# Lidar QaQc Report
# Hawaii TO26: Big Island, Oahu, and Kauai
August 2007

Prepared by:
Dewberry
Fairfax, VA

# EXECUTIVE SUMMARY

This Lidar project covered the southern shores of 3 Hawaii islands (Big Island, Kauai and Oahu). 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 FEMA *Guidelines and specifications for Flood Hazard Mapping Partners*). To meet 2 ft contour accuracy, the data needed to be accurate to 1.19 ft at the 95% confidence level. These data were tested 0.51 ft (Hawaii), 0.99 ft (Kauai) and 0.69 ft (Oahu) fundamental vertical accuracy at 95 percent confidence level in open terrain using RMSE x 1.96 using 68, 68 and 64 survey points, respectively, for these islands.

Secondly, 50% of the tiles were reviewed at macro level for data completeness: all tiles were delivered and data are exempt of systematic errors except for several remote-sensing data void (only one was localized under the 10m contour limit required by the contract and two at the upper limit). 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 meets the specifications. Minor errors were found (like sparse ground density in dense vegetation, cornrows and possible vegetation remains) but are not representative of the majority of the data.

In essence, this Lidar dataset is of good quality and meets the needs of FEMA and FEMA contractors for coastal mapping.

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# 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. As a consequence of this precision, millions of points with potential measurement and processing accuracy issues must be verified. This constitutes a challenge from the quality assessment aspect. Our expertise is to provide both a quantitative and qualitative evaluation of the Lidar mass points and its usability for coastal mapping.

First of all, 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.

To fully address the data for overall accuracy and quality, a qualitative review for anomalies and artifacts is also conducted based on the expertise of Dewberry's analysts. As no automatic method exists yet, we perform a manual visualization assessment. 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-Quality control process, three fundamental questions were addressed:

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

# 2 Quality Assurance

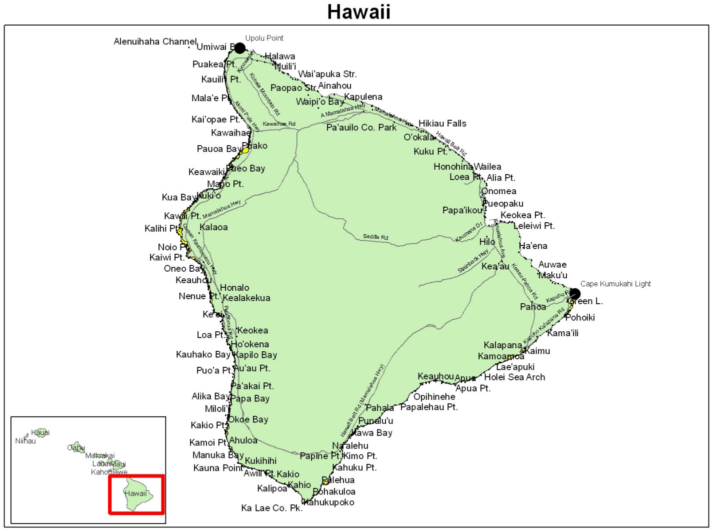
## *2.1 Completeness of Lidar deliverables*

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.

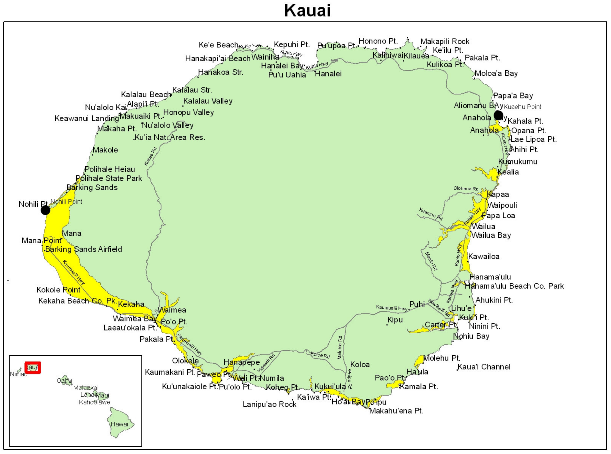
### 2.1.1 Inventory and location of data

The goal of this project was to collect Lidar data for the southern shores of 3 Hawaii islands: Big Island, Kauai and Oahu. No definitive boundary was defined by FEMA for this project. 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 as illustrated at Figure 1. This data will be used to perform the Hurricane Study for the Hawaiian Islands.

Hawaii



Kauai



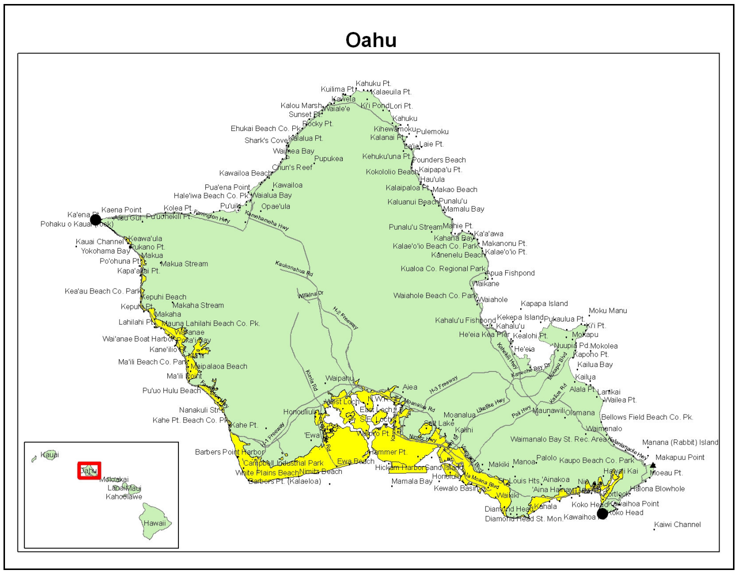



**Figure 1 – Project limits (black dots) and indicated 10ft contour**

Lidar data were correctly acquired by our 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.

After asking for a reprojection of Kauai which was initially delivered in UTM meters, we verified that all data are in Hawaii State Plane coordinates referenced to the appropriate zone (zone 1 for Big Island, zone 3 for Oahu and zone 4 for Kauai) referenced to the NAD 83 horizontal datum, the elevations are orthometric heights referenced to Local Mean Sea Level[1] (typically referred to as local tidal datum).

All files were delivered, covering the entire required area (see Figure 2 and Figure 3). For the Big Island, we had to remove duplicate tiles submitted in two different deliveries.

**Table 1 – Number of tiles delivered**

| **Island** | **Number of unique LAS files** |
|---|---|
| **Big Island** | **1075** |
| **Kauai** | **286** |
| **Oahu** | **434** |

[1] NAVD88 or NGVD29 does not exist for Hawaii

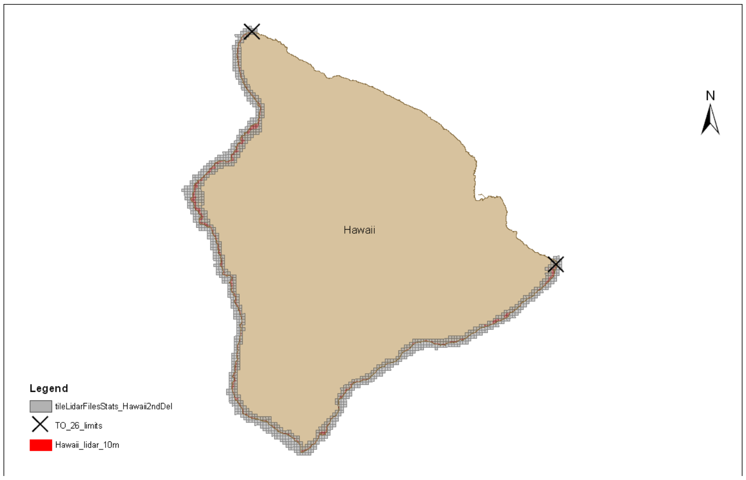



**Figure 2 – Inventory of the Las files; Hawaii**

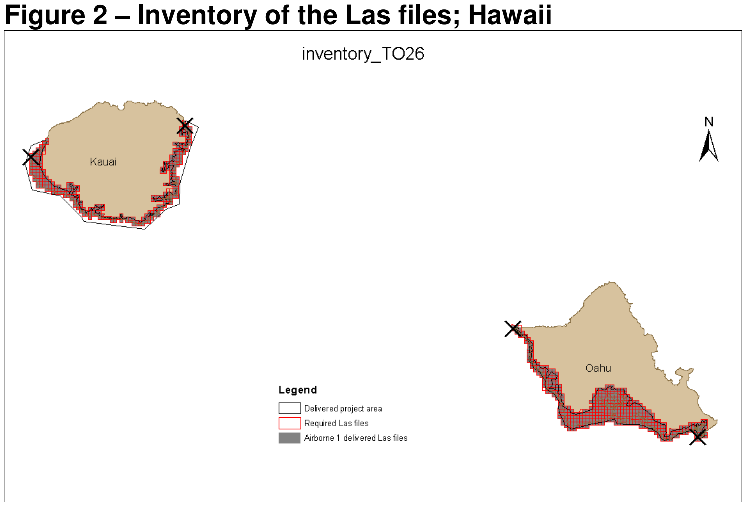



**Figure 3 – Inventory of the Las files; Kauai and Oahu islands**

### 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.

- *Big Island:*

Each tile was queried to extract the number of Lidar points and all tiles are within the anticipated size range, except for where fewer points are expected (near the project boundary or in water) as illustrated in Figure 4. To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. Figure 5 shows the minimum elevation value for each tile. Lowest values were found in water. In addition, Figure 6 illustrates the tiles with the highest elevation values. We verified that highest z-maximum values in ground files are legitimate Lidar points on top of cliffs (Figure 7).

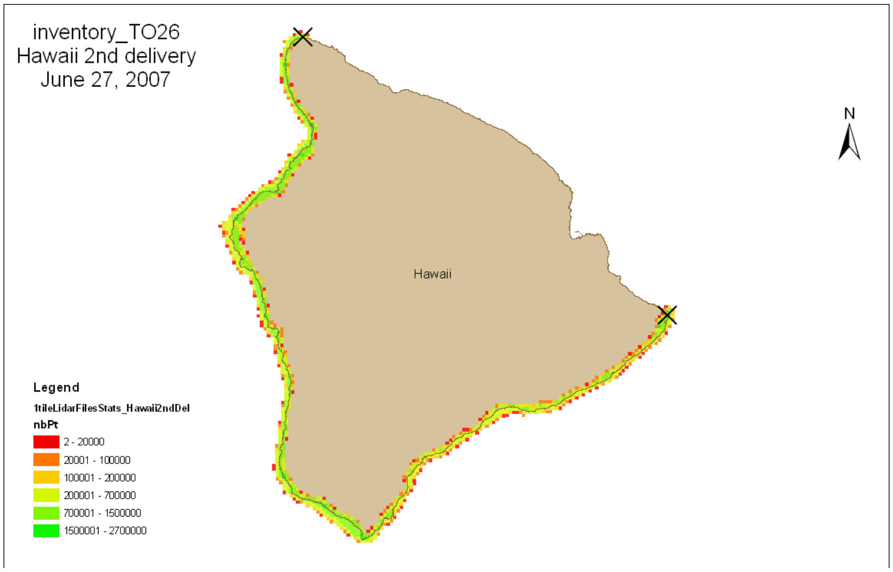



**Figure 4 - Number of points per tile (ground LAS files, mean: 500000 points)**

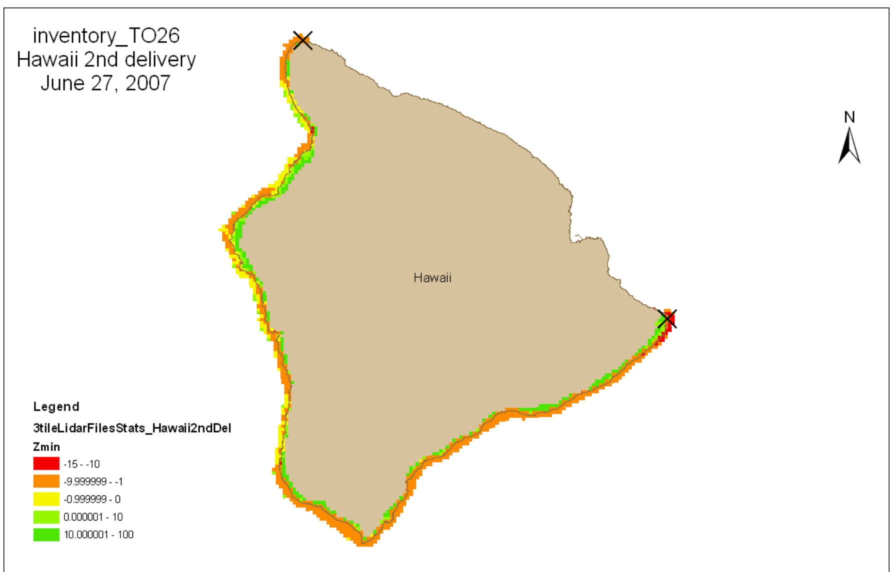



**Figure 5 – Minimum elevation in each ground LAS file (in feet)**

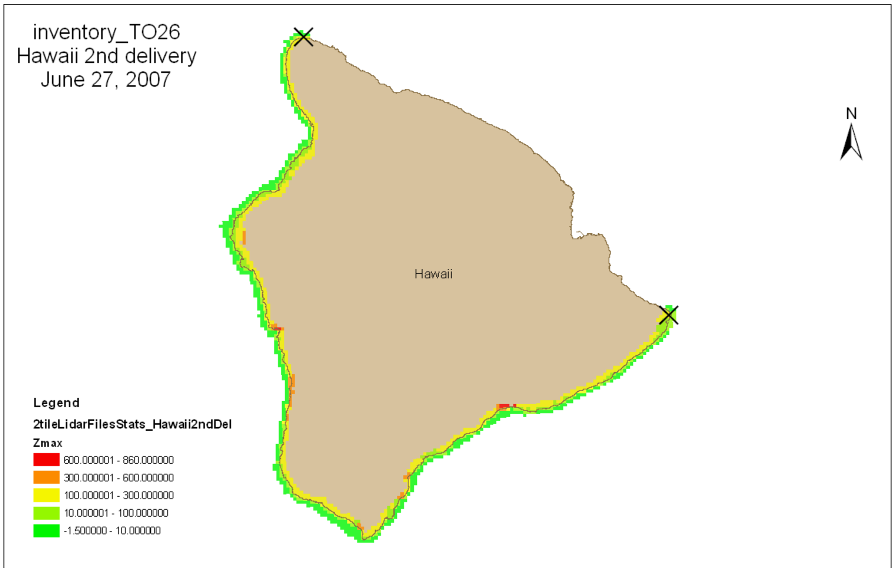



**Figure 6 - Maximum elevation in each ground LAS file (in feet)**

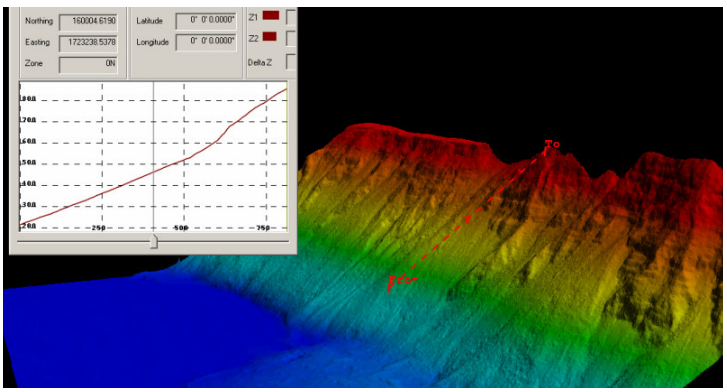


**Figure 7 – Legitimate high points on cliffs (elevations in feet)**

- *Kauai:*

The number of Lidar points per tile is within the anticipated size range, except for where fewer points are expected (near the project boundary). Figure 8 presents a map of the number of records in each LAS file (ground).

Figure 9 shows the z min value for each tile; a lot of files contain negative minimum z (167 files). About 40 files have minimum values below -1.5 m[2], for the most part, they are partially covered with water and the negative values are situated in water, except for tile 001222 where a divot was found illustrated in Figure 10. The other files with negative elevations do not exhibit noticeable anomalies; the lowest values are situated in ditches or in riverbeds for instance.

Figure 11 illustrates the tiles with the highest elevation values. We verified that all highest z-maximum values on ground files are legitimate Lidar points on mountains.

[2] The first delivery of Kauai data was projected in UTM meters, the inventory was performed on this delivery, therefore elevations are given in m. Note that the final data are in NAD83 State Plane Hawaii Zone 4, feet.

However, extracted feature files contain spikes as illustrated in Figure 12. Such anomalies are normal and they were correctly removed from the ground dataset, but this may imply a preprocessing of the data if the extracted features need to be used.

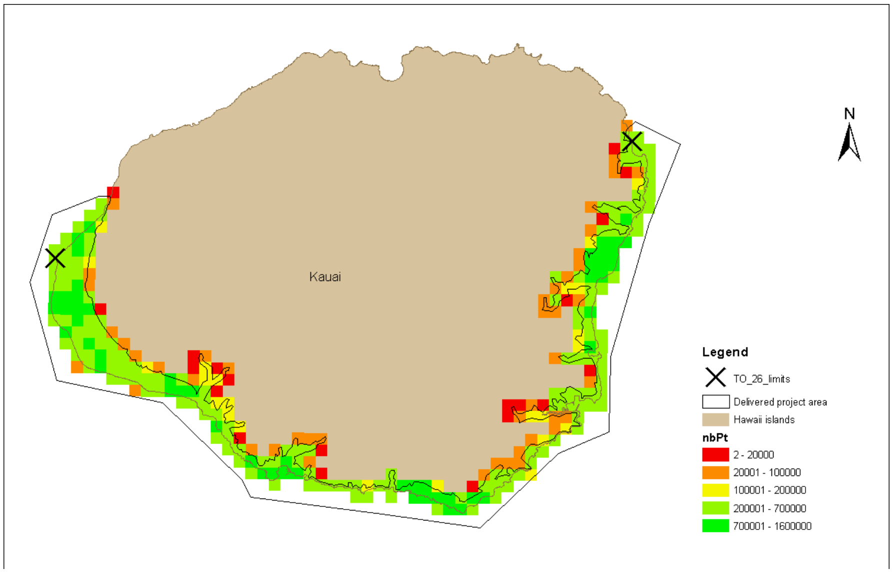



**Figure 8 - Number of points per tile (ground LAS files)**

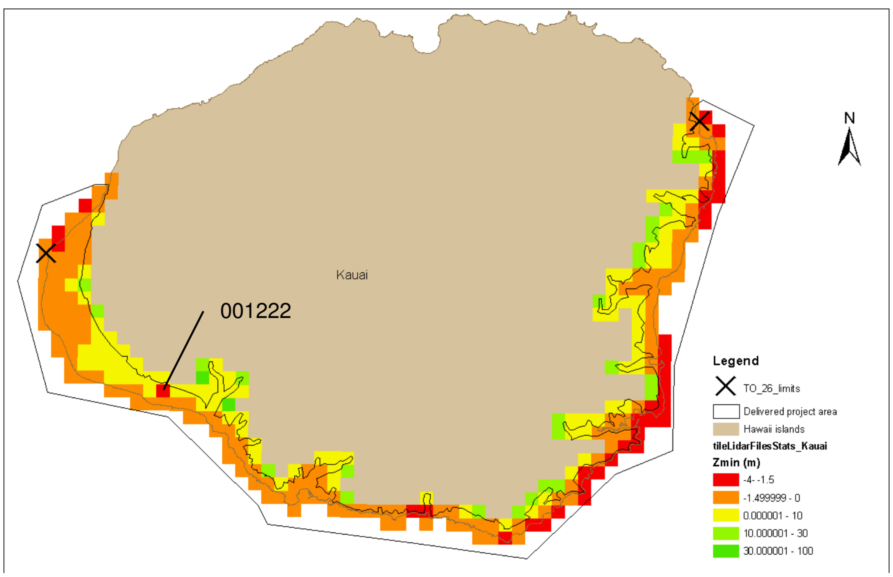



**Figure 9 – Minimum elevation in each LAS file (in meters)**

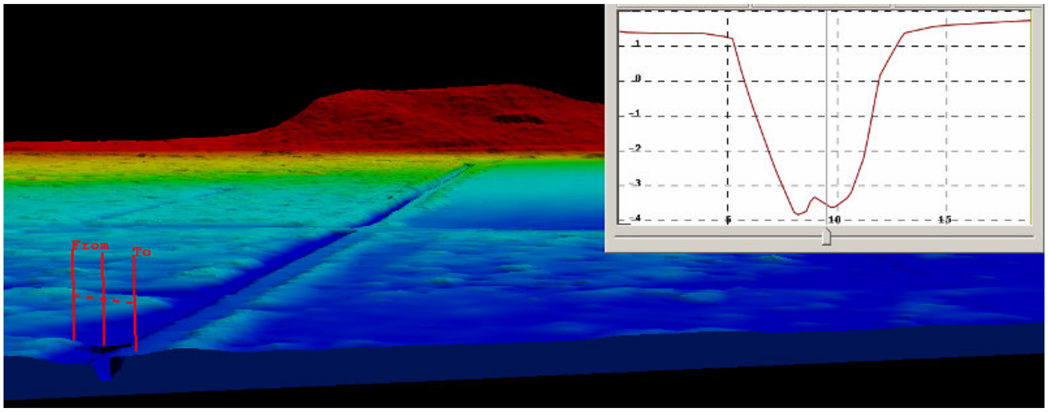



**Figure 10 – Minimum elevation value of -4m: divot in tile 001222**

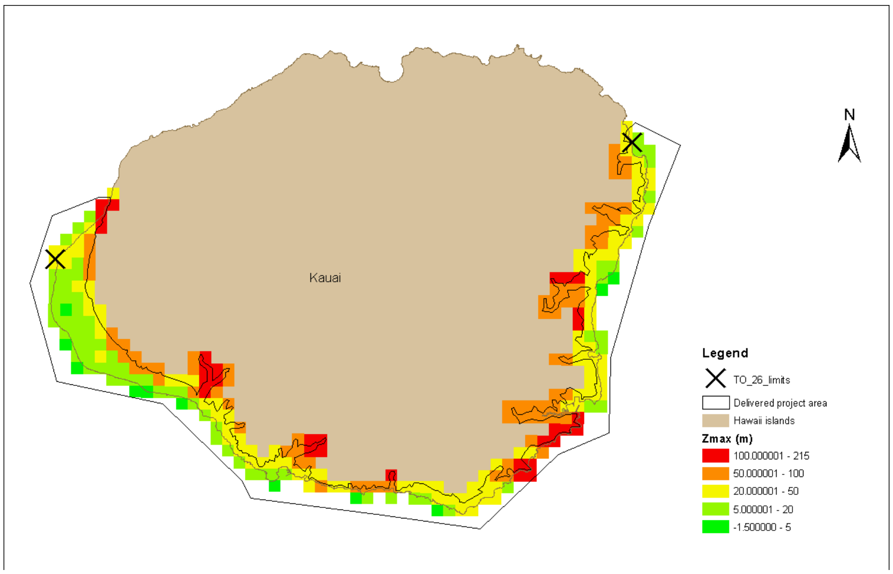



**Figure 11 - Maximum elevation in each LAS file (in meters)**

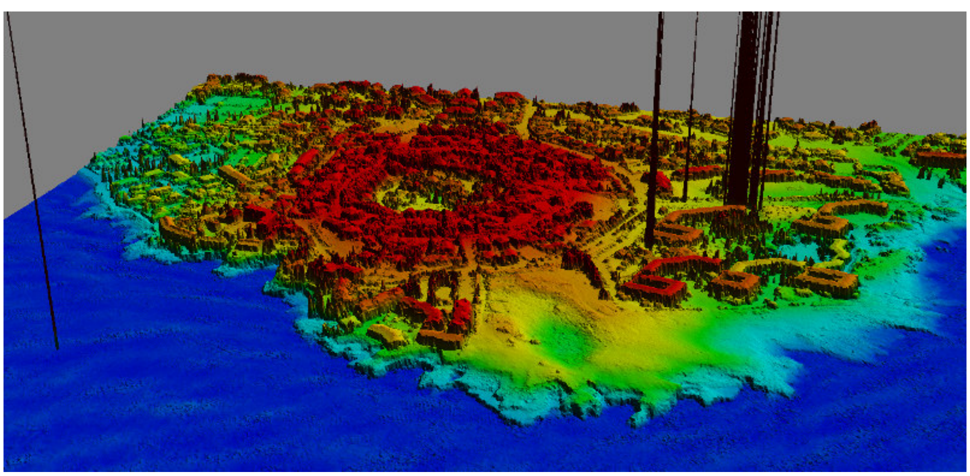


**Figure 12 – Spikes in extracted feature tile 001545**

- *Oahu*

As previously stated, the number of Lidar points for each tile is lower along the coast and the project boundary. Figure 13 presents a map of the number of records in each LAS file (ground).

Figure 14 shows the z minimum value for each tile; it can be noticed that all the files with the lowest elevation are situated along the shoreline or along a bay. Minimum elevation values lower than -40 ft have been found in three files situated over a harbor, in what seems to be maritime canals (see Figure 15), proving that these low elevation values are legitimate. In addition, we can see on Figure 16 that the tiles with the highest elevation values are situated inland and we have verified that all highest elevations values are legitimate Lidar points on mountains.

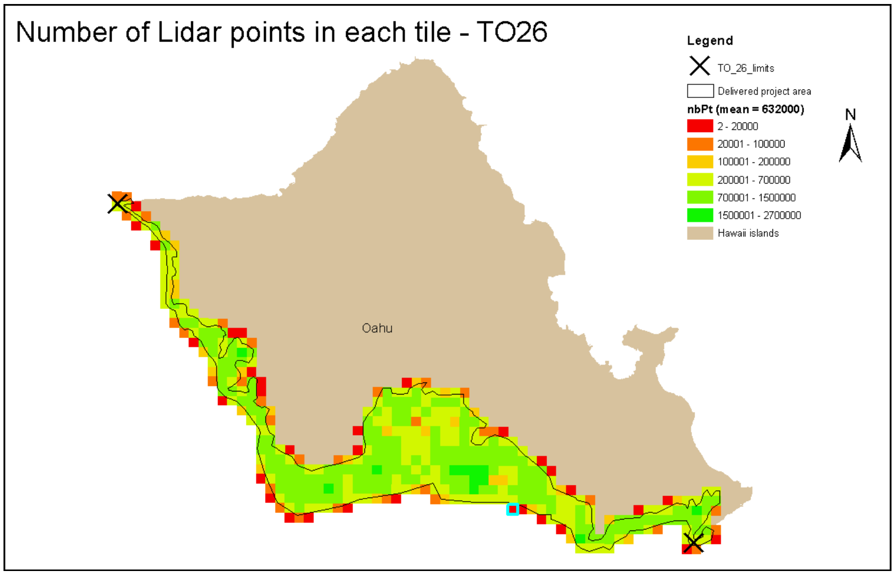



**Figure 13 - Number of points per tile (ground LAS files)**

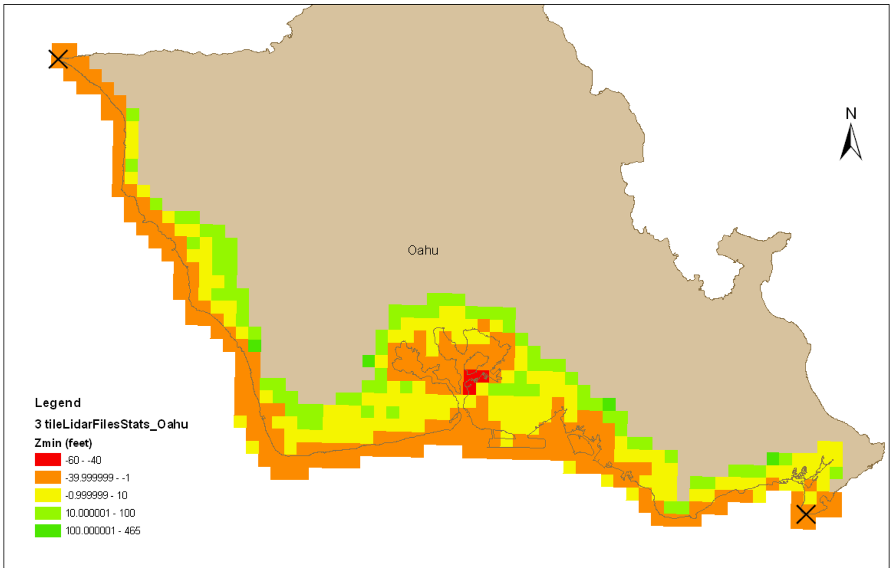



**Figure 14 – Minimum elevation in each ground LAS file**

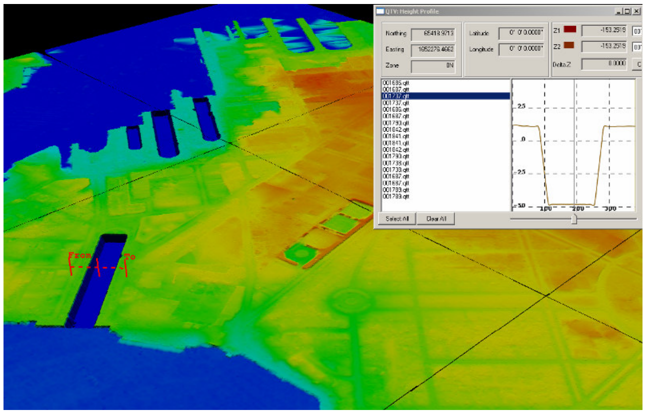


Figure 15 – Minimum value around -50 ft in maritime canals (Tile 001737)

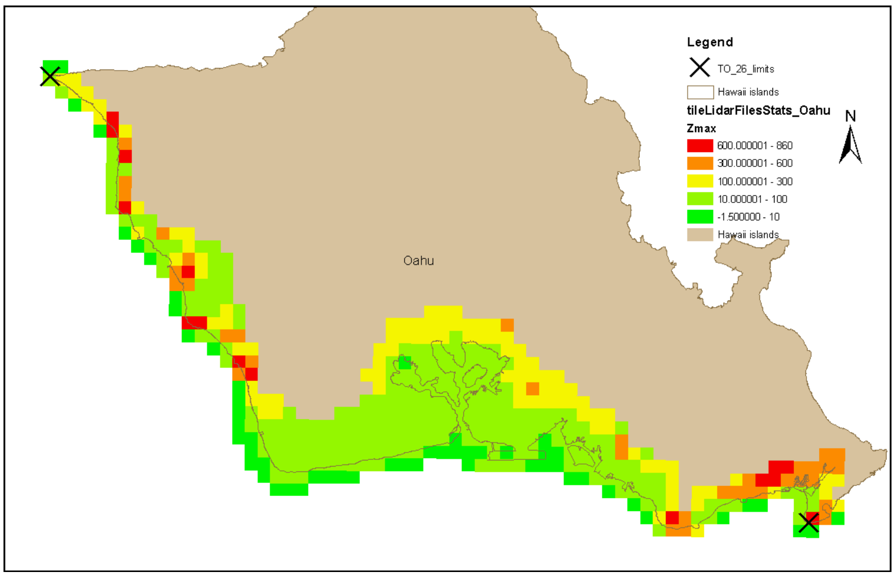



Figure 16 - Maximum elevation in each ground LAS file

## 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 **Error! Reference source not found.**.

To satisfy FEMA Guidelines and Specifications for Flood Hazard Mapping Partners (Section A.6.4 of Appendix A) a minimum of 20 checkpoints per land cover representative of the floodplain should be surveyed. In this project area three land cover types were considered representative:

1. Open bare-earth terrain – sand, dirt, rock, short grass (less than 0.5 feet)
2. Weeds, Crop and Forested areas – tall grass, crops, bushes, deciduous trees
3. Urban – paved streets, parking lots, areas of buildings

All check points used and the associated errors are provided in **Error! Reference source not found.** of this document.

### 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.

Concerning Big Island, the consolidated RMSE (0.35 ft) meets the specifications. The mean and the median were fairly high indicating that the data has a positive bias, this is also enhanced by Figure 17 which illustrates the distribution of the elevation differences between the Lidar data and the surveyed points by land cover type, sorted from lowest to highest. Moreover, the maximum and skew had high ranges, showing that the errors are non-symmetrically distributed.

Finally, one point was considered as a legitimate outlier and removed from the computations as the survey point was located 5.03 ft above the ground Lidar surface which has no apparent anomaly (point no 608).

**Table 2 – Big Island: Descriptive statistics (FEMA guidelines) by land cover category**

| 100 % of Totals | RMSE (ft) Spec=0.61ft | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | # of Points | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|
| Consolidated | 0.35 | 0.18 | 0.18 | 0.50 | 0.30 | 68 | -0.56 | 1.01 |
| Open Terrain | 0.26 | 0.11 | 0.13 | 0.98 | 0.24 | 24 | -0.31 | 0.86 |
| Weeds/Crop/Forest | 0.47 | 0.31 | 0.27 | 0.36 | 0.36 | 23 | -0.36 | 1.01 |
| Urban | 0.29 | 0.13 | 0.20 | -0.89 | 0.27 | 21 | -0.56 | 0.50 |

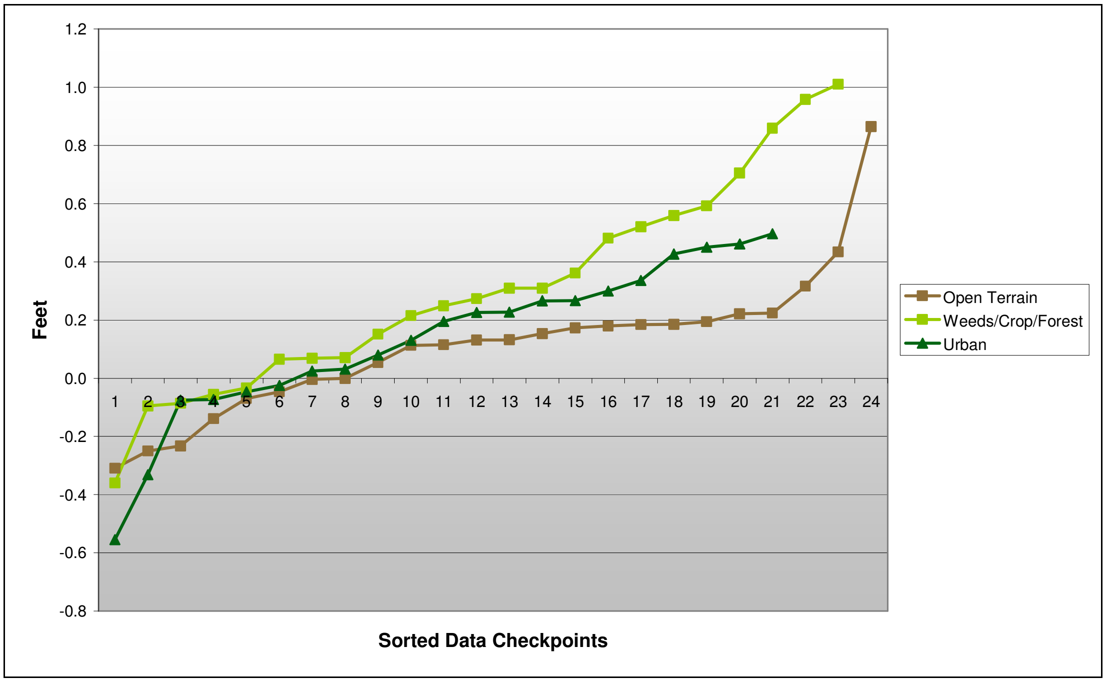



**Figure 17 – Big Island: Elevation differences between the interpolated Lidar and the surveyed QAQC checkpoints**

Concerning Kauai Island, the consolidated RMSE (0.45 ft) meets the specifications. In this case, the mean and the median were negatives indicating that the data has a negative bias (see Figure 18). Moreover, the minimum, maximum and skew had high ranges (except for open terrain), showing that the errors are not symmetrically distributed. However, all the differences remain within acceptable ranges and do not constitute an issue.

**Table 3 – Kauai: Descriptive statistics (FEMA guidelines) by land cover category**

| 100 % of Totals | RMSE (ft) Spec=0.61ft | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | # of Points | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|
| Consolidated | 0.452 | -0.287 | -0.307 | 0.202 | 0.352 | 68 | -1.250 | 0.691 |
| Open Terrain | 0.503 | -0.411 | -0.320 | -1.215 | 0.297 | 20 | -1.250 | 0.041 |
| Weeds/Crop/Forest | 0.409 | -0.123 | -0.175 | -0.026 | 0.399 | 24 | -0.976 | 0.691 |
| Urban | 0.447 | -0.346 | -0.389 | 0.529 | 0.289 | 24 | -0.917 | 0.411 |

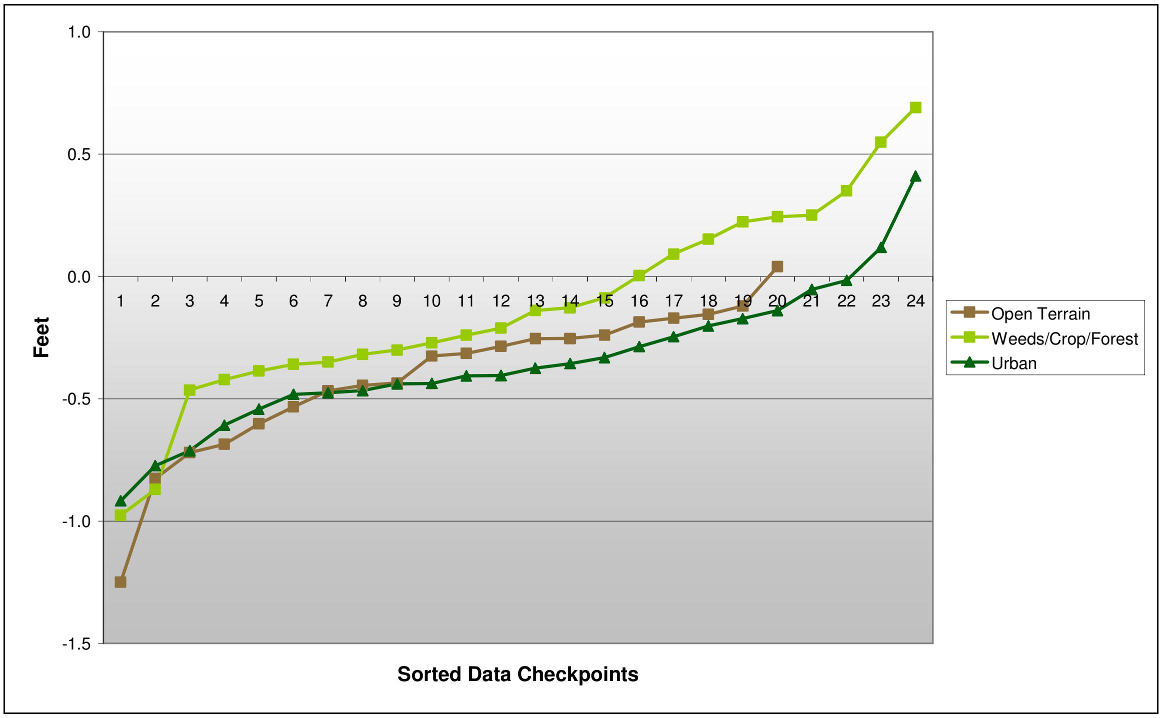



**Figure 18 – Kauai: Elevation differences between the interpolated Lidar and the surveyed QAQC checkpoints**

Concerning Oahu Island, the consolidated RMSE (0.37 ft) meets the specifications. As for Kauai, the mean and the median were negatives (except for the weeds/crops/forest category) indicating that the data might have a negative bias. Moreover, the minimum, maximum and skew had high ranges, showing that the errors are non-symmetrically distributed either.

**Table 4 - Oahu: Descriptive statistics (FEMA guidelines) by land cover category**

| 100 % of Totals | RMSE (ft) Spec=0.61ft | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | # of Points | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|
| Consolidated | 0.37 | -0.18 | -0.22 | 0.96 | 0.33 | 64 | -1.00 | 0.99 |
| Open Terrain | 0.35 | -0.27 | -0.26 | -1.46 | 0.23 | 22 | -1.00 | 0.01 |
| Weeds/Crop/Forest | 0.39 | 0.06 | -0.08 | 0.81 | 0.40 | 20 | -0.45 | 0.99 |
| Urban | 0.37 | -0.30 | -0.28 | -0.45 | 0.22 | 22 | -0.72 | 0.04 |

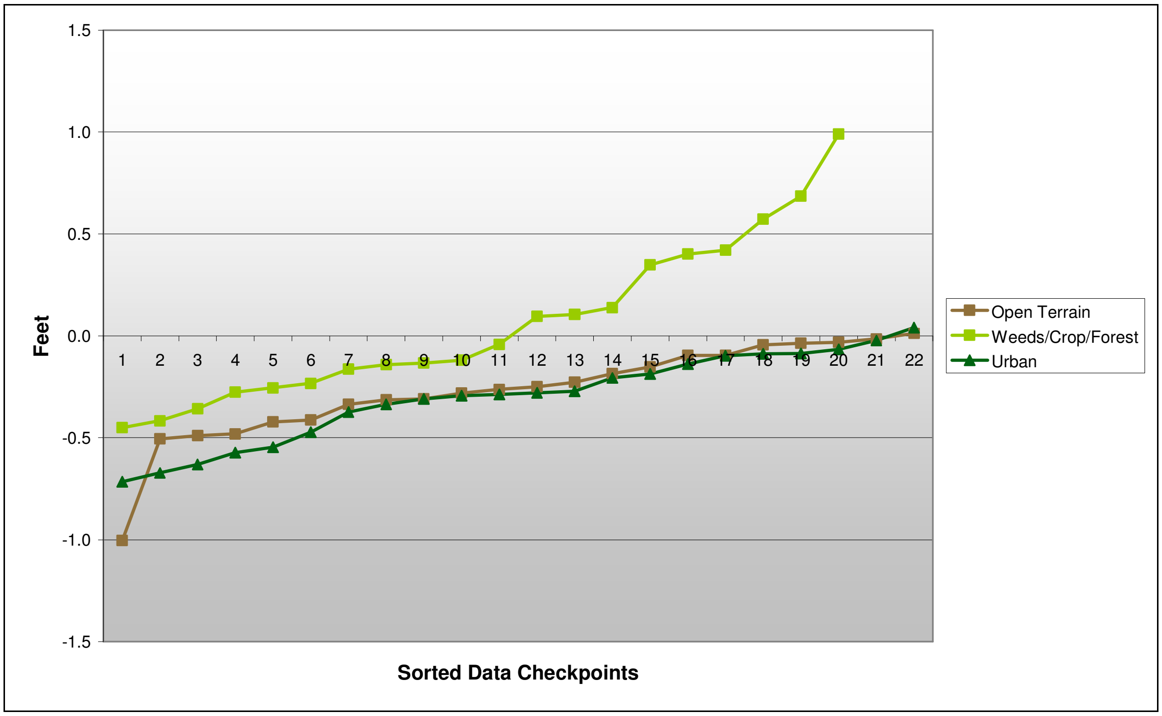
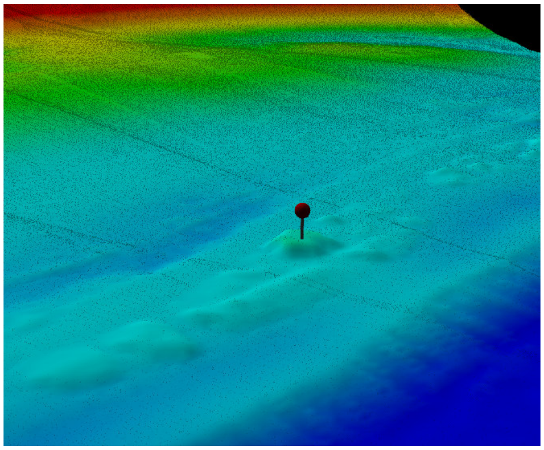


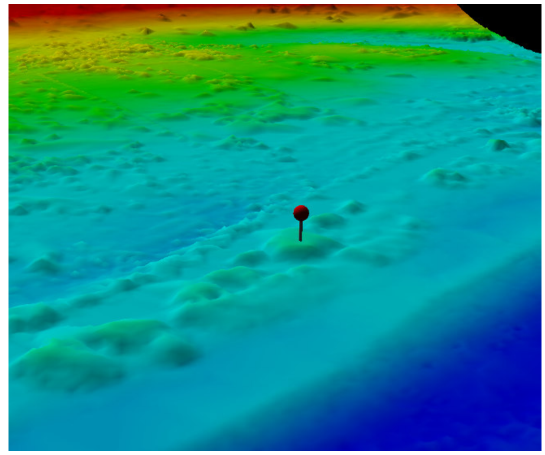

**Figure 19 – Oahu: Elevation differences between the interpolated Lidar and the surveyed QAQC checkpoints**

Moreover, one outlier was removed from the dataset for Oahu Island. This point has an error of 5.7 ft and the associated survey photo shows that this is a dense forested area (about 5 ft high estimated on Figure 20). We can notice on Figure 21, by comparing the Lidar model built with the extracted features files and the bare earth Lidar model, that the vegetation has not been extracted at the precise location of the survey point. This could explain the high discrepancy between the measured elevation and the Lidar elevation. This outlier survey checkpoint was influencing the overall Root Mean Square Error especially for the vegetated land cover type. Consequently, it has been discarded.

**Figure 20 – Survey photo of outlier (point 103)**



Check point 103 with bare earth model and Lidar points



Check point 103 with extracted feature model

**Figure 21 – Check point with erroneous Lidar elevation (possibility that the vegetation has not been properly removed)**

### 2.2.4 Vertical Accuracy Assessment Using the NDEP Methodology

The RMSE method assumes that the errors follow a normal distribution and experience has shown that this is not always the case as vegetation and manmade structures can limit the ground detection causing errors greater than in unobstructed terrain. The NDEP methodology therefore assumes that the data does not follow a normal distribution and tests the open terrain (bare-earth ground) separately from other ground cover types.

The *Fundamental Vertical Accuracy* (FVA) at the 95% confidence level equals 1.96 times the RMSE in open terrain only (as previously explained: the RMSE methodology is appropriate in open terrain). *Supplemental Vertical Accuracy* (SVA) at the 95% confidence level utilizes the 95$^{th}$ percentile error individually for each of the other land cover categories, which may have valid reasons (e.g. problems with vegetation classification) why errors do not follow a normal distribution. Similarly the *Consolidated Vertical Accuracy* (CVA) at the 95% confidence level utilizes the 95$^{th}$ percentile error for all land cover categories combined. This NDEP methodology is used on all 100% of the checkpoints.

The target objective for this project was to achieve bare-earth elevation data with an accuracy equivalent to 2 ft contours, which equates to an RMSE of 0.61 ft when errors follow a normal distribution. With these criteria, the Fundamental Vertical Accuracy of 1.19 ft must be met. Furthermore, it is desired that the consolidated Vertical Accuracy and each of the Supplemental Vertical Accuracy statistics also meet the 1.19 ft criteria to ensure that elevations are also accurate in vegetated areas. As summarized in **Error! Reference source not found.**, **Error! Reference source not found.** and **Error! Reference source not found.**, this data:

- Does satisfy the NDEP's mandatory Fundamental Vertical Accuracy criteria for 2 ft contours.
- Does satisfy the NDEP's target Supplemental Vertical Accuracy criteria for 2 ft contours.
- Does satisfy the NDEP's mandatory Consolidated Vertical Accuracy criteria for 2 ft contours.

**Table 5 - Accuracy using NDEP methodology; Hawaii**

| 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=1.19 ft | SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.19 ft |
|---|---|---|---|---|
| Consolidated | 68 | | 0.805 | |
| Open Terrain | 24 | 0.511 | | 0.416 |
| Weeds/Crop/Forest | 23 | | | 0.948 |
| Urban | 21 | | | 0.497 |

**Table 6 - Accuracy using NDEP methodology; Kauai**

| Land Cover Category | # of Points | FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=1.19 ft | CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=1.19 ft | SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.19 ft |
|---|---|---|---|---|
| Consolidated | 68 | | 0.854 | |
| Open Terrain | 20 | 0.986 | | 0.847 |
| Weeds/Crop/Forest | 24 | | | 0.843 |
| Urban | 24 | | | 0.764 |

**Table 7 - Accuracy using NDEP methodology; Oahu**

| 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=1.19 ft | SVA — Supplemental Vertical Accuracy (95th Percentile) Target=1.19 ft |
|---|---|---|---|---|
| Consolidated | 64 | | 0.684 | |
| Open Terrain | 22 | 0.691 | | 0.505 |
| Weeds/Crop/Forest | 20 | | | 0.701 |
| Urban | 22 | | | 0.670 |

### 2.2.5 Vertical Accuracy Conclusion

Although the errors exhibits non symmetrical behavior that could imply a possible slight offset of the Lidar data, the 3 islands meets both methods of vertical accuracy testing. This data is of good quality and should satisfy most users for high accuracy digital terrain models.

## 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 a 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 1.7 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.

One of the variables established when creating the models is the threshold for missing data. For each individual triangle, the point density information is stored, if it meets the threshold, the corresponding surface will be displayed in green, if not it will be displayed in red (see Figure 22).

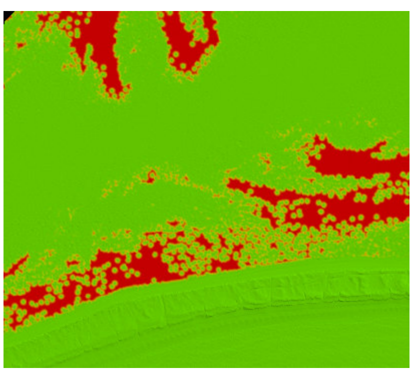


**Figure 22 – Ground model with density information (red means no data)**

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 23, Figure 24, and Figure 25. Contact sheets of all potential issues found are provided in **Error! Reference source not found.**.

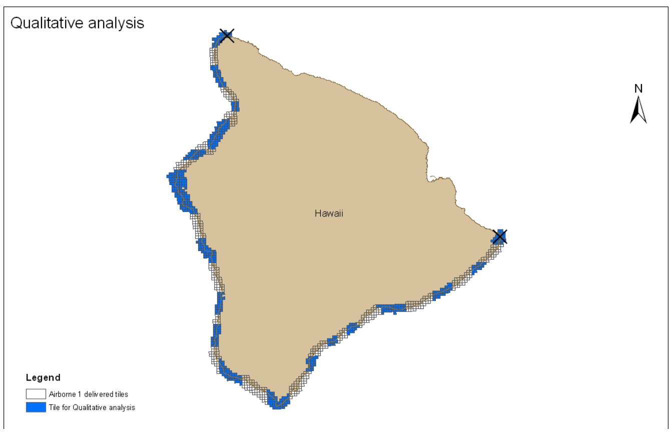



**Figure 23 – Big Island: Tiles evaluated for the qualitative analysis**

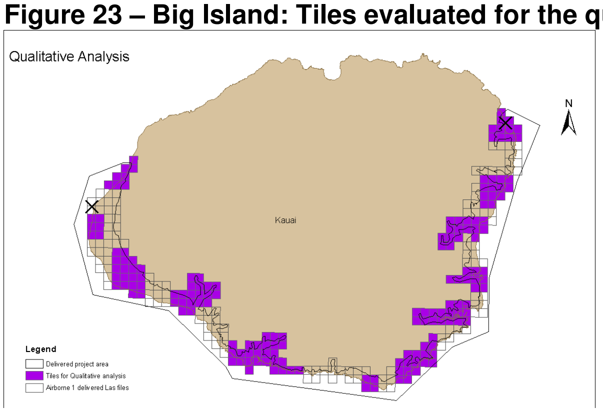



**Figure 24 - Kauai: Tiles evaluated for the qualitative analysis**

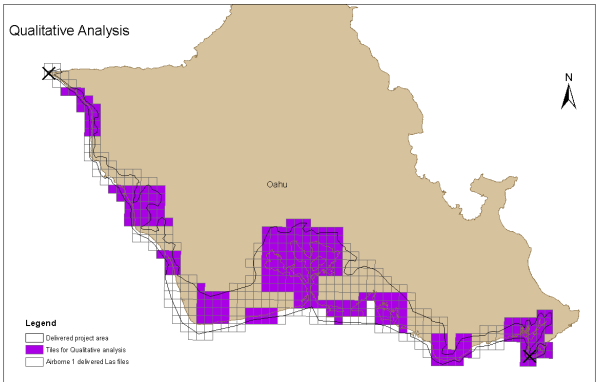



**Figure 25 - Oahu: Tiles evaluated for the qualitative analysis**

Overall, the bare earth model is consistent and of good quality, providing an adequate definition of the coast as seen in Figure 26. Although we observed that the ground was sometimes noisy or sparse in densely vegetated area, we believe that these errors were not serious enough to render the data unusable for the user's needs. Several data holidays exist that may require further processing for specific applications, however it should be noted that the majority of them were located above the 10m contour limit required by the contract. Therefore they are not expected to impact hurricane modeling. A list of the data holidays is provided in Table 8; only 3 of them were under or at the limit of the 10m boundary

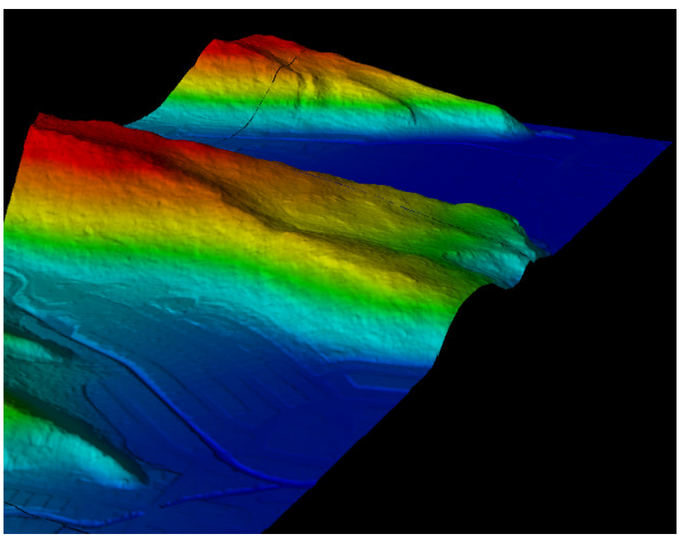


**Figure 26 – Tile 2079: Good coastal definition**

**Table 8 – Data holidays under and above the 10m contour**

| Island | Tile | Area (sq ft) | elevation m | Above 10m |
|---|---|---|---|---|
| Hawaii | 2373 | 2000000 | 80ft | yes |
| **Hawaii** | **8063** | **633152** | **40ft** | **limit** |
| Oahu | 1827 | 121528 | 60ft | yes |
| **Oahu** | **1937** | **131762** | **1ft** | **no** |
| Oahu | 2031 | 21140 | 45ft | yes |
| **Oahu** | **2171** | **46121** | **17ft** | **limit on cliff** |
| Kauai | 693 | 470000 | 150ft | yes |

- *Big island*

The types of issues more frequently encountered are:

1. Poor Lidar penetration in dense vegetated areas
2. Sparse points along shoreline
3. Void areas
4. Cleanliness of artifacts (possible vegetation and building remains)

A large part of the south shores of this island are lava bare earth areas with almost no vegetation. In this case, ground models are exceptionally clean and well defined (Figure 27).

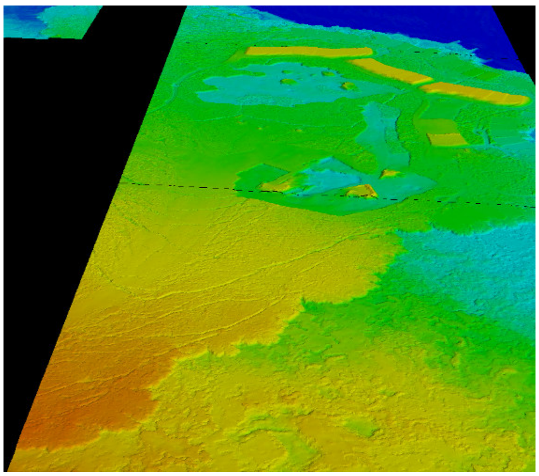
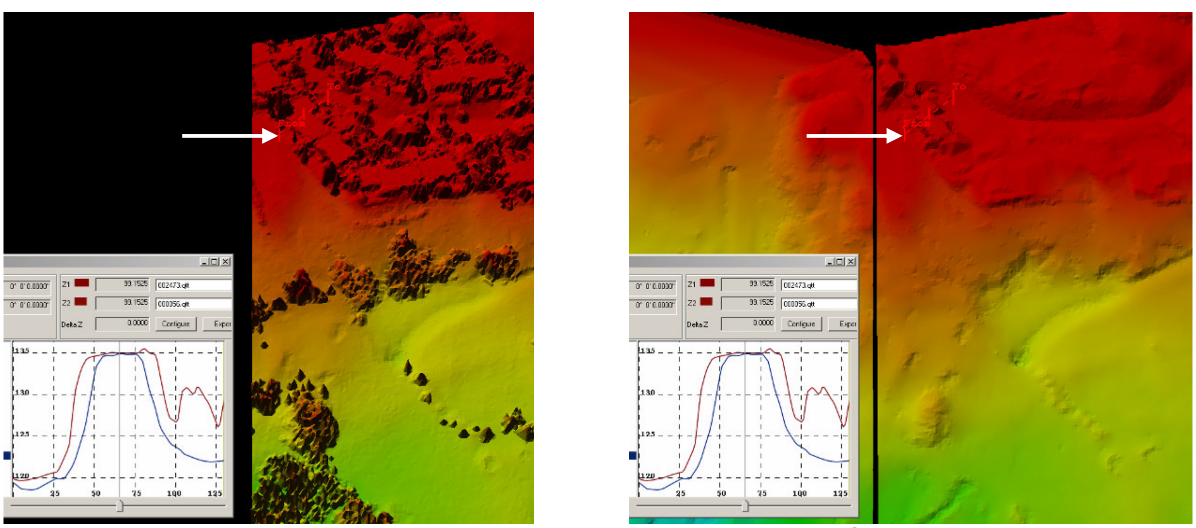


**Figure 27 – Tile 3329; Clean lava bare earth area**

In a few isolated tiles, potential artifacts were found in built-up zones (Figure 28) most likely due to a misclassification. Due to the large spectrum of geographic patterns, there are instances where the algorithms erroneously classify the data. However it is evident that these potential areas are relatively small and do not require additional process.



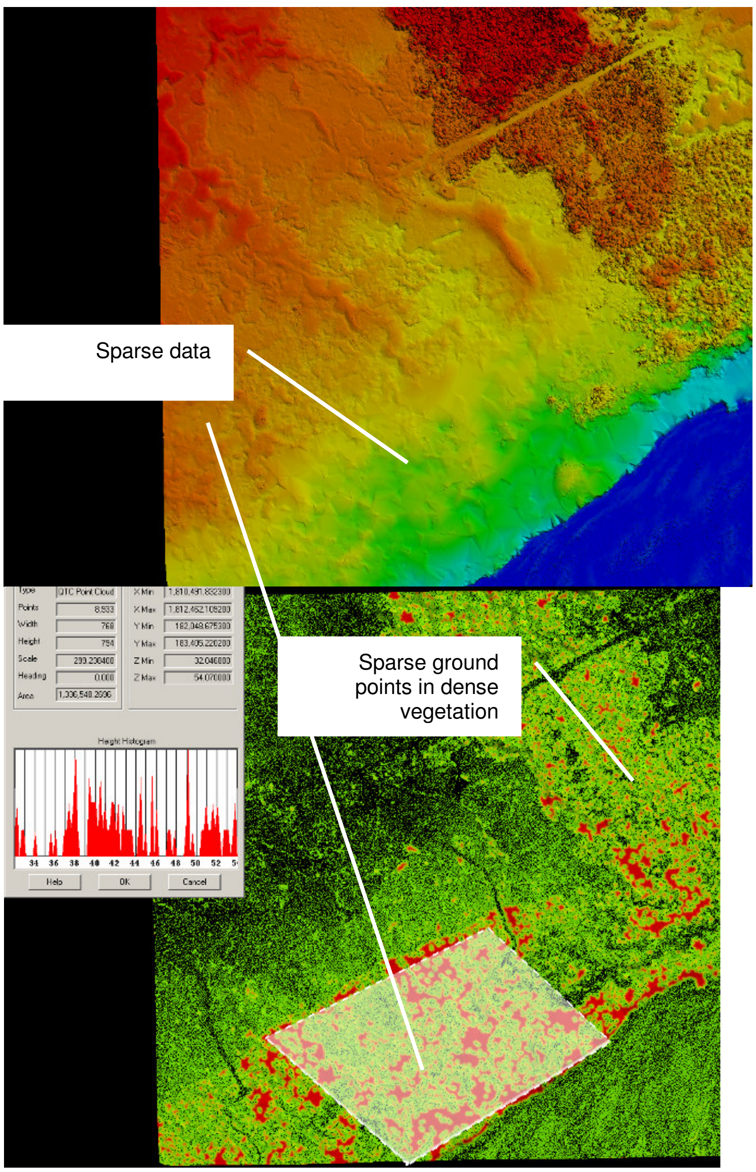
**Extracted features model** **Ground model**

**Figure 28 – Possible building remains, tile 1543**

On the east side, we noticed instances of scattered points. Two different causes were found (both cases are illustrated in the same tile in Figure 29).

Firstly, we encountered a low density of ground points in really thick vegetation. It is believed that this may be caused by a poor penetration of the Lidar beam through the leaves and branches because of their density. However the few ground points where the Lidar did actually penetrate are sufficient to define a bare earth model.

Secondly, small fringes of land situated along the coast have a low density of points in both bare earth and in extracted features files. As a consequence, the coast is less precisely defined, however the remaining elevations are in essence correct, keeping the general integrity of the resulting model.




Extracted features model

Bare earth model colored according to density of Lidar points, red indicates a poor density, with ground points in black as overlay

**Figure 29 – Low density in dense vegetation (upper right corner) and along coast (middle lower part). Tile 10197**

Sparse density along coast line occurred on a fairly large portion of the coast (Figure 30) in a volcanically active region (an eruption has occurred in August-September 2006 in East Ka'ili'Ili, correlation with the date of flight must be made). We therefore assume that the Lidar beam was stopped by fumes rising from the sea where lava encounters water as illustrated in Figure 31.

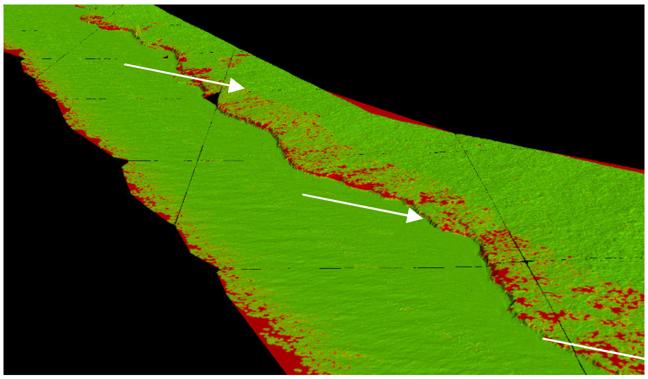
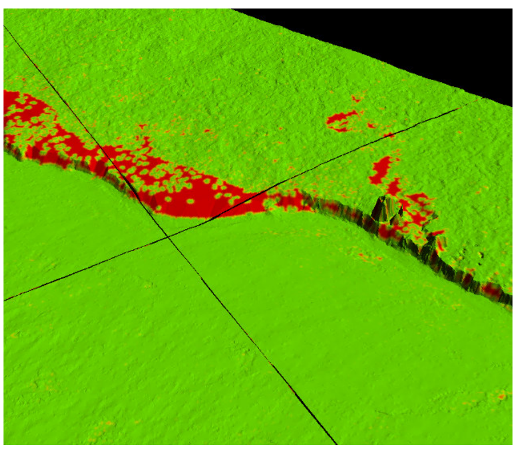
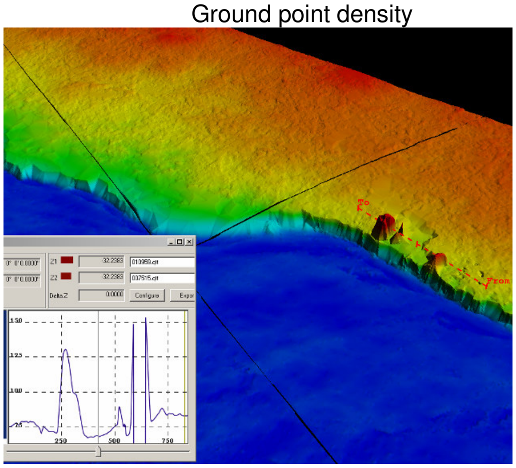


**Figure 30 – Low density of points along coast (around tile 10324)**

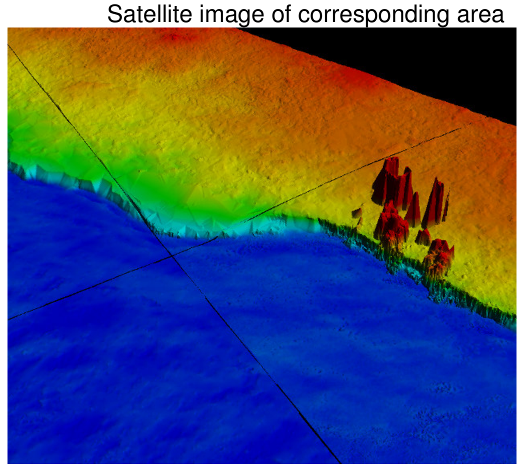


Ground point density

Satellite image of corresponding area



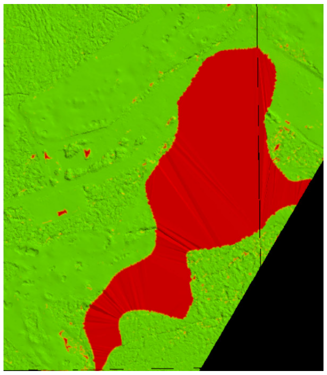
Bare earth



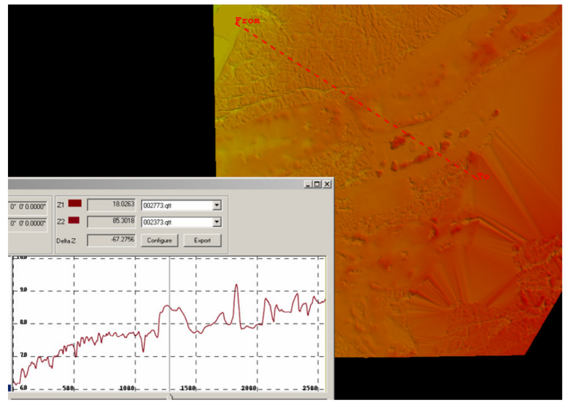
Extracted features

**Figure 31 – Tile 10464, Low density of points and artifacts possibly caused by lava fumes**

Finally, two data holidays from 14 to 45 acres have been encountered in the Big Island (see example in Figure 32 and Figure 33). These data holidays may be caused by a failure of the emission or acquisition system.



Bare earth colored by density



Bare earth colored by elevation with cross section (in red)

**Figure 32 – Data holiday of about 45 acres along the project boundary starting at an elevation of 90 feet, tile 2373**

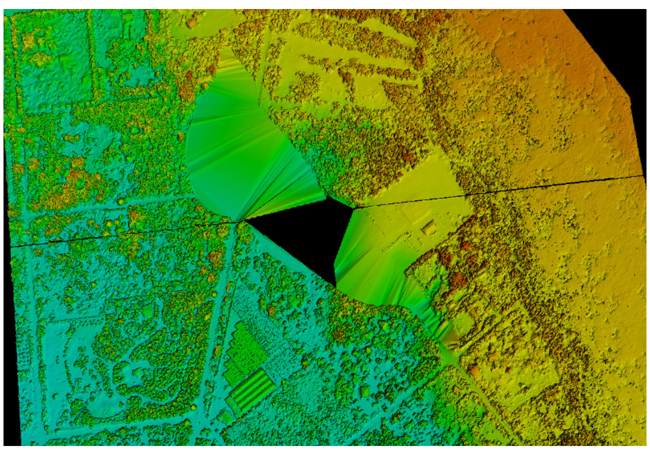


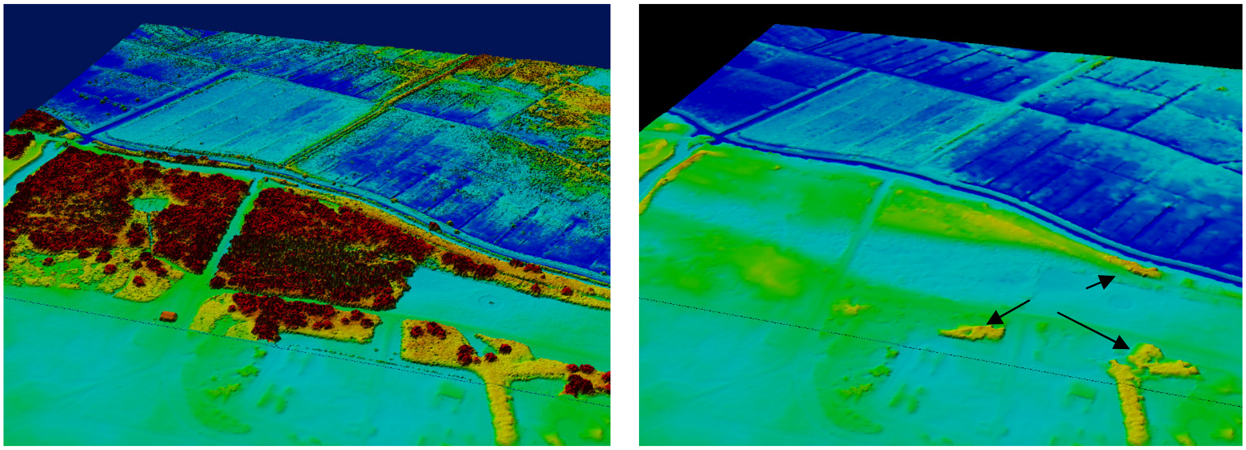
**Figure 33 - Data holiday of about 14 acres starting at an elevation of 40 feet, tile 8064**

- *Kauai*

The types of issues more frequently encountered in Kauai are:

1. Cleanliness of artifacts (possible noise and vegetation remains)
2. Sparse density on slopes,
3. Confusion of tile coverage at the project boundary (non requested tiles)
4. Poor Lidar penetration in dense vegetated areas and/or aggressive removal of vegetation,
5. Bundles of spikes in extracted feature cloud data,
6. Divots in ground models
7. Data holiday (above 10m),

As previously explained, classification algorithms may sometimes miss some vegetated area as illustrated at Figure 34; nevertheless the cleanliness of the data remains good at a global level.



Extracted feature Bare earth

**Figure 34 – Tile 0795; Possible vegetation remains**

Along the project boundary, the tiles are supposed to be clipped, Figure 35 illustrates two tiles not clipped along the polygon delivered with data whereas the adjacent tiles were clipped, and this creates what seem to be data voids where data were not actually required. Although it may create confusion, we do not consider this as an issue.

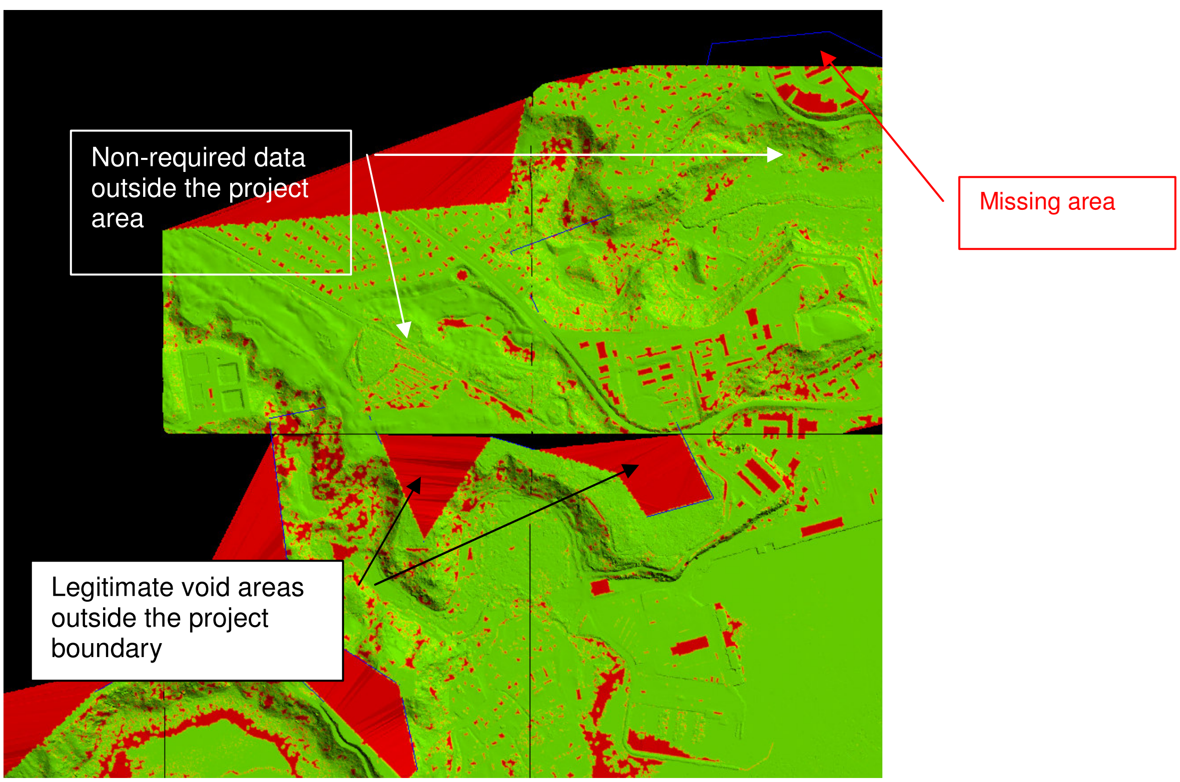



**Figure 35 – Tile 1334; Non-requested data outside the project boundary (light blue line) apparently causes data holidays (symbolized in red in this point density model) and one tile with a small area is missing.**

What typically is seen throughout the project is sparse density of ground points in thick vegetation. However, ground points are still regularly available as seen in Figure 36, allowing a fair definition of a bare earth model, the trails or irrigation canals are still easily identifiable.

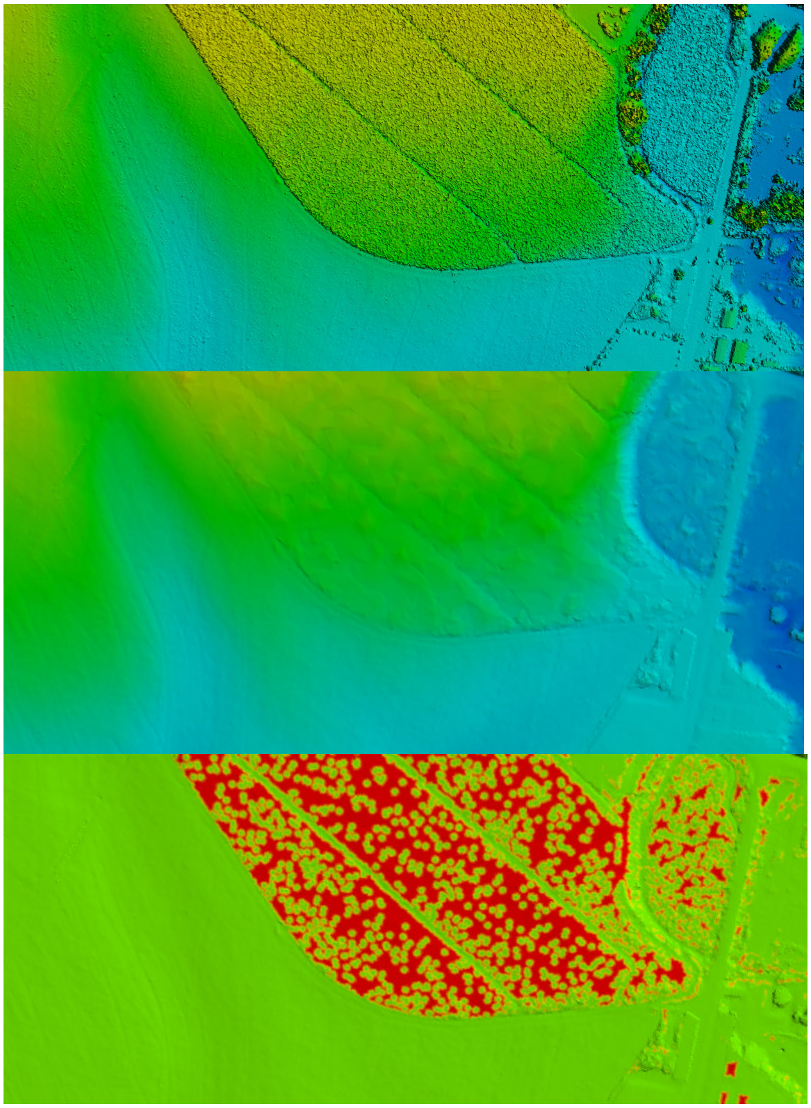


**Figure 36 – Tile 1495; Poor Lidar penetration in highly dense vegetated area (top: extracted feature model; middle: bare earth model; bottom: density model – red is sparse data)**

Extracted spikes were found, sometime associated with data holidays indicating a temporary problem in the emission/acquisition system (see Figure 37).

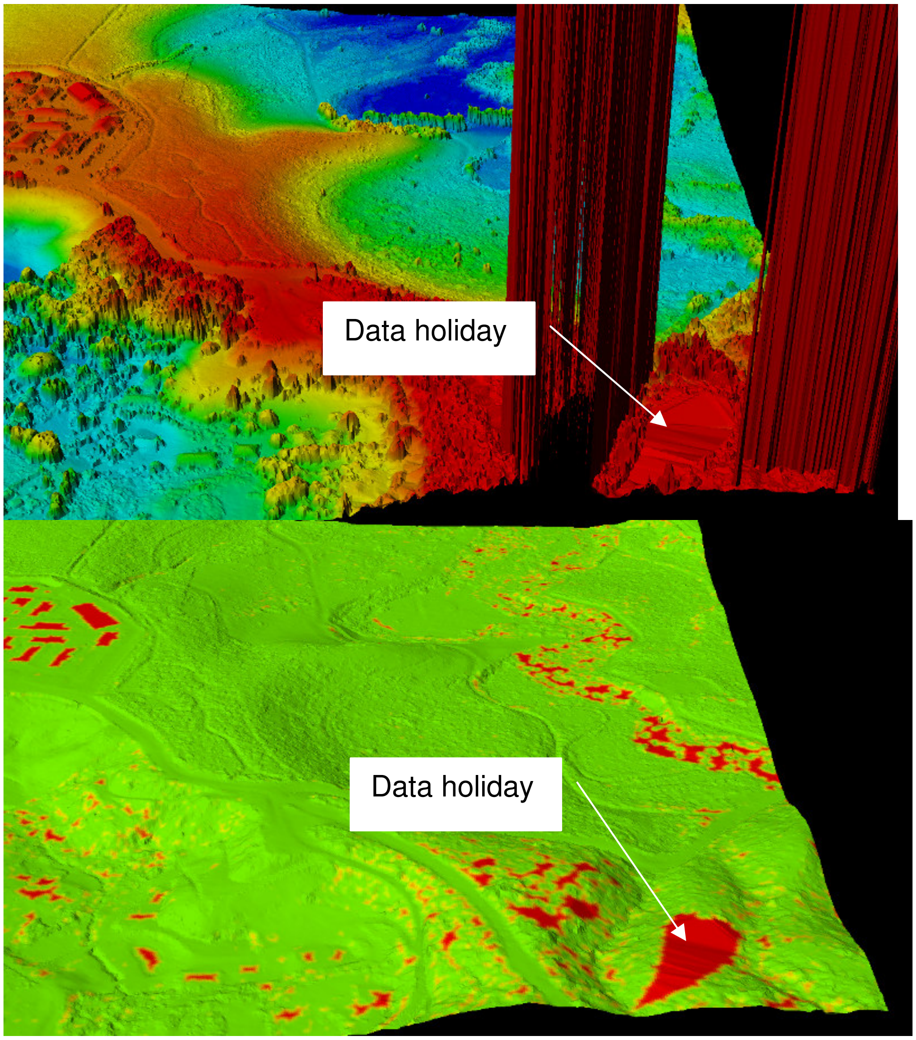



**Figure 37 – Tile 0693; Spikes in the extracted feature model (top) and hole in data visible in both images (bottom: ground point density model). These anomalies are above the 10m boundary.**

- *Oahu*

The types of issues more frequently encountered in Oahu are:

1. Cleanliness of artifacts (noise and building remains)
2. Data holidays (missing Lidar points, few acres),
3. Poor Lidar penetration in dense vegetated areas and/or aggressive removal of vegetation leaving almost no ground points.
4. Noise in flat bare earth areas (possible aggressive classification)
5. “Cornrow” effect
6. Spikes in extracted features
7. Divots in ground models

The following figures illustrate the type of errors specific to Oahu Island.

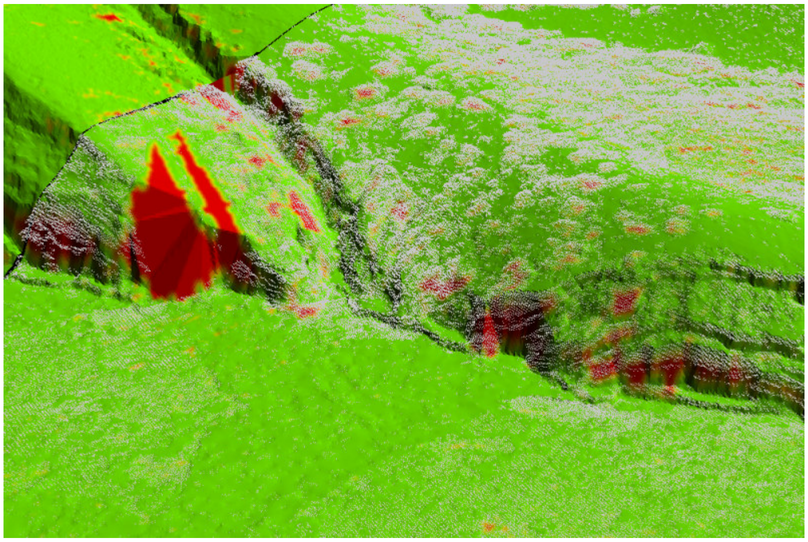
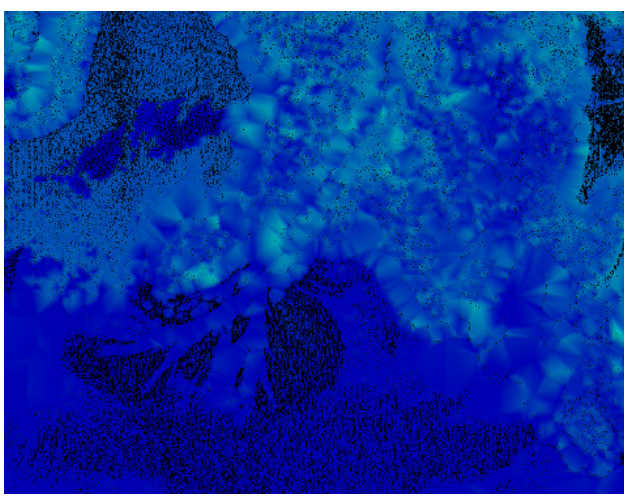
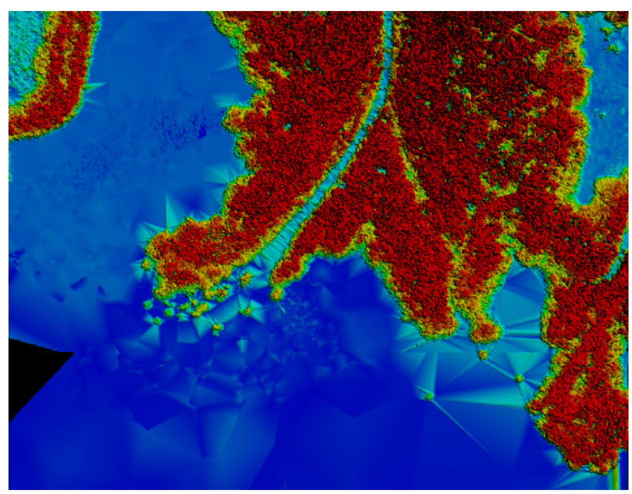


**Figure 38 – Tile 2171; Data holiday. Bare earth models colored according to the density of points (red symbolized the lack of data), overlaid with the extracted points in white**

As previously explained, dense vegetation causes sparse ground data. In the case illustrated in Figure 39, Lidar seems to struggle to penetrate as almost no points are left on land. Consequently, the bare earth model lacks definition in this area. The majority of points visible in Figure 39-left are Lidar points over water; a direct reflection on water is indeed possible at a very low angle of scan. In addition, users should be aware that the contract for acquisition and processing identified only two classes: Class "1" for unclassified and Class "2" for ground. There is no distinction for water and therefore some water points may be classified as ground since their elevations are equal to the surrounding ground points.



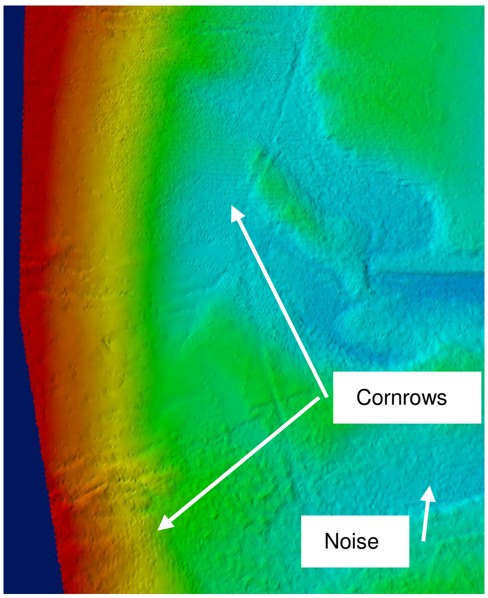
**Bare earth model with corresponding Lidar ground points in black**

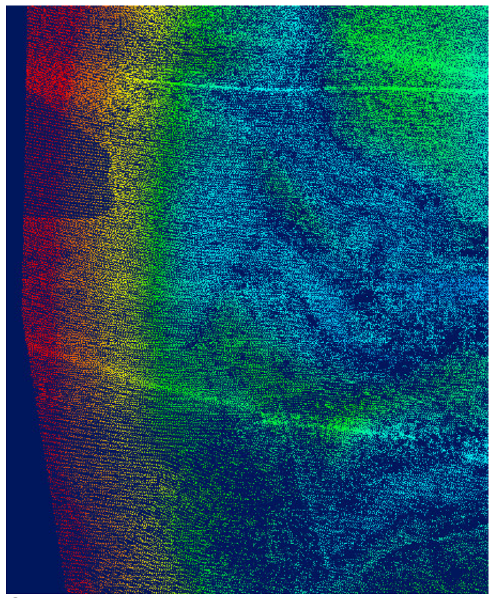


**Extracted feature model**

**Figure 39 – Tile 1578. Really densely vegetated area along coast, very few points left on ground**

Cornrows were sporadically seen throughout Oahu. 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 that the occurrences are minimized, it is acceptable since 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 40). Another type of noise possibly caused by the acquisition process is presented Figure 41, with small dimples aligned with the scan line contrasting with the general smoothness of the neighboring bare earth; however this remains a minor issue, and the “dimples” could really exist.





**Bare earth model** **Corresponding Lidar ground**

**Figure 40 – Tile 0508 Noisy bare earth and cornrows within acceptable ranges**

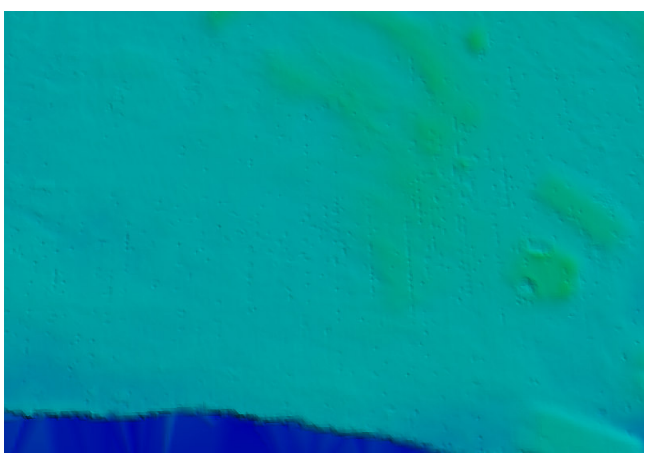


**Figure 41 - Tile 1897; Dimples in bare earth model**

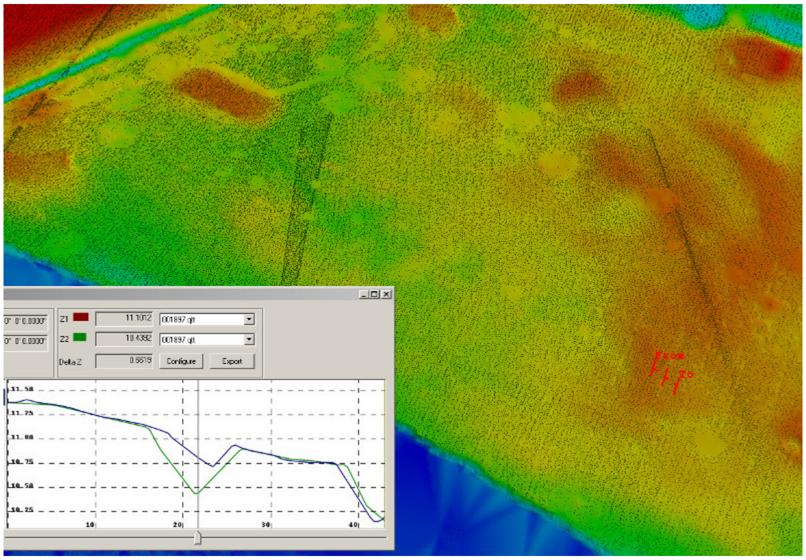


**Figure 42 – Tile 1897; Detail of one dimple in bare earth model with ground points overlaid in black; the green cross section corresponds to the model, the blue one to the point cloud**

Typical of most Lidar sensors, anomalies of isolated low points termed ‘divots” can be found intermittently throughout the project. Although it is a fairly common occurrence most of the elevations are incorrect for only one point which causes the depressions. Figure 43 illustrates one point located in the middle of a built-up area that is over 5 ft deep which we can assume is not correct. Although this data does contain potential divots, there are very few to warrant reprocessing.

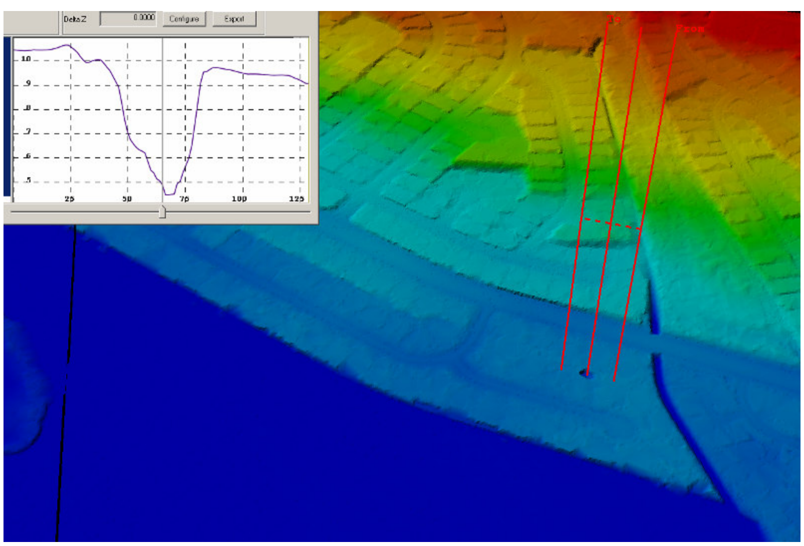
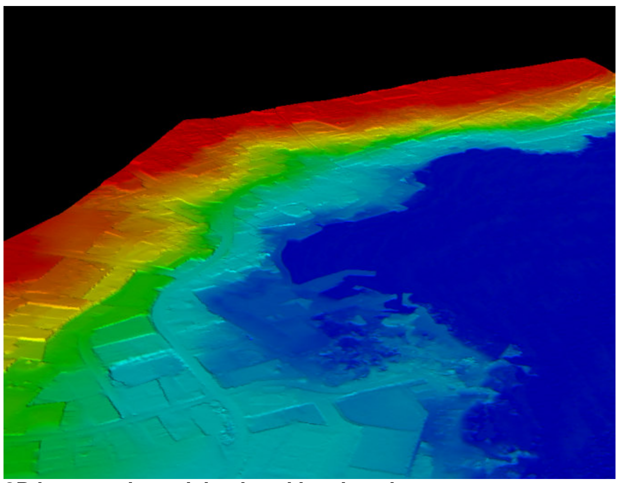


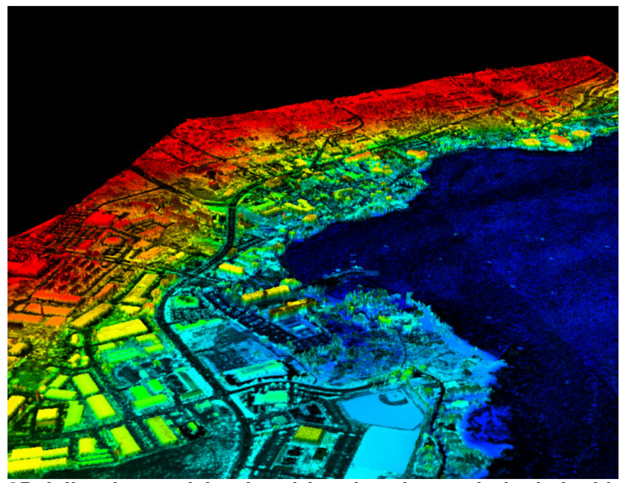
**Figure 43 – Divot (elevations in feet)**

## 3 Conclusion

Overall, the data exhibit a good quality and meet the specifications for both the absolute and relative accuracy. Underneath dense vegetation, which limits the Lidar penetration the quality is slightly reduced. The level of cleanliness for the bare-earth terrain is satisfying. Several data holidays are present in these data; however the majority of them is above the 10m contour limit and is not expected to impact hurricane modeling. Although generally isolated, they would need special care from the end-user. These issues remain minor and are not representative of the majority of the data; we are confident that these data are suitable for coastal modeling.



**3D bare earth model colored by elevation**



**3D full point model colored by elevation and shaded with intensity**

**Figure 44 - Hawaii. This is an excellent example of the level of details given by the data**

## Appendix A Control survey reports

See 3 attached PDF:
Survey Report-Hawaii.pdf
Survey Report-rev_Kauai.pdf
Survey Report-rev_Oahu.pdf

# Appendix B Control points and corresponding Lidar elevation

## Hawaii

| pointNo | e | n | elevation | zLidar | LandCoverType | DeltaZ |
|---|---|---|---|---|---|---|
| 513 | 1874006.324 | 239591.745 | 10.597 | 10.288 | Open Terrain | -0.310 |
| 507 | 1874506.848 | 242780.650 | 9.842 | 9.592 | Open Terrain | -0.250 |
| 502 | 1875569.707 | 240407.524 | 6.824 | 6.591 | Open Terrain | -0.233 |
| 630 | 1481018.987 | 263802.294 | 19.390 | 19.250 | Open Terrain | -0.139 |
| 530 | 1867267.985 | 227251.809 | 6.266 | 6.197 | Open Terrain | -0.070 |
| 510 | 1875977.810 | 244044.919 | 16.535 | 16.489 | Open Terrain | -0.046 |
| 650 | 1637612.637 | 108789.809 | 26.083 | 26.078 | Open Terrain | -0.005 |
| 654 | 1639303.414 | 109970.285 | 8.891 | 8.890 | Open Terrain | -0.001 |
| 636 | 1500207.006 | 128149.777 | 43.471 | 43.525 | Open Terrain | 0.054 |
| 639 | 1501267.929 | 132686.480 | 25.787 | 25.900 | Open Terrain | 0.112 |
| 629 | 1481583.946 | 265150.323 | 32.808 | 32.924 | Open Terrain | 0.115 |
| 628 | 1479862.526 | 268561.733 | 26.968 | 27.100 | Open Terrain | 0.131 |
| 623 | 1473311.948 | 286912.385 | 23.031 | 23.163 | Open Terrain | 0.132 |
| 621 | 1470774.060 | 292113.294 | 11.352 | 11.505 | Open Terrain | 0.153 |
| 640 | 1500821.408 | 134647.369 | 35.039 | 35.212 | Open Terrain | 0.173 |
| 525 | 1495246.222 | 229883.858 | 23.360 | 23.539 | Open Terrain | 0.180 |
| 642 | 1501747.850 | 135991.099 | 32.940 | 33.124 | Open Terrain | 0.184 |
| 519 | 1498495.264 | 213102.920 | 7.579 | 7.764 | Open Terrain | 0.185 |
| 641 | 1501574.228 | 135329.749 | 43.143 | 43.337 | Open Terrain | 0.194 |
| 624 | 1474862.273 | 283059.276 | 10.335 | 10.556 | Open Terrain | 0.221 |
| 526 | 1494711.971 | 229265.486 | 16.043 | 16.267 | Open Terrain | 0.224 |
| 644 | 1502844.534 | 137021.445 | 35.335 | 35.651 | Open Terrain | 0.316 |
| 610 | 1528535.919 | 426160.926 | 17.093 | 17.527 | Open Terrain | 0.434 |
| 655 | 1623076.478 | 91686.923 | 10.794 | 11.659 | Open Terrain | 0.865 |
| 609 | 1529568.201 | 432858.714 | 21.489 | 21.129 | Weeds/Crop/Forest | -0.360 |
| 506 | 1873607.998 | 242537.868 | 14.665 | 14.570 | Weeds/Crop/Forest | -0.095 |
| 647 | 1636341.412 | 107502.607 | 10.105 | 10.019 | Weeds/Crop/Forest | -0.086 |
| 504 | 1875590.179 | 240746.599 | 7.743 | 7.687 | Weeds/Crop/Forest | -0.056 |
| 651 | 1638274.545 | 108842.400 | 7.940 | 7.906 | Weeds/Crop/Forest | -0.033 |
| 648 | 1636685.014 | 108028.688 | 15.682 | 15.747 | Weeds/Crop/Forest | 0.065 |
| 529 | 1870155.380 | 231126.998 | 11.581 | 11.650 | Weeds/Crop/Forest | 0.069 |
| 649 | 1637064.410 | 108612.644 | 20.374 | 20.445 | Weeds/Crop/Forest | 0.071 |
| 606 | 1524473.329 | 441071.395 | 31.890 | 32.041 | Weeds/Crop/Forest | 0.151 |
| 605 | 1525811.286 | 439329.863 | 37.861 | 38.076 | Weeds/Crop/Forest | 0.215 |
| 620 | 1468957.134 | 293746.853 | 11.942 | 12.191 | Weeds/Crop/Forest | 0.249 |
| 613 | 1526932.248 | 418295.686 | 22.146 | 22.419 | Weeds/Crop/Forest | 0.273 |
| 512 | 1874801.598 | 240328.391 | 14.239 | 14.548 | Weeds/Crop/Forest | 0.309 |
| 627 | 1479443.465 | 270317.668 | 7.644 | 7.954 | Weeds/Crop/Forest | 0.309 |
| 518 | 1498767.311 | 212306.104 | 10.761 | 11.123 | Weeds/Crop/Forest | 0.362 |
| 622 | 1472841.083 | 287785.186 | 10.171 | 10.652 | Weeds/Crop/Forest | 0.481 |
| 611 | 1528912.821 | 427558.200 | 14.993 | 15.514 | Weeds/Crop/Forest | 0.521 |
| 524 | 1496002.979 | 231291.138 | 27.034 | 27.593 | Weeds/Crop/Forest | 0.559 |
| 614 | 1527343.829 | 419059.759 | 32.349 | 32.941 | Weeds/Crop/Forest | 0.592 |
| TU0011 * | 1577603.341 | 28868.446 | 33.268 | 33.973 | Weeds/Crop/Forest | 0.705 |
| 503 | 1874503.600 | 240809.656 | 17.290 | 18.149 | Weeds/Crop/Forest | 0.859 |
| 657 | 1627772.138 | 97648.558 | 39.993 | 40.951 | Weeds/Crop/Forest | 0.958 |
| 656 | 1624072.211 | 93163.528 | 16.634 | 17.644 | Weeds/Crop/Forest | 1.010 |
| 511 | 1874510.227 | 238496.111 | 3.281 | 2.725 | Urban | -0.556 |
| 509 | 1875354.090 | 243191.508 | 8.202 | 7.870 | Urban | -0.332 |
| 508 | 1874900.745 | 242412.737 | 2.657 | 2.583 | Urban | -0.075 |
| 653 | 1638813.159 | 110020.023 | 6.201 | 6.127 | Urban | -0.073 |
| 505 | 1874648.219 | 241134.459 | 16.962 | 16.915 | Urban | -0.047 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 652 | 1638635.962 | 109241.350 | 15.256 | 15.231 | Urban | -0.025 |
| 607 | 1529345.596 | 435705.789 | 9.285 | 9.310 | Urban | 0.025 |
| 634 | 1499927.938 | 126794.136 | 10.663 | 10.694 | Urban | 0.032 |
| 635 | 1500082.269 | 127563.393 | 9.318 | 9.398 | Urban | 0.080 |
| 522 | 1496326.371 | 232370.828 | 15.518 | 15.649 | Urban | 0.130 |
| 604 | 1526818.272 | 437900.535 | 6.824 | 7.019 | Urban | 0.195 |
| 517 | 1498877.842 | 214051.704 | 6.332 | 6.559 | Urban | 0.227 |
| 523 | 1495898.747 | 231865.678 | 12.861 | 13.088 | Urban | 0.227 |
| 619 | 1469393.682 | 293368.541 | 7.054 | 7.320 | Urban | 0.266 |
| 521 | 1496036.116 | 233122.270 | 17.290 | 17.557 | Urban | 0.267 |
| 643 | 1502651.588 | 136527.877 | 27.461 | 27.760 | Urban | 0.299 |
| 637 | 1500557.202 | 129656.073 | 26.640 | 26.977 | Urban | 0.336 |
| 638 | 1500776.756 | 131204.364 | 49.573 | 50.000 | Urban | 0.427 |
| 520 | 1498595.067 | 214972.109 | 14.403 | 14.853 | Urban | 0.450 |
| 626 | 1479959.803 | 271025.606 | 15.945 | 16.407 | Urban | 0.462 |
| 625 | 1476419.685 | 281298.978 | 12.926 | 13.423 | Urban | 0.497 |

## Kauai

| pointNo | easting | northing | elevation | zLidar | LandCoverType | DeltaZ |
|---|---|---|---|---|---|---|
| 433 | 1695878.564 | 74702.114 | 12.500 | 11.250 | Open Terrain | -1.250 |
| 316 | 1610093.401 | 25129.969 | 4.659 | 3.833 | Open Terrain | -0.825 |
| 435 | 1694979.779 | 77107.260 | 4.888 | 4.169 | Open Terrain | -0.719 |
| 314 | 1610510.132 | 24229.906 | 10.269 | 9.583 | Open Terrain | -0.686 |
| 311 | 1609716.630 | 26321.240 | 6.102 | 5.500 | Open Terrain | -0.602 |
| 411 | 1584471.864 | 42255.427 | 9.908 | 9.376 | Open Terrain | -0.533 |
| 419 | 1652592.823 | 16754.166 | 41.306 | 40.839 | Open Terrain | -0.467 |
| 315 | 1612407.274 | 23029.350 | 36.778 | 36.333 | Open Terrain | -0.445 |
| 308 | 1548561.043 | 74486.990 | 11.352 | 10.917 | Open Terrain | -0.435 |
| 320 | 1608029.166 | 26899.421 | 9.908 | 9.583 | Open Terrain | -0.325 |
| 420 | 1655198.297 | 15731.629 | 18.898 | 18.583 | Open Terrain | -0.314 |
| 302 | 1547853.138 | 64564.799 | 3.937 | 3.651 | Open Terrain | -0.286 |
| 425 | 1701889.870 | 85263.773 | 6.004 | 5.750 | Open Terrain | -0.254 |
| 403 | 1575121.456 | 46518.312 | 7.087 | 6.833 | Open Terrain | -0.253 |
| 309 | 1546004.093 | 74107.398 | 7.907 | 7.667 | Open Terrain | -0.240 |
| 424 | 1700963.134 | 81335.730 | 9.186 | 9.000 | Open Terrain | -0.186 |
| 304 | 1547291.164 | 66959.709 | 1.837 | 1.667 | Open Terrain | -0.171 |
| 408 | 1584090.959 | 43429.277 | 6.988 | 6.833 | Open Terrain | -0.155 |
| 326 | 1689400.525 | 45113.296 | 10.203 | 10.083 | Open Terrain | -0.120 |
| 325 | 1690263.385 | 43647.813 | 4.626 | 4.667 | Open Terrain | 0.041 |
| 438 | 1695753.367 | 76768.416 | 15.584 | 14.608 | Weeds/Crop/Forest | -0.976 |
| 319 | 1603558.309 | 24476.788 | 6.037 | 5.167 | Weeds/Crop/Forest | -0.870 |
| 434 | 1695445.855 | 76265.530 | 42.880 | 42.417 | Weeds/Crop/Forest | -0.464 |
| 321 | 1693934.375 | 45946.201 | 83.005 | 82.583 | Weeds/Crop/Forest | -0.422 |
| 313 | 1610680.014 | 27031.573 | 4.298 | 3.911 | Weeds/Crop/Forest | -0.387 |
| 318 | 1610181.425 | 28768.676 | 4.692 | 4.333 | Weeds/Crop/Forest | -0.358 |
| 423 | 1656067.751 | 15647.278 | 30.184 | 29.834 | Weeds/Crop/Forest | -0.350 |
| 407 | 1582585.811 | 44418.349 | 8.235 | 7.917 | Weeds/Crop/Forest | -0.318 |
| 427 | 1700185.084 | 82585.924 | 4.134 | 3.833 | Weeds/Crop/Forest | -0.301 |
| 310 | 1606187.864 | 23652.479 | 23.031 | 22.760 | Weeds/Crop/Forest | -0.272 |
| 439 | 1696486.371 | 78549.646 | 8.989 | 8.750 | Weeds/Crop/Forest | -0.239 |
| 428 | 1697312.944 | 79807.747 | 14.961 | 14.750 | Weeds/Crop/Forest | -0.211 |
| 327 | 1687198.332 | 42074.260 | 2.756 | 2.617 | Weeds/Crop/Forest | -0.139 |
| 402 | 1572382.091 | 46551.810 | 9.711 | 9.583 | Weeds/Crop/Forest | -0.128 |
| 322 | 1689889.107 | 46861.980 | 4.101 | 4.014 | Weeds/Crop/Forest | -0.087 |
| 307 | 1546341.297 | 71616.359 | 3.150 | 3.153 | Weeds/Crop/Forest | 0.004 |
| 303 | 1547814.096 | 66347.243 | 1.575 | 1.667 | Weeds/Crop/Forest | 0.092 |
| 324 | 1690325.392 | 45195.218 | 6.430 | 6.583 | Weeds/Crop/Forest | 0.153 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 415 | 1651531.736 | 16329.856 | 18.110 | 18.333 | Weeds/Crop/Forest | 0.223 |
| 306 | 1545470.072 | 68825.683 | 2.756 | 3.000 | Weeds/Crop/Forest | 0.244 |
| DH5813 | 1550358.743 | 63681.992 | 12.566 | 12.817 | Weeds/Crop/Forest | 0.252 |
| 429 | 1699153.721 | 80710.239 | 7.316 | 7.667 | Weeds/Crop/Forest | 0.350 |
| 305 | 1545961.311 | 67613.644 | 3.051 | 3.600 | Weeds/Crop/Forest | 0.549 |
| DH5814 | 1546538.180 | 72463.044 | 6.693 | 7.384 | Weeds/Crop/Forest | 0.691 |
| 312 | 1609935.396 | 27364.414 | 4.167 | 3.250 | Urban | -0.917 |
| 436 | 1694316.428 | 77437.804 | 4.134 | 3.361 | Urban | -0.773 |
| 422 | 1657514.959 | 13871.035 | 12.697 | 11.985 | Urban | -0.712 |
| 409 | 1585104.343 | 44912.804 | 5.774 | 5.167 | Urban | -0.608 |
| 417 | 1648711.466 | 17548.193 | 7.283 | 6.742 | Urban | -0.541 |
| 426 | 1701823.663 | 83767.254 | 9.482 | 9.000 | Urban | -0.482 |
| 416 | 1650386.332 | 16558.267 | 13.058 | 12.583 | Urban | -0.474 |
| 430 | 1695571.248 | 72742.243 | 20.669 | 20.203 | Urban | -0.466 |
| 406 | 1582760.548 | 46103.025 | 32.940 | 32.500 | Urban | -0.440 |
| 413 | 1652583.506 | 15684.942 | 8.104 | 7.667 | Urban | -0.437 |
| 432 | 1695406.878 | 74061.138 | 38.156 | 37.750 | Urban | -0.406 |
| 404 | 1579096.612 | 46314.212 | 8.071 | 7.667 | Urban | -0.404 |
| 421 | 1656336.189 | 14600.857 | 12.467 | 12.093 | Urban | -0.375 |
| 437 | 1694005.536 | 69910.720 | 29.856 | 29.500 | Urban | -0.356 |
| 414 | 1652920.480 | 15795.277 | 9.285 | 8.954 | Urban | -0.331 |
| 317 | 1610664.397 | 28358.638 | 7.119 | 6.833 | Urban | -0.286 |
| 418 | 1644834.506 | 18328.671 | 10.663 | 10.417 | Urban | -0.246 |
| 329 | 1688277.923 | 42546.306 | 4.035 | 3.833 | Urban | -0.202 |
| 412 | 1585071.272 | 42910.544 | 31.923 | 31.750 | Urban | -0.173 |
| 328 | 1686148.891 | 42365.138 | 8.727 | 8.587 | Urban | -0.140 |
| 330 | 1687232.977 | 43455.228 | 6.890 | 6.837 | Urban | -0.053 |
| 323 | 1690008.070 | 45987.146 | 12.598 | 12.583 | Urban | -0.015 |
| 331 | 1689208.728 | 44241.644 | 5.381 | 5.500 | Urban | 0.119 |
| 410 | 1587394.135 | 47852.857 | 11.089 | 11.500 | Urban | 0.411 |

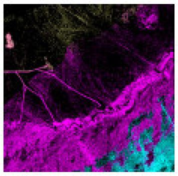
## Oahu

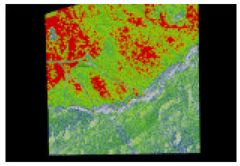
| pointNo | e | n | elevation | zLidar | LandCoverType | DeltaZ |
|---|---|---|---|---|---|---|
| TU0617 | 1593652.160 | 73676.296 | 12.172 | 11.167 | Open Terrain | -1.005 |
| 102.000 | 1556078.351 | 141302.900 | 21.096 | 20.590 | Open Terrain | -0.505 |
| TU0329 | 1735344.266 | 42726.981 | 4.364 | 3.874 | Open Terrain | -0.489 |
| 218.000 | 1642964.201 | 59696.731 | 17.552 | 17.072 | Open Terrain | -0.481 |
| 205.000 | 1569597.976 | 107011.203 | 8.793 | 8.370 | Open Terrain | -0.423 |
| 215.000 | 1633290.139 | 51325.258 | 7.743 | 7.331 | Open Terrain | -0.412 |
| 212.000 | 1643269.351 | 54007.569 | 3.707 | 3.373 | Open Terrain | -0.335 |
| 217.000 | 1639543.571 | 55820.262 | 15.486 | 15.172 | Open Terrain | -0.314 |
| 229.000 | 1649378.624 | 77738.526 | 9.154 | 8.844 | Open Terrain | -0.309 |
| 127.000 | 1677766.953 | 58004.412 | 5.905 | 5.625 | Open Terrain | -0.281 |
| 220.000 | 1739400.819 | 36404.980 | 38.845 | 38.582 | Open Terrain | -0.263 |
| 206.000 | 1576460.659 | 103577.975 | 14.403 | 14.154 | Open Terrain | -0.249 |
| 124.000 | 1681794.701 | 50590.712 | 6.168 | 5.941 | Open Terrain | -0.227 |
| 104.000 | 1562791.888 | 130710.533 | 20.899 | 20.713 | Open Terrain | -0.186 |
| 121.000 | 1679368.689 | 51075.554 | 7.283 | 7.131 | Open Terrain | -0.152 |
| 240.000 | 1649789.811 | 80737.896 | 20.341 | 20.246 | Open Terrain | -0.095 |
| 131.000 | 1678265.607 | 54821.249 | 11.975 | 11.880 | Open Terrain | -0.095 |
| 109.000 | 1607492.225 | 48418.965 | 10.072 | 10.029 | Open Terrain | -0.044 |
| 128.000 | 1679997.132 | 55606.385 | 12.467 | 12.431 | Open Terrain | -0.037 |
| 110.000 | 1606641.734 | 48284.221 | 9.121 | 9.089 | Open Terrain | -0.032 |
| 101.000 | 1562776.664 | 132905.968 | 16.831 | 16.816 | Open Terrain | -0.015 |
| 225.000 | 1740643.599 | 43807.622 | 7.546 | 7.558 | Open Terrain | 0.012 |
| 222.000 | 1740878.014 | 41754.182 | 8.301 | 7.851 | Weeds/Crop/Forest | -0.450 |
| 204.000 | 1566217.012 | 112108.404 | 15.387 | 14.971 | Weeds/Crop/Forest | -0.416 |
| 111.000 | 1605811.060 | 48019.195 | 8.497 | 8.140 | Weeds/Crop/Forest | -0.358 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 224.000 | 1744571.675 | 45925.367 | 7.480 | 7.204 | Weeds/Crop/Forest | -0.276 |
| 106.000 | 1562438.509 | 121074.102 | 14.764 | 14.509 | Weeds/Crop/Forest | -0.254 |
| 113.000 | 1604652.959 | 47702.890 | 8.071 | 7.838 | Weeds/Crop/Forest | -0.233 |
| 114.000 | 1607076.248 | 49654.363 | 13.025 | 12.862 | Weeds/Crop/Forest | -0.163 |
| 211.000 | 1640572.211 | 53661.474 | 6.070 | 5.929 | Weeds/Crop/Forest | -0.141 |
| 122.000 | 1680676.265 | 51164.563 | 6.923 | 6.790 | Weeds/Crop/Forest | -0.133 |
| 116.000 | 1602488.035 | 49882.971 | 5.643 | 5.524 | Weeds/Crop/Forest | -0.119 |
| TU1679 | 1640845.832 | 53731.717 | 5.545 | 5.503 | Weeds/Crop/Forest | -0.041 |
| 125.000 | 1684391.677 | 48654.299 | 6.496 | 6.592 | Weeds/Crop/Forest | 0.096 |
| 216.000 | 1635679.373 | 54002.025 | 9.875 | 9.980 | Weeds/Crop/Forest | 0.105 |
| 126.000 | 1683822.945 | 50190.746 | 5.479 | 5.618 | Weeds/Crop/Forest | 0.139 |
| 119.000 | 1678897.561 | 52502.487 | 9.121 | 9.469 | Weeds/Crop/Forest | 0.348 |
| 203.000 | 1561963.576 | 115028.444 | 15.617 | 16.018 | Weeds/Crop/Forest | 0.402 |
| 105.000 | 1563044.741 | 127078.978 | 19.554 | 19.974 | Weeds/Crop/Forest | 0.420 |
| 226.000 | 1736823.036 | 43062.873 | 9.842 | 10.414 | Weeds/Crop/Forest | 0.572 |
| 115.000 | 1608828.935 | 48542.029 | 10.827 | 11.512 | Weeds/Crop/Forest | 0.686 |
| 223.000 | 1742104.062 | 44509.721 | 7.940 | 8.929 | Weeds/Crop/Forest | 0.989 |
| 236.000 | 1650950.241 | 76948.042 | 14.993 | 14.278 | Urban | -0.715 |
| 230.000 | 1650398.602 | 75086.530 | 8.465 | 7.793 | Urban | -0.672 |
| 207.000 | 1580724.398 | 95495.806 | 8.333 | 7.703 | Urban | -0.630 |
| 232.000 | 1651207.393 | 75705.032 | 13.386 | 12.813 | Urban | -0.573 |
| 231.000 | 1649510.481 | 75158.445 | 12.631 | 12.085 | Urban | -0.546 |
| 120.000 | 1678226.105 | 52643.989 | 3.871 | 3.400 | Urban | -0.471 |
| 237.000 | 1650563.628 | 77908.374 | 8.333 | 7.959 | Urban | -0.374 |
| 238.000 | 1649649.949 | 78054.601 | 12.434 | 12.098 | Urban | -0.336 |
| 235.000 | 1649439.254 | 76704.866 | 15.026 | 14.717 | Urban | -0.309 |
| 112.000 | 1605964.701 | 47424.774 | 5.282 | 4.989 | Urban | -0.293 |
| 107.000 | 1567134.933 | 109788.570 | 18.471 | 18.184 | Urban | -0.287 |
| 234.000 | 1649114.287 | 75753.326 | 11.220 | 10.941 | Urban | -0.279 |
| 221.000 | 1740810.462 | 39247.691 | 11.647 | 11.375 | Urban | -0.272 |
| 208.000 | 1581173.117 | 86913.507 | 15.551 | 15.345 | Urban | -0.206 |
| 108.000 | 1608093.667 | 48530.743 | 10.597 | 10.411 | Urban | -0.186 |
| 117.000 | 1604418.182 | 48837.632 | 10.597 | 10.459 | Urban | -0.138 |
| 239.000 | 1649908.741 | 78924.908 | 8.957 | 8.860 | Urban | -0.097 |
| 213.000 | 1636753.091 | 52416.299 | 4.757 | 4.669 | Urban | -0.089 |
| 129.000 | 1680045.984 | 58822.947 | 19.751 | 19.664 | Urban | -0.086 |
| 123.000 | 1683404.376 | 49952.492 | 6.496 | 6.430 | Urban | -0.066 |
| 233.000 | 1650685.609 | 76227.439 | 11.122 | 11.099 | Urban | -0.023 |
| 214.000 | 1635350.371 | 51999.896 | 6.365 | 6.405 | Urban | 0.040 |

# Appendix C Qualitative issues contact sheets

TO26 - Hawaii


011746_SparseDensity_groundPtBySource.png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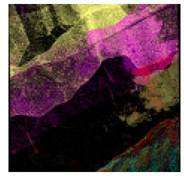
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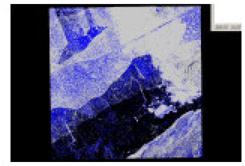
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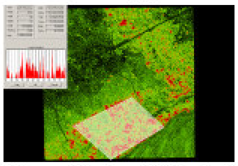
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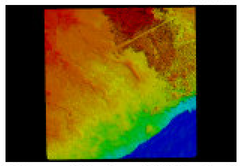
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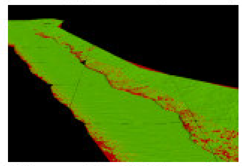
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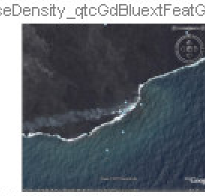
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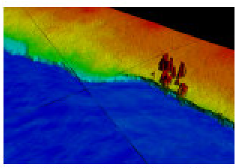
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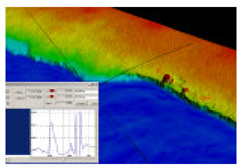
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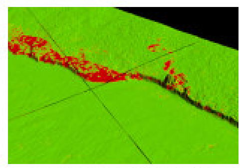
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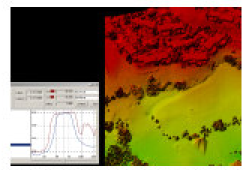
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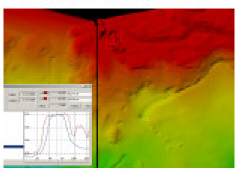
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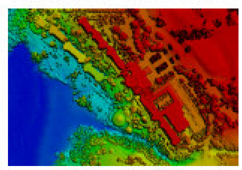
1621_possibleArtifact_ortho.png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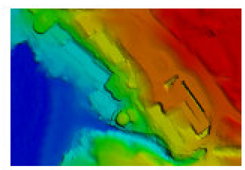
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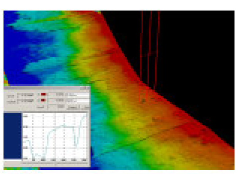
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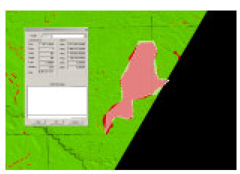
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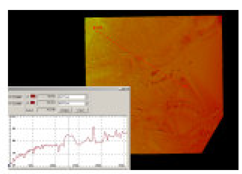
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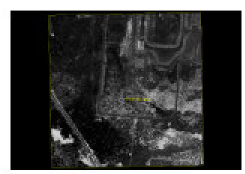
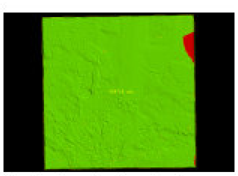

4716_misclassificationAggRemoval_qttExtFeatInt.png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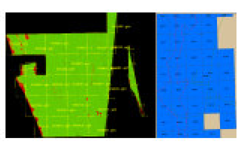
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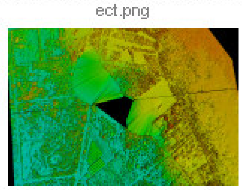
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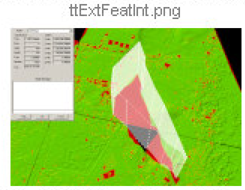
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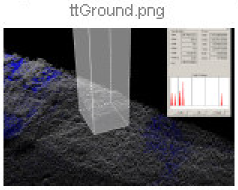
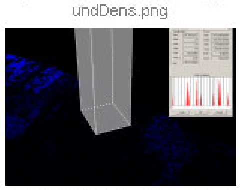

9332_poorLidarPenetration_qtcExtFeatGrey.png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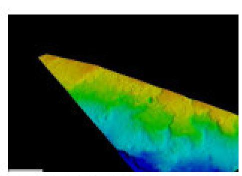
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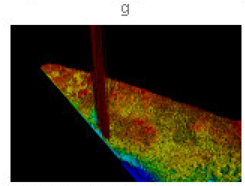
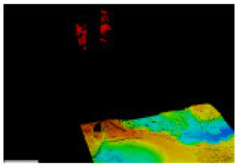
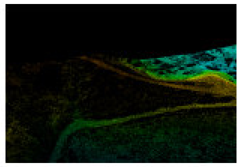

9332_poorLidarPenetrationSpikes_qttExtFeat.png

TO26 - Kauai


0693_dataHolidayAndSpikes_qtcExtFeat.png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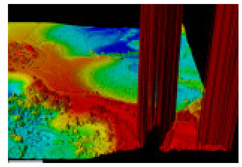
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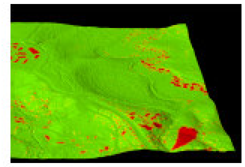
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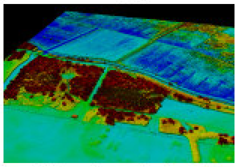
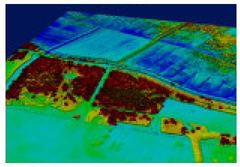

0795_noise and potentiel artifact_qttExtFeat.bmp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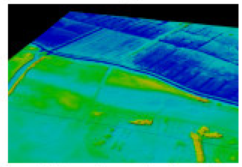
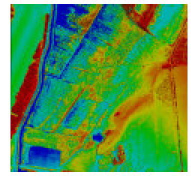
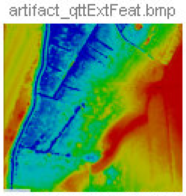

0795_noise and potentiel artifact_qttGround.png


0844_lowDens agressivRemovVegeor poorPenetrLidar_qttExtFeat.png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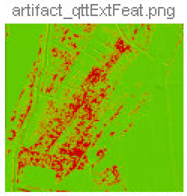
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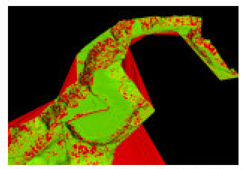
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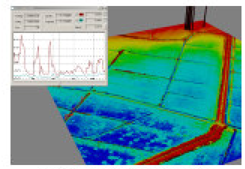
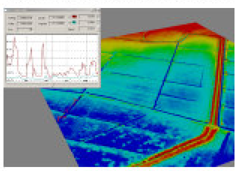
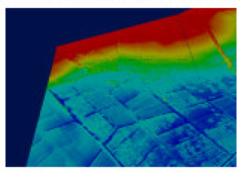
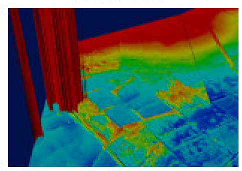

0940_negValuesInDitch Spikes_qttExtFeat.png


0940_negValuesInDitch Spikes_qttGround.png


0988__extractedSpikes and sparseDens_qttGround.png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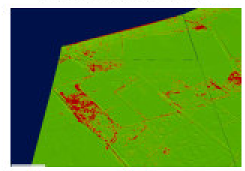
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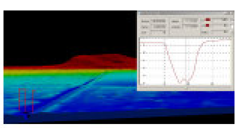
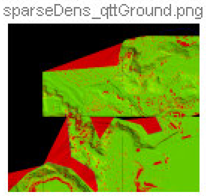

1222_divotMinus4m_qttGround.png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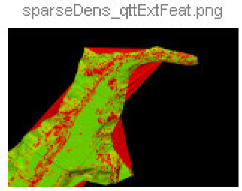
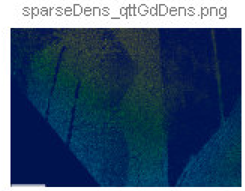
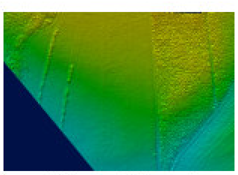

1367_sparseDensity_qttGdDens.png


1494_scanEdge and poorLidarPenetrInVege_qtcGround.pn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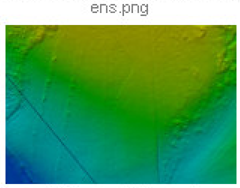
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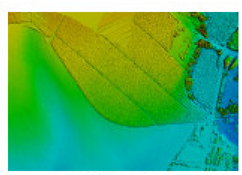
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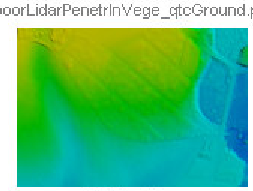
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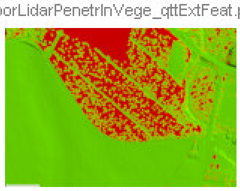
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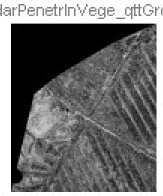
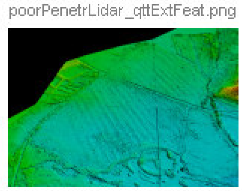
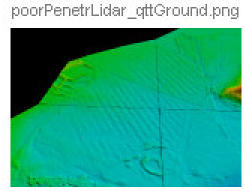
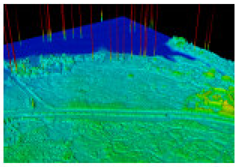

1508_possibleArtifact_intensity_fullCloudOfPoints.png

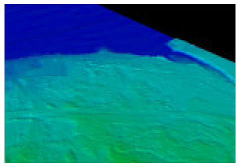

1530_possibleArtifact_qttExtFeat.png


1530_possibleArtifact_qttGround.png

TO26 - Kauai



1537_spikesAndAgressivRemovalOf Veg_qttExtFeat.png



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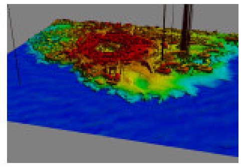

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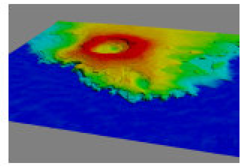

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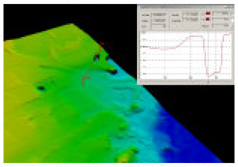

1545_divotAndPossibleAgressiveSmo othing_qttGround.png

TO26 - Oahu

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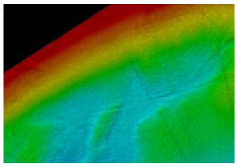
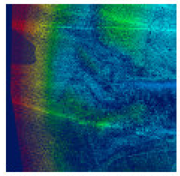
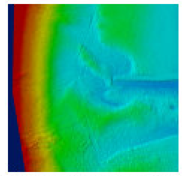
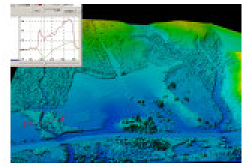
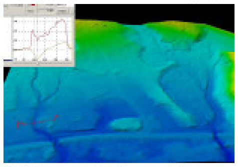
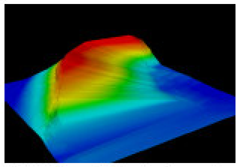
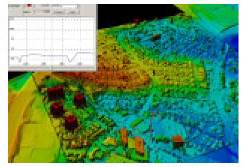
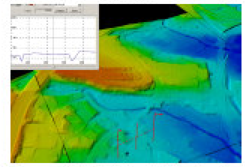
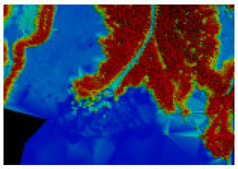
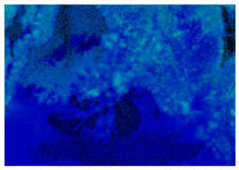
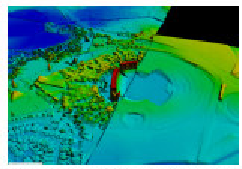
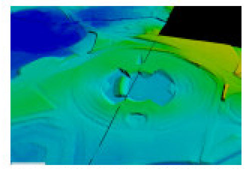
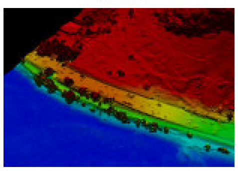
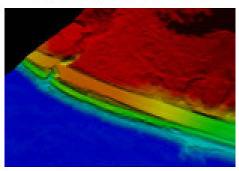
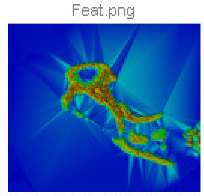
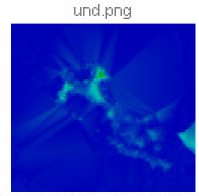
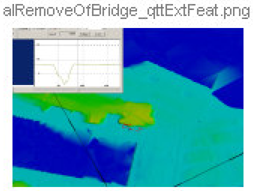
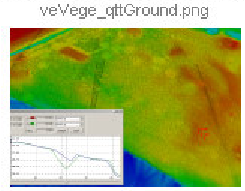
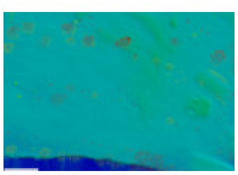
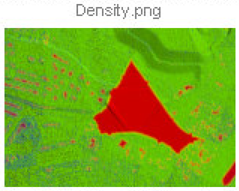
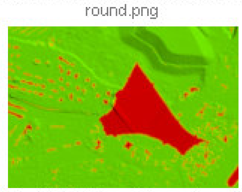
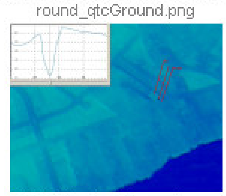
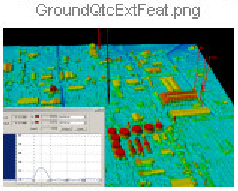
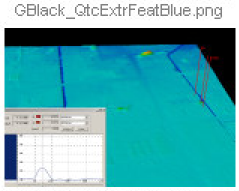
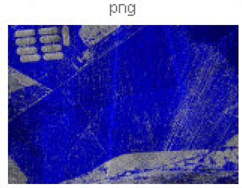
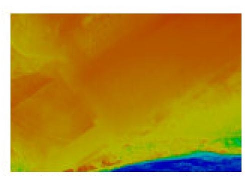
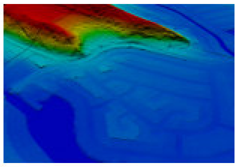
|  0508_cornRowOtherArtifact_qttGroundAndGroundPointCloud.png |  0508_ScanPattern_qtcGround.png |  0508_ScanPattern_qttGround.png |  0653_agressiveRemovVege and goodRemovBridge_qttExtFeat.png |
|  0653_agressiveRemovVege and goodRemovBridge_qttGround.png |  1179_highZmaxOnProjectBoundary_ground.png |  1534_possibleBuildingArtifact_divots_qttFpc.png |  1534_possibleBuildingArtifact_divots_qttGround.png |
|  1578_onlyVegetationNoGround_extrFeat.png |  1578_onlyVegetationNoGround_qttGroundWithCloudPoint.png |  1586_possibleBuildingArtifact_qttExctFeat.png |  1586_possibleBuildingArtifact_qttGround.png |
|  1617_aggressiveVegetRemovOrPartialRemoveOfBridge_qttExtFeat.png |  1617_aggressiveVegetRemovOrPartialRemoveOfBridge_qttGround.png |  1630_poorLidarPenetrationAggrRemoveVege_qttExtFeat.png |  1630_poorLidarPenetrationAggrRemoveVege_qttGround.png |
|  1635_divot_qttGround.png |  1827_dataHolidayOnEdge_qttGroundDensity.png |  1897_smallDimplePossibleAcqPb_qttGround.png |  1897_smallDimplePossibleAcqPb_qttGround_qtcGround.png |
|  1897_smallDimplePPossibleAcqPb_qttGroundQtcExtFeat.png |  1937_dataHoliday_qttGdDenstity_QtcGBlack_QtcExtrFeatBlue.png |  1937_dataHoliday_qttGroundDenstity.png |  1944_divot_qttGround.png |
|  1989_buildingArtifactInGround_spikesInExtFeat_qttExtFeat.png |  1989_buildingArtifactInGround_spikesInExtFeat_qttGround.png |  1991_scanNoise_qtcBlueGroundGreyExtFeat.png |  1991_scanNoise_qttGround.png |

TO26 - Oahu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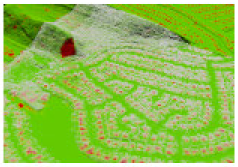
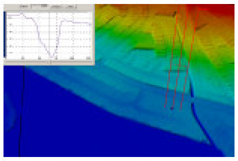
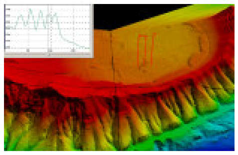
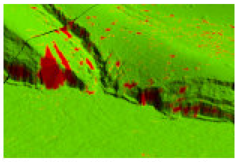

2031_dataholiday_qttGroundDensityQtcExtFeat.png


2032_divot_qttGround.png


2160_possibleArtifact_qttGround.png


2171_dataholiday_qttGround.png


2171_dataholiday_qttGroundDensityQtcExtFeat.png