPSreceiver configured to log data at 1 Hz, and at 10 degrees mask.

GPS static observations for OT04, HG07 and LT06 were conducted with a with Leica System 500 dual-frequency GPSreceivers with a Leica AT502 antenna configured to log data at 1 Hz, and at a 10 degree mask, for a minimum duration of twenty (20) minutes.

All check points collected represent differing types of ground cover observed during the course of both surveys and were conducted between March 2015 and May 2015.

The purpose of this survey was to collect ground check points for use during the processing of the LiDAR data to ensure that the highest possible accuracy was achieved.

A graphical representation of all the Ground Cover Classification Check Points is provided in figure 2:

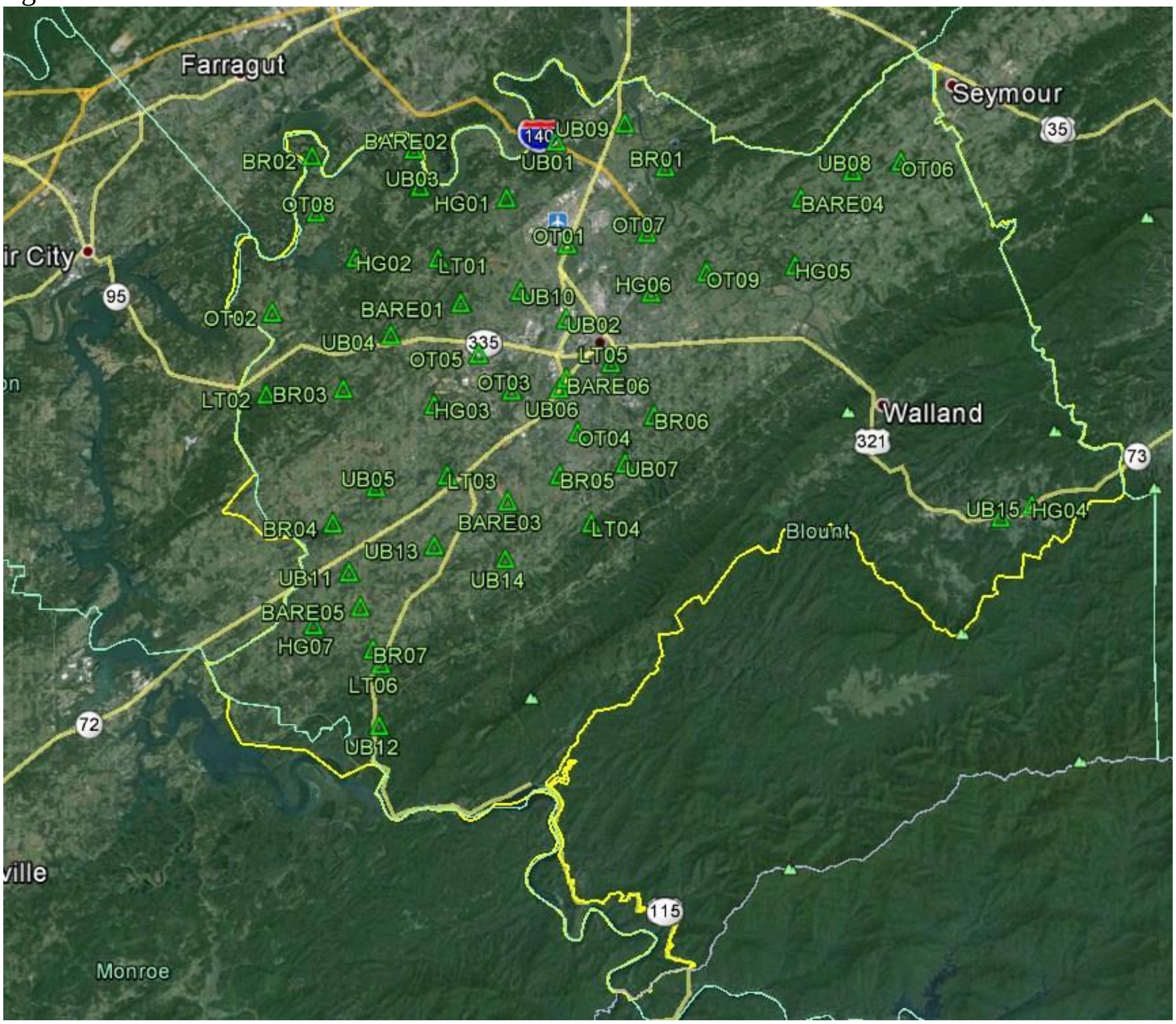

Figure 2: Ground Cover Classification Check Points

3.2 Check Point Data Processing and Analysis

Data collected for OT04, HG07 and LT06 were uploaded to the National Geodetic Survey's (NGS) On-Line Positioning User Service (OPUS) server with their respective GPS antenna type, and antenna height reading. The resulting solution for each observation is referenced to NAD-83 (North American Datum). The RMS values for the latitude, longitude and ellipsoid heights for each result were reviewed to ensure that they are within acceptable limits. The Ellipsoidal elevations supplied by NGS were transformed into Geoid12A orthometric heights.

A tabulated summary of the final coordinates resulting from the Ground Cover Classification Survey are listed in sections 3.2.1

3.2.1 GROUND COVER CLASSIFICATION CHECK POINTS

NAD83 (2011), State Plane Tennessee, NAVD88, Geoid12A, U.S. Survey Feet.

LiDAR Check Points				
Point ID	Easting (ft)	Northing (ft)	Elevation (ft)	Description
BARE01	2547542	530375.1	996.702	Bare Earth
BARE02	2539193	555474	863.925	Bare Earth
BARE03	2556011	497937.1	1038.762	Bare Earth
BARE04	2603378	548719.4	1009.545	Bare Earth
BARE05	2532017	480072.4	991.154	Bare Earth
BARE06	2565289	518326.9	1030.693	Bare Earth
OT01	2564932	540411.8	940.564	Open Terrain
OT02	2516417	528143.4	963.534	Open Terrain
OT03	2556293	516139.2	946.459	Open Terrain
OT04	2567317	509461.8	1030.736	Open Terrain
OT05	2550670	522053.6	962.092	Open Terrain
OT06	2619746	555142.4	998.212	Open Terrain
OT07	2578027	542533	877.223	Open Terrain
OT08	2523310	544761.7	862.709	Open Terrain
OT09	2587997	536253.4	984.866	Open Terrain
UB01	2562726	557314.5	916.699	Urban Terrain
UB02	2565037	528083.9	877.681	Urban Terrain
UB03	2540433	549327.5	868.77	Urban Terrain
UB04	2536091	524892.6	956.24	Urban Terrain
UB05	2534178	499805	936.903	Urban Terrain
UB06	2564156	516669.1	1033.435	Urban Terrain

UB07	2575265	504562.7	1074.977	Urban Terrain
UB08	2611786	553411.7	1025.018	Urban Terrain
UB09	2574034	560460.4	934.663	Urban Terrain
UB10	2557340	532541.9	907.972	Urban Terrain
UB11	2530025	485693.7	995.05	Urban Terrain
UB12	2535536	460570.7	848.465	Urban Terrain
UB13	2544037	490397.1	965.75	Urban Terrain
Point ID	Easting (ft)	Northing (ft)	Elevation (ft)	Description
UB14	2555822	488466	1032.595	Urban Terrain
UB15	2637432	496995.1	1080.588	Urban Terrain
BR01	2580852	553425.9	991.595	Brush
BR02	2522462	554063.9	823.351	Brush
BR03	2528431	515836.1	877.219	Brush
BR04	2527166	493686.9	889.405	Brush
BR05	2564504	502416.3	1050.966	Brush
BR06	2579883	512496.5	1025.921	Brush
BR07	2534235	473080.9	927.251	Brush
HG01	2554727	547801.9	869.786	High Grass
HG02	2530043	537457.5	876.134	High Grass
HG03	2543544	513505.3	1113.221	High Grass
HG04	2642545	499179.5	1074.449	High Grass
HG05	2602644	537673.6	929.399	High Grass
HG06	2578959	532707.8	986.804	High Grass
HG07	2524379	476909.6	935.802	High Grass
LT01	2543658	537694.2	862.116	Low Trees
LT02	2515726	514650.6	835.094	Low Trees
LT03	2545918	501977	974.636	Low Trees
LT04	2569884	494626.9	1025.811	Low Trees

LT05	2572597	521043.8	991.203	Low Trees
LT06	2535590	470737.2	917.052	Low Trees

Appendix B: Complete List of Delivered Tiles

2500453NE
2500453SE
2500461NE
2500461NW
2500461SE
2500469NE
2500469SE
2500469SW
2500485NE
2500493NE
2500493SE
2500501NE
2500501SE
2500509NE
2500509SE
2500517NE
2500517SE
2500525NE
2500525SE
2500533NE
2500533SE
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2514453SW
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2514461NW
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2598549SE
2598549SW
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2612493NE	2612533SW	2626485NW	2626533NE	2640509NE
2612493NW	2612541NE	2626485SE	2626533NW	2640509NW
2612493SE	2612541NW	2626485SW	2626533SE	2640509SE
2612493SW	2612541SE	2626493NE	2626533SW	2640509SW
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2612501SE	2612549NW	2626493SW	2626541SE	2640525NW
2612501SW	2612549SE	2626501NE	2626541SW	2640525SW
2612509NE	2612549SW	2626501NW	2626549NW	2654493NW
2612509NW	2612557NE	2626501SE	2626549SW	2654501NW
2612509SE	2612557NW	2626501SW	2626557NW	2654501SW
2612509SW	2612557SE	2626509NE	2626557SW	2654509SW
2612517NE	2612557SW	2626509NW	2640485NE	
2612517NW	2612565NE	2626509SE	2640485NW	
2612517SE	2612565NW	2626509SW	2640485SW	
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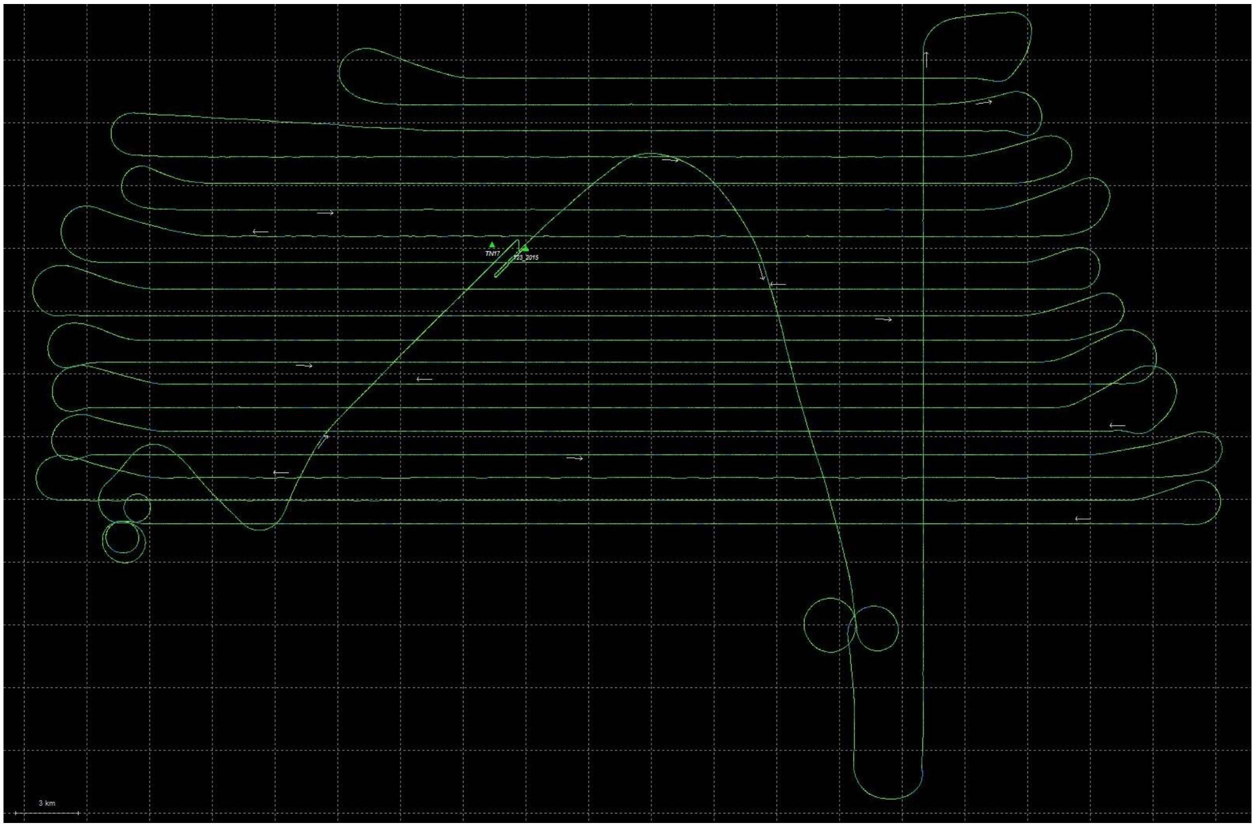
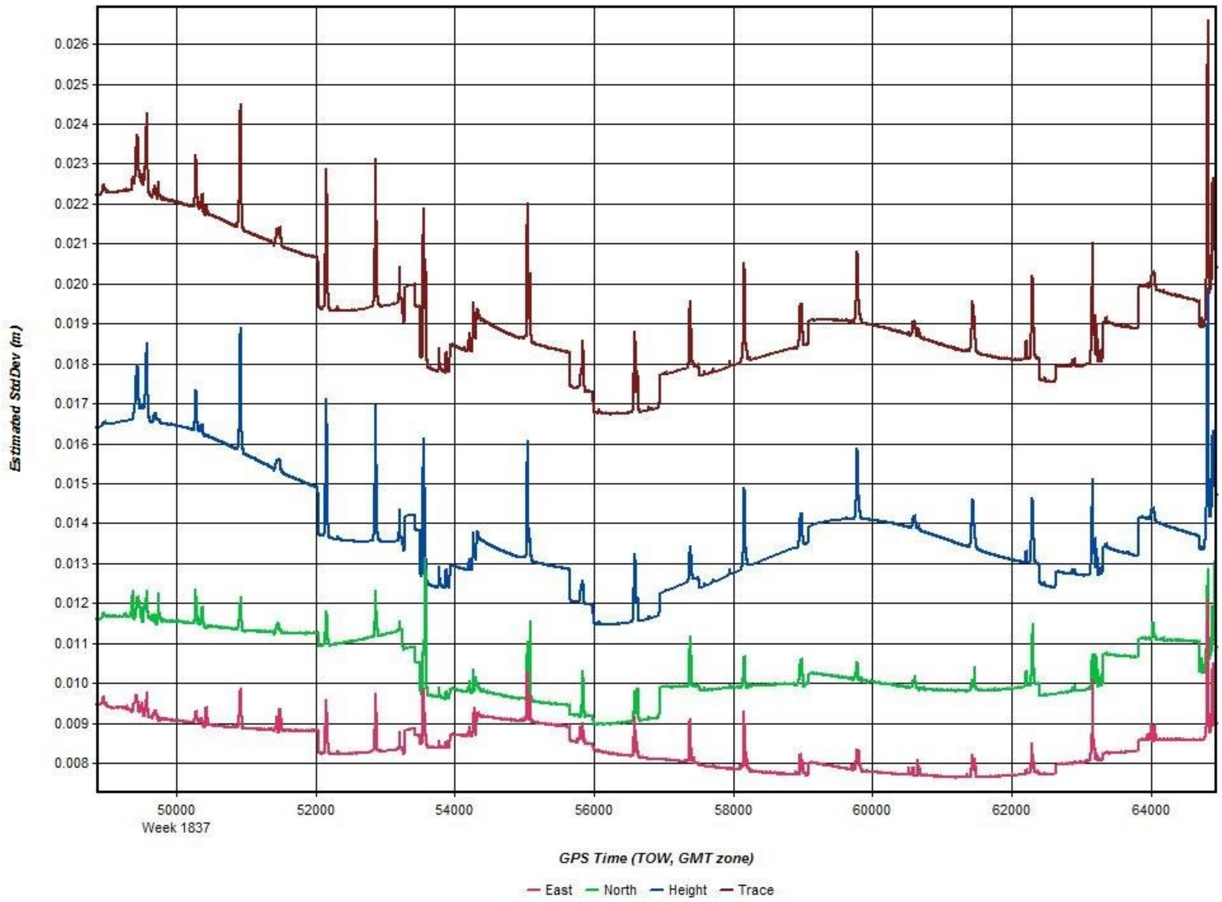
Appendix C: GPS Processing

123_20150322_1

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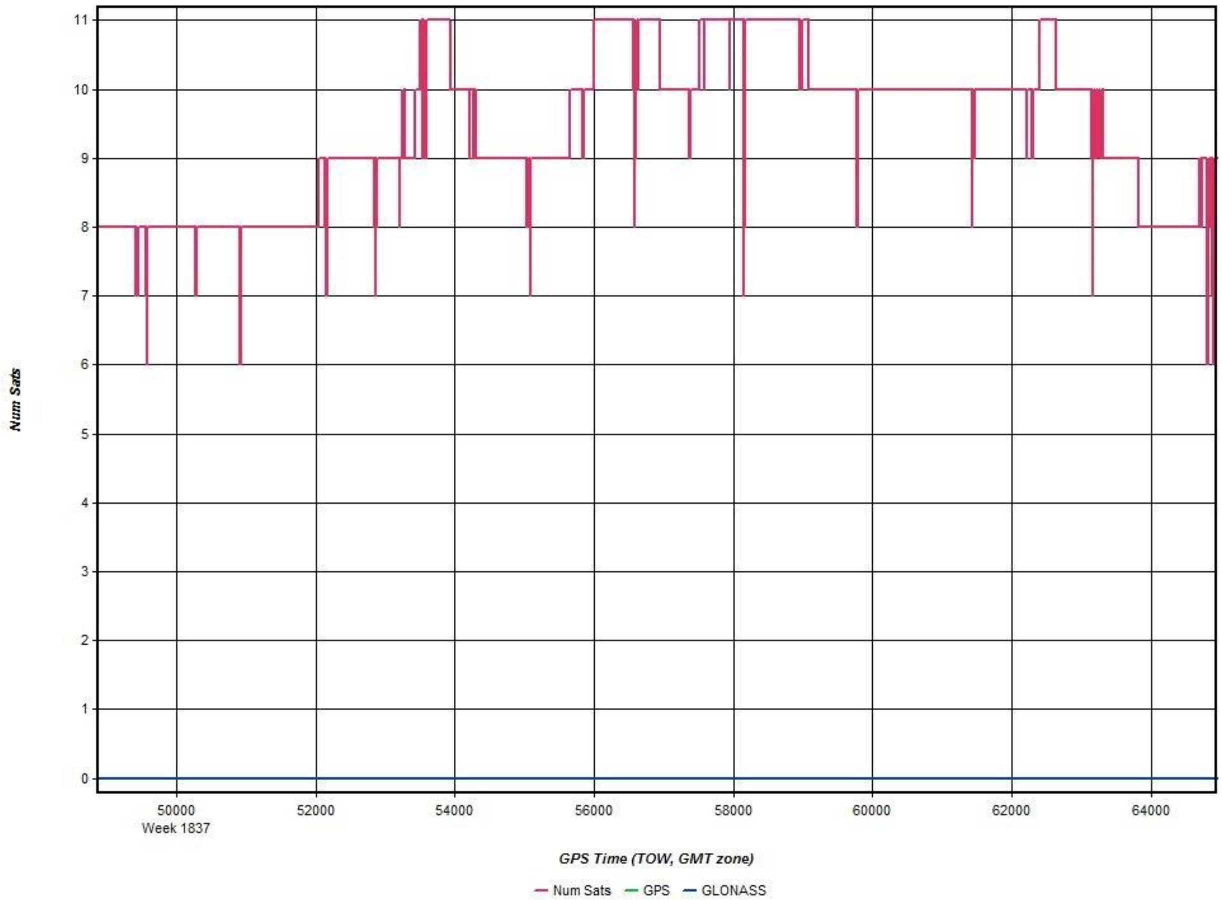
0.024
0.023
0.022
0.021
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
0.008
Estimated StdDev (m)
50000
Week 1837
52000
54000
56000
58000
60000
62000
64000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
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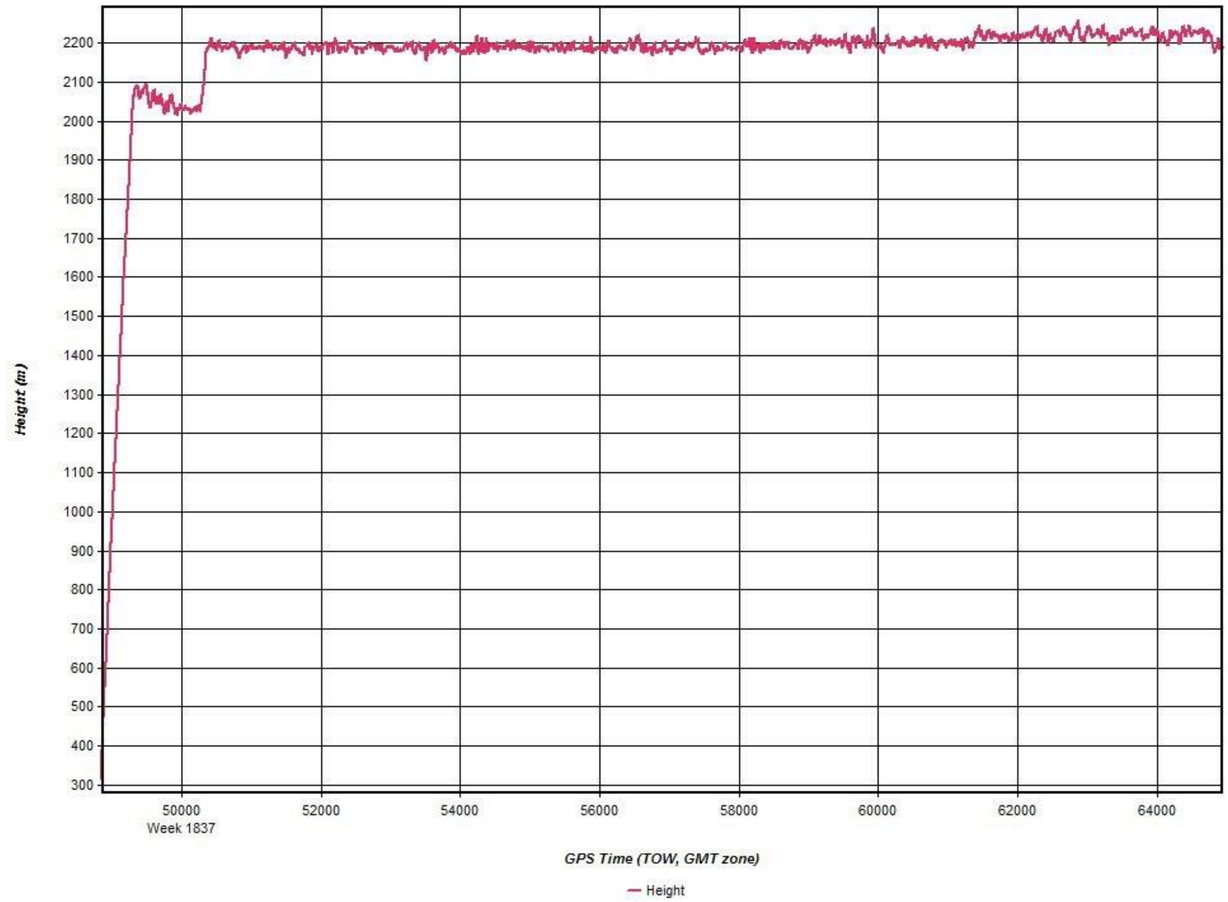
10
9
8
7
6
5
4
3
2
1
0
50000
Week 1837
52000
54000
56000
58000
60000
62000
64000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS


Height (m)
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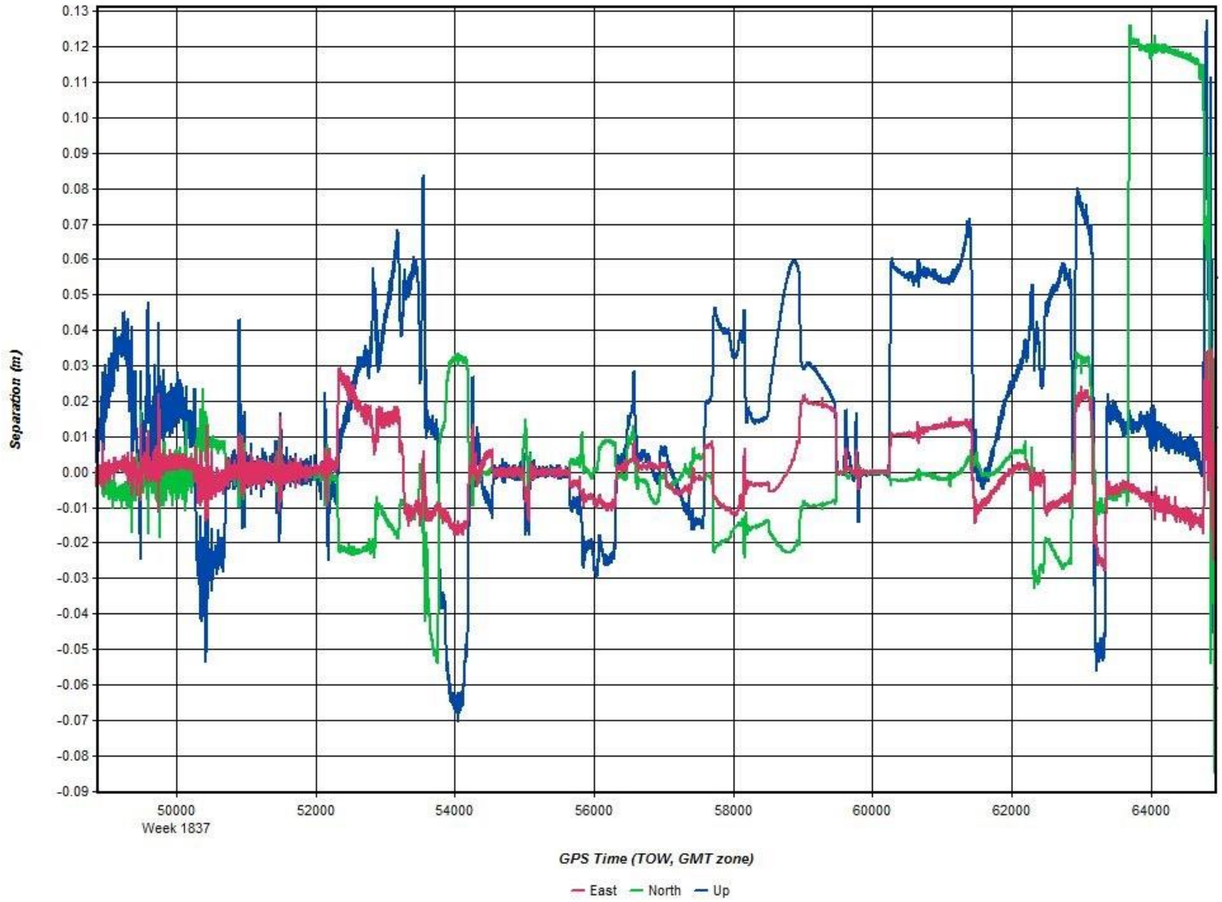
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
50000
Week 1837
52000
54000
56000
58000
60000
62000
64000
GPS Time (TOW, GMT zone)
Height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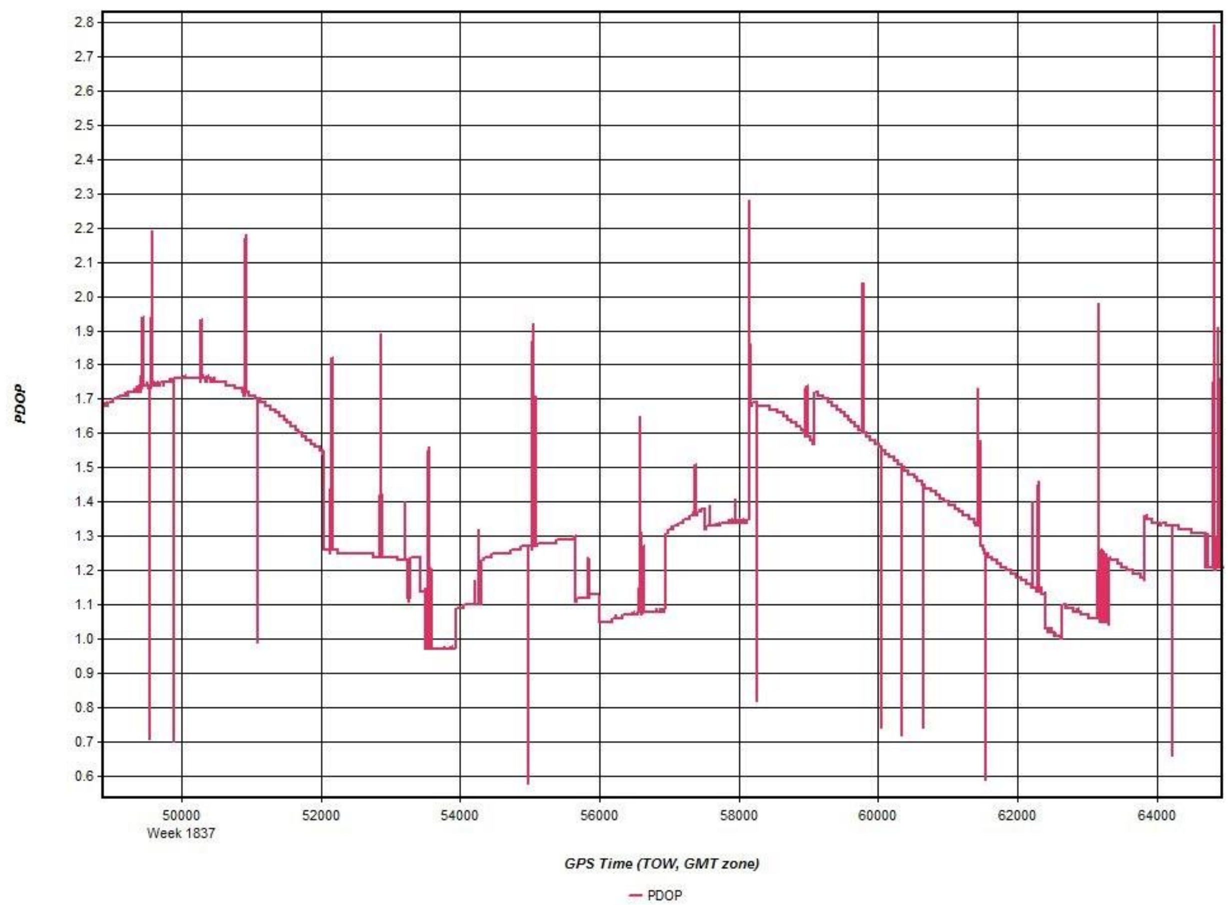
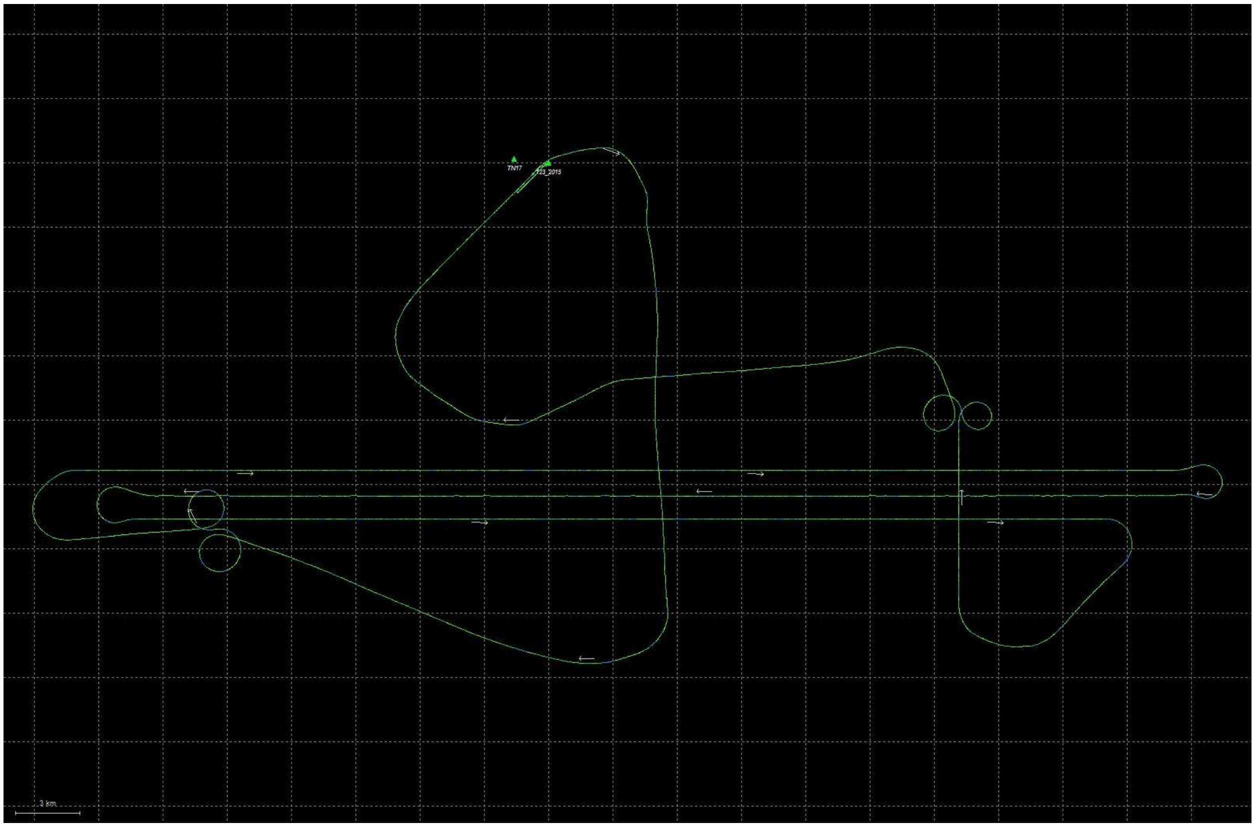
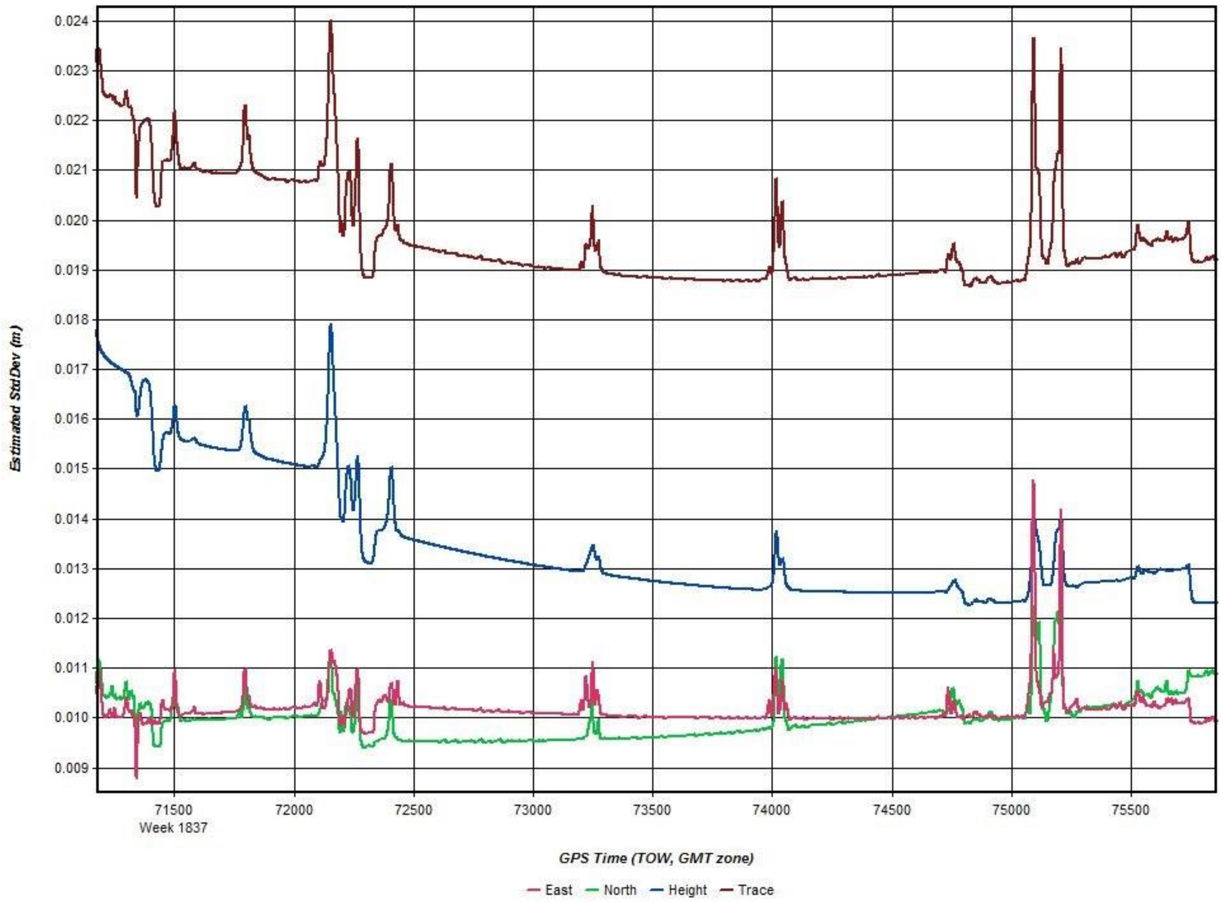
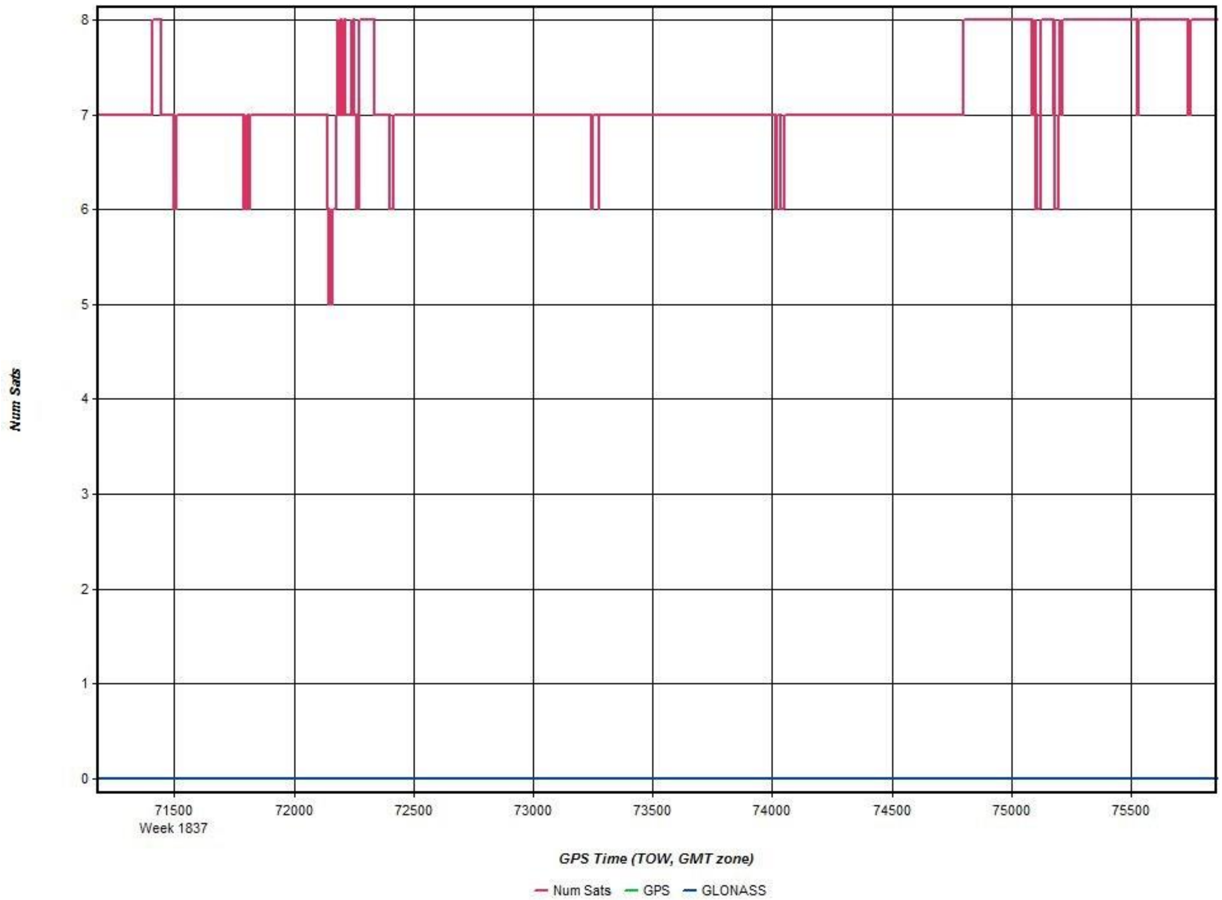
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
-0.08
-0.09
Separation (m)
50000
Week 1837
52000
54000
56000
58000
60000
62000
64000
GPS Time (TOW, GMT zone)
East
North
Up

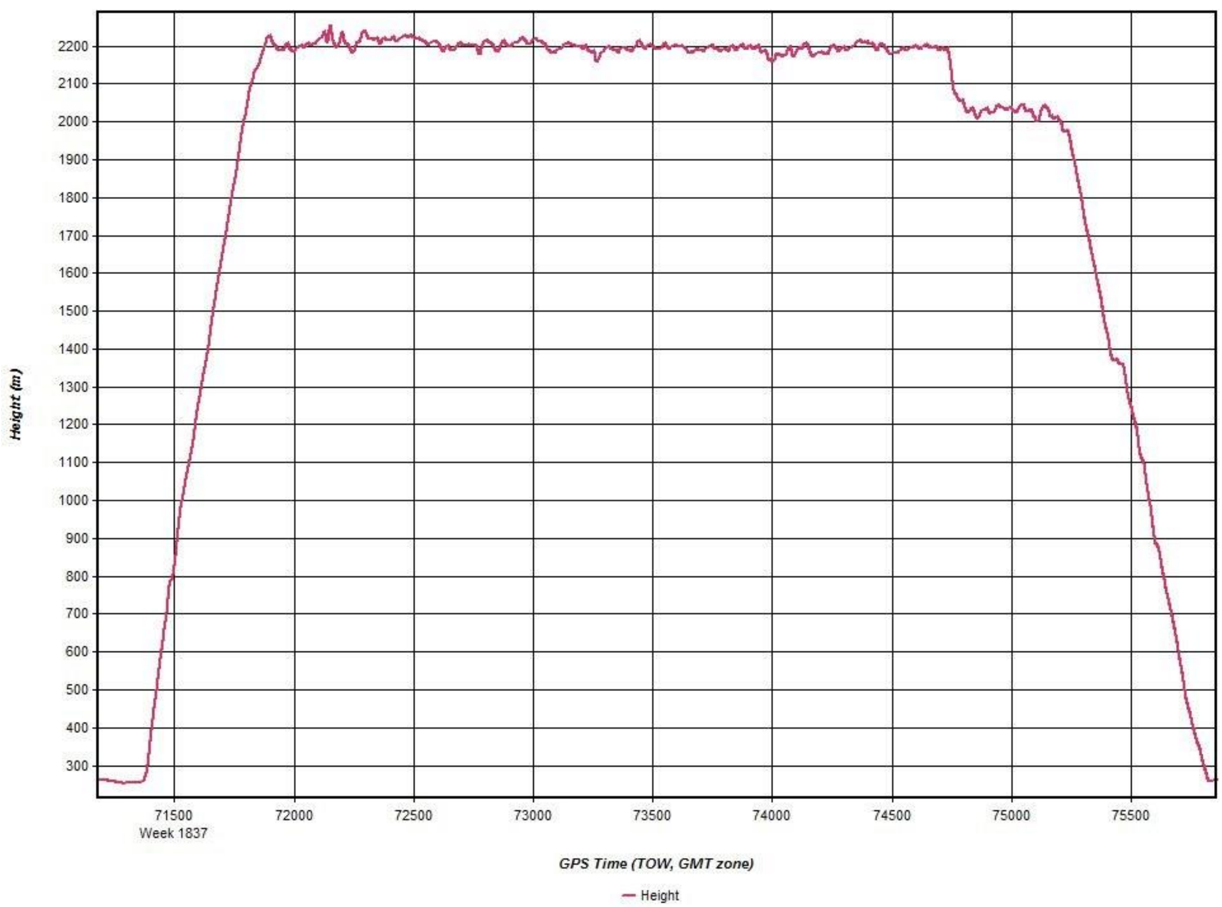


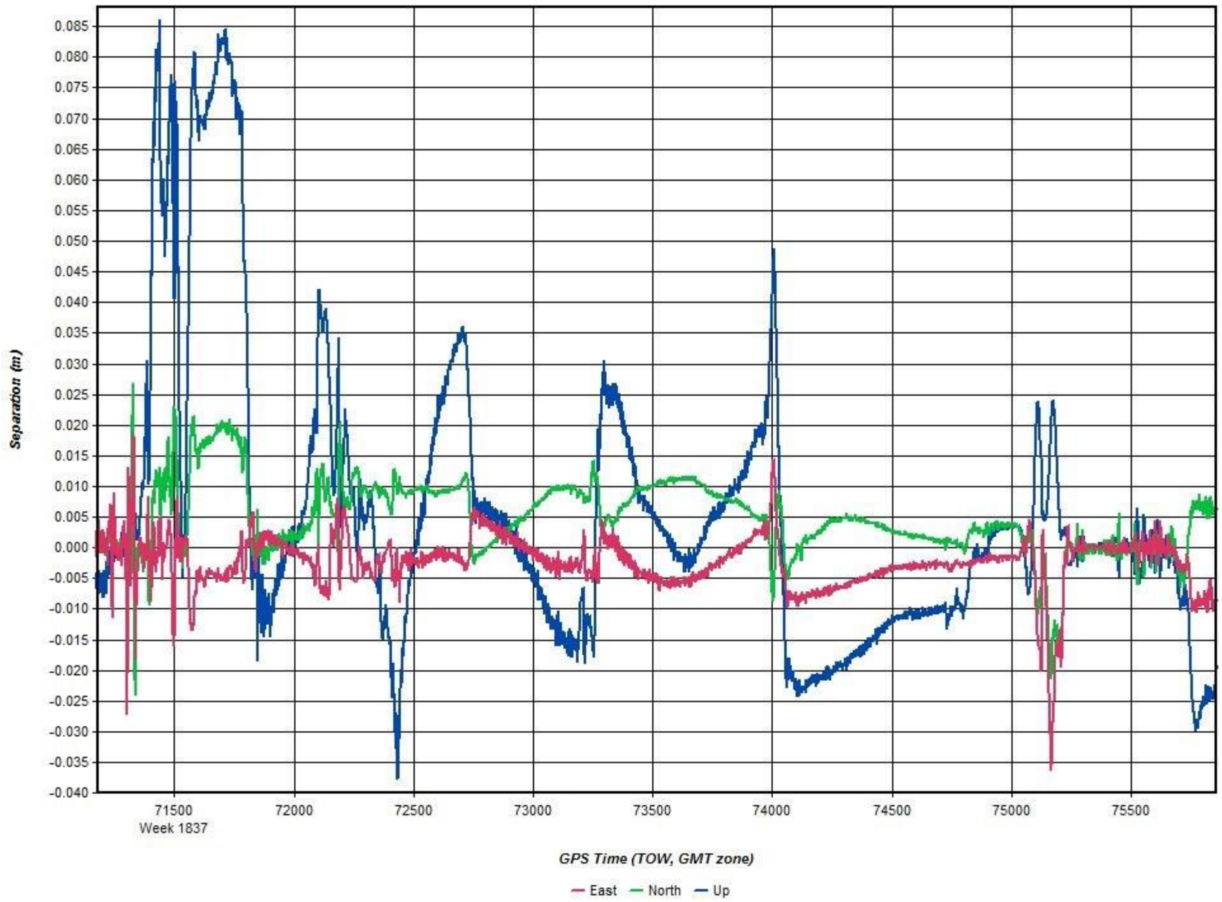
123_20150322_2


TN17
123_2015
3 km


0.024
0.023
0.022
0.021
0.020
0.019
0.018
0.017
0.016
0.015
0.014
0.013
0.012
0.011
0.010
0.009
Estimated StdDev (m)
71500
Week 1837
72000
72500
73000
73500
74000
74500
75000
75500
GPS Time (TOW, GMT zone)
East
North
Height
Trace


8
7
6
5
4
3
2
1
0
Num Sats
71500
Week 1837
72000
72500
73000
73500
74000
74500
75000
75500
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS


Height (m)
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
71500
Week 1837
72000
72500
73000
73500
74000
74500
75000
75500
GPS Time (TOW, GMT zone)
Height


Separation (m)
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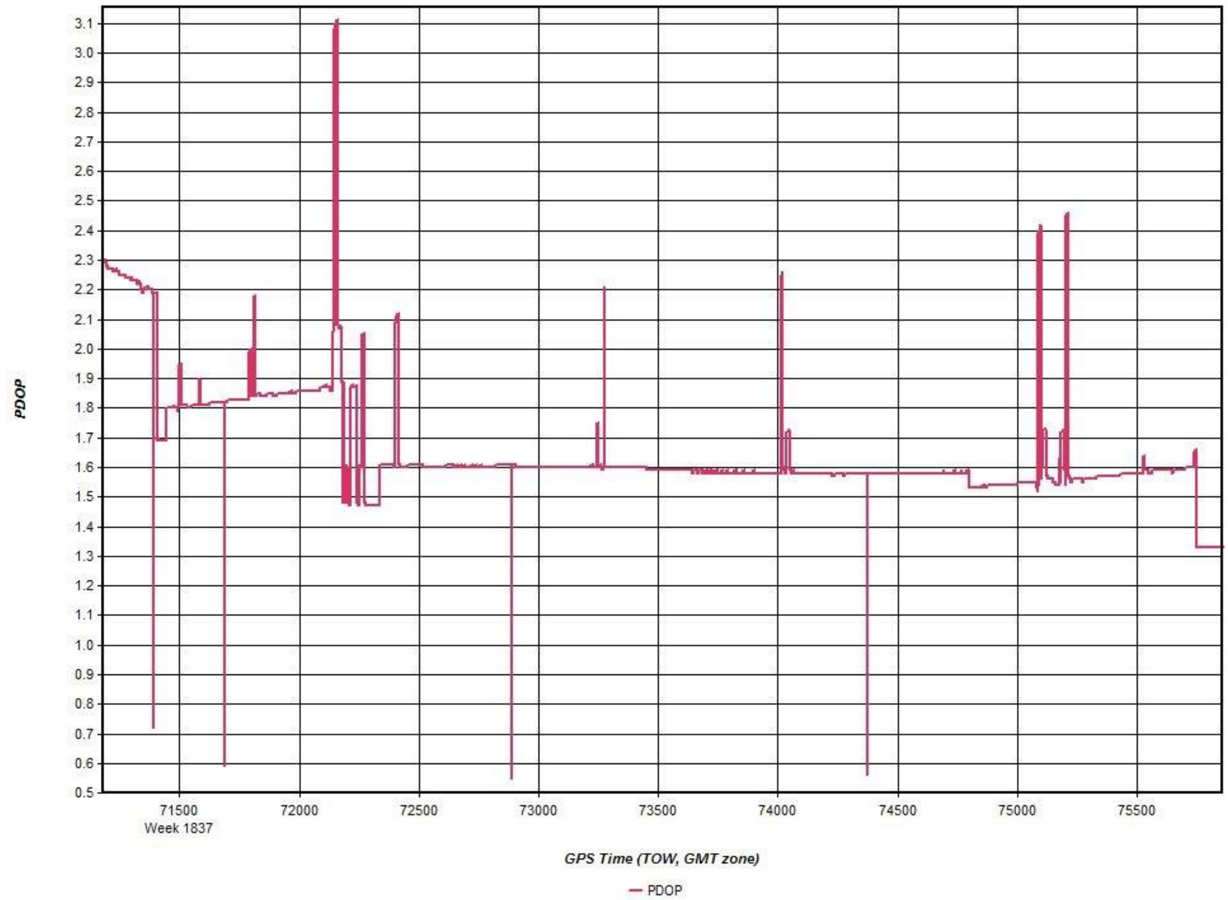
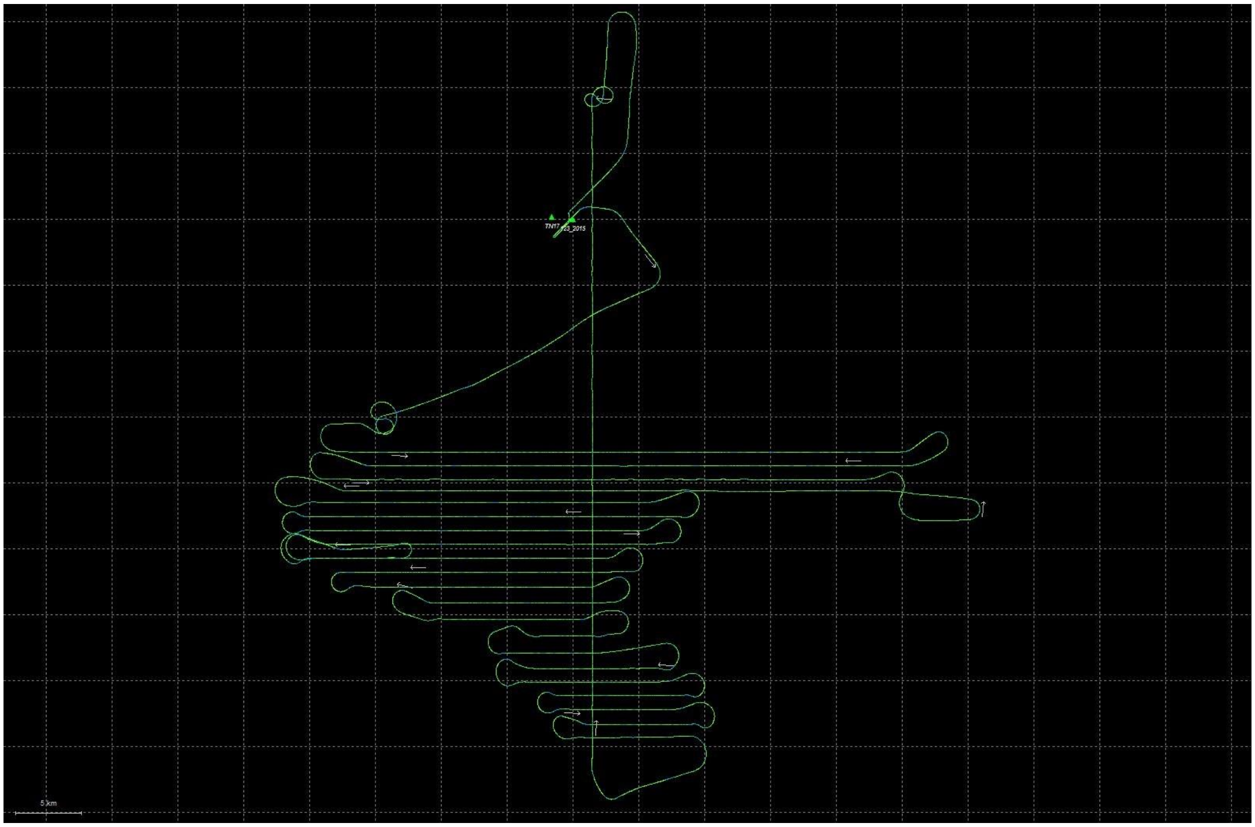
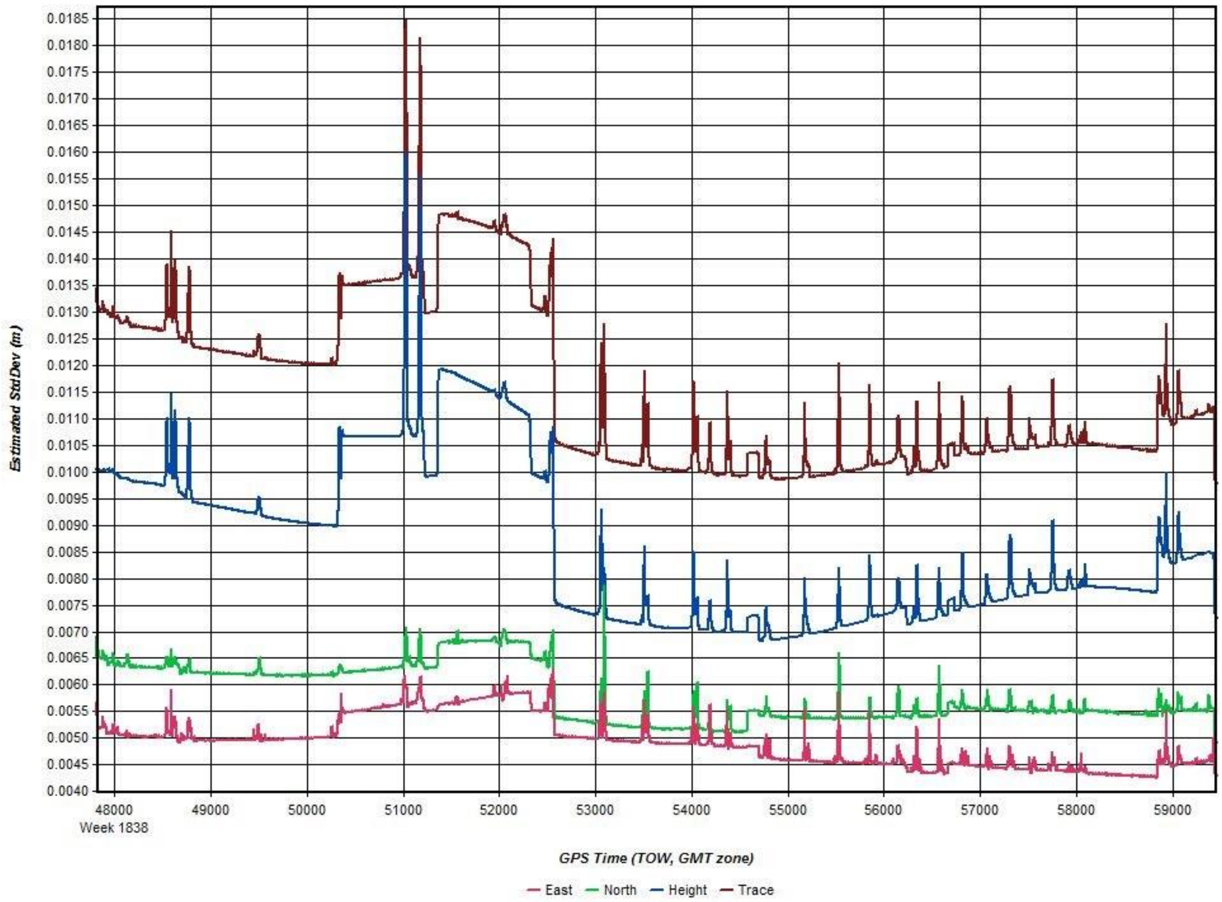
0.080
0.075
0.070
0.065
0.060
0.055
0.050
0.045
0.040
0.035
0.030
0.025
0.020
0.015
0.010
0.005
0.000
-0.005
-0.010
-0.015
-0.020
-0.025
-0.030
-0.035
-0.040
71500
Week 1837
72000
72500
73000
73500
74000
74500
75000
75500
GPS Time (TOW, GMT zone)
East
North
Up



123_20150329_1




Estimated StdDev (m)
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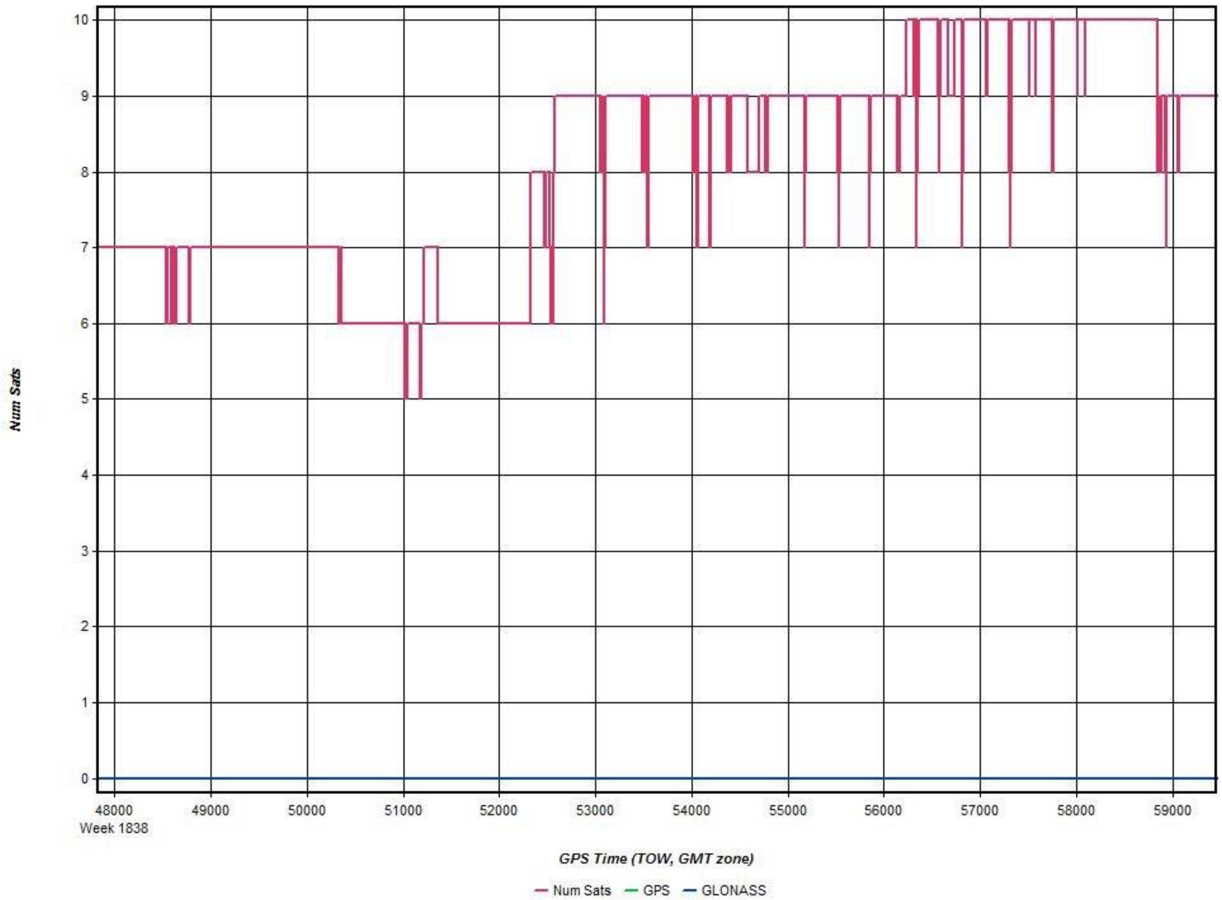
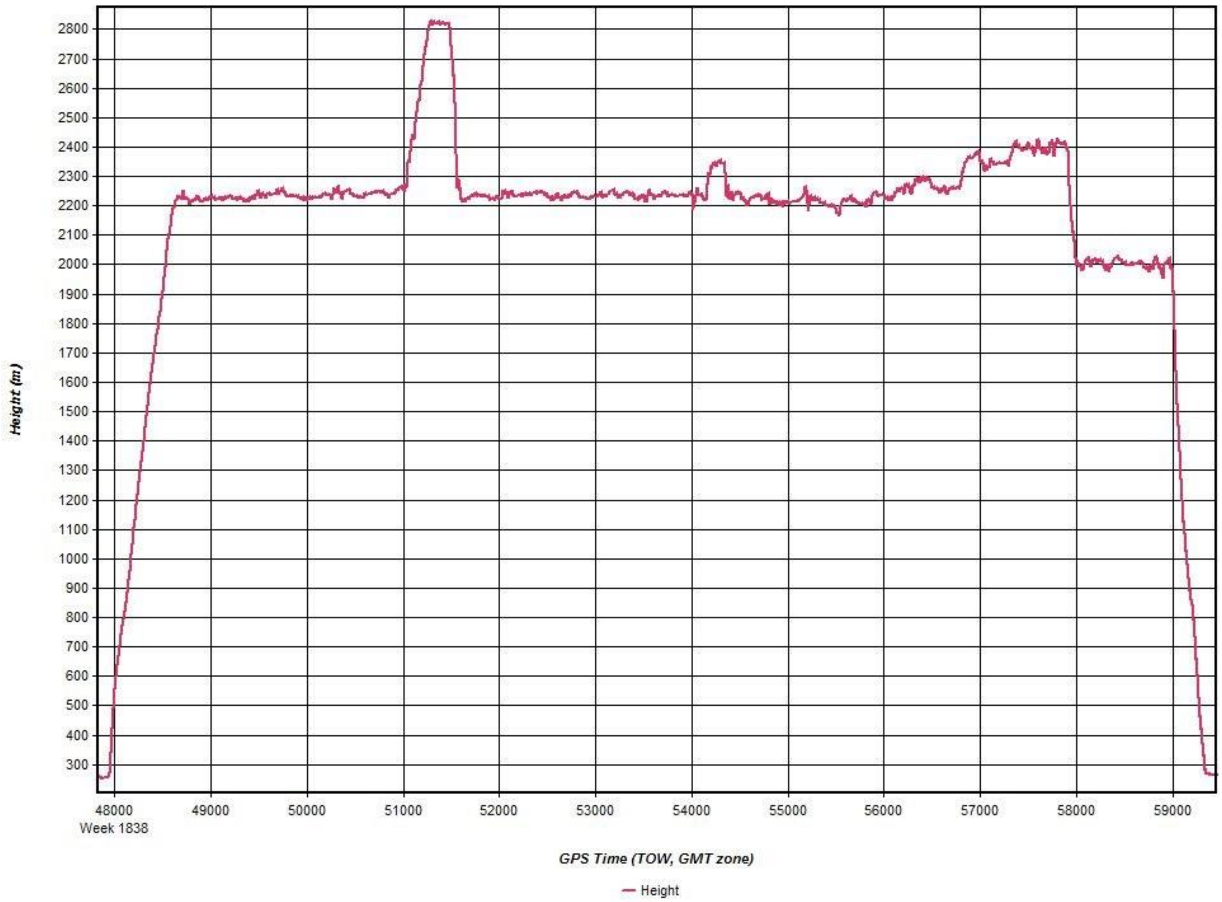
0.0175
0.0170
0.0165
0.0160
0.0155
0.0150
0.0145
0.0140
0.0135
0.0130
0.0125
0.0120
0.0115
0.0110
0.0105
0.0100
0.0095
0.0090
0.0085
0.0080
0.0075
0.0070
0.0065
0.0060
0.0055
0.0050
0.0045
0.0040
48000
Week 1838
49000
50000
51000
52000
53000
54000
55000
56000
57000
58000
59000
GPS Time (TOW, GMT zone)
East
North
Height
Trace


Num Sats
10
9
8
7
6
5
4
3
2
1
0
48000
Week 1838
49000
50000
51000
52000
53000
54000
55000
56000
57000
58000
59000
GPS Time (TOW, GMT zone)
Num Sats
GPS
GLONASS


Height (m)
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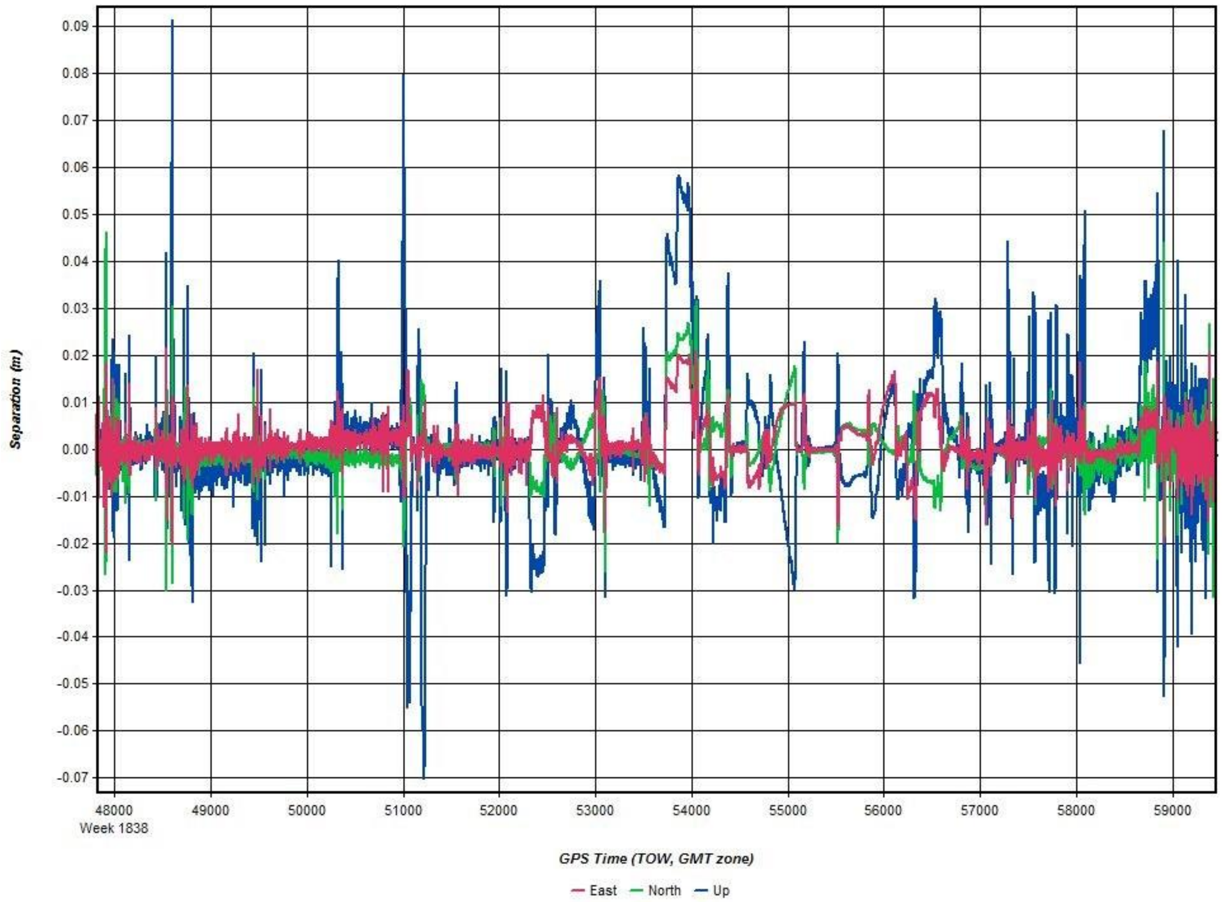
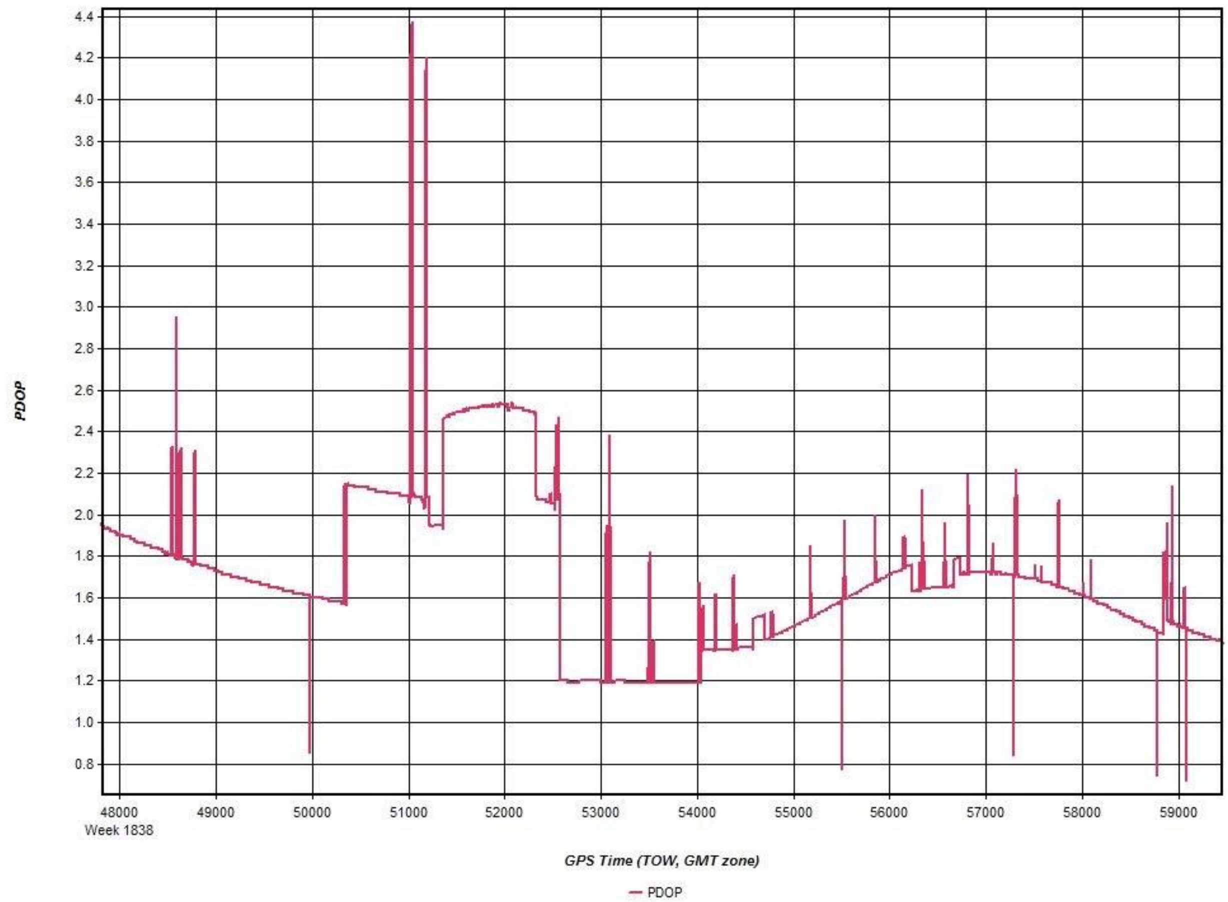
2700
2600
2500
2400
2300
2200
2100
2000
1900
1800
1700
1600
1500
1400
1300
1200
1100
1000
900
800
700
600
500
400
300
48000
Week 1838
49000
50000
51000
52000
53000
54000
55000
56000
57000
58000
59000
GPS Time (TOW, GMT zone)
Height


0.09
0.08
0.07
0.06
0.05
0.04
0.03
0.02
0.01
0.00
-0.01
-0.02
-0.03
-0.04
-0.05
-0.06
-0.07
Separation (m)
48000
Week 1838
49000
50000
51000
52000
53000
54000
55000
56000
57000
58000
59000
GPS Time (TOW, GMT zone)
East
North
Up


4.4
4.2
4.0
3.8
3.6
3.4
3.2
3.0
2.8
2.6
2.4
2.2
2.0
1.8
1.6
1.4
1.2
1.0
0.8
PDOP
48000
Week 1838
49000
50000
51000
52000
53000
54000
55000
56000
57000
58000
59000
GPS Time (TOW, GMT zone)
PDOP