LiDAR QAQC Report
Hawaii TO12: Molokai, Maui, Lanai islands
March 2008

Prepared by:
Dewberry
Fairfax, VA

EXECUTIVE SUMMARY

This LiDAR project covered the southern shores of 3 Hawaii islands (Molokai, Lanai, and Maui). The product is a mass point dataset with an average point spacing of 3ft. The data are tiled, stored in LAS format, and LiDAR last returns are classified in 2 classes stored in two separated files: ground and extracted features.

Dewberry's Fairfax office performed quality control reviews of these data including a quantitative and a qualitative assessment.

First, the elevation meets the accuracy required for this project, (accuracy equivalent to 2 ft contours according to NSSDA accuracy requirement from which FEMA *Guidelines and specifications for Flood Hazard Mapping Partners* were derived. To meet 2 ft contour accuracy, 20 points shall be tested and the data need to be accurate to 1.19 ft at the 95% confidence level. These data were tested 0.46ft (Molokai), 0.435ft (Lanai) and 1.165ft (Maui) fundamental vertical accuracy at 95 percent confidence level in open terrain/urban using RMSE x 1.96 using 24, 21 and 16 survey points, respectively, for these islands. Vertical biases were detected in the data but they do not prevent the data to pass the standards.

Secondly, 50% of the tiles were reviewed at macro level for data completeness: Maui North West part is missing and was replaced by NOAA data vertically adjusted with a -1ft vertical bias to better match the Maui LiDAR data, no additional blending was apply and it supplements ground data only. Lanai south shore was completely acquired even though only a small section was required. Data are exempt of systematic errors except for several small remote-sensing data void. Spikes were removed from the ground product but kept in the extracted feature product. The cleanliness of the bare earth model was assessed on 20% of the tiles at micro level and Maui central part exhibits inconsistent editing and bad stream definition. In addition, minor errors were found (like sparse ground density in dense vegetation, cornrows and possible vegetation remains) that can be accepted considering the density of the local vegetation.

In essence, this LiDAR dataset is of acceptable quality and may be used by FEMA and FEMA contractors for coastal mapping; however caution must be exercised in using the Maui data.

TABLE OF CONTENT

QAQC REPORT

1 Introduction

LiDAR technology data gives access to precise elevation measurements at a very high resolution, resulting in a detailed definition of the earth's surface topography. Dewberry's role is to provide an independent verification of this data using a vertical accuracy assessment, a completeness validation of the LiDAR mass points and a qualitative review of the derived bare earth surface.

First, a quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. As the accuracy is tested in several land cover types (open terrain, vegetated areas) but always at ground level, the classification accuracy is indirectly evaluated. LiDAR ground points will be consistent with survey ground points in vegetated areas only if the vegetation is correctly removed by classification and if the LiDAR penetrated the canopy to the ground. Although only a small amount of points are actually tested through the quantitative assessment, there is an increased level of confidence with LiDAR data due to the relative accuracy. This relative accuracy in turn is based on how well one LiDAR point "fits" in comparison to the next contiguous LiDAR measurement as acquisition conditions remain similar from one point to the next.

Secondly, the completeness verification is conducted at a project scale level (files are considered as the entities). It consists of a file inventory and a validation of conformity to format, projection, and georeference specifications. General statistics over all fields are computed per file and analyzed to identify anomalies especially in elevations and LAS classes.

Finally, to fully address the data for overall accuracy and quality, a qualitative review for anomalies and artifacts is conducted at the data level. As no automatic method exists yet, we perform a manual visualization process based on the knowledge of Dewberry's analysts. This includes creating pseudo image products such as 3-dimensional models. By creating multiple images and using overlay techniques, not only can potential errors be found, but we can also find where the data meets and exceeds expectations.

Within this Quality Assurance process, three fundamental questions were addressed:

- Did the LiDAR system perform to specifications?
- Was the data complete?
- Did the ground classification process yield desirable results for the intended bare-earth terrain product?

2 Quality Assurance

2.1 Completeness of LiDAR deliverables

Once the data are acquired and processed, the first step in our review is to inventory the data delivered, to validate the format, projection, georeferencing and verify if elevations fall within an acceptable range.

2.1.1 Inventory and location of data

The goal of TO12 was to collect LiDAR data for the southern shores of 3 Hawaii islands: Molokai, Maui, and Lanai. This included acquiring new data but also utilizing existing data flown for other FEMA projects. No definitive boundary was defined by FEMA for this project however the limits were based on two criteria; geographic coastal start and end points, and a requirement to include the coast up to the 10 meter contour elevation. This data will be used to perform the Hurricane Study for the Hawaiian Islands.

LiDAR data were correctly acquired by the subcontractor Airborne 1 along the southern shorelines and they met the 10m contour requirement; actually, data were acquired largely above this threshold.

Data were provided in LAS format 1.0 and points were separated in two files:

- Ground Last Return (classification code 2)
- Extracted feature Last Return (classification code 1)

The average point distance is 3 ft and meets the specifications.

All the LAS files are in HI state plane Zone 2 (NAD 83/Local tidal HI) US survey feet.

In total there were 77 LAS files for Lanai, 265 LAS files for Maui, and 175 LAS files for Molokai. There were multiple deliveries for the islands, because of missing files, missing annotation, and duplication. The result of our first inventory indicated, on the one hand, that 32 files were missing for the westerly coastlines of Molokai and the north-west coastlines of Maui. On the other hand, too many data were acquired on the south-east and south-west part of Lanai shore and on the south-east part of the Maui shore. This is illustrated on Figure 1. The criteria that Airborne1 seems to have followed is to acquire on the south oriented side of the coastlines without considering the limits points provided. The missing files for Molokai were delivered on 06/01/2007. All the required tiles were present (and more), as illustrated on Figure 2.

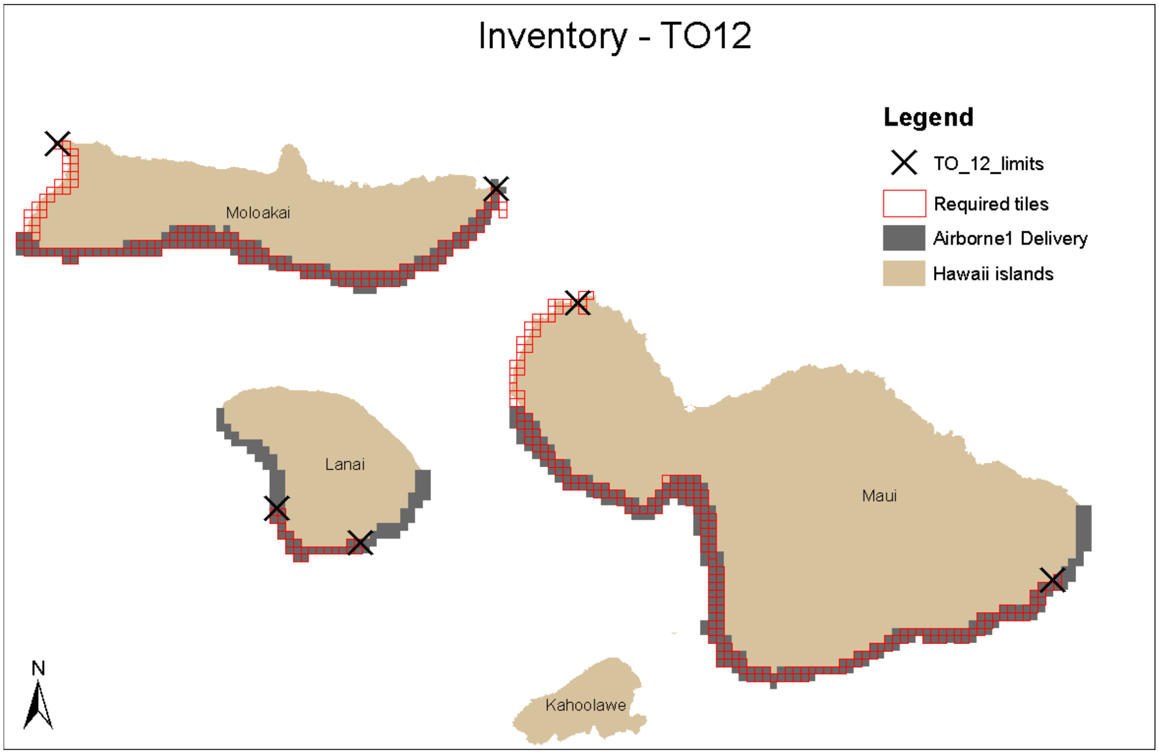


Figure 1 – Comparison of delivered data and required tiles (first deliveries); location of the check points

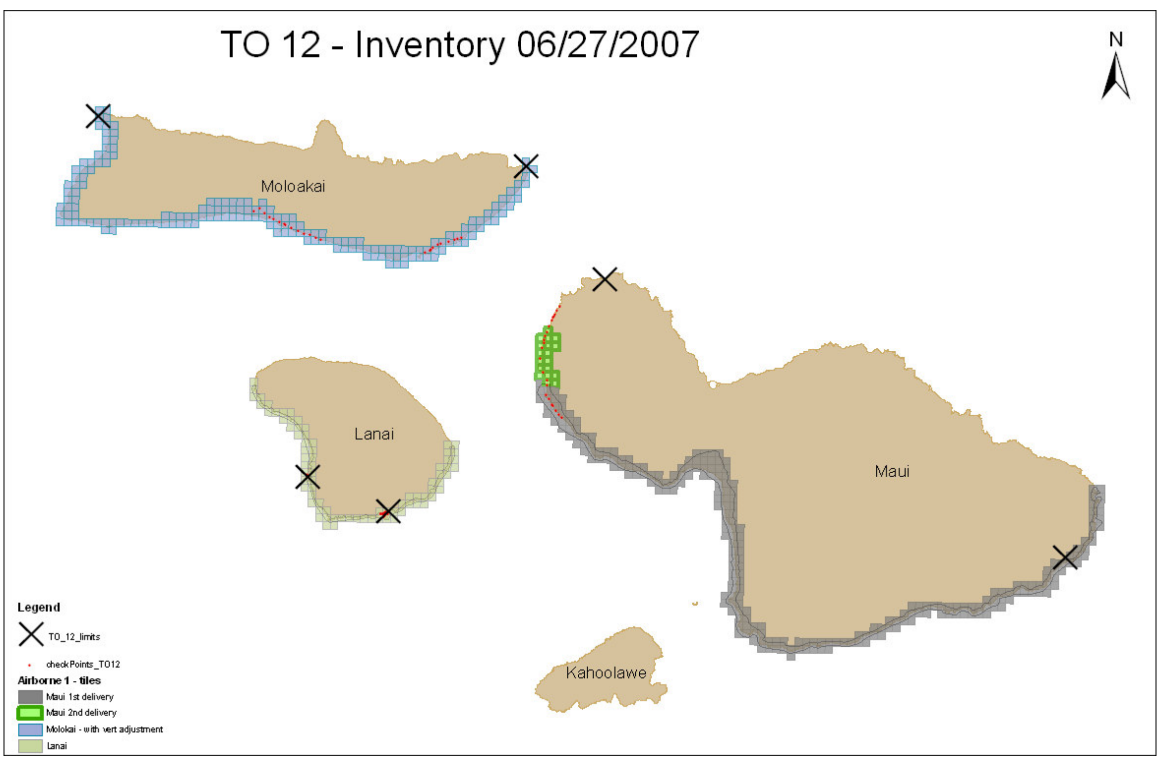


Figure 2 – Comparison of delivered data and project limits (final deliveries); location of the check points

For Maui, we are still missing 21 tiles. Besides, it should be noted that 7 over of the 23 check points reside in this missing area. In order to replace these missing data we have downloaded a ground LIDAR dataset from NOAA (see Figure 3):

- Originator: NOAA Coastal Services Center Coastal Remote Sensing Program, http://www.csc.noaa.gov/LiDAR
- Publication_Date: 20070710
- Title: Oahu/Maui 2005 LiDAR mapping project
- ASCII files (xyz), ground only (we also downloaded a full point cloud dataset which covers in a slightly larger area)
- State plane Hawaii Zone 2 US Feet, Z in feet

The overall quality and point spacing are comparable to the data that we already have. This dataset will completely overlap the Airborne 1 tile 000146 and partially overlap tiles no. 000178 and 000179 (Figure 4). If the data ties in adequately with the A-1 acquired data is further analyzed in this report.

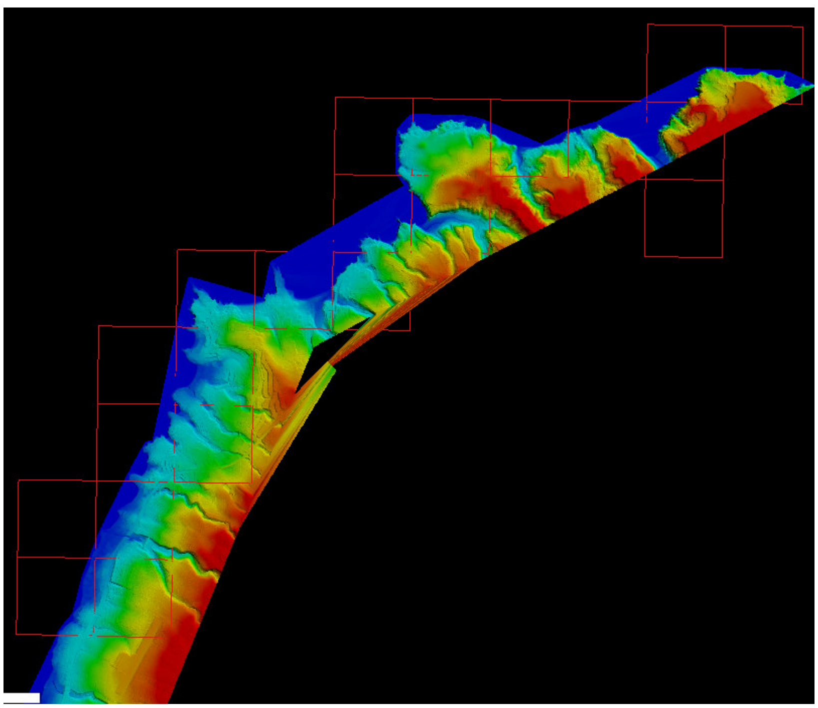


Figure 3 – Maui missing tiles (red outlines) and replacing dataset from NOAA, 3D model colorized by elevation

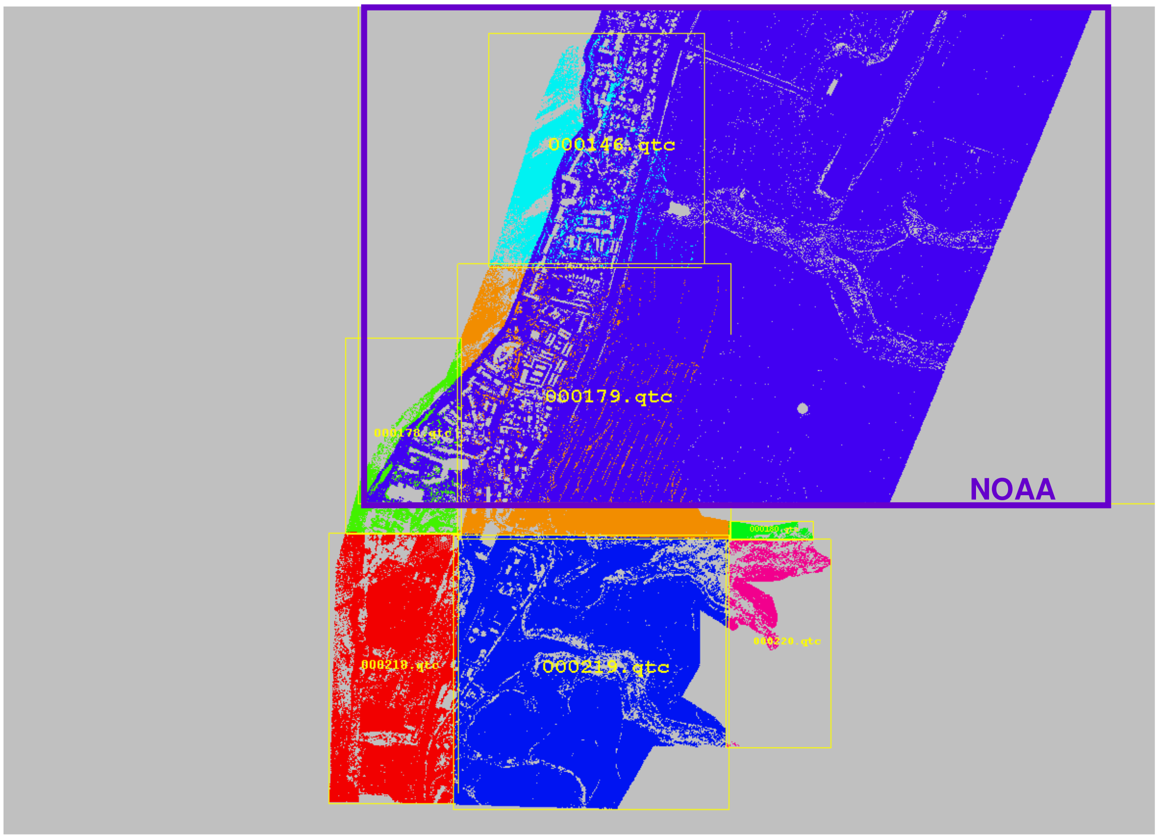


Figure 4 – Overlap between NOAA dataset and tiles 000146, 000178 and 000179

For delivery purpose, the Airborne1 data was clipped to the extent of the NOAA dataset (affects tiles 178 and 179 and remove tile 146). The NOAA ground points and the remaining ground points in tiles 178 and 179 were then used to populate the missing tiles. In total 24 tiles were created (21 plus 3 replaced) shown in red in Figure 5. These tiles were also renamed with an N in front of the old tile name in order to identify them. See Appendix A for the list of tiles.

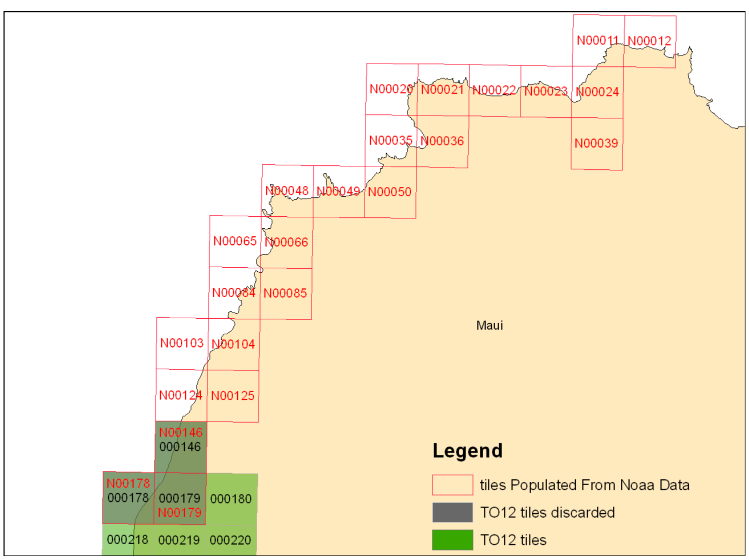


Figure 5 – Tiles populated from NOAA data

2.1.2 Statistical analysis of tile content

To verify the contents of the data and to validate the data integrity, a statistical analysis is performed on all the data. This process allows us to statistically review 100% of the data to identify any gross outliers. This statistical analysis consists of:

1. Extract the header information
2. Read the actual records and compute the number of points, minimum, maximum and mean elevation for ground class
3. Compare the LiDAR file extent with the tile extent.

An examination of the number of points for all ground classified files indicates that the files are within the anticipated size range, except for where fewer points are expected (because of water features or near the project boundary). Figure 6 presents a map of the number of records in each LAS files (ground).

We checked the minimum and maximum elevation values in each ground classified files. Figure 7 illustrates the Zmin value for each tile; it can be noticed that a lot of the files situated on the east part of Maui have negative Zmin values, and 30 files have a Zmin value under -5ft, further investigation may be needed to explain this. Nevertheless, we can see on Figure 8 that there is no noticeable anomaly for the max value. The 3 tiles in Lanai Island that have values above 600ft are very steep cliffs right on the coast as seen in Figure 9. Consequently, all highest Zmax values are legitimate LiDAR points. We can also see that the project boundary is very close to the shoreline on this particular area.

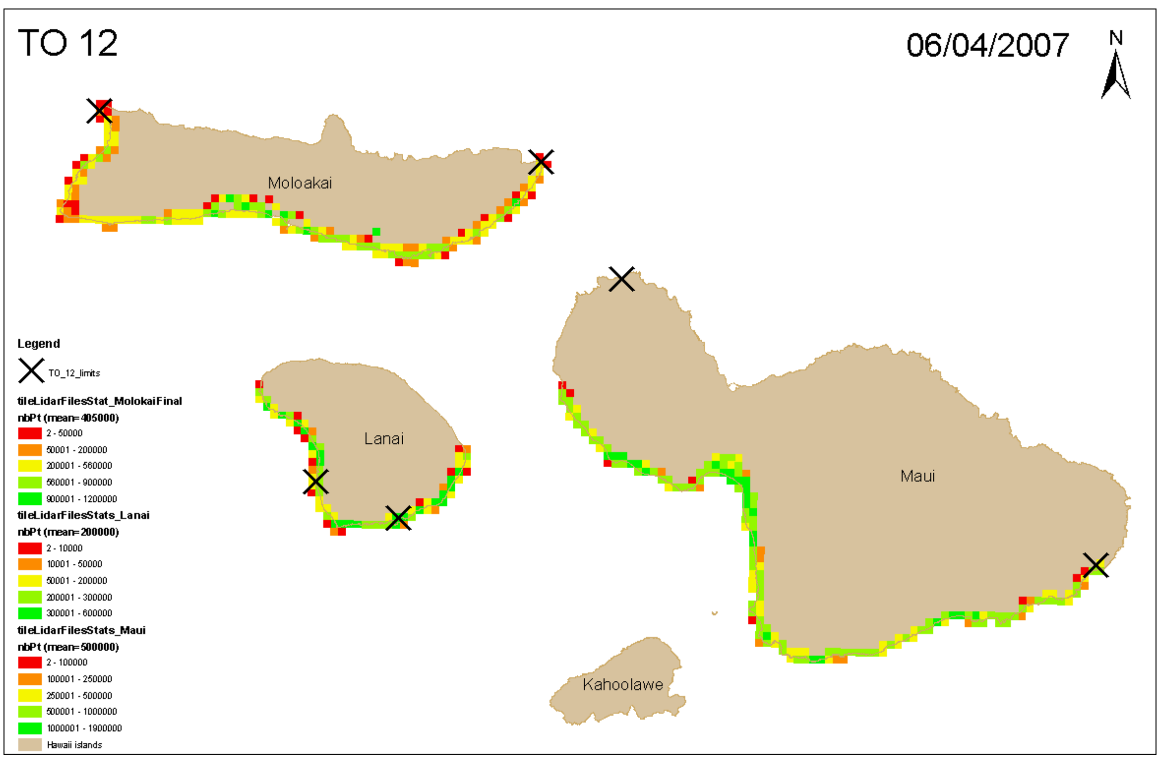


Figure 6 - Number of records in ground LAS files

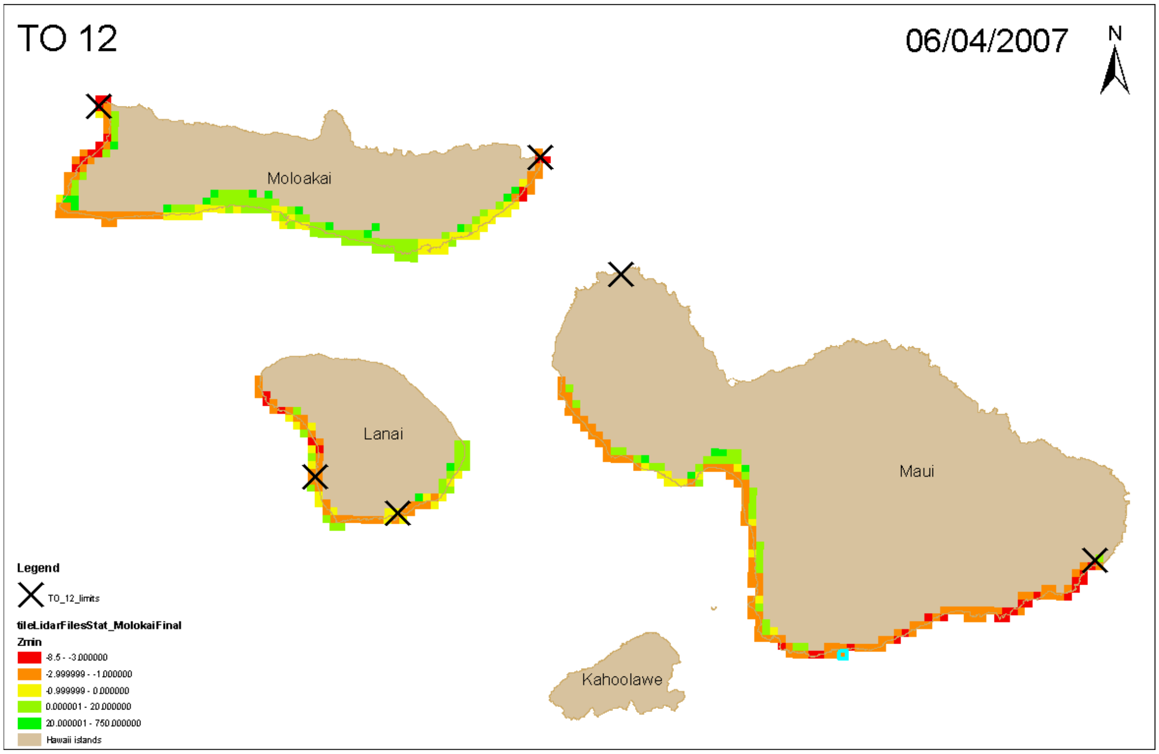


Figure 7 – Minimum elevation in ground LAS files (in feet)

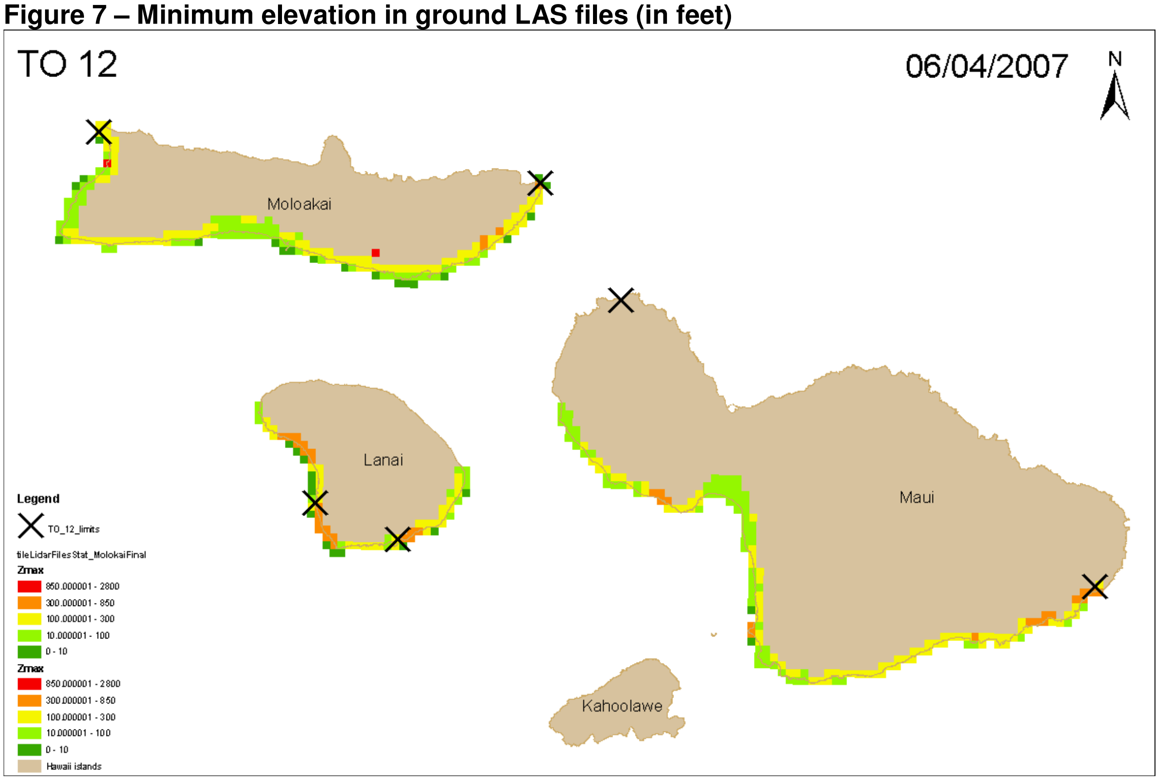


Figure 8 – Maximum elevation in ground LAS files (in feet)

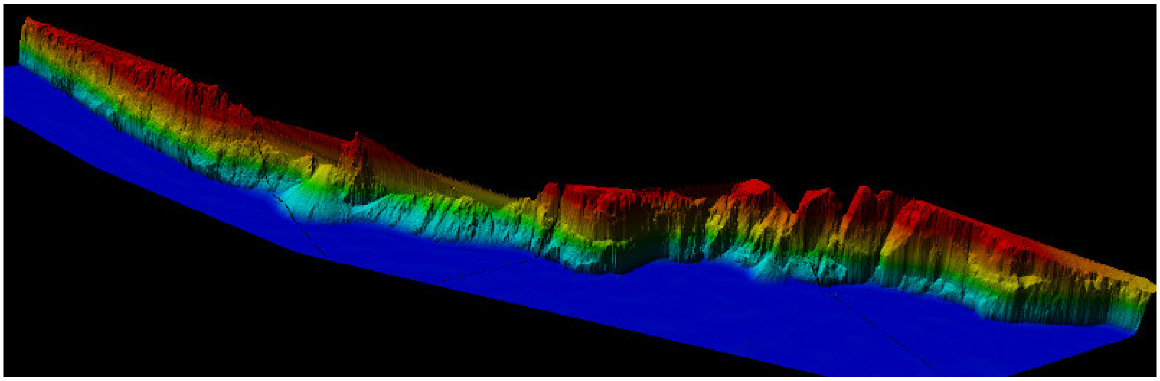


Figure 9 – High Zmax on cliff, the project boundary is very close to the shoreline

2.2 Quantitative assessment

2.2.1 Inventory of survey points

Dewberry is using an independent verification survey to verify the accuracy of the LiDAR data. Detailed survey reports can be found in Appendix B.

All check points used and the associated errors are provided in Appendix C.

2.2.2 Vertical Accuracy: elevation comparison

Using the ground truth checkpoint survey as the reference, elevations at the same x and y positions are interpolated from the LiDAR data. The method used to extract the elevation from the LiDAR mass points at a given location is to create a triangular irregular network from the ground classified points and to interpolate the elevation at the given x and y coordinates using the 3 nearest LiDAR neighbors. To compare the two types of measured elevations, statistics are then computed following two different guidelines further explained in the following sections.

2.2.3 Vertical Accuracy Assessment Using the RMSE Methodology

The first method of testing vertical accuracy will use the FEMA specifications which essentially follows the National Standard for Spatial Data Accuracy (NSSDA) procedures. The accuracy is reported at 95% confidence level using the Root Mean Square Error (RMSE) which is valid when errors follow a normal distribution. To be equivalent to 2 ft contours, the vertical RMSE should be ≤ 0.61 ft, and vertical accuracy at the 95% confidence level should be ≤ 1.19 ft (based on RMSE x 1.96). This methodology measures the square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent source of higher accuracy for identical points. The vertical accuracy assessment compares the measured survey checkpoint elevations with those of the TIN as generated from the bare-earth LiDAR. The survey checkpoint's X/Y location is overlaid on the TIN and the interpolated Z value is recorded. This interpolated Z value is then compared to the survey checkpoint Z value and this difference represents the amount of error between the measurements. The following tables and graphs outline the vertical accuracy and the statistics of the associated errors.

2.2.4 Molokai

For this island, only 24 check points were available, separated in 2 areas.

A quantitative analysis of the accuracy has been conducted on the data using 24 check points in one wide land cover type including level open bare terrain, short grasses, gravel roads, concrete pads, AC roads, AC parking lots.

The initial data was tested and the RMSE value was slightly over 1ft and did not meet the NSSDA standard. There were no actual outliers as the errors are regularly distributed between 0.79 and 1.51ft, but 2 errors were larger than the 95th percentile (1.37ft), which itself was larger than the specification (1.19ft).

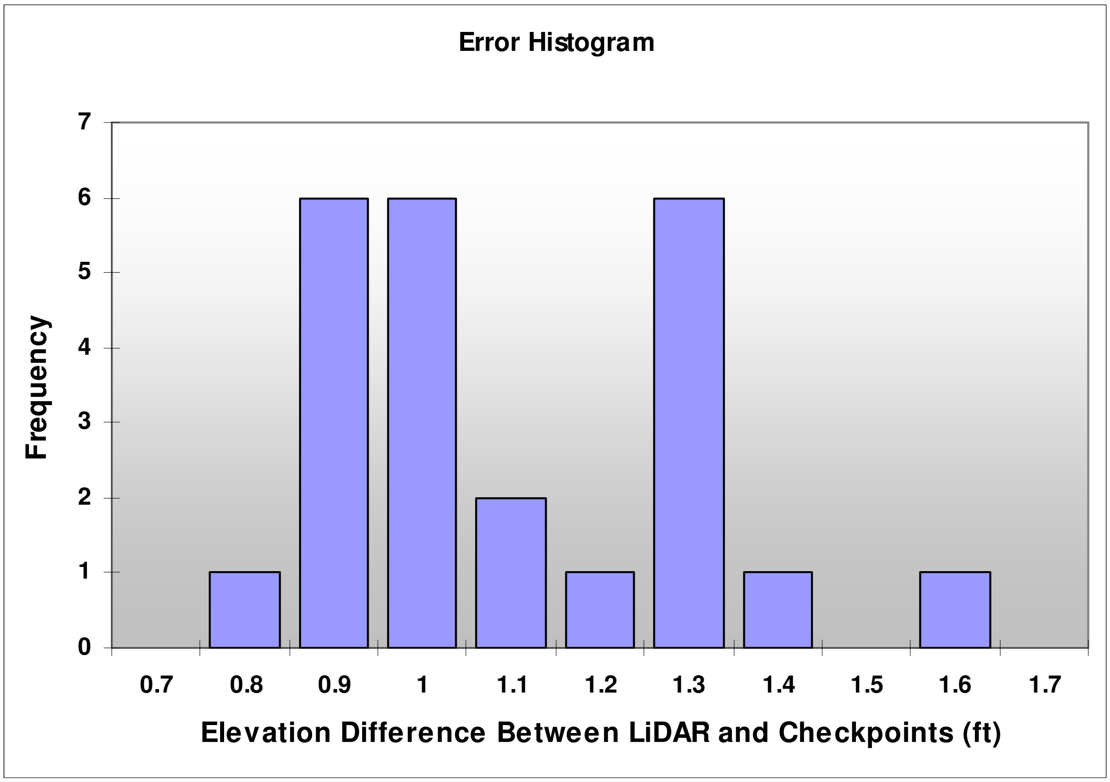


Figure 10 – Histogram of the elevation differences between LiDAR and Checkpoints

By reviewing the distribution of the errors in Figure 10, it was apparent that there was a systematic positive bias in the data. Based on what we know of the islands and the lack of an official vertical datum, it was conceivable that Airborne 1 used different vertical values for their control and the processing of the LiDAR data. Due to our knowledge of vertical control issues on this island we suggested that the data be reexamined by Airborne1 to investigate the cause of this discrepancy.

After review by Airborne 1 the data was vertically adjusted based on utilizing the same control as the checkpoints and resubmitted to us. The survey report by McGee Surveying clearly outlines how the vertical control was derived for the checkpoints and why these values take precedent over other local vertical datums for this area (see Appendix B. By utilizing the same control values and recomputing the RMSE, the Airborne 1 data meets the specifications as shown in Table 1.

Table 1 - RMSE on 100% of the check points (after vertical adjustment)

100 % of Totals	RMSE (ft) Spec=0.61ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated	0.23	0.13	0.08	0.51	0.20	24	-0.13	0.56

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=1.19 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=1.19ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.19 ft
Consolidated	24		0.429	
Open Terrain/Urban	24	0.459		0.429

2.2.5 Lanai

For this island, only 23 check points were available, separated in 2 clusters as can be seen in Figure 2. Most of the points are located in the eastern area (Figure 11) and 3 are located near Kaumalapau (Figure 12).

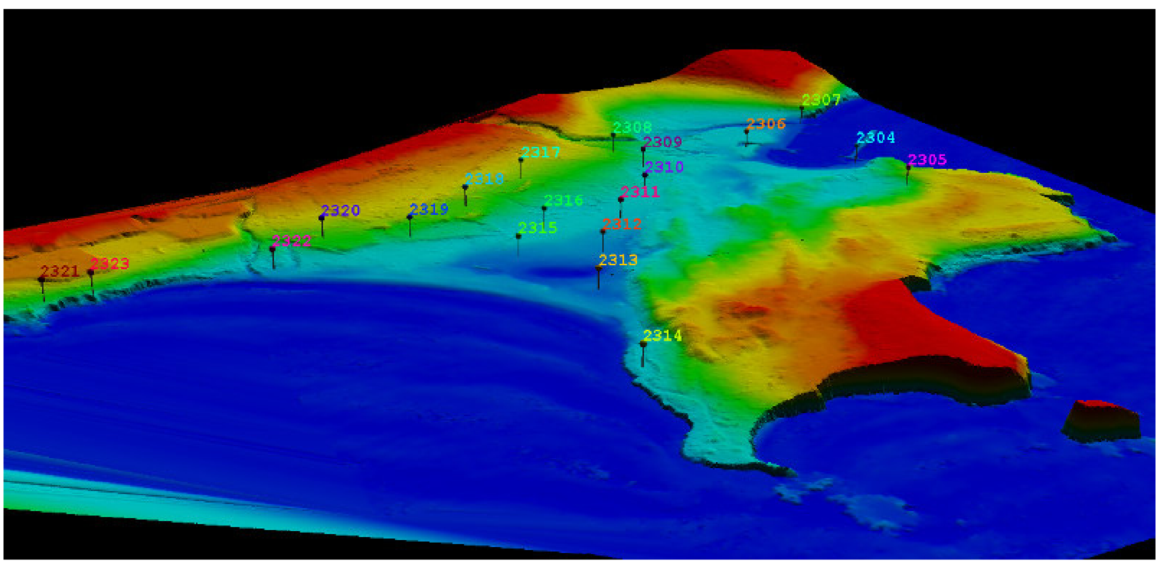


Figure 11 – East check points for Lanai

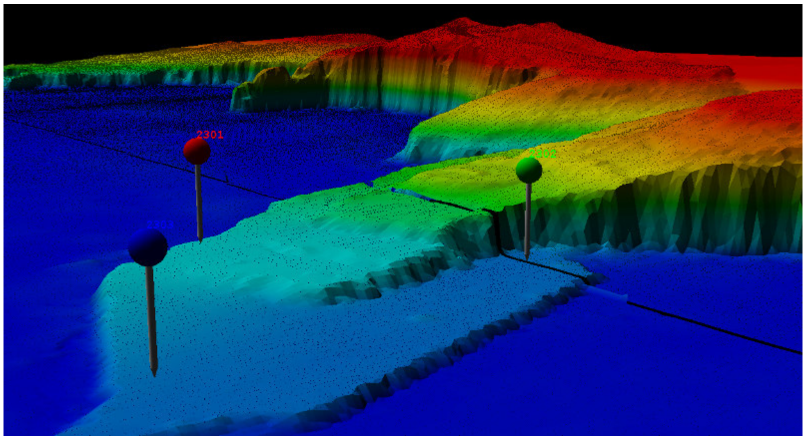


Figure 12 – West check points for Lanai

A quantitative analysis of the accuracy has been conducted on the data using 23 check points in one wide land cover type including level open bare terrain, short grasses, gravel roads, concrete pads, roads, parking lots, two of the points were acquired in level grassy areas (1-2ft), possible among trees. All the results are shown in Table 2 and Table 3.

Table 2 – RMSE on 100% of the check points

100 % of Totals	RMSE (ft) Spec=0.61ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated	0.23	-0.17	-0.21	2.26	0.16	23	-0.33	0.39

Table 3 – Accuracy (NDEP guidelines)

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=1.19 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=1.19ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.19 ft
Consolidated	23		0.332	
Open Terrain/Urban	21	0.435		0.310
Grass/Scrub	2			0.375

The consolidated RMSE meets the NSSDA standard. However, we noticed that all the errors are negative or close to 0 but one (point 2321 at 0.39ft, which is one of the points acquired in a level grassy area);

2.2.6 Maui

23 check points were available for Maui, all situated on the west coast as can be seen in Figure 2. We computed the RMSE with only 16 check points since 7 were situated within the missing area. The quantitative analysis has been computed in one wide land cover type including mowed lawn, parking lot, and road.

Table 4 – RMSE on 100% of points for Maui

100 % of Totals	RMSE (ft) Spec=0.61ft	Mean (ft)	Median (ft)	Skew	Std Dev (ft)	# of Points	Min (ft)	Max (ft)
Consolidated	0.59	-0.55	-0.59	0.46	0.24	16	-0.92	-0.10

Land Cover Category	# of Points	FVA — Fundamental Vertical Accuracy ($RMSE_z$ x 1.9600) Spec=1.19 ft	CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=1.19ft	SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.19 ft
Consolidated	16		0.826	
Open Terrain/Urban	16	1.165		0.826

The consolidated RMSE meets the NSSDA standard. We noticed that all the errors are negative as seen in Figure 13 indicating that a bias exists in the data.

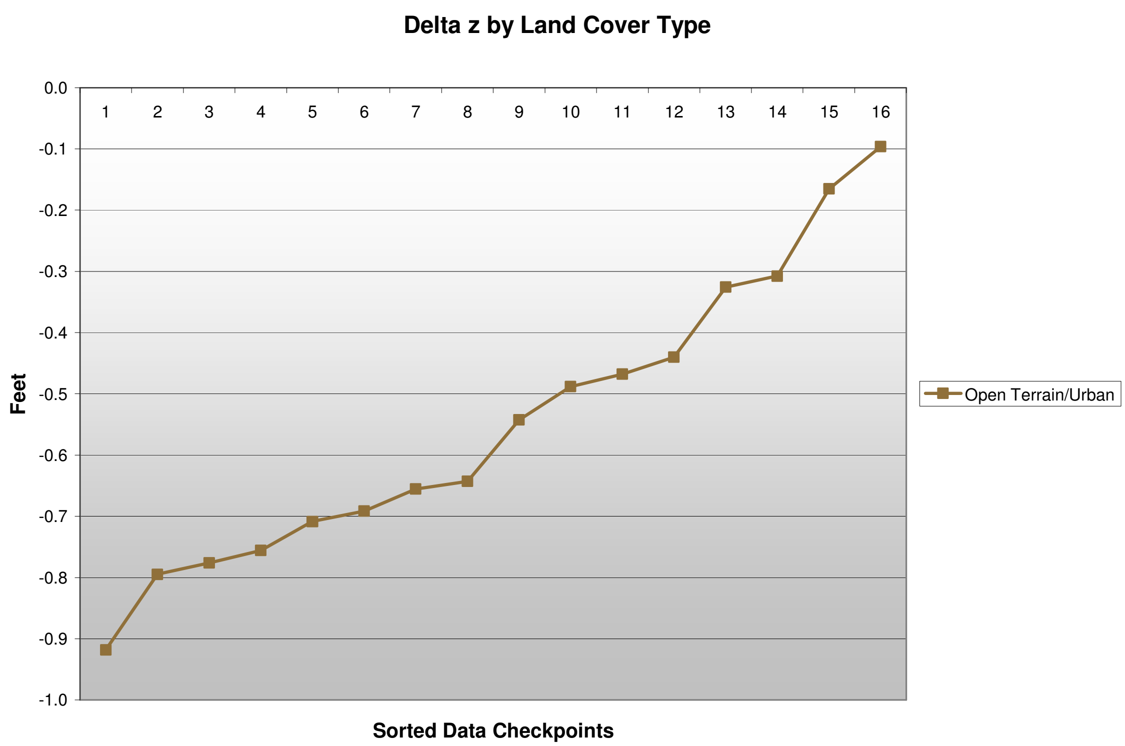


Figure 13 – Elevation errors (sorted)

We checked the elevation matching between the two sources and found about 1 feet discrepancy between NOAA and A-1 data (NOAA data is generally above the A-1 data as shown in Figure 14). When computing the RMSE over a mixed dataset, we noticed that, except for one point, the NOAA data fit our survey points (see check point error graph in Figure 15) confirming that the Maui data might have a bias. However, in order to merge the datasets, we applied a -1ft correction to the NOAA data.

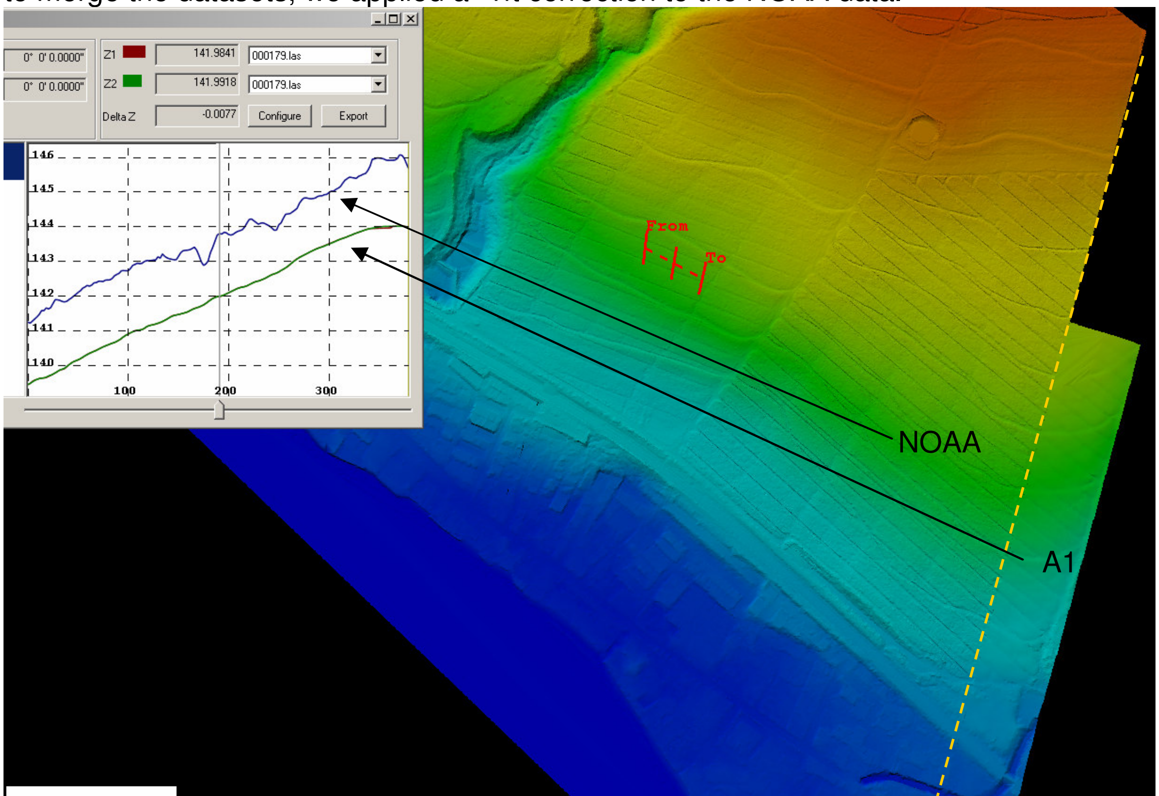


Figure 14 – 3D models of ground LiDAR data from NOAA (left from the yellow dashed line) and Airborne 1. The cross section has been drawn where the 2 datasets are overlapping. (Tile Number 000179)

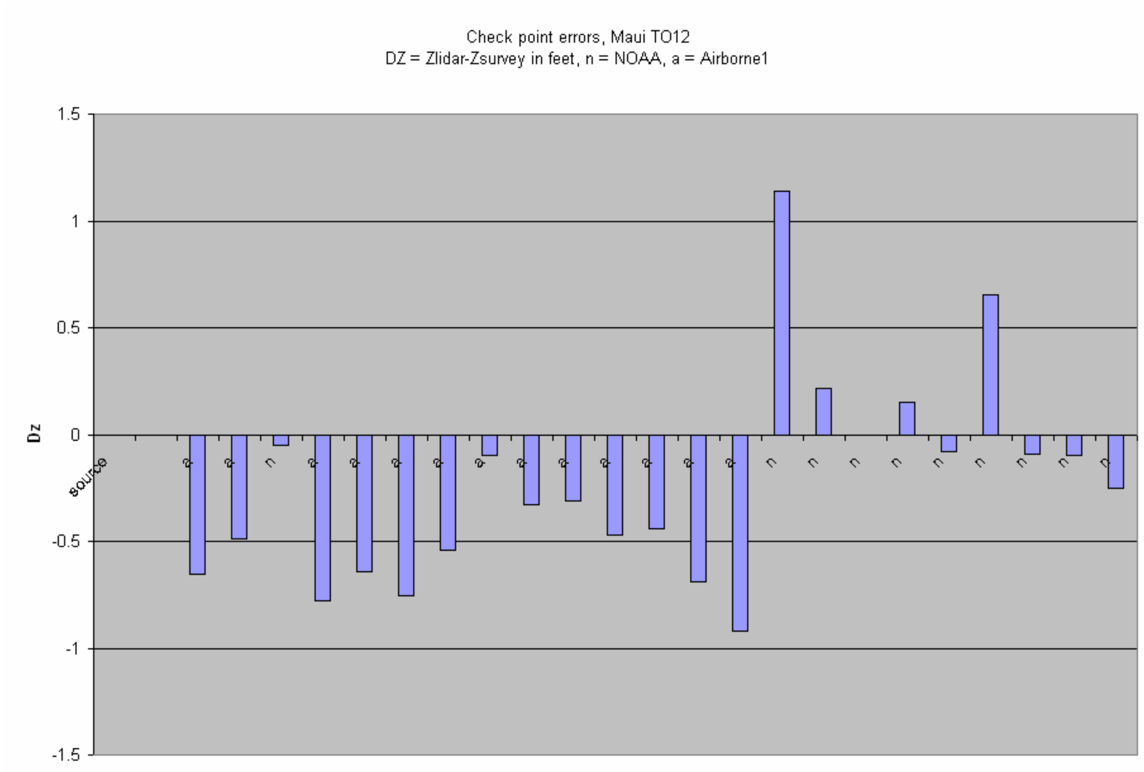


Figure 15 – Check point errors separated by LiDAR dataset (a= Airborne 1, n=NOAA)

2.3 Qualitative assessment

2.3.1 Protocol

The goal of this qualitative review is to assess the continuity and the level of cleanliness of the data. The acceptance criteria we have reviewed are the following:

- If the density of point is homogeneous and sufficient to meet the user needs,
- If the ground points have been correctly classified (no manmade structures and vegetation remains, no gap except over water bodies),
- If the ground surface model exhibits a correct definition (no aggressive removal, no over-smoothing, no inconsistency in the post-processing), in a context of flood modeling and storm surge. Special attention is given to the stream channels and coastal definition,
- If no obvious anomaly due to sensor malfunction or systematic processing artifact is present (data holidays, spikes, divots, ridges between tiles, cornrows…).

Dewberry analysts, experienced in evaluating LIDAR data, performed a visual inspection of a bare-earth digital elevation model (DEM). LiDAR mass points are first gridded with a grid distance of approximately 2 times the full point cloud resolution. Then, a triangulated network is built based on this gridded DEM and is displayed as a 3D surface. A shaded relief effect is applied which enhances 3D rendering. The software used for visualization allows the user to navigate, zoom and rotate models and to display elevation information with an adaptive color coding in order to better identify anomalies.

The first step of our qualitative workflow is therefore to verify data completeness and continuity using the bare-earth DEM with density information, displayed at a macro level. If, during this macro review of the ground models, we find potential artifacts or large voids, we use the digital surface model (DSM) based on the full point cloud including vegetation and buildings to help us better pinpoint the extent and the cause of the issue. Moreover, the intensity information stored in LiDAR data can be visualized over this surface model, helping in interpretation of the terrain.
Finally, in case the analyst suspects a systematic errors relating to data collection, a visualization of the 3D raw mass points is performed, rather than visualizing as a surface. This particular type of display helps us visualize and better understand the scan pattern and the flight line orientation.

The process of importing, comparing and analyzing these two later types of models (DSM with intensity and raw mass point), along with cross section extraction, surface measurements, density evaluation, constitutes our micro level of review.

2.3.2 Quality report

As stated in the scope of work, we reviewed 50% of all bare earth models, uniformly distributed over the all flown area as illustrated in Figure 16 – Location of reviewed tiles. We decided to review all Lanai tiles exclusively situated between the two limit points initially defined for the project area. All extra tiles will not been reviewed as they were not requested.

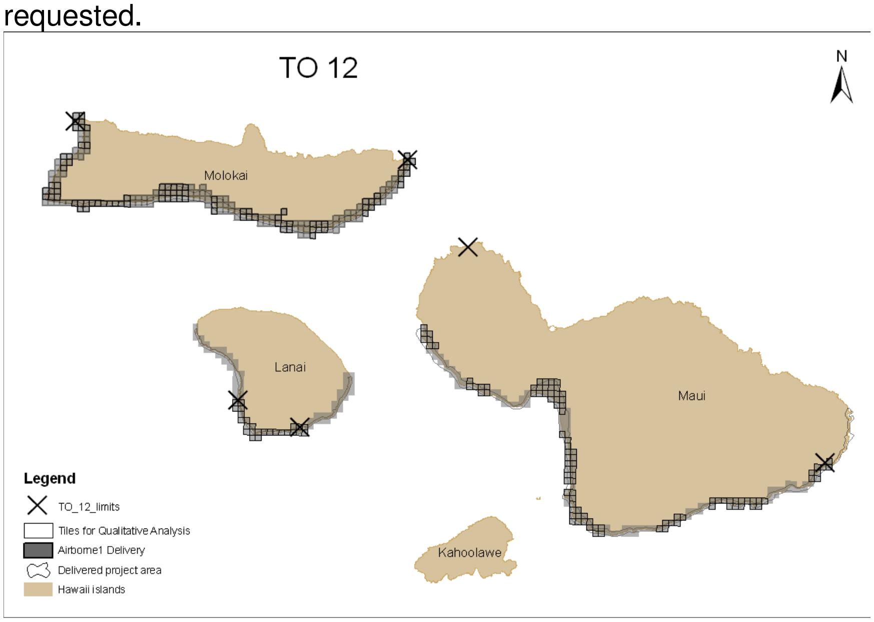


Figure 16 – Location of reviewed tiles

We listed the more frequently issues encountered. We then reviewed each island individually. Recurrent issues are:

1. Poor LiDAR penetration in dense vegetated areas and/or aggressive removal of vegetation, causing bare earth model to have no point left
2. Cleanliness of artifacts (noise, vegetation or building remains)
3. Spikes in full point cloud data
4. Small divots in ground models
5. Holes in data (Figure 17 shows the gaps with reviewed tiles)

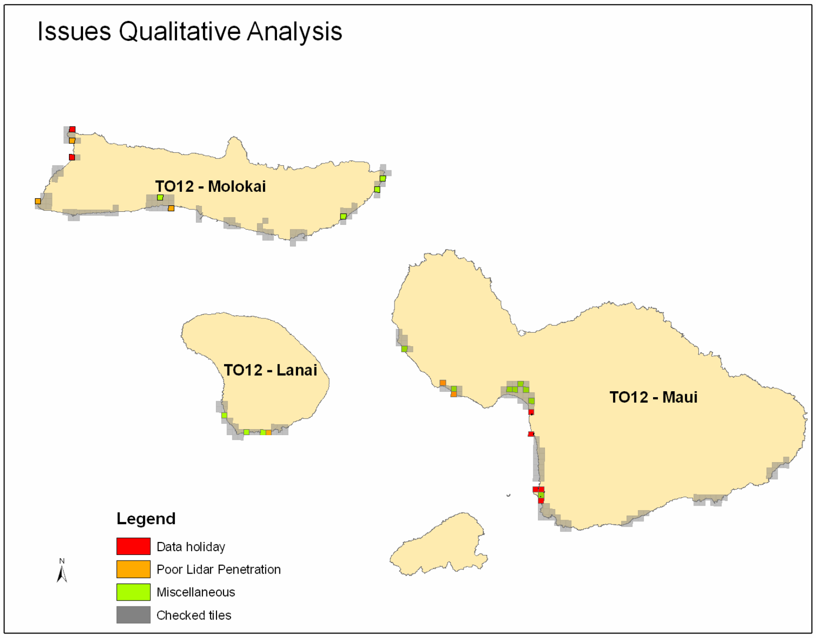


Figure 17 – Gaps in Molokai and Maui.

2.3.3 Lanai

The west part of Lanai project area consist of steep bare earth cliffs, consequently, the inland extent of the data is very limited as illustrated in Figure 18. On this portion of the data, almost no problems were found except some spikes in the extracted feature product (see Figure 19) which are acceptable since they are contained in the "unclassified" class of the LAS data.

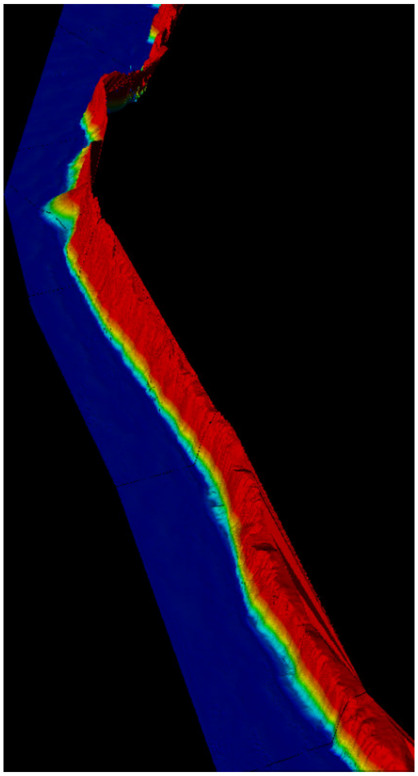


Figure 18 – Lanai coast, the area coverage is very narrow

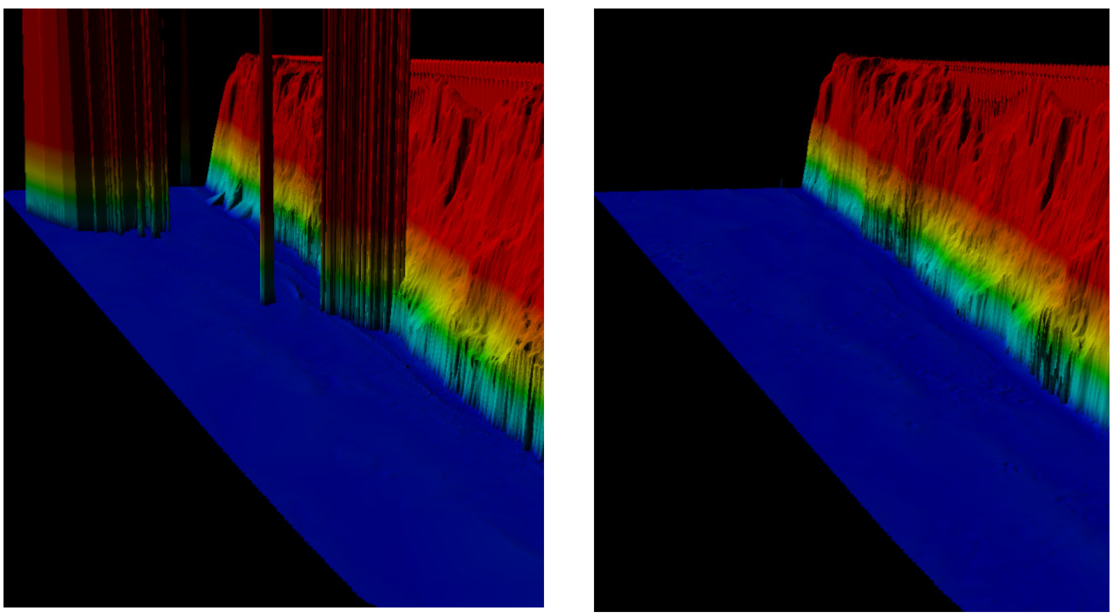


Figure 19 – Spikes in the extracted feature product (left), they have been eliminated from the ground file (right)

The east part of the project area (south facing shoreline) exhibits a slightly smoother topography. On this area, well defined stream channels were noticed. The only types of issues we faced were possible remains of vegetation and one instance of poor LiDAR penetration in highly vegetated area (this issue is documented in the next section).

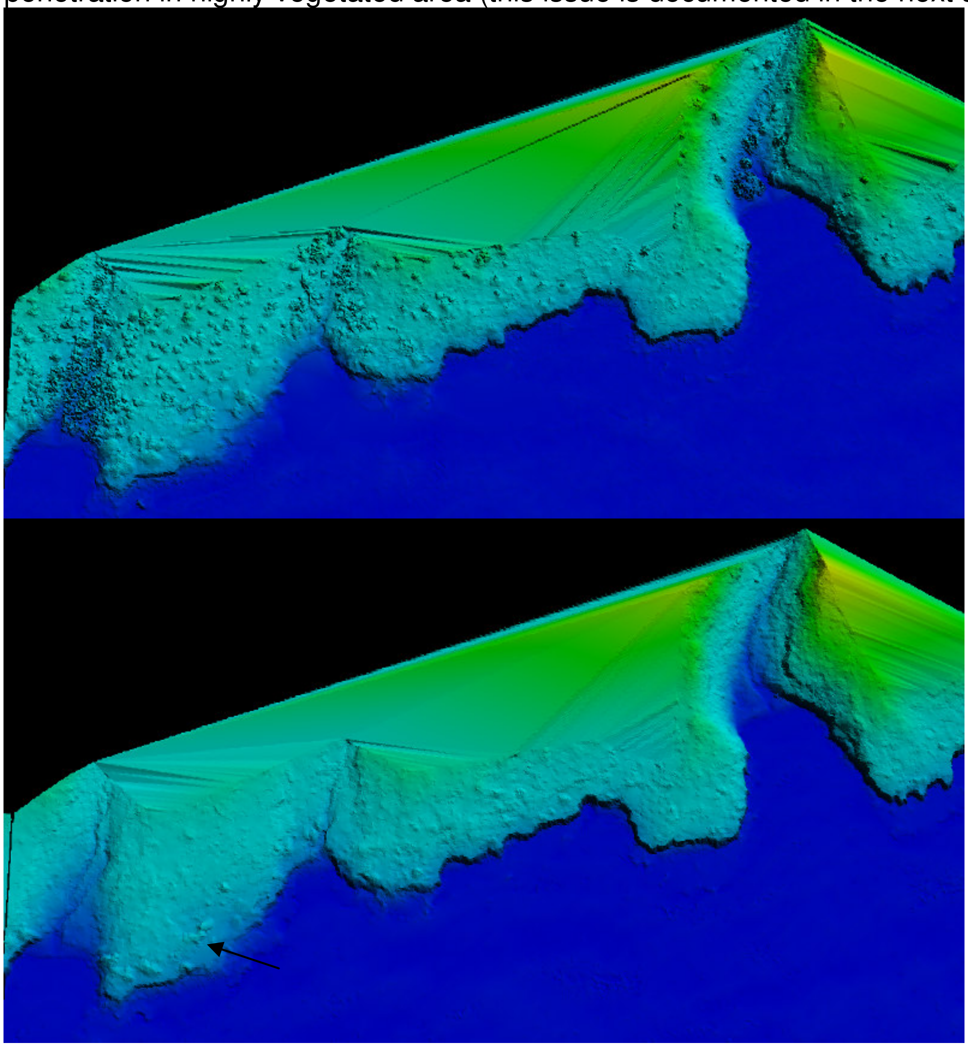


Figure 20 – Extracted feature model (up) and bare earth model (down). Well defined stream channel and possible vegetation remains on the slopes. (Tile 0441)

2.3.4 Maui

As previously stated, cliffs and naturally bare earth areas tend to exhibit fewer issues and are of better quality than other zones (see Figure 21 and Figure 22).

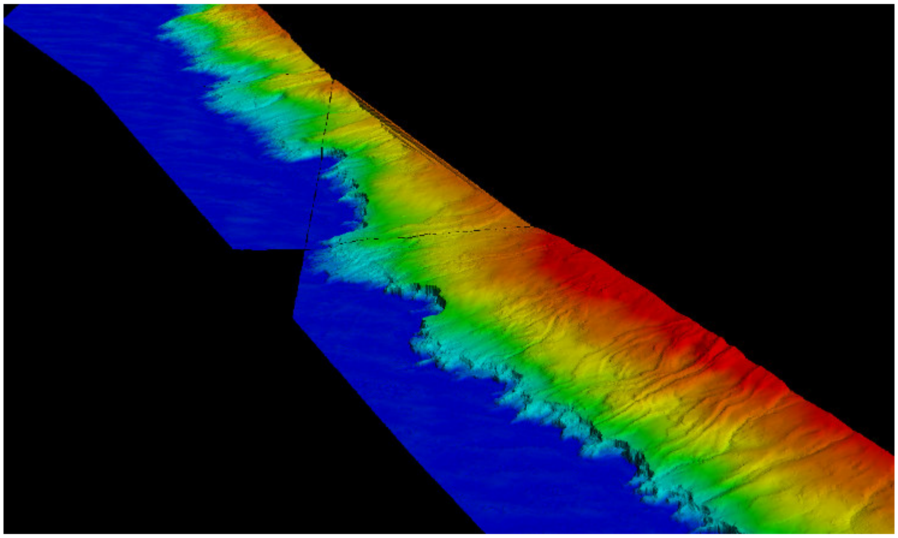


Figure 21 – Perspective view of a well define coast

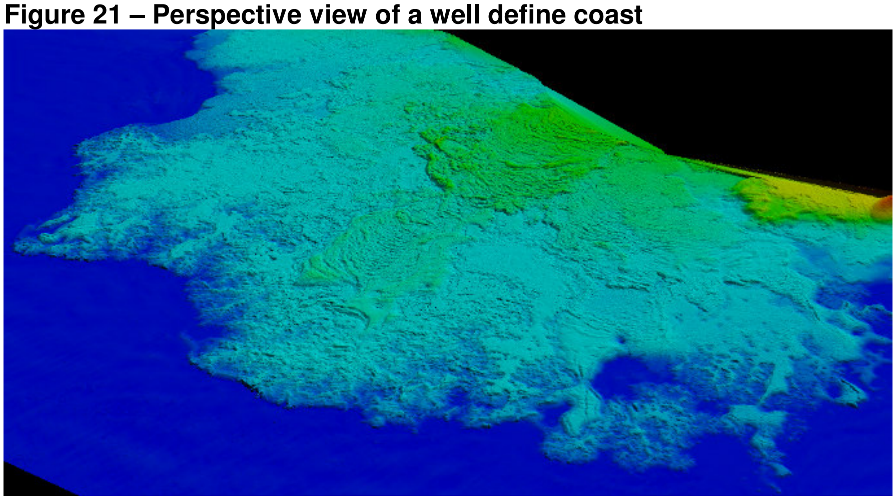
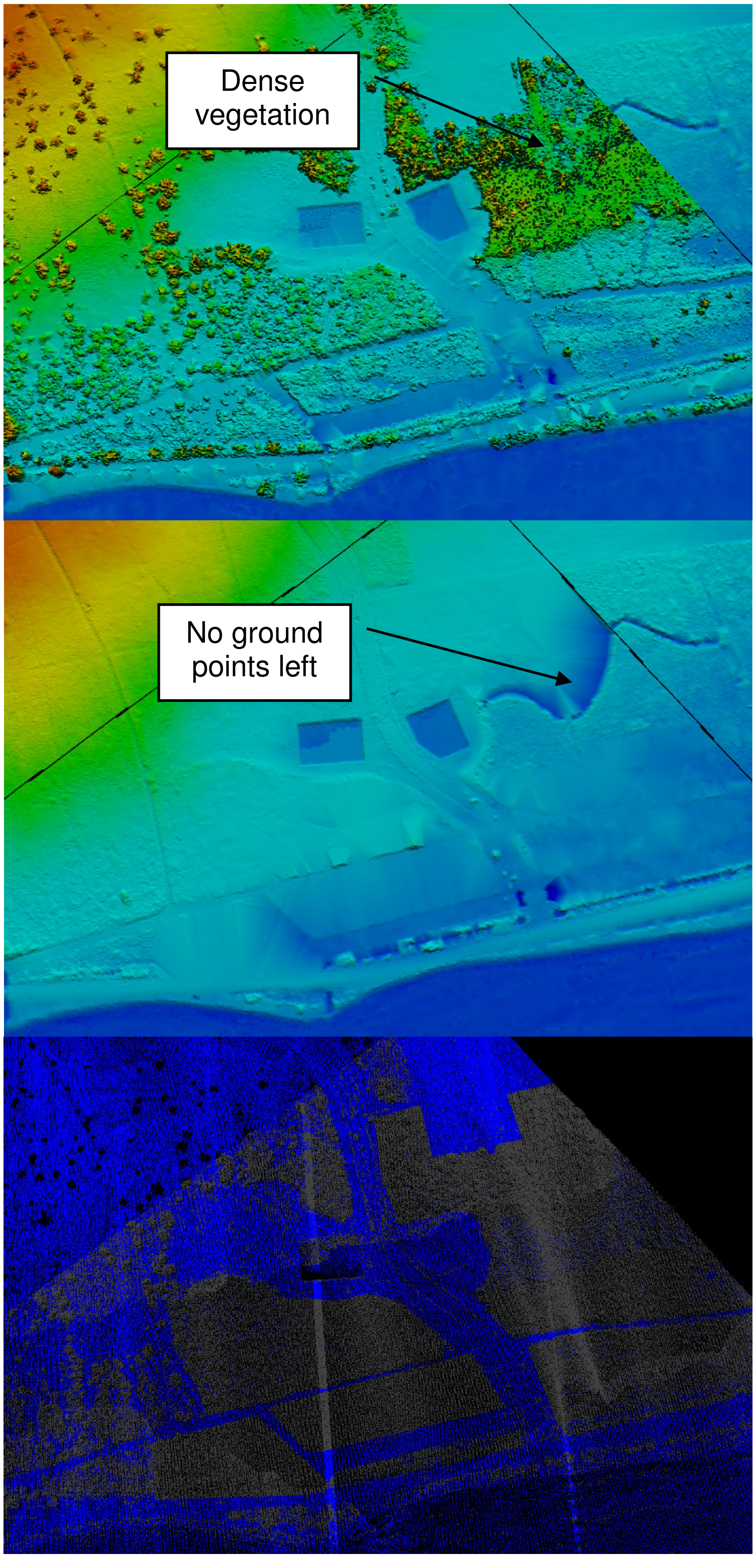


Figure 22 – Lava extrusion

Nevertheless, we have also often encountered more problematic tiles during our review of Maui. First, we have faced a recurring (over all three islands) issue of dramatic low density of points in really densely vegetated areas (see Figure 23 and Figure 26, upper right corner). It is believed that this may be caused by a poor penetration of the LiDAR beam between the leaves and branches because of their density.

In addition, the Maalaea Bay Area especially catches our attention as significant classification issues were found there. Its location is given in Figure 25. In this case, instances of low density of ground points seem to be caused by an overaggressive classification of vegetation. Indeed, processing discrepancies were noticeable between two adjacent tiles as illustrated Figure 27 and Figure 28. Moreover, a few divots were found along roads (Figure 29).



Extracted feature model

Ground model

LiDAR point cloud (ground in blue, extracted feature in gray)

Figure 23 – Poor LiDAR penetration in dense vegetation. (Tile 1045)

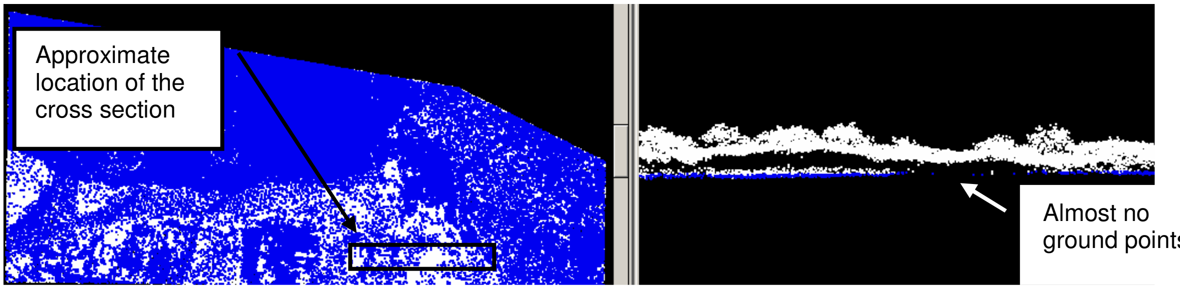


Figure 24 – Full point cloud colored by class (blue = ground, white = extracted features). (Tile 1045)

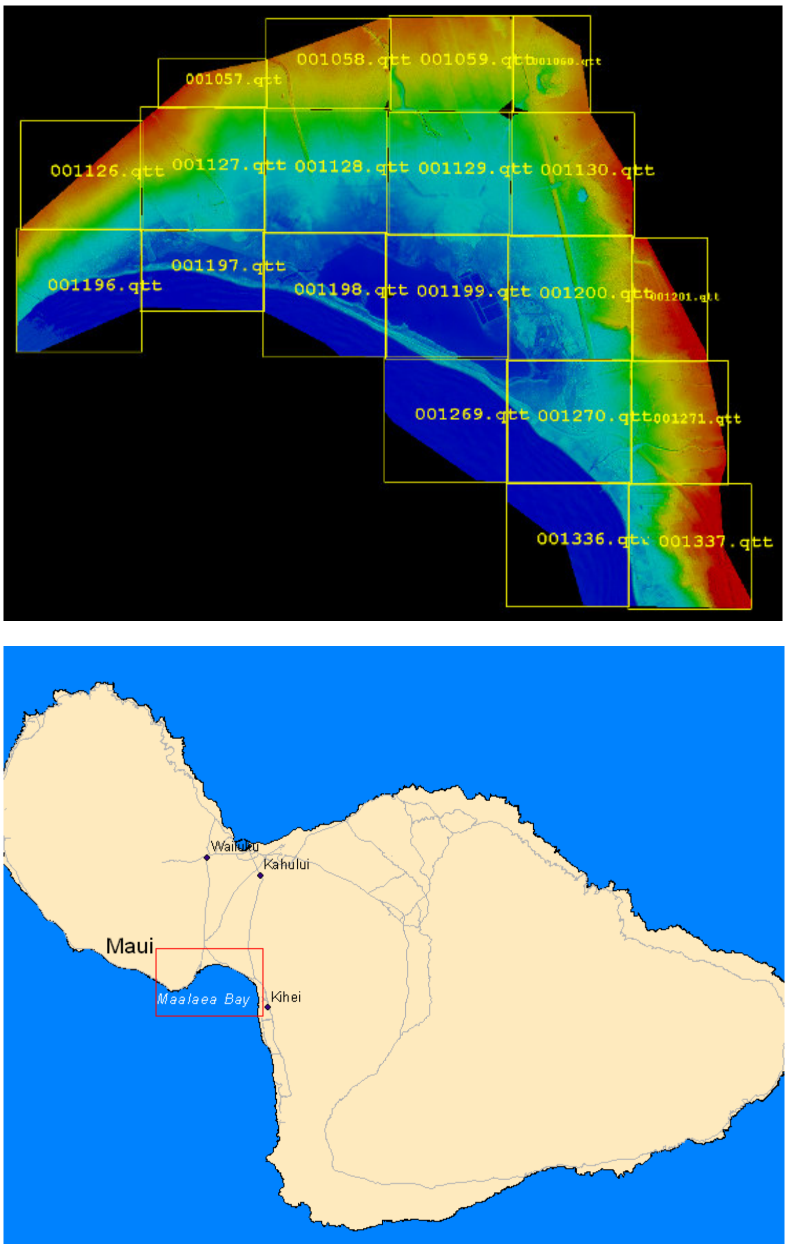


Figure 25 – Maalaea Bay. Problematic area

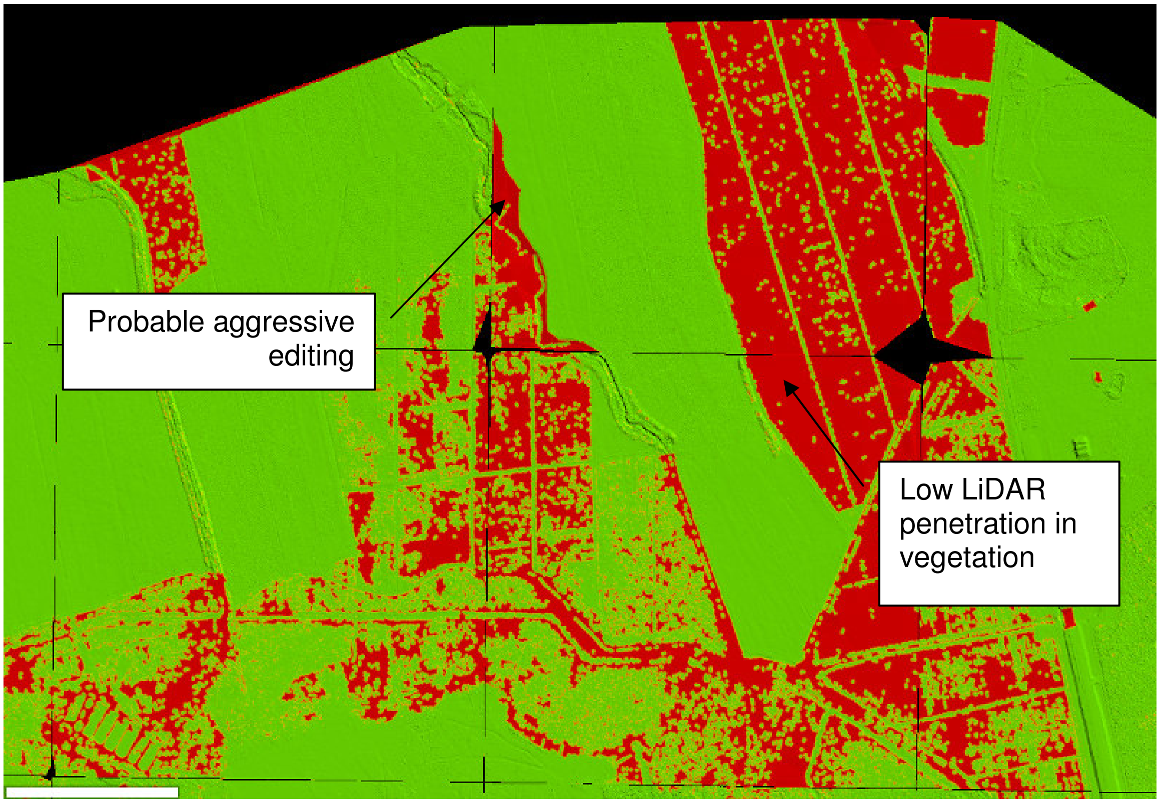


Figure 26 – Point density on bare earth model. Red indicates low density areas. Black holes in corners of adjacent tiles are caused by the absence of ground points at this location. (Tile 1059)

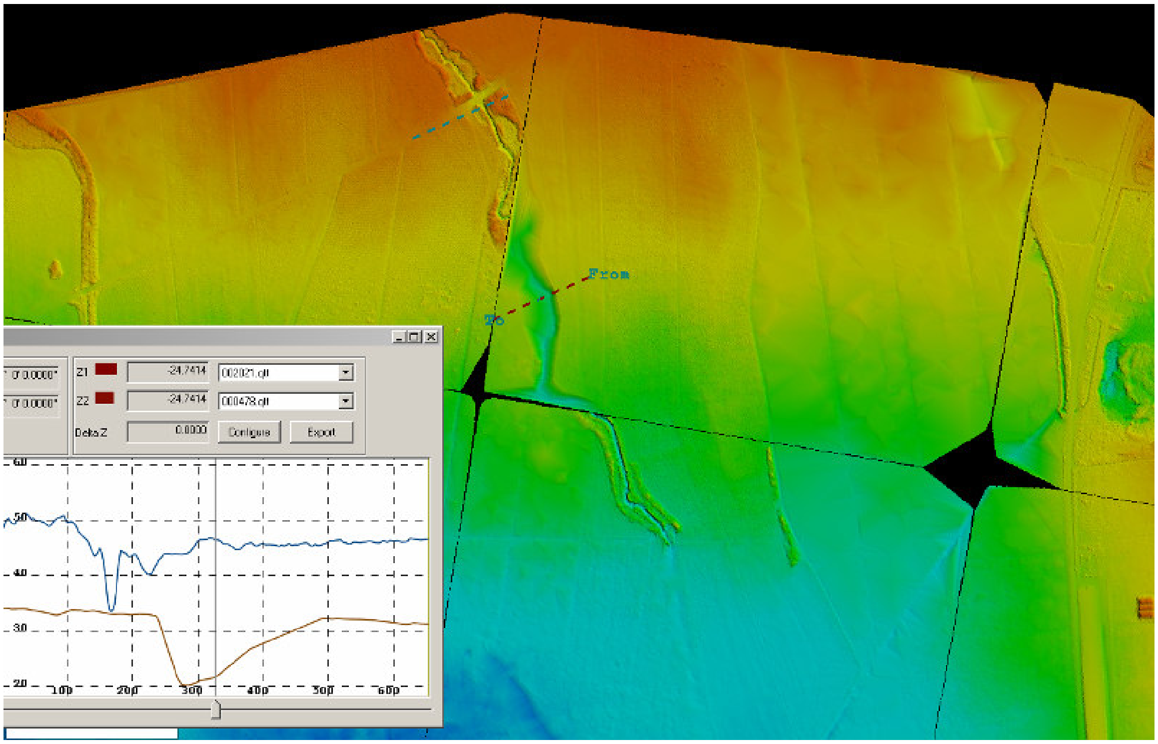


Figure 27 – Bare earth model, different level of processing between two tiles. The blue profile shows a well preserved stream channel whereas the dark red profile computed in the other tile is oversimplified (elevations in feet). (Tile 1059)

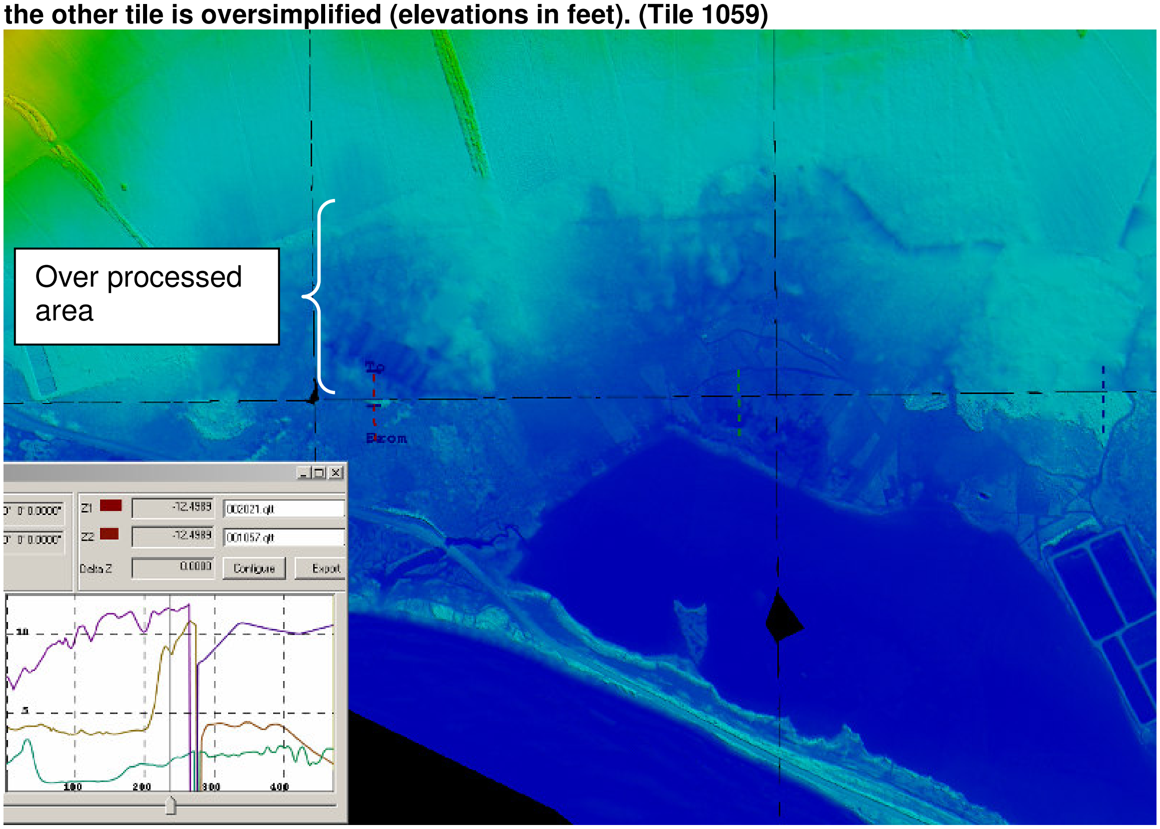


Figure 28 – Ridge between two tiles (Maui, Tile 1128)

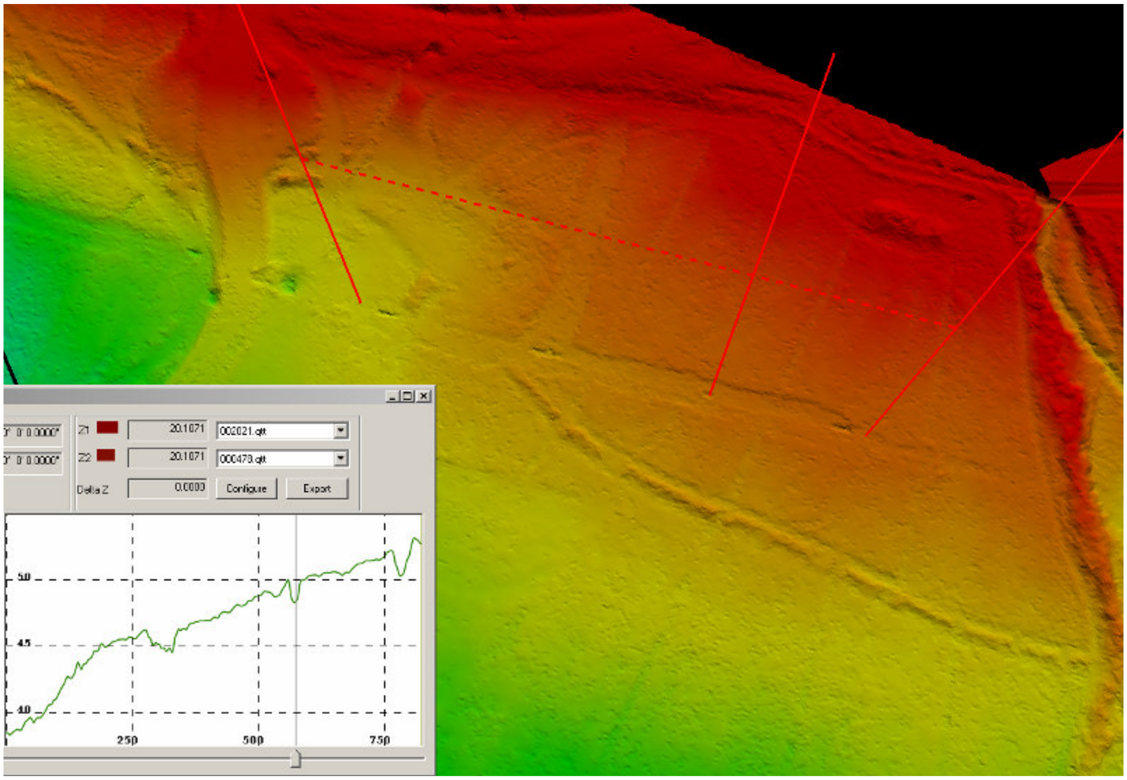


Figure 29 – Divots along a road (Maui, Tile 1117)

Finally, Airborne 1 stated to us in a letter that there were multiple data gaps found in the Maui tiles. On average, these gaps have an area of 1 acre or less (see example Figure 30).

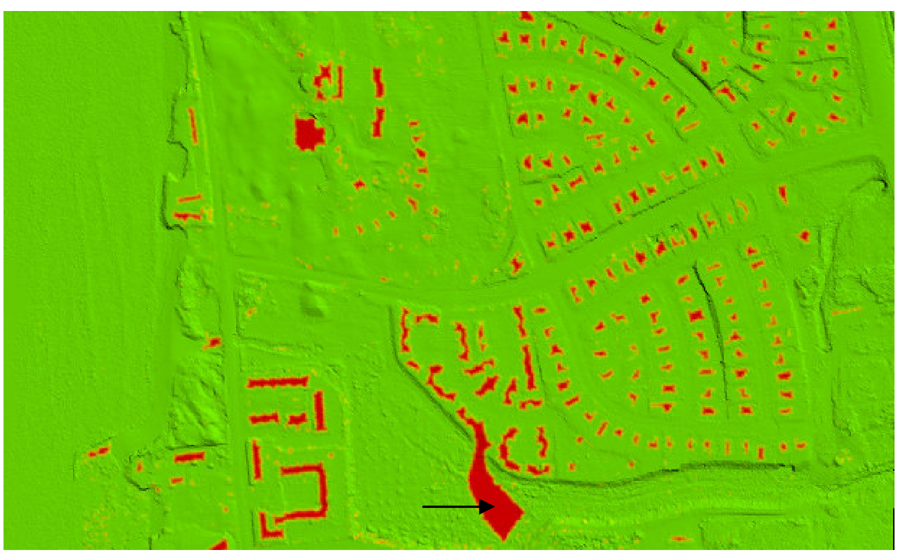


Figure 30 – Gap in data (point density of ground model, red indicates no data), the small rectangular red shapes are legitimate removed building footprint (Maui, Tile 1398)

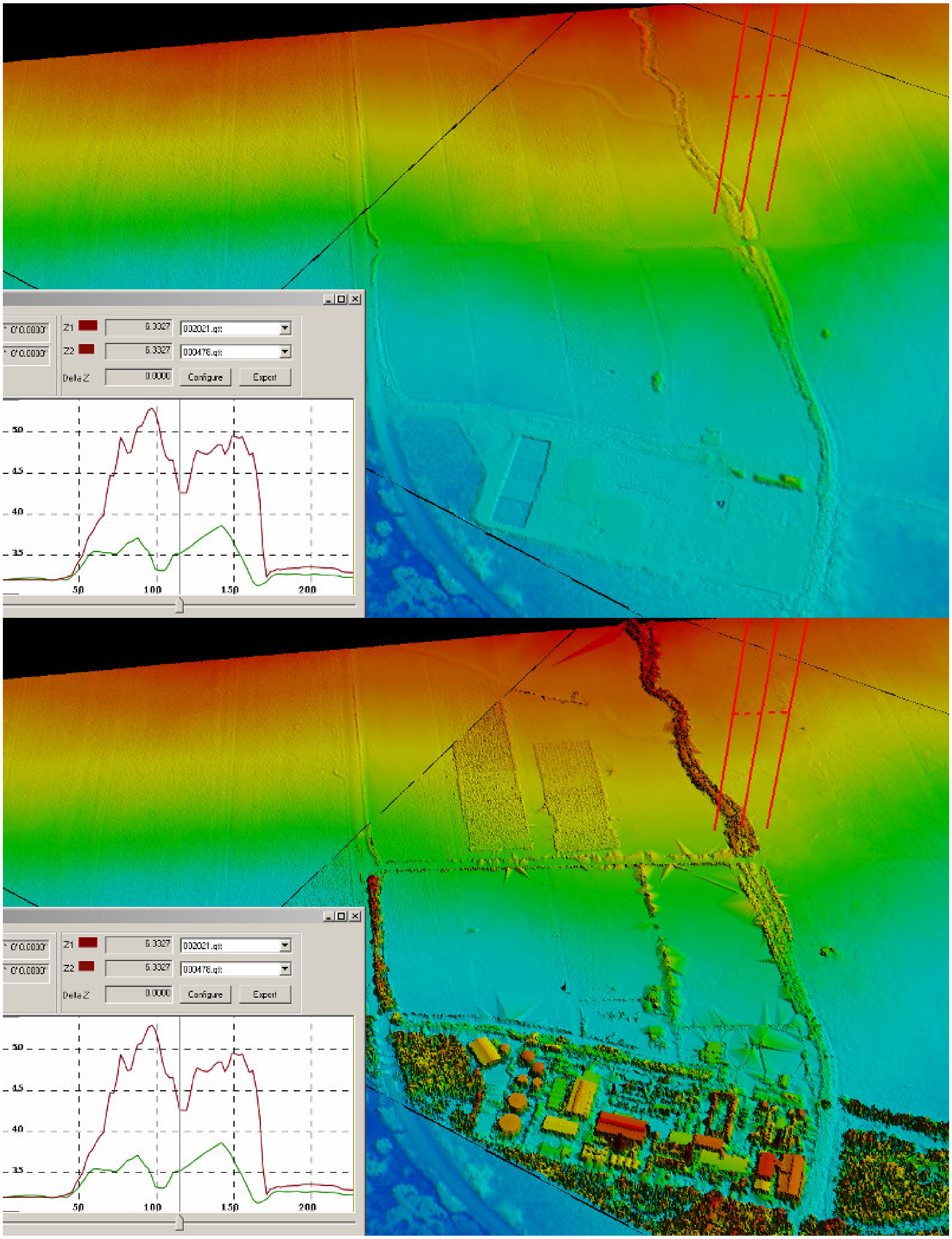


Figure 31 – Possible vegetation remains (Maui, Tile 1127)

2.3.5 Molokai

Molokai Island exhibits the same issue of low penetration of LiDAR in densely vegetated areas, which were typically seen throughout the project. As previously illustrated, we

also found some divots and some spikes in the extracted features files but one tile has also a spike anomaly in the bare earth product.
In addition, instances of holes in the data were found, especially in the upper west side of the project area as illustrated in Figure 32 and Figure 33. Another specific issue for this island was a cornrow effect visible in several adjacent tiles (Figure 34). There are multiple reasons as to why this happens but the end result is that adjacent scan lines are slightly offset from each other. This will give the effect that there are alternating rows of higher and then lower elevations. Although this is common with LiDAR data, as long as the elevation differences are less than 20 cm and the occurrences are minimized, it is acceptable because it is within the noise and accuracy levels. However this also can be an indication that the sensor is mis-calibrated, or offsets exist between adjacent flight lines so each area identified is analyzed.

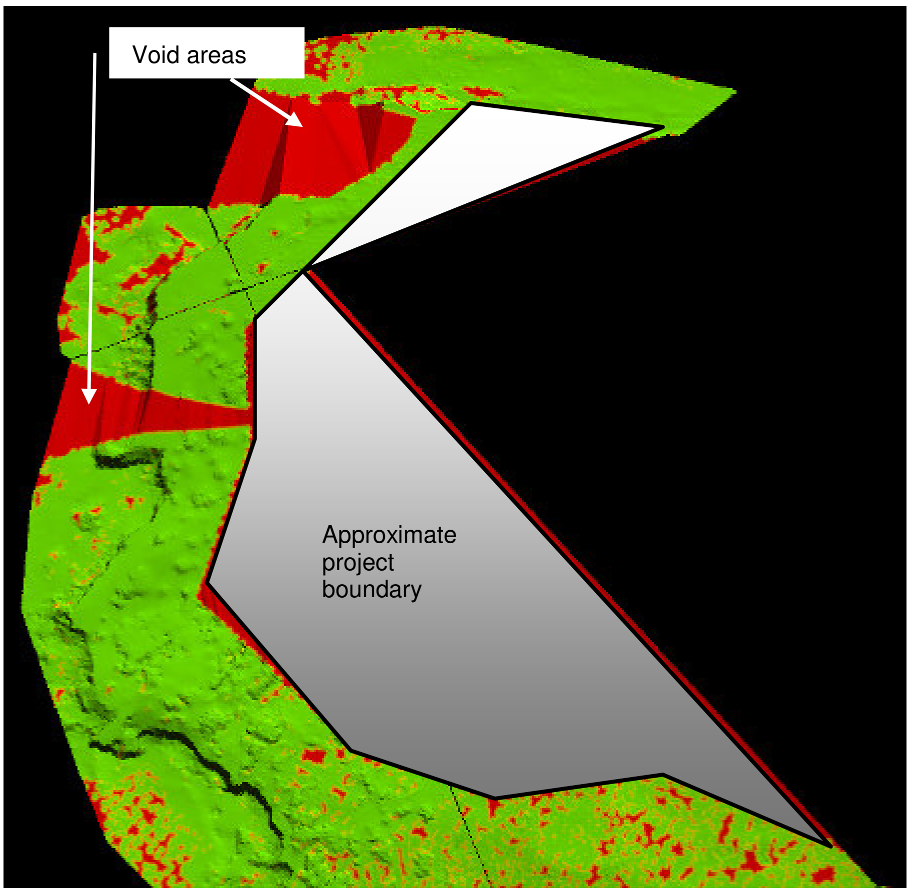


Figure 32 – Hole in data - Ground point density (Tile 002)

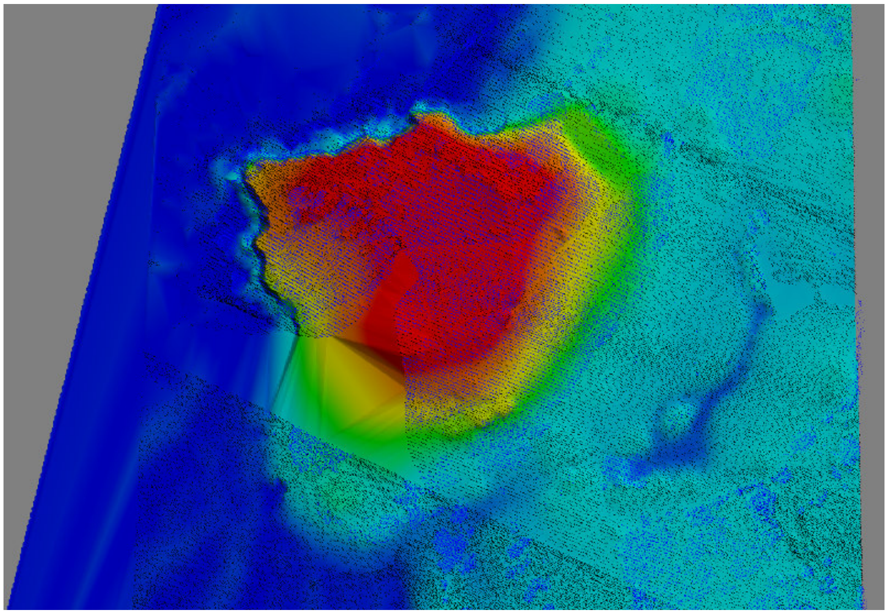


Figure 33 – Hole in data (ground model, full point cloud)

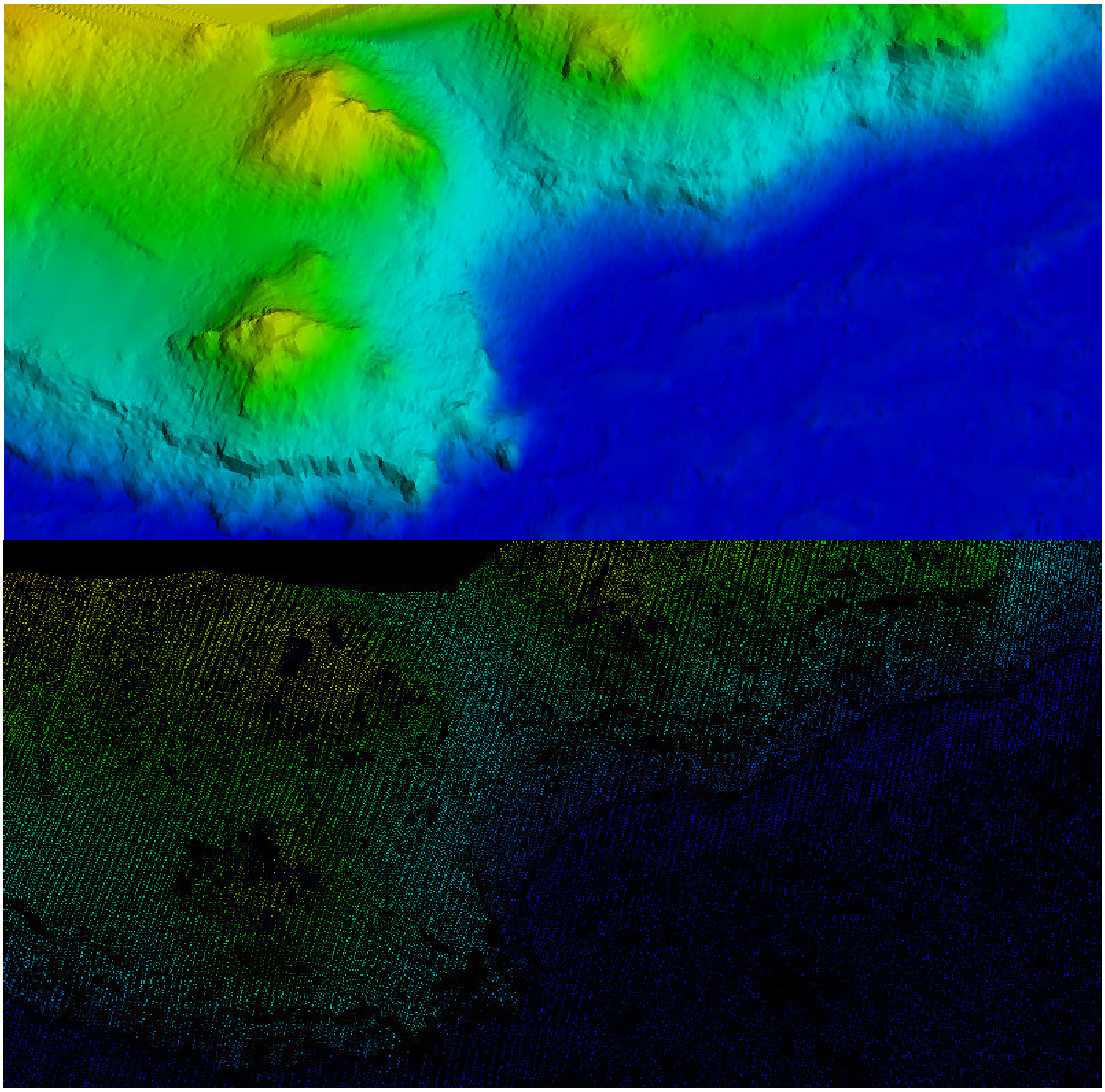


Figure 34 – Cornrow effect (up: bare earth model, down: ground point cloud)

3 Conclusion

Lanai is more than complete as we have more data than was required. Molokai was complete after 2 deliveries and was entirely resubmitted to correct a vertical adjustment. Maui is incomplete and exhibits a vertical bias that does not prevent the data to pass the required standard. Minor errors were found in the bare earth quality assessment, especially inconsistent editing in central Maui. Maui also consists of multiple projects flown at different times and with slightly different control values. Therefore offsets occur at project boundaries and these have not been resolved in these datasets. Globally the level cleanliness of the data is acceptable considering the dense vegetation even though some artifacts remain. Small data holidays were found throughout the project and missing tiles were identified in Maui however it was finally decided not to reacquire them. NOAA LiDAR data has been proposed to supplement Maui.

These data should fit most users' needs; however caution should be exercised for the Maui Island.

Appendix A Maui replaced tiles

Original tile name	TileNoStr	Source
11	N00011	Noaa
12	N00012	Noaa
20	N00020	Noaa
21	N00021	Noaa
22	N00022	Noaa
23	N00023	Noaa
24	N00024	Noaa
35	N00035	Noaa
36	N00036	Noaa
39	N00039	Noaa
48	N00048	Noaa
49	N00049	Noaa
50	N00050	Noaa
65	N00065	Noaa
66	N00066	Noaa
84	N00084	Noaa
85	N00085	Noaa
103	N00103	Noaa
104	N00104	Noaa
124	N00124	Noaa
125	N00125	Noaa
146	N00146	Noaa
178	N00178	Noaa and TO12
179	N00179	Noaa and TO12

NOAA:

- Originator: NOAA Coastal Services Center Coastal Remote Sensing Program, http://www.csc.noaa.gov/LiDAR
- Publication_Date: 20070710
- Title: Oahu/Maui 2005 LiDAR mapping project
- ASCII files (xyz) converted in LAS, ground only
- State plane Hawaii Zone 2 US Feet, Z in feet

Appendix B Survey Report

See attached document: 2007 TO-12 LiDAR QAQC GPS Survey Report

Appendix C Checkpoints

Molokai

Point #	Easting	Northing	Elevation	zLiDAR	LandCoverType	DeltaZ
2508	1522399.81	273292.96	5.77	5.6469	Open Terrain/Urban	-0.13
2523	1596768.97	268896.04	4.86	4.75	Open Terrain/Urban	-0.11
2501	1508832.89	281727.67	28.74	28.6556	Open Terrain/Urban	-0.08
2517	1584559.58	264731.21	12.50	12.4167	Open Terrain/Urban	-0.08
2521	1594097.97	267957.75	10.66	10.5808	Open Terrain/Urban	-0.08
2505	1517450.88	275605.46	8.43	8.3789	Open Terrain/Urban	-0.05
2520	1583154.17	263485.66	14.37	14.3395	Open Terrain/Urban	-0.03
2516	1588056.83	266444.32	13.98	13.9908	Open Terrain/Urban	0.01
2513	1533243.01	268999.32	5.05	5.0833	Open Terrain/Urban	0.03
2522	1595293.12	268598.98	6.10	6.138	Open Terrain/Urban	0.04
2506	1520114.13	274591.62	5.12	5.1667	Open Terrain/Urban	0.05
2519	1580862.84	262635.26	14.50	14.5725	Open Terrain/Urban	0.07
2518	1583528.62	263849.20	11.02	11.1111	Open Terrain/Urban	0.09
2500	1506304.55	280516.72	10.86	10.9809	Open Terrain/Urban	0.12
2524	1586712.59	265735.30	23.23	23.3735	Open Terrain/Urban	0.15
2502	1510855.28	279512.09	15.22	15.3803	Open Terrain/Urban	0.16
2515	1591320.63	267064.43	3.15	3.4729	Open Terrain/Urban	0.32
2507	1519398.77	275123.77	6.86	7.1824	Open Terrain/Urban	0.33
2509	1525512.88	271912.62	7.09	7.4167	Open Terrain/Urban	0.33
2504	1514945.85	277140.50	6.00	6.3394	Open Terrain/Urban	0.34
2503	1513114.75	277780.30	11.61	11.9625	Open Terrain/Urban	0.35
2510	1527958.66	270832.53	4.23	4.5833	Open Terrain/Urban	0.35
2514	1535322.19	268038.53	5.31	5.7582	Open Terrain/Urban	0.44
2511	1530840.99	270227.08	4.69	5.25	Open Terrain/Urban	0.56

Lanai

Point #	Easting	Northing	Elevation	zLiDAR	LandCoverType	DeltaZ
2114	1634461.07	206436.34	22.64	21.7193	Open Terrain/Urban	-0.92
2115	1633736.41	225739.59	4.72	3.9296	Open Terrain/Urban	-0.79
2104	1632400.93	220761.95	10.86	10.0833	Open Terrain/Urban	-0.78
2106	1632725.45	210013.56	11.09	10.3333	Open Terrain/Urban	-0.76
2123	1634600.24	227602.69	12.27	11.5617	Open Terrain/Urban	-0.71
2113	1634283.59	204490.67	11.84	11.1522	Open Terrain/Urban	-0.69
2101	1636519.18	195611.34	7.97	7.3169	Open Terrain/Urban	-0.66
2105	1631253.96	215918.71	9.28	8.6416	Open Terrain/Urban	-0.64
2107	1639628.34	191277.33	11.48	10.9403	Open Terrain/Urban	-0.54
2102	1633081.46	222977.64	20.18	19.689	Open Terrain/Urban	-0.49
2111	1635073.01	198269.93	9.81	9.3418	Open Terrain/Urban	-0.47
2112	1633923.66	199894.59	8.27	7.8276	Open Terrain/Urban	-0.44
2109	1638433.25	193049.65	11.25	10.9278	Open Terrain/Urban	-0.33
2110	1637202.12	195185.89	7.32	7.0085	Open Terrain/Urban	-0.31
2103	1633287.60	224232.72	9.88	9.7102	Open Terrain/Urban	-0.17
2108	1640854.46	190150.46	5.94	5.8423	Open Terrain/Urban	-0.10

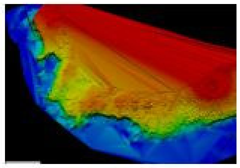
Maui

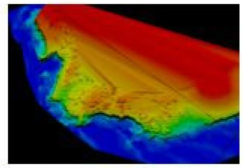
Point #	Easting	Northing	Elevation	zLiDAR	LandCoverType	DeltaZ
2322	1562386.72	147842.85	10.99	10.9851	Grass/Scrub	-0.01
2321	1561658.19	147769.94	29.56	29.9549	Grass/Scrub	0.39
2306	1564532.89	148580.16	18.18	17.8411	Open Terrain/Urban	-0.33
2319	1562887.01	147947.57	28.61	28.2989	Open Terrain/Urban	-0.31
2310	1563865.25	148142.15	19.32	19.0223	Open Terrain/Urban	-0.30
2318	1563177.83	148197.09	36.61	36.3165	Open Terrain/Urban	-0.30
2317	1563498.01	148460.86	38.22	37.9425	Open Terrain/Urban	-0.28
2311	1563654.78	147900.68	14.01	13.7349	Open Terrain/Urban	-0.27
2312	1563447.13	147592.71	8.96	8.7032	Open Terrain/Urban	-0.25
2314	1563115.88	146585.50	16.34	16.0854	Open Terrain/Urban	-0.25
2303	1529274.20	164787.16	10.89	10.6505	Open Terrain/Urban	-0.24
2302	1529645.75	164908.21	10.04	9.81	Open Terrain/Urban	-0.23
2316	1563360.24	147897.38	18.96	18.752	Open Terrain/Urban	-0.21
2320	1562604.93	148035.05	34.97	34.7672	Open Terrain/Urban	-0.21
2315	1563171.53	147663.25	8.14	7.9594	Open Terrain/Urban	-0.18
2305	1564800.62	147816.51	29.27	29.0887	Open Terrain/Urban	-0.18
2304	1564849.14	148249.40	4.76	4.5829	Open Terrain/Urban	-0.17
2307	1564981.10	148900.28	4.89	4.7239	Open Terrain/Urban	-0.16
2308	1563982.02	148683.91	35.37	35.2168	Open Terrain/Urban	-0.15
2309	1564013.94	148470.99	22.31	22.1831	Open Terrain/Urban	-0.13
2313	1563280.65	147256.26	6.92	6.8583	Open Terrain/Urban	-0.06
2301	1529421.79	165048.66	26.48	26.4395	Open Terrain/Urban	-0.04
2323	1561806.94	147794.81	25.49	25.5103	Open Terrain/Urban	0.02

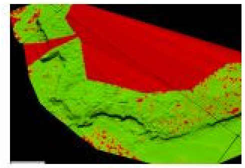
Appendix D Qualitative Issues Contact Sheets

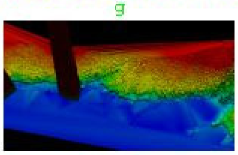
T012 - Molokai

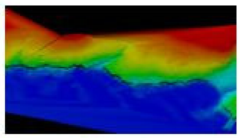

002_dataHolidayInDataBeginProject_qttGround.png

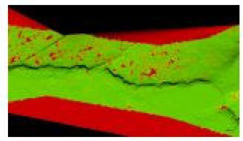

002_dataHolidaySparseData_qttExtFeat.png

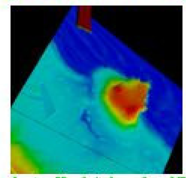

002_dataHolidaySparseData_qttGround.png

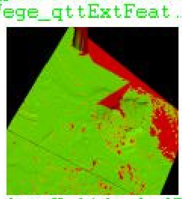

002_dataHolidaySparseData_qttGrounddens.png

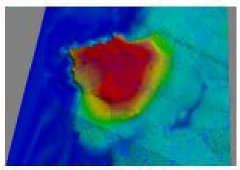

017_poorLidarPentrationInVege_qttExtFeat.png

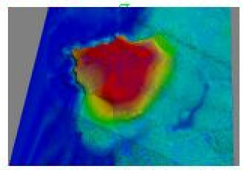

017_poorLidarPentrationInVege_qttGround.png

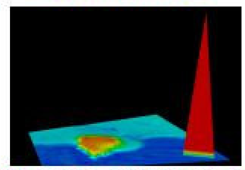

017_poorLidarPentrationInVege_qttGroundDens.png

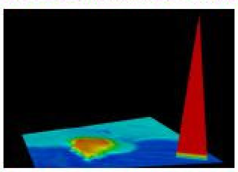

091_dataHolidayAndSpike_qttGround.png

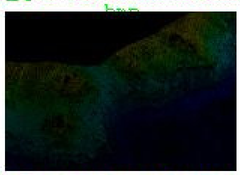

091_dataHolidayAndSpike_qttGroundDensity.png

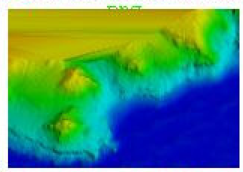

091_missingData_qttGround_qtcGroundAndExtFeat.bmp

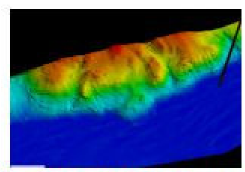

091_missingData_qttGround_qtcGroundAndExtFeat.png

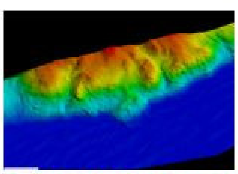

091_spike_qttGround.bmp

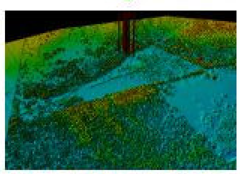

091_spike_qttGround.png

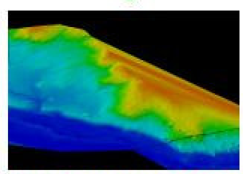

318_cornrow_qtcGround.png

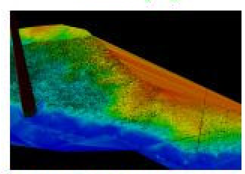

318_cornRow_qttGround.png

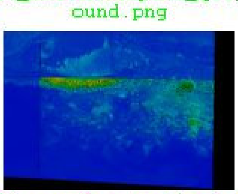

443_noiseAndSpike_qttextfeat.png

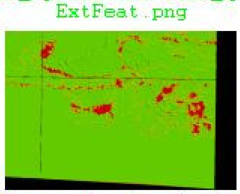

443_noiseAndSpike_qttground.png


529_spikesInExtFeat_qttExtFeat.png

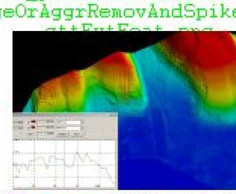

568_poorPenetrationInVegeOrAggrRemov_qttGround.png

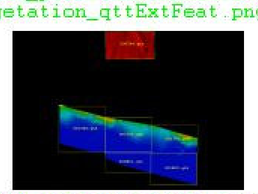

568_poorPenetrationInVegeOrAggrRemovAndSpikes_qttExtFeat.png

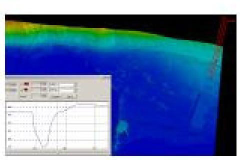

652_poorPenetrationInVegetation_qttExtFeat.png


652_poorPenetrationInVegetation_qttGround.png

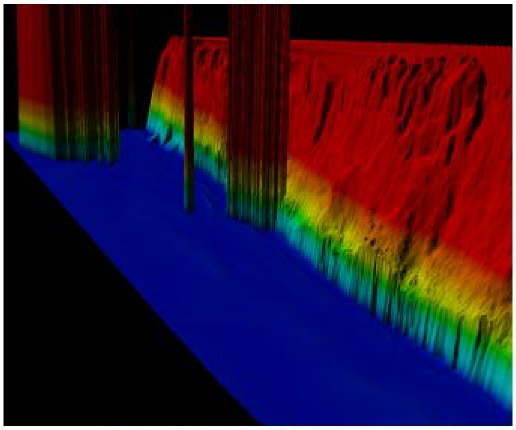

733_cornrowEffect_qttExtFeat.png


733_cornrowEffect_qttGround.png

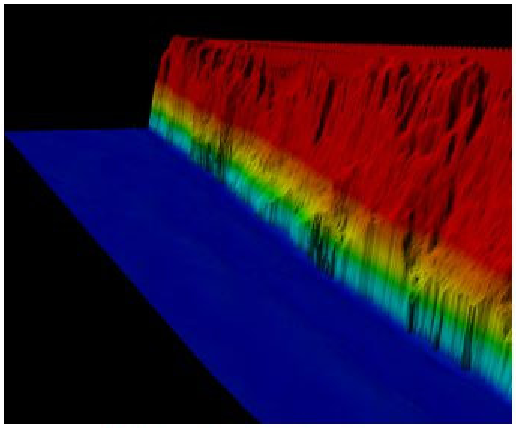

749_unrequiredTile_qttGround.png


797_Divot_cornRow_qttGriund.png

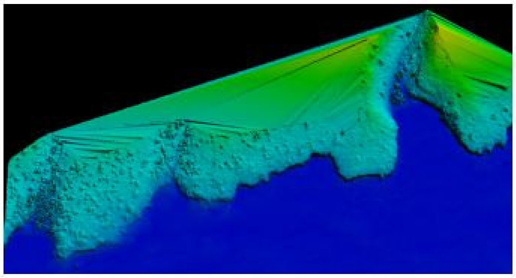
T012 – Lanai



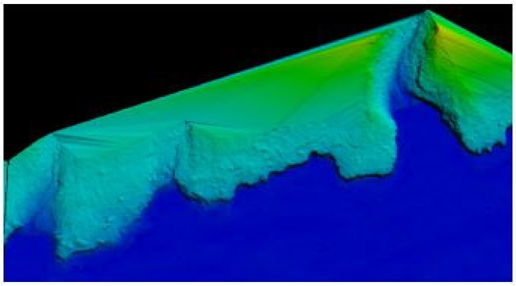
0389_spikes_qttExtfeat.png



0389_spikes_qttGround.png

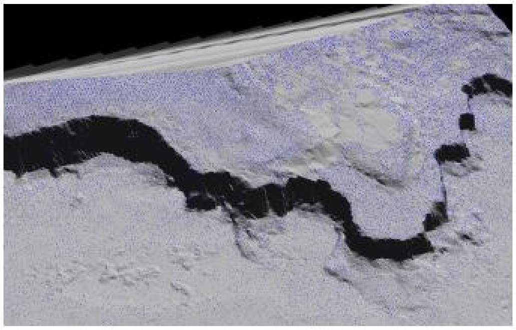


0441_possibleVegetRemains_qttextFeat.png



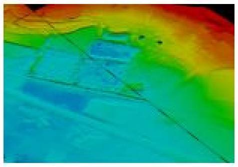
0441_possibleVegetRemains_qttGround.png

0445_poorPenetrationInVegetation_qtcExtFeatGreyQtcGroundBlue.png

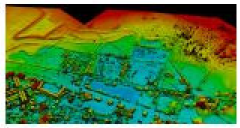


0445_poorPenetrationInVegetation_qttGroundQtcGround.png

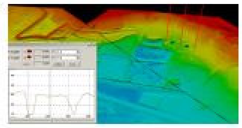
TO12 – Maui



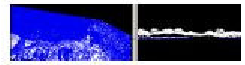
0655_vegetationRemain_qttGround.png



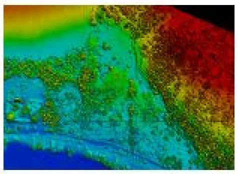
0655_vegetationRemainsAndDivots_qttExtFeat.png



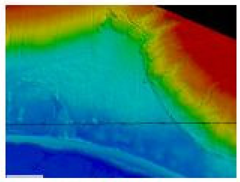
0655_vegetationRemainsAndDivots_qttGround.png



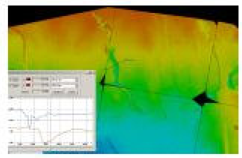
1045_poorLidarPenetrationInVegetation.PNG



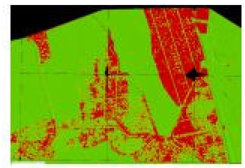
1045_poorLidarPenetrationInVegetation_qttExtFeat.png



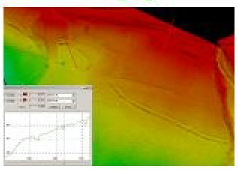
1045_poorLidarPenetrationInVegetation_qttGround.png



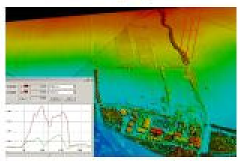
1059_aggressiveRemovalOfVege_qttGround.png



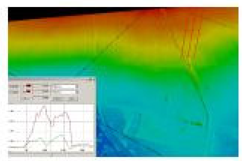
1059_aggressiveRemovalOfVege_qttGroundDensity.png



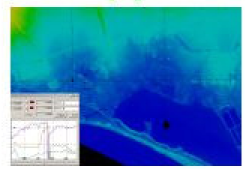
1117_divotAlongRoad_qttGround.png



1127_possibleVegetationRemainOnStreamBanks_qttExtFeat.png

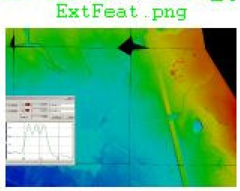


1127_possibleVegetationRemainOnStreamBanks_qttGround.png

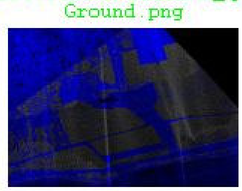


1128_tileEdgeMatchingIssue.png

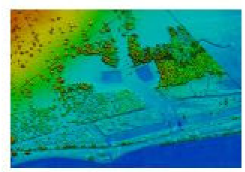
1128_tileEdgeMatchingIssue_qtcground.png



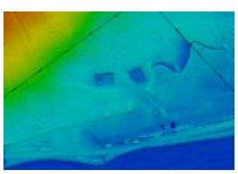
1130_possibleArtifact_qttGround.png



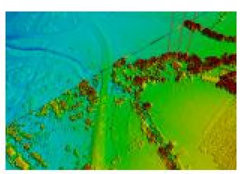
1187_poorLidarPenetrInVege_qtcGroundBlueQtcExtFeatGrey.png



1187_poorLidarPenetrInVege_qttExtFeat.png



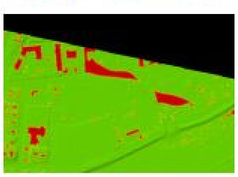
1187_poorLidarPenetrInVege_qttGround.png



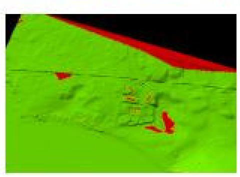
1271_divotAndGoodBridgeRemoval_qttExtFeat.png

1271_divotAndGoodBridgeRemoval_qttGround.png

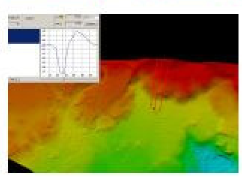
1398_dataHoliday_qttGroundDEns.png



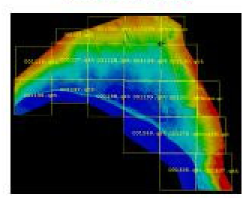
1613_dataHoliday_qttGroundDEns.png



2113_dataHoliday_qttGroundDens.png

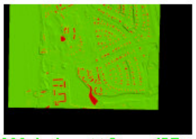


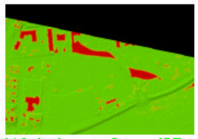
2159_divot_qttGround.png

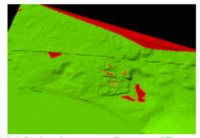


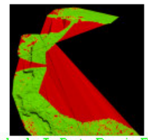
problematicArea.png

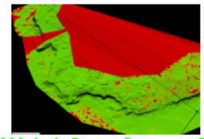
TO12 - Data Holidays

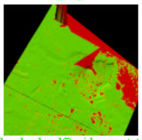

1398_hole_qttGroundDEns.png


1613_hole_qttGroundDEns.png


2113_hole_qttGroundDens.png


002_holeInDataBeginProject_qttGround.png


002_holeSparseData_qttGrounddens.png


091_holeAndSpike_qttGroundDensity.png