LIDAR DENSITY AND SPACING SPECIFICATION

Version 1.0

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Presented on behalf of the ASPRS PAD Lidar Committee

The Problem

- "Nominal Pulse Spacing (NPS) of 1-2 meters…"[1]
- "Nominal Pulse Spacing (NPS) – The estimated average spacing of irregularly-spaced lidar points in both the along-track and cross-track directions…"[2]
- How do we derive empirical NPS consistent with design NPS?
- How do we measure something as irregular as lidar points?

1 - U.S. Geological Survey National Geospatial Program Lidar Guidelines and Base Specification, Version 13

2 - FEMA Procedure Memorandum No. 61 – Standards for Lidar and Other High Quality Digital Topography

The Goal

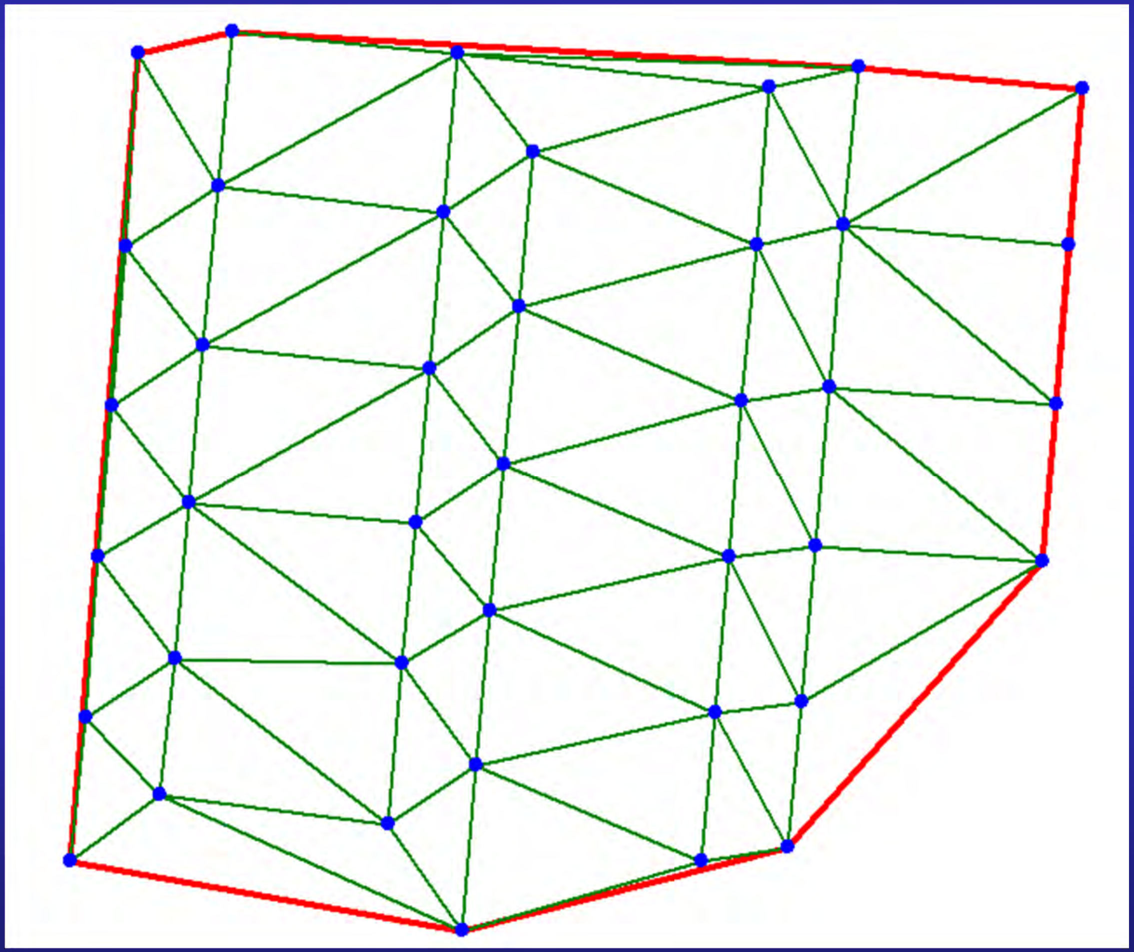
- Simple
- Easy to implement
- Unbiased towards a sensor configuration and scan pattern
- Consistent
- Conform to existing standards, specifications and guidelines
- Flexible

The Procedure

- Delaunay Triangulation
  - “Point” or “Pulse” spacing = average edge length (2D) to all neighbor points
- Voronoi Diagram
  - Point density = 1 / Voronoi polygon area
- Nominal
  - An LDSS measurement at a specified percentile from a set of lidar points

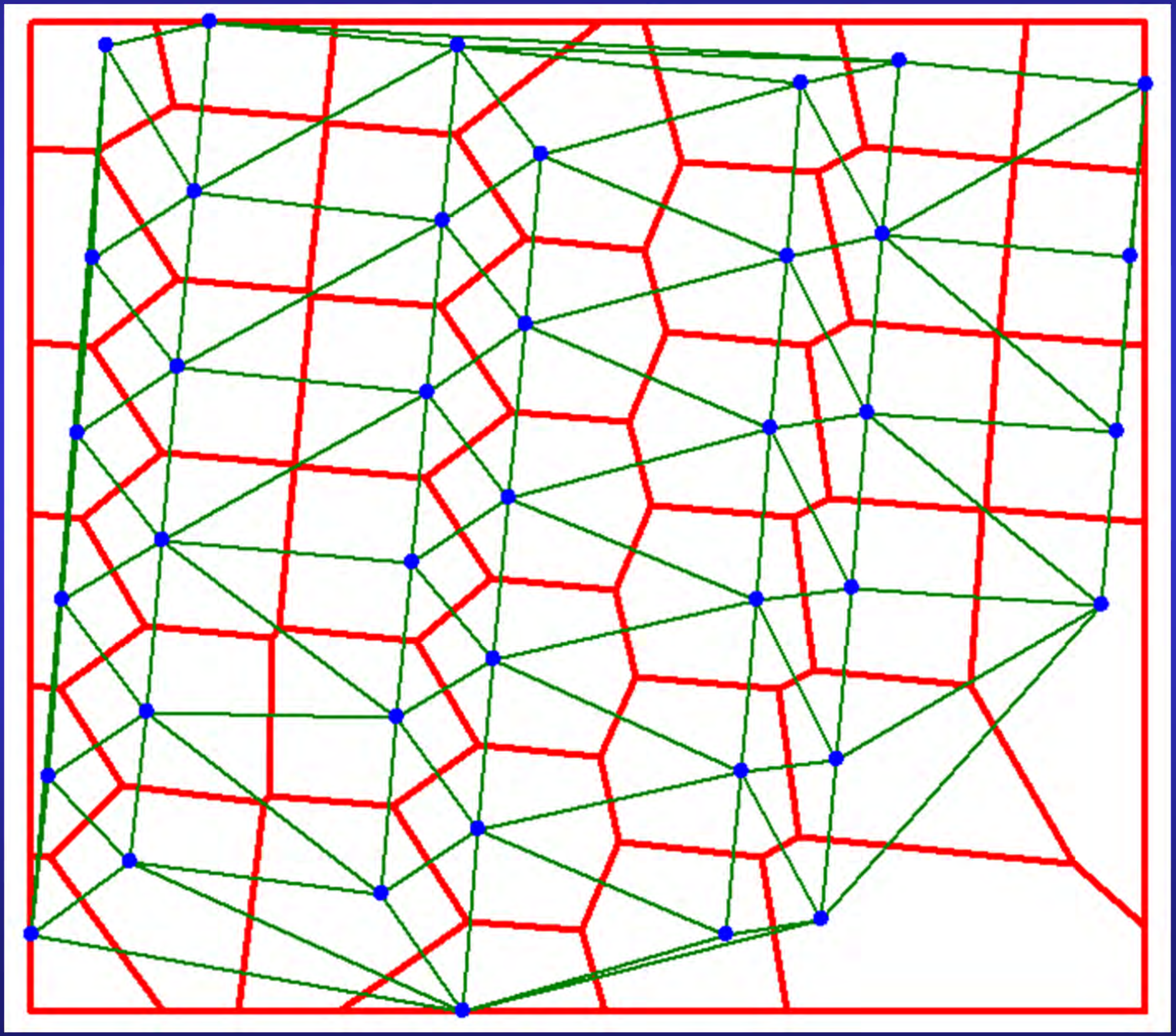
TIN Elements

- Nodes
- Edges
- Triangles
- Convex Hull

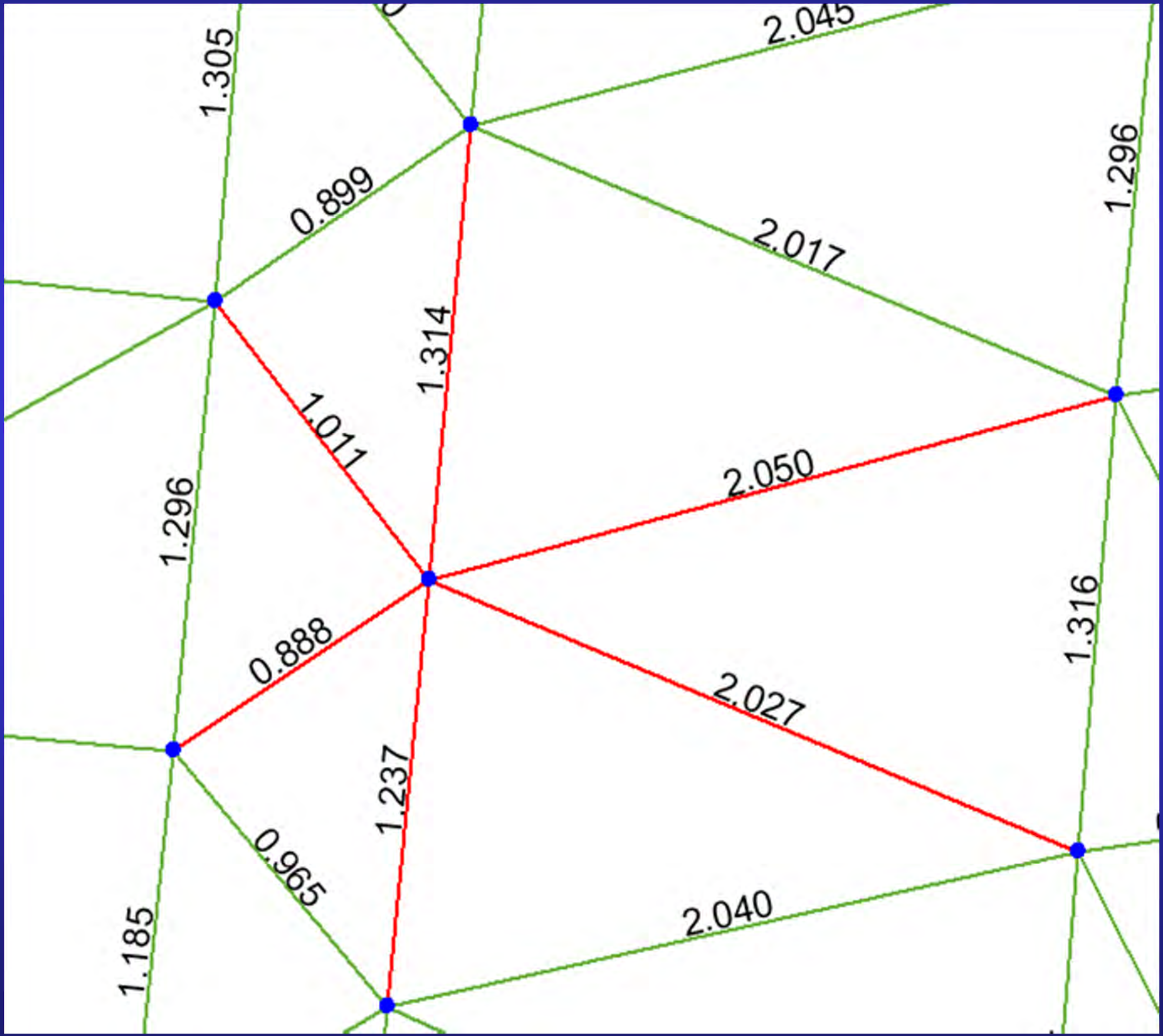


Voronoi Diagram

The dual graph of the Delaunay triangulation for the same set of points



Spacing Measurement



Spacing for the given point =

1.314 +

2.050 +

2.027 +

1.237 +

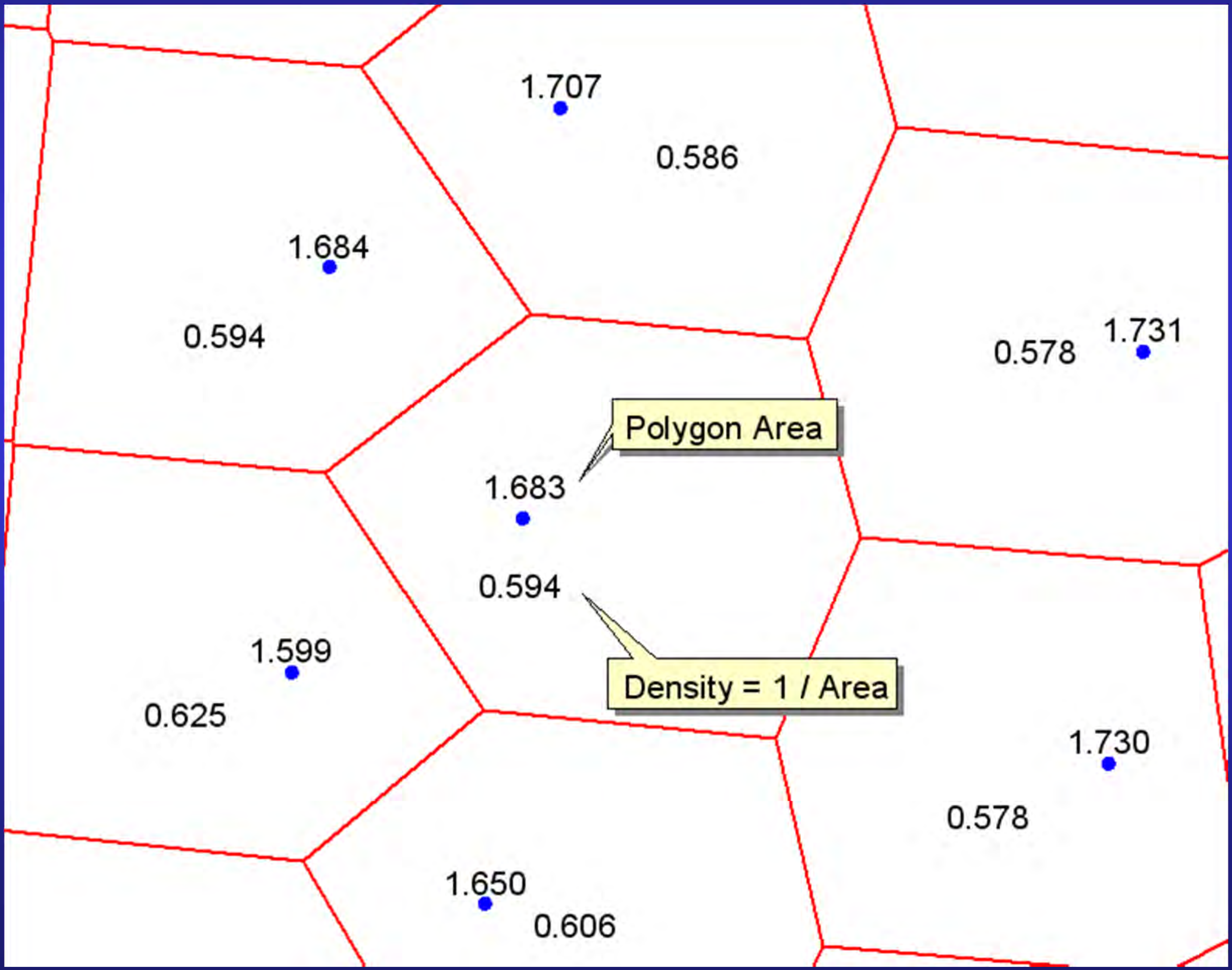
0.888 +

1.011

= 8.527 / 6

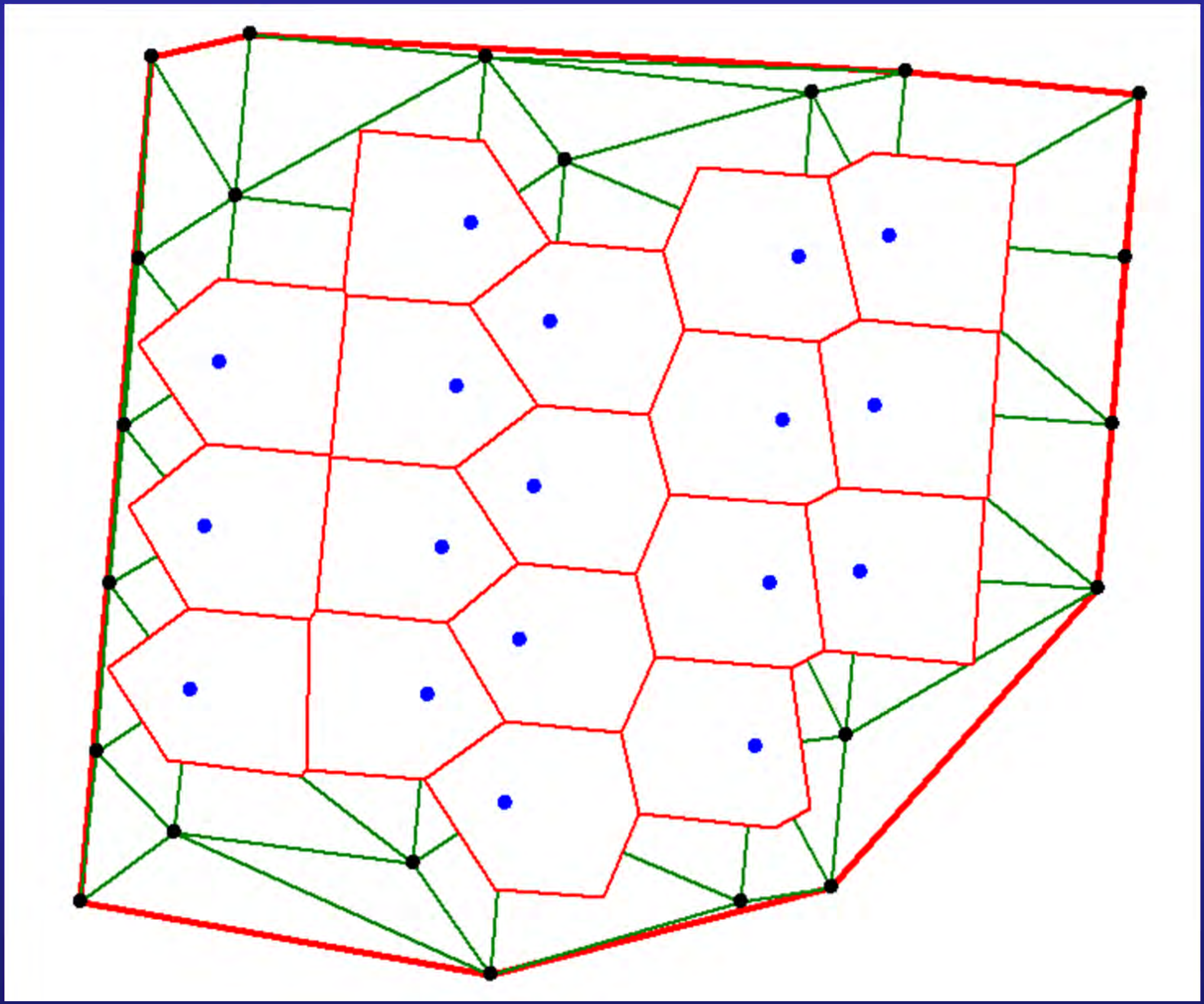
= **1.421**

Density Measurement



Nominal Values

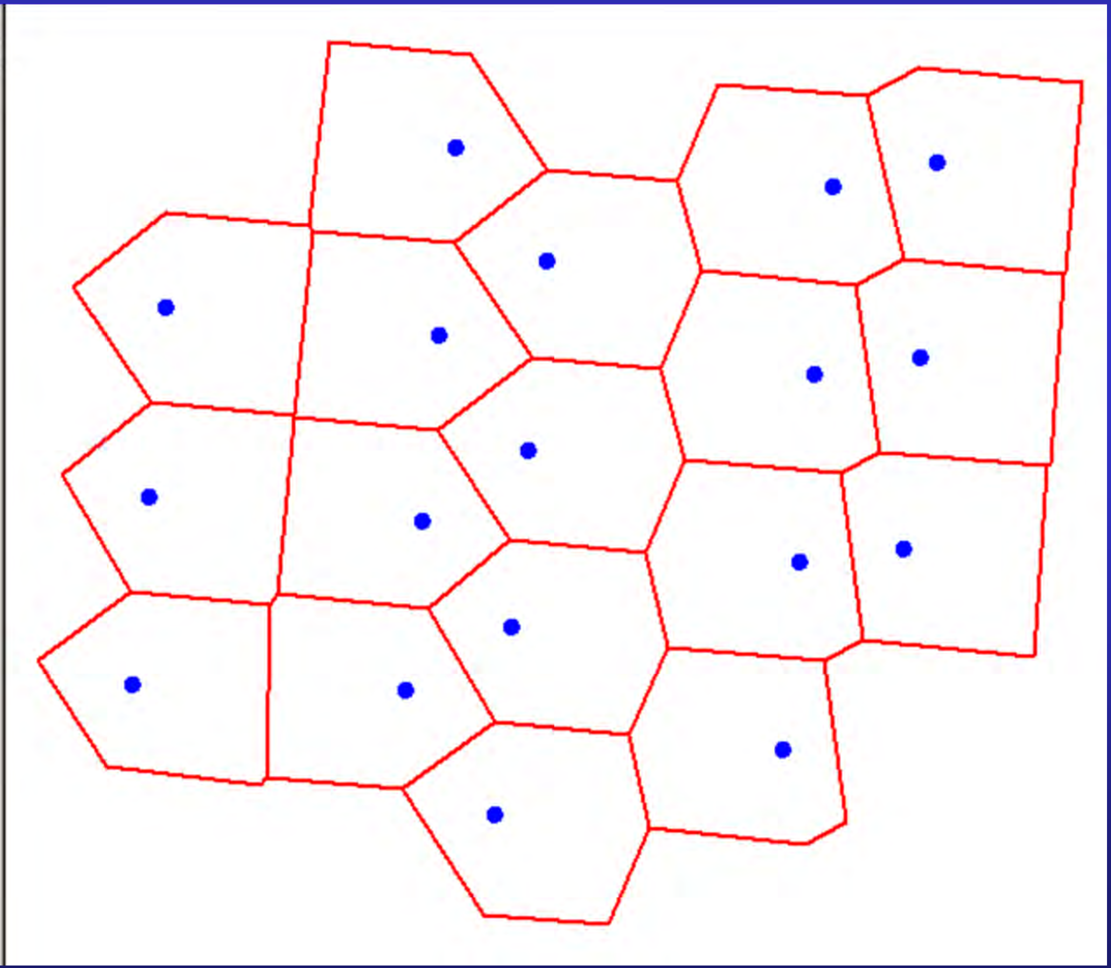
We exclude points associated with the convex hull because they have “long” edges



1. Sort spacing or density values from low to high
2. Extract a value at a percentile = nominal definition

- Point spacing (50%) = 1.447 = median
- Point spacing (95%) = 1.566 (problematic small population)

Shape	Spacing	Density
Point	1.246	0.625
Point	1.324	0.580
Point	1.410	0.606
Point	1.421	0.594
Point	1.425	0.608
Point	1.425	0.612
Point	1.430	0.586
Point	1.440	0.596
Point	1.447	0.574
Point	1.452	0.594
Point	1.454	0.588
Point	1.460	0.578
Point	1.462	0.578
Point	1.463	0.578
Point	1.465	0.578
Point	1.490	0.575
Point	1.566	0.589
Point	1.602	0.577



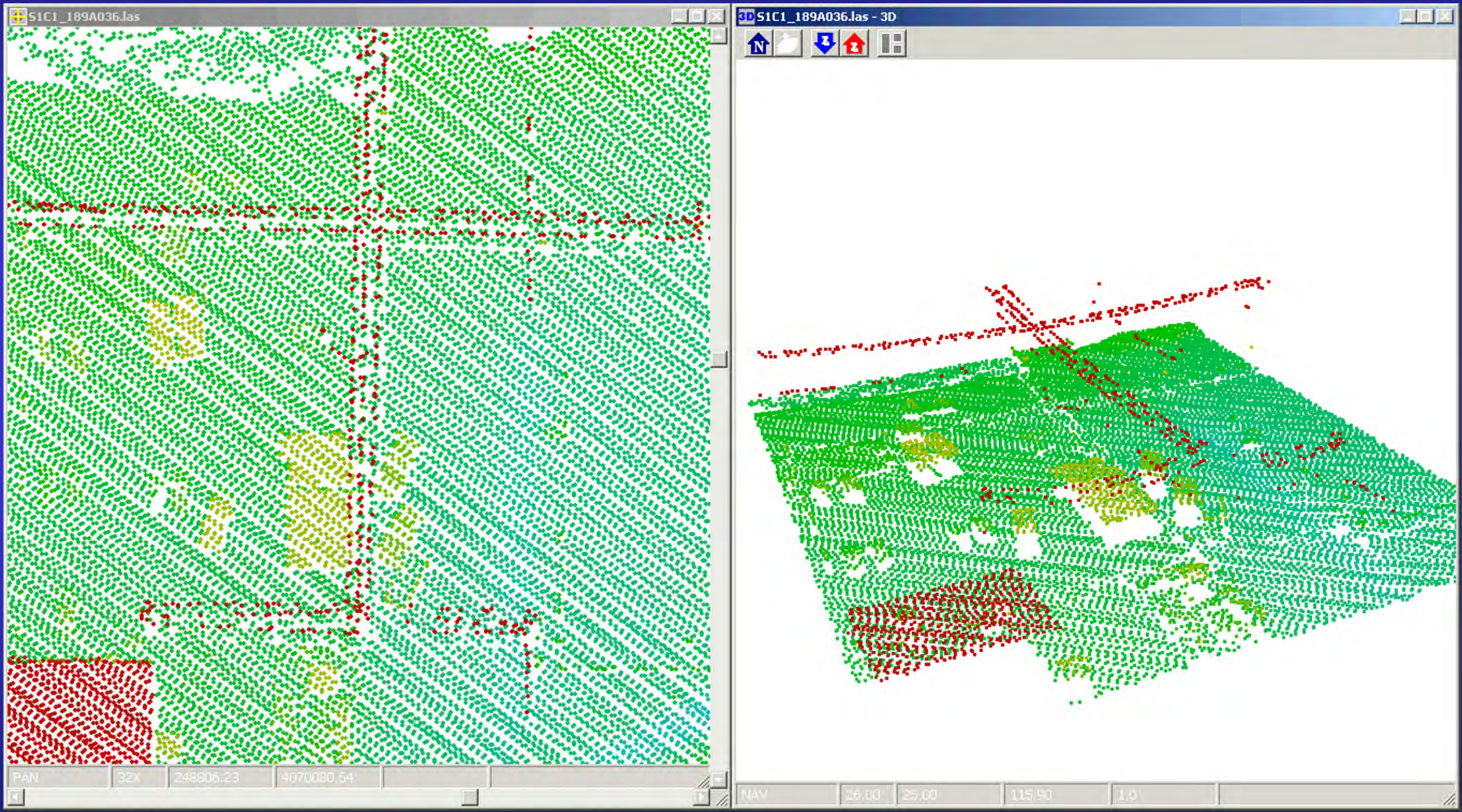
Sample Area Selection

- Use same checkpoints for vertical accuracy reporting conforming to:
  - ASPRS Guidelines, Vertical Accuracy Reporting for Lidar Data, Version 1.0
  - NDEP Guidelines for Digital Elevation Data, Version 1.0
  - U.S. Geological Survey National Geospatial Program Lidar Guidelines and Base Specification, Version 13
- These are convenient, thoroughly distributed, and fall within various land cover categories
- Supplement with additional areas if needed

Point Population Selection

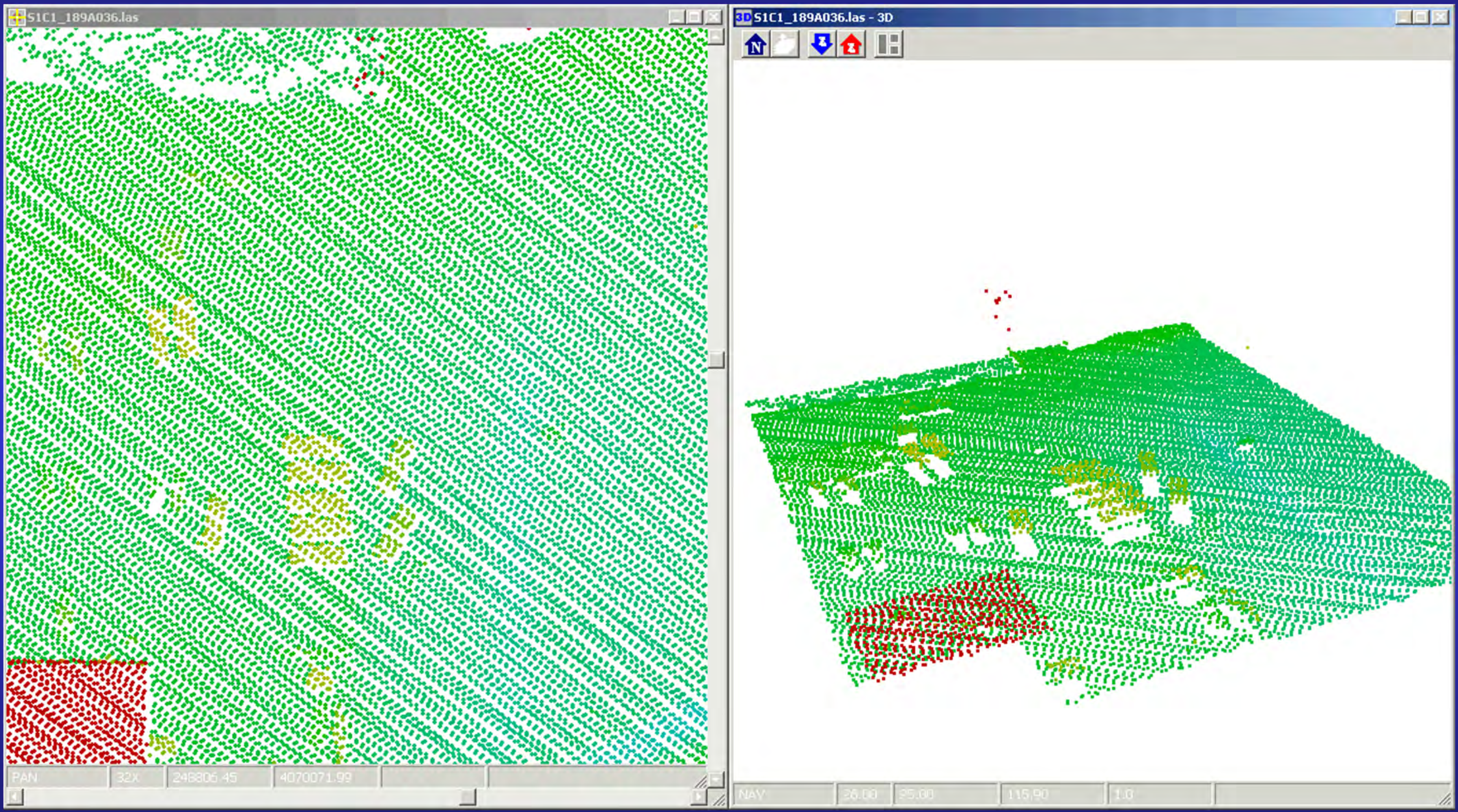
- The LDSS follows NPS criteria defined in USGS Lidar Guidelines and Base Specifications v13 where:
  - Single swath points
  - Located in center portion of swath (~90%)
  - First pulse returns? Can be used, but not best choice…
  - Last pulse returns are much more likely to resemble the design NPS

First vs. Last Returns



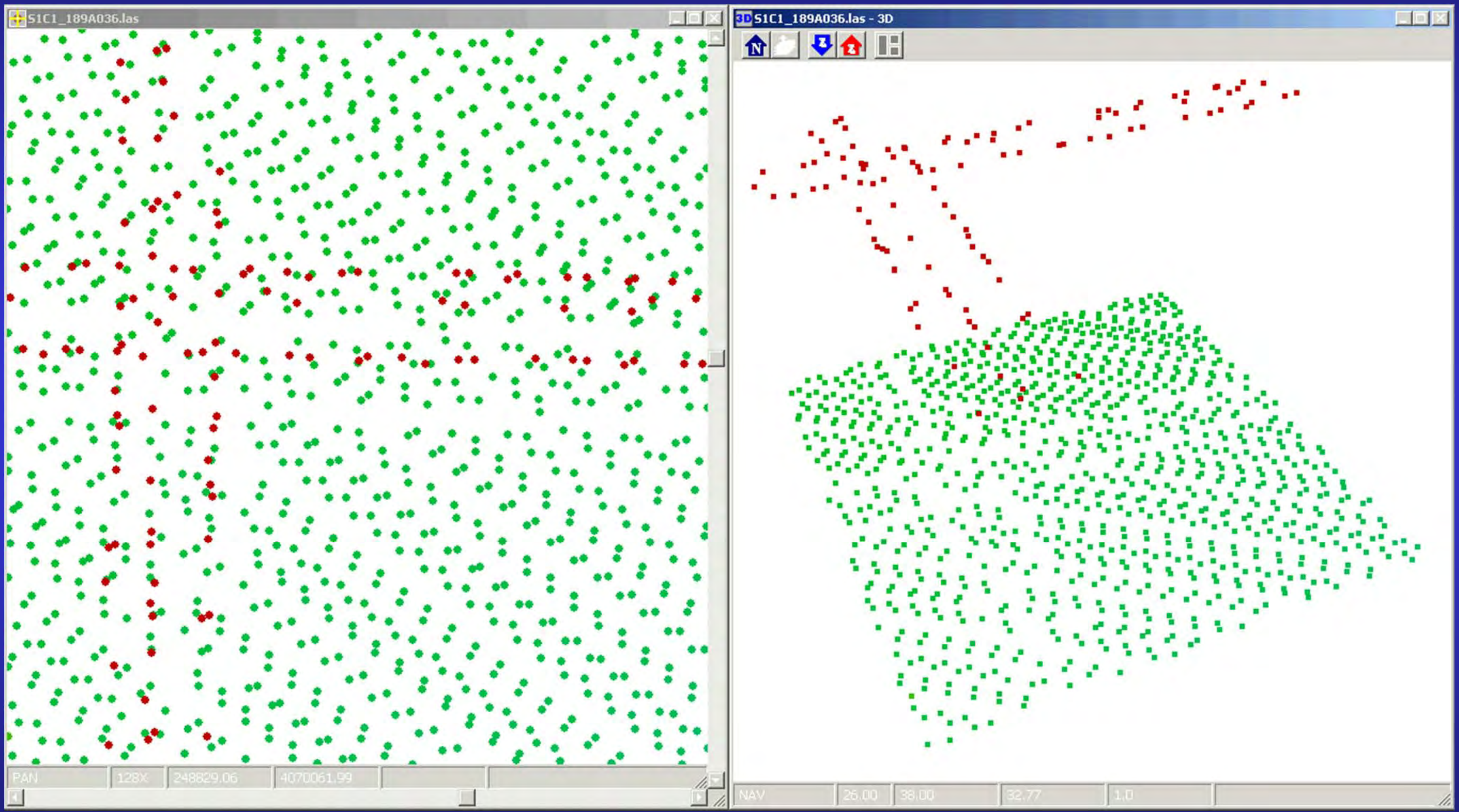
Optech point cloud data, first returns, Fresno, California

First vs. Last Returns



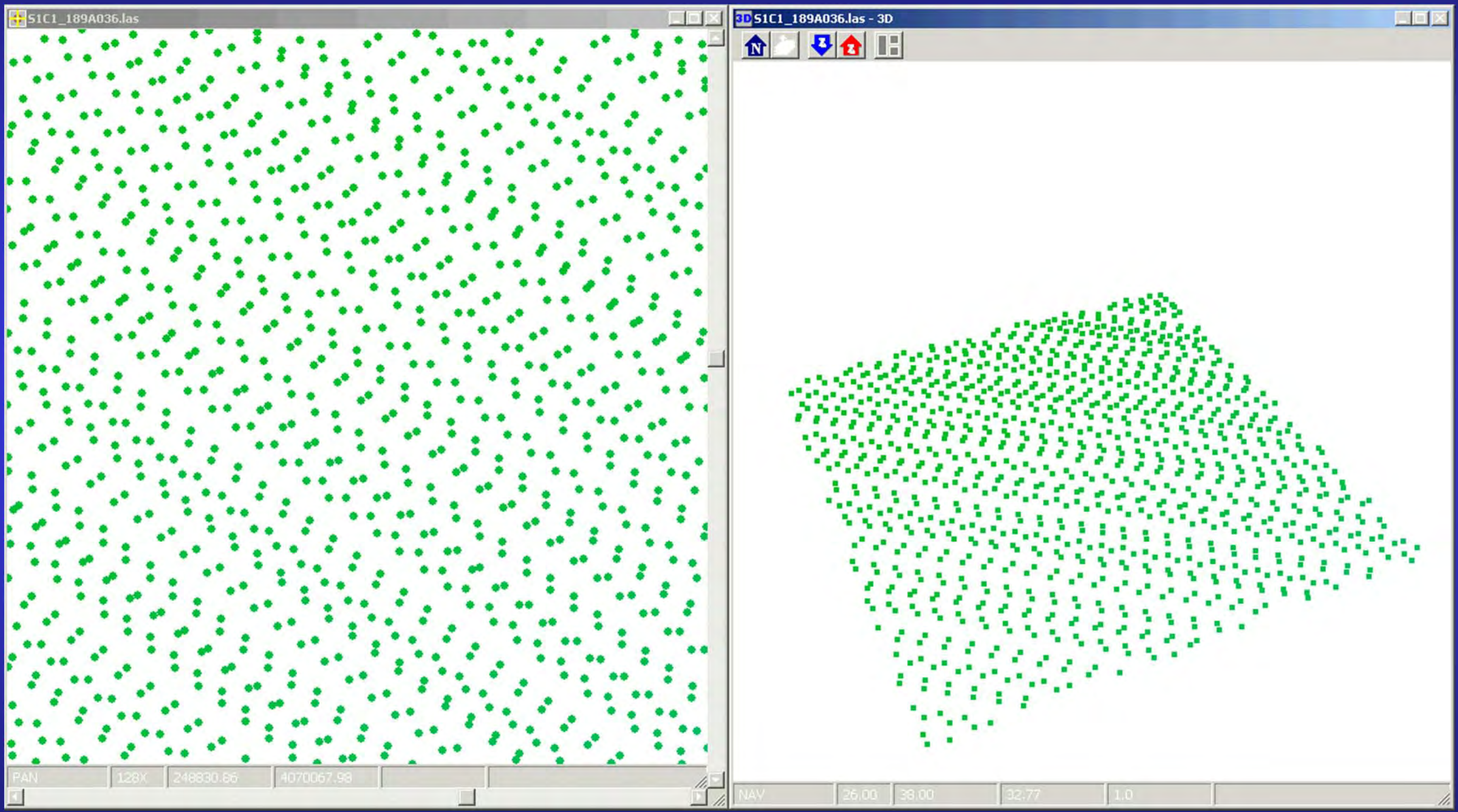
Optech point cloud data, last returns, Fresno, California

First vs. Last Returns



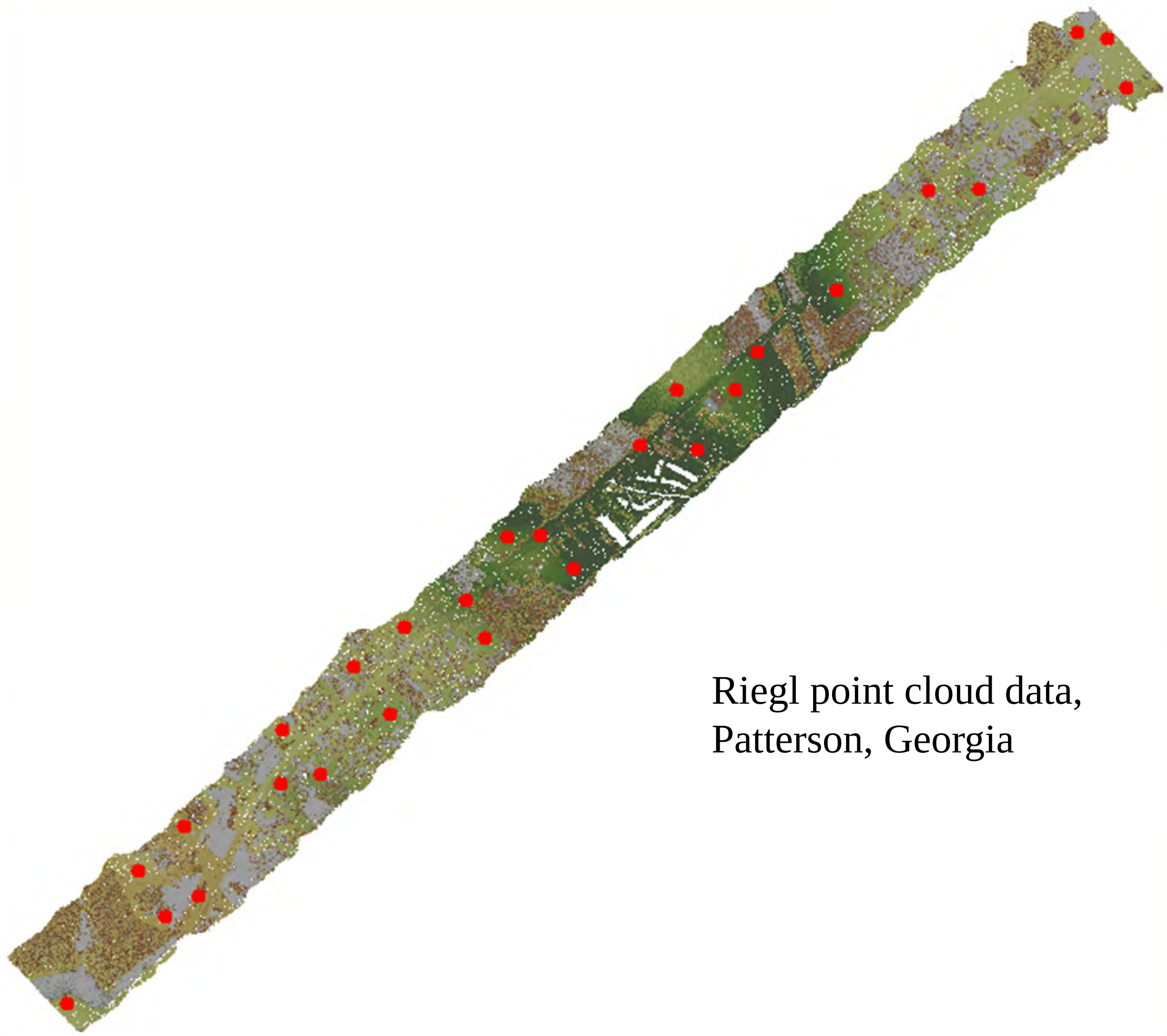
Optech point cloud data, first returns, Fresno, California

First vs. Last Returns



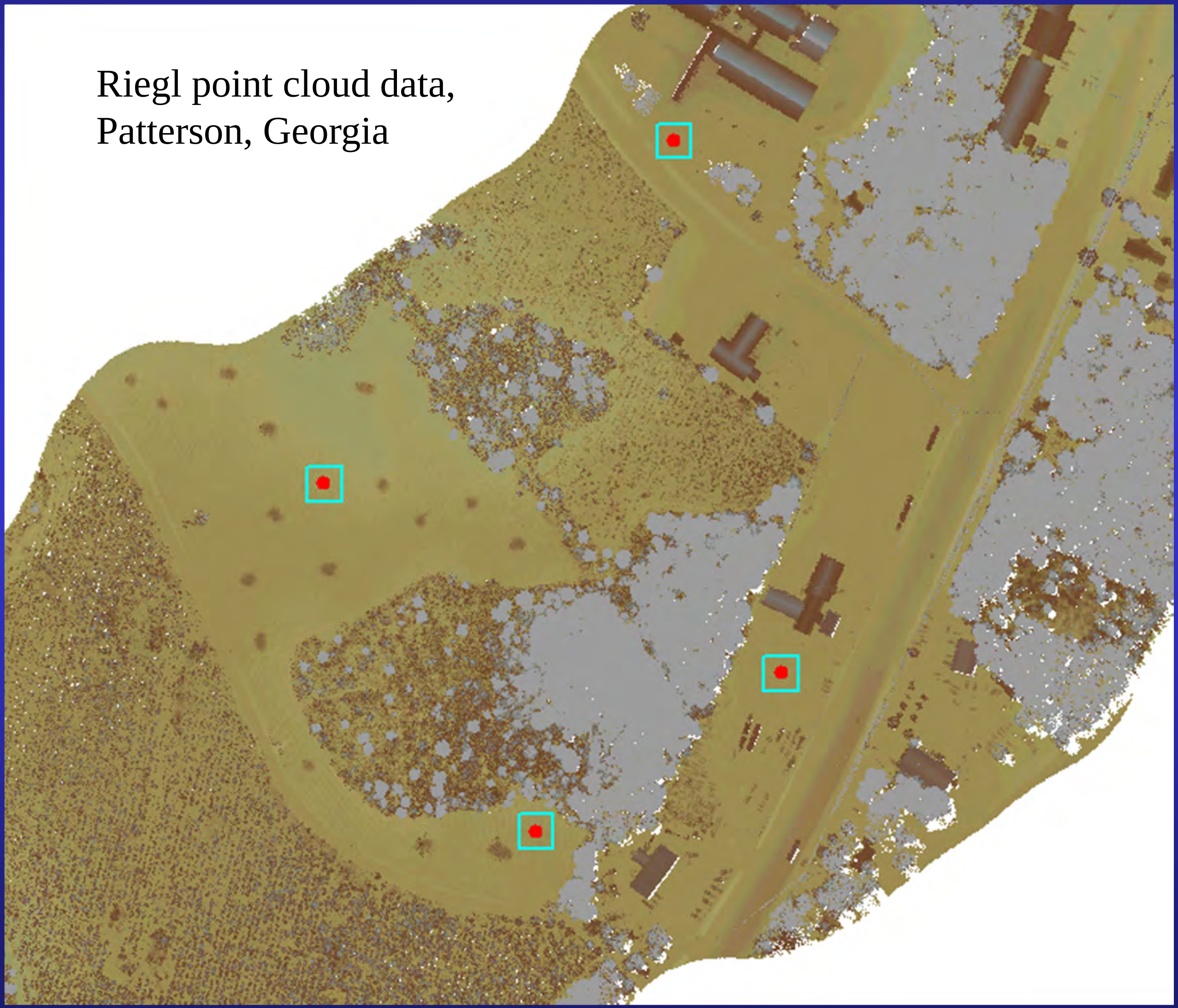
Optech point cloud data, last returns, Fresno, California

Swath Checkpoints



Riegl point cloud data,
Patterson, Georgia

Checkpoint Areas



Keep things simple and use a box for selection of lidar points.

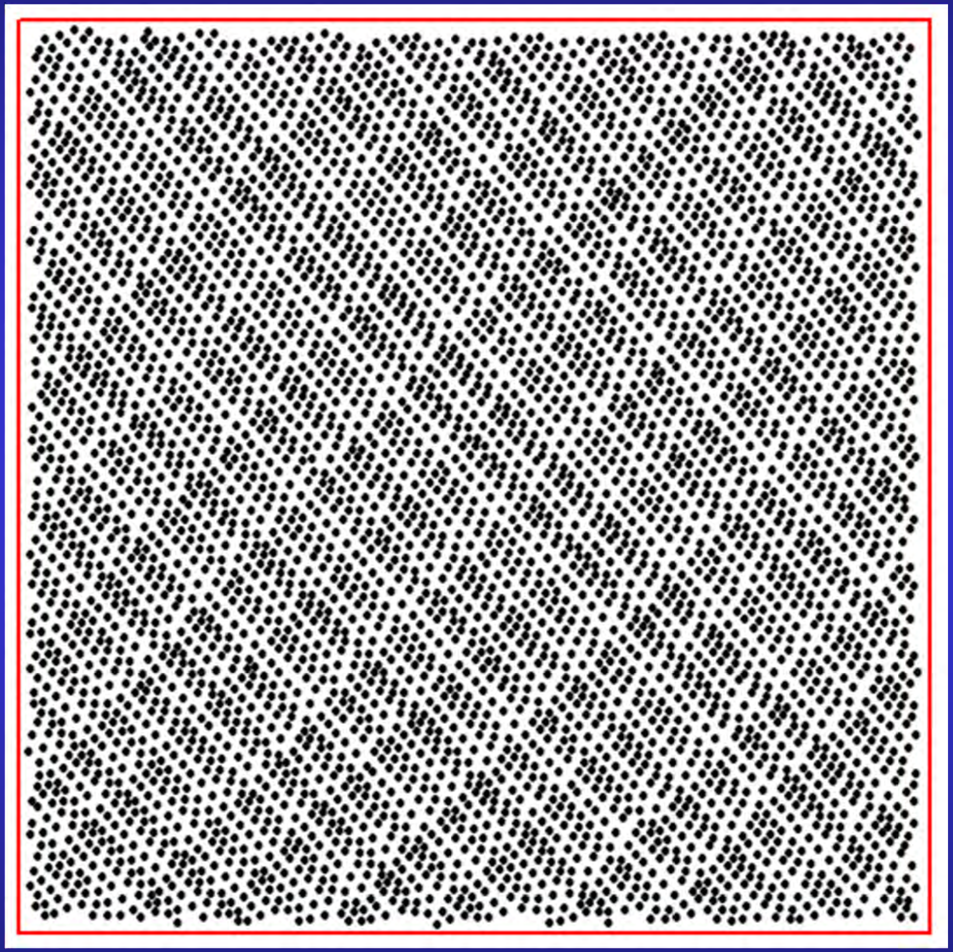
•Fast search

•Small TIN's

•Consistent size

•Uniform land cover category

Reporting



Checkpoint Area: 400.000

5105 points in search box used for statistics

Average Spacing: 0.296

Median Spacing: 0.296

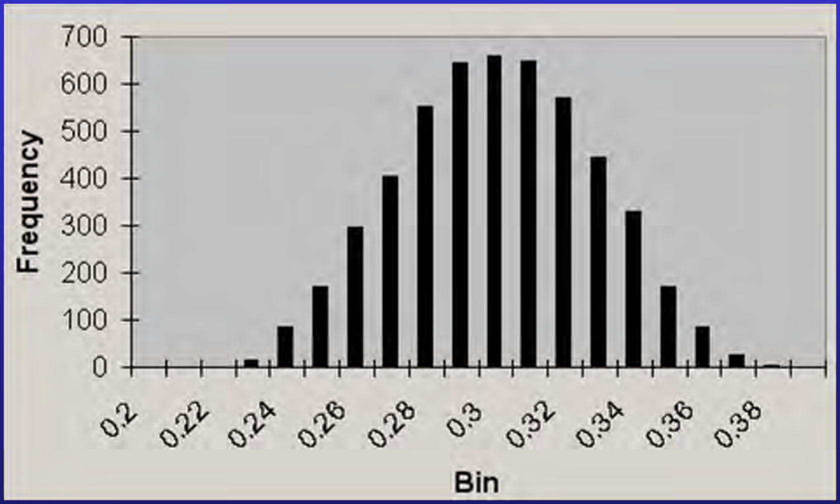
Spacing Standard Deviation: 0.028

Spacing Variance: 0.00079

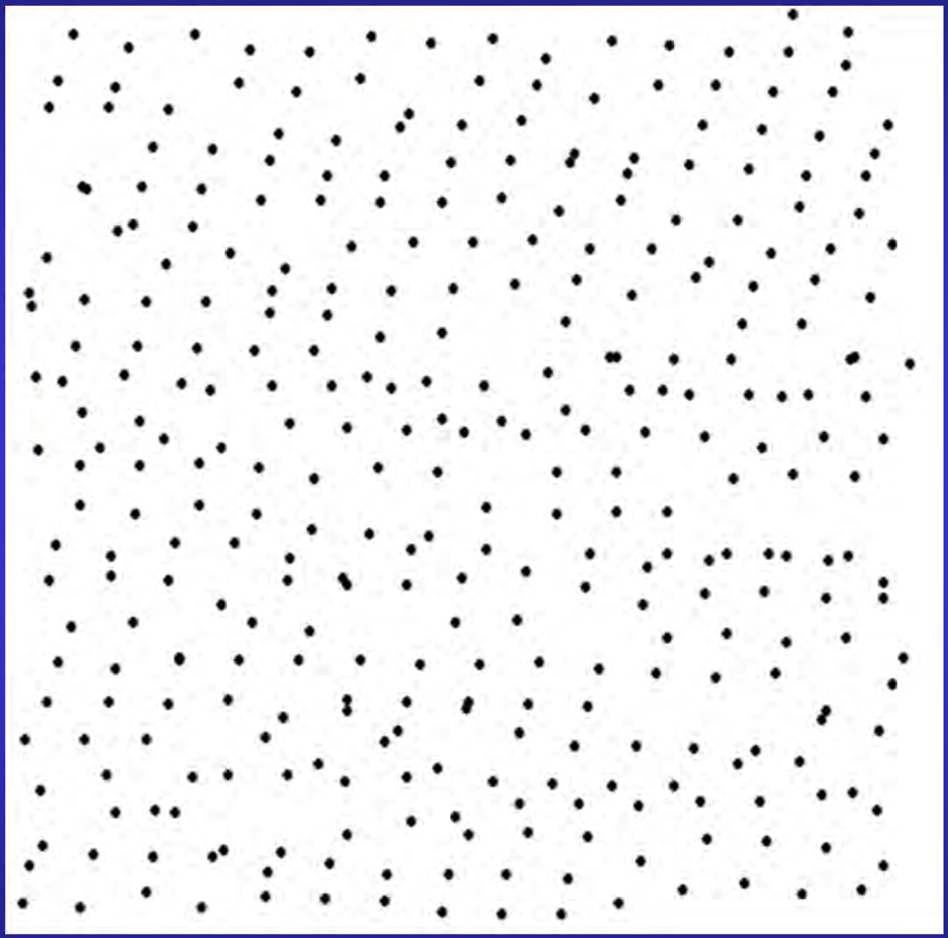
Spacing Skewness: -0.0058

Spacing Kurtosis: -0.5279

Nominal Spacing (95): 0.342



Reporting



Leica point cloud data, last returns, forested land cover category, Hagerstown, Maryland

Checkpoint Area: 400.000

336 points in search box used for statistics

Average Density (pts / unit squared): 1.041

Median Density (pts / unit squared): 1.052

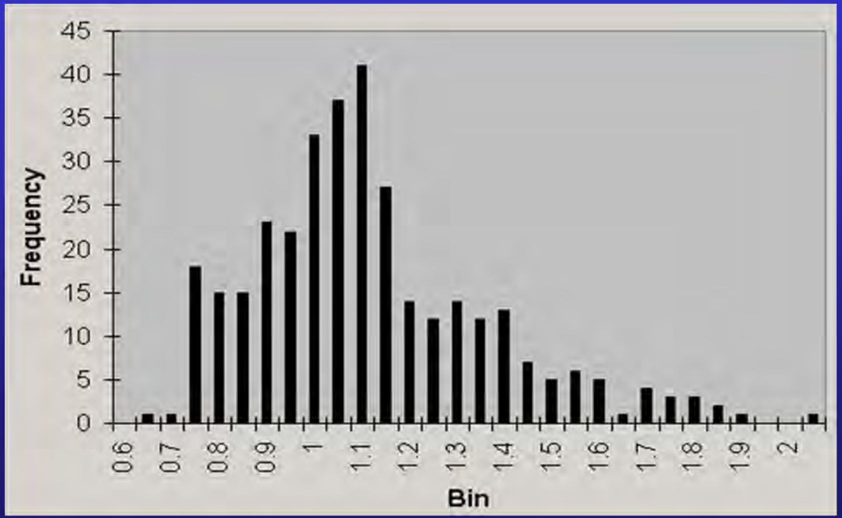
Density Standard Deviation: 0.254

Density Variance: 0.06465

Density Skewness: 1.4432

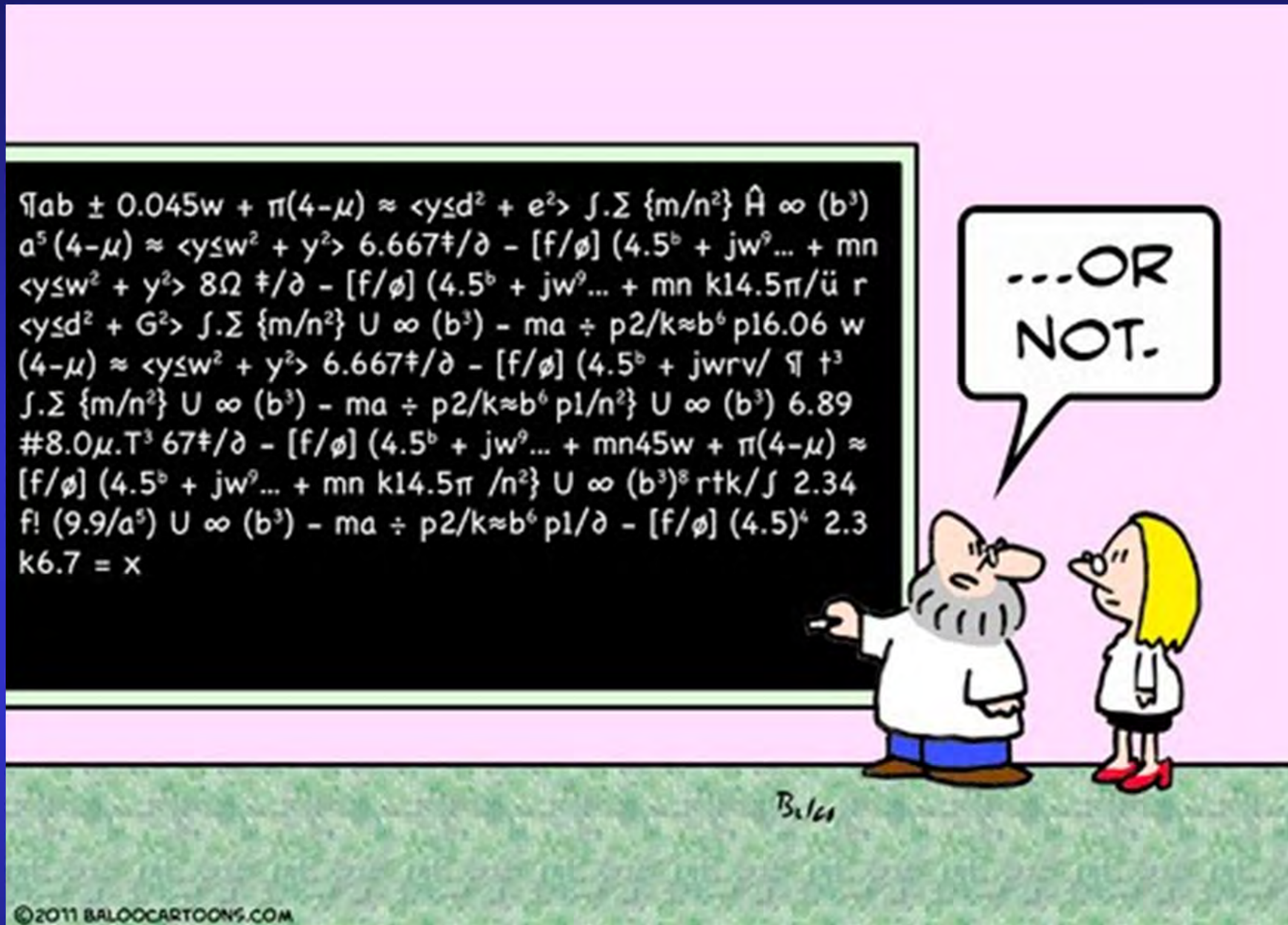
Density Kurtosis: 1.4410

Nominal Density (95): 0.744



Summary and Conclusions

- The LDSS measurement method can be applied to any regular or irregular point distribution
- Defining a nominal value as a specified percentile eliminates ambiguity and provides flexibility
- Qualitative statistics provide additional insight into the character of the distribution in a given area
- Supplement the ASPRS Vertical Accuracy and USGS v13 guidelines
- Simple 3-step process


¶ab ± 0.045w + π(4–μ) ≈ <y≤d² + e²> ∫.Σ {m/n²} Â ∞ (b³)
a⁵ (4–μ) ≈ <y≤w² + y²> 6.667ǂ/∂ – [f/ø] (4.5ᵇ + jw⁹... + mn
<y≤w² + y²> 8Ω ǂ/∂ – [f/ø] (4.5ᵇ + jw⁹... + mn k14.5π/ü r
<y≤d² + G²> ∫.Σ {m/n²} U ∞ (b³) – ma ÷ p2/k≈b⁶ p16.06 w
(4–μ) ≈ <y≤w² + y²> 6.667ǂ/∂ – [f/ø] (4.5ᵇ + jwrv/ ¶ †³
∫.Σ {m/n²} U ∞ (b³) – ma ÷ p2/k≈b⁶ p1/n²} U ∞ (b³) 6.89
#8.0μ.T³ 67ǂ/∂ – [f/ø] (4.5ᵇ + jw⁹... + mn45w + π(4–μ) ≈
[f/ø] (4.5ᵇ + jw⁹... + mn k14.5π /n²} U ∞ (b³)⁸ rtk/∫ 2.34
f! (9.9/a⁵) U ∞ (b³) – ma ÷ p2/k≈b⁶ p1/∂ – [f/ø] (4.5)⁴ 2.3
k6.7 = x
...OR NOT.
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Questions?