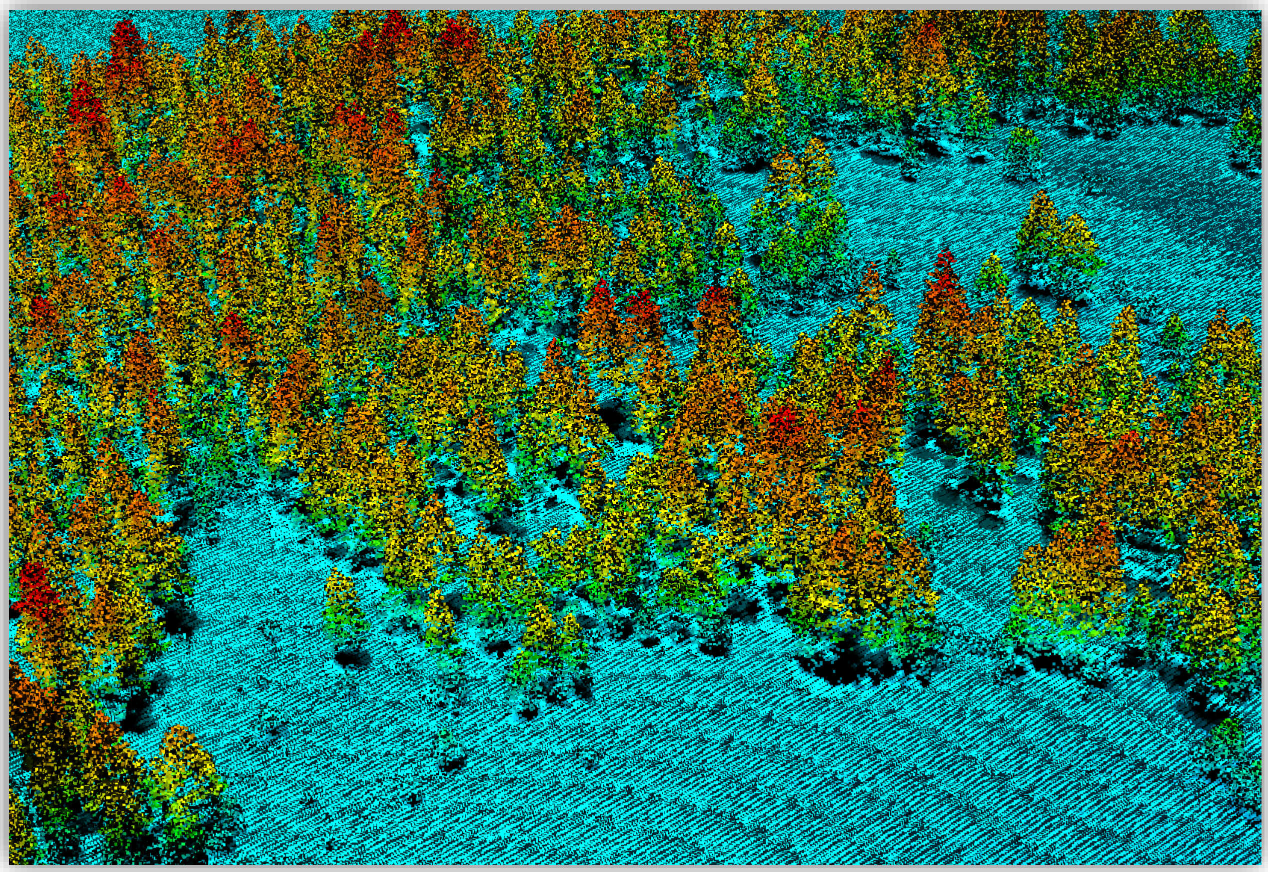
TECHNICAL PROJECT REPORT

SYCAN USFS R6 AERIAL SURVEY

LAKE AND KLAMATH COUNTIES, OREGON

June & July, 2020



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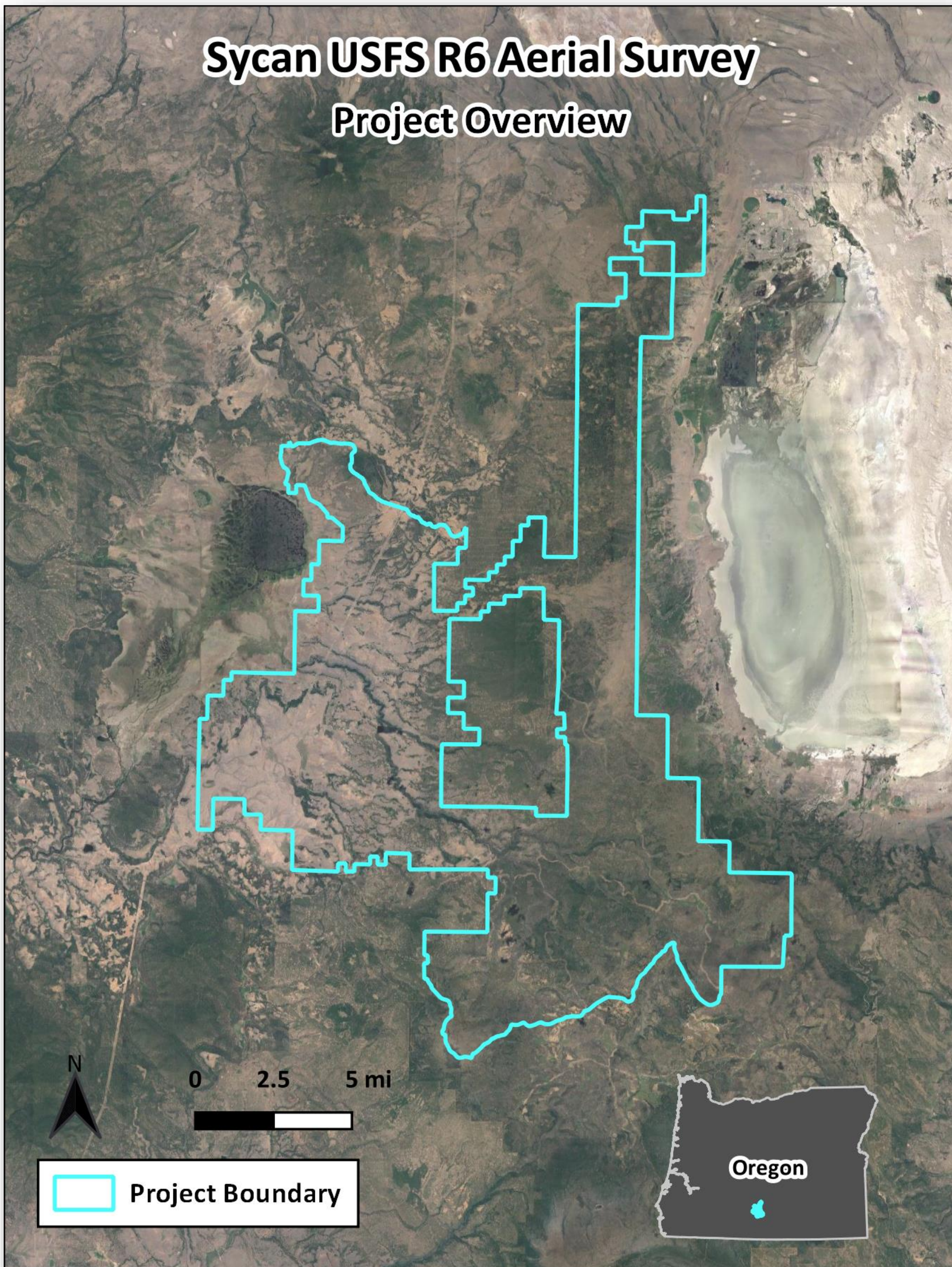
1. Overview

Aero-Graphics was contracted to perform aerial LiDAR scanning over the Sycan USFS R6 project area in Lake and Klamath Counties, OR. The project area covers approximately 182 square miles. This report describes the planning, acquisition, and processing of the LiDAR dataset.

***Exhibit 1**: Sycan USFS R6 project boundary*



2. Acquisition

2.1 Airborne Acquisition – Equipment and Methodology

LiDAR and imagery acquisition for the Sycan USFS R6 project was performed with an Optech Galaxy PRIME LiDAR sensor. The LiDAR sensor was placed in a customized mount to minimize error and increase accuracy. Aero-Graphics flew at an approximate altitude of 5,249 ft above ground level (AGL) and made appropriate adjustments to compensate for topographic relief over the project's over 71 flightlines. LiDAR acquisition was planned with 60% side overlap and an aggregate point density of 8 points per square meter throughout the project area. The settings used for collection consisted of a pulse rate frequency (PRF) of 400 kHz, a scan frequency of 67.5 Hz, and a scan angle of +/- 20° from the nadir position (full scan angle 40°).

Exhibit 2: *Summary of flight parameters*

Altitude (ft AGL)	Sidelap (%)	Speed (kts)	PRF (kHz)	Scan Freq (Hz)	Scan Angle ° (full)
5,249	60	120	400	67.5	40

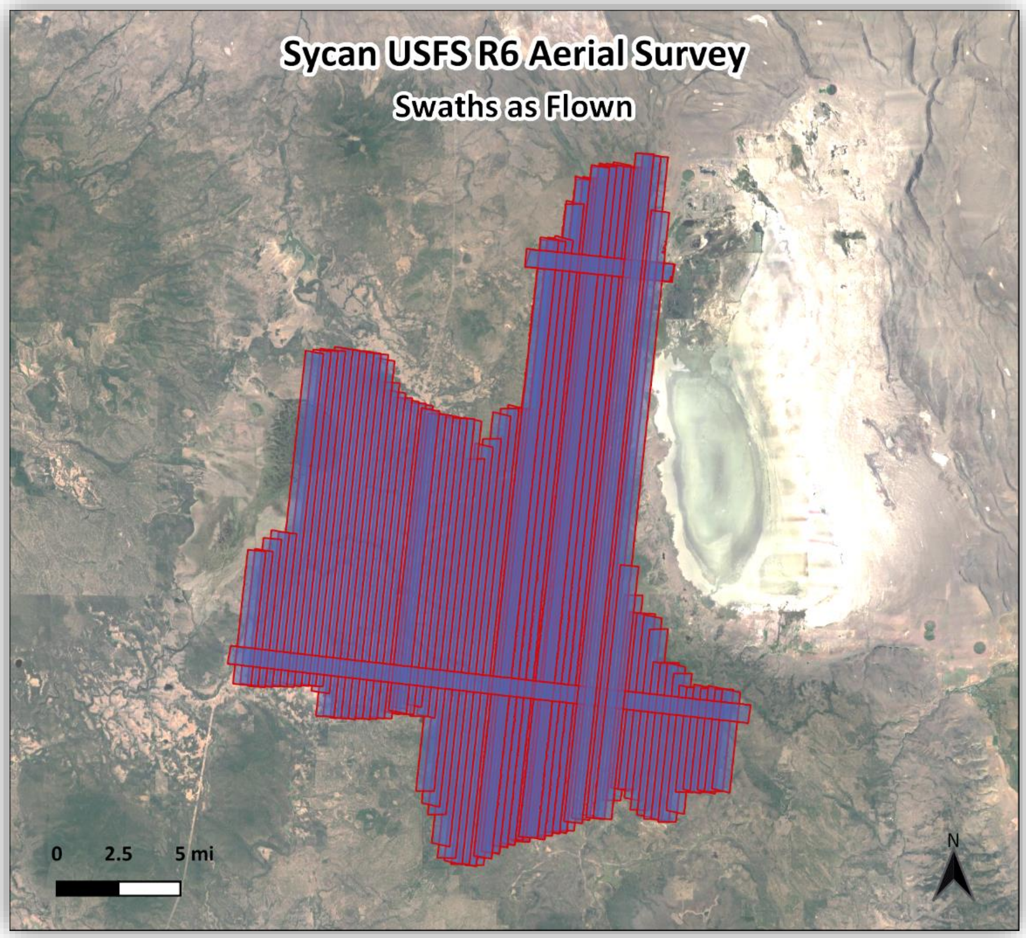
Aggregate Point Density p/m^2	Post spacing Cross Track (m)	Post Spacing Down Track (m)	Swath Width (m)	# Flightlines
4.8 * 2	0.46	0.46	1,165	71

The Optech Galaxy PRIME is one of the most productive and accurate sensors available in the industry. This sensor features SwathTRAK technology, which dynamically adjusts the scan FOV in real time during data acquisition. It also features a 1MHz effective pulse rate, providing on the-ground point density and efficiency formerly reserved for dual-beam sensors. Up to 8 returns per pulse are possible for increased vertical resolution of complex targets without the need for full waveform recording and processing. Industry-leading data precision and accuracy (<5cm RMSEz) results in the highest-quality datasets possible.

Exhibit 3: *The acquisition platform for the Sycan USFS R6 project was a turbocharged Cessna 206. Our 206 has been customized for LiDAR and other airborne sensors with an upgraded power system and avionics. The stability of this platform is ideal for efficient imagery collection at high and low altitudes and a variety of airspeeds.*

Aero-Graphics utilizes Optech's Airborne Mission Manager (AMM) software to plan flight lines and sensor settings. AMM allows the aerial department to simulate the effects of different sensors, mounts, and settings, ensuring the flight plan will meet the needs of the project while being as efficient as possible. To complement the flight planning process, the Galaxy PRIME LiDAR sensor is equipped with FMS Nav, the latest data collection and navigation software release from Optech. The use of FMS Nav helps ensure an accurate and consistent acquisition mission with real-time quality assurance while still airborne. The system operator can monitor the point density and swath during the mission to confirm adequate coverage within the area of interest, as shown in **Exhibit 4**.

Exhibit 4: *Swath data for the Sycan USFS R6 project was recorded and viewed real-time by the sensor operator.*



2.2 Ground Control and Check Point Survey

Aero-Graphics' professional land surveyor identified, targeted, and surveyed 5 ground control points for use in data calibration as well as 120 QC check points in Non-Vegetated land cover classification as an independent test of accuracy for this project. A combination of precise GPS surveying methods, including static and RTK observations were used to establish the 3D position of ground control points. Ground control coordinates can be found in Appendix A. A summary of LiDAR calibration control vertical accuracy can be found in section 4.2 as well as a more detailed report in Appendix B.

Exhibit 5: *Static ground control for the Sycan USFS R6 project*

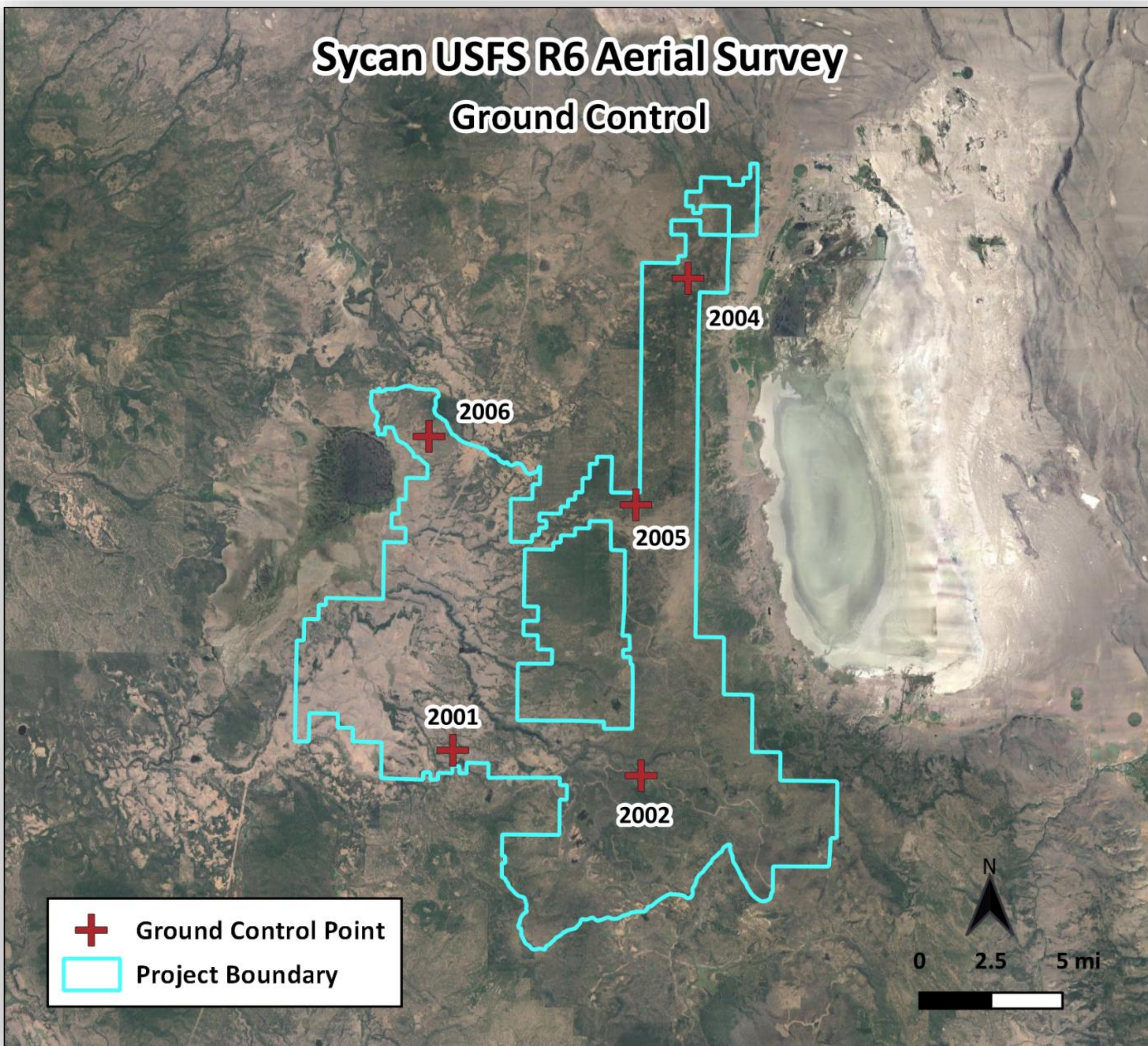
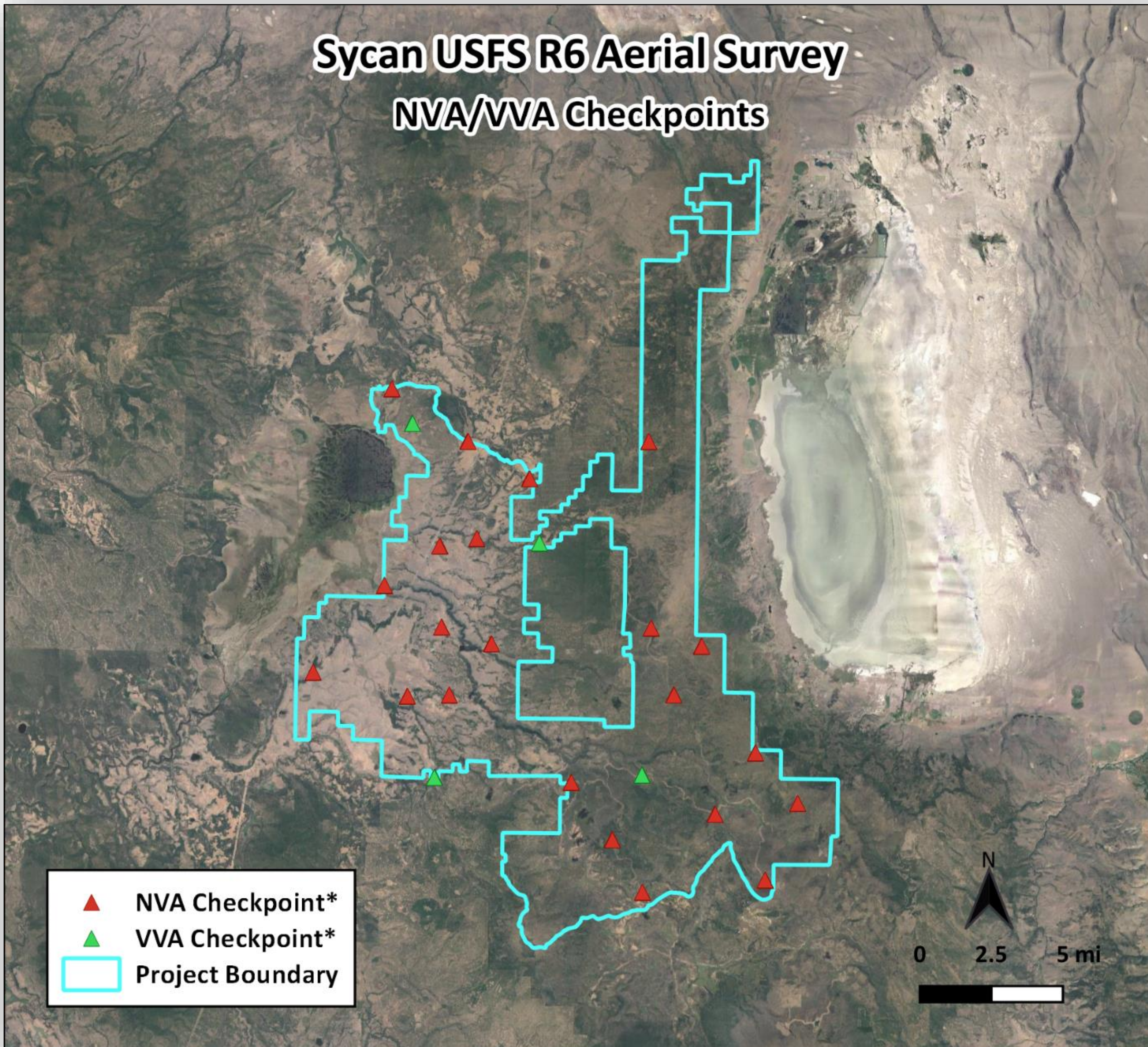


Exhibit 6: *NVA Check Points for the Sycan USFS R6 project*



*Several adjacent checkpoints were collected at each of the locations displayed above for a total of 120 NVA checkpoints and 20 VVA checkpoints

3. LiDAR Processing Workflow

a. **Absolute Sensor Calibration.** Our absolute sensor calibration adjusted for the difference in roll, pitch, heading, and scale between the raw laser point cloud from the sensor and surveyed control points on the ground.

b. **Kinematic Air Point Processing.** Differentially corrected the 1/5-second airborne GPS positions with ground base station; combined and refined the GPS positions with 1/200-second IMU (roll-pitch-yaw) data through development of a smoothed best estimate of trajectory (SBET).

c. **Raw LiDAR Point Processing (Calibration).** Combined SBET with raw LiDAR range data; solved real-world position for each laser point; produced point cloud data by flight strip in ASPRS v1.4 .LAS format; output in local coordinate system.

d. **Relative Calibration.** Performed relative calibration by correcting for roll, pitch, heading, and scale discrepancies between adjacent flightlines; tested resulting relative accuracy. Results presented in Section 4.1.
    a. Generated a **Dz Ortho Raster** which identifies clustering of larger residuals, 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.

e. **Vertical Accuracy Assessment.** Performed comparative tests that showed Z-differences between each static survey point and the laser point surface. Results presented in Section 4.2.

f. **Tiling & Long/Short Filtering.** Cut data into project-specified tiles and filtered out grossly long and short returns.

g. **Classification & QA/QC.** Ran classification algorithms on points in each tile; separated into bare earth and unclassified points; revisited areas not completely classified automatically and manually corrected them.

4. Results

4.1 Relative Calibration Accuracy Results

Between-swath relative accuracy is defined as the elevation difference in overlapping areas between a given set of two adjacent flightlines. The statistics are based on the comparison of the flightlines and points listed below.

Sycan USFS R6 project area: (71 flightlines, > 12 billion points)

- Between-swath relative accuracy **average** of 0.0272 foot

4.2 Calibration Control Vertical Accuracy

Vertical absolute accuracy reports were generated as a quality assurance check. The location of each control point is displayed in the Surveyed Ground Control map in **Exhibit 5**. Detailed results for each point are included in **Appendix B**.

Exhibit 7: *Calibration control vertical accuracy results summary*

Calibration Control Accuracy$_z$: Sycan USFS R6 Project Area	
Average Error = +0.004 m	RMSE = 0.020 m
Minimum Error = -0.022 m	σ = 0.022 m
Maximum Error = +0.025 m	Average Magnitude = 0.020 m
Survey Sample Size: n = 5	

4.3 Data Accuracy Summary

Accuracy has been tested to meet 19.6 cm or better Non-Vegetated Vertical Accuracy at 95% confidence level using RMSEz x 1.96 as defined by the National Standards for Spatial Data Accuracy (NSSDA); assessed and reported using National Digital Elevation (NDEP)/ASPRS Guidelines.

Exhibit 8: *NVA and VVA vertical accuracy results summary*

Raw Point Cloud NVA (m)	DEM NVA (m)	DEM VVA (m)	Points Tested NVA	Points Tested VVA
0.030	0.043	0.031	120	20

4.4 Data Density

The goal for this project was to achieve a minimum LiDAR point density of 4 points per square meter per swath for an aggregate of 8 points per square meter. First return density is the best representation of the quality of the acquisition because the density of first returns is independent of vegetation and other random factors that could increase the overall point density. The acquisition mission achieved an actual average aggregate of **13.8** points per square meter for first returns. The following two exhibits show the density of first return points.

Exhibit 9: *Sycan USFS R6 Project– **First returns** Laser Point Density by Frequency, points/m^2. Demonstrates the percentage of project tiles with points in a given density range*

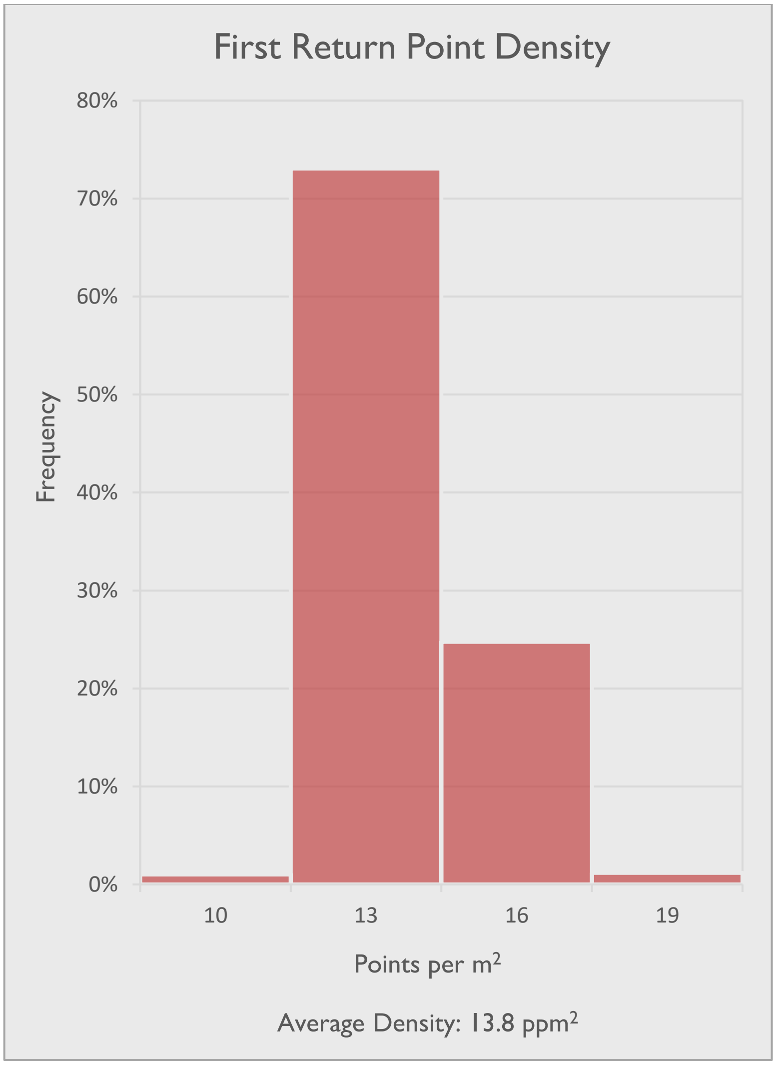
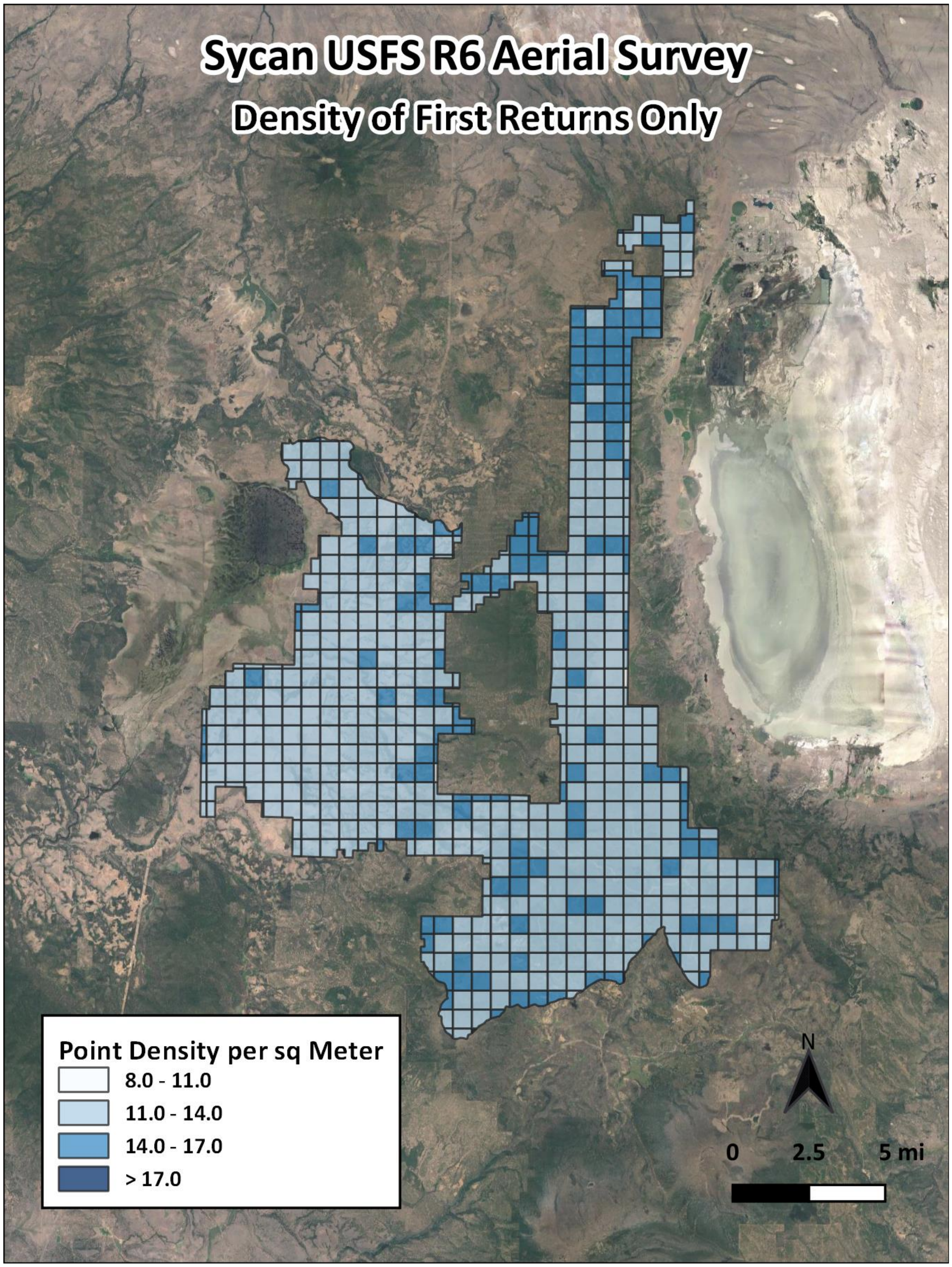


Exhibit 10: *Laser point density of first returns by tile, points per square meter*



5. Projection, Datum, Units

Projection		NAD 1983 Oregon Washington Albers
Datum	Vertical	NAVD88 (Geoid12B)
	Horizontal	NAD83 (2011)
Units		Meters

6. Deliverables

LiDAR Data	• All-return point cloud in LAZ format
Raster Data	• Canopy top elevation model DSM at 50 cm resolution in IMG format • Normalized and non-normalized intensity imagery in IMG format at a 50 cm resolution
Vector Data	• Aircraft trajectory and IMU data in SHP format
Report of Survey & Support	• Reports, supporting SHP files, and metadata as described in SOW

APPENDIX A – GROUND CONTROL COORDINATES

Survey Point	Sycan USFS R6 Aerial Survey (NAD 1983 Oregon Washington Albers)		
	Easting	Northing	Elevation (m)
2001	517549.315	959668.746	1649.615
2002	528151.986	958244.358	1860.265
2004	530798.472	986249.357	2023.312
2005	527862.386	973489.020	1986.730
2006	516205.348	977341.845	1636.629

APPENDIX B – CALIBRATION CONTROL ACCURACY REPORT

Sycan USFS R6 Project Area			
Survey Point	Known Z (m)	Laser Z (m)	Dz (m)
2001	1649.615	1649.640	0.025
2002	1860.265	1860.280	0.015
2004	2023.312	2023.290	-0.022
2005	1986.730	1986.750	0.020
2006	1636.629	1636.610	-0.019

Average Dz (m)	+0.004
Minimum Dz (m)	-0.022
Maximum Dz (m)	+0.025
Average Magnitude (m)	0.020
RMS (m)	0.020
Std. Deviation (m)	0.022