Resolution and Precision of Geiger-mode Lidar Systems

Dale Fried and the 3DEO Team

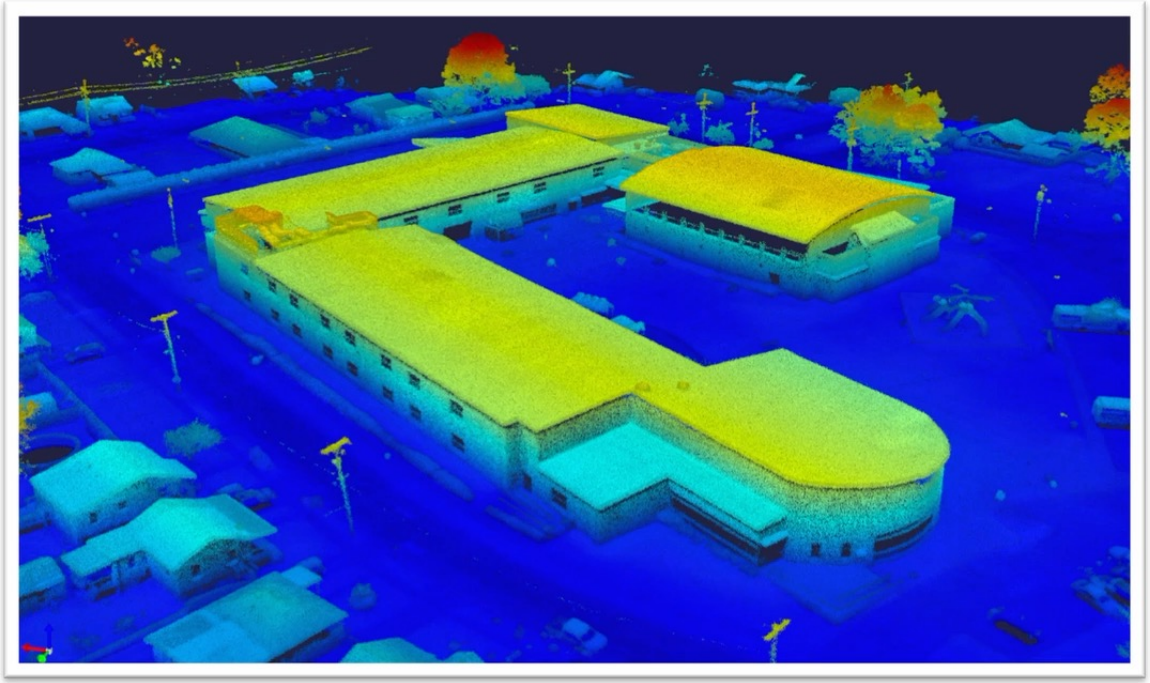
February 17, 2026

See us at Booth 1515

Overview

- Geiger-mode data collection
- Geiger-mode data processing
- Assessment of resolution and precision
- State-of-the-art GM systems

Geiger-Mode Lidar



movie

3D EO

Fast, Efficient 3D Imaging

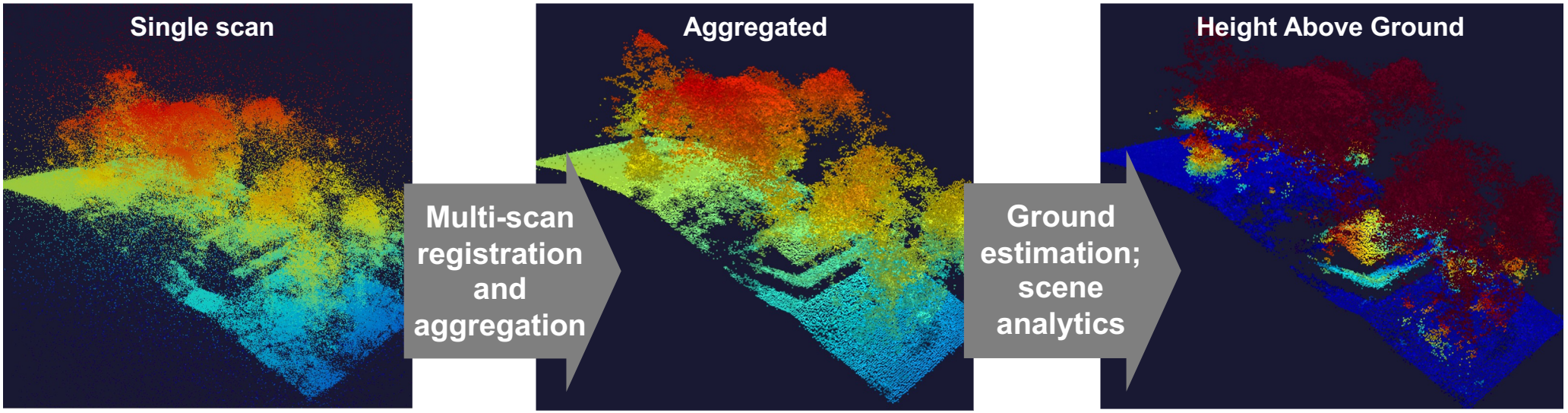
sales@3deoLidar.com

3deolidar.com

Sensor Physics – GM and LM

	Geiger Mode (GM)	Linear Mode (LM)
Laser	• Pulsed • Typically <1 nanosecond • Wide beam flood-illuminates scene	• Pulsed • Typically several nanoseconds • Narrow beam defines spatial resolution
Scanner	• Two-axis for Agile Georeferenced Scanning • Spinning wedge (Palmer) for fixed scan pattern	• Spinning polygon for fixed pattern • Oscillating single-axis for adjustable width
Receiver	• **GM Camera behind imaging optics** • **Commercial: 1k or 4k pixels** • **R&D: 33k pixels**	• **RF photodiode and RF amplifiers** • **Peak detection and triggering** • **Fast waveform digitization**
Received photons	• **Typically 20 photons required to minimize voids** • **Aggregated over all pulses and scans**	• **Typically 300 photons to get above noise** • **All photons must be received in one laser pulse**
Post-processing	• **Aggregate all raw photo-detection events** • **Estimate scene geometry from clumps of detections**	• **Simple: detection times to 3D space** • **Medium: online waveform** • **Complex: full-waveform**

GM Processing



Raw Data

- Individual photon detections
- Significant noise
- Typically 15 – 20 GB/minute of recording

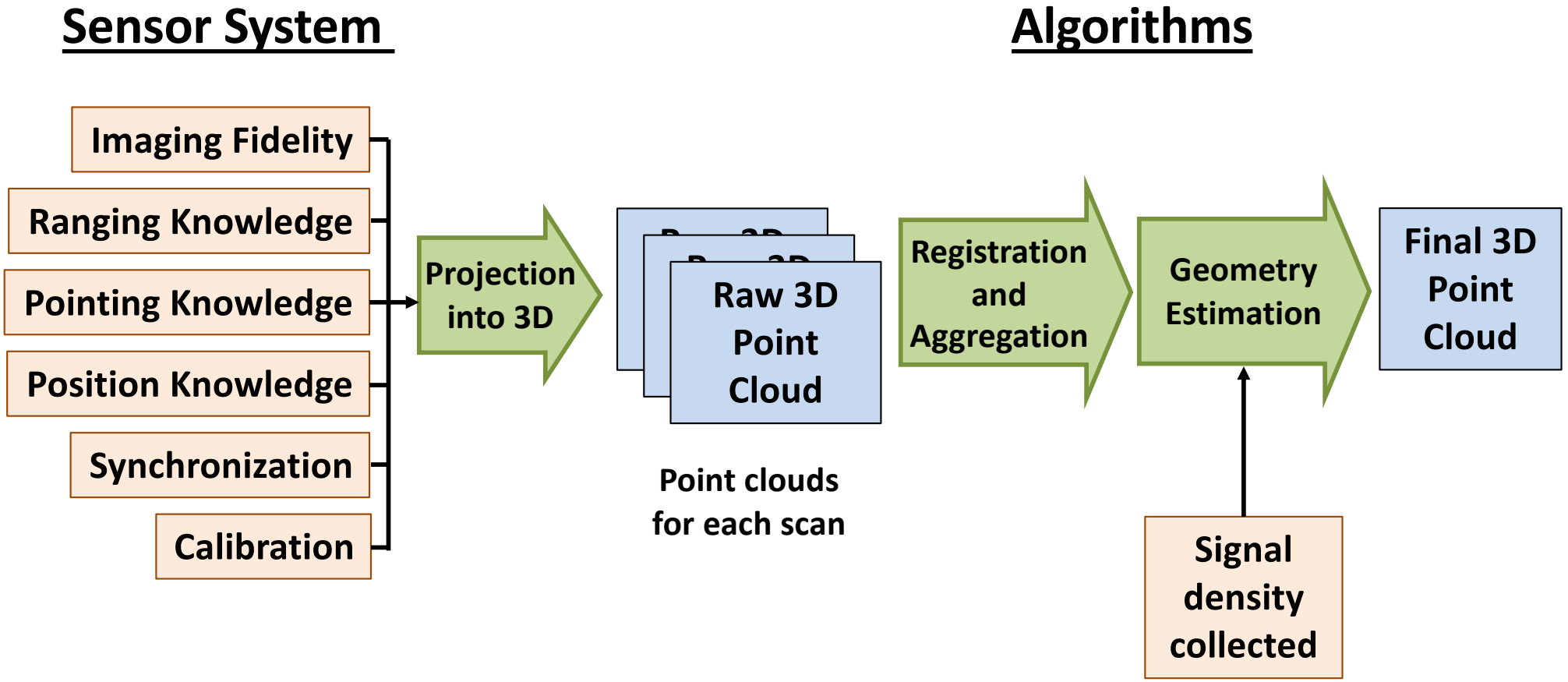
Aggregated Point Cloud

- Complete picture of scene
- Minimal shadowing
- Noise removed
- Points labeled with relative reflectivity and confidence

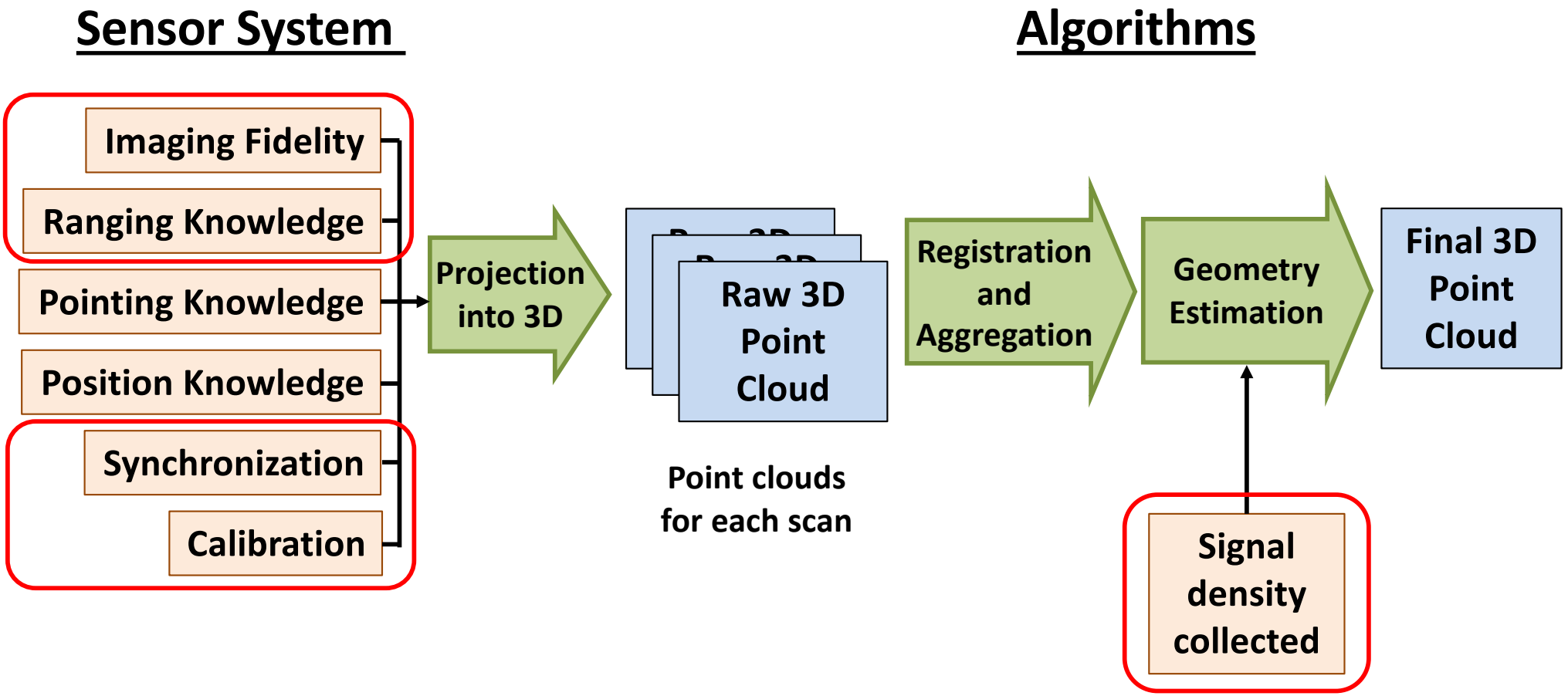
Products

- Point clouds labelled with height above ground
- High-resolution DTM
- Geometric change detection
- Motion detection
- Customer-specific GeoTIFFs

Product Quality Requires Sensor and Algorithms



Product Quality Requires Sensor and Algorithms



Overview

- Geiger-mode data collection
- Geiger-mode data processing
- **Assessment of resolution and precision**
- **State-of-the-art GM systems**

Vertical Resolution and Precision

Resolution:

Ability to distinguish closely-spaced objects

Fundamental characteristic of the hardware

LM equivalence: peak widths in full-waveform data

Determined by

- **Laser pulse width**
- **Timing jitter**
- **Digitization electronics**

Precision / Repeatability:

Ability to return the same answer over many measurements

Involves the algorithms that estimate scene geometry from clumps of raw photo-detections

LM equivalence: placement of peaks

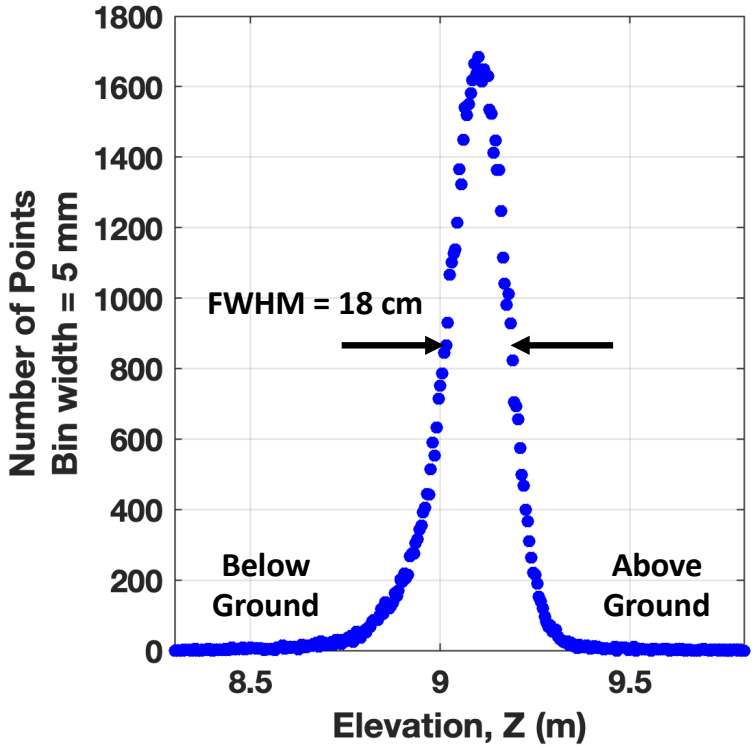
Determined *also* by

- **Amount of signal detected**
- **Algorithm to find center of peak**

Vertical Resolution and Precision

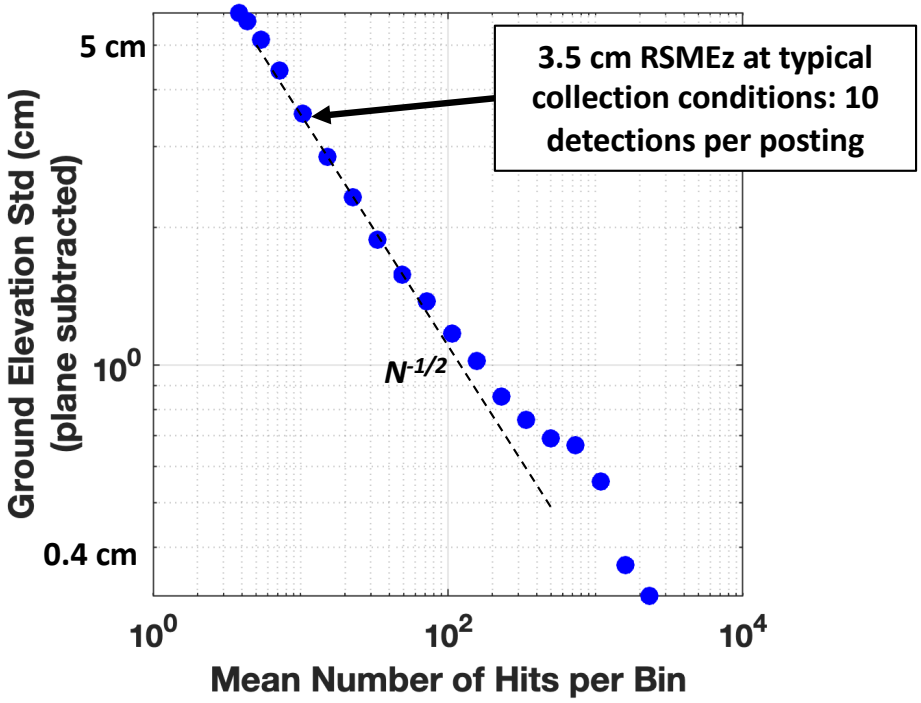
Range Resolution

all raw photodetections from 79 m² area.



Range Precision

Area gridded into cells. Maximum likelihood estimator for each cell with at least three detections.



Collection: 8500 ft (2615 m), 10 deg off vertical, one scan. Sensor: Wrangell series

Horizontal Resolution

Resolution:

Ability to distinguish closely-spaced objects in the cross-range directions

Fundamental characteristic of the hardware

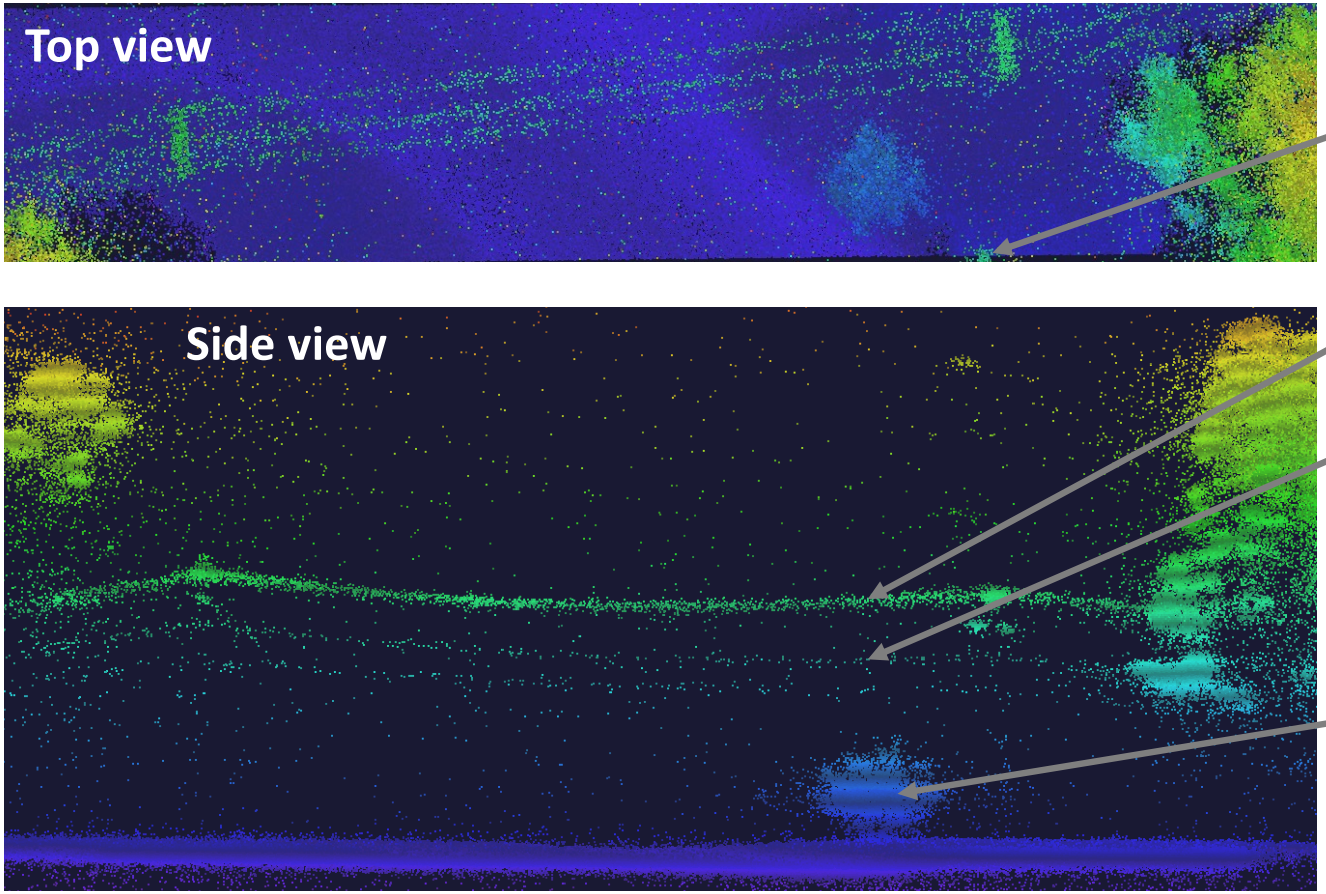
Has equivalence in imagery as the ground spatial resolution (GSR) (not GSD)

Determined by

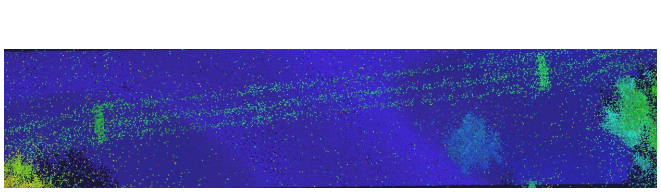
- **Imaging optics**
- **Scanner synchronization and accuracy**
- **Inertial Navigation System (INS)**
- **Calibration**

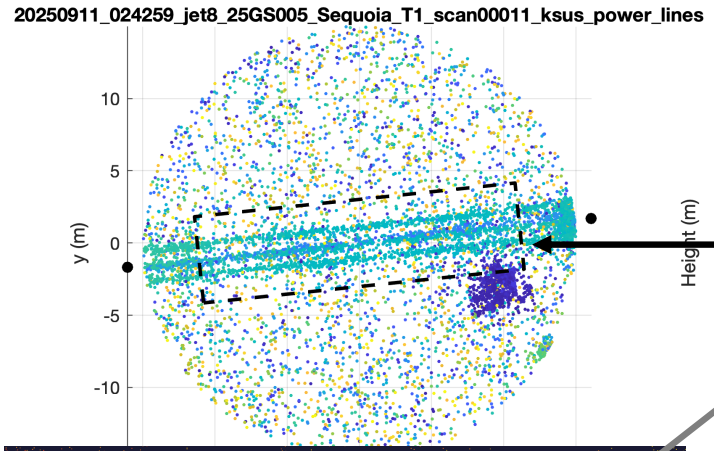
Line Spread Function Target

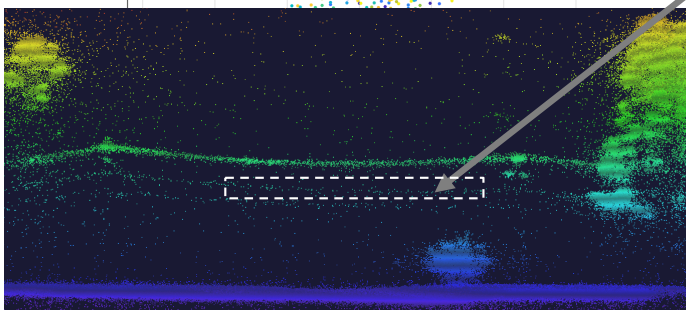
Measure width of point distribution from infinitesimally thin wire

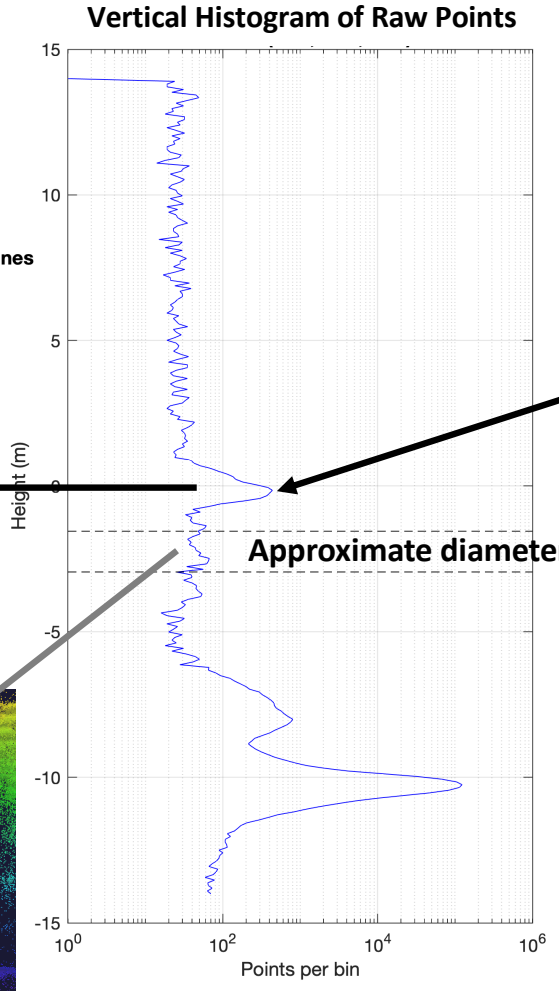


Line Spread Function Target



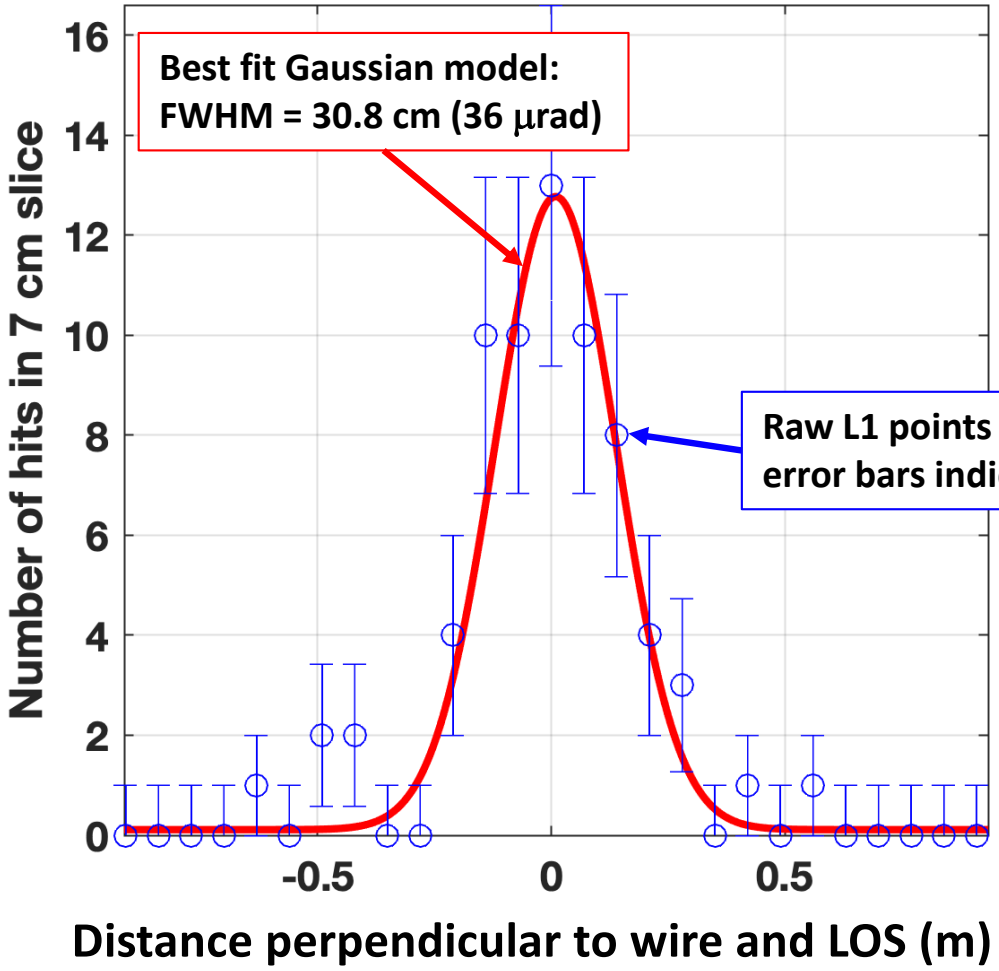






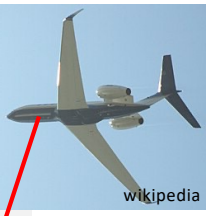
Approximate diameter: 1 cm

Line Spread Function Result

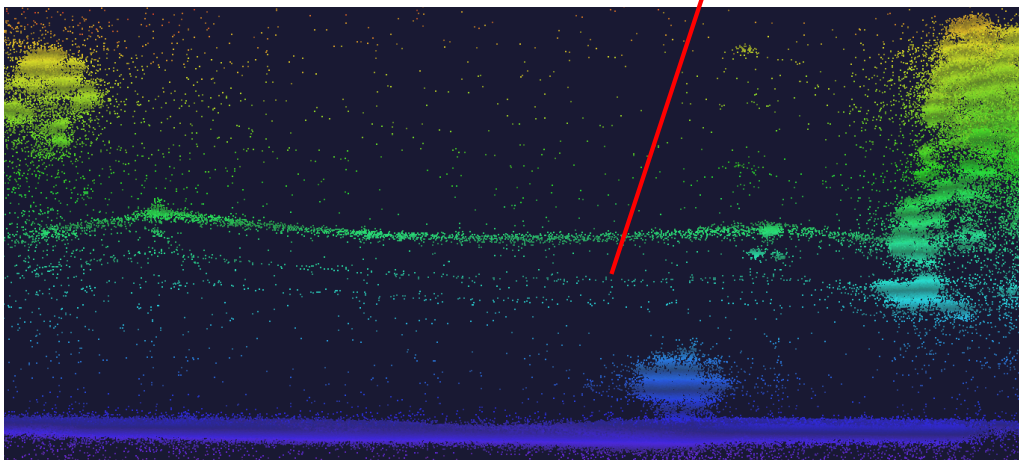


Analysis steps:

- Isolate points near wire
- Fit parabola to wire; find distances to points
- Decompose errors into range and cross-range
- Fit Gaussian to cross-range errors



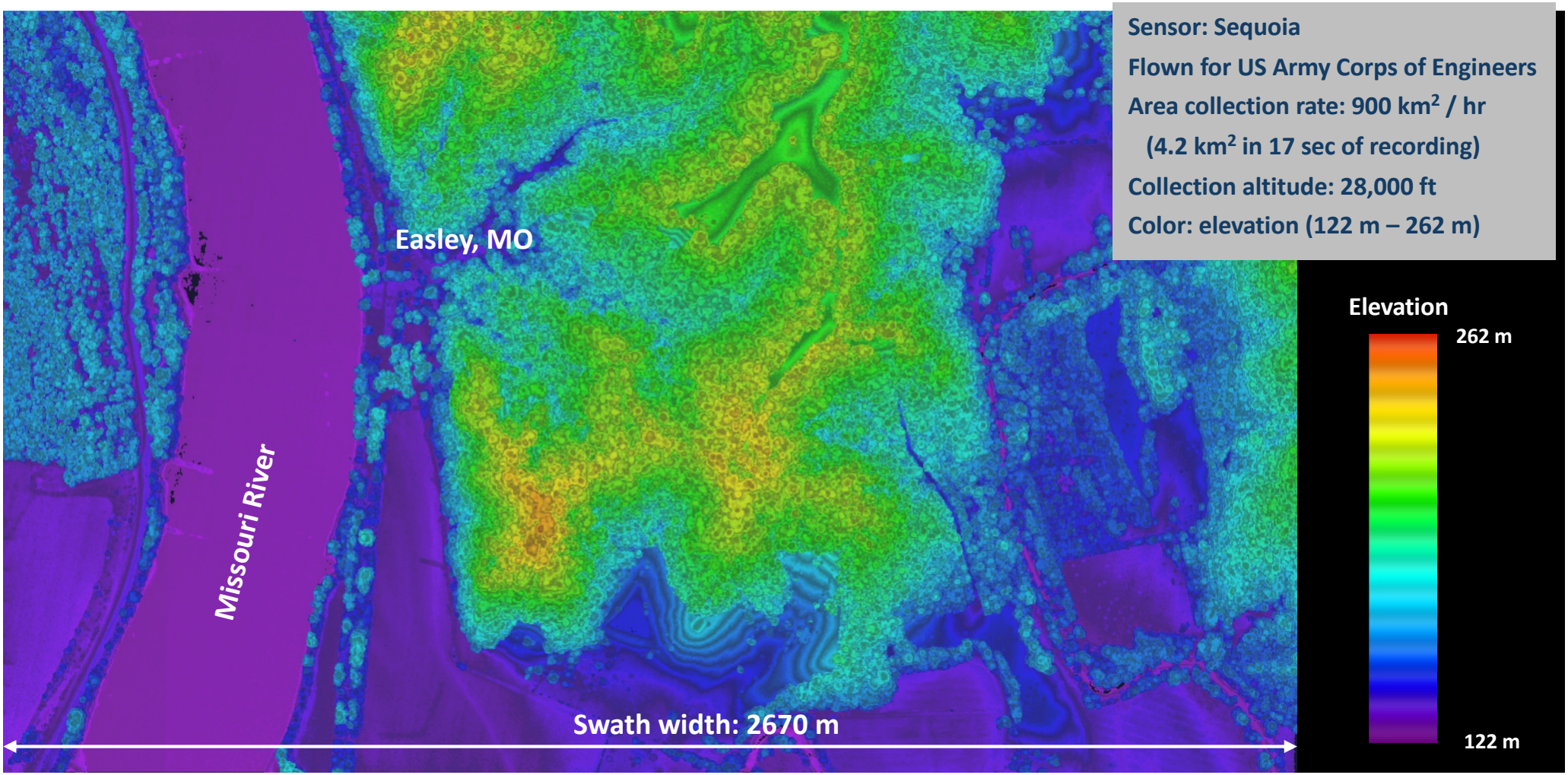
8,490 m AGL
(27,850 ft)



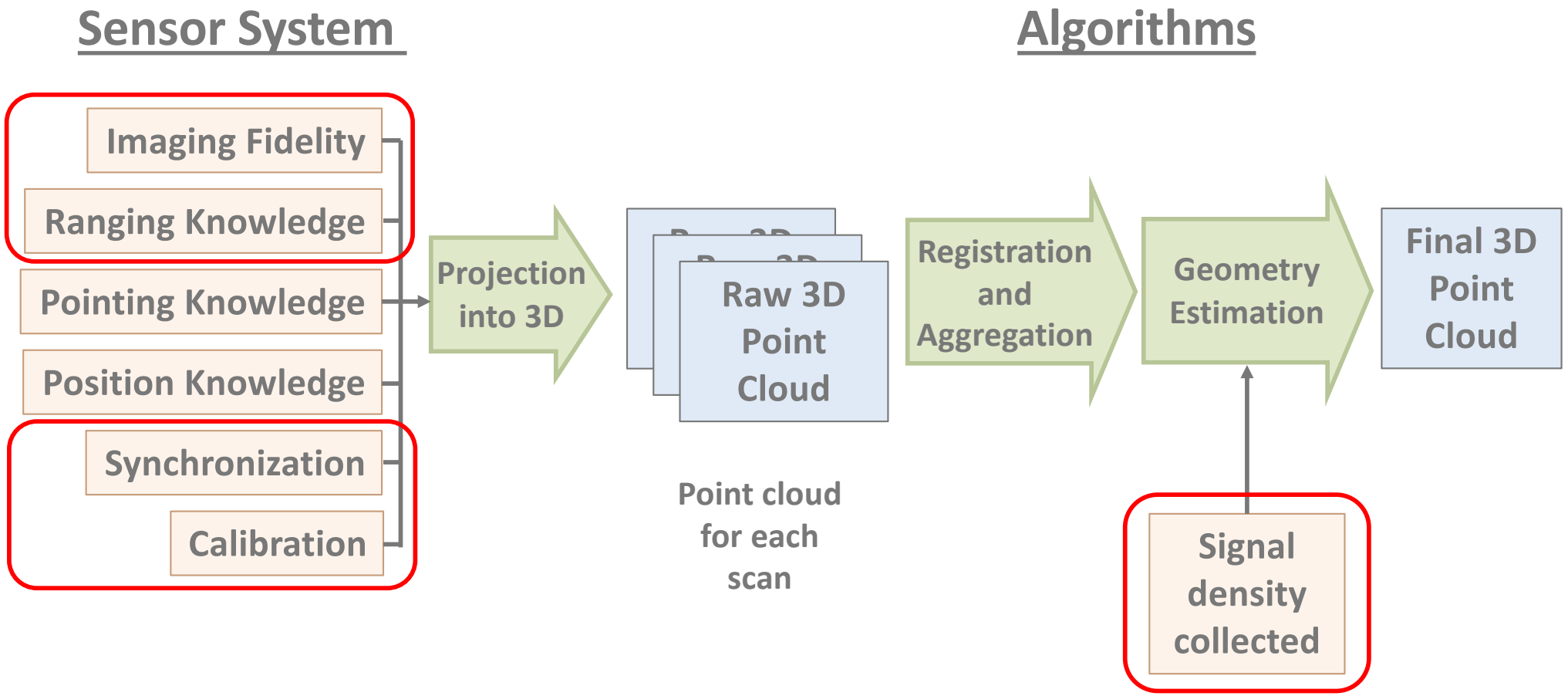
3DEO Geiger-mode Lidar Systems

	Zion ($)	Wrangell ($$)	Sequoia ($$$)
Typical flying height	3,000 – 12,000 ft	5,000 – 16,000 ft	20,000 – 50,000 ft
Collection rate (de-noised points / sec)	9 – 12 million/sec at 8,000 ft	16 – 20 million/sec at 8,000 ft	20 – 30 million/sec at 27,000 ft
Ground spatial resolution (FWHM)	76 µrad 19 cm at 8,000 ft	76 µrad 19 cm at 8,000 ft	36 µrad 30 cm at 27,000 ft
Field of regard	40 x 40 deg (-35 to +5 deg cross-track)	40 x 40 deg (-35 to +5 deg cross-track)	54 x 60 deg (-18 to +36 deg cross-track)
Laser power and system aperture	36 W, 4 cm	50 W, 4 cm	100 W, 13 cm
Development status	All have been deployed operationally outside the US by government entities		

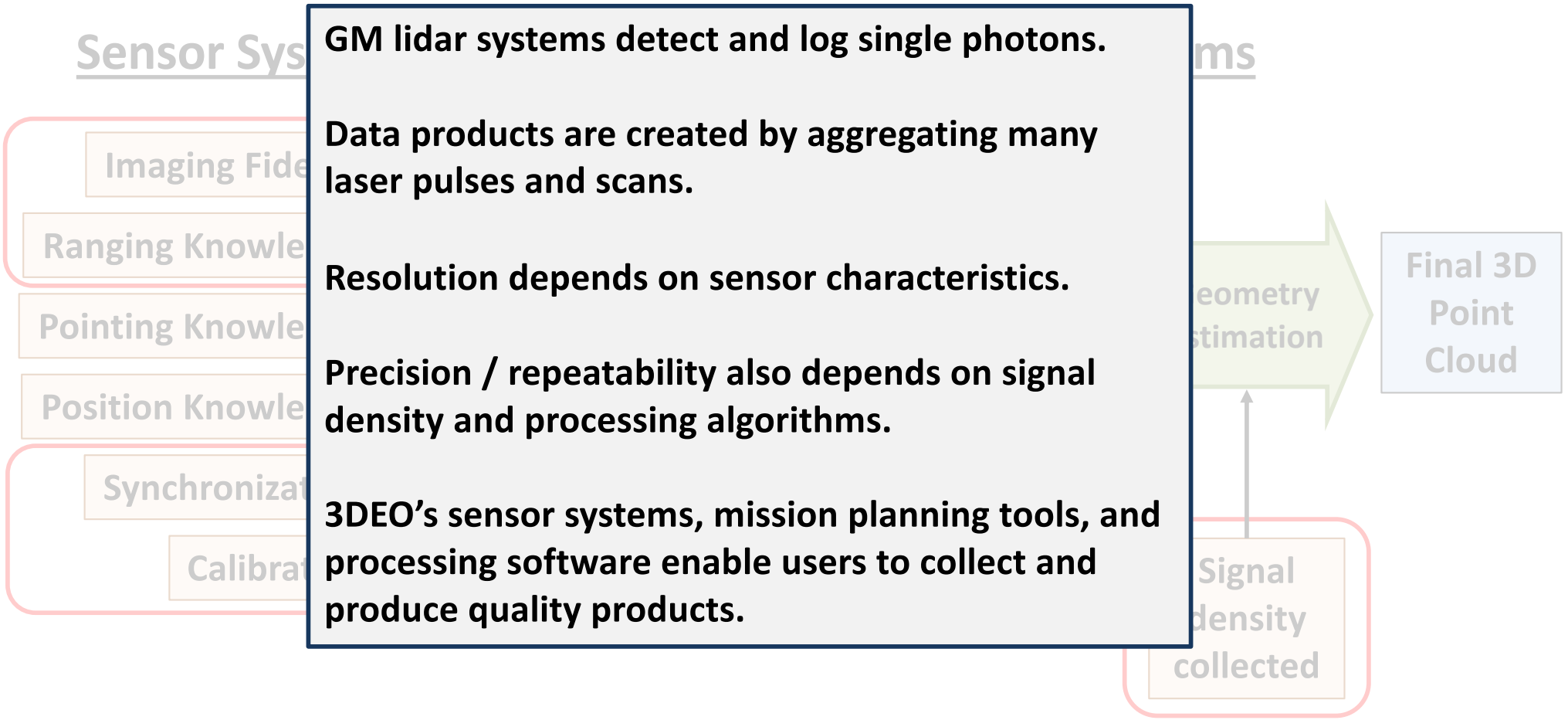
Sequoia Point Cloud



With Great Power Comes Great Responsibility



With Great Power Comes Great Responsibility



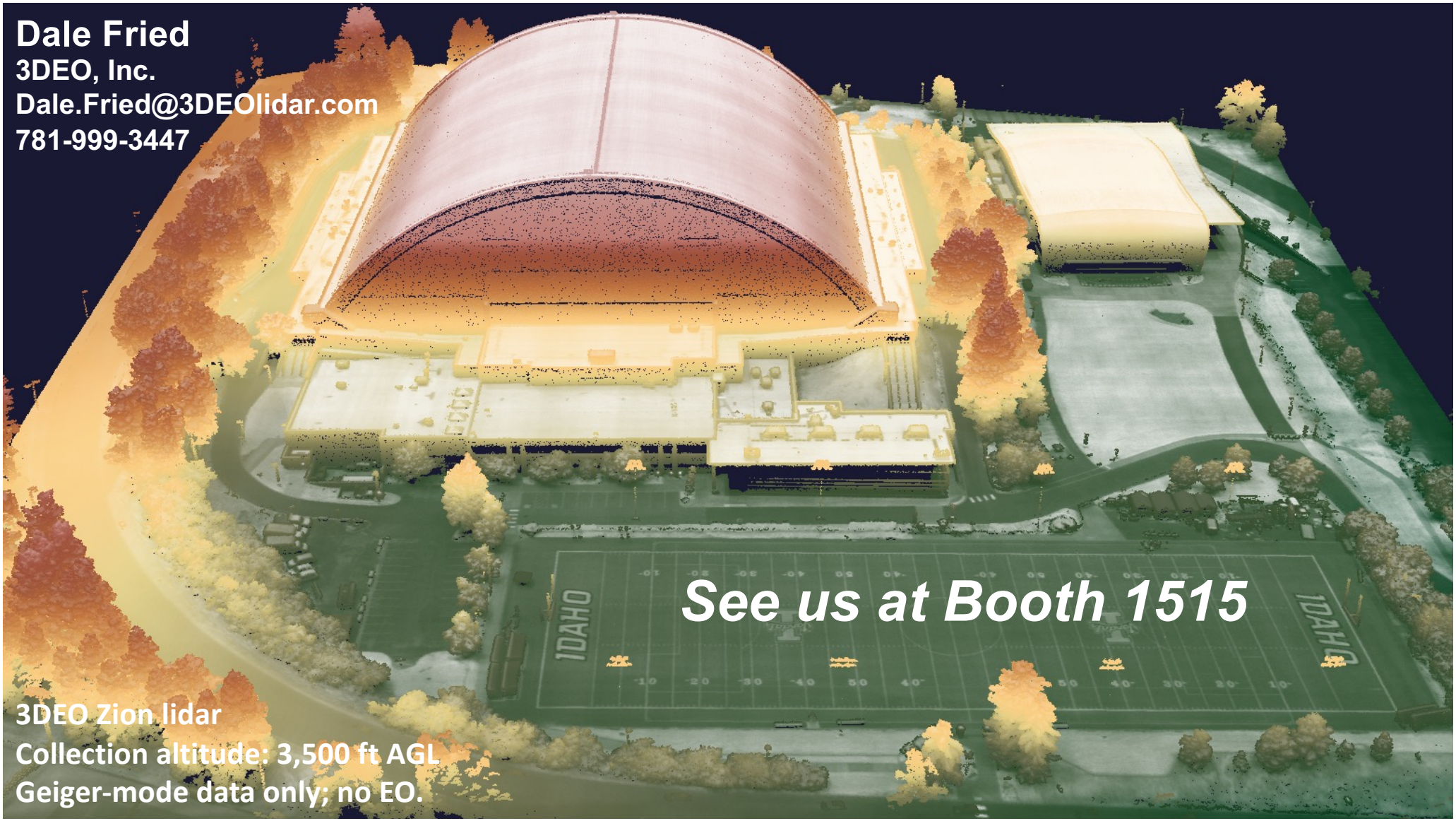
GM lidar systems detect and log single photons.

Data products are created by aggregating many laser pulses and scans.

Resolution depends on sensor characteristics.

Precision / repeatability also depends on signal density and processing algorithms.

3DEO's sensor systems, mission planning tools, and processing software enable users to collect and produce quality products.


Dale Fried
3DEO, Inc.
Dale.Fried@3DEOlidar.com
781-999-3447
See us at Booth 1515
3DEO Zion lidar
Collection altitude: 3,500 ft AGL
Geiger-mode data only; no EO.