

Update: SPL100 LiDAR, software for filtering/quality control

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So, what's new with single-photon LiDAR?

- Lots!
- Taking advantage of advancements in linear-mode LiDAR
 - Hardware
 - Workflow
- SPL “World Tour”



Airborne LiDAR sensor history



ALS40

1998 – 2003

- 45 kHz
- The original ALS



ALS50-II

2006 – 2008

- 150 kHz
- MPiA
- Expanded altitude range



ALS70

2011 – 2014

- 500 kHz
- Dual output LiDAR for increased pulse / scan rates
- User selectable scan patterns



ALS80-UP

2016 – now

- 1000 kHz
- Highest-altitude linear mode airborne LiDAR



ALS50-I

2003 – 2006

- 83 kHz
- Compact installation



ALS60

2008 – 2011

- 200 kHz
- Increased productivity and robustness



ALS80

2014 – now

- 1000 kHz
- Improved laser, GNSS and IMU



Airborne LiDAR sensor history and evolution to fused sensors



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ALS80-UP

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SPL100

2017 – now

- 6000 kHz
- First commercial single-photon LiDAR



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ALS80

2014 – now

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- Improved laser, GNSS and IMU



CityMapper

2016 –

- 700 kHz
- FWD based
- RGB/CIR Oblique imaging sensor



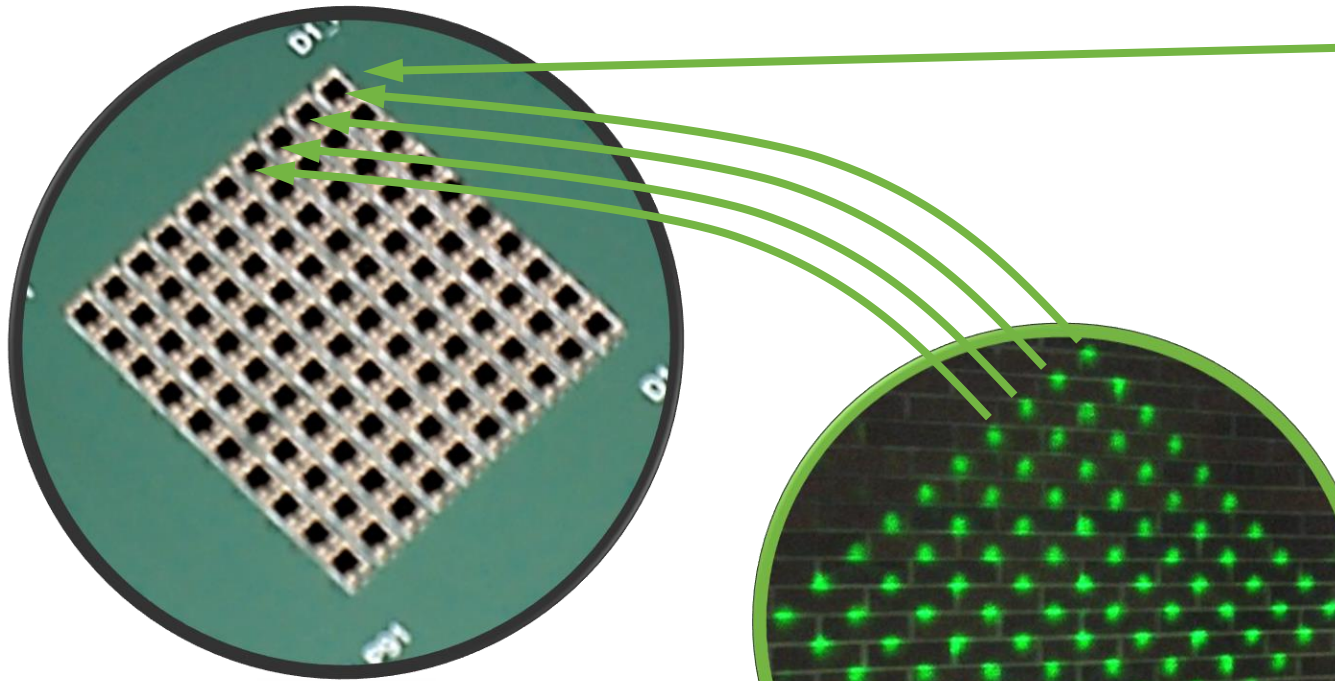
TerrainMapper

2018 –

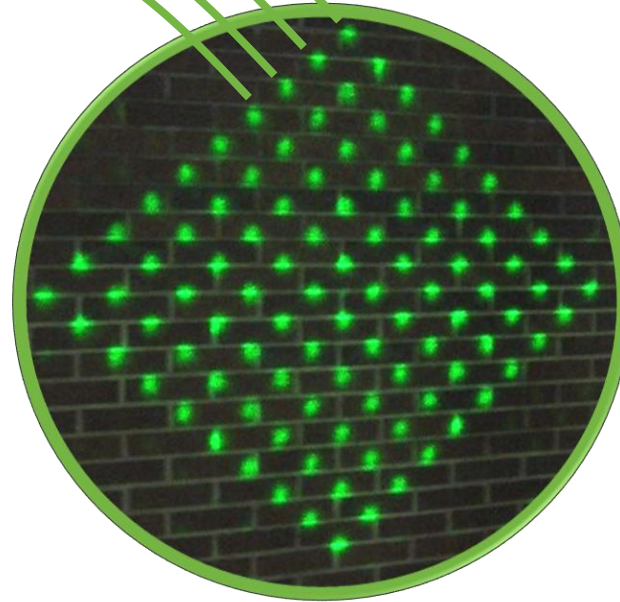
- 2000 kHz
- Gateless MPiA
- FWD based



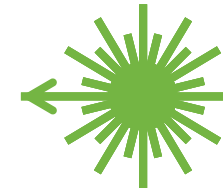
Why is single-photon technology unique?



- Single-Photon Avalanche Diode (SPAD) detectors are far more sensitive than Avalanche Photo Diode (APD) detectors used in linear-mode LiDAR systems
- Less laser output required for detection of a target
- Output from a single laser pulse can be split to illuminate multiple locations on the ground, each illuminating an individual detector element

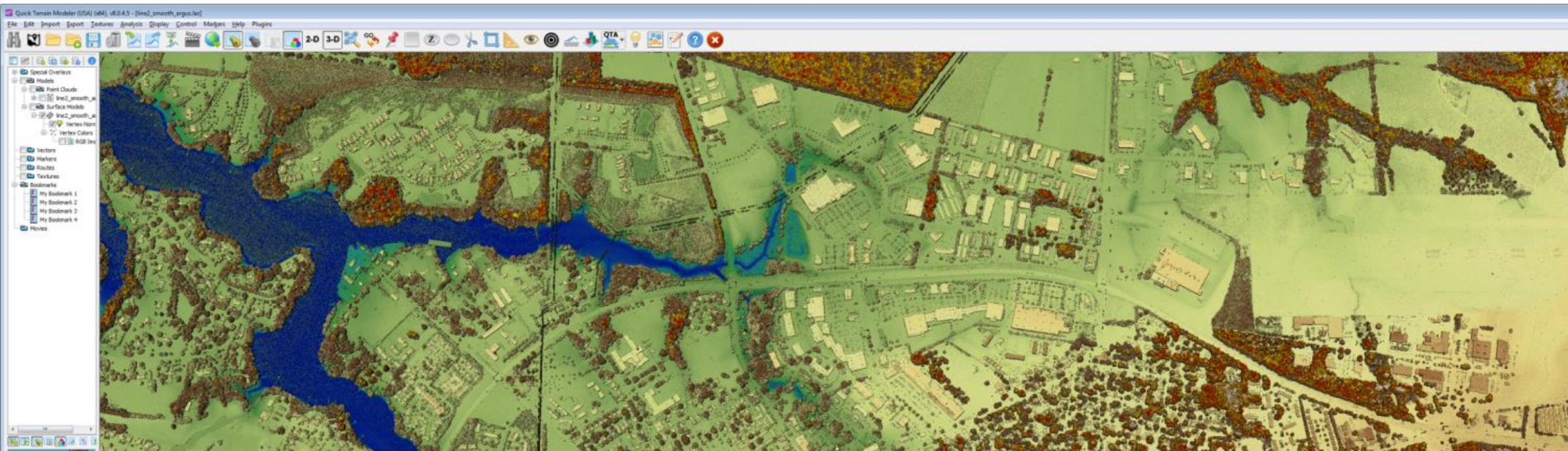


- BONUS: predictable point distribution on a single-laser-shot basis!!!



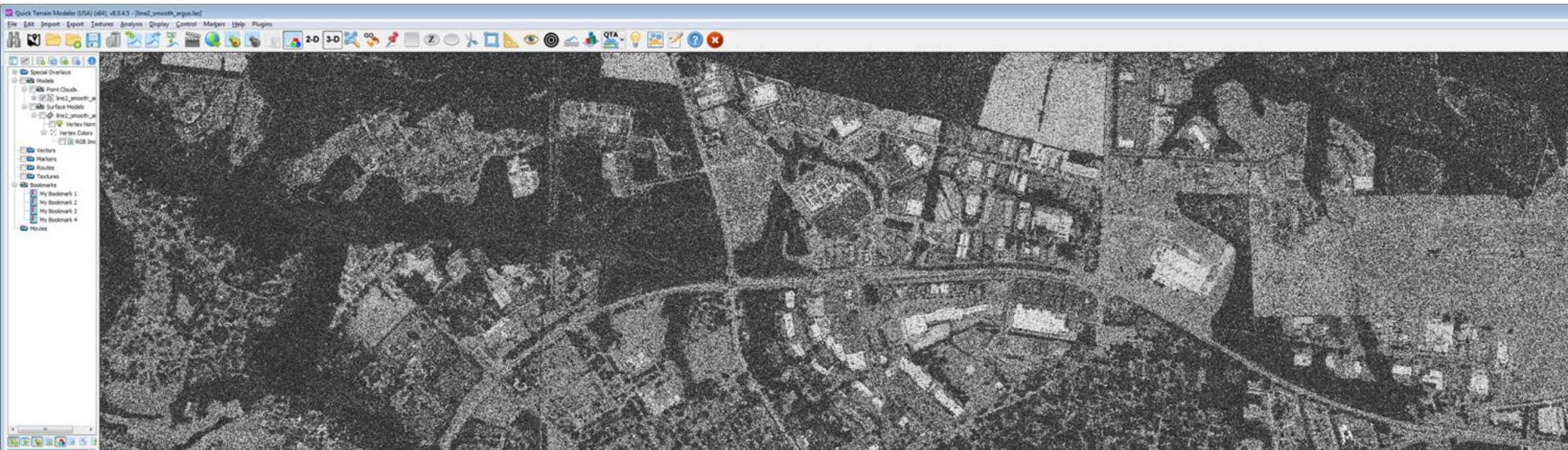
Capture & deliver dense LiDAR & Imagery

Color by elevation



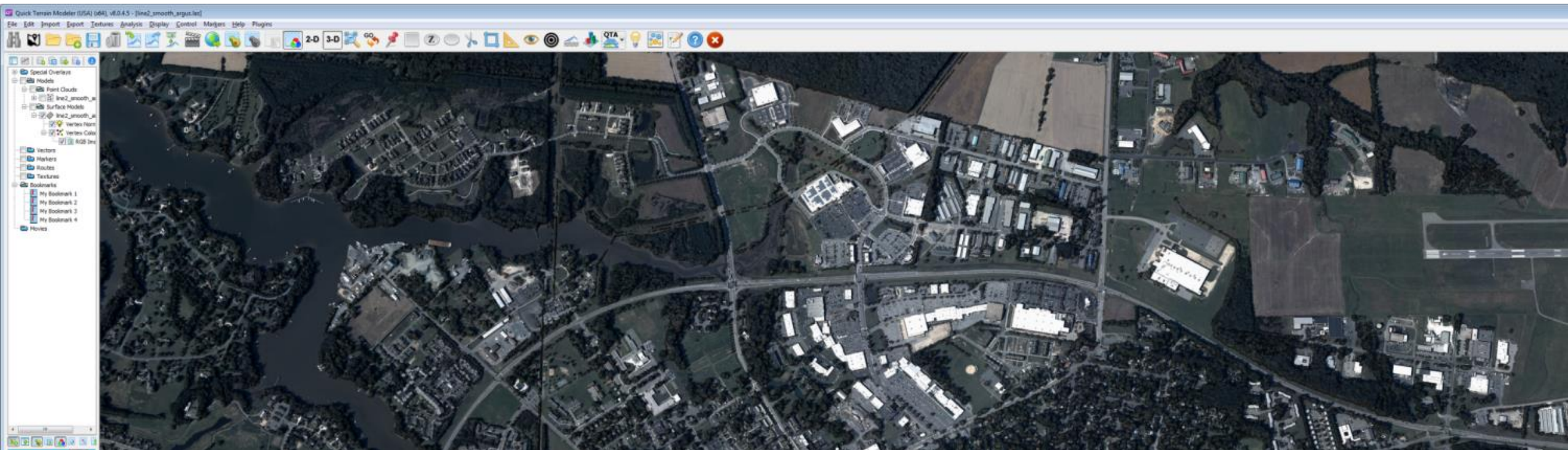
Capture & deliver dense LiDAR & Imagery

Gray-scale by intensity for enhanced classification



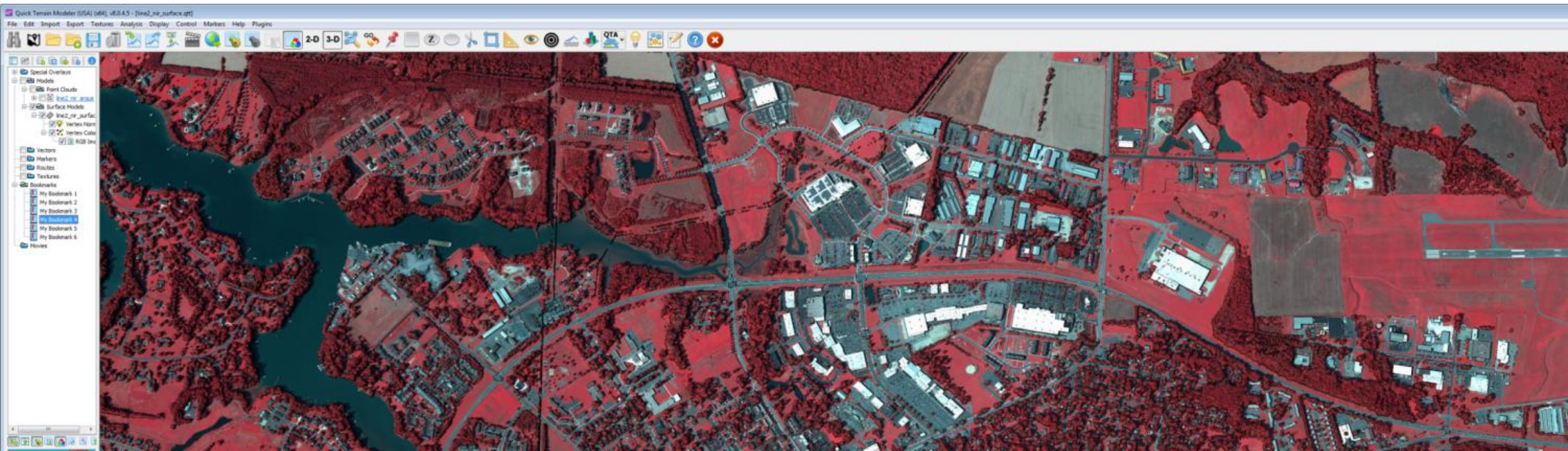
Capture & deliver dense LiDAR & Imagery

Natural color point cloud for easy object identification



Capture & deliver dense LiDAR & Imagery

False-color infrared for vegetation classification



Single-photon LiDAR noise challenge

- Image at right shows the consequence of operation in high-sensitivity/low SNR regime (“Jell-O mold” per Glennie)
- Ways to minimize (operation):
 - Limit observation duration (“range gate”), but also deal with varying terrain height
 - Non-zero detection threshold
 - Solar noise filtering
- Ways to deal with residual noise (processing):
 - Take advantage of noise “randomness” and target “structure”
 - Contextual factors such as return density, spacing useful

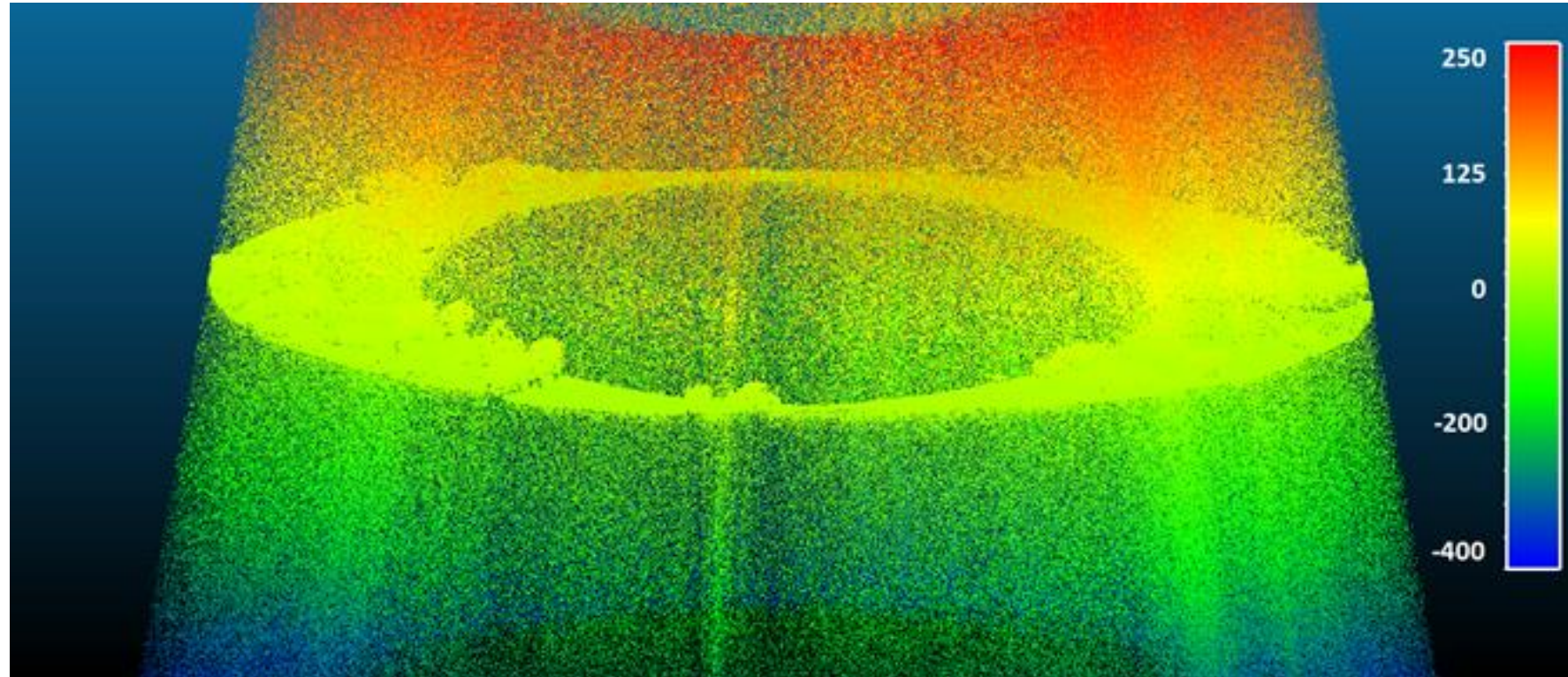


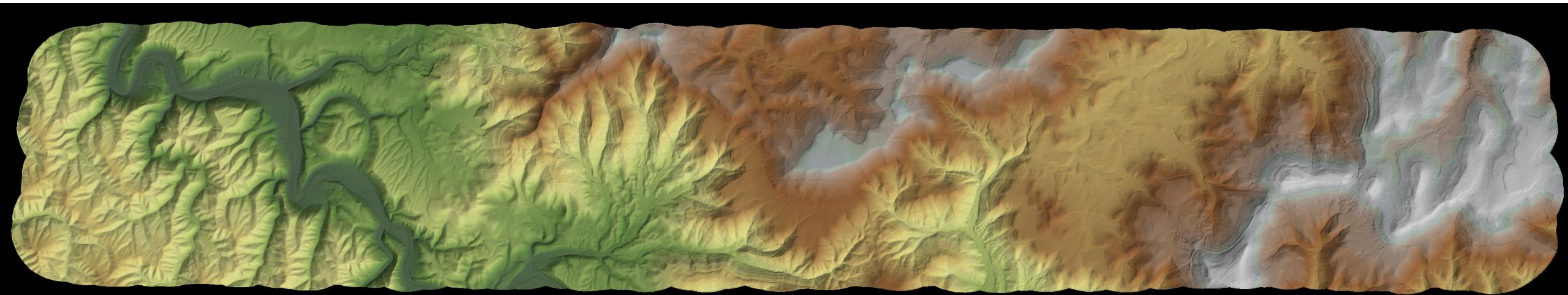
Image: Glennie et al “Automated Noise and Afterpulse Removal from Single Photon Sensitive Lidar Observations”

SPL100 recent hardware improvements

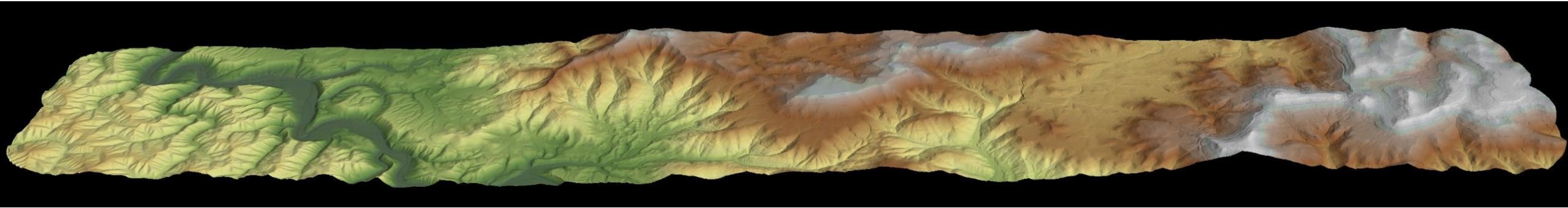
- Heating system maintains optical throughput over wider operating temperature range
- Electromagnetic compatibility (EMC) improvements to minimize electrical noise from external sources
- Operation in alternate altitude regimes/pulse rates
 - High-flying-heights (5000-6000m AGL) with lower pulse rates (just like linear mode systems)
 - Maintains SNR
 - Wider elevation accommodation range within single MPiA zone
 - Lower flying heights (2000m AGL)
 - Ultra-high point densities
 - Maximum scan rates
- Automatic Range Gate (ARG) to track changes in terrain elevation

SPL100 Gated MPiA solution: Increasing ease of operation with automatic range gate

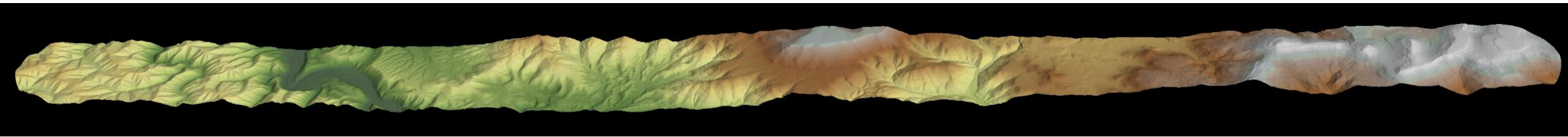
- How to accommodate terrain relief larger than range gate size
- Marlinton, VW (US) test



Marlinton, WV site: 4 lines in rugged terrain



Focus on Line 3: largest terrain relief within single line – 830 m!



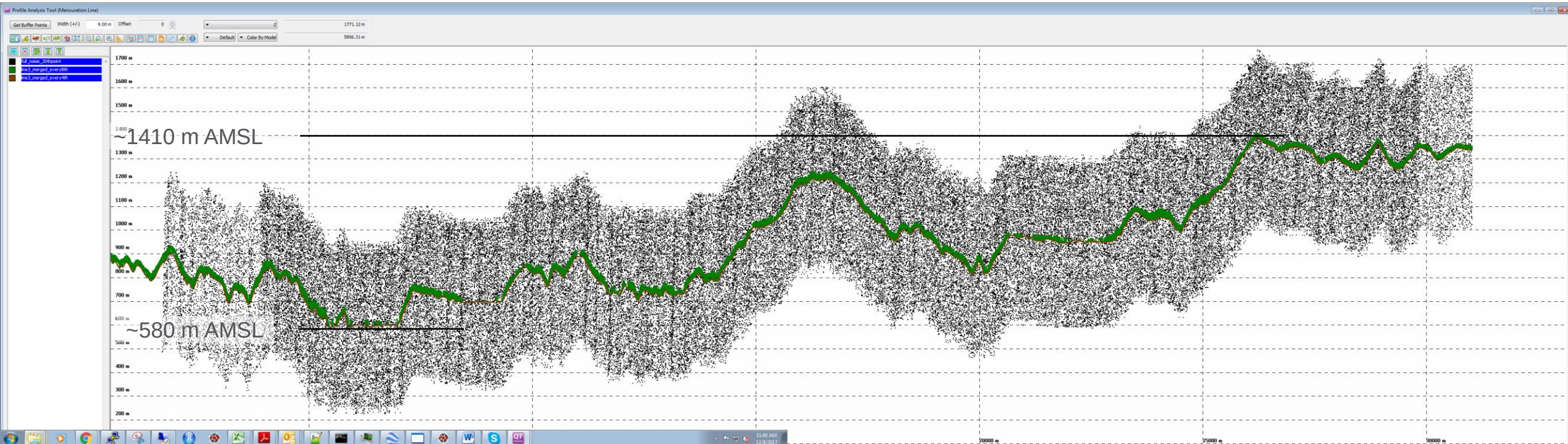
Challenge of planning/flying with terrain height variations larger than gate width

- Section along Line 3



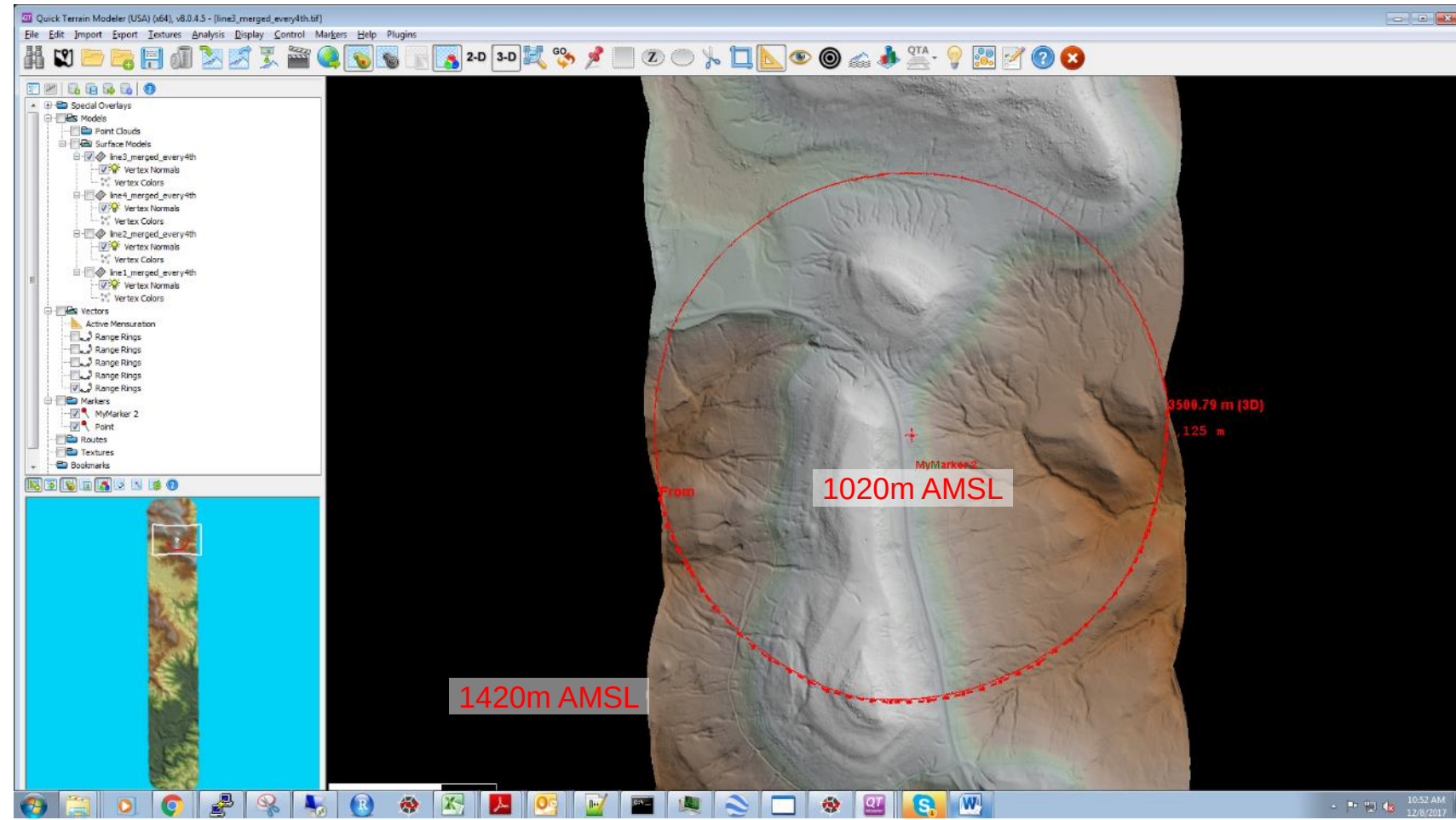
With ARG: Gate center moved from ~580 m AMSL to ~1410 m AMSL = 830 m

- gray = all noise (i.e., full 700 m gate)
- green = veg
- brown = DEM



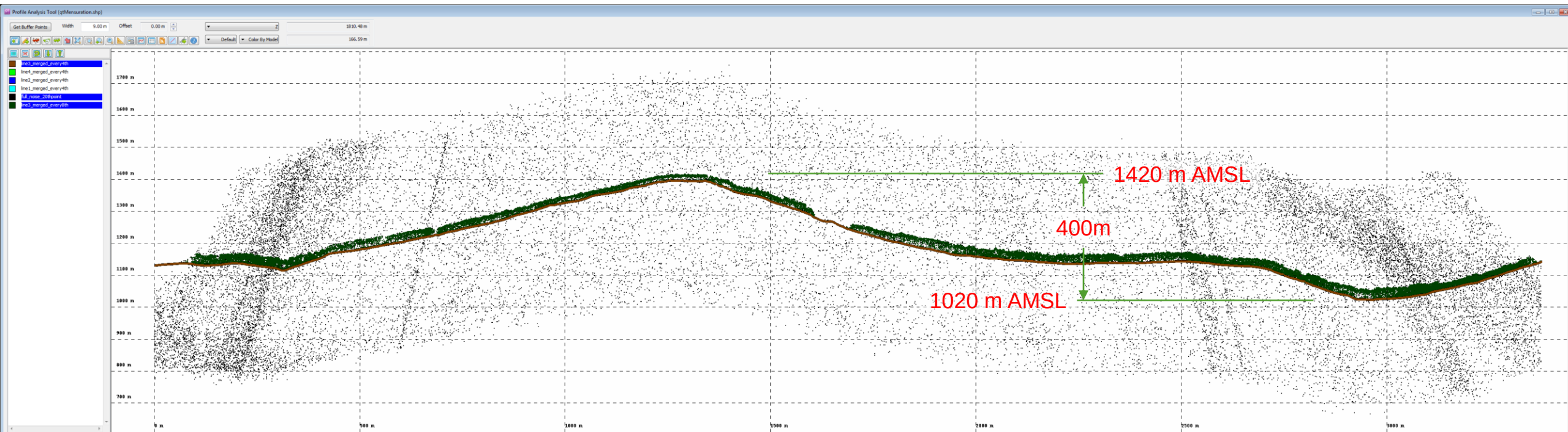
Range gate responds rapidly, even within each scan

- see dotted line from ~9 o'clock to ~3 o'clock position (back scan)



Section following scan: ~0.02 seconds duration from left to right:

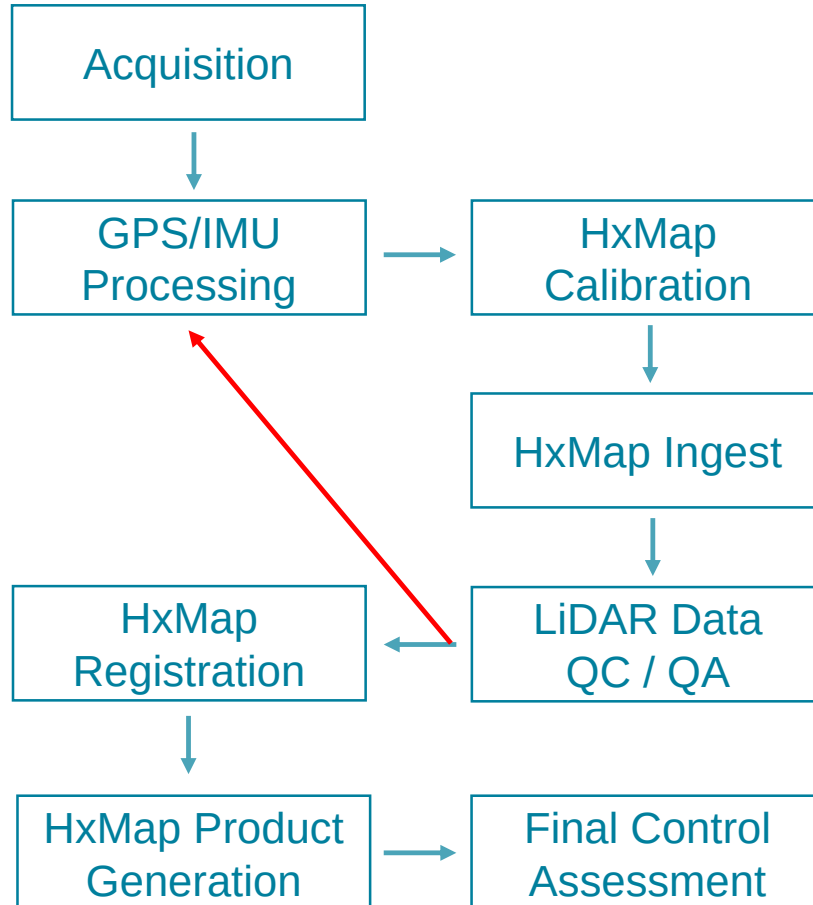
- Gate moves ~400m in ~0.01 seconds!



Processing advancements for single-photon data

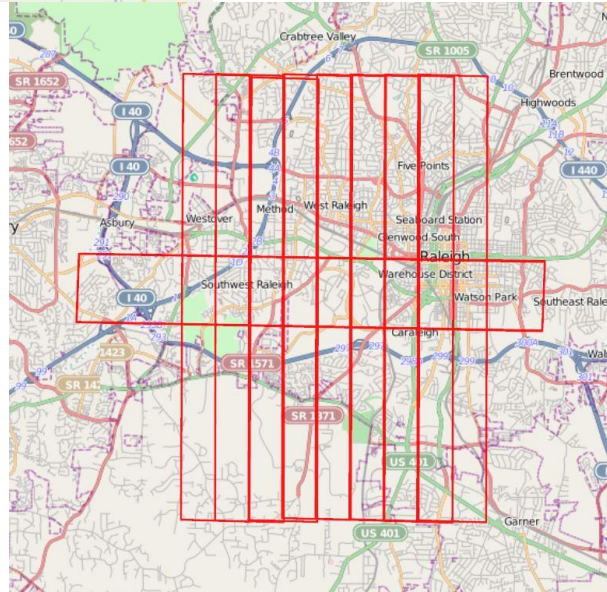
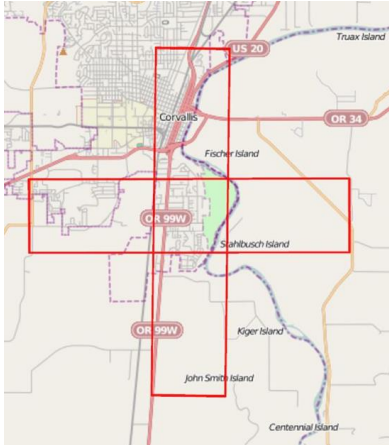
- Full implementation in HxMap
- Improved scan angle encoding
- Calibration improvements
 - Expanded calibration parameters
 - Fore/aft scan registration
 - Line/line registration
- Further improvement of noise filtering
- Improvements in intensity data processing
- QC tools

SPL100 Workflow



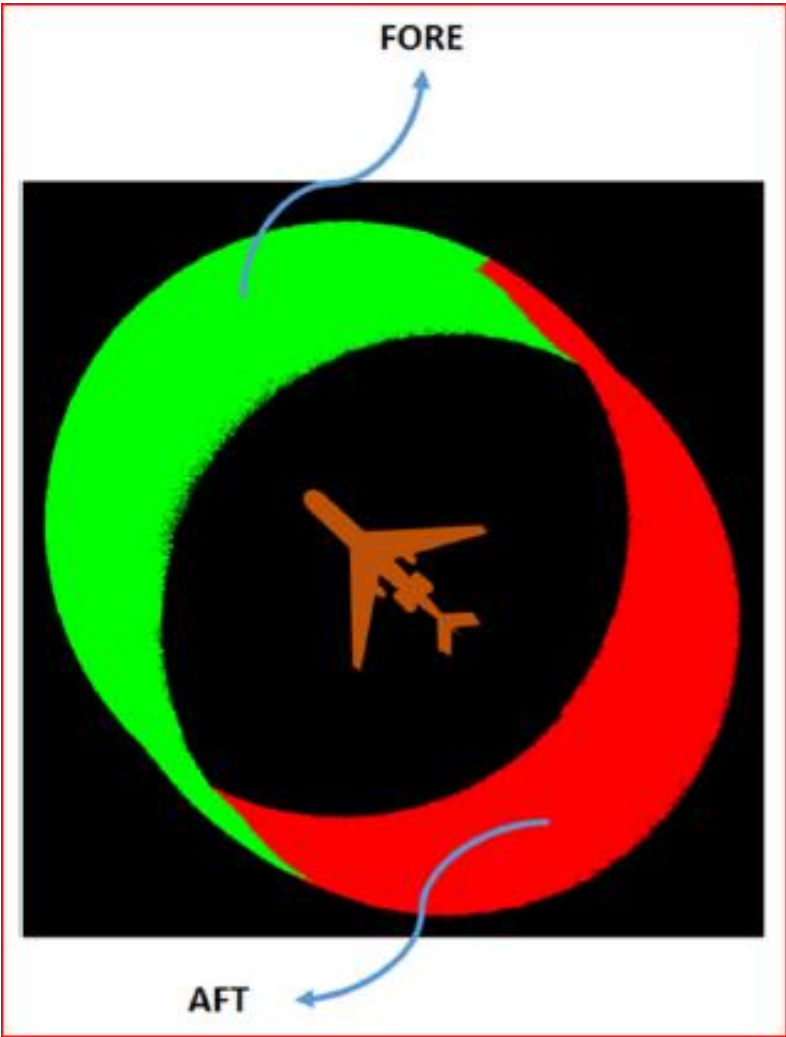
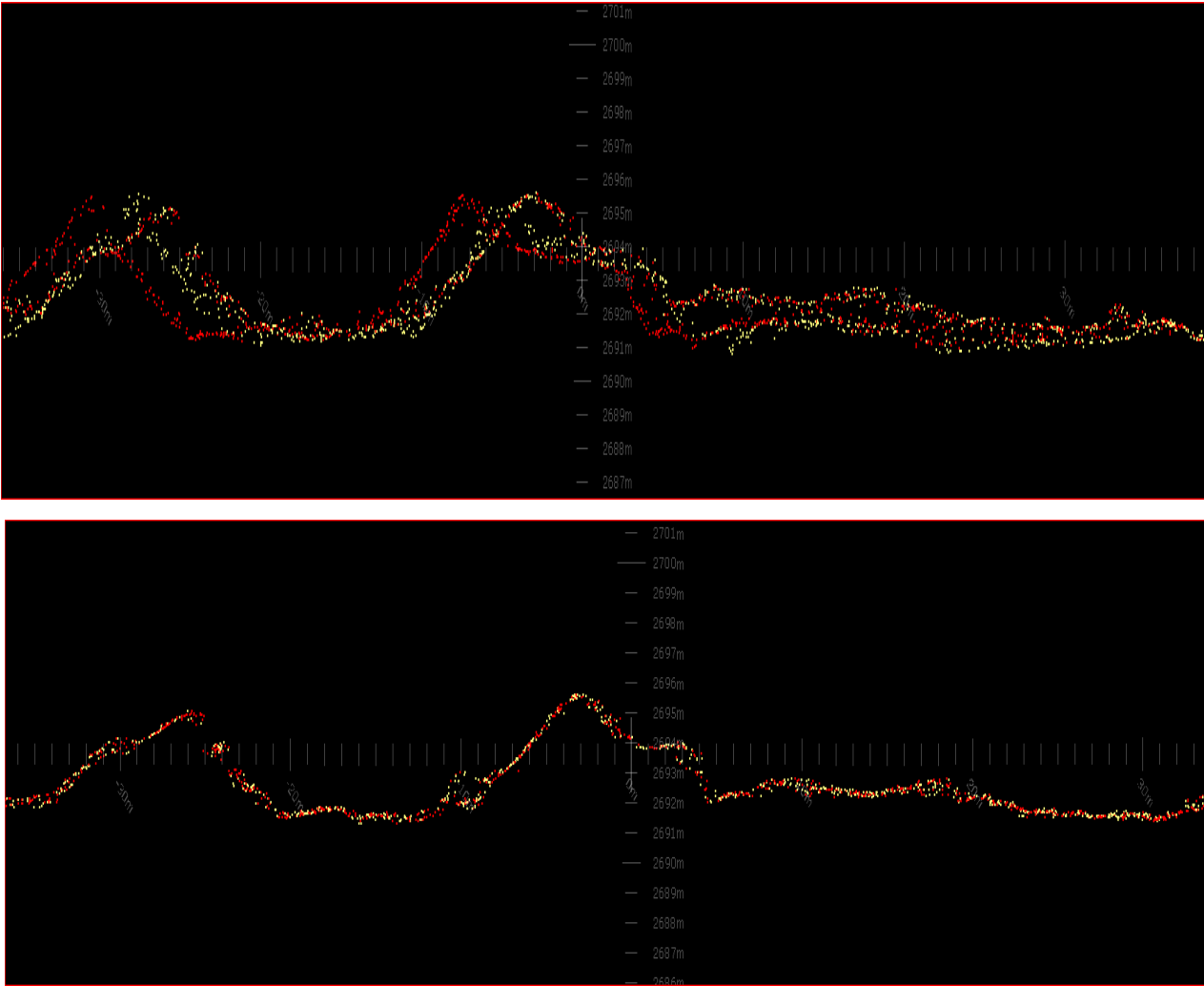
- Flight planning / Acquisition
- GPS/IMU Processing
- Calibration
- Ingest / Point Cloud Generation
- LiDAR Data QC
- Registration / Re-Projection
- Final Deliverables

SPL100 Workflow – HxMap LiDAR Calibration

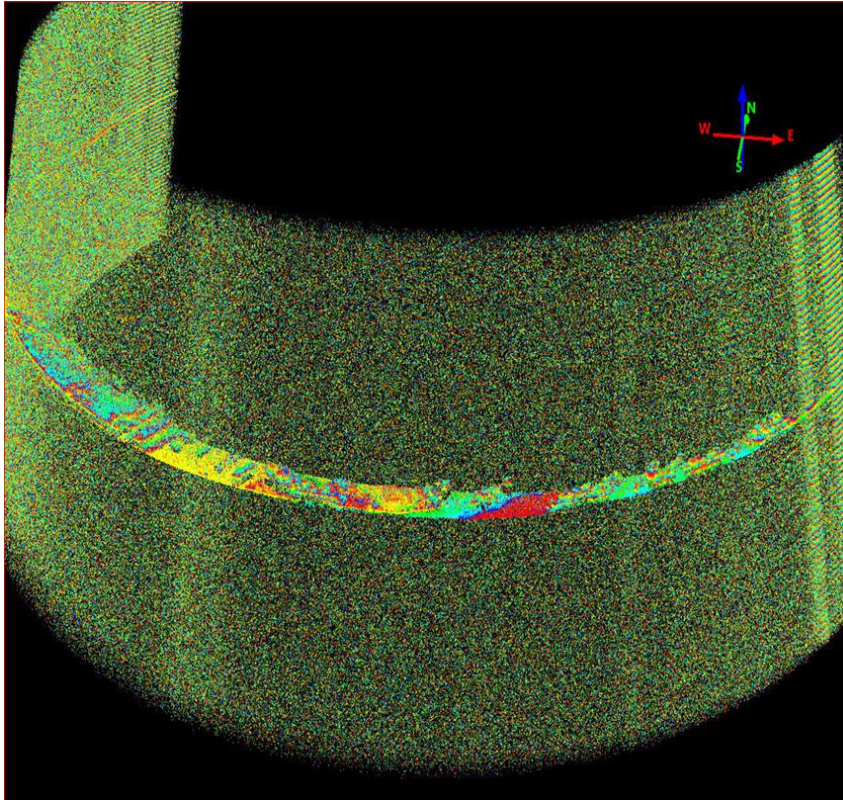


- Flight by flight calibrations required
- 14 Calibration parameters
 - 3 boresight angles (roll, pitch, heading)
 - 1 wedge angle bias
 - 10 Fourier coefficients
- Iterative Least Squares Adjustment used for calibration parameter estimation
- Report alignment quality internally within a flightline (fore/aft) and externally between flightlines (line/line)

SPL100 Workflow – HxMap LiDAR Calibration



SPL100 Workflow – HxMap Ingest / Point Cloud Generation



- Generates georeferenced Point Clouds
- HxMap ARGUS/PGSUS
 - Noise Filtering & Reduction
 - KDE Filter
 - Statistical Outlier Removal
- Smoothing filter to reduce “jitter”
- Decimation Filter
- Intensity Based Range Corrections & Averaging

SPL100 Workflow - HxMap intensity development

Old method



New method



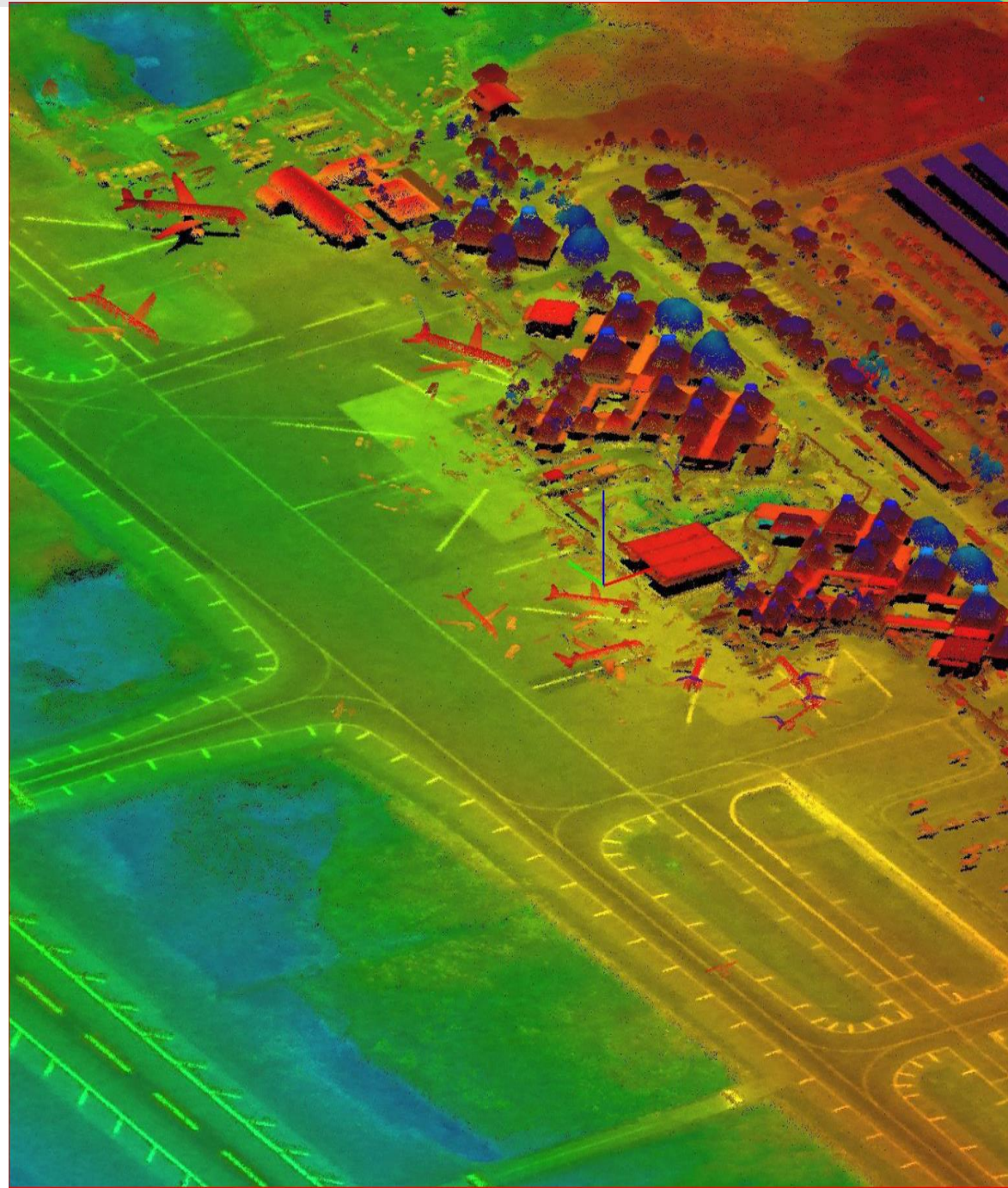
SPL100 – Hawaii, Kona Airport

- Ortho view of intensity data

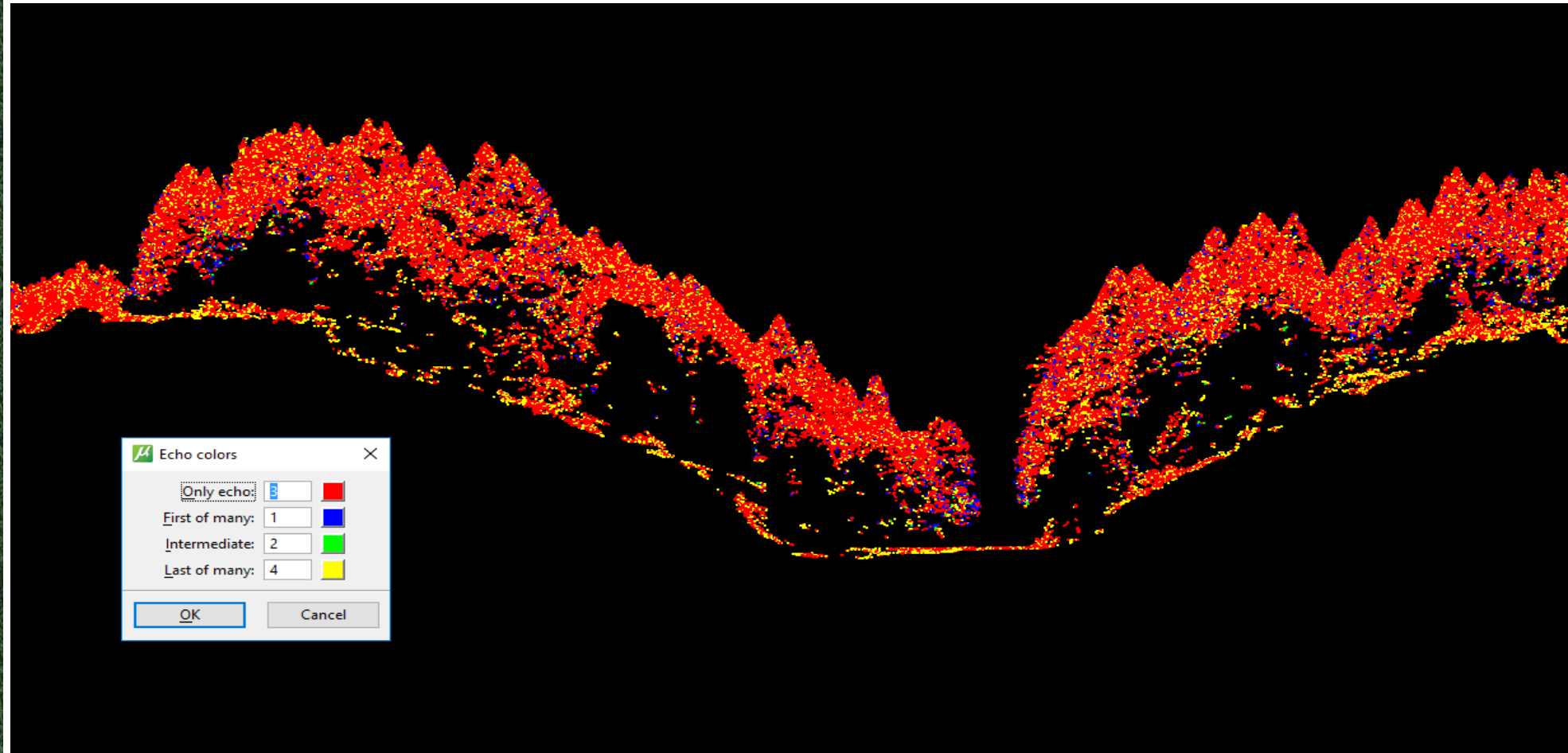


SPL100 – Hawaii, Kona Airport

- Oblique view of fused intensity and elevation



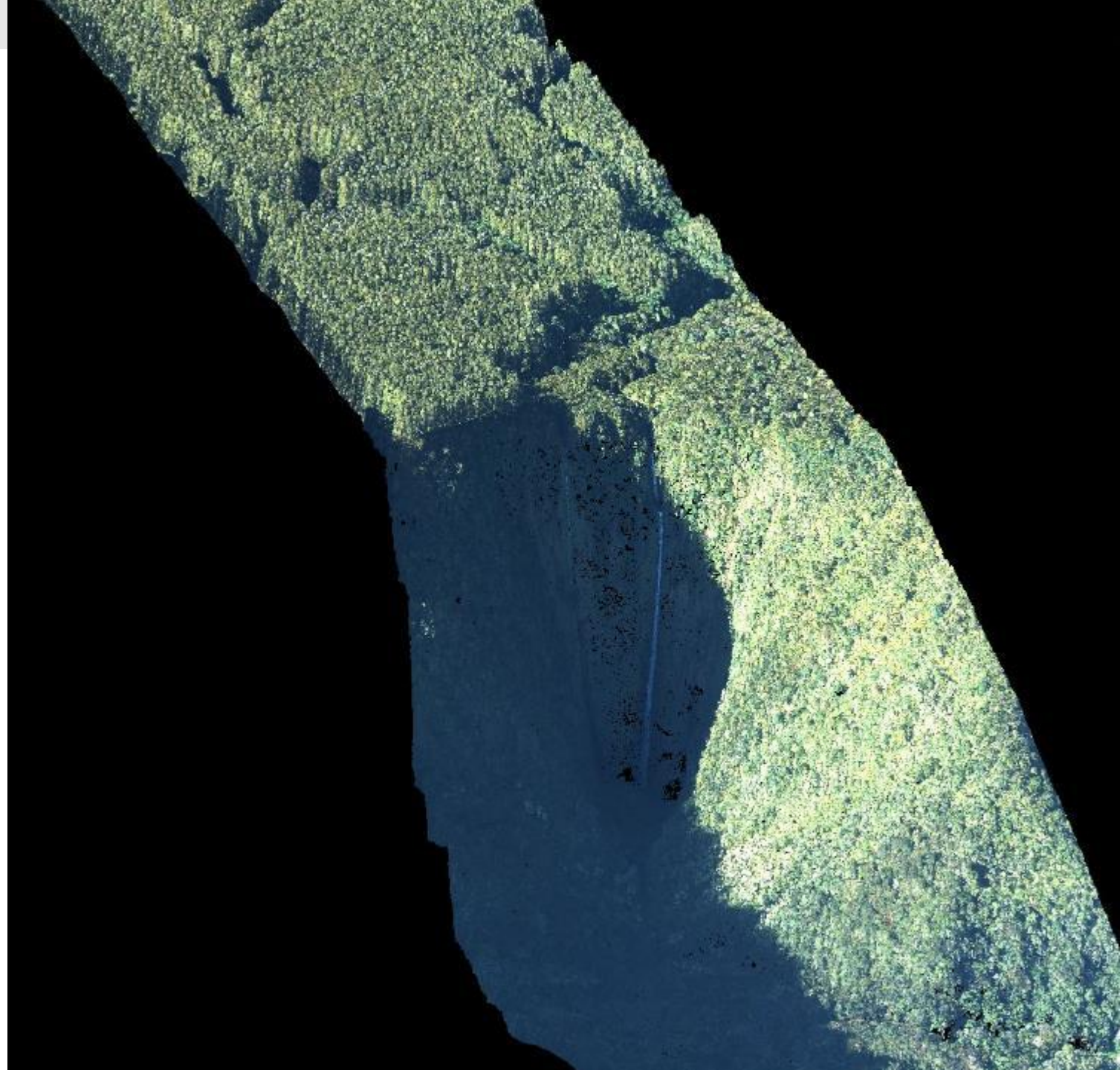
SPL100 – Vegetation Penetration & Multi>Returns



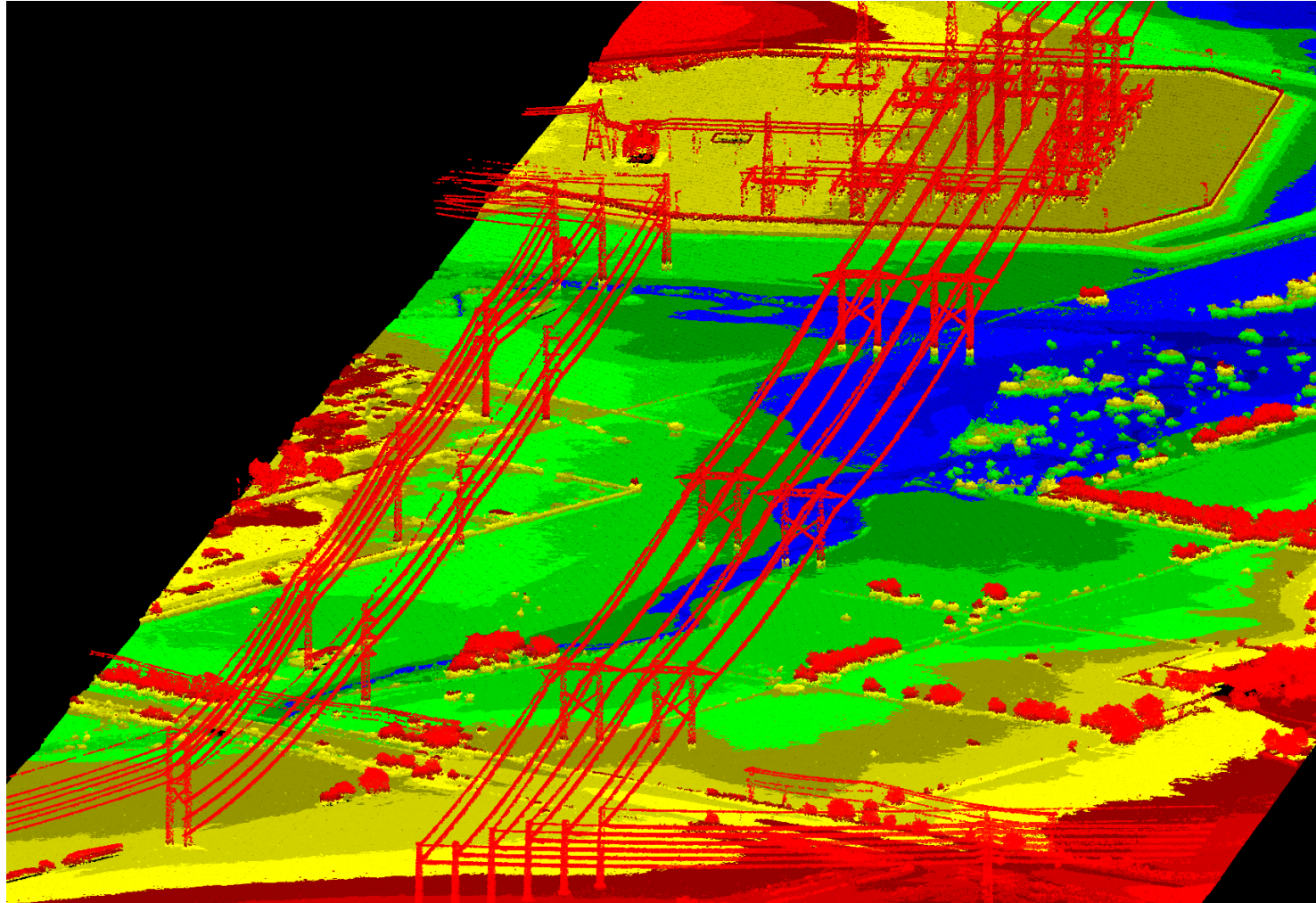
Hawaii data collection

Colorized point cloud

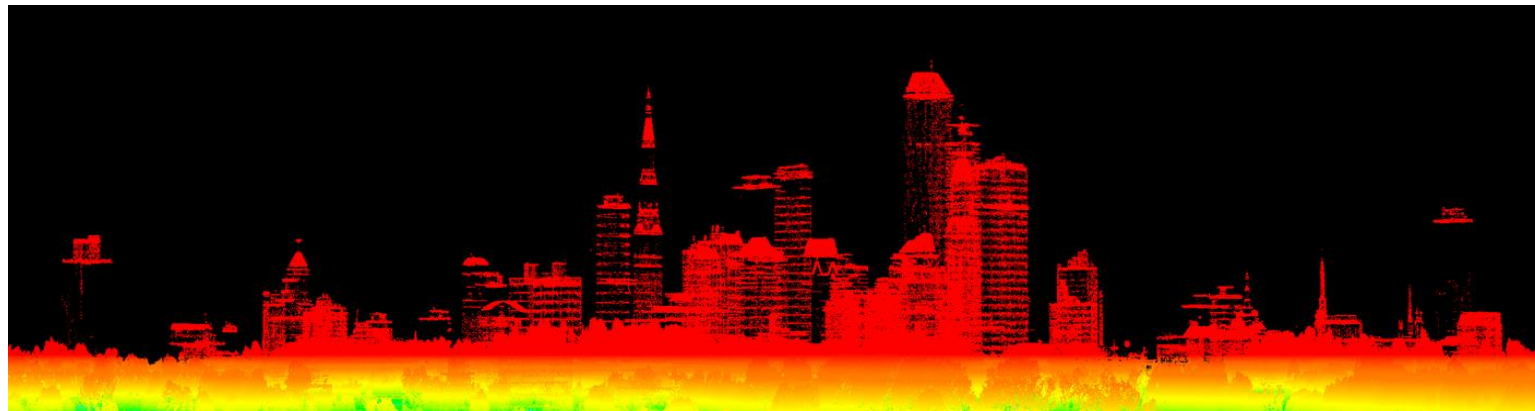
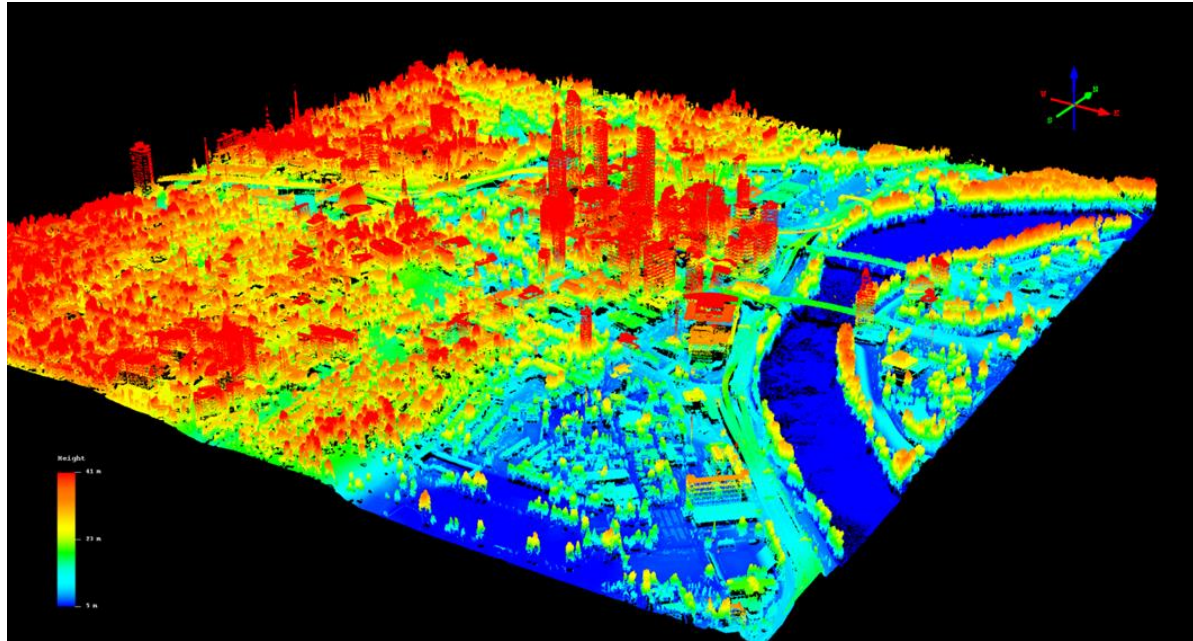
- Extremely mountainous terrain
- Heavy (triple canopy) vegetation
- Automatic range gate thoroughly tested
- Still achieved ground detection in 90% of all 1m x 1m sample squares from 2000m AGL



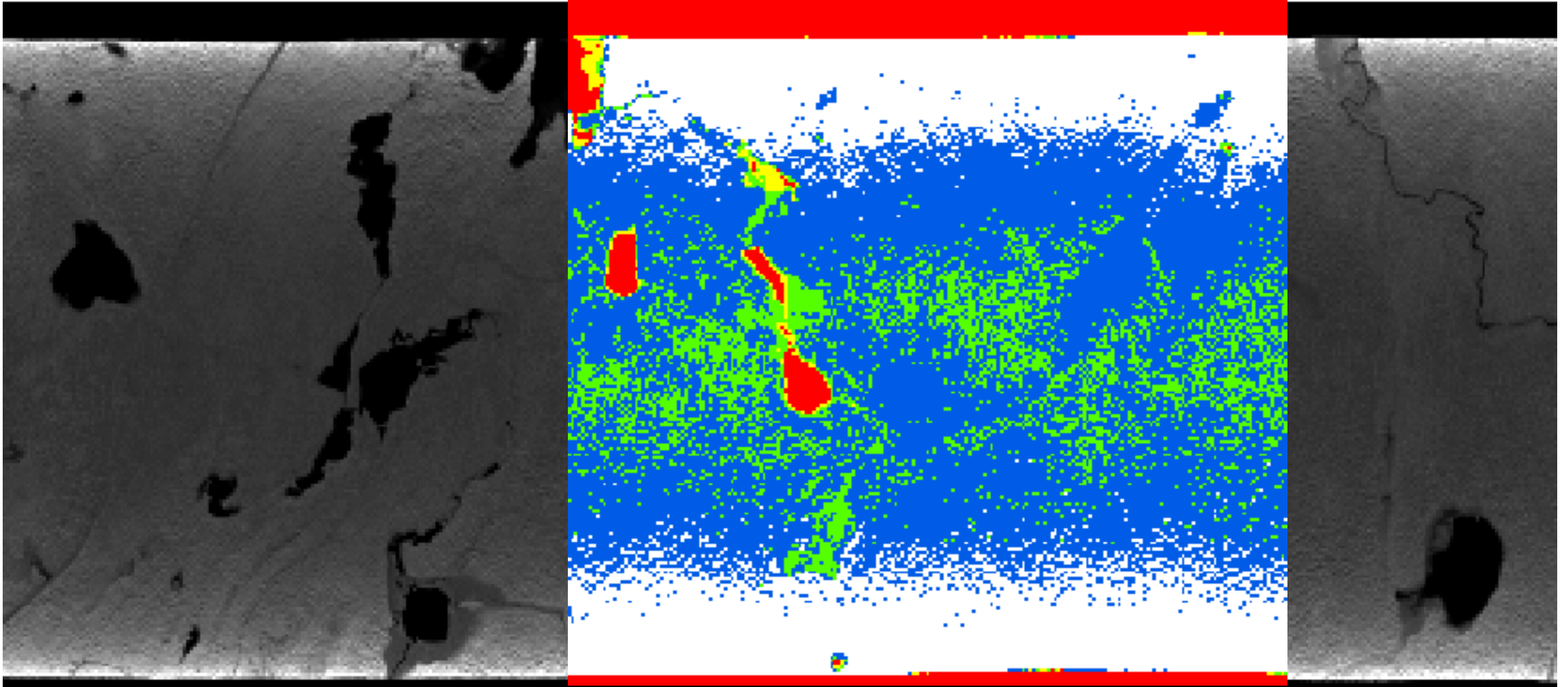
SPL100 – Powerlines



SPL100 – Hartford, CT (USA)



HxMap Workflow tools: Point density diagrams with gray scale or false color coding



HxMap workflow tools: fore/aft, line/line match diagrams

- Performs match test using horizontal planar patches
- User-settable criteria (limits)
- Provides excellent idea of goodness-of-fit between forward and aft scans and between overlapping lines

H001_2000C_vs_H002_2000C

1387325 valid patches with size of 2 m found. Only patches with standard deviation < 0.05 m and minimum of 5 points are included.

Color	Limits [m]	Number of patches	Proportion of total number of patches [%]
Dark Green	≤ 0.03	1343186	96.82
Light Green	0.03-0.05	41780	3.01
Yellow	0.05-0.1	2326	0.17
Red	> 0.1	33	0.00



Vertical difference

HxMap Workflow tools: Registration & Georeference

- Registration uses HxMap proprietary line registration algorithms
- Phase Correction
 - Corrections applied in all three axes x, y, z
 - Max correction: 1m
- Final point clouds are output from HxMap in the desired coordinate reference system for the end user. Several CRS are defined in HxMap and the user can add additional CRS to suit their needs.
- A vertical shift can be applied during this step if it is required to fit the ground control.

 Generate Product

?

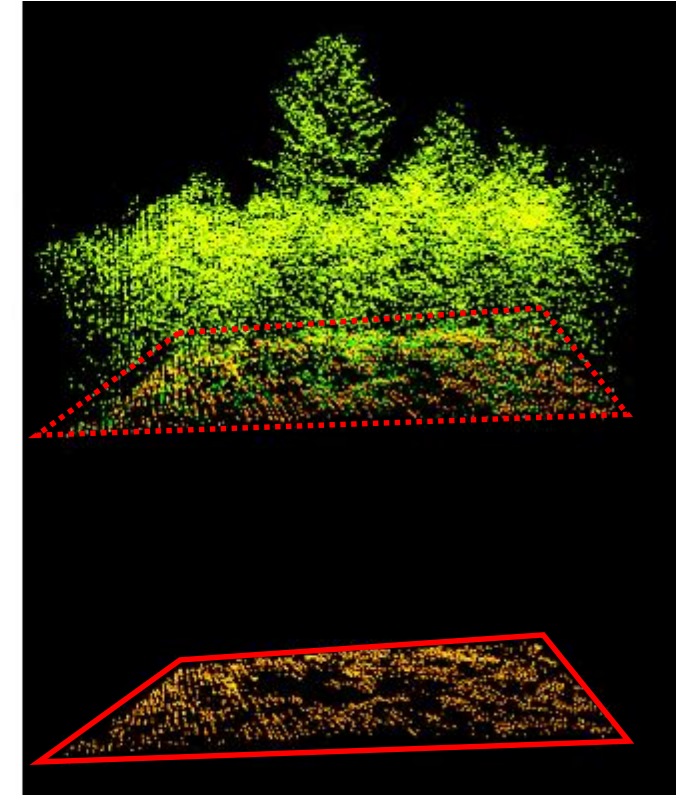
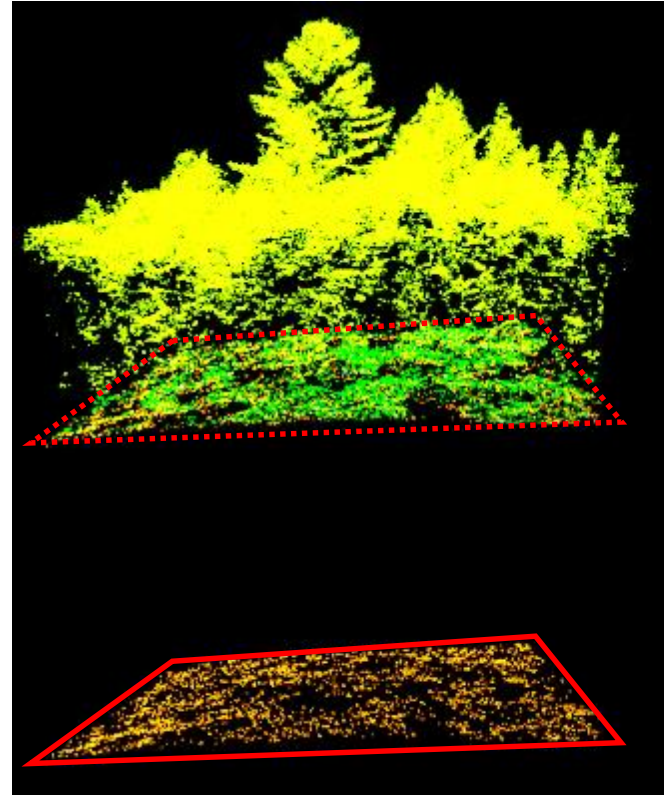
×

Project Specification Settings

Reference System	
Coordinate System:	Projection System
	UTM_18N
Datum:	NAD83-CSRS Epoch 2010 (OMNR)
Vertical Reference:	Canadian gravimetric geoid model of 2013
Horizontal Units:	metres
Vertical Units:	metres
AOI:	
Output Root:	Y:/SPL_Lidar/S18-011_OMNR/Products/Output/NAD83_CSRS
Output:	Y:/SPL_Lidar/S18-011_OMNR/Products/Output/NAD83_CSRS/1/LiDAR_Las1.2_Default_Product
Prefix:	
Suffix:	
Apply Z-Shift (m)	0.00

SPL100 proves utility for determining forest metrics

- Petawawa research forest, Ontario, Canada
- Mixed species (~60% pine, 40% hardwood)
- SPL100 in 2018
 - Flying height AGL: 12,000'
 - Pulse rate: 50kHz
 - Scan rate: 20Hz
 - FOV: 30 degrees
 - Speed: ~170 knots
 - Density (50% side overlap) 25/m²
 - Ground hits this area: 2983 points
- ALS in 2012
 - Point density: 15/m²
 - Ground hits this area: 1858 points
- SPL gives 1.66x the point density of linear mode on the tree crowns
- SPL gives 1.60x the point density of linear mode on the forest floor



see also video lecture by Murray Woods of the Canadian Wood Fibre Center and Ian Sinclair of the Ontario Ministry of Natural Resources. This particular lecture is part of a series of CIF/IFC Electronic Lectures.

<http://cif-ifc.adobeconnect.com/ptu6q4capftm/>

Applications: Summary of USGS LIDAR Base Specification (R1.3)

USGS Quality Level	Aggregate Nominal Pulse Spacing (ANPS, m)	Aggregate Nominal Pulse Density (ANPD, pts/m ²)	Smooth Surface Repeatability (cm) ^{1, 2}	Swath Overlap Difference (RMSDz, cm)	Swath Overlap Difference, Maximum (cm)	RMSEz (non-vegetated, cm)	Non Vegetated Accuracy (NVA) @ 95% confidence level (cm)	Vegetated Vertical Accuracy (VVA) at 95 th percentile (cm)	Sample Cell Size (m) ^{3,4}
QL0	≤0.35	≥8.0	≤3	≤4	±8	≤5.0	≤9.8	≤15	2
QL1	≤0.35	≥8.0	≤6	≤8	±16	≤10.0	≤19.6	≤30	2
QL2	≤0.71	≥2.0	≤6	≤8	±16	≤10.0	≤19.6	≤30	2
QL3	≤1.41	≥0.5	≤12	≤16	±32	≤20.0	≤39.2	≤60	4

¹ defined as the maximum hash about a plane fitted through each sample cell, where the largest value from any sample cell within the 50m² test area must be within the specified value

² with outliers removed; definition of outlier is not given, but removal of too many outliers would also affect delivered point density

³ ANPS, rounded to the next higher meter, then multiplied by 2

⁴ 100-cell sample area is defined for all Quality Levels, but cells can be from different areas

Conclusions

- SPL technology can be used for many applications within USGS QL1 constraints for accuracy, density and surface smoothness
 - General purpose wide-area mapping (general guideline >30,000 km²)
 - Forest metrics, particularly on an area basis
 - Power distribution network mapping/vegetation management
 - Some city modeling applications

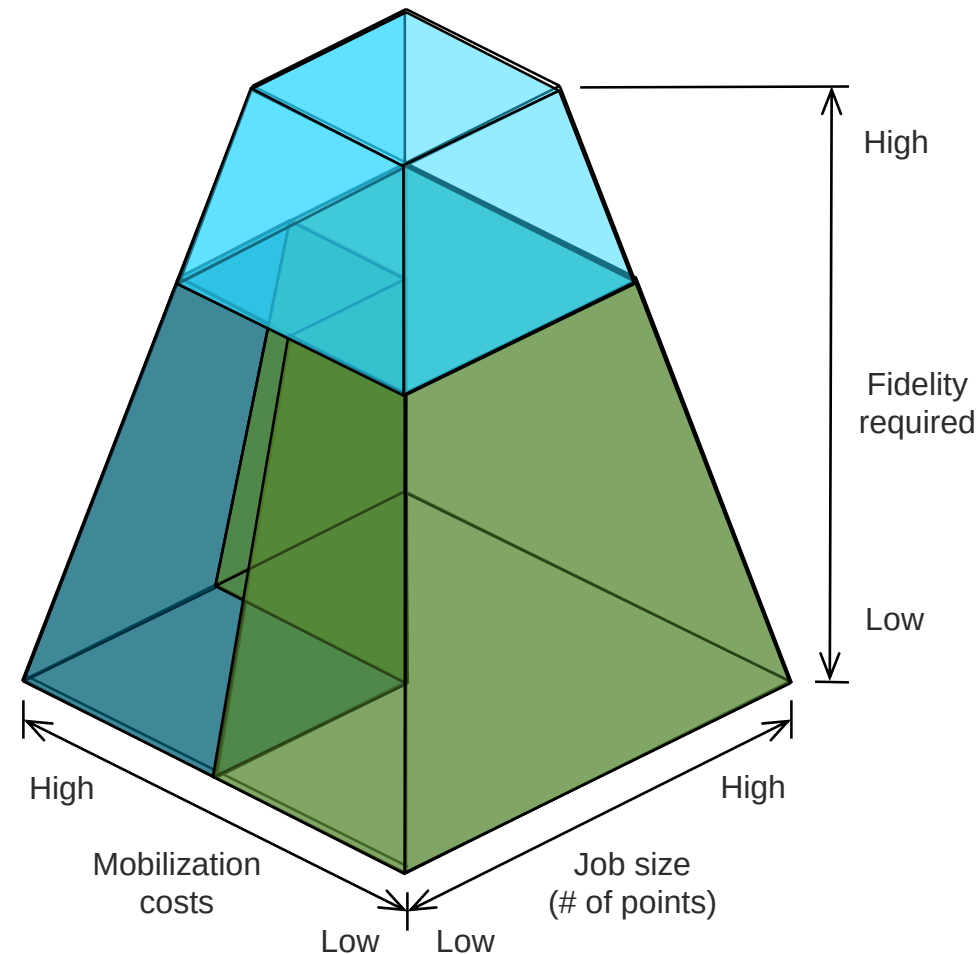
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- SPL technology will **not** be a replacement for existing linear-mode technology for some applications, i.e.,
 - Where USGS QL0 accuracy (<5cm RMSEz) or smoothness (<3cm RMSDz) are required
 - For bathymetry (even if 532nm SPL wavelength does penetrate water at some level)
- SPL technology will continue to grow and improve, taking advantage of synergies with linear-mode developments (and vice versa)

SPL
capability

Parting thought: How to employ single-photon technology: market segmentation

- Light Blue = can only be satisfied by linear-mode systems
- Green = can be satisfied single-photon technology
- Dark Blue = can be satisfied by either system, but may not be the best use of capital for SPL technology
- Single-photon technology is best used for data acquisition where higher point densities are required over very large areas (provincial to continental scale)





• Thank You!
• ron.roth@hexagon.com