Performance Considerations in Drone LIDAR Systems
TRB AKD70 Summer 2020 Meeting

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GeoCue Group Inc. Background

- Founded in 2003
  - Jim Meadlock, founder and 30+ year CEO of Intergraph
  - Lewis Graham, founding CEO of Z/I Imaging
- Located
  - HQ - Huntsville, Alabama USA
  - Satellite office – Toronto, Canada
  - GeoCue Australia – Brisbane, Australia (August 2020)
- Ownership
  - Private - Jim, Lewis, employees, minority outside investors
  - GeoCue Australia is 55% owned by GeoCue Group Inc.
- Our Focus – LIDAR and Imagery technology
  - Providing geospatial processing solutions close to the sensor
  - Providing data management solutions
  - Providing end-to-end drone mapping solutions

What we do…

*ALS/MLS Solutions

- Terrasolid sales & support
- LP360 Point Cloud S/W
- Data Management
- Workflow consulting
- Training

30%

Drone Mapping

- True View Sensors
- Complete workflow S/W
- Cloud-hosted Data Management
- Direct Geopositioning H/W (Loki)
- DJI Enterprise sales
- H/W Integration
- Consulting services
- Mapping Services

50%

Enterprise Solutions

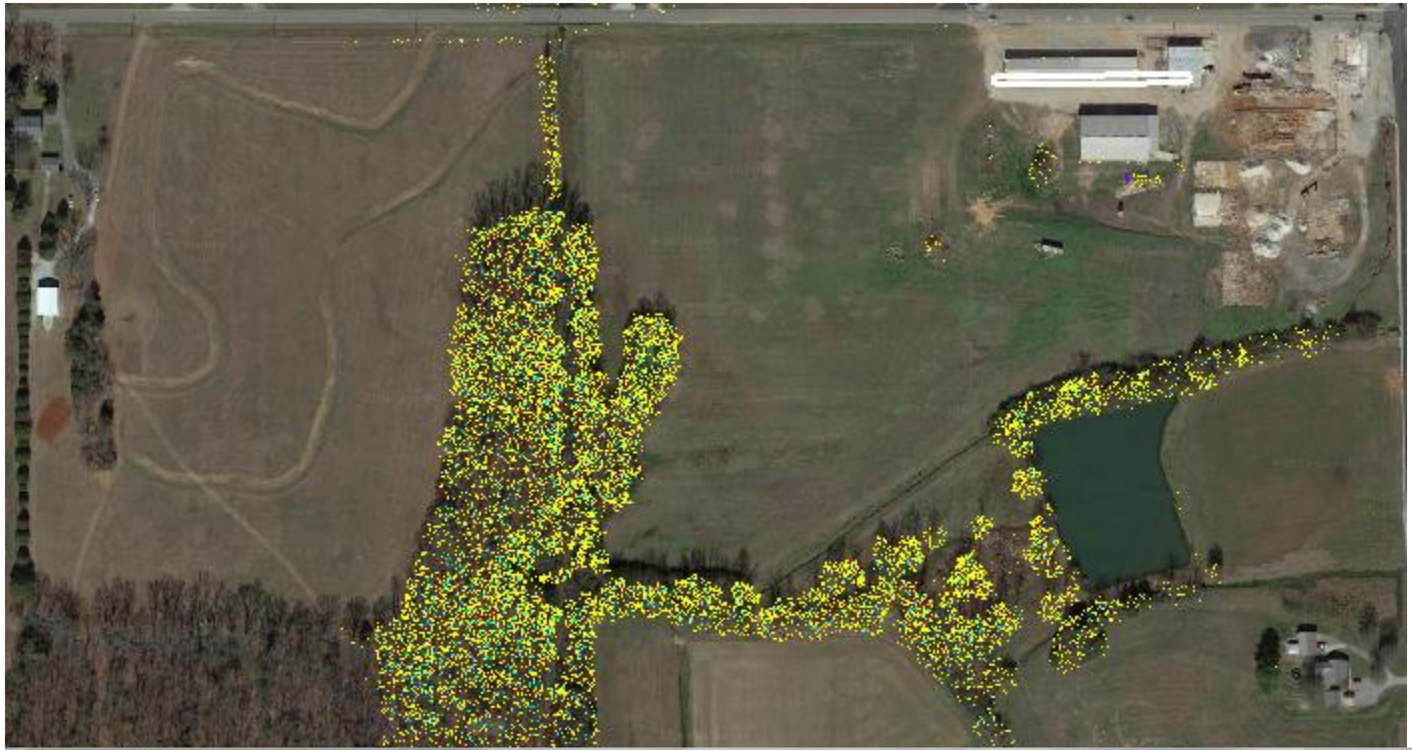
- Bespoke cloud-hosted (AWS) data processing systems
- Earth Sensor Portal – AWS LIDAR/Imagery Management
- LIDAR data modernization services

20%

*ALS/MLS – Traditional "manned" airborne and mobile laser scanning

GeoCue Services: 3,000+ drone mapping projects

GeoCue Test Range - The “Shop”



We have our own test range (the “Shop”) monumented with control and check points

New Headquarters – Triana (Huntsville), Alabama USA

Consolidates Operations

- Administration
- R&D
- Manufacturing
- Training Facility
- Drone Flight testing on site
- Close to Tennessee River for bathymetric testing
- 6 miles from Huntsville International Airport

Anticipate completion in early 2021

A Few Opening Remarks

- Be careful of vendor specifications – most are for ideal circumstances that you will seldom encounter
- Some specifications (especially from automotive LIDAR vendors) are misleading:
  - e.g. – A 300 kHz system capable of 2 returns advertised as:
    "600,000 pulses per second, all returns"
- All range and precision claims are extremely optimistic
- Selecting a system is always a compromise
- Do not believe general hype you may hear such as routinely achieving 1/10th foot accuracy with no ground control

We have owned …

Velodyne VLP-32 (Ultra)
APX-15 POS

We currently own…

YellowScan Vx-15

Riegl MiniVUX 1UAV
APX-15 POS

YellowScan Surveyor

Velodyne VLP-16
APX-15 POS

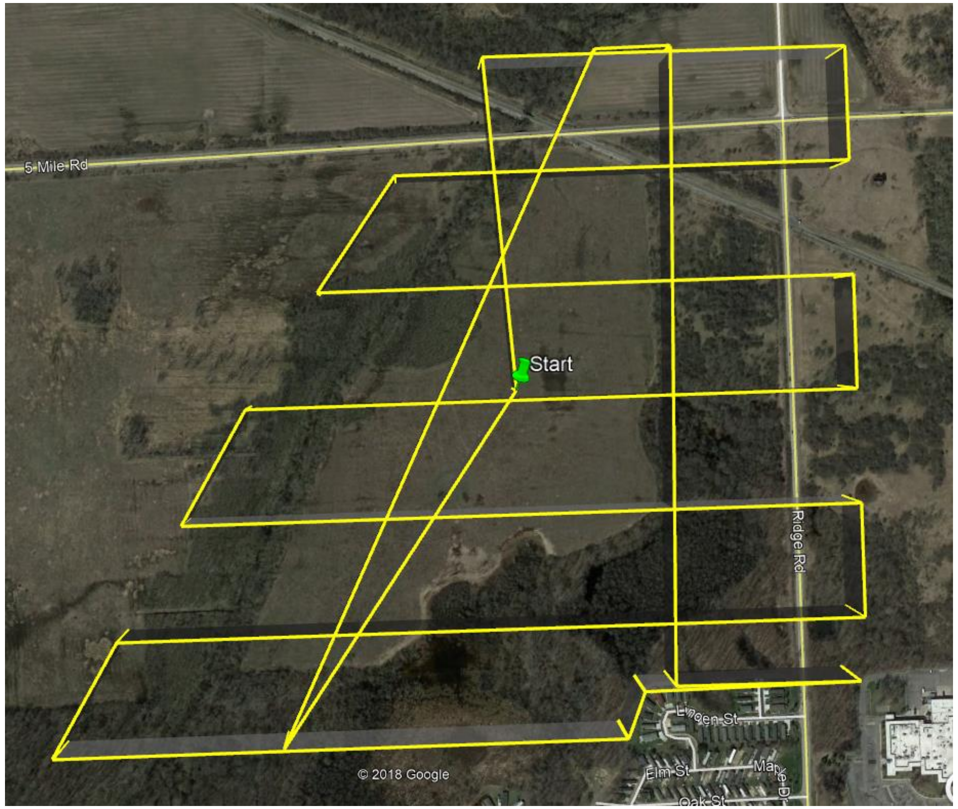
We build …

True View 410
APX 15
Quanergy M8 Ultra
Dual Mapping Cameras
Winner – 2020 ILMF LIDAR Innovation Award

True View 615/620
APX 15 (TV-615)/APX 20 (TV-620)
Riegl miniVUX2-UAV
Dual Mapping Cameras

Why Drone LIDAR?

Why Drones?

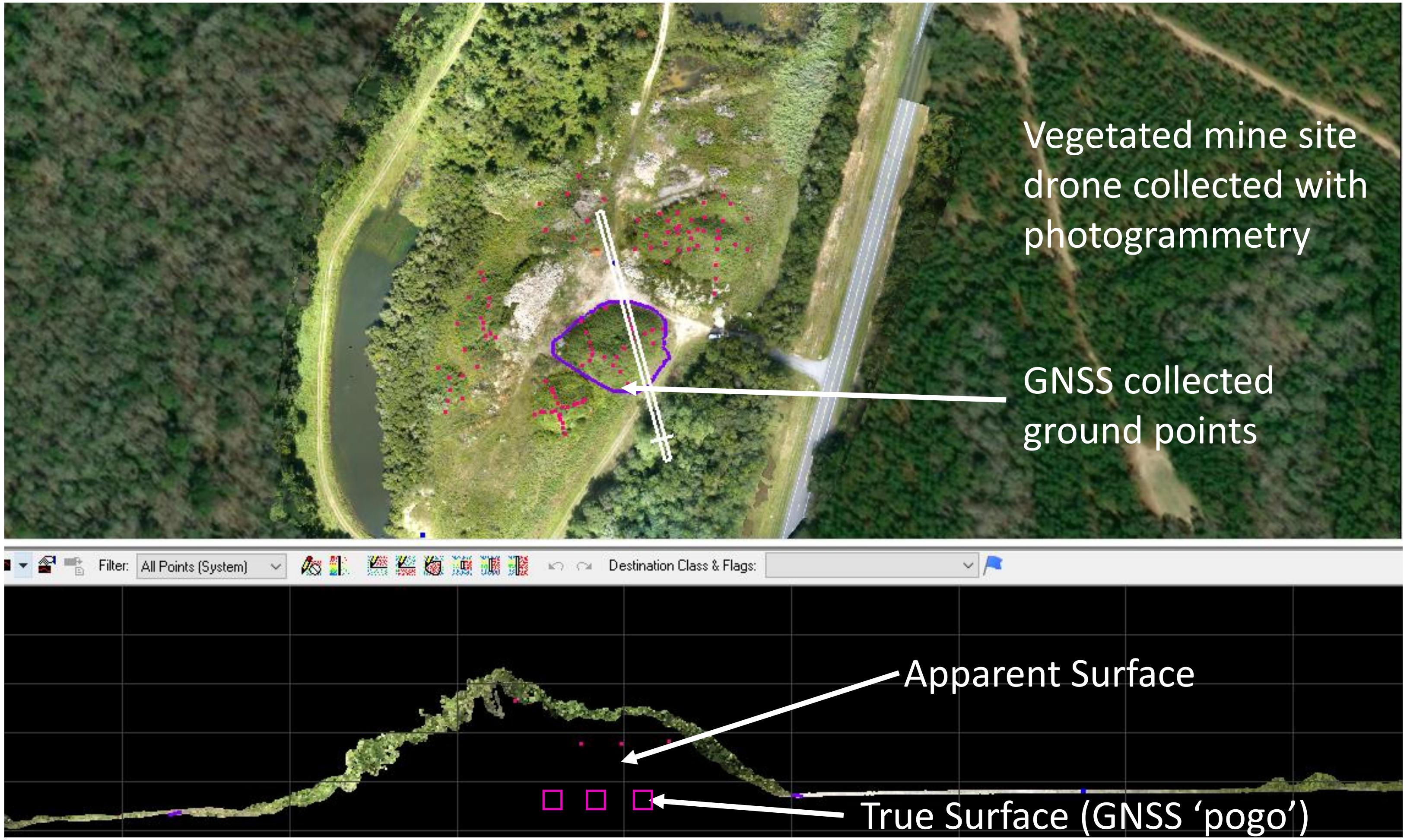


LIDAR Mission - 6.46 miles of flight line

- Small projects where manned aircraft prove prohibitively expensive
- Democratizes aerial data collection – small firms can afford to collect high quality aerial projects
- *Ad hoc projects – decide spontaneously the optimal technology*
- Weather factors – fly under cloud cover

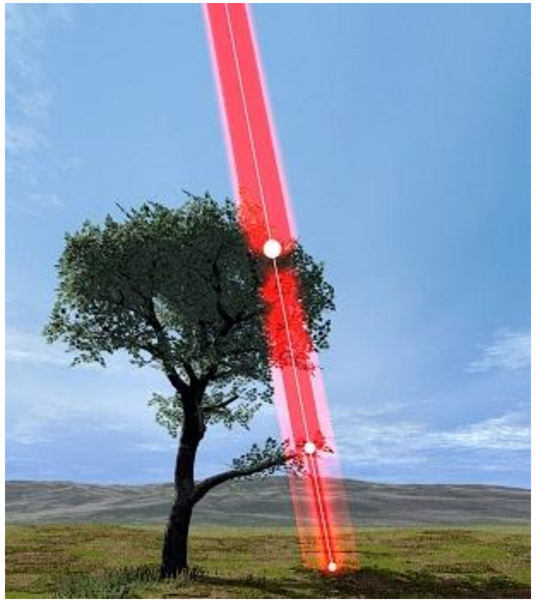
TrueView GeoCue

Why Drone LIDAR (vs Photogrammetry)?



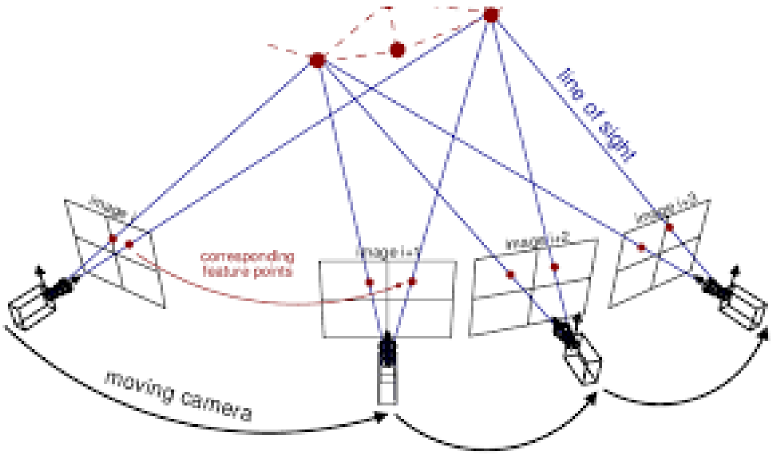
Data collected by GeoCue at CW Roberts Mine Site - Florida

Only a single ray required



This is the strength of LIDAR as compared to photogrammetry

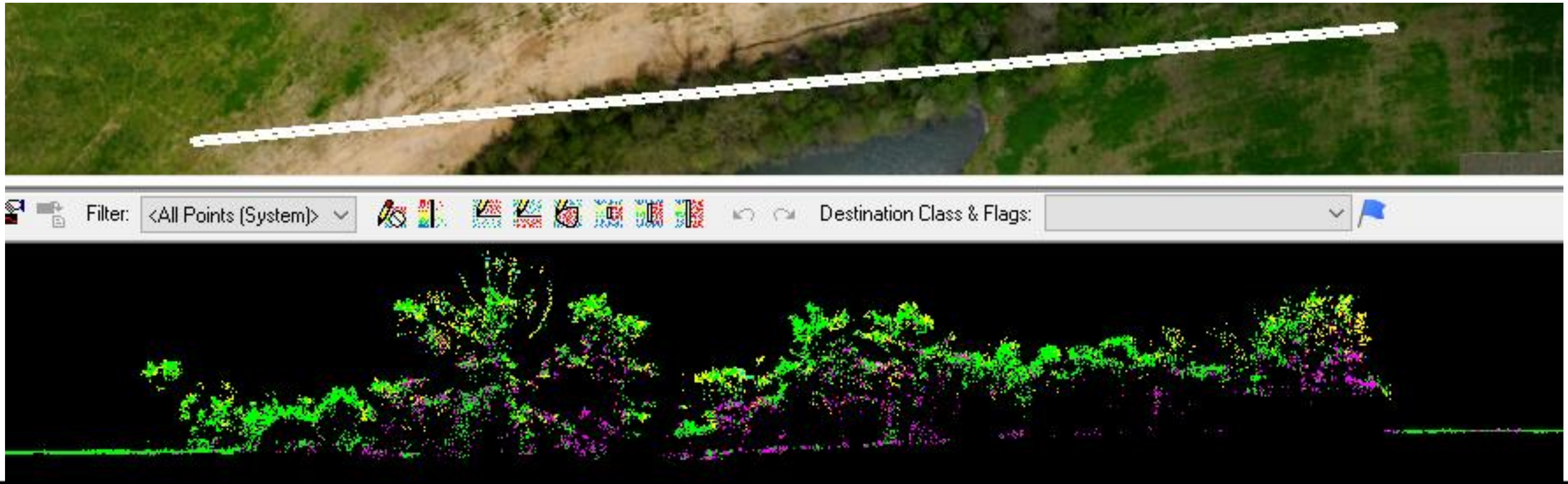
This is the REALLY BIG DEAL about LIDAR!



With photogrammetry (“SfM”), one must see the same object point from multiple camera stations.

Photogrammetry fails in vegetation

Structure from Motion



LIDAR

Bare Earth Scenarios are best for Photogrammetry ("SfM")

Example - Volumetrics for a sand mine

Drone LIDAR is very impactful

Experience of surveyor transitioning from Drone photogrammetry to 3D Imaging (LIDAR/Cameras)

July 31, 2020,

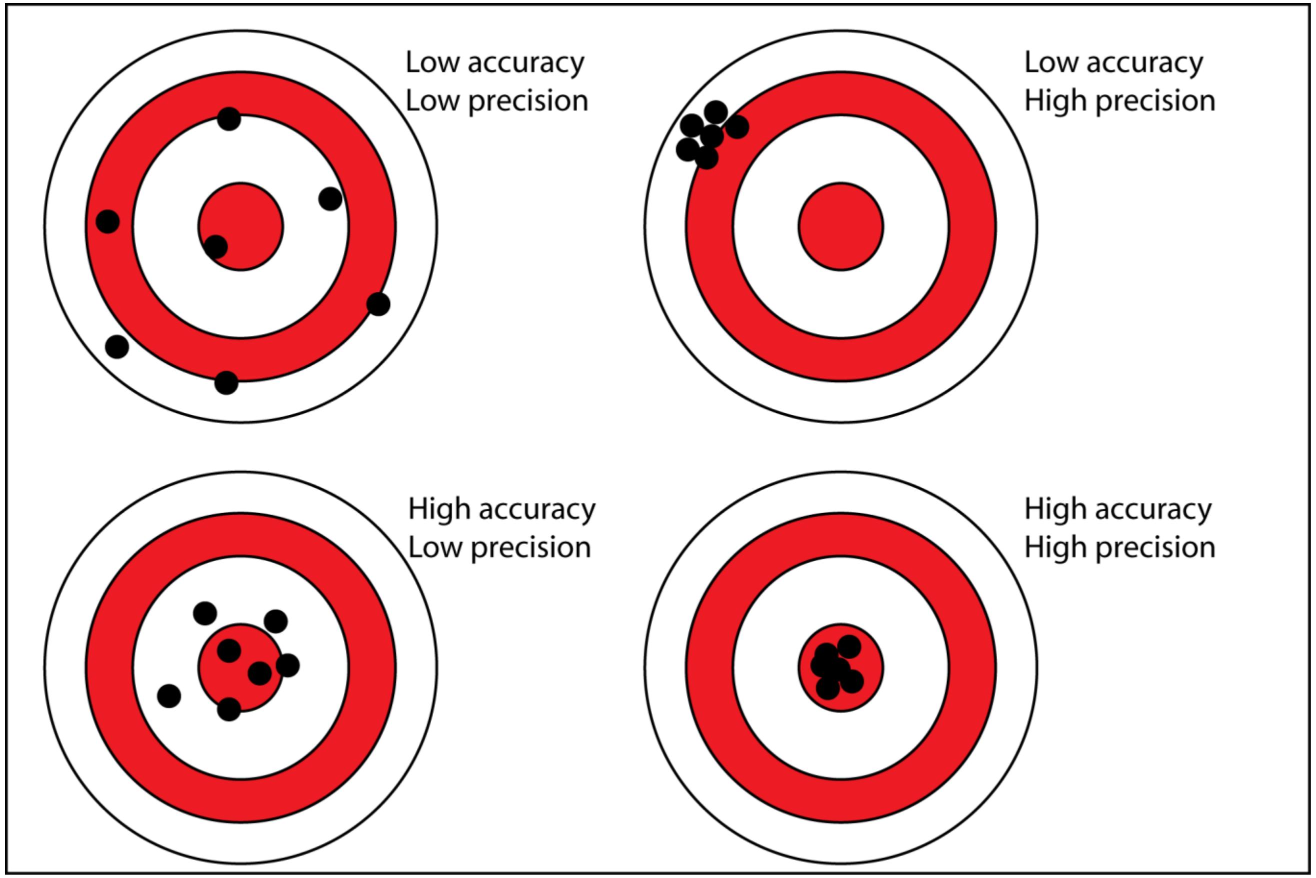
I want to start off by saying that the True View 410 unit we purchased this year has been one of the best pieces of equipment that I have ever bought for my department. We have been using drones for years but this LiDAR unit is like no other. It has tremendously increased productivity. We have been using it 50% of the work weeks since we have had it and flown just about anything you could imagine.

Jon Ham, BARRETT-SIMPSON, INC.
Civil Engineers & Land Surveyors

Some background information

Considerations for evaluating the various aspects of LIDAR characteristics

A reminder…

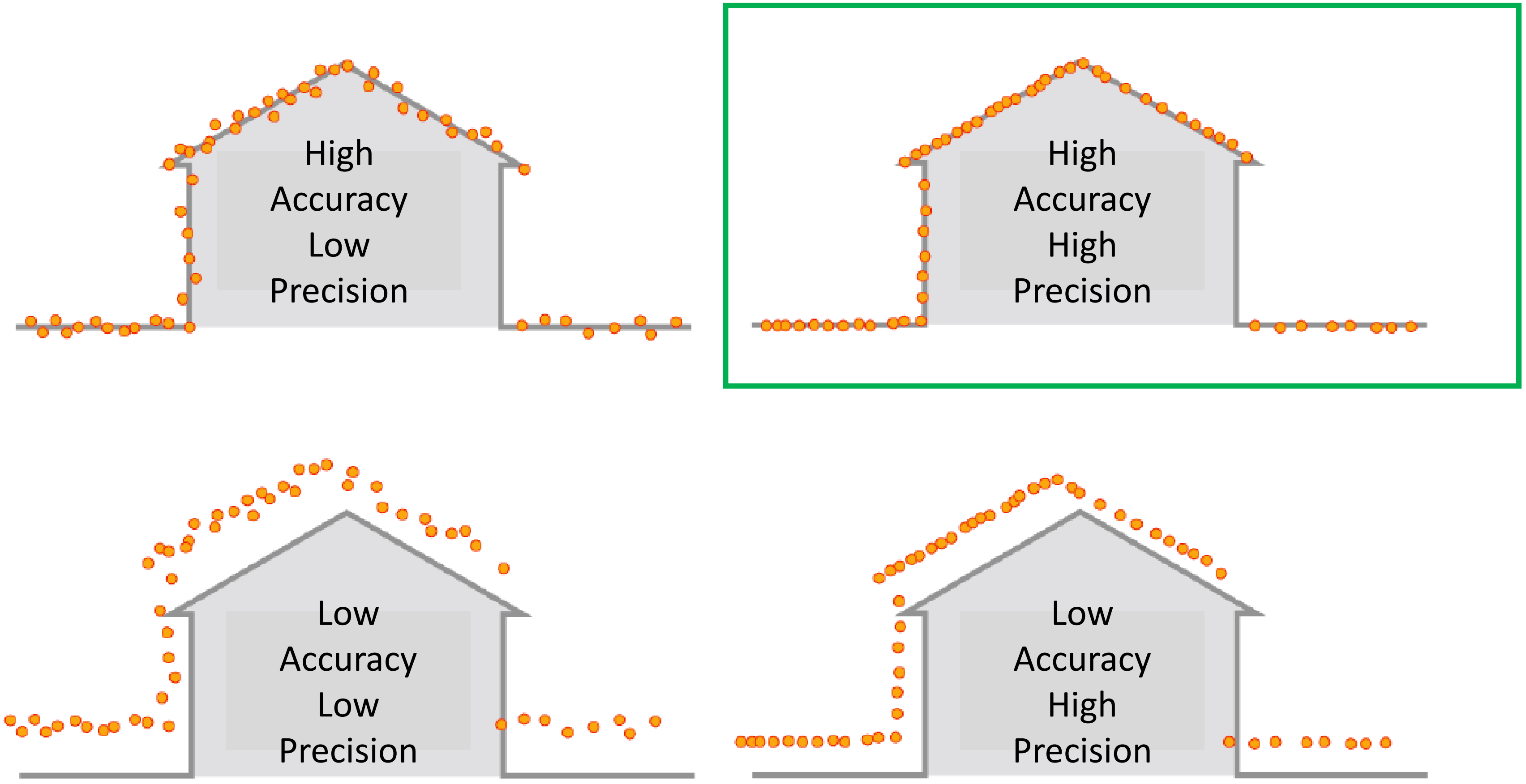


Resolution is designated by the number/width of the bands

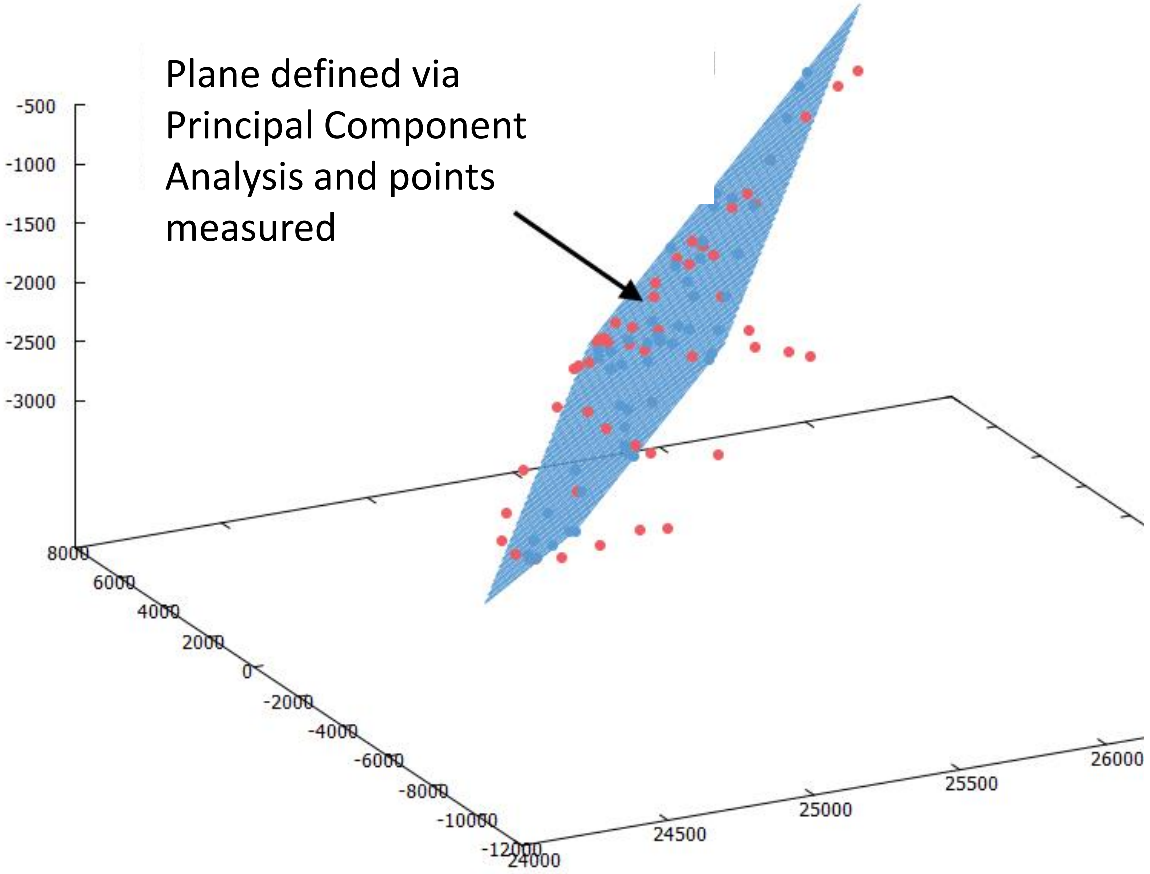
Accuracy is related to μ

Precision is related to σ

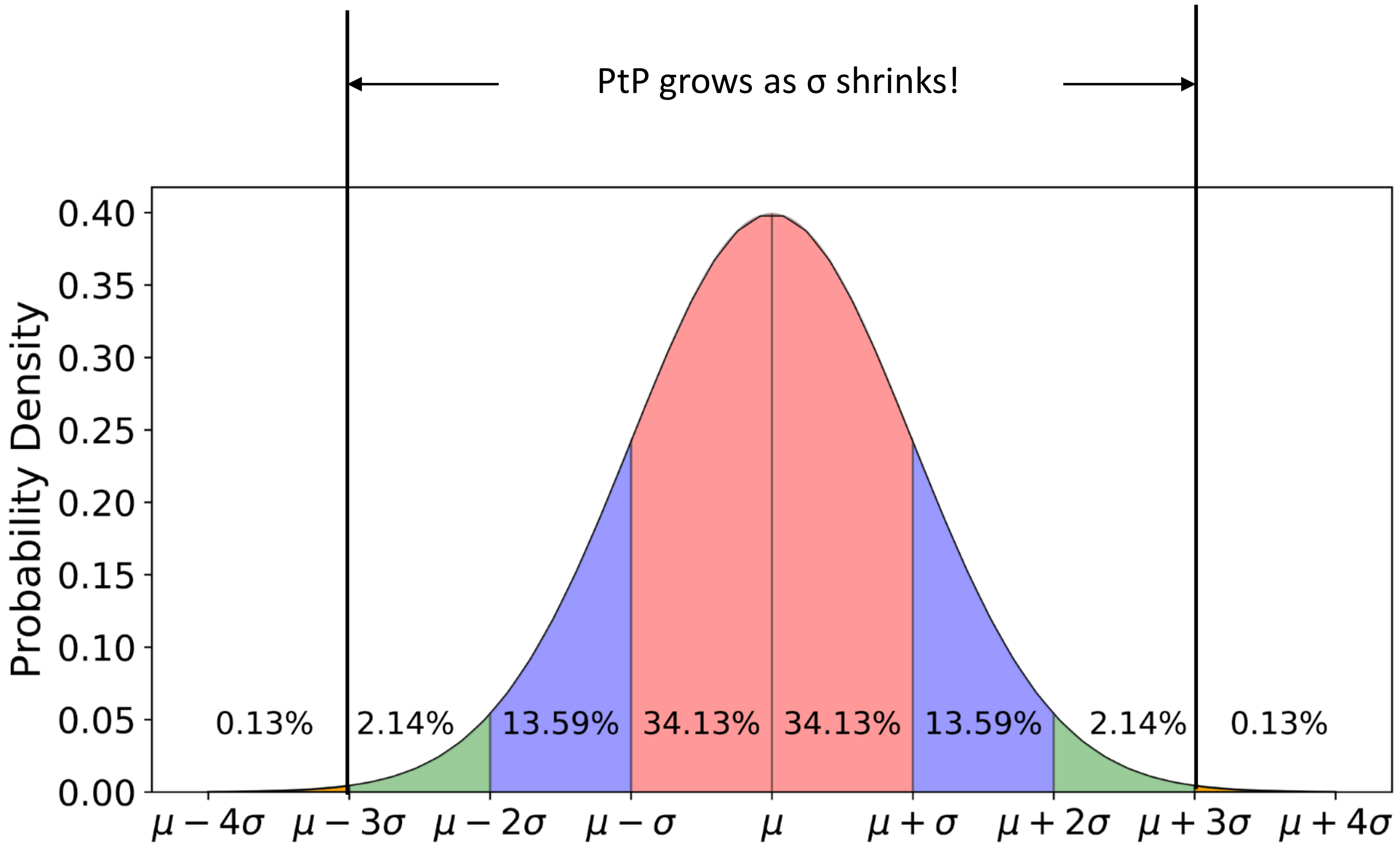
Affect on Data



Precision Testing ("noise")
(tool in GeoCue's True View Evo, LP360)



Std Dev vs Peak to Peak



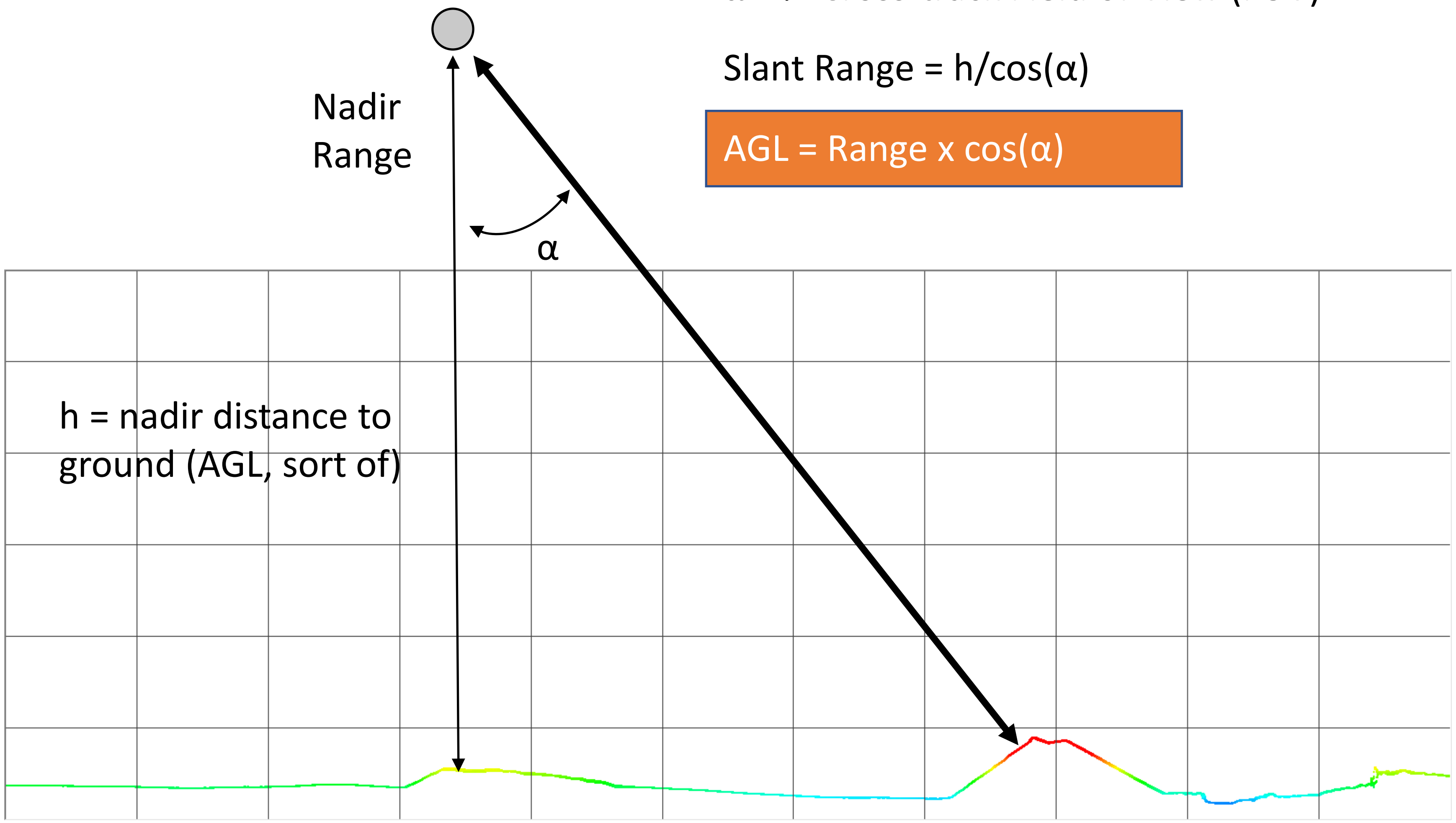
Percentages are true only if the distribution is Gaussian

Slant Range is the distance to consider

α = ½ Cross-track Field of View (FOV)

Slant Range = h/cos(α)

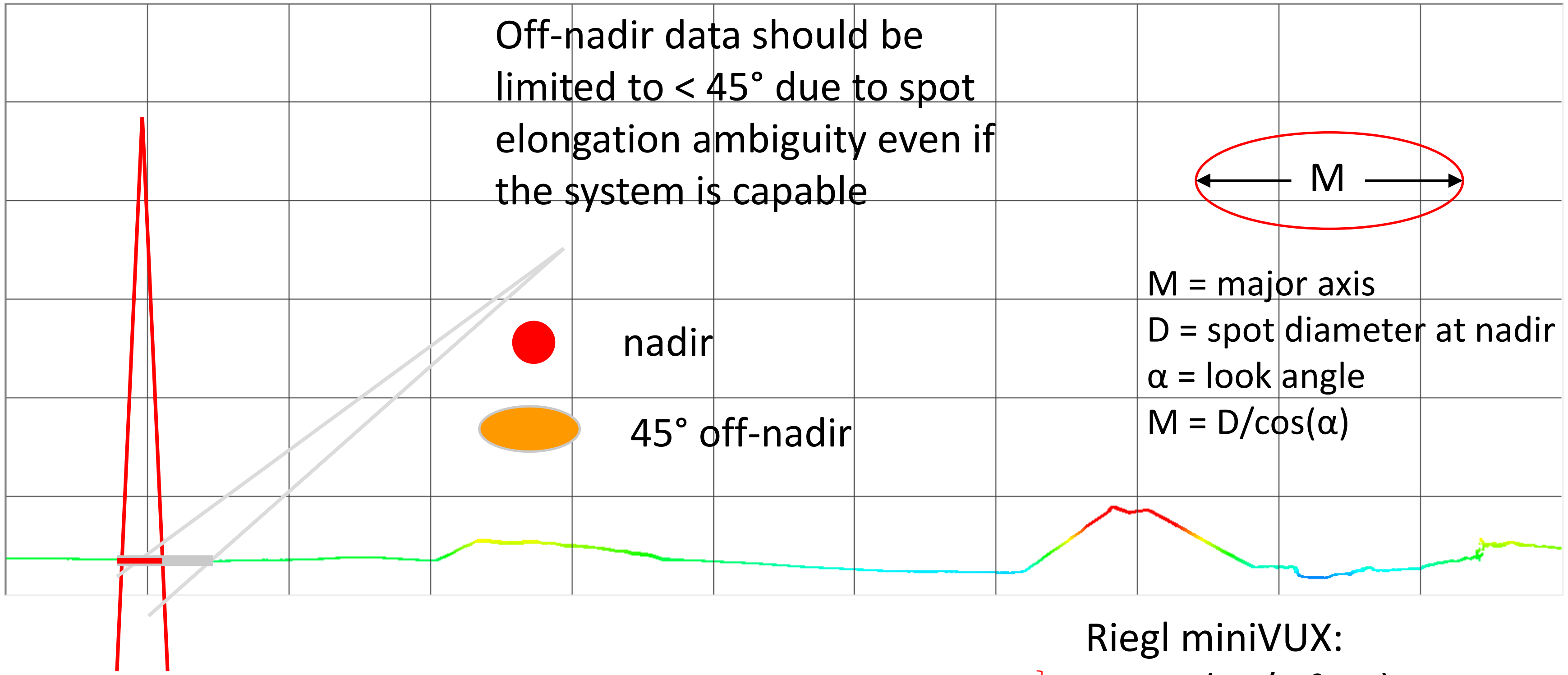
AGL = Range x cos(α)



Example – 75 m AGL has a slant range of 106 m at a 45° cross-track look angle

Beam divergence impacts off-nadir accuracy

Off-nadir data should be limited to < 45° due to spot elongation ambiguity even if the system is capable

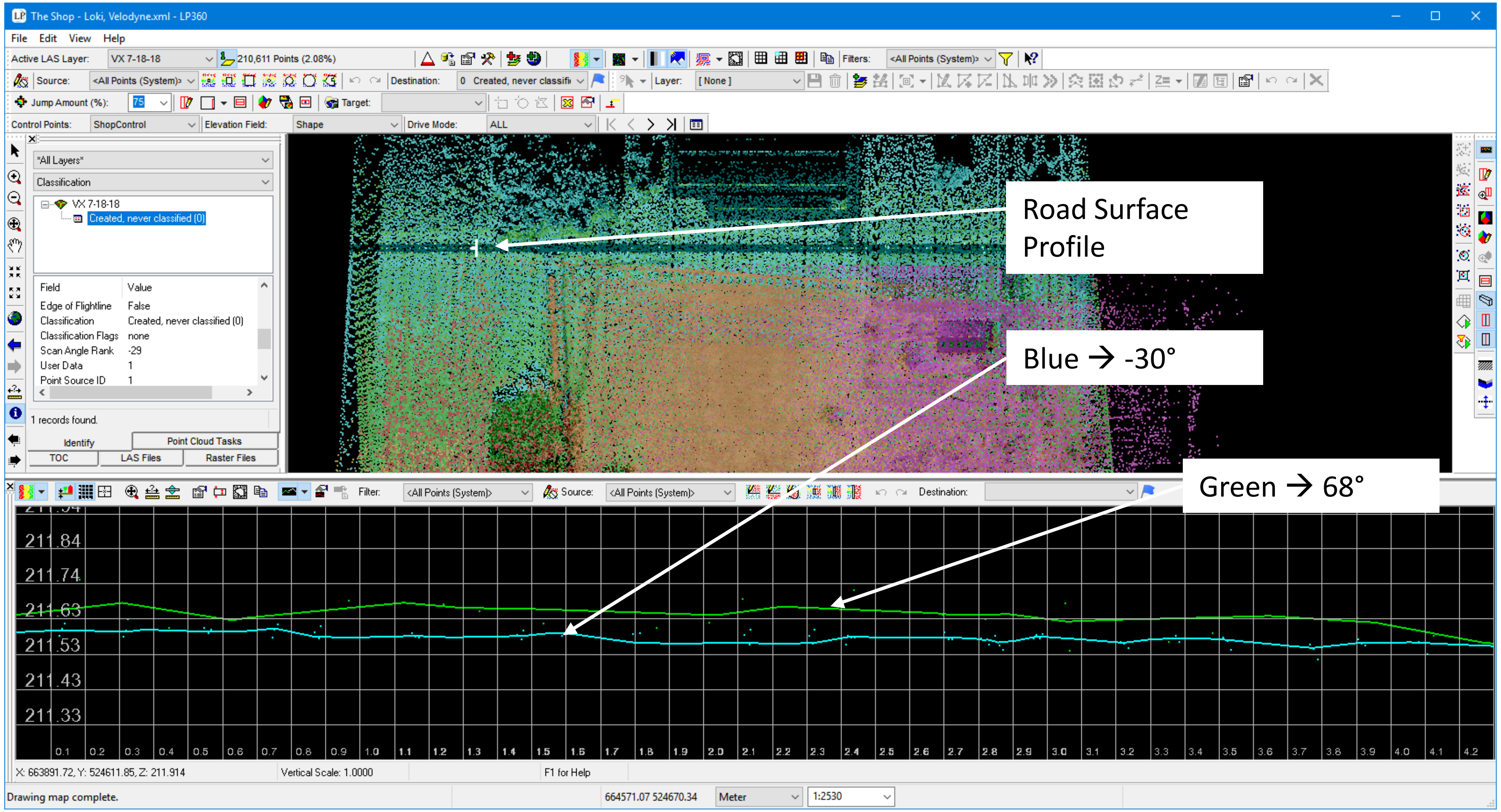


M = major axis
D = spot diameter at nadir
α = look angle
$M = D/\cos(\alpha)$

Laser Beam Divergence [8] 1.6 x 0.5 mrad

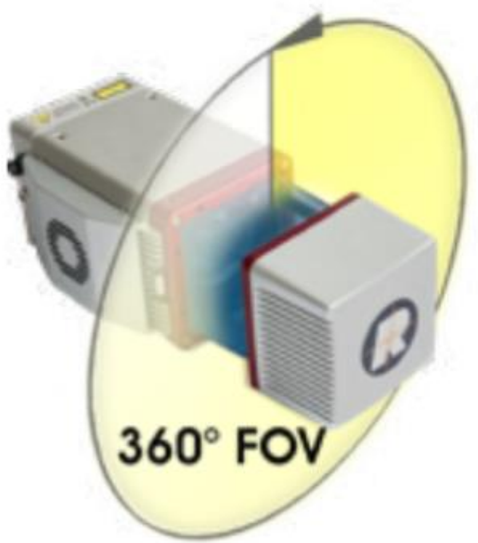
Riegl miniVUX:
16 cm (~1/2 foot) spot size at 100 m range
M = 22.6 cm at α = 45°

High Scan Angle Accuracy Impact



miniVUX – Blue surface profile is correct. High angle on green line is causing the vertical error (over 10 cm in places!)

Scanning Rates



Pulse Repetition Rate (PRR) = Number of outgoing laser pulses per second

Scan Speed = Rotation per second for a rotating system

Angular Step Width = Distance, in degrees (radians) stepped between each pulse

Example: miniVUX-1UAV at 100,000 pulses/second
range to target = 100 m, speed = 4 m/s
Resulting Point Density ~ 40 pts/m^2

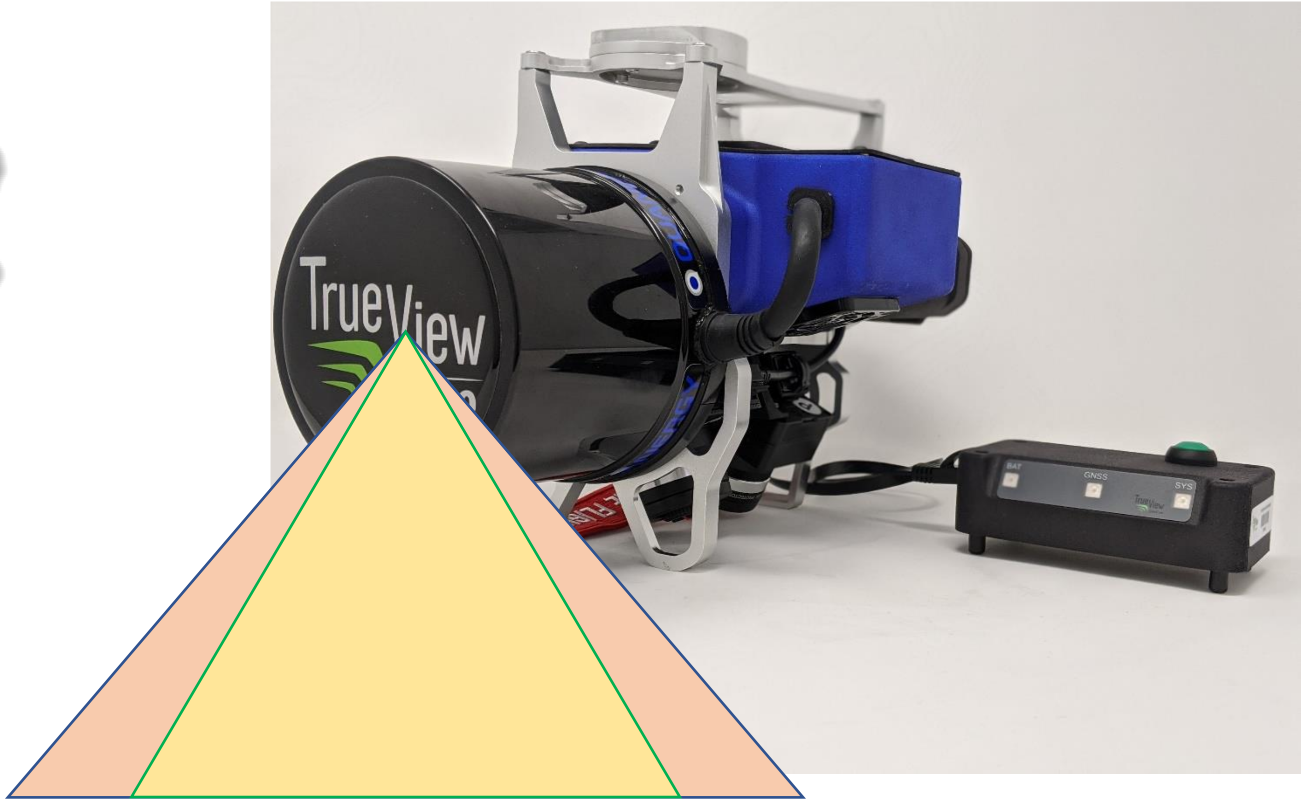
Converting pts/s to useful pts/s

- Precision: 4 cm[1]
- Accuracy: 5 cm[2]

NB: Can be optimized with standard post-processing.

- Scanner field of view: 360°
- 300 000 shots per second
- Multi-echo technology: up to 2 echoes per shot
- 220 Channels GNSS : GPS, GLONASS, BeiDou

Point per second (pts/s) for a 360° scanner are for the full circle. Only about ¼ of these points should be used (90° swath width)



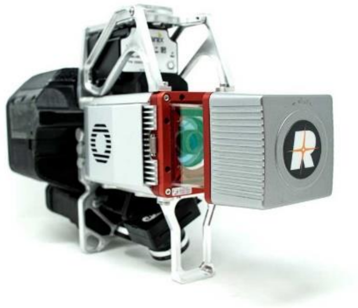
Quanergy M8 Ultra:

430K pts/s total

→ 143.3K pts/s in gross swath (120°)

→ 107.5K pts/s in retained swath (90°)

Effective pts/sec at ±45° FOV



Riegl MiniVUX2
50,000 pts/s

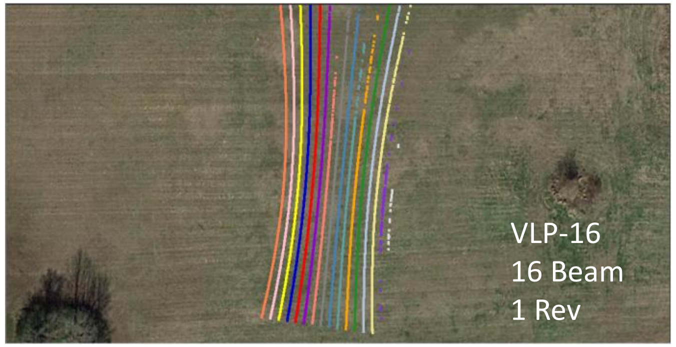
Velodyne VLP-16
75,000 pts/s

Quanergy M8 Ultra Ultra
107,500 pts/s

Velodyne Ultra
150,000 pts/s

These are outgoing pulse rates. The return rate will be higher in the presence of multiple returns

Single vs Multi Beam



Single beam systems must have a higher PRR to achieve the same density as a multibeam.

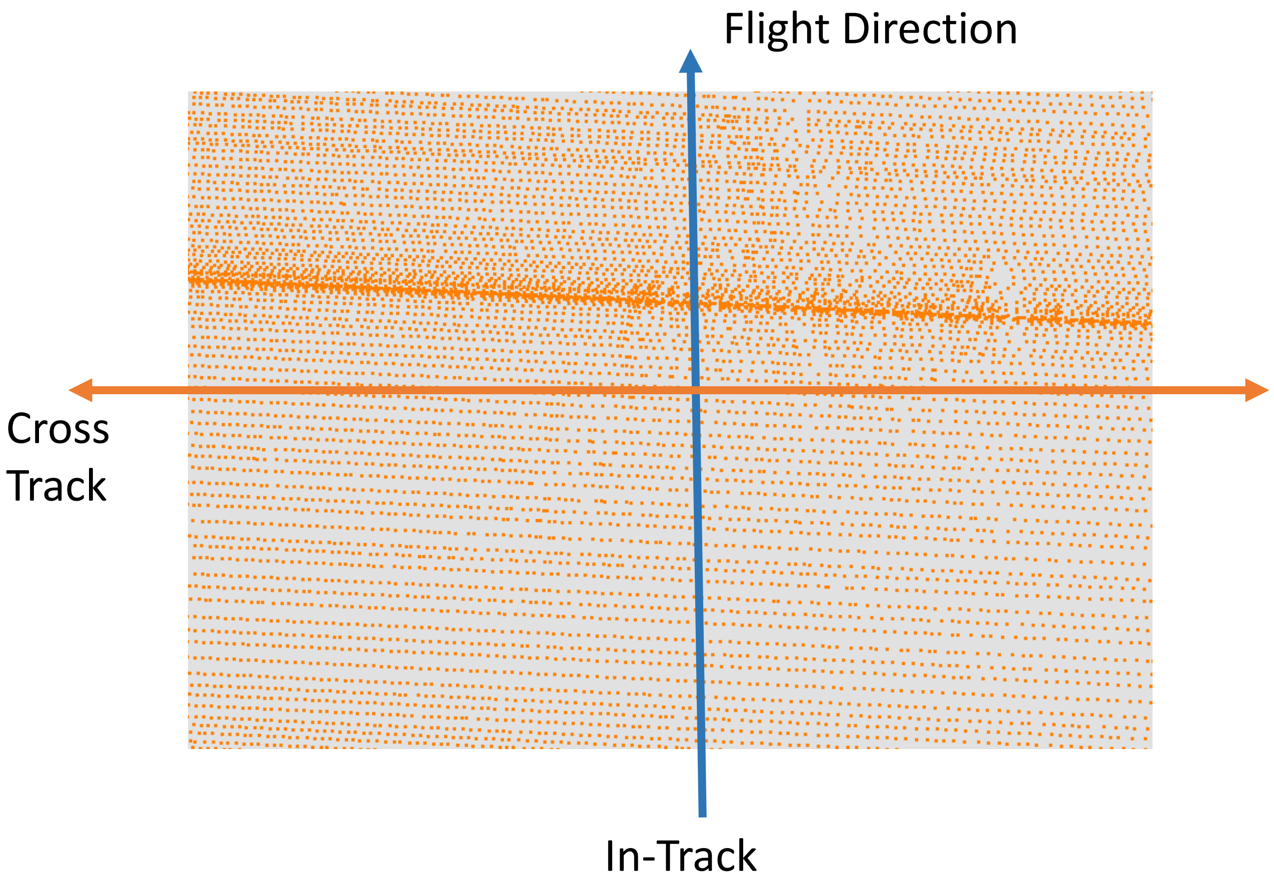
Single beam systems are inherently lower noise since adjacent scan lines are correlated in time

Single beam systems generally have bigger (better) collector optics

Multibeam systems used in mapping must have each beam individually calibrated – GeoCue calibrates each individual beam of the True View 410

[These are actual beams visualized in True View Evo]

Composite Scan Pattern



Cross-Track spacing is a function of PRR and Step Size

In-Track spacing is a function of scanner rotational speed and vehicle forward velocity

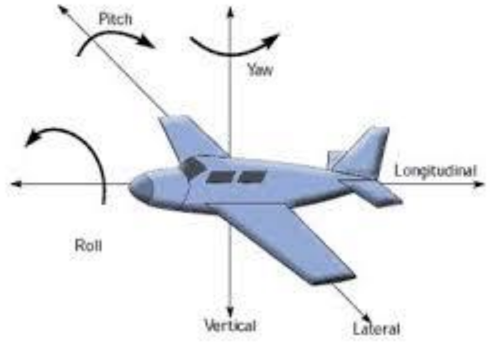
- Slant pattern is due to forward motion of the scanner while rotating
- Uneven scan line separation is due to pitching of the drone

Position and Orientation Systems

Positioning and Orientation System

True View 410, 615 APX Board stack contains internal IMU (IMU-59)

APX-20 adds an external IMU (IMU 82)



Applanix Position and Orientation System (POS) - proven, industry standard for UAV position and orientation

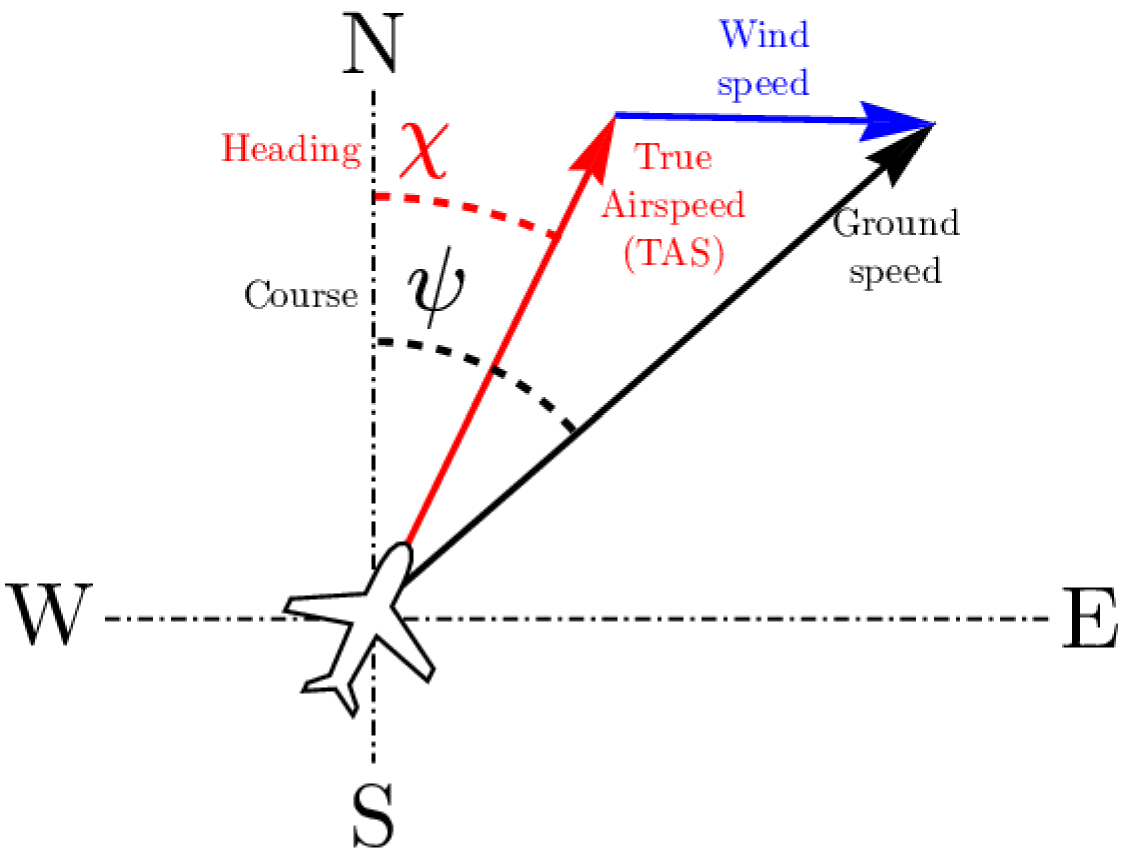
- 336 Channel multifrequency GNSS
    - GPS, GLONASS, BeiDou, Galileo
- Solid State MEMS inertial sensor/200 Hz data rate
    - APX-15: Internal (board-mounted) IMU-59
    - APX-20: Internal (IMU-59) and external (IMU-82)
- Provides system reference time (1PPS)

APX-15 vs APX-20 Accuracy

	APX-15	APX-20
Position (m)	0.02 – 0.05	0.02 – 0.05
Velocity (m/s)	0.015	0.010
Roll (deg)	0.025	0.015
Pitch (deg)	0.025	0.015
Heading (deg)	0.080	0.035

All accuracy values are Root Mean Square (RMS)

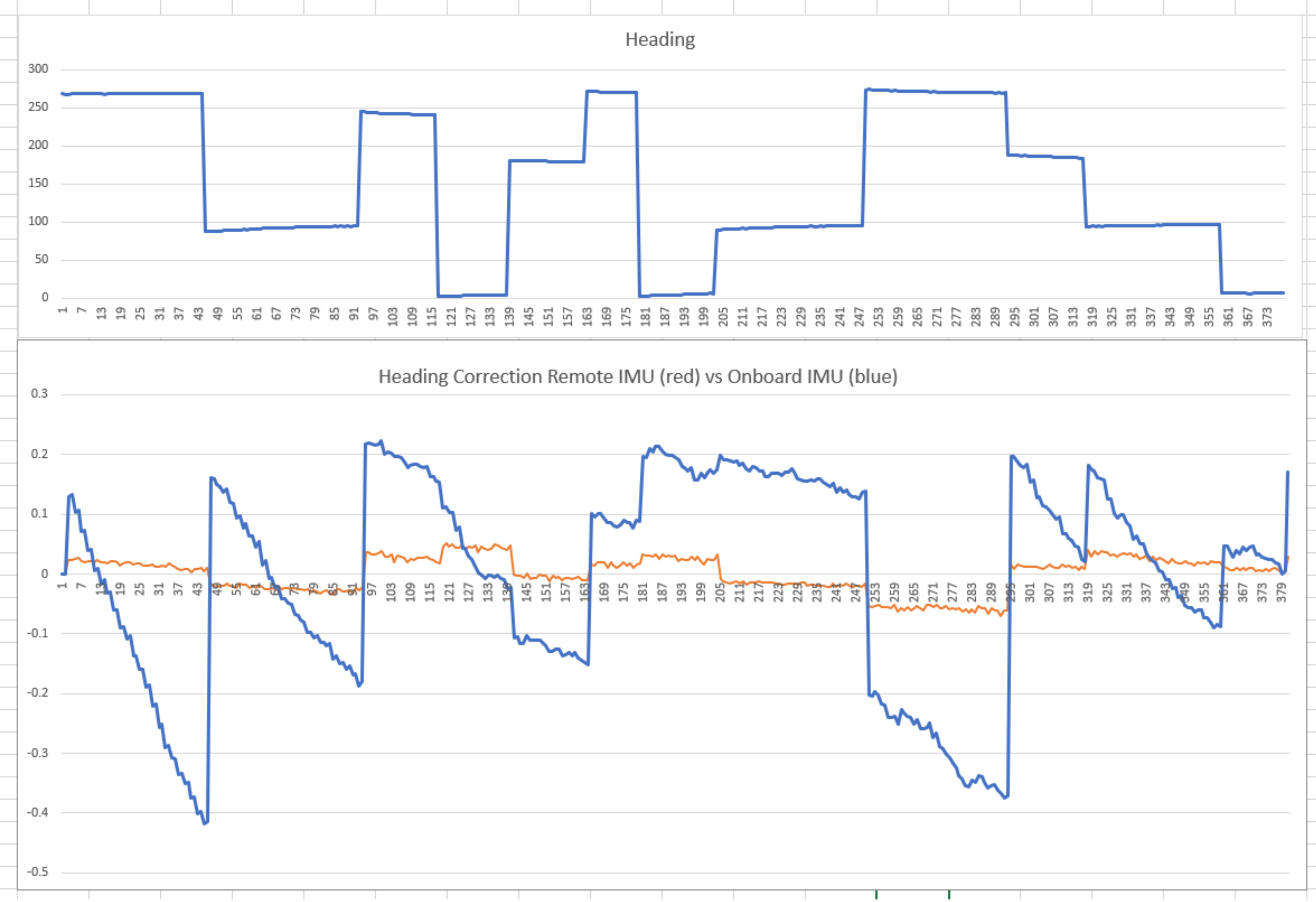
Heading vs Course over Ground



- Heading (red arrow) is the direction the In-Track axis is pointing
- Course over Ground (COG- black arrow) is the track the aircraft is making in the spatial reference system
- COG can be determined from vehicle velocity (GNSS)
- Heading can only be determined from the IMU (if you do not have dual GNSS antennas)
- Heading drifts and can only be corrected (short of external aiding) by vehicle accelerations

see “The Seven Ways to Find Heading”, Kenneth Gade, 2016

Heading Error Example: APX-15 vs APX-20



Absolute Heading (deg)

Heading Error (deg):

Blue – APX-15

Orange – APX-20

Note – heading error estimated from photogrammetric block bundle adjustment of concurrently collecting imagery

Data Source = True View 620

Data Comparison

- Riegl miniVUX
- True View 410 with Quanergy M8 Ultra Scanner, Dual Mapping Cameras
- Velodyne VLP-16

-- All systems use the Applanix APX-15 Position and Orientation System

Comparative Sensors

Riegl MiniVUX-1

True View 410

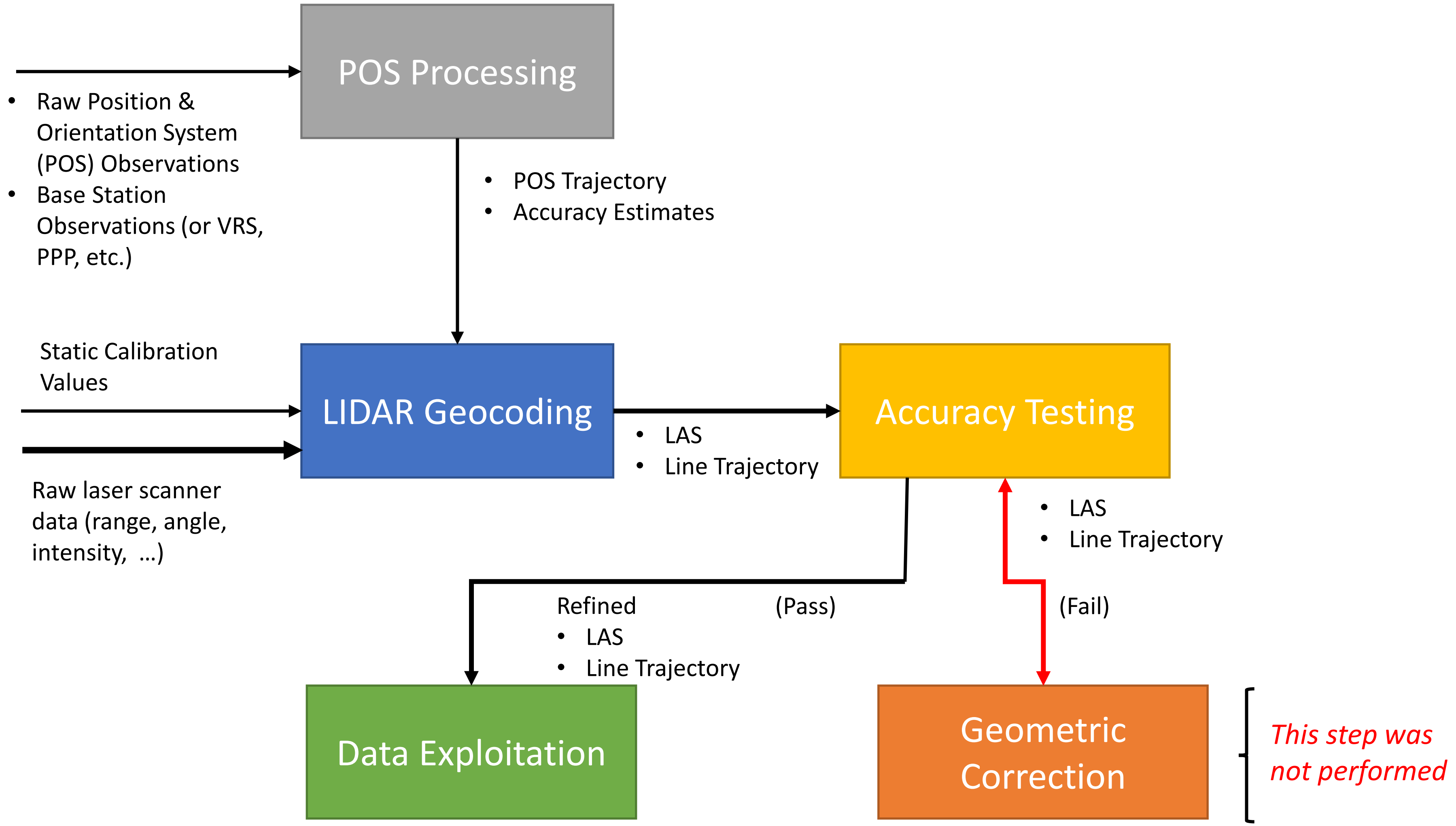
Velodyne VLP-16

True View 410 has integral dual mapping cameras. Other sensors are LIDAR only.

Data Collections

- All three sensors flown within a two-day period in July 2019 using the same mission parameters:
  - Flying height is 75m (246 ft) above ground level (AGL)
  - Speed of 5 m/s
- All three sensors have been calibrated
- All three use the Applanix APX-15 Position and Orientation System (POS)
- LIDAR Geocoding performed on all sets using
  - Applanix trajectory data
  - Sensor Calibration data
  - Manufacturer’s Geocoding software (True View Evo for the True View 410)
- All data analysis limited to ±40°
- No data correction beyond calibration has been performed (see next slide)
  - RMSE can be reduced if a vertical bias is observed in the data (True View Evo has a function for removing point cloud vertical bias)
  - Data accuracy could be improved for all data sets with post-process geometric correction (e. g. TerraMatch)
- Only the True View 410 has RGB populated in the LAS data since it is the only sensor with integral cameras

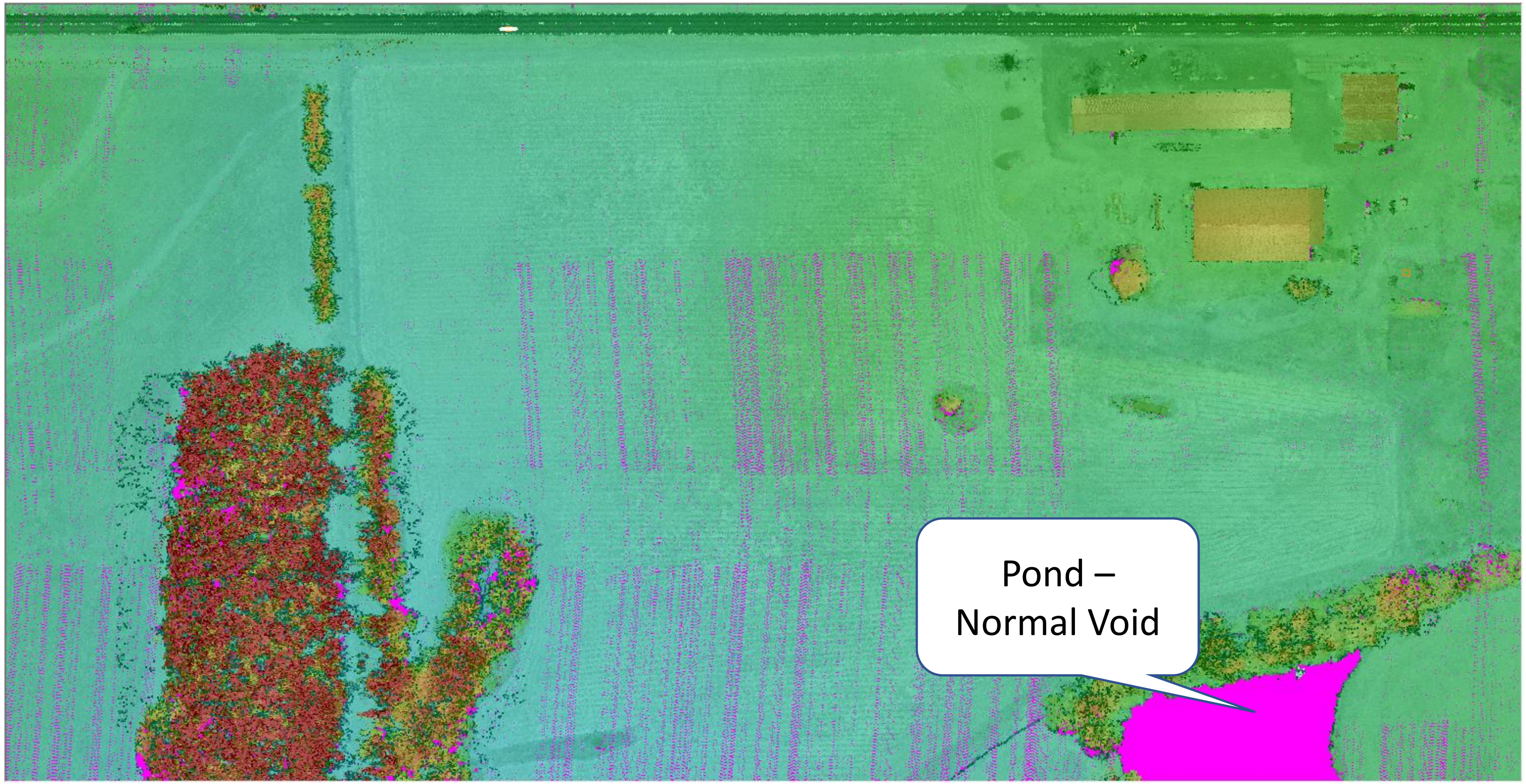
LIDAR Geometric Processing



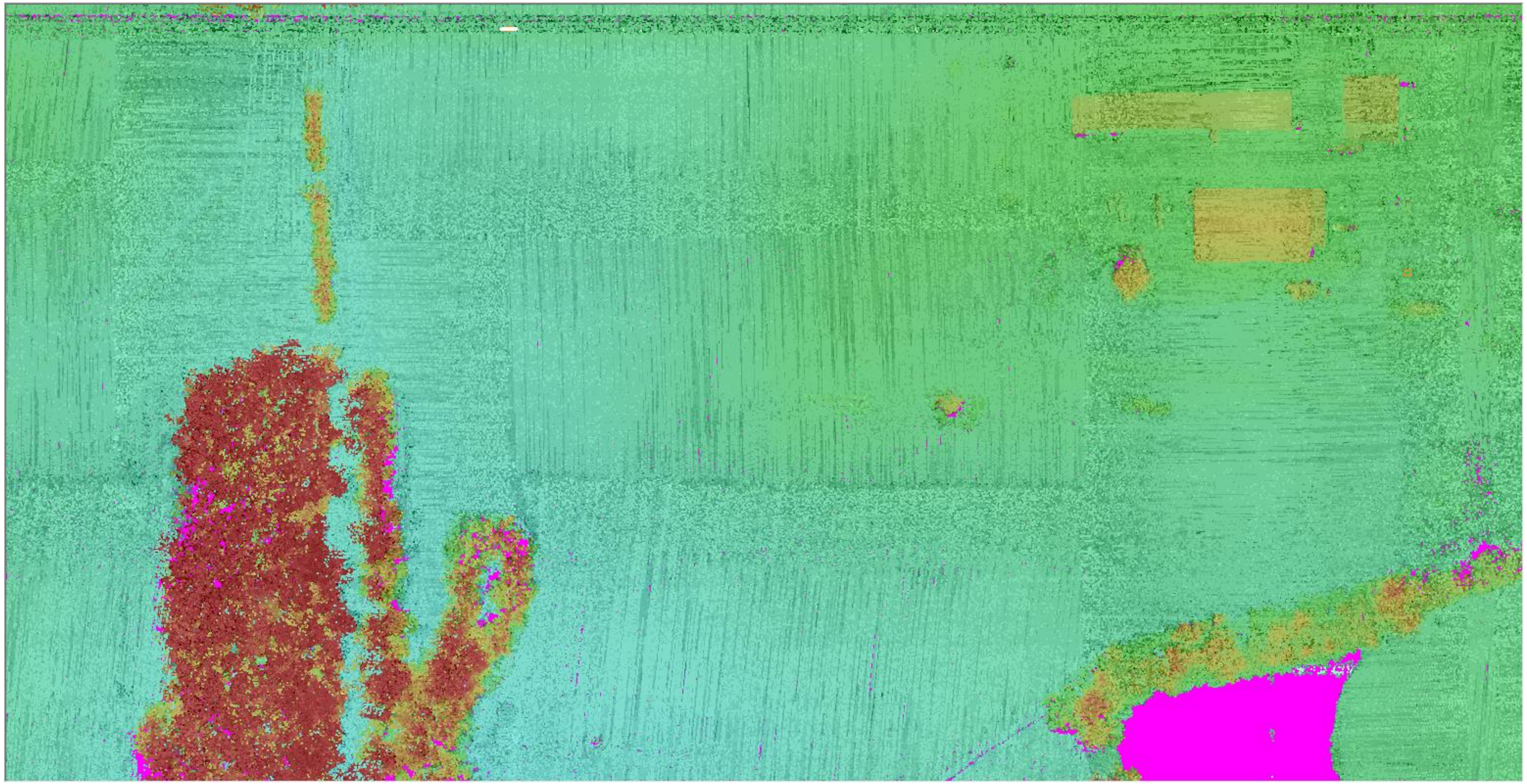
General coverage

Magenta indicates areas with no returns

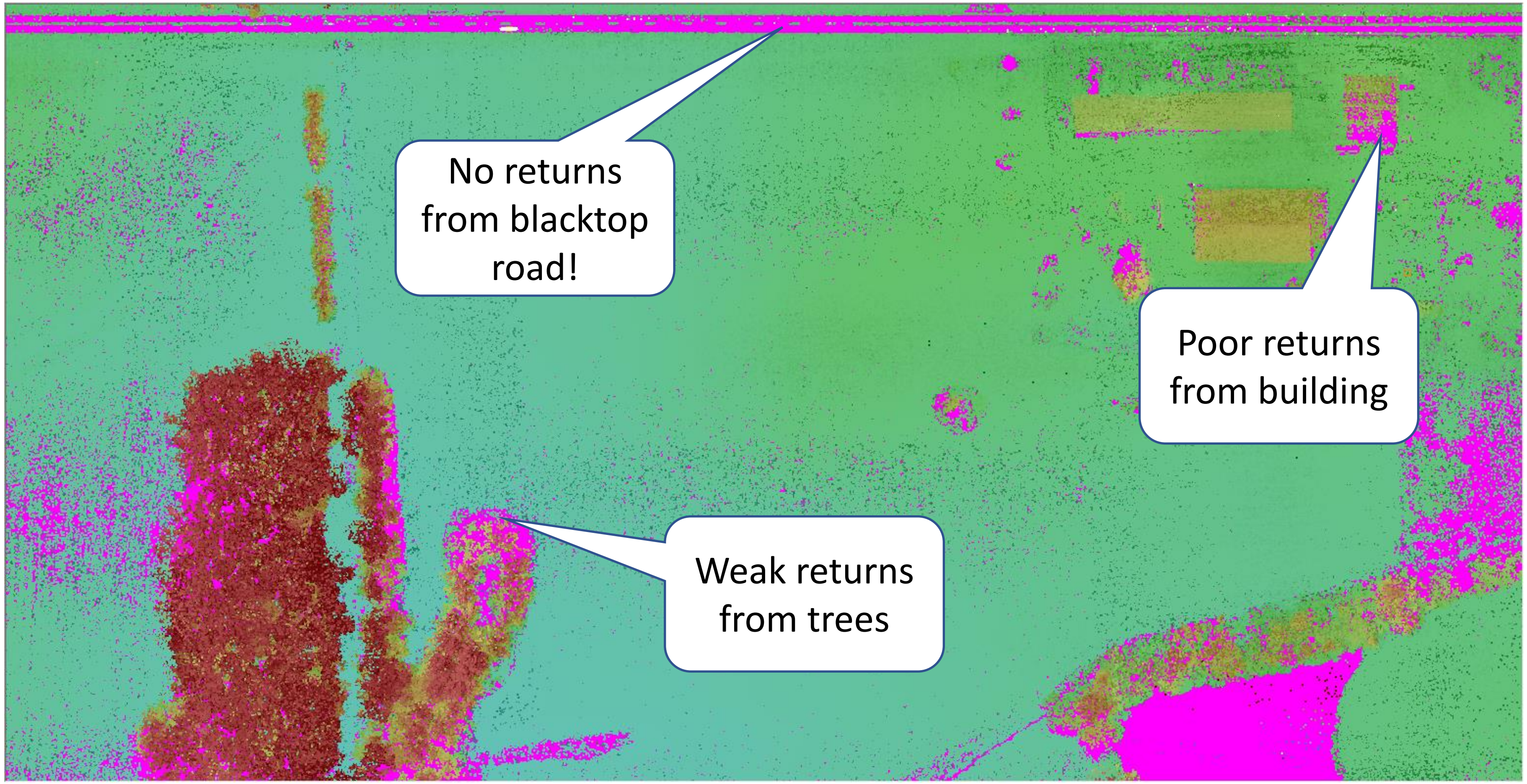
Riegl miniVUX



True View 410



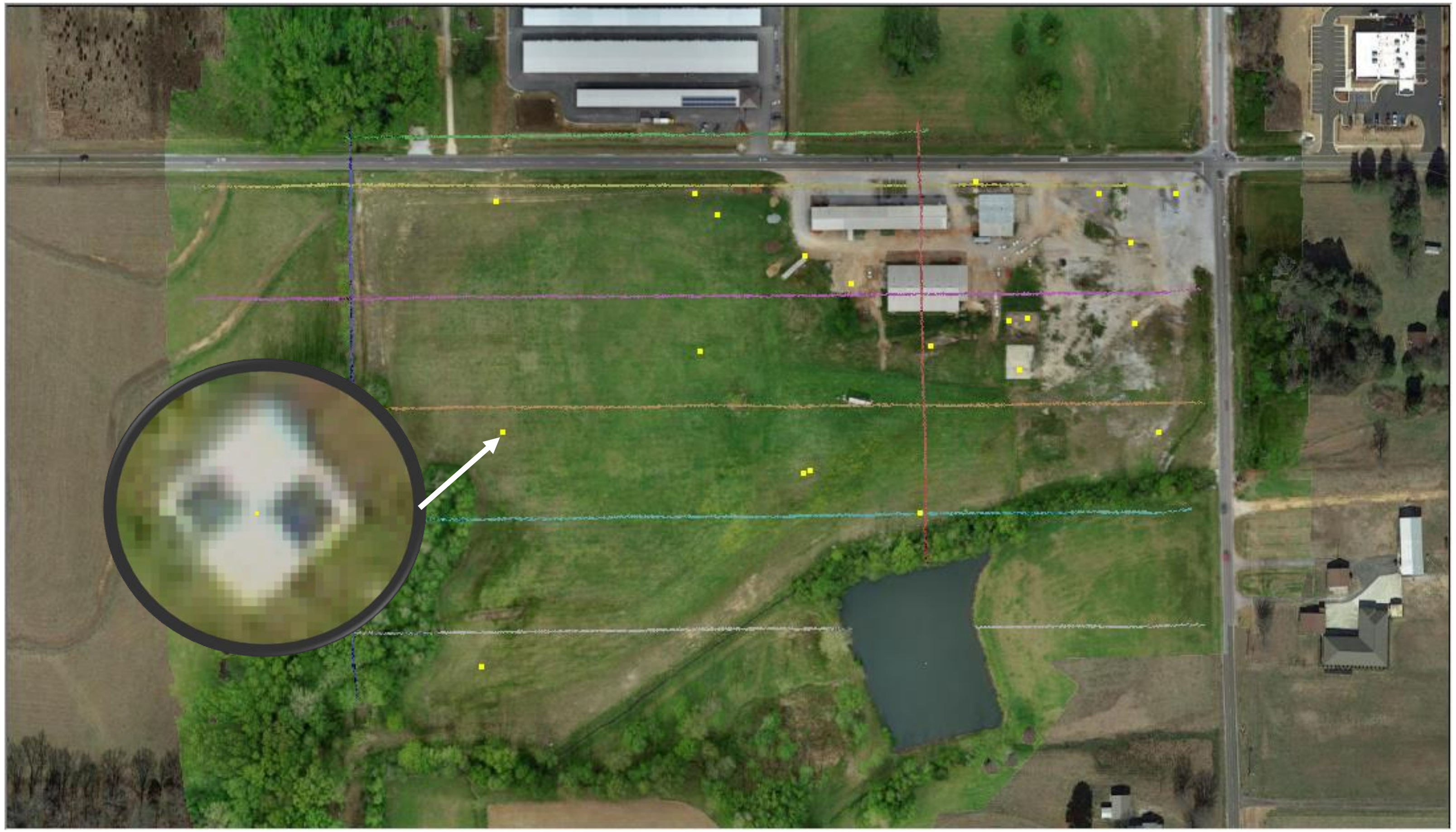
Velodyne VLP-16



Network Accuracy

Measured from Local control set with GNSS RTK

Network Vertical Accuracy Test



Vertical Network Accuracy

Vertical	
Mean Error:	-0.022
SDOM:	0.002
Sz:	0.008
Error Min, Max:	[-0.038, -0.007]
Error Range:	0.031
RMSE:	0.024
ASPRS Accuracy Class:	0.024
Min Contour Interval:	0.072

Riegl miniVUX
RMSE = 2.4 cm

Vertical	
Mean Error:	0.004
SDOM:	0.006
Sz:	0.023
Error Min, Max:	[-0.052, 0.039]
Error Range:	0.090
RMSE:	0.023
ASPRS Accuracy Class:	0.024
Min Contour Interval:	0.072

True View 410
(Quanergy M8 Ultra)
RMSE = 2.3 cm

- All units are meters
- 75 m AGL
- All returns
- Max off-nadir angle = ±40°
- 15 Check Points
- IDW, 1 m radius probe
- No Geometric Correction!

Vertical	
Mean Error:	0.052
SDOM:	0.005
Sz:	0.017
Error Min, Max:	[0.024, 0.088]
Error Range:	0.064
RMSE:	0.055
ASPRS Accuracy Class:	0.055
Min Contour Interval:	0.165

VLP-16
RMSE = 5.5 cm

Range Precision – Hard Surface – Single Swath

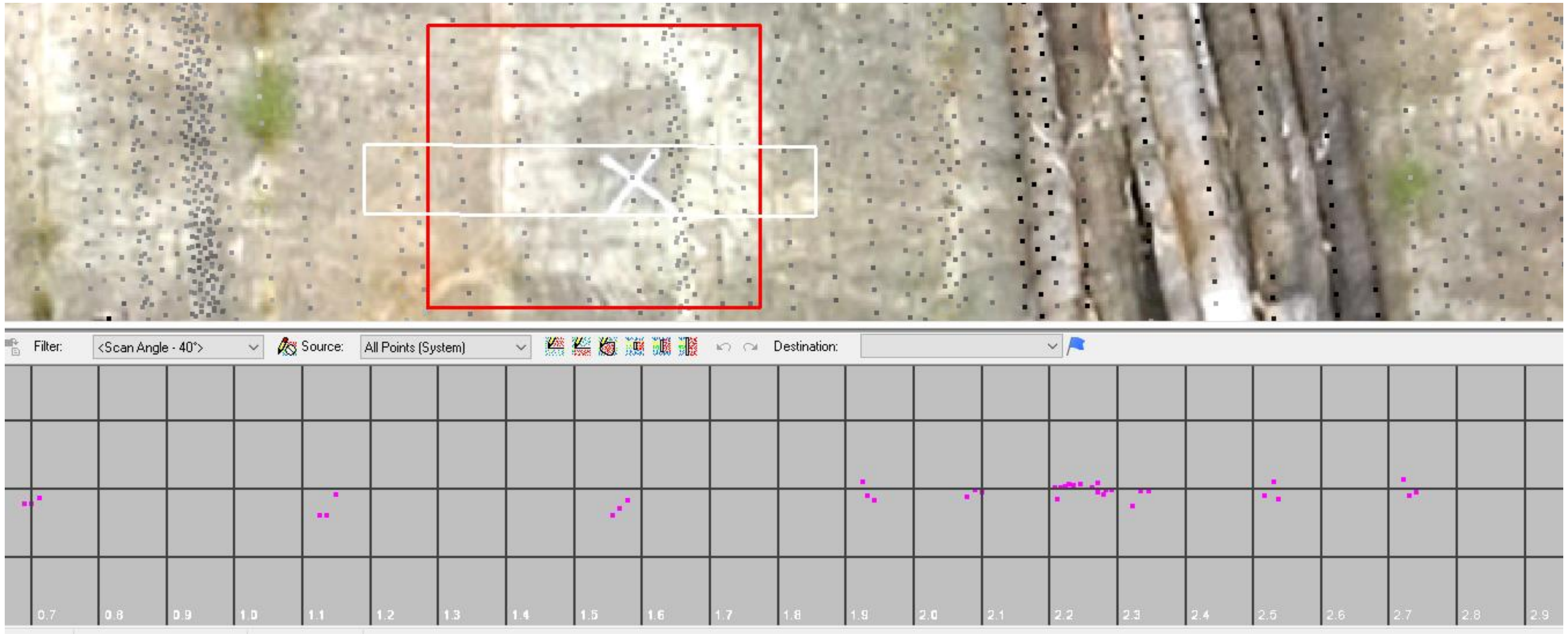
Single flight line

4.9 m^2 Planar Surface Sample area

0.50 m profile cross section

Profile grid is 10 cm × 10 cm

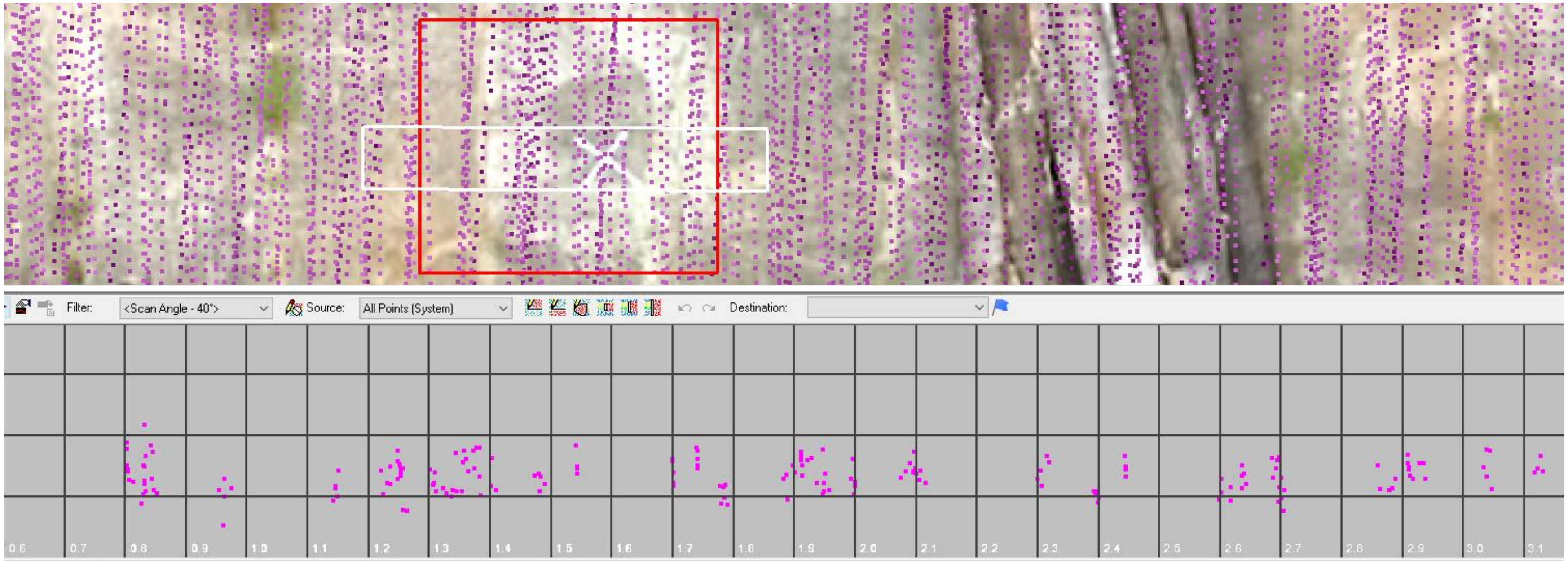
Riegl miniVUX



PntDen	Azimuth	Slope	StdDev	Out1Sig	In1Sig	SqrtEigen1	Eigen1	Eigen2	Eigen3	Normal	MaxDis	MinDis	Range
75.7028	310.3416	0.4652	0.0122	116	254	0.0122	0.0001	0.3337	0.4445	-0.006180, 0.005272, 0.999967	0.0320	-0.0332	0.0652

1 σ precision = 1.22 cm

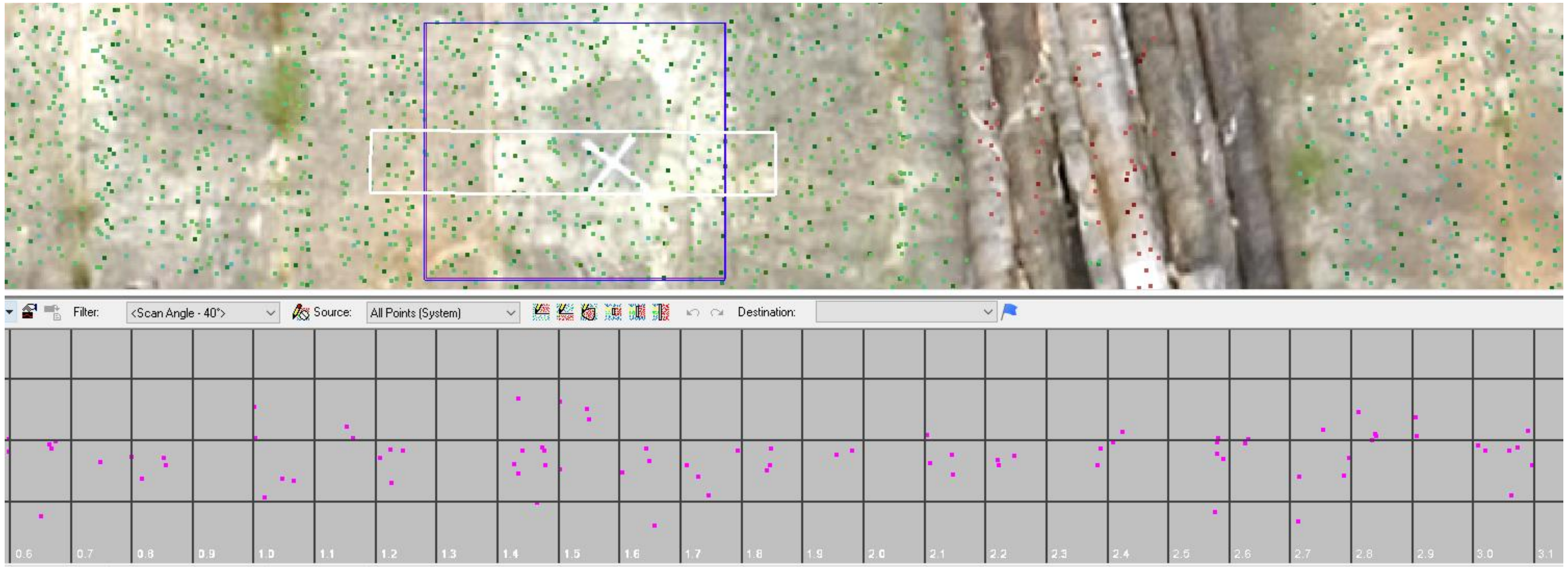
True View 410



PntDen	Azimuth	Slope	StdDev	Out1Sig	In1Sig	SqrtEigen1	Eigen1	Eigen2	Eigen3	Normal	MaxDis	MinDis	Range
257.6756	311.3839	0.5042	0.0360	412	856	0.0360	0.0013	0.3339	0.4206	-0.006593, 0.005835, 0.999961	0.1329	-0.1244	0.2573

1 σ precision = 3.60 cm

VLP-16



PntDen	Azimuth	Slope	StdDev	Out1Sig	In1Sig	SqrtEigen1	Eigen1	Eigen2	Eigen3	Normal	MaxDis	MinDis	Range
91.1091	342.0958	0.7345	0.0445	136	316	0.0445	0.0020	0.3451	0.4923	-0.003913, 0.012213, 0.999918	0.1351	-0.1351	0.2701

1 σ precision = 4.45 cm

Range Precision – Hard Surface – All Swaths

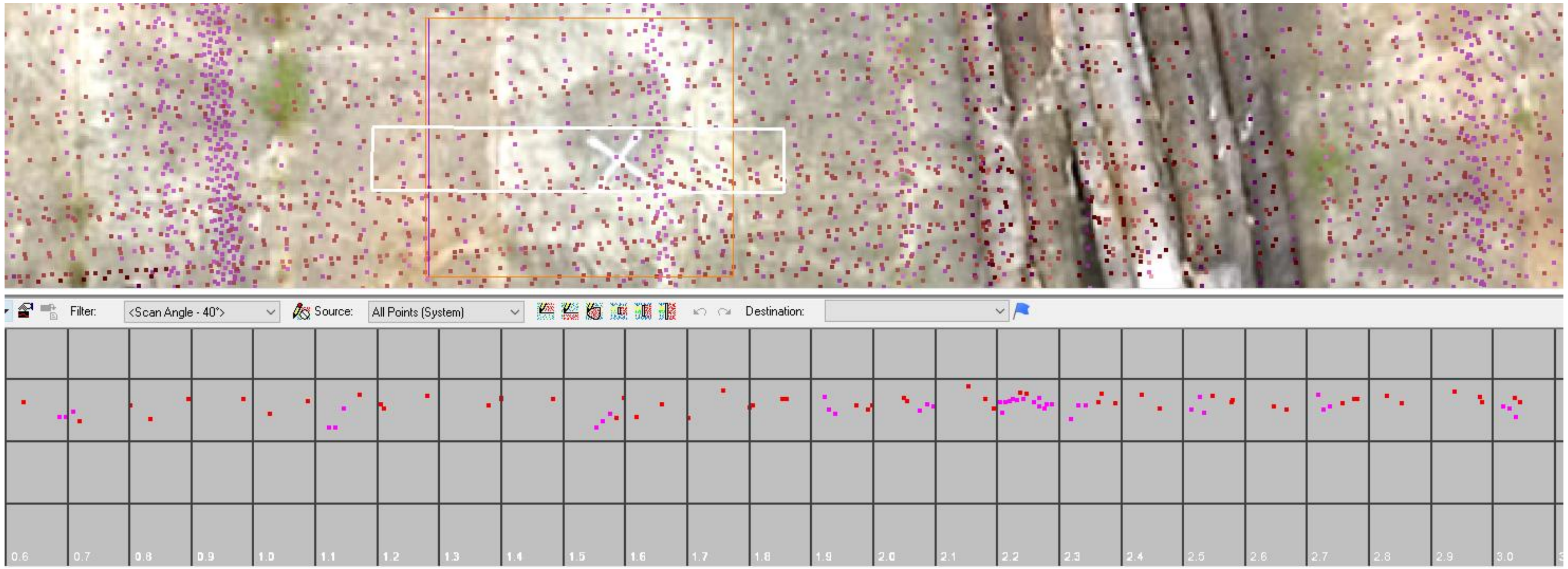
All flight lines

4.9 m^2 Planar Surface Sample area

0.50 m profile cross section

Profile grid is 10 cm × 10 cm

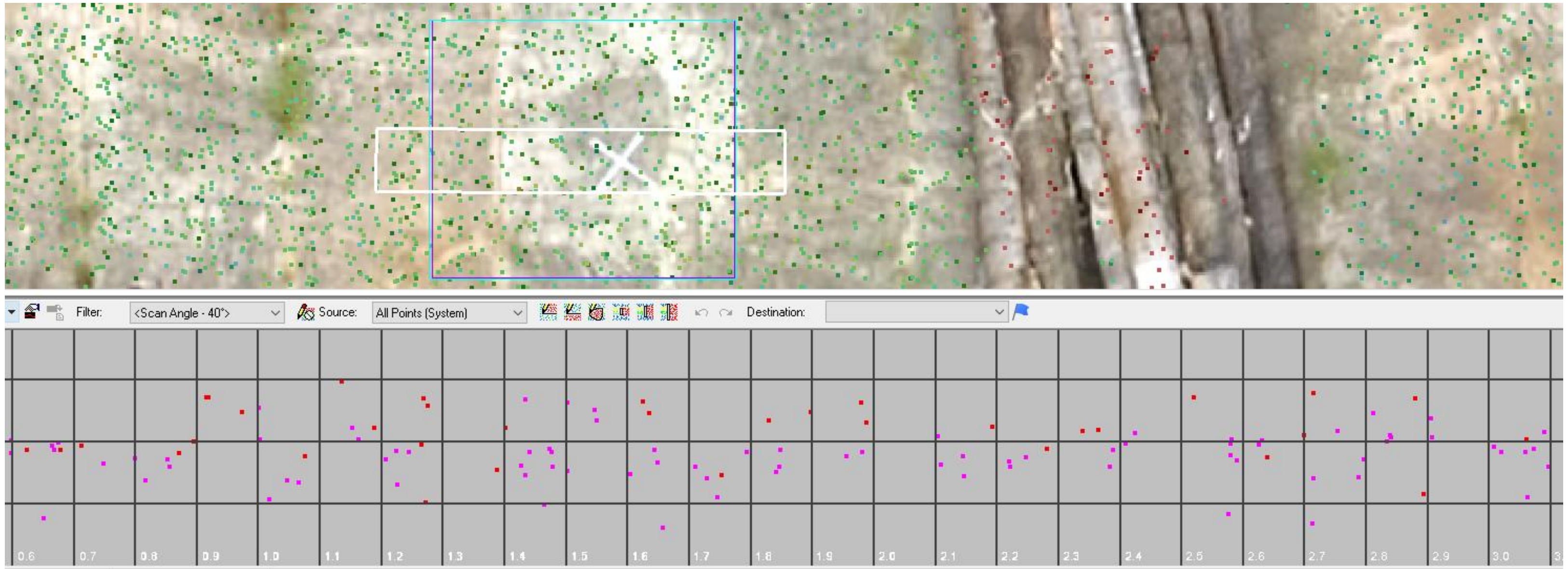
Riegl miniVUX



PntDen	Azimuth	Slope	StdDev	Out1Sig	In1Sig	SqrtEigen1	Eigen1	Eigen2	Eigen3	Normal	MaxDis	MinDis	Range
75.8130	310.1397	0.4595	0.0122	116	256	0.0121	0.0001	0.3380	0.4385	-0.006122, 0.005185, 0.999968	0.0320	-0.0330	0.0651

1 σ precision = 1.22 cm

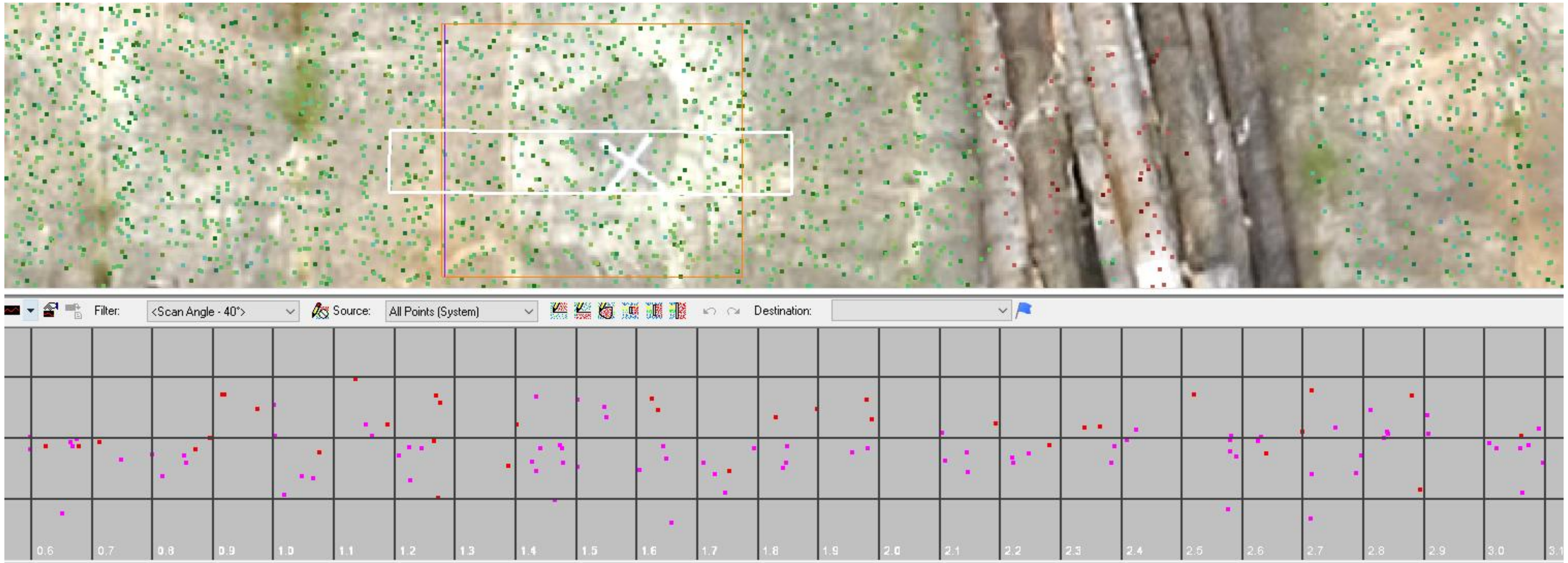
True View 410



PntDen	Azimuth	Slope	StdDev	Out1Sig	In1Sig	SqrtEigen1	Eigen1	Eigen2	Eigen3	Normal	MaxDis	MinDis	Range
256.9962	311.0772	0.4792	0.0361	414	869	0.0361	0.0013	0.3348	0.4302	-0.006295, 0.005511, 0.999965	0.1329	-0.1248	0.2577

1 σ precision = 3.61 cm

VLP-16



PntDen	Azimuth	Slope	StdDev	Out1Sig	In1Sig	SqrtEigen1	Eigen1	Eigen2	Eigen3	Normal	MaxDis	MinDis	Range
91.8270	339.6842	0.7570	0.0444	137	318	0.0444	0.0020	0.3400	0.5025	-0.004560, 0.012407, 0.999913	0.1345	-0.1356	0.2701

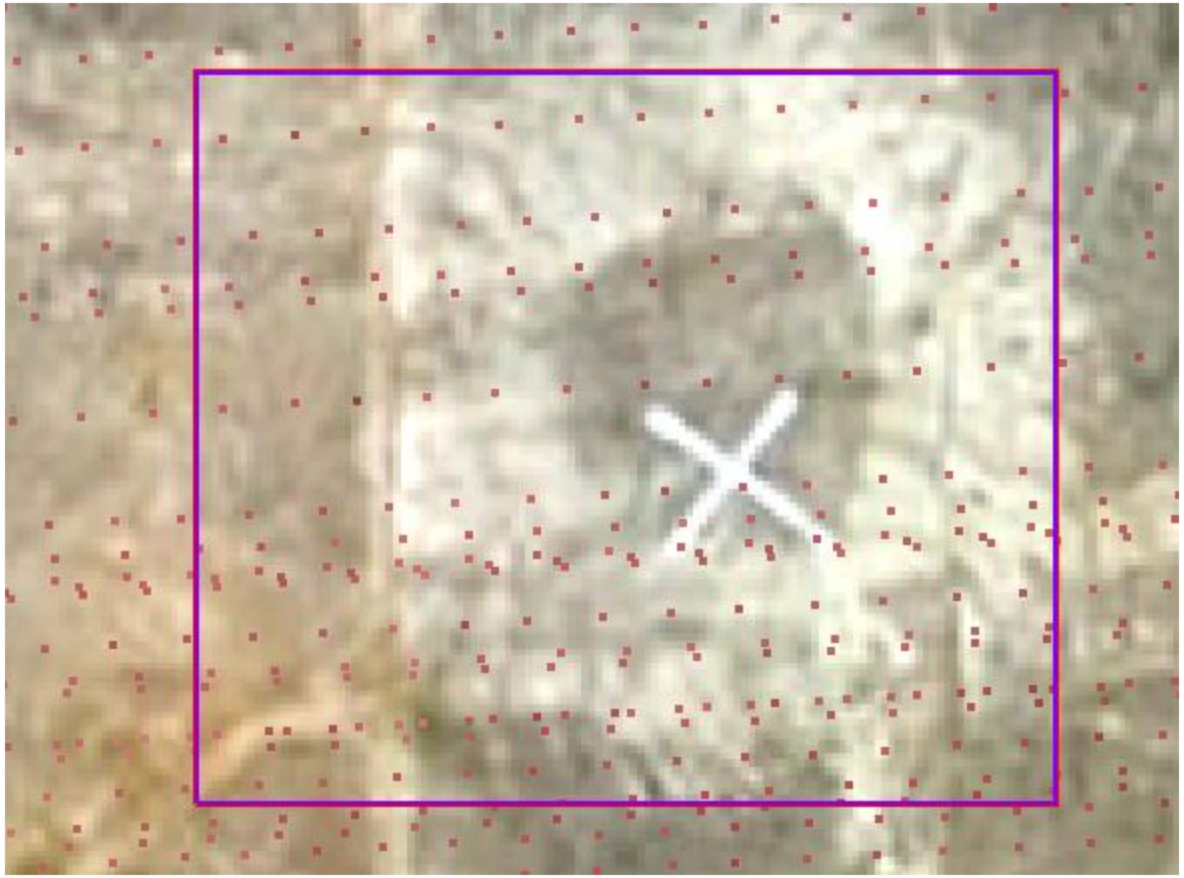
1 σ precision = 4.44 cm

Point Density – Single Flight Line

Single flight lines

4.9 m^2 Planar Surface Sample area

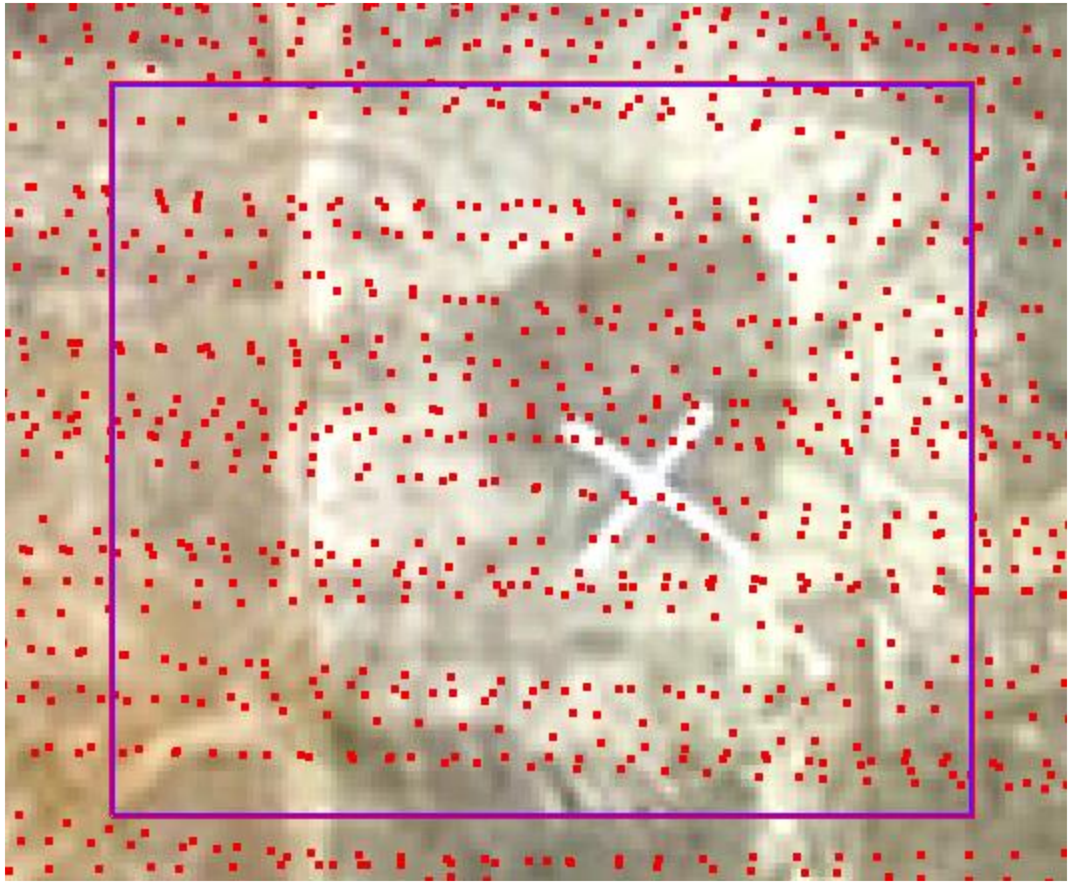
Riegl miniVUX



PntCnt	CLCnt_0	PntDen
373.0000	373	75.2048

Point Density = 75 pts/m^2

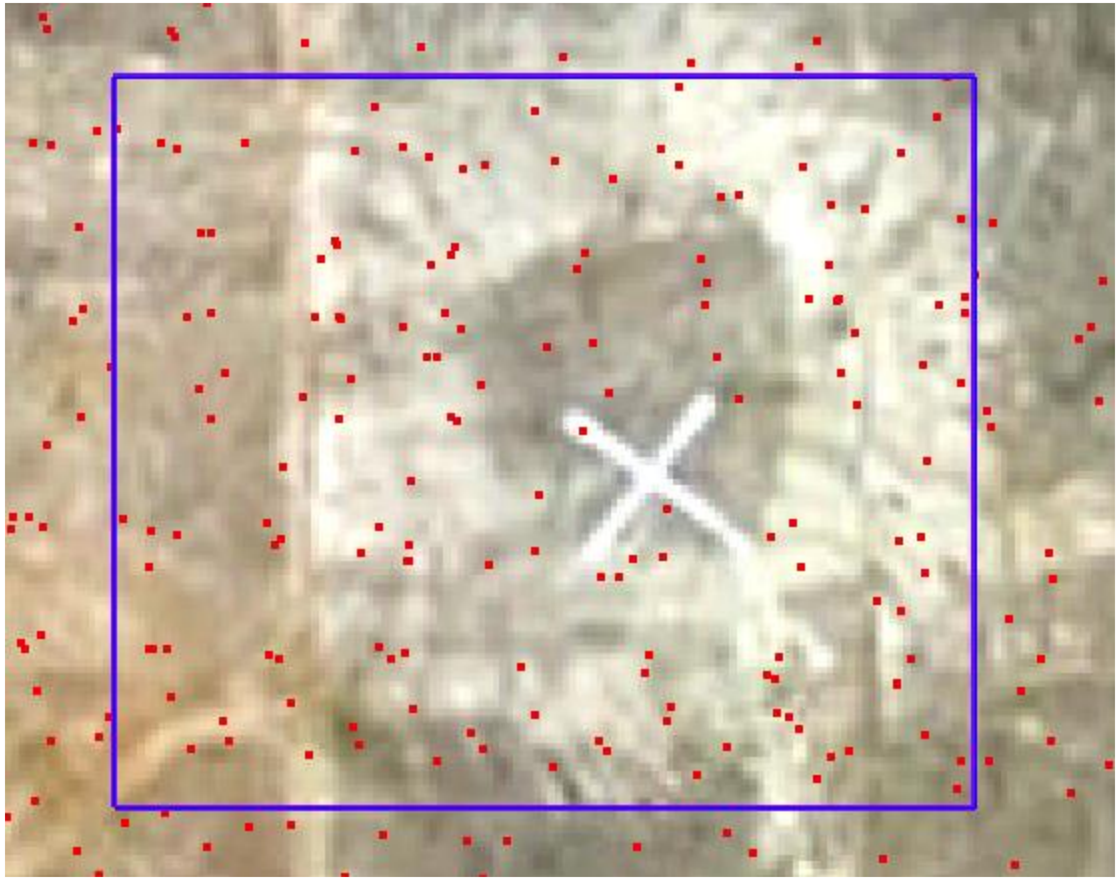
True View 410



PntCnt	CLCnt_0	PntDen
1,274.0000	1,274	257.6729

Point Density = 257 pts/m^2

VLP-16



PntCnt	CLCnt_0	PntDen
456.0000	456	92.1899

Point Density = 92 pts/m^2

Vegetation penetration

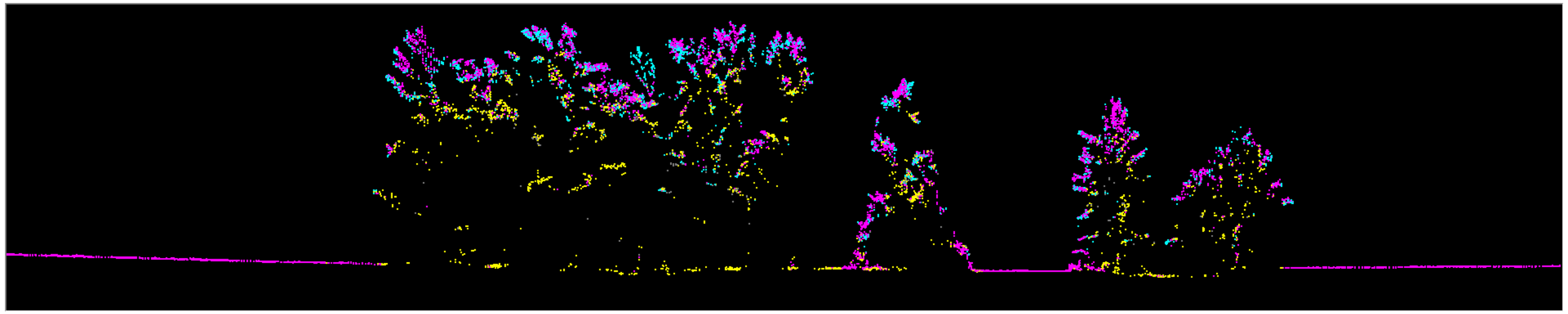
Qualitative view

1 m profile width

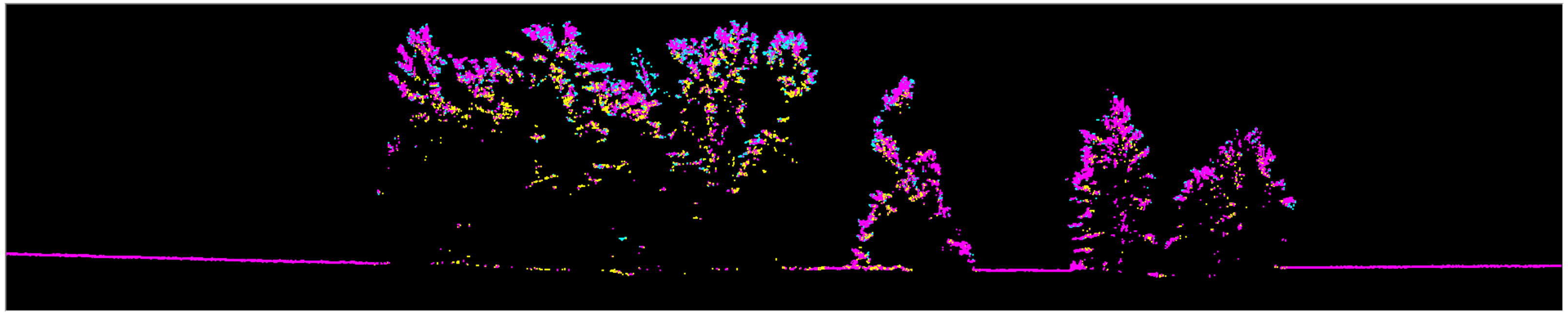
Test Strip

1 m wide profile through moderately dense tree canopy (July 2019)

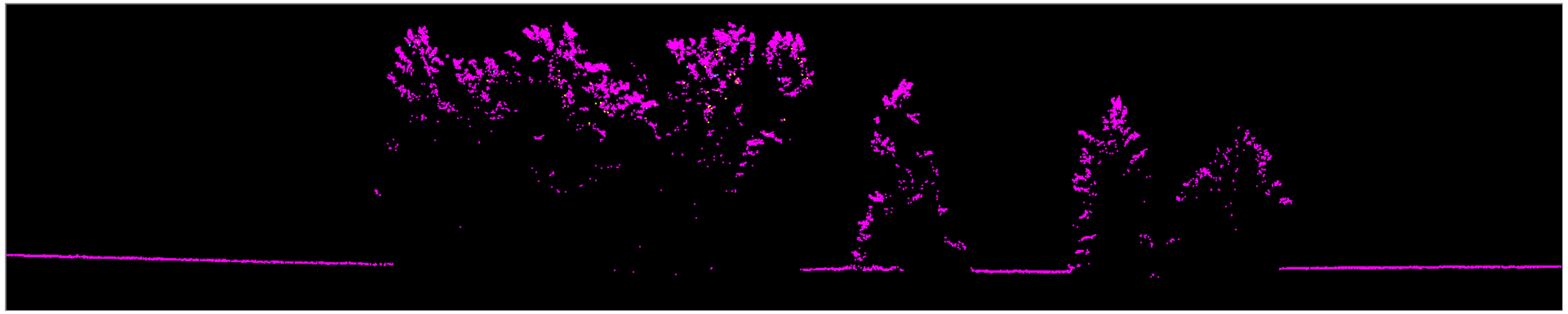
Display by Return (1 m profile)



Riegl miniVUX



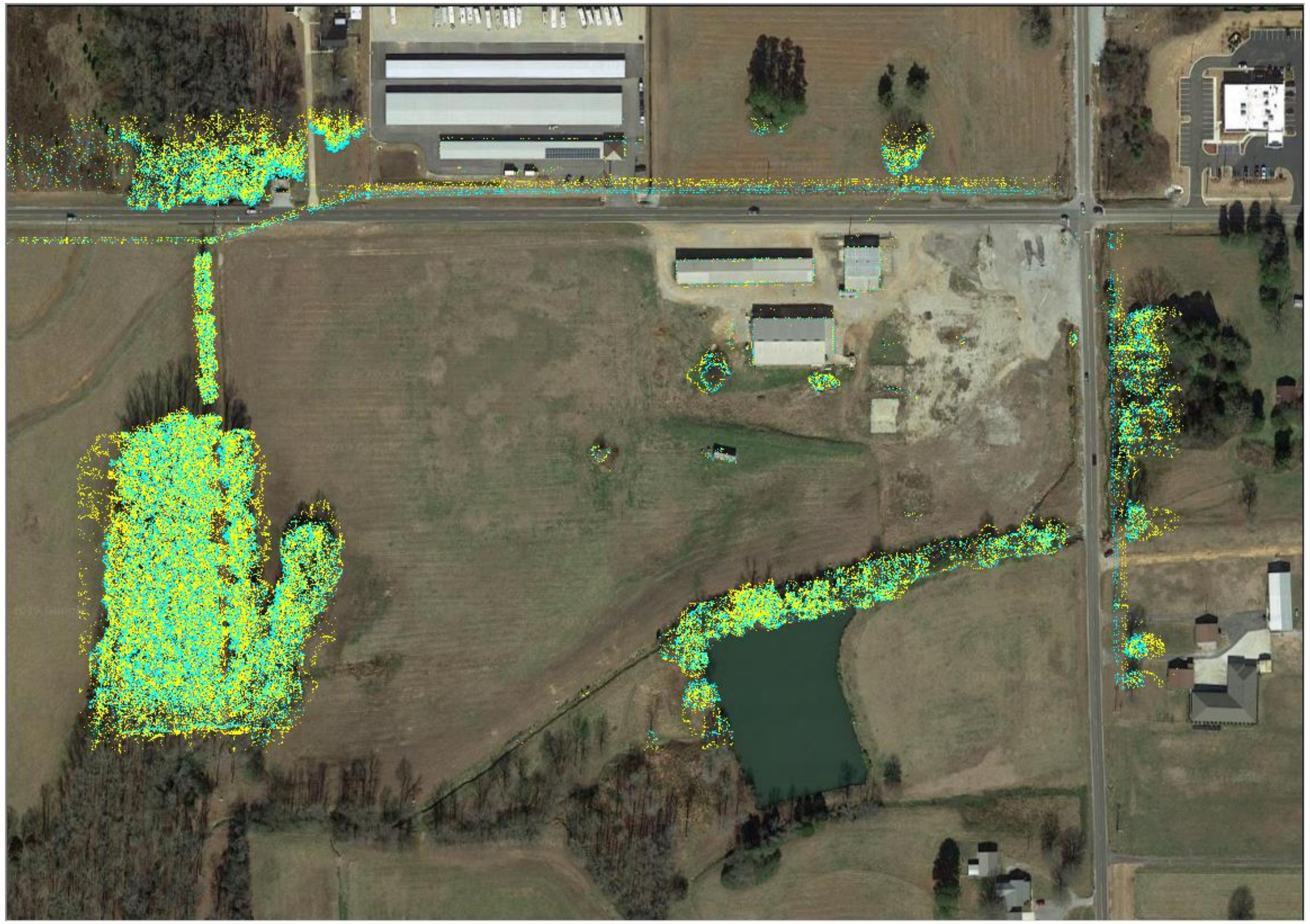
True View 410



VLP-16

multiple returns

Riegl miniVUX – First Returns Omitted



2nd through 5th Returns – Riegl miniVUX

Multi-return is invaluable in overhead structure detection

Lack of multi-return is not compensated by denser data

A dual (2) return system is usually adequate

If you do not need multiple returns, you probably don't need LIDAR

True View 410 – First Returns Omitted

2nd and 3rd Returns – True View 410

VLP-16 - First Returns Omitted

2^{nd} Returns – VLP-16 (this is a two-return system)

Summary of Considerations

Property	Notes
Range	Consider Slant Range. Normalize to 20% reflectivity
Precision	Remember that Peak to Peak is at least 6 x σ
Point density on the ground	Consider a 90° FOV as the maximum (80° preferred) useable data
Field of View (FOV)	You need ~25% → 30% overlap between flight lines for geometric correction. A more narrow FOV means more flight lines.
Accuracy at nadir	You will probably have to test this. There is no industry standard
Accuracy at 45°	Requires testing data
At least 2 "solid" returns per pulse	Longer range systems have higher abilities to provide a useful 2^{nd} return
System Mass ("weight")	Lower Mass → Longer flight time
Power Supply Duration	At least as long as the longest flight possible with your drone

White Paper on Specs

I am creating a white paper on Drone LIDAR Specifications. If you would like a copy, send me a note at:

LGRAHAM@GEOCUE.COM