INFORMATION VS. POINTS
TOWARDS A BETTER ASSESSMENT OF PRODUCT INFORMATION AND INTERPRETABILITY

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Product Quality Establishes Fitness for an Application

Helps determine if:
- Product captures necessary details
- Product faithfully represents reality

May specifically address:
- Is any data missing?
- Can heritage be traced and verified?
- Is data relevant to time frame of application?
- Do surfaces vary within acceptable tolerances?
- Are features placed accurately?
- Are features resolved acceptably?
- Does data carry sufficient attribution?

Quality is ultimately determined by a product’s ability to be used for a specific purpose.
## Current USGS LBS Quality Levels are a Great Launch Point

<table>
<thead>
<tr>
<th>Quality Level</th>
<th>Aggregate Nominal Pulse Spacing (m)</th>
<th>Aggregate Nominal Pulse Density (pls/m²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QL0</td>
<td>≤ 0.35</td>
<td>≥ 8.0</td>
</tr>
<tr>
<td>QL1</td>
<td>≤ 0.35</td>
<td>≥ 8.0</td>
</tr>
<tr>
<td>QL2</td>
<td>≤ 0.71</td>
<td>≥ 2.0</td>
</tr>
<tr>
<td>QL3</td>
<td>≤ 1.41</td>
<td>≥ 0.5</td>
</tr>
</tbody>
</table>

### Resolution

<table>
<thead>
<tr>
<th>Quality Level</th>
<th>Smooth Surface Repeatability, RMSD₂ (m)</th>
<th>Swath Overlap Difference, RMSD₂ (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QL0</td>
<td>≤ 0.03</td>
<td>≤ 0.04</td>
</tr>
<tr>
<td>QL1</td>
<td>≤ 0.06</td>
<td>≥ 0.08</td>
</tr>
<tr>
<td>QL2</td>
<td>≤ 0.06</td>
<td>≥ 0.08</td>
</tr>
<tr>
<td>QL3</td>
<td>≤ 0.12</td>
<td>≥ 0.16</td>
</tr>
</tbody>
</table>

### Consistency

<table>
<thead>
<tr>
<th>Quality Level</th>
<th>RMSE₂ (non-vegetated) (m)</th>
<th>NVA 95% C.I. (m)</th>
<th>VVA 95% C.I. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>QL0</td>
<td>≤ 0.050</td>
<td>≤ 0.098</td>
<td>≤ 0.150</td>
</tr>
<tr>
<td>QL1</td>
<td>≤ 0.100</td>
<td>≤ 0.196</td>
<td>≤ 0.300</td>
</tr>
<tr>
<td>QL2</td>
<td>≤ 0.100</td>
<td>≤ 0.196</td>
<td>≤ 0.300</td>
</tr>
<tr>
<td>QL3</td>
<td>≤ 0.200</td>
<td>≤ 0.392</td>
<td>≤ 0.600</td>
</tr>
</tbody>
</table>

### Accuracy
Resolution
- No ANPD/ANPS assessment approach beyond coarse grid
- Sample-based
- Based on first returns
- Density and spacing relationship based on square raster assumption
- Regularity assessment is coarse w.r.t. density
- Regularity does not flag over-collection

Consistency
- Cell sizing results in large point counts for high-res data
- Range is not a robust statistic
- Slope-corrected range may be negative
- Inter-swath assessment is pairwise
- Only assessed in vertical

Completeness
- Void criteria is coarse w.r.t. density
- Based on first returns
- No foliage penetration assessment

Accuracy
- Only assessed in vertical
Dimension Reduction for ANPS/ANPD Assessment

General
• Always filter withheld and overage points
• ANPS and ANPD are Horizontal assessments
• Need to reduce data dimension from 3D to 2.5D

Multiple Return per Pulse Systems
• Filter data to only first returns

Aggregate and Synthetic Systems
• Compute mean horizontal distance to nearest-neighbor
• Perform raster-based stratified sampling with cells sized to $1/\sqrt{2}$ mean nearest-neighbor distance
  • Top point per cell – similar to first return
  • Closest to Mass-Point – cluster based sampling
  • Closest to Cell-Center – least jitter
  • Random – most jitter

Terrain Recovery Assessment
• Filter data to only LAS Class 2 (“Ground”) points
ANPS and ANPD Assessment

Two primary methods currently used:

- Coarse grid - vulnerable to sampling variance
- Hit/Miss Raster - vulnerable to aliasing

Proposed alternative: TIN/Voronoi Diagram

- Scale, Rotation, and Translation invariant
- Directly computes area coverage per point
- Set ANPD to 95th Percentile of densities
- TIN is dual to Voronoi Diagram
- TIN edges are used to establish ANPS
Point Density by Voronoi Cells

Cumulative Distribution of Observed Point Densities

Probability Distribution of Observed Point Densities

- Cumulative Probability
- Ideal
- 95th Percentile

Population (%) vs. Point Density (pt/m²)

Probability Density vs. Point Density (pt/m²)

- Probability Density
- Ideal
- 95th Percentile
Ground Classified Point Density by Voronoi Cell

472110
472117
472413
473015
473313

473317
473620
473911
473917
474212
Qualitative Ground Sampling Uniformity Assessment

Approach:

- Filter data to only non-withheld LAS Class 2 (“Ground”) points.
- Create a 2D rectangular raster over each tile with $2\sqrt{2}\times$ ANPS sampling in Easting and Northing.
- Compute density vs. ANPD in each raster cell (Num Points/(Cell Area*ANPD)).

- Colorize the raster using a heat map gradient (mnemonic – Cool is “Sparse”, Hot is “Dense”):
  - Extremely Oversampled: $2.0 \times$ Target NPD
  - Oversampled: $1.5 \times$ Target NPD
  - Objective: $1.0 \times$ Target NPD
  - Median: $0.5 \times$ Target NPD
  - Threshold: $0.2 \times$ Target NPD

- Any cell below Threshold is considered void (black + transparent).
Qualitative Sampling Uniformity Comparison

**Ground Density Heat Map:**
- Black: 0 pt/m²
- Yellow: ≥ 60.0 pt/m²

**Data Set A**
- 473317
- 472117
- 473917
- 473015

**Data Set B**
- 473317
- 472117
- 473917
- 473313
Qualitative FOPEN/Terrain Recovery Assessment

Approach:
- Filter data to only non-withheld LAS Class 2 ("Ground") points.
- Create a 2D rectangular raster over each tile with $2\sqrt{2}$x ANPS sampling in Easting and Northing.
- Compute average density in each raster cell (Num Points/Cell Area).

Colorize the raster using a stoplight gradient (mnemonic – Green is "Good", Red is "Bad"):  
- Objective Performance: 100.0% × Unobscured ANPD
- Median Performance: 62.5% × Unobscured ANPD
- Threshold Performance: 25.0% × Unobscured ANPD

- Any cell below Threshold Performance is considered void (black + transparent).
Qualitative FOPEN Comparison

Ground Density Stoplight:
Red: \( \leq 6.0 \text{ pt/m}^2 \)
Green: \( \geq 24.0 \text{ pt/m}^2 \)

Data Set A
473317 472117 473917 473015 473313

Data Set B
473317 472117 473917 473015 473313
Resolution Should be a Concern for High-Res Products

- Sampling can only limit achievable product resolution.
- The maximum product resolution is 2x the ANPS
  - Assumes that sensor resolution is finer than product sampling
  - Assumes that product is uniformly sampled
- Resolution depends on several other factors:
  - LASER Beam Divergence
  - Sensor Optics
  - Diffraction
  - Look Angle
  - Atmosphere

Sampling beyond supported resolution does not improve quality, just data volume.
Resolution is a Key Factor for Establishing Interpretability

- Resolution is a key factor influencing interpretability
- Several criteria exist to relate resolution to fitness (e.g., NIIRS and Johnson Criteria)
- Johnson criteria establishes a 50% confidence interval for success.

Example:
- What does 8 pt/m² data support?

<table>
<thead>
<tr>
<th>Discrimination Level</th>
<th>Cycles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection</td>
<td>1.0 ±0.25</td>
</tr>
<tr>
<td>Orientation</td>
<td>1.4 ±0.35</td>
</tr>
<tr>
<td>Recognition</td>
<td>4.0 ±0.80</td>
</tr>
<tr>
<td>Identification</td>
<td>6.4 ±1.50</td>
</tr>
</tbody>
</table>

Summary of Johnson Criteria

<table>
<thead>
<tr>
<th>Discrimination Level</th>
<th>Object Dimension (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Detection</td>
<td>0.46–0.96</td>
</tr>
<tr>
<td>Orientation</td>
<td>0.64–1.34</td>
</tr>
<tr>
<td>Recognition</td>
<td>2.03–3.63</td>
</tr>
<tr>
<td>Identification</td>
<td>3.03–6.03</td>
</tr>
</tbody>
</table>

Johnson Criteria Applied to 8pt/m² Product
Data is Valuable Because of the Information it Provides

Data Measurements:
- Unorganized
- Meaningless

Information
- Organized
- Classified
- Attributed
- Contextualized

Knowledge
- Analyzed
- Synthesized
- Understood

Wisdom
- Applying
- Leveraging

We need to continue evolving quality criteria to convey information content and interpretability.
QUESTIONS
Revise Consistency Assessments

**Intra- and Inter-swath Assessments**
- Update cell sizing to target consistent cell population regardless of QL:
  \[ \text{Cellsize} = \sqrt{\frac{N}{ANPD}} \]

**Intraswath Assessment**
- Establish best-fit plane for each cell in AOI
- Compute point-to-plane distances for each point in the cell
- Report deviation of distances summarized for AOI
- Optional: Generate qualitative mask from per-cell deviations

**Interswath Assessment – Traditional Product**
- Identify how representative cell value is computed
- Modify raster differences to deviations
- Report mean deviation summarized for AOI
- Optional: Generate qualitative mask from per-cell deviations

**Interswath Assessment – Aggregate Product**
- Identify swaths contributing to point estimates
- Compute deviation of look centroids for each point
- Report mean deviation for points identifying as “Only” returns
- Optional: Generate qualitative mask from per-cell deviations