University of Illinois

Acquisition, Processing, and Delivery of Airborne LiDAR Elevation Data for Greene, Macoupin, and Montgomery Counties, IL (aka IL-3 Counties) LiDAR Mapping Report

Prepared for:

ILLINOIS STATE GEOLOGICAL SURVEY
PRAIRIE RESEARCH INSTITUTE

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Project Summary

Merrick & Company (Merrick) was contracted by the University of Illinois Urbana-Champaign / Illinois State Geological Survey (ISGS) to provide a lidar validation ground survey, aerial lidar data collection and processing of approximately 2,220.50 square miles for Greene, Macoupin, and Montgomery Counties, IL (IL-3 Counties). The project was accomplished in two Phases:

- U17071 - Data Acquisition (Phase 1): project data acquisition of Light Detection and Ranging (lidar) data, initial processing and data quality assurance (QA) and quality control (QC) to validate the quality of newly acquired data, and delivery of two (2) Pilot Project areas containing a sample of classified LAS files and related data within each county.
- U17072 – Data Processing (Phase 2): data processing to create contract deliverables including las classification, creation of hydrological breaklines, generation of derivative products, creation of metadata and reports, and final delivery of all data.

Unless otherwise stated, the lidar mapping requirements and deliverables will meet the Quality Level Two (QL2) standards as outlined in the USGS-NGP Lidar Base Specifications, Techniques and Methods 11–B4, Version 1.2, November 2014 (TM11-B4) (http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). QL2 lidar specifications suggest a point density of greater than or equal to two points per square meter (≥2ppsm), or less than or equal to seven-tenths of a meter (≤0.71m) Aggregate Nominal Pulse Density (ANPD).

The vertical accuracy requirements of the lidar data meets or exceeds the following:

Vertical accuracy (absolute for the Non-Vegetated Vertical Accuracy [NVA])

- ≤10cm RMSEz
- ≤19.6cm at the 95% confidence level (AccuracyZ)
- Vegetated Vertical Accuracy (VVA) ≤29.4cm at the 95% percentile

Relative accuracy

- ≤6cm Smooth surface repeatability
- ≤8cm RMSDz
- ±16cm maximum difference

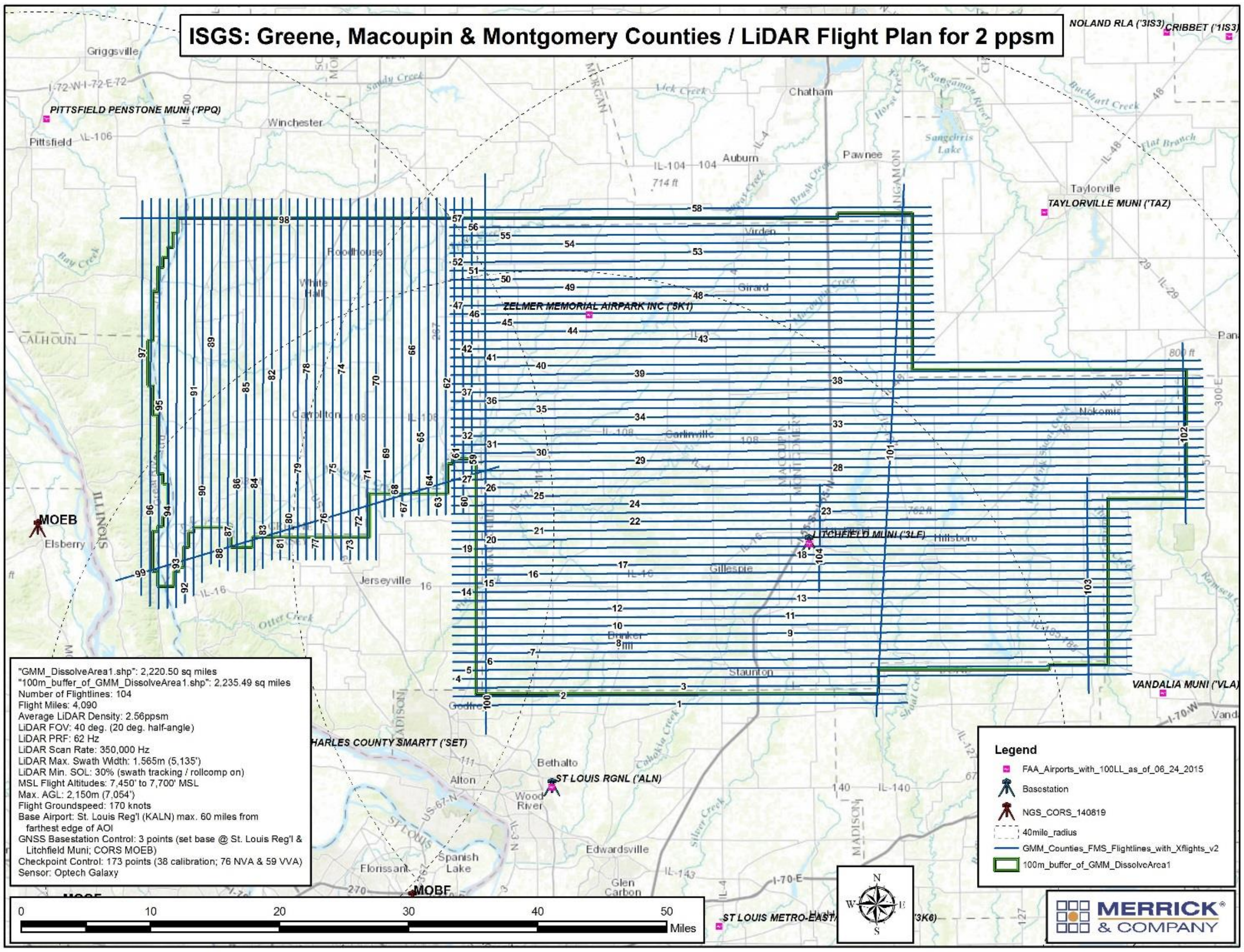
Project Spatial Reference

- Projection – Illinois State Plane Coordinate System (SPCS), West Zone (FIPSZone 1202)
- Horizontal Datum - North American Datum of 1983 (NAD 83), National Adjustment of 2011 (NA2011)
- Vertical Datum – North American Vertical Datum of 1988 (NAVD 88); GEOID 12B
- Units – U.S. Survey Foot

The contents of this report summarize the methods used to calibrate and classify the lidar and data as well as the results of these methods for project IL-3 Counties.

Lidar Flight Information

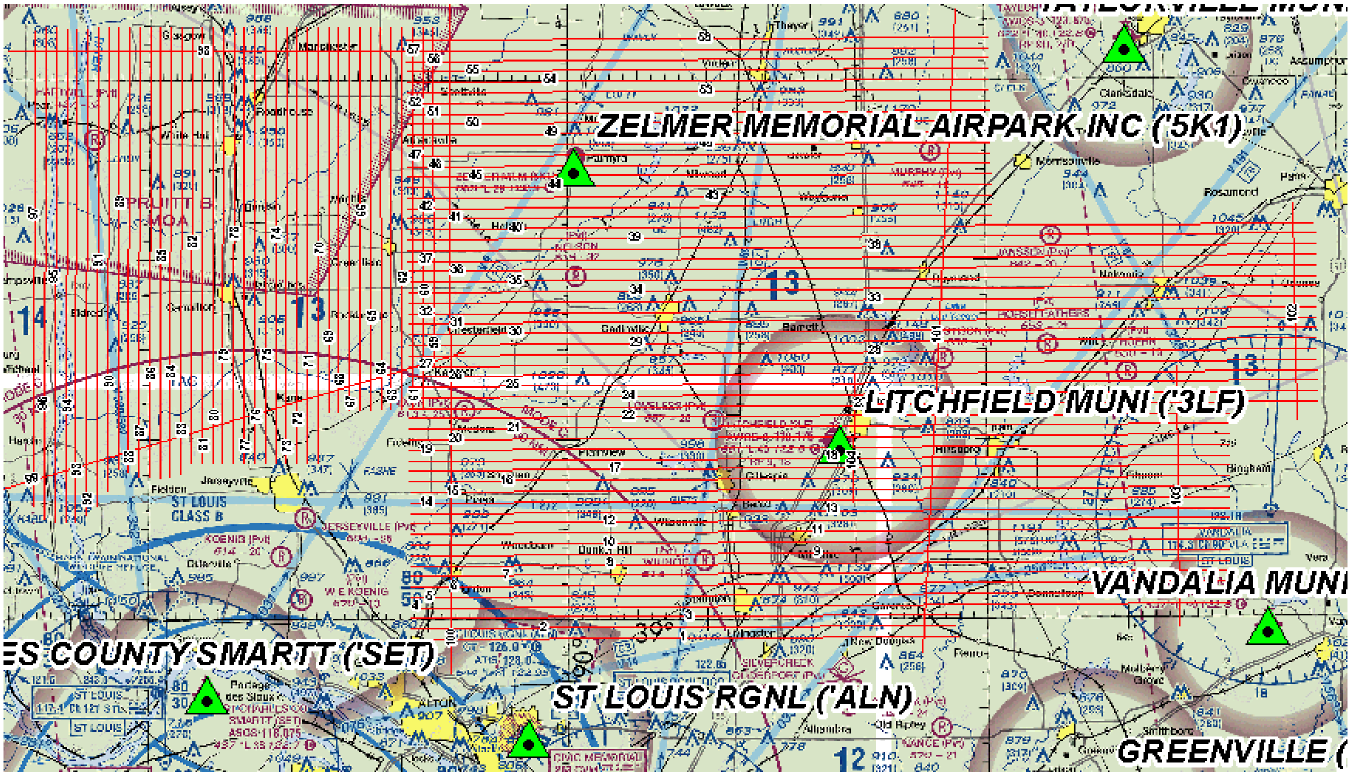
The acquisition area for the IL-3 Counties project is defined by the client-provided Esri shapefile *IL_BNDY_Greene_Macoupin_Montgomery,shp*. While the collection area is larger than the project boundary, only data within the boundary was processed.



Airports of Operation

Multiple airports were used for the collection of this project. See below for a list of the airports used as well as an image of the project area with all the regional airports displayed.

- St. Louis Regional
- Litchfield Municipal



Aerial Mission(s) Duration / Time

Merrick collected the project with one lidar fixed wing aircraft, tail number N274MR. Lidar data collection for the project was accomplished between April 7, 2017 and April 24, 2017 with one Optech Galaxy sensor. Each mission represents a lift of the aircraft and system from the ground, collects data, and lands again. Multiple lifts within a day are represented by Mission A, B, C, D. The table below relates each mission to the date collected, the sensor and serial number used, the start/end time and number of global navigation satellite system (GNSS) records taken. The time is shown in Global Positioning System (GPS) seconds of the week.

Mission(s)	Date	Sensor S/N	Start Time GPS sec.	End Time GPS sec.	Number of GNSS Solution Records
170407_A	April 7, 2017	G-5060356	500886.00	406104.0	8588.00
170408_A	April 8, 2017	G-5060356	574446.00	592376.00	17918.00
170412_A	April 12, 2017	G-5060356	311283.00	330436.00	19112.00

170412_B	April 12, 2017	G-5060356	332659.00	344438.00	11774.00
170415_A	April 15, 2017	G-5060356	567672.00	576222.00	8531.00
170418_A	April 18, 2017	G-5060356	260838.00	267809.00	6938.00
170422_A	April 22, 2017	G-5060356	599547.00	612811.00	3253.00
170423_A	April 23, 2017	G-5060356	47706.00	67260.00	19510.00
170423_B	April 23, 2017	G-5060356	72554.00	85468.00	12911.00
170424_A	April 24, 2017	G-5060356	144984.00	134064.00	141195.00
170424_B	April 24, 2017	G-5060356	144984.00	159010.00	13992.00

GNNS / IMU Data

A five-minute INS initialization is conducted on the ground, with the aircraft engines running, prior to flight, to establish fine-alignment of the INS. GPS ambiguities are resolved by flying within ten kilometers of the base stations. During the data collection, the operator recorded information on log sheets which includes weather conditions, lidar operation parameters, and flight line statistics. Near the end of the mission, GPS ambiguities were again resolved by flying within ten kilometers of the base stations to aid in post-processing. Data is sent back to the main office for preliminary processing to check overall quality of GPS / INS data and to ensure sufficient overlap between flight lines. Any problematic data may be re-flown immediately as required.

The airborne GPS data was post-processed using Applanix POSPac Mobile Mapping Suite version 8.x. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, lidar acquisition was limited to periods when the PDOP (Positional Dilution Of Precision) was less than 4.0. PDOP indicates satellite geometry relating to position. Generally, PDOP's of 4.0 or less result in a good quality solution, however PDOP's between 4.0 and 5.0 can still yield good results most of the time. PDOP's over 6.0 are of questionable results and PDOP's of over 7.0 usually result in a poor solution. Usually as the number of satellites increase the PDOP decreases. Other quality control checks used for the GPS include analyzing the combined separation of the forward and reverse GPS processing from one base station and the results of the combined separation when processed from two different base stations. An analysis of the number of satellites, present during the flight and data collection times, is also performed.

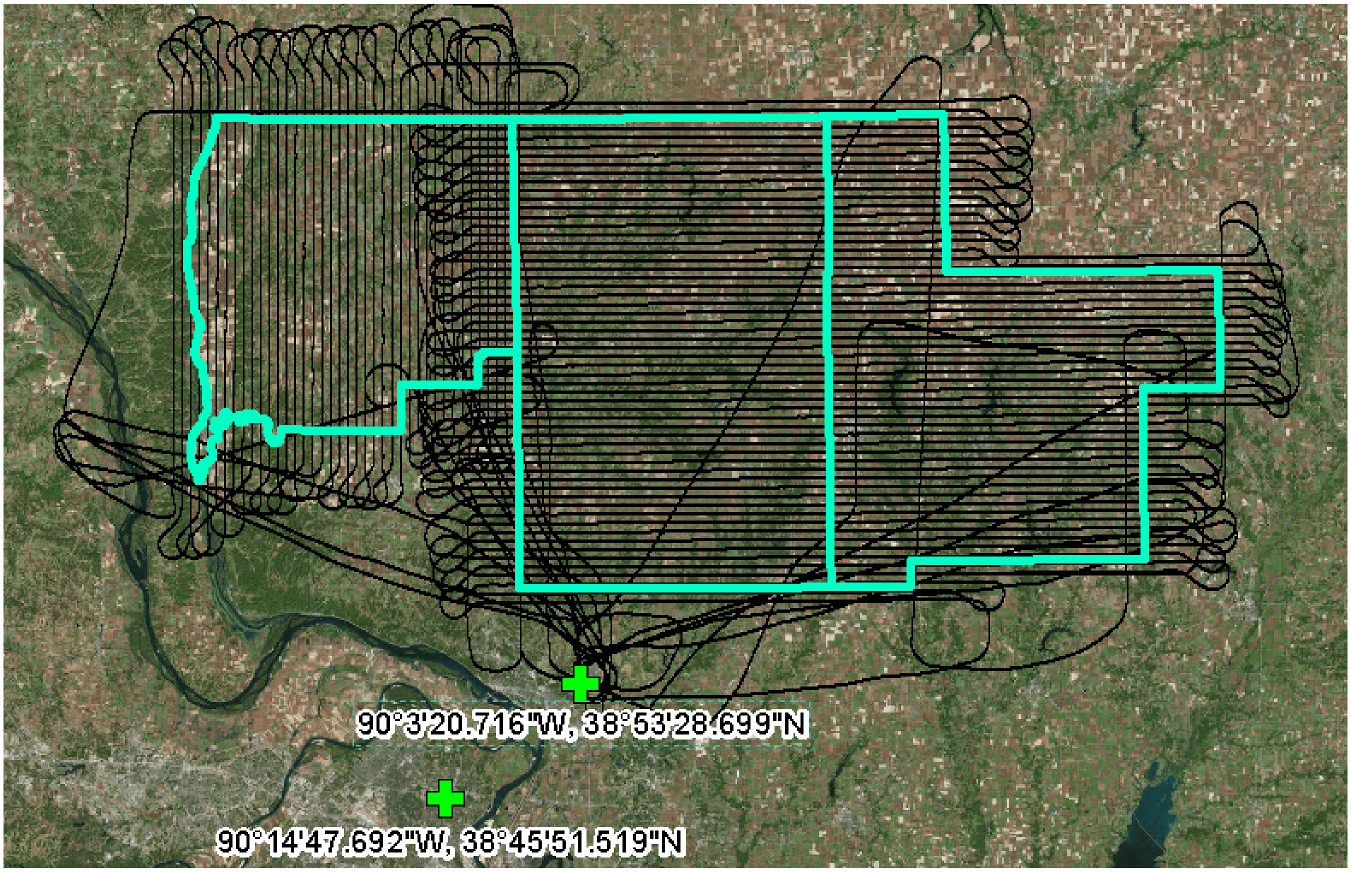
The GPS trajectory was combined with the raw IMU data and post-processed using POSPac Mobile Mapping Suite version 8.x. The Smoothed Best Estimated Trajectory (SBET) and refined attitude data are then utilized in the LMS Post Processor to compute the laser point-positions – the trajectory is combined with the attitude data and laser range measurements to produce the 3-dimensional coordinates of the mass points. Up to four return values are produced within the Optech lidar Mapping Suite (LMS) processor software for each pulse which ensures the greatest chance of ground returns in a heavily forested area.

GPS Controls

Ground GNSS Base Stations were set up to control the lidar airborne flight lines. In addition, CORS (Continually Operating Reference Stations) are at times used to further enhance the airborne solution. The ground GNSS Base Stations coordinates were obtained from NGS (National Geodetic Survey) Online Positioning User Service

(OPUS) solutions. CORS coordinates were obtained from NGS datasheets. See the following table and map for ground GNSS Base Station information and locations:

Point ID	Latitude (NAD83 – 2011)	Longitude (NAD83 – 2011)	Ellipsoid Height (m)
Base KALN	N38°53'28.69883"	W90°03'20.71589"	132.798
MOBF (CORS)	N38°45'51.51926"	W90°14'47.69246"	132.628



Lidar Calibration

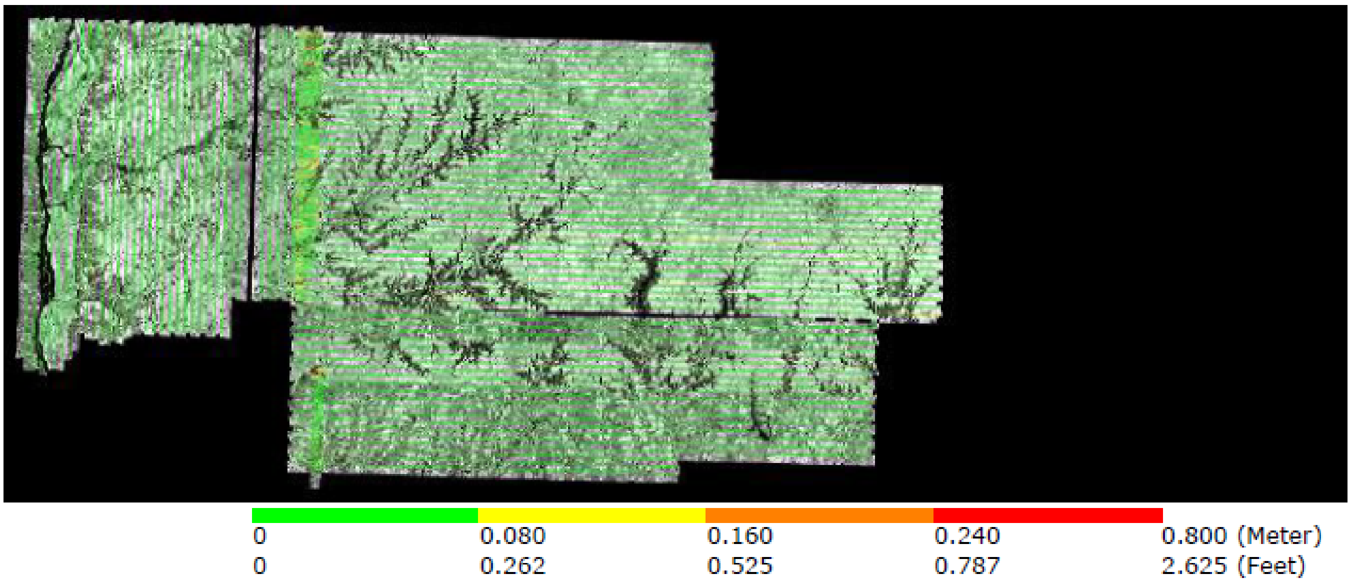
Merrick takes great care to ensure all lidar acquisition missions are carried out in a manner conducive to post-processing an accurate data set. This begins in the flight-planning stage with attention to GPS baseline distances and GPS satellite constellation geometry and outages. Proper AGPS surveying techniques are always followed including pre- and post-mission static initializations. In-air IMU alignments (figure-eights) are performed both before and after on-site collection to ensure proper calibration of the IMU accelerometers and gyros.

A minimum of one cross-flight is planned throughout the project area across all flightlines and over roadways where possible. The cross-flight provides a common control surface used to remove any vertical discrepancies in the lidar data between flightlines. The cross-flight is critical to ensure flightline ties across the project area. The areas of overlap between flightlines are used to boresight (calibrate) the lidar point cloud to achieve proper flightline to flightline alignment in all three axes. This includes adjustment of both IMU and scanner-related variables such as roll, pitch, heading, timing interval (range), and torsion. Each lidar mission flown by Merrick is accompanied by a hands-on boresight in the office.

After boresighting is complete a detailed statistical report is generated to check relative and absolute accuracies before filtering of lidar begins.

Relative Accuracy – flight line to flight line

This graphic shows the vertical separation of flight lines by thematically coloring the separation magnitude on a color ramp based on absolute distance. This color thematic rendering is modulated by intensity to show land cover features.



Unfiltered lidar Control Point Report

The following tables illustrate the results of the lidar data compared to the lidar control points post-calibration. The listing is sorted by the Z Error column showing, in ascending order, the vertical difference between the lidar points and the 13 surveyed ground points used for lidar validation.

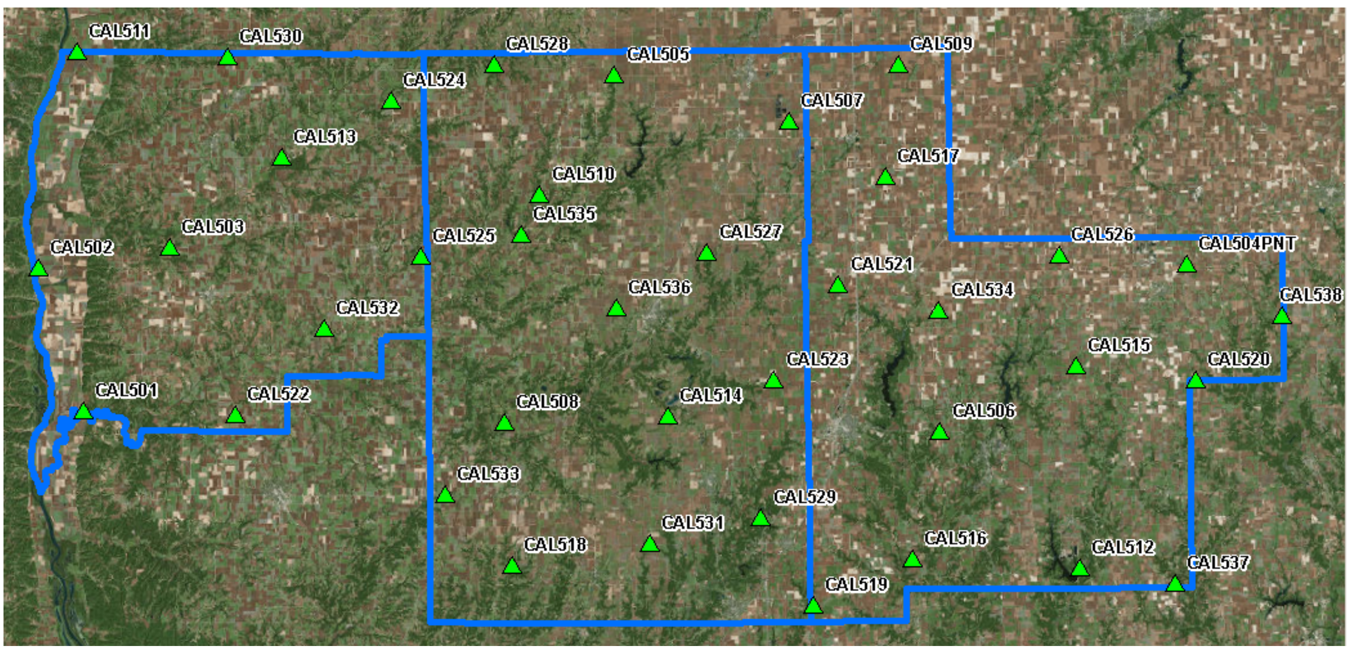
Project Data Unit	U.S. Survey Foot		
Vertical Accuracy Class tested	10.0-cm		
Elevation Calculation Method	Interpolated from TIN		
LiDAR Classifications Included	All Points		
Check Points in Report	38		
Check Points with LiDAR Coverage	38		
Check Points (NVA)	38		
Check Points (VVA)	0		
Average Vertical Error Reported	0	U.S. Survey Foot	
Maximum (highest) Vertical Error Reported	0.27	U.S. Survey Foot	
Median Vertical Error Reported	-0.017	U.S. Survey Foot	
Minimum (lowest) Vertical Error Reported	-0.288	U.S. Survey Foot	
Standard deviation of Vertical Error	0.128	U.S. Survey Foot	
Skewness of Vertical Error	-0.009		
Kurtosis of Vertical Error	-0.145		
Non-vegetated Vertical Accuracy (NVA) RMSE(z)	3.843	cm	PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-	7.532	cm	PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-	7.532	cm	
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM):	3.879	cm	PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM):	7.602	cm	PASS

Check Point Id	Check Point X	Check Point Y	Coverage	Check Point Z	Z from lidar	Z Error
CAL501	2187480.69	919798.69	Yes	441.38	441.212	-0.168
CAL502	2172529.2	967432.36	Yes	423.6	423.573	-0.027
CAL503	2216164.5	974577.78	Yes	554.15	554.153	0.003
CAL511	2185149.42	1039907.9	Yes	424.41	424.479	0.069
CAL513	2253566.39	1004666.73	Yes	547.48	547.524	0.044
CAL522	2238056.67	918546.32	Yes	583.75	583.883	0.133
CAL524	2290055.67	1023348.57	Yes	569.94	569.903	-0.037
CAL525	2300124.18	971694.88	Yes	580.84	580.857	0.017
CAL530	2235364.11	1038043.74	Yes	660.25	660.445	0.195
CAL532	2267890.39	947532.9	Yes	536.04	535.779	-0.261
CAL505	2364651.11	1032100.48	Yes	682.2	682.161	-0.039
CAL507	2422843.54	1016634.39	Yes	675.37	675.315	-0.055
CAL508	2327955.75	916050.76	Yes	597.96	597.984	0.024
CAL510	2339735.88	991970.27	Yes	628.99	628.977	-0.013
CAL514	2382497.56	918208.43	Yes	638.85	639.024	0.174
CAL518	2330524.89	868281.87	Yes	611.88	611.79	-0.09
CAL523	2417924.97	930068.32	Yes	664.8	664.754	-0.046
CAL527	2395590.08	972604.6	Yes	633.23	633.297	0.067
CAL528	2324621.18	1035486.06	Yes	630.91	631.032	0.122
CAL529	2413603.21	884099.13	Yes	653.89	653.822	-0.068
CAL531	2376486.03	875570.51	Yes	651.59	651.535	-0.055
CAL533	2308288.89	891854.2	Yes	617.42	617.625	0.205
CAL535	2333347.92	978614.18	Yes	593.97	593.996	0.026
CAL536	2365303	954187.48	Yes	629.57	629.747	0.177
CAL504PNT	2555557.68	968954.88	Yes	669.06	669.189	0.129

CAL506	2473364.13	913293.86	Yes	629.47	629.263	-0.207
CAL509	2459523.87	1035662.02	Yes	626.07	626.007	-0.063
CAL512	2519783.6	867364.06	Yes	599.03	599.3	0.27
CAL515	2518807.73	934978.35	Yes	664.53	664.483	-0.047
CAL516	2464142.58	870480.17	Yes	599.81	599.522	-0.288
CAL517	2454960.56	998078.94	Yes	646.45	646.472	0.022
CAL519	2431003.17	854990.96	Yes	629.87	629.849	-0.021
CAL520	2558607.03	930108.79	Yes	674.34	674.286	-0.054
CAL521	2439369.44	962201.66	Yes	644.65	644.526	-0.124
CAL526	2513078.84	971925.45	Yes	632.19	632.089	-0.101
CAL534	2472932.18	953390.27	Yes	635.15	635.142	-0.008
CAL537	2551578.83	862298.45	Yes	635.88	636.075	0.195
CAL538	2587314.77	951849.43	Yes	667.67	667.586	-0.084

NOTE: The Complete Ground Survey report conducted by Compass Data, Inc. is attached as Appendix 1.

Lidar Control Point Layout



Lidar Filtering and Classification

The lidar filtering process encompasses a series of automated and manual steps to classify the boresighted point cloud data set. Each project represents unique characteristics in terms of cultural features (urbanized vs. rural areas), terrain type and vegetation coverage. These characteristics are thoroughly evaluated at the onset of the project to ensure that the appropriate automated filters are applied and that subsequent manual filtering yields correctly classified data. Data is most often classified by ground and "unclassified", but specific project applications can include a wide variety of classifications including but not limited to buildings, vegetation, power lines, etc. Merrick's MARS® software is used for the auto-filtering, manual filtering and QC of the classified data.

Merrick used the American Society for Photogrammetry and Remote Sensing's (ASPRS) LAS Specification Version 1.4 – Point Data Record Format 6, 7, 8, 9, or 10.R13, 15 July 2013 for this project and classified the lidar point cloud in accordance with the following classification classes and bitflags.

- Class 1 = Unclassified
- Class 2 = Bare-earth Ground
- Class 3 = Low Vegetation
- Class 4 = Medium Vegetation
- Class 5 = High Vegetation
- Class 6 = Buildings
- Class 7 = Low point (noise)
- Class 9 = Water
- Class 10 = Ignored ground (near a breakline)
- Class 17 = Bridge decks
- Class 18 = High noise
- Bitflags
    - Overlap: Any part of a swath that also is covered by any part of any other swath.
    - Withhled: Within the LAS file specification, a single bit flag indicating that the associated lidar point is geometrically anomalous or unreliable and should be ignored for all normal processes.

Merrick has developed several customized automated filters that are applied to the lidar data set based on project specifications, terrain, and vegetation characteristics. A filtering macro, which may contain one or more filtering algorithms, is executed to derive LAS files separated into the different classification groups as defined in the ASPRS classification table. The macros are tested in several portions of the project area to verify the appropriateness of the filters. Often, there is a combination of several filter macros that optimize the filtering based on the unique characteristics of the project. Automatic filtering generally yields a ground surface that is 85-90% valid, so additional editing (hand-filtering) is required to produce a more robust ground surface.

Lidar data is next taken into a graphic environment using MARS® to manually re-classify (or hand-filter) "noise" and other features that may remain in the ground classification after auto filter. A cross-section of the post auto-filtered surface is viewed to assist in the reclassification of non-ground data artifacts. The following is an example of re-classification of the non-ground points (elevated features) that need to be excluded from the true ground surface. Certain features such as berms, hilltops, cliffs and other features may have been aggressively auto-filtered and points will need to be re-classified into the ground classification. Data in the profile view displays non-ground (Unclassified, class 1) in grey and ground in brown/tan (Class 2). In figure 1, a small building was not auto-filtered and needs to be manually re-classified. Note that figure 2 has the building points reclassified to unclassified from the true ground surface.

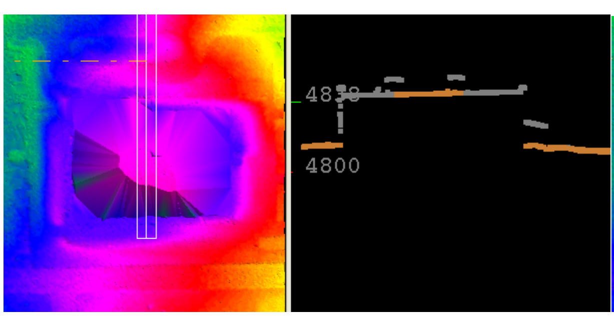


Figure 1

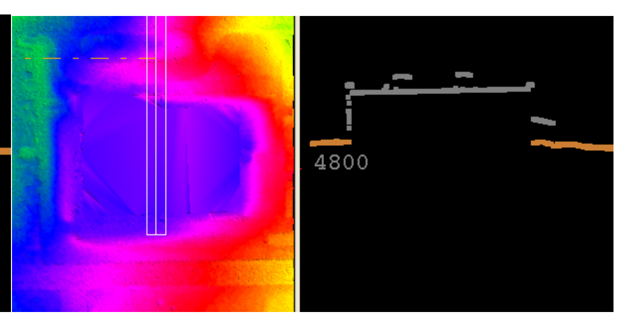


Figure 2

Merrick uses a combination of automated and semi-automated routines to classify buildings and vegetation. We expect that the classified buildings will meet a filtering criterion in the range of 90-95%.

At this point, individual lidar points from the original point cloud have now been parsed into separate classifications.

After the hand-filtering has been completed and quality checked, a Check Point Report is generated to validate that the accuracy of the ground surface is within the defined accuracy specifications. Each surveyed ground check point is compared to the lidar surface by interpolating an elevation from a Triangulated Irregular Network (TIN) of the surface. The MARS® derived report provides an in-depth statistical report, including an RMSE of the vertical errors; a primary component in most accuracy standards and a statistically valid assessment of the overall accuracy of the ground surface.

Filtered lidar Check Point Report

Project Data Unit	U.S. Survey Foot		
Vertical Accuracy Class tested	10.0-cm		
Elevation Calculation Method	Interpolated from TIN		
LiDAR Classifications Included	2/0 Ground (All)/0W		
Check Points in Report	147		
Check Points with LiDAR Coverage	144		
Check Points (NVA)	83		
Check Points (VVA)	61		
Average Vertical Error Reported	0.008	U.S. Survey Foot	
Maximum (highest) Vertical Error Reported	0.561	U.S. Survey Foot	
Median Vertical Error Reported	-0.004	U.S. Survey Foot	
Minimum (lowest) Vertical Error Reported	-0.41	U.S. Survey Foot	
Standard deviation of Vertical Error	0.162	U.S. Survey Foot	
Skewness of Vertical Error	0.501		
Kurtosis of Vertical Error	0.669		
Non-vegetated Vertical Accuracy (NVA) RMSE(z)	4.914	cm	PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-	9.632	cm	PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile +/-	17.8	cm	PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-	9.632	cm	
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM):	4.948	cm	PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM):	9.698	cm	PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile +/- (DEM):	18.224	cm	PASS

Check Point Id	Check Point X	Check Point Y	Coverage	Check Point Z	Z from lidar	NVA or VVA
NVA603	2171706.79	958594.92	No	426.88		NVA
NVA610	2180350.37	979319.49	Yes	429.25	429.417	NVA
NVA612	2234995.37	959524.6	Yes	619.41	619.559	NVA
NVA612_PID	2228006.87	959723.17	Yes	617.59	617.924	NVA
NVA615	2274334.34	942477.72	Yes	516.34	516.28	NVA
NVA615_PID	2284457.09	971420.02	Yes	577.57	577.411	NVA
NVA619	2246008.95	1039192.05	Yes	668.7	668.796	NVA
NVA629	2290296.56	980940.74	Yes	614.76	614.595	NVA
NVA632	2175000	908058.07	Yes	425.55	425.526	NVA
NVA634	2167178.53	985715.12	Yes	437.36	437.431	NVA

NVA635	2204387.2	997211.07	Yes	598.19	598.342	NVA
NVA638	2216666.6	1019722.2	Yes	621.77	621.869	NVA
NVA638_PID	2230463.02	1012460.85	Yes	589.79	590.002	NVA
NVA641	2212157.66	954859.75	Yes	597.06	597.22	NVA
NVA642	2260490.66	986820.73	Yes	574.17	573.926	NVA
NVA643	2286368.77	948113.11	Yes	544.26	544.16	NVA
NVA648	2274203.38	1012648.04	Yes	492.57	492.53	NVA
NVA655	2243448.94	919233.22	Yes	564.56	564.717	NVA
NVA658	2258313.08	1034014.21	Yes	630.31	630.33	NVA
NVA662	2188579.96	1013213.73	Yes	430.76	430.719	NVA
NVA667	2221275.65	914212.17	Yes	592.42	592.266	NVA
NVA670	2185832.58	1036865.75	Yes	428.3	428.345	NVA
VVA703	2186579.52	936105.81	Yes	455.03	454.964	VVA
VVA710	2180280.77	979242.95	Yes	428.81	429.177	VVA
VVA712	2235702.36	959583.86	Yes	623.53	623.743	VVA
VVA715	2273203.66	942575.55	Yes	512.85	513.021	VVA
VVA719	2244868.18	1037361.91	Yes	667.89	668.12	VVA
VVA729	2290409.55	982304.84	Yes	616.52	616.633	VVA
VVA732	2174921.04	908500.96	Yes	425.09	425.166	VVA
VVA734	2166882.62	985165.87	No	423.68		VVA
VVA735	2202185.38	997268.81	Yes	549.32	549.591	VVA
VVA738	2219631.23	1019753.53	Yes	627.75	628.076	VVA
VVA741	2207601.04	955117.59	Yes	536.99	537.235	VVA
VVA742	2260663.35	983194.62	Yes	556.6	556.567	VVA
VVA743	2292412.73	947662.59	Yes	509.68	509.455	VVA
VVA748	2274131.47	1012521.46	Yes	489.41	489.528	VVA
VVA755	2243306.06	920084.77	Yes	561.57	561.979	VVA
VVA758	2256965.17	1035369.81	Yes	636.15	636.418	VVA
VVA760	2300111.61	970113.18	Yes	575.76	576.344	VVA
NVA601	2548238.25	916779.44	Yes	654.7	654.917	NVA
NVA607	2550345.54	964377.34	Yes	667.7	667.569	NVA
NVA608	2443847.7	951849.37	Yes	646.32	646.316	NVA
NVA614	2450434.6	879753.81	Yes	639.54	639.5	NVA
NVA617	2513762.2	905750.13	Yes	656.92	657.116	NVA
NVA620	2549186.07	892614.5	Yes	630.94	631.501	NVA
NVA623PNT	2510389.06	870631.23	Yes	601.53	601.51	NVA
NVA624	2534004.58	929917.16	Yes	655.19	655.124	NVA
NVA628	2437190.12	1022038.09	Yes	657.24	657.098	NVA
NVA636	2489483.85	886969.55	Yes	619.9	620.19	NVA
NVA639	2583574.03	941223.72	Yes	664.71	664.581	NVA
NVA644	2482038.58	953413.46	Yes	629.95	630.005	NVA
NVA645	2428947.28	987409.16	Yes	625.96	625.694	NVA
NVA646	2507832.65	961919.88	Yes	634.49	634.357	NVA
NVA650	2474210.73	998538.59	Yes	645.2	645.208	NVA

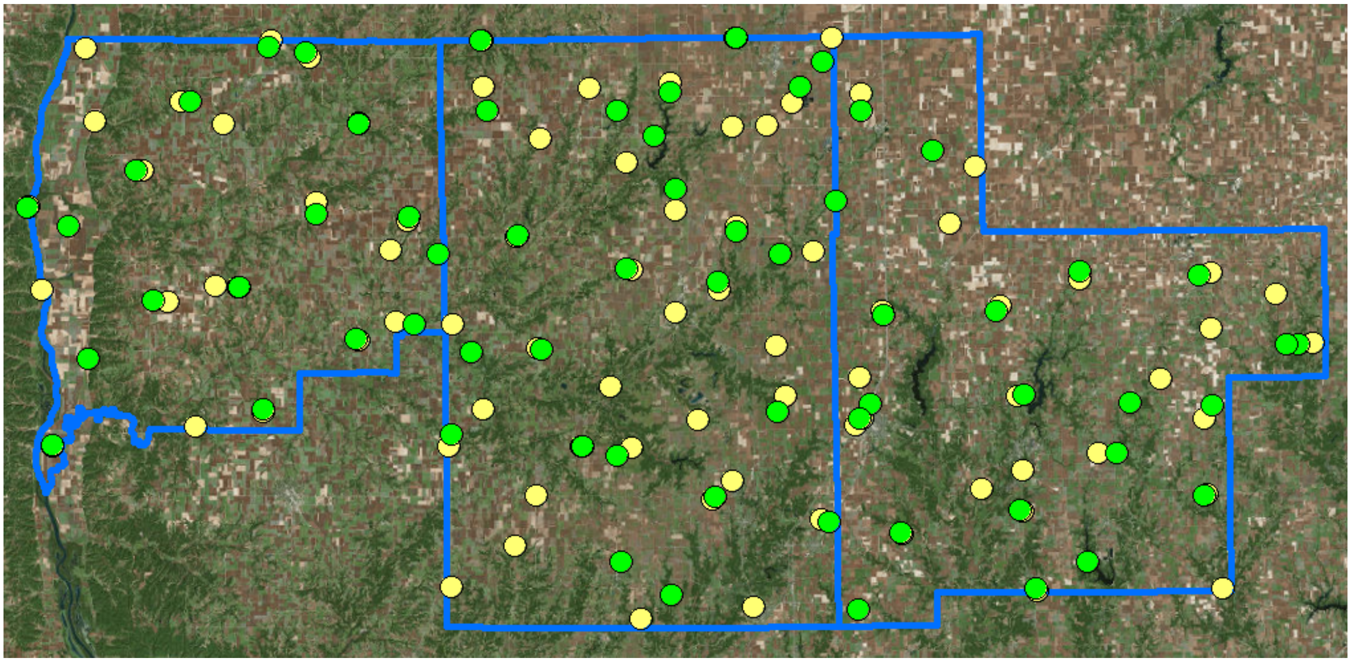
NVA651	2487744.31	924160.8	Yes	630.2	630.15	NVA
NVA654	2494292.07	861245.51	Yes	614.78	614.851	NVA
NVA656	2436365.71	855049.64	Yes	624.44	624.415	NVA
NVA657	2436759.18	930088.51	Yes	663.45	663.491	NVA
NVA659	2435200.88	914712.33	Yes	678.3	678.307	NVA
NVA659PNT	2437696.71	916867.34	Yes	676.63	676.677	NVA
NVA661	2571519.17	957169.75	Yes	670.95	670.819	NVA
NVA668	2465679.96	979888.28	Yes	630.47	630.655	NVA
NVA669	2476205.48	894102.97	No	612.1		NVA
NVA669PNT	2489564.9	900259.18	Yes	630	630.347	NVA
NVA674	2550567.19	946124.94	Yes	706.43	706.317	NVA
NVA676	2554245.14	861756.39	Yes	587.59	587.793	NVA
VVA701	2550930.65	921437.68	Yes	649.41	649.582	VVA
VVA707	2546552.45	963376.25	Yes	659.56	659.638	VVA
VVA708	2444427.12	950283.87	Yes	645.59	645.901	VVA
VVA714	2449823.04	879891.24	Yes	638.88	638.927	VVA
VVA717	2520138.86	905712.66	Yes	659.11	659.643	VVA
VVA720	2548207.58	892099.44	Yes	623.18	623.999	VVA
VVA723	2510322.49	870681.9	Yes	603.16	603.255	VVA
VVA724	2524119.23	922271.07	Yes	643.45	643.906	VVA
VVA728	2437178.29	1016722.3	Yes	646.42	646.406	VVA
VVA736	2488760.44	887107.96	Yes	621.1	621.818	VVA
VVA739	2578805.45	941073.84	Yes	590.05	590.342	VVA
VVA739A	2575002.53	941012.72	Yes	649.39	649.666	VVA
VVA744	2480835.12	951596.61	Yes	640.75	640.855	VVA
VVA745	2428921.1	987445.54	Yes	626.54	626.422	VVA
VVA746	2507843.15	964783.58	Yes	616.74	616.941	VVA
VVA750	2460194.02	1003931.66	Yes	642.1	642.343	VVA
VVA751	2490012.68	924637.2	Yes	636.9	637.063	VVA
VVA754	2493861.56	861850.38	Yes	614.4	614.812	VVA
VVA756	2436351.47	855153.45	Yes	625.54	625.516	VVA
VVA757	2440103.72	921676.94	Yes	667.53	667.813	VVA
VVA759	2436603.98	916834.59	Yes	673.59	673.805	VVA
NVA602	2332211.14	939722.06	Yes	600.37	600.186	NVA
NVA604	2414859.17	1019167.75	Yes	677.61	677.512	NVA
NVA604_PID	2406553.22	1012103.24	Yes	670.67	670.683	NVA
NVA605	2375261.5	1025441.22	Yes	659.56	659.575	NVA
NVA606	2365946.08	851910.41	Yes	613.54	613.618	NVA
NVA609	2376889.79	984329.41	Yes	657.51	657.436	NVA
NVA611	2423970.25	884387.84	Yes	690.56	690.519	NVA
NVA613	2303448.62	907788.3	Yes	614.17	614.032	NVA
NVA616	2388799.74	890708.39	Yes	657.95	658.223	NVA
NVA616_PID	2395351.2	896749.81	Yes	658.13	658.371	NVA
NVA618	2421550.63	970904.27	Yes	636.48	636.28	NVA

NVA621	2314014.35	1039288.08	Yes	604.98	605.001	NVA
NVA625	2346413.52	907708.91	Yes	619.75	619.605	NVA
NVA625_PID	2331864.25	892205.35	Yes	633.8	633.875	NVA
NVA626	2412585.11	924249.5	Yes	666.8	666.992	NVA
NVA627	2427759.8	1040416.2	Yes	628.19	628.22	NVA
NVA630	2362564.55	965163.15	Yes	632.33	632.516	NVA
NVA631	2314487.92	920011.21	Yes	603.46	603.05	NVA
NVA633	2396842.76	979202.53	Yes	642.72	642.825	NVA
NVA637	2314437.61	1024245.59	Yes	655.74	655.796	NVA
NVA640	2391168.44	958561.84	Yes	622.83	622.687	NVA
NVA640_PID	2376945.22	951351.74	Yes	622.44	622.508	NVA
NVA647	2348858.66	1023861.72	Yes	683.64	683.613	NVA
NVA649	2325571.61	975969.85	Yes	536.73	536.659	NVA
NVA652	2362861.11	907427.57	Yes	635.64	635.54	NVA
NVA653	2396311.69	1040275.13	Yes	659.66	659.778	NVA
NVA660	2332992.61	1007770.29	Yes	671.57	671.414	NVA
NVA663	2360843.4	999951.41	Yes	644.11	643.913	NVA
NVA664_PID	2355950.15	927200.68	Yes	537.93	537.767	NVA
NVA665	2324794.41	875499.51	Yes	644	643.958	NVA
NVA666	2409722.43	940611.04	Yes	647.42	647.453	NVA
NVA671_PID	2402343.06	855970.03	Yes	619.42	619.27	NVA
NVA672	2395519.72	1011406.25	Yes	659.24	659.167	NVA
NVA673	2304444.77	862273.1	Yes	651.71	651.491	NVA
NVA675	2384404.18	916497.68	Yes	642.54	642.79	NVA
NVA677	2304848.46	947503.64	Yes	540.25	540.161	NVA
VVA702	2333735.53	939469.45	Yes	586.92	587.132	VVA
VVA704	2417378.35	1024465.74	Yes	671.37	671.478	VVA
VVA705	2375219.21	1022477.69	Yes	647.31	647.827	VVA
VVA706	2375477.56	859783.23	Yes	614.82	615.09	VVA
VVA709	2376857.63	991408.65	Yes	661.24	662.027	VVA
VVA711	2426560.02	883330.17	Yes	679.58	679.828	VVA
VVA713	2304172.03	911933.71	Yes	611.69	611.819	VVA
VVA716	2389720.33	891554.04	Yes	658.57	659.107	VVA
VVA718	2410896	970329.23	Yes	587.76	587.719	VVA
VVA721	2313828.01	1039336.69	Yes	604.94	605.045	VVA
VVA722	2359501.88	870443.51	Yes	638.67	638.692	VVA
VVA725	2347016.88	907869.78	Yes	615.6	615.471	VVA
VVA726	2409962.14	918961.55	Yes	658.13	658.419	VVA
VVA727	2424738.01	1032649.85	Yes	658.2	658.556	VVA
VVA730	2361060.39	965313.96	Yes	631.2	631.583	VVA
VVA731	2310874	938640.38	Yes	562.19	562.3	VVA
VVA733	2396808.65	977420.31	Yes	639.56	639.858	VVA
VVA737	2315749.23	1016739.22	Yes	662.14	662.16	VVA
VVA740	2390504.42	961128.07	Yes	609.43	609.144	VVA

VVA747	2358052.46	1016730.11	Yes	660.34	660.474	VVA
VVA749	2325662.11	976058.17	Yes	534.4	534.384	VVA
VVA752	2358180.16	904991.51	Yes	622.81	623.08	VVA
VVA753	2396649.84	1040230.26	Yes	649.46	649.928	VVA
VVA761	2370061.12	1008288.08	Yes	647.18	646.972	VVA

NOTE: The Complete Ground Survey report conducted by Compass Data, Inc. is attached as Appendix 1.

Lidar Check Point Layout



Hydro-flattening Breakline Collection

Merrick uses a unique approach for breakline collection from lidar data. Hydrographic breaklines are collected in 2D from the lidar bare earth data. Color cycles provide a clear indication of where breaklines are to be collected, especially hydrographic breaklines. Figure 3 demonstrates no breaklines, where Figure 4 is breakline enforced displayed using color cycles within the MARS® software environment.

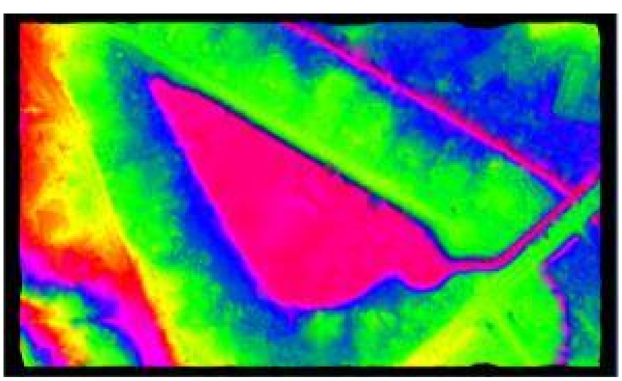


Figure 3

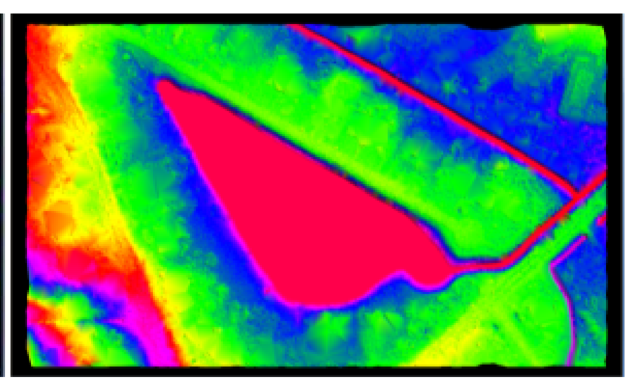


Figure 4

As each breakline is collected, the MARS® software automatically attributes the x, y and z of each breakline point collected directly (i.e., "on-the-fly") from the lidar bare-earth data.

The collection of breaklines in a 2D environment provides significant advantages over a "lidargrammetry" approach; this approach being one in which breaklines are collected as a separate task using stereo intensity imagery. With the Merrick approach:

- No stereo model setups or stereo vision is required.
- Breakline elevations are extracted directly from the lidar bare earth data. There is no risk of a mismatch, either positionally or vertically, between the lidar data set and a stereo-model setup. This is extremely critical. With a "lidargrammetry" approach, there is a significant risk that a breakline collected stereo-scopically may "float" above the surface or "dig" below the surface relative to the lidar data.
- The MARS® software enforces monotonicity (downhill directionality) for linear hydrographic features. Hydrographic breakline collection is always completed in a downhill direction. Any point collected (extracted from the lidar bare earth) must always be lower in elevation from the previous point; if not, it retains the same elevation as the previous point.

Bare-Earth Surface (DEM)

Merrick uses MARS® to develop a DEM from the hydro-flattening breakline enforced ground surface. MARS® is proprietary software that Merrick has developed to provide clients with several significant advantages for managing enormous amounts of lidar information. Internal to Merrick, the MARS® Software application also includes additional modular suites of tools that are used for contour interpolation and other applications. The points in the DEM are related and connected to each other by creating a Triangulated Irregular Network (TIN) and then exporting tiled and project-wide DEM formats per project deliverable specifications.

List of Deliverables

- Raw lidar point cloud
    - Fully compliant ASPRS LAS 1.4, point record format 6, 7, 8, 9 or 10
    - Calibrated
    - By swath
    - Intensity values normalized to 16-bit
    - FGDC-compliant metadata
- Control
    - Survey report
    - Esri shapefile format
    - FGDC-compliant metadata
- FGDC-compliant metadata (project level)
- Detailed lidar Mapping / Project Report
- Project-wide
    - Classified lidar point cloud
    - Fully compliant ASPRS LAS 1.4, point record format 6, 7, 8, 9 or 10
    - By tile
    - Intensity values normalized to 16-bit
    - FGDC-compliant metadata

- Bare-earth DEM
  - 1m cell size 32-bit DEM development in ERDAS IMG format
  - Bare-earth (hydro-flattened)
    - Culverts will not be removed from the DEMs
    - Bridges will be removed from the DEMs
  - By tile and by county
  - FGDC-compliant metadata
- Hydro-flattened breaklines
  - Project-wide Esri feature class(es) for insertion into file geodatabase
  - FGDC-compliant metadata
- Intensity Images
  - 1m cell size in ERDAS IMG format
  - By tile and by county
  - FGDC-compliant metadata

Appendix 1

Following is a more detailed lidar calibration workflow description.

LIDAR CALIBRATION AND BLOCK LAS OUTPUT

Note: All figures represented on the following pages are for general illustration purposes, and are not examples derived from the project.

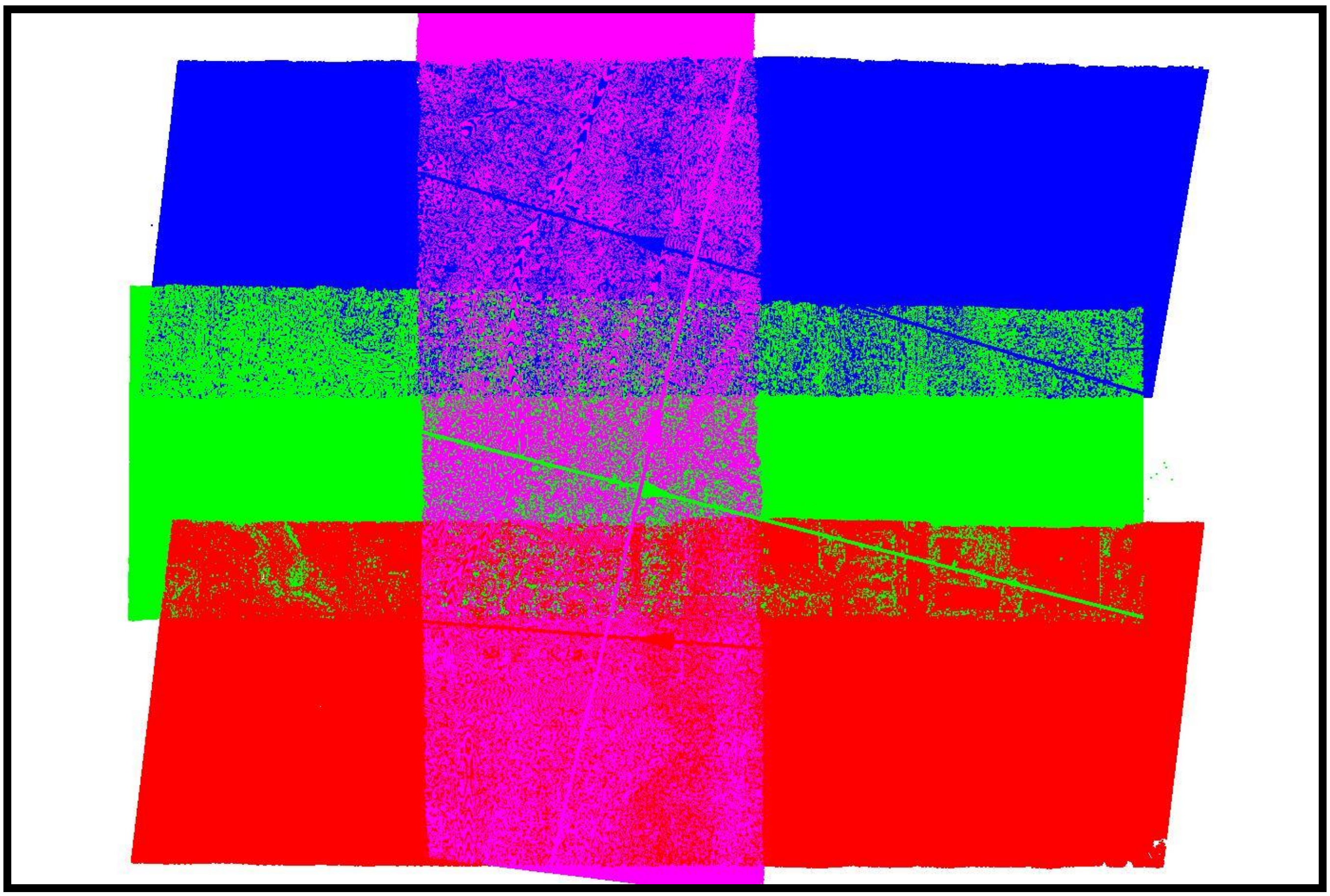
Initial Processing

Lidar data is output as LAS point data using Optech's Lidar Mapping Suite (LMS). LMS matches ground and roof planes plus roof lines to self-calibrate and correct system biases. These biases occur within the hardware of the laser scanning systems, within the Inertial Measurement Unit (IMU) and because of environmental conditions which affect the refraction of light. The systemic biases that are corrected for include scale, roll, pitch, and heading.

In addition to the self-calibration mode LMS runs a "production" mode which applies the self-calibration parameters and then analyzes each individual flight line and applies small adjustments to each line to tie overlapping lidar points even more tightly together.

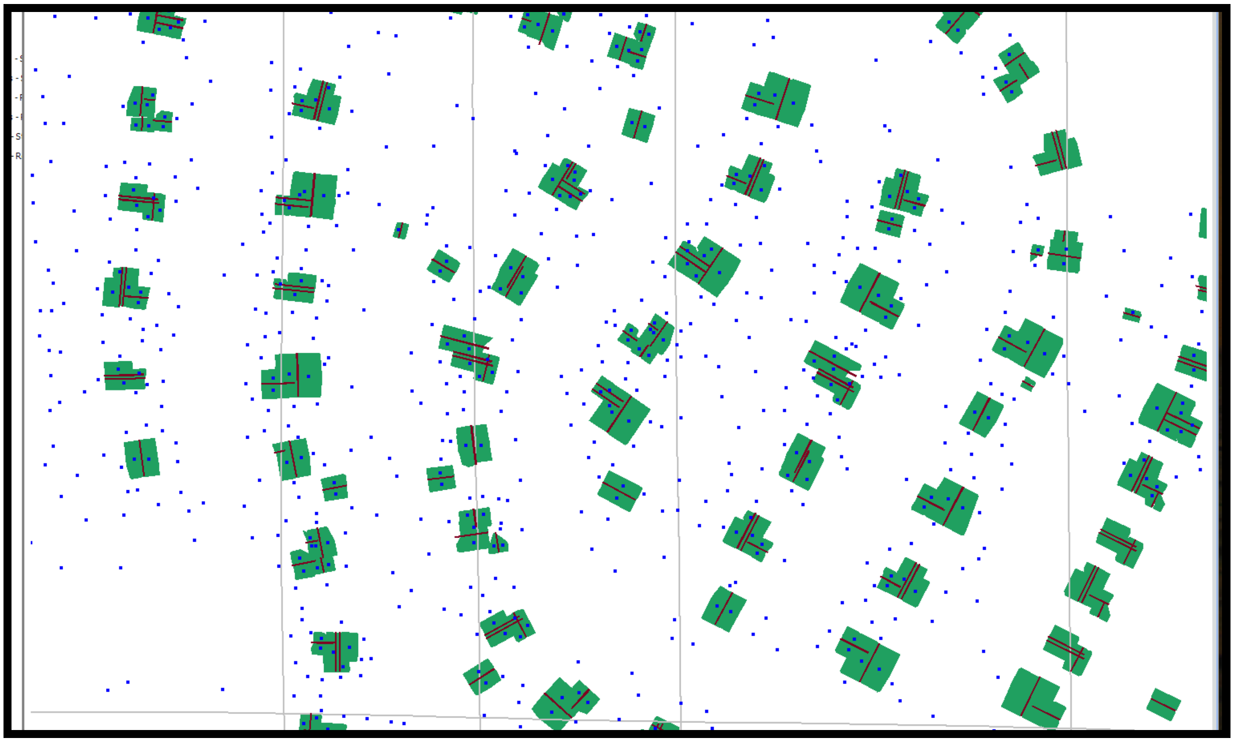
Boresight Self-Calibration Processing Procedures

An LMS boresight calibration is performed on an as-needed basis to correct scale, roll, pitch and heading biases. A minimum of three overlapping flights are flown in opposing directions with one cross flight.



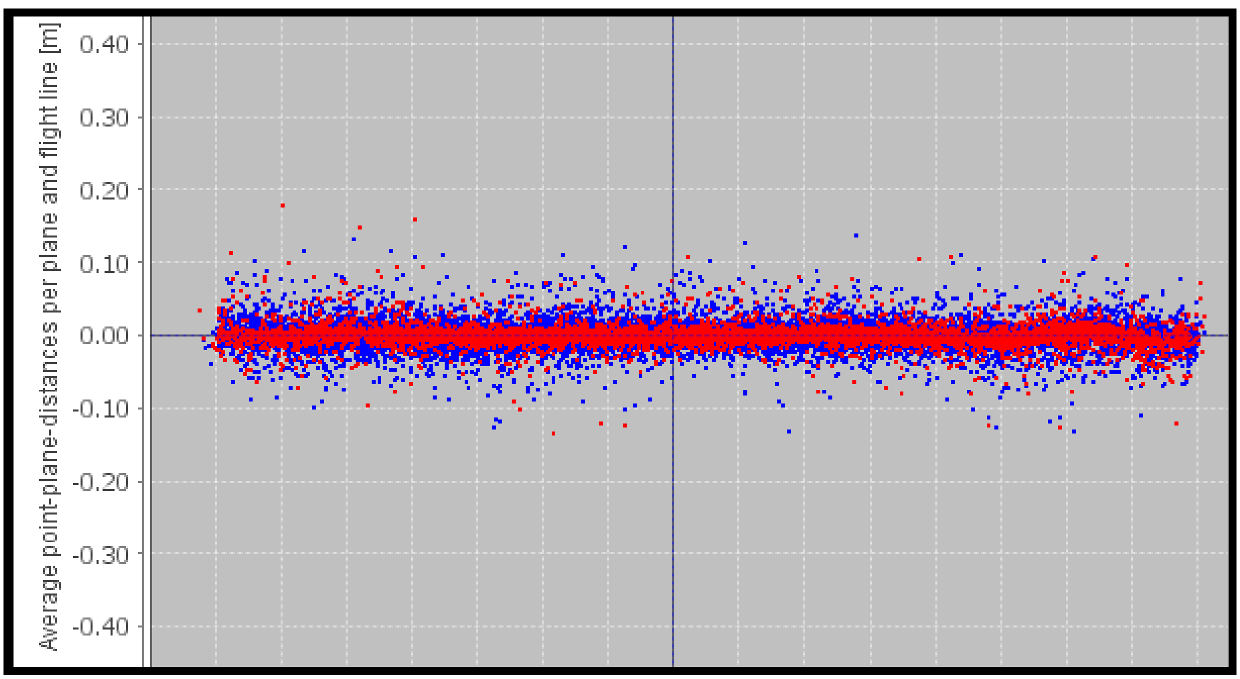
The Boresighting module frees scan angle scale, scan angle lag, XYZ boresight corrections and elevation position corrections while locking scan angle offset and XY position corrections.

The picked calibration site will have a good distribution of buildings for the self-calibration software to match ground planes, roof planes and roof lines.

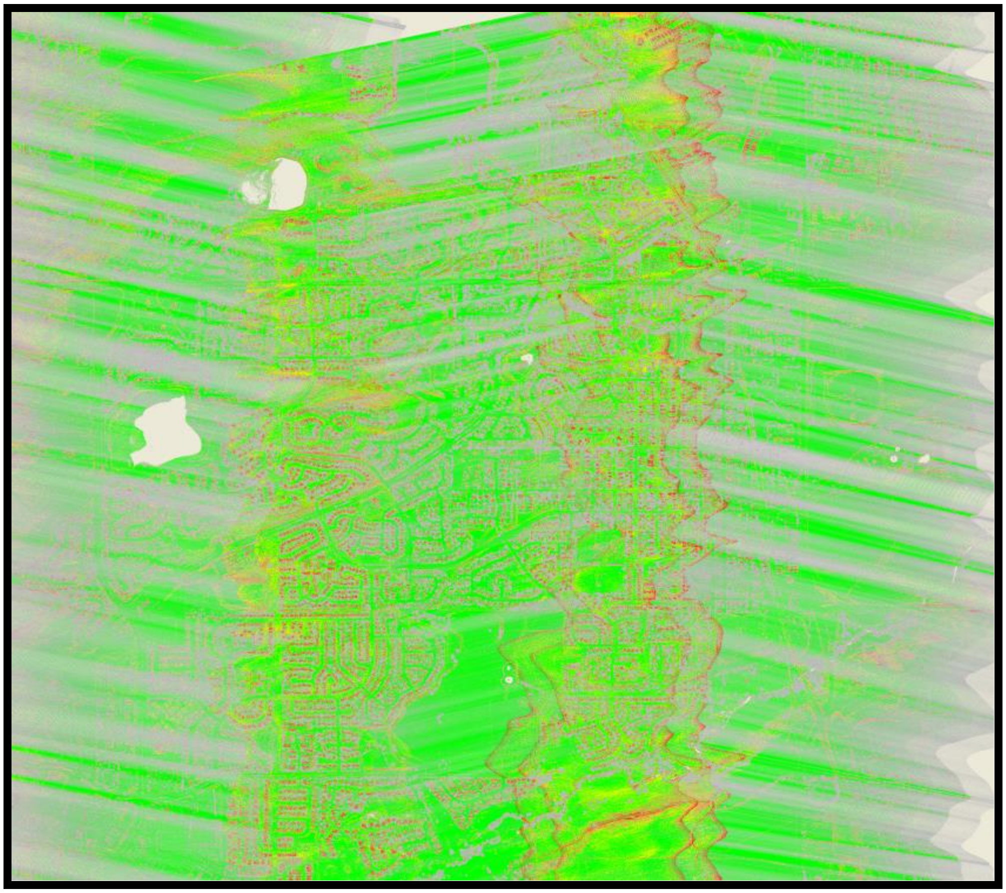


At the conclusion of the self-calibration run the data is quality checked with LMS plots

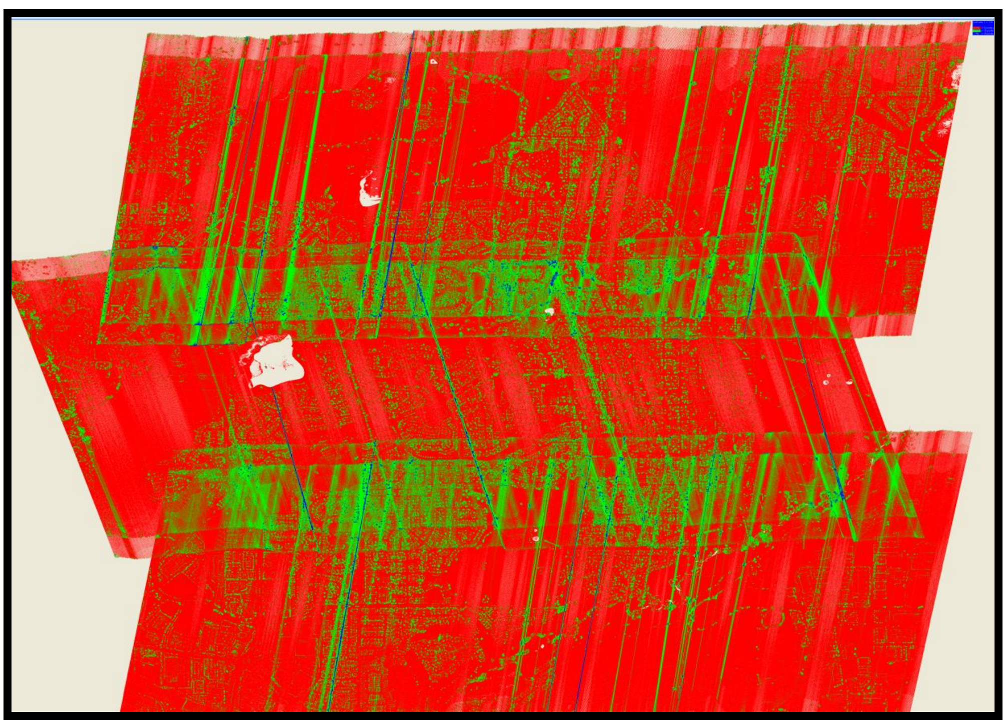
Plot of plane vertical distances from datum plane.



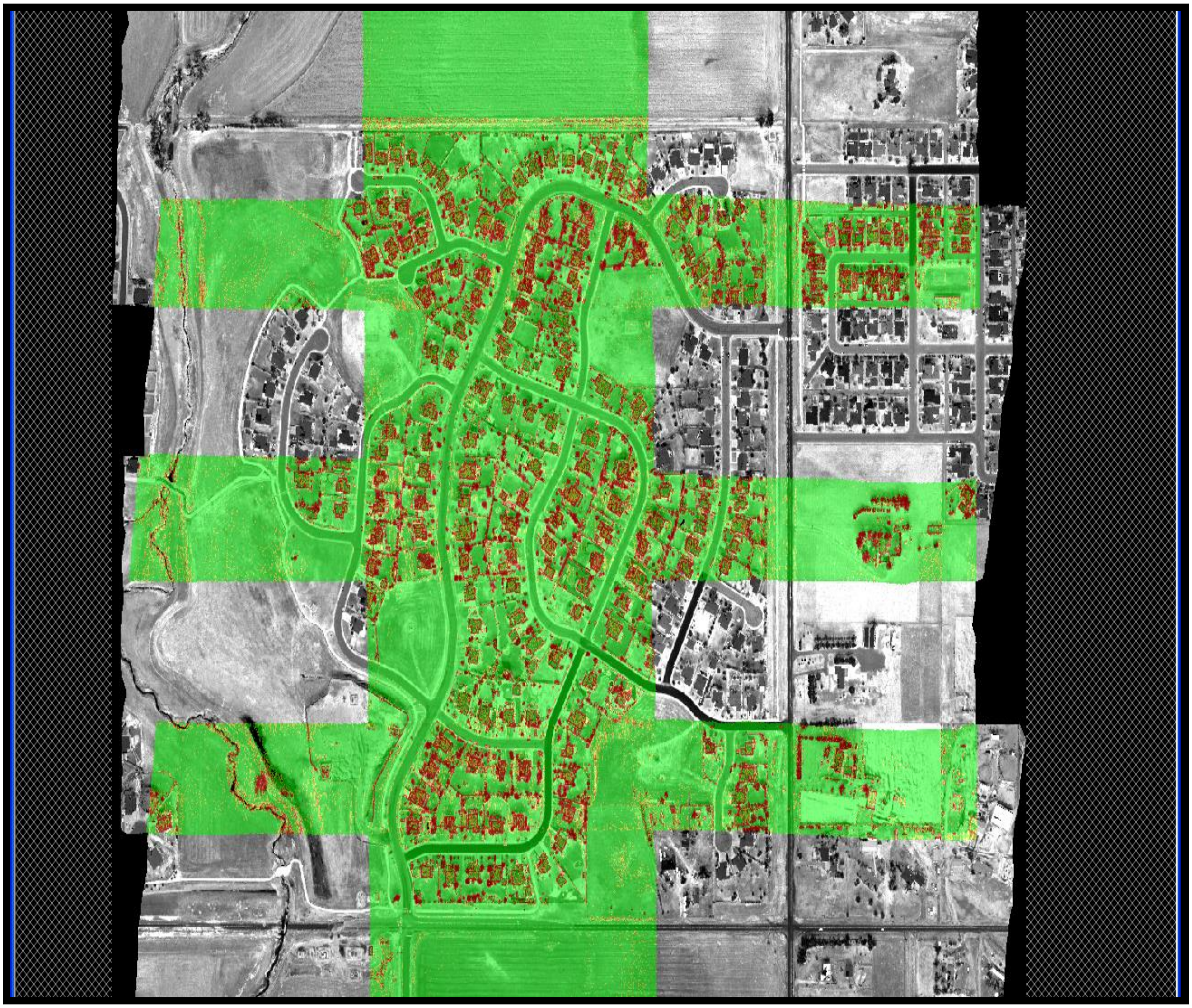
Plot of height differenced between flight lines. (Green=less than 5cm).



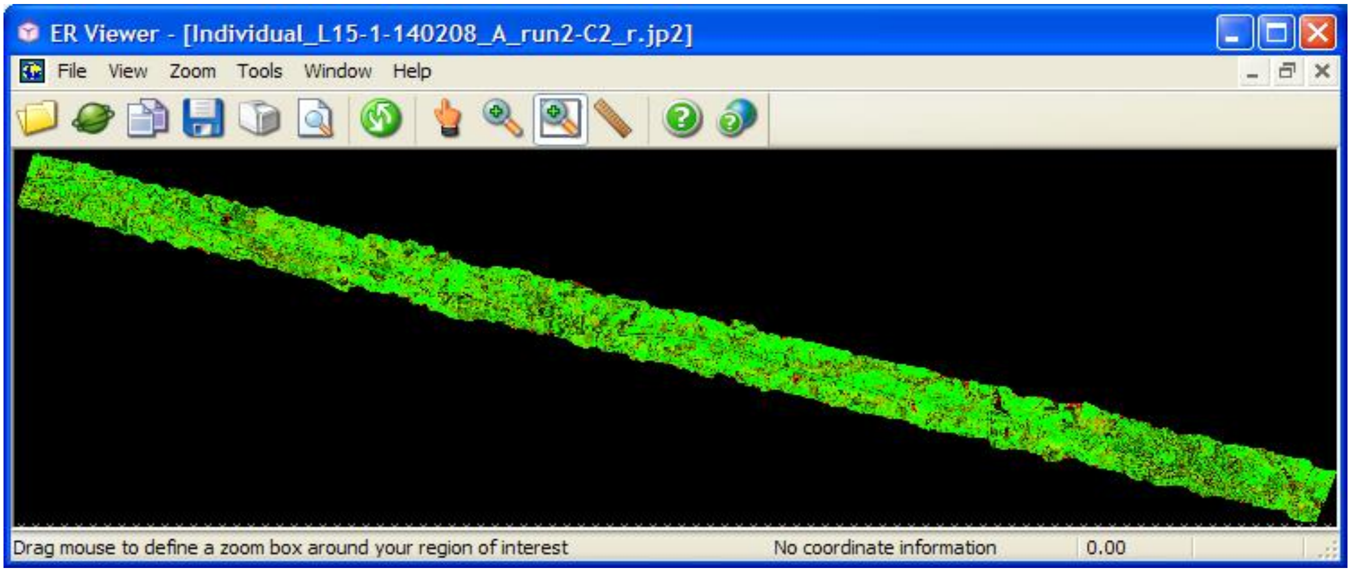
Plot of point densities. (Red=5-9 points per cell, green 10+ points per cell).



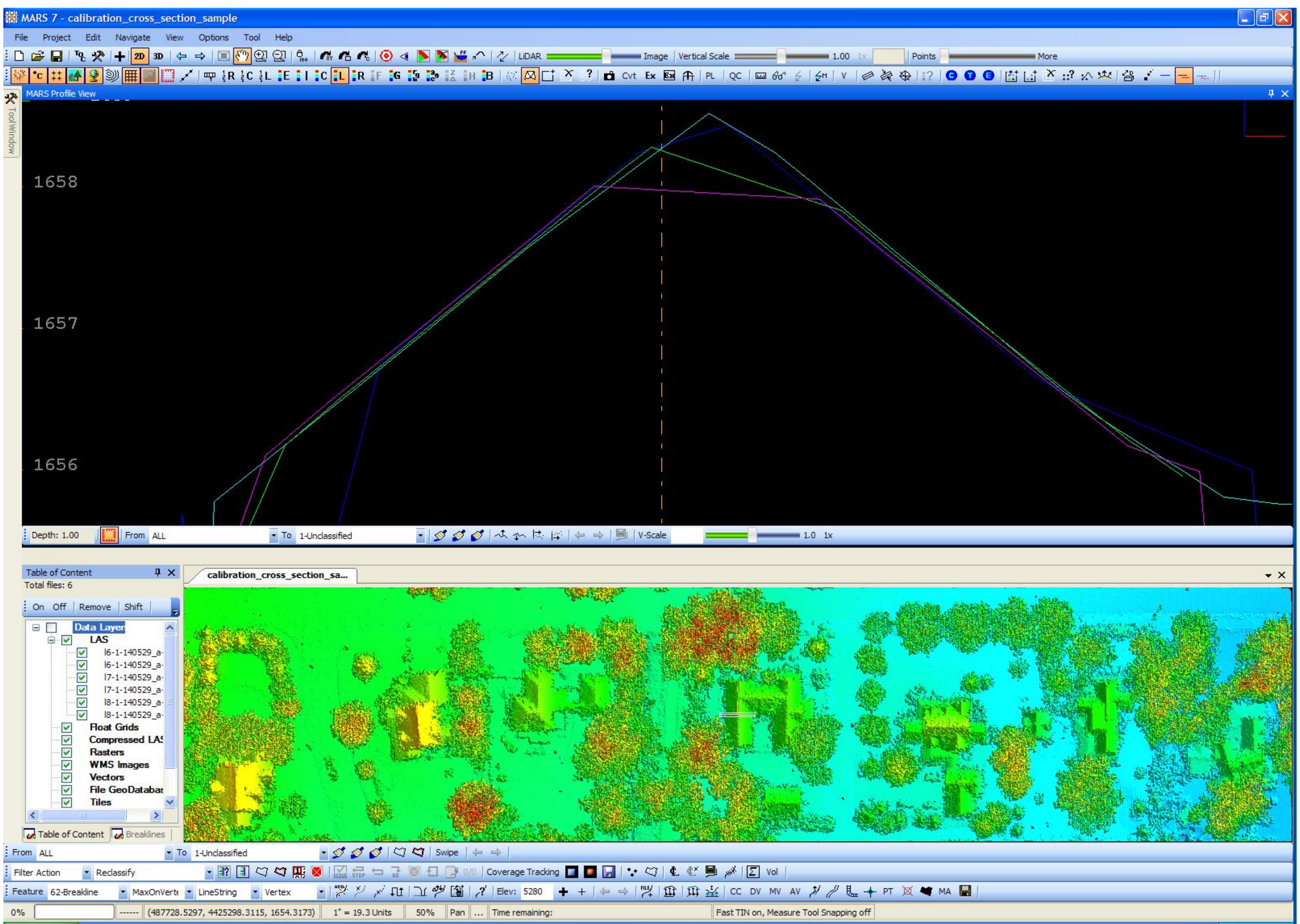
A Flight Line Separation Raster image is generated in Merrick Advanced Remote Sensing Software (MARS®), in this example ground returns from multiple flight lines that are fitting within 3 centimeters are colored green.



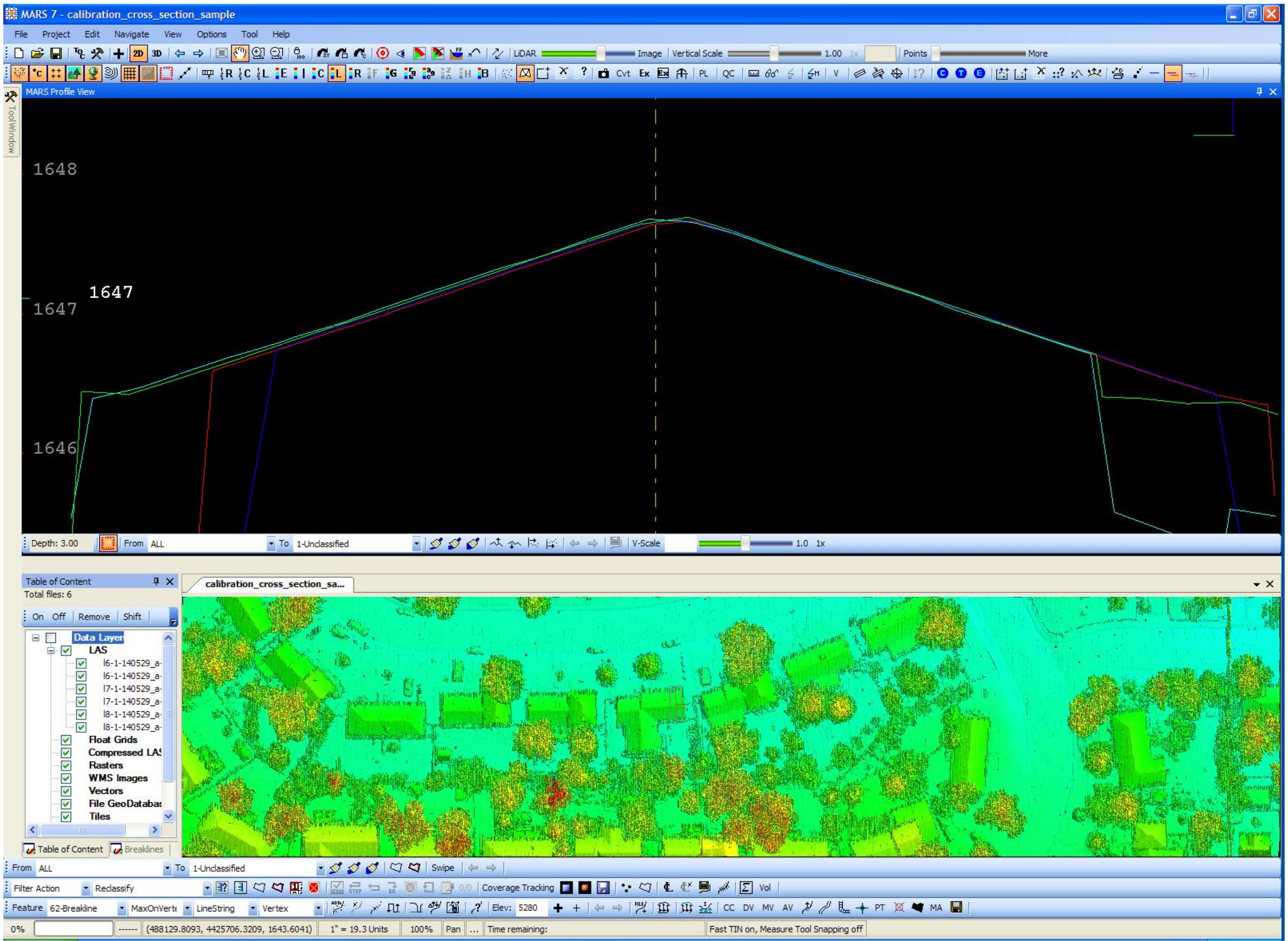
MARS® tests for internal relative vertical accuracy using inbound and outbound scan values. Again, Green is showing inbound and outbound scan data fitting to 3 centimeters.



Building cross sections are checked for good alignment. Pitch and heading are checked on roof planes parallel to the flight direction.



Roll and scale are checked on roof planes perpendicular to the flight direction.

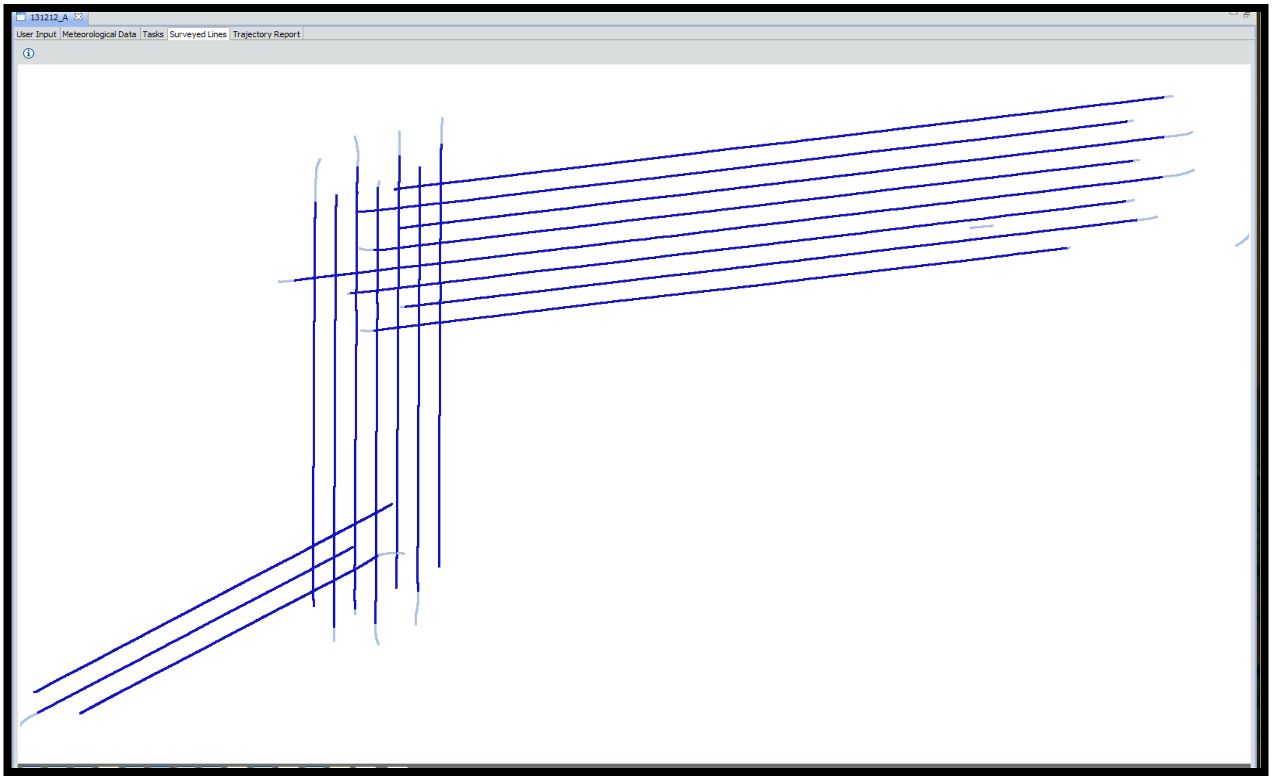


The LMS program outputs a "LCP" file with all the correction parameters. The calibration process may be run several times until the boresight adjustments are acceptable. When the boresight solution is acceptable the LCP file adjustments are saved and also applied to subsequent projects. Each new project is again analyzed and when the adjustment biases show too much drift a new boresight calibration is run. The LCP file may hold calibration tolerances for several projects.

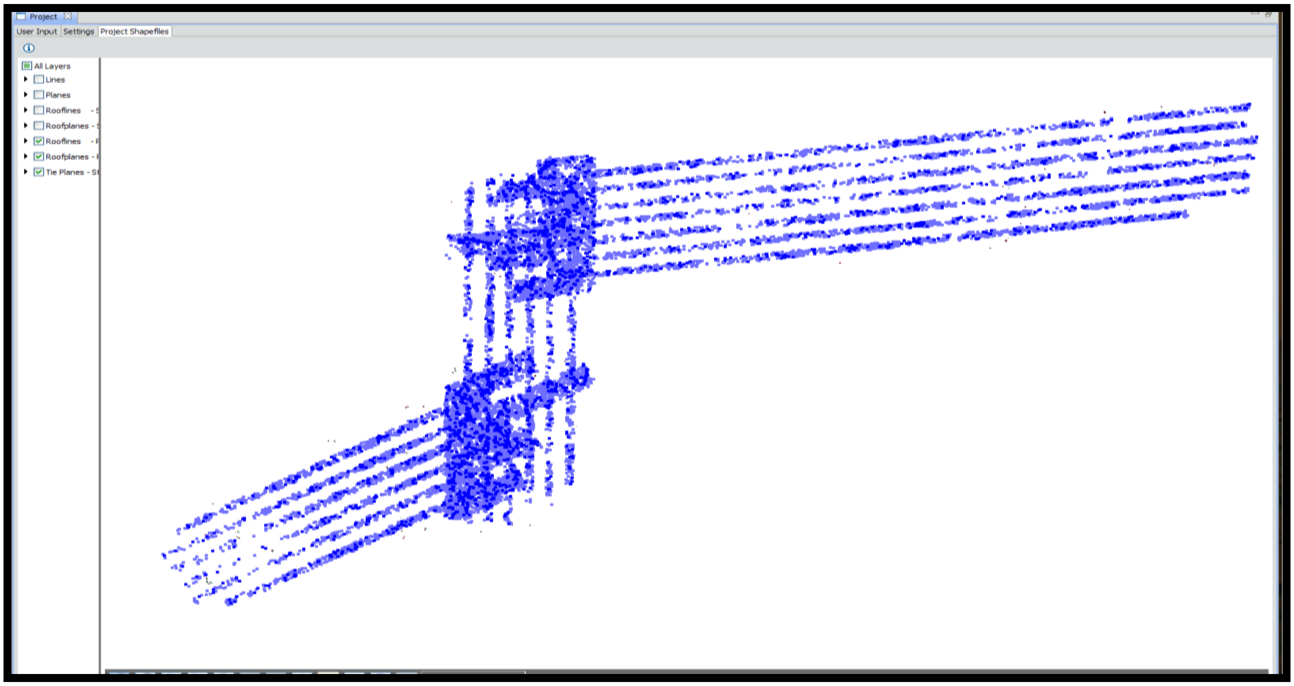
Block LAS Production Processing Procedures

The LMS production mode is run on each flight line to further tie the final lidar LAS flight line files tightly together. Production settings allow scan angle scale, scan angle lag to float and allows elevation to move slightly during flight line to flight line comparison thus further tying flight lines together. A cross flight with locked elevation data is used for controlling flight line elevations.

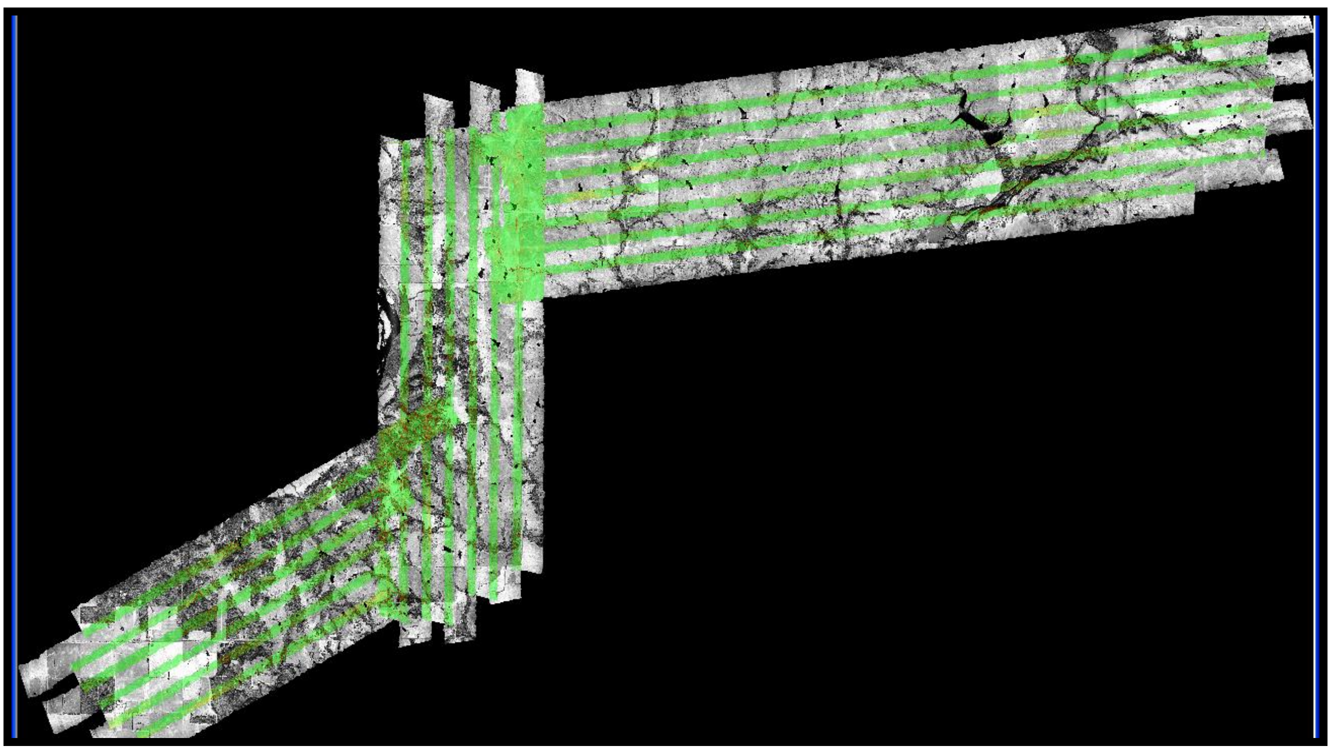
A block of data is selected to process with LMS production settings. Data collected during turns at the ends of flight lines is deselected (light blue lines).



As in self-calibration the LMS production program analyses ground, roof planes and rooflines. One cross flight is locked in elevation and all other lines are adjusted to it. Unlike the calibration site the distribution of roof planes is usually much less dense. Here matched ground tie planes are blue.

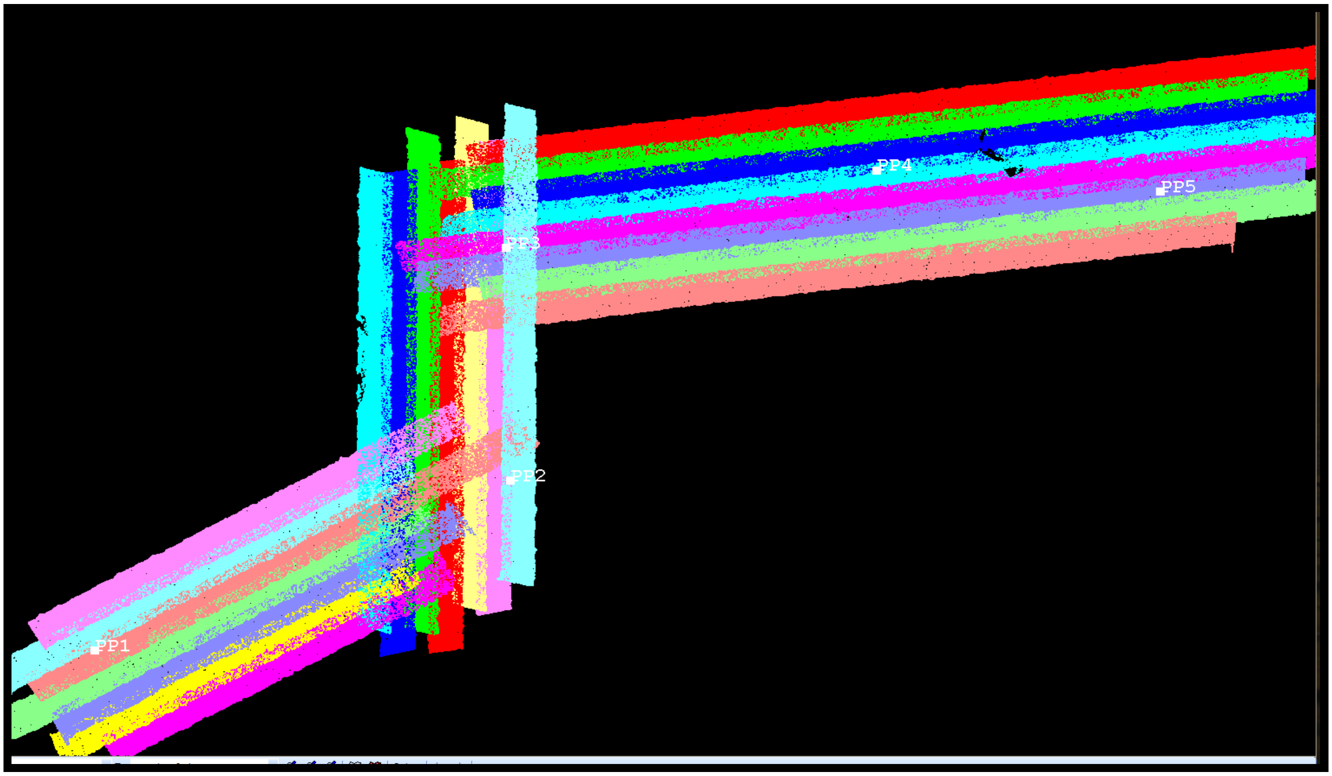


The same quality control outputs used to check self-calibrations are available to analyze the production run. Output plots are again available in LMS and cross sections plus a Flight Line Separation Raster are generated in MARS® to check coverage and quality.



Correcting the Final Elevation

After all the lines are tied together a ground control network is imported into MARS®. The ground control network may be pre-existing or collected by a licensed surveyor.



The next step is to match the ground control elevations to the lidar data set. A control report is run and the data set is shifted slightly to zero out the average elevation error and points checked for quality.

The final step before boresighted, leveled LAS files are ready for filtering is to run the MARS® QC Module on the block data. The Boresighted lidar QC Report outputs individual reports on Point Density, Nominal Pulse Spacing, Data Voids, Spatial Distribution, Scan Angles, Control Report, Flight Line Separation, Flight Line Overlap, Buffered Boundary, LAS Formats, Datums and Coordinates.
These reports are checked with the required specifications in the Project Management Plan.

<u>LIDAR CLASSIFICATION</u>

Auto-Filter (automated)

Merrick-Surdex JV uses customizable software to classify an automated bare-earth (i.e., ground / Class 2) solution from the lidar point cloud. The software uses several different algorithms combined in a macro to determine the classification for each point. Filter parameters are adjusted based on the terrain and land cover for each project to produce the best ground result and to minimize hand-filter. Automated filters typically classify 85- to 90-percent of the ground.

Hand-Filter (manual editing)

The remaining 10- to 15-percent of the points resulting from the automated filtering techniques are possibly misclassified and require final editing. Merrick-Surdex JV has several manual edit tools which allow us to re-classify these features to the appropriate class. All the data within the project extent is viewed by an operator to ensure all artifacts are removed, and that we are meeting project specifications. Bridges are classified to Class 17. Once it is deemed the best ground solution is met, a final auto-filter is run to classify all points to meet the ASPRS LAS 1.4 specification. During this process, all non-ground and non-bridge points are classified to Class 1 (Unclassified), and following this is a height-from-surface auto-filter is run to re-class noise to Classes 7 and 18.

The following table represents the ASPRS LAS 1.4 classifications used:

- Class 0 = Never classified (Noise Withheld Flags set)
- Class 1 = Unclassified (Noise Withheld Flags set)
- Class 2 = Bare-earth Ground (Note: Model keypoints bitflagged)
- Class 2 MKP bit-flag = Model Keypoint bitflag
- Class 7 = Low point (noise)
- Class 9 = Water
- Class 10 = Ignored ground (near a breakline)
- Class 17 = Bridge decks
- Class 18 = High noise