IL_Champaign_City_QL1 Lidar 2019 Final Report

Report Produced for U.S. Geological Survey

TASK ORDER: G17PC00007

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Overview

The original purpose of this project was to develop a consistent and accurate surface elevation dataset derived from high-accuracy Light Detection and Ranging (LiDAR) technology for the USGS IL_8County_PlusChampaign_2019_B19 project Area. The AOI covered approximately 6,337 square miles in total and include the counties of Champaign, Jo Daviess, Stephenson, Carroll, Ogle, Whiteside, Lee, Rock Island, and Henry. Option 1 allows for an increase in the quality level of the areas over the cities of Champaign and Urbana (~116 sq. mi.) to QL1 (ANPS≤0.35m). Adverse ground conditions during the spring 2019 flight season limited Lidar acquisition to a small portion of the entire project area. Approximately 116 square miles of Option 1 referred to as IL_Champaign_City_QL1+ Lidar 2019 was acquired in the spring of 2019.

The LiDAR data for IL_Champaign_City QL1 was processed and classified according to project specifications. Detailed breaklines, bare earth Digital Elevation Models (DEMs), and Intensity Images were produced for the Option 1 project area. Data was formatted into tiles with each tile covering an area of 1000 meters by 1000 meters. A total of 301 LAS files, 301 DEMs, and 301 Intensity Images were produced for the project, encompassing the Option 1 AOI of approximately 116 square miles and formatted into 301 total tiles.

PROJECT TEAM

Aerial Services, Inc. (ASI) served as the prime contractor for the project. In addition to project management ASI was responsible for LiDAR acquisition and calibration, LAS classification, LiDAR products, Digital Elevation Model (DEM) production, Intensity Image production, and quality assurance. All follow-on processing was completed by the prime contractor.

Surveying and Mapping, LLC (SAM) completed ground surveying for the project and delivered surveyed checkpoints. SAM was to acquire surveyed checkpoints for the project to use in independent testing of the vertical accuracy of the LiDAR-derived surface model. Please see SURVEY REPORT 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 Option 1 IL_Champaign_City, covering only the cities of Champaign and Urbana Illinois.

DATE OF SURVEY

LiDAR acquisition for IL_Champaign_City was conducted on April 16, 2019.

COORDINATE REFERENCE SYSTEM

Data produced for the project was 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: Albers Equal Area.
Units: Horizontal units are in meters, Vertical units are in meters.
Geoid Model: Geoid12B

LIDAR VERTICAL ACCURACY

For the IL_Champaign_City QL1 project, the tested RMSEz of the classified LiDAR data for checkpoints in non-vegetated terrain equaled 0.019 meters compared with the 10 cm specification: The 95% confidence value of NVA of the classified LiDAR data computed using RMSEz x 1.96 and was found to equal 0.037 meters compared with the 19.6 cm specification.

For the IL_Champaign_City QL1 project, the tested VVA of the classified LiDAR data computed using the 95th percentile was equal to 0.046 meters, compared with the 29.4 cm (0.96 ft) specification.

Additional accuracy information and statistics for the classified LiDAR data, raw swath data, and bare earth DEM data can be found in 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. Intensity Images (8-bit gray scale, tiled, GeoTIFF format)
4. Breakline Data (File GDB)
5. Independent Survey Checkpoint Data (File GDB)
6. Calibration Points (File GDB)
7. Metadata
8. Project Report (Acquisition, Processing, QC)
9. Project Extent (Included in breakline GDB)
10. Tile Index (included in breakline GDB)

PROJECT TILING FOOTPRINT

301 tiles, 301 LAS files, 301 DEM tiles, and 301 Intensity Image tiles were delivered for the project. Each tile's extent is 1000 meter by 1000 meter. (See Appendix A for a complete listing of delivered tiles.)

IL_Champaign City QL1 LiDAR

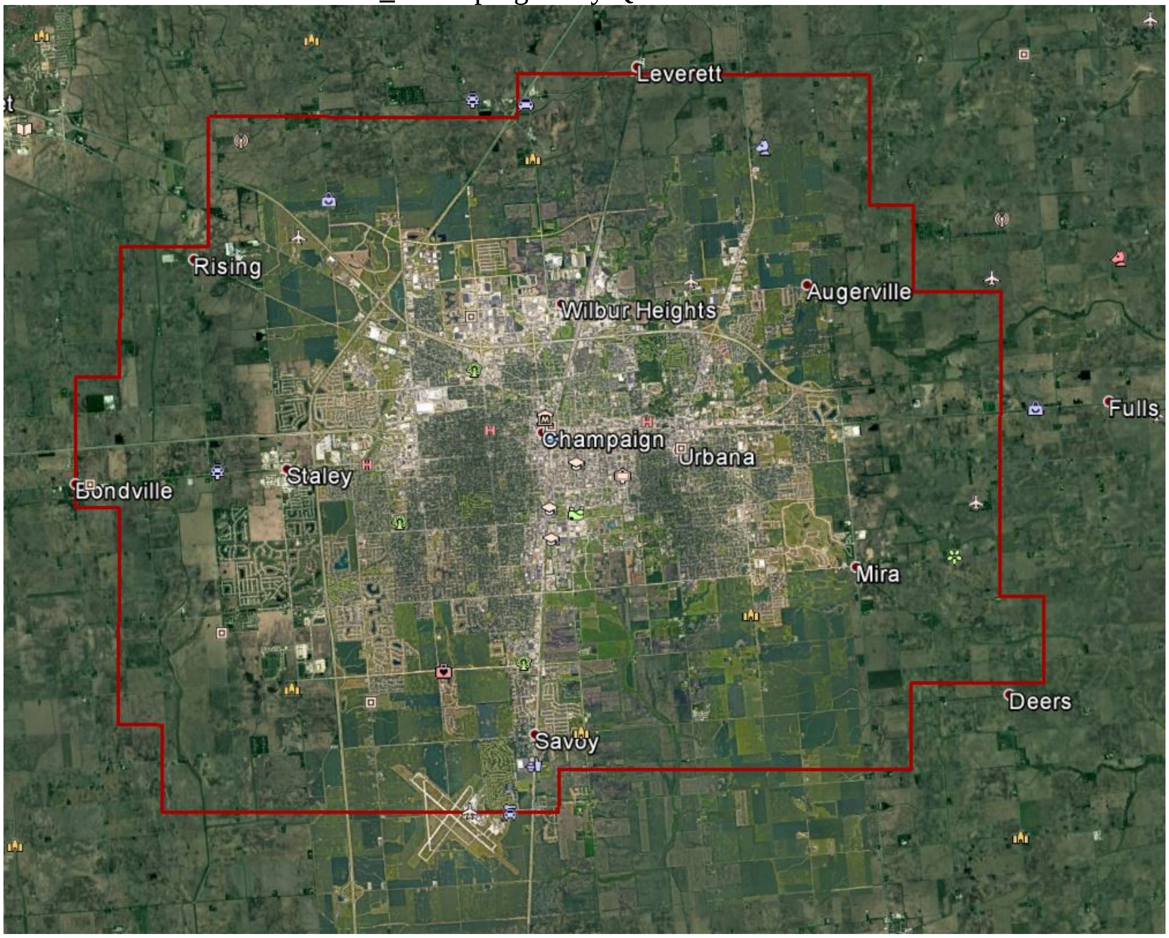


Figure 1 – Option Area of Interest

LIDAR ACQUISITION DETAILS

Aerial Services, Inc. served as prime contractor for the IL_Champaign_City QL1 project and preformed the LiDAR Acquisition and Calibration.

Aerial Services, Inc. planned 43 passes for the project area as well as two additional cross flightlines for the purposes of quality control in our own processing which are not included in delivery. 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, Aerial Services, Inc. followed FEMA's Appendix A "guidelines" for flight planning and, at a minimum, includes the following criteria:

- A digital flight line layout using LEICA MISSION PRO flight design 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 have been investigated so that required permissions can be obtained in a timely manner with respect to schedule. Additionally, Aerial Services, Inc. will file our flight plans as required by local Air Traffic Control (ATC) prior to each mission.

Aerial Services, Inc. monitored weather and atmospheric conditions and conducted lidar missions only when no conditions exist below the sensor that will affect 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. Aerial Services, Inc. accesses 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, Aerial Services, Inc. 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.

Aerial Services, Inc. lidar sensors are calibrated at a designated site located at the Waverly Municipal Airport in Waverly, Iowa and are periodically checked and adjusted to minimize corrections at project sites.

LIDAR SYSTEM PARAMETERS

Aerial Services, Inc. operated a Cessna (Tail # N5531A) outfitted with a LEICA ALS70-HP lidar system during the collection of the study area. Table 1 illustrates Aerial Services, Inc. system parameters for lidar acquisition on this project.

Item	Parameter
System	Leica ALS-70 HP
Maximum Number of Returns per Pulse	4
Nominal Pulse Spacing (single swath), (m)	0.354
Nominal Pulse Density (single swath) (ppsm), (m)	8
Aggregate NPS (m) (if ANPS was designed to be met through single coverage, ANPS and NPS will be equal)	0.354
Aggregate NPD (m) (if ANPD was designed to be met through single coverage, ANPD and NPD will be equal)	8
Altitude (AGL meters)	1100
Approx. Flight Speed (knots)	150
Total Sensor Scan Angle (degree)	60
Scan Frequency (hz)	60
Scanner Pulse Rate (kHz)	246
Did the Sensor Operate with Multiple Pulses in The Air? (yes/no)	Yes
Nominal Swath Width on the Ground (m)	589
Swath Overlap (%)	30
Max. Point Spacing Along Track (m)	0.39
Max. Point Spacing Across Track (m)	1.29

Table 1: Aerial Services, Inc. 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.

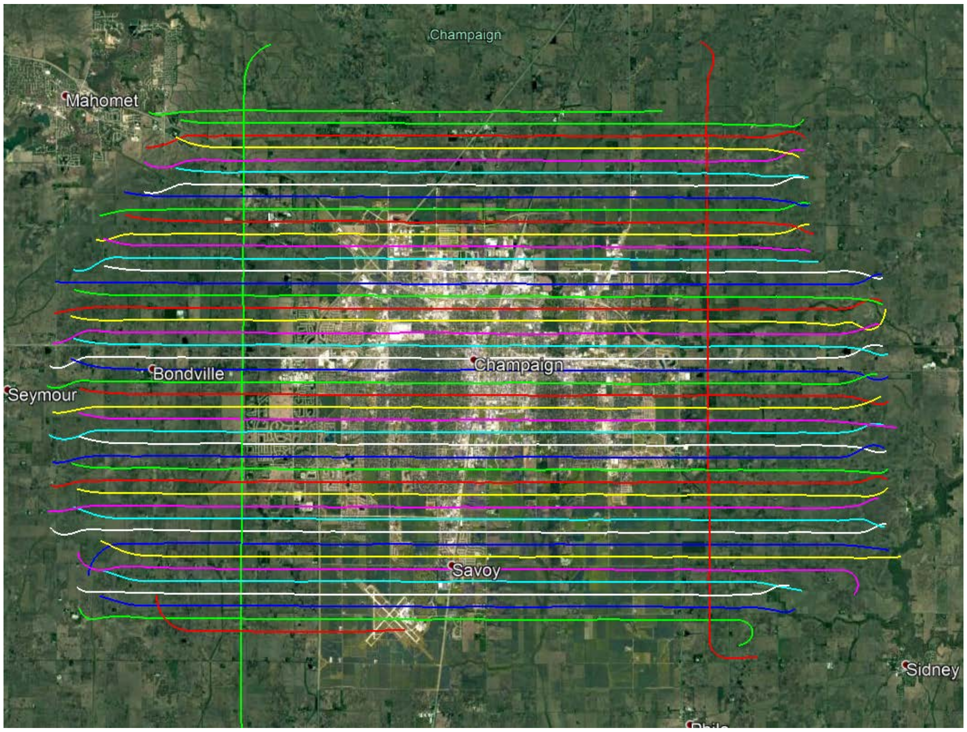


Figure 2: G17PC00007_IL_Champaign_City_2019_B19 trajectories as flown by Aerial Services, Inc.

ACQUISITION CONTROL

Aerial Services, Inc. conducted the survey which provided the established base stations used to control the lidar acquisition for the IL_Champaign_City project area. The coordinates of the base stations are provided in the table below.

Name	**NAD83(2011) UTM 16**		**Ellipsoid Ht (WGS84, m)**
	Easting X (m)	**Northing Y (m)**	
ILUC	**865961.636**	**382794.804**	**233.775**

Table 2 – Base station used to control lidar acquisition for the Project.

AIRBORNE GPS KINEMATIC

Airborne GPS data was processed using Waypoint's Inertial Explorer version 8.60 software suite. All flights were flown with PDOP less than or equal to 3.0 and with at least 6 satellites in common view of both a stationary reference receiver and the airborne GPS. Distances from base station to aircraft were kept to a maximum of 50 km.

For all flights, the GPS data can be classified as excellent, with GPS residuals no larger than 10 cm being recorded.

GPS processing reports for each mission are included in Appendix B.

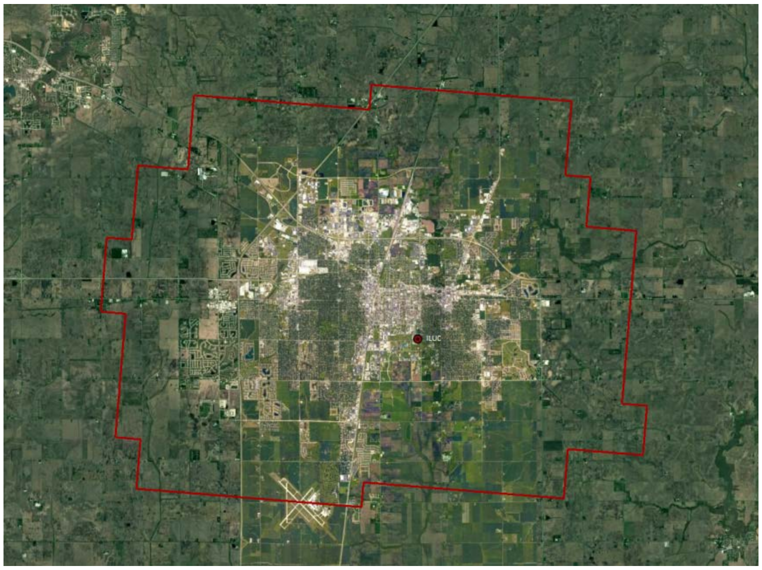


FIGURE 3 – G17PC00007_IL_CHAMPAIGN_CITY_2019_B19 BASESTATION LOCATION

GENERATION AND CALIBRATION OF LASER POINTS (RAW DATA)

After processing the GNSS/GPS and IMU data in Inertial Explorer, the data is then exported to raw LAS files using Leica's CloudPro software. CloudPro combines the raw data collected with the ALS 70 HP sensor, combines it with the airborne trajectory data, applies the sensor's calculated boresight correction angles, and then outputs the point cloud to the specified coordinate reference system and file format.

The initial step of calibration is to verify the complete coverage of the AOI with no internal voids present, as well as ensuring that minimum point density of 8.0 ppsm has been achieved.

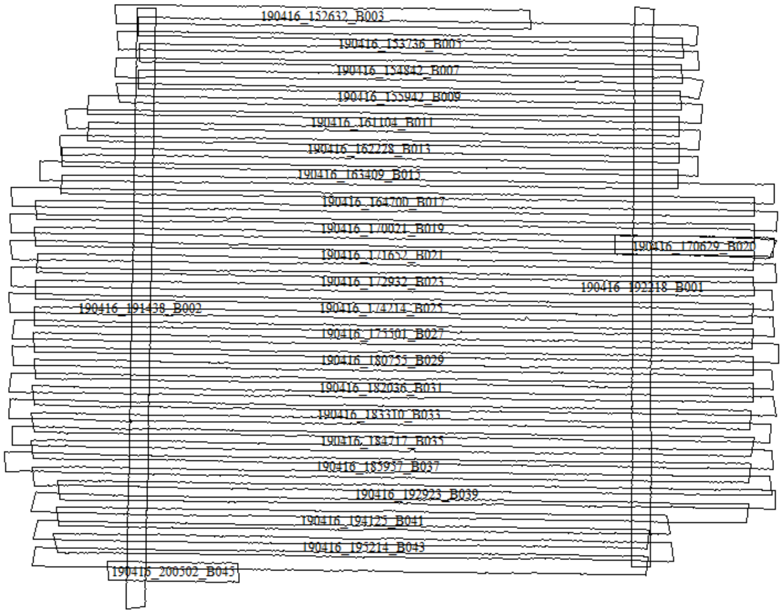


Figure 4 – Lidar swath coverage over AOI.

Boresight and Relative accuracy

Subsequently, the project's data is then loaded into Microstation/TerraScan for viewing and post-processing of calibration errors. Roll, pitch, and heading corrections are calculated to produce the best relative accuracy that can be achieved, and at minimum 8 cm RMSDz with a 16 cm maximum difference. Tested interswath RMSDz was 0.013 meters.

The relative accuracy of every swath is checked and QC'd at 3 different points along its length. Cross sections are visually inspected across each block to validate point to point, flight line to flight line and mission to mission agreement to verify that the project meet the specifications.

For this project the specifications used are as follow
Relative accuracy <= 6 cm maximum differences within individual swaths and <=8 cm RMSDz between adjacent and overlapping swaths.

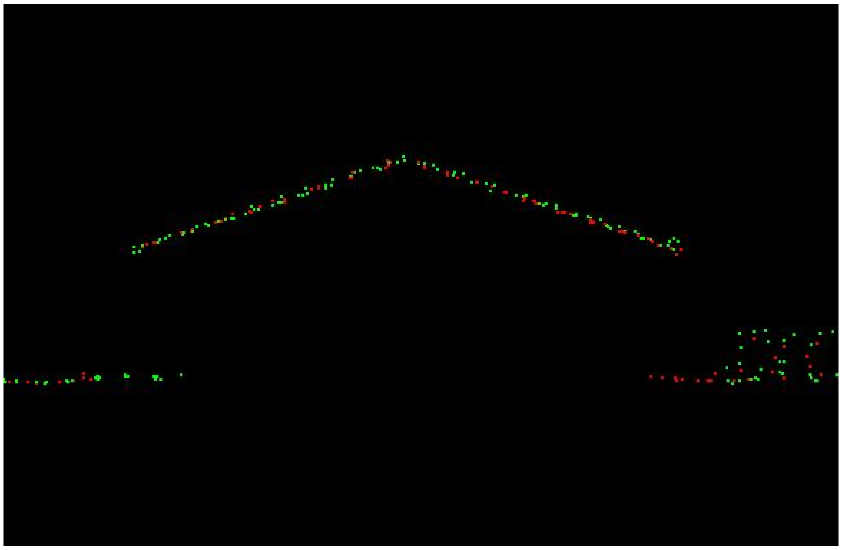


Figure 5 – Profile view showing proper interswath calibration.

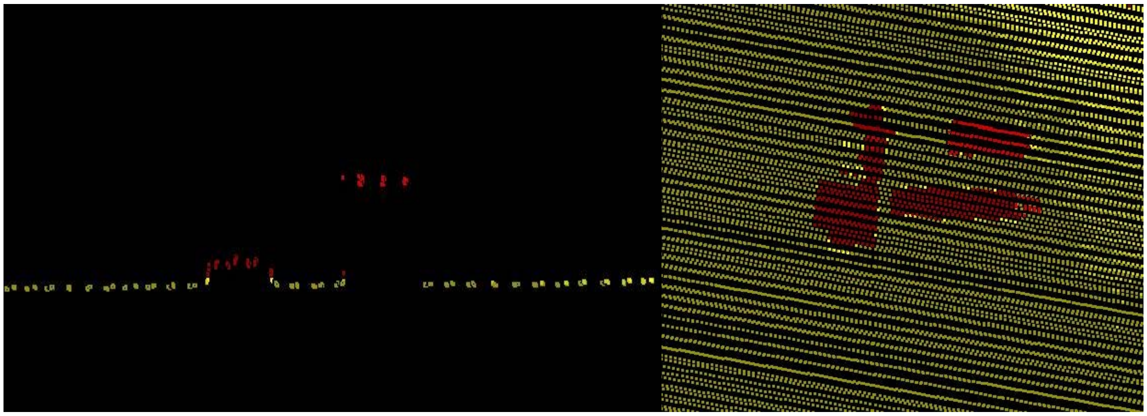


Figure 6 – Top view showing a parking lot with a car and raised feature on a single swath demonstrating intraswath accuracy. Yellow color is scaled to a range of 6 cm in elevation. Points are within 6 cm of variation until the raised curb and car. Also shown is a profile view showing low variability of ranges within the swath.

FINAL CALIBRATION VERIFICATION

Surveying and Mapping, LLC (SAM) conducted the survey for 9 ground control points (GCPs) which were used to test the accuracy of the calibrated swath data. These 9 GCPs were available to use as control in case the swath data exhibited any biases which would need to be adjusted or removed. The coordinates of all GCPs are provided in table 3 and the accuracy results from testing the calibrated swath data against the GCPs is provided in table 4; no further adjustments to the swath data were required based on the accuracy results of the GCPs. Accuracy of the raw point cloud against GCP: 0.015 meters (0.049 ft.) with a 95% confidence value of 0.029 meters (0.095 ft.).

Point ID	NAD83 (2011 adj) UTM 16		NAVD88 (Geoid 12B)		
	Easting X (m)	Northing Y (m)	Z-Survey (m)	Z-LiDAR (m)	Dz
GCP-01	394374.060	4444096.600	227.820	227.830	0.010
GCP-02	393605.730	4434531.720	221.090	221.080	-0.010
GCP-03	388145.330	4441169.780	226.720	226.740	0.020
GCP-04	400679.150	4441379.440	218.300	218.320	+0.020
GCP-05	399456.680	4449437.800	222.770	Outside	*
GCP-06	394557.220	4441349.170	221.980	221.960	-0.020
GCP-07	388115.870	4446416.220	238.250	238.230	-0.020
GCP-08	397729.440	4437773.940	224.190	224.190	0.000
GCP-09	387039.810	4435032.600	213.430	213.420	-0.010

Table 3 – IL Champaign City Project surveyed ground control points (GCPs).

This project must meet Non-vegetated Vertical Accuracy (NVA) ≤ 0.64 ft (19.6 cm) at the 95% confidence level based on RMSE_z ≤ 0.33 ft (10 cm) x 1.9600.

100 % of Totals	# of Points	RMSEz NVA (m)	NVA- Non-vegetated Vertical Accuracy ((RMSEz x 1.9600) m	Mean (m)	Median (m)	Skew	Std Dev (m)	Min (m)	Max (m)	Kurtosis
GCP	13	0.019	0.037	-0.003	-0.007	0.731	0.020	-0.048	0.003	0.271

Table 4 - Ground control points (GCPs) vertical accuracy results.

DATA CLASSIFICATION AND EDITING

Once the calibration, absolute swath vertical accuracy, and relative accuracy of the data were confirmed, ASI utilized TerraScan software for data processing. The acquired 3D laser point clouds, in LAS binary format, were imported into the 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. 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.

Once the ground surface had been deduced through the filtering process a vegetation class was then extracted by distance from ground from remaining class 1. With Building size parameters set, extraction of buildings (class 6) from the vegetation class occurred via an automated method. Once buildings had been deduced the remaining vegetation points were re-filtered by distance into Low Vegetation is 0.5-5 feet, Medium Vegetation is 5-20 feet, High Vegetation is >20 feet from the ground. Classes 3, 4, and 5 define low, medium, and high vegetation points respectively and were classified using an automated method. These vegetation classes represent all non-noise points that fall into the distances above the ground surface, and will likely include buildings and/or parts of building that the automated filters didn't detect utility poles, powerlines, and other infrastructure.

In TerraScan surface models for each tile was created to examine the ground classification. ASI analysts visually reviewed the ground surface model for artifacts left in the ground classification. Theses artifacts consist of vegetation, buildings, and bridges that were still present in the ground after initial processing. ASI analysts employ 3D visualization techniques to view the point cloud at multiple angles and in profile to ensure that errant points are removed from the ground classification. Bridge decks are manually classified to class 17. Building rooftops were manually reviewed to ensure that proper classification had occurred. After the ground classification and building corrections completed, the dataset was processed through a water classification routine that utilizes breaklines compiled by the prime ASI 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, ground points that are within 2x NPS or less of the hydrographic features are moved to class 20 ignored ground, due to breakline proximity. Overage points are then identified in TerraScan and used to set the overlap bit for those points. The withheld points identified during the classification routine are used to set the withheld bit. The LiDAR tiles were classified to the following classification schema:

- Class 1 – Default, Processed, but unclassified
- Class 2 – Ground, Bare-earth
- Class 3 – Low Vegetation is 0.5-5 feet
- Class 4 – Medium Vegetation is 5-20 feet
- Class 5 – High Vegetation is >20 feet
- Class 6 – Buildings (Champaign County only)
- Class 7 – Low Noise (low and manually identified)
- Class 9 – Water
- Class 17 – Bridge Decks
- Class 18 – High Noise (high, manually identified)
- Class 20 – Ignored Ground (Breakline Proximity)
- Class 21- Snow (if present and identifiable)
- Class 22- Temporal Exclusion (typically non-favored data in intertidal zones, as necessary)

After manual classification, the LAS tiles were peer reviewed and then underwent a final QA/QC. After the final QA/QC and corrections, the LAS files were then converted from LAS v1.2 to LAS v1.4 using TerraScan software to flag the overlap bit and withheld bit. LP360 64bit was used to deduce the Well Known Text (WKT) and an ASI proprietary software was used to format the LAS to the final LAS v1.4 Format 6 version. LAStools by rapidlasso GmbH, open source, lasvalidate (open source LGPL) and ASI proprietary software was used to perform final analysis to checks on LAS header information, LAS point classes, and LAS timestamps.

LIDAR QUALITATIVE ASSESSMENT

ASI'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 issues identified in LiDAR data and the results of the visual review for IL_Champaign_City project.

Data Voids

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 IL_Champaign_City project.

Bridge Removal Artifacts

The DEM surface models are created from TINs or Terrains. TIN and Terrain models create continuous surfaces from the inputs. Because a continuous surface is being created, the TIN or Terrain will use interpolation to continue the surface beneath the bridge where no LiDAR data was acquired. Locations where bridges were removed will generally contain less detail in the bare-earth surface because these areas are interpolated. The DEM in the bottom view shows an area where a bridge has been removed from ground. The surface model must make a continuous model and in order to do so, points are connected through interpolation. This results in less detail where the surface must be interpolated. The profile in the top view shows the LiDAR points of this particular feature colored by class. All bridge points have been removed from ground (orange) and are bridge deck (blue).

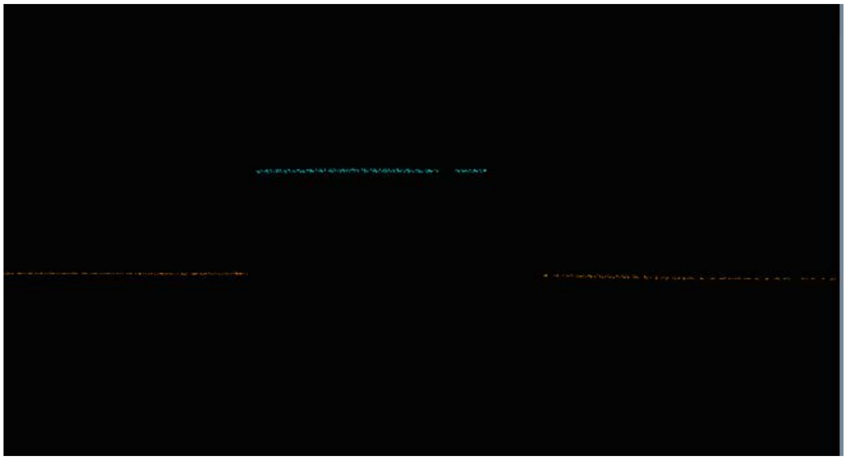


Figure 7: Profile view of a classified bridge deck (blue) and ground (orange).

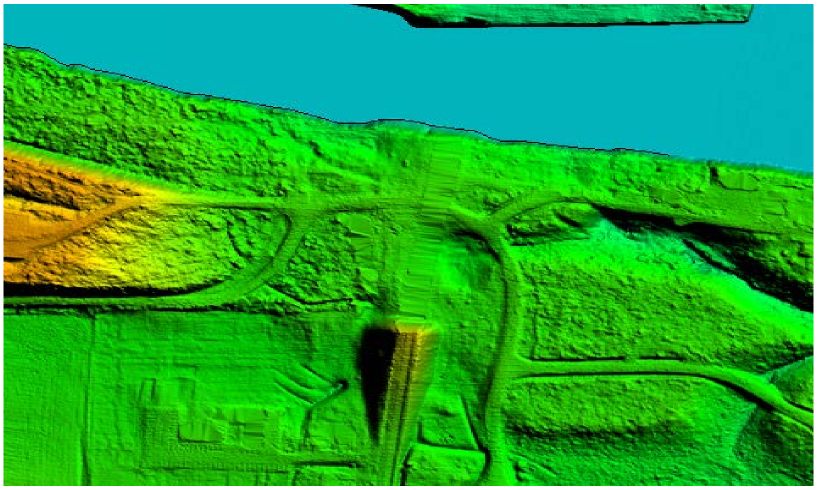


Figure 8: DEM with bridge removed from surface model.

Culverts

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

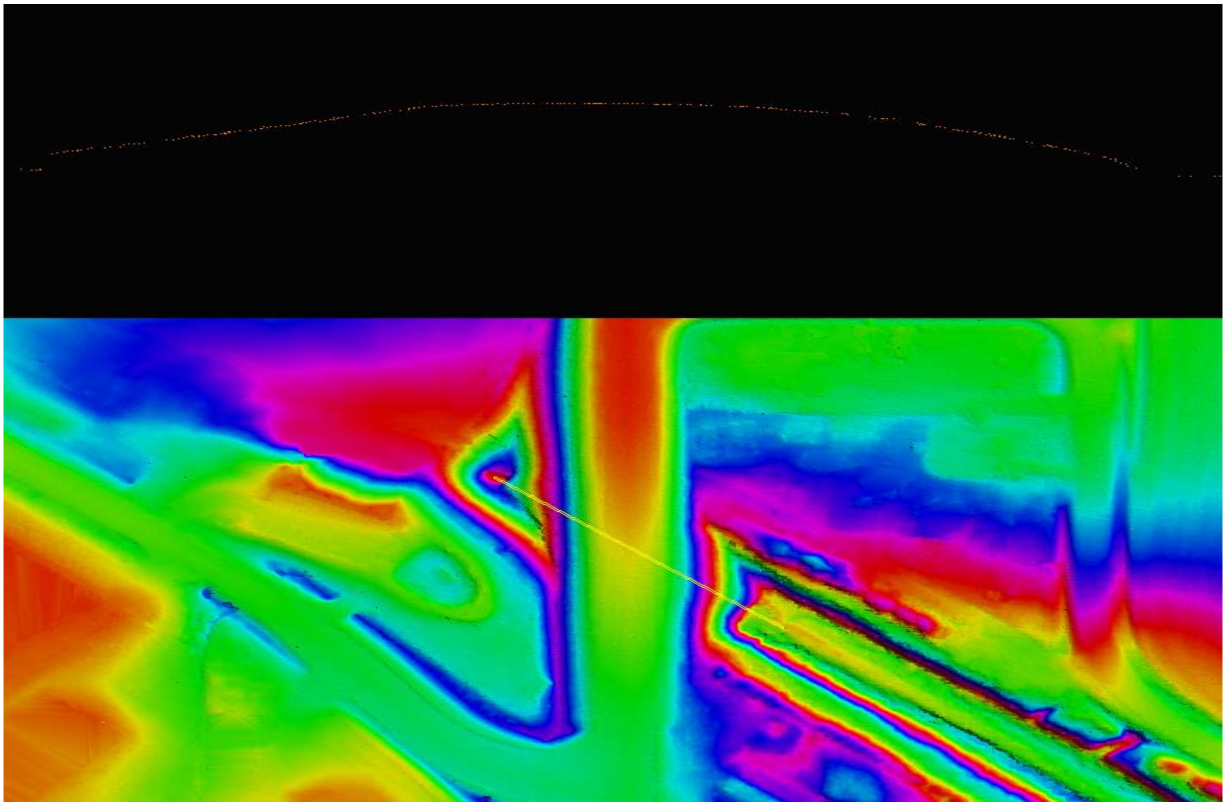


Figure 9: Profile with points colored by class (class 1=white, class 2=orange) is shown in the top view and the DEM is shown in the bottom view. This culvert remains in the bare earth surface. Bridges have been removed from the bare earth surface and classified to class 17.

Dirt Mounds

Irregularities in the natural ground exist and may be misinterpreted as artifacts that should be removed. Hills and dirt mounds are present throughout the project area. These features are correctly included in the ground.

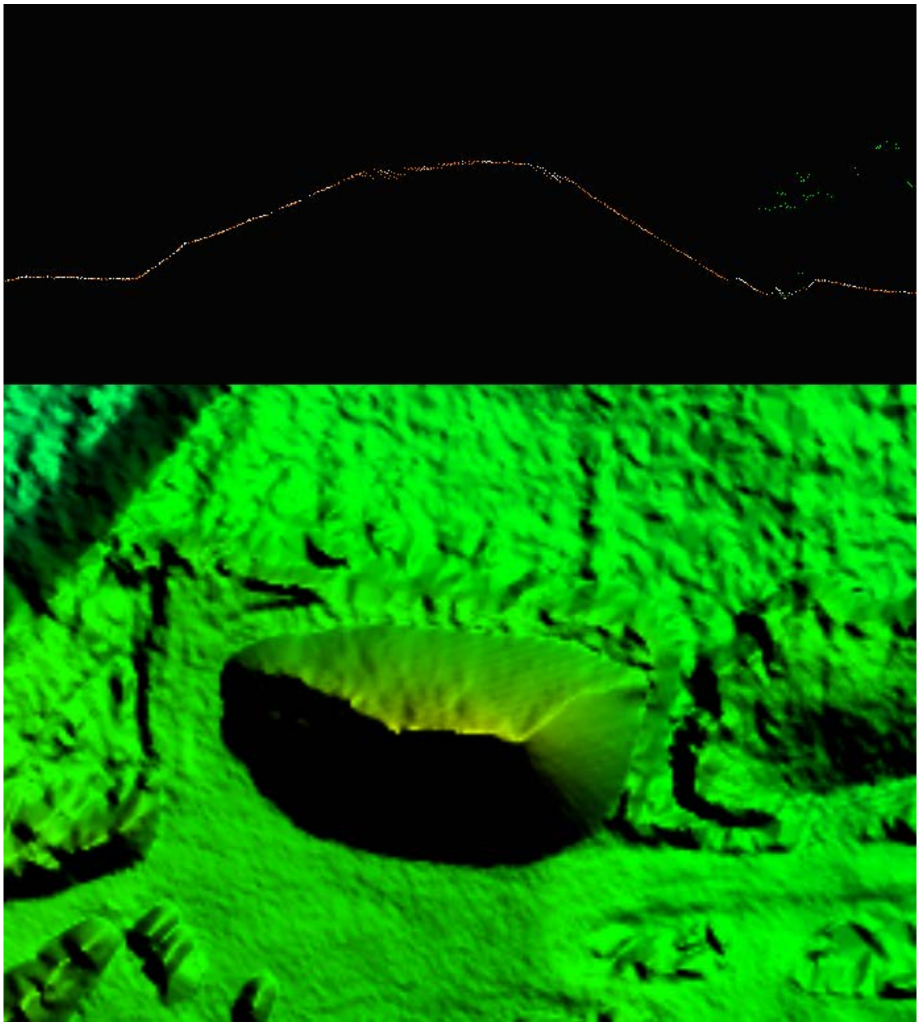
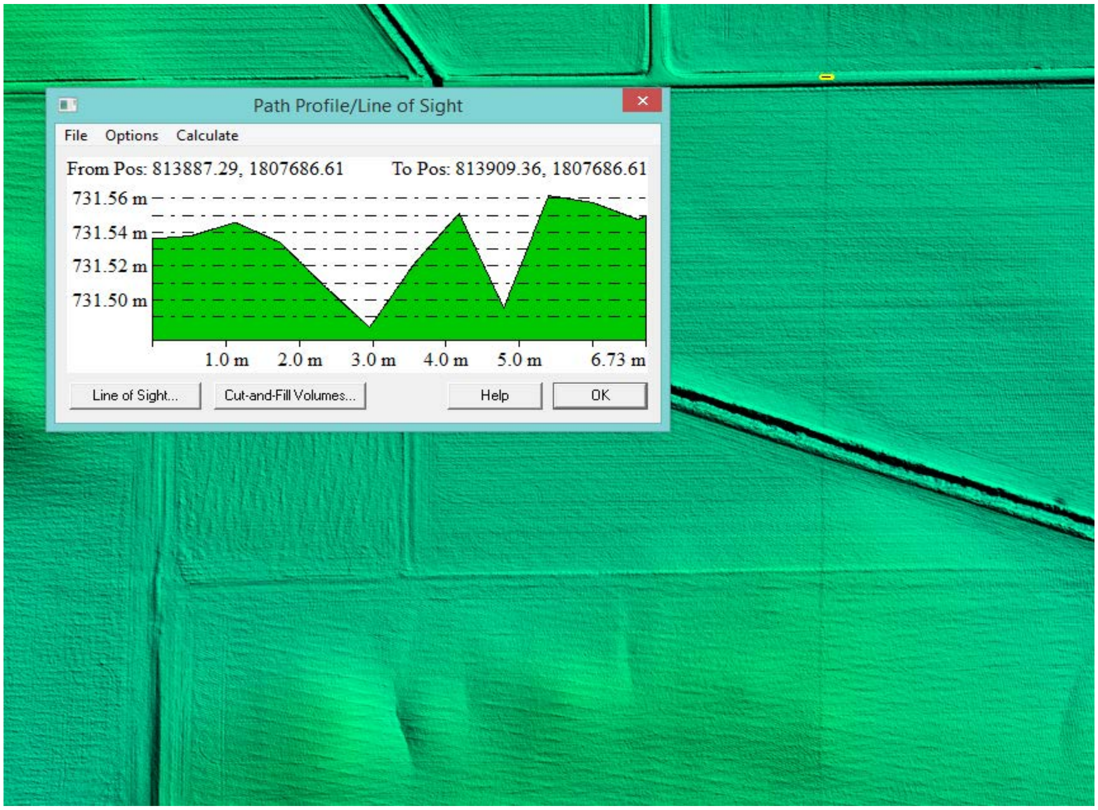


Figure 10 - Profile with the points colored by class (unclassified points are white, ground points are orange) is shown on the right and a DEM of the surface is shown to the left. These features are correctly included in the ground classification.

Flightline Ridges

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



From Pos: 813887.29, 1807686.61

To Pos: 813909.36, 1807686.61

Figure 11 – The flight line ridge is less than 8 cm. Overall, the IL_Champaign_City project data meets the project specifications for 8 cm RMSDz relative accuracy requirement.

Dam and Lock system

Irregularities in the natural water flow exist in sections of river affected by Lock and Dam systems. Series of locks enable vessels to "step" up or down a river or canal from one water level to another. There are no Dam and Lock systems in the IL_Champaign_City Lidar project area.

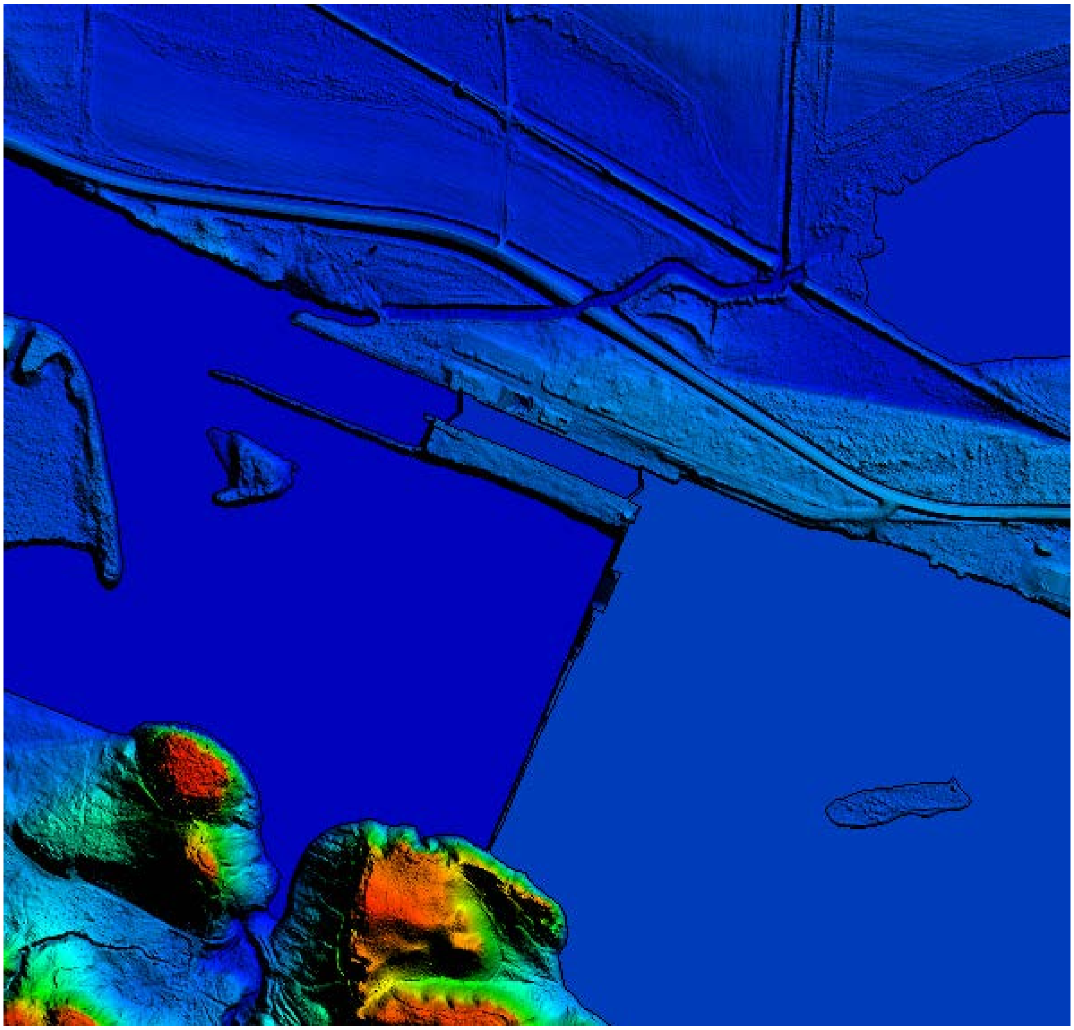


Figure 12 – DEM shows Large Dam structure that disrupts natural monotonic river flow, coupled with a lock system.

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 ASI proprietary tools. ASI routinely reviews for: proper LAS versions, Coordinate Reference System, Global Encoder Bit, Time Stamp, System ID, Multiple Returns, Intensity, Classification, Overlap and Withheld Points, Scan angle, XYZ Coordinates.

LiDAR Positional Accuracy

BACKGROUND

ASI 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. ASI 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 of IL_Champaign_City project, thirteen check points were surveyed. With this project being converted into its own smaller project area IL_Champaign_City the NVA and VVA, requirement would have been that there needed to be 20 NVA and 0 VVA checkpoints. But the end clients and USGS waived that requirement since the checkpoints were not laid out for that design. Instead the available 13 NVA checkpoints were accepted and used. All of those check points are located within bare earth/open terrain (13 NVA points). Please see provided 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) Albers Equal Area	NAD83 (2011) Albers Equal Area	NAVD88 (Geoid12B)
	Easting (M)	Northing (M)	Elevation (M)
NVA_47	650909.866	1928393.034	233.392
NVA_48	655106.949	1924700.919	224.315
NVA_19	657866.726	1926939.638	214.852
NVA_149	653512.253	1930692.204	227.688
NVA_150	648439.747	1923050.665	217.363
NVA_151	651062.915	1924668.668	220.325
NVA_152	655144.476	1927482.600	223.871
NVA_153	655221.329	1919407.989	218.883
NVA_154	661626.112	1923926.129	212.226
NVA_160	648096.526	1919656.033	211.983
NVA_169	659362.198	1929565.858	217.881
NVA_177	661810.248	1926670.814	214.357
NVA_190	644143.981	1925020.781	217.131
VVA_105	658985.924	1931640.266	222.810
VVA_106	653761.138	1925741.699	233.251
VVA_107	657761.795	1925679.091	221.431
VVA_108	661362.812	1923647.559	212.391
VVA_109	648949.267	1922584.355	219.308
VVA_111	644032.638	1925013.092	217.277
VVA_115	654084.892	1919802.719	226.699
VVA_138	654697.227	1929823.996	228.063

Table 5 – IL_Champaign_City project LiDAR Checkpoints.

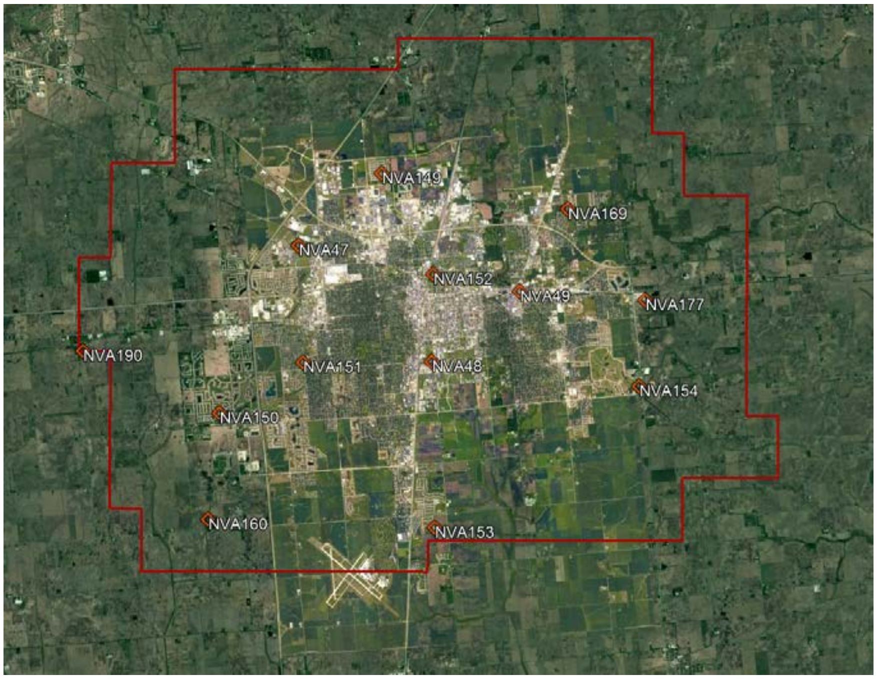


Figure 13 – Location of Champaign City LiDAR NVA Checkpoints

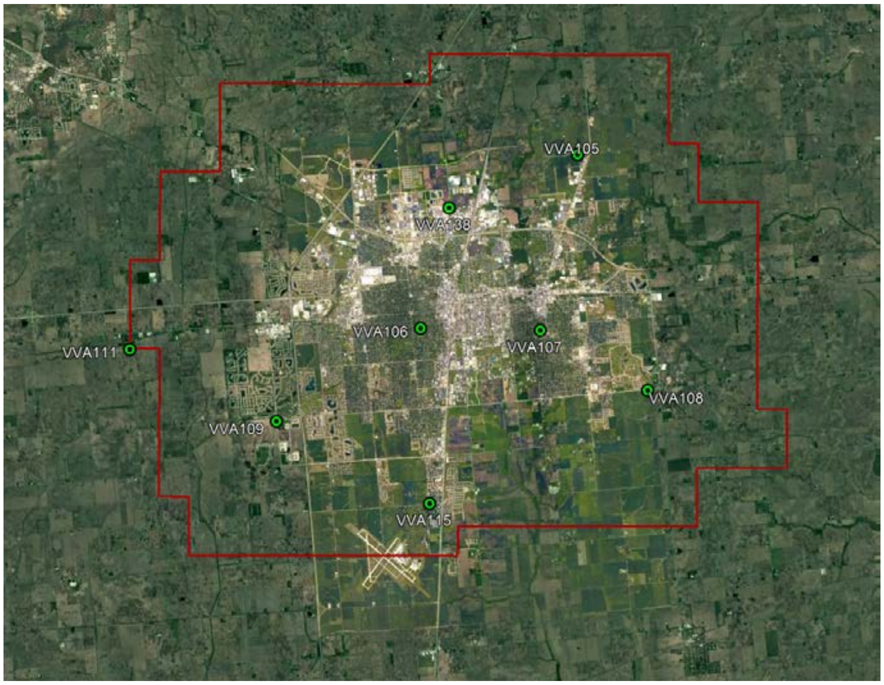


Figure 14- No VVA Checkpoints were Located in Champaign City

VERTICAL ACCURACY TEST PROCEDURES

NVA (Non-vegetated Vertical Accuracy) is determined with check points located only in nonvegetated 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 IL_Champaign_City 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 Champaign City LiDAR project VVA standard is 0.96 ft (29.4 cm) based on the 95th percentile.

Quantitative Criteria	Measure of Acceptability
Non-Vegetated Vertical Accuracy (NVA) in open terrain and urban land cover categories using RMSEz *1.96	19.6 cm (based on RMSEz (10 cm)*1.96)
Vegetated Vertical Accuracy (VVA) in all vegetated land cover categories combined and at the 95th Percentile error	29.4 cm (based on combined 95th percentile)

Table 6 – Acceptance Criteria.

The primary QA/QC vertical accuracy testing steps used by ASI are summarized as follows:

1. SAM surveyed QA/QC vertical checkpoints in accordance with the project's specifications.

2. Next, ASI interpolated the bare-earth LiDAR DTM to provide the z-value for every checkpoint.

3. ASI 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 ASI 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 (95% confidence)Spec = 0.196 m	VVA – Vegetated Vertical Accuracy (95th Percentile) spec = 0.294 m
NVA	13	0.037	
VVA	8		0.046

Table 7 – Tested NVA and VVA.

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. ASI reviews all NVA checkpoints to determine which, if any, of these checkpoints are located on photo-identifiable features in the intensity imagery. Photo-identifiable checkpoints are a subset of NVA checkpoints and are used for horizontal accuracy testing.

The primary QA/QC horizontal accuracy testing steps used by ASI are summarized as follows:

1. SAM 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, ASI identified the well-defined features in the intensity imagery.

3. ASI 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 ASI 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.

Too few checkpoints were determined to be photo-identifiable in the IL_Champaign_City project area to be used for horizontal accuracy testing of this LiDAR dataset.

BREAKLINE PRODUCTION METHODOLOGY

MicroStation, in conjunction with TerraSolid's TerraScan and TerraModeler was utilized for the collection of hydrologic breaklines, which occurred independently of manual edit. Collection was done using 2D information in the LAS format, intensity format, and ground surface. Breaklines are developed to the limit of the project boundary. Breaklines are in the same coordinate reference system and unit of measure as the LiDAR point delivery. Hydrologic water-surface edges are set at or just below the immediately surrounding terrain. Breaklines are developed to the limit of the project boundary.

BREAKLINE QUALITATIVE ASSESSMENT

Completeness and horizontal placement is verified through visual review against LiDAR intensity imagery, and bare earth surface. Breakline features are check for connectivity of features, enforced monotonicity on linear hydrographic breaklines, and flatness on water bodies.

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

FEATURE DEFINITION

Inland Streams and Rivers

Streams and Rivers with a nominal width of 30 meters (100 feet), were collected to best fit the shoreline by using information in the LAS format; intensity format, ground surface TIN, and sometimes "quick guide" contours. Streams and rivers do not break at bridges, but they are closed ended breaks at culvert locations. Steams and Rivers breaklines have been delivered in PolylineZ format in the final GDB.

Inland Ponds and Lakes

Inland ponds and lakes of 2 acres (86,111 square feet/ ~350'/~106 meter diameter for a round pond) or greater were collected. Inland pond and Lakes were collected to best fit the shoreline by using information in the LAS format; intensity format, ground surface TIN, and sometimes "quick guide" contours. Inland pond and Lakes Breaklines have been delivered in PolygonZ format in the final GDB.

Islands

Permanent island 4046m² (1 acre) or larger were delineated within all water bodies. Breaklines have been delivered in PolygonZ format in the final GDB

Bridge Breaklines

Breaklines were placed across the bottom of the bridge embankment when triangulation occurred due to bridge deck classification. Breaklines have been delivered in PolylineZ format in the final GDB.

INTENSITY IMAGERY PRODUCTION & QUALITATIVE ASSESSMENT

INTENSITY PRODUCTION METHODOLOGY

ASI utilized MicroStation in conjunction with TerraSolid's TerraScan for Intensity production. Global Mapper was used to QC the products. ArcGIS was used finalize the Intensity's projection.

Intensity Images are created for each tile in the tiling schema. The Intensities are reviewed for any issues requiring corrections. Tiles are verified for final formatting and loaded into Global Mapper to ensure there are no missing, or corrupt tiles, and to check for seamlessness across tile boundaries.

INTENSITY QUALITATIVE ASSESSMENT

ASI performed a qualitative assessment of the Intensity deliverables to ensure that all tiled Intensity products were delivered with the proper extents, and contained proper referencing information.

The image below show an example of an Intensity Image:

Figure 15 – Intensity Image example.

DEM PRODUCTION & QUALITATIVE ASSESSMENT

DEM PRODUCTION METHODOLOGY

ASI utilized MicroStation in conjunction with TerraSolid's TerraScan and TerraModeler for DEM production. Global Mapper was used to format and QC the products. ArcGIS was used finalize the DEMs projection.

The final bare earth LiDAR points are used to create a terrain. The final 3D breaklines collected for the project are enforced in the terrain. The terrain is then converted to raster format using linear interpolation. DEMs are created for each tile in the tiling schema. The DEMs are reviewed for any issues requiring corrections, including remaining LiDAR ground misclassification, erroneous breakline elevations, poor hydro flattening, and processing artifacts. Tiles are verified for final formatting and loaded into Global Mapper to ensure there are no missing, or corrupt tiles, and to check for seamlessness across tile boundaries.

DEM QUALITATIVE ASSESSMENT

ASI performed a 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 proper referencing information.

The image below shows an example of a bare earth DEM.

Figure 16 – IL_Champaign_City County project bare earth DEM

DEM VERTICAL ACCURACY RESULTS

The same 13 checkpoints that were used to test the vertical accuracy of the LIDAR will be 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. The DEM pixel does not average several LiDAR point's together, it interpolates (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 survey elevations.

Table 9; summarizes the tested vertical accuracy result from a comparison of surveyed checkpoint to the elevation values present within the final DEM dataset.

Land Cover Category	# of Points	NVA – Non-vegetated Vertical Accuracy (RMSEz x 1.960)	VVA – Vegetated Vertical Accuracy (95th percentile)
NVA	13	0.042	
VVA	8		0.039

Table 9– DEM vertical accuracy summary

DEM datasets were tested to meet ASPRS Positional Accuracy Standards for Digital Geospatial Data (2014) for a 10 cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 0.021 m with a 0.042 m accuracy at 95 % confidence level. Actual VVA accuracy tested 0.039 meters using checkpoints located in forested land cover categories at the 95th percentile, derived according to ASPRS guidelines, tested against the DEM.
Based on the vertical accuracy testing conducted by ASI, the DEM dataset for the IL_Champaign_City project satisfies the project's pre-defined vertical accuracy criteria.

Appendix A: List of Delivered LAS Files

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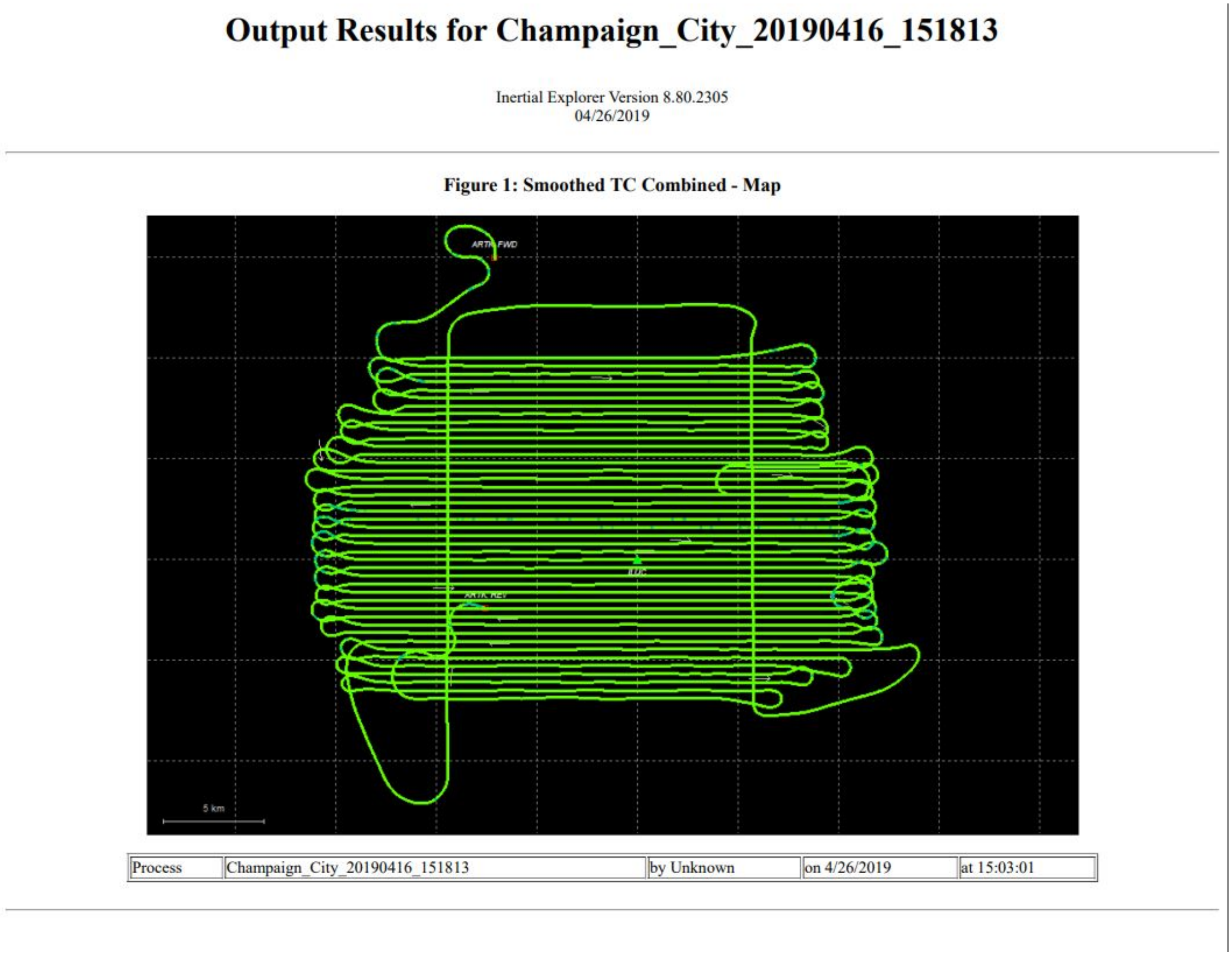
Appendix B: Mission GPS and IMU Processing Report



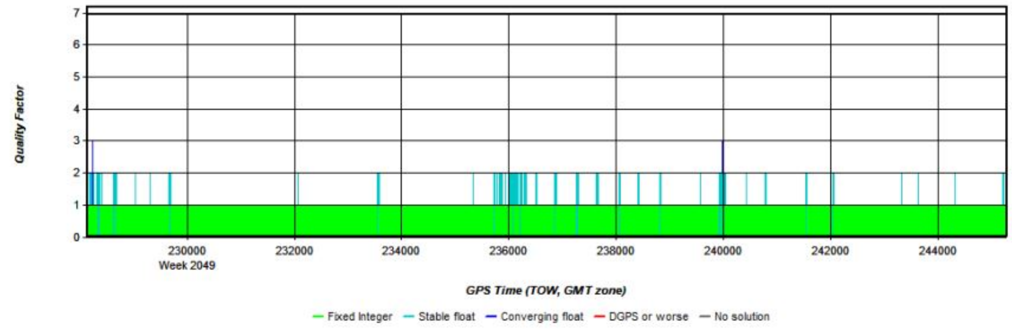
Output Results for Champaign_City_20190416_151813

Inertial Explorer Version 8.80.2305
04/26/2019

Figure 1: Smoothed TC Combined - Map

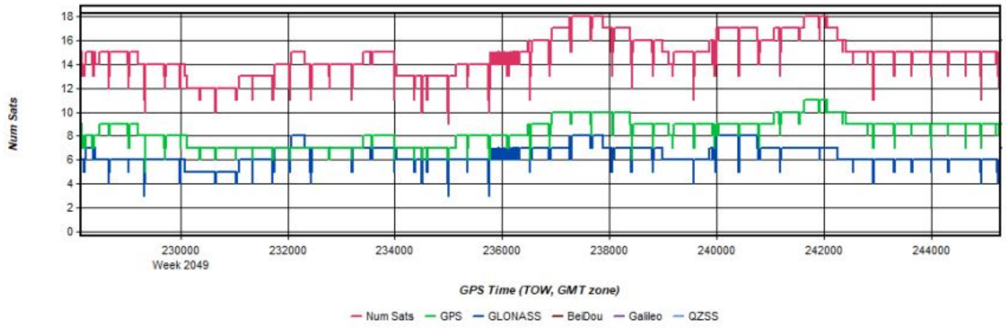
Process	Champaign_City_20190416_151813	by Unknown	on 4/26/2019	at 15:03:01

Figure 2: Champaign_City_20190416_151813 [Smoothed TC Combined] - Quality Factor Plot



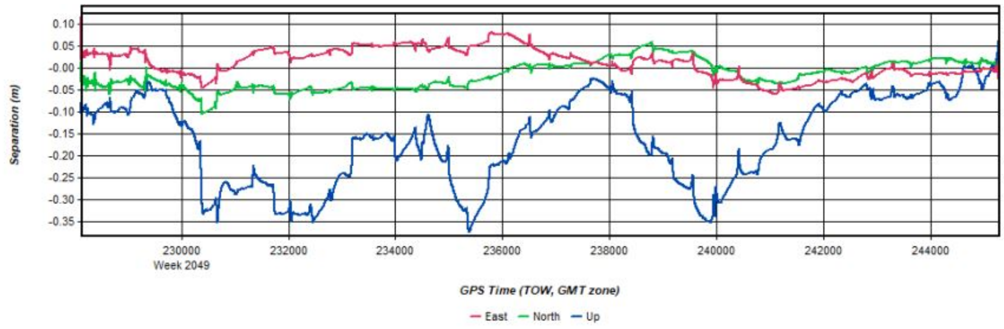
Process	Champaign_City_20190416_151813	by Unknown	on 4/26/2019	at 15:03:01

Figure 3: Champaign_City_20190416_151813 [Smoothed TC Combined] - Number of Satellites Line Plot



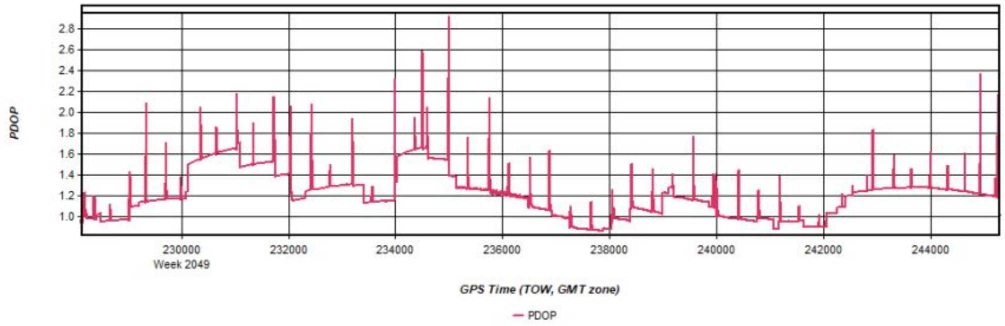
Process	Champaign_City_20190416_151813	by Unknown	on 4/26/2019	at 15:03:01

Figure 4: Champaign_City_20190416_151813 [Smoothed TC Combined] - Forward/Reverse or Combined Separation Plot



Process	Champaign_City_20190416_151813	by Unknown	on 4/26/2019	at 15:03:01

Figure 5: Champaign_City_20190416_151813 [Smoothed TC Combined] - PDOP Plot



Process	Champaign_City_20190416_151813	by Unknown	on 4/26/2019	at 15:03:01