Lidar Mapping Report

Acquisition, Processing, and Delivery of Airborne Lidar Elevation Data for the 2018 Clark County Project

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SOUTHERN NEVADA WATER AUTHORITY

desert conservation PROGRAM

Submitted To:

SOUTHERN NEVADA WATER AUTHORITY

Submitted By:

MERRICK®

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Glossary of Terms

Term	Description
AGL	Above Ground Level
AGPS	Airborne Global Positioning System
ANPD	Aggregate Nominal Pulse Density
ANPS	Aggregate Nominal Pulse Spacing
ASPRS	American Society of Photogrammetry and Remote Sensing
AT	Aerial Triangulation
CD	Compact Disk
CMS	Certified Mapping Scientist
CORS	Continuous Operating Reference Station
CP	Certified Photogrammetrist
CVA	Consolidated Vertical Accuracy
DACS™	Digital Airborne Camera System
DEM	Digital Elevation Model
DFIRM	Digital Flood Insurance Rate Maps
DSM	Digital Surface Model
DTM	Digital Terrain Model
DVD	Digital Versatile Disk / Digital Video Disk
DXF	Data Exchange Format / Drawing Interchange
FIRM	Flood Insurance Rate Maps
FEMA	Federal Emergency Management
FGDC	Federal Geographic Data Committee
FVA	Fundamental Vertical Accuracy
FY	Fiscal Year
GIS	Geographic Information System
GISP	Geographic Information System Professional
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSD	Ground Sample Distance
HARN	High Accuracy Reference Network
HDD	Hard Drive Disk
HPGN	High Precision Geodetic Network
IMU	Inertial Measurement Unit
INS	Inertial Navigation System
LAS	(or .las) – industry accepted LIDAR data exchange file format
LB	License Business
LS	Land Surveyor
LiDAR	(or Lidar) Light Detection And Ranging
MARS®	Merrick Advanced Remote Sensing
Merrick	Merrick & Company
MSL	Mean Sea Level
NAD	North American Datum
NDEP	National Digital Elevation Program
NGP	National Geospatial Program
NGS	National Geodetic Survey
NMAS	National Map Accuracy Standards
No.	Number
NPS	Nominal Point Spacing

NSRS	National Spatial Reference System
NSSDA	National Standard for Spatial Data
NVA	Non-vegetated Vertical Accuracy
OPUS	Online Positioning User Service
PDOP	Positional Dilution Of Precision
PLS	Professional Land Surveyor
PLSS	Public Land Survey System
ppsm	Points (or pulses) per square meter
PSM	Professional Surveyor and Mapper
QL1	Quality Level One
QL2	Quality Level Two
RLS	Registered Land Surveyor
RGB	Red, Green, Blue (i.e., three-band image)
RGBNIR	Red, Green, Blue, Near Infra-Red (i.e., four-band image)
RMSE	Root Mean Square Error
SBET	Smoothed Best Estimated Trajectory
SHA	Secured Hash Standard
SPCS	State Plane Coordinate System
SVA	Supplemental Vertical Accuracy
TIN	Triangular Irregular Network
USGS	United State Geological Survey
VVA	Vegetated Vertical Accuracy
XML	eXtensible Markup Language

Project Summary

Merrick was awarded the Clark County Aerial LiDAR project by the Southern Nevada Water Authority (SNWA). The final deliverables will assist with managing the region's water resources and to develop solutions that will ensure adequate future water supplies for the Las Vegas Valley within Clark County, Nevada. Additionally, the Desert Conservation Program (DCP) contributed funds to SNWA for specific Scope of Work (SOW) tasks and deliverables. The AOI consists of 5 non-contiguous areas covering approximately 289 square miles in total within the Las Vegas Valley.

The lidar mapping requirements and deliverables meet Quality Level Two (QL2) standards for SNWA final deliverables and Quality Level One (QL1) for DCP final deliverables as outlined in the USGS-NGP Lidar Base Specifications, Techniques and Methods 11–B4, Version 1.3, November 2014 (TM11-B4) (http://pubs.usgs.gov/tm/11b4/pdf/tm11-B4.pdf). QL2 lidar specifications suggest a pulse density of greater than or equal to two pulses per square meter (≥2ppsm) Aggregate Nominal Pulse Density (ANPD), and pulse spacing of less than or equal to seventy-one centimeters (≤0.71m) Aggregate Nominal Pulse Spacing (ANPS). QL1 lidar specifications suggest a pulse density of greater than or equal to eight pulses per square meter (≥8ppsm) Aggregate Nominal Pulse Density (ANPD), and pulse spacing of less than or equal to thirty-five centimeters (≤0.35m) Aggregate Nominal Pulse Spacing (ANPS).

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

Absolute Vertical Accuracy

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

Relative Vertical Accuracy

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

Project Spatial Reference

- Horizontal Datum – North American Datum of 1983 (NAD 83)
- Epoch – National Adjustment of 2011 (NA2011) (epoch 2010.00)
- Geoid – GEOID 12B
- Vertical Datum – North American Vertical Datum of 1988 (NAVD 88)
- Projection
  - SNWA – Nevada State Plane Coordinate System, East Zone (FIPS 2701)
    - Units – U.S. Survey Foot
  - DCP – Universal Transverse Mercator (UTM), Zone 11 North
    - Units – Meters

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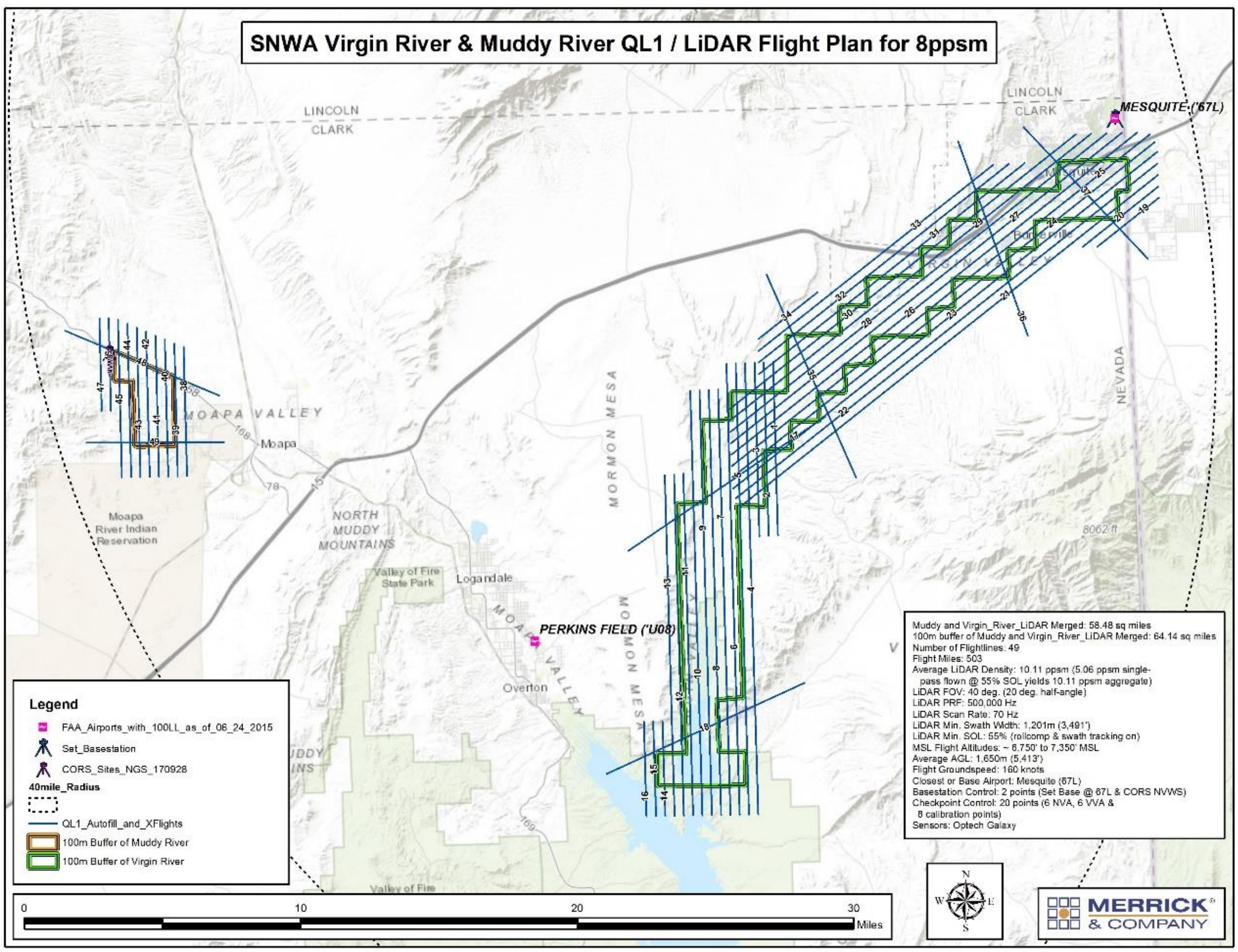
Project Report

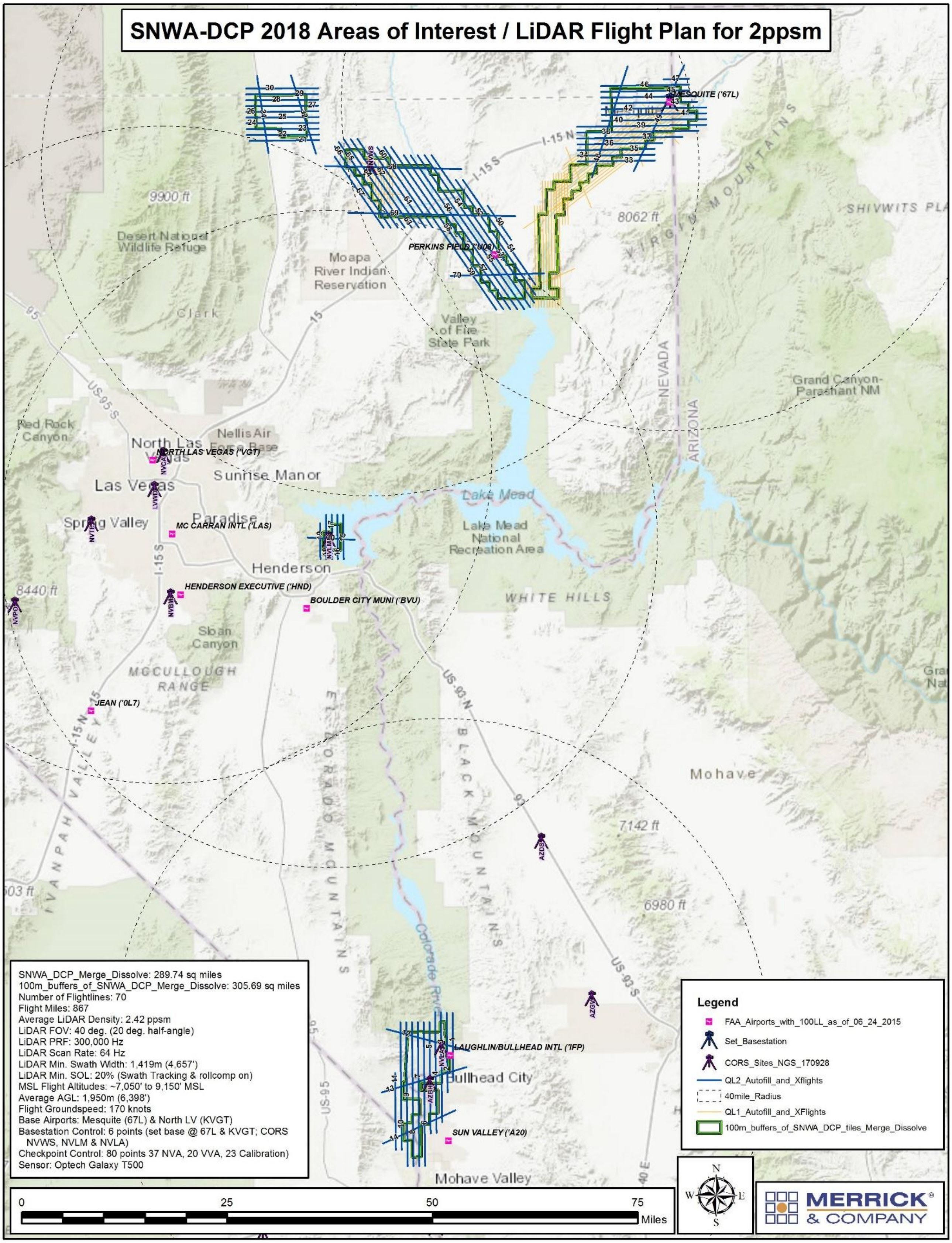
The contents of this report summarize the methods used to calibrate and classify the lidar data as well as the results of these methods for the project Clark County Aerial LiDAR.

Lidar Flight Information

The acquisition area for the Clark County Aerial LiDAR project is delineated by the extent of the client-approved Esri shapefiles (*Virgin_River_Lidar_SA, Muddy_river_LiDAR, SNWA_DCP_tiles_Merge*) and cover 259 full PLSS section-formatted tiles. Merrick acquired both QL1 and QL2 lidar point cloud utilizing an Optech Galaxy lidar sensor. The Galaxy is a high performance 550 kHz lidar sensor capable of collecting large areas efficiently.

Merrick planned an acquisition area of approximately 289 square miles, to include a one hundred-meter (100m) buffer per TM11-B4. See below illustrations of the proposed lidar flight plan.

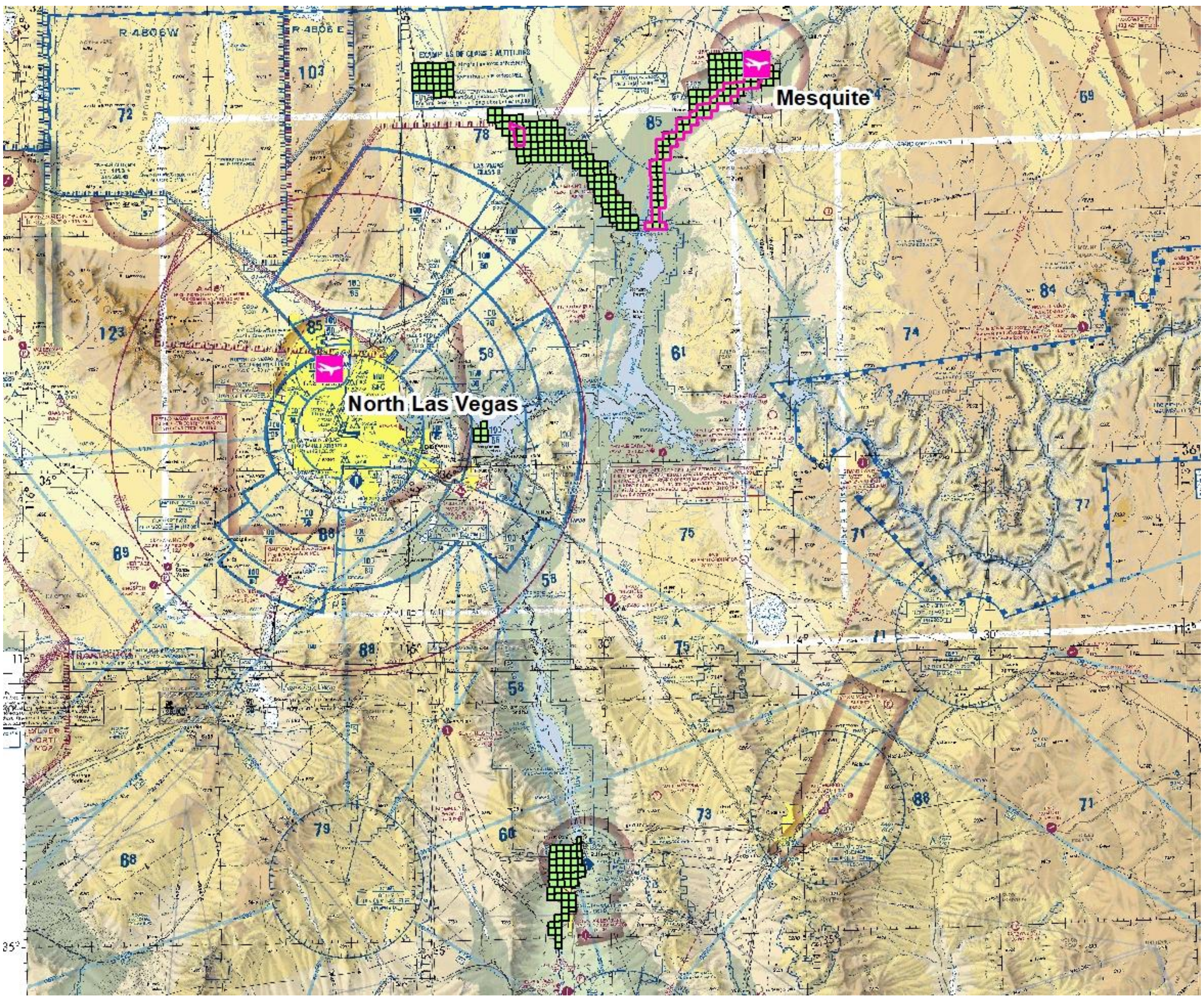



SNWA-DCP 2018 Areas of Interest / LiDAR Flight Plan for 2ppsm
SNWA_DCP_Merge_Dissolve: 289.74 sq miles
100m_buffers_of_SNWA_DCP_Merge_Dissolve: 305.69 sq miles
Number of Flightlines: 70
Flight Miles: 867
Average LiDAR Density: 2.42 ppsm
LiDAR FOV: 40 deg. (20 deg. half-angle)
LiDAR PRF: 300,000 Hz
LiDAR Scan Rate: 64 Hz
LiDAR Min. Swath Width: 1,419m (4,657')
LiDAR Min. SOL: 20% (Swath Tracking & rollcomp on)
MSL Flight Altitudes: ~7,050' to 9,150' MSL
Average AGL: 1,950m (6,398')
Flight Groundspeed: 170 knots
Base Airports: Mesquite (67L) & North LV (KVGT)
Basestation Control: 6 points (set base @ 67L & KVGT; CORS NVWS, NVLM & NVLA)
Checkpoint Control: 80 points 37 NVA, 20 VVA, 23 Calibration)
Sensor: Optech Galaxy T500
Legend
FAA_Airports_with_100LL_as_of_06_24_2015
Set_Basestation
CORS_Sites_NGS_170928
QL2_Autofill_and_Xflights
40mile_Radius
QL1_Autofill_and_XFlights
100m_buffers_of_SNWA_DCP_tiles_Merge_Dissolve
0
25
50
75
Miles
MERRICK
& COMPANY
MESQUITE ('67L)
PERKINS FIELD ('U08)
NORTH LAS VEGAS ('VGT)
MC CARRAN INTL ('LAS)
HENDERSON EXECUTIVE ('HND)
BOULDER CITY MUNI ('BVU)
JEAN ('0L7)
LAUGHLIN/BULLHEAD INTL ('IFP)
SUN VALLEY ('A20)
Las Vegas
Henderson
Bullhead City
Mohave Valley
Lake Mead
Lake Mead National Recreation Area
Valley of Fire State Park
Moapa River Indian Reservation
Desert National Wildlife Refuge
Grand Canyon-Parashant NM
NEVADA
ARIZONA
BLACK MOUNTAINS
ELDORADO MOUNTAINS
WHITE HILLS
MCCULLOUGH RANGE
VIRGIN MOUNTAINS
Mohave

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 airports displayed.

- Mesquite Airport – Mesquite, Nevada
    - FAA Identifier: 67L
    - Lat/Long: 36-49-59.3000N / 114-03-21.2000W
    - Elevation: 1978.1 ft. / 602.9 m (surveyed)
    - From City: 2 miles N of MESQUITE, NV
    - Zip Code: 89027
- North Las Vegas Airport – Las Vegas, Nevada
    - FAA Identifier: KVGT
    - Lat/Long: 36-12-38.5000N / 115-11-40.0000W
    - Elevation: 2205 ft. / 672.1 m (surveyed)
    - From City: 3 miles NW of LAS VEGAS, NV
    - Zip Code: 89032



Aerial Mission(s) Duration / Time

Merrick's lidar acquisition was collected using a fixed wing aircraft and an Optech Galaxy lidar sensor. Lidar data collection for the project was accomplished between April 13, 2018 and April 17, 2018. 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, and D. The table below relates each mission to the date collected, the sensor and serial number used, the start/end time and the actual average MSL in meters. The time is shown in GPS seconds of the week.

Mission(s)	Date	Sensor S/N	Start Time GPS sec.	End Time GPS sec.	Actual Avg. MSL (m)
180413_A	April 13, 2018	5060385	530704	550016	2,500
180413_B	April 13, 2018	5060385	551731	556904	2,350
180414_A	April 14, 2018	5060385	602540	618660	2,500
180414_B	April 14, 2018	5060385	16170	28114	2,350
180415_A	April 15, 2018	5060385	83127	94133	2,100
180417_A	April 17, 2018	5060385	235388	247608	2,200

GNSS / 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.

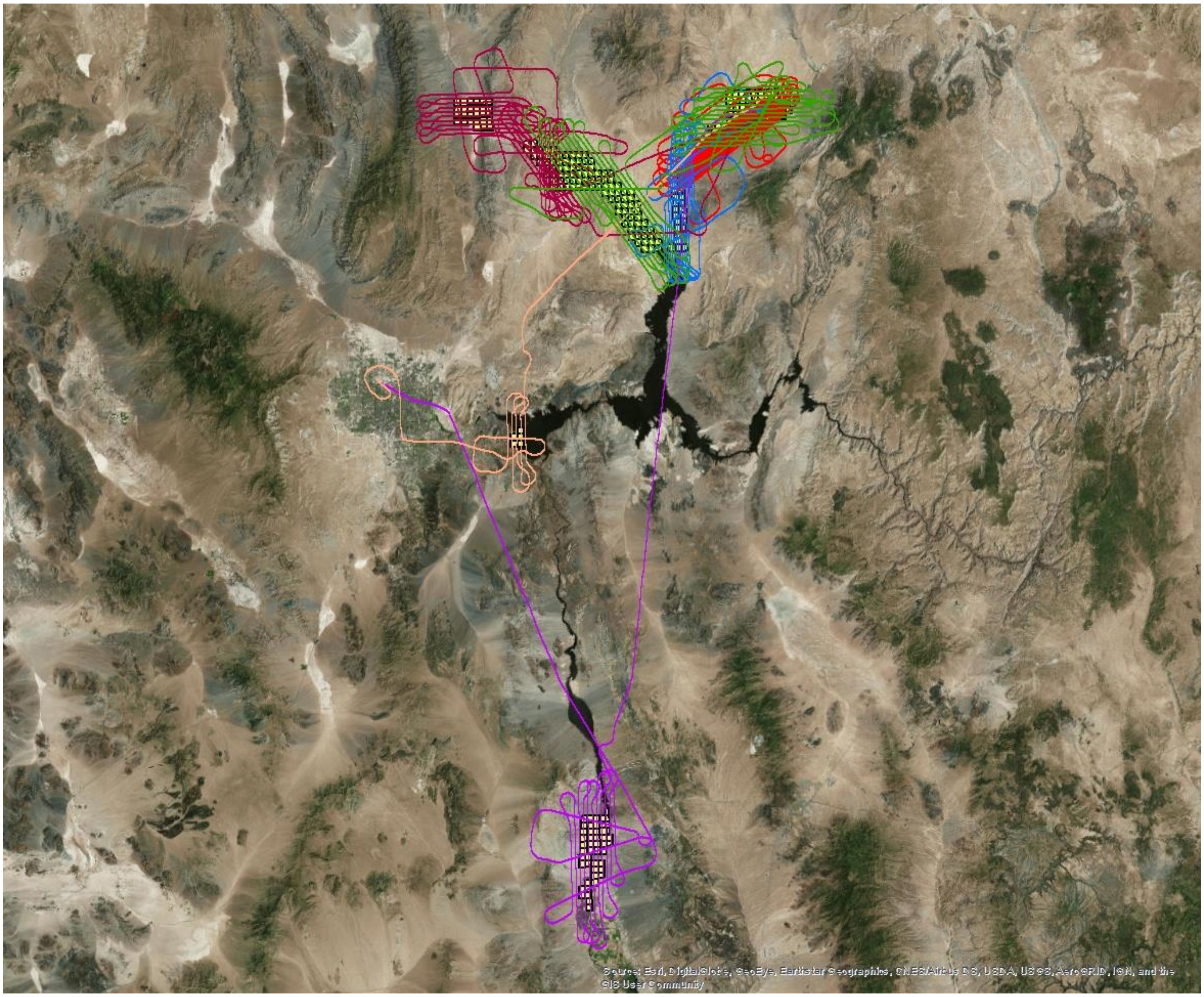
The airborne GPS data was post-processed using Applanix POSPac Mobile Mapping Suite version 8.x. A fixed-bias carrier phase solution was computed in both the forward and reverse chronological directions. Whenever practical, lidar acquisition was limited to periods when the PDOP was less than 4.0. PDOP 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 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 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 are at times used to further enhance the airborne solution. The ground GNSS Base Stations coordinates were obtained from NGS OPUS solutions. CORS coordinates were obtained from NGS datasheets. See the following map for post-processed aircraft trajectories.

Aerial Missions – missions color-coded



Lidar Calibration – see appendix 1 for a more detailed workflow description

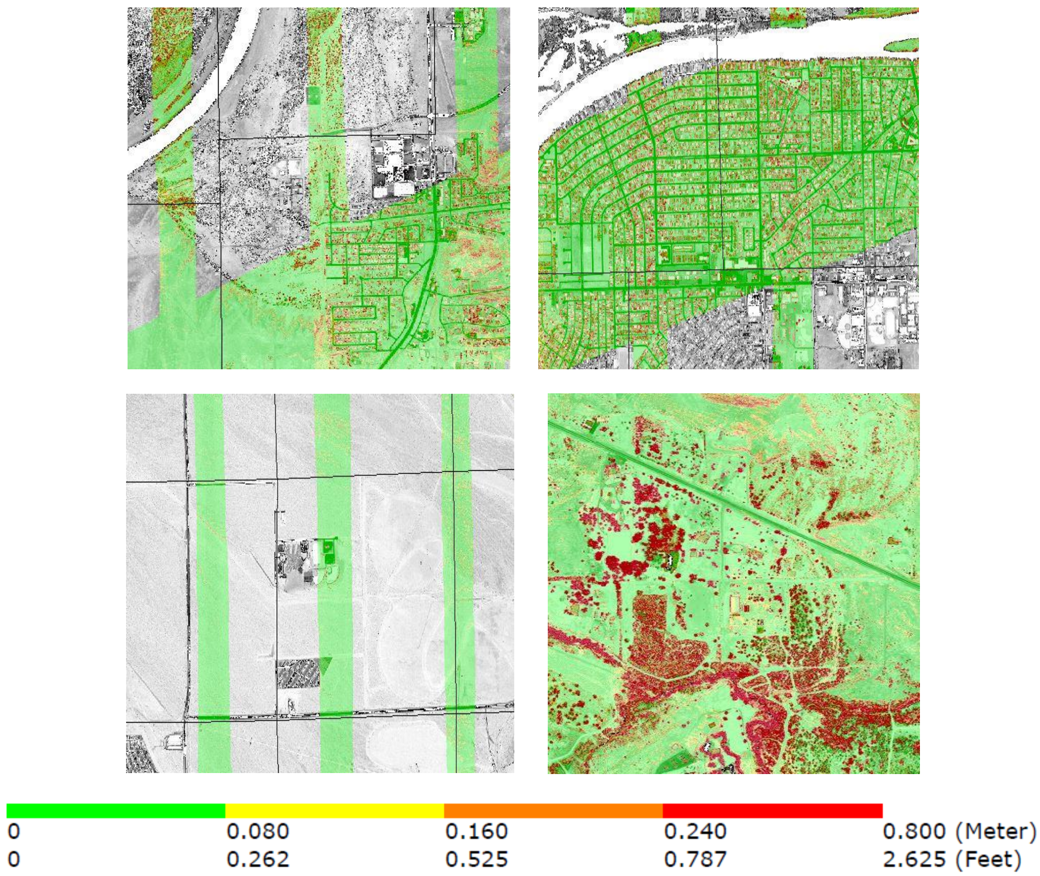
Merrick takes great care to ensure all lidar acquisition missions are carried out in a manner conducive to post-processing an accurate data set. This begins in the flight-planning stage with attention to GPS baseline distances and GPS satellite constellation geometry and outages. Proper AGPS surveying 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 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

The project representative flight line separation raster examples (below) depict the vertical separation of flight lines by thematically coloring the separation magnitude on a color ramp based on relative distance. This color thematic rendering is modulated by intensity to show land cover features.



Survey – Lidar Calibration Control / Lidar Checkpoints

Under the direction from SNWA, Clark County surveyors established lidar checkpoints spatially distributed across the project AOI as the method to validate absolute accuracy. Lidar checkpoints were categorized as Non-vegetated Vertical Accuracy [NVA] checkpoints and Vegetated Vertical Accuracy [VVA] checkpoints. Additionally, a smaller quantity of checkpoints (control) were collected for use (independently) to support the lidar calibration task.

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 twenty-two (22) surveyed ground points used for lidar calibration.

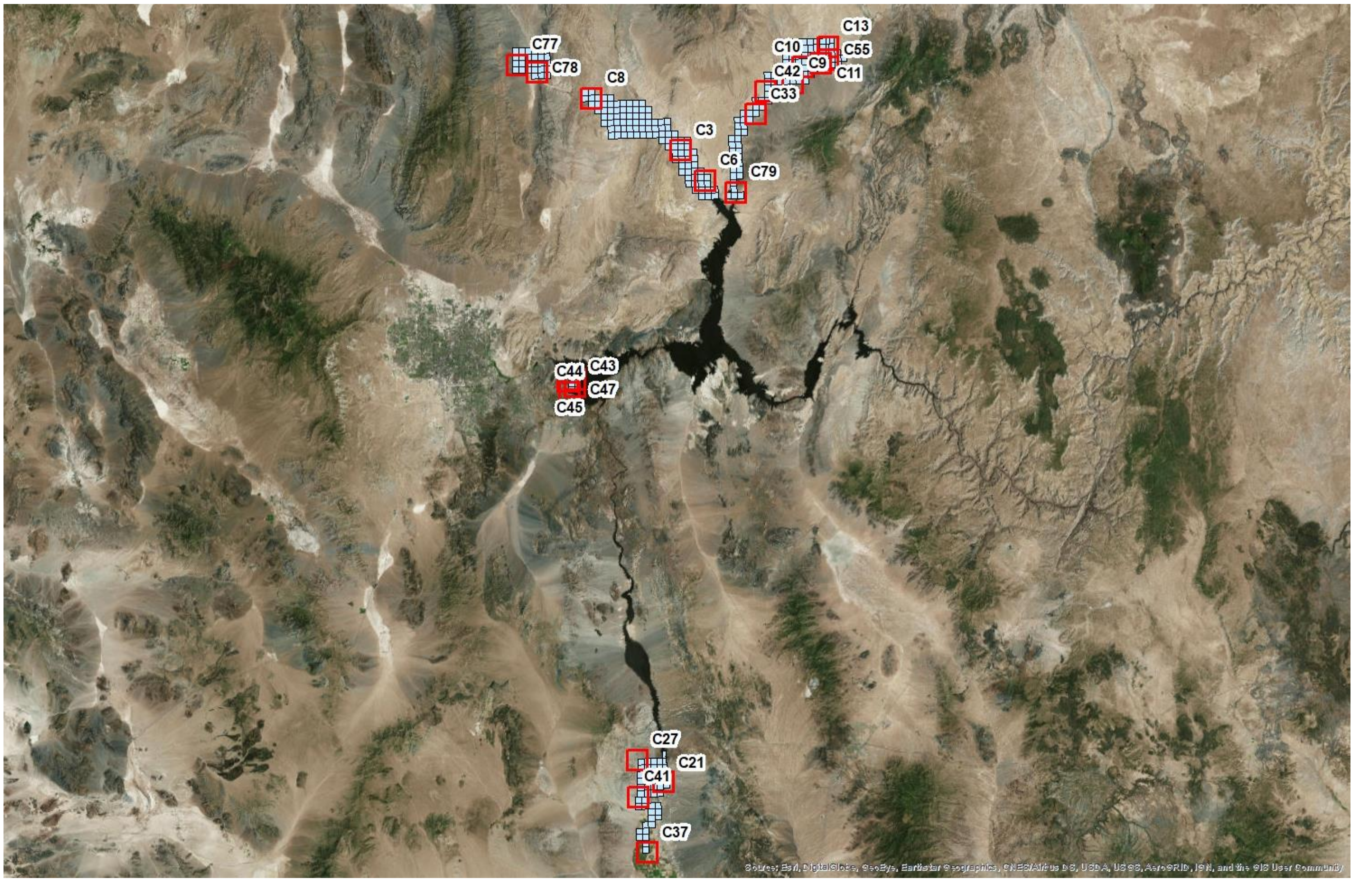
Project Data Unit: U.S. Survey Foot
Vertical Accuracy Class tested: 10.0-cm
Elevation Calculation Method: Interpolated from TIN
LiDAR Classifications Included: 0/0W

Check Points in Report: 22
Check Points with LiDAR Coverage: 22
Check Points (NVA): 22
Check Points (VVA): 0
Average Vertical Error Reported: 0.000 U.S. Survey Foot
Maximum (highest) Vertical Error Reported: 0.139 U.S. Survey Foot
Median Vertical Error Reported: 0.016 U.S. Survey Foot
Minimum (lowest) Vertical Error Reported: -0.134 U.S. Survey Foot
Standard deviation of Vertical Error: 0.072 U.S. Survey Foot
Skewness of Vertical Error: -0.165
Kurtosis of Vertical Error: -0.612
Non-vegetated Vertical Accuracy (NVA) RMSE(z): 2.152cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/-: 4.219cm PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-: 4.219cm
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM): 2.148cm PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- (DEM): 4.210cm PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10.0-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 2.152cm, equating to +/- 4.219cm at the 95% confidence level.

Checkpoint Id	Checkpoint X	Checkpoint Y	Coverage	Checkpoint Z	Z from lidar	Z Error
C3	978782.01	26924573.59	Yes	1389.86	1389.726	-0.134
C6	999020.61	26898637.12	Yes	1288.63	1288.515	-0.115
C79	1025320.85	26888257.39	Yes	1253.83	1253.717	-0.113
C9	1074398.8	26979621.44	Yes	1554.61	1554.54	-0.07
C45	881073.56	26730511.22	Yes	1389.36	1389.292	-0.068
C8	904360.55	26969494.04	Yes	1822.93	1822.872	-0.058
C41	935237.35	26378646.84	Yes	514.17	514.126	-0.044
C78	858484.67	26992070.83	Yes	2175.64	2175.605	-0.035
C21	956496.63	26390856.93	Yes	634.57	634.575	0.005
C43A	886552.03	26725962.55	Yes	1251.42	1251.432	0.012
C47	886856.33	26731999.07	Yes	1152.25	1152.266	0.016
C27	935044.33	26410132.22	Yes	1681.08	1681.096	0.016
C44	882005.49	26721504.75	Yes	1281.06	1281.081	0.021
C43	886552.02	26726036.75	Yes	1250.79	1250.811	0.021
C37	942393.15	26331593.43	Yes	498.18	498.203	0.023
C10	1083527.08	26993423.08	Yes	1576.16	1576.193	0.033
C77	841912.99	26998708.75	Yes	2540.63	2540.665	0.035
C33	1042933.99	26954510.66	Yes	1377.02	1377.082	0.062
C11	1098480.13	26995978.81	Yes	1576.67	1576.735	0.065
C42	1051617.5	26973247.28	Yes	1630.73	1630.809	0.079
C55	1104918.8	26999329.98	Yes	1594.08	1594.188	0.108
C13	1104612.54	27009990.59	Yes	1968.59	1968.729	0.139

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. MARS® software is used for the auto-filtering, manual filtering and QC of the classified data.

Merrick used the ASPRS LAS Specification Version 1.4 – R13, 15 July 2013, Point Data Record Format 6 for this project and classified the lidar point cloud in accordance with the following classification classes and bitflags. The following outlines project specific requirements.

SNWA

- Class 1 = Unclassified
- Class 2 = Bare-earth Ground
- Class 7 = Low point (noise)
- Class 9 = Water
- Class 10 = Ignored ground (near a breakline)
- Class 17 = Bridge decks
- Class 18 = High noise

DCP

- Class 1 = Unclassified
- Class 2 = Bare-earth Ground
- Class 3 = Low Vegetation
- Class 4 = Medium Vegetation
- Class 5 = High Vegetation
- Class 64 = Excessive vegetation
- Class 7 = Low point (noise)
- Class 9 = Water
- Class 10 = Ignored ground (near a breakline)
- Class 17 = Bridge decks
- Class 18 = High noise

- Bitflags
  - <u>Withheld</u>: 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.

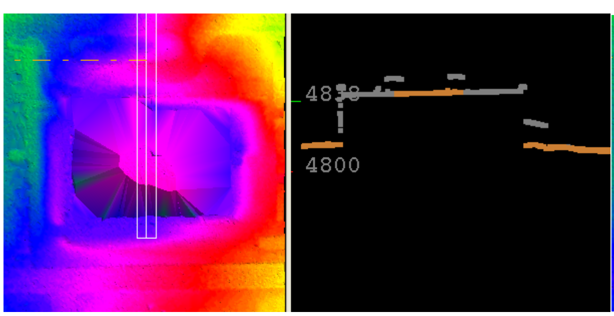


Figure 1

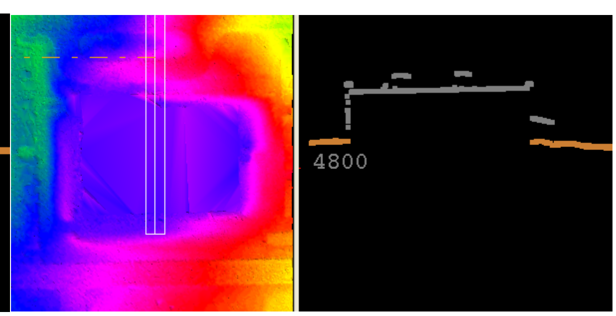


Figure 2

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.

Filtered Lidar Checkpoint Report

After hand-filtering has been completed and quality checked, a Checkpoint 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.

The below lidar check point report provides statistics for 36 NVA and 39 VVA ground survey points used to validate the final filtered lidar surface.

Units: Meter (/US Survey Feet)

Vertical Accuracy Class tested: 10-cm

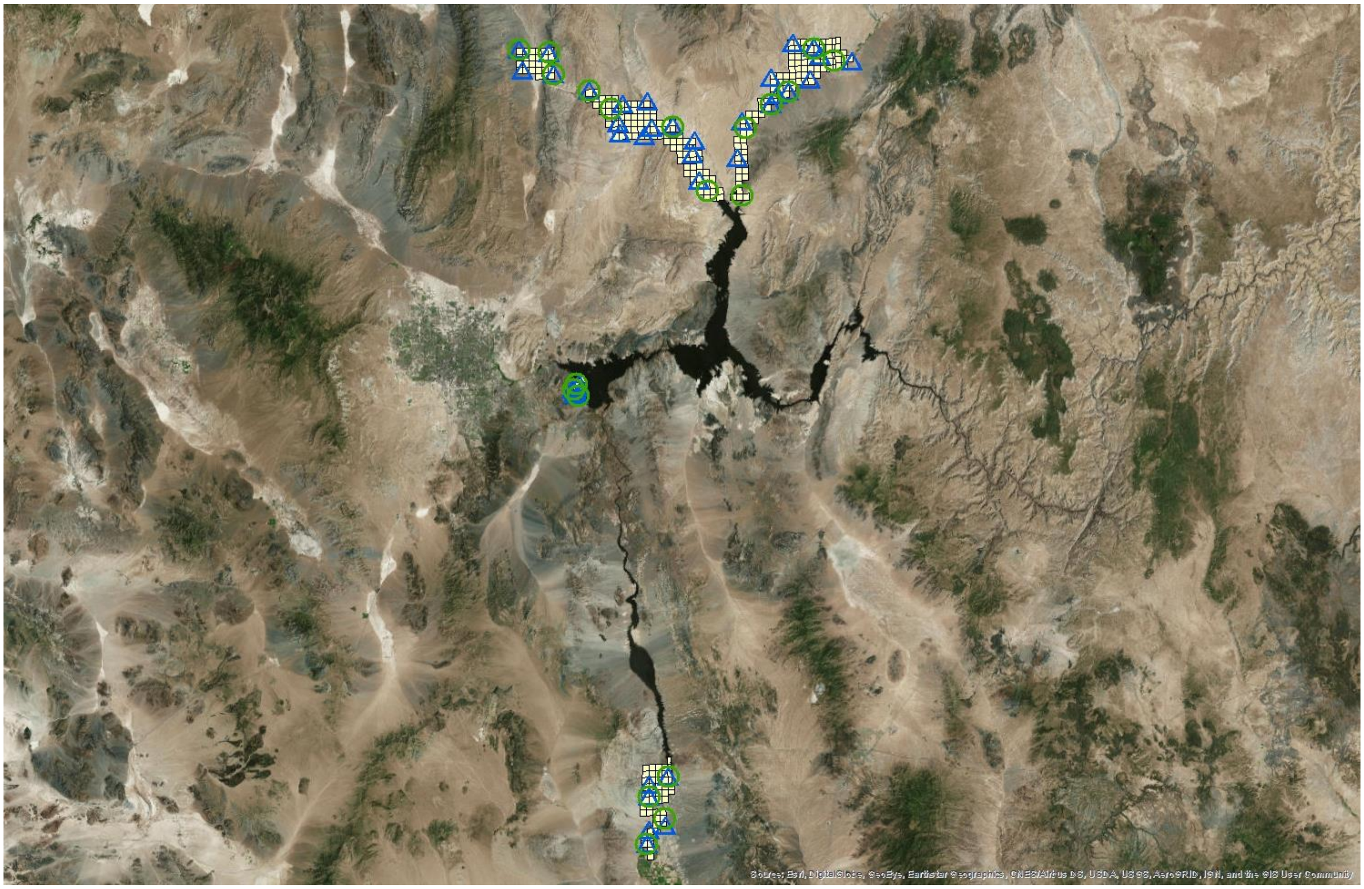
Check Points in defined project area (DPA):	75
Check Points with Lidar Coverage	75
Check Points with Lidar Coverage (NVA)	36
Check Points with Lidar Coverage (VVA)	39
Average Z Error (NVA)	-0.003/-0.011
Maximum Z Error (NVA)	0.176/0.578
Median Z Error (NVA)	-0.002/-0.005
Minimum Z Error (NVA)	-0.118/-0.387
Standard deviation of Vertical Error (NVA)	0.046/0.150
Skewness of Vertical Error (NVA)	1.376
Kurtosis of Vertical Error (NVA)	5.795
Non-vegetated Vertical Accuracy (NVA) RMSE(z) [1]	0.045/0.148 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level +/- [1]	0.088/0.290 PASS
FGDC/NSSDA Vertical Accuracy at the 95% Confidence Level +/-	0.088/0.290
Non-vegetated Vertical Accuracy (NVA) RMSE(z) (DEM) [2]	0.031/0.102 PASS
Non-vegetated Vertical Accuracy (NVA) at the 95% Confidence Level (DEM) +/- [2]	0.061/0.200 PASS
Vegetated Vertical Accuracy (VVA) at the 95th Percentile (DEM) +/- [2]	0.230/0.755 PASS

This data set was tested to meet ASPRS Positional Accuracy Standard for Digital Geospatial Data (2014) for a 10-cm RMSEz Vertical Accuracy Class. Actual NVA accuracy was found to be RMSEz = 4.508cm, equating to +/- 8.836cm at the 95% confidence level. Actual VVA accuracy was found to be +/- 23.004cm at the 95th percentile.

[1] This value is calculated from TIN-based testing of the raw swath lidar point cloud data.

[2] This value is calculated from RAM-based grid testing of the classified tiled lidar data. The grid cells are sized according to the Quality Level selected, and are defined in the USGS NGP Lidar Base Specification Version 1.2 (page 15, Table 7).

Lidar Checkpoint Layout



Hydro-flattening Breakline Collection

Hydro- flattening breaklines are captured per the USGS National Geospatial Program Lidar Base Specification Version 1.2. Final hydro-flattened breaklines features are appropriately turned into polygons (flat elevations) and polylines (decreasing by elevation) and are used to reclassify ground points in water to Water (Class 9). The lidar points around the breaklines are reclassified to Ignored Ground (Class 10) based on predetermined buffer.

Linear hydrographic features

To collect hydrographic features, Merrick uses a methodology that directly interacts with the lidar bare-earth data to collect drainage breaklines. To determine the alignment of a drainageway, the technician first views the area as a TIN of bare-earth points using a color ramp to depict varying elevations. In areas of extremely flat terrain, the technician may need to determine the direction of flow based on measuring lidar bare-earth points at each end of the drain. The operator will then use the color ramped TIN to digitize the drainage in 2D with the elevation being attributed directly from the bare-earth LAS data. MARS® software has the capability of “flipping” views between the elevation TIN, Intensity and imagery, as necessary, to further assist in the determination of the drainage. All drainage breaklines are collected in a downhill direction. For each point collected, the software uses a five-foot (5’) search radius to identify the lowest point within that proximity. Within each radius, if a bare-earth point is not found that is lower than the previous point, the elevation for subsequent point remains the same as the previous point. This forces the drain to always flow in a downhill direction. Waterbodies that are embedded along a drainageway are validated to ensure consistency with the downhill direction of flow.

This methodology may differ from those of other vendors in that Merrick relies on the bare-earth data to attribute breakline elevations. As a result of our methodology, there is no mismatch between lidar bare-earth data and breaklines that might otherwise be collected in stereo 3D as a separate process. This is particularly important in densely vegetated areas where breaklines collected in 3D from imagery will most likely not match (either horizontally or vertically), the more reliable lidar bare-earth data.

Merrick has the capability of “draping” 2D breaklines to a bare-earth elevation model to attribute the “z” as opposed to the forced downhill attribution methodology described above. However, the problem with this process is the “pooling “effect or depressions along the drainageway caused by a lack of consistent penetration in densely vegetated areas.

Criteria of linear hydrographic breaklines are as follows:

- Linear hydrographic features (e.g., visible streams, rivers, shorelines, canals, etc.) greater than one hundred feet (100’) wide will be captured as a double-lined polygon
    - linear hydrographic features must be flat and level bank-to-bank (perpendicular to the apparent flow centerline) with gradient following the immediately surrounding terrain
    - water surface edge must be at or just below the immediately surrounding terrain
    - streams should break at road crossings (e.g., culverts), and streams and rivers should not break at bridges

Waterbodies

Waterbodies are digitized from the color ramped TIN, similar to the process described above. The elevation attribute is determined as the technician collects the hydro feature by using the lowest bare-earth point within the polygon.

Criteria of waterbody breaklines are as follows:

- Waterbodies (e.g., lakes, ponds, reservoirs) greater than two (2) acres in size are surrounded by a water breakline (i.e., closed polygon)
    - waterbodies must be flat and level with a single elevation for every bank vertex
    - water surface edge must be at or just below the immediately surrounding terrain
    - long impoundments, such as reservoirs or inlets, whose water surface elevations drop when moving downstream should be treated as rivers

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.

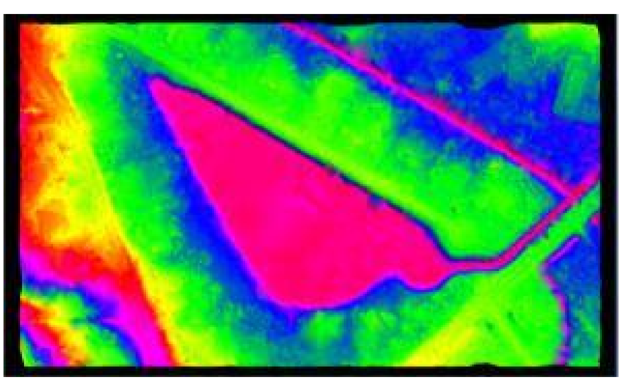


Figure 3

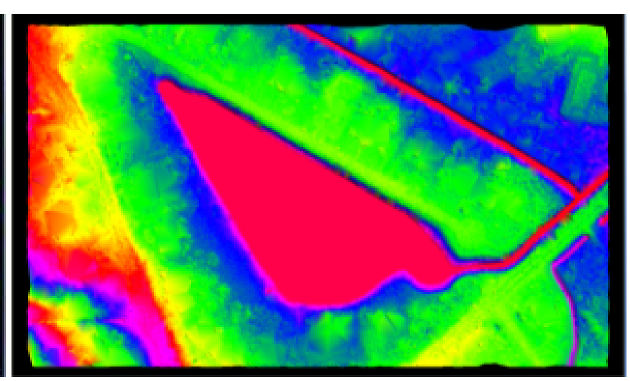


Figure 4

Bare-Earth DEM

Merrick exports the hydro-flattening breakline enforced Class 2 (ground) lidar points to a one-meter (1m) cell size, 32-bit format using MARS®, the DEMs are exported to the project tiling scheme. Projection information is applied that reflects the project requirements.

Intensity Images

Merrick exports all lidar points to a one-meter (1m) cell size 16-bit client desired format using MARS®, the intensity images are exported to the project tiling scheme and / or project-wide boundary. Projection information is applied that reflects the project requirements.

List of Deliverables

- Minimum standards as outlined in **TM11-B4 / Exhibit 1**
- SNWA
    - Raw LiDAR point cloud
        - Fully compliant ASPRS LAS 1.4, point record format 6
        - Calibrated
        - By swath
        - Intensity values normalized (rescaled) to 16-bit
        - FGDC-compliant metadata
    - Classified LiDAR point cloud
        - Fully compliant ASPRS LAS 1.4, point record format 6
        - By tile
        - Intensity values normalized (rescaled) to 16-bit
        - FGDC-compliant metadata
    - Hydro-flattened breaklines
        - Project-wide Esri feature class(es) for insertion into file geodatabase
        - FGDC-compliant metadata
    - Bare-earth DEM
        - Two-foot (2’) cell size 32-bit floating point raster in GeoTIFF format
        - Bare-earth (hydro-flattened)
            - Culverts will not be removed from the DEMs
            - Bridges will be removed from the DEMs
        - By tile
        - FGDC-compliant metadata
    - FGDC – compliant metadata (project level)
    - Miscellaneous Esri shapefiles
        - Boundary(ies)
        - Tiles
        - Control
        - LiDAR checkpoints (NVA/VVA)
        - Raw LiDAR swaths
- DCP
    - Classified LiDAR point cloud
        - Fully compliant ASPRS LAS 1.4, point record format 6
        - By tile

        - Intensity values normalized (rescaled) to 16-bit
        - FGDC-compliant metadata
    - Hydro-flattened breaklines
        - Project-wide (AOI-wide) Esri feature class(es) or shapefile(s) for insertion into file geodatabase
        - FGDC-compliant metadata
    - Bare-earth DEM
        - One-meter (1m) cell size 32-bit floating point raster in GeoTIFF format
        - Bare-earth (hydro-flattened)
            - Culverts will not be removed from the DEMs
            - Bridges will be removed from the DEMs
        - By tile and AOI (mosaic)
        - FGDC-compliant metadata
    - Hillshades
        - 1m cell size in GeoTIFF format
        - By tile and AOI
        - FGDC – compliant metadata
    - Vegetation classified images
        - 1m cell size in GeoTIFF format
        - By tile and AOI
        - FGDC – compliant metadata
    - Intensity Images
        - 1m cell size 8-bit, 256 color gray scale in GeoTIFF format
        - By tile and AOI
        - FGDC – compliant metadata
    - FGDC – compliant metadata (project level)
    - Miscellaneous Esri shapefiles
        - Boundary(ies)
        - Tiles
        - Control
        - LiDAR checkpoints (NVA/VVA)
        - Raw LiDAR swaths
- Detailed LiDAR Mapping / Project Report

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.

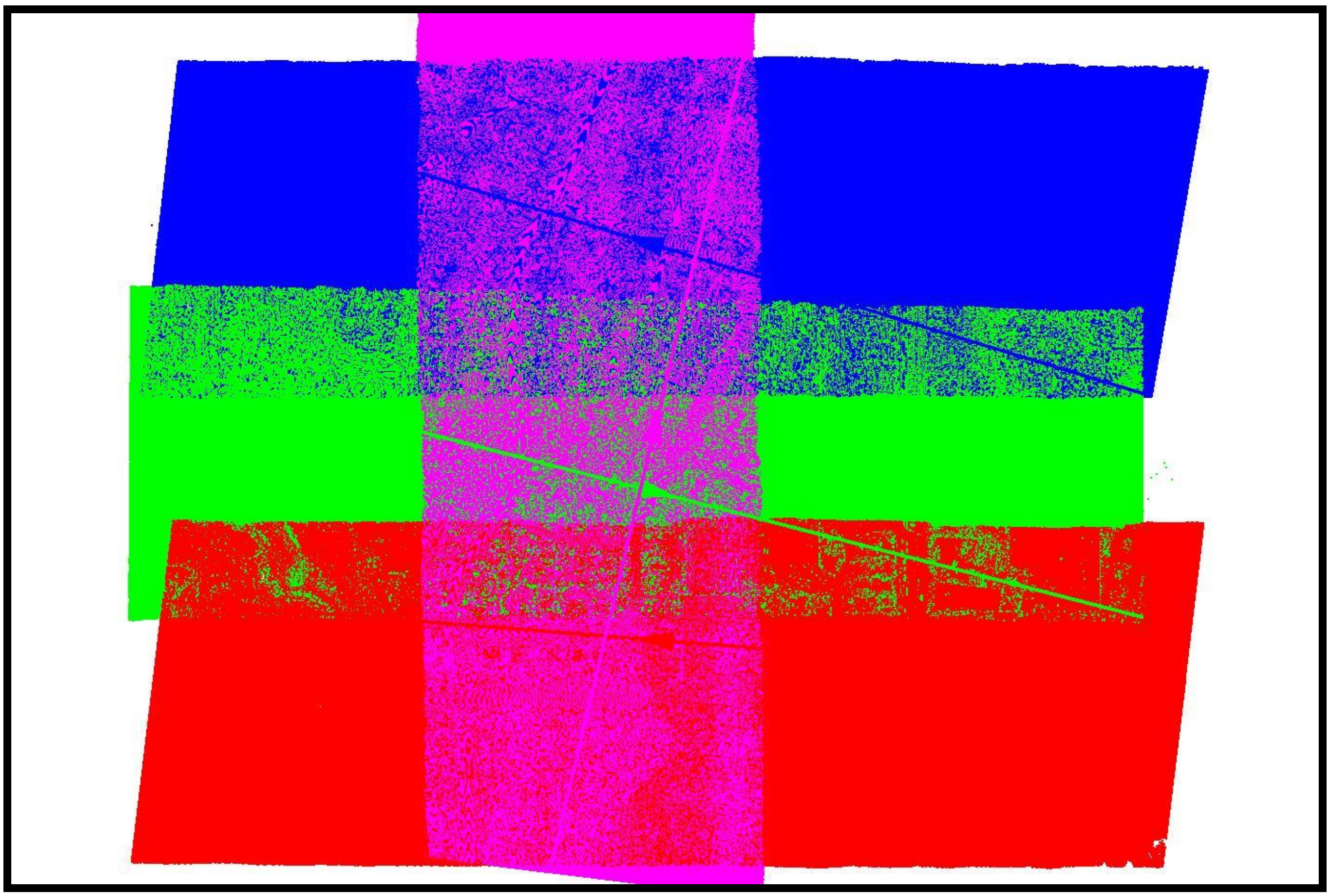
Initial Processing

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.

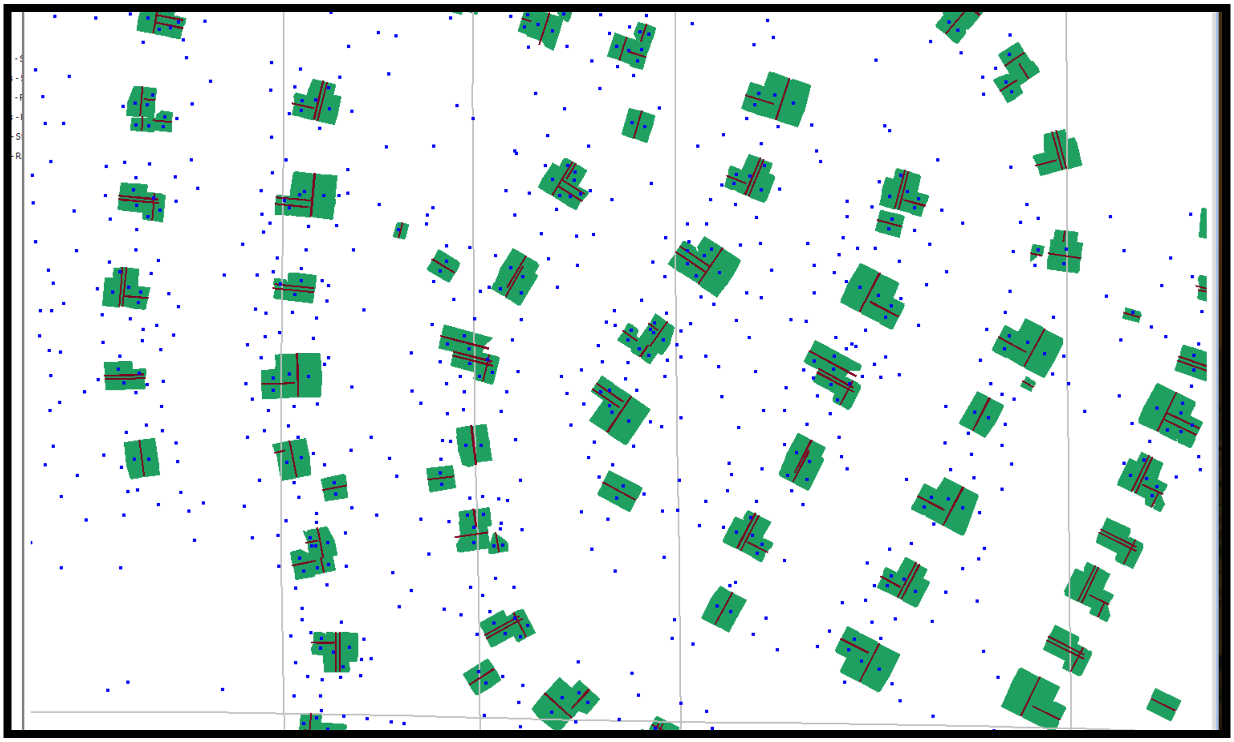
Boresight Self-Calibration Processing Procedures

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.



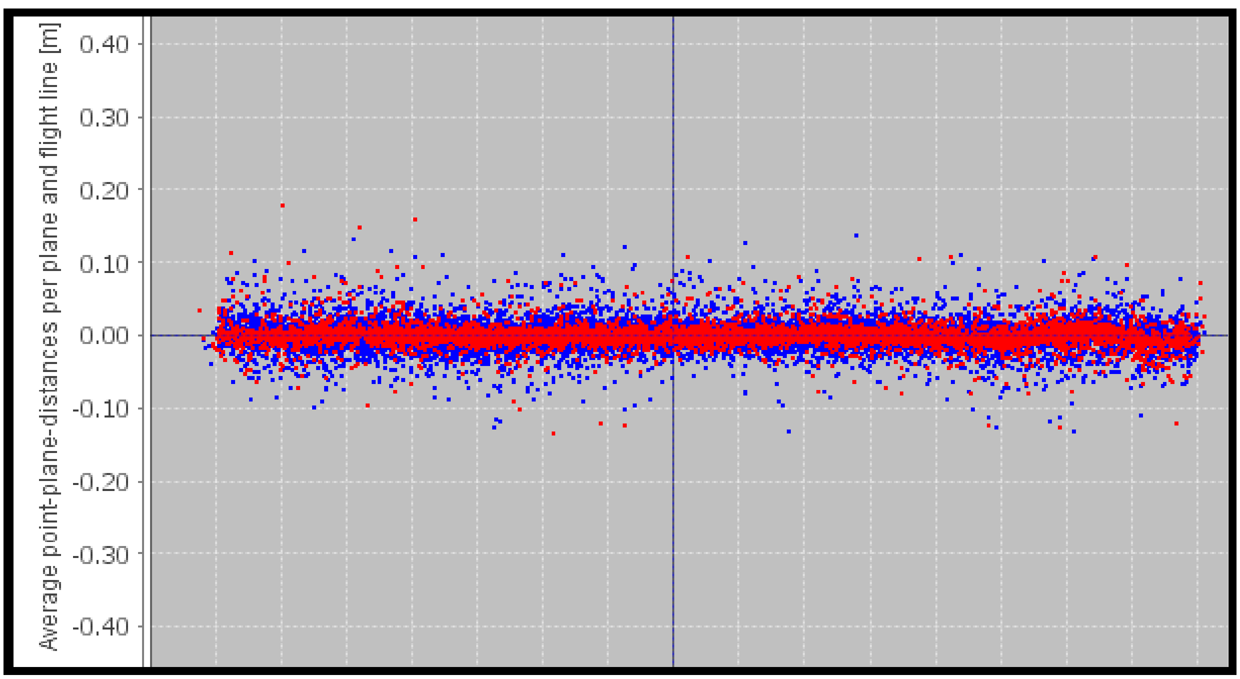
The Boresighting module frees scan angle scale, scan angle lag, XYZ boresight corrections and elevation position corrections while locking scan angle offset and XY position corrections.

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.

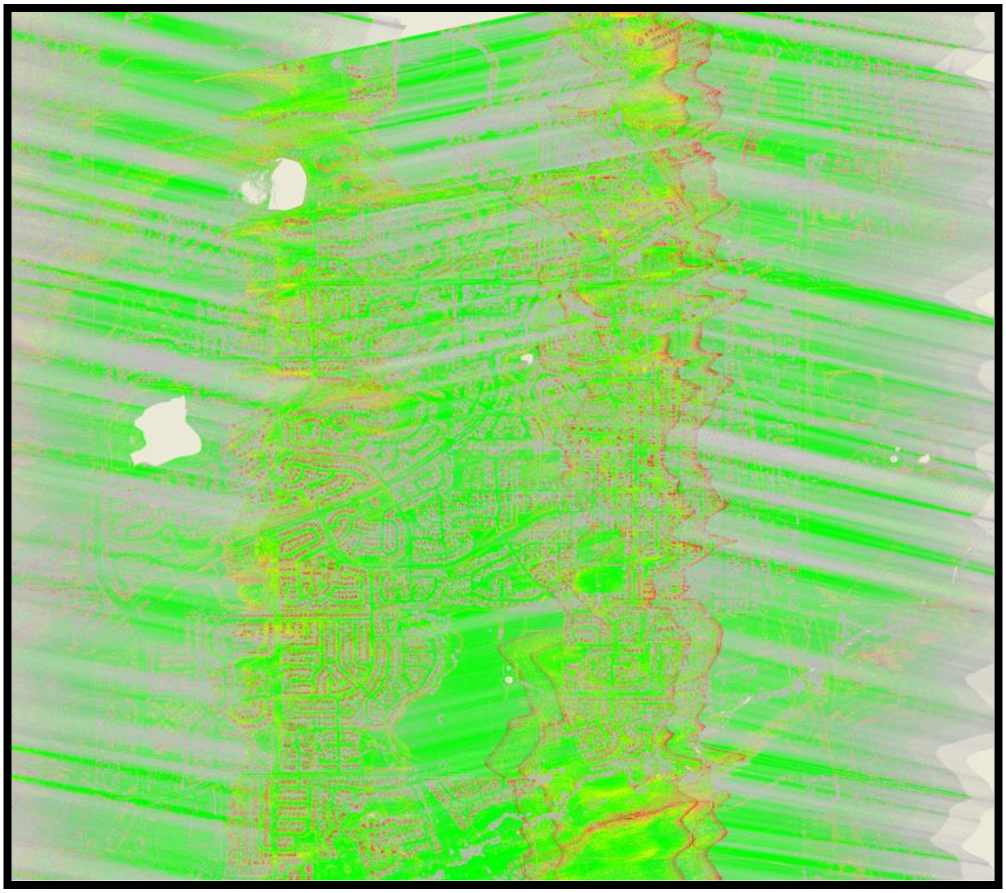


At the conclusion of the self-calibration run the data is quality checked with LMS plots

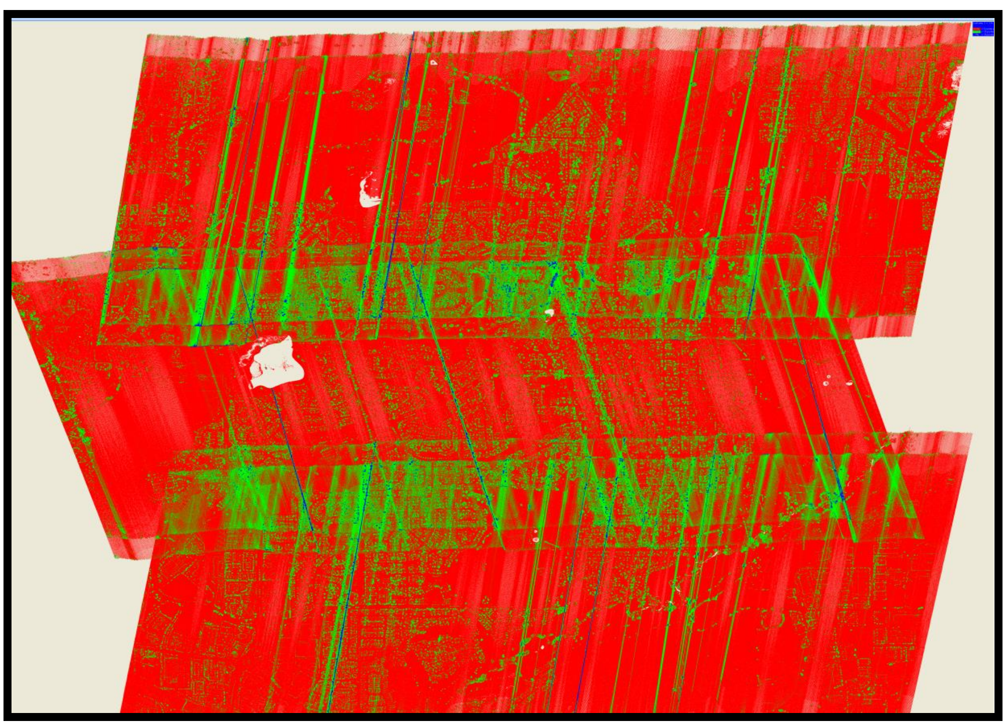
Plot of plane vertical distances from datum plane.



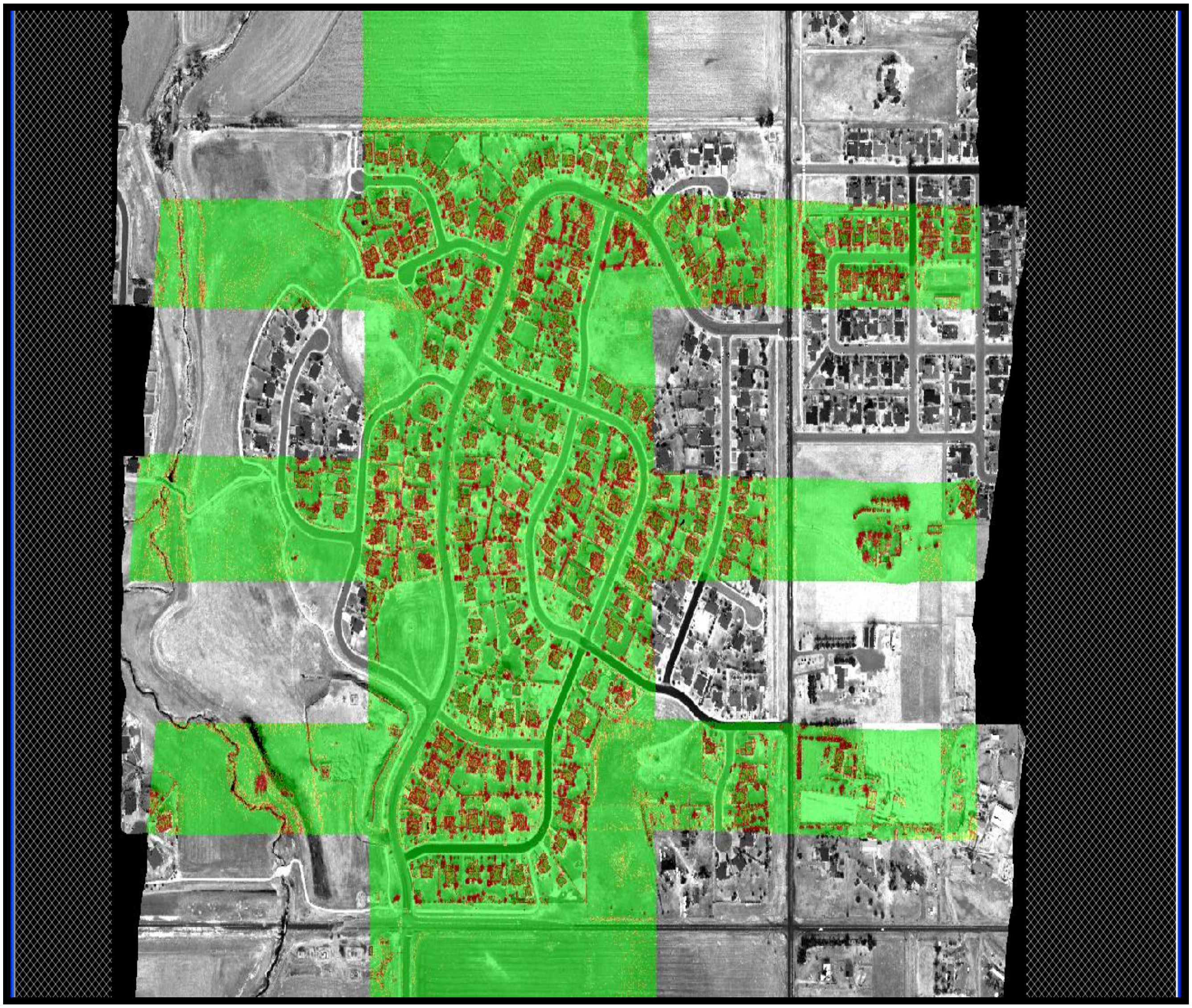
Plot of height differenced between flight lines. (Green=less than 5cm).



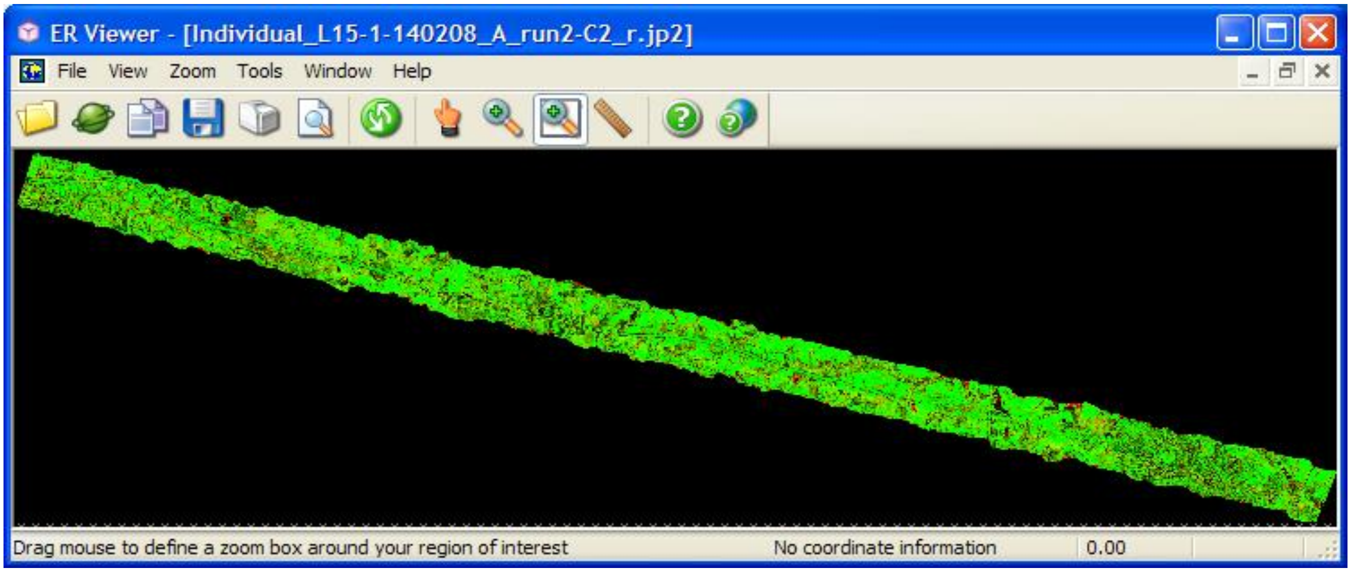
Plot of point densities. (Red=5-9 points per cell, green 10+ points per cell).



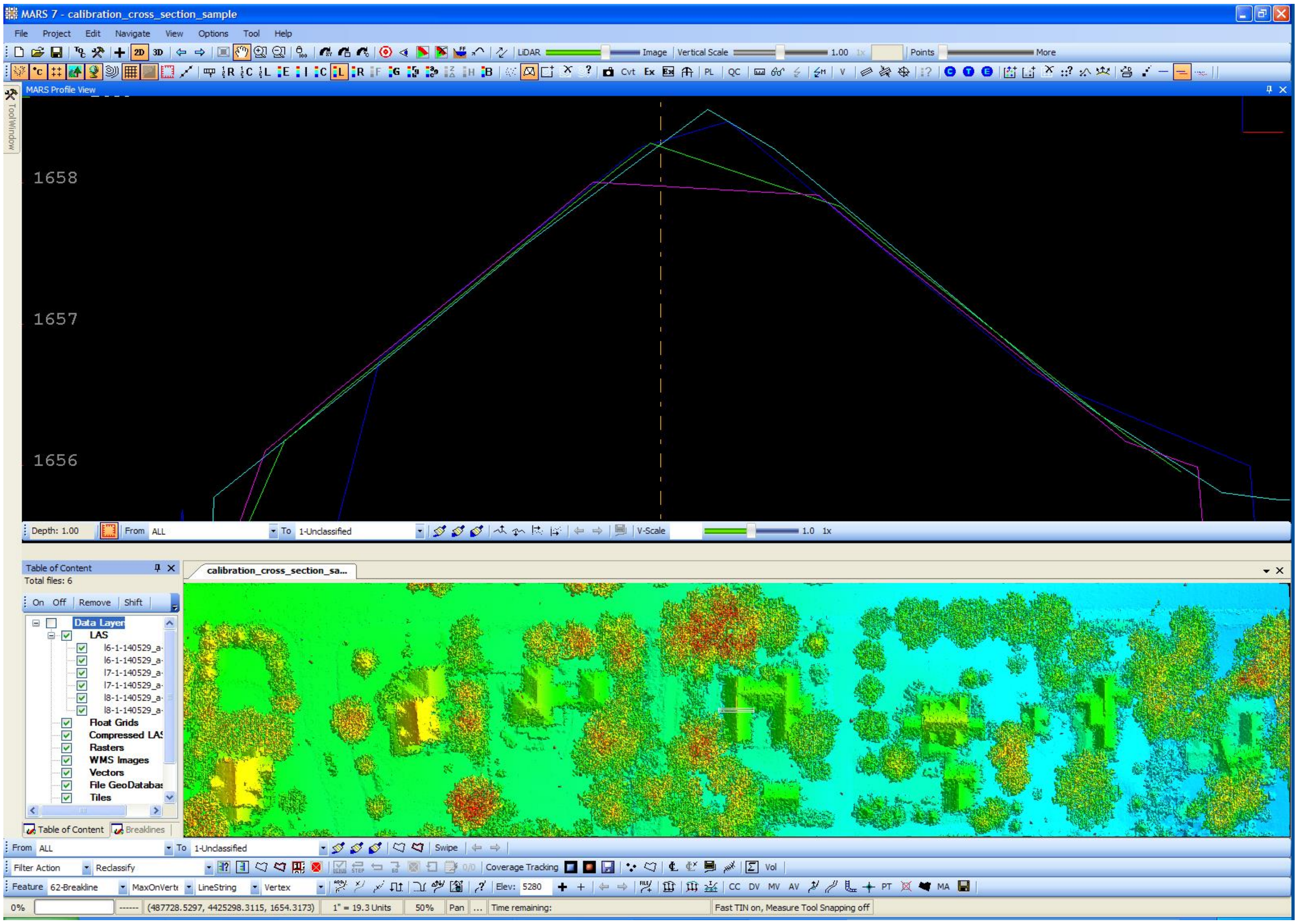
A Flight Line Separation Raster image is generated in Merrick Advanced Remote Sensing Software (MARS®), in this example ground returns from multiple flight lines that are fitting within 3 centimeters are colored green.



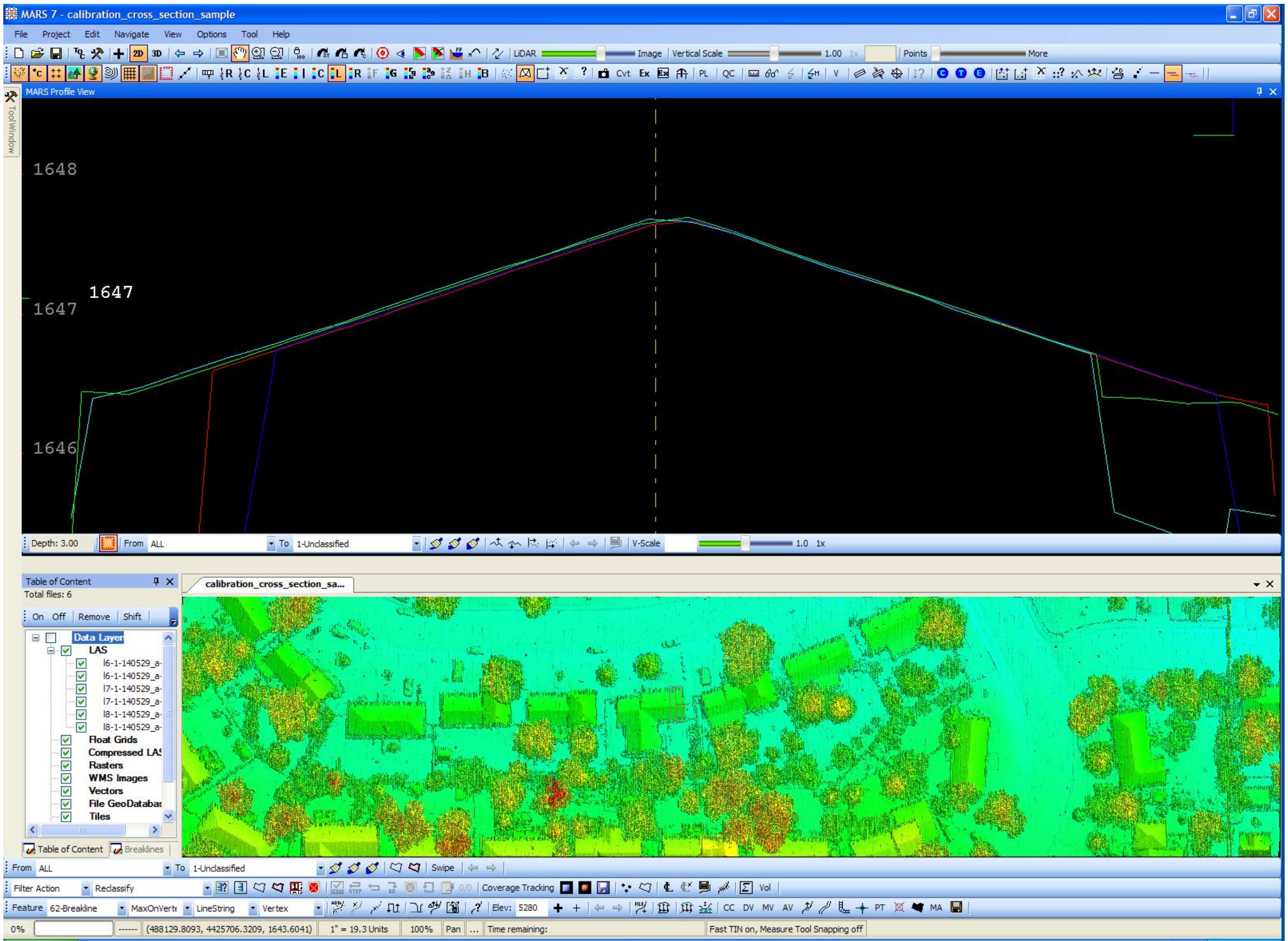
MARS® tests for internal relative vertical accuracy using inbound and outbound scan values. Again, Green is showing inbound and outbound scan data fitting to 3 centimeters.



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.

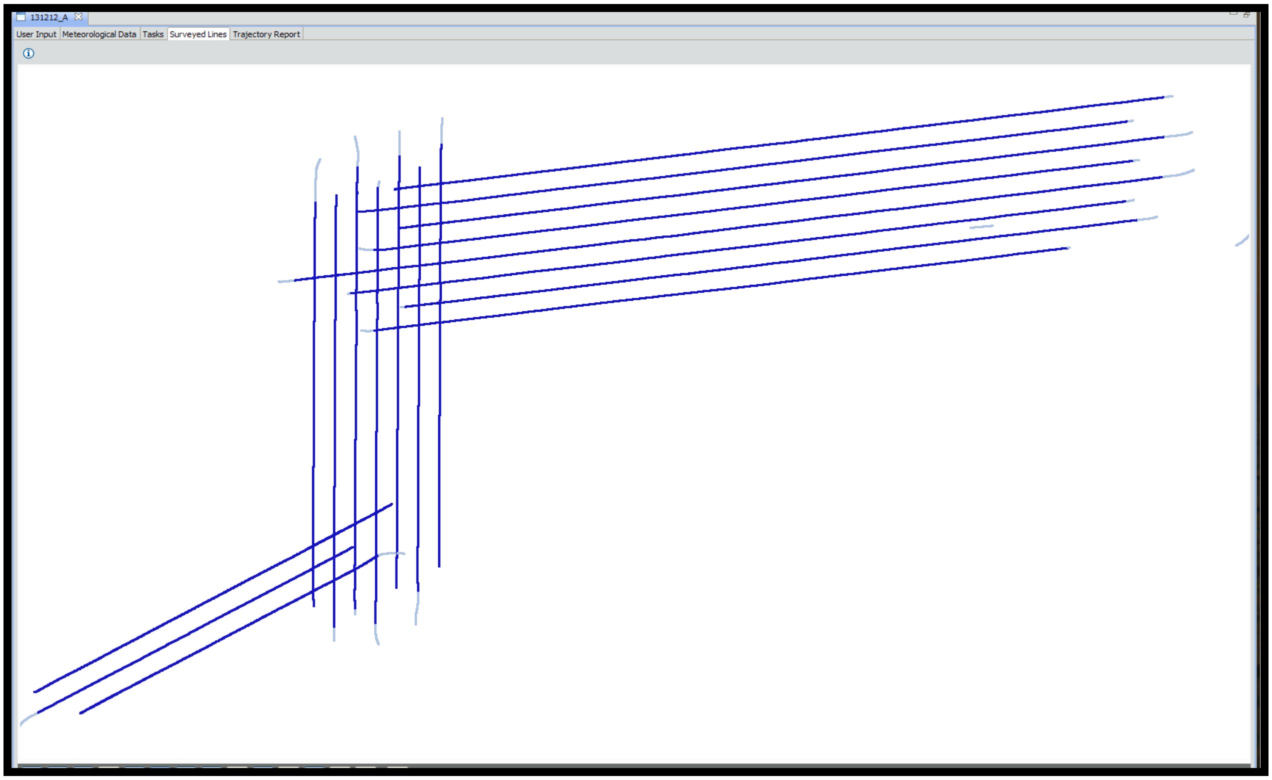


The LMS program outputs a "LCP" file with all the correction parameters. The calibration process may be run several times until the boresight adjustments are acceptable. When the boresight solution is acceptable the LCP file adjustments are saved and also applied to subsequent projects. Each new project 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.

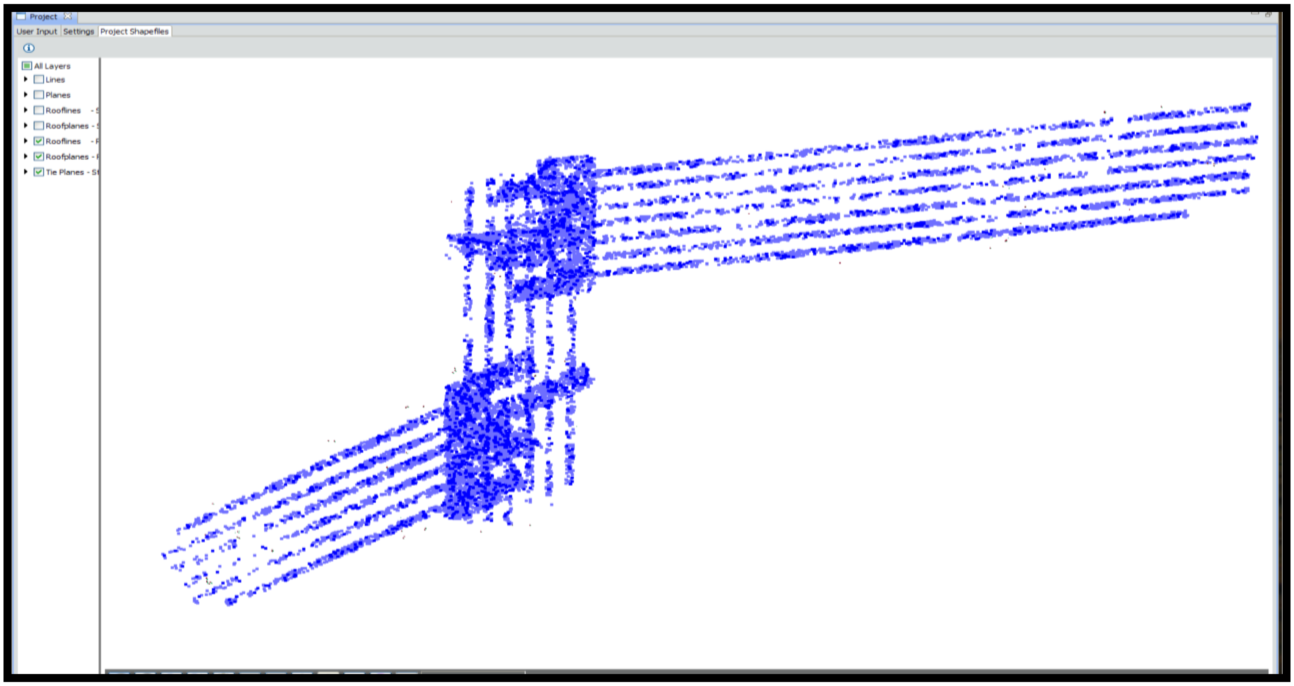
Block LAS Production Processing Procedures

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.

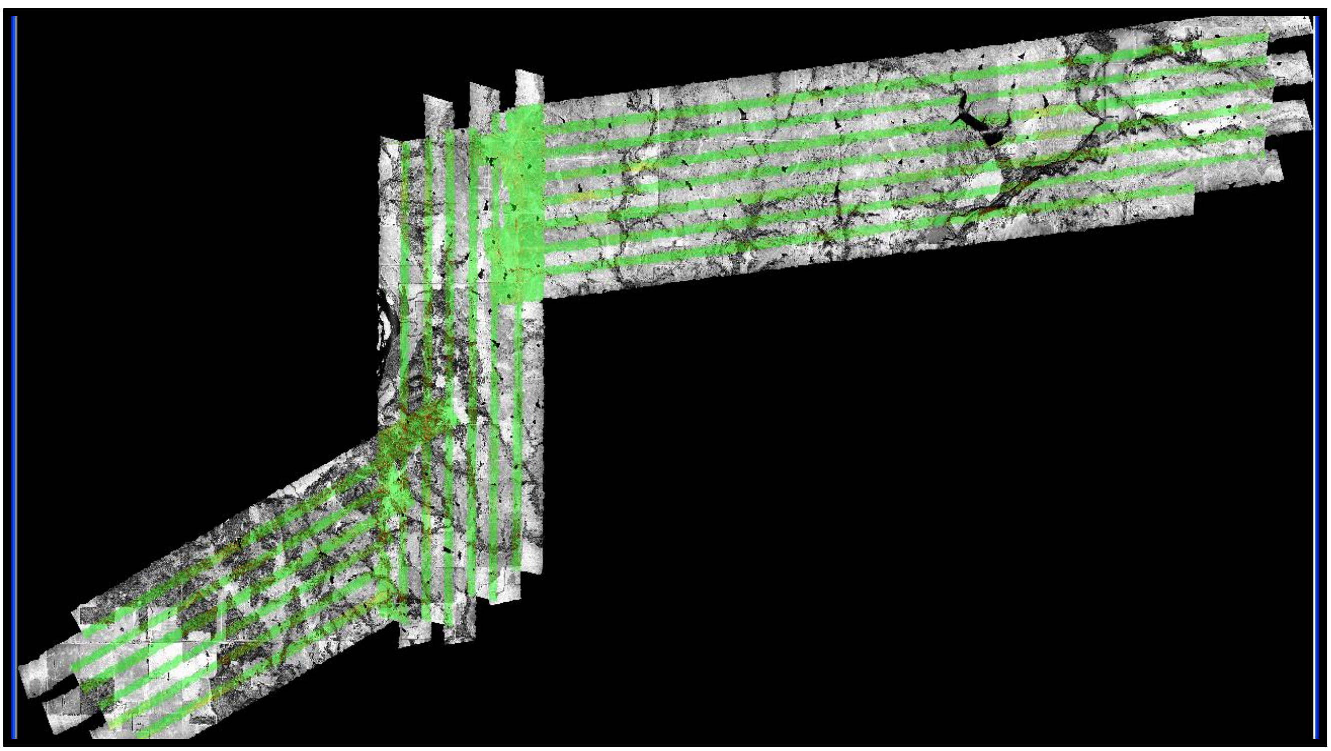
A block of data is selected to process with LMS production settings. Data collected during turns at the ends of flight lines is deselected (light blue lines).



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.

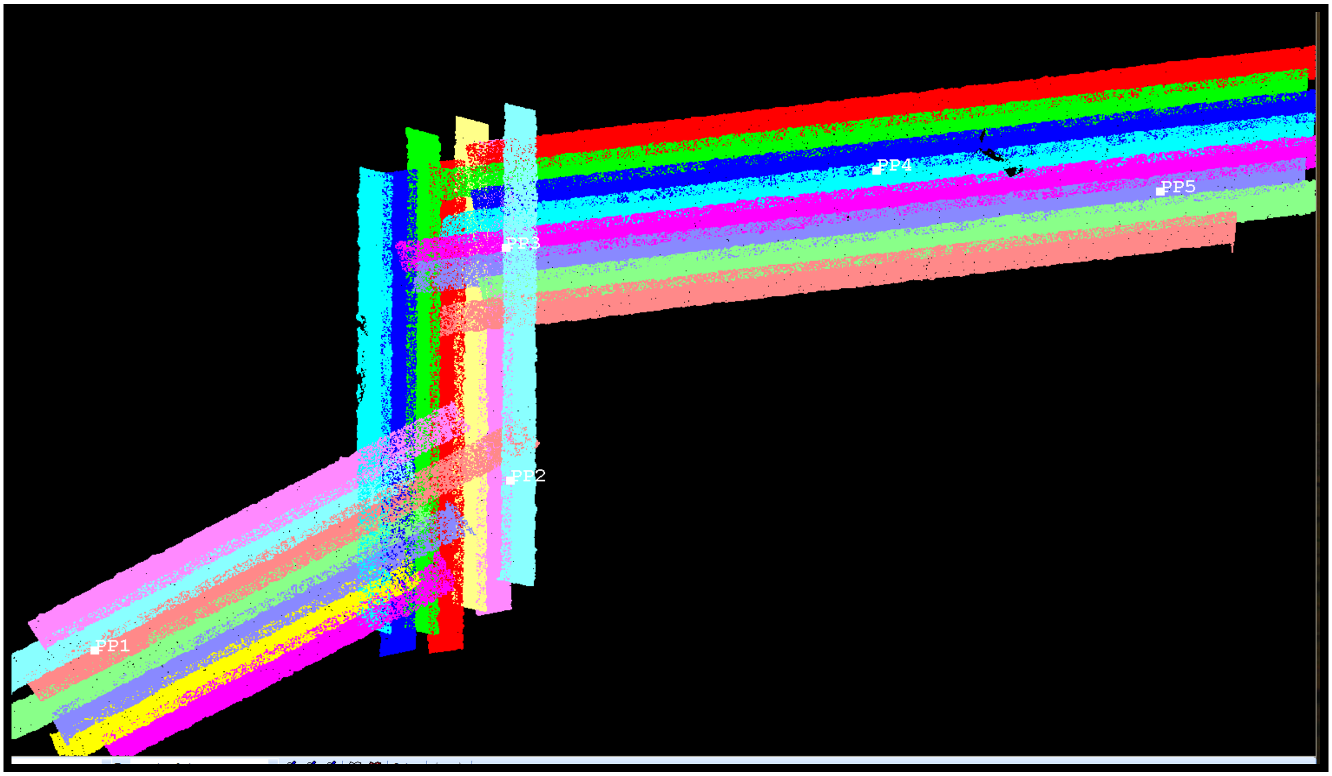


The same quality control outputs used to check self-calibrations are available to analyze the production run. Output plots are again available in LMS and cross sections plus a Flight Line Separation Raster are generated in MARS® to check coverage and quality.



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.