LiDAR Technology and Applications

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Presentation Outline

- Introduction to LiDAR
- QA/QC of LiDAR data
- Differences in LiDAR projects
- Things to know that are not often discussed
- Topo vs. Bathy
- Software applications
- Uses of the data
- Summary
- Questions

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INTRODUCTION TO LIDAR

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Introduction to LiDAR

- Generate an accurate 3D model of the earth's surface
- Use an infrared laser and scanning mirror in measurement
- Sensors have the ability to measure multiple returns from each pulse
- Also measure the intensity of each of the returns

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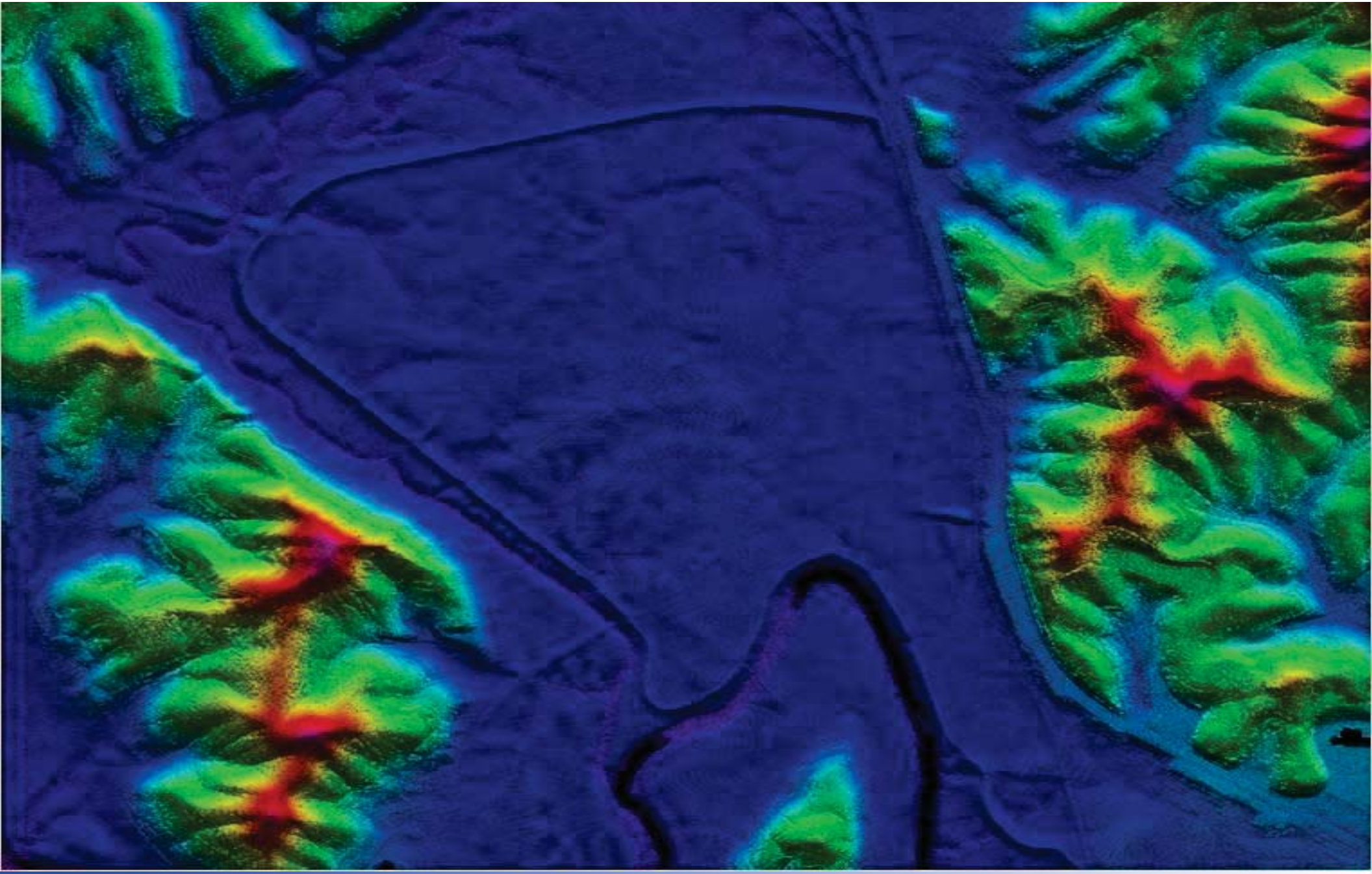

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Introduction to LiDAR

- Time of flight of the laser provides an accurate distance to the ground
- Airborne GPS provides the 3D position (XYZ)
- Inertial Navigation Systems (INS) provides the 3D rotation of the sensor (omega, phi, kappa)
- A galvanometer provides the swing angle of the scanning mirror
- Must solve for 8 variables for each laser return

Introduction to LiDAR

- Laser rates in sensors today are generally in the 150 kHz to 200 kHz range
- Many sensors can work in the mode of discrete returns (typically 1st, 2nd, 3rd, and last) or full waveform technology
- High end systems are made by Leica, Optech, and Riegl
- Sensor costs are typically more than $1M

Introduction to LiDAR

- LiDAR is an active sensor, generating infrared light and can be flown day or night
- LiDAR is not an all weather sensor; it cannot be flown above clouds and should not be flown with standing water on the ground
- LiDAR can pass through gaps in some vegetation so generally better results will be gained during “leaf off” conditions for deciduous vegetation

Introduction to LiDAR

- Automated routines used to help classify the returns (e.g., removing artifacts, vegetation, structures, vehicles, etc.)
- These routines are typically 90 to 95% efficient
- Manual editing is necessary to produce a quality LiDAR product

Introduction to LiDAR

- Deliverables include
  - Classified data in a LAS format
  - metadata
- Projects may include
  - Breakline collection
  - DEMs
  - Intensity images
  - Accuracy analysis
  - Hydro enforcement (flattening of water/downward flow of streams)

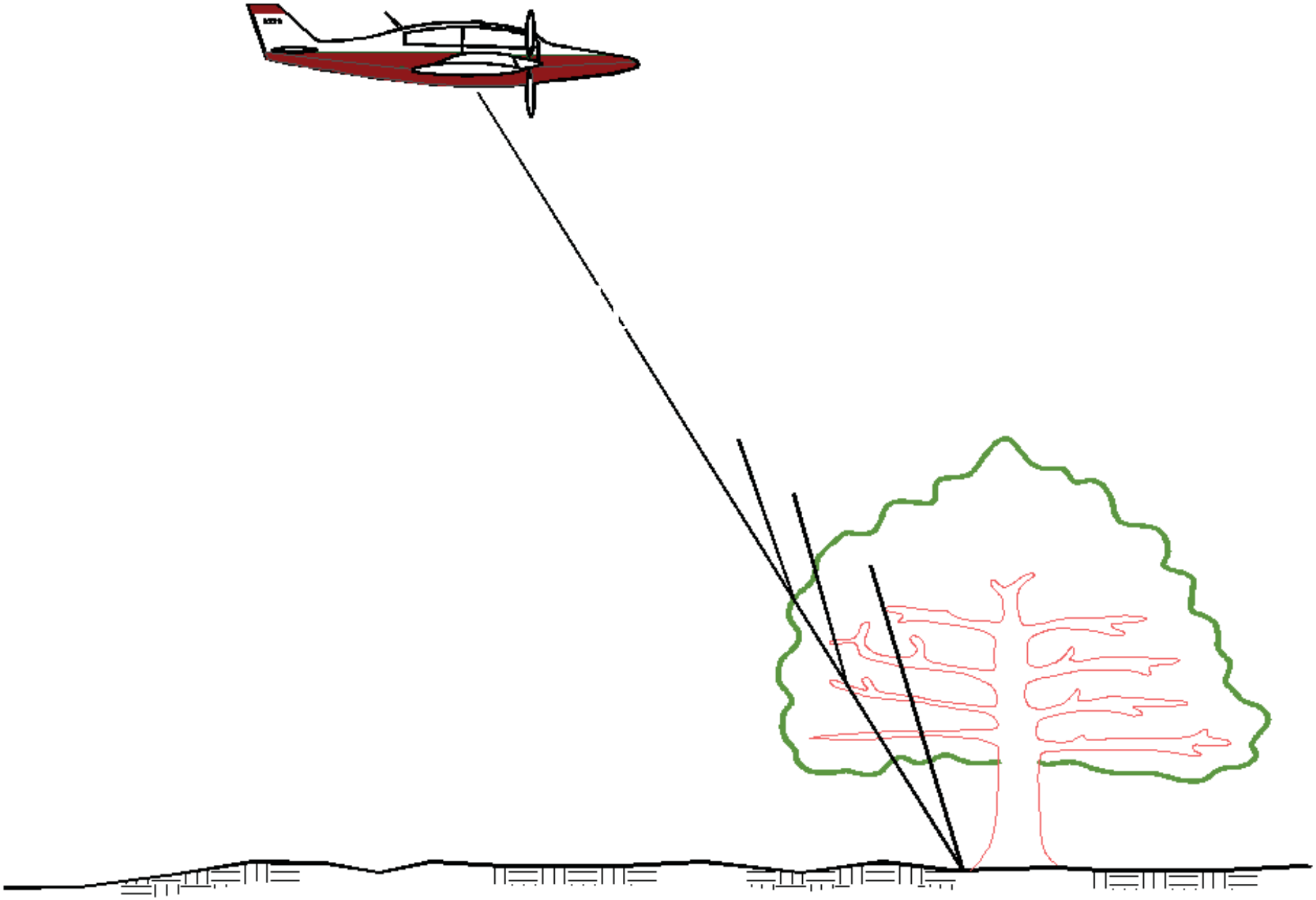
Some Definition of Terms

- Nominal Post Spacing (NPS)
  - Average distance between adjacent LiDAR points (ft or m)
- Point Density
  - Number of LiDAR points per unit area (points per square meter)
- Root Mean Square Error (RMSE)
  - Statistical value equal to the square root of the average of the squares of the differences between known points and modeled points in the LiDAR surface
- Accuracy
  - 95% confidence interval of the data (vertical = RMSE x 1.96)

Introduction to Lidar

	Fixed Wing	Rotary Wing	Mobile Mapping
Acquisition Heights	3,000-8,000’ AMT	300-800’ AMT	Ground based
Acquisition Speeds	90-200 knots	20-50 knots	10-60 mph
Vertical Accuracy	9-25 cm	3-15 cm	2-10 cm
Horizontal Accuracy	0.5-1.0 m	10-50 cm	3-10 cm
Point Density	0.5-8 ppsm	20-80 ppsm	1,000-8,000 ppsm

NOTE: All accuracies expressed as RMSE



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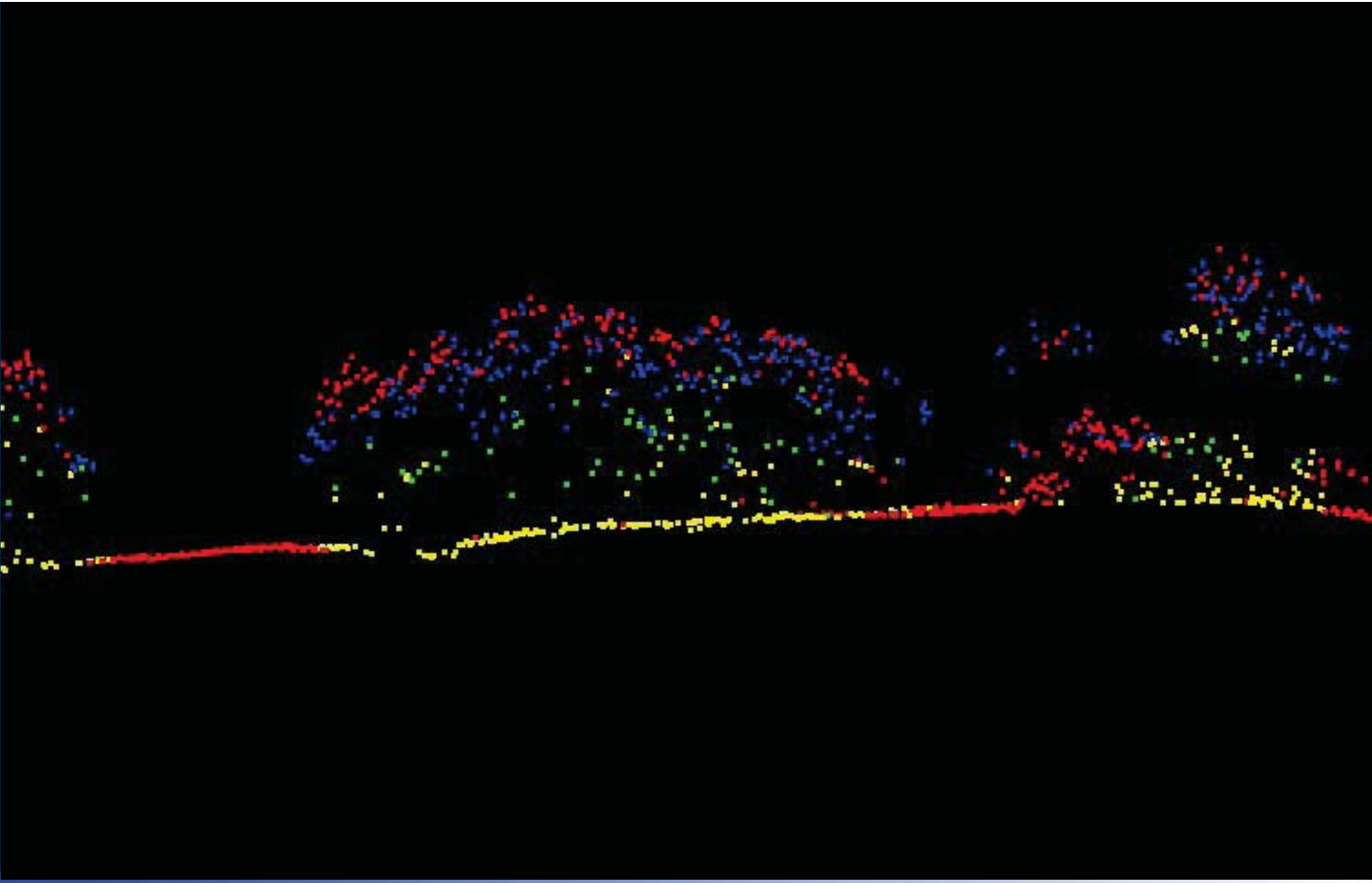

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Cincinnati Airport – Photo

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Cincinnati Airport – Intensity

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QA/QC

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QA/QC of LiDAR Data

- Quantitative
  - Vertical accuracy
  - Horizontal accuracy
  - Clustering of points
  - Nominal posting
- Qualitative
  - Quality of the elevation surface (look and feel)
  - Removal of artifacts, etc.

Vertical Accuracy

- Relatively easy to assess, often required
- Normally look at various types of land cover… bare earth, urban, forest, brush, high grasses
- Typically find a location with no abrupt changes in the ground surface (within 3 to 5 meters)
- Determine precise 3D location with field techniques… then determine elevation from the LiDAR surface at that XY, subtract, and statistically summarize
- Control at least 3x better than required accuracy

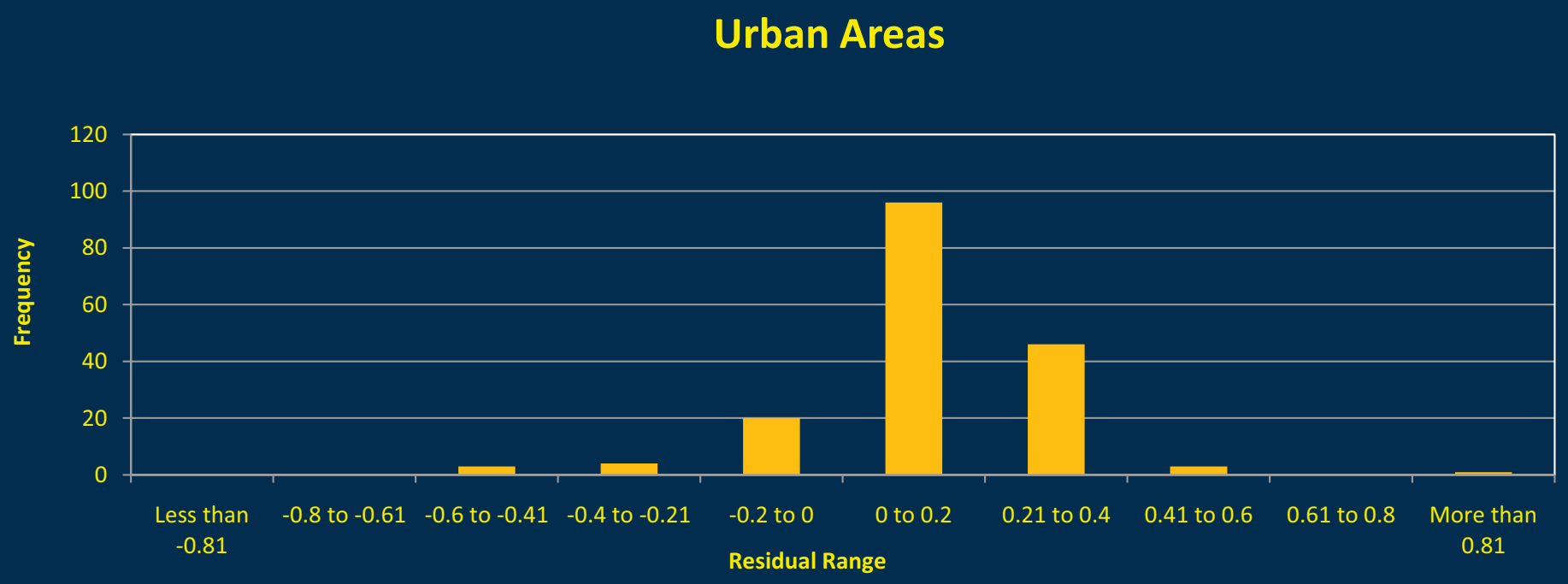
Vertical Accuracy

- Fundamental, Supplemental, and Consolidated Accuracies
  - Fundamental – the accuracy in open terrain
  - Supplemental – the accuracy in other areas
  - Consolidated – the accuracy in all areas combined

LiDAR Accuracy

Orange County – 204 Square Mile LiDAR Set

Ave: 0.13’ Min: -0.57’ Max: 0.90’ RMSE: 0.21’ Shots: 180



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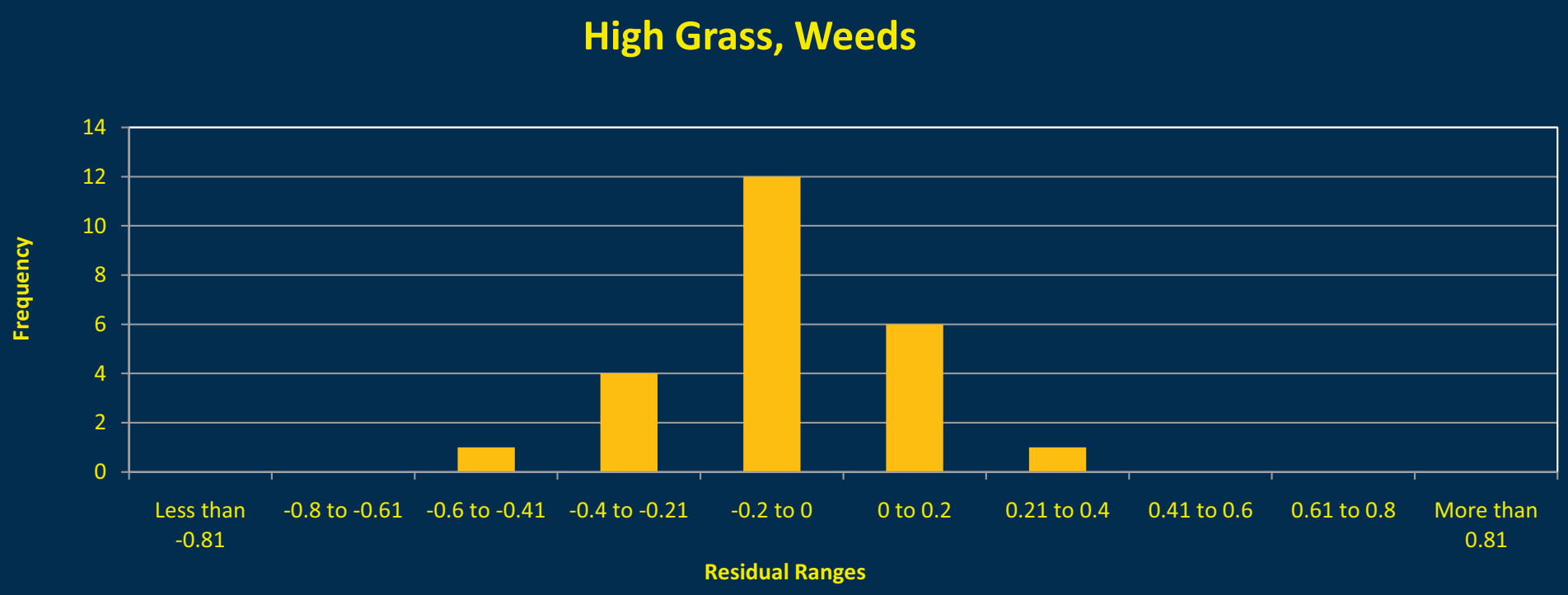
LiDAR Accuracy

Orange County – 204 Square Mile LiDAR Set

Ave: -0.07’ Min: -0.43’ Max: 0.21’ RMSE: 0.17’ Shots: 26



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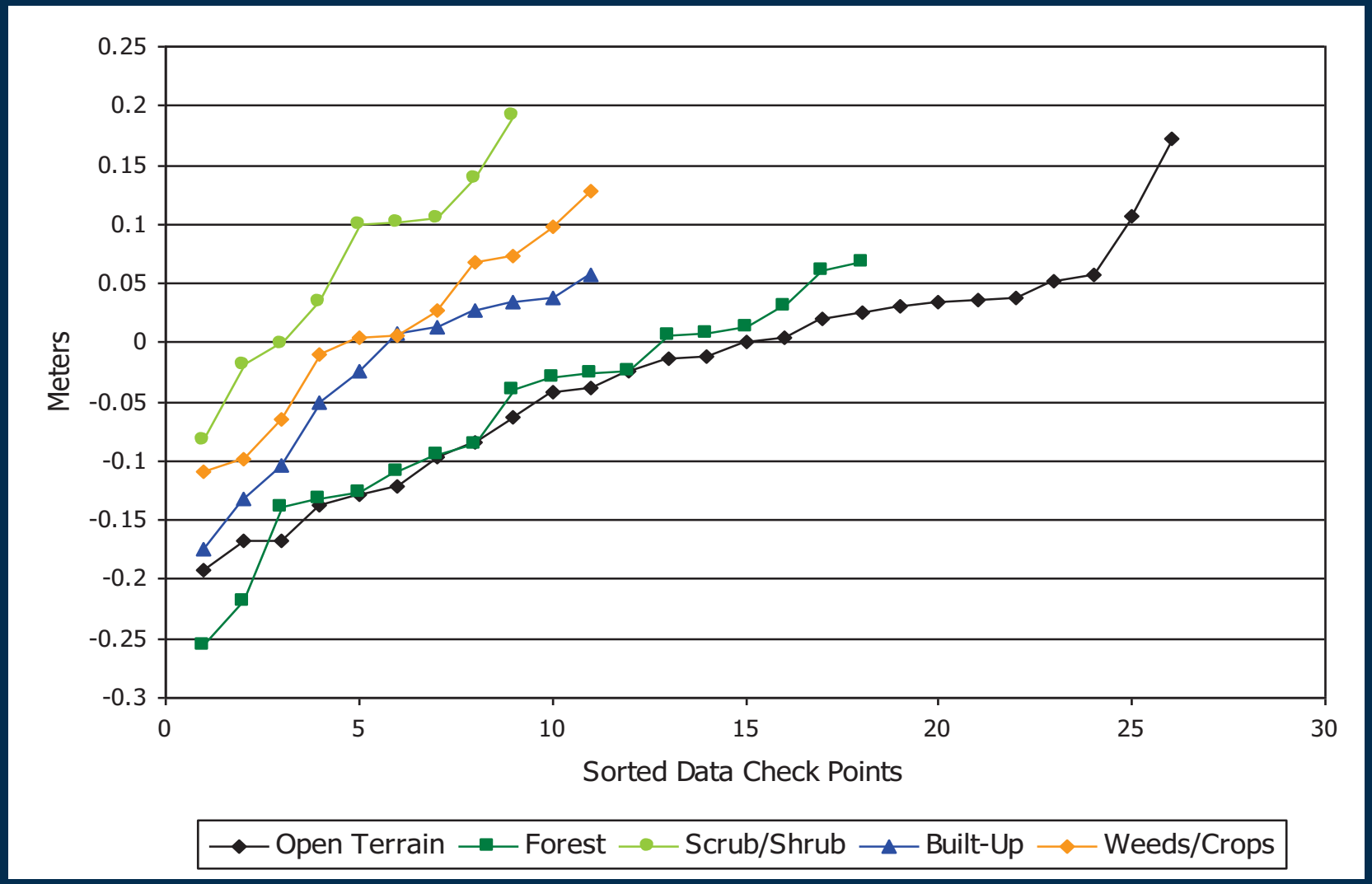
Impact of Cover on Accuracy



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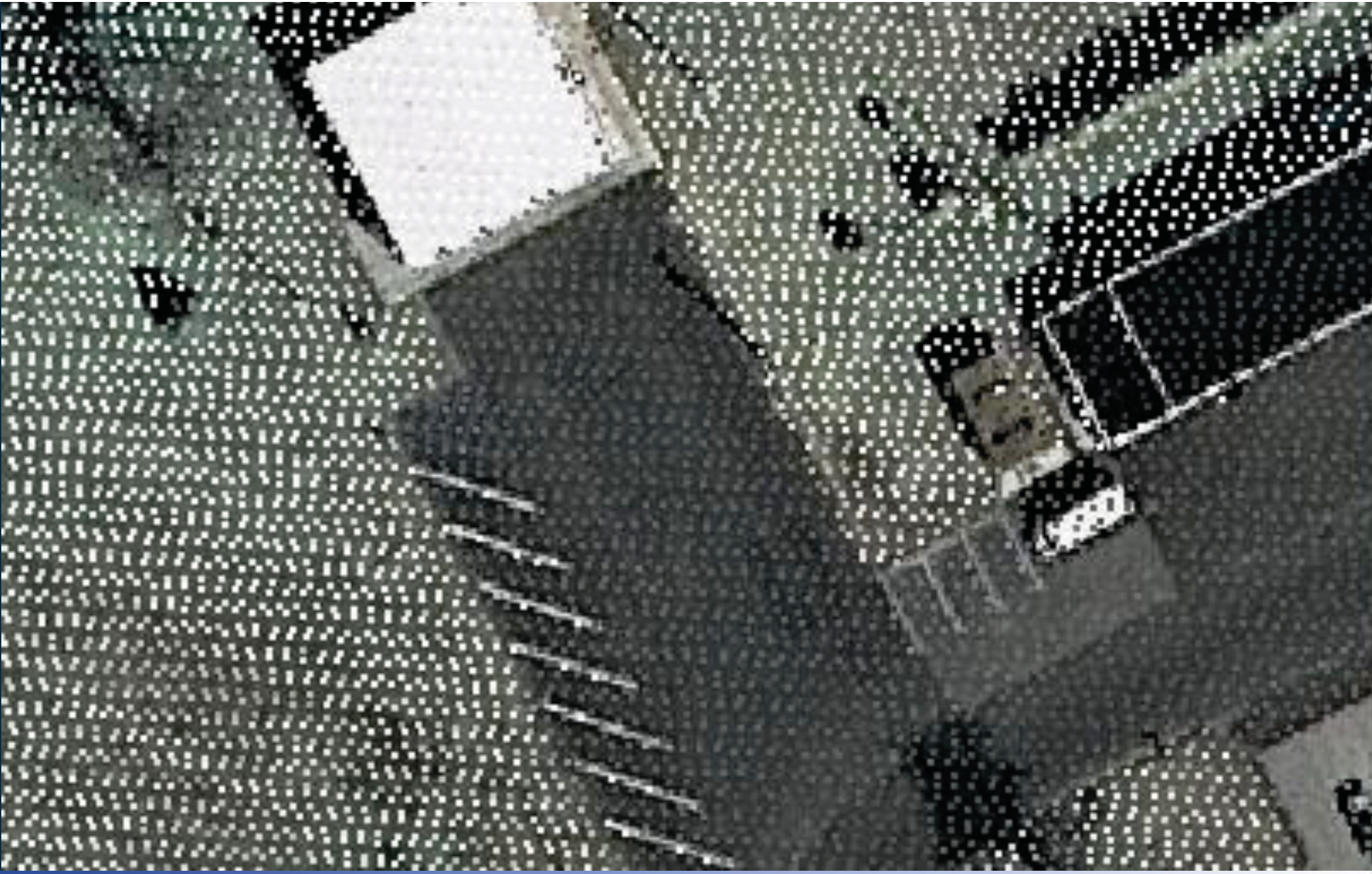
Horizontal Accuracy

- More difficult to assess, not often required
- Possible to find identifiable objects in the intensity images… paint stripes, concrete-asphalt edges, etc.
- Building corners can be very useful; best to use multiple points on the building and intersect planes to determine the correct XY location



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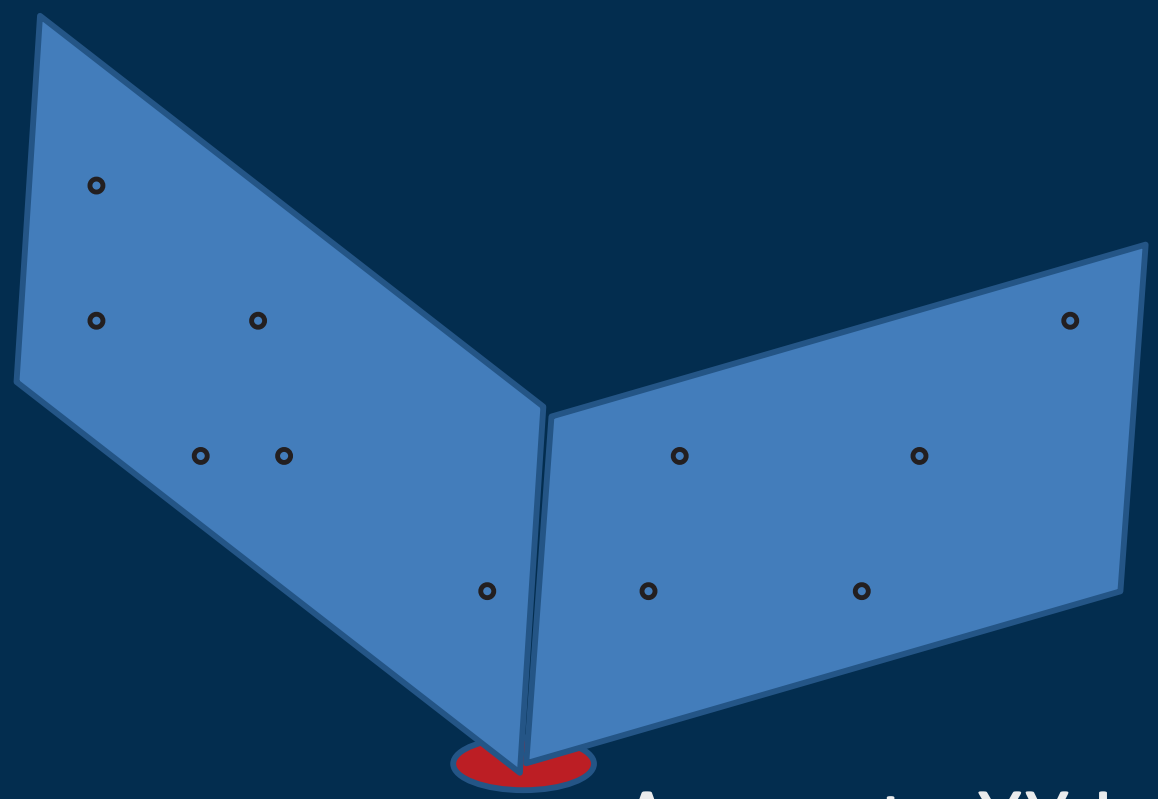
Building Corners



Accurate XY Location

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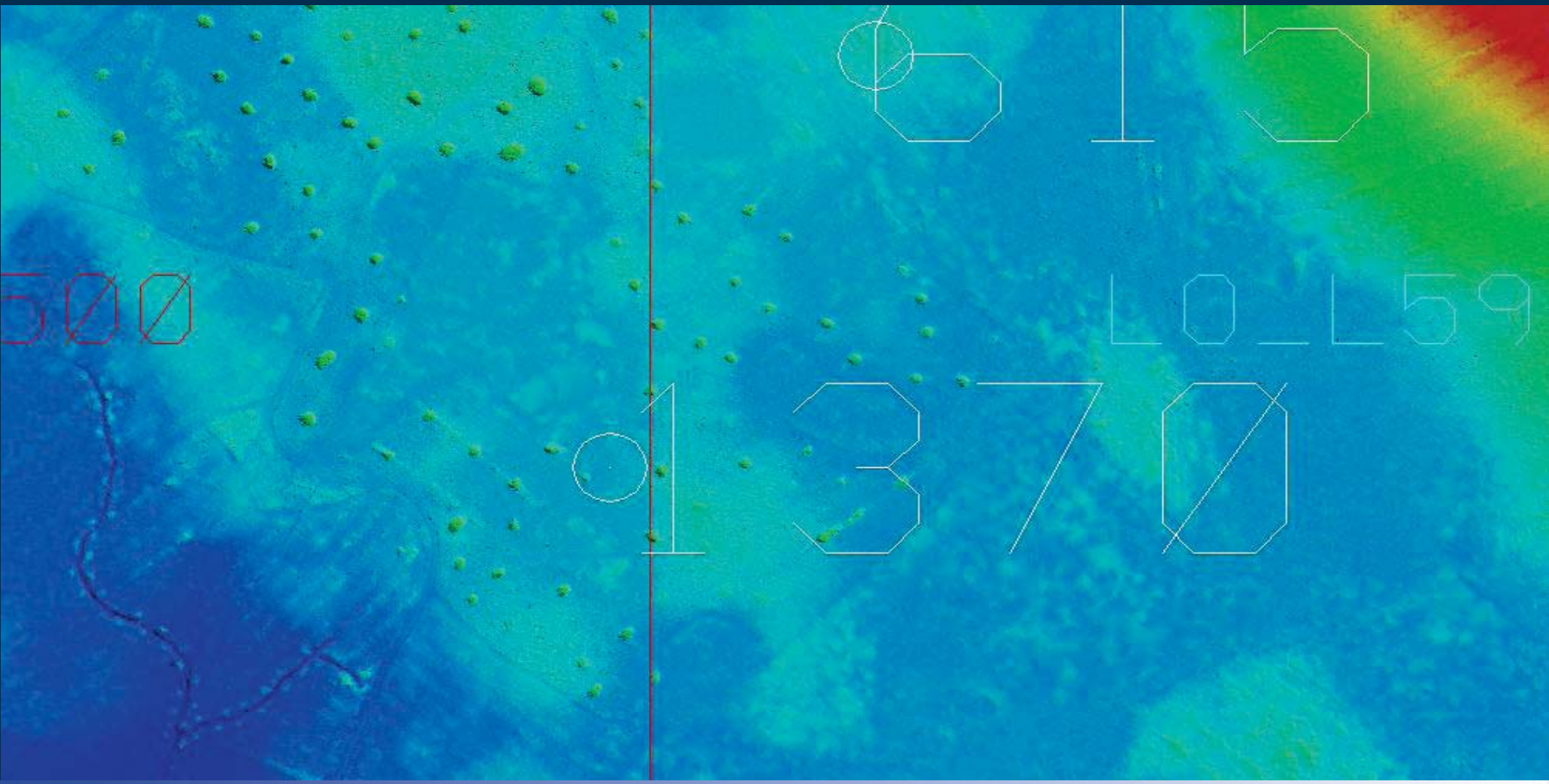
Qualitative Review of the Data



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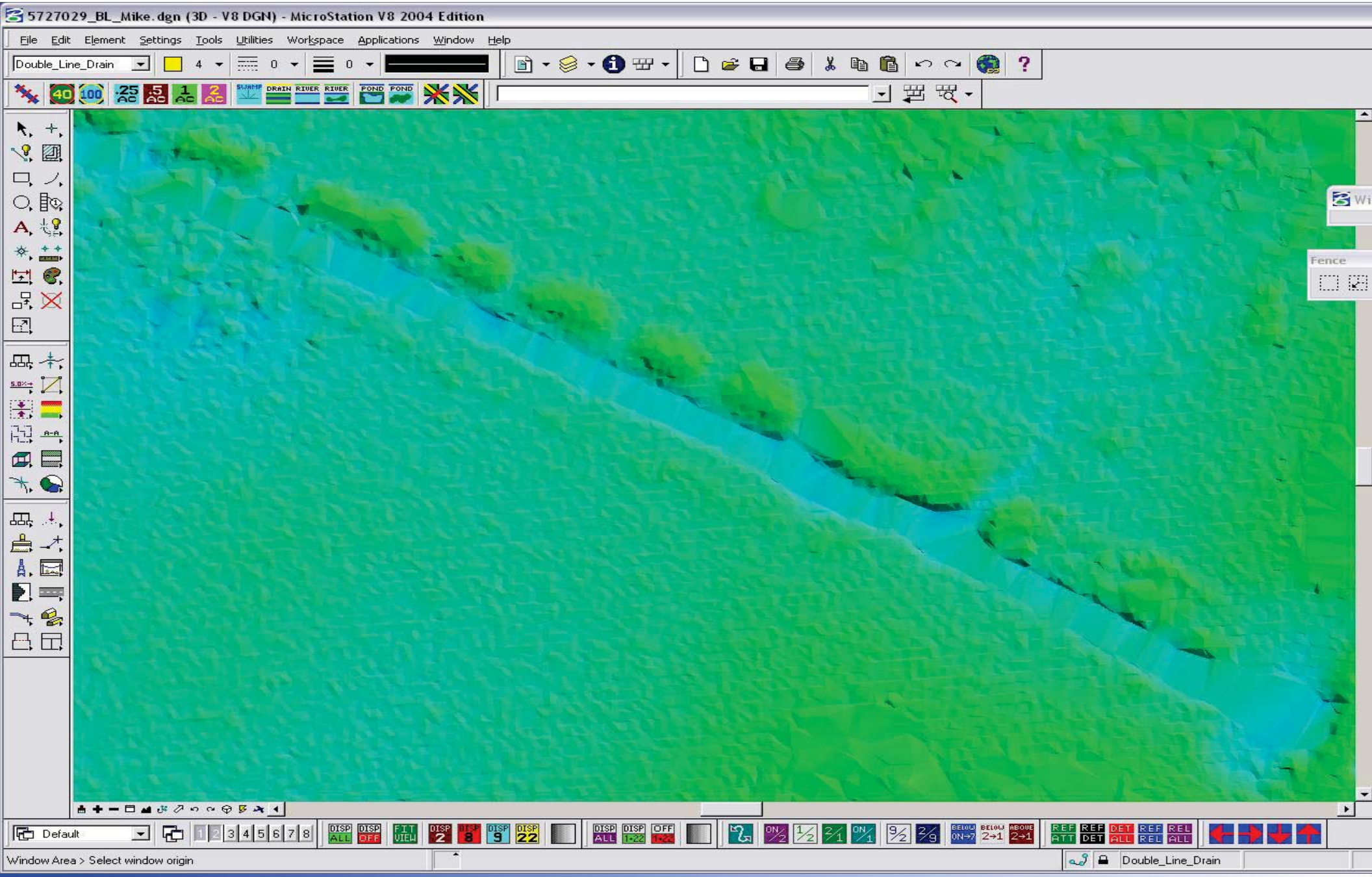

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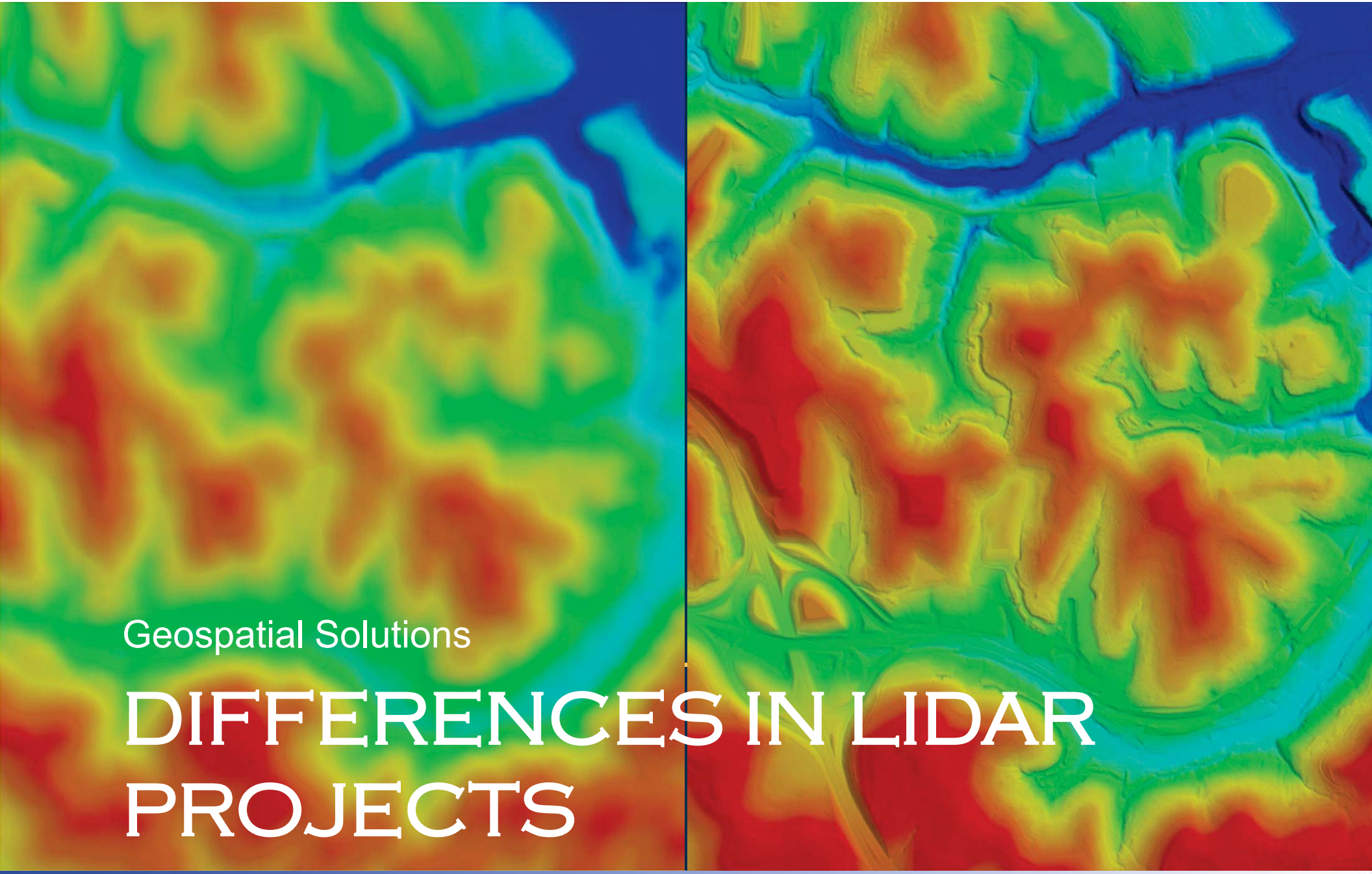

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DIFFERENCES IN LIDAR PROJECTS

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Differences & Price Variations

- Project approach and other factors can have a significant impact on project costs
- Well written, complete specifications are critically important to ensure that you get what you want
- USGS V13 specifications are a very good place to start…

Differences in Approach

- Point density, vertical accuracy, point classification, deliverables are quite often very clear in the specifications
- *Flying height, GPS considerations (maximum PDOP), field of view, maximum baseline length, cleanliness of data, health of the LiDAR sensor, system calibration, other steps taken to ensure quality data are not always readily apparent*

Differences in Approach

- Flying height and field of view can have significant effects on vegetation penetration and data quality
- USGS V13: 34˚ preferred, 40˚ maximum

- 5,000' AMT & 34˚ Swath of 3,057 feet
- 5,500' AMT & 40˚ Swath of 4,005 feet
- *Increase of 31%*

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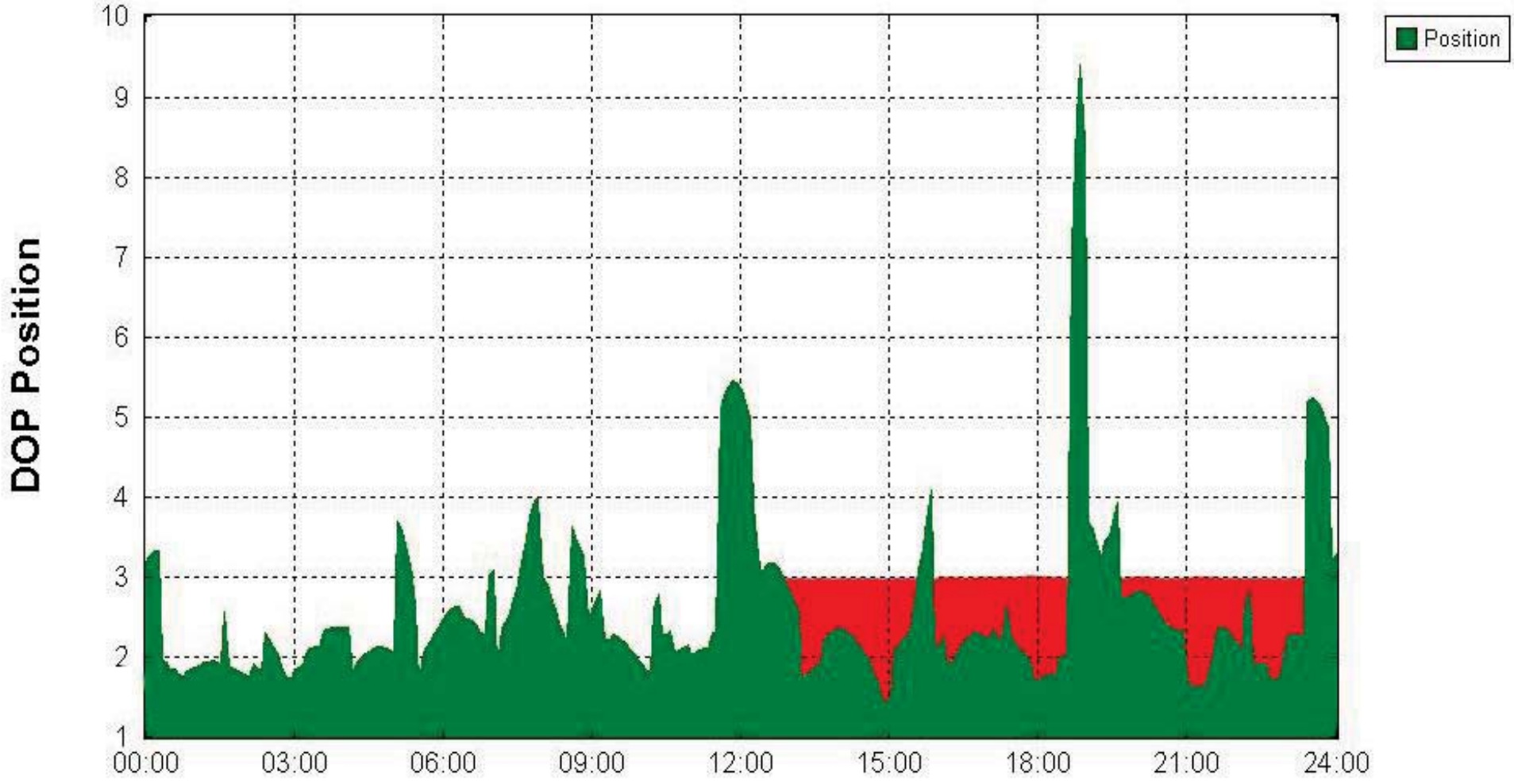
DOP Position



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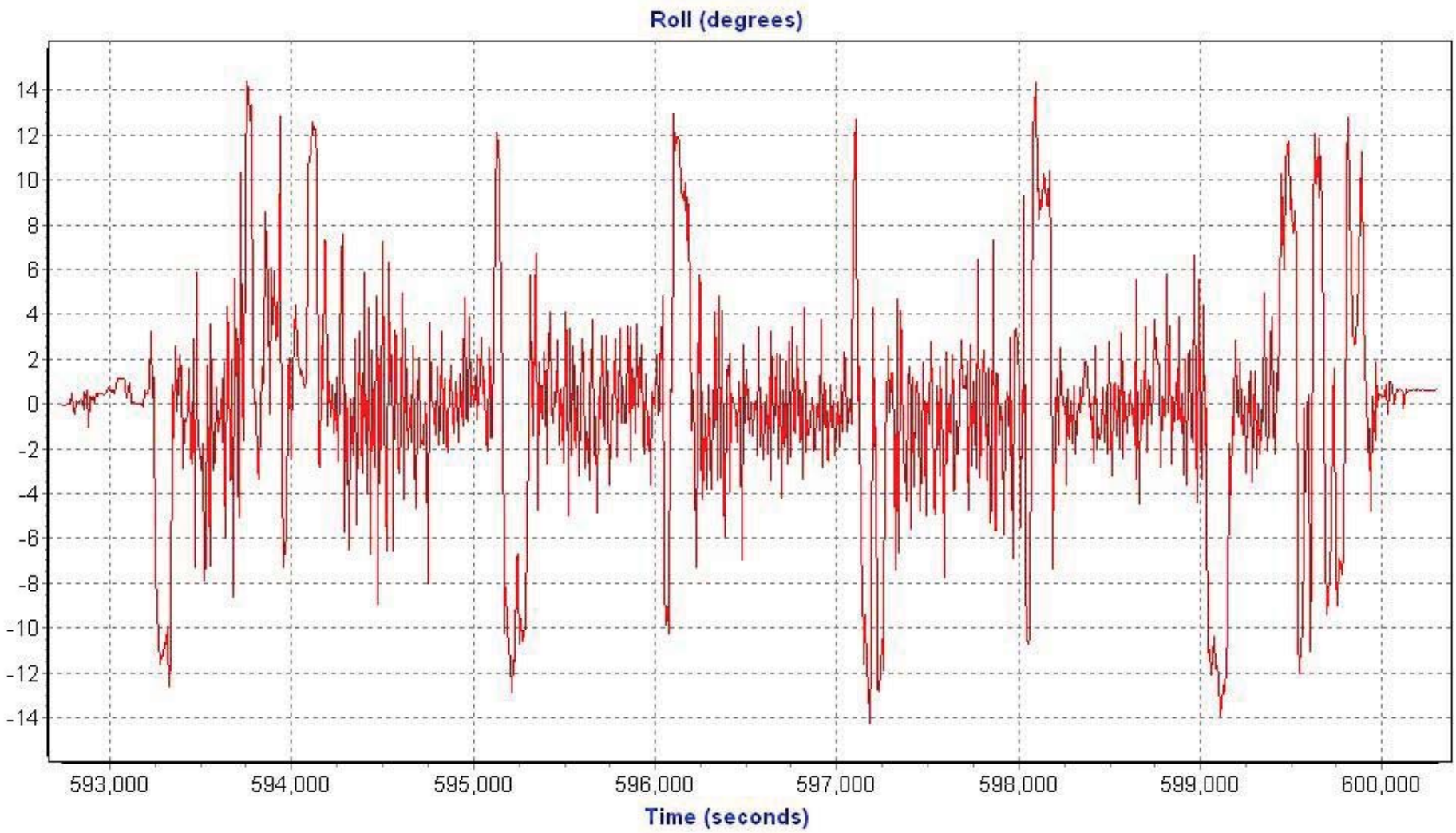

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THINGS TO KNOW

And That aren't always disclosed

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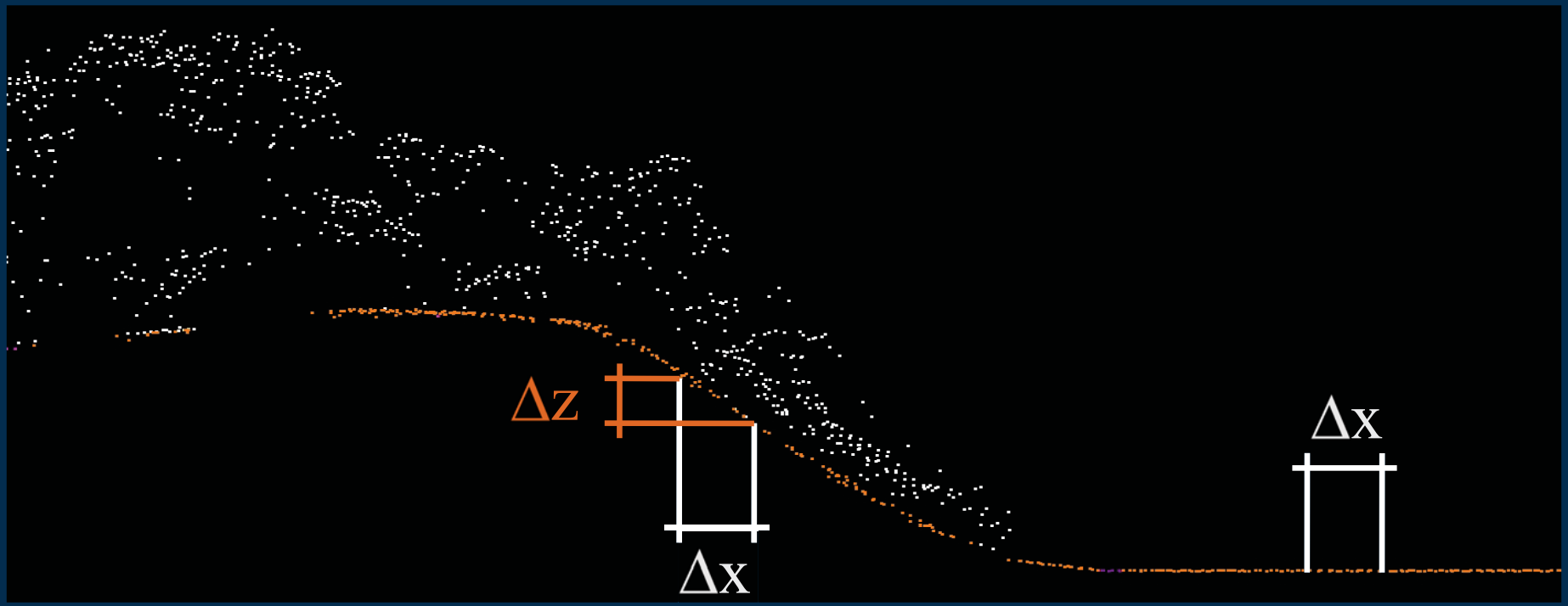
Things to Know

- Horizontal accuracy of the surface is important
- Vertical accuracy is more difficult in sloping terrain



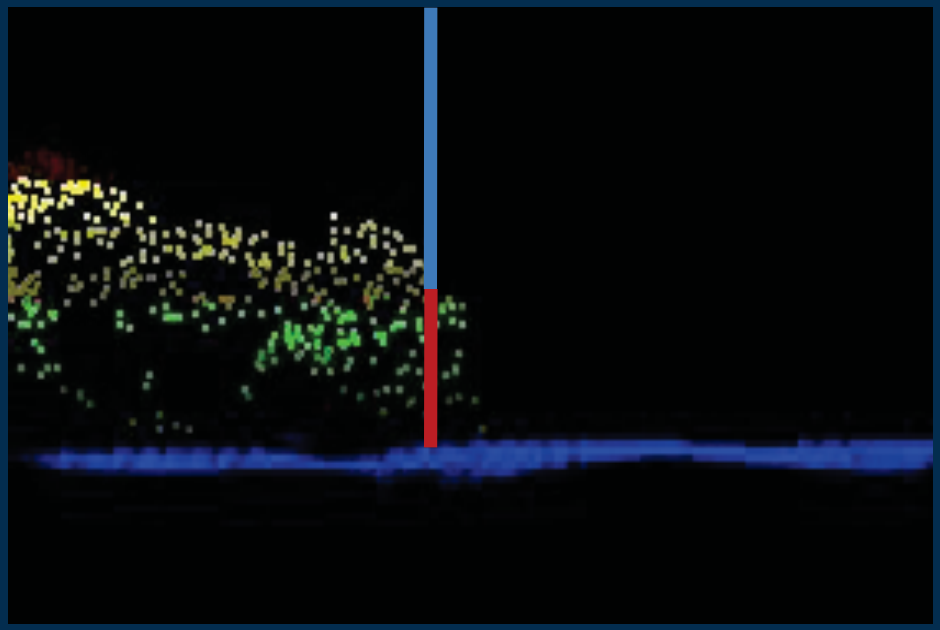
Things to Know

- Vertical accuracy of LiDAR is commonly specified as the Root Mean Square Error ($RMSE_z$), not an "absolute" accuracy

- $RMSE_z$ is the 68% confidence interval
- $RMSE_z$ x 1.96 is the 95% confidence interval
- $RMSE_z$ x 3.0 is the 99.7% confidence interval

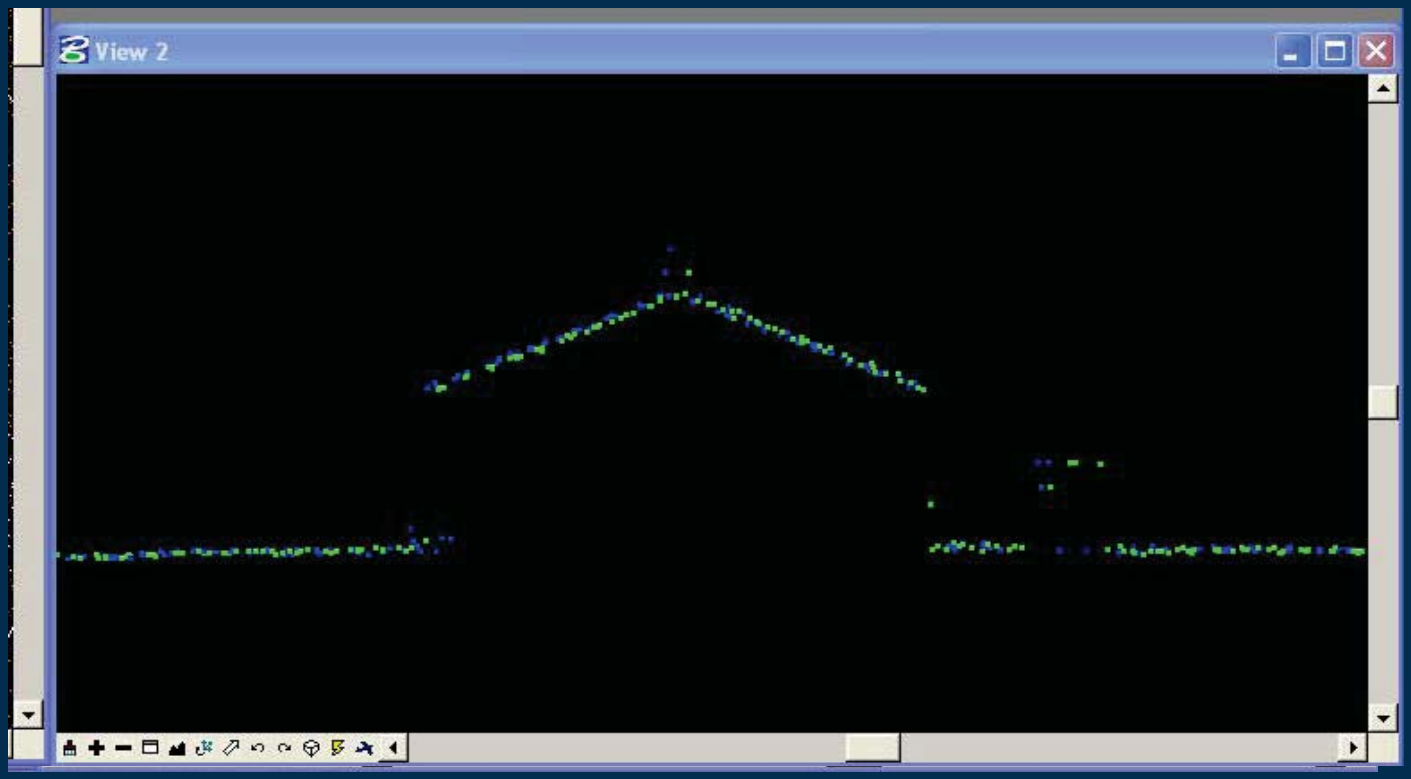
Things to Know

- All sensors have a vertical discrimination ranging from about 1 to 3 meters
- This is the minimum distance between successive returns…
- May lose ground



Things to Know

- Proper calibration of both the sensor and LiDAR surface are critical to quality



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Things to Know

- There is significant value in manual cleanup (after automatic filtering)… this also is a significant cost factor
- Up to 90% of the post-processing costs can be associated with manual edits
- Ensure clear communication with LiDAR provider regarding expectations

Things to Know

- For cost efficiency, projects should be designed for compatibility in accuracy and posting
- Compatible pairs would include
  - 9.25 cm $RMSE_z$ & 0.5 m point spacing
  - 15 cm $RMSE_z$ & 1 m point spacing
  - 25 cm $RMSE_z$ & 2 m point spacing
  - Not a major issue, but openly discuss options with your LiDAR provider

Things to Know

- Achieving ultra high densities can result in
  - Significant costs
  - Increased data storage
  - Data manipulation issues
- Acquisition costs can increase to 2x or 4x
- Data requirements:
  - 1 ppsm point density would equate to 200 Megabytes *per square mile*
  - 4 ppsm would be 4X, or 800 Megabytes per mi^2
  - 8 ppsm would be 8X, or 1.6 Gigabytes per mi^2

Who To Turn To?

- LiDAR Sensor manufacturers
  - Commercial
    - Ex: Leica, Optech, Riegl, AHAB, etc.
  - Government
    - NASA
      - EAARL (now USGS)
      - AOL
  - Academia?
- LiDAR Data Providers
  - Private industry
    - Geospatial/mapping; survey; photogrammetric; engineering firms
  - Government
    - USGS
    - USACE (Optech SHOALS)
  - Academia
    - Some universities have their own assets

Who To Turn To?

- LiDAR Data Hosts
  - Private industry
    - ???
  - State Government
    - Geospatial portals (e.g., PASDA – PA Spatial Data Access)
  - Government
    - USGS CLICK (EROS Data Center)
    - NOAA Digital Coast (Coastal Services Center)
    - *respective agencies*
  - Academia
    - *Sometimes operate state-level portals*

Considerations

When seeking LiDAR data provider, consider:

- Schedule/turn-around time vs. cost
  - How soon do you need the data?
  - Can the provider process the data within your timeframe?
  - Does the cost outweigh turn-around time?
- Experience/Expertise
  - How much experience does the provider have?
  - Does the provider have production capability/capacity?
- Support
  - What kind of technical support can be expected by the provider?
- Contract vs. agreement
  - Contracts typically require a deliverable that meets expectations and has “teeth”

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TOPO VS. BATHY LIDAR

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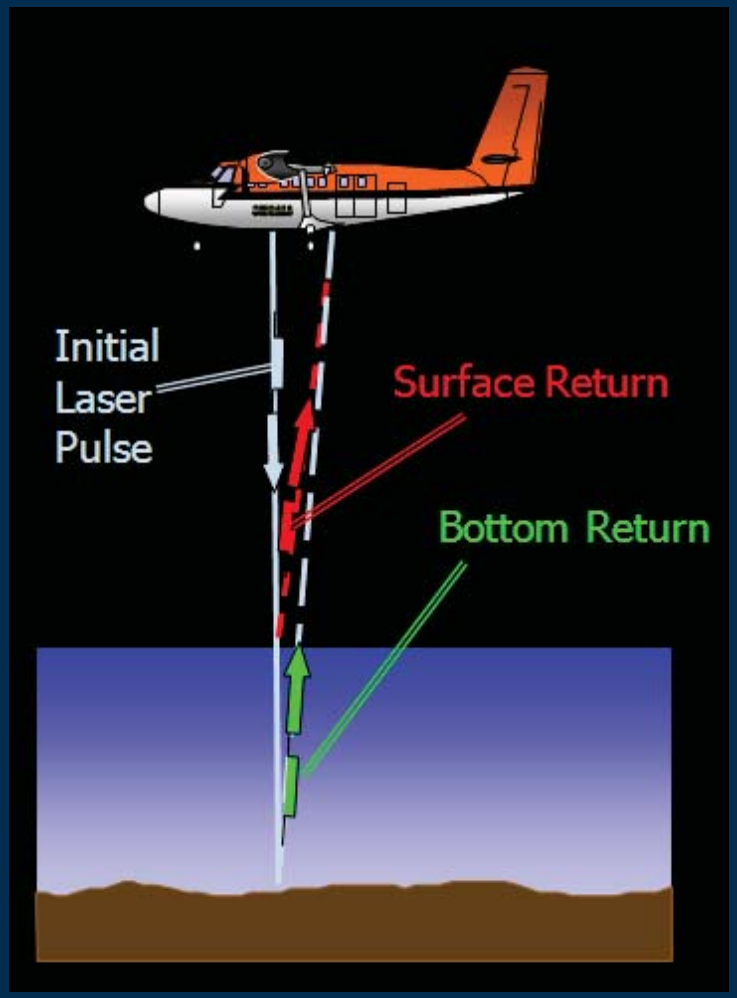
Topo-Bathy Sensors

- *Bathymetric or hydrographic*
- Transmit two light waves
  - NIR laser
    - Used to detect water surface (energy absorbed by water – no penetration)
    - Used to map land features
  - Blue-Green laser
    - Used to detect bottom (slower pulse rate, longer pulse, higher power)
    - Streams, lakes, ponds, coastal environments
    - Limited by turbidity
- Water penetration highly dependent on water clarity
  - In very clear water, depth measurements from 40m - 60m

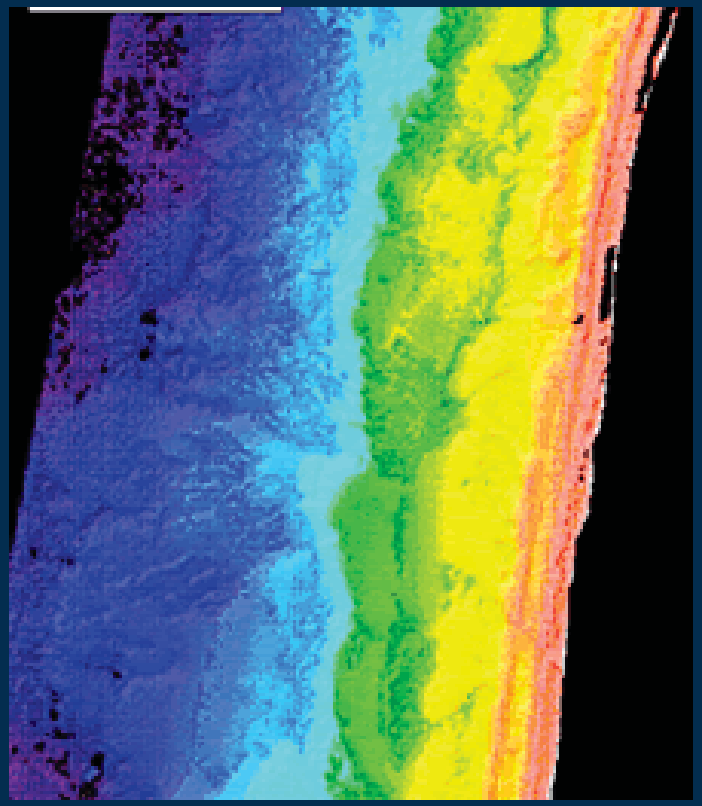


Pennsylvania State University

Topo-Bathy Sensors

- Sensors:

Manufacturer	Sensor	Operator
Optech	SHOALS (1000-T)	USACE/Navy (CHARTS), Fugro
Tenix-LADS (Fugro)	LADS	Fugro
AHAB	HawkEye	Pelydryn
NASA (USGS)	EAARL (shorter pulse length; lower power; potentially more accurate less depth penetration)	USGS Coastal & Marine Geology Program (St. Petersburg, FL)



USACE Coastal Mapping Program

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SOFTWARE APPLICATIONS

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Software Applications

- LiDAR production packages
  - TerraSolid suite of software
  - MicroStation to post process
  - GeoCue is often used for managing projects
  - Other packages (e.g., MARS)

Software Applications

- COTS software has made significant gains recently and overall is very good
- Very important as a LiDAR provider to have programming staff to automate and assist in LiDAR processing
  - intersecting building corners
  - flagging and removing anomalies
  - assessing completeness

Software Applications

- Software to ingest the LAS format for classified LiDAR data
  - ESRI
  - MicroStation
  - AutoCAD
- QT Modeler, LP 360
- Freeware for viewing, manipulating, rendering, etc.
  - US Forest Service LDV (LiDAR Data Viewer)

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USES OF THE DATA

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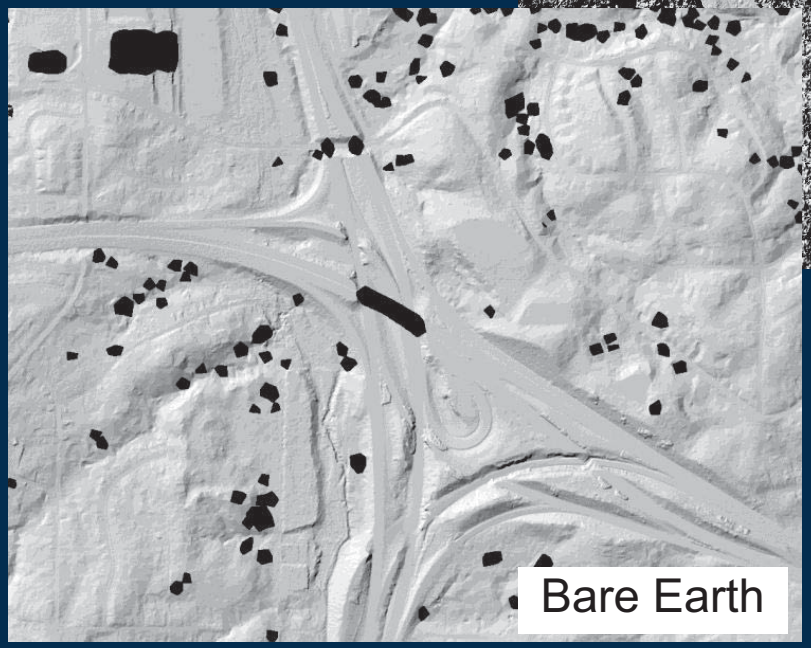
Standard Outputs

- *.las files
- Bare earth DEM
- Contours



Surface Model Outputs

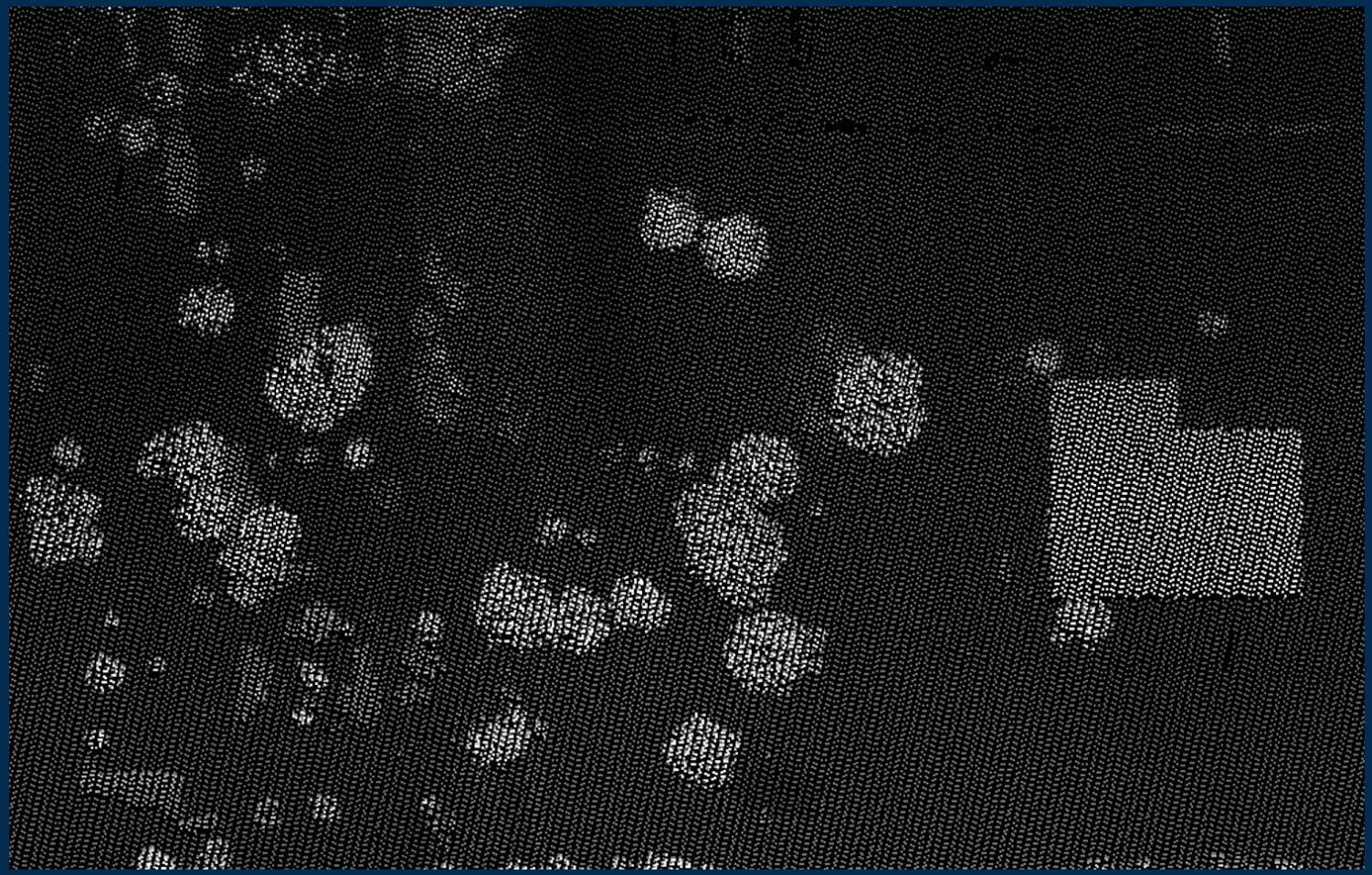
- Urban
  - Buildings
  - Impervious
  - Tree canopy
- Rural
  - Tree canopy
  - Forestry
  - Vegetation type

"One man's noise is another man's signal"
J. Kellndorfer

Data Used

- First return – intensity and elevation
- Last return – intensity and elevation
- Bare earth DEM
- Can also use
  - Multiple returns and intensity
- Interested in the “noise”

Data



Intensity Values

Building Footprints

Yellow: over-classified
Blue: under-classified

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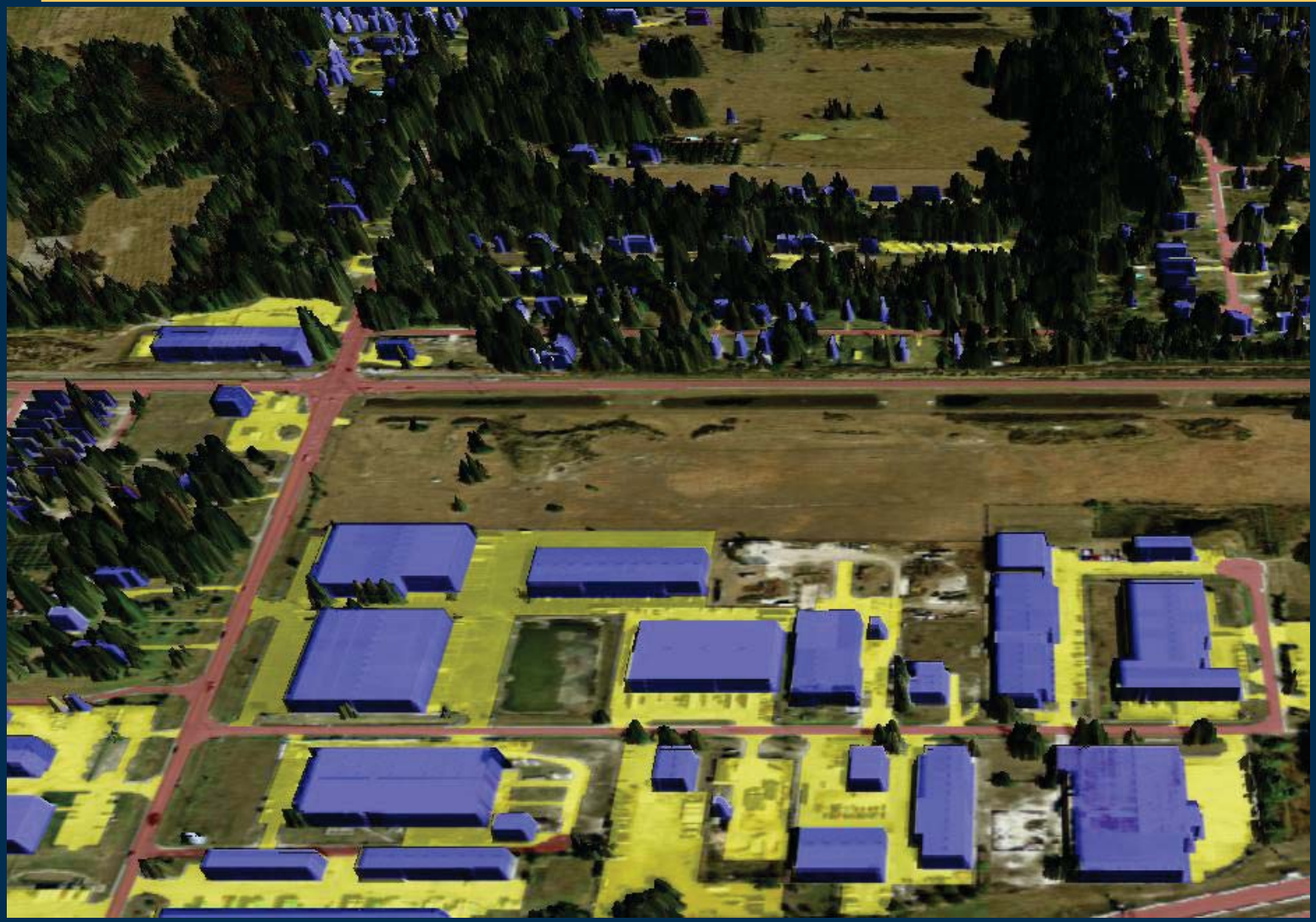
Impervious



Legend

- Building Footprints
- Roads
- Other Impervious

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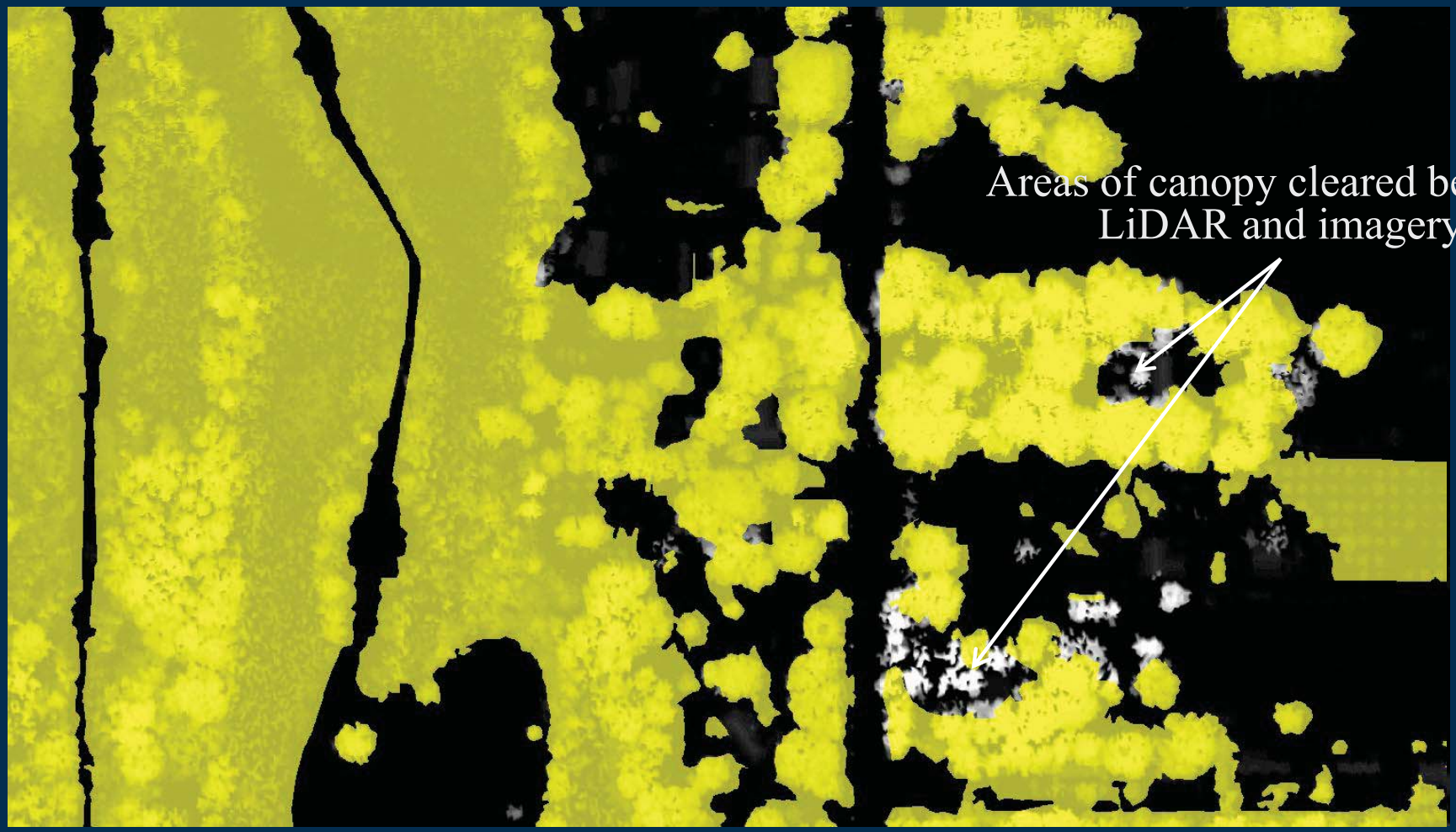
Canopy



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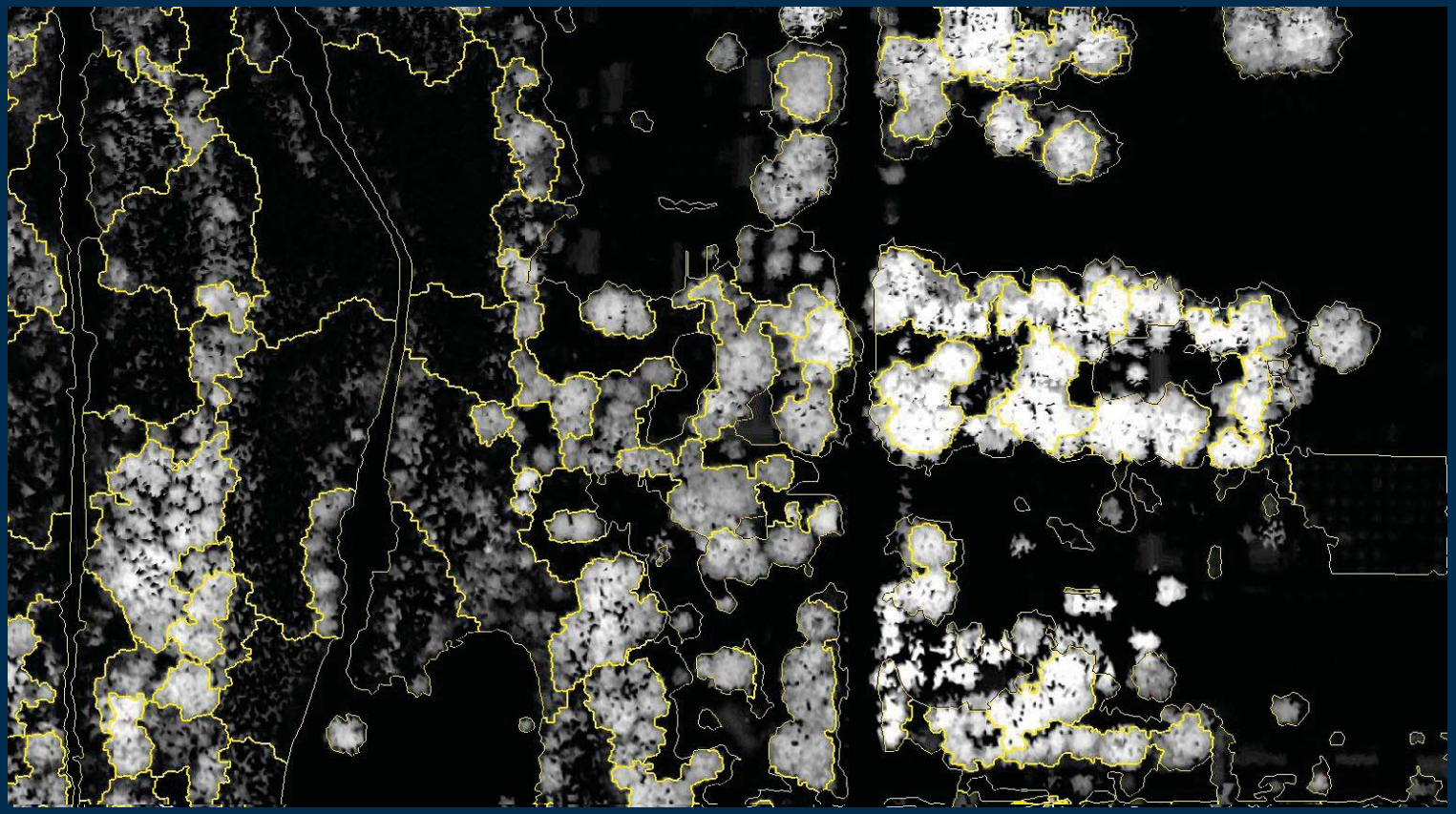
Scale of Analysis



Sub-stand Elements

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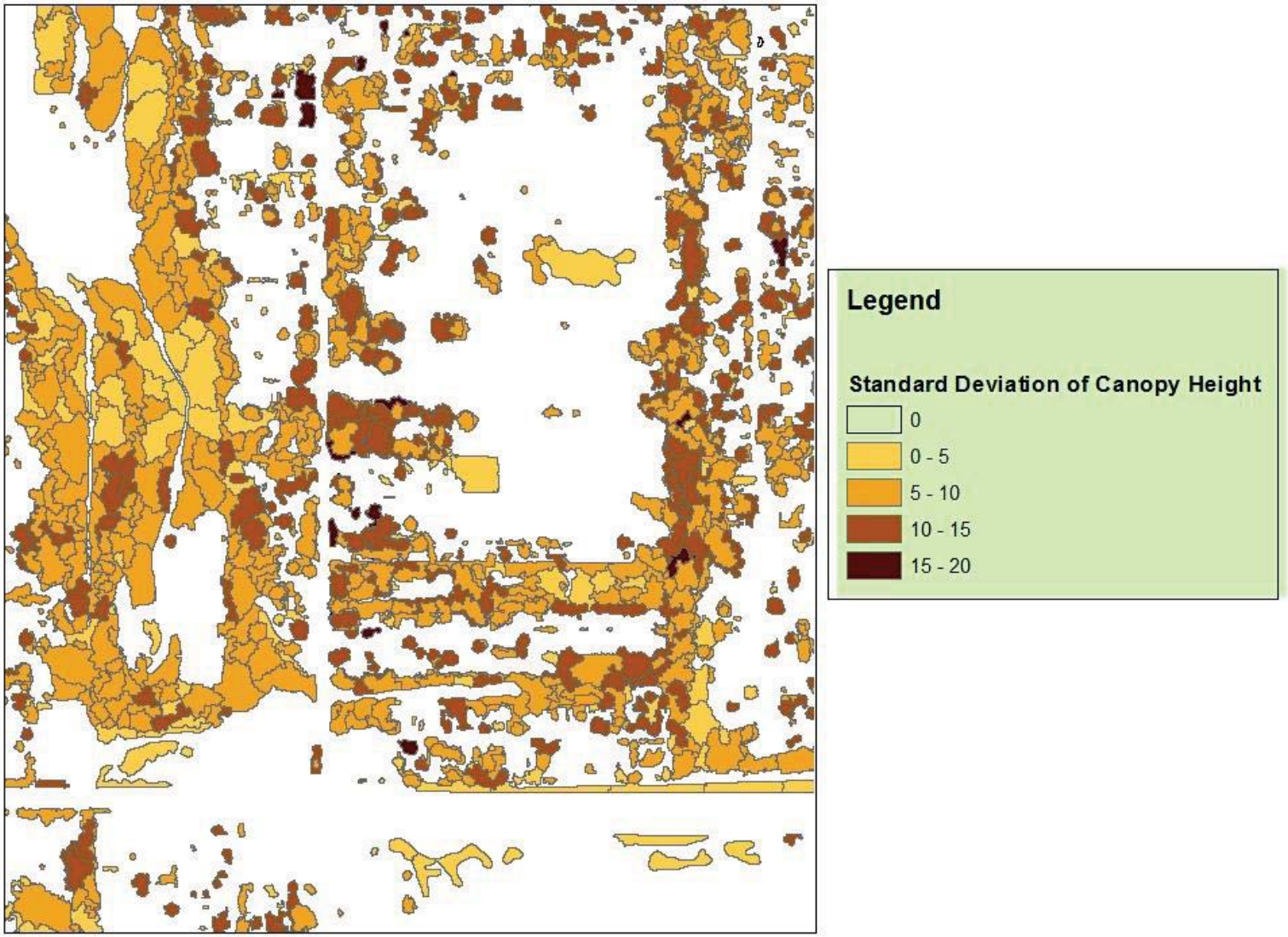
Classification



Outputs: 3D Land Cover

Classes

Impervious

Bare

Water

Woody Veg.

Nonwoody Veg.

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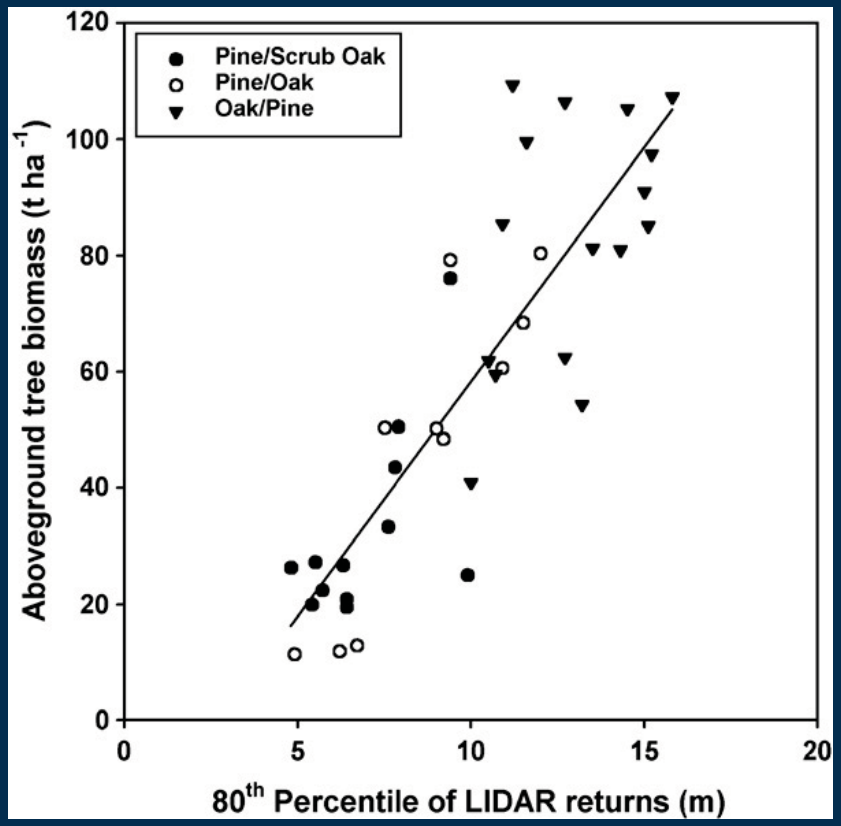
Natural resources

- LiDAR is valuable but will not solve all your problems
- Considerations
  - Time of year – phenology
  - Point density
  - Number of returns
- Conceptualize the problem
- Be careful with research findings
- Define goals

Example: Project

- "Remotely sensed measurements of forest structure and fuel loads in the Pinelands of New Jersey", Nicholas Skowronski, Kenneth Clark, Ross Nelson, John Hom, Matt Patterson, RSE 2007

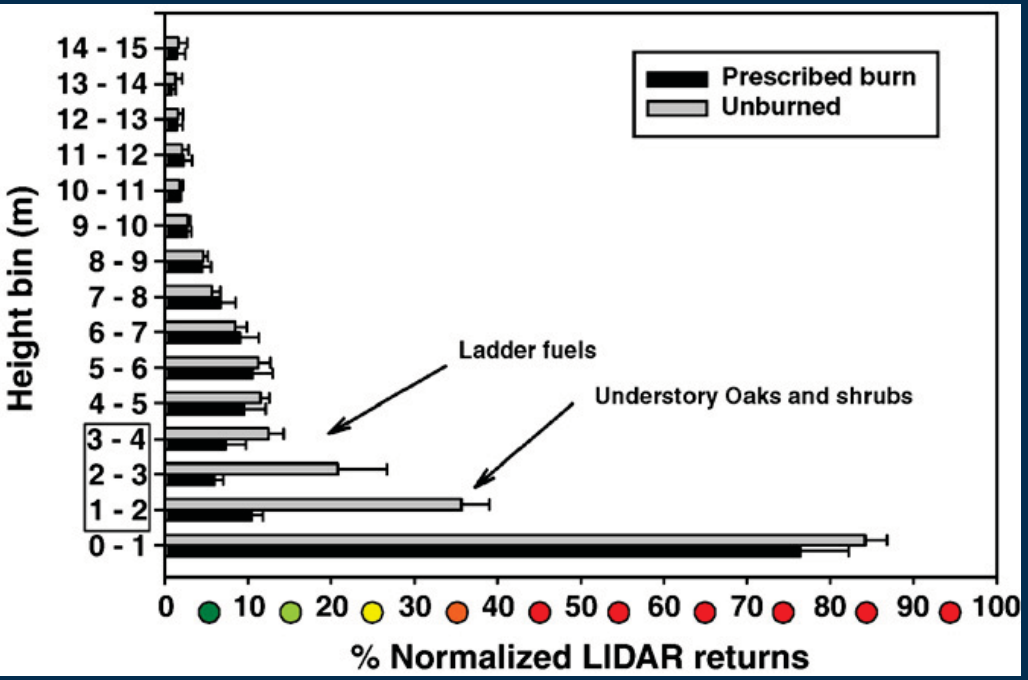


Relationships between LIDAR 80th percentile height and overstory biomass (t ha-
for the three 1 km2 sites collectively (n=36) or separately (n=12 plots for each site

Attribute	Equation	r2	P value
All plots	y=6.022x	0.687	< 0.01
Oak/Pine	y=6.404x	0.228	NS
Pine/Oak	y=5.684x	0.636	<0.01
Pine/Scrub Oak	y=4.795x	0.355	NS
Equations were forced through zero.			

LiDAR Point spacing 0.125 m

Example: understory



Structural characteristics for prescribed fire treatment and unburned areas				
Attribute	**Treated**	**Unburned**	***p* value**	**Sig.**
	Overstory			
Cover (%)	50.0±8.3	51.0±7.4	1.59	NS
Height (m)	6.4±2.8	5.5±2.5	2.47	<0.01
DBH (cm)	12.0±6.7	8.7±5.7	5.91	<0.001
	Understory			
Sapling cover (%)	0.0±0.0	21.9±13.7	37.33	<0.001
Seedling cover (%)	16.6±1.9	15.6±2.8	2.91	<0.01
Shrub cover (%)	36.5±4.9	72.0±14.4	50.98	<0.001
Sapling height (m)	1.3±0.7	1.7±0.1	2.82	<0.05
Seedling height (m)	1.0±0.1	1.1±0.1	1.41	NS
Shrub height (m)	0.5±0.4	0.7±0.1	1.78	NS
Shrub biomass (t ha−1)	0.85±0.75	3.29±1.20	109.98	<0.001

- % vegetation cover and height estimated from LIDAR measurements.
- The recently burned area was the site of a prescribed fire 2 months previously
- Unburned site has not burned since 1995.
- Differences between normalized percentage of LIDAR returns are significant for 1–2 m and 2–3 m height class bins at $p<0.05$

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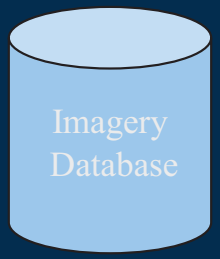
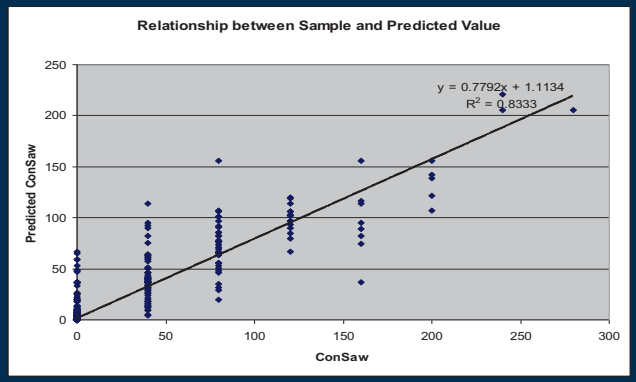
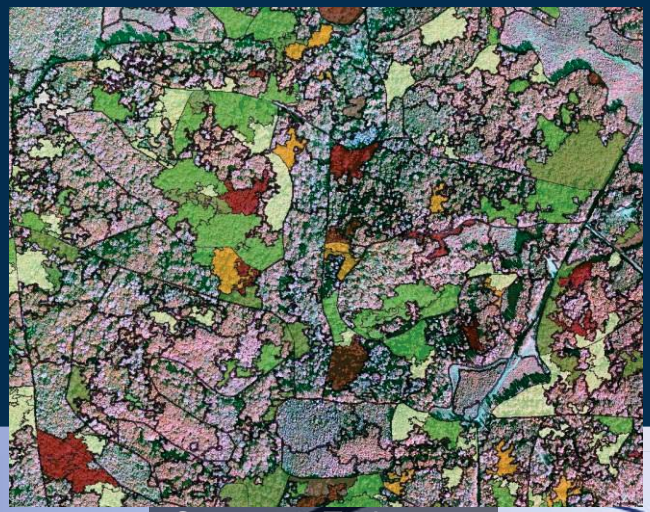
Stand Parameterization

Plots within segments

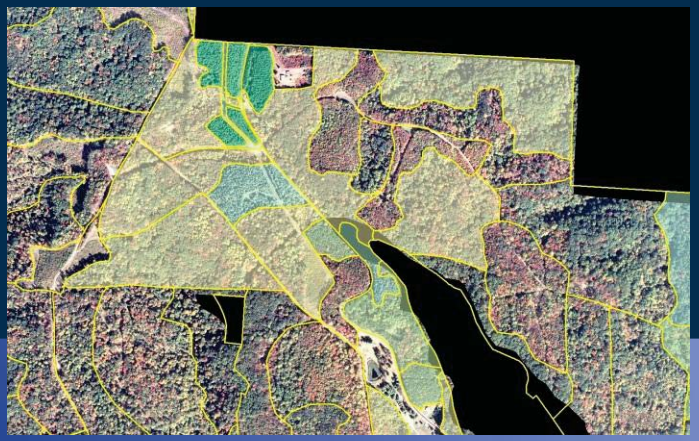




Segment Level Analysis



Segment Estimates



Stand Estimates

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SUMMARY

- LiDAR technology is mature and specifications are well defined
- Users have to know why they are purchasing the data so that the specifications meet the needs
- The bare earth products are only the start to what the data can provide
- Need to ensure that the type of analysis you want to do is supported by the data
- LiDAR will not solve all your problems but will probably help you with many of them

Questions

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