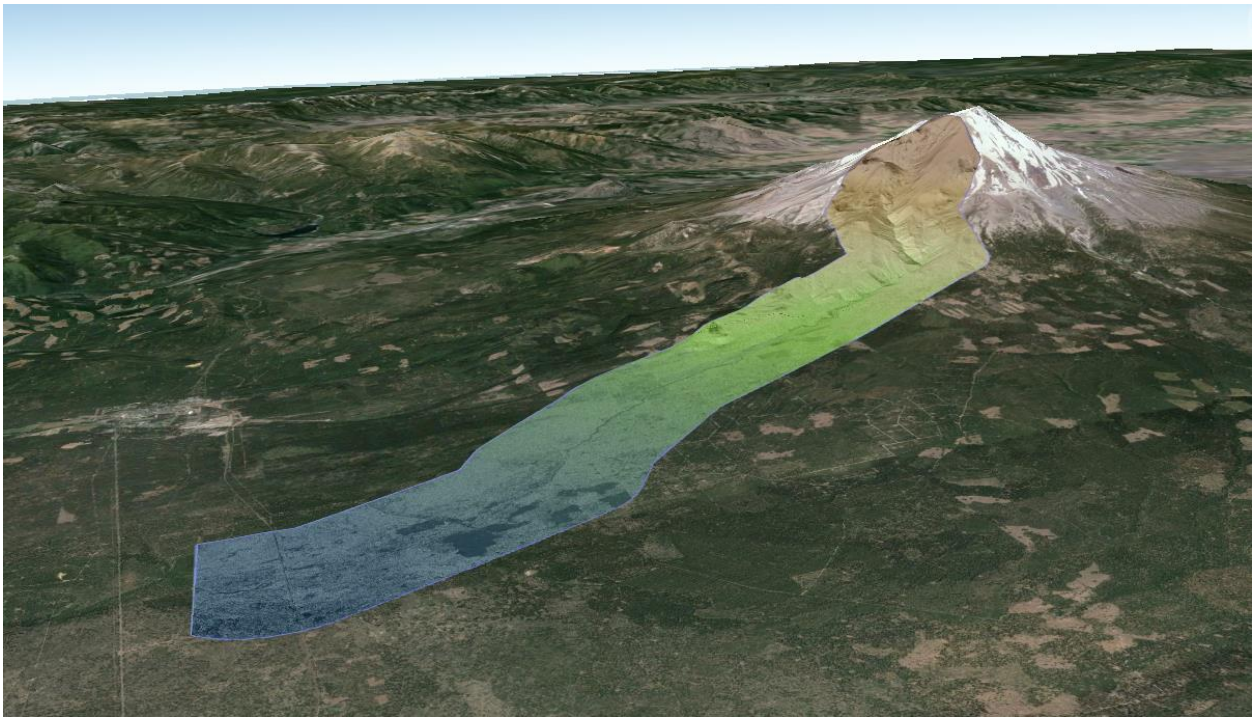
USDA Forest Service
Pacific Southwest Region
Mud Creek
Shasta National Forest, CA

Project Report – November 2015



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Airborne LiDAR Acquisition

Tetra Tech was contracted by the USDA Forest Service, Pacific Southwest Division to provide airborne LiDAR data for an area within the Shasta National Forest region. Figure 1 shows the location of the LiDAR project on the South face of the Mount Shasta.

This report presents the results of the data acquisition that took place on September 28, 2015 and September 29, 2015. During the time of acquisition, the ground was free of snow except for some areas on top of Mount Shasta where there is continual snowpack. The total project area covers approximately 12,800 acres.

The LiDAR data has been collected using an Optech ALTM Orion H300 LiDAR sensor. The aircraft flew at an average altitude of 3,775 feet above the ground level. The acquisition was performed with 50% overlap and a scan angle of +/- 17˚ from the nadir position (FOV=34˚) and yielded an average 9 points per square meter. The airborne trajectory has been monitored with kinematic AGPS combined with IMU observations collected at 200 Hz. Two individual flight missions were accomplished in order to cover the entire project area. Figure 2 depicts the aircraft trajectories on top of the project area.

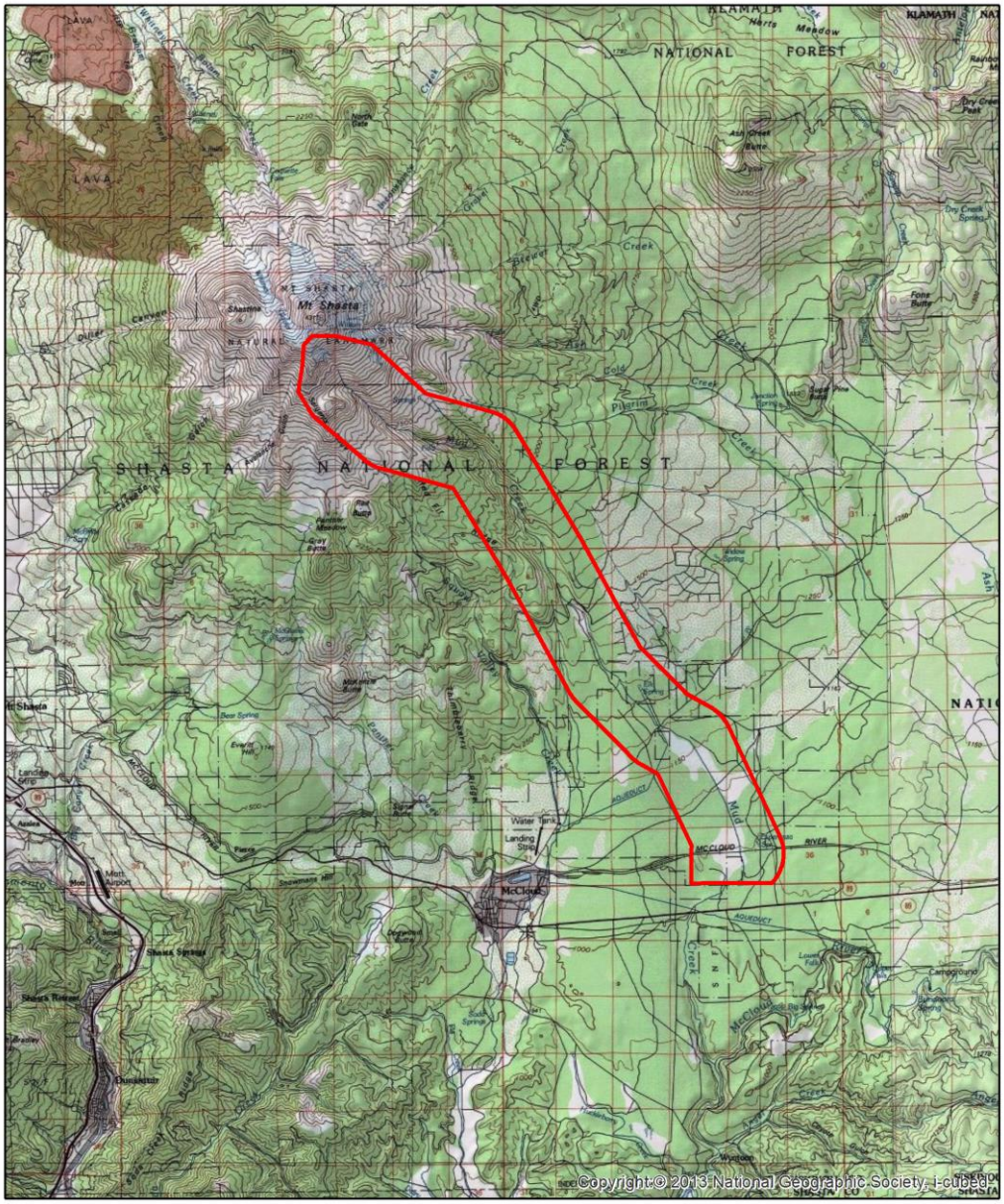


Figure 1: Boundaries of the Mud Creek LiDAR project.

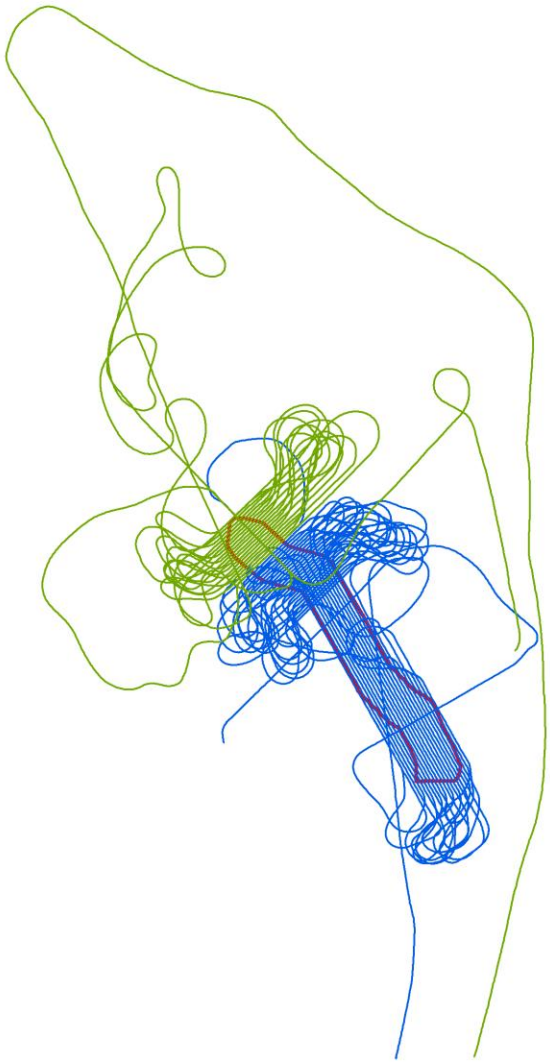


Figure 2: Aircraft trajectories on top of the project boundary.

Tiling Scheme

The LiDAR data processing as well as the deliverables are based on a very specific tiling scheme. The LiDAR point cloud is saved in tiles that are rectangular in geographic coordinates, corresponding to 1/100th USGS quadrangle (0.75 minute by 0.75 minute region). The deliverables (DTM grids, DSM grids and intensity images) are stored in quarter USGS quadrangle (3.75 minute by 3.75 minutes region). The name of each file is derived from the tiling scheme, as requested in the scope of work. Both levels of the selected tiling scheme are illustrated with Figure 3 and Figure 4.

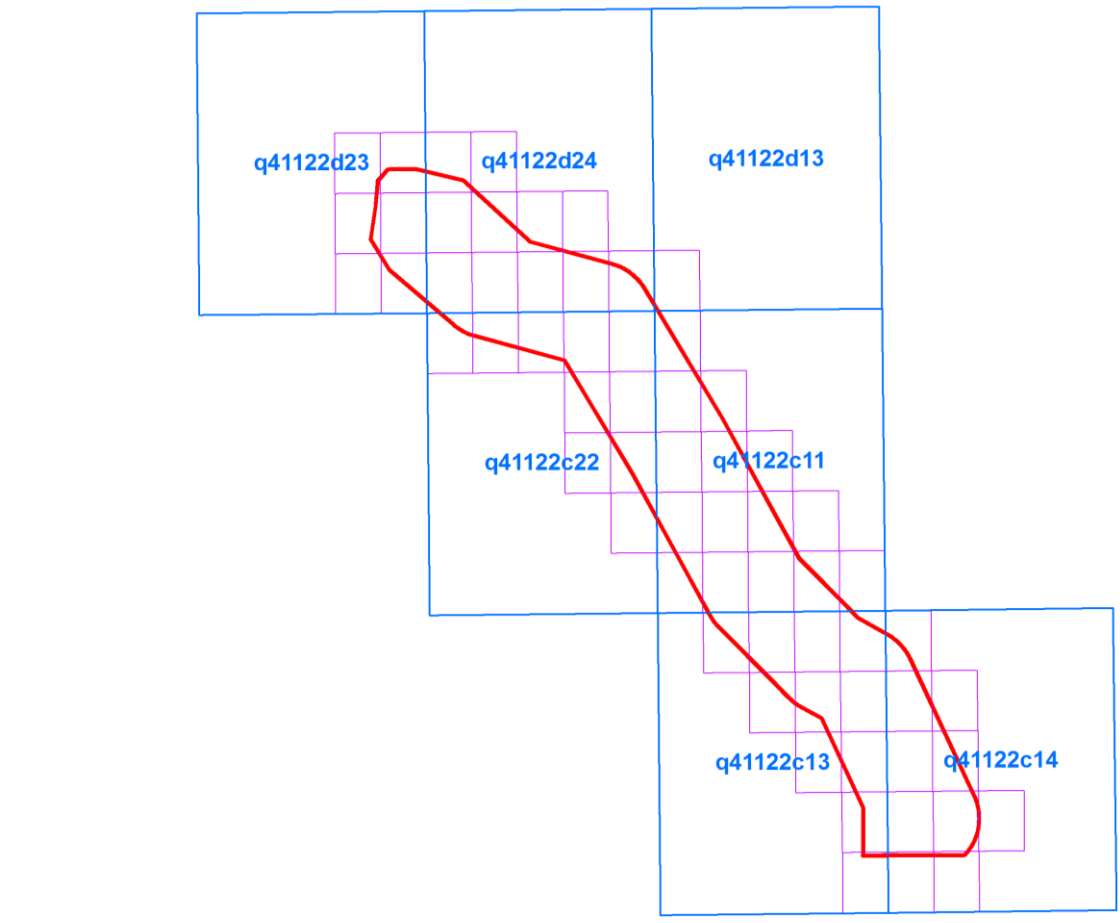


Figure 3: Tiling scheme for the Mud Creek project area, quarter USGS quadrangles.

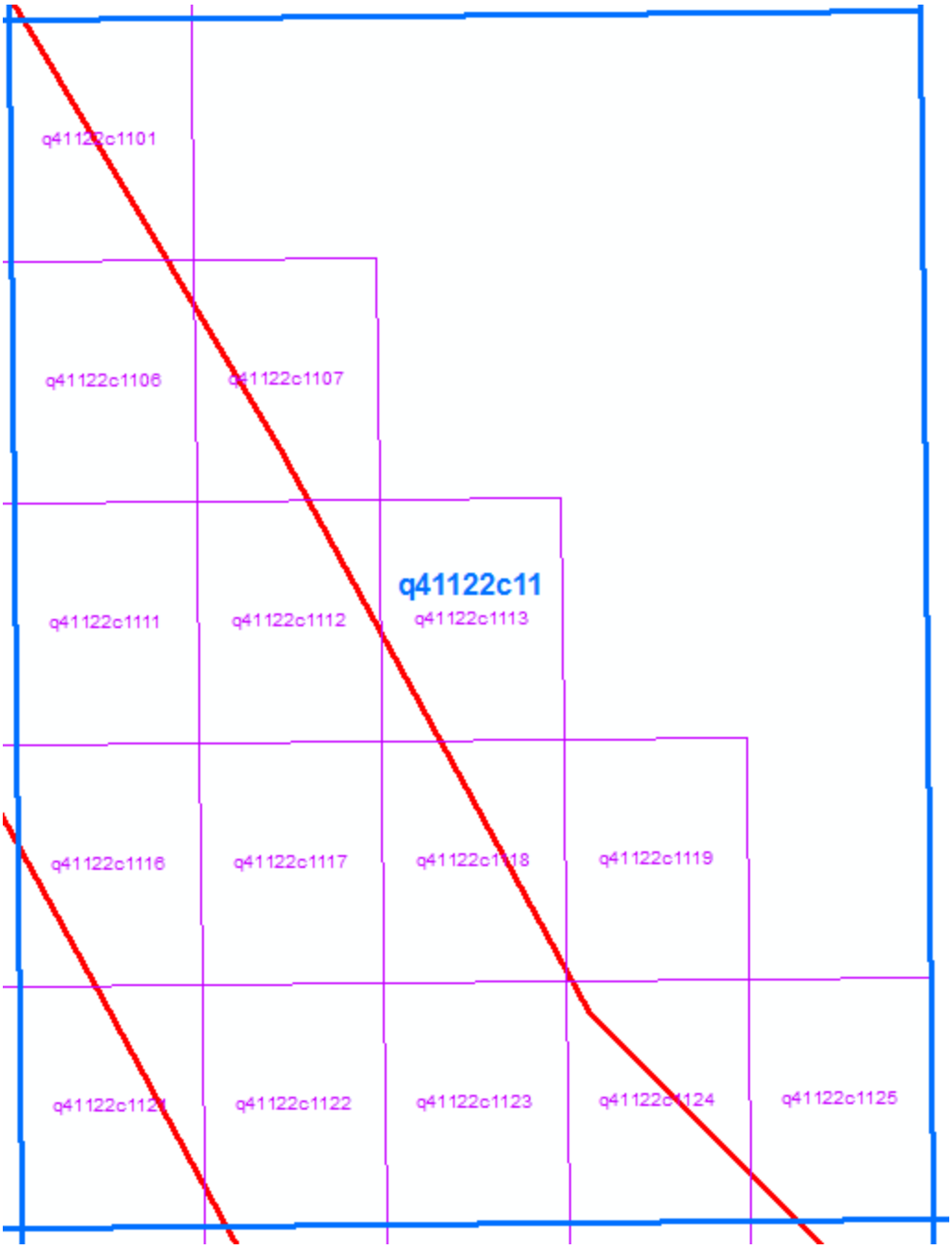


Figure 4: Tiling scheme for the Mud Creek project area, 1/100th quad organization chart.

Data Coverage

The entire project area is covered by the LiDAR data, divided in 64 individual tiles. All the raster deliverables are made of a subset of 7 quarter quad tiles. Figure 5 and Figure 6 below show the LiDAR and raster data coverage for the Mud Creek project.

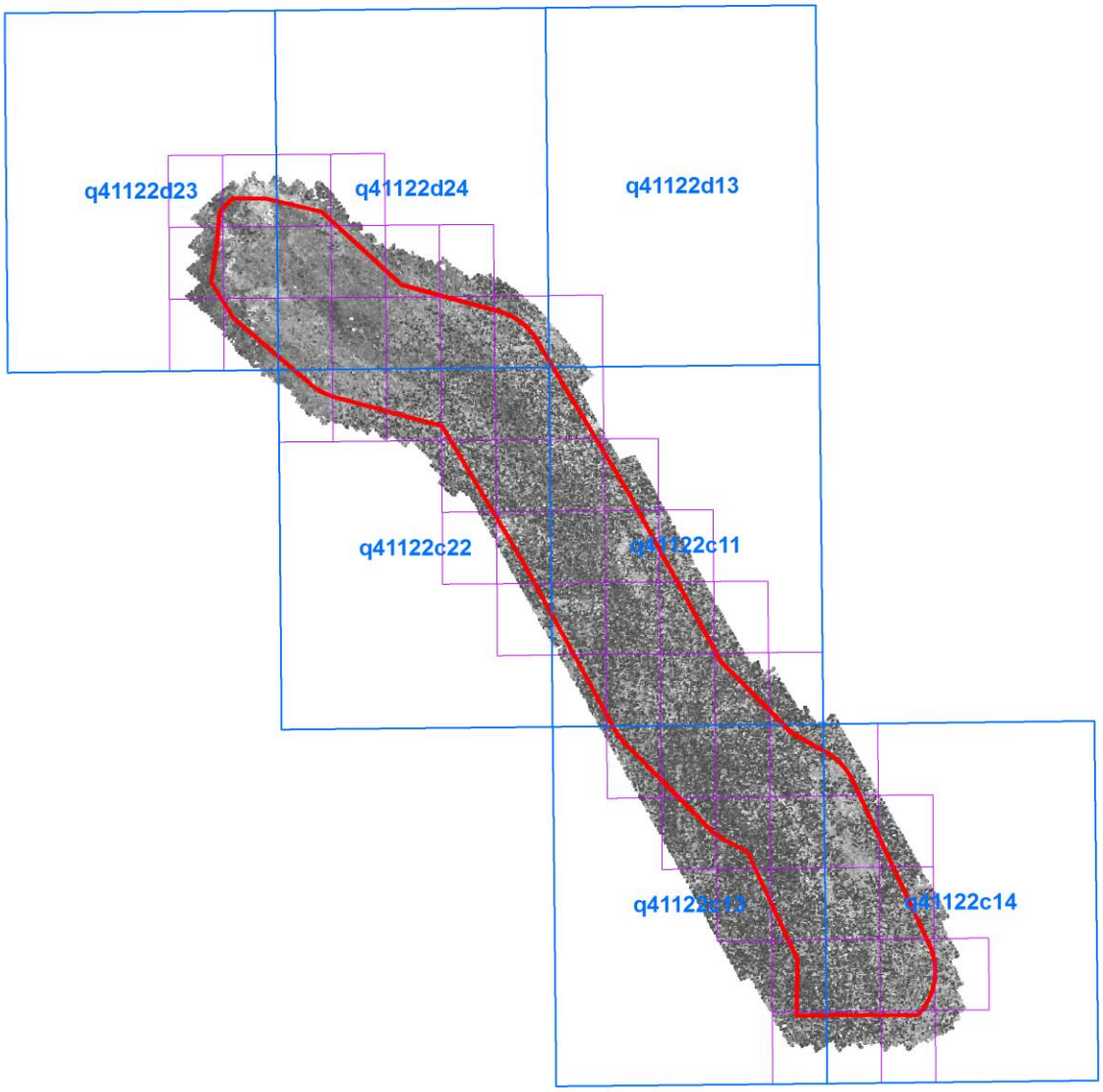


Figure 5: Mud Creek - LiDAR data coverage.

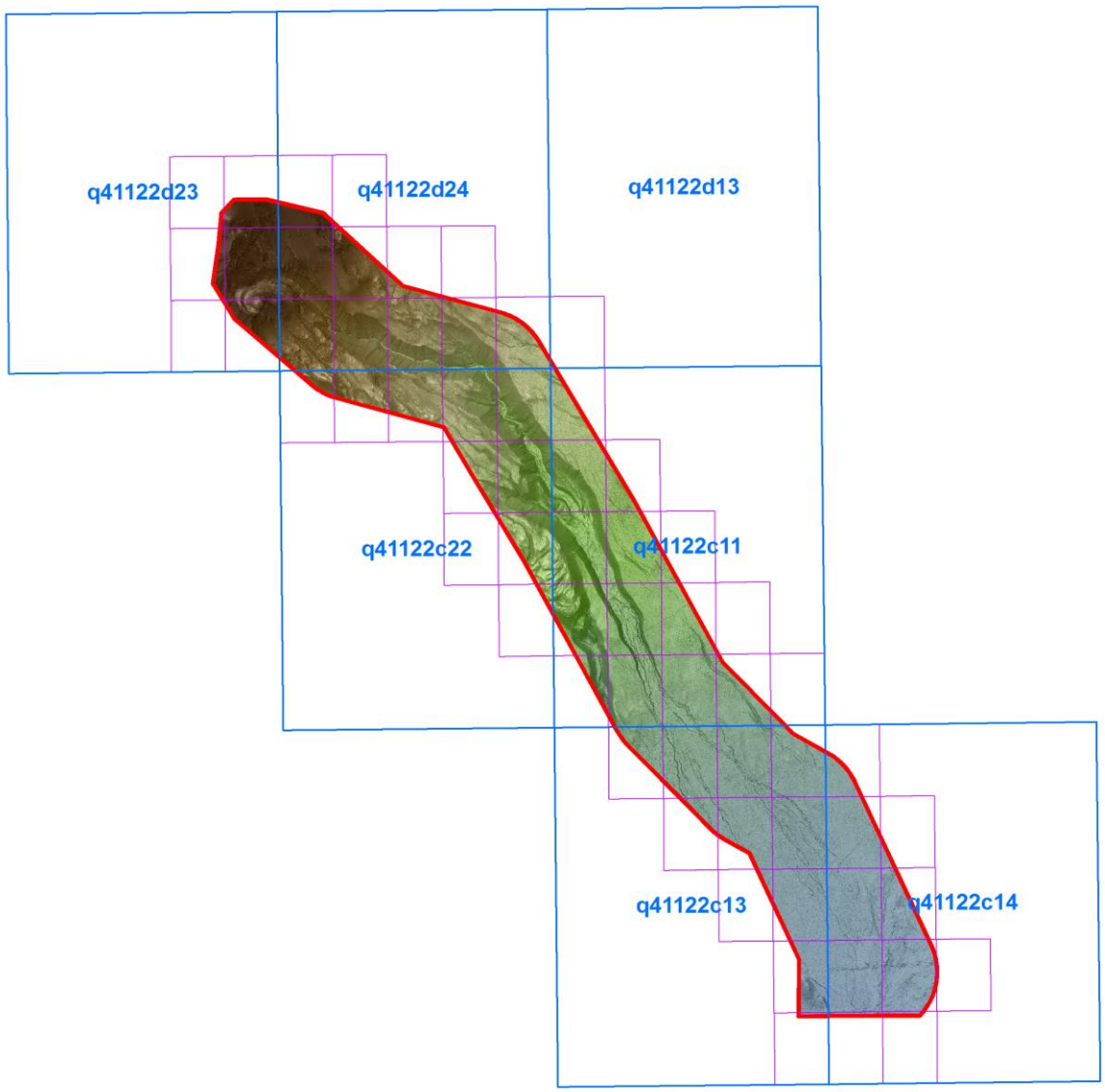


Figure 6: Mud Creek - Raster data coverage.

Quality Assessment

Coverage and swath-to-swath reproducibility

As the project area is mostly located on mountainous terrain and undeveloped territory, it is hard to find well distributed portions of the LiDAR that are flat. Therefore, the analysis of the internal noise of each LiDAR swath is not achievable. The accuracy and the frequency of the trajectory, as well as the calibration of the LiDAR sensor, ensure departures from planarity that are lower than 5 cm over flat areas within a single swath.

More critical could be the swath-to swath reproducibility. This is especially true since this project has requested two separate acquisition flights. To sense the quality of the swath-to-swath reproducibility, an image of the differences between the last returns of overlapping flightlines has been generated. This same image also confirms that most of the area has been at least covered twice by the LiDAR beams. As displayed, only the grey areas are single swath area. Most of them are located outside of the boundary of the project and should not been considered in the analysis. All the results are presented in an overview image presented in Figure 7.

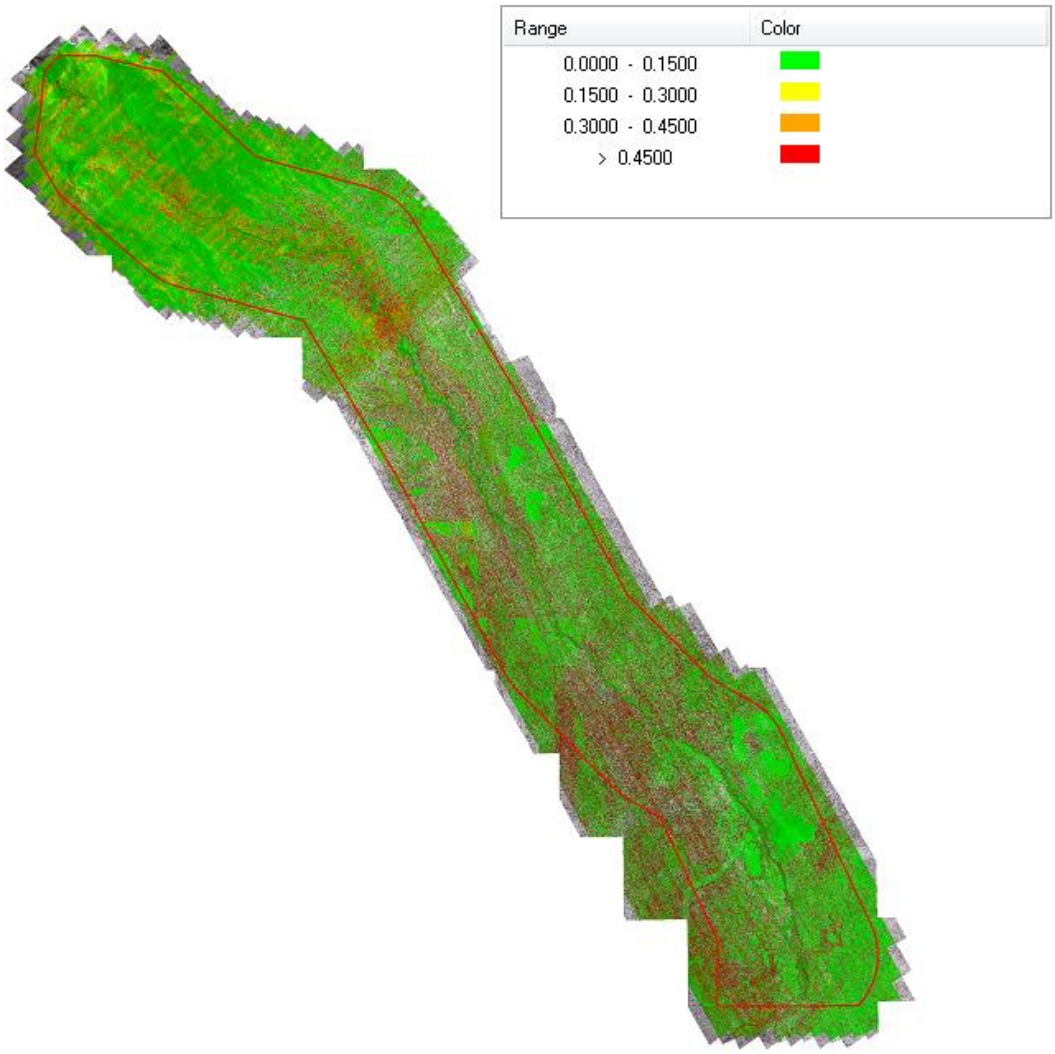


Figure 7: Last returns swath-to-swath comparison (values are in meter).

In order to have a better understanding of the inter-swath quality of the dataset, two additional images are presented below in Figure 8. The graphics below that display the zoom in two areas show that the different flightlines are matching well with each other. The red areas are generated by the vegetation as the last echoes sometimes stop on a tree. However, the differences at the bare earth level are always presenting values lower than 0.15 cm, even in presence of slope. This provides an example of the good quality of the sensor's calibration and of the GPS-IMU trajectory.

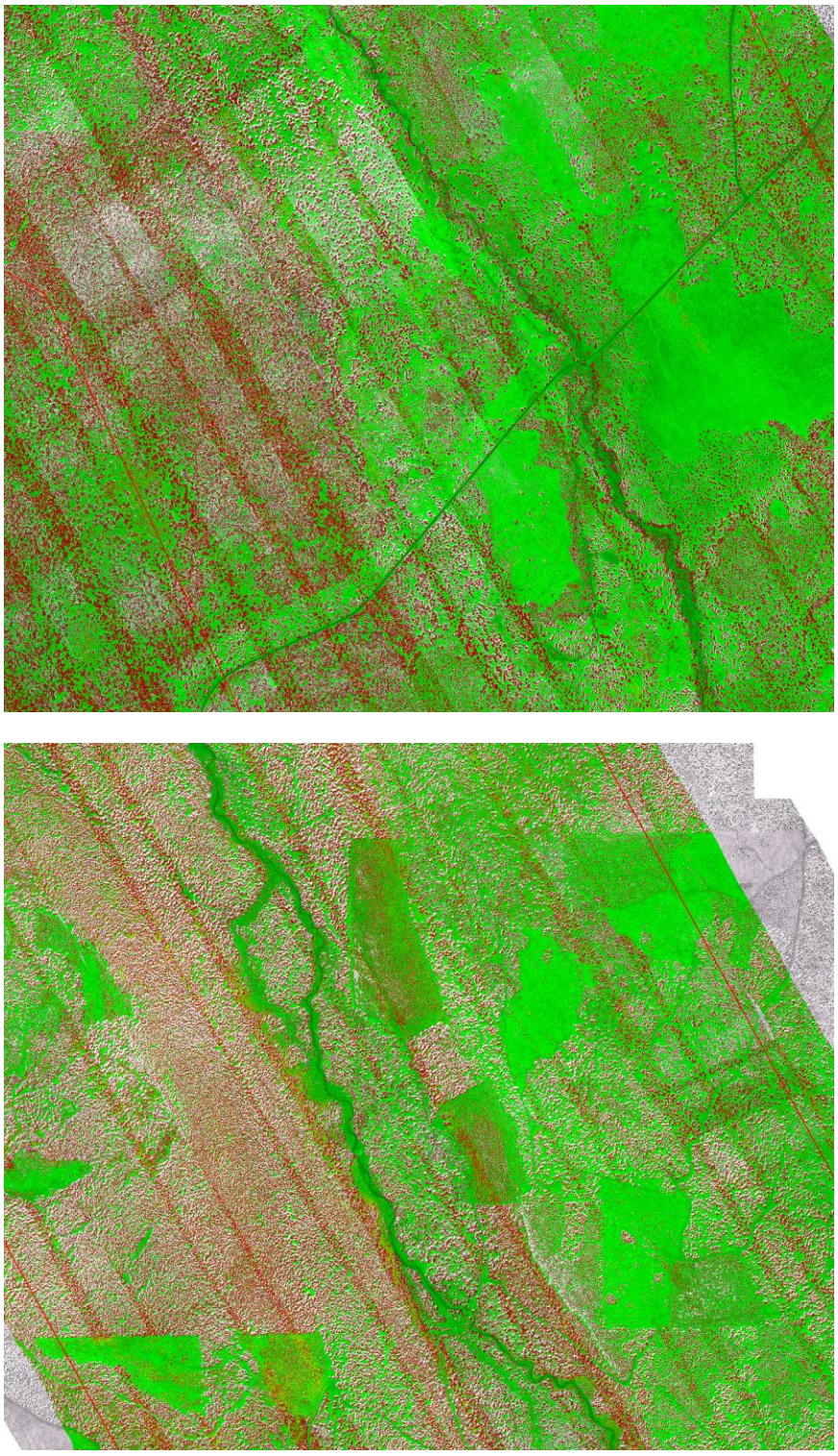


Figure 8: Two zooms over the swath-to-swath image.

Absolute accuracy

In order to assess the absolute accuracy of the LiDAR data, a set of 30 Ground Control Points (GCP) have been surveyed. Those points are well distributed over the project area. All the survey measurements are tied to eight reference stations, which are listed in the table below. The coordinates of the reference stations are in WGS84 Latitude/Longitude in Degrees Minutes and Seconds together with ellipsoidal heights in feet.

NAME	Latitude [DMS]	Longitude [DMS]	Ellipsoidal Height [ft.]
DH6408	41-17-21.349300	122-03-26.840540	3513.2700
MW0377	41-15-34.770400	121-58-54.752610	3584.3980
P655	41-17-40.135260	122-12-22.703460	5140.2700
P660	41-24-34.515280	122-04-03.584470	5286.2750
P657	41-22-52.447570	122-17-37.798360	6416.6370
P658	41-28-45.023120	122-11-27.227490	6284.9020
P661	41-27-48.939020	122-18-45.557890	4345.9000
P663	41-31-54.969190	122-09-10.465960	7344.0210

Figure 9: Overview and detailed view of the main base station (DH6408).

Based on these stations, 30 GCPS have been measured using static GPS records. These points have been used to assess the quality of the LiDAR dataset. The following table presents the coordinates of each GCP. The projection used is UTM Zone 10 with NAD83, CSRS 2011 (epoch 2011.29) as horizontal datum. The vertical datum is NAVD 88. The published orthometric height of the point MX0377 was used to place orthometric heights on DH6408 and the other base stations. Units are in meters.

Soil Cover	Name	Easting	Northing	Elevation	Soil Cover	Name	Easting	Northing	Elevation
VVA	100P	578965.245	4571297.346	1094.367	VVA	4A	573900.792	4576143.735	1548.140
NVA	1A	578175.072	4569190.009	1051.648	NVA	4B	574350.884	4576325.737	1478.317
NVA	1B	578553.082	4569214.557	1048.185	VVA	4C	574530.595	4577236.354	1619.588
NVA	1C	579049.434	4569183.617	1045.504	NVA	4D	574949.483	4576361.675	1526.162
NVA	1D	580363.323	4569248.882	1053.770	VVA	4E	575021.024	4576584.328	1535.704
NVA	1E	580169.163	4569777.700	1055.615	NVA	5A	576921.763	4572742.490	1196.512
VVA	2B	578431.015	4570873.102	1091.000	NVA	5B	576972.544	4572806.657	1196.409
NVA	2C	578684.723	4571171.117	1096.368	NVA	5C	577144.538	4572984.542	1200.131
NVA	2D	578885.889	4571321.194	1097.085	NVA	5D	577536.178	4573274.881	1206.238
NVA	2E	579015.208	4571464.923	1098.906	NVA	5E	577657.949	4573348.556	1207.122
VVA	3A	572905.602	4581135.529	2078.241	NVA	6A	575499.038	4574616.012	1347.191
VVA	3B	572794.890	4581109.401	2096.583	NVA	6B	575353.568	4574618.346	1352.058
VVA	3C	572729.037	4581114.735	2111.001	VVA	6C	575449.419	4574466.820	1333.629
VVA	3D	572669.041	4581143.682	2123.460	VVA	6D	575527.087	4574425.548	1326.192
VVA	3E	572551.396	4581160.249	2141.963	VVA	6E	575656.237	4574361.085	1319.246

The spatial distribution of the ground control points is depicted on Figure 10.

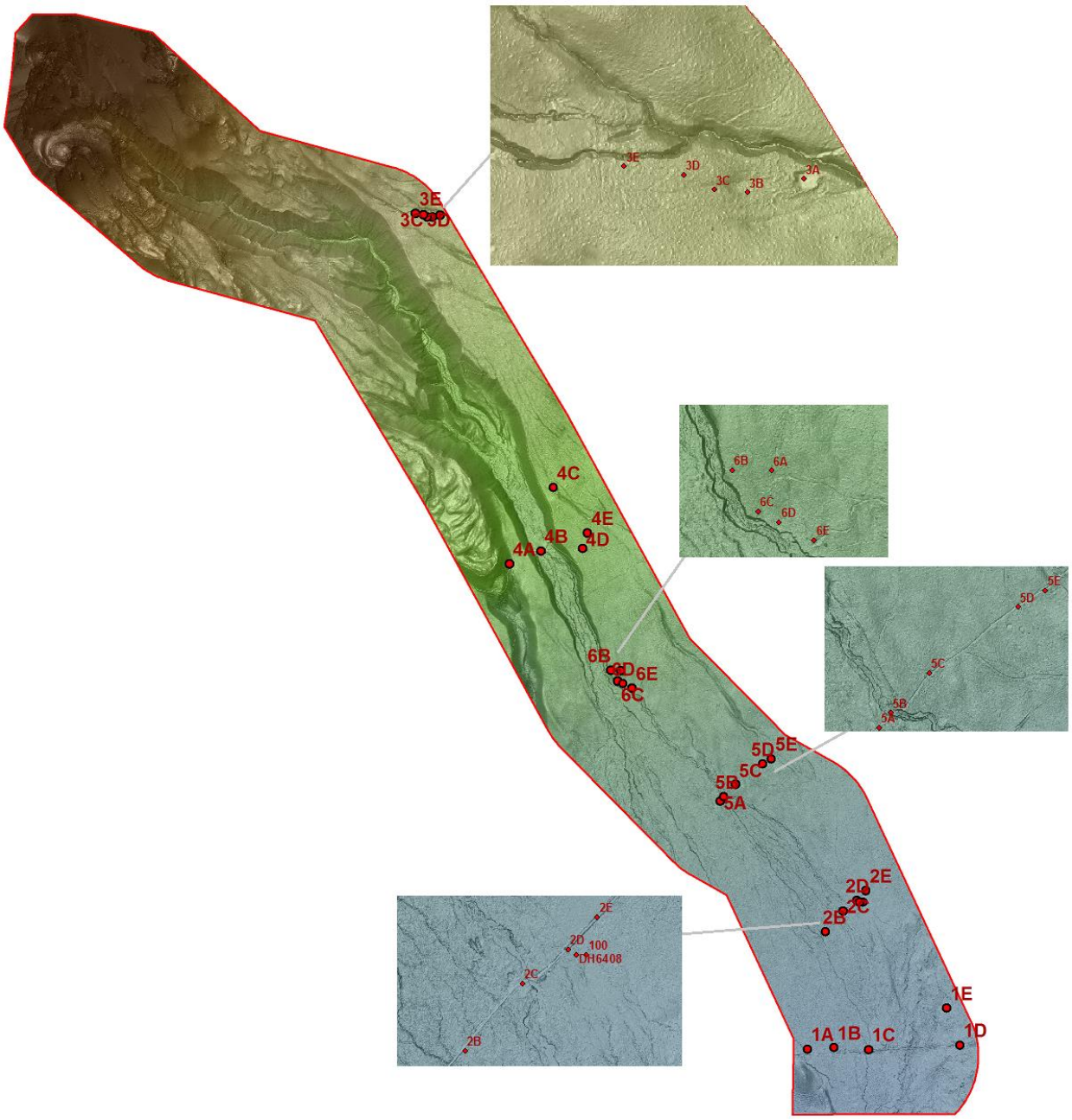


Figure 10: Spatial distribution of the GCP over the project area.

The absolute accuracy of the LiDAR dataset was assessed by comparison with the GCPs. Figure 11 represents the distribution of the vertical residuals.

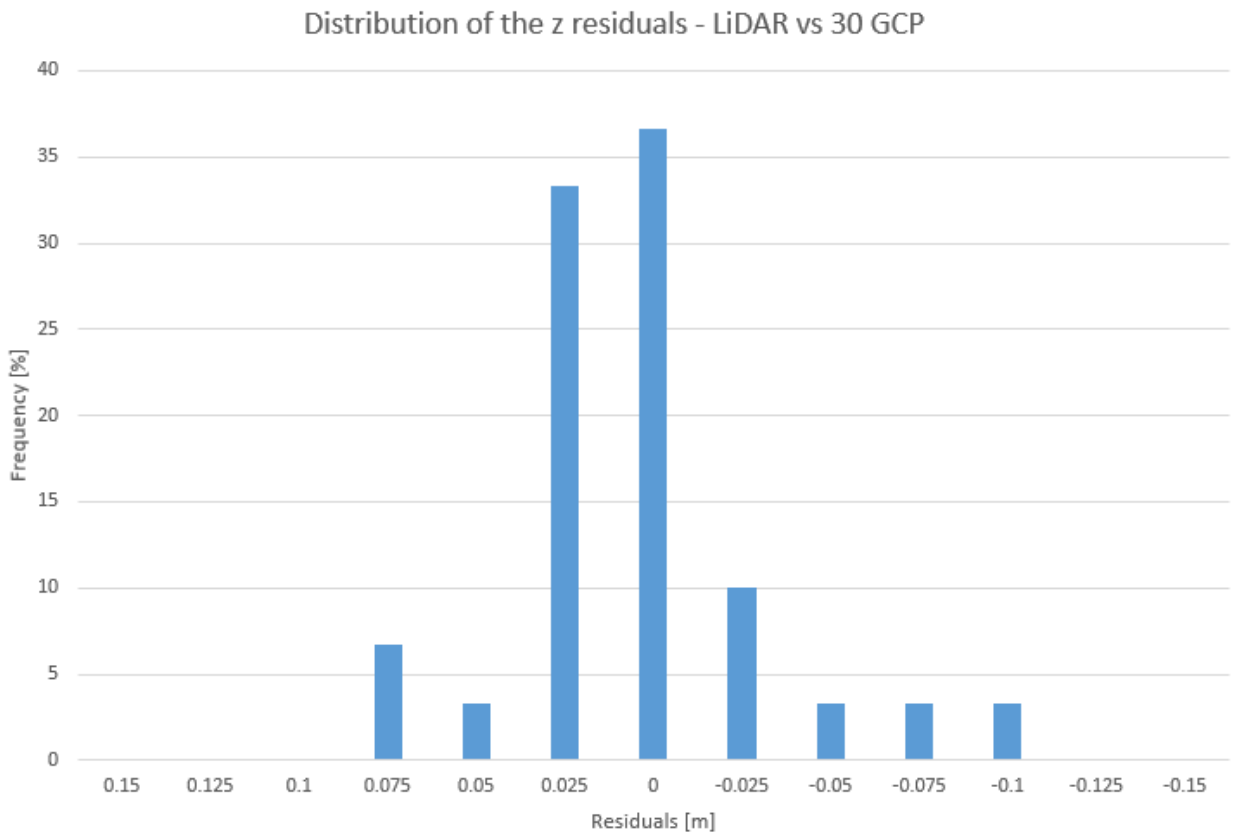


Figure 11: Distribution of the residuals computed with 30 GCP.

The minimal departure from the GCP is -10.0 cm and the maximum departure from the GCP is +6.3 cm. The median over the 30 measurements is -0.4cm and the RMSEz for this LiDAR dataset is 3.5 cm. Therefore, the vertical accuracy at 95% is 6.9 cm which meets the project expectations. The entire results of the statistical study are presented in the table below.

Inter-swath departures statistics	
Minimum departure	-10.0 cm
Maximum departure	6.3 cm
Average departure	-0.6 cm
Median departure	-0.4 cm
Standard deviation	3.5 cm
Root Mean Square Error, vertical	3.5 cm
Vertical Accuracy @ 95%	6.9 cm

Analysis by soil cover category

In order to better sense the quality of the data and to conform to the USGS specifications, the GCP were classified into two soil cover categories. The comparison between the LiDAR dataset and the control points was therefore conducted again, in order to quantify the Nonvegetated Vertical Accuracy (NVA) and the Vegetated Vertical Accuracy (VVA) The Figure 12 presents an example of each of the above soil cover classes.

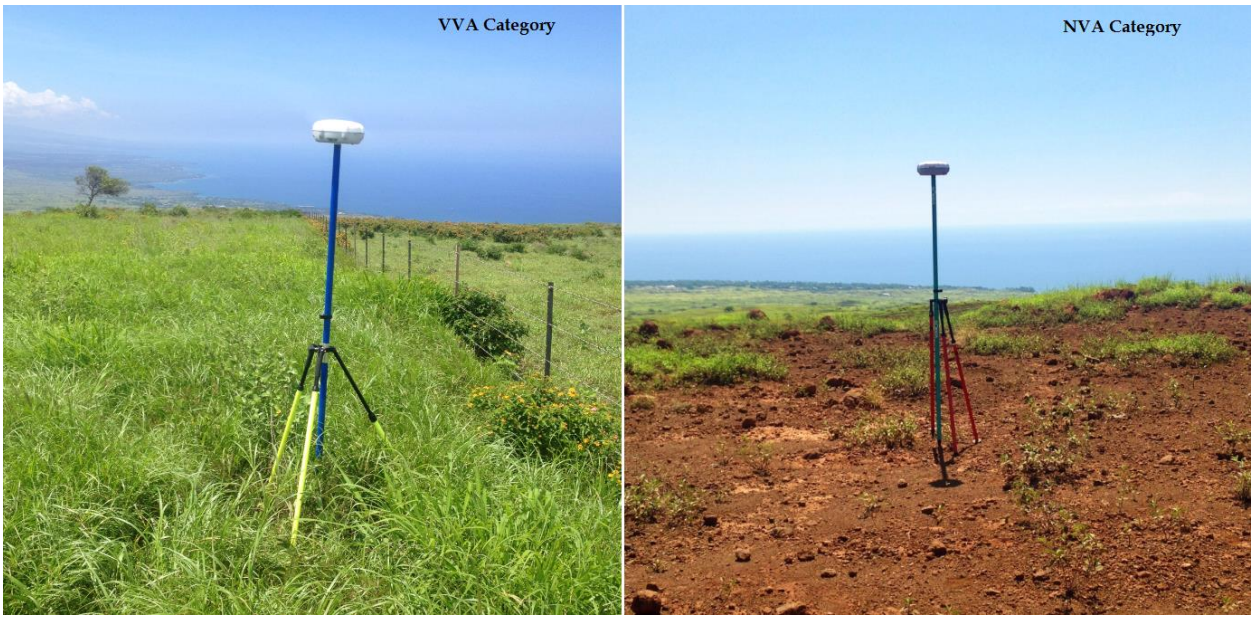


Figure 12: Comparison between VVA and NVA Ground Control Points.

The tables below summarize the results of this accuracy check with respect to these two categories. The NVA results are computed on 17 GCP and the VVA are based on a set of 13 GCP. Both categories meet the project expectations for the vertical accuracy.

Absolute vertical accuracy analysis by soil cover category

Values in meter

NVA		
	Min. value	-0.075
	Average	-0.008
	Median	-0.002
	Max. value	0.025
	Std Dev	0.028
	RMSEz	0.028
	95 % acc z	0.055

VVA		
	Min. value	-0.101
	Average	-0.002
	Median	-0.009
	Max. value	0.063
	Std Dev	0.044
	RMSEz	0.043
	95 % acc z	0.083

Completeness and density

The LiDAR flight has been planned in order to achieve a 50 % overlap over the whole project area. As a result, there are no voids between swaths as depicted on Figure 13.

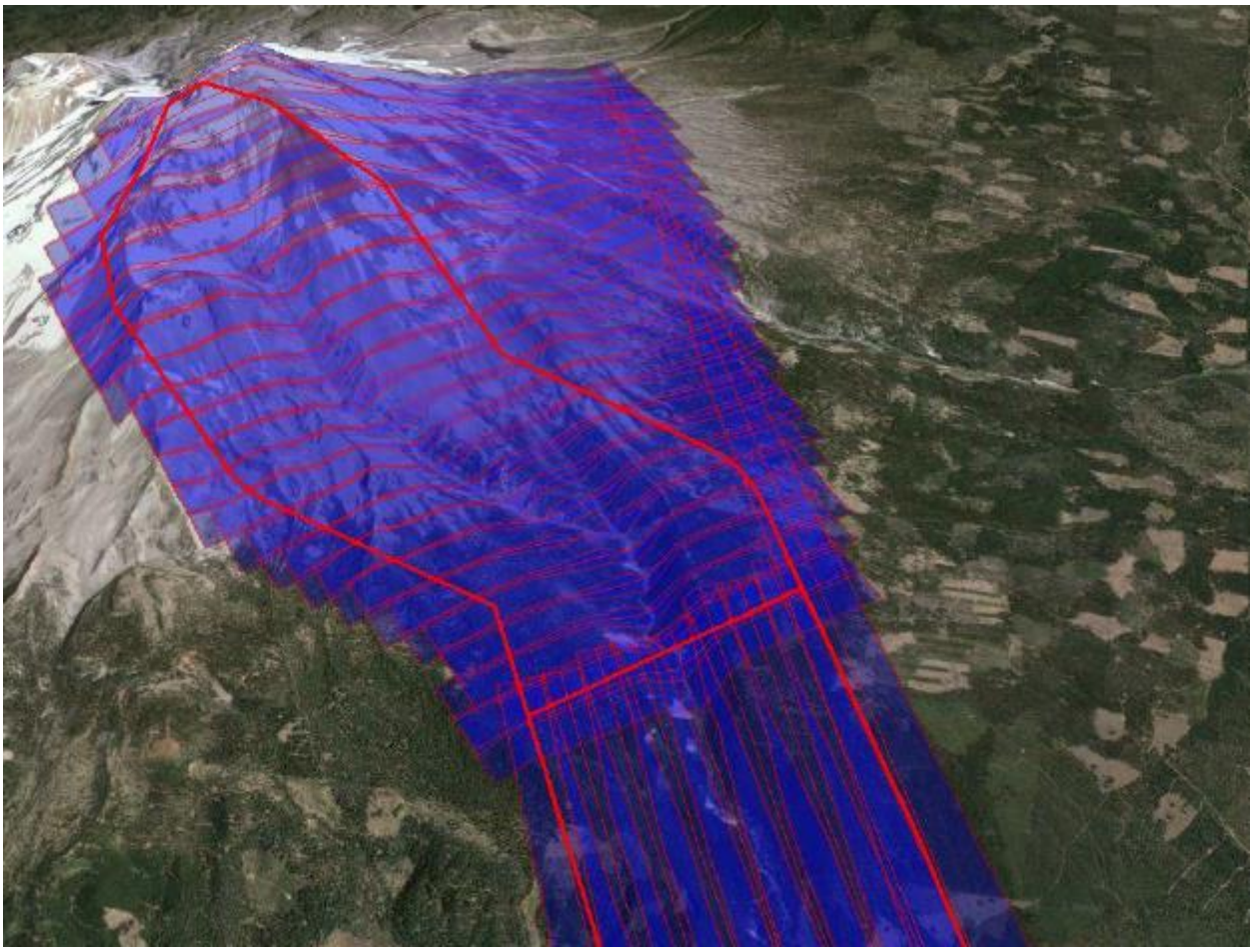


Figure 13: Swaths overlap and coverage over the project boundary.

In Figure 14, the point density computed using the first returns only for each 1/100th quad tile shows that the whole project area is covered with at least 85% of the design pulse density (~6 ppsm). The tiles located on the edge of the project are not complete and therefore, their density values are skewed.

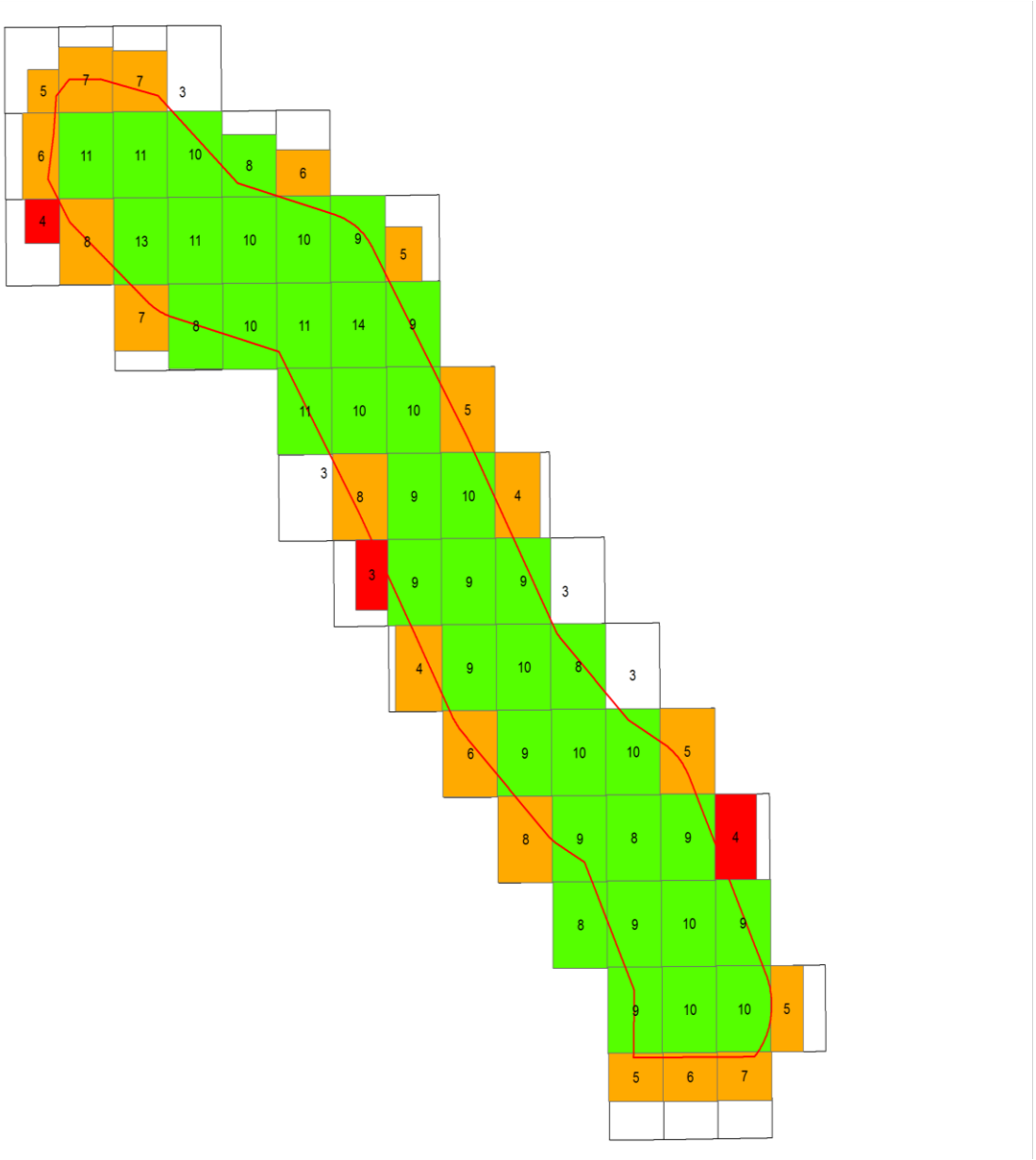


Figure 14: First return point density computed for each LiDAR tile (Units: PPSM).

In order to get a better view of the point density, the same computation was done with a 100m by 100m grid. The results are presented in the Figure 15. Cells that are green exhibit a first return point density greater than 8ppsm. The yellow cells are densities between 4 and 8 ppsm as the red one are cells with less than 4 ppsm (typically cells over water bodies or areas without overlap).

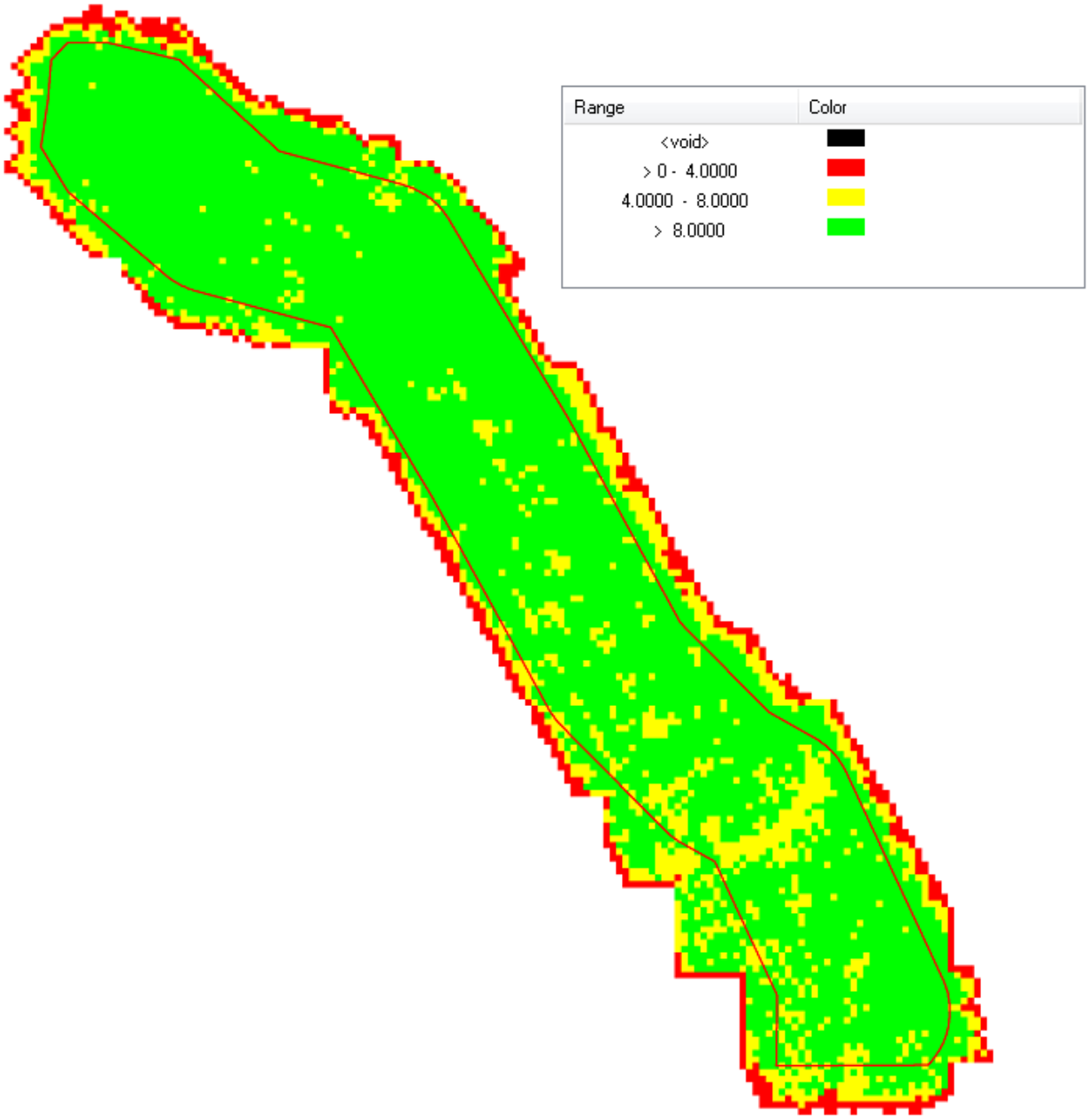


Figure 15: First return point density computed for a 100m x 100m grid (Units: PPSM).

Surface quality

For this project area, three types of raster surfaces are delivered. All of them are exempt of voids or tile-boundary artifacts. One overview and a zoom of each raster deliverable are presented below.

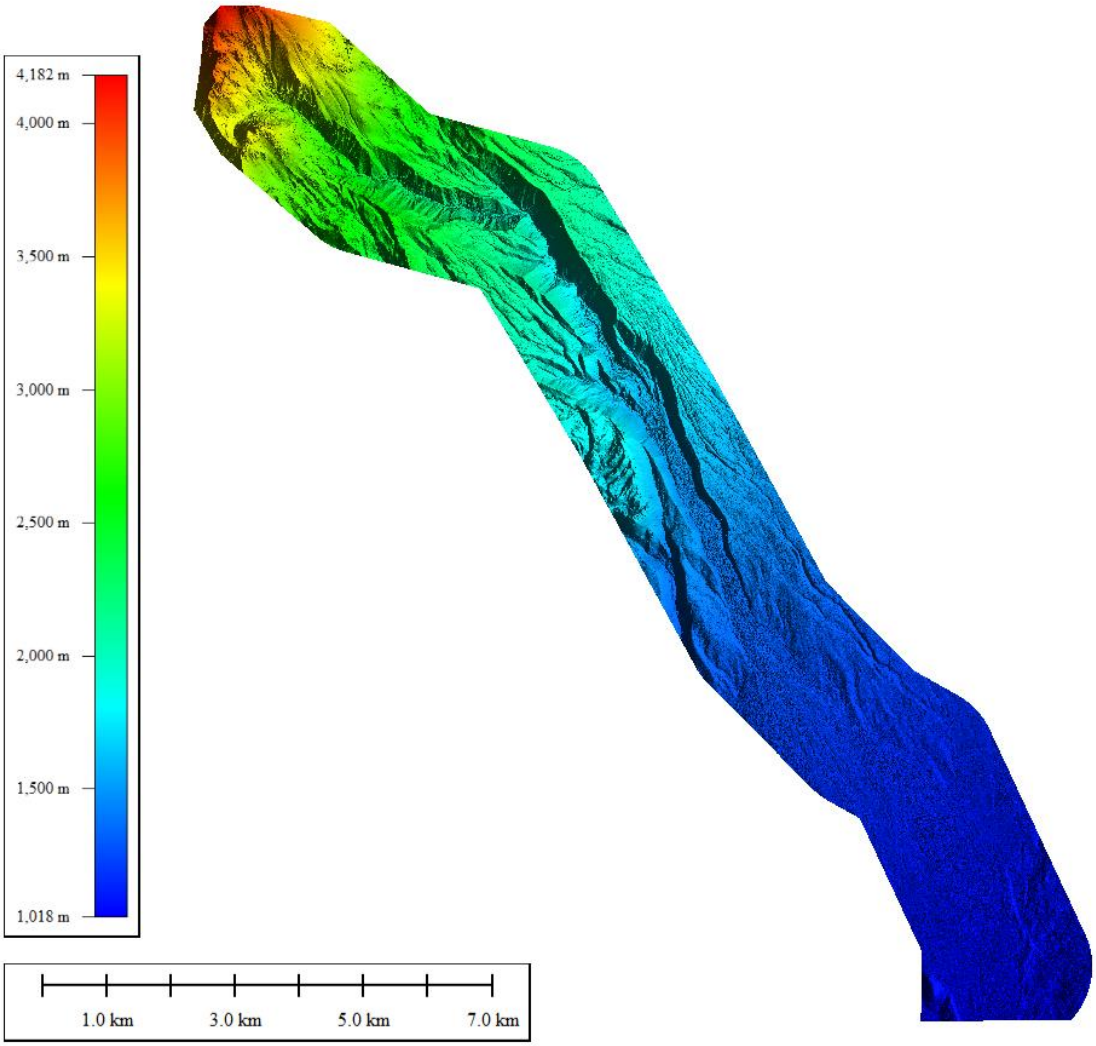


Figure 16: Overview of the Digital Elevation Model.

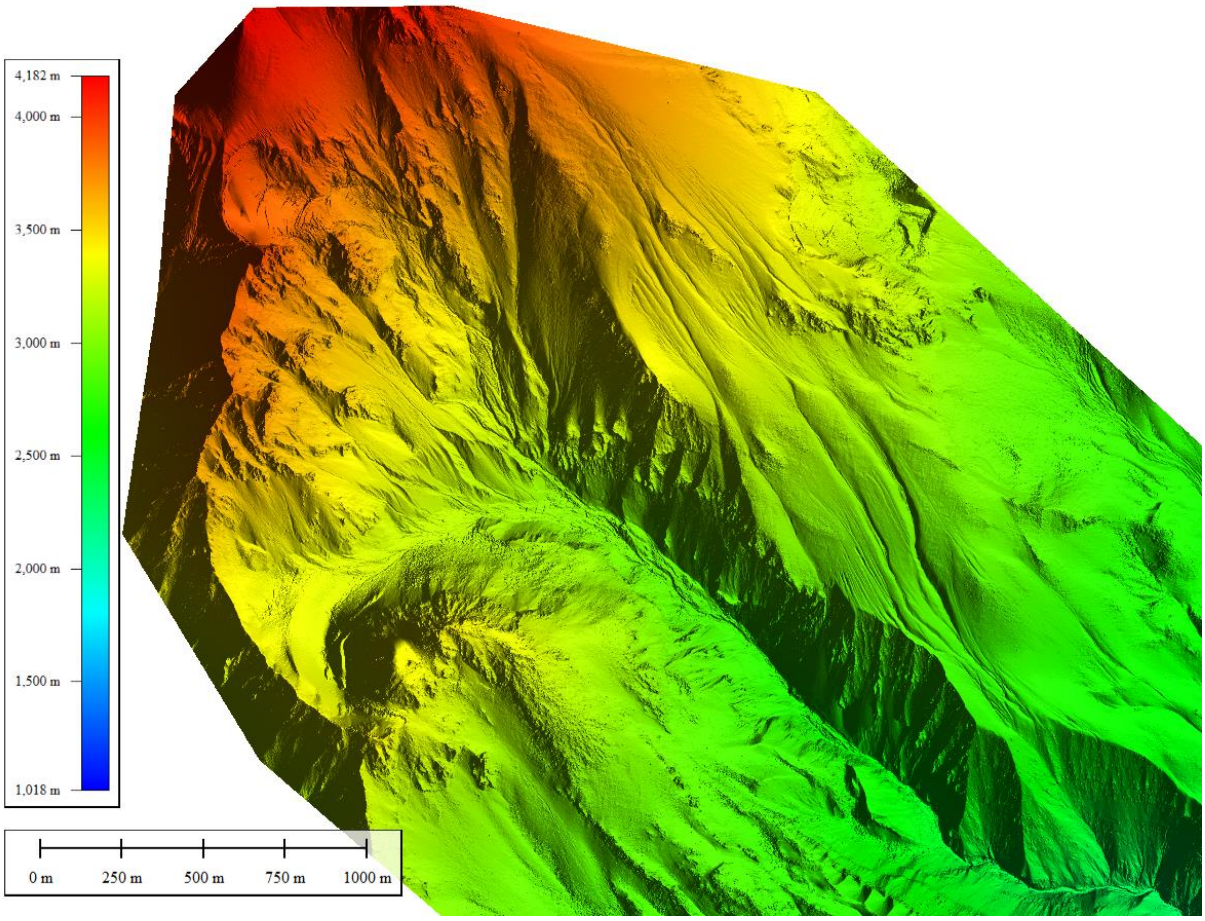


Figure 17: Detailed view of a DEM grid.

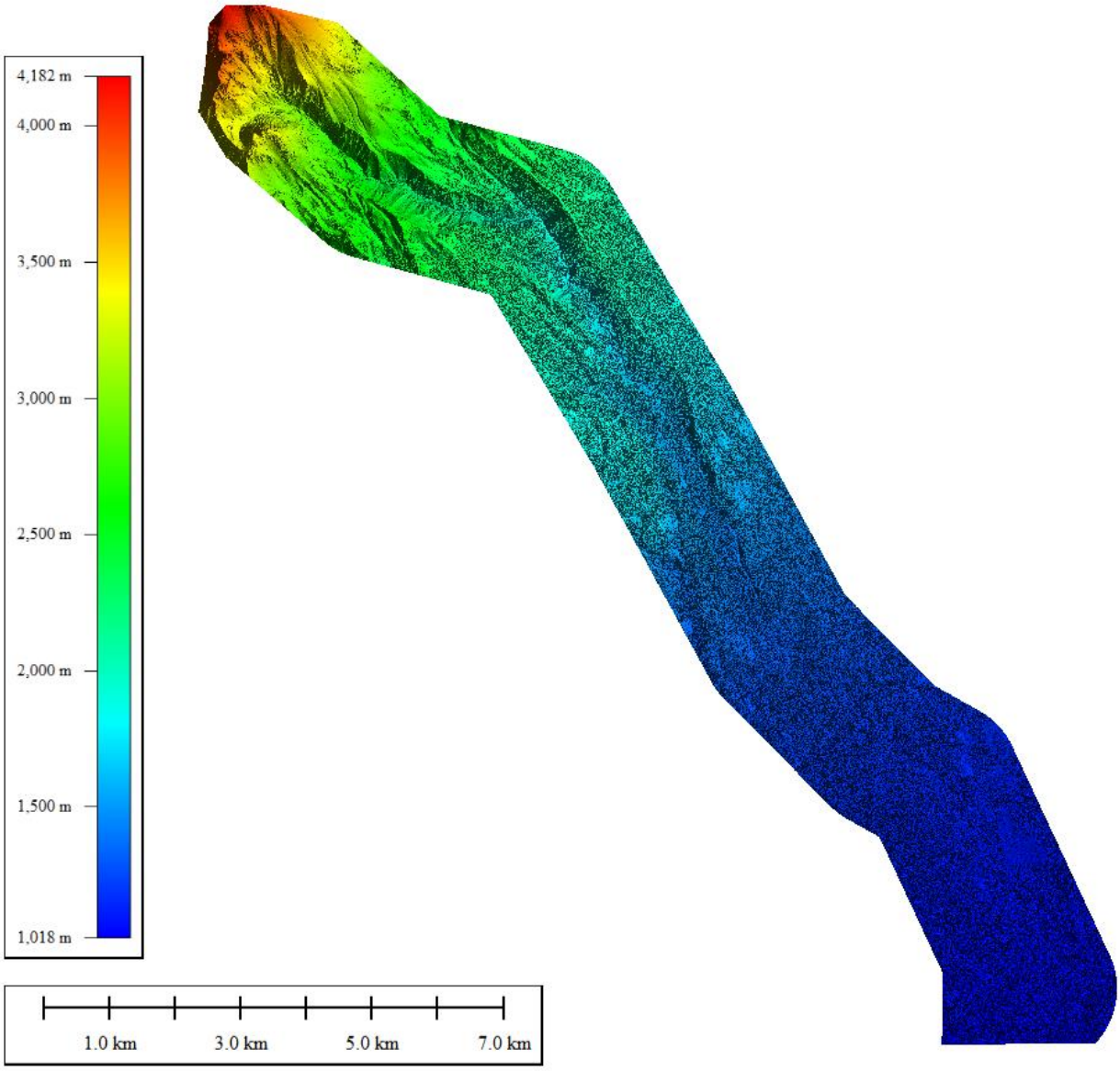


Figure 18: Overview of the Digital Surface Model.

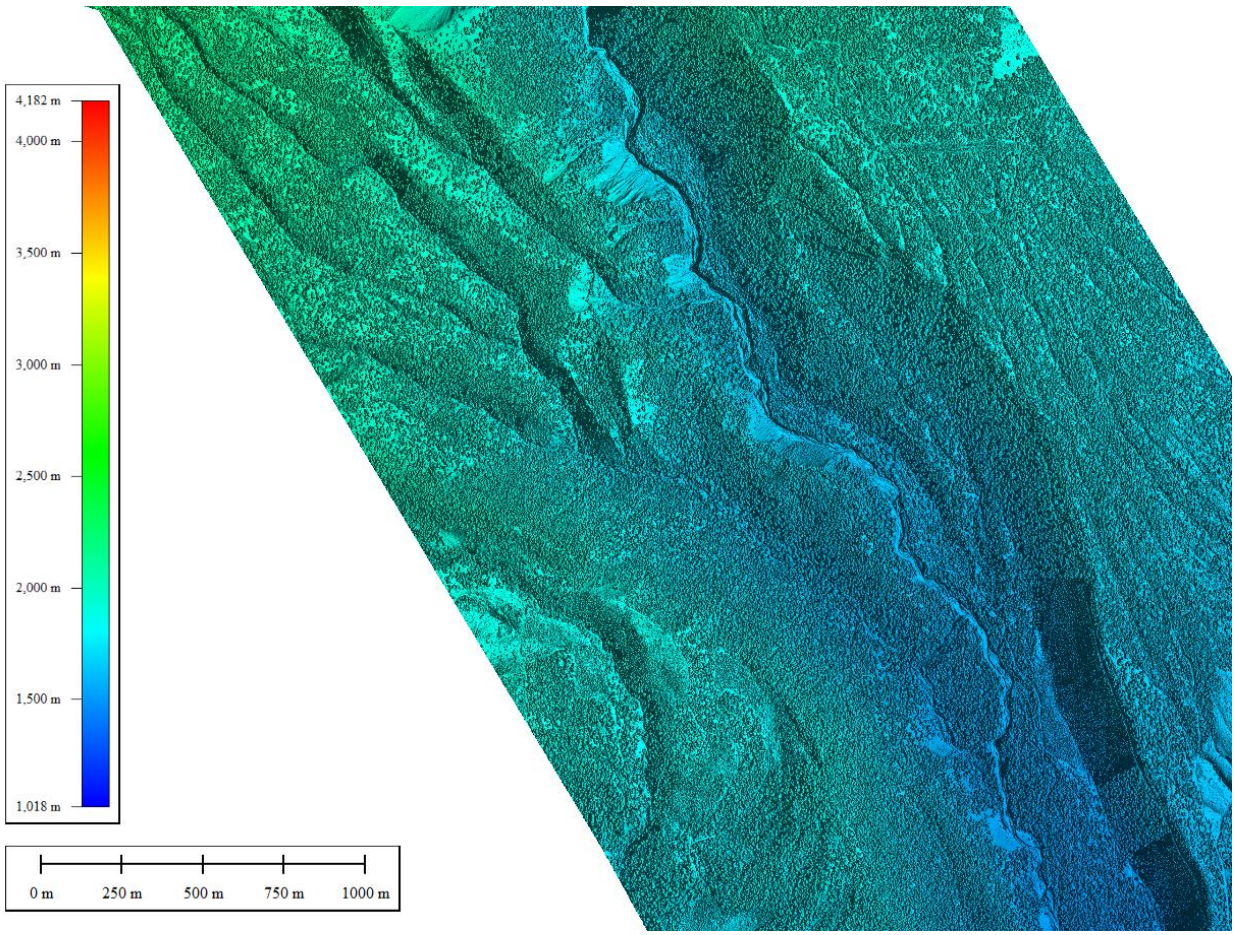


Figure 19: Detailed view of the DSM grid.

Figure 20: Overview of the intensity image.

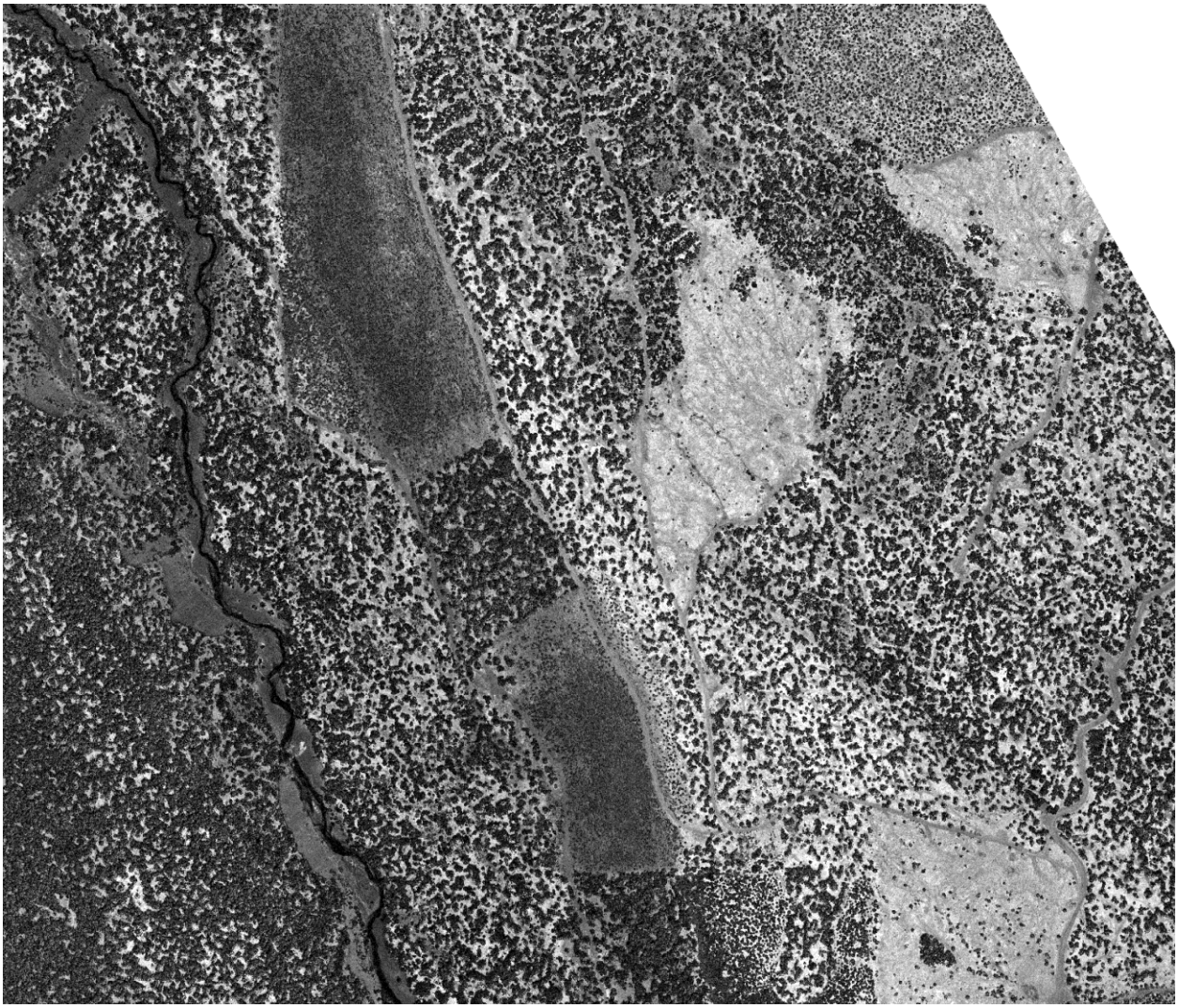


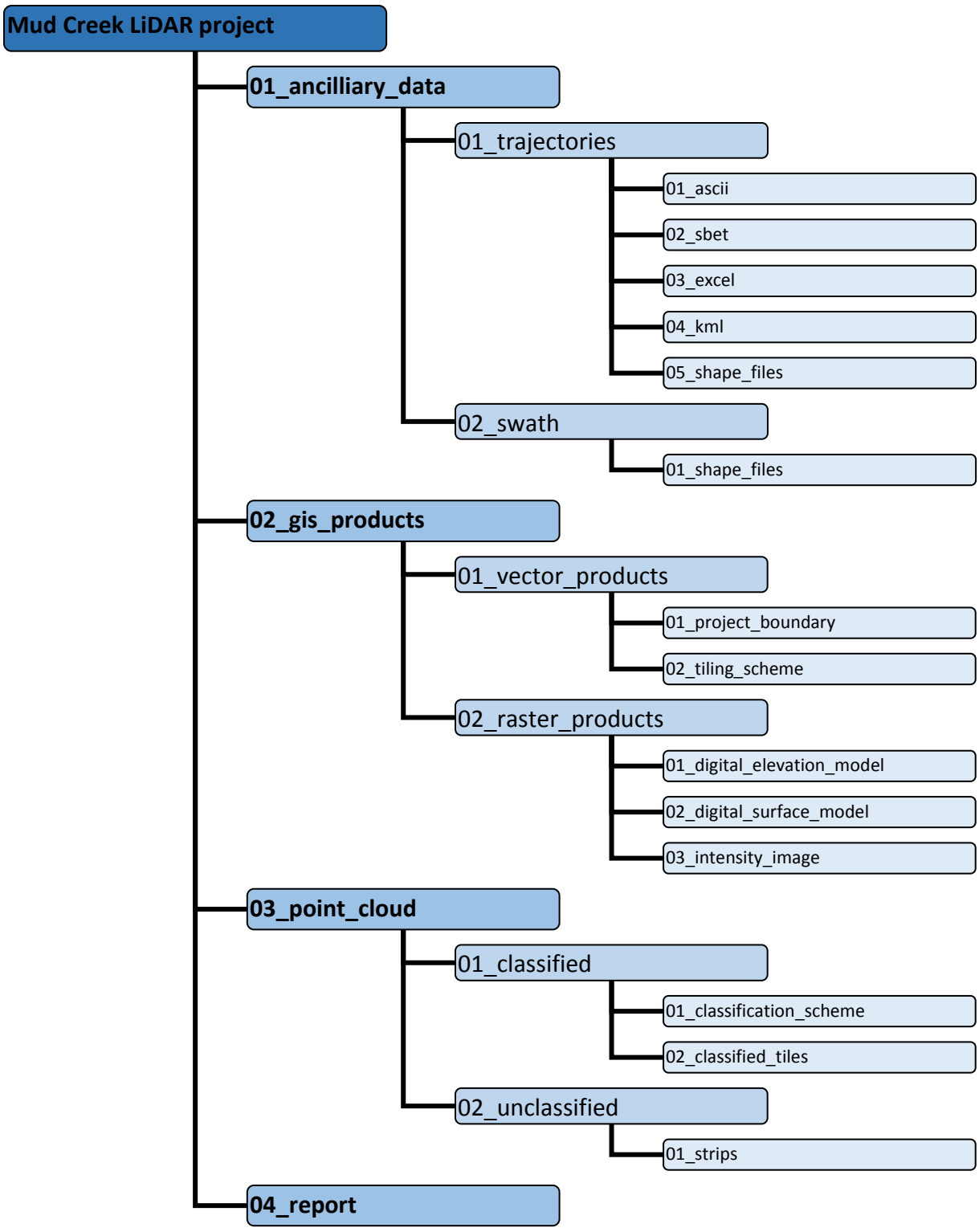
Figure 21: Detailed view of the intensity image.

Projection/Datum and Units

Projection		UTM Zone 10 North
Datum	**Vertical**	NAVD 88
	Horizontal	NAD83 (2011), epoch of 2011.29
Units		Meters

Deliverables

All of the deliverables are saved on a USB 3.0 hard drive. The architecture used to organize the delivery folder is presented on the next figure.


Mud Creek LiDAR project
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03_point_cloud
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