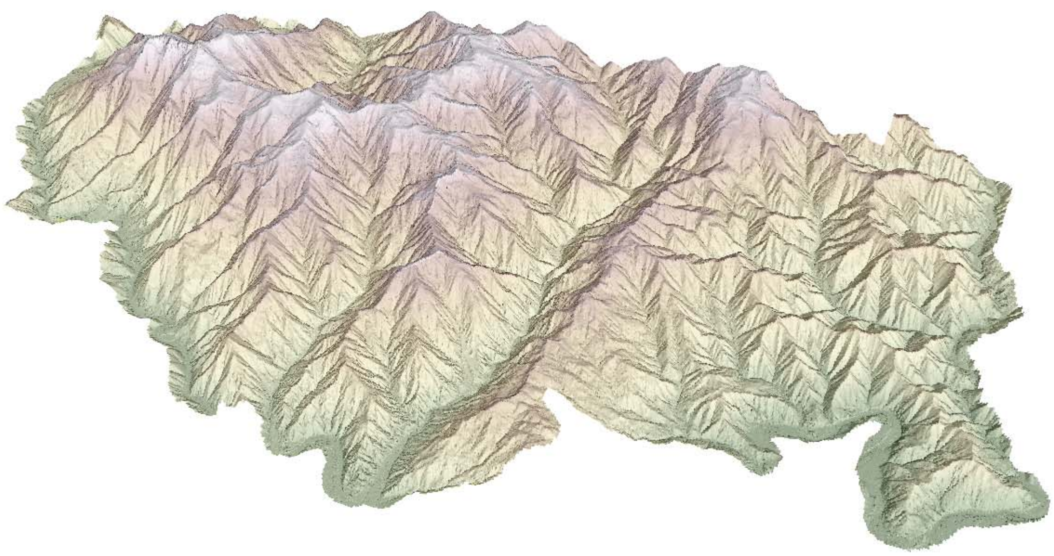
# USDA Forest Service
# Pacific Southwest Region
# Happy Camp Complex - North
## Klamath National Forest, CA

AG-91S8-D-15-0014 Project Report – June 2015

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TETRA TECH

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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 Klamath Forest region. The critical challenge for this project was to acquire the data before the leaf-on conditions but without snow on the highest peaks. For this particular reason, the Happy Camp Complex project area was cut in two subdivisions, one of rather low altitude (in green below) and a second one (in red below) regrouping the highest peaks. This report presents the results of the first data acquisition which covers the northern part of the global area of interest.

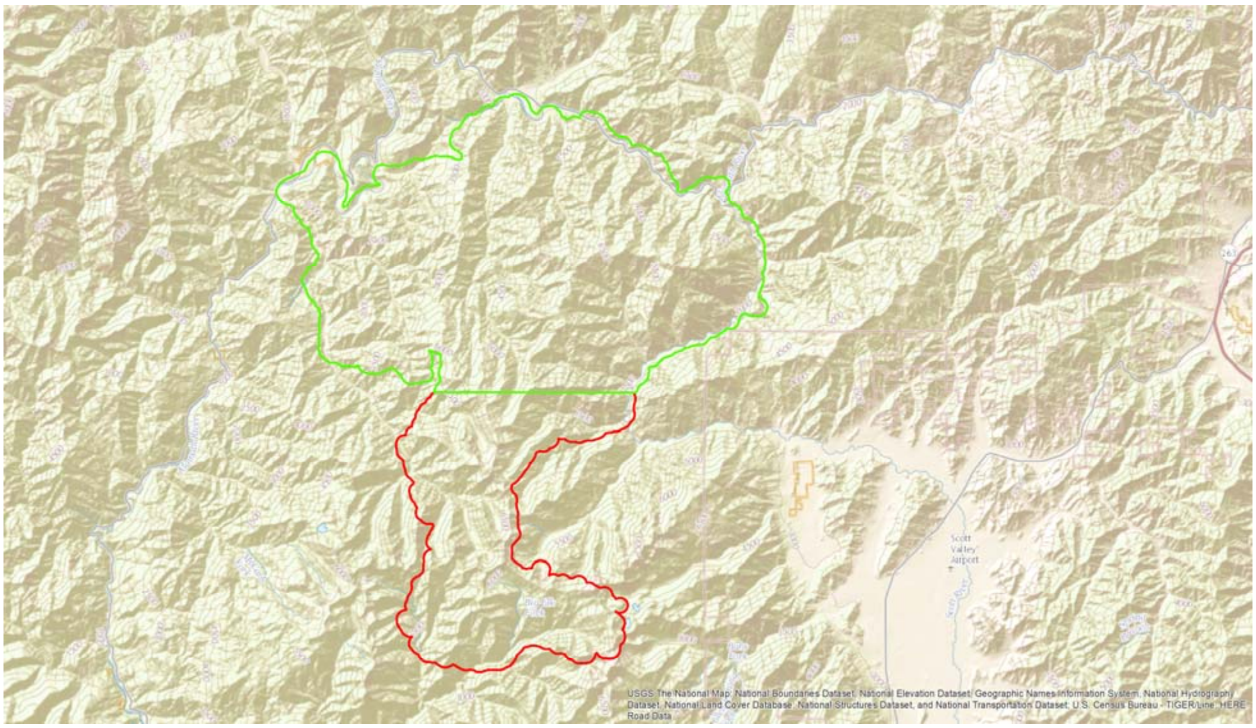



Figure 1:Happy Camp Complex subdivisions.

The acquisition over the northern area of interest took place between the 16 February 2015 and 08 March 2015. During the time of acquisition the ground was free of snow. The LiDAR data have been collected using an Optech Orion M300 system. The airborne trajectory has been monitored with kinematic AGPS combined with IMU observations collected at 200 Hz. Eleven individual flight missions were accomplished in order to cover the entire project area. The following picture shows the aircraft trajectories on top of the project area.

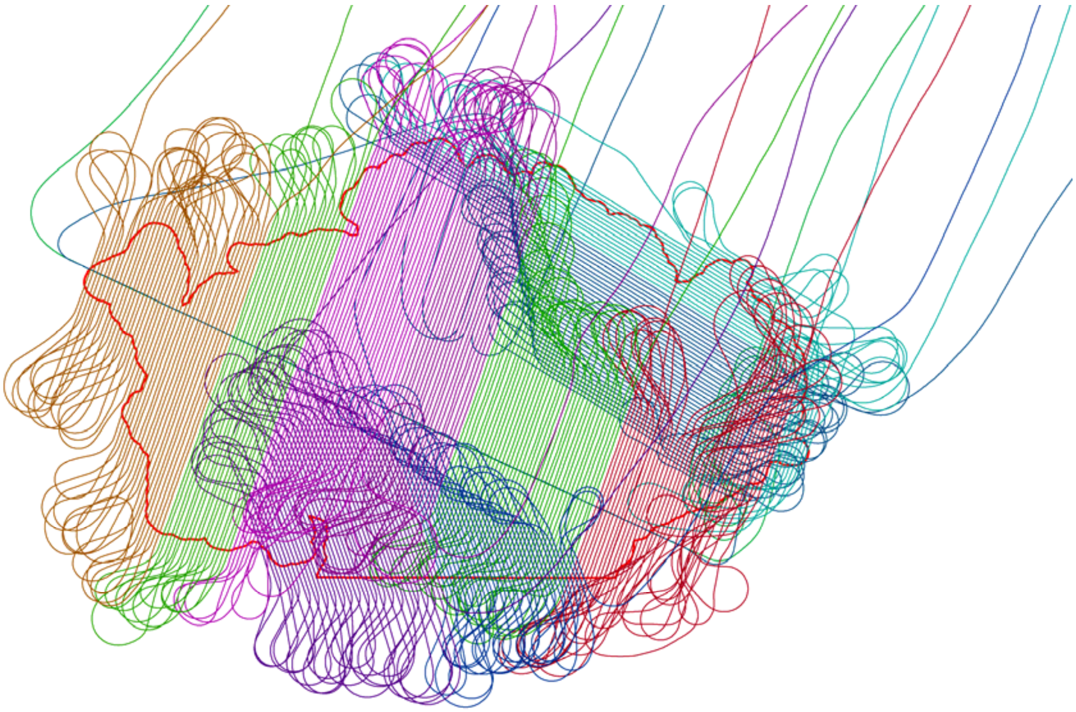


Figure 2:Aircraft trajectories on top of the project boundary.

# Tiling Scheme

The LiDAR data processing as well as the production deliverables are based on the same tiling scheme. The LiDAR point cloud files are 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 the next two images.

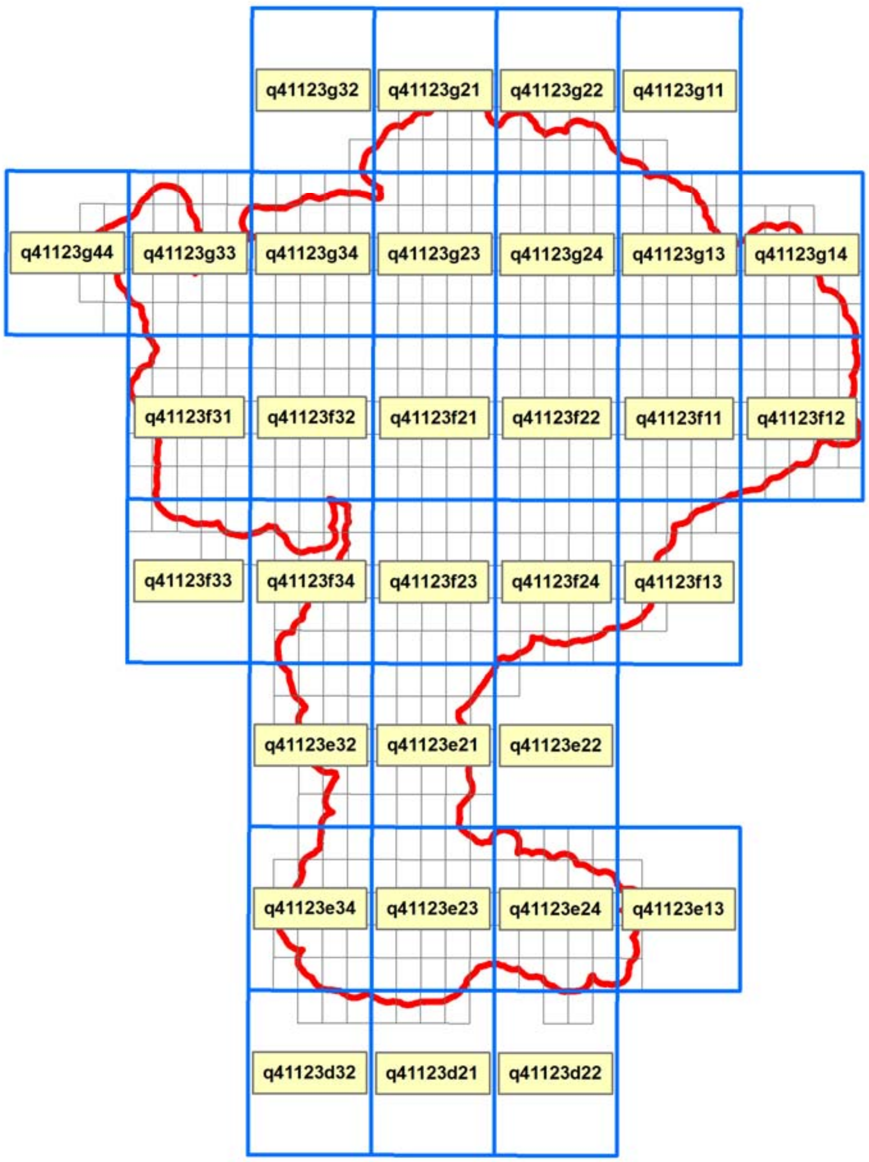



Figure 3:Tiling scheme for the complete Happy Camp area, quarter USGS quadrangles.

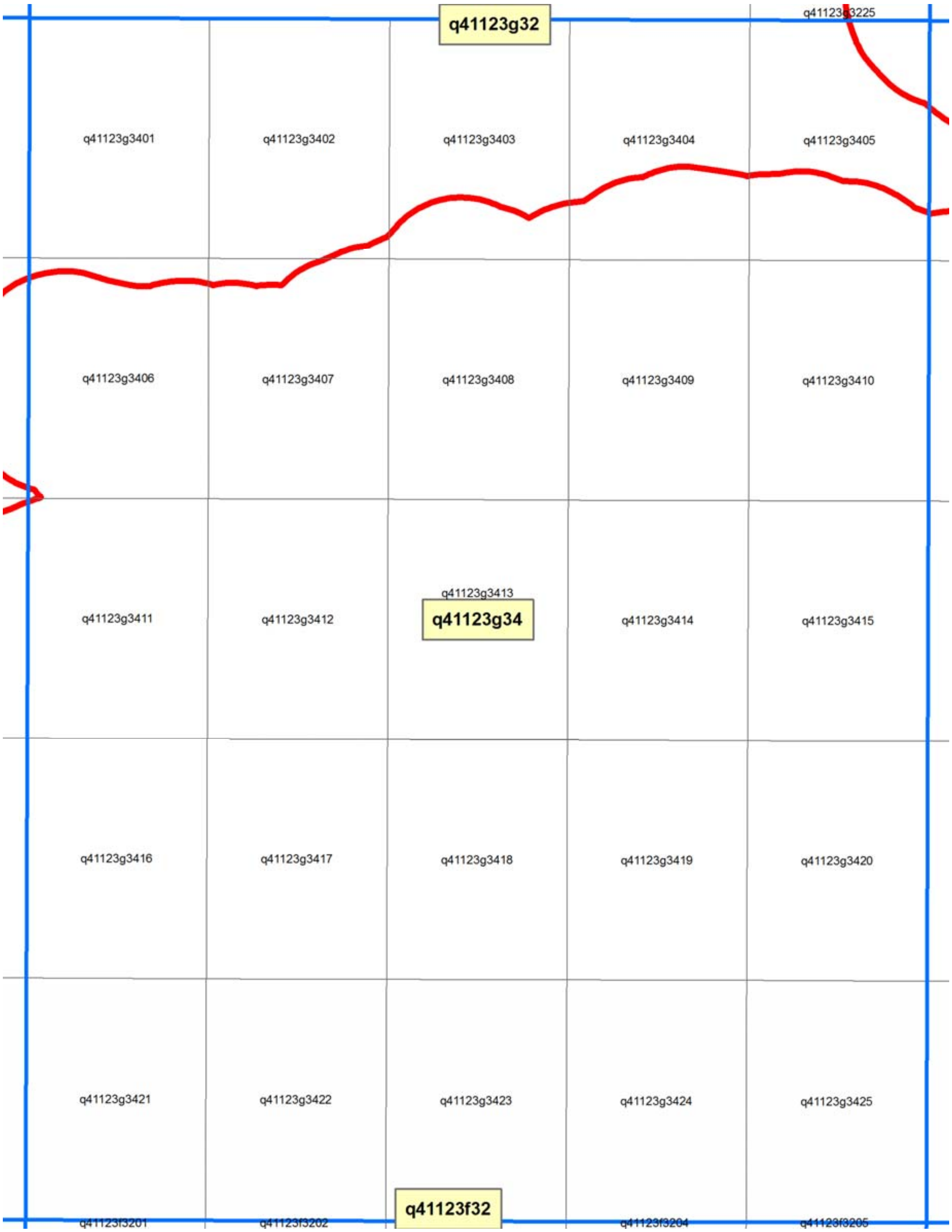



Figure 4:Zoom on one particular quarter quad, 1/100th quad organization chart.

## Data Coverage

For the northern project area, only full tiles are being delivered. The whole project area is covered by LiDAR data as it is delivered in 1/100th quad tiles. Since each raster grid is a combination of 25 individual LiDAR tiles, some of the quarter quad tiles require LiDAR data from the south area (not acquired so far) in order to be complete. For this reason, those incomplete grids are not yet included in the deliverables.

The two figures below show the data coverage for the northern part of the Happy Camp Complex project.

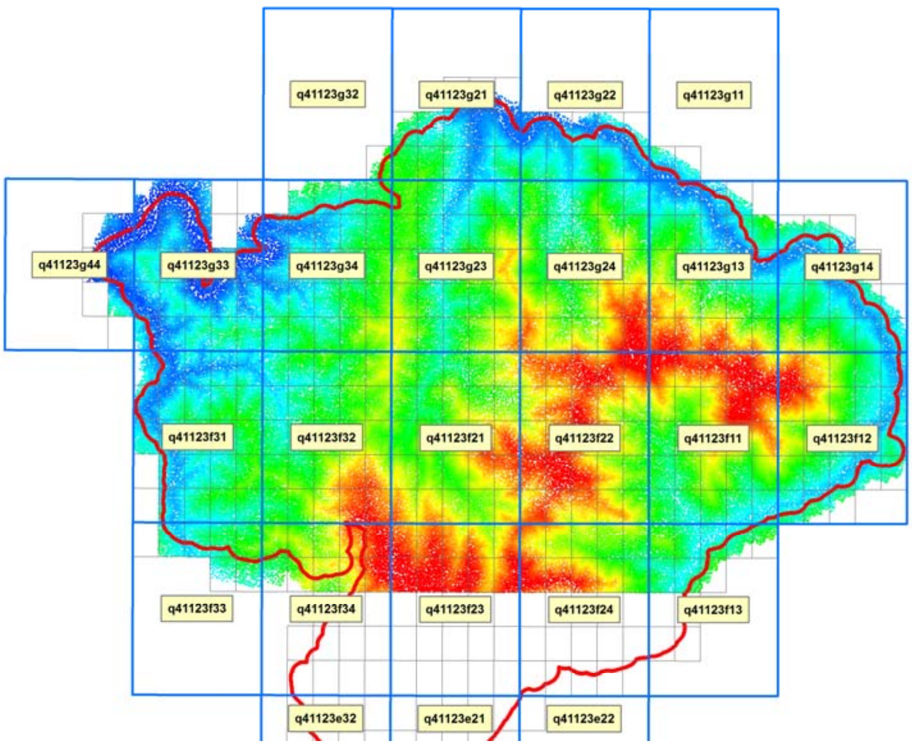



Figure 5:LiDAR data coverage.

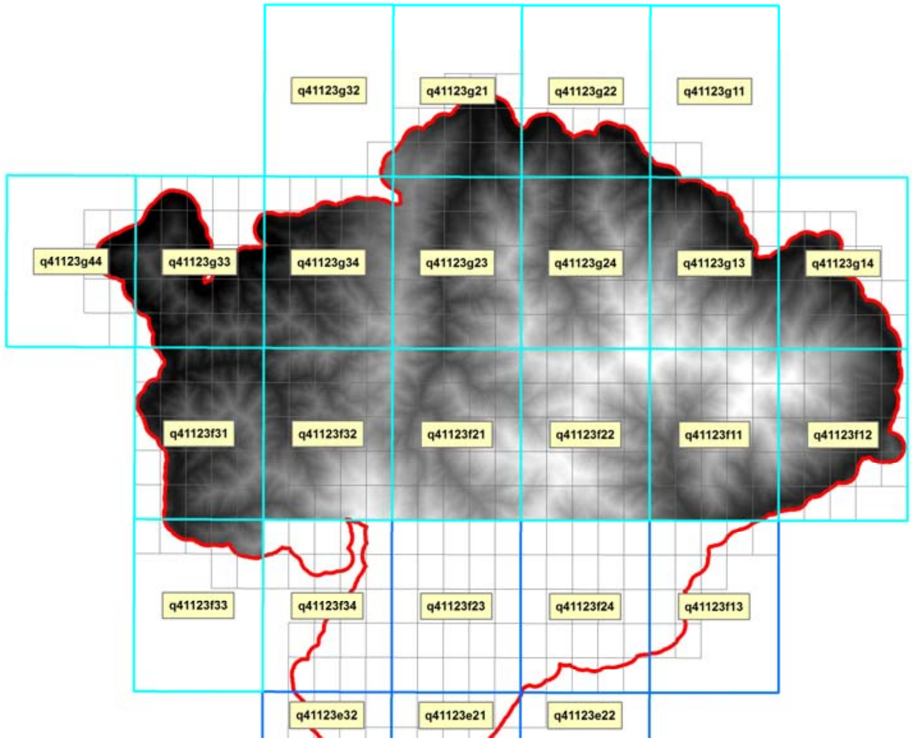



Figure 6:Raster data coverage. Only complete tiles are delivered (cyan).

# Quality Assessment

## *Coverage and swath-to-swath reproducibility*

As the project area is mostly located on mountainous and not developed 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 even truer since this project has requested no less than 11 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 below.

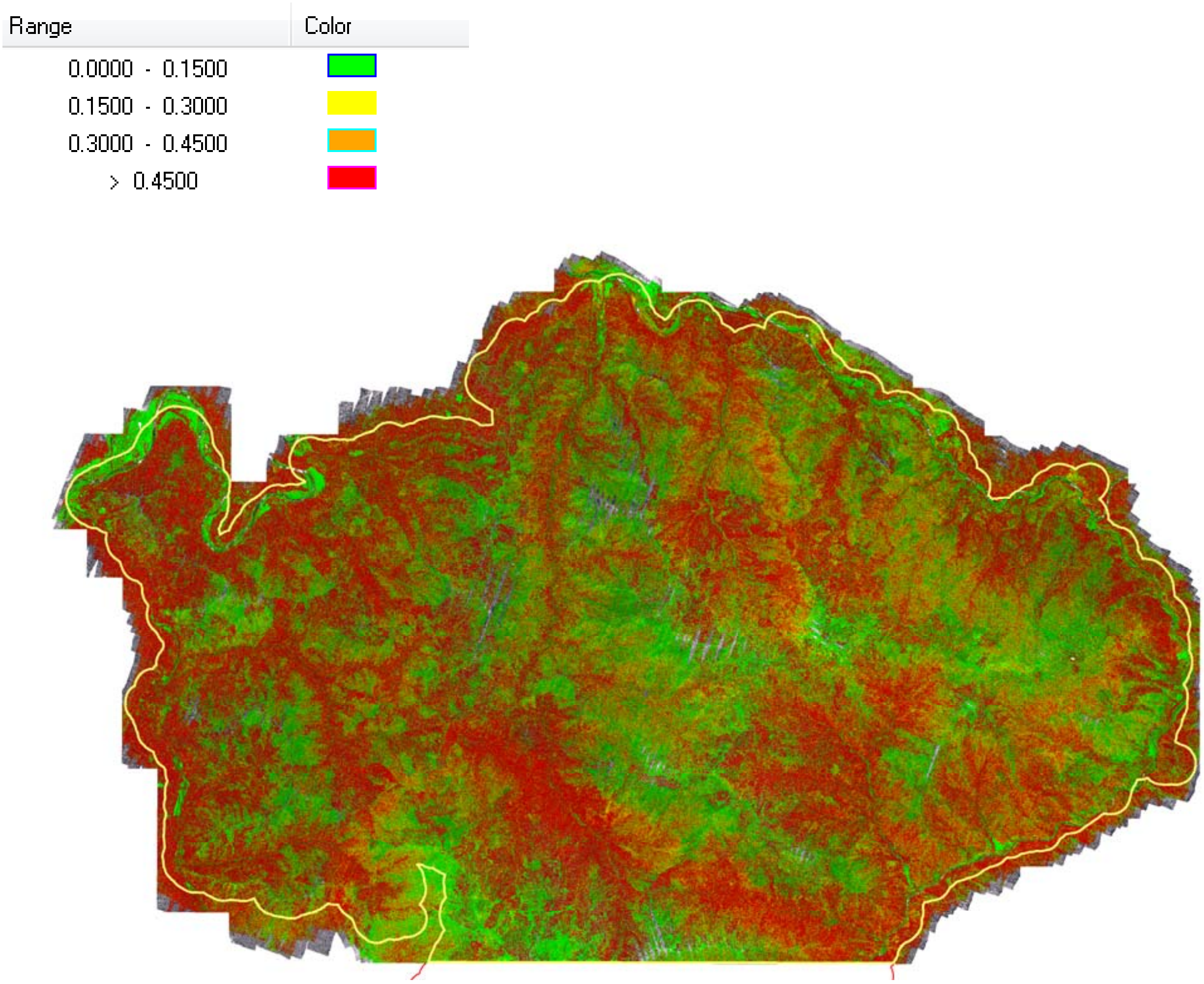



Figure 7:Last returns swath-to-swath comparison (values in meters).

In order to have a better understanding of the inter-swath quality of the dataset, two additional images are presented below. 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.

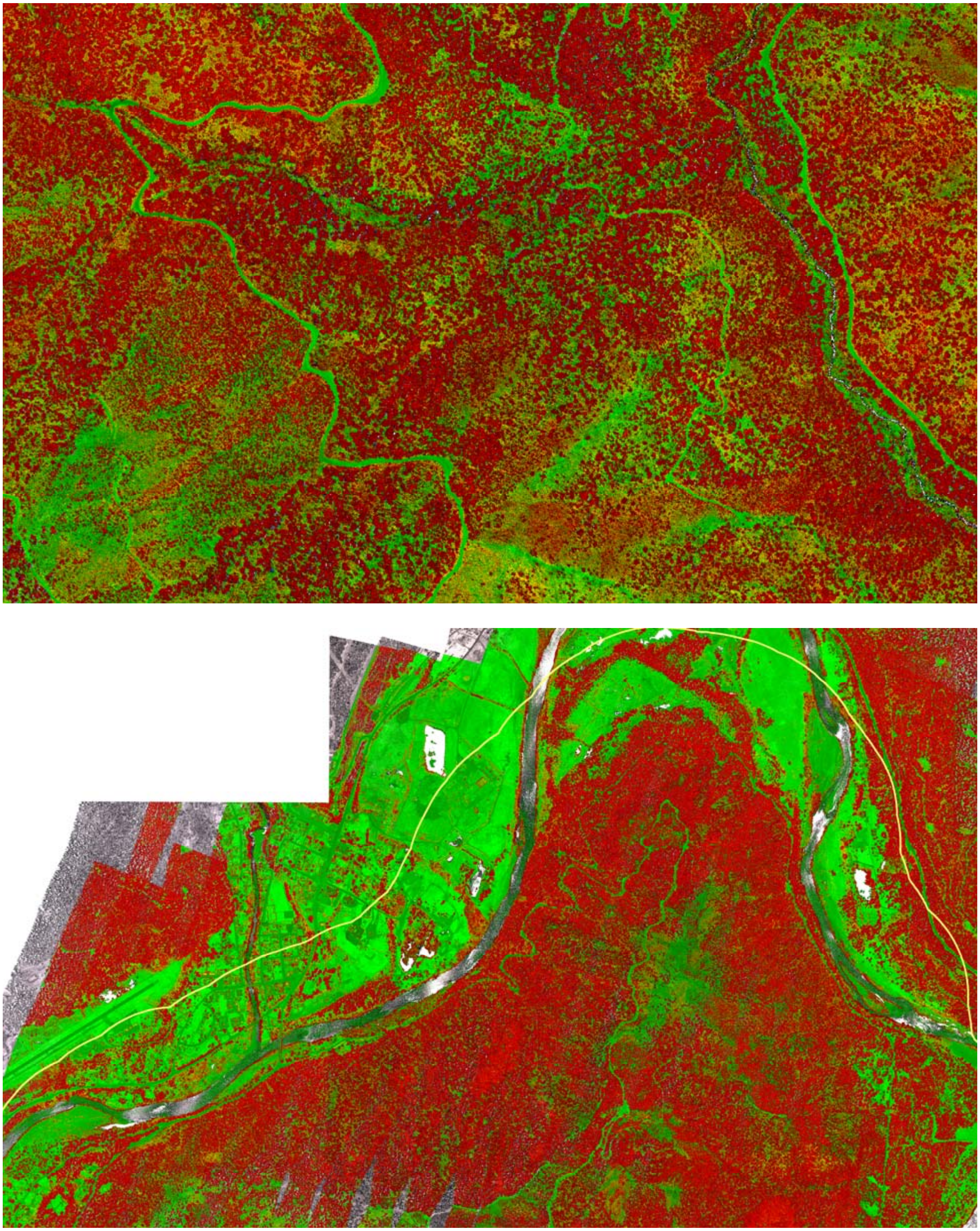


Figure 8:Two zooms over the swath-to-swath image.

## *Absolute accuracy*

In order to assess the absolute accuracy of the LiDAR data, a set of 39 Ground Control Points (GCP) have been surveyed. Those points are well distributed over the project area. All the survey measurements are tight to reference survey monuments, which are listed in the table below.

| NAME | Latitude | Longitude | Ellipsoidal Height [m] |
|---|---|---|---|
| **PLH 000 Base1** | 41 46 3.79518 | 123 8 55.38345 | 1481.519 |
| **PLH 000 KMFR_Temp** | 42 22 15.20326 | 122 52 44.35822 | 375.015 |
| **PLH 000 P154** | 41 48 25.48410 | 123 21 36.12407 | 320.320 |
| **PLH 000 P191** | 42 16 31.26720 | 123 37 56.08933 | 371.812 |
| **PLH 000 P370** | 42 11 27.53922 | 122 39 22.88081 | 555.487 |

Based on these survey monuments, 39 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 as horizontal datum. The vertical datum is NAVD 88 as realized by the published ellipsoidal heights of the Plate Boundary Observatory and CORS station, as well as the addition of the geoid model. Units are in meters.

| ID | X | Y | Z | ID | X | Y | Z |
|---|---|---|---|---|---|---|---|
| KK01 | 487579.0855 | 4624001.587 | 1501.6293 | KK21 | 471167.7975 | 4625207.158 | 374.5766 |
| KK02 | 488100.5152 | 4621875.092 | 1702.1825 | KK22 | 474557.0707 | 4626092.039 | 355.7258 |
| KK03 | 487018.2883 | 4627415.638 | 1062.1695 | KK23 | 478796.668 | 4630246.712 | 1053.0081 |
| KK04 | 499640.5184 | 4621263.746 | 514.2056 | KK24 | 482294.1386 | 4629402.967 | 496.5887 |
| KK05 | 490588.3632 | 4612565.743 | 660.3629 | KK25 | 491414.4998 | 4628499.377 | 448.3789 |
| KK06 | 492974.2432 | 4615131.02 | 620.2344 | KK26 | 492382.713 | 4614822.344 | 643.4849 |
| KK07 | 498113.7995 | 4618209.085 | 607.977 | KK27 | 490505.1573 | 4617483.477 | 872.8867 |
| KK08 | 488184.3285 | 4625556.985 | 1505.5613 | KK28 | 496699.6086 | 4616827.274 | 657.6163 |
| KK09 | 483455.9845 | 4632452.198 | 416.5143 | KK29 | 498753.4315 | 4619310.569 | 613.7668 |
| KK10 | 487095.483 | 4631112.378 | 430.406 | KK30 | 494095.2796 | 4625386.632 | 484.3225 |
| KK11 | 489741.9976 | 4629075.096 | 449.0711 | KK31 | 473431.8571 | 4622871.954 | 862.3901 |
| KK12 | 492155.9315 | 4627442.893 | 481.3156 | KK32 | 476713.5003 | 4622094.108 | 1123.0724 |
| KK13 | 495598.6876 | 4626233.843 | 463.566 | KK33 | 478774.85 | 4621168.162 | 1416.5243 |
| KK14 | 496967.1122 | 4625141.181 | 477.5377 | KK34 | 479607.171 | 4615971.198 | 1623.6605 |
| KK15 | 498427.1258 | 4623537.533 | 506.989 | KK35 | 477998.3321 | 4618334.432 | 1338.6319 |
| KK16 | 489397.6962 | 4624651.516 | 1521.9488 | KK36 | 475414.5068 | 4618818.629 | 808.5762 |
| KK17 | 469197.5076 | 4628006.678 | 346.9405 | KK37 | 472654.8291 | 4621452.759 | 483.4148 |
| KK18 | 470014.2471 | 4622811.966 | 430.1398 | KK38 | 477827.1744 | 4625988 | 888.8916 |
| KK19 | 470135.3494 | 4618511.505 | 532.6746 | KK39 | 478656.4503 | 4623042.815 | 1416.2673 |
| KK20 | 470515.8534 | 4621151.56 | 431.5217 | KK40 | 480059.0883 | 4628042.655 | 1166.9945 |

The spatial distribution of the ground control points is depicted on the figure below.

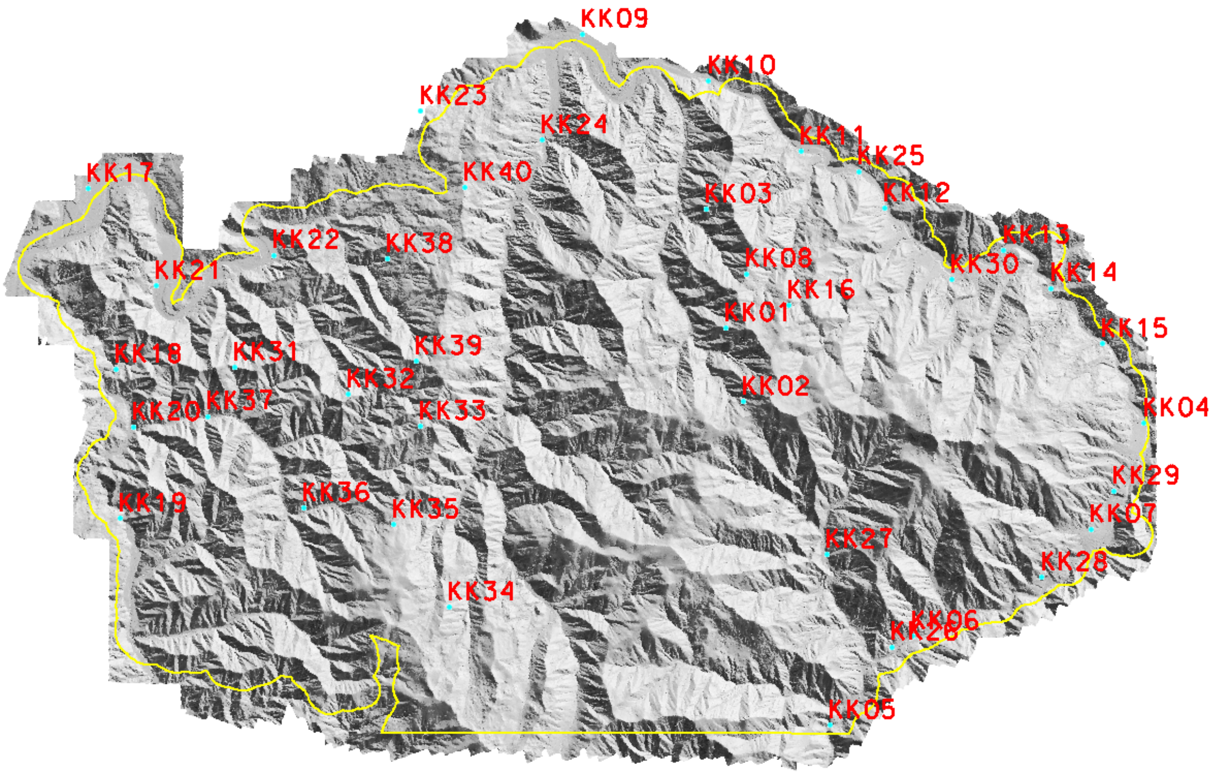



Figure 9:Spatial distribution of the GCP over the project area.

The absolute accuracy of the LiDAR dataset was assessed by comparison with the GCPs. The following figures represent the distribution of the vertical residuals. The minimal departure from the GCP is – 9 cm and the maximum departure from the GCP is +11cm. The median over the 39 measurements is -0.003cm and the RMSEz for this LiDAR dataset is 3.8 cm.

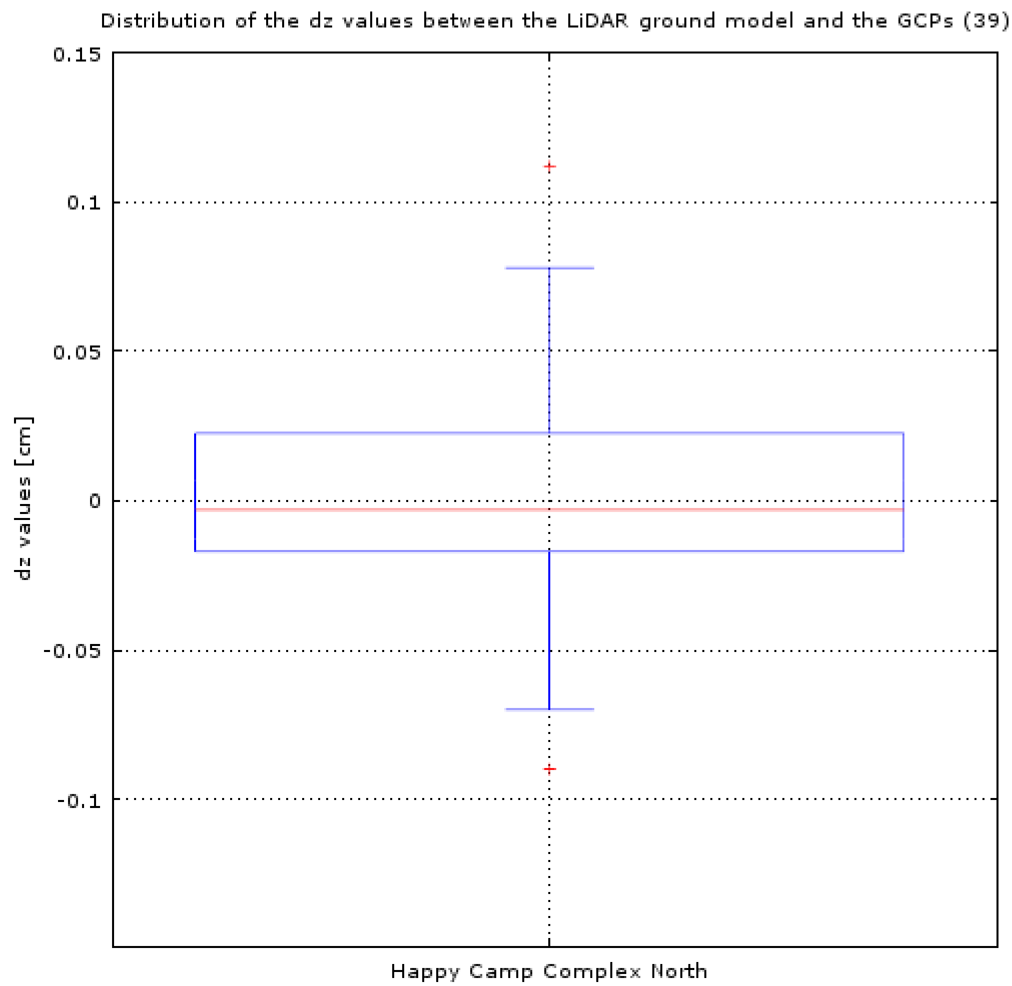



Figure 10:Box plot of the residuals computed with 39 GCP.

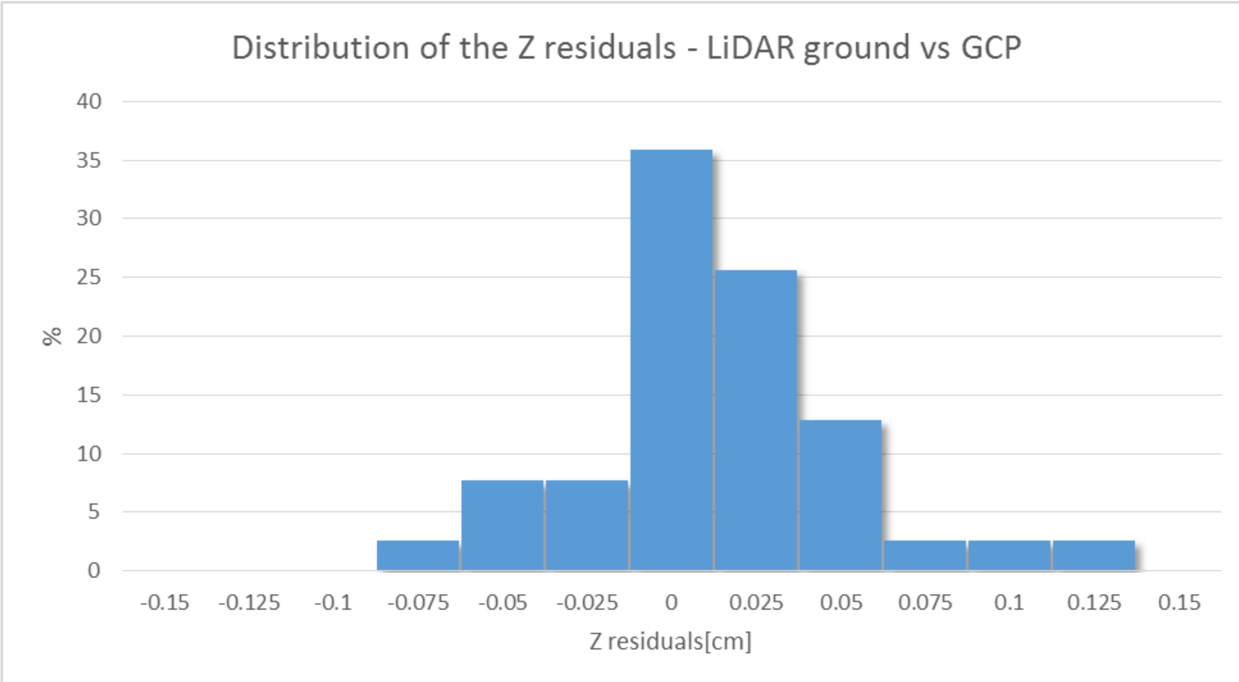



Figure 11:Distribution of the residuals computed with 39 GCP

## *Completeness*

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 the figure below.

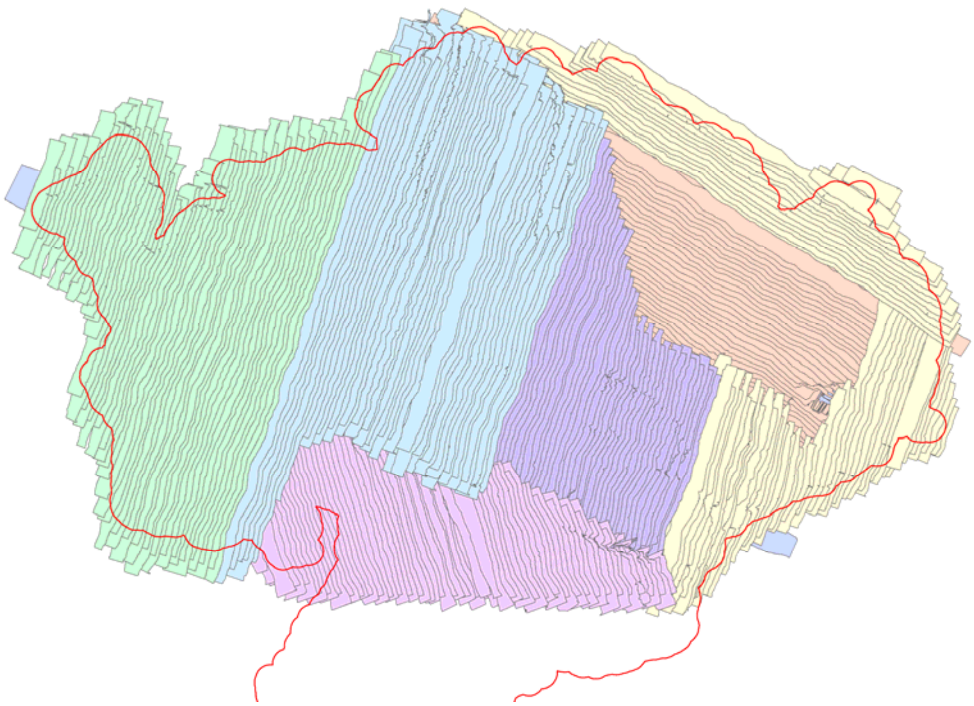


Figure 12: Swaths overlap and coverage over the project boundary.

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.

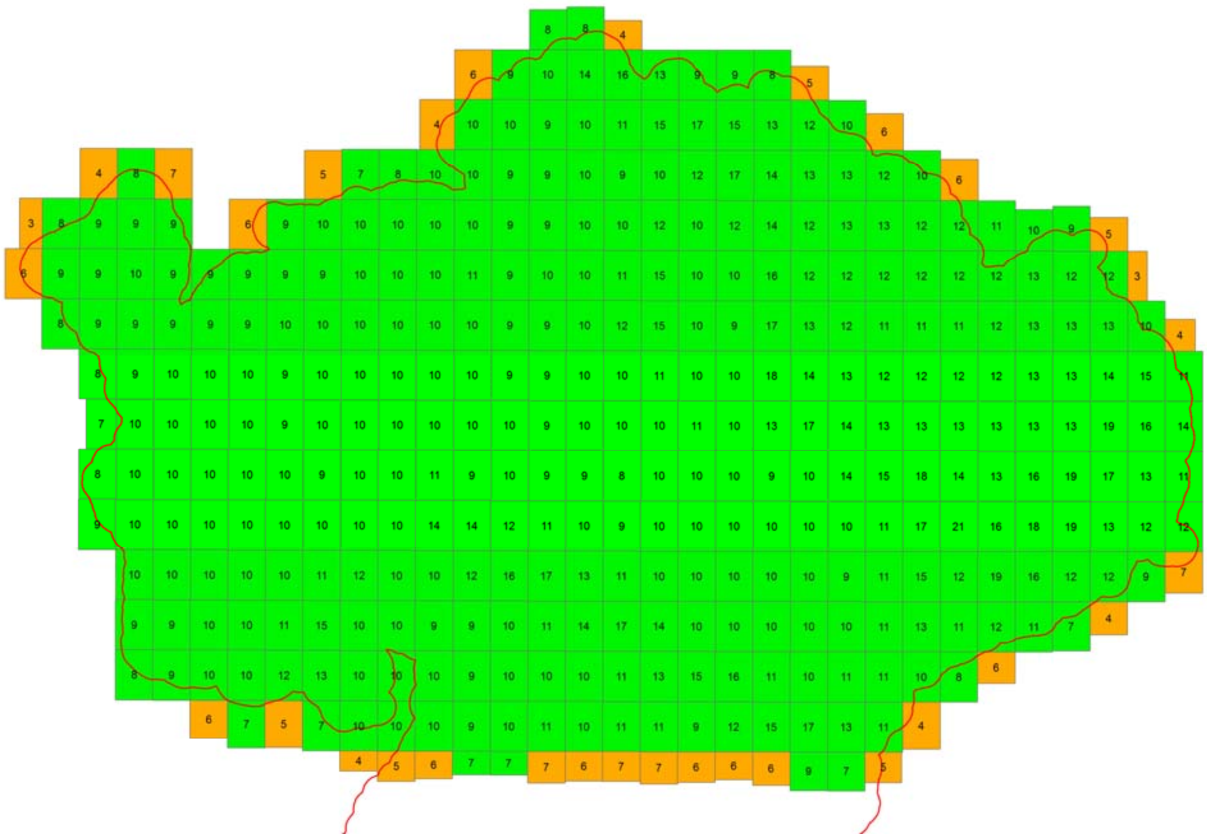


Figure 13: First return point density computed for each LiDAR tile (Units: PPSM).

In order to get a better view of the point density, the same computation was done with a 100m by 100m grid. 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).

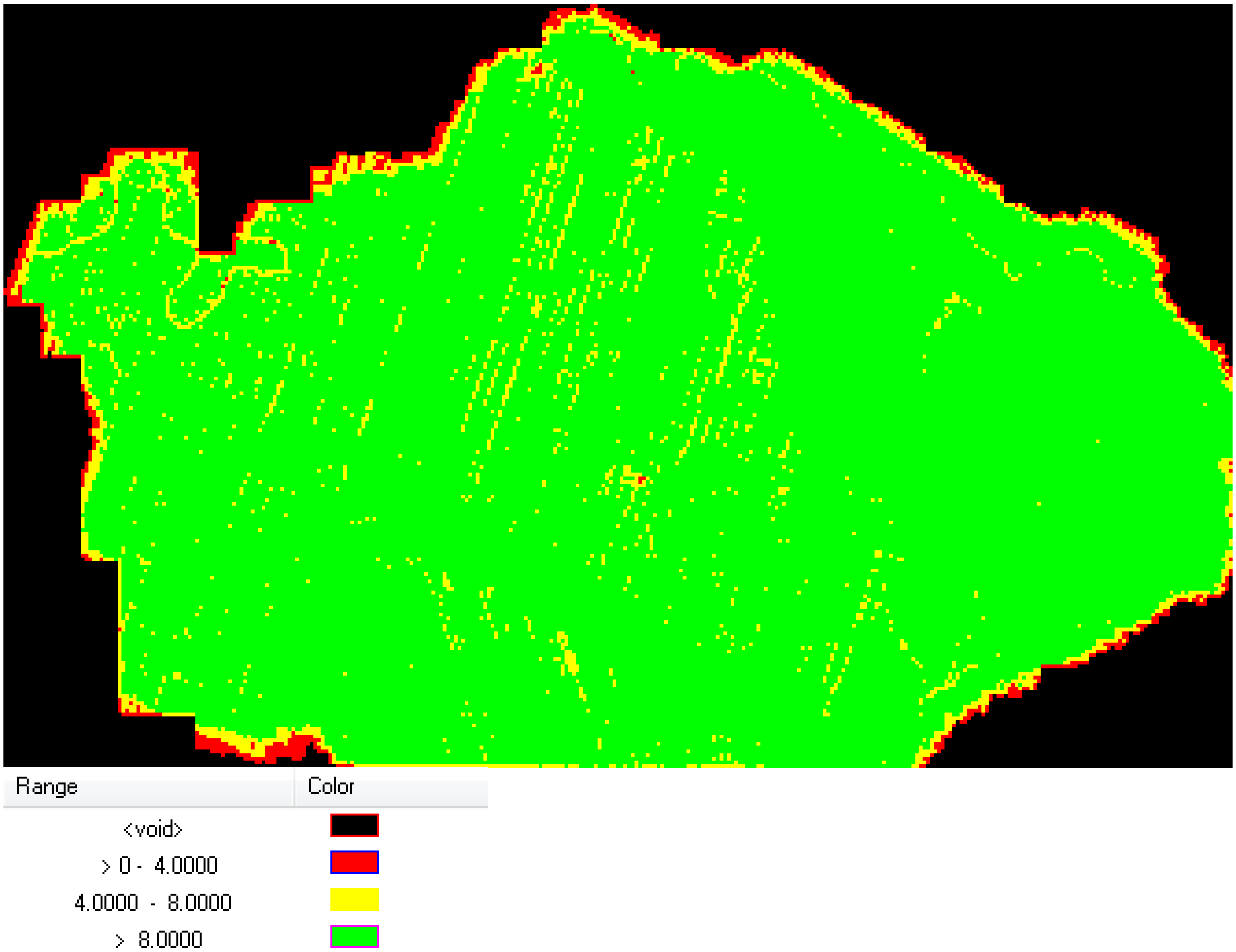



Figure 14: First return point density computed for a 100m x 100m grid (Units: PPSM).

## *Surfaces 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 is presented below.

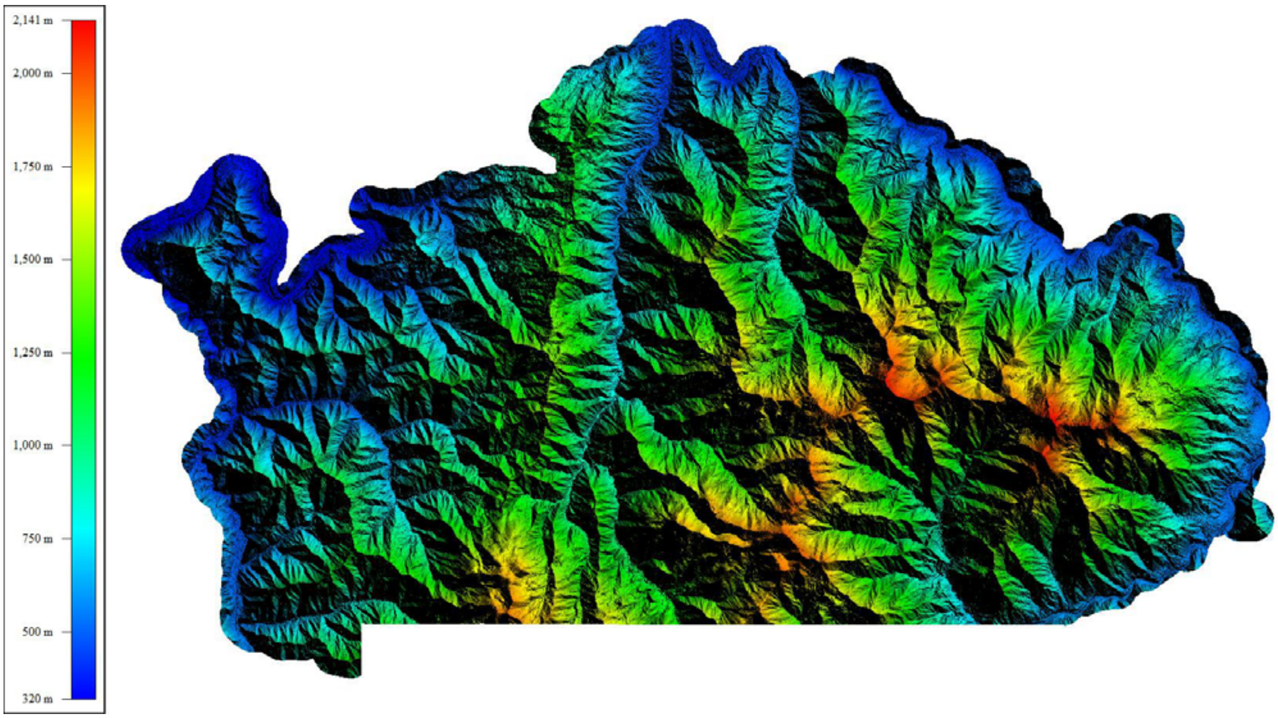



Figure 15: Overview of the Digital Elevation Model.

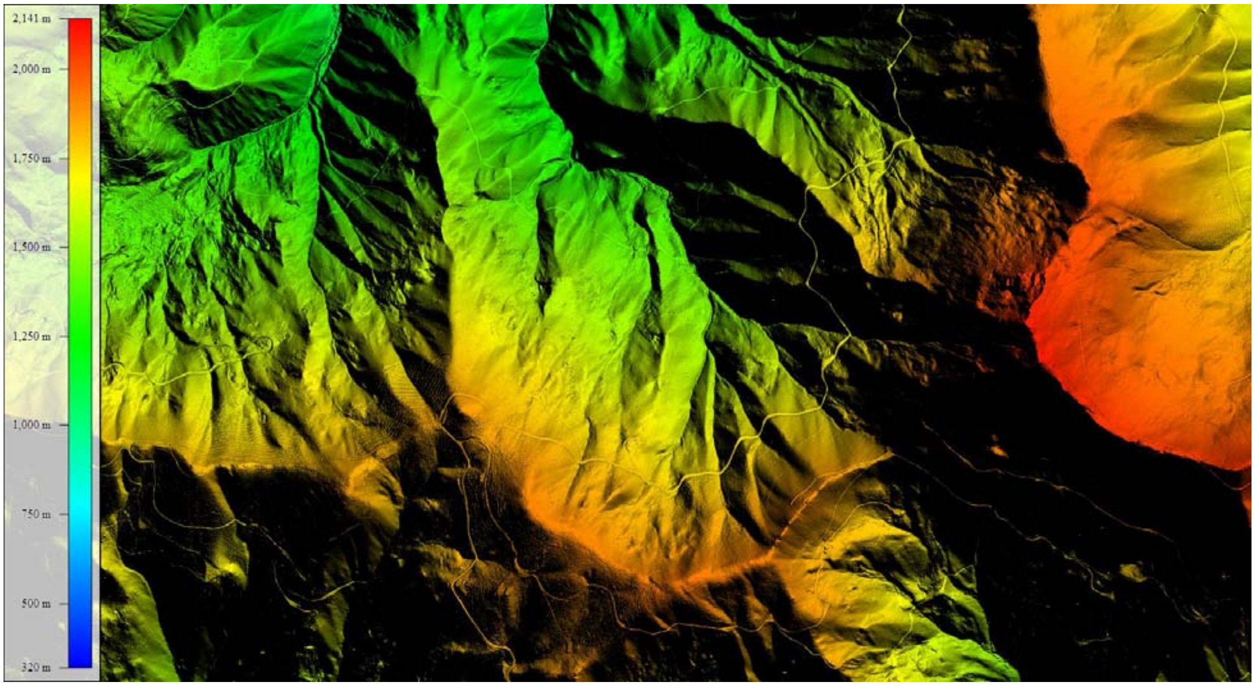



Figure 16: Detailed view of a DEM grid.

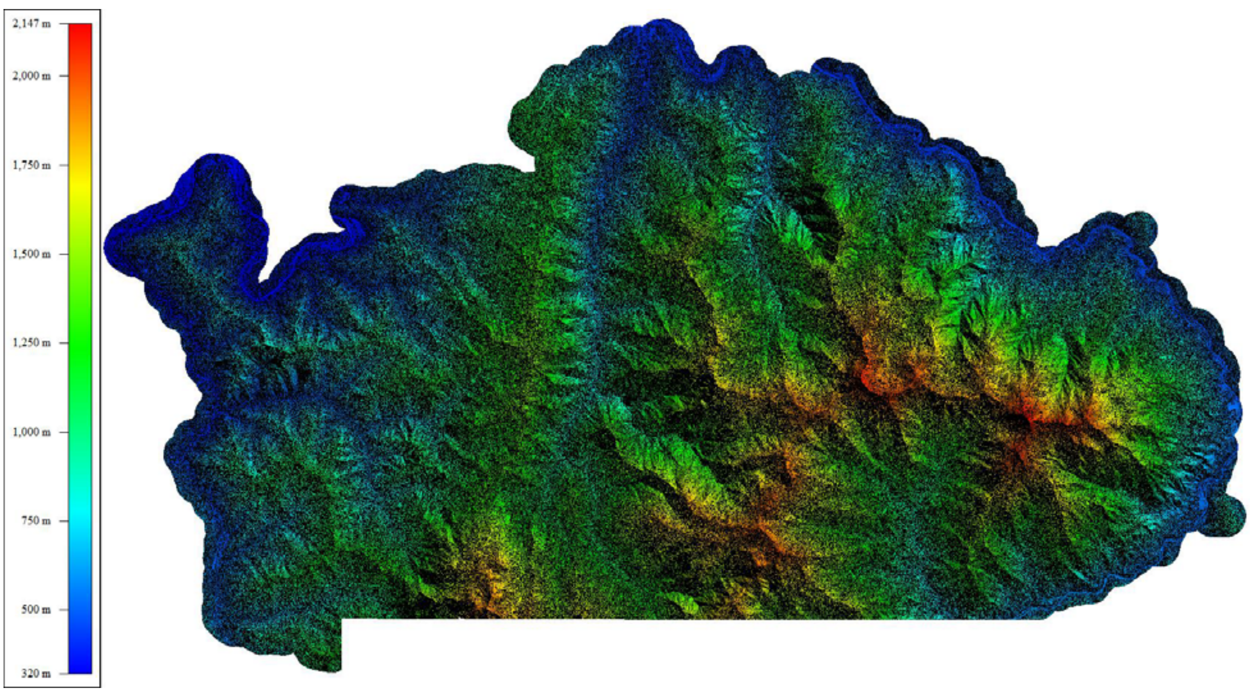



Figure 17: Overview of the Digital Surface Model.

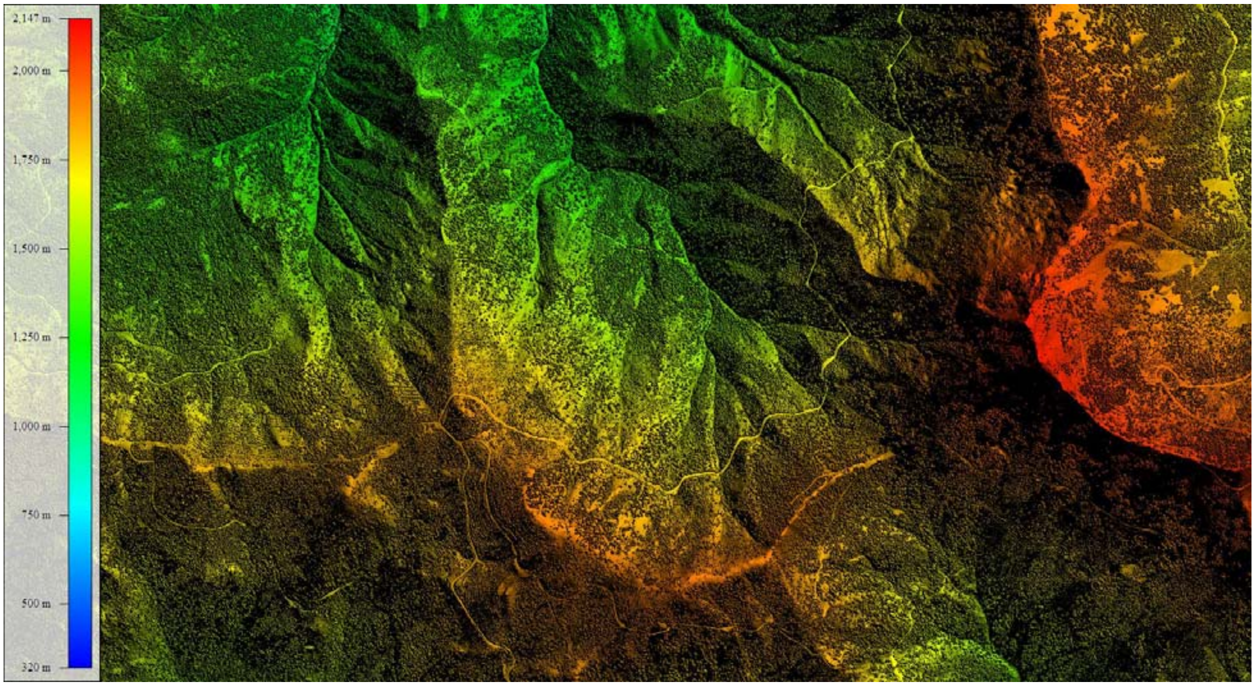



Figure 18: Detailed view of the DSM grid.

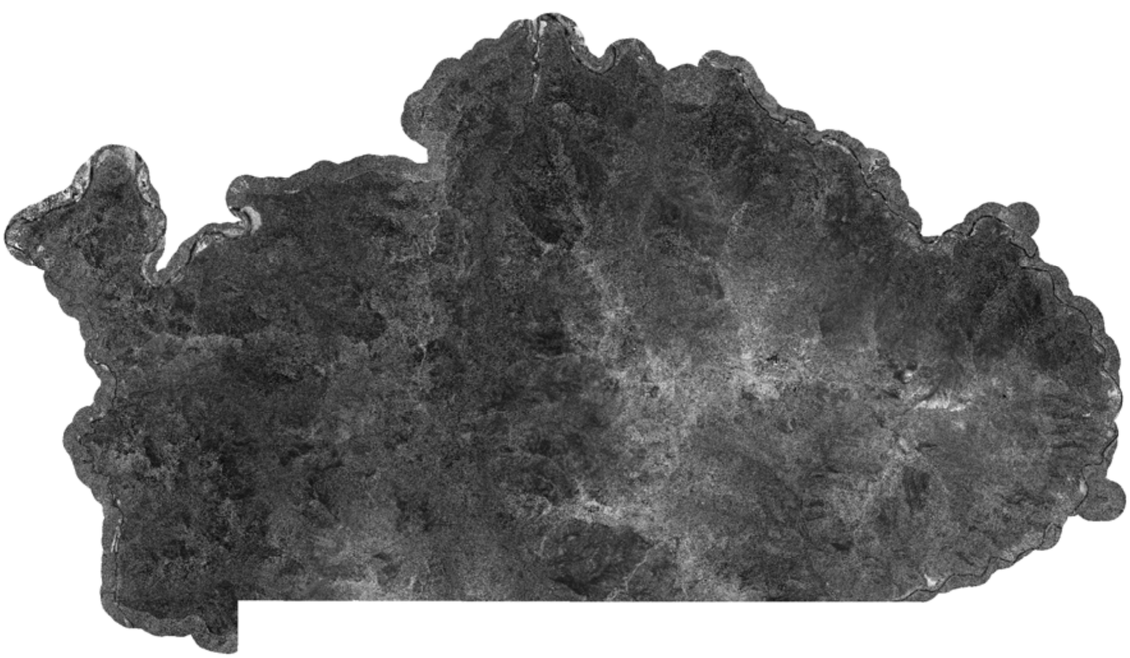


Figure 19: Overview of the intensity image.

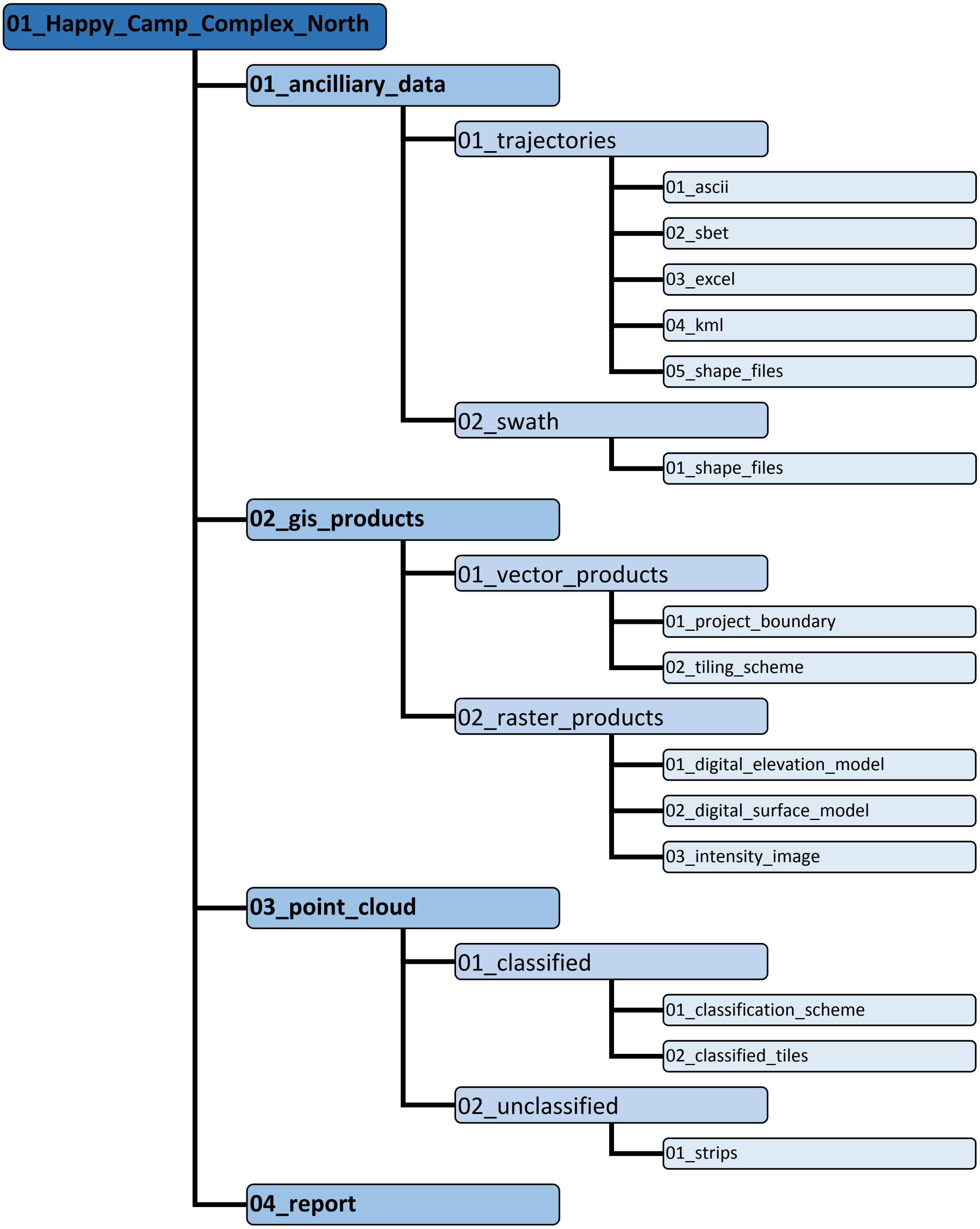
Figure 20: Detailed view of the intensity image

## Projection/Datum and Units

<table>
<tr><td colspan="2">Projection</td><td>UTM Zone 10 North</td></tr>
<tr><td rowspan="2">Datum</td><td>Vertical</td><td>NAVD 88</td></tr>
<tr><td>Horizontal</td><td>NAD83 (2011), epoch of 2010.0</td></tr>
<tr><td colspan="2">Units</td><td>Meters</td></tr>
</table>

## 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.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