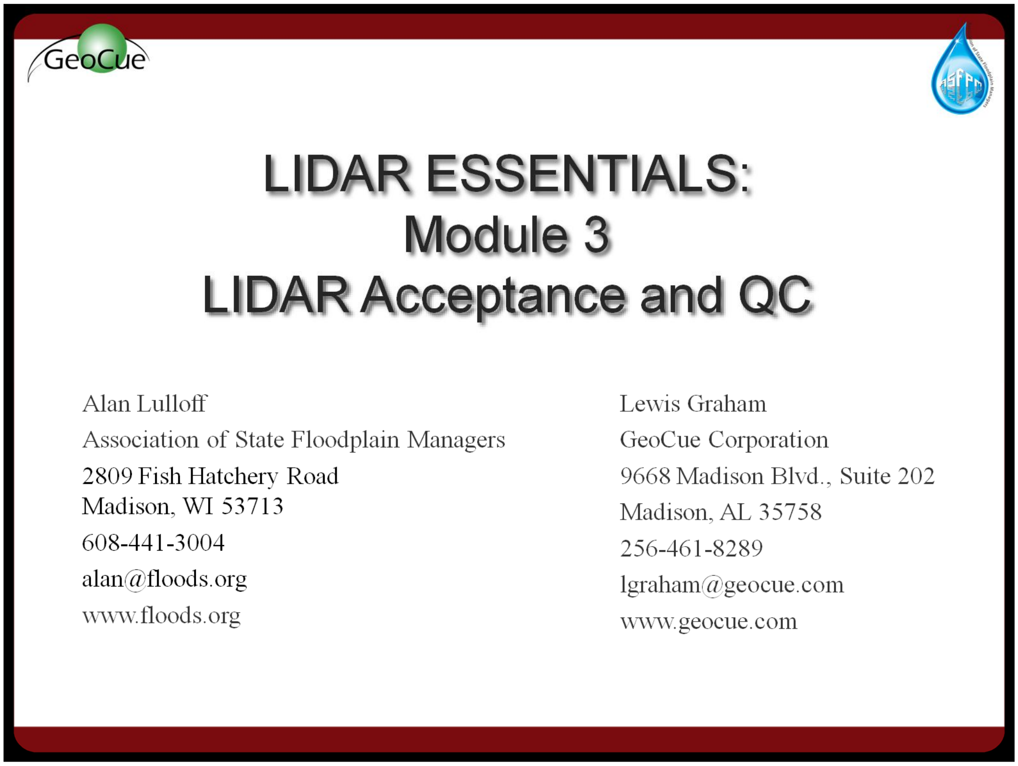
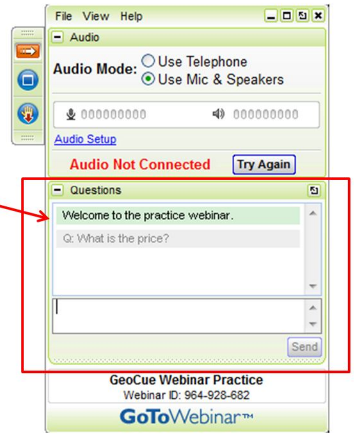


This is Module 3 of a total of 4 Modules in the ASFPM/GeoCue LIDAR Webinar series.

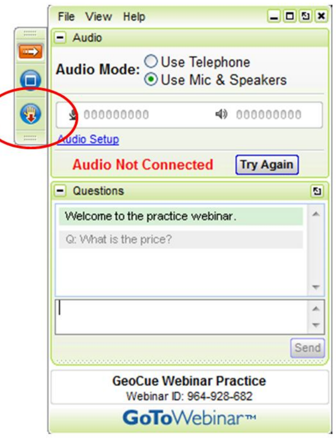
The Webinar Will Begin Shortly

- Group audio is disabled for this webinar.
- To ask a question, please type it in your "Questions Box".
- We will pause at points throughout the webinar to answer questions.
- The webinar is scheduled for 60 minutes.



Audio Check

- Please "raise your hand" if you can hear me.



Webinar Hosts

Alan Lulloff, PE, CFM

- Science Services Prog. Mgr. at ASFPM
- Member of Multihazard Mitigation Council Board of Direction
- Member of HAZUS Flood Committee
- Member of Great Lakes Coastal Flood Study Oversight Committee
- Member National Flood Determination Association eLOMA Oversight Board
- Member North Carolina Integrated Hazard Risk Management Advisory Committee

Lewis Graham

- CTO/President of GeoCue Corporation
- Division Director, ASPRS LIDAR Division
- Chair of the LAS Working Group
- Member of the Transportation Research Board (TRB) oversight committee for the mobile laser scanning standards development project
- Board member of The ISPRS Foundation
- Author of various chapters of various LIDAR manuals


GeoCue
The ASFPM Webinar Series
• Session 1: An Overview of LIDAR
– Sept 10, 2012
• Session 2: Specifying LIDAR Collection Projects
– Oct 22, 2012
• Session 3: LIDAR Acceptance and QC
– Nov 9, 2012
• Session 4: Using LIDAR Data
– Dec 10, 2012
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5

Acknowledgment

We would like to thank Jim Scott, State Geographic Information Officer & Director, Texas Natural Resources Information System TNRIS) for his review and input to this project

General Information

- ASFPM does not endorse specific companies or software solutions
- We would like to thank Brown County, WI for providing sample LIDAR data

GeoCue

Continuing Education Credit (CEC)

CFM CECs will be automatically provided to those that attend the full webinar. Due to the large number of people participating it will take some time for the CECs to be recorded. Please do not send individual requests for CECs to ASFPM.

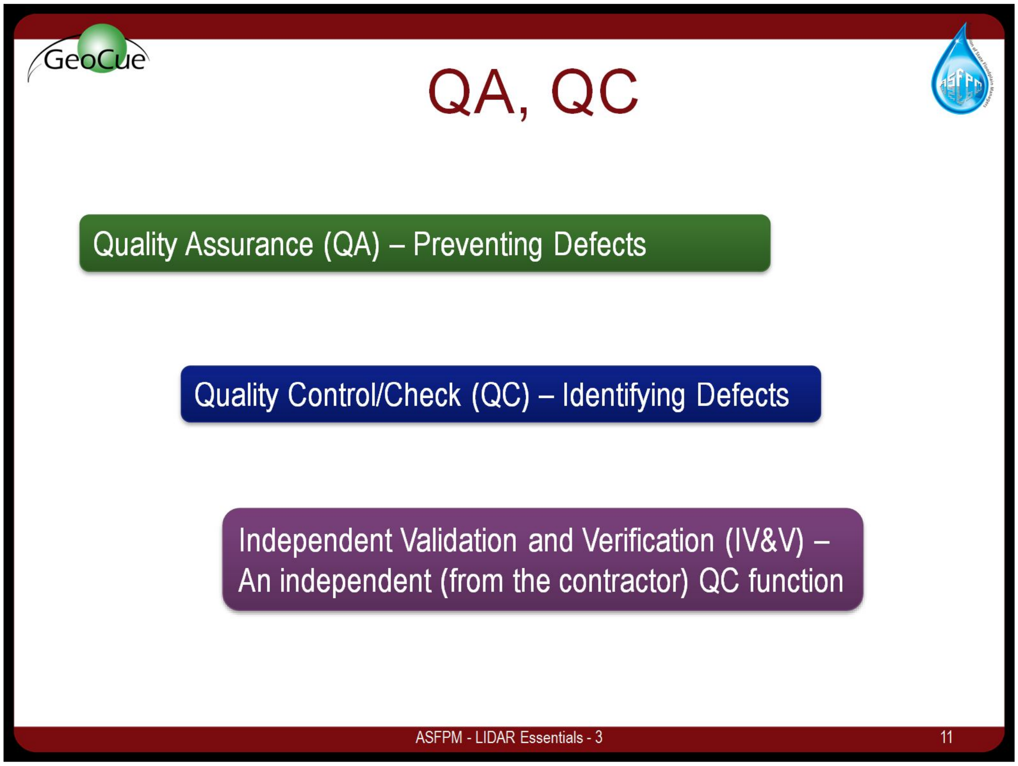
For those attending in a group setting please have a sign up sheet and have someone responsible for providing that list to CFM@floods.org.

You can interactively learn!

- LIDAR Samples:
  - http://www.floods.org/LidarWebinar/SampleData/
- Evaluation Software:
  - www.LP360.com
    - Click the “Download Now” link under “Free LP360 Evaluation”
    - Download Questions/Problems? – info@lp360.com
- A few tutorials on You Tube, LIDARLAB channel

Topics

- What is the cost of not doing QC?
- Data issues that cannot be corrected, post-collection
- A discussion of performance parameters (point spacing, intensity, classes, relative and absolute accuracy)
- Importance of independent ground control
- Data delivery strategies
- QC Program Strategies
- Quantitative Checks (file formats, coordinate reference systems, data gaps, data density, density by class, etc.)
- Vertical accuracy testing - relative and absolute
- Qualitative Checks (quality of classification, intensity range, etc.)
- Communicating issues

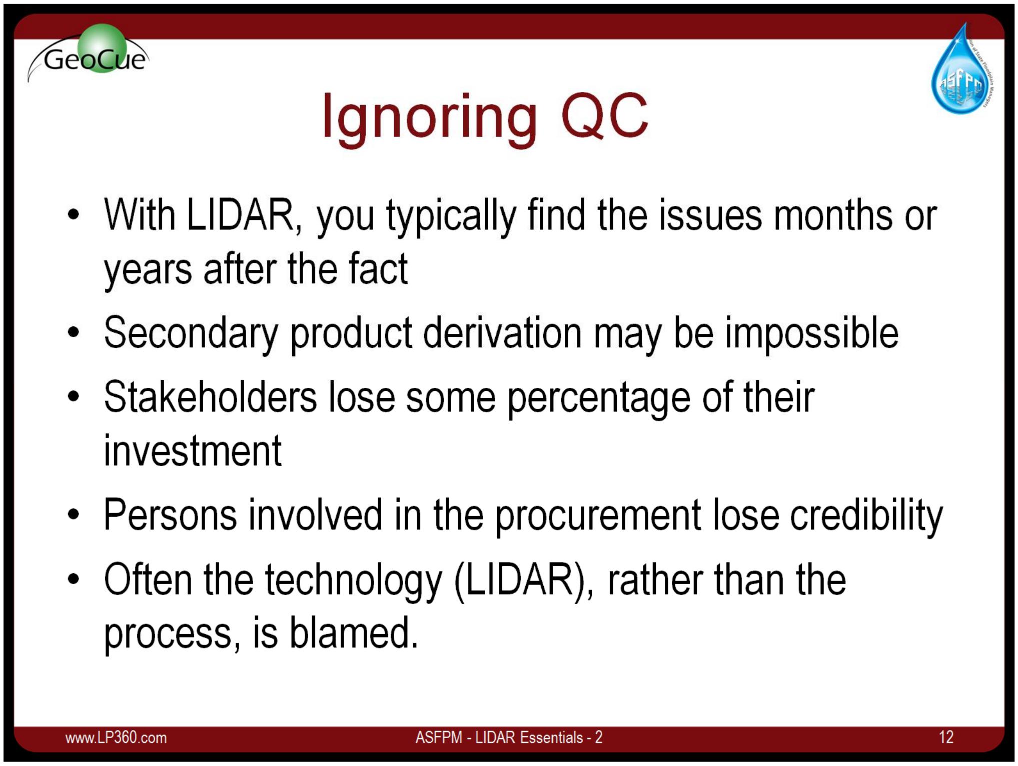


Quality Assurance (QA) is a role of the contractor. It comprises the systems that are in place to identify and correct problems prior to the data being delivered to the customer. It should involve both internal Quality Checks (QC) and feed-in from external QC. It is an integral part of a contractor's continuous improvement process.

Quality Checks are the inspection of results to ensure the QA system works! Continuous QC is an absolute must. The contractor must perform internal QC, of course, to ensure that his QA processes are working. However, an independent QC function must be in place for all contracts. Unless you have a skilled staff with the appropriate tools, you must budget for an external and independent QC contractor. That said, if you have a competent GIS staff, they can be easily trained to supervise and perform QC. We have seen a number of very successful projects where the in-house GIS team supervised QC of LIDAR data and the actual QC work was performed by student interns (GeoCue offers QC training for data recipients).

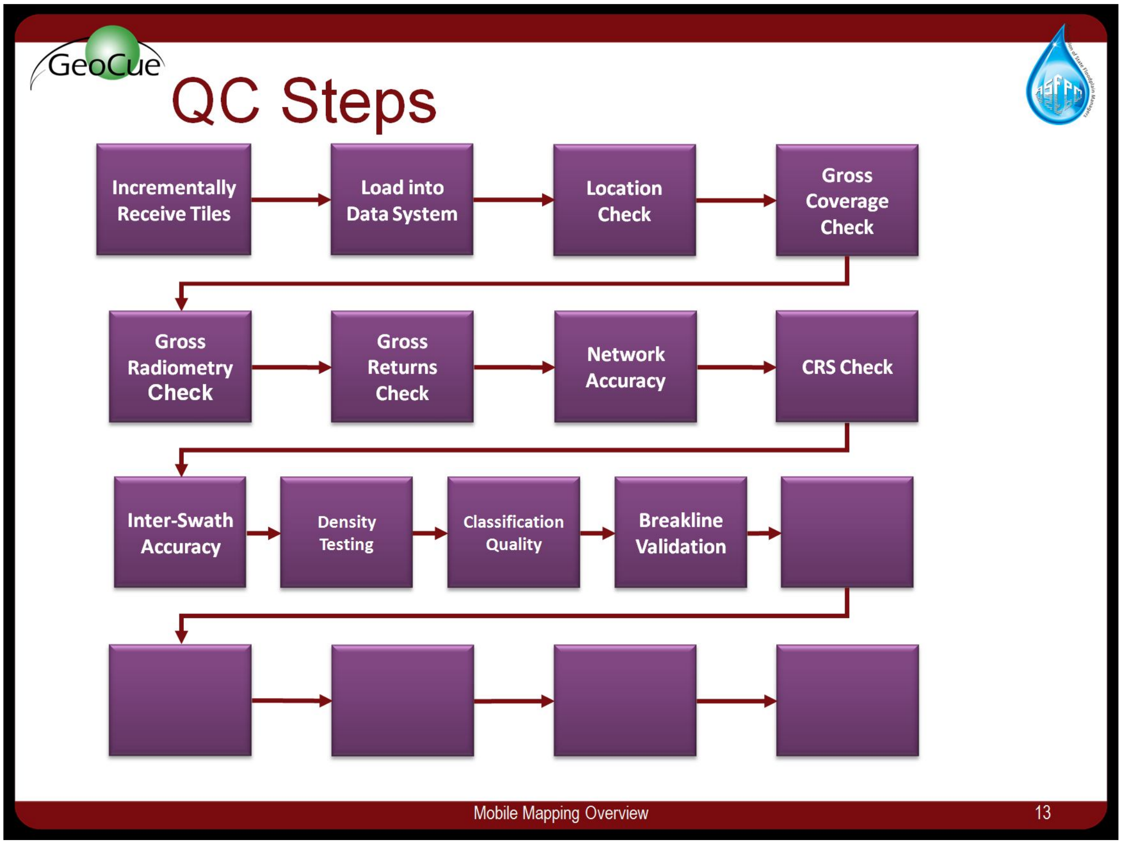
If you are not capable of performing in-house QC (due to lack of staffing, lack of skills, etc.) then you must contract for Independent Validation and Verification (IV&V). This will require you to budget for and issue a separate RFP.

You should allocate about 15% of the total acquisition budget for basic data management and QC.

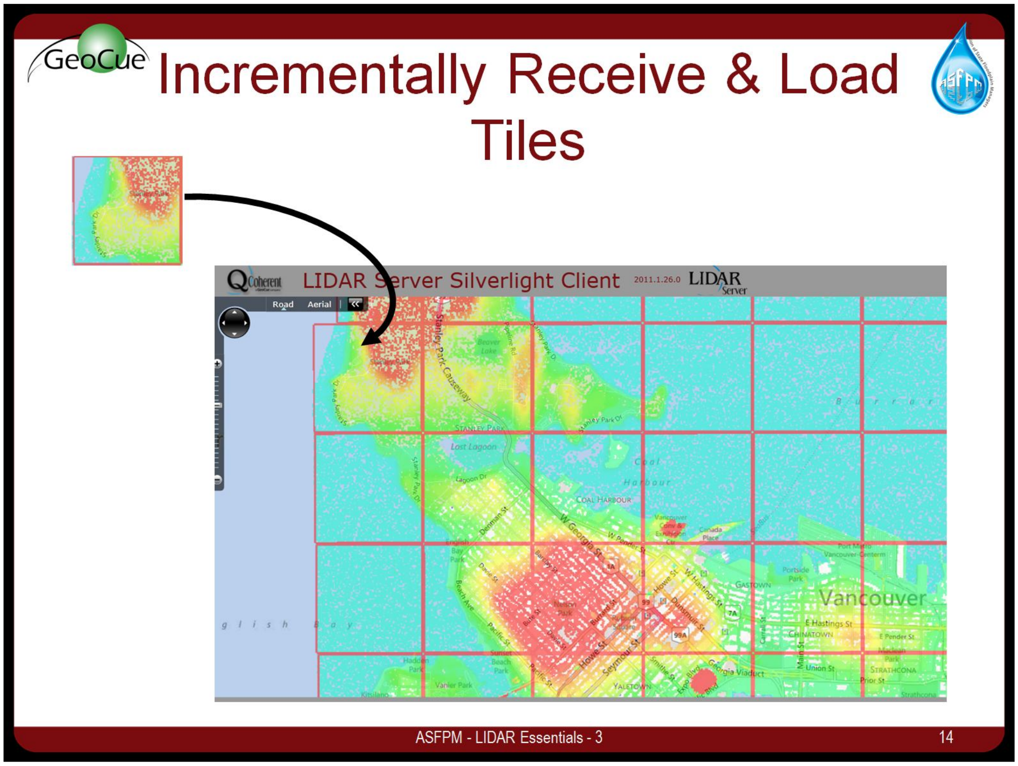


While it would seem obvious that a comprehensive QC program is needed for all LIDAR acquisiti0on projects, it is surprising how many times we see this critical part of project neglected.

The most common scenario is for a client to inspect derivative products but to store LIDAR data, uninspected. This leads, of course, to serious problems at the future point when the data are loaded for derivative product generation or secondary exploitation.



This diagram illustrates the steps of LIDAR QC appropriate for an organization that is receiving data from a production company. While the collection company has primary responsibility for performing all of the steps, it is critically important that the recipient of data perform the above steps on at least a statistically significant subsample of the data.



It is essential to stay organized as data are delivered. You will want to set up an incremental delivery scheme since this will allow you to identify problems early and provide your vendor an opportunity to correct issues early in the program.

We strongly recommend that you adopt a visual indexing system for organizing data. This makes it very easy to monitor the status of tile delivery and any coverage issues.

While your specification may call for a wide range of deliverables, the most useful for LIDAR QC are tiles that contain all data (all returns, all classifications, all overlap points). This allows you to do all QC steps on a single data source.

INITIAL QUALITATIVE ASSESSMENT

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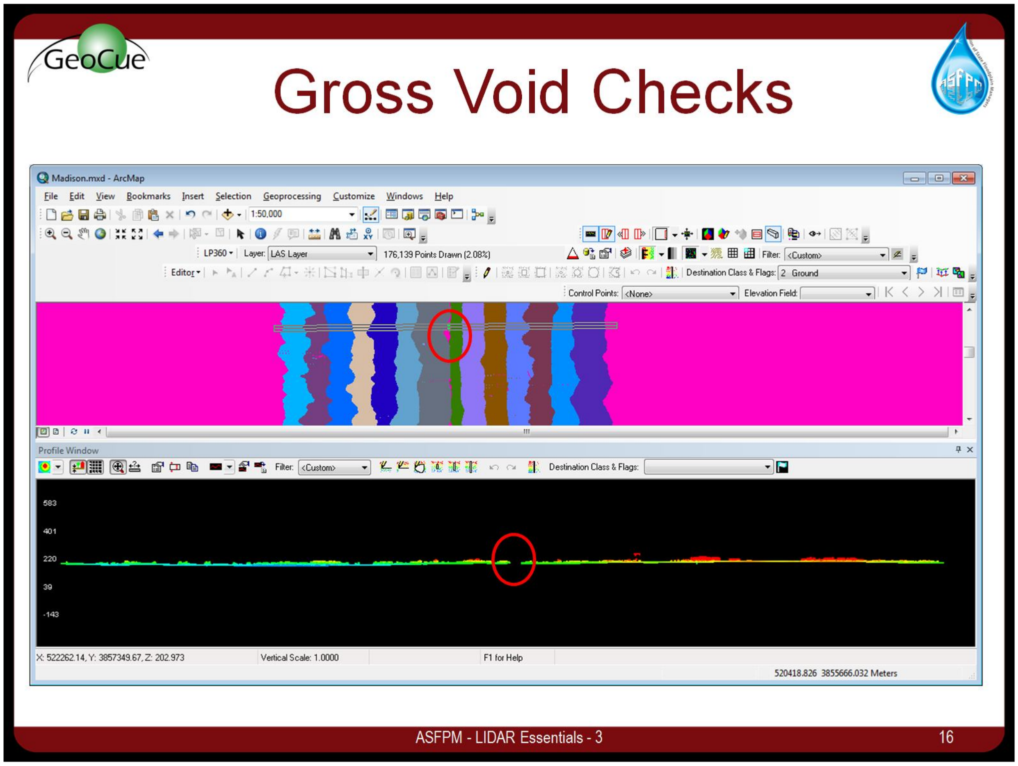
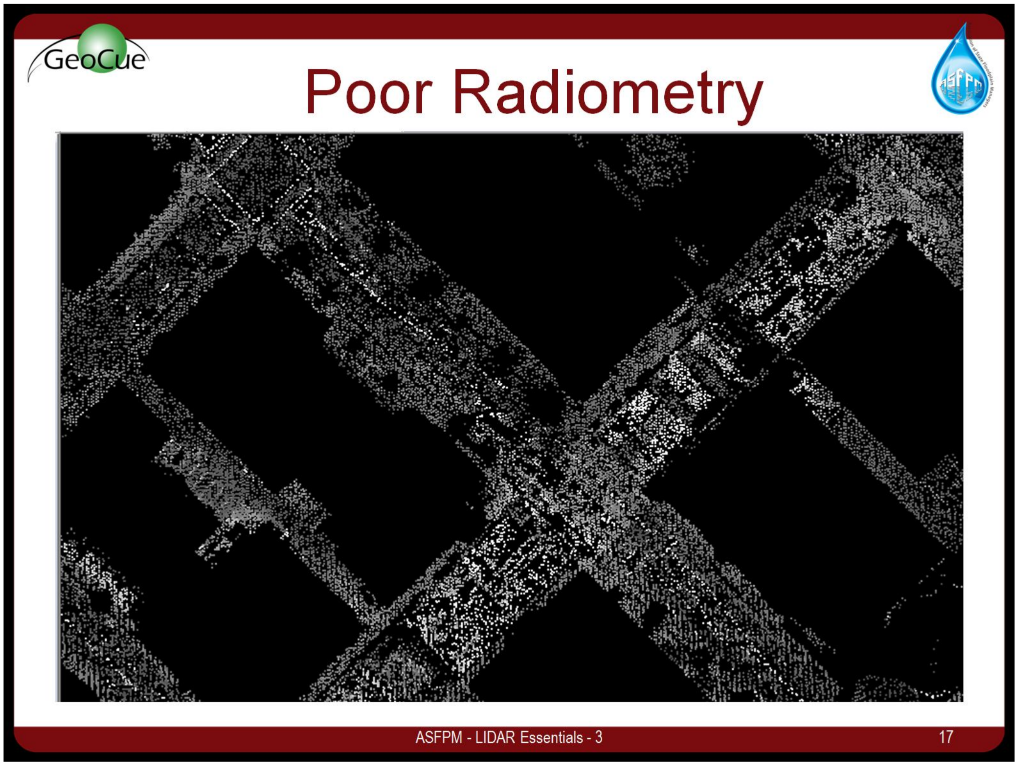
This phase of QC focuses on visual inspection of the data.



A void is an area with no LIDAR coverage. This can be normal (or at least expected) in the case of water bodies. However, it is an error when the void occurs over a non-water, project area. Voids of this type can be caused by a variety of factors. The void in this example was caused by inadequate side-lap between adjacent flight lines. Air turbulence caused the aircraft to roll more than expected, resulting in a area of no coverage.

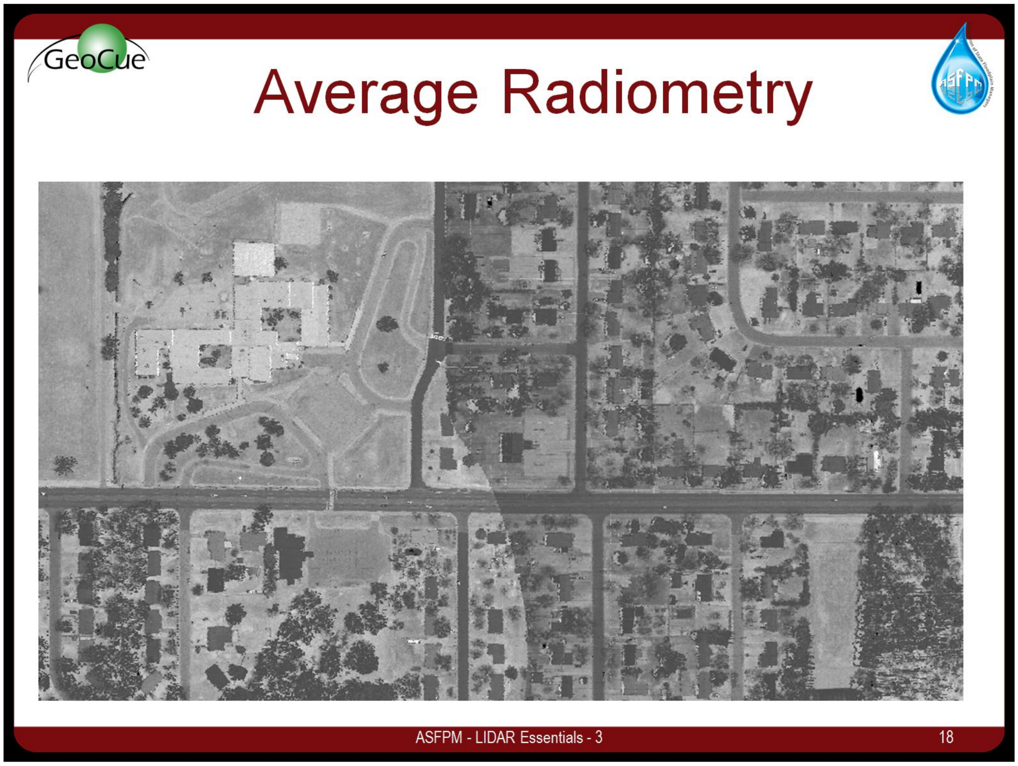
Other causes include a sensor failure, highly absorbent surfaces such as asphalt and a simple mission planning error.

Your data acquisition specification should include a requirement that sets the size of the largest acceptable void. A void can only be corrected by a reflight.



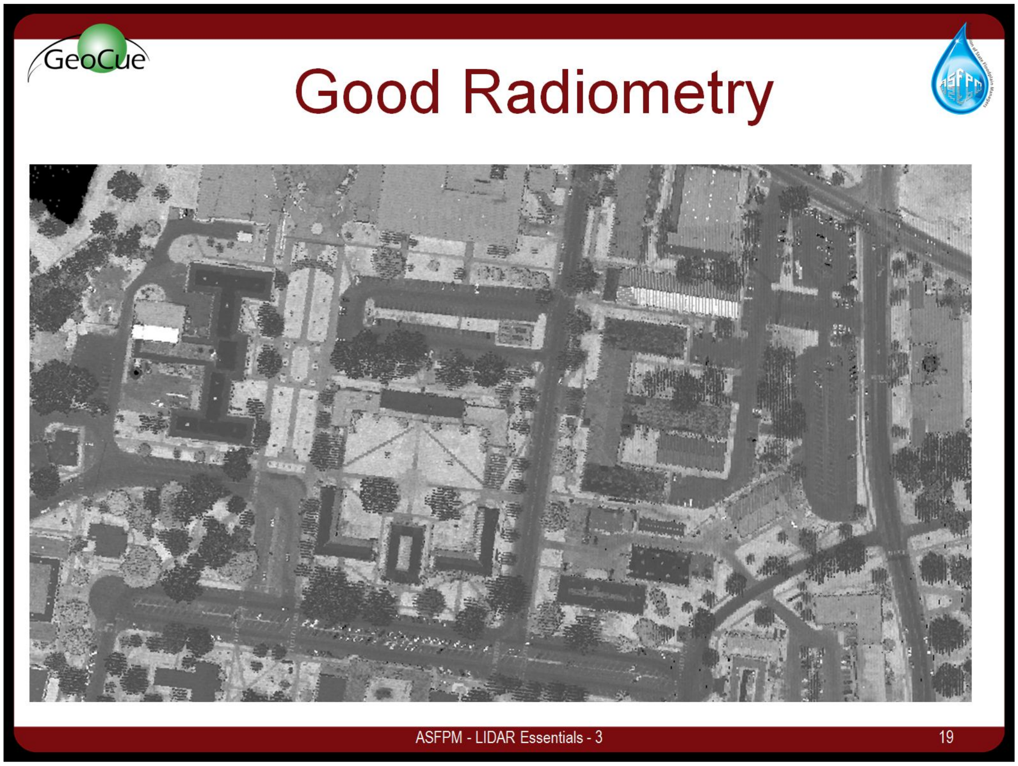
The quality of the intensity return (radiometry) of the LIDAR data is an important characteristic of your data delivery. The requirements specification should require a wide dynamic range to ensure that the data are useable over a variety of reflectance surfaces.

This slide illustrates a collection area with compressed radiometry (few gray levels). This makes it very difficult to discern features.



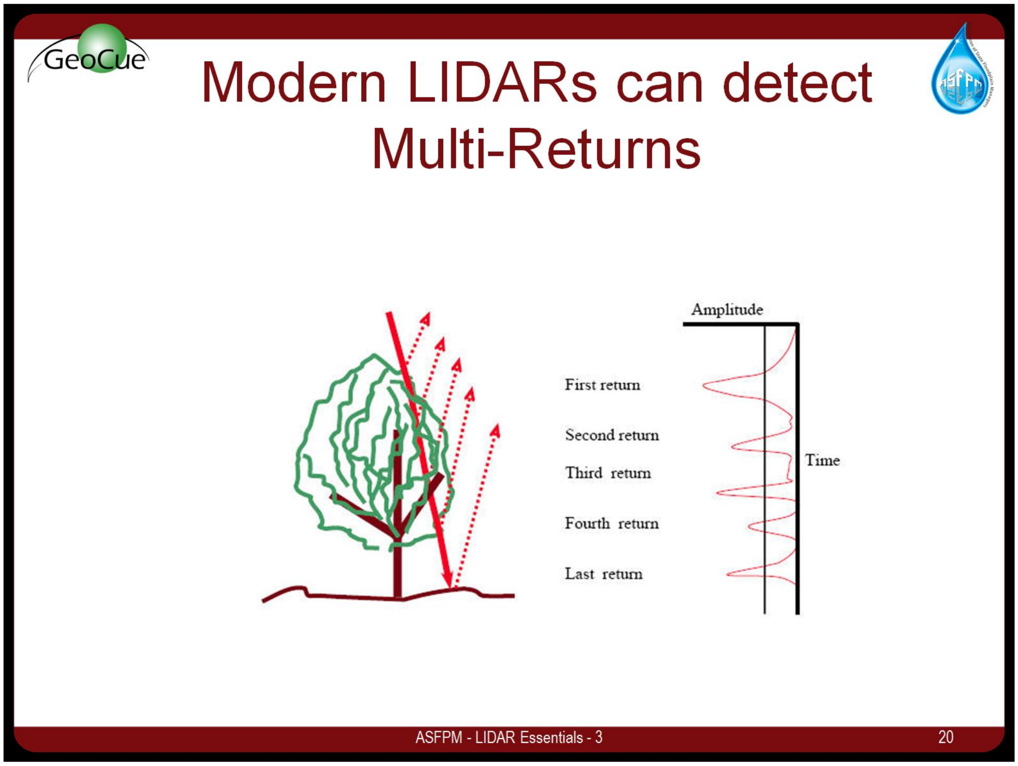
This project exhibits what we would classify as average radiometry. Note that features can be fairly easily discerned such as paint strips on highways and building outlines.

The shift to lighter on the left side of the image is due to denser data on the left. This denser data is caused by the overlap of two or more flight lines.



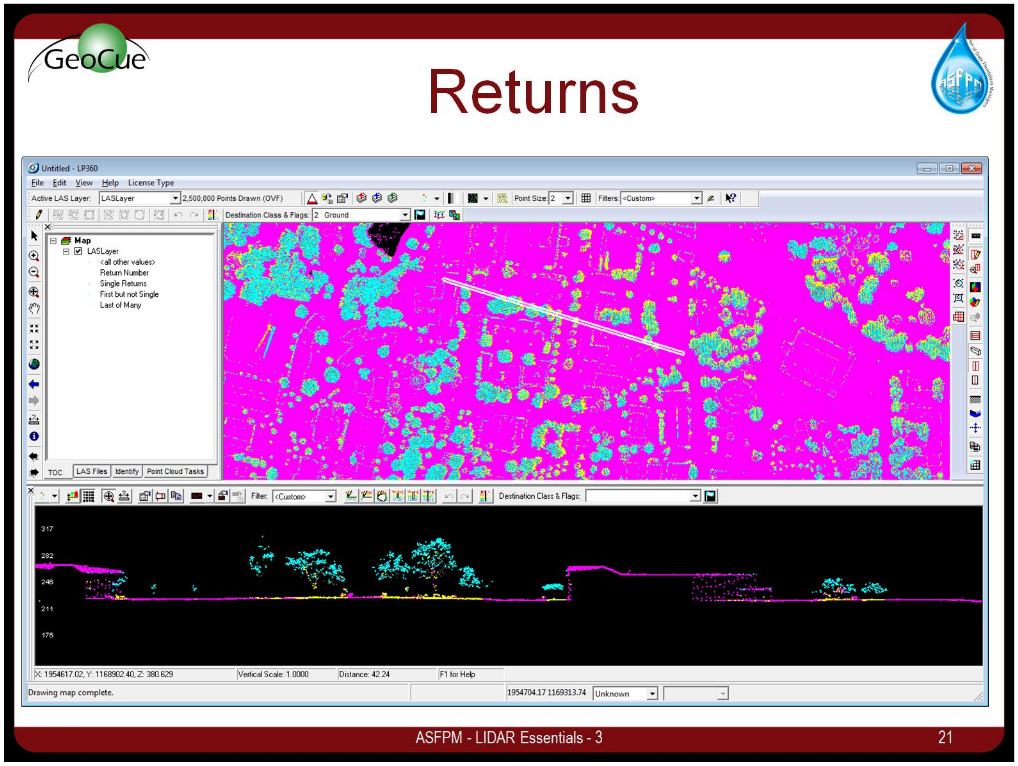
This image presents the best radiometry of our three samples. Note the good range of gray level in this example. Subtle details in roof structures are easily discernible.

Radiometry is typically much better from LIDAR sensors with 16 bit radiometric dynamic range.



All modern airborne LIDAR systems have the capability of detecting multiple returns from a single outgoing pulse. Multiple returns occur when the outgoing pulse encounters object s that partially reflect the pulse while allowing some of the pulse to penetrate to the next object in the scene. A common example are trees, birds, wires, light posts and other objects that present a cross-section smaller than the diameter of the laser pulse.

This multiple return capability of the LIDAR system is very important in 'classification' algorithms. For example, when detecting the bare earth surface, only 'last return' pulse need be considered. This significantly improves the removal of vegetation.



This data sample (colored by return) exhibits very good multiple return characteristics in the data.

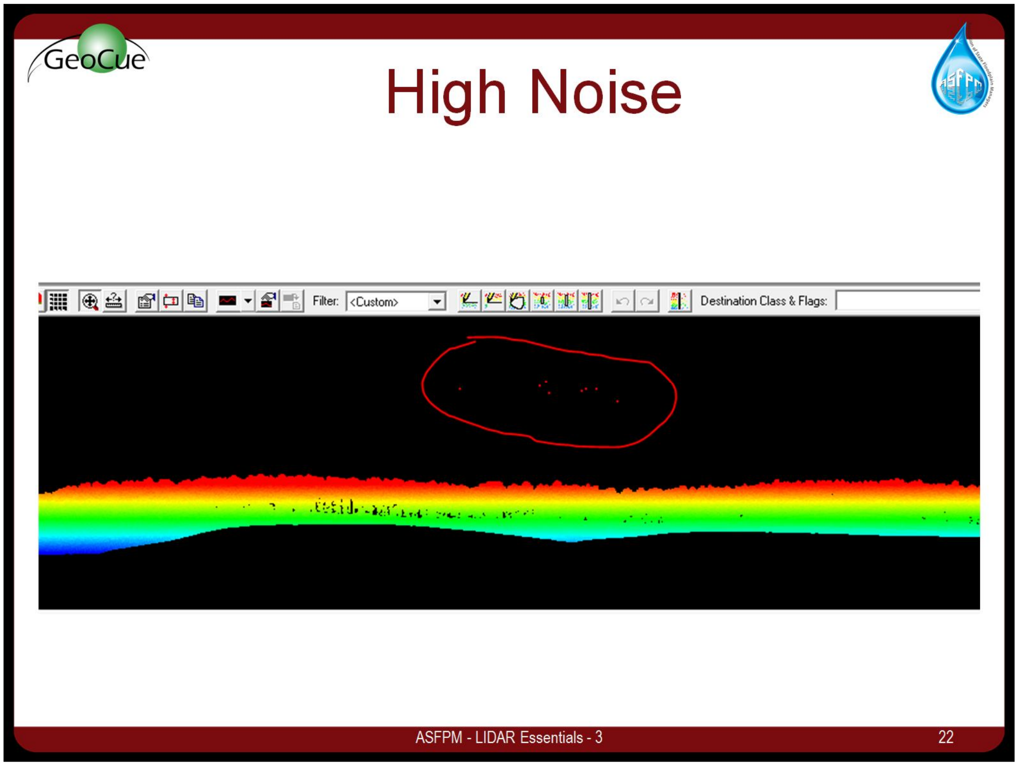
Note in the profile view the characteristics of multiple returns:

Magenta are return 1 of 1 return (single returns)

Cyan are return 1 of 2 returns

Yellow are return 2 of 2 returns

Note that ground is always the last return (1 of 1, 2 of 2, 3 of 3 and so forth). This fact is extensively used in classification algorithms (e.g. “when extracting ground, consider last returns only”).



Here is an example of High Noise. This can be caused by a variety of factors:

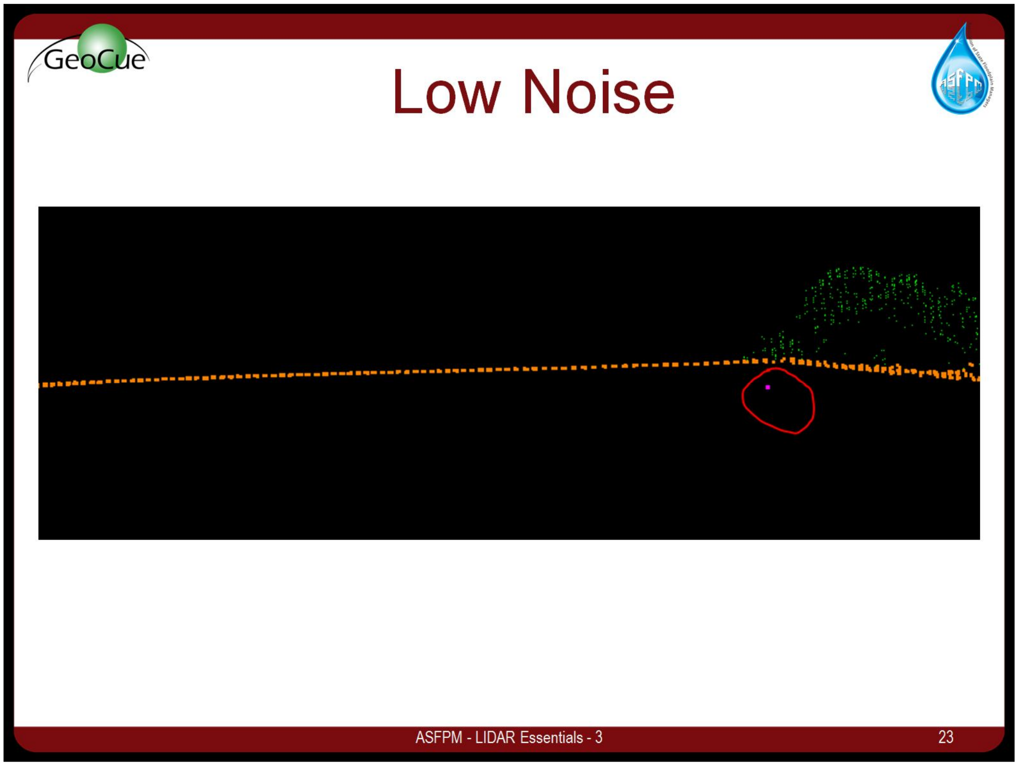
• Bird hits

• LIDAR range ambiguity (this can occur in Multiple Pulse in the Air systems)

• Cloud returns

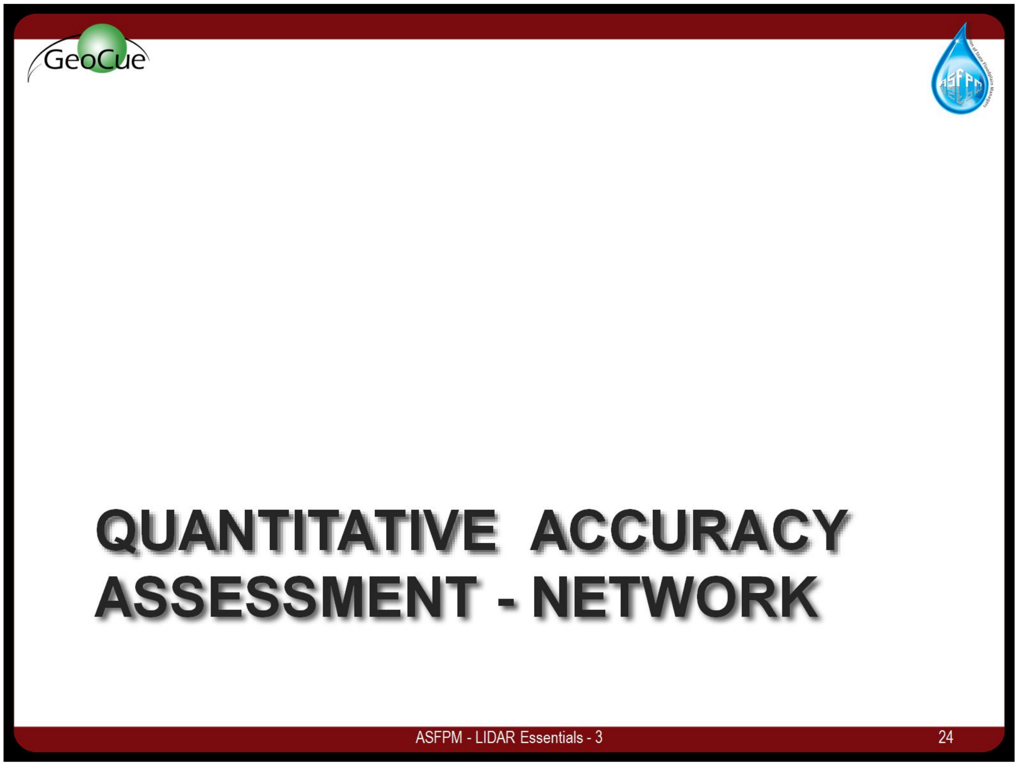
High noise is usually left in the data set but toggled to class 18 (the ASPRS class reserved for High Noise).

If the data set has an unusually large number of high noise points, it is indicative of either poor data acquisition conditions (e.g. cloudy) or a sensor anomaly. In either case, the situation needs to be discussed with the acquisition contractor.



Low noise is usually caused by either a threshold error in the LIDAR unit or by a multipath error in the GPS signal.

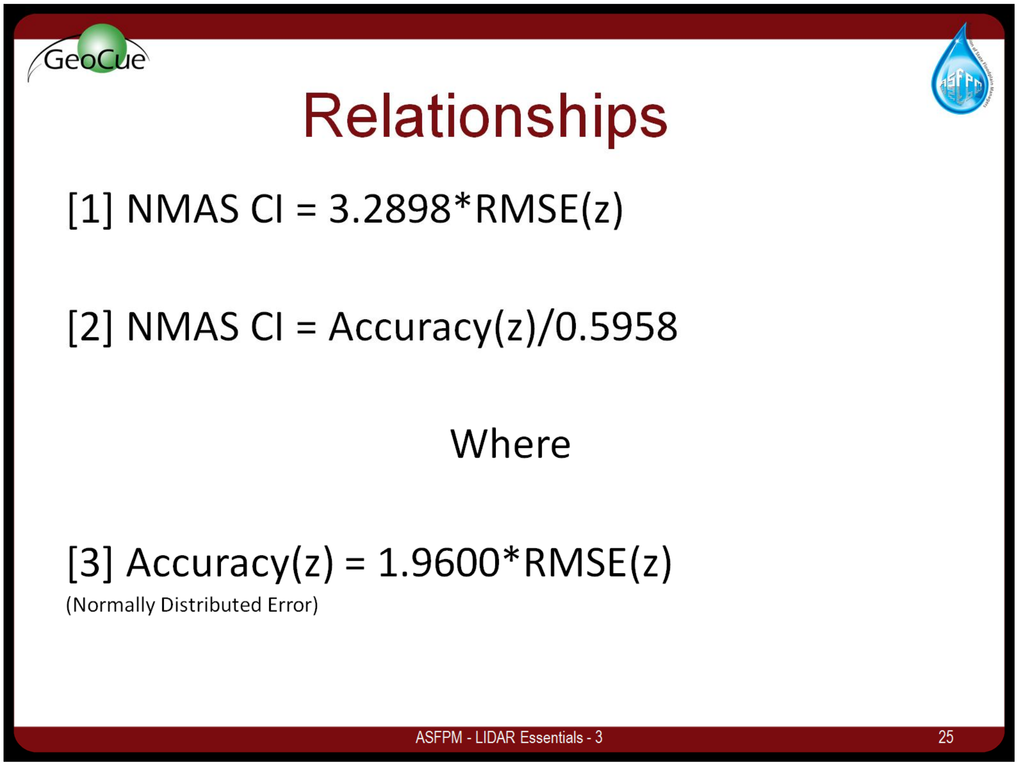
Again, these points will not be removed from the data but rather classified as low noise (ASPRS class 7).



Network Accuracy (sometimes referred to as “absolute” accuracy) refers to how well the LIDAR data fit an external reference network.

This external reference is usually control points that have been independently collected (for example, by GPS techniques).

Control points should always be collected by a licensed surveyor. They should be collected by a contractor who is independent from the LIDAR processing contractor.



NMAS = National Map Accuracy Standards

CI = Contour Interval

RMSE = Root Mean Squared Error

Comparison to Contour Interval (CI) Standards

NMAS Equivalent Contour Interval (ft)	NSSDA RMSE(z)	NSSDA Accuracy(z)	Required QC Accuracy for “Tested to Meet”
0.5	0.15 ft or 4.6 cm	0.30 ft or 9.1 cm	0.10 ft
1	0.30 ft or 9.25 cm	0.60 ft or 18.2 cm	0.20 ft
2	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm	0.40 ft
3	0.91 ft or 23.2 cm	1.79 ft or 45.4 cm	0.60 ft
4	1.22 ft or 37.0 cm	2.38 ft or 72.6 cm	0.79 ft
5	1.52 ft or 46.3 cm	2.98 ft or 90.8 cm	0.99 ft
10	3.04 ft or 92.7 cm	5.96 ft or 181.6 cm	1.98 ft

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NSSDA = National Standard for Spatial Data Accuracy

The green band indicates the most common specification of Contour Interval accuracy.

Potential LIDAR Errors

Systematic

- Biases in Measurement Of:
  - Aircraft Position & Altitude
  - Scanning Angles
  - Time Measurements
- Boresight Error:
  - Misalignment between laser sensor, positional and attitude systems
  - Calculates Magnitude of Above Errors
- GPS Error
  - Base Stations too Far Away
  - PDOP too High
  - Post-Processing Done Incorrectly

Random

- Noise in Recording:
  - Aircraft Position & Altitude
  - Scanning Angles
  - Time Between Pulse Emissions
- System Calibration
  - Calculates Magnitude of Above Errors

Fundamental Accuracy

- The **fundamental vertical accuracy (FVA)** of a dataset must be determined with checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface.
- ***Fundamental accuracy is calculated at the 95-percent confidence level as a function of RMSE(z).***

The fundamental accuracy is the value by which vertical accuracy can be equitably assessed and compared among different datasets.

Supplemental Accuracy

- In addition to the fundamental accuracy, **supplemental or consolidated accuracy** values may be calculated for other ground cover categories or for combinations of ground cover categories respectively.
- A normal distribution of error cannot be assumed and, therefore, RMSE(z) cannot be used to calculate the 95-percent accuracy value.
- ***Consequently a nonparametric testing method (95th Percentile) is required for supplemental and consolidated accuracy tests.***

For extended discussion, see, K. Schuckman , L. Graham:"A New Framework for Accuracy Assessment of LIDAR Data and Derived Elevation Models", 2nd National LIDAR Meeting, May 2008

Reporting By Land Cover Class

- ASPRS recommends collecting a minimum of 20 checkpoints (30 is preferred) in <u>each</u> of the major land cover categories representative of the area for which LIDAR data vertical accuracy is to be verified.
- It is up to the LIDAR data producer and client to determine the significant land cover categories to be tested.

Has significant implications for contracting agencies with projects that cover more than one land cover class.

Output Summary Values

- ***RMSEz:*** *root mean square error for the compared data points calculated using the equation below.*

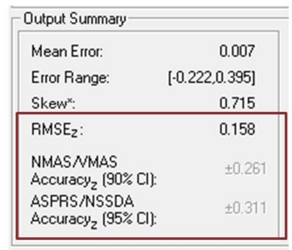
$$\sqrt{\left(\sum_{i}^{n}\left[\left(\text{error}^2\right)/n\right]\right)}$$

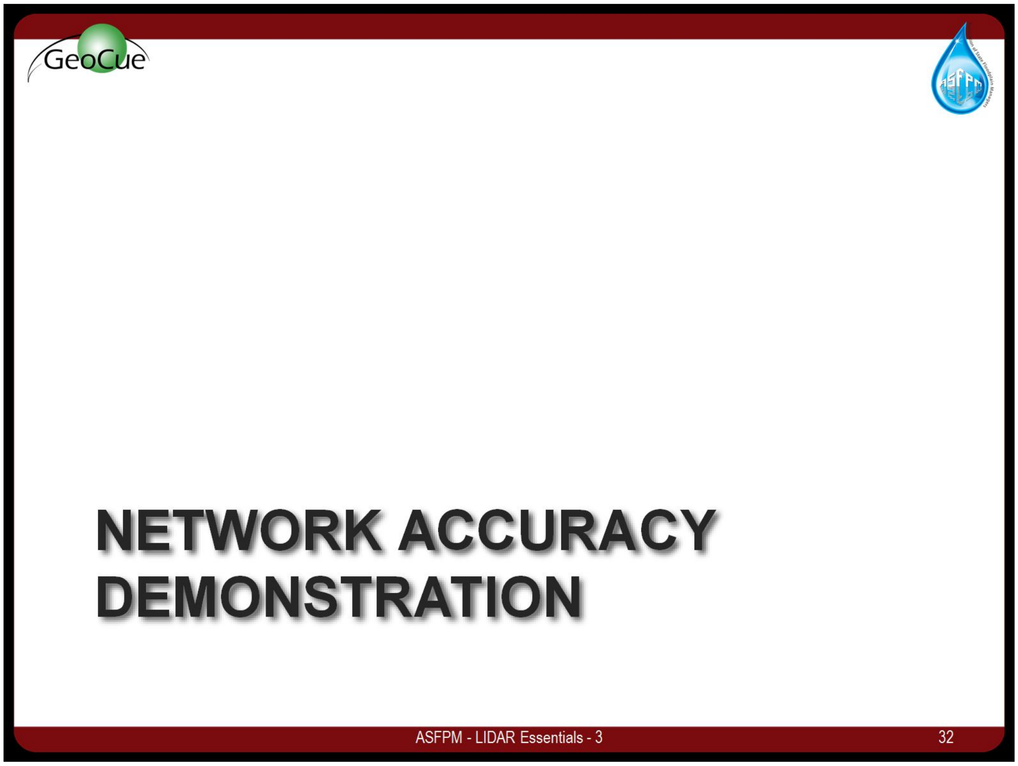
- ***NMAS/VMAS AccuracyZ (90% CI):*** vertical accuracy of the surface for 90% confidence level calculated as shown in equation below.

$$\text{RMSE}_Z * 1.645$$

- ***ASPRS/NSSDA AccuracyZ (95% CI):*** The vertical accuracy of the surface for 95% confidence level calculated as shown in equation below.

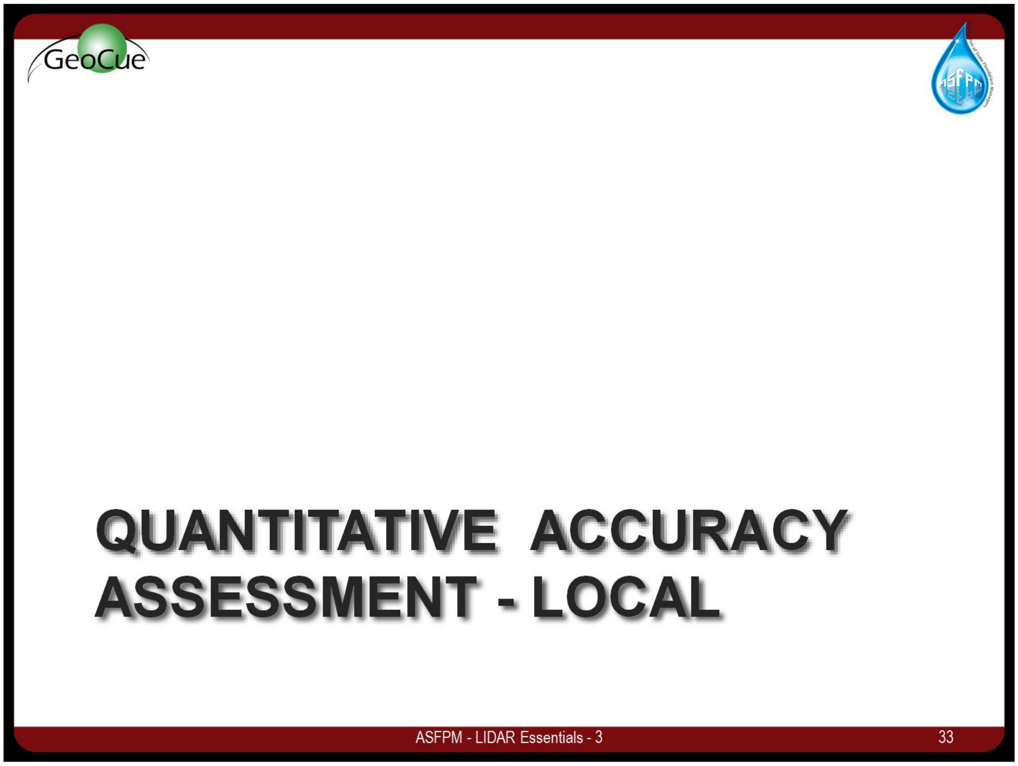
$$\text{RMSE}_Z * 1.96$$





Local Accuracy (also called “Relative Accuracy”) refers to point to point accuracy within the LIDAR point cloud, irrespective of Network Accuracy.

In specialized applications, Local Accuracy is important in measuring heights and distances. In most floodplain mapping applications, the most important Local Accuracy consideration is strip to strip accuracy.



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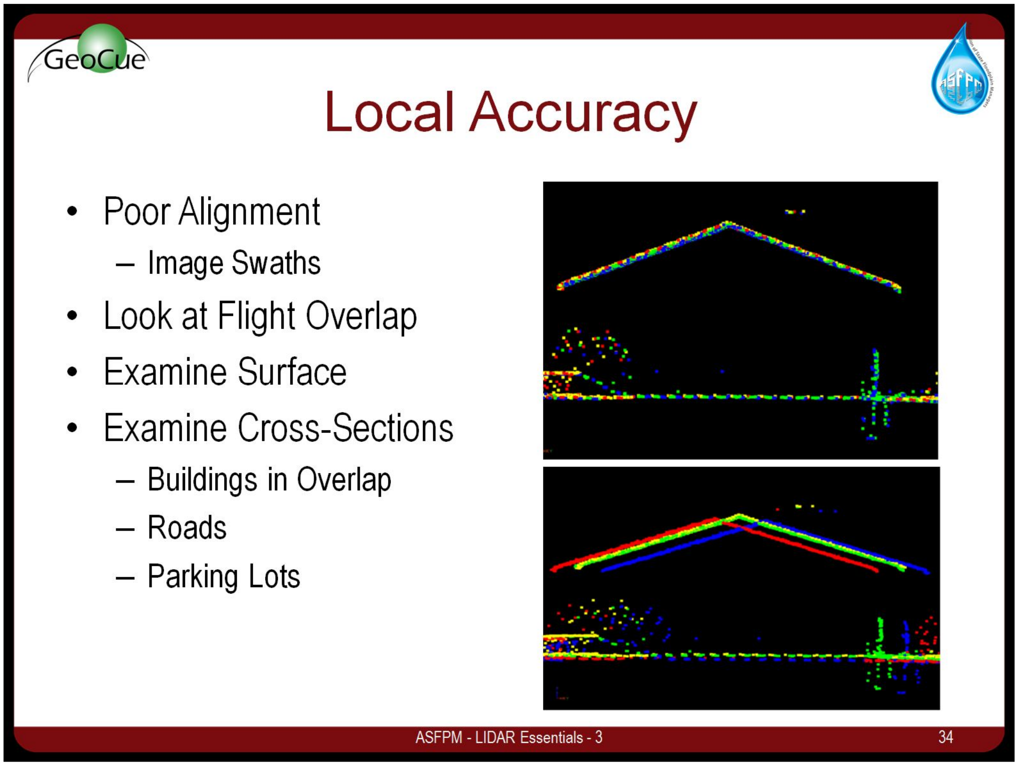
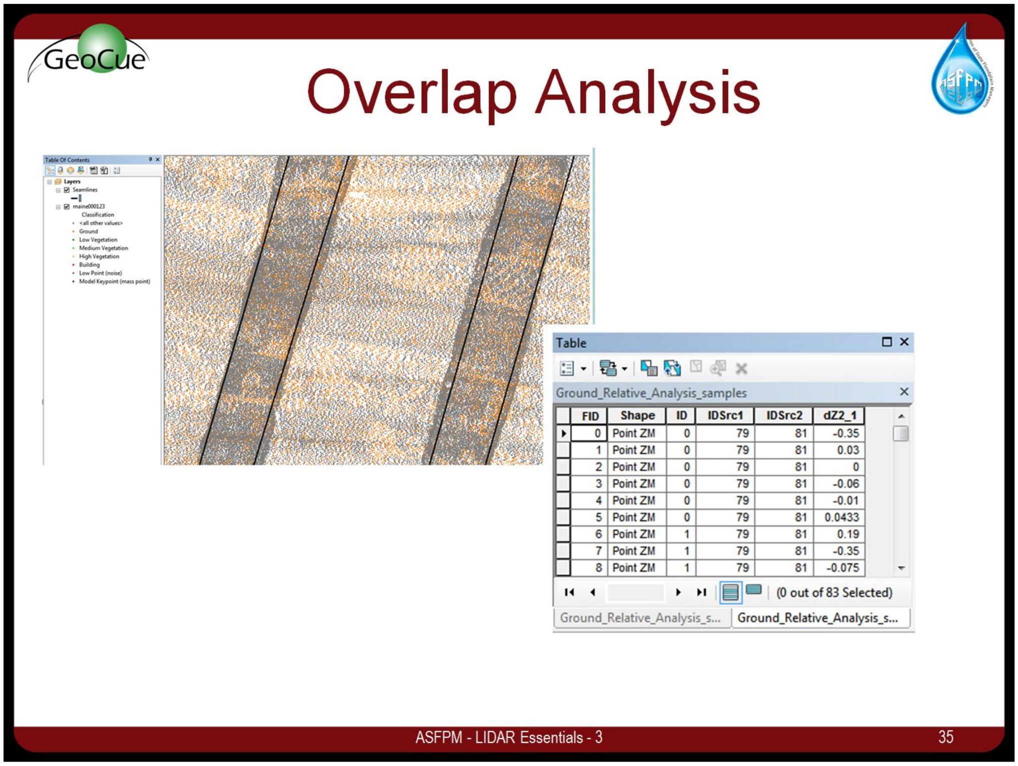


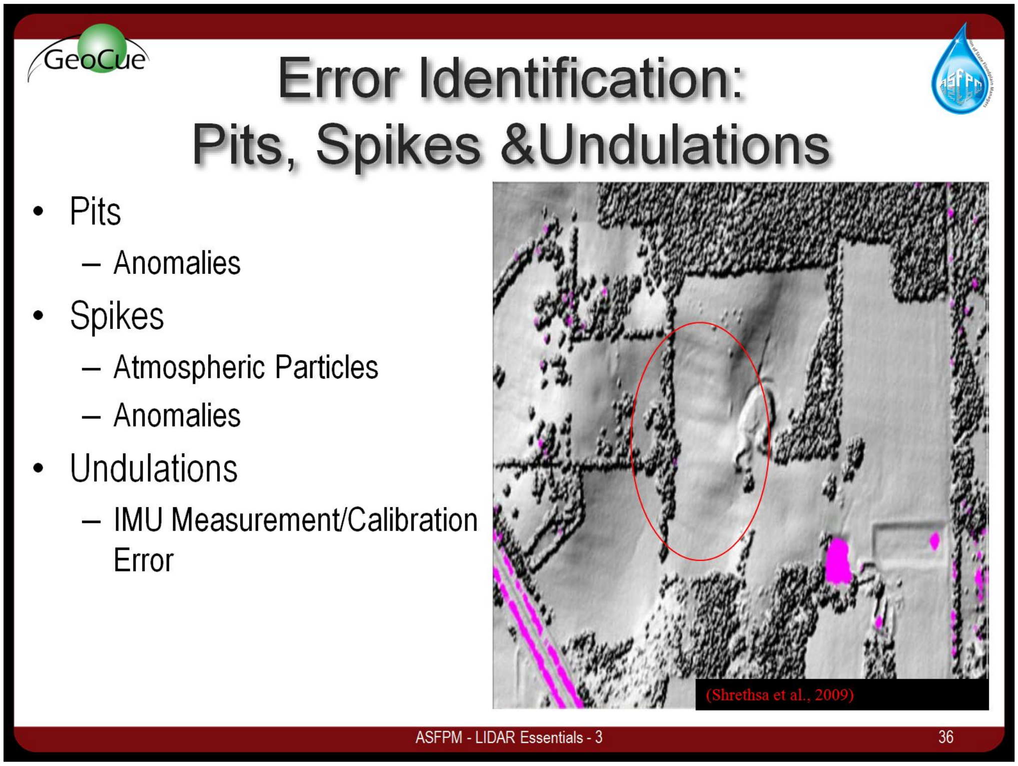
A visual inspection of sloped, flat surfaces with points colored by flight line will provide a visual indication of the overall adjustment of the data. In the top view, the data are nearly perfectly adjusted. In the lower view, there is significant misalignment of the data as indicated by the fact that the various passes (flight lines) over the same area of the roof structure (flights are indicated in different colors – red, green and blue) are not aligned.



It is very important to make a quantitative test of the overlap of seam lines in a LIDAR project.

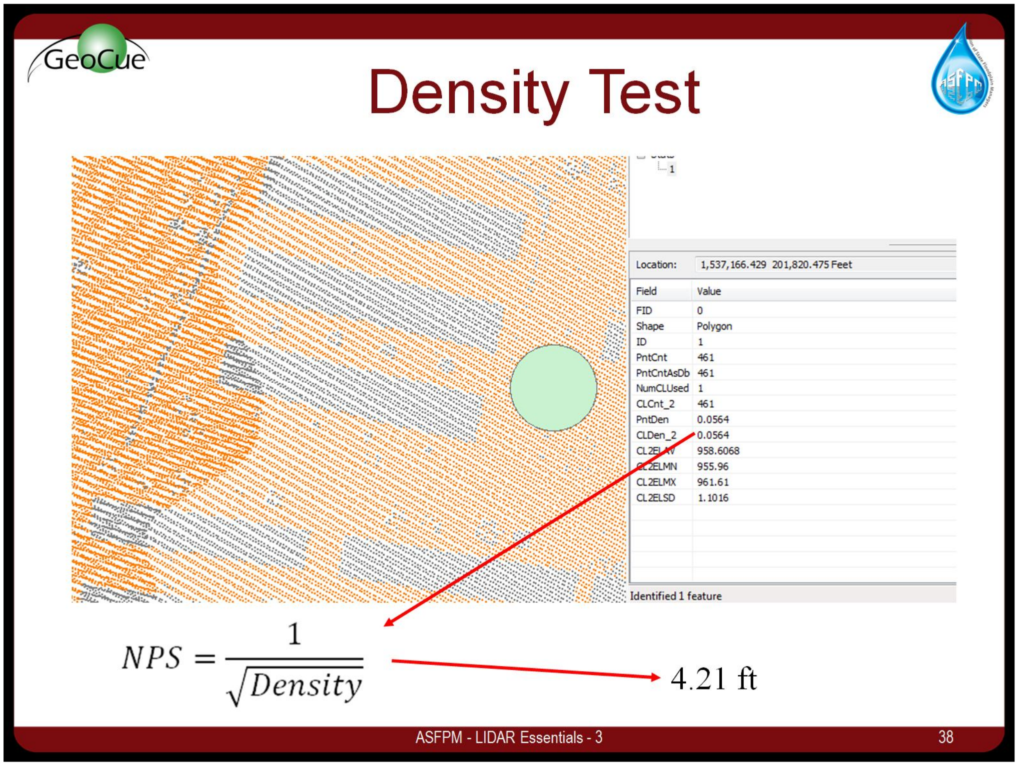
In this example, we have used the seam line analysis tool in LP360 to analyze the vertical deviations between overlaps in the project.

Typically, your procurement specification will specify absolute maximum errors and per-line RSME(Z) values.

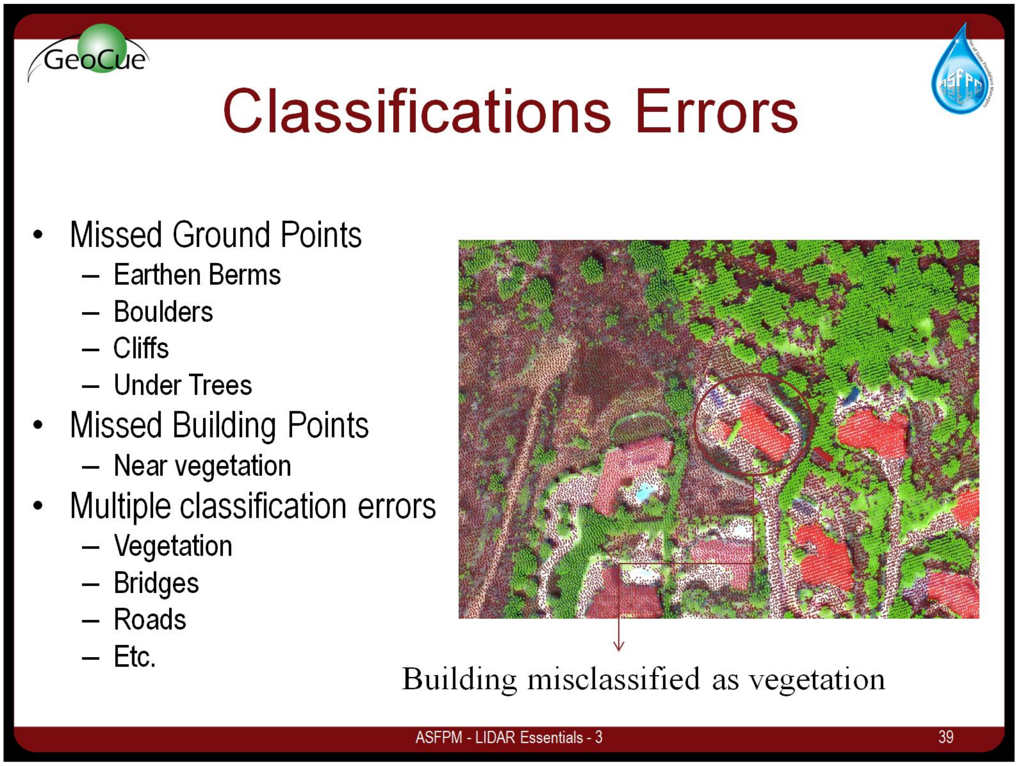


These are general geometry errors that would come under the heading of Local errors (or geometric anomalies). They can be analyzed quantitatively by comparing profile sections to expected geometry.

QUANTITATIVE DENSITY & CLASSIFICATION TESTING



The required density in the ground class should be explicitly measured in a number of locations. It is a good idea to visually inspect the ground class for areas that look thin and perform measurements. Rather than zooming in and measuring the distance between points, measure the density of an area and compute the Nominal Point Spacing using the reciprocal square root relationship.



Classification errors can be grossly checked by visual inspection. Errors in which objects such as vegetation and buildings have been misclassified as ground are particularly problematic as this type of error propagates into extracted DEMs and contours.

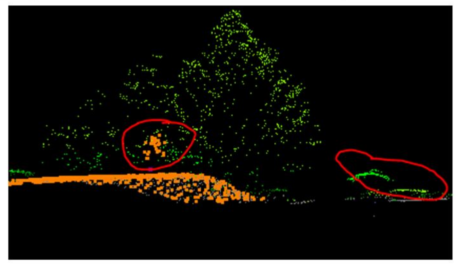
Poor ground classification will also cause many problems for subsequent extraction algorithms such as automatic building classification and “height above ground” vegetation classification.

Quantifying Classification Accuracy

A Classification "Confusion" Matrix

		Ground Truth				
		B	V	C	G	Total
Classified Data	B	**16326**	2178	224	1486	20214
	V	1709	**24635**	62	1535	27941
	C	111	252	**263**	327	953
	G	667	4827	257	**20257**	26008
	Total	18813	31892	806	23605	**75116**

B = Building
V = Vegetation
C = Car
G = Ground



(misclassified Ground and Building

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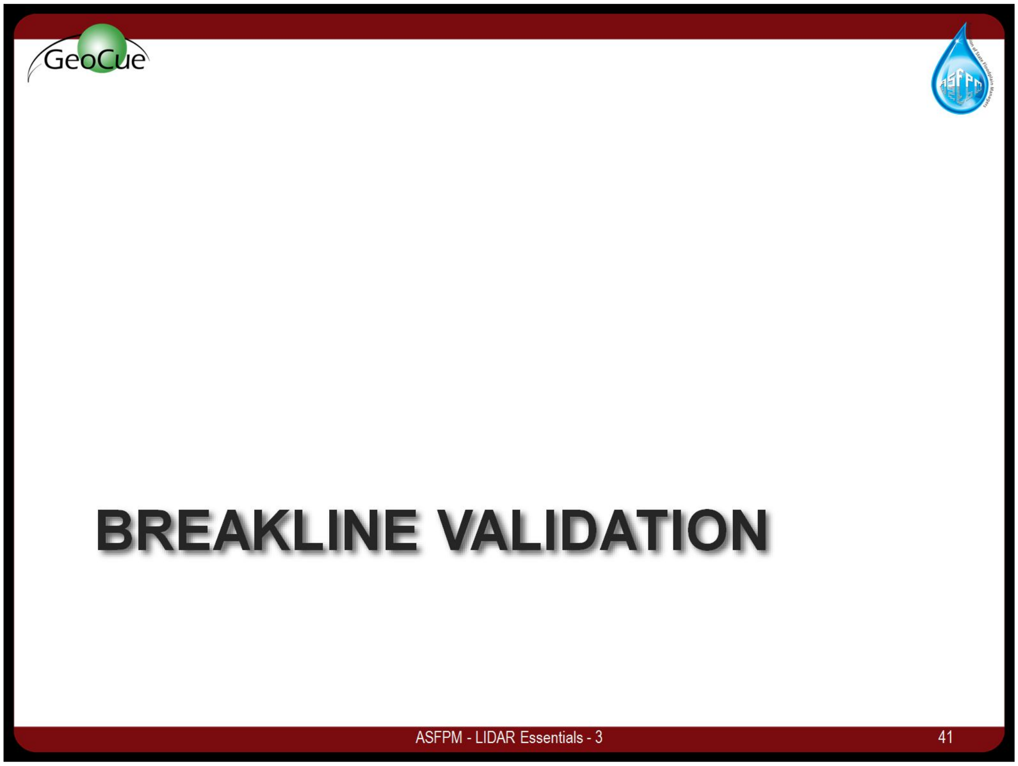
A Confusion Matrix is used to tabulate the accuracy of classification. Typically, classification accuracy is specified as errors of omission (should be in the class but is not) and commission (should not be in the class but is).

Usually the concern with ground class centers on two issues:

1) Having sufficient points in the ground class to meet the project density (or Nominal Point Spacing, NPS) requirements. Thus you do not really care if a large number of points that should be in the ground class are left in the "unclassified" state so long as the project density for the ground class is uniformly maintained throughout the project. Obviously if this ratio is high, the collection density will have to be significantly higher than the ground classification specified density.
2) Having a very low number of non-ground points in the ground class. Building, vegetation and other non-ground points classified as ground will cause significant errors in the derived elevation models. Additionally, these errors will cause major issues if you attempt to do value add data extraction such as building footprints.


BREAKLINE VALIDATION
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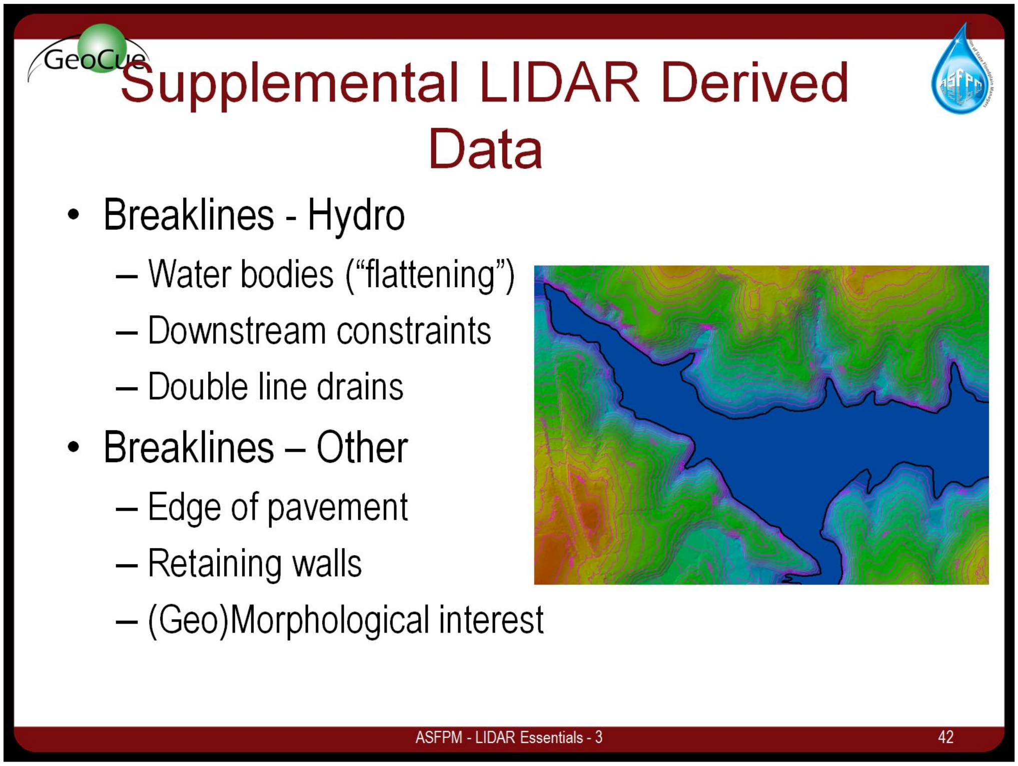
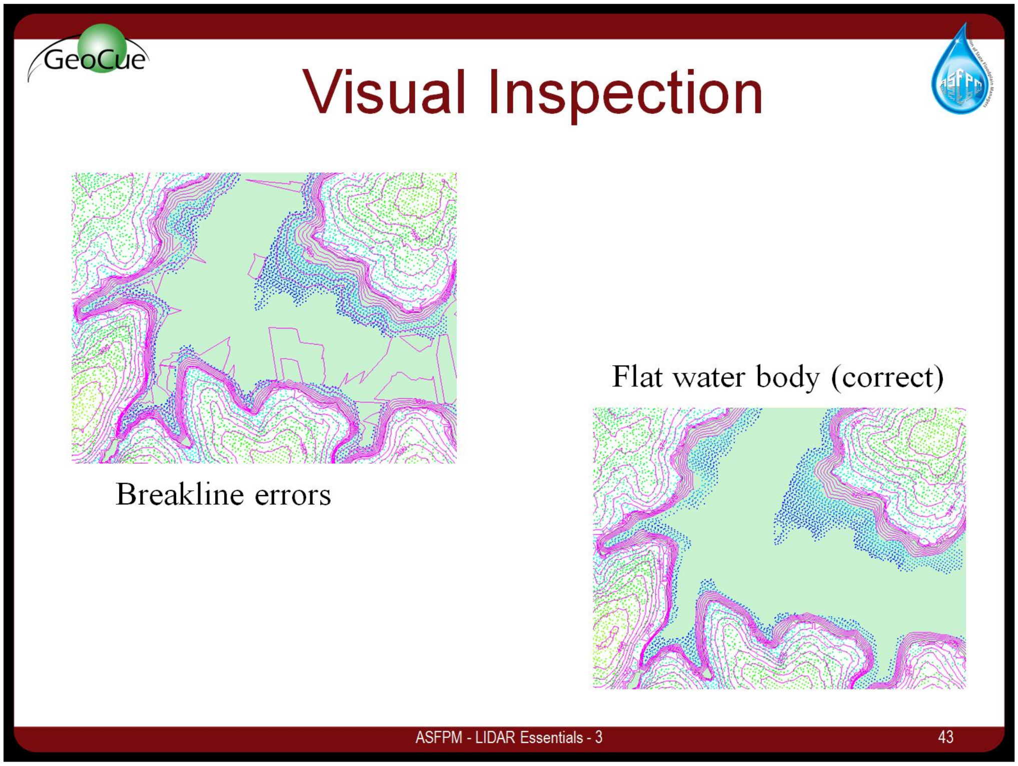


Breaklines and their importance were discussed in the previous two sessions. Basically, breaklines alter the LIDAR topography to ensure that constraint conditions are met such as flat water bodies and down stream flows.

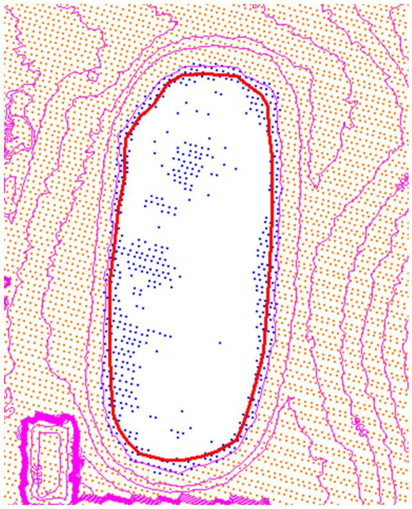


Breaklines such as flat water bodies are easily checked using a constrained contour display (where the Triangulated Irregular Network, TIN, is being constrained by the breaklines).

In the figure on the left, the contours are projecting into the water body. This is a clear indication that the water body is not 'flat."

In the figure to the right, the contours follow the shore line and no contours are crossing or jutting into the water body. This indicates a correct, flat model.

Body Flattening



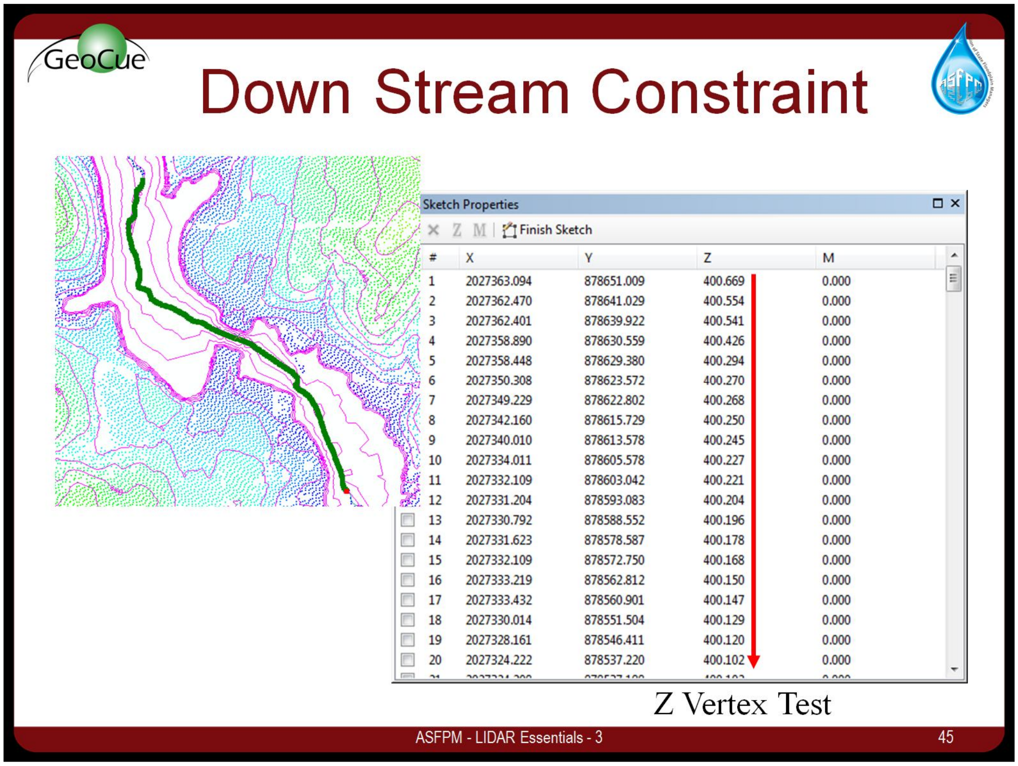
Conflated

#	X	Y	Z
0	1538613.317	201745.421	896.792
1	1538627.091	201739.064	896.909
2	1538635.037	201735.356	897.873
3	1538635.037	201716.814	896.388
4	1538636.627	201671.783	896.805
5	1538635.567	201631.521	896.878
6	1538631.859	201575.365	897.168
7	1538623.382	201534.573	896.604

Conflated & Flattened

#	X	Y	Z
0	1538557.161	201729.528	896.750
1	1538565.637	201742.243	896.750
2	1538575.703	201748.070	896.750
3	1538591.066	201748.600	896.750
4	1538610.668	201747.541	896.750
5	1538617.555	201741.713	896.750
6	1538627.621	201734.826	896.750
7	1538631.859	201727.409	896.750

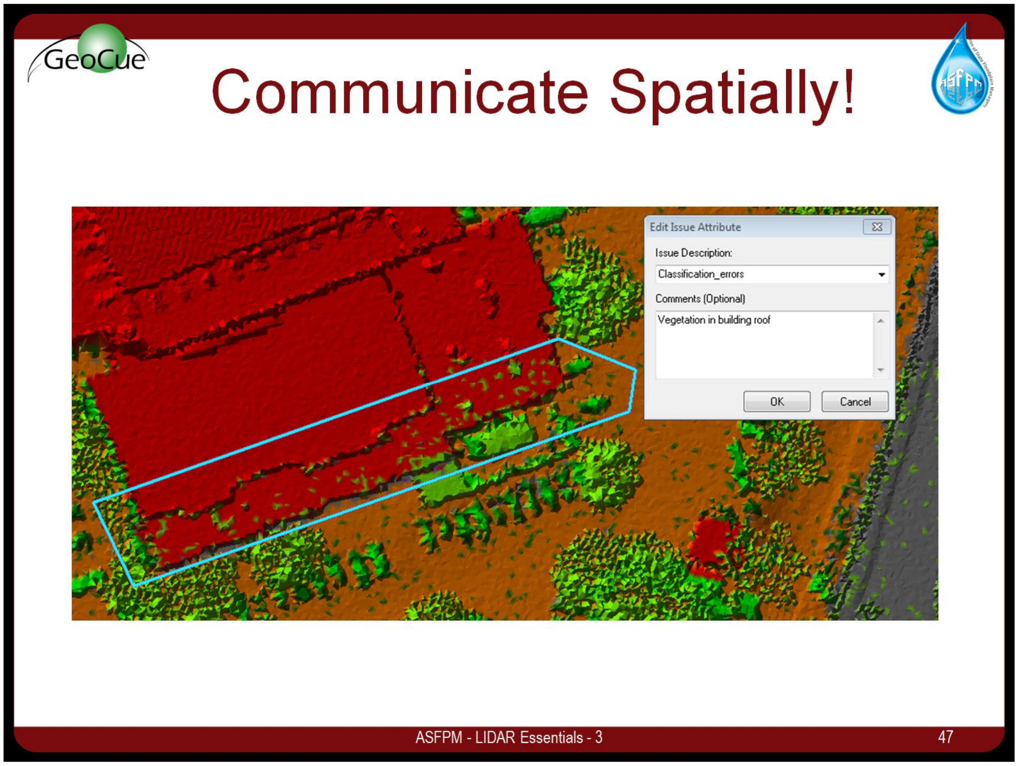
Water body flattening simply says still water must all be at the same elevation. As with all breakline applications, the exact placement of the land-water boundary can be quite ambiguous. If it is critical that this be correct (or if the banks are very steep), supplemental information from water gauges or field survey data must be introduced.



Downstream constraints can also be visually inspected using contours. This inspection requires experience with the result of downstream constraints on contours.

A qualitative check can be made by inspecting the vertices of the stream thalweg. Note in the Z column the monotonically decreasing values.

COMMUNICATING ISSUES



We think the most straightforward way of communicating issues to the contractor is via annotated shape files. The contractor can import the files and see, spatially, exactly where the error is located. The description of the error and any necessary associated parameters are included in the attributes.

Poll

Questions?

Useful References

- Minimum LIDAR Data Density Considerations for the Pacific Northwest
  - (http://www.oregongeology.org/sub/projects/olc/minimum-lidar-data-density.pdf)
- Lidar Base Specification Version 1.0 (USGS)
  - http://pubs.usgs.gov/tm/11b4/
- Procedure Memorandum No. 61 - Standards for Lidar and Other High Quality Digital Topography (FEMA)
  - http://www.fema.gov/library/viewRecord.do?id=4345

Thank You!

Download Evaluation Software from:
www.LP360.com

Download Sample Data from:
http://www.floods.org/LidarWebinar/SampleData/

View tutorials on You Tube from the LIDARLAB Channel

Direct questions to GeoCue:
info@lp360.com