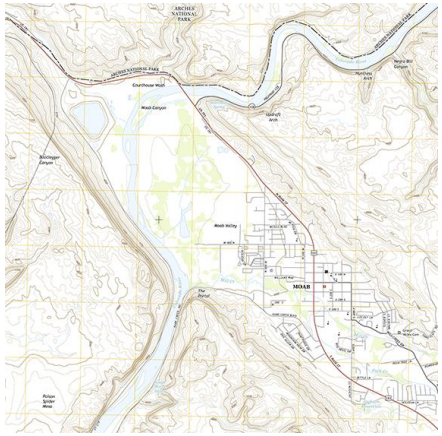
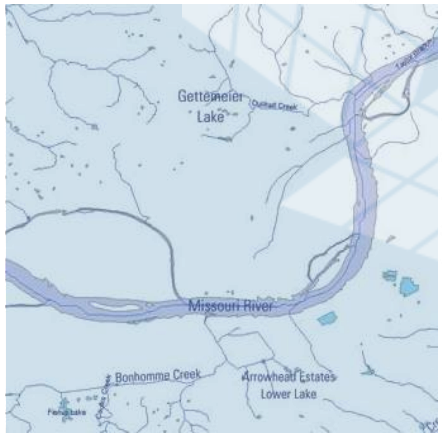
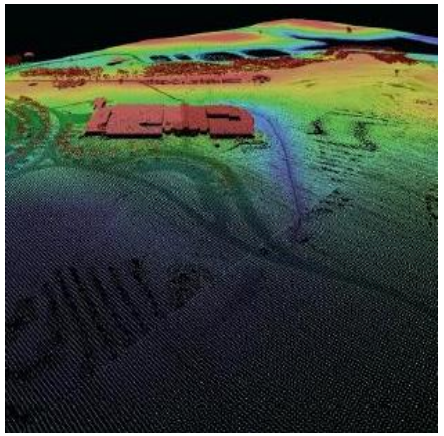
Geiger Mode and Single Photon Evaluation







Jason Stoker, USGS
Qassim Abdullah, Woolpert
Amar Nayegandhi, Dewberry

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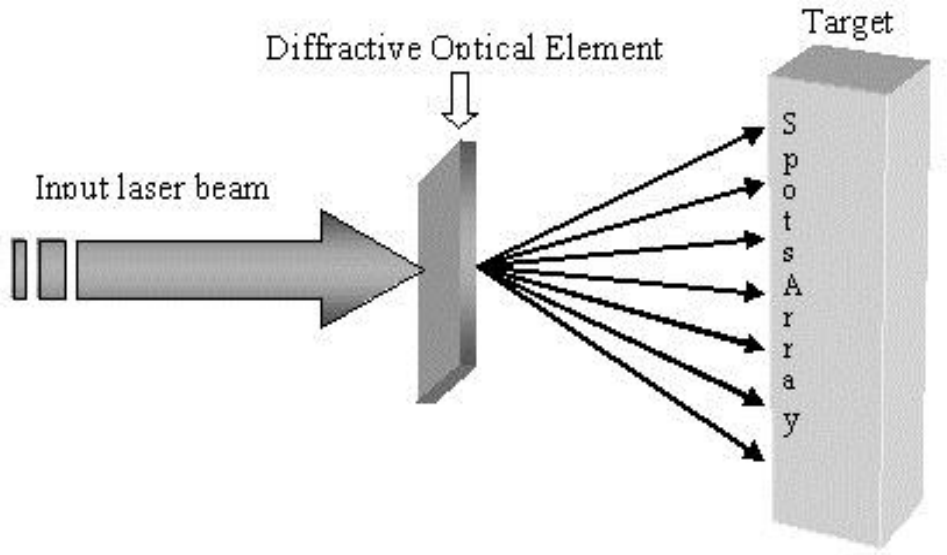
Outline

- Introduction (Qassim)
- Data sets and evaluation methodologies (Amar)
- Results (Amar/Qassim/Jason)
- Conclusions and next steps (Jason)

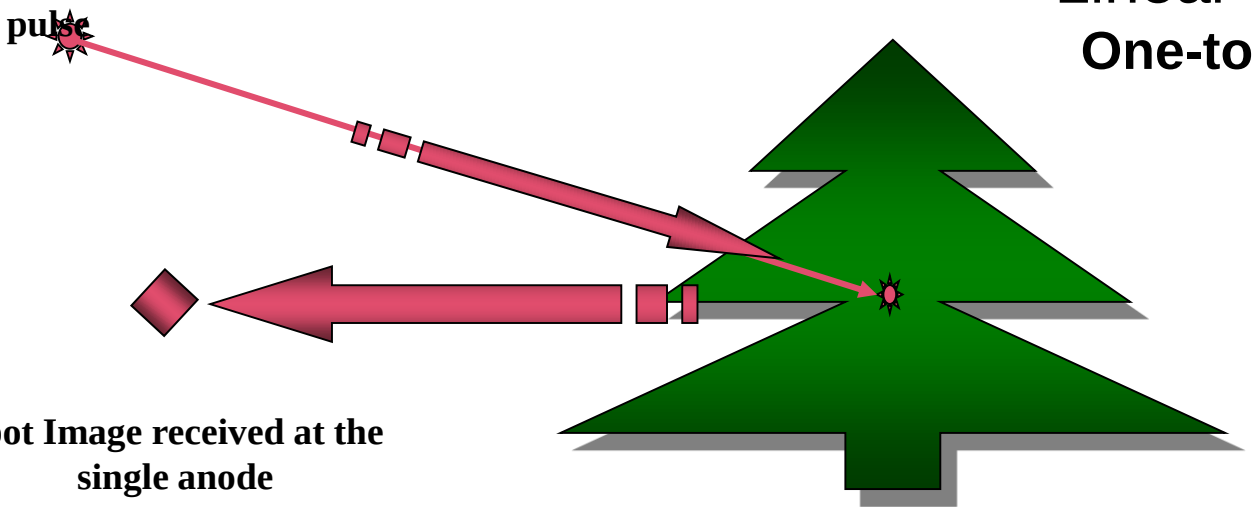
Single Photon and Geiger Mode Lidar

It is like a Laser-based Digital Camera



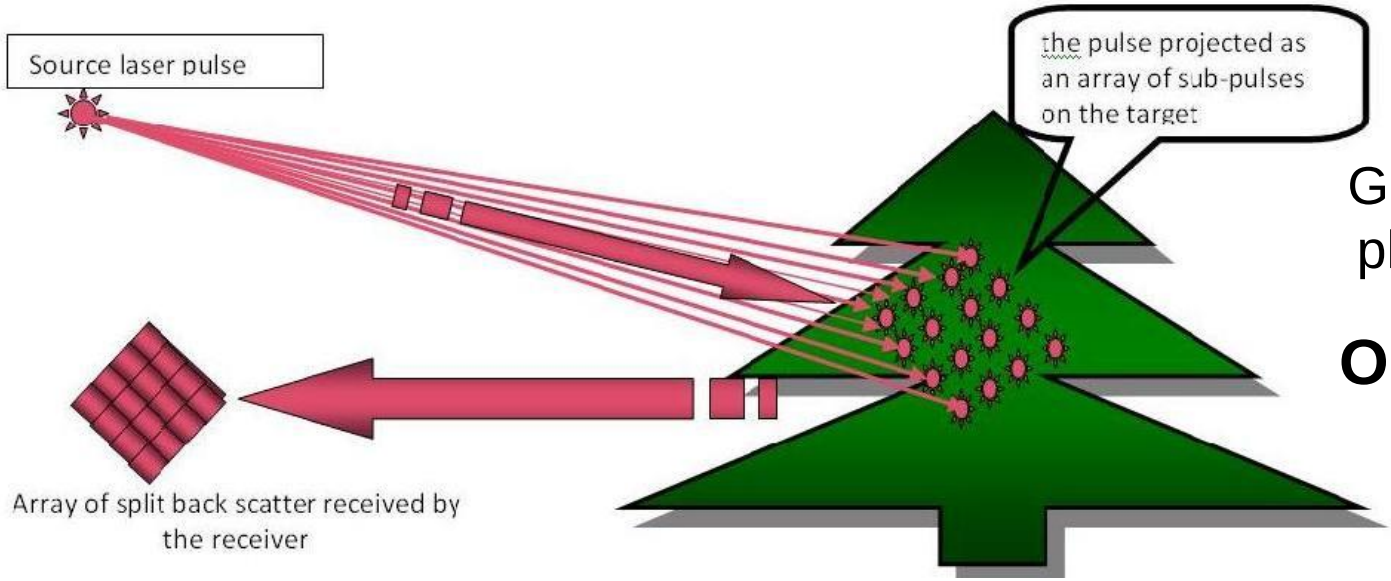
Linear Lidar

One-to-one



Geiger/single photon Lidar

One-to-many



Background

Emergent Technologies and 3DEP

- GM and SP lidar advertised as commercially ready
- Interest due to potential gains in data density, acquisition speed, and potential cost savings for the 3DEP program, advertised even in leaf-on conditions
- Extensive marketing, but little independent ground truthing and public domain data
- Study to address suitability of new techs for 3DEP use and provide baseline
- Independent evaluations of collections of same location with existing linear mode data available
- Not interested in picking a winner, just in evaluating and exploring the new data

GPSC Task Order

Dewberry and Woolpert GPSC tasks

- Collect some leaf-on data using linear-mode lidar system (Woolpert) for comparison of leaf on canopy penetration
- Assess effect of solar reflectance on data (day vs night collects)
- Assess Quality of Reflectance/Intensity Images
- Process as much as possible to USGS Lidar base specification
- Comprehensive Reports on findings and recommendations
- Not assessing cost in this evaluation - only performance

Data Sets Evaluated for this Study

Abbreviation	Data Type	Acquired By	Type of Collect	Date / Year Collected	Collection Altitude (AGL)
LMDewLF14	Linear Mode	Dewberry	Leaf-Off	April/May 2014	3,000 ft
LMWptLO15	Linear Mode	Woolpert	Leaf-On	September 2015	7,000 ft
GMHarLO15_26k	Geiger Mode	Harris	Leaf-On	September 2015	26,000 ft
GMHarLO15_7.5kDT	Geiger Mode	Harris	Leaf-On, Day Time	September 2015	7,500 ft
SPSigLO15_7.5k	Single Photon	Sigma Space	Leaf-On	August 2015	7,500 ft
GMHarLF15_26k*	Geiger Mode	Harris	Leaf-Off	December 2015	26,000 ft

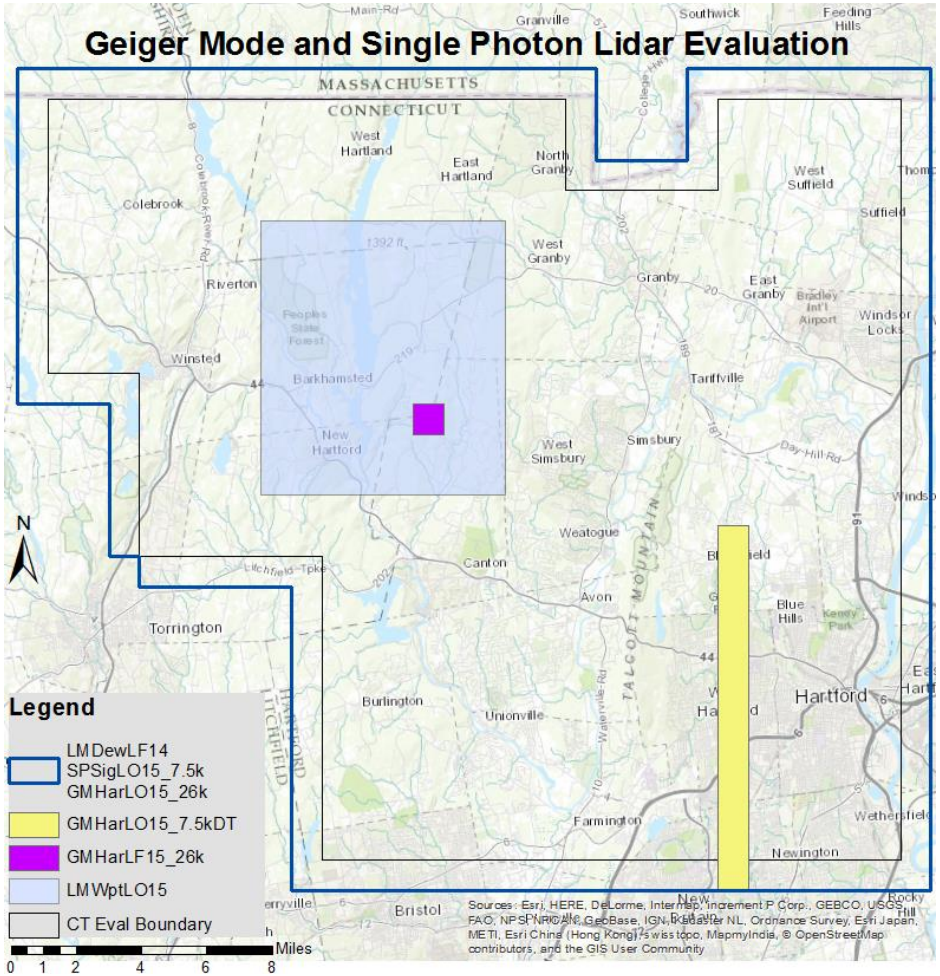
* Collected after original leaf on evaluation collection

Observations on the Delivered Data

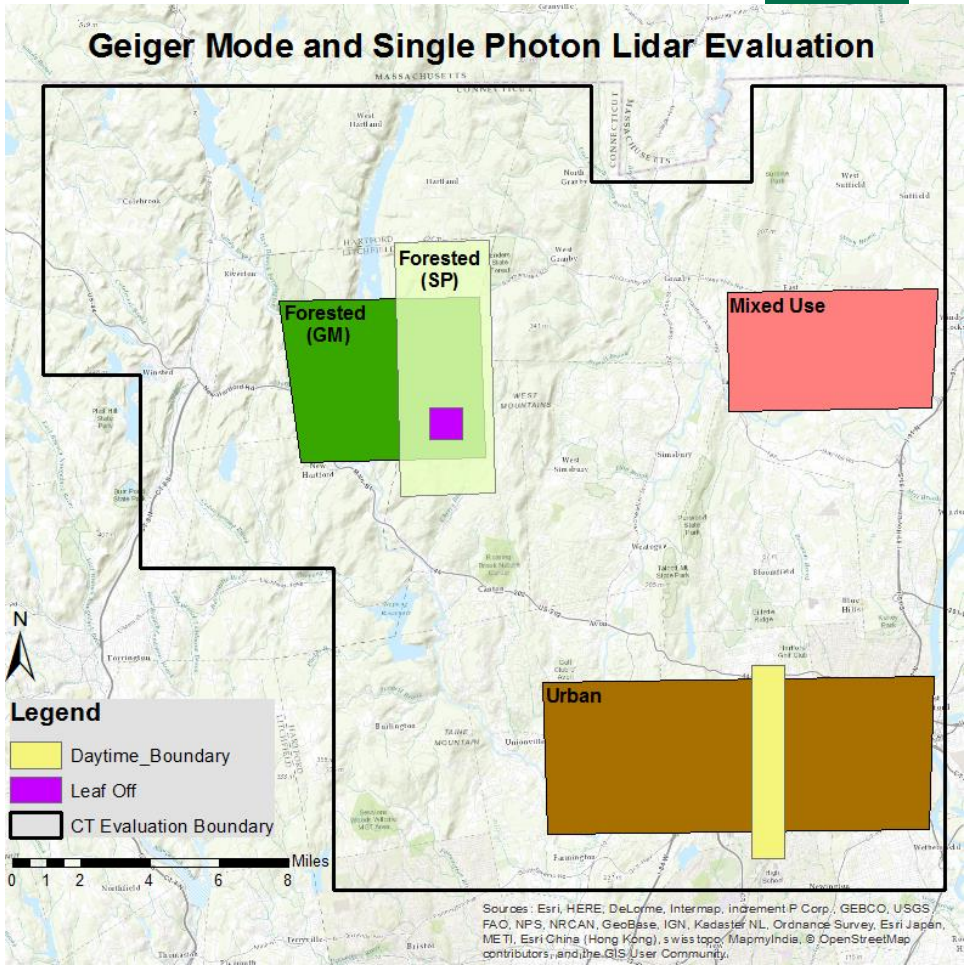
- Geiger Mode from Harris Corporation (IntelliEarth):
  - Data coverage was complete
  - Received LAS v1.4 for point clouds + Reflectance images
  - Tiled delivery, no swath information
  - Data collected using 23 flight lines acquisition plan
- Single Photon from Sigma Space Corporation (HRQLS):
  - Data was missing some areas affected by fog
    - Due to quick turnaround for evaluation
  - Received LAS v1.2 for point clouds, no intensity / reflectance images
  - Data delivered on swath-based as requested
  - Data collected using 109 flight lines acquisition plan

Project Area and Evaluation Boundaries

Data Acquired for this Study



Data Processed for this Study



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Compliance with Current Specification

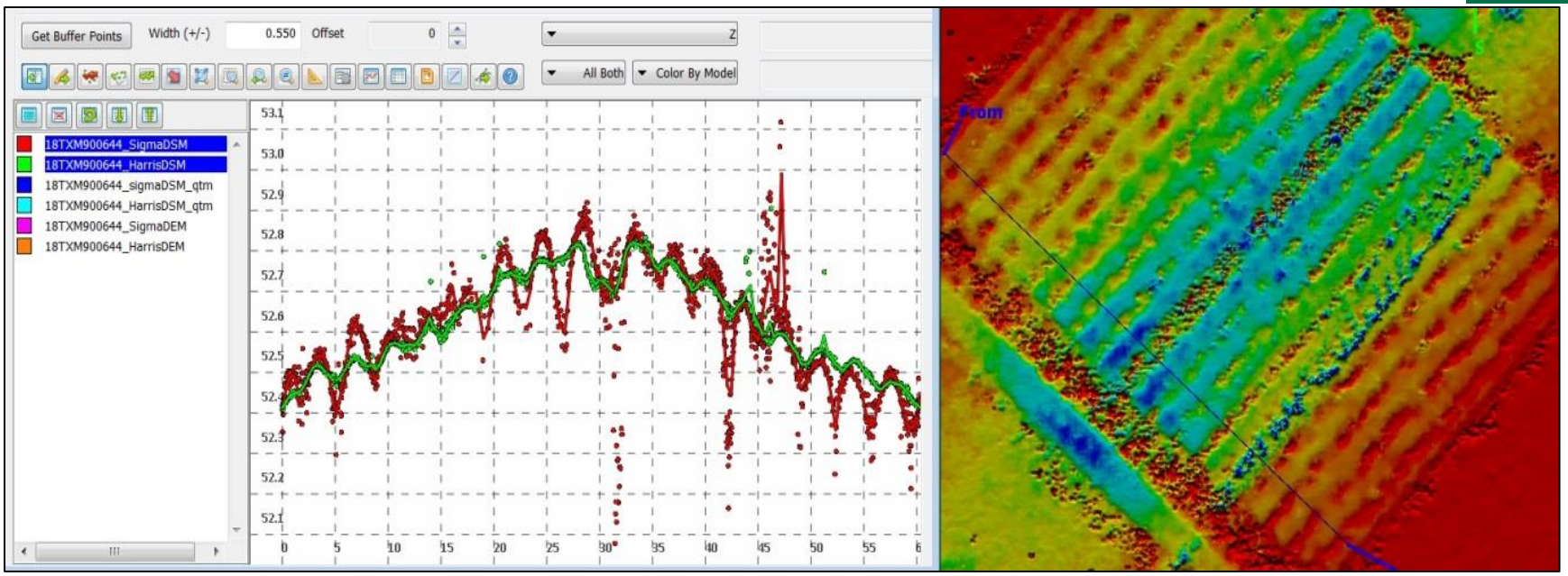
Requirement	IntelliEarth	HRQLS	Comments
LAS Version 1.4	LAS v1.4	LAS v1.2	Both data sets LAS v1.4 compatible
Point Data Format	Compliant	Compliant	
Coordinate Reference System	Compliant	Compliant	
Global Encoder bit	Compliant	Compliant	
Time Stamp	Compliant	Not Compliant	IntelliEarth – unique but not based on acquired swaths. HRQLS – none provided.
System ID	Compliant	Compliant	
Multiple Returns	Not Compliant	Not Compliant	Both datasets did not include multiple returns.
Point Source ID	Not Compliant	Compliant	IntelliEarth – No flight swaths.
Intensity	Reflectance	Not Compliant	IntelliEarth – similar to linear-mode HRQLS – no intensity data
Overlap and withheld	Not Compliant	Compliant	IntelliEarth – No flight swaths.
Scan Angle	Not Compliant	Not Compliant	Spec not compatible with these sensors.
XYZ Coordinates	Compliant	Compliant	

Data Density

- Data from both GML and SPL were found to be extremely dense throughout the project area.
- Point clouds density ranged from 16 to 33 points per square meter depending on the location and ground cover type.
- Average Density for HRQLS = 23.2 ppsm @7,500ft AGL
- Average Density for IntelliEarth = 25.4 ppsm @26,000ft AGL

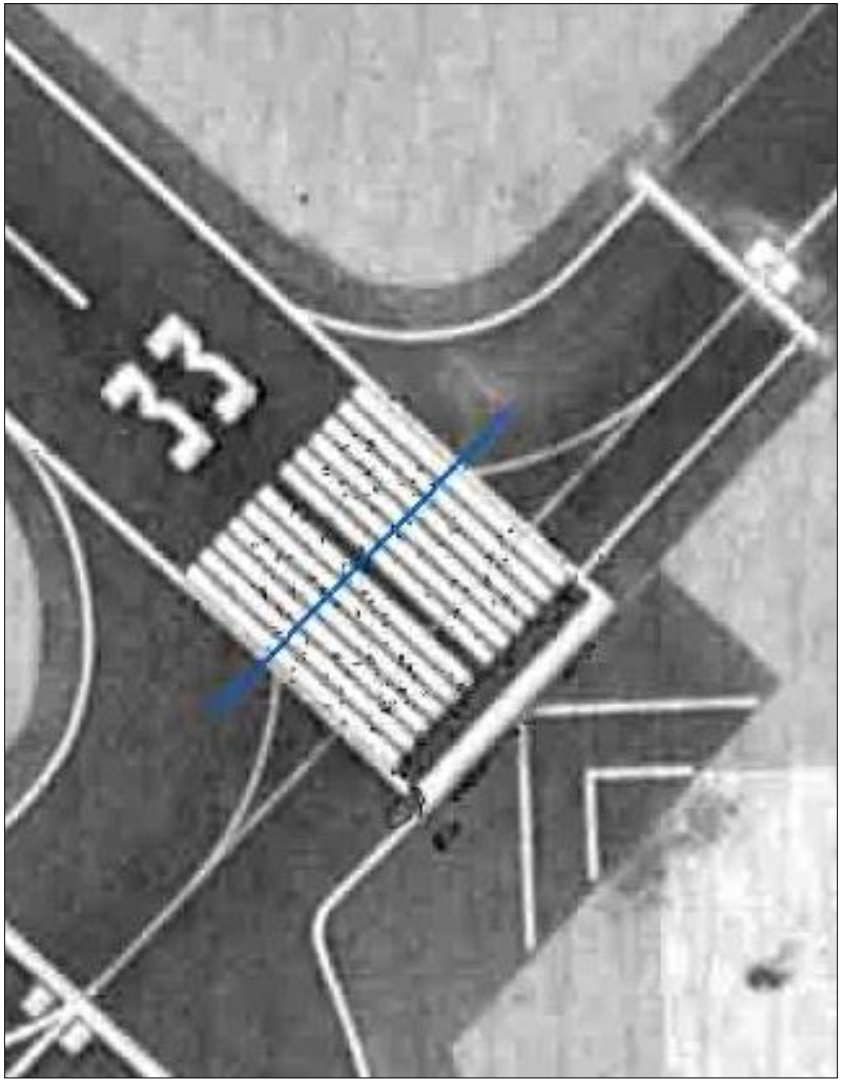
TILE #	Terrain Cover Type	Sigma Space HRQLS		Harris IntelliEarth™	
		Point Density (pts/m2)	Nominal Post Spacing (m)	Point Density (pts/m2)	Nominal Post Spacing (m)
18TXM720639	heavy vegetation	19	0.23	32	0.17
18TXM915635	vegetation	23	0.21	29	0.19
18TXM900644	mixed use - open	30	0.18	16	0.25
18TXM915645	mixed use - open	30	0.18	16	0.25
18TXM720639	heavy vegetation	19	0.23	32	0.18
18TXM705642	heavy vegetation	18	0.24	33	0.18

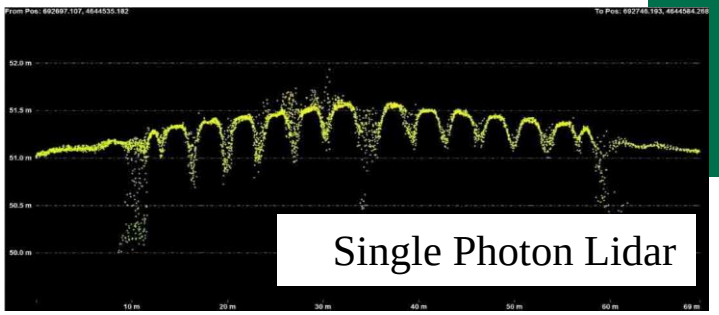
Data Smoothness: Painted Road Stripes

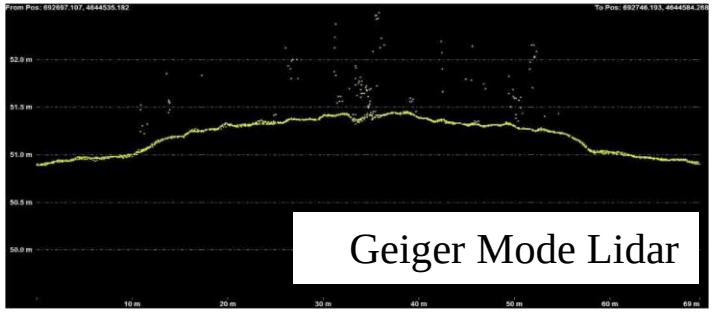


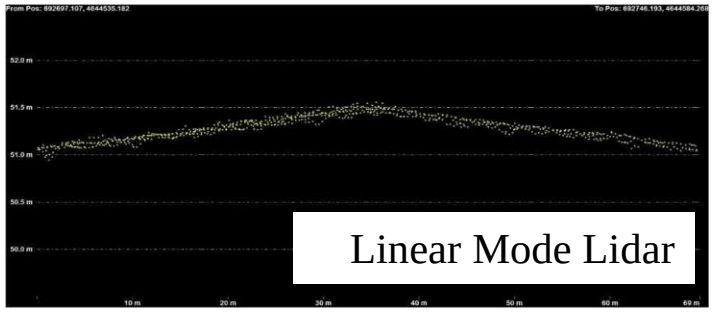
Noise in both SPL and GML due to painted stripes on runway (Green = GML Red = SPL).

Range “walk” on retro-reflective surfaces









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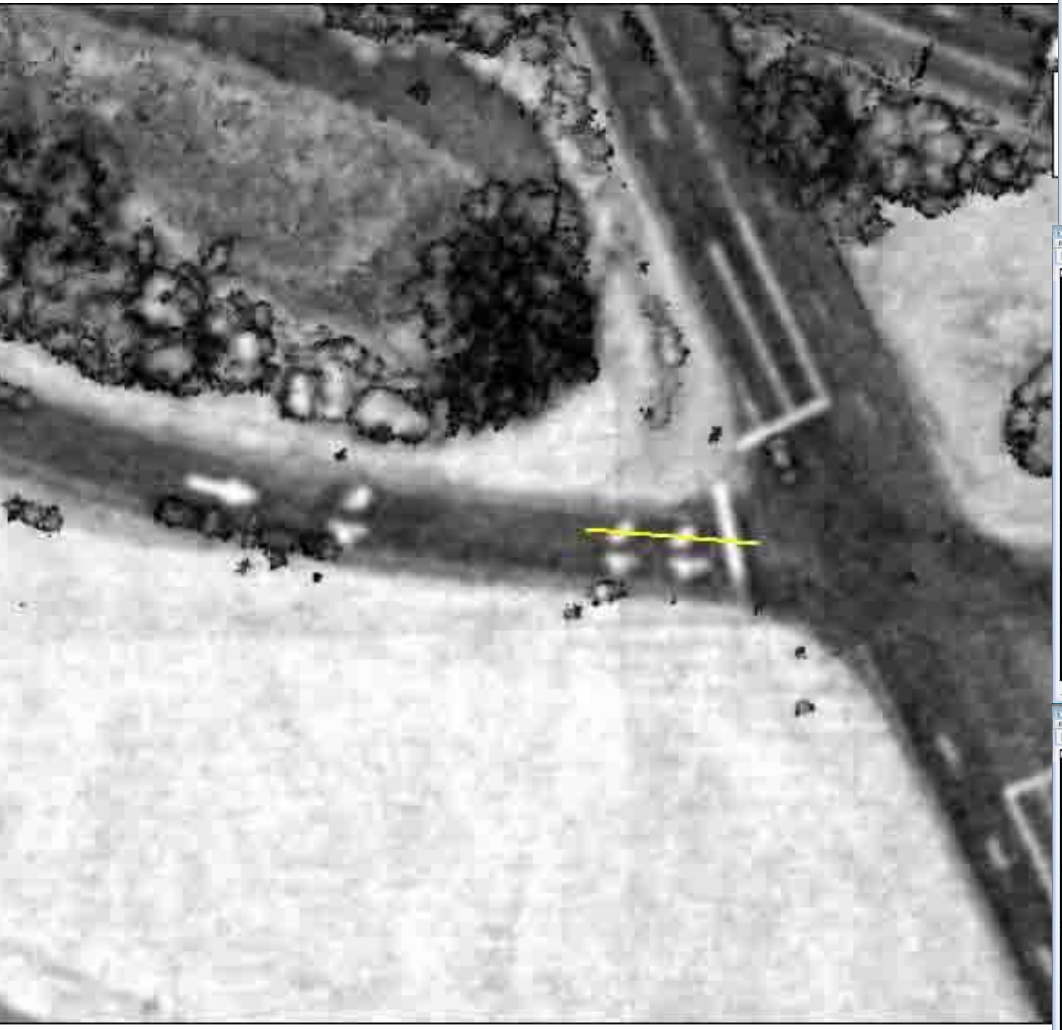
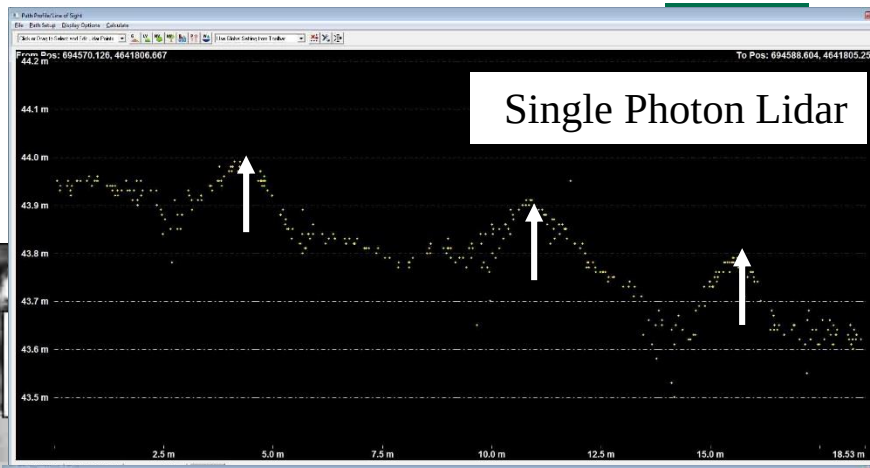
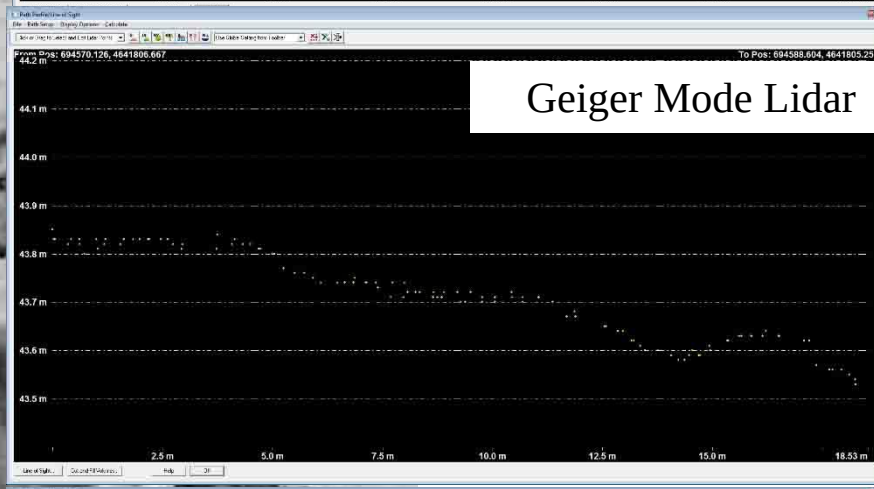
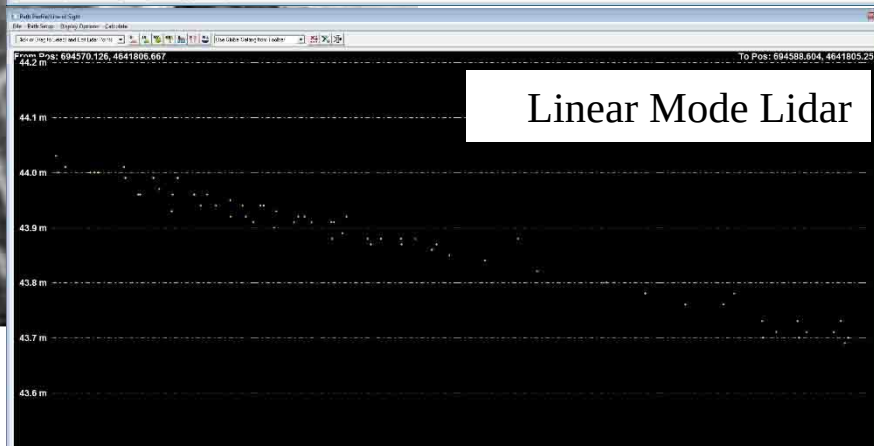
Range “walk” – road signs









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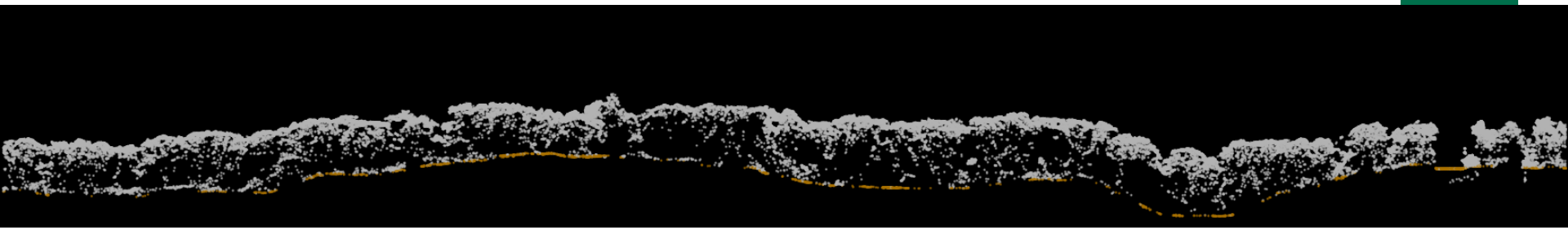
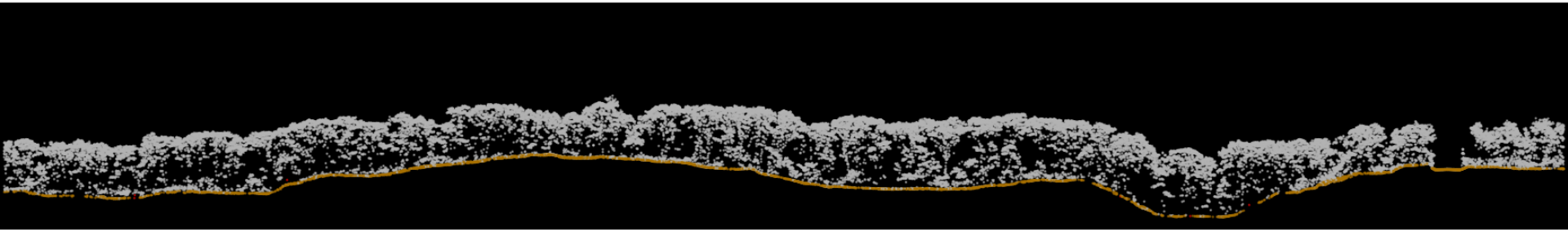
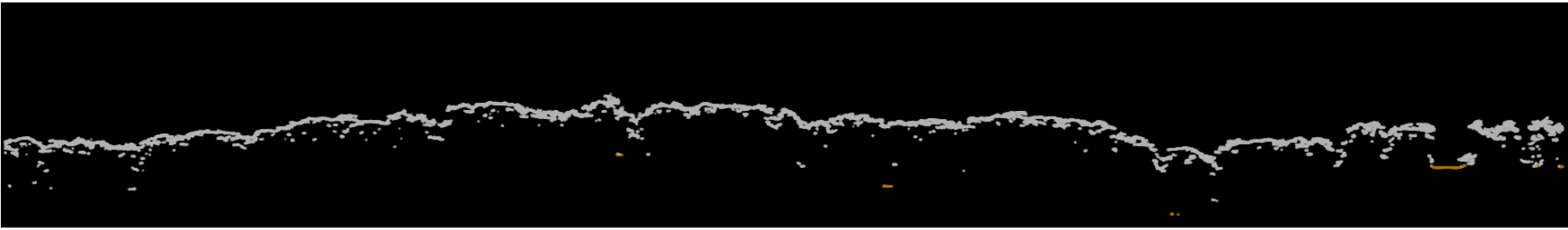
Profile comparisons



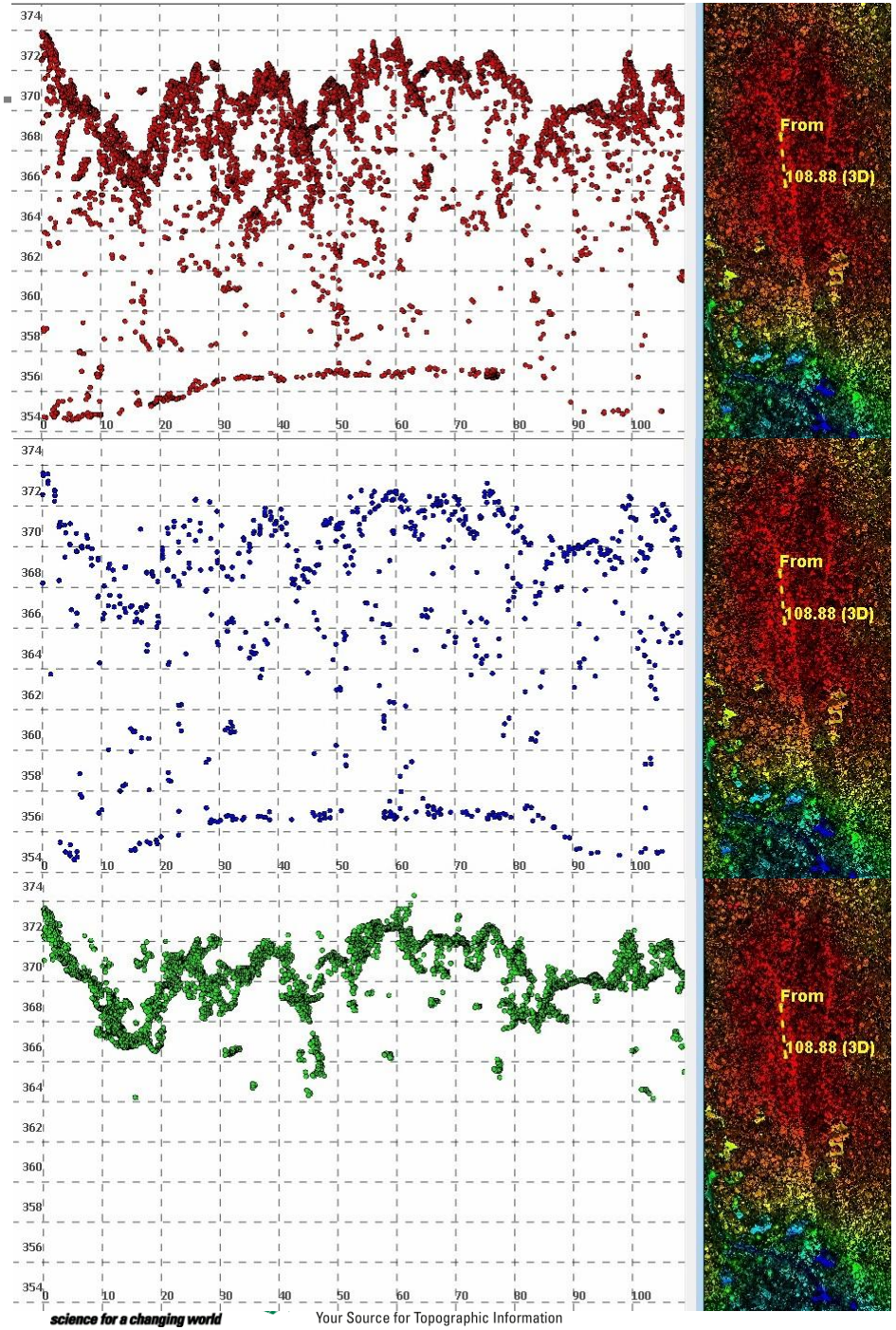
Sigma Space (Leaf on 7,500 ft)



Linear-mode (Leaf off, 3,000 ft)



Harris (Leaf on, 26,000 ft)



Sigma Space (Leaf on 7,500 ft)

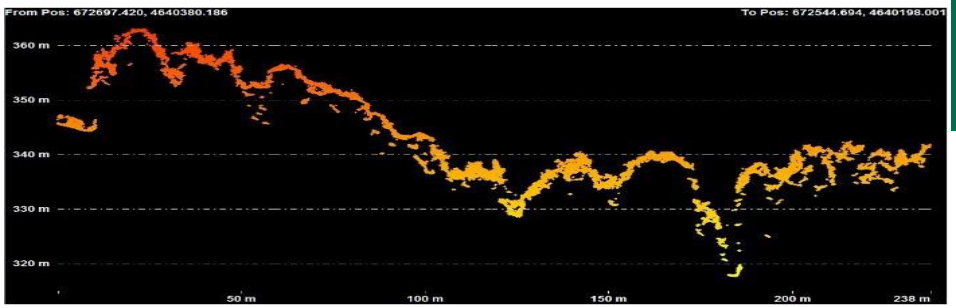
Linear-mode (Leaf on, 7,000 ft)

Harris (Leaf on, 26,000 ft)

Improved canopy penetration with Harris Sensor 2

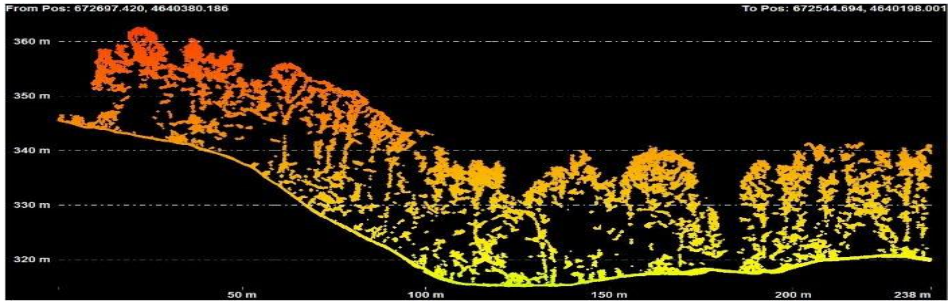
GMHar15LO15_26k

Geiger Mode Leaf On Collect – Sensor 1
(September 2015, @26,000 ft)



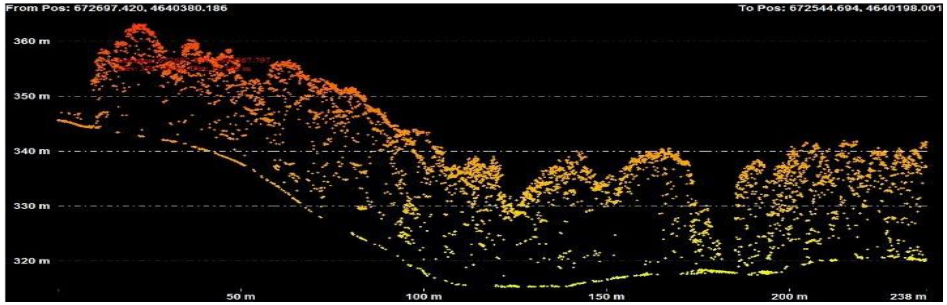
GMHar15LF15_26k

Geiger Mode Leaf Off Collect – Sensor 2
(December 2015, @26,000 ft)



LMDewLF14

Linear Mode Leaf Off Collect
(April 2014, @3,000 ft)



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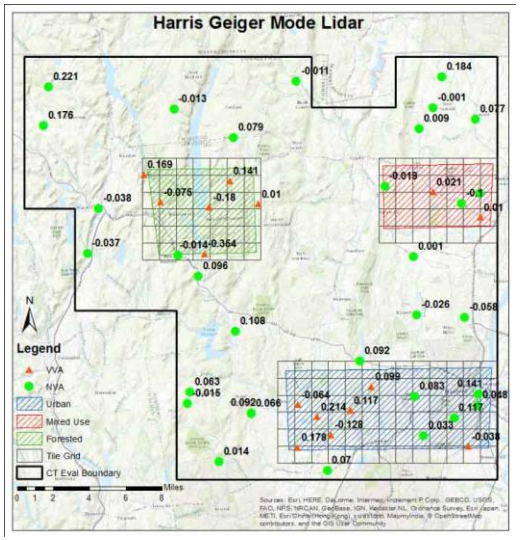
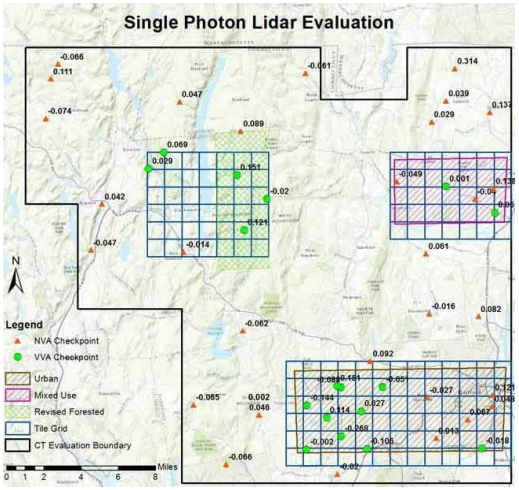
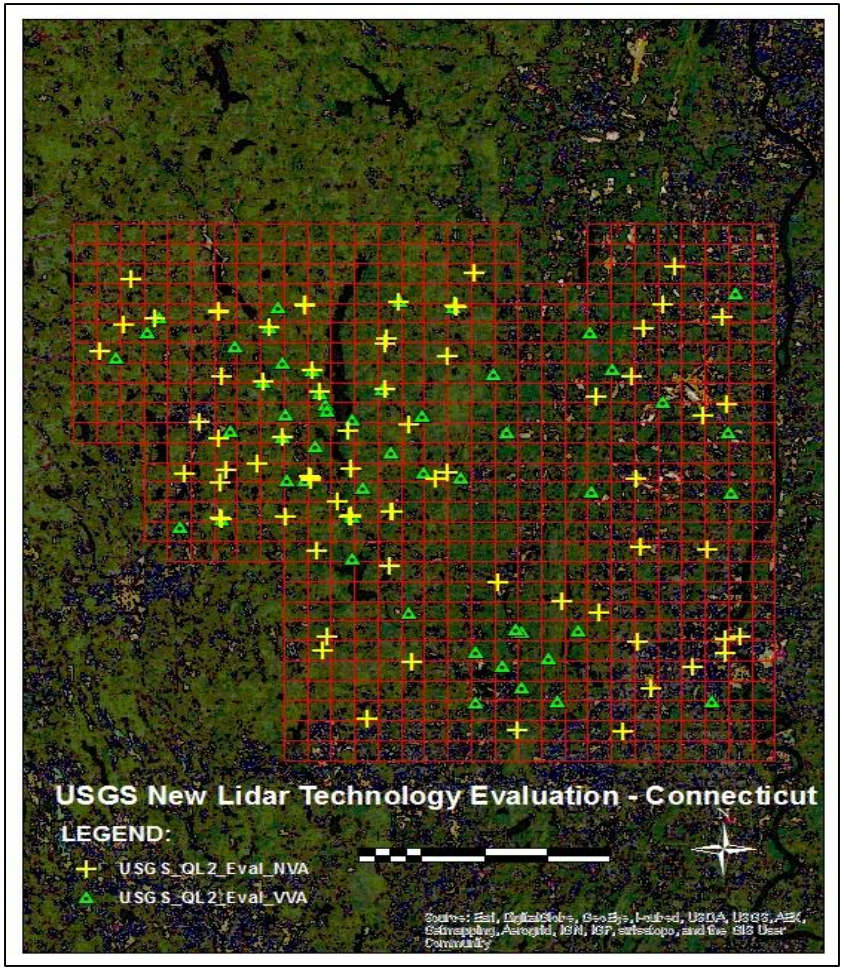
Absolute Accuracy Assessment

- Absolute accuracy verified using ground checkpoints independently acquired in 2014 and 2015.
- Two types of Accuracy Assessments done:
  - Assessment against point clouds
  - Assessment against derived bare earth DEMs
- VVA assessed in two ways:
  - Derived from interpolated TIN of the final bare-earth DEM.
  - only where a valid lidar point was within 20 m of the checkpoint.
- Accuracy assessment made against DEMs included interpolated areas as well.

Testing Absolute Accuracy







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Vertical Accuracies

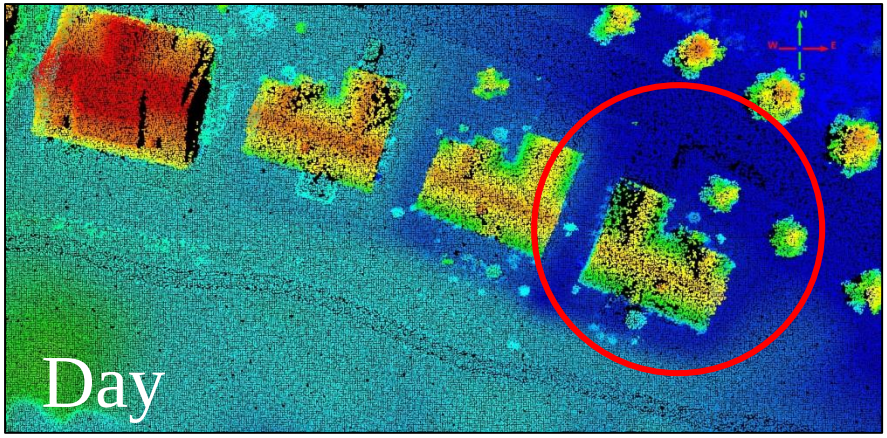
A major objective of this evaluation is to assess absolute horizontal and vertical accuracy

Specification	
Non-vegetated Vertical Accuracy (NVA)	Vegetated Vertical Accuracy (VVA)
≤19.6 cm at 95% confidence level	≤29.4 cm at 95th percentile

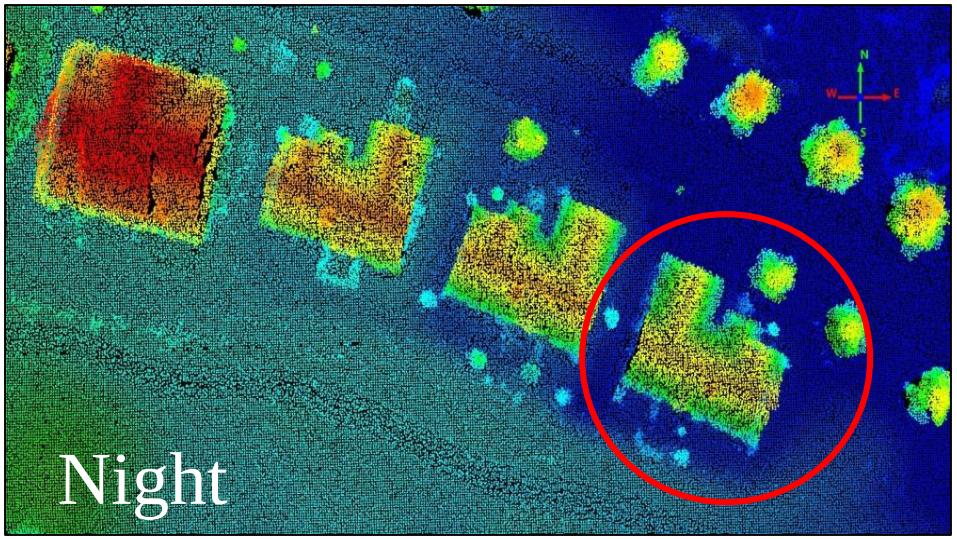
	Test #1 – Points		Test #2 – DEM	
	NVA	VVA	NVA	VVA
HRQLS (7,500 ft AGL)*	17.2 cm	17.4 cm	14.1 cm	40.6 cm
IntelliEarth (26,000 ft AGL)*	17.0 cm	25.6 cm	15.2 cm	92.0 cm
Existing, accepted 3DEP QL2 data (3,000 ft AGL)	12.3 cm	19.8 cm	14.6 cm	25.0 cm

* Leaf on

GML Day & Night Acquisition

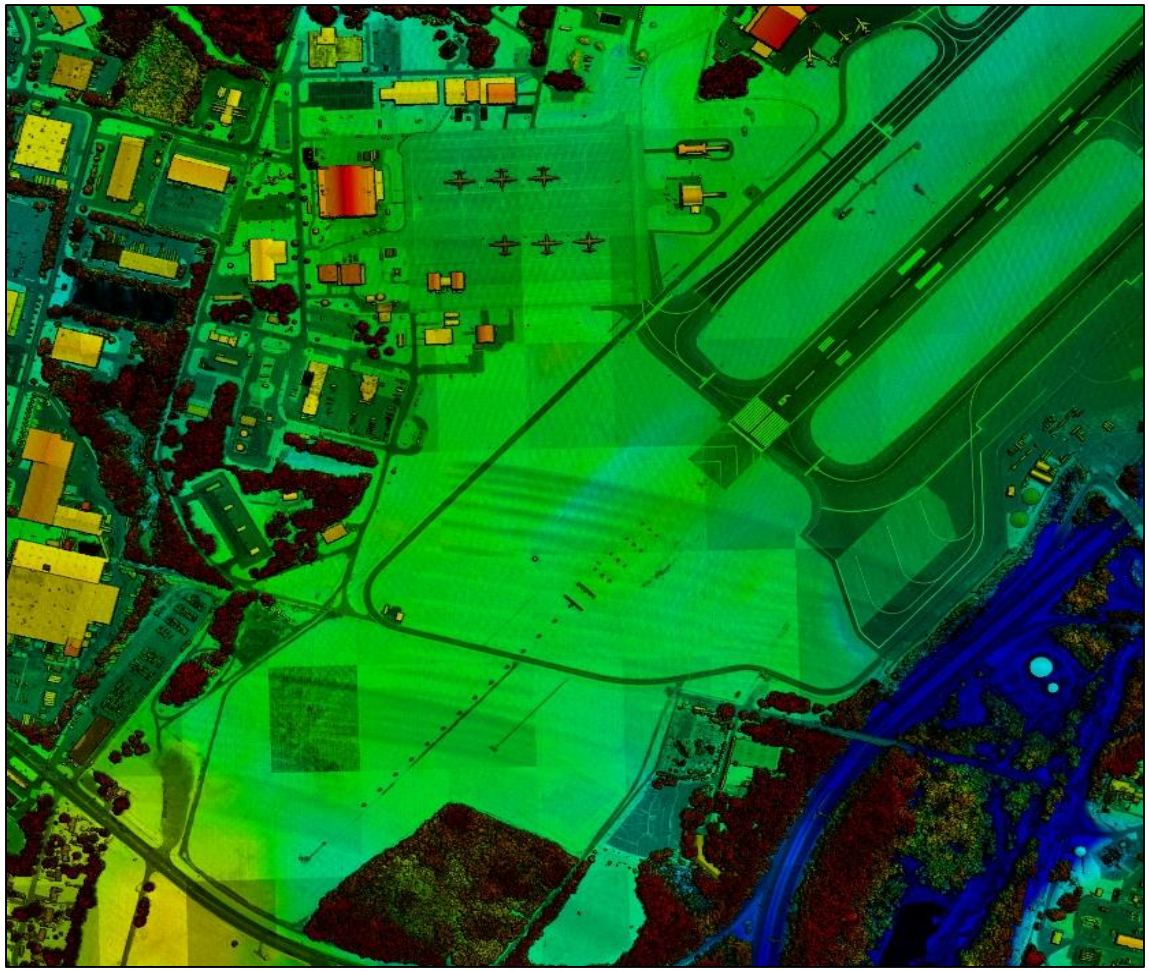


7,500 ft AGL



26,000 ft AGL

Quality of GML Reflectance Images



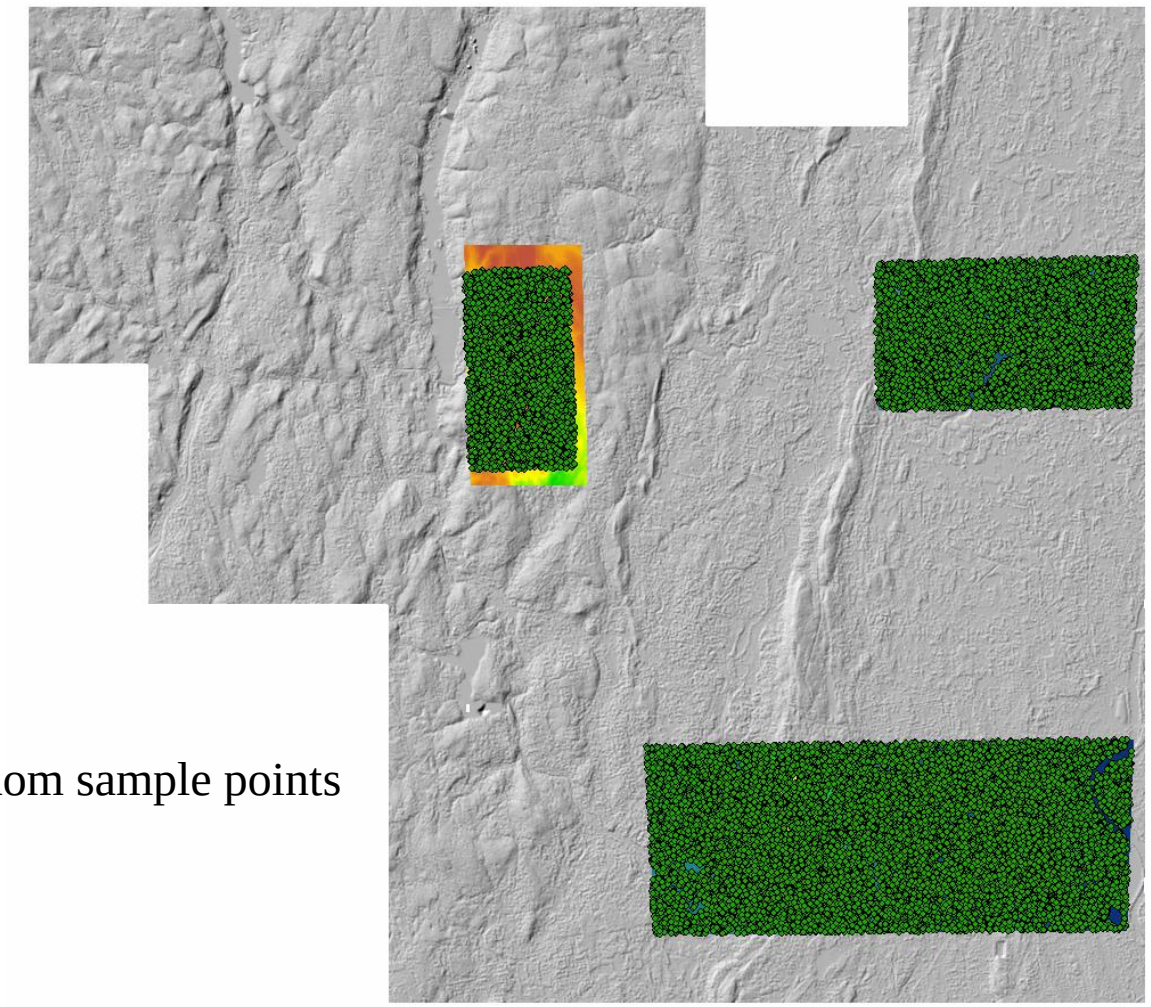
Quality of GML Reflectance Images

Reconciliation

Comparing evaluations

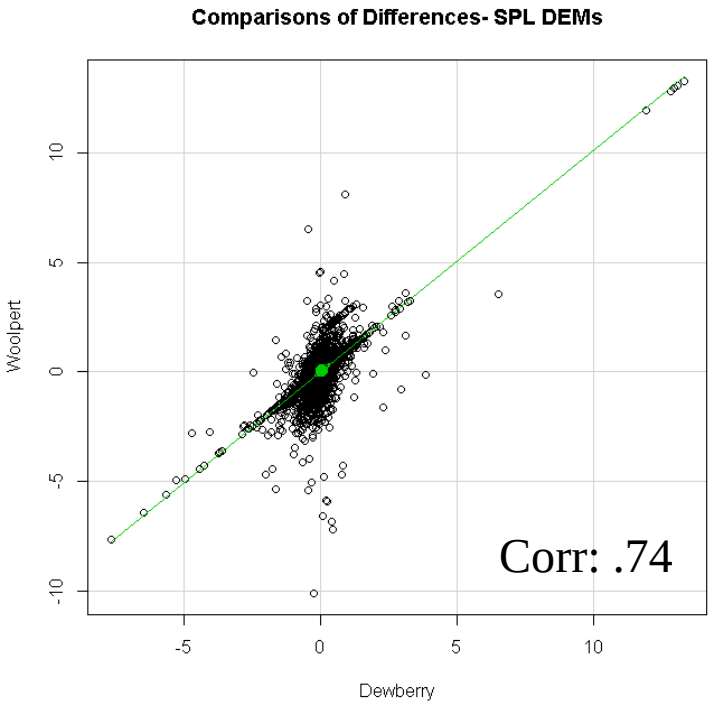
- Independent looks at data
- Statistical comparisons of results- random sample
- Dewberry and Woolpert independently bare earth processed data, using their own internal processes- so some differences are expected
- Initial thoughts and recommendations
- Next steps

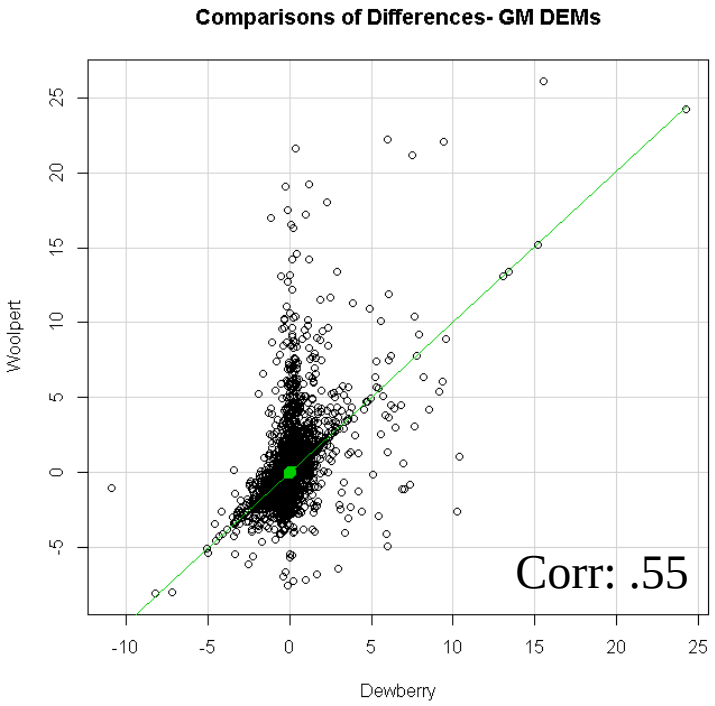
Comparing Dewberry vs Woolpert



24,820 random sample points

Comparing Results





n=24,820

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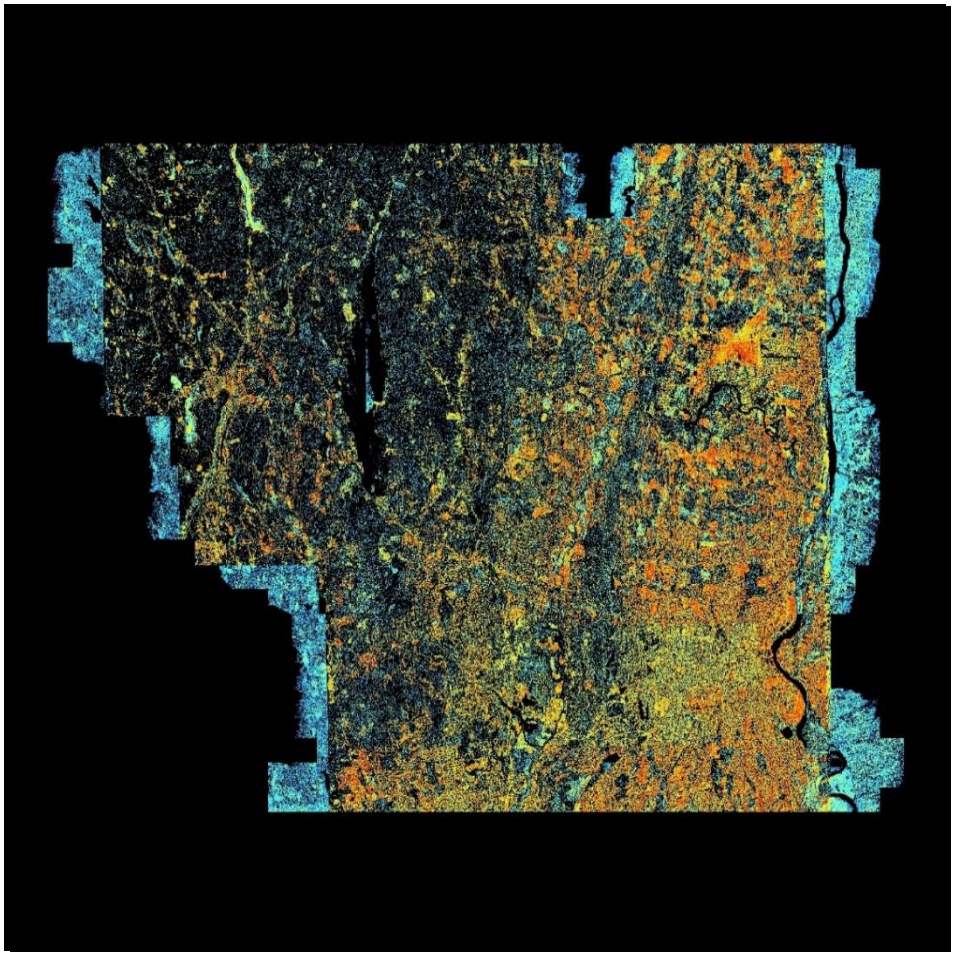
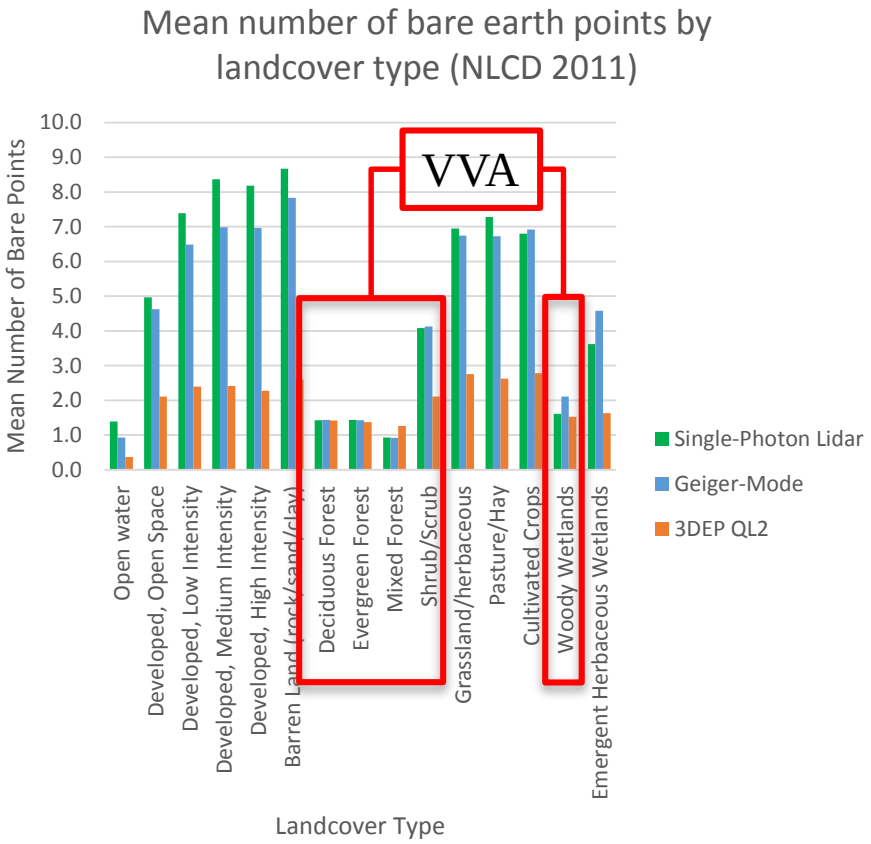
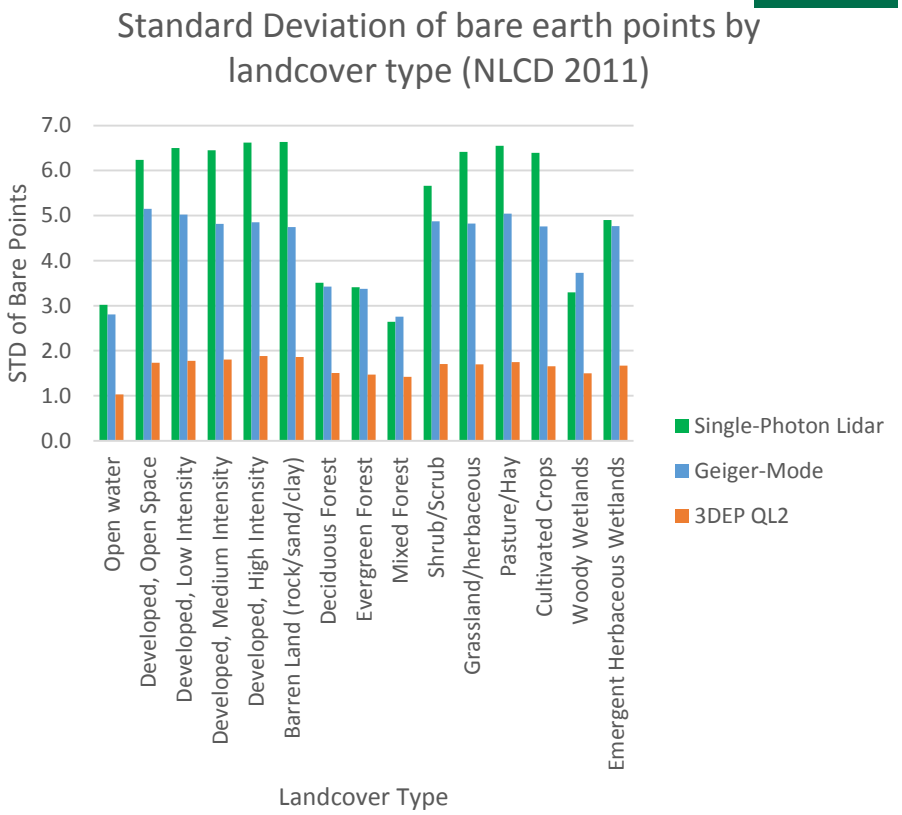
+ Comparisons of number of classified bare earth points



Single photon (leaf on, 7500 ft AGL)

Mean and STD of number of classified bare earth points





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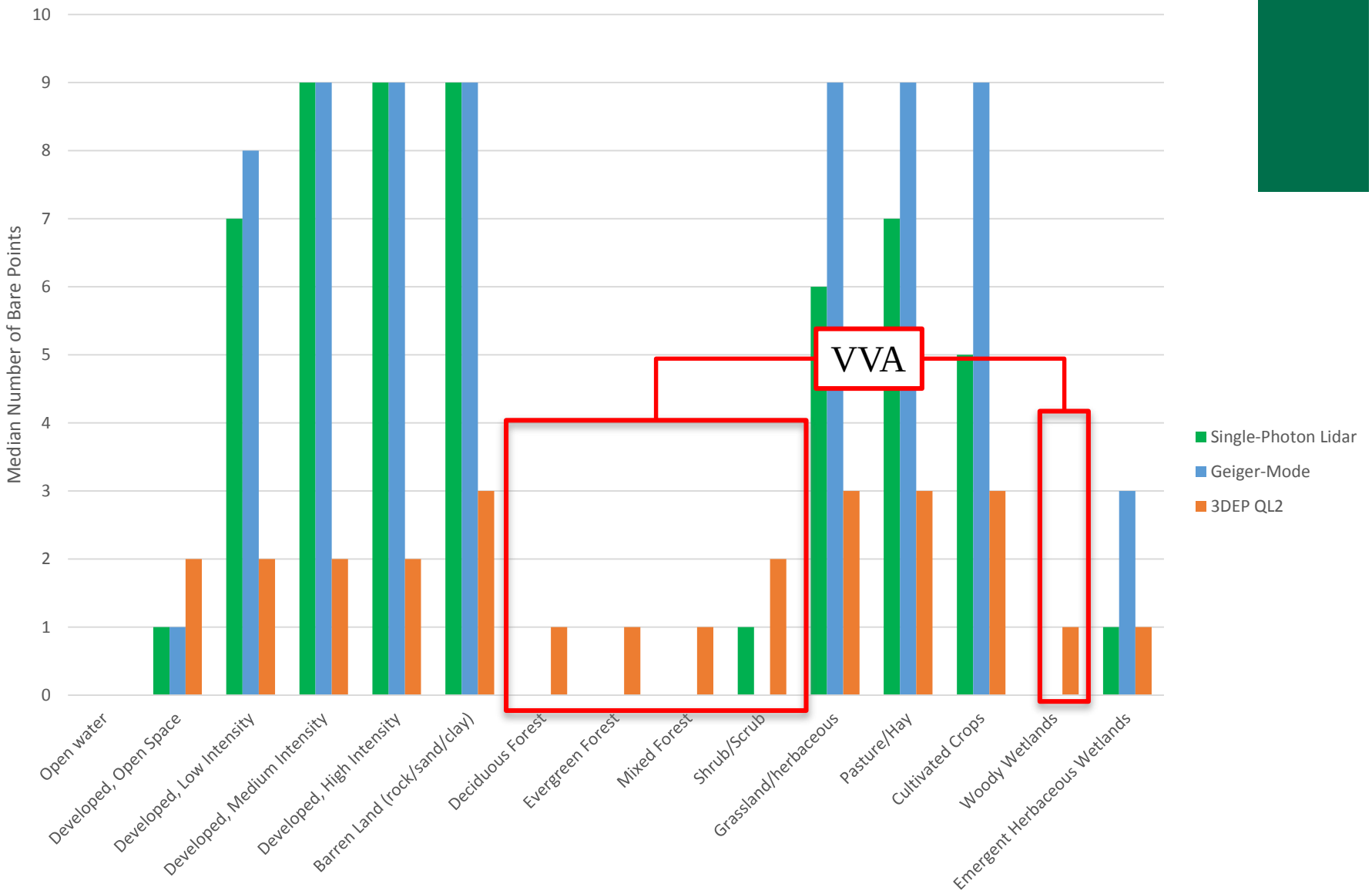
Median number of bare earth points by landcover type (NLCD 2011)



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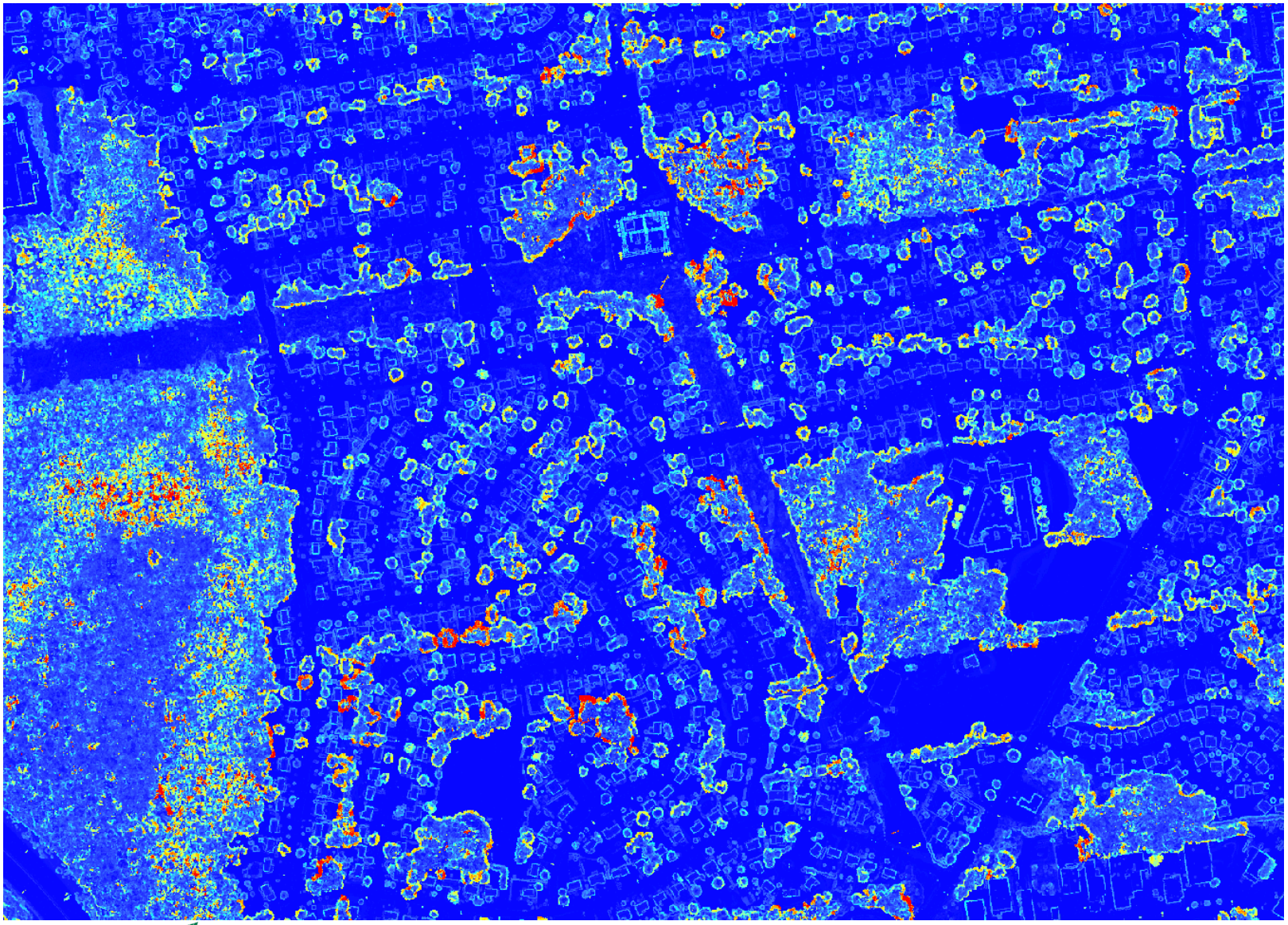
STD per 1m2 pixel: Harris IntelliEarth



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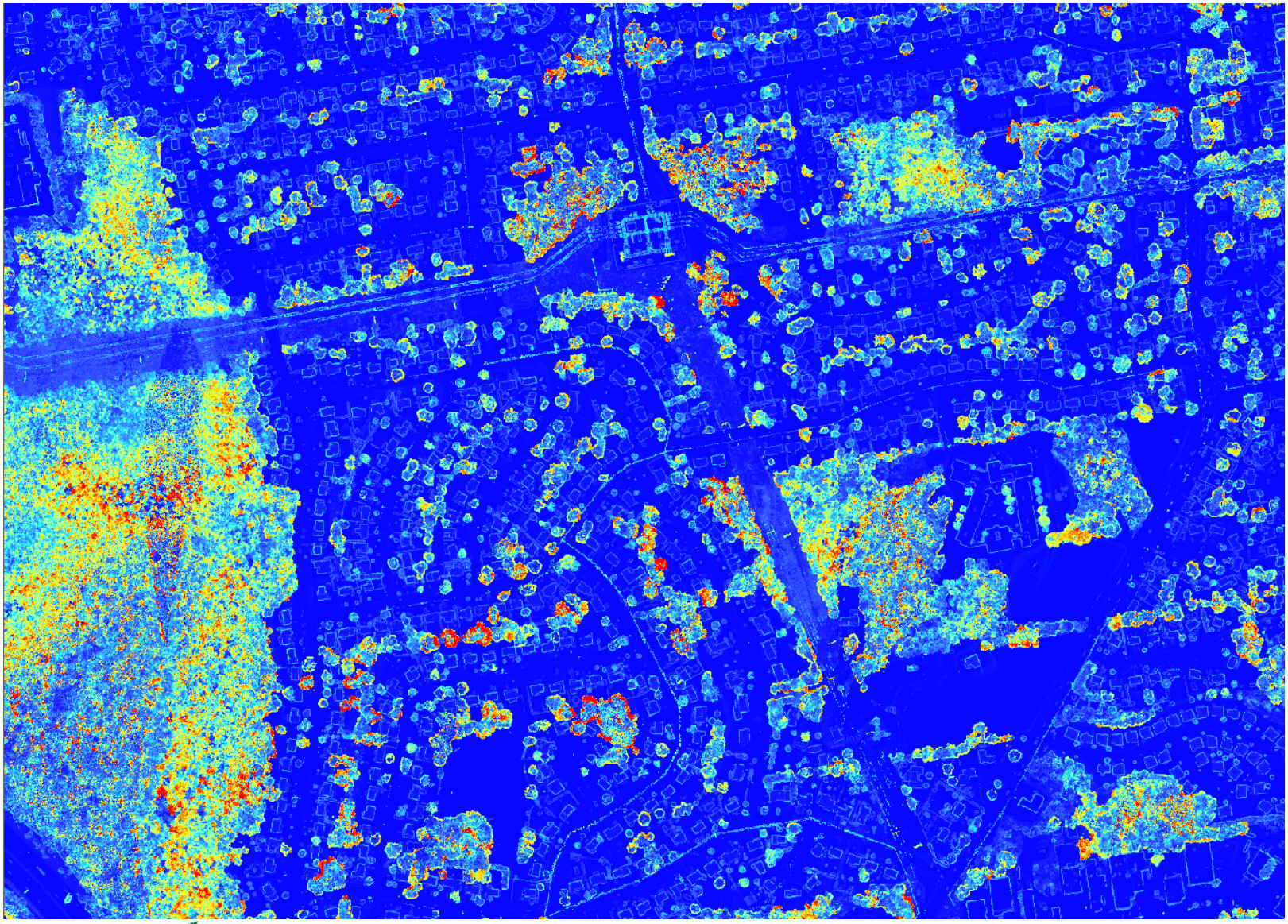
ANPD = 25.4 ppsm

Leaf on, 26,000 ft

STD per 1m2 pixel: Sigma Space HRQLS



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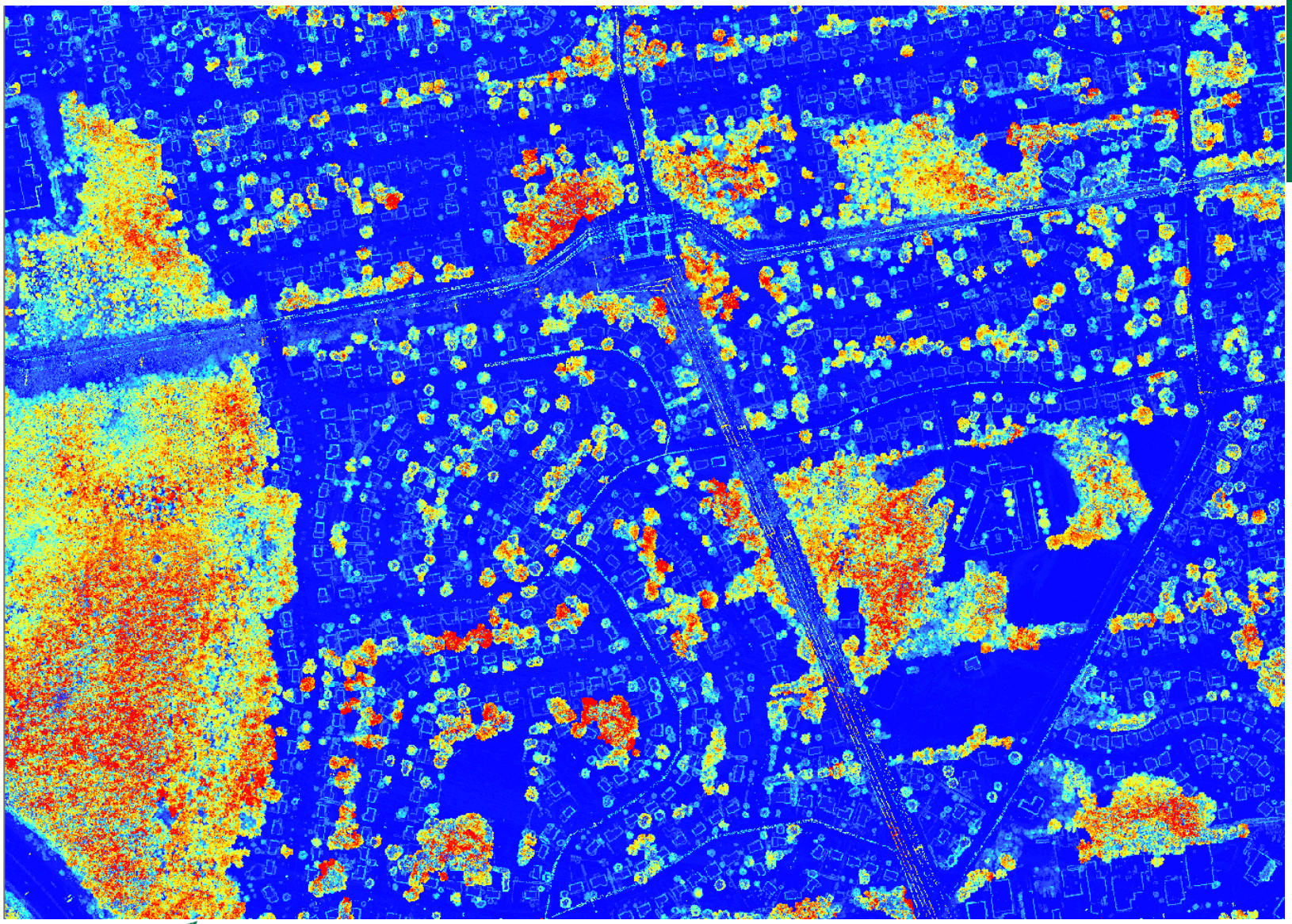
ANPD 23.2 ppsm

Leaf on 7,500 ft

STD per 1m2 pixel: 3DEP QL2 linear mode lidar



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Leaf off, 3,000 ft

Preliminary Observations

Assessment is ongoing

- Point densities and relative accuracies more than adequate
- Non-vegetated vertical accuracies (NVAs) are within specification
- More and deeper analyses and continued dialog with Harris and Sigma Space. Both companies say that many of these issues have been addressed
  - Already claim sensor improvements since evaluation collection
  - Need to do evaluations/validations on new instruments and in traditional leaf-off conditions
- Begin working on making USGS Lidar Base Spec more flexible and less linear-mode only focused
- Need to work with ASPRS to adapt the LAS file format spec (or develop a new specification) to allow these sensors to be ‘fully compliant’

Conclusions

- Range walk was a significant issue with the SP sensor. Range errors exceeded 50 cm over paint stripes on airport runway and 5 – 25 cm over directional signs and stop bars on roads.
- Range walk also present in GM data, with errors of about 15 cm on the runway paint stripes and 3 – 6 cm over retro-reflective road signs. Harris offered an explanation that suggested a phenomenon known as ‘cross talk’ was causing these range errors over some reflective targets.
- Concerns about point densities and vertical accuracies using DEMs under dense vegetation in leaf-on conditions
  - Assumption is better performances under leaf-off, but not what we had to evaluate
- Non-compliance of attributes for USGS Lidar Base Specification 1.2 - must be worked through the 3DEP-WG and the broader community to develop policy and adapt specification and file formats

+ Conclusions

- There were no intensity values or timestamps in current SP data.
- Lack of intensity data in current SP sensors affects the ability to derive breaklines using lidargrammetric methods
- GM “reflectance” imagery similar to intensity imagery from LM sensors.
- No major differences between day and night time collection for both sensors. Note GM data was acquired at 7,500 ft AGL for daytime flight vs. 26,000 ft AGL for nighttime flights. Sigma Space flew ROI in a combination of day and night
- Minimum requirements for LAS v.1.4 format based on USGS v.1.2 specs will need to be modified for accepting GM/SP data
  - point source ID and overlap/withheld bit
  - Timestamp – meaning and intent
  - Scan angle
  - Multiple returns

+ Next Steps

- Need to get these findings and recommendations completely vetted by E3D-WG
- Need to better understand the full lifecycle costs of managing such data, especially data with NPS greater than QL1.
  - NEEA/3DEP has not assessed the cost/benefits of data greater than QL1
  - Increased storage costs, longer/more difficult processing, noise points, etc.
- Overall the technology shows potential - warrants additional testing and next steps – need to continue to learn about, adapt to, and help these systems come in to full compliance with our specifications, and we will adapt our specifications where needed.
- Concerns over how Harris data gets filtered to meet our QLs
- USGS will continue to work with these new sensors in an ‘incubation phase’

Questions?