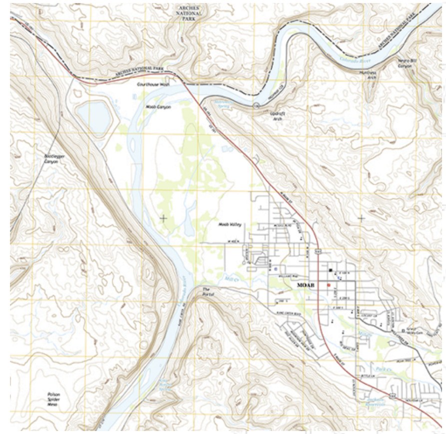
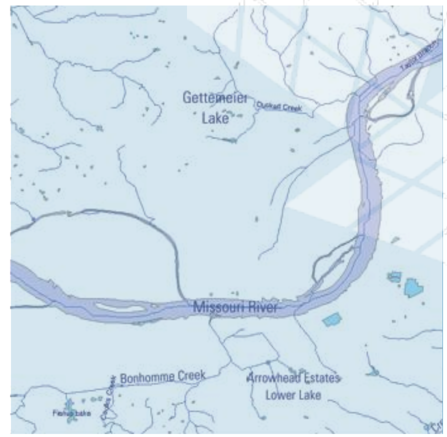
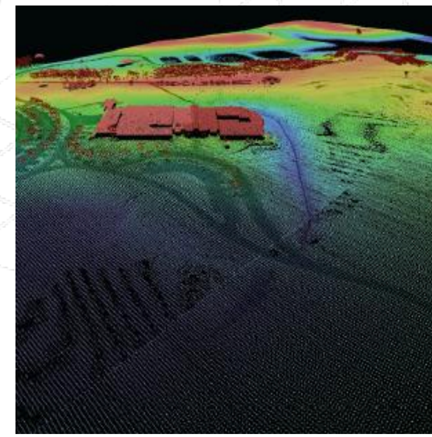
Evaluation of Single Photon and Geiger-mode lidar

…my signal may be your noise



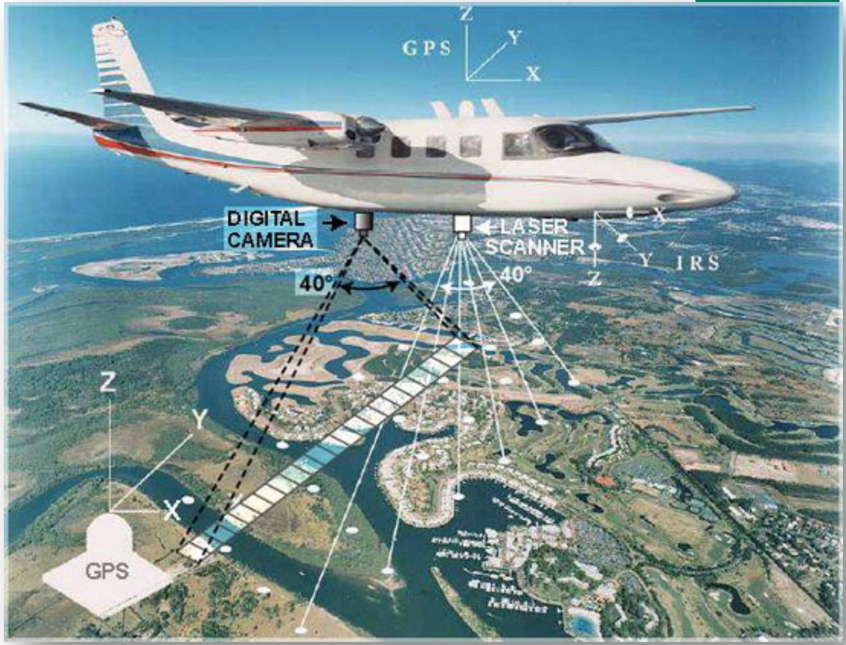


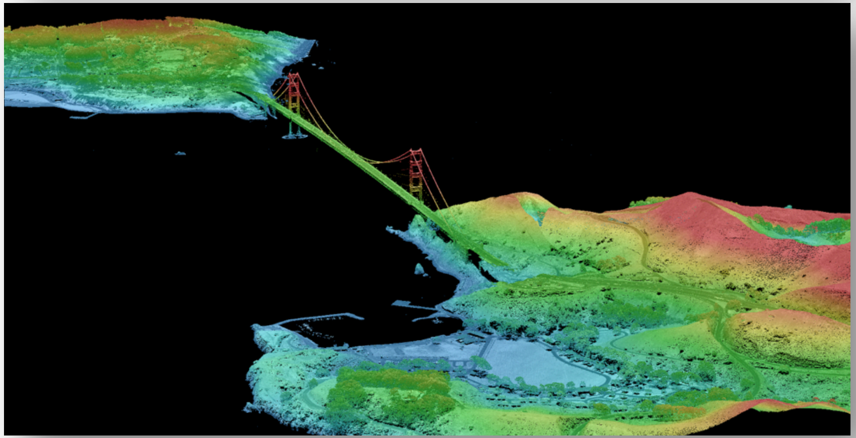


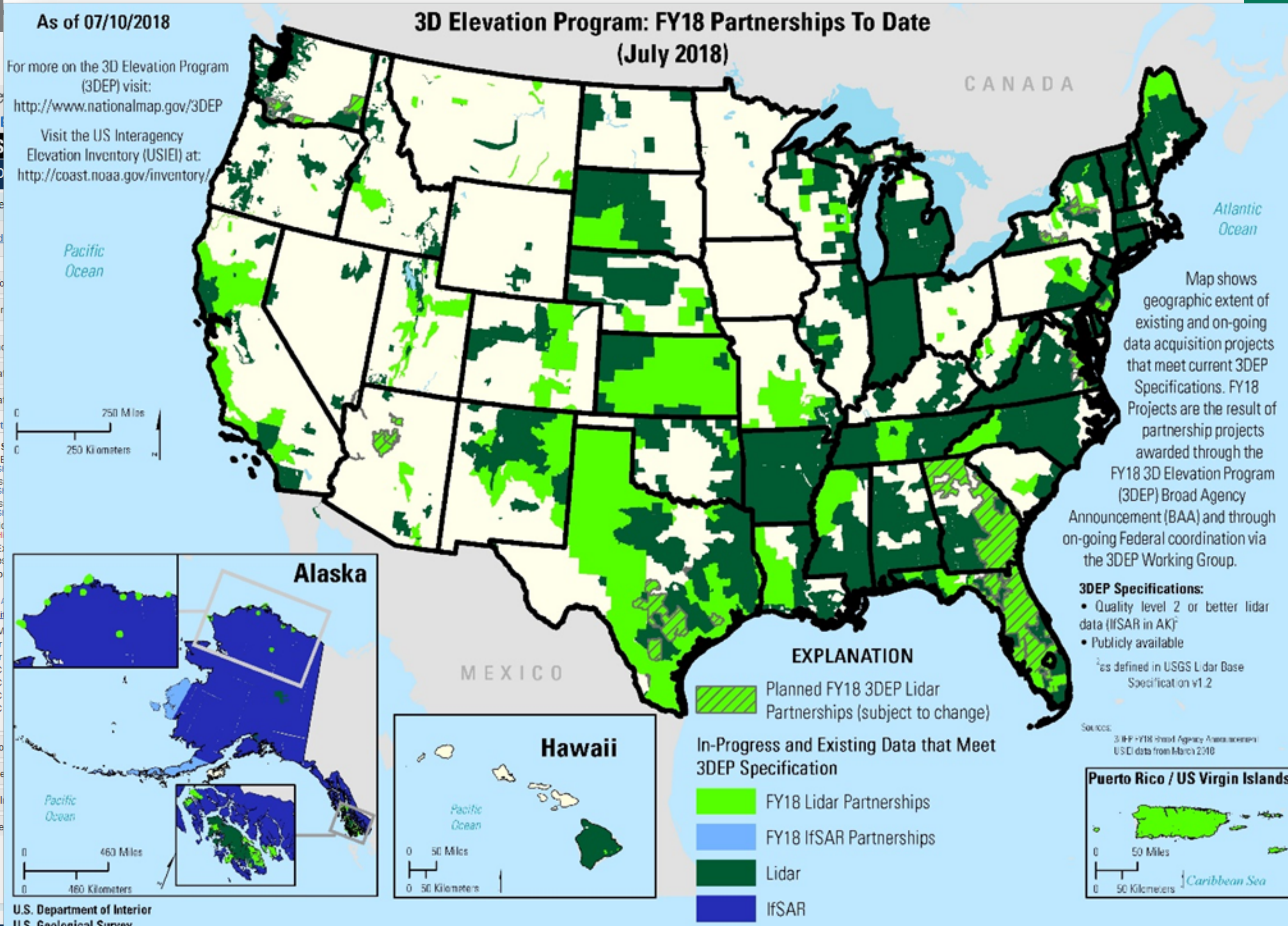
Jason Stoker, PhD
USGS National Geospatial Program
HRT workshop
August 22nd, 2018

3D Elevation Program (3DEP)

- Apply lidar technology to map bare earth and 3D data of natural and constructed features; increase the quality level of lidar being acquired to enable more accurate understanding, modeling, and prediction
- Goal to complete acquisition of national lidar coverage with IfSAR in Alaska in 8 years
- Address the mission-critical requirements of 34 Federal agencies, 50 states, and other organizations documented in the National Enhanced Elevation Assessment
- ROI 5:1, conservative benefits of $690 million/year with potential to generate $13 billion/year
- Leverage the capability and capacity of private industry mapping firms
- Achieve a 25% cost efficiency gain by collecting data in larger projects
- Completely refresh national elevation data holdings with new products and services







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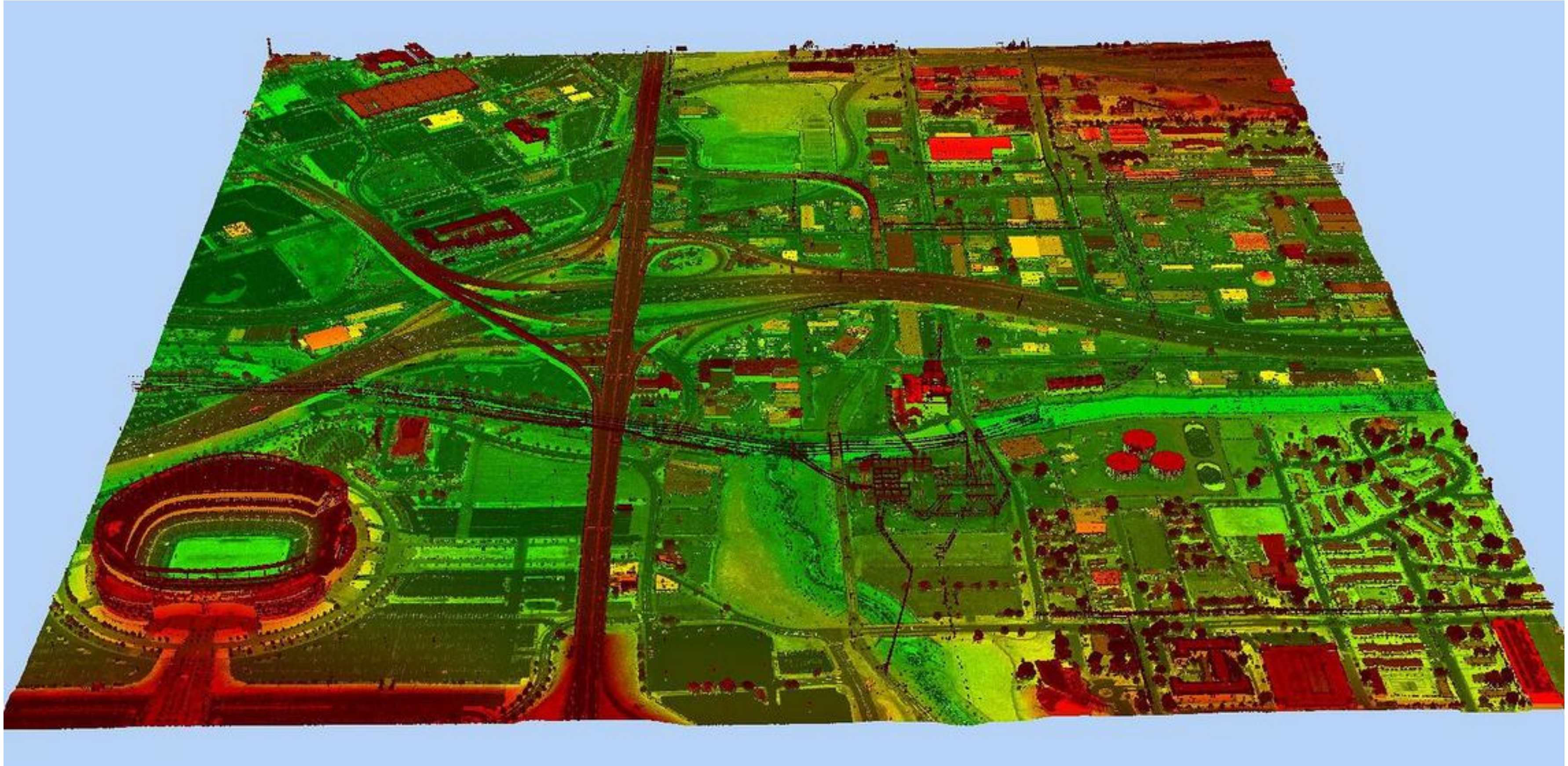
Provide the raw materials a user can “mine”

Moving away from a download-first paradigm, with focus on provisioning, data management, standardization- creating a ‘data lake’ in S3



More 'bang for your buck'

Higher altitudes, more points per sq meter

How do they achieve this?

- More Sensitive Detectors
- Means separating signal from noise becomes very important
- Pre-processing "raw" data becomes very important

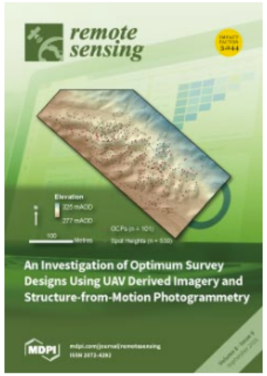
Geiger-mode LIDAR

- ## Technology Background
  - Department of Defense (DoD) investments ongoing for ~15 years
  - Technology just recently (last 3 years) made available for commercial use
  - Operation is somewhat similar to linear mode (using a laser to make time of flight measurements along line of sight)
  - Higher altitudes, larger area collection rates vs linear mode systems
  - BUT – uses an array of 1000's of detectors rather than a single detector like in most linear mode systems

8 points/m2 Collection	Current Linear Mode	Flash (Linear Array)	Photon Counting PMT	Harris Geiger-mode Sensors
Altitude (AGL)	150 - 1500m	500-2000m	1000-8500m	4000-11000m
Field of View	45-60º	5-10º	10-40º	30º
Flight Speed	50-100 kn	200-250 kn	100-200kn	200-450kn
Laser Power	200-500mW	120-400mW	1-2W	20-40W
PDE	N/A	N/A	10-15%	25-40%
Pulse Width (Resolution)	1 - 10 ns	5 - 10 ns	700-900ps	300-600ps
Timing Jitter (Precision)	50-500ps	50-500ps	50-100ps	250-500ps
Pulse Repetition Frequency	100 - 800kHz	20-30Hz	20-35kHz	50-90kHz
Detector Count	less than 10	16k	100	4096
Ground Samples/Second	100k-800k	325k-500k	200-350k	200M-400M
Return Surface(s)	1,4,Full Waveform	1, Multiple	Multiple	Multiple
Area Coverage Rate (w/ desired overlap)	**50-180km^2/hour**	**40-160km^2/hour**	**170-500km^2/hour**	**1000-1600 km^2/hour**
Operational Maturity	**20-25 years of airborne operation; Evolutionary Improvements**	**Limited operations in airborne mapping; Technology undergoing incremental improvement**	**< 5 years in experimental mapping operations; Emerging technology undergoing rapid improvement**	**5-10 years in defense operations mapping hundreds of thousands of km^2; Over 15 years in experimental use; Emerging technology undergoing rapid improvement**

Chart from Harris.com

Volume 8, Issue 9



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Article

Evaluation of Single Photon and Geiger Mode Lidar for the 3D Elevation Program

Jason M. Stoker [1,*], Qassim A. Abdullah [2], Amar Nayegandhi [3] and Jayna Winehouse [4]

[1] U.S. Geological Survey, Reston, VA 20192, USA

[2] Woolpert, Arlington, VA 22206, USA

[3] Dewberry Consultants LLC, Fairfax, VA 22031, USA

[4] U.S. Geological Survey, Lakewood, CO 80225, USA

* Author to whom correspondence should be addressed.

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Abstract: Data acquired by Harris Corporation's (Melbourne, FL, USA) Geiger-mode IntelliEarth™ sensor and Sigma Space Corporation's (Lanham-Seabrook, MD, USA) Single Photon HRQLS sensor were evaluated and compared to accepted 3D Elevation Program (3DEP) data and survey ground control to assess the suitability of these new technologies for the 3DEP. While not able to collect data currently to meet USGS lidar base specification, this is partially due to the fact that the specification was written for linear-mode systems specifically. With little effort on part of the manufacturers of the new lidar systems and the USGS Lidar specifications team, data from these systems could soon serve the 3DEP program and its users. Many of the shortcomings noted in this study have been reported to have been corrected or improved upon in the next generation sensors.

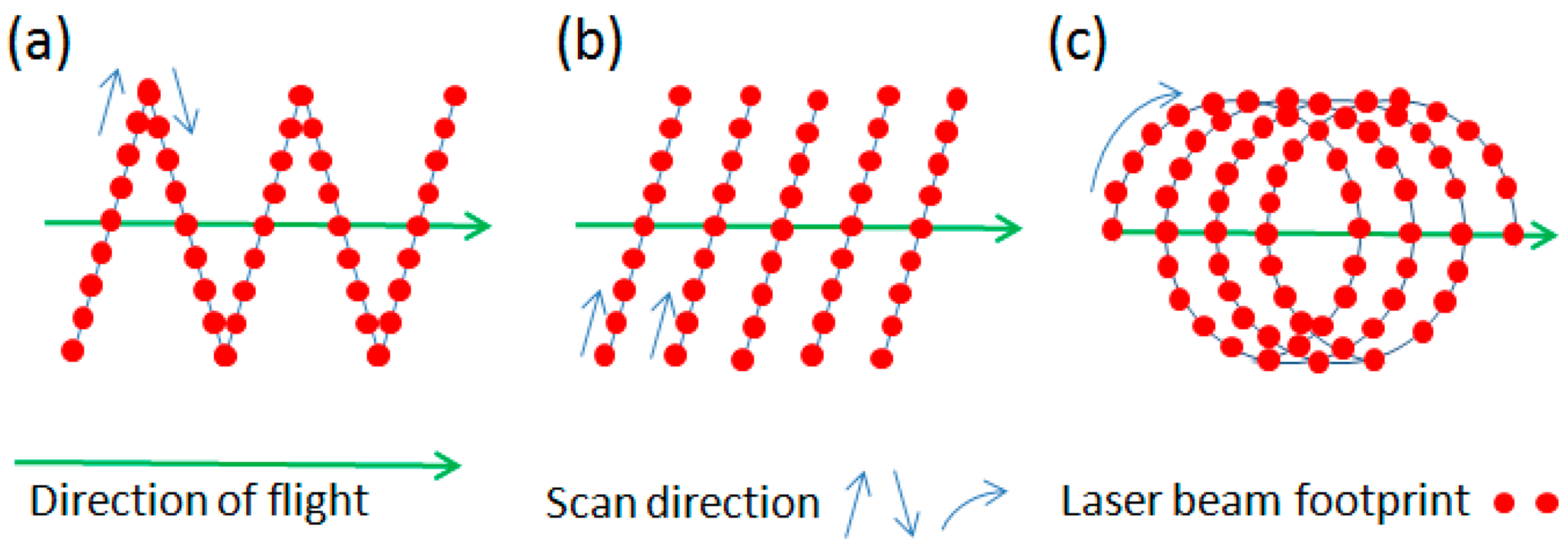
Keywords: lidar; Geiger-mode; single photon

How these systems are different

Palmer scanner

Both SPL and GML employ Palmer scanners- which allow for fore and aft looks along flight line

Not unique to these systems however



From: Fernandez-Diaz, J.C.; Carter, W.E.; Shrestha, R.L.; Glennie, C.L. Now You See It… Now You Don't: Understanding Airborne Mapping LiDAR Collection and Data Product Generation for Archaeological Research in Mesoamerica. *Remote Sens.* **2014**, *6*, 9951-10001.

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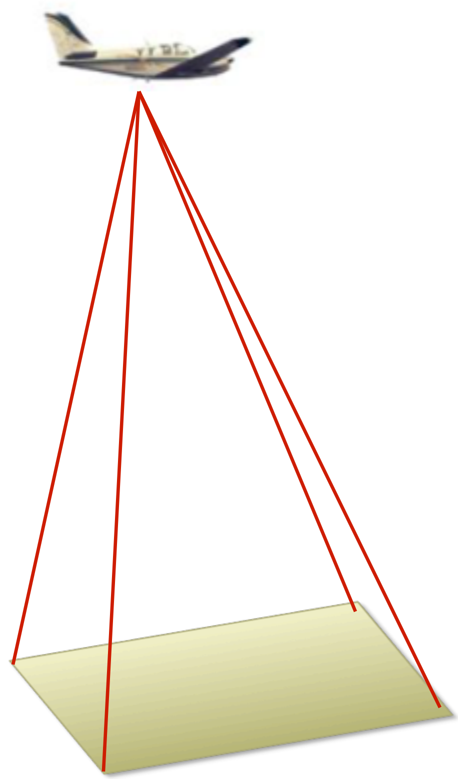
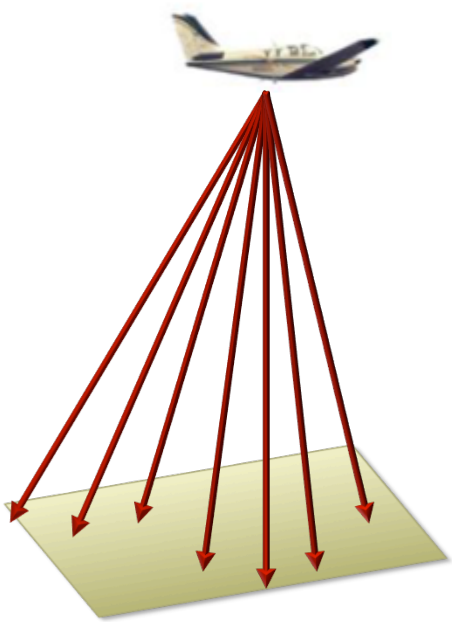
How these systems are different

Array-based detectors

SPL & GML lidar



Linear-mode lidar



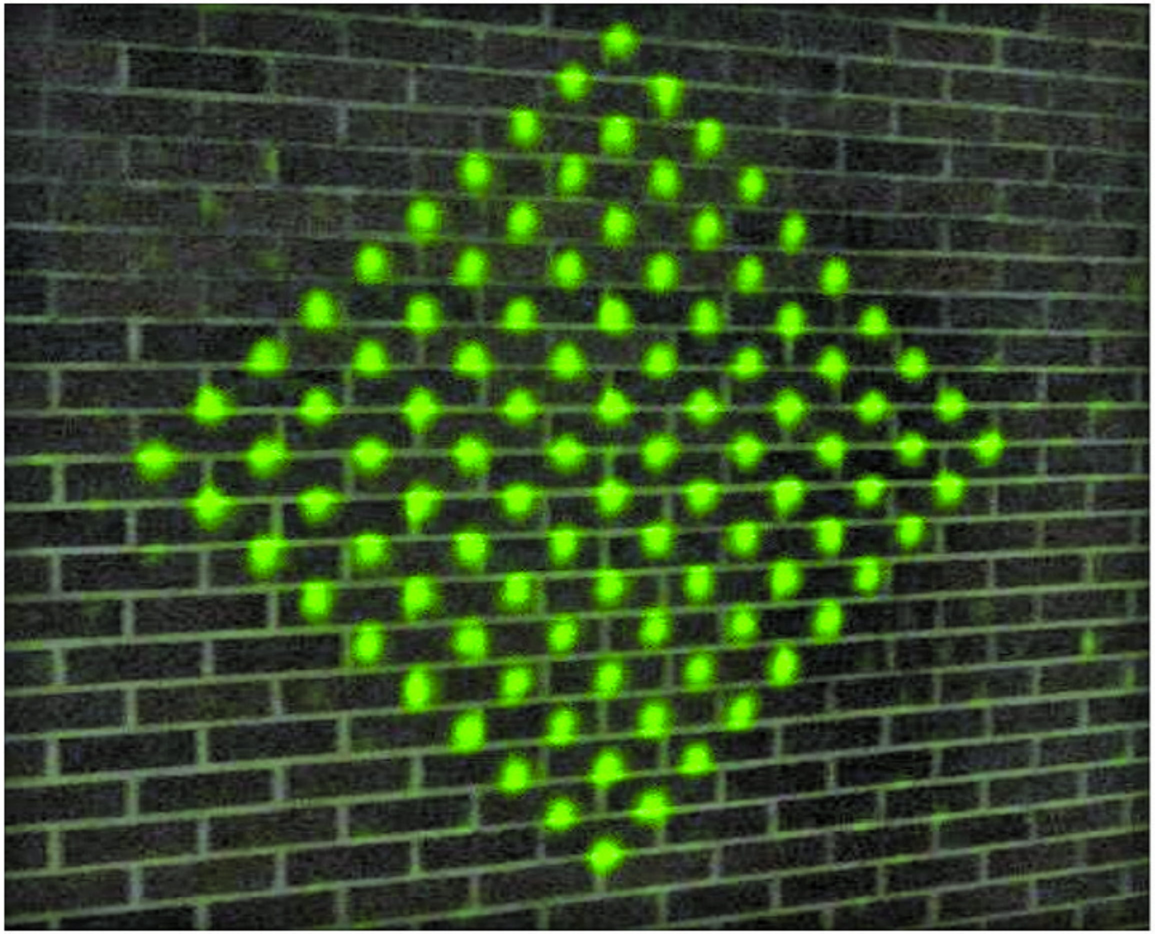
- Both SPL & GML use very sensitive array-based detectors, instead of a single detector in most linear-mode lidar systems

- SPL array: 10 x 10
- up to 10 returns per channel per laser shot, plus intensity

- Harris GML array: 32 x 128
- 1 return per channel per laser shot
- Synthetic intensity

SPL laser split in to 100 beamlets

Beamlets imaged on to an array of 10 × 10 micro-channel plate photomultiplier detectors

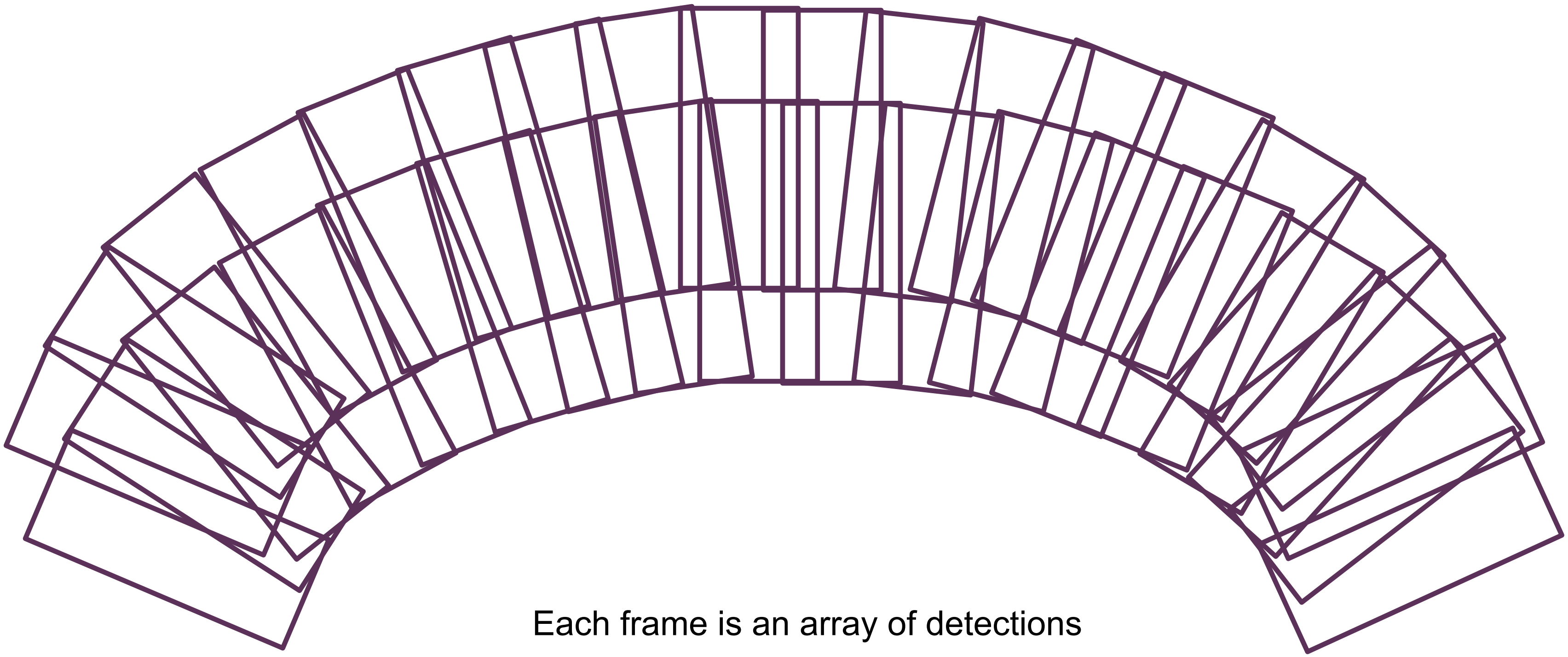


In SPL, the laser pulse is distributed through a holographic optical element to produce 100 individual beamlets.

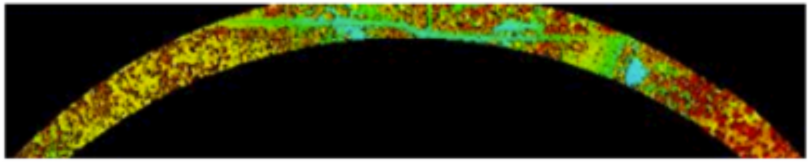
https://www.xyht.com/aerialuas/single-photon-lidar/

Building GML point clouds from aggregation

Not direct time-of-flight solution



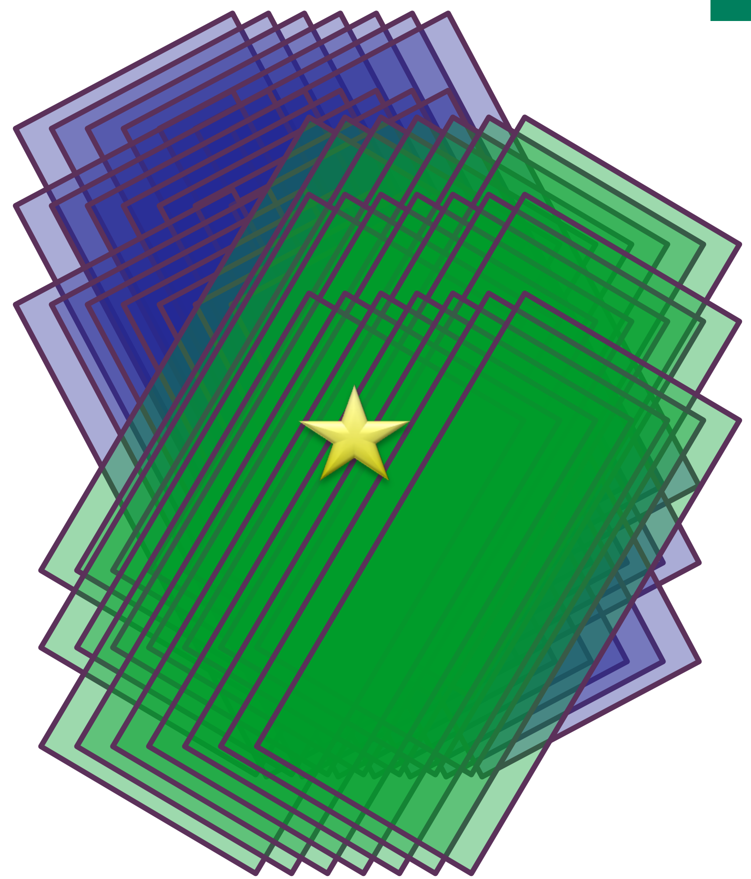
Each frame is an array of detections



GML multi-look, multiple pulses

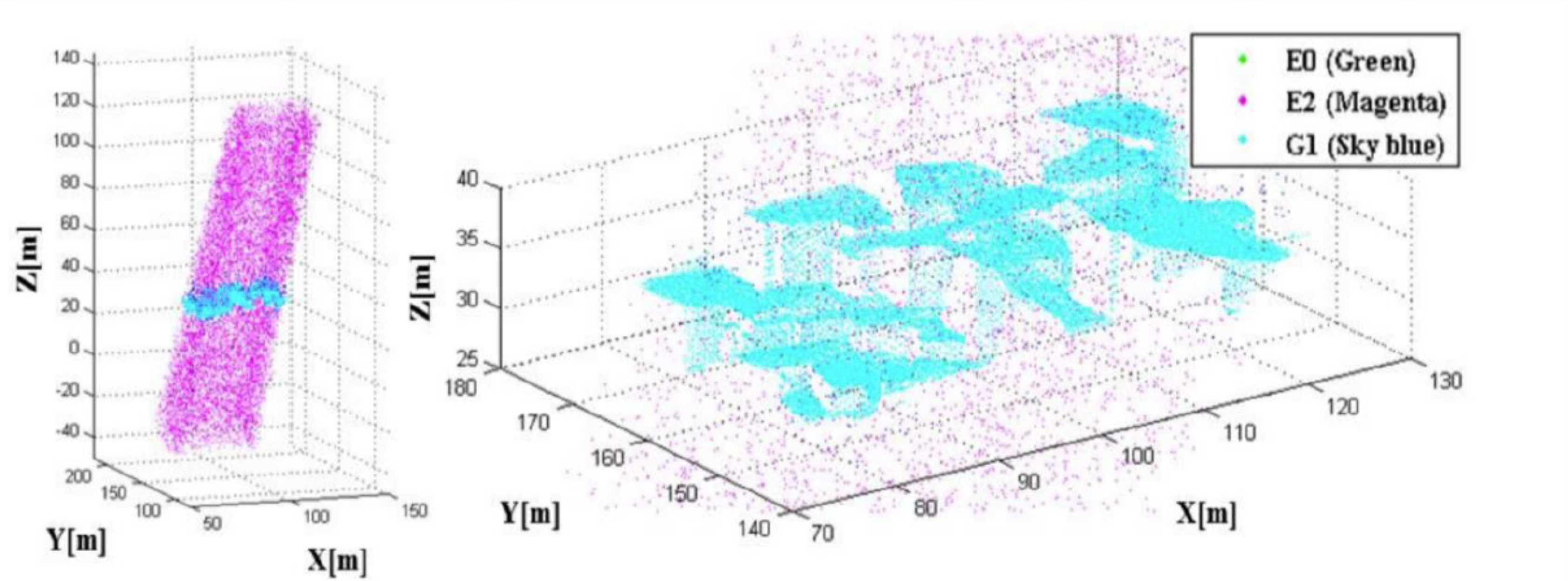
Building a histogram of photons from many angles

- Up to 4096 possible measurements per flash
- 50 khz
- Every spot is illuminated many times
- All the photons recorded are processed to determine if they are real objects
- Need multiple 'hits' per space to know if photons bounced off target, or just random solar photons hitting detector
- More hits you get, higher your probability is that it is real feature



How noisy is this stuff?

- Take a look!



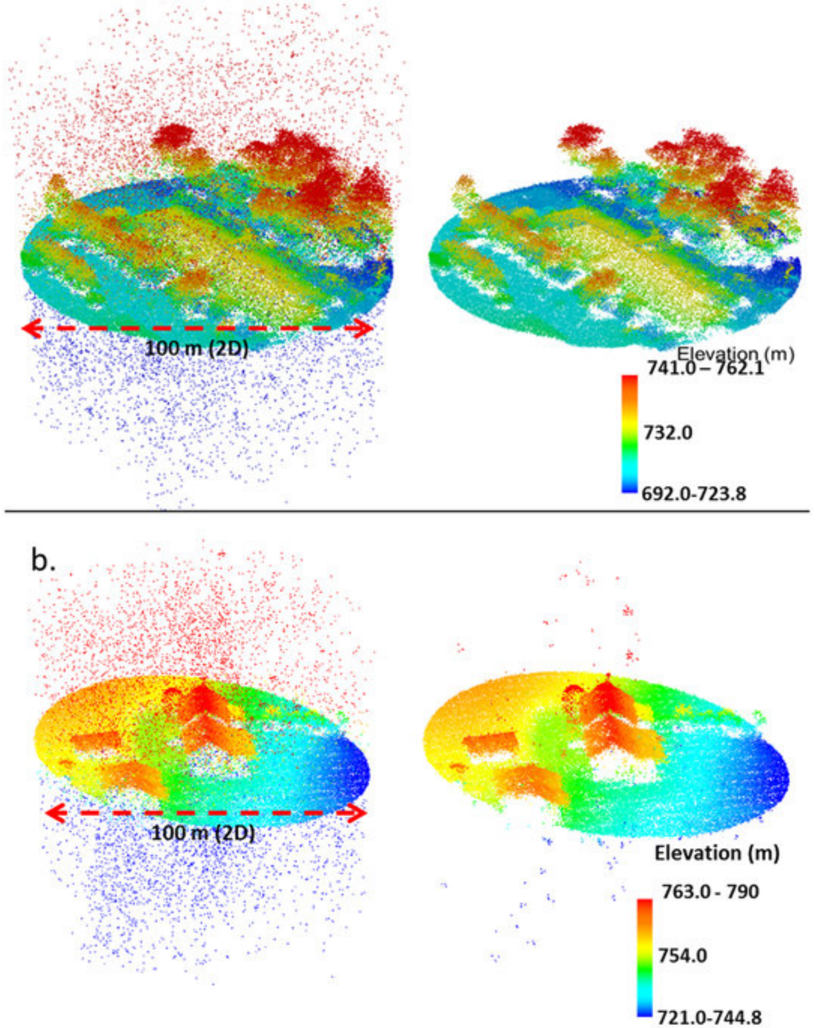
Magenta – Sky noise, Blue – real returns

Image from Kim, Seongjoon, I. Lee, and Y.J. Kwon, "Simulation of a Geiger-Mode Imaging LADAR System for Performance Assessment," *Sensors*, Vol 13, 2013.

Single Photon Example – Pre and post Noise Filter

- A lot of solar noise points in the pre-filtered data

- People are constantly building better and better noise filters



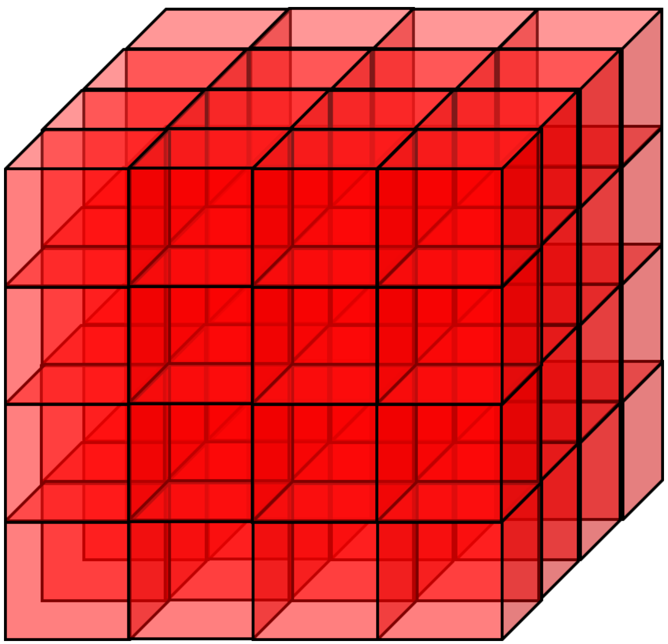
From: Swatantran, Anu & Tang, Hao & Barrett, Terence & Decola, Phil & Dubayah, Ralph. (2016). Rapid, High-Resolution Forest Structure and Terrain Mapping over Large Areas using Single Photon Lidar. Scientific Reports. 6. 28277. 10.1038/srep28277

More on the data processing methodology

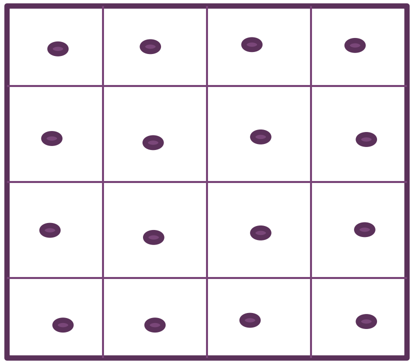
- The processing chain is more complicated than linear mode systems
- This is described through "levels" of data moving from L0 to L4
- L0 – data resides in sensor-space
- L1 – georeferenced point cloud, collection of X, Y, Z points along with sensor-specific metadata such as position information, pixel number, and frame (pulse) number, very noisy (~25% of points are noise)
- L1 to L2 – lots happens here, each vendor has their own solution, many different competing methods (will be even more as new vendors market Geiger mode)
- L2 – Denoised point cloud with synthetic intensity measurements
- L3 – Registered and merged L2 files over the same area (multiple looks)
- L4 – Point cloud-derived products (DSMs or DTMs, for example)

GML processing

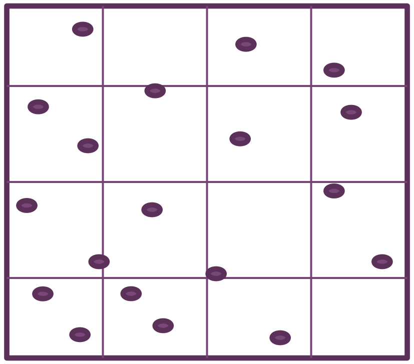
Aggregating in to voxel space to create outputs



- Aggregate consensus model using coincident GML frames
- Raw data pushed in to voxel space in ground coordinates
- Hard surface signal detection determined by number of samples per voxel
- Resolving power is much higher than linear systems at same altitudes
- **Product ground sample distance created via processing rather than pulses- adjust voxel size to get more points per unit area**

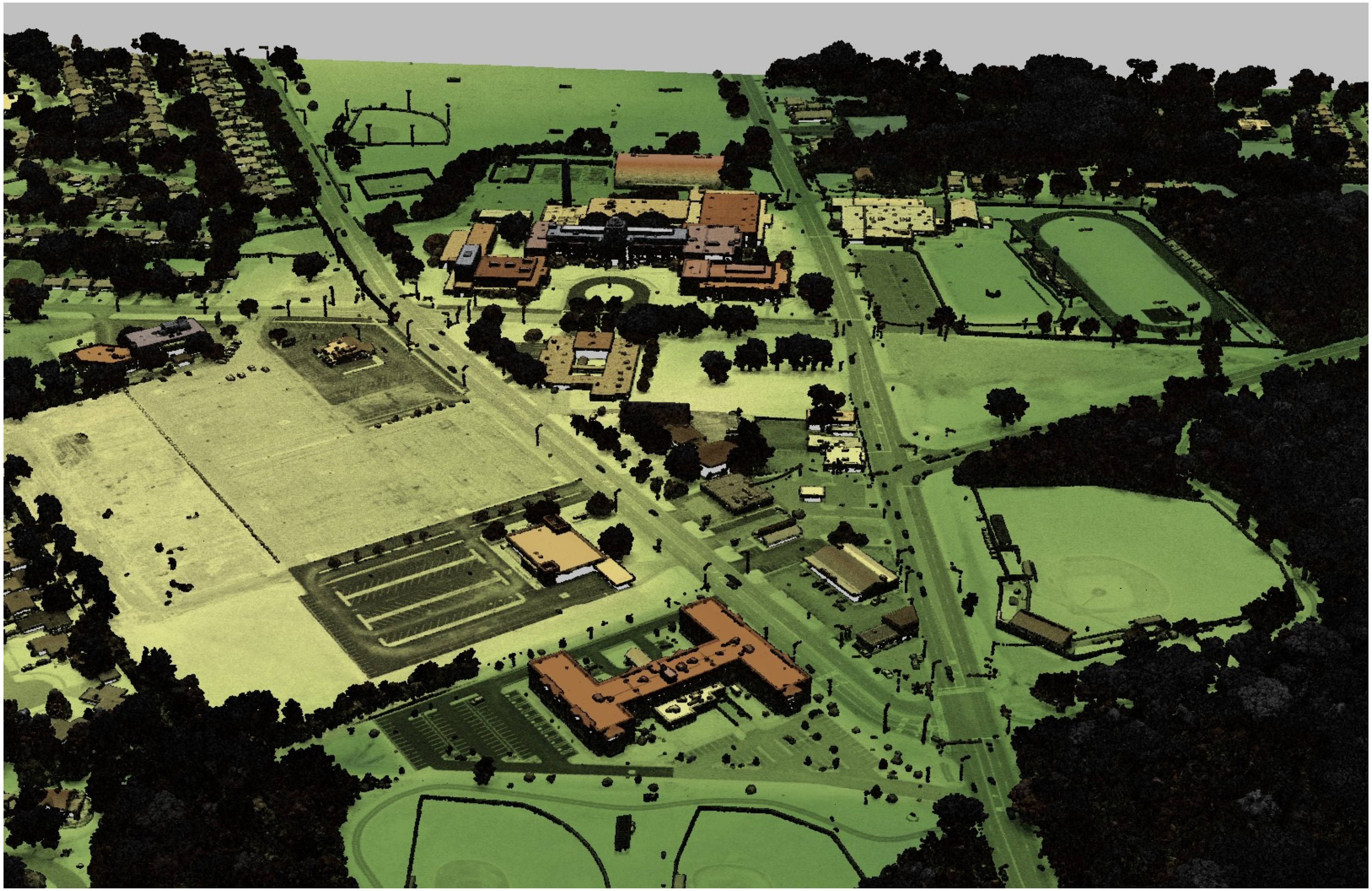


GML points



Linear points

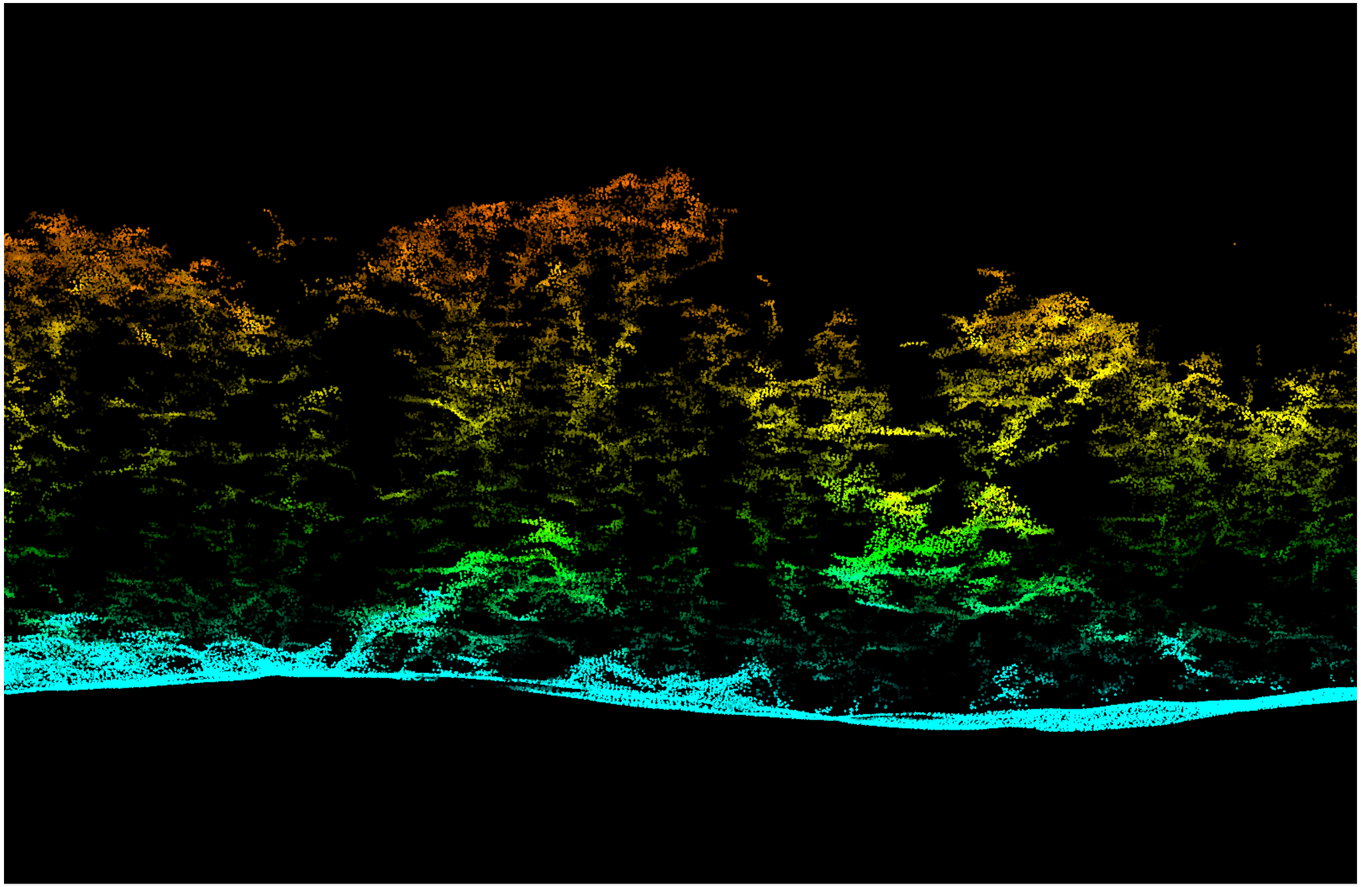
L3 GML Data- final filter



* Did not get access to noisy data

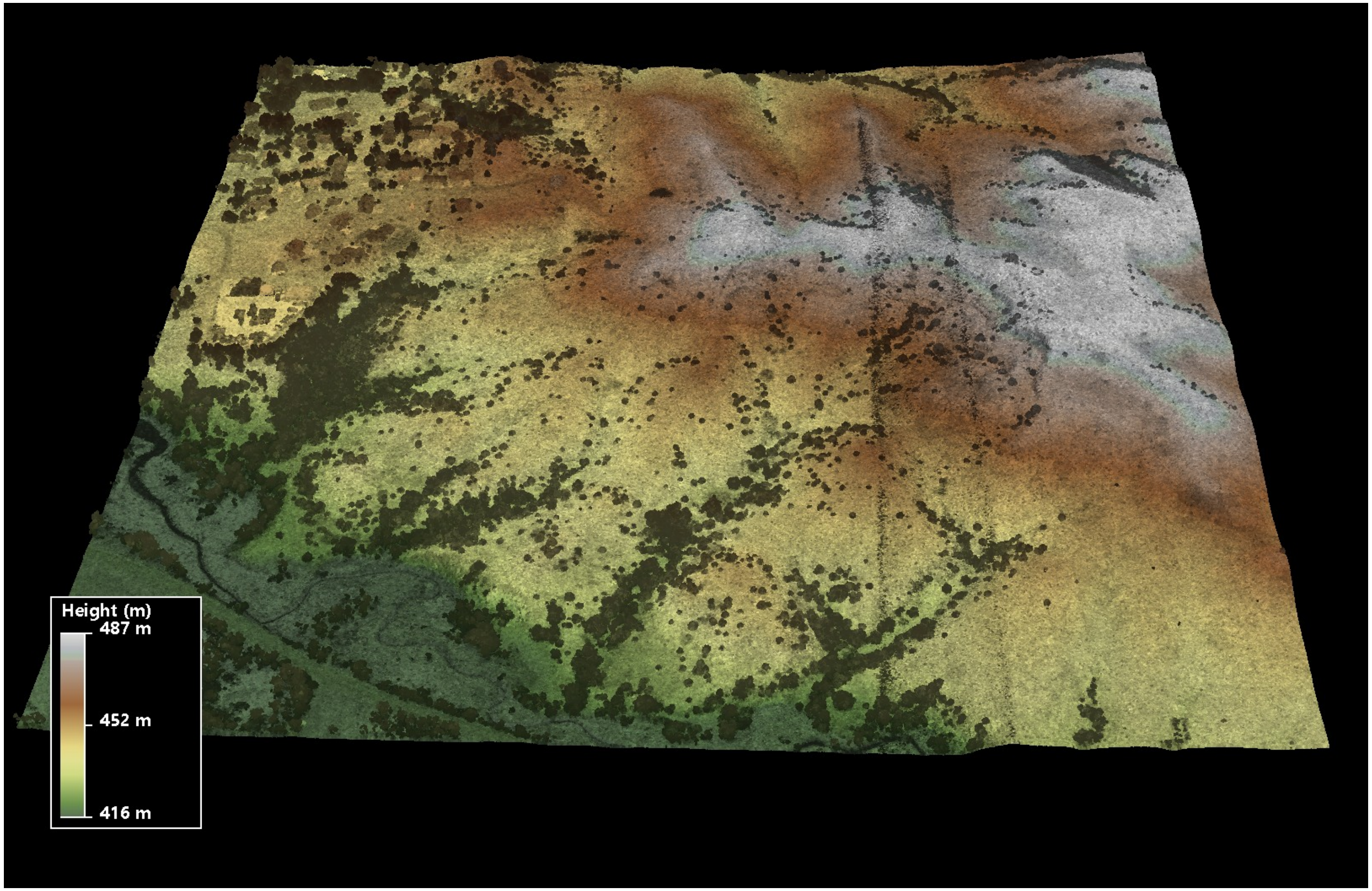
L3 Data- inside vegetation

Great FOPEN, but are we 100% sure all veg points are ‘hits’?



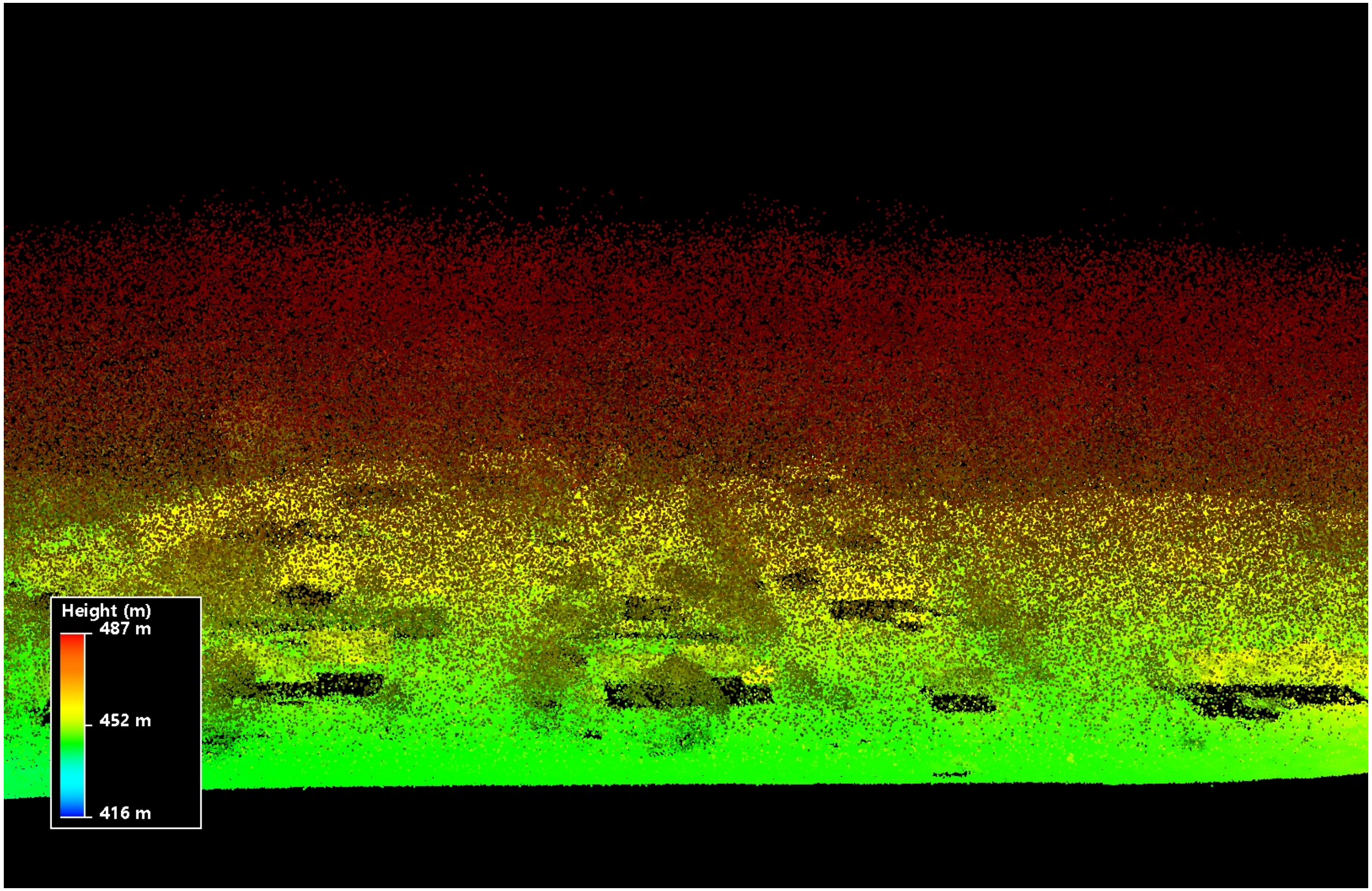
Single photon

Separating signal from noise



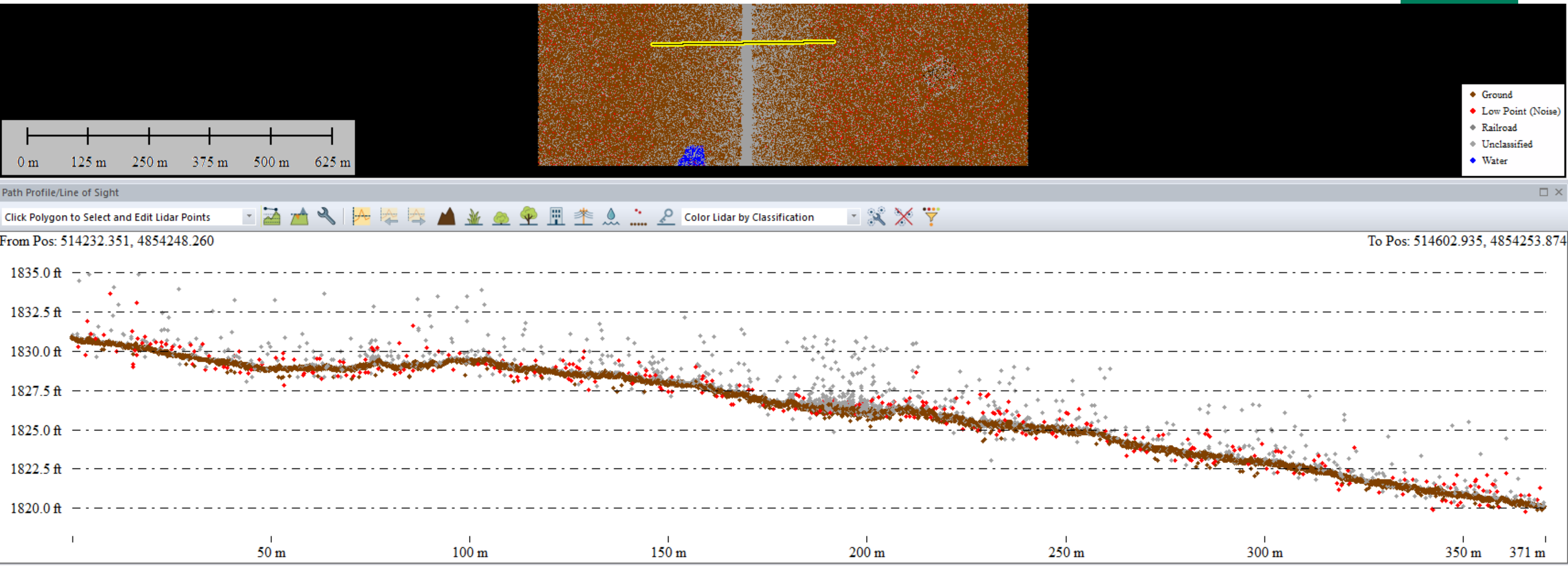
Single photon

Separating signal from noise



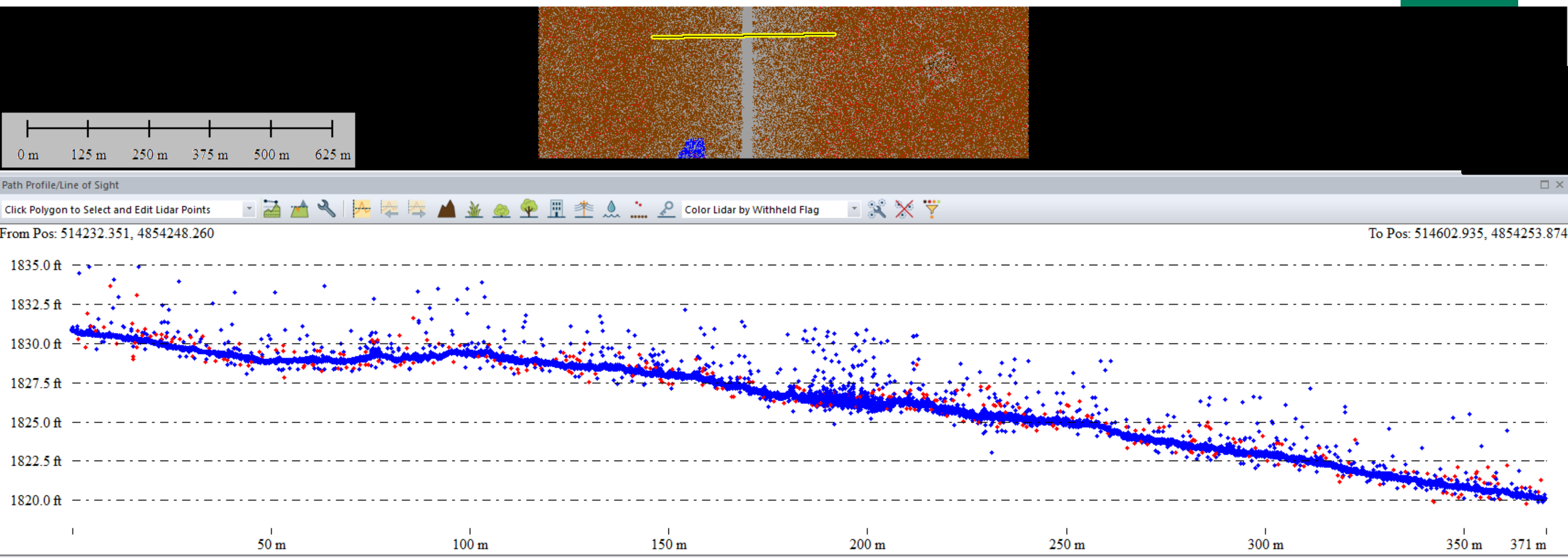
Push noise points to noise/withheld classes

SD Single Photon Example



Push noise points to noise/withheld classes

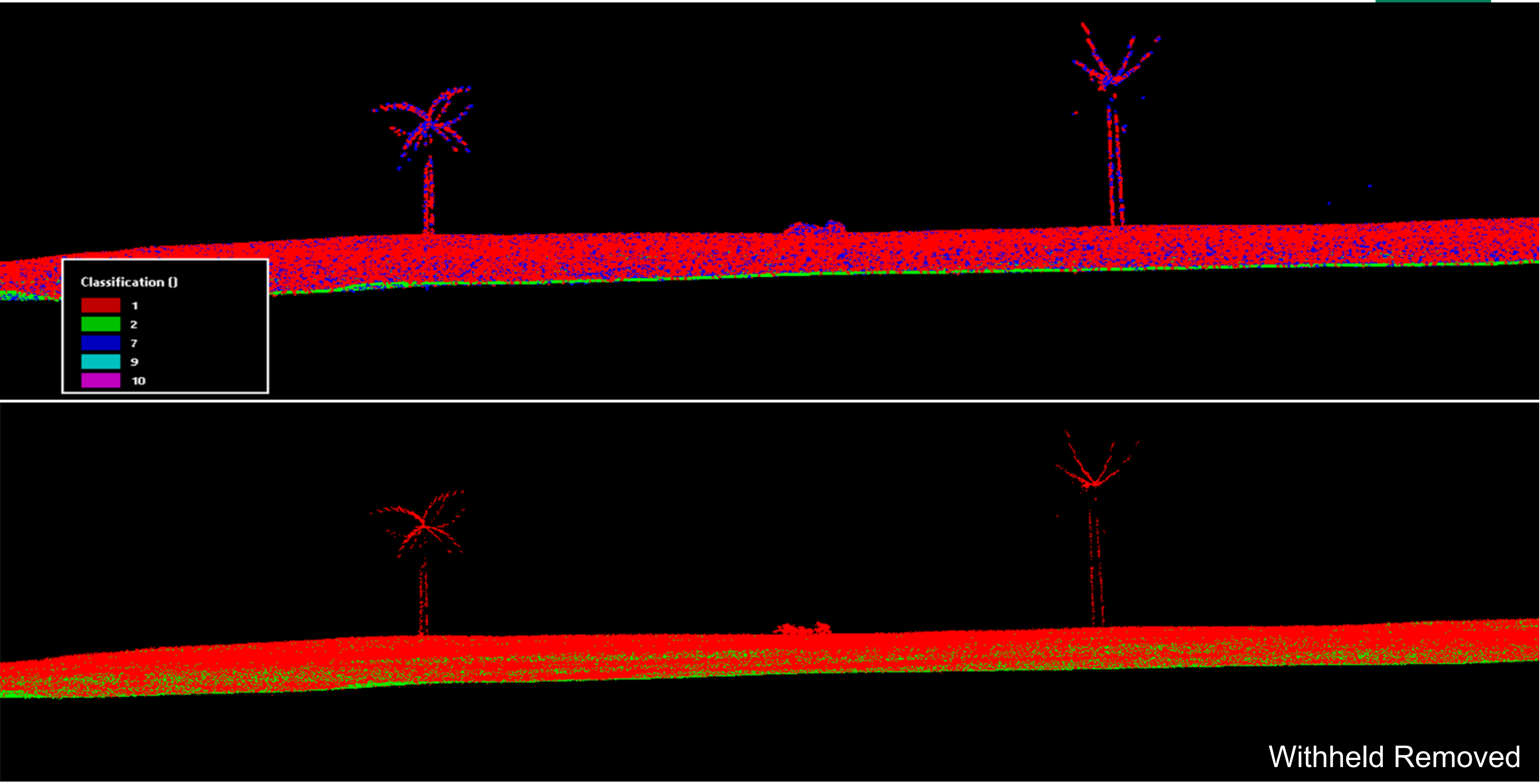
SD Single Photon Example



Red- withheld
Blue- not withheld

+ Push noise points to noise/withheld classes

SD Single Photon Example



Differences in data volumes for 3DEP

Example Single Photon project- South Dakota

Data volumes are calculated from total LAZ data volume per project divided by project area in square miles (calculated using Albers Equal Area SRS). These numbers are only from projects processed since July.

- QL2 linear mode: **73 MB/sq mile** (megabytes per square mile)
- Two QL1 linear mode projects: 148 & 589 MB/sq mile, respectively
- Average for three QL1 single photon projects: **863 MB/sq mile**
- **Single photon QL1 is >10x our QL2 average** in terms of data volumes per equal sized area. I also find it interesting that the SP data is significantly larger than the other two recent QL1 linear mode projects- but that is likely b/c they pushed noise points to noise/ withheld/ overlap.

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Collect once, sell many times

New business model for these GML/SPL systems

- A GML/SPL operator can fly once, then change filtering algorithm to create custom filtered point cloud datasets for different customers

- 3DEP is trying to respond to this model- what do we ask for?
  - Currently getting QL2 (2 pts/sq m) or QL1 (8+ pts/sq m) data, but who controls what points we get? Do we get the 'best points'?
    - What does that even mean?

Some "thought-provoking" questions for Breakouts

- Regarding technologies such as GML and SPL, is there a community demand for 'raw' L1/L2 data?
  - If L1/L2 is proprietary (or unaffordable), then what?
- Who/where should that L1/L2 data be stored?
- How should we share de-noising algorithms?
  - Should there be a multi-use 'winner', or app-specific filters?
    - e.g. filter works great on bare earth, but sucks on veg
- Should these methods be standardized? A standard community definition for L1 vs L3?
- How can we make sure that GML, SPL and linear-mode lidar data are interoperable (e.g. extracting vegetation information or for change detection)?