LiDAR QA/QC

– Quantitative and Qualitative Assessment Report –

Jefferson County FL

May 6, 2008

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# EXECUTIVE SUMMARY

This LiDAR project covered approximately 513 sq miles and covers the north part of Jefferson County, Florida. The LiDAR data were acquired and processed by Sanborn in February 2007. The product is a mass point dataset with an average point spacing of 0.7m projected in UTM Zone 16 North, NAD83 with linear units in Meters. Elevations are expressed as orthometric heights using vertical datum NAVD 88 and utilizing Geoid 03 with vertical units in US Survey Feet. The data is tiled, stored in LAS format, and LiDAR returns are classified in 4 ASPRS classes: non-ground (1), ground (2), noise (7) and water (9). DEM (1 meter pixels) are also delivered.

Sanborn provided the vertical accuracy of these data and Dewberry reviewed their testing methodology. Dewberry also performed a quality assessment of these data including a completeness check and a qualitative review to ensure accuracy and usability for floodplain mapping and the needs of the North West Florida Water Management District (NWFWMD). This report is the re-assessment of the data due to issues first identified by Dewberry and subsequently reprocessed by Sanborn.

First, based on acquisition survey data provided by Sanborn, the LiDAR meets the accuracy required for this project (RMSEz Open terrain: 0.366ft compared to the specified 0.492ft for accuracy, and Vegetation: 0.464ft compared to the specified 0.885ft). It should be noted that the methodology used does not explicitly conform to FEMA Appendix A but is similar and acceptable. Additionally the data also complies with the NSSDA standard for vertical accuracy testing. This LiDAR dataset was tested 0.218m (0.716ft) fundamental vertical accuracy at 95% confidence level, based on consolidated RMSEz (0.366ft) x 1.9600.

Secondly, Dewberry inventoried the files and confirmed that all tiles were delivered by Sanborn in the specified format and correctly geographically projected. However one tile contained only ground points. We visually inspected 100% the data at a macro level; no remote-sensing data void was found but the data exhibit a recurrent sensor issue resulting in 0.5ft ridges at the edge of the flightlines which is within an acceptable range. The cleanliness of the bare earth model was of adequate quality although noisy due to a poor LiDAR penetration in dense vegetation. Minor errors were found (such as cornrows, possible vegetation remains) but are not representative of the majority of the data. It should be noted that although the first report indentified many issues, only 20% of these issues were corrected.

In essence, this LiDAR dataset produced by Sanborn passes the quantitative accuracy requirement but the qualitative aspects of this data, although subjectively acceptable, are not to the level expected. However the data should meet most users' needs.

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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. 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, the quantitative analysis addresses the quality of the data based on absolute accuracy of a limited collection of discrete checkpoint survey measurements. For this project, the data provider assessed the vertical accuracy of the data and Dewberry thoroughly reviewed it.

Then, the completeness verification is conducted at a project scale (files are considered as the entities). It consists of a file inventory and a validation of; data format conformity 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/Quality Control 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 Vertical accuracy Assessment

Typically for this type of data collection, a ground truth survey is conducted following the *FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial mapping and Surveying*. This methodology collects a minimum of 20 points for each of the predominant land cover types (i.e. bare-earth, weeds and crop, forest, urban etc.). By verifying the data in these different classes, the data accuracy is tested but it also tests whether the classification of the LiDAR by land cover type has been performed correctly at those test point locations. However since this survey did not have an independent ground truth survey, the LiDAR provider internal checkpoints were utilized.

For this project Sanborn collected 55 checkpoints in Jefferson County (Appendix A). Their initial QA/QC Report yielded an overall RMSE of 0.363 ft. Sanborn's results were obtained using LAS files in ellipsoid heights and checkpoint data in ellipsoid heights. In order to confirm this accuracy, Dewberry converted the checkpoints elevations to orthometric heights as this is the format of the final LAS data. We also expressed the accuracy for the different landcover types as recommend in the FEMA guidelines. The 55 checkpoints were separated by Sanborn into five categories (bare, short grass, tall grass, urban and "perimeter" plus one point without class). For the purposes of our QA/QC report we classified "bare" and "short grass" as Open Terrain, urban as Urban, "tall grass" as Vegetation, and the "perimeter" and the "unknown" as Unknown. Meanwhile, the targeted vertical accuracy in Sanborn scope of work was:

- 15cm RMSE for Bare Earth (0.492ft)
- 27cm for Vegetation (0.885ft)

Figure 1 shows the distribution of the checkpoints throughout Jefferson County. All of the checkpoints were within the project boundaries and there is a good distribution of points across the county.

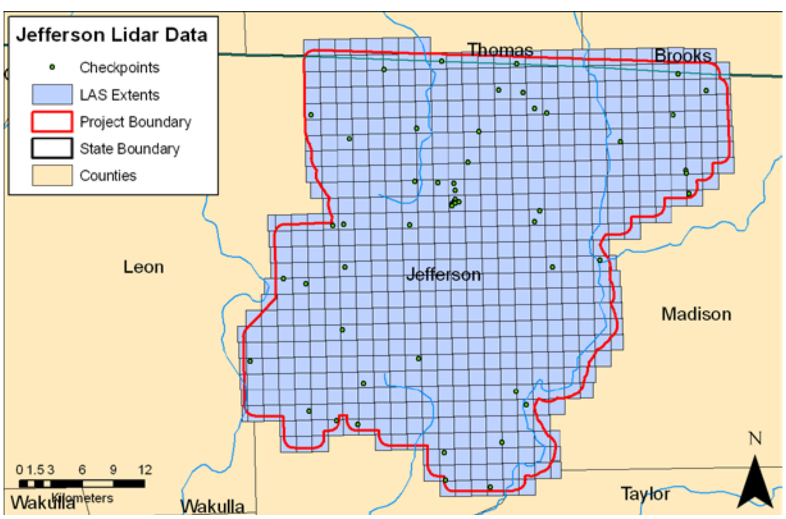


*Figure 1 – Check Points for Sanborn Survey*

To compute the accuracy, the checkpoints z-values are compared to z-values computed at the same horizontal locations from a TIN generated from the bare-earth LiDAR.

The statistics computed on the elevation differences between LiDAR and GPS are presented below. Table 1 and Table 2 show the complete results of the Sanborn data set run through the Dewberry RMSE process. The consolidated RMSE for the data set was 0.363 feet which confirms Sanborn results. In addition, both classes Open Terrain (0.366ft compared to 0.492ft) and Vegetation (0.464ft compared to 0.885ft) meet the specifications. The Figure 2 illustrates the distribution of the elevation differences between the LiDAR data and the surveyed points. Open Terrain errors points are well distributed around 0 but the vegetation error points, except for one point, are all positives, indicating that the LiDAR gives higher ground elevation than the actual when vegetation is present; this is a common issue in dense vegetation as the LiDAR beam may not penetrate all the way to the ground.

While Sanborn did not apply the prescribed methods in the FEMA Guidelines and Specifications for Flood Hazard Mapping Partners Appendix A: Guidance for Aerial Mapping and Surveying explicitly, we believe that that the methodology and results are comparable and still hold true. The premise is that if the LiDAR system was accurate for the fundamental checks in the land cover groups used then the same type of accuracy should be present in all other groups not surveyed, such as woods. However, as this area exhibits an especially dense vegetation in wooded areas with several layers of under story vegetation, and as the accuracy of the bare earth in vegetated areas is based on the classification quality and on correct Laser penetration, bare earth model in forests may not be as accurate as expected and caution should be used.

*Table 1 - Dewberry RMSE Report*

| 100 % of Totals | RMSE (ft) Spec OT =0.492ft, V=0.885ft | Mean (ft) | Median (ft) | Skew | Std Dev (ft) | # of Points | Min (ft) | Max (ft) |
|---|---|---|---|---|---|---|---|---|
| Consolidated | 0.363 | -0.010 | -0.003 | -0.149 | 0.367 | 55 | -0.841 | 0.632 |
| **Open Terrain (OT)** | **0.366** | **-0.128** | **-0.119** | **-0.097** | **0.349** | **26** | **-0.841** | **0.520** |
| **Vegetation (V)** | **0.464** | **0.362** | **0.406** | **-2.491** | **0.309** | **9** | **-0.424** | **0.617** |
| Unknown | 0.309 | 0.083 | 0.114 | -0.088 | 0.310 | 12 | -0.400 | 0.632 |
| Urban | 0.296 | -0.183 | -0.104 | -0.401 | 0.249 | 8 | -0.542 | 0.142 |

*Table 2 - Dewberry RMSE Report*

| Land Cover Category | # of Points | FVA — Fundamental Vertical Accuracy (RMSEz x 1.9600) Spec=0.964 ft | CVA — Consolidated Vertical Accuracy (95th Percentile) Spec=0.964 ft | SVA — Supplemental Vertical Accuracy (95th Percentile) Spec BE=0.964ft V=1.735ft |
|---|---|---|---|---|
| Consolidated | 55 | | 0.608 | |
| **Open Terrain** | **26** | **0.716** | | **0.599** |
| **Vegetation** | **9** | | | **0.589** |
| Unknown | 12 | | | 0.505 |
| Urban | 8 | | | 0.525 |

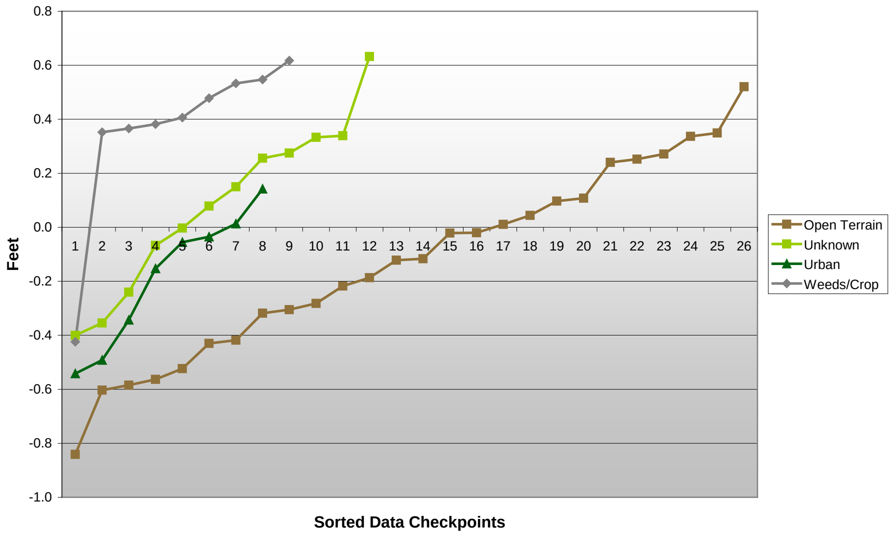



*Figure 2 - Sorted checkpoint errors*

# 3 Quality Assurance

## *3.1 Completeness of LiDAR deliverables*

The first step in our review is to inventory the data delivered, to validate the format, projection, georeferencing and verify the range of elevations.

### 3.1.1 Inventory and location of data

The project area is approximately 513 sq miles and covers the north part of Jefferson County, Florida.

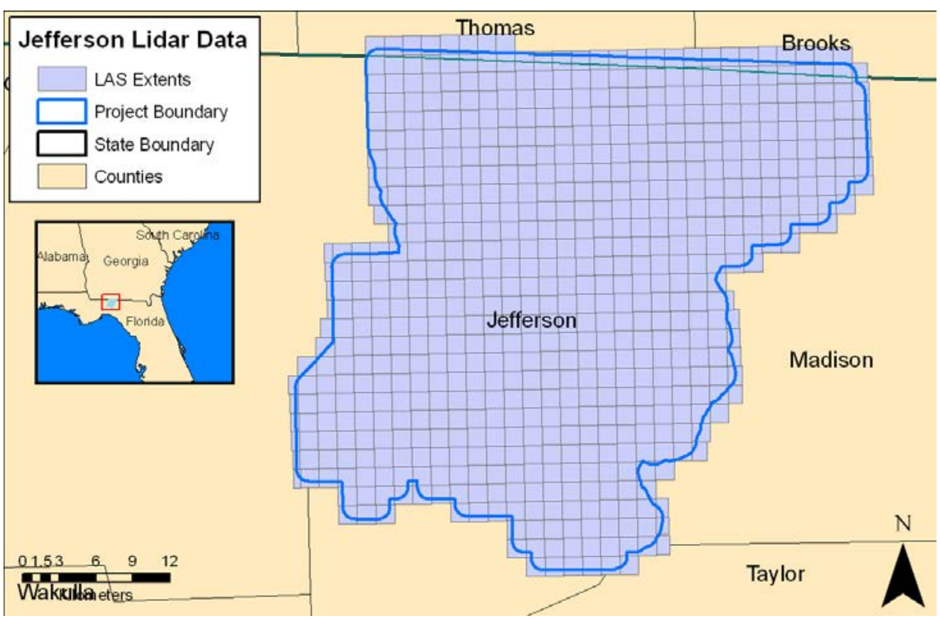
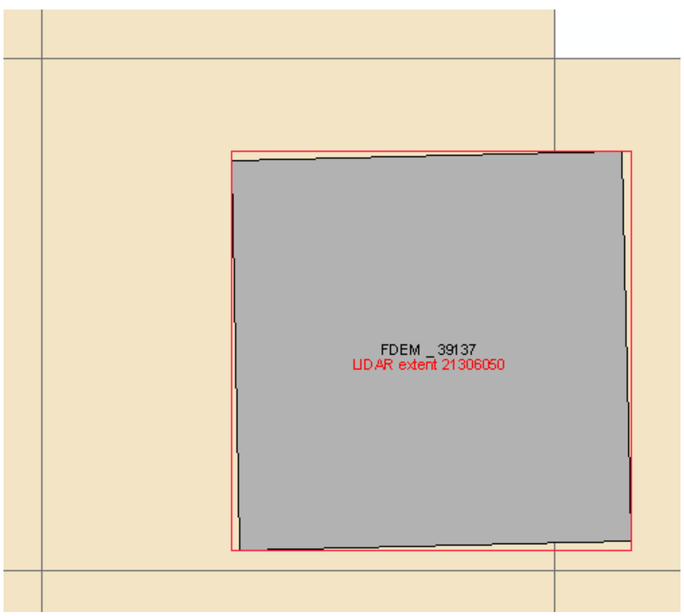



*Figure 3 - Delivered LiDAR tiles – extent of the LAS files*

We verified that the data is in the correct projection:

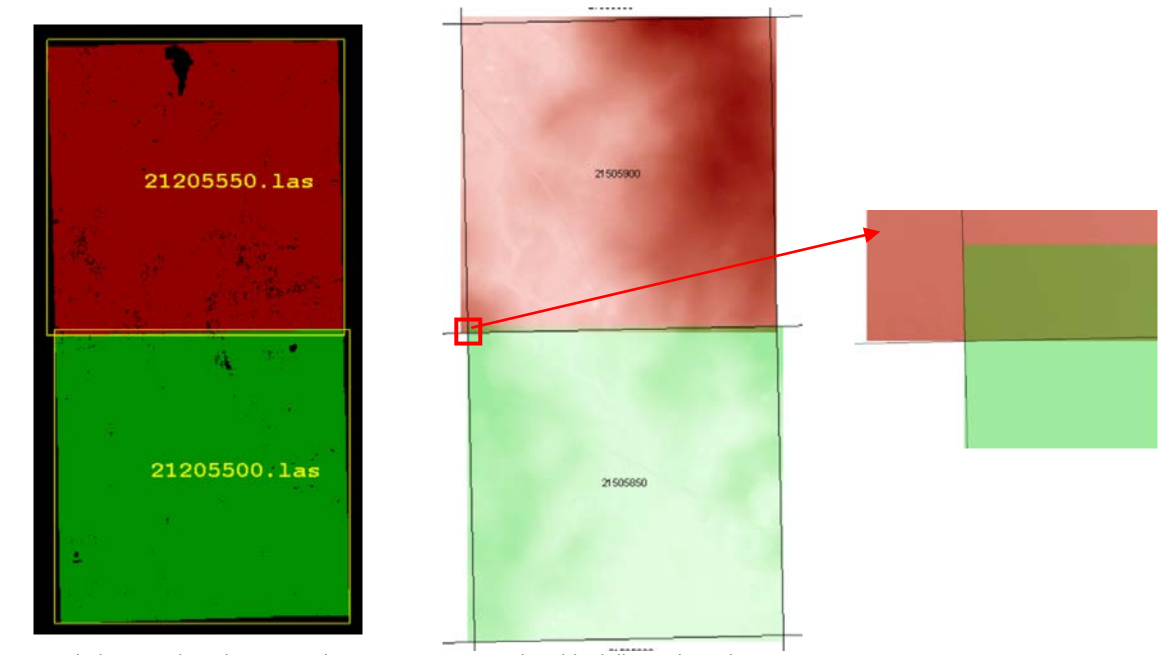
- UTM Zone 16 North
- Horizontal Datum: NAD83
- Vertical Datum: NAVD 88 Geoid 03
- Units: Horizontal – Meters, Vertical – US Survey Feet

A total of 635 LAS tiles and 635 DEM rasters in ArcGIS GRID format were delivered by Sanborn for the entire project overlapping all the required area. The data are tiled using FDEM (Florida Division of Emergency Management) tile scheme, but do not follow the FDEM naming convention. Moreover, this tile grid was originally created in State Plane Florida North, each tile being orthogonal; for this project it was reprojected in UTM 16N (see Figure 4). As a consequence, the tile shape used to divide the dataset is rotated as compared to the state plane coordinate tile scheme. It should be noted that even though the extent shapes (or bounding rectangle in UTM) created from the LAS files will seem to have an overlap, the LiDAR points actually do not overlap. However, the DEM rasters have to be orthogonal in UTM, as a consequence, adjacent DEM will overlap, pixels being duplicated between 2 DEM, this is illustrated in Figure 5. We verified that the overlapping section matches between adjacent DEMs in 5 cases, all the differences were within the excepted tolerance.




Beige background: tile scheme sent by Sanborn, grey: FDEM tile = location of the LiDAR point; red: corresponding LiDAR extent rectangle (projection used for the display: UTM 16N)

*Figure 4 – Tiling scheme illustration*




Real LiDAR points do not overlap; LiDAR extents (yellow lines) overlap but not the points

DEM overlap; black lines show the FDEM tile scheme (green DEM displayed with a transparency)

DEM overlap detail

*Figure 5 – Tiling scheme illustration for LAS files and DEM rasters*

LiDAR data were delivered in LAS (extension .las) version 1.1 with a point data format including GPS time. Each record includes the following fields:

- XYZ coordinates
- Flightline number
- Intensity
- Return number, Number of return, scan direction, edge of a flight line and scan angle, GPS time
- Classification:
    - code 1 for non-ground,
    - code 2 for ground
    - code 7 for noise (low and high points)
    - code 8, model key-point (observed as water on some tiles and is considered an error)
    - code 9 for water

Concerning the DEM rasters, their pixel resolution is 1m. All the files correctly open in ArcCatalog. We verified 12 of them for consistency against the LiDAR. LiDAR ground points were converted to a TIN then converted to a raster with 1m resolution. The DEM and the raster derived from the LiDAR were compared by subtraction. No anomalies were found, the differences were within the expected range in steeper areas.
DEMs inherit LiDAR ground masspoint data issues, therefore, DEM may appear noisy and DEM located at the projected boundary are partial although not clipped by the project boundary.

### 3.1.2 Statistical analysis of tile content

To verify the content of the data and to validate the data integrity, a statistical analysis was 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 each class. Minimum and maximum for other relevant variables are also evaluated.

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 when the tile was truncated) as illustrated in Figure 6. Even though the LiDAR masspoint dataset is not clipped by the boundary polygon, the LiDAR points do not cover the entire tile outside the boundary in some tiles intersecting the boundary, this is especially true on the east-south and west-south sides.

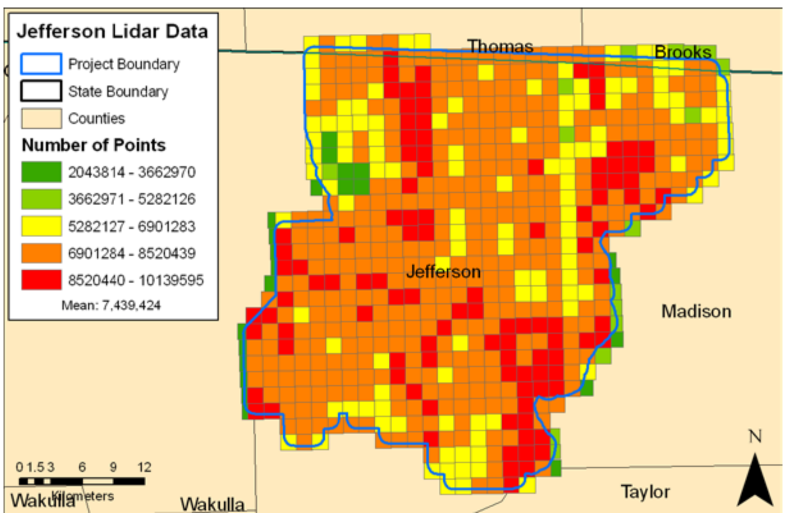



*Figure 6 – Number of Points per Tile.*

The four tiles shown in green in the northwest quadrant of Figure 6 were examined more closely and we found that there was a large amount of swampy area or water in these tiles. Therefore, the cluster of tiles with few points is normal. Figure 7 illustrates this area.

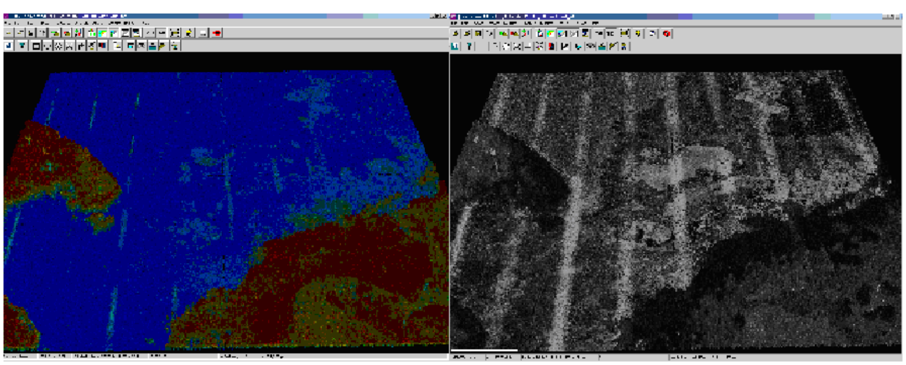
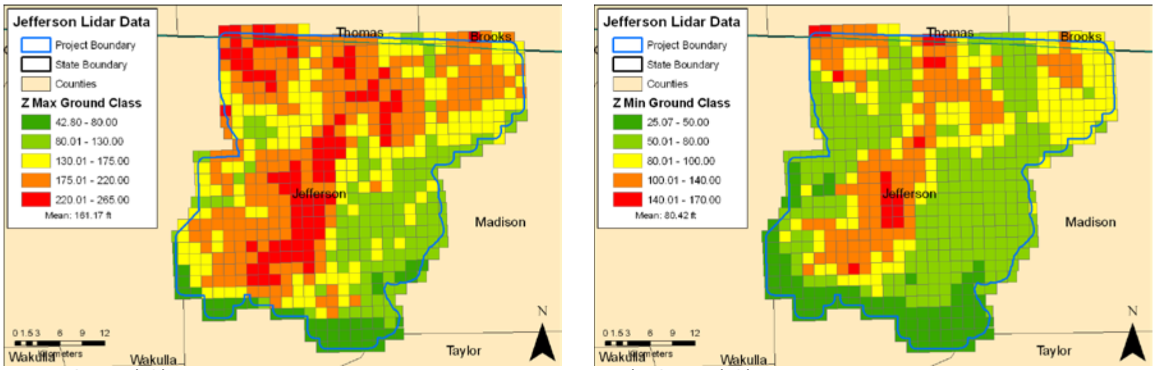


*Figure 7 – Tile with less points due to swamp of water*

To first identify incorrect elevations, the z-minimum and z-maximum values for the ground class were reviewed. With maximum values between 40 and 265ft, no noticeable anomalies were identified. Figure 8 shows the spatial distribution of these elevations, following the anticipated terrain topography and the Z Max ground and the Z Min ground seem to correlate with one another.




Z Max Ground Class Z Min Ground Class

*Figure 8 – Max and min elevation statistics per tiles*

The class review allowed us to identify a tile (22405850) with all the points in class 2 (see Figure 9). A visualization confirmed that this tile was correctly classified as far as the ground is concerned (buildings and vegetation are removed) and would be correct to create a bare earth model. However, all the other classes are missing.

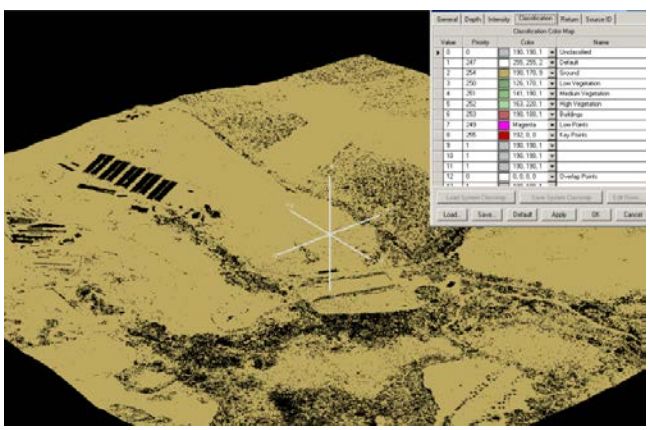


*Figure 9 – Tile 22405850; only ground class is present in the file*

Class 7 (Low point - noise) contains the lowest points in the files. These elevations are not necessarily anomalies. Only one tile (21904850) contained an elevation of -3295 feet. It should be noted higher error points (spikes, isolated anomalies) remain in class 1 (Unclassified) as illustrated in Figure 10.

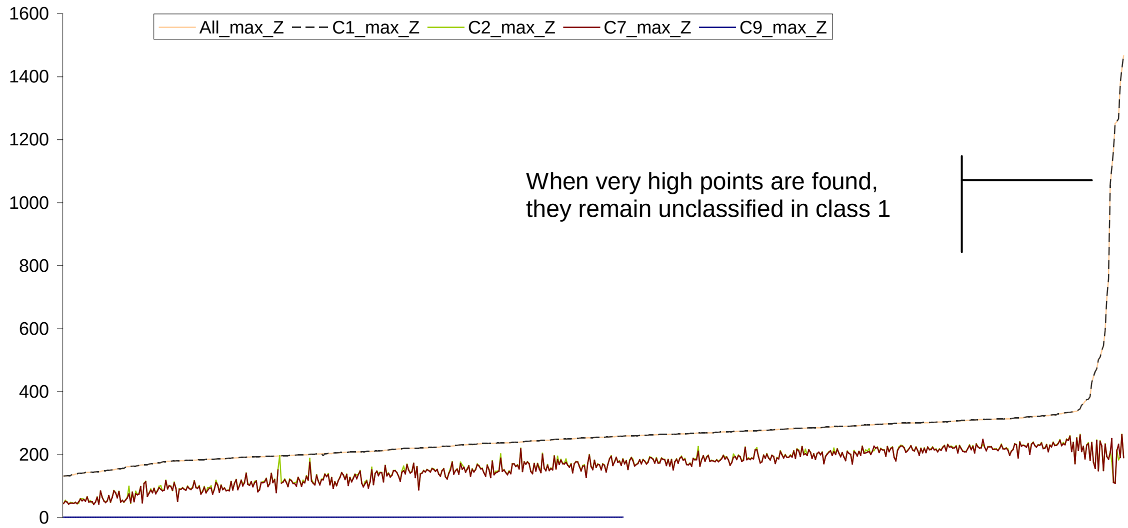
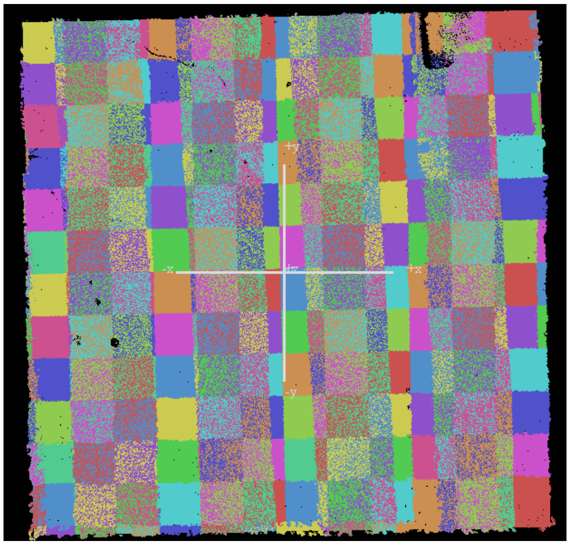
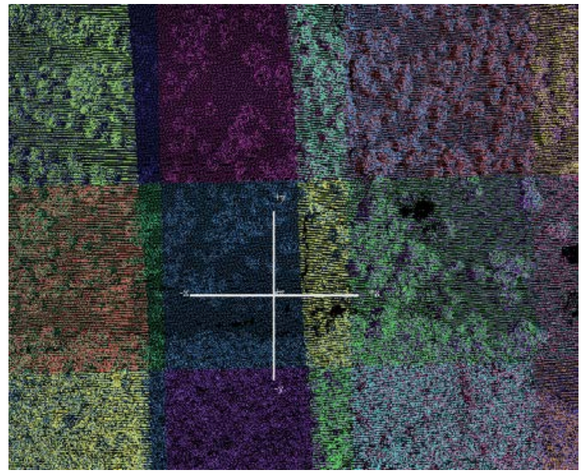



*Figure 10 - Maximum elevation in feet for each tile sorted by Max_Z, each class is also plotted separately*

Statistics on the Point Source Id parameter, usually holding the flight line number, extracted 23 files having only one flightline number equal to 1, whereas it was clear that several flightlines were stored in the file (see Figure 12, right), this is a minor issue as no explicit specification was made for this parameter. Another tile (22156000) exhibits an unusual pattern for the flightline id with sections (squares) within a flight line being classified as different flightlines (Figure 11).

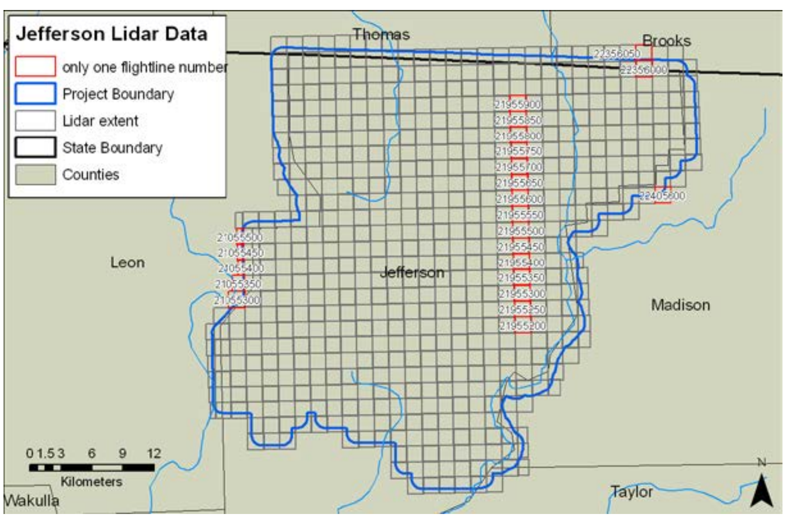


Full point cloud displayed by flight line



Close up

*Figure 11 – Tile 22156000 with mosaic of Flightline numbers*



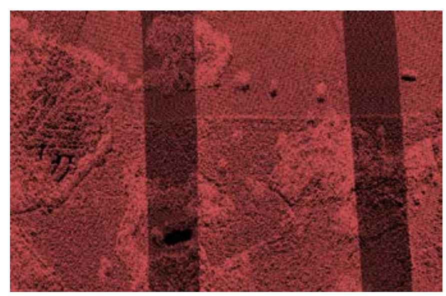



*Figure 12 – Tiles with only one 'Point Source ID' or flight line number*

## 3.2 Qualitative assessment

### 3.2.1 Protocol

The goal of this qualitative review is to assess the continuity and the level of cleanliness of the bare earth product and to ensure its conformance to support the intended final product. The acceptance criteria we have reviewed are the following:

- If the density of point is homogeneous, correctly supported by flightline overlap 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 classification, no over-smoothing, no inconsistency in the post-processing), in a context of flood modeling, special attention is given to the stream channels,
- If no obvious anomalies 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 the bare-earth digital elevation model (bare-earth DEM). LiDAR mass points were first gridded with a grid distance of 2x the full point cloud resolution. Then, a triangulated irregular network (TIN) was built based on this gridded DEM and displayed as a 3D surface. A shaded relief effect was 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 13*).

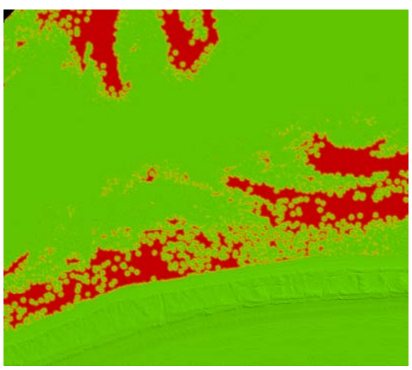


*Figure 13 – Ground model with density information (red means no data)*

The first step of our qualitative workflow was to verify the point distribution by systematically loading a percentage of the tiles as mass points colored by class or by flightline. This particular type of display helps us visualize and better understand the scan pattern, the flight line orientation and coverage and gives an additional confirmation that all classes are present and seem to logically represent the terrain.

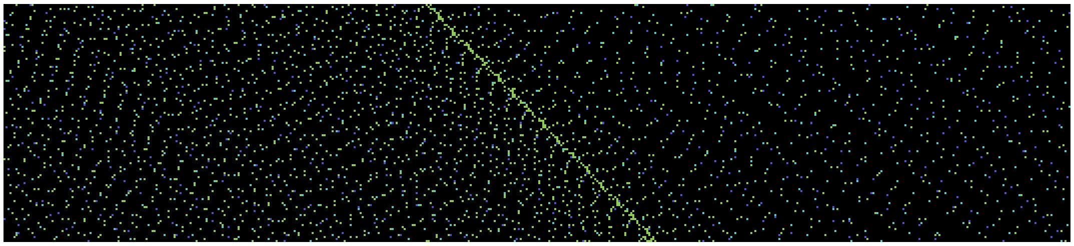


*Figure 14 – LiDAR points colored by flightline. Detail of the point distribution. Note the variations in the scan pattern*

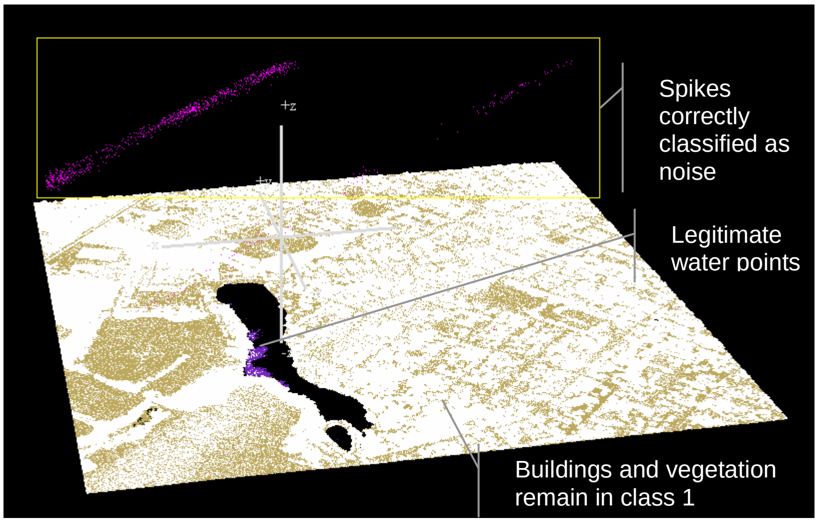



*Figure 15 – Full point cloud colored by class (white: non ground, brown: ground, pink: noise, dark violet: water)*

The second step was 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 the 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.

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.

### 3.2.2 Quality report

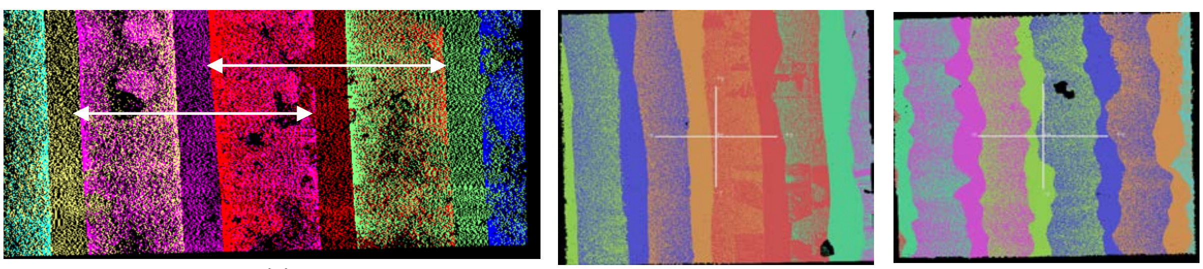
Our Qualitative review was to perform a macro visual inspection of all the tiles and to inspect a minimum of 30% at a micro level of detail. Additionally we reviewed 10% of the data for the scanning and flightline consistency.

Our professional judgment is that the majority of the bare earth models are of adequate quality but some minor issues do exist that may need to be rectified for specific cases. The cleanliness of artifacts (classification of the data) is satisfactory; however the smoothness of the ground may not be as good as expected. No remote sensing voids were found. Dewberry did find errors in the data as outlined in the text and images below (contact sheets of all the errors found during the review are given in Appendix C).

*Point pattern*

The adjacent flightline overlap seen in the images was 40% (see Figure 16). It represents the actual overlap during acquisition since the flightline edges were not clipped (the zig-zag pattern at the end of each scan line is easily visible). The flightlines are either really straight or curvy, possibly due to windy conditions. Moreover, wind could also be the cause of slight variation in the plane pitch resulting in an apparent "bunching" of the scans as in Figure 17. In this case, it does not compromise the integrity of the data.

When considered over an entire tile, the point density meets the specifications of 0.7m and is even better in overlapping areas. However in the sections where only one pass was acquired, which correspond to the middle of each flightline (nadir), the point spacing may be wider (1.2m along scan, 1 to 1.2m along track at nadir).



straight curvy more curvy

*Figure 16 – Points displayed by flight line showing 40% overlap, the white arrows show the width of 2 adjacent flightlines*

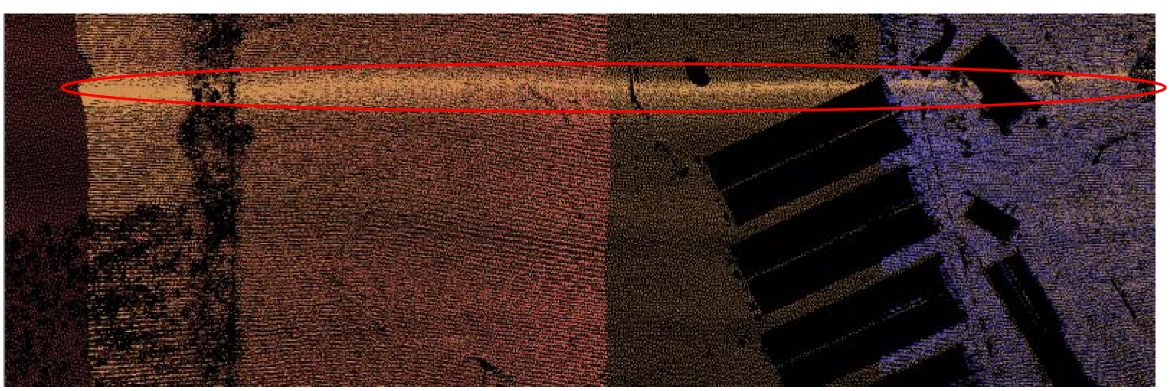


*Figure 17 – Point "bunching" in the yellow flightline*

### *Flight line ridges and cornrows*

The fact that the flightlines do not completely overlap and that the far edges were not clipped results in recurrent issues in the bare earth model. Indeed, we found a lot of false ridges located exactly along these edges as illustrated in Figure 18. Actually, the central sections of the flightlines (where there is no overlap) sometime exhibit a delta z from 0.25 to 0.5 foot compared to the overlapping sections. If we examine the full point cloud using a cross section as in Figure 19 and Figure 20, we can clearly see that this is due to the fact that more points were available where two flightlines have been acquired and that points located at the edge of a flightline (larger scan angle) were lower than points acquired at nadir. It could be due to a better penetration in the vegetation at a large angle or due to a mirror speed anomaly when it changed direction at the end of a scan.

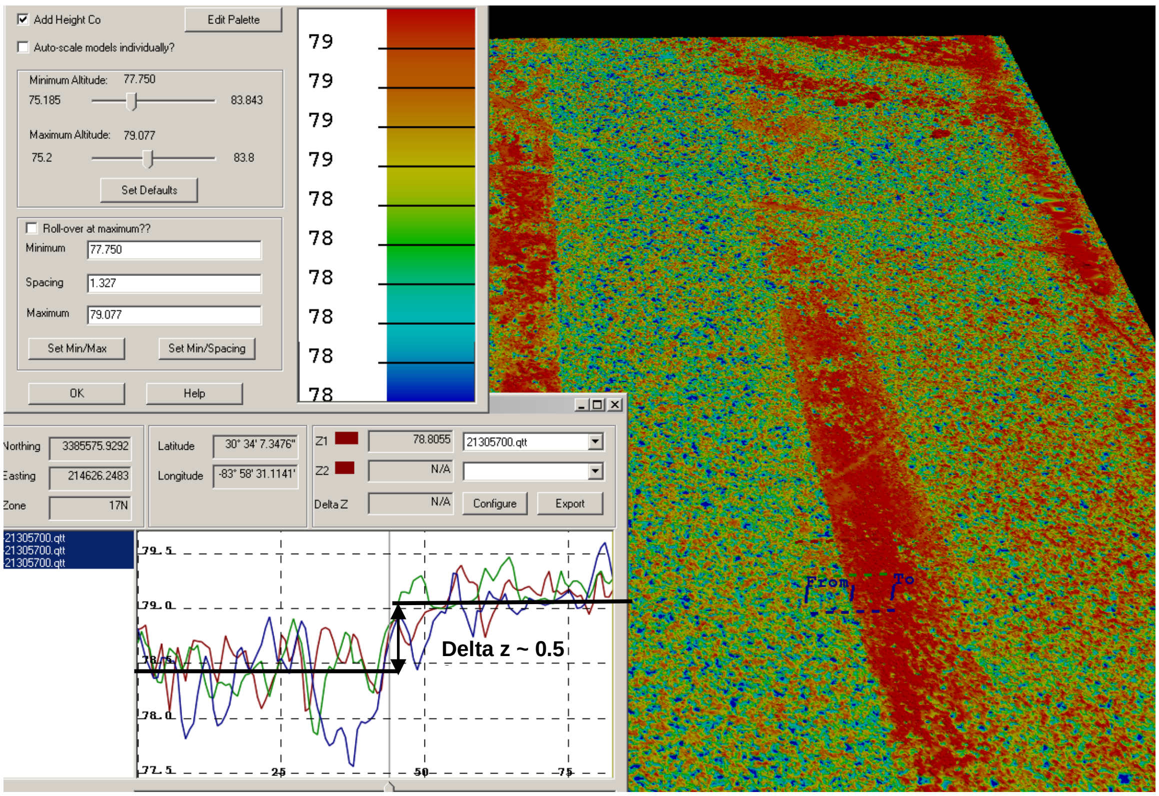



*Figure 18 – Tile 21305700; Bare earth model colored by elevation. The 3 profiles illustrate a ridge along the flightline edge; actually all the central sections of each flightline (where there is no overlap) exhibit a deltaz of 0.5 foot compared to the overlapping sections.*

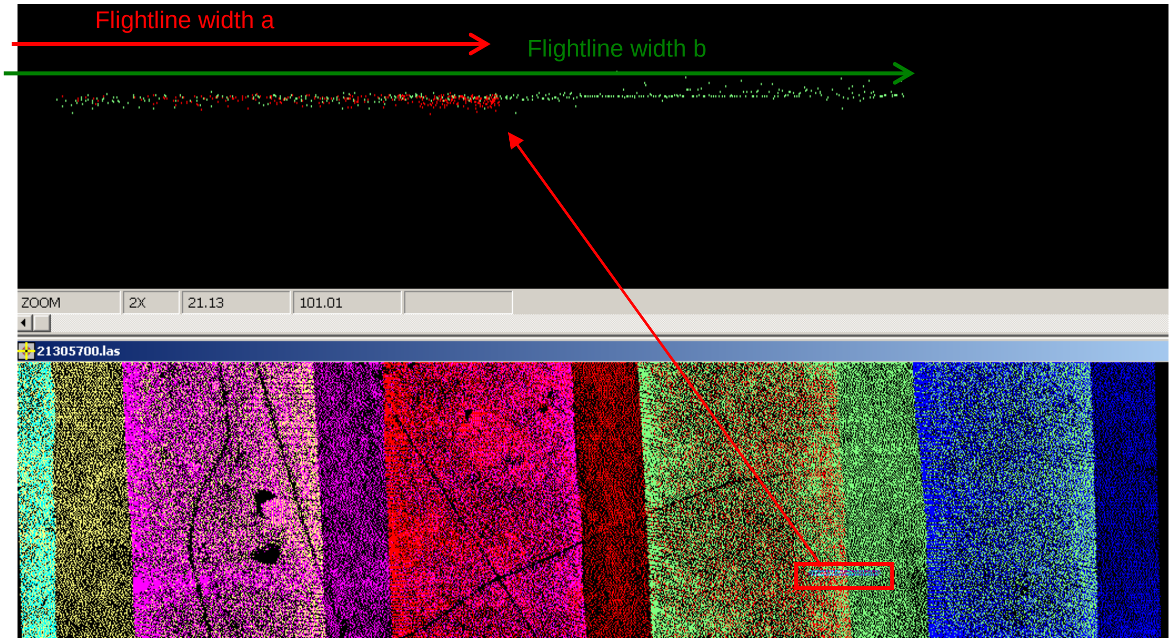



*Figure 19 – Tile 21305700; Full point cloud colored by flighline number, the top cross section shows the point elevation at the edge of a flightline. At the edge of the red scan, a majority of the lower points are red.*

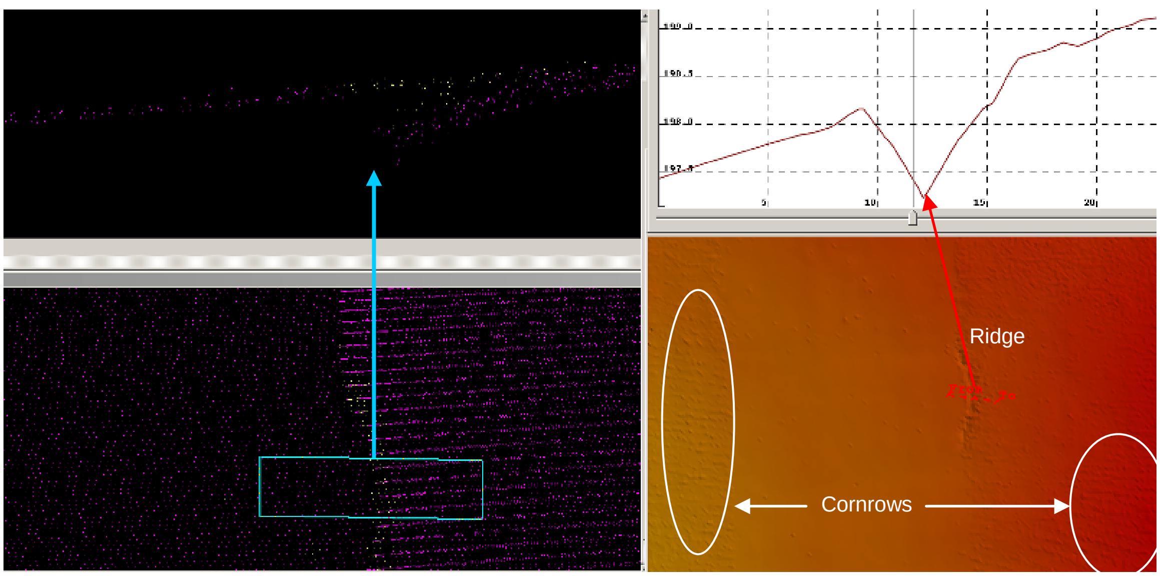



*Figure 20 – Tile 21305100; Full point cloud colored by class, the top cross section shows the point elevation at the edge of adjacent flightlines. Ground points are colored in pink, showing that ground points are higher when only one flightline is available.*

Cornrows were typically seen throughout the project. 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. We think that these cornrows are a side effect of the previously mentioned ridges between overlapping flightlines as the cornrows mainly occur along the edges of these flightlines (see Figure 20). Our review found several negligible instances of the cornrow effect as in Figure 21 and the remainder of this effect was within acceptable limits.

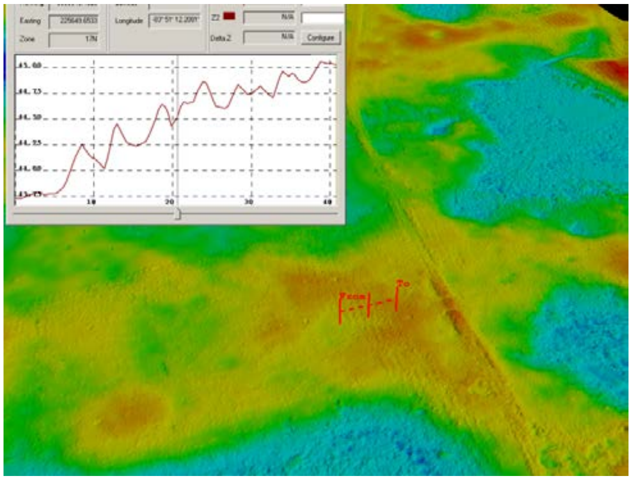
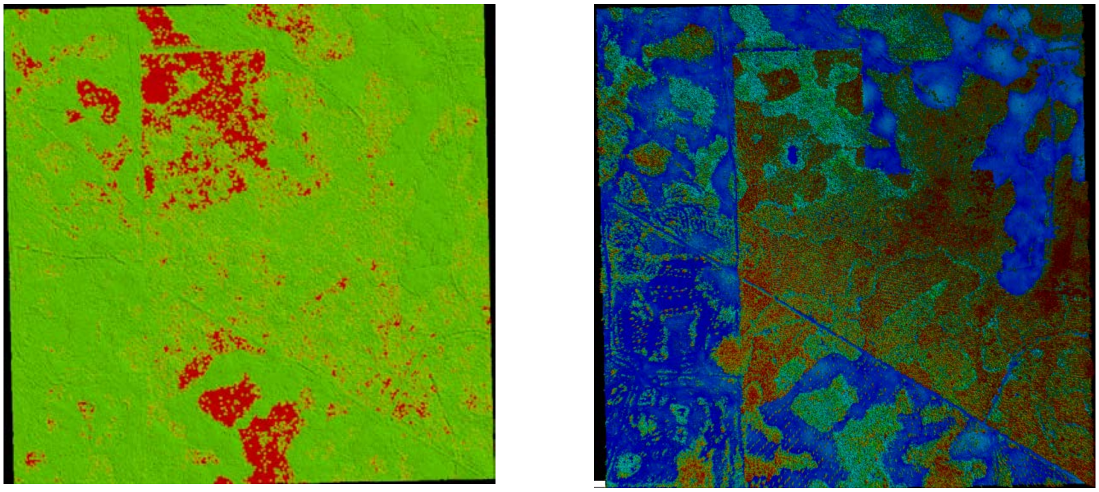


*Figure 21 - Cornrows under the acceptable limit (0.25feet)*

## *Poor LiDAR penetration*

Another problem that we often found is patches with lower density of ground points. When the vegetation is very dense, the LiDAR may not penetrate the canopy all the way to the ground, therefore only a few ground points remain after classification of the vegetation. Nevertheless, as soon as a few points are present, a 3D model can be built with an acceptable reliability, especially in flat areas. However, the smoothness of the surface is often of less quality since low understory vegetation that completely blocks the pulse may be classified as ground resulting in a rather noisy surface. This is illustrated in Figure 22 and Figure 23. Figure 24 shows the corresponding bare earth DEM raster that exhibits the same kind of noisy features and a cross section of the full point cloud clearly proving that dense bushes are blocking the LiDAR.

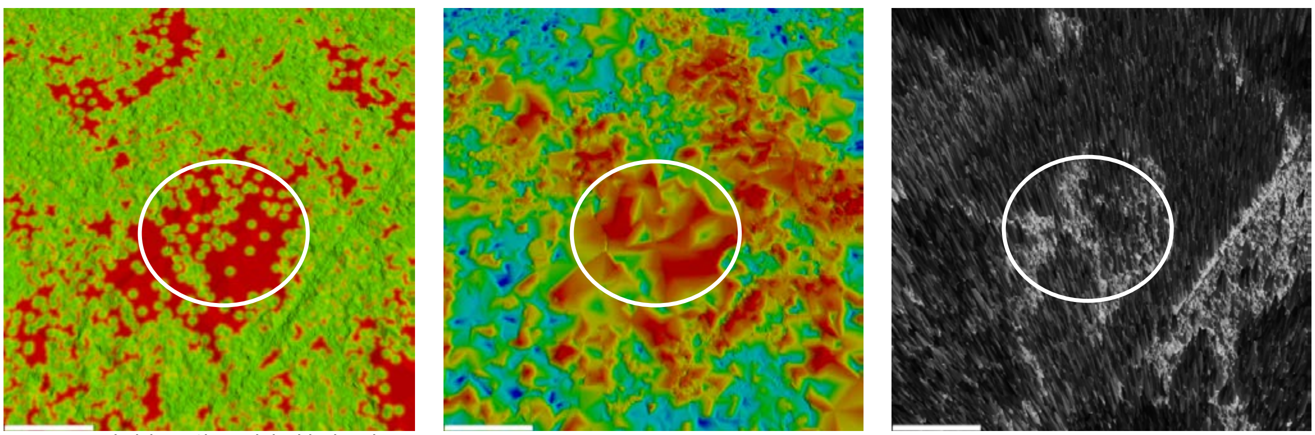
However, it should be noted that the noisy look of the ground may be falsely enhanced by the fact that the vertical units are feet whereas the horizontal units are meters. Indeed, some software will by default assume both dimensions to be in the same units resulting in a vertical exaggeration in displayed images.



Bare-earth (class 2) model with density information (red = no points),

Surface model with elevation (all classes)

*Figure 22 – Tile. Sparse density and noise in ground surface due to poor LiDAR penetration in really dense vegetation.*

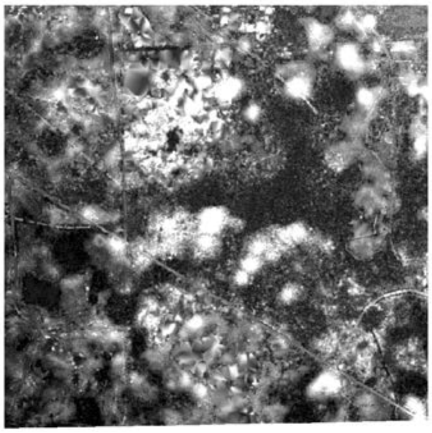


Bare-earth (class 2) model with density information (red = no points),

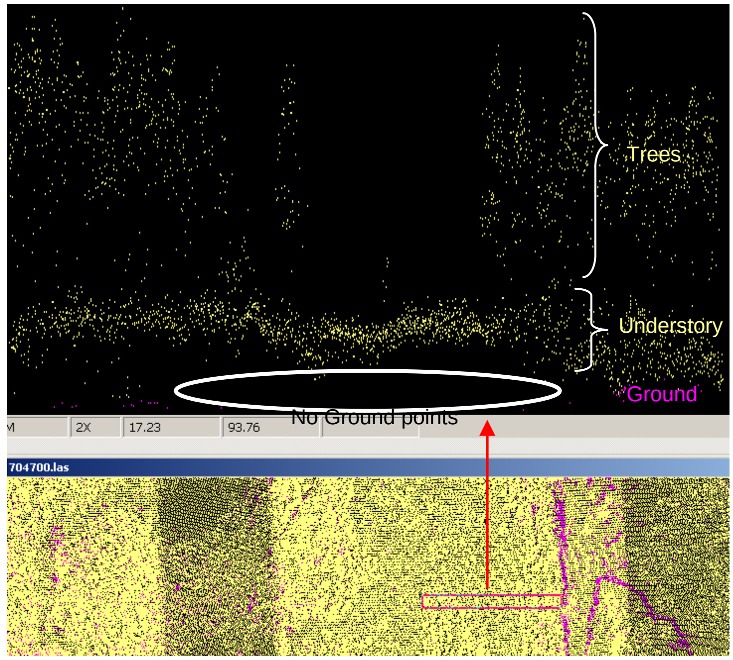
Bare-earth (class 2) colored by elevation

Surface model with intensity (all classes

*Figure 23 – Tile 21704700, detail. Sparse density and noise in ground surface due to poor LiDAR penetration in really dense vegetation. The white circle pinpoints the same area in the three images.*



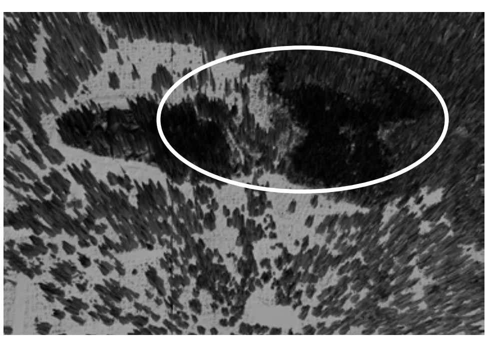
Noisy Bare earth DEM raster



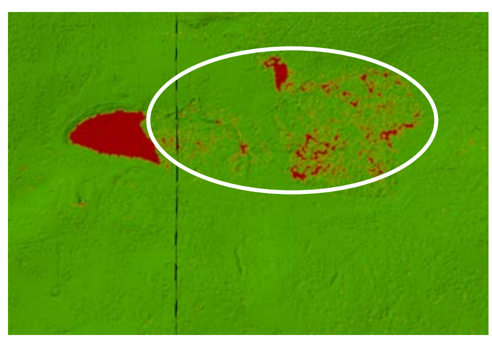

Full Point cloud colored by class (ground is pink)

*Figure 24 – Tile 21704700. Poor LiDAR penetration in dense brush areas*

We did find some isolated spots of sparse density of points in the bare earth model with no apparent change in the vegetation density at these locations; however the intensity image is characterized by a darker tone. After carefully inspecting the full point cloud, which really shows presence of LiDAR points inside the vegetation but fewer at ground level and based on the dark coloration of the intensity images we assumed that these are swamp areas where the LiDAR is not reflected by the wet ground surface. Indeed, except at angles close to nadir, the Near Infrared LiDAR beam is usually not reflected by water (Figure 25).



Surface model with intensity (all classes)



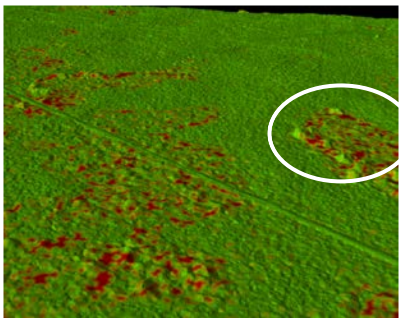
Bare-earth (class 2) model with density information (red = no points),

*Figure 25 - Poor LiDAR reflection in swamp area, the LiDAR do not seem to be reflected by the underlying surface.*

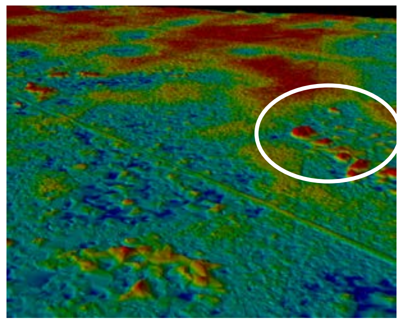
### *Misclassification*

- Vegetation artifacts

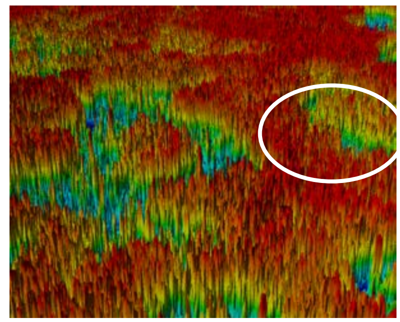
Another classification issue that we encountered is the presence of vegetation artifacts (see Figure 26). Although it is conceivable that the soil exhibits natural small relief, we believe that they are vegetation remains as they occur in areas where we also notice a sparse density of the ground points. These two types of issues are actually linked together; if LiDAR is blocked by the understory vegetation it is more likely that the classification routine treats these last points over vegetation as ground. These artifacts are limited in height but add to the general noise of the bare earth model.



Bare-earth (class 2) model with density information (red = no points),



Bare-earth (class 2) colored by elevation

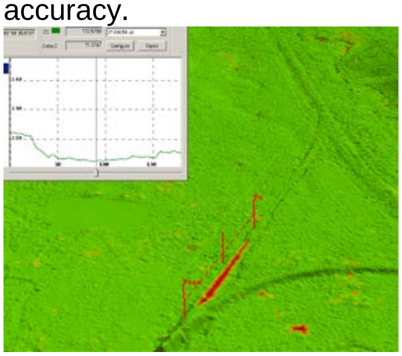


Surface model colored by elevation (all classes

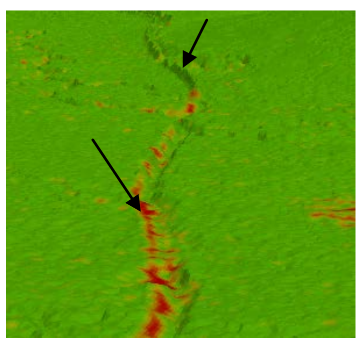
*Figure 26 – Tile 21404850. Poor LiDAR penetration, possible vegetation artifacts*

- Aggressive classification/stream definition

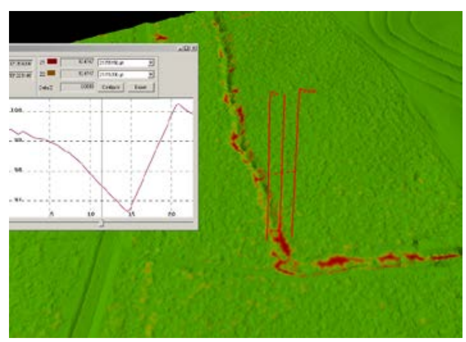
The other classification issues that were observed are inconsistencies in the processing of stream banks or natural elevated embankments. Portions of these features were removed from the ground whereas others are kept. Along stream edges, we also noticed possible aggressive classification; as a result, cross sections of the channel may lose accuracy.



Tile 21306050 - Natural embankment partially removed



Tile 21055100 - Stream edge bump inconsistently removed



Tile 21755600 - Poor channel definition

*Figure 27 – Inconsistencies in classification (Bare-earth-class 2 model with density information, red = no points)*

In summary, the types of issues more frequently encountered are (in order of occurrence):

- Poor LiDAR penetration resulting in a noisy surface
- Classification issues (aggressive classification)
- Flightline ridges and cornrows

It should be noted that these data may have unidentified errors at a local scale as we are not performing an exhaustive review at micro level.

# 4 Conclusion

Overall the data exhibits both adequate detail as well as some minor issues. The data does meet the absolute accuracy requirement using the similar FEMA testing methodology but the data also complies with the NSSDA for test vertical accuracy. Additionally there were sufficient fundamental checkpoints coupled with the qualitative review which indicates that the Fundamental Vertical Accuracy (RMSEz x 1.9600) 0.716ft ft is valid for this dataset (with a criteria of 1.19 ft) and this data will meet the requirements for the use in hydrologic and hydraulic studies.

These data meet the quantitative accuracy requirements and the level of cleanliness for the bare-earth terrain is of acceptable quality due to the vegetation type. Finally, the user should be aware one tile contained only ground points and that localized sensor anomalies (edge of flightlines) create ridges; however they are within an acceptable level of noise.

# Appendix A Control points

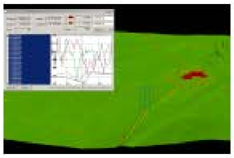
| pointNo | easting | northing | elevation | zLiDAR | LandCoverType | DeltaZ |
|---|---|---|---|---|---|---|
| G6 | 804514.5720 | 3394257.5250 | 175.8780 | 175.0369 | Open Terrain | -0.841 |
| G9 | 809090.8220 | 3392033.3790 | 136.3680 | 135.7645 | Open Terrain | -0.603 |
| G14 | 796407.7370 | 3385422.4800 | 86.7260 | 86.1412 | Open Terrain | -0.585 |
| g20 | 789484.0500 | 3371137.4770 | 203.0590 | 202.4959 | Open Terrain | -0.563 |
| G29 | 808431.0730 | 3382588.7700 | 108.0440 | 107.5207 | Open Terrain | -0.523 |
| G12 | 796751.6120 | 3368359.8250 | 194.5590 | 194.1286 | Open Terrain | -0.430 |
| G36 | 800317.8490 | 3383375.4400 | 232.4710 | 232.0525 | Open Terrain | -0.418 |
| g42 | 806164.7340 | 3365202.7190 | 69.6960 | 69.3778 | Open Terrain | -0.318 |
| g57 | 822547.9690 | 3386218.7750 | 124.5190 | 124.2140 | Open Terrain | -0.305 |
| G35 | 800362.8670 | 3383439.5600 | 235.5020 | 235.2201 | Open Terrain | -0.282 |
| g13 | 798617.1020 | 3385322.5650 | 127.9530 | 127.7351 | Open Terrain | -0.218 |
| G16 | 796603.7840 | 3390582.6250 | 107.9500 | 107.7634 | Open Terrain | -0.187 |
| g41 | 799219.6570 | 3359316.3000 | 41.1390 | 41.0168 | Open Terrain | -0.122 |
| G39 | 814220.2590 | 3377901.5080 | 83.4350 | 83.3183 | Open Terrain | -0.117 |
| g15 | 790135.1260 | 3389507.1720 | 97.6510 | 97.6298 | Open Terrain | -0.021 |
| g22 | 790938.9600 | 3362026.7390 | 40.3760 | 40.3555 | Open Terrain | -0.020 |
| G24 | 821772.7800 | 3395784.3580 | 121.5090 | 121.5199 | Open Terrain | 0.011 |
| g25 | 824467.6000 | 3394174.9950 | 95.6940 | 95.7378 | Open Terrain | 0.044 |
| g52 | 806208.5110 | 3396782.5630 | 117.9800 | 118.0766 | Open Terrain | 0.097 |
| g2 | 800197.9910 | 3385210.5750 | 161.0000 | 161.1078 | Open Terrain | 0.108 |
| g7 | 806831.0040 | 3394009.8750 | 95.9620 | 96.2020 | Open Terrain | 0.240 |
| g26 | 822539.5960 | 3386482.6700 | 137.9180 | 138.1703 | Open Terrain | 0.252 |
| G19 | 785951.0670 | 3375525.7210 | 86.4150 | 86.6862 | Open Terrain | 0.271 |
| g31 | 809614.8130 | 3377168.0450 | 83.4130 | 83.7496 | Open Terrain | 0.337 |
| g5 | 802577.2740 | 3390234.8430 | 172.3740 | 172.7229 | Open Terrain | 0.349 |
| G23 | 821315.5120 | 3391830.6800 | 160.7200 | 161.2403 | Open Terrain | 0.520 |
| x48 | 807106.6830 | 3363919.4870 | 63.9040 | 63.5038 | Unknown | -0.400 |
| x62 | 799317.9070 | 3356675.8520 | 37.4930 | 37.1387 | Unknown | -0.354 |
| x53 | 798969.9130 | 3396979.9240 | 116.0260 | 115.7857 | Unknown | -0.240 |
| x61 | 803720.2340 | 3355997.0770 | 40.2490 | 40.1816 | Unknown | -0.067 |
| x50 | 780594.9200 | 3368160.2200 | 48.1190 | 48.1160 | Unknown | -0.003 |
| x58 | 822840.5720 | 3384275.8420 | 95.5610 | 95.6393 | Unknown | 0.078 |
| x59 | 788499.3630 | 3381209.2680 | 140.0930 | 140.2429 | Unknown | 0.150 |
| x45 | 789589.0660 | 3381283.7780 | 104.1510 | 104.4067 | Unknown | 0.256 |
| x60 | 788858.5490 | 3362344.8340 | 37.7800 | 38.0548 | Unknown | 0.275 |
| x51 | 786396.3020 | 3391854.7450 | 93.8270 | 94.1601 | Unknown | 0.333 |
| x49 | 783751.5140 | 3376070.7810 | 91.3730 | 91.7118 | Unknown | 0.339 |
| x1 | 807929.6320 | 3381564.2410 | 165.8250 | 166.4572 | Unknown | 0.632 |
| u54 | 800353.2260 | 3383328.3800 | 228.6850 | 228.1429 | Urban | -0.542 |
| u34 | 800723.7510 | 3383489.1220 | 210.4930 | 210.0011 | Urban | -0.492 |
| u56 | 800354.0860 | 3383720.8790 | 236.7740 | 236.4305 | Urban | -0.344 |
| u32 | 800316.6040 | 3384538.0140 | 213.8170 | 213.6642 | Urban | -0.153 |
| u55 | 800009.3800 | 3383109.3560 | 231.9700 | 231.9146 | Urban | -0.055 |
| u37 | 800224.3560 | 3383322.1490 | 232.5310 | 232.4961 | Urban | -0.035 |
| u38 | 800046.4800 | 3383265.8580 | 239.9800 | 239.9929 | Urban | 0.013 |
| u32 | 800211.9990 | 3383480.6250 | 225.1690 | 225.3111 | Urban | 0.142 |
| p8 | 807918.7260 | 3392450.8310 | 145.4450 | 145.0206 | Weeds/Crop | -0.424 |
| p18 | 789700.3640 | 3377165.3930 | 175.7680 | 176.1202 | Weeds/Crop | 0.352 |
| p40 | 804807.3280 | 3360297.9210 | 50.2260 | 50.5916 | Weeds/Crop | 0.366 |
| p27 | 816172.4980 | 3389218.6750 | 128.7960 | 129.1781 | Weeds/Crop | 0.382 |
| p21 | 791496.5110 | 3365975.1350 | 221.1730 | 221.5792 | Weeds/Crop | 0.406 |
| p3 | 793434.8340 | 3396180.3250 | 138.1930 | 138.6709 | Weeds/Crop | 0.478 |
| p4 | 801548.4430 | 3387240.1870 | 145.9890 | 146.5220 | Weeds/Crop | 0.533 |
| p11 | 786211.1260 | 3363310.4090 | 47.2690 | 47.8160 | Weeds/Crop | 0.547 |
| p17 | 795937.6520 | 3381256.5430 | 193.0450 | 193.6622 | Weeds/Crop | 0.617 |

## Appendix B Tiles with all flightline numbers set to 1

| tileNo | All_min_PtSrcId | All_max_PtSrcId |
|---|---|---|
| 21055300 | 1 | 1 |
| 21055350 | 1 | 1 |
| 21055400 | 1 | 1 |
| 21055450 | 1 | 1 |
| 21055500 | 1 | 1 |
| 22356000 | 1 | 1 |
| 22356050 | 1 | 1 |
| 22405600 | 1 | 1 |
| 21955200 | 1 | 1 |
| 21955250 | 1 | 1 |
| 21955300 | 1 | 1 |
| 21955350 | 1 | 1 |
| 21955400 | 1 | 1 |
| 21955450 | 1 | 1 |
| 21955500 | 1 | 1 |
| 21955550 | 1 | 1 |
| 21955600 | 1 | 1 |
| 21955650 | 1 | 1 |
| 21955700 | 1 | 1 |
| 21955750 | 1 | 1 |
| 21955800 | 1 | 1 |
| 21955850 | 1 | 1 |
| 21955900 | 1 | 1 |

# Appendix C Qualitative issues contact sheets

Classification issues



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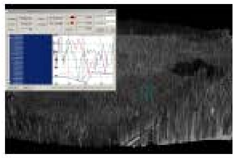

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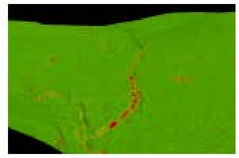
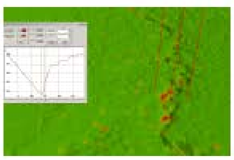


21055100_streamdef-InconsistentEdit_qttground.bmp

21055100_StreamDef-InconsistentEdit_qttINT.bmp



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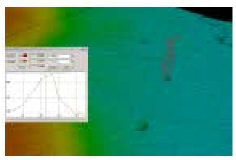

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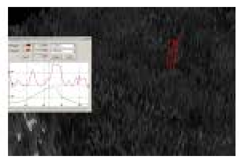

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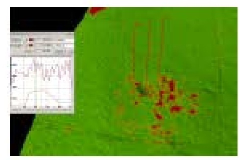

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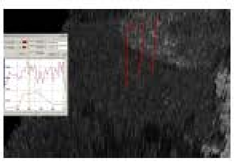

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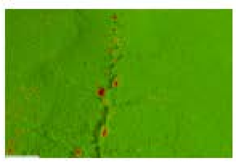

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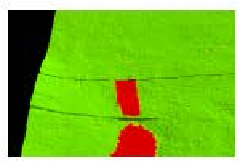

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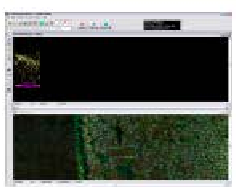
21256000_misclassification_qttINT.bmp

21305050_MultipleIssues_qttground.bmp



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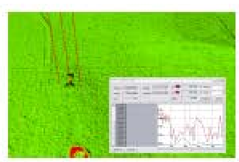

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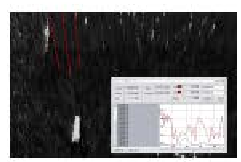
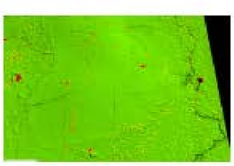


21305150_VegeArtifact_qttINT.bmp



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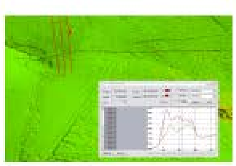

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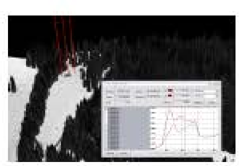
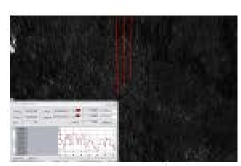


21305400_VegeArtifact_qttINT.bmp



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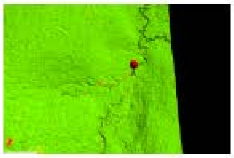
Classification issues



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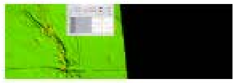
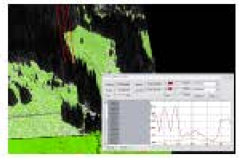


21305500_StreamDef_qttground.bmp



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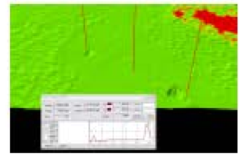

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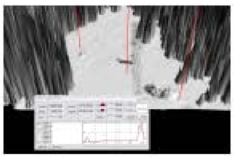
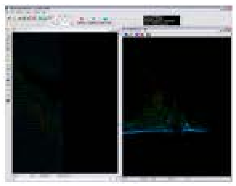
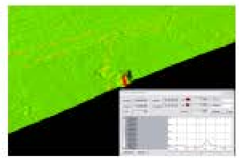


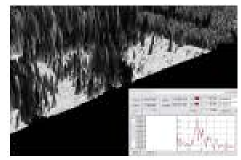
21305500_vegartifact_qttINT.bmp



21305500_vegartifact2_FPC.bmp



21305500_vegartifact2_qttground.bmp



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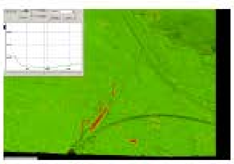
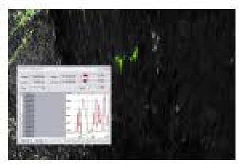


21306050_aggrClassification_qttGd.bmp

21306050_possibleaggrclassorvegartifact_attground.bmp



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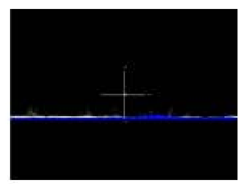
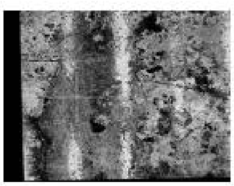
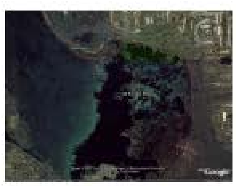


21355700_misclassification WaterEdge_fpcByClass-Blu9-Wht1.bmp

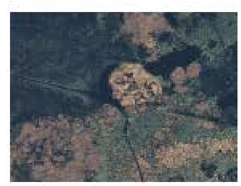


21355700_misclassification WaterEdge_fpcIntensity.bmp

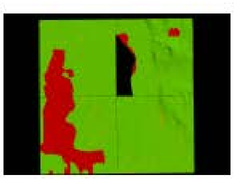


21355700_misclassification WaterEdge_googleEarth.bmp

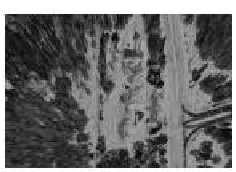
21355700_misclassification WaterEdges_ORTHO.png



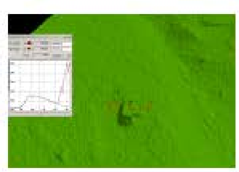
21355700_misclassification WaterEdges_ORTHOcloseup.png



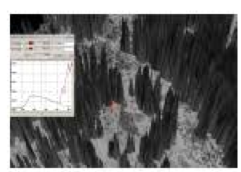
21405700_misclassificationWater_qttGd.bmp



21505100_inconsistentremoval_qttINT.bmp

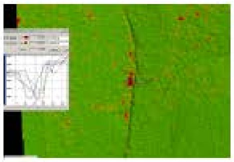


21505150_artifact_qttground.bmp



21505150_artifact_qttINT.bmp

Classification issues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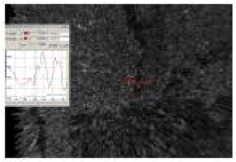
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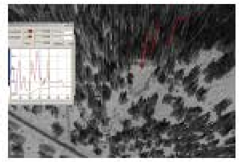
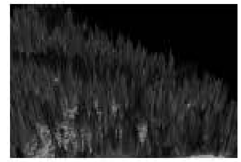
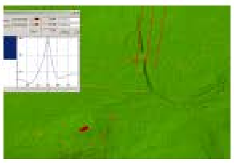
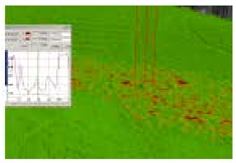
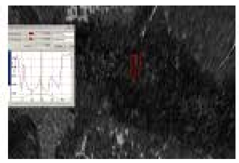

21505550_aggrclass_qttINT.bmp


21505600_noiseartifact_qttINT.bmp


21554950_potArtifact_qttground.bmp


21555200_vegartifact_qttground.bmp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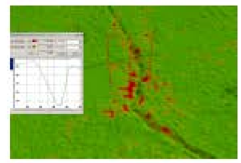
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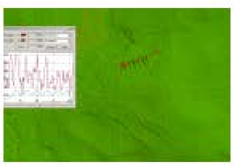
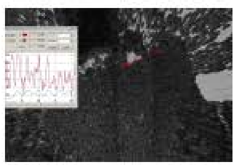

21605150_potentialArtifact_qttground.bmp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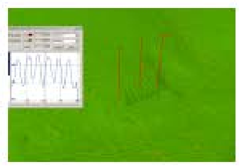
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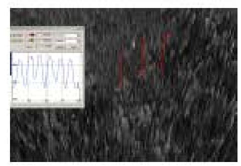
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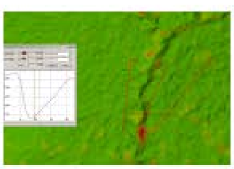
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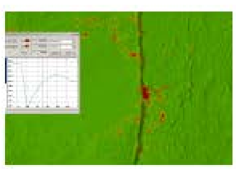
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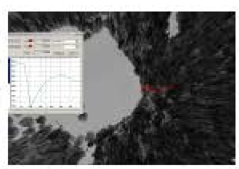
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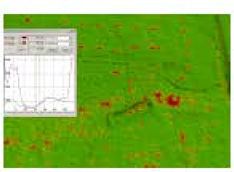
21655450_inconstistentEditing_qttINT.bmp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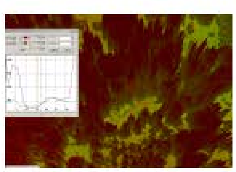
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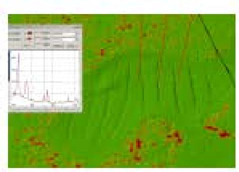
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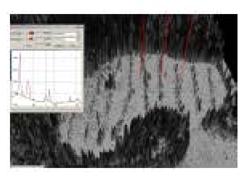
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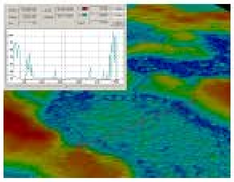
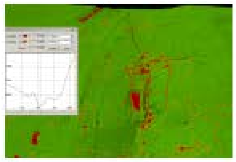
Classification issues



21704800_possibleVegeArtifact_qttGnd.bmp



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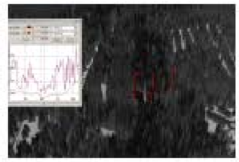

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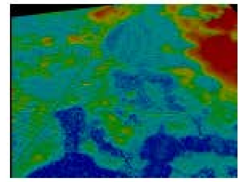
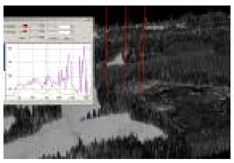
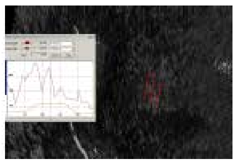


21754700_noise_qttGnd.bmp



21754800_vegartifact_qttINT.bmp



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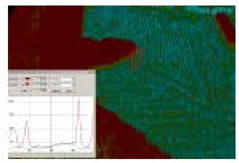

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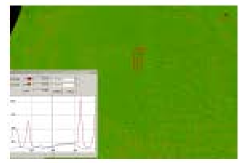

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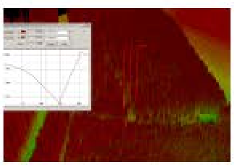

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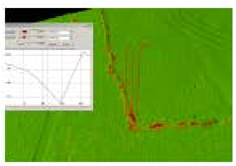

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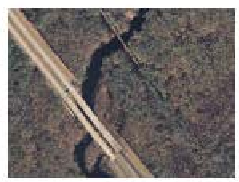
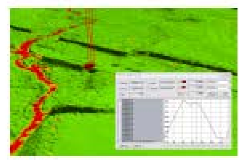


21854950_bridgeRemain_ORTHO.png



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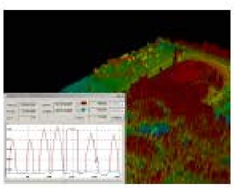
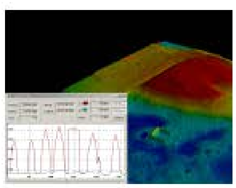
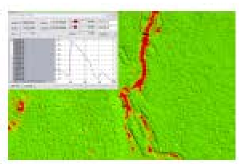


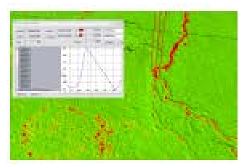
21855450_possibleBuildingRemain_qttFpc.bmp



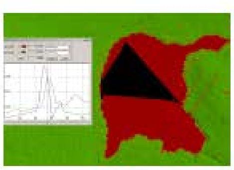
21855450_possibleBuildingRemain_qttGd.bmp



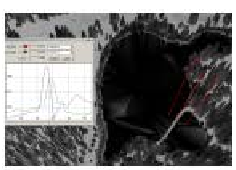
21905000_VegeArtifact_qttground.bmp



21905000_VegeArtifact2_qttground.bmp



21956000_missclassification_qttground.bmp



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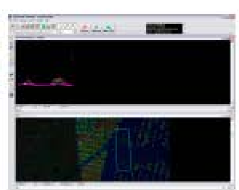
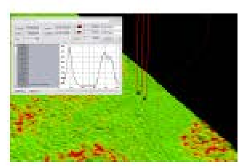


22105150_buildingArtifact_FPC.bmp



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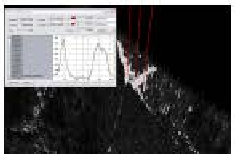
Classification issues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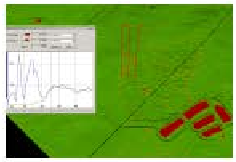
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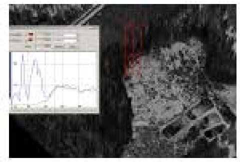
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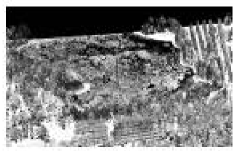
22156050_misclassification8redisWater_fcpAllclasses.bmp


22205950_misclassificationclass8isWater_fpcallClasses.bmp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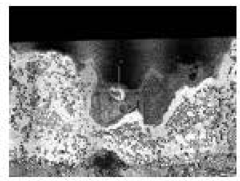
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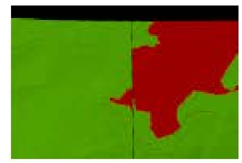
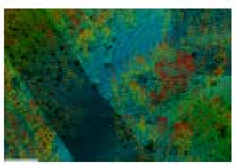
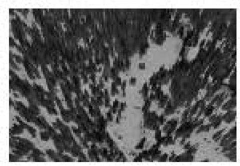

22256000_missclassWater_qttGd.bmp


22256050_missclassification_qtcFPC.bmp


22256050_missclassification_qttground.bmp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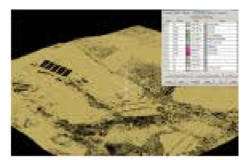
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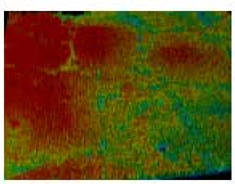
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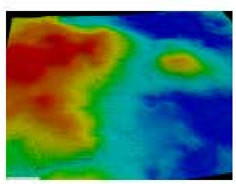
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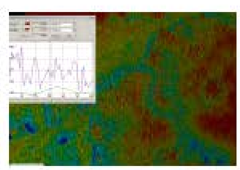
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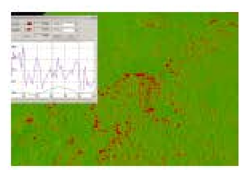
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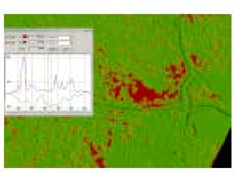
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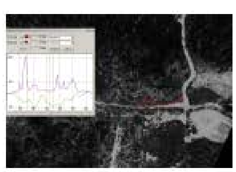
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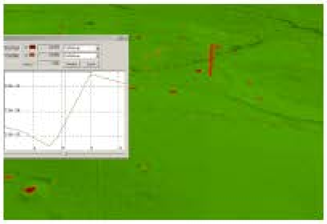
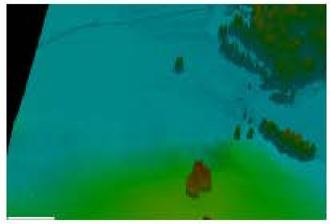
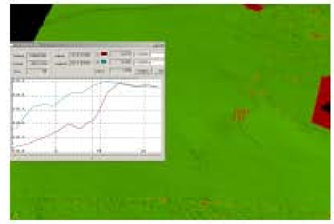
FlightLineEdges



21205450_ridge_qttground.bmp



21205850_scannerissue_qttFPCdensity.bmp



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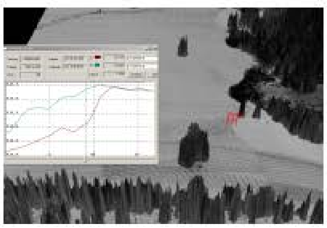

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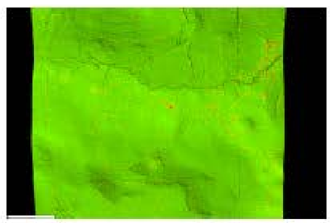

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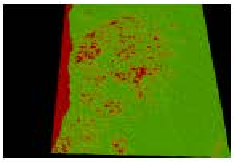
Poor Lidar Penetration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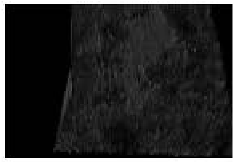
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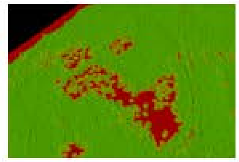
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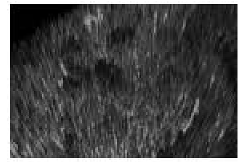
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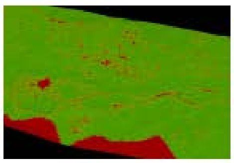
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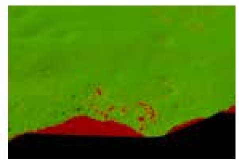
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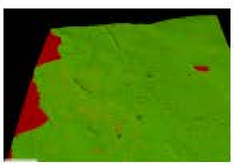
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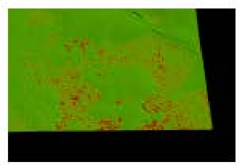
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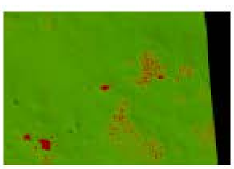
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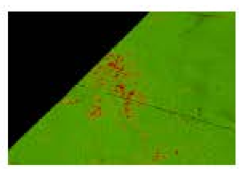
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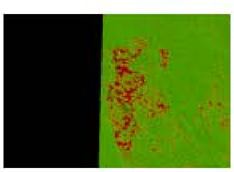
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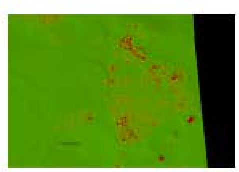
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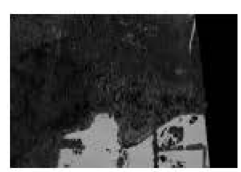
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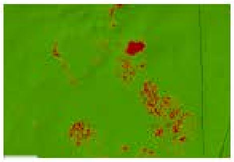
Poor Lidar Penetration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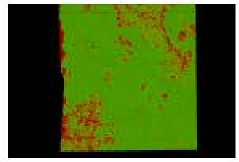
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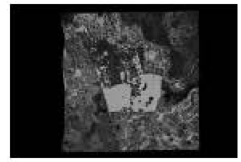
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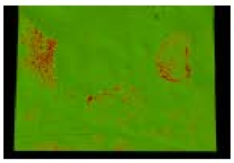
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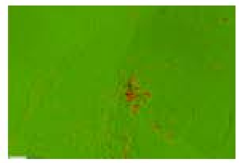
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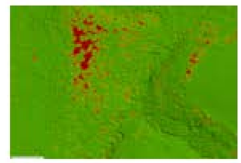
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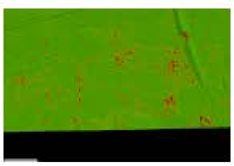
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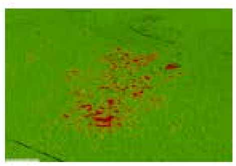
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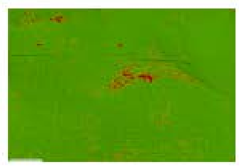
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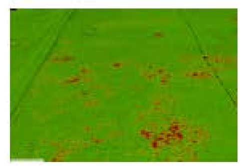
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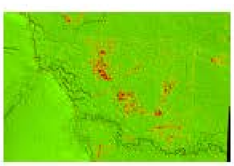
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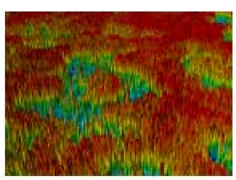
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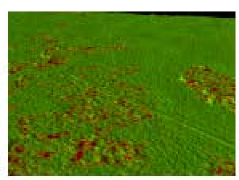
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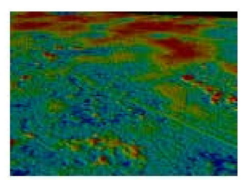
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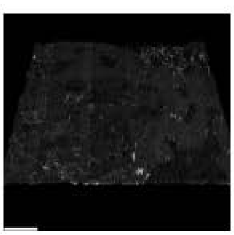
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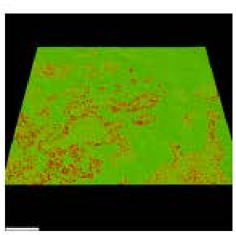
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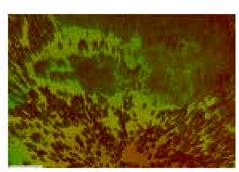
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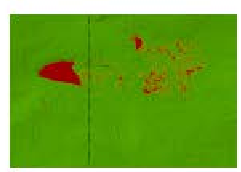
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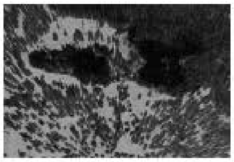
Poor Lidar Penetration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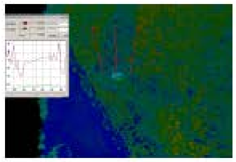
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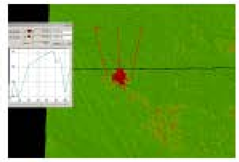
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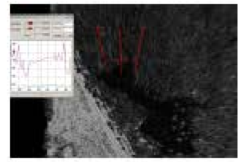
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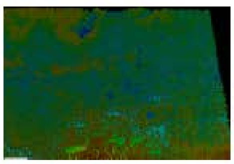
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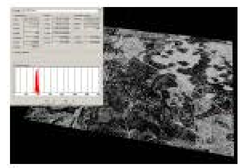
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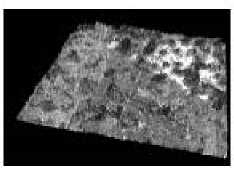
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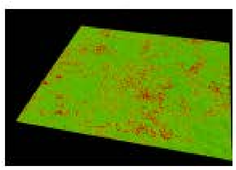
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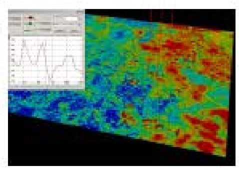
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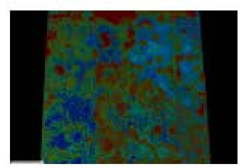
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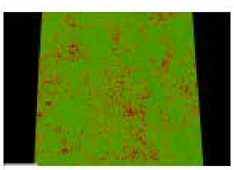
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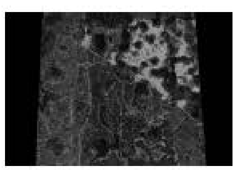
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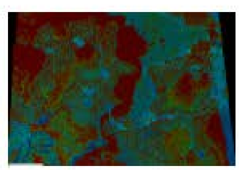
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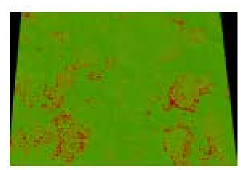
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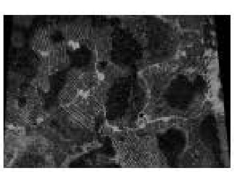
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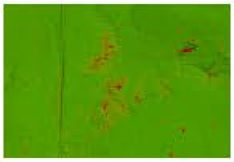
Poor Lidar Penetration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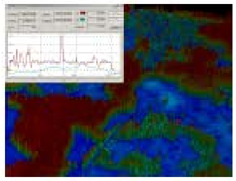
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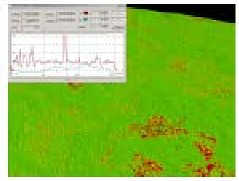
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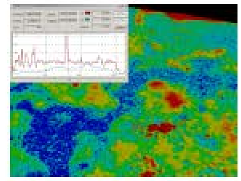
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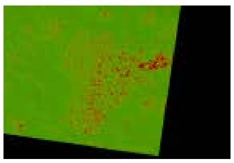
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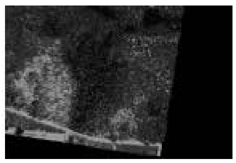
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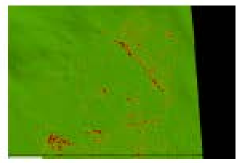
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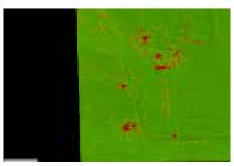
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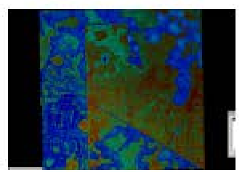
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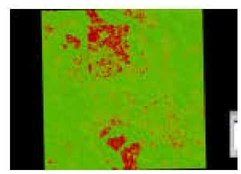
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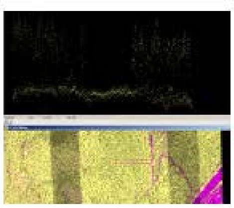
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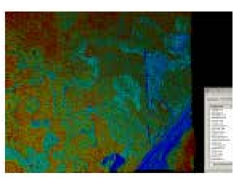
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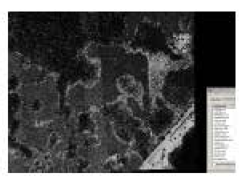
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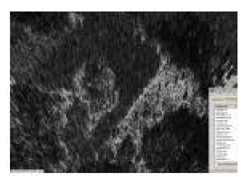
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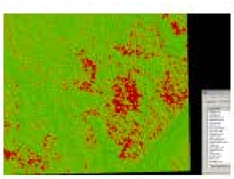
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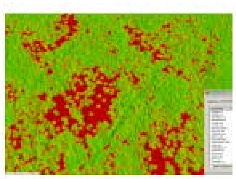
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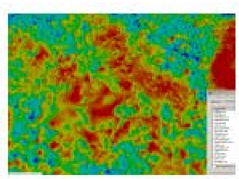
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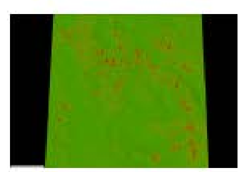
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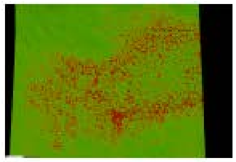
Poor Lidar Penetration


21704750_poorLidarpenetr_qttINT.bmp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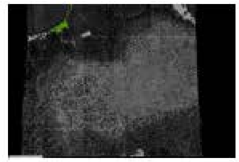
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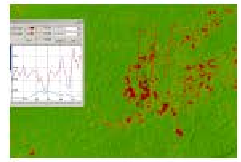
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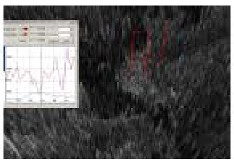
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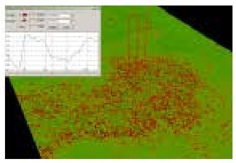
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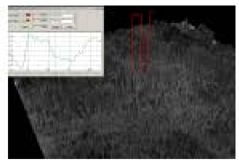
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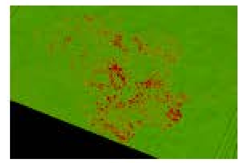
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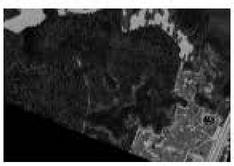
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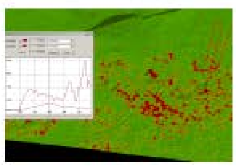
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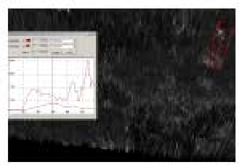
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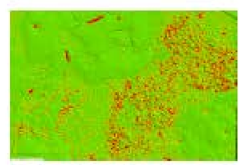
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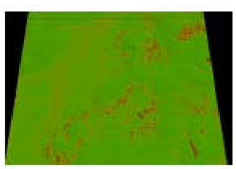
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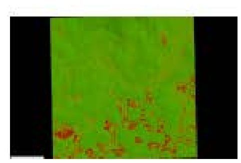
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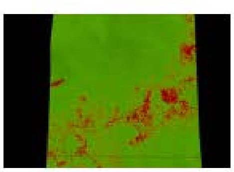
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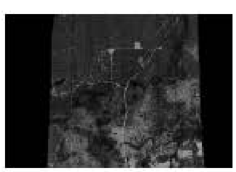
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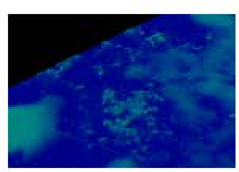
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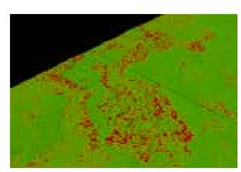
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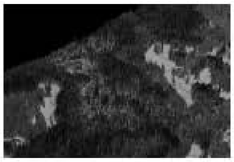
Poor Lidar Penetration



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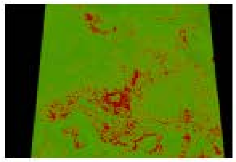

22505750_poorLidarpenetr_qttground.bmp

22505750_poorLidarpenetr_qttINT.bmp