TECHNICAL PROJECT REPORT

UTAH 3DEP - STRAWBERRY AERIAL SURVEY

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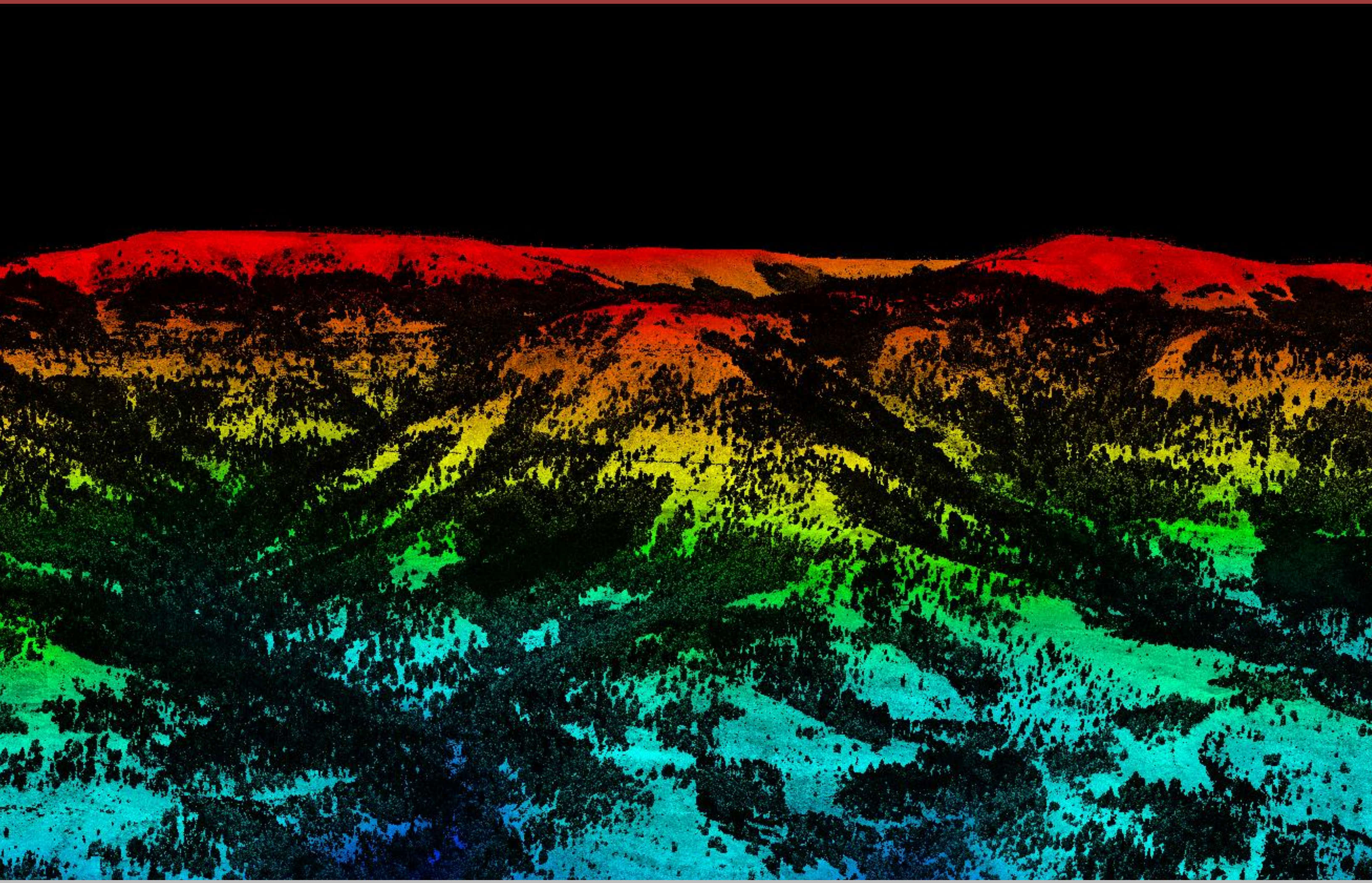

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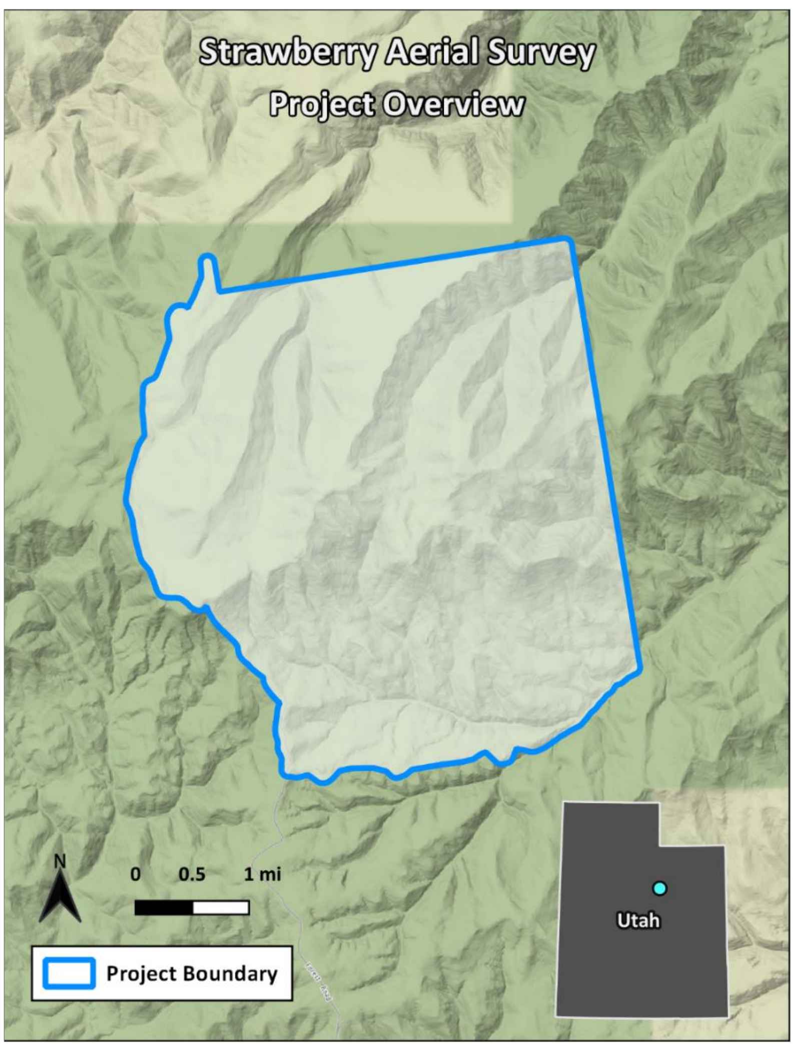
1. Overview

1.1 Project Overview

Aero-Graphics, Inc., a full-service geospatial firm located in Salt Lake City, Utah, was contracted by the U.S. Geological Survey (USGS) and partners to acquire, process, and deliver aerial lidar data and derivative products that adhere to U.S. Geological Survey (USGS) National Geospatial Program (NGP) Lidar Base Specification 2022, Revision A, QL1 standards. The assigned project area covers approximately 16 mi^2 in Wasatch County, Utah. Lidar data was delivered as processed Classified LAZ 1.4 files, formatted to 58 individual 1000 m x 1000 m tiles, as tiled Intensity Imagery, and as tiled bare earth DEMs and DSMs; all tiled to the same 1000 m x 1000 m schema.

Exhibit 1: Overview of the Strawberry project area.



1.2 Project Deliverables

LiDAR Data	▪ Classified point cloud data in LAZ v1.4 format
Raster Data	▪ Bare-earth DEM, Digital Surface Model (DSM), and intensity imagery with a cell size of 0.5 meter for QL1 AOIs and 1.0 meter for QL2 AOIs in GeoTIFF format ▪ Swath separation images and maximum surface height rasters in GeoTIFF format
Vector Data	▪ Breaklines in SHP format, Flight index in SHP format ▪ Surveyed GCPs and checkpoints in .gpkg format
Report of Survey	▪ Reports and metadata as described in TO

1.3 Projection, Datum, Units

Projection		UTM12
EPSG		6341
Datum	**Vertical**	NAVD88 (Geoid18)
	Horizontal	NAD83 (2011)
Units		Meters

2. LiDAR Acquisition

2.1 Flight Planning

Aero-Graphics' Aerial Department created a customized flight plan for this project using Optech's Airborne Mission Manager (AMM) flight planning software. AMM simulates flight plans based on a project area's terrain, as well as the sensor's model, mount, and settings. These features helped ensure all contract specifications are met in the most efficient way possible. Prior to mobilizing to the acquisition sites, Aero-Graphics' staff monitored all site conditions and potential weather hazards including wind, rain, snow, and blowing dust. Additionally, Aero-Graphics ensured all airspace clearances were secured by the proper officials before acquisition occurred. A summary of the flight parameters and sensor settings for the Strawberry area is outlined in **Exhibit 2**.

Exhibit 2: Summary of planned flight parameters and sensor settings

Planned Specifications		
Aircraft		Cessna 206
LiDAR Sensor		Optech Galaxy Prime
Altitude (ft above ground level)		4,300
Speed (kts)		135
PRF (kHz)		650
Scan frequency (Hz)		104
Scan Angle	From nadir	± °15
	Full	°30
Planned Average Point Density (p/m²)		9.83
Post Spacing at Nadir	Cross Track (m)	.30
	Down Track (m)	.33
Swath Width (m)		702
Sidelap (%)		30

2.2 Data Acquisition

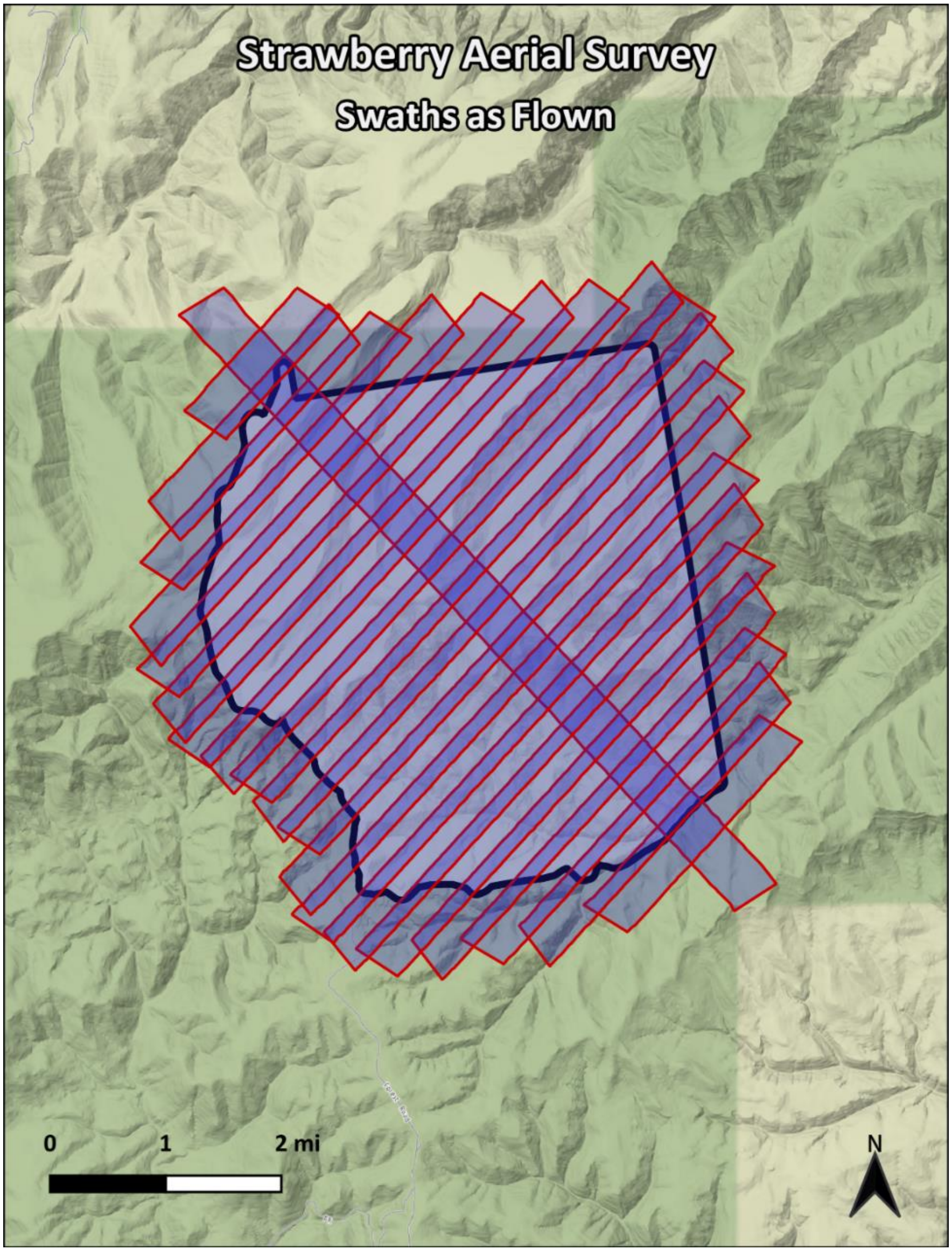
The acquisition platforms were our turbocharged Cessna 206s (**Exhibit 3**). The stability of these platforms is ideal for efficient data collection at high and low altitudes and at a variety of airspeeds. Additionally, our Cessna 206s have been customized to house a variety of airborne sensors, and the power systems and avionics have been upgraded specifically to meet aerial survey needs.

Exhibit 3: A Cessna 206 was the acquisition platform for this project

The Optech Galaxy Prime was selected for this project due to its high accuracy and efficiency (**Exhibit 4**). This sensor uses SwathTrak technology, which dynamically adjusts the scan field of view in real time to maintain a constant swath width over a variety of terrains. It also features up to 8 returns per pulse, which increase the vertical resolution of complex terrains. The sensor is complemented with the use of FMS Nav, which allowed the system operators to monitor the point density and swath attributes of this project in real time, ensuring quality data and full coverage, as shown in **Exhibit 5**. More information about point density can be found in Section 4.3.

Exhibit 4: The Optech Galaxy Prime was used for data acquisition

Exhibit 5: **Swath data for the project was recorded and viewed real-time by the sensor operator.**



3. LiDAR Processing Workflow

1. **Absolute Sensor Calibration.** Following sensor installation, lever arm values were surveyed. A boresight mission was flown over our fully controlled local range, and when adjusted to the surveyed ground control for roll, pitch, heading, and scale errors, boresight angles were developed for application to the POS processing in subsequent steps.

2. **Kinematic Air Point Processing.** The airborne GPS positions (collected at 1-second intervals) were post-processed using Applanix's POSPac MMS GNSS Inertial software (PP-RTX). A smoothed best estimate of trajectory (SBET) was developed by combining the corrected GPS positions with 1/200-second inertial measurement unit (IMU) data, which tracked the plane's roll, pitch, and yaw throughout the flight.

3. **Raw LiDAR Point Processing (Calibration).** The SBET and LiDAR range data were combined to solve for the real-world positions of each laser point. Point cloud data was produced by flight strip in ASPRS v1.4 LAS format. Flight strips were output in the project's coordinate system.

4. **Relative Calibration.** Discrepancies between adjacent flightlines were corrected for roll, pitch, heading, and scale, and were tested for relative accuracy. These results are presented in Section 4.1.

    a. A **Dz Ortho Raster** was generated as part of this process (**Exhibit 6**). This raster identifies clusters of large residuals and differences in measured elevations between overlapping flightlines. These errors are usually caused by topographic relief or environmental factors and require manual adjustments to correct. In most cases, multiple iterations of the Dz ortho raster are created to aid in fine tuning relative calibration parameters. The breaks used in the creation of the Dz raster are shown in **Exhibit 7**.

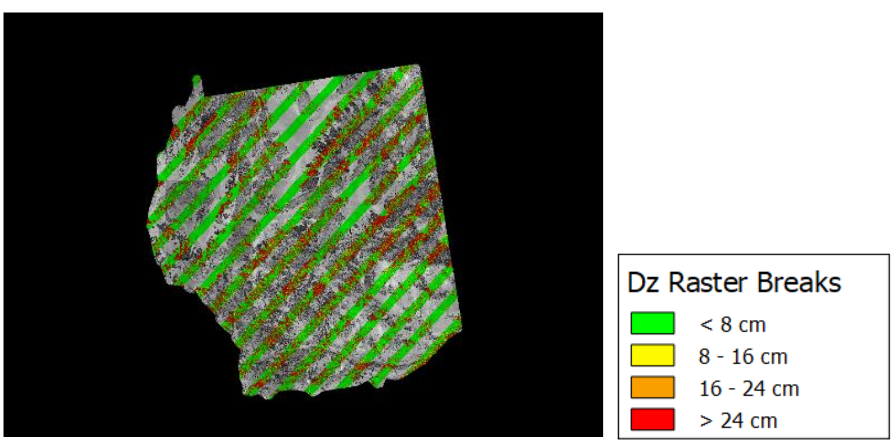


Exhibit 6: The Dz ortho raster generated for the 3DEP Strawberry project

5. **Vertical Accuracy Assessment.** Height differences between each static survey point and the laser point surface are identified through comparative tests. Results are presented in Section 4.2.

6. **Tiling & Long/Short Filtering.** Data was clipped to match the project specified tiles. Extremely long and short returns were also filtered out as outliers.

7. **Classified LAS Processing.** The point classification was performed with the ASPRS classes described in **Exhibit 7**. The bare-earth surface is classified using a combination of Terrascan macro functionality as well as proprietary Aero-Graphics software. The bare-earth surface is then manually reviewed and corrected to ensure correct classification on the Class 2 (Ground) points. No features requiring hydro flattening were located on this project. All data is then manually reviewed and any remaining artifacts removed using functionality provided by TerraScan. LP360 is then used as a final check of the bare-earth dataset. TerraScan is then used to create the deliverable industry-standard LAZ files for the Classified Point Cloud Data. LP360 and TerraScan software was used to perform statistical analysis of the classes in the LAS files, on a per tile level to verify classification metrics and full LAS header information then LASzip is used to create the final deliverable LAZ files.

Exhibit 7: The ASPRS classes used in lidar point classification

USGS Version 1.4 minimum point cloud classification scheme		
CLASS #	CLASS NAME	DESCRIPTION
1	Processed, but unclassified	Points that do not fit any other classes
2	Bare earth	Bare earth surface
7	Low noise	Low points identified below surface
9	Water	Points inside of lakes/ponds
17	Bridge decks	Points on bridge decks
18	High noise	High points identified above surface
20	Ignored ground	Points near breakline features; ignored in DEM creation process
21	Snow	If present and identifiable
22	Temporal exclusion	Non-favored data in intertidal zones

8. **Hydro-Flattened Raster DEM Creation.** A hydro-flattened raster digital elevation model (DEM) was created using the ground classified LiDAR points, and the DEM was then tiled in GeoTIFF format using LP360 and automated scripting routines within ArcMap. Each surface was reviewed in ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

9. **First Return Raster DSM Creation.** A first-return raster digital surface model (DSM) was created using the first-return LiDAR points, which was then tiled in

GeoTIFF format using LP360 and automated scripting routines within ArcMap. Each surface was reviewed in ESRI ArcMap and ArcScene to check for any surface anomalies or incorrect elevations found within the surface.

10. **Intensity Image Creation.** Intensity imagery was created using LP360 by averaging all points excluding withheld flagged and any noise points. The intensity imagery was reviewed in ESRI ArcMap for anomalies and to verify coverage.

11. **Maximum Surface Height Raster (MSHR) Generation.** Using the Tile Index to set the origin and raster dimensions , a pdal pipeline is used to create the MSHR. In the pipeline points flagged as Withheld are filtered out and all other points are passed. Then the gdal writer is used with the dimension set to "Z" and the type set to "max". This produces a raster holding the maximum z value in each cell. The resulting rasters are loaded into QGIS and reviewed and QC calls are made on any areas containing noise that has not been flagged using the withheld bit. If needed these calls are corrected and the MSHRs are regenerated and reviewed again.

4. Accuracy Testing and Results

4.1 Relative Calibration Accuracy Results

Interswath relative accuracy is defined as the elevation difference in the overlapping area of parallel swaths. During the calibration process, coincident tie-lines are created in the overlapping regions of each swath. The elevation difference between these tie lines was used to measure the between-swath relative accuracy of the dataset. During calibration, this process is carried out to verify consistency from swath to swath, but as a quality assurance measure it can also point toward the internal consistency of the overall dataset. A final set of DZ rasters is created upon completion of classification to ensure that no errors were introduced in processing and also to quantify interswath accuracy. DZs were generated with all non-noise points and encoded to RBG with the following breaks: 8 cm, 16 cm, and 24 cm. The results are based on the comparison of the flightlines and points for each area. The results below include any reflights that were completed over each area, increasing the number of flightlines from what was originally planned.

Strawberry project area: (20 flightlines, > 920 million points)

- Interswath relative accuracy **average** of 0.031 m

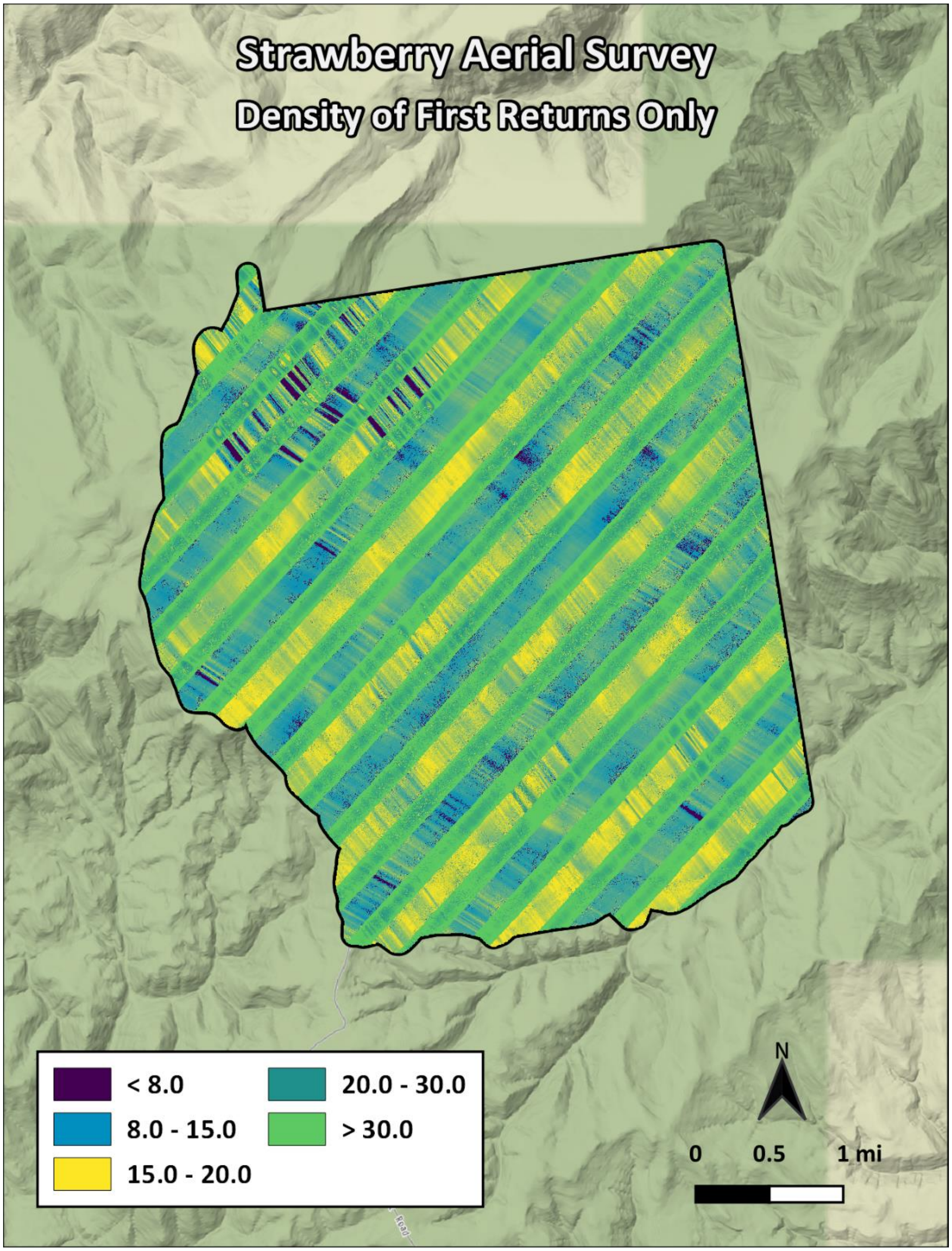
4.2 Calibration Control Vertical Accuracy

Due to field inaccessibility, new control and checkpoints were not surveyed for this AOI. However, the data was calibrated to 2019 and 2020 LBS-compliant lidar that was flown and processed by Aero-Graphics through a cooperative agreement with the Utah Automated Geographic Reference Center. This data completely surrounds the Strawberry AOI and is calibrated in an ideal geometrically distributed manner which maximizes vertical and horizontal consistency between the datasets.

4.3 Data Density

In order to fulfill USGS LBS 2022, Revision A QL1 density requirements, the density of the point cloud must be greater than or equal to 8 points per meter^2. Average density per tile for the Strawberry QL1 project area was calculated based on first returns only. **Exhibits 8-10** illustrate that the acquisition met or exceeded the required density except in areas where bodies of water impeded the collection of data or tiles contained a proportionally significant area outside of the project boundaries. The QL1 project achieved and average per tile density of 22.7 points per meter^2 for first returns.

Exhibit 8: Laser Point Density of First Returns, points/m²



<u>Exhibit 9:</u> First returns laser point density per tile by frequency, points/m².

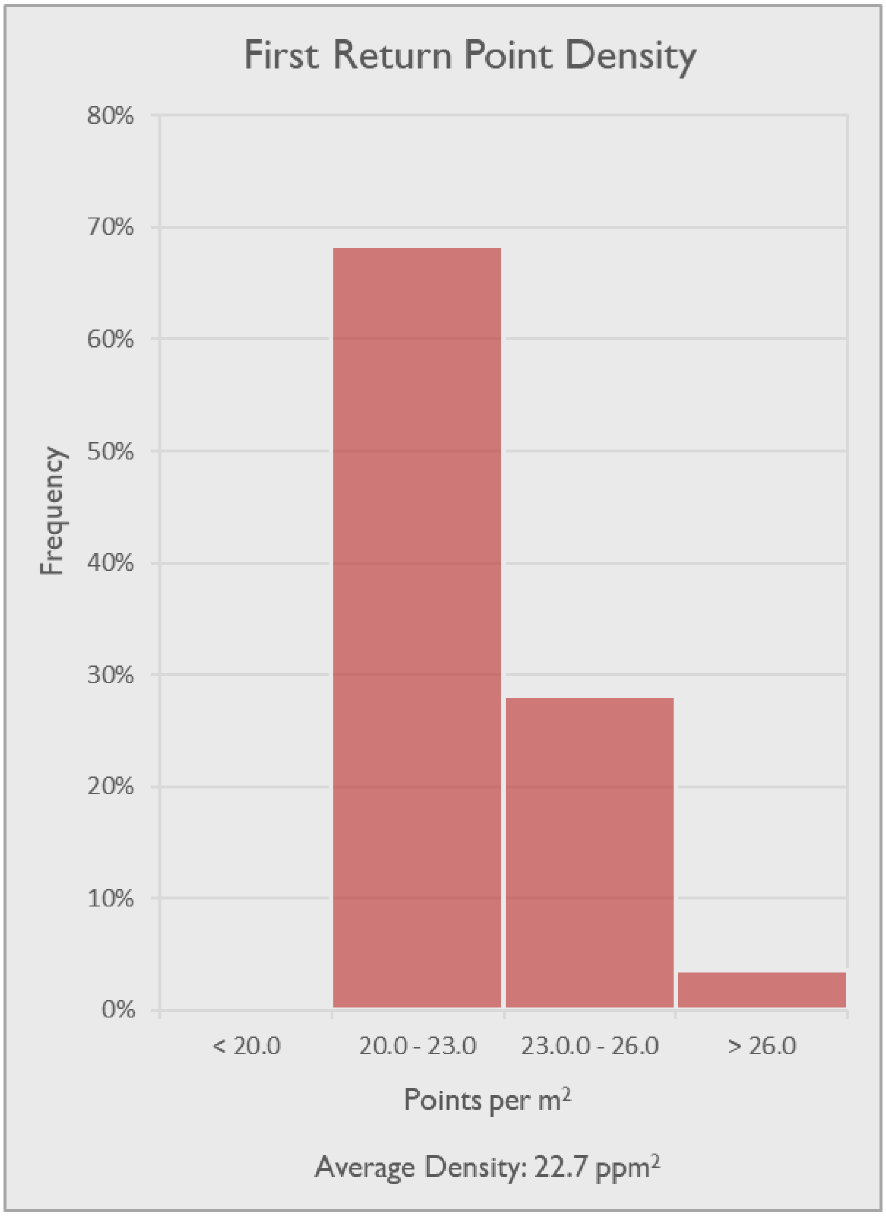


Exhibit 10: **Spatial Distribution per flight line, percent void cells.**

Flight Line	Spatial Distribution (% void cells)
1001	2.284944567
1002	1.351032174
1003	1.35213937
1004	1.146476792
1005	2.147545011
1006	1.786408763
1007	3.011754549
1008	2.53468611
1009	2.756288444
1010	2.103916715
1011	2.342127984
1012	1.541244424
1013	1.944038101
1014	1.565935089
1015	2.45272328
1016	2.54314916
1017	2.626506911
1018	2.560717885
1019	3.055856044