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ARCHITECTURE | ENGINEERING | GEOSPATIAL

UAS-based Lidar: Performance comparison of Four Lidar systems

Qassim Abdullah, Woolpert

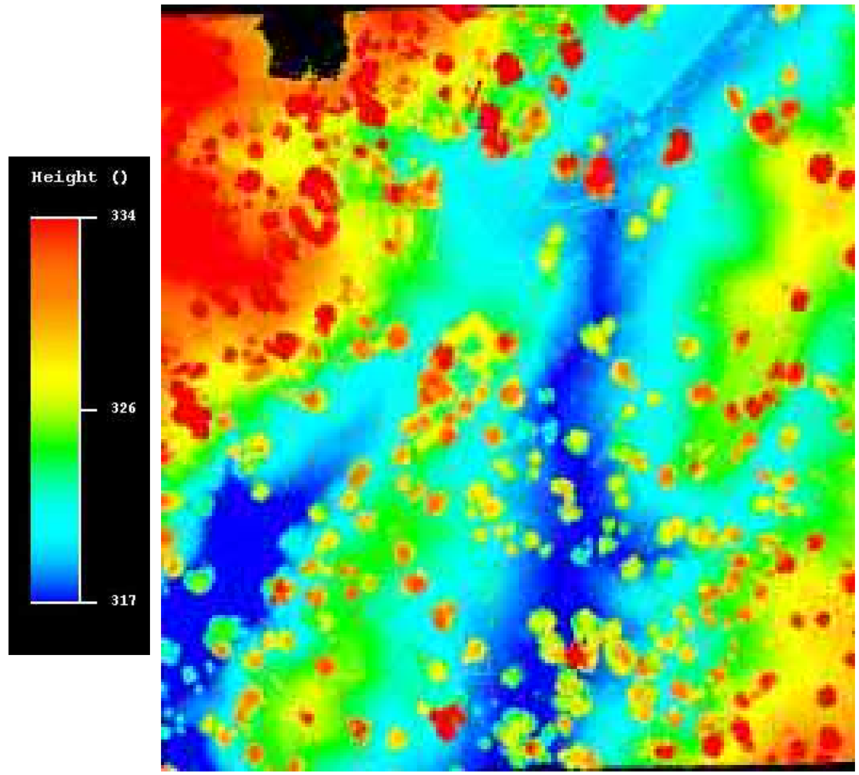
AFB80 Committee Summer 2019 Meeting – July 22-24, 2019 Daytona Beach, FL

The Project

- Woolpert was contracted by CSU-Fresno Foundation to acquire data over their testing field using UAS-based imagery and lidar
- Woolpert flew eBee X RTK UAS for imagery and four lidar systems
- I will brief you on our analysis of the data

CSU Testing site, North of Fresno California

400x400 meter



The Digital Imaging Technology

We deployed Sensefly eBee X with RTK/PPK Capability

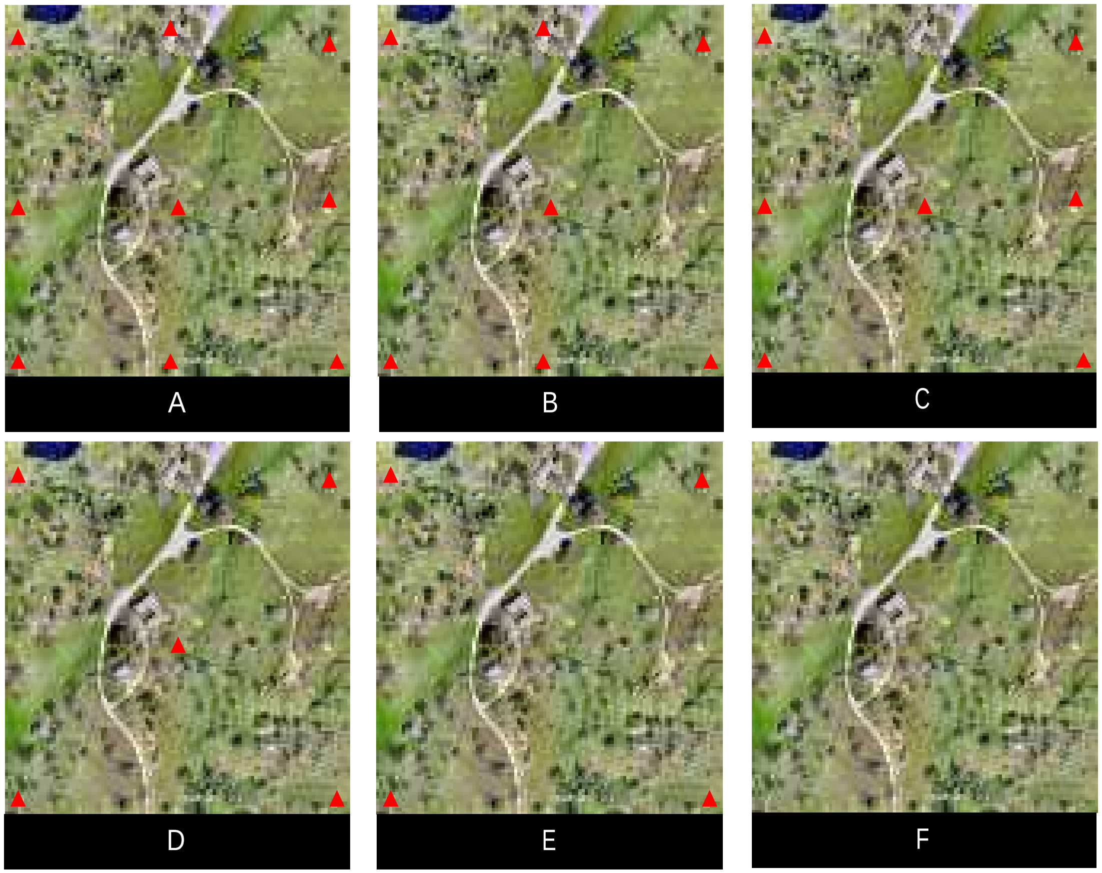
eBee X
Fixed-Wing Drone

senseFly S.O.D.A. 3D
Mapping Camera

CSU Testing Site

- 81 Targeted GCPs
- Surveyed to accuracy of:
  - Vertical one-sigma = 0.3-cm
  - Horizontal one-sigma = 1.0-cm
- Woolpert was provided with 40 check points for the analysis

Ground Controls and Accuracy – The eBee X Evaluation



Accuracy Term	Residual Values (m)			Delta Z after Z-bias Removed (m)
	Error in Easting (m)	Error in Northing (m)	Error in Elevation (m)	
Mean Error	-0.008	0.003	-0.053	0.000
Standard Deviation (StDEV)	0.013	0.013	0.030	0.030
Root Mean Squares Error ($RMSE_{x\ or\ y\ or\ z}$)	0.015	0.013	0.061	0.029
Radial $RMSE_r$	0.020			
NSSDA Horiz Accuracy at 95% accuracy Level	0.035			
NSSDA Vert Accuracy at 95% accuracy Level	0.119			
NSSDA Vert Accuracy at 95% accuracy Level after z-bias removal	0.058			

Accuracy Term	Processing Scenario					
	A	B	C	D	E	F
Number of GCPs in AT	9	7	7	5	4	0
Number of Check Points	30	32	32	34	35	39
RMSE E (m)	0.015	0.011	0.017	0.016	0.015	0.016
RMSE N (m)	0.013	0.016	0.013	0.015	0.015	0.017
Radial RMSE N,E (m)	0.020	0.020	0.021	0.022	0.021	0.023
RMSE Elev. (m)	0.029	0.029	0.031	0.032	0.032	0.030
Horizontal Accuracy at 95% (m)	0.035	0.034	0.037	0.037	0.037	0.040
Vertical Accuracy at 95% (m)	0.058	0.057	0.061	0.062	0.062	0.060


The Lidar Technology

Anatomy Of a UAS-based Lidar System

Impact relative accuracy

Impact absolute accuracy

Laser

+

GPS-Aided INS

+

UAS

-->

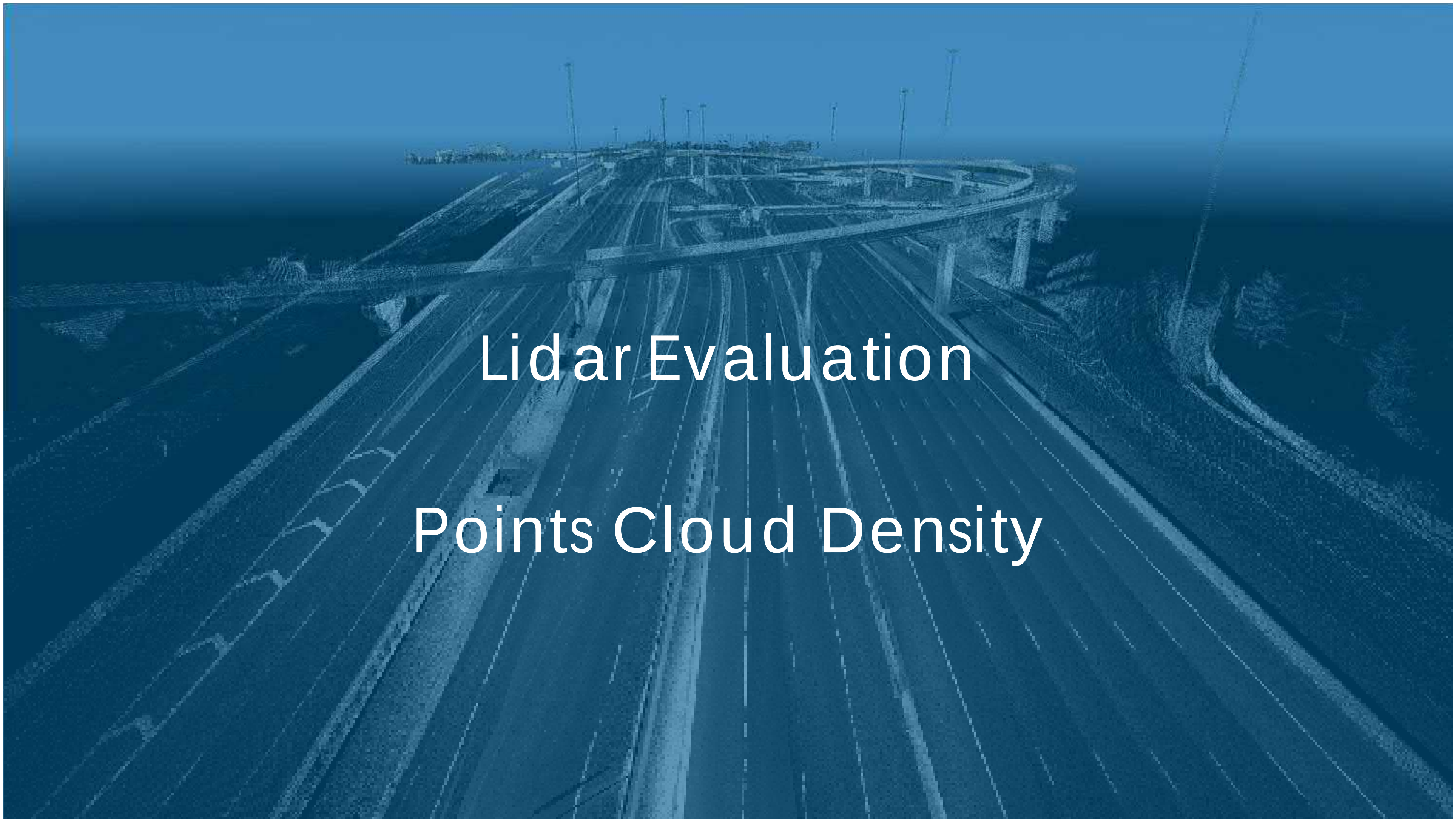
Images courtesy, Lidar USA, DJI, and VECTORNAV

Dynamics governing putting Lidar system on a drone

- Has to be light weight
  - Limited physical size and weight impact its performance
    - Lower power laser
    - Lower performance GPS and IMU
- Has to be affordable to fly it on a small drone over a small size project
  - Low cost lidar means degraded performance
    - Low cost lidar means lower quality laser, GPS, and IMU
    - Lower quality sub-systems means lower quality points cloud

We deployed four Lidar systems

leased from Lidar USA through a contract with MODUS



Lidar Evaluation

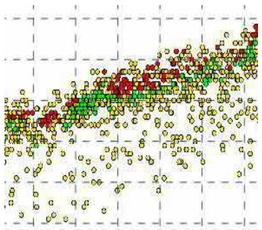
Points Cloud Density

Points Density, standard processing

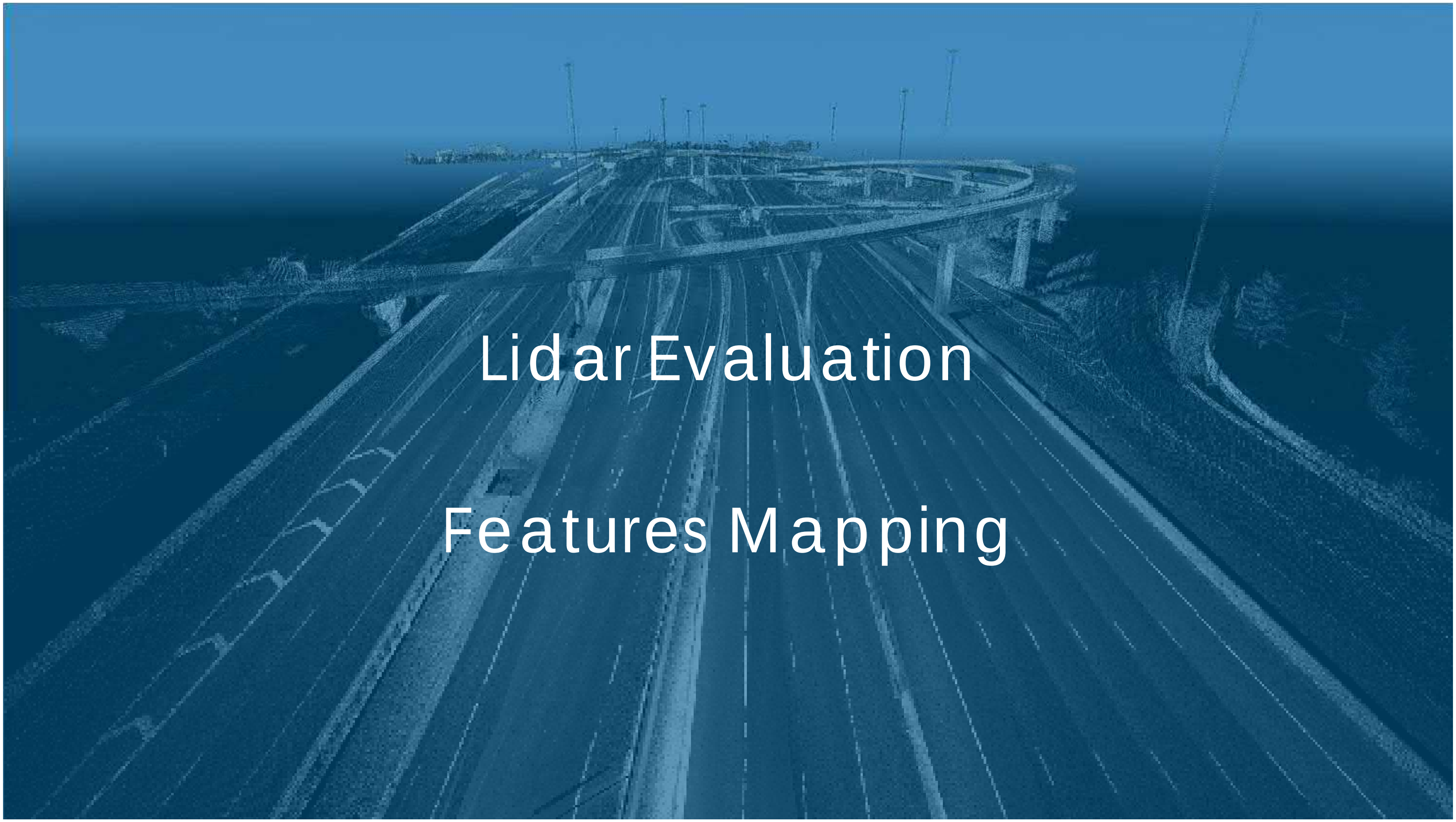
Sensor	Ground ONLY		All Classes (pts/m2)	
	Density (pts/m2)	Nominal Point Spacing (m)	Density (pts/m2)	Nominal Point Spacing (m)
MiniVUX	7.6	0.36	155	0.08
Quanergy_M8	9.6	0.32	570	0.04
Velodyne HDL32	7.5	0.365	521	0.04
Velodyne VLP16	4.7	0.461	305	0.06

Points Density, after allowing some noisy points**

Sensor	Ground ONLY		All Classes (pts/m2)	
	Density (pts/m2)	Nominal Point Spacing (m)	Density (pts/m2)	Nominal Point Spacing (m)
MiniVUX	42	0.15	155	0.08
Quanergy_M8	76	0.12	570	0.04
Velodyne HDL32	56	0.13	521	0.04
Velodyne VLP16	18	0.23	305	0.06



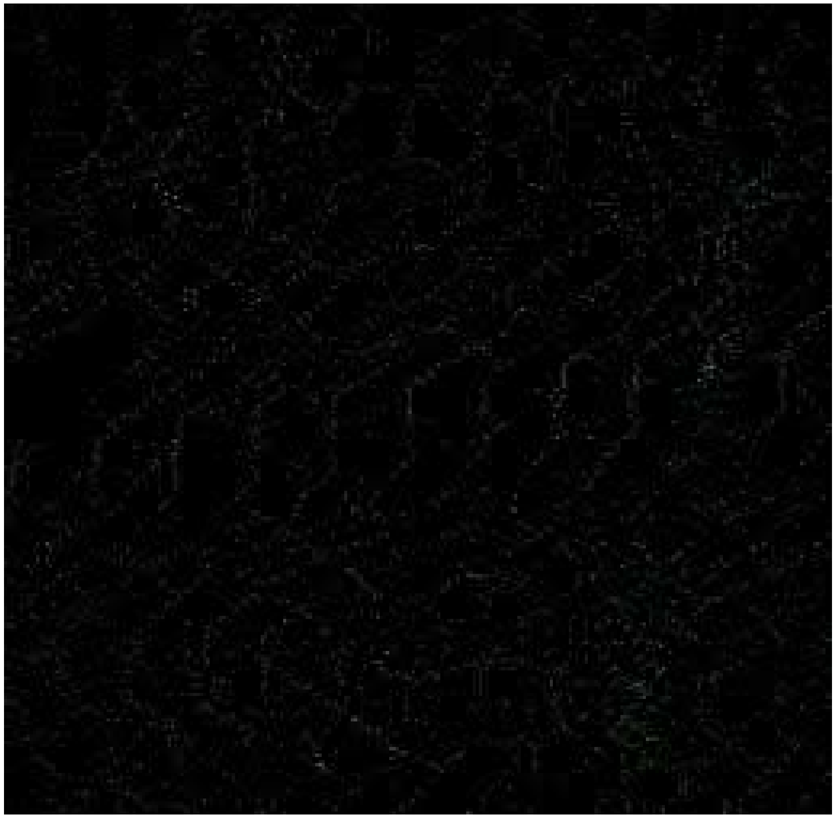
** Used "Classify above ground" routine


Lidar Evaluation
Features Mapping

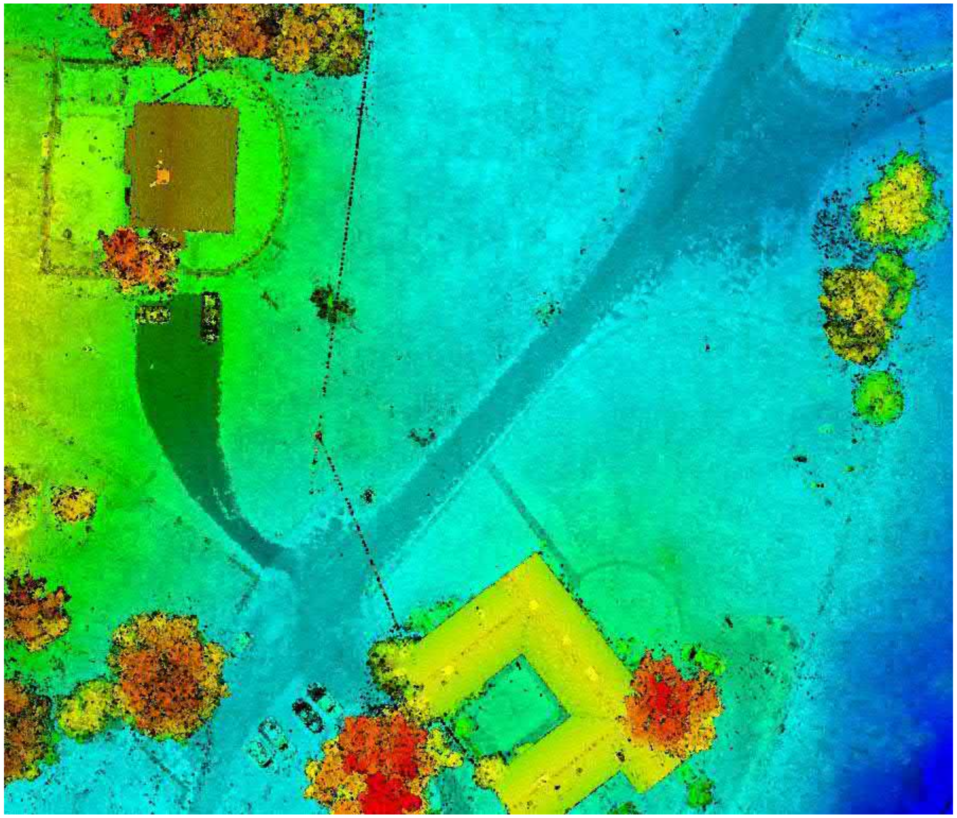
Lidar Evaluation

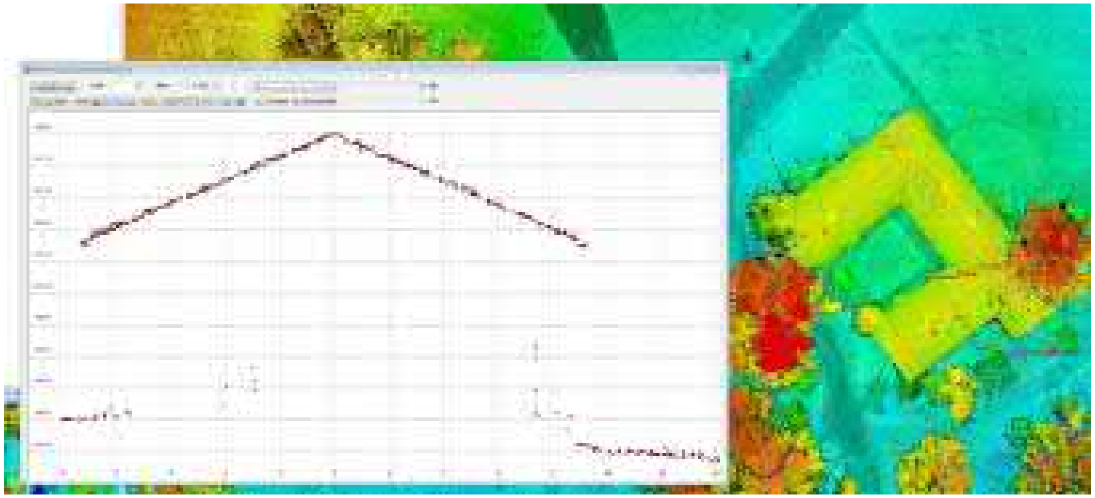
Riegl Mini VUX

Scan Pattern

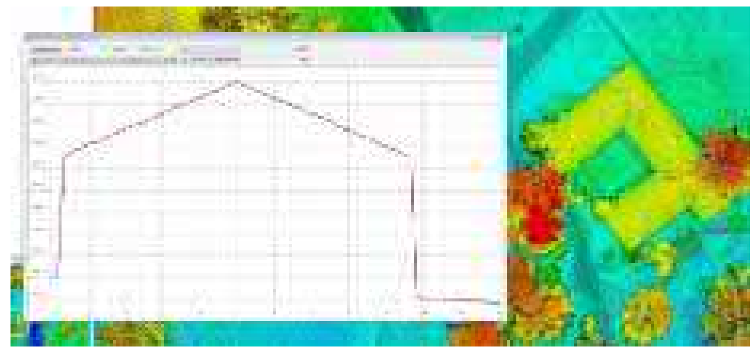


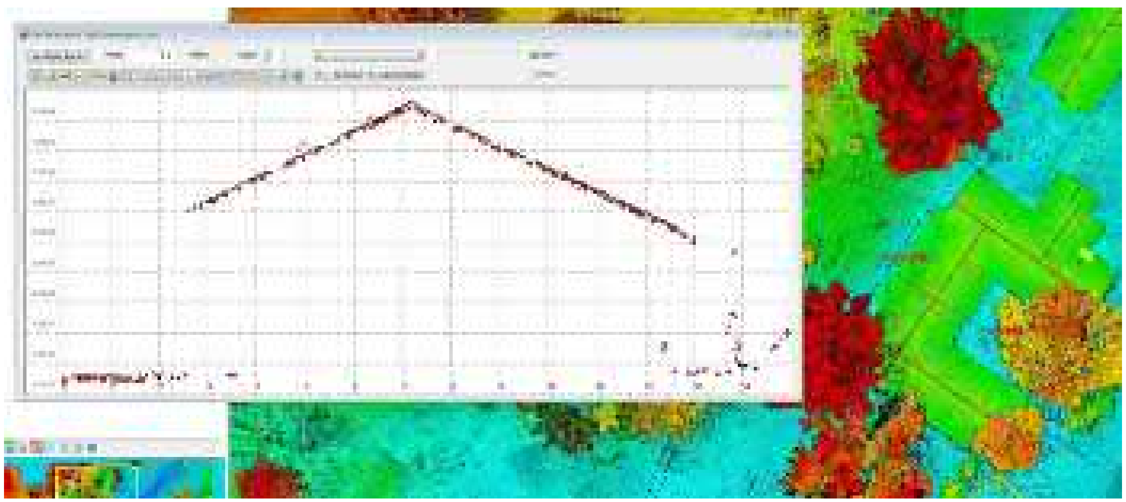
Intensity Quality



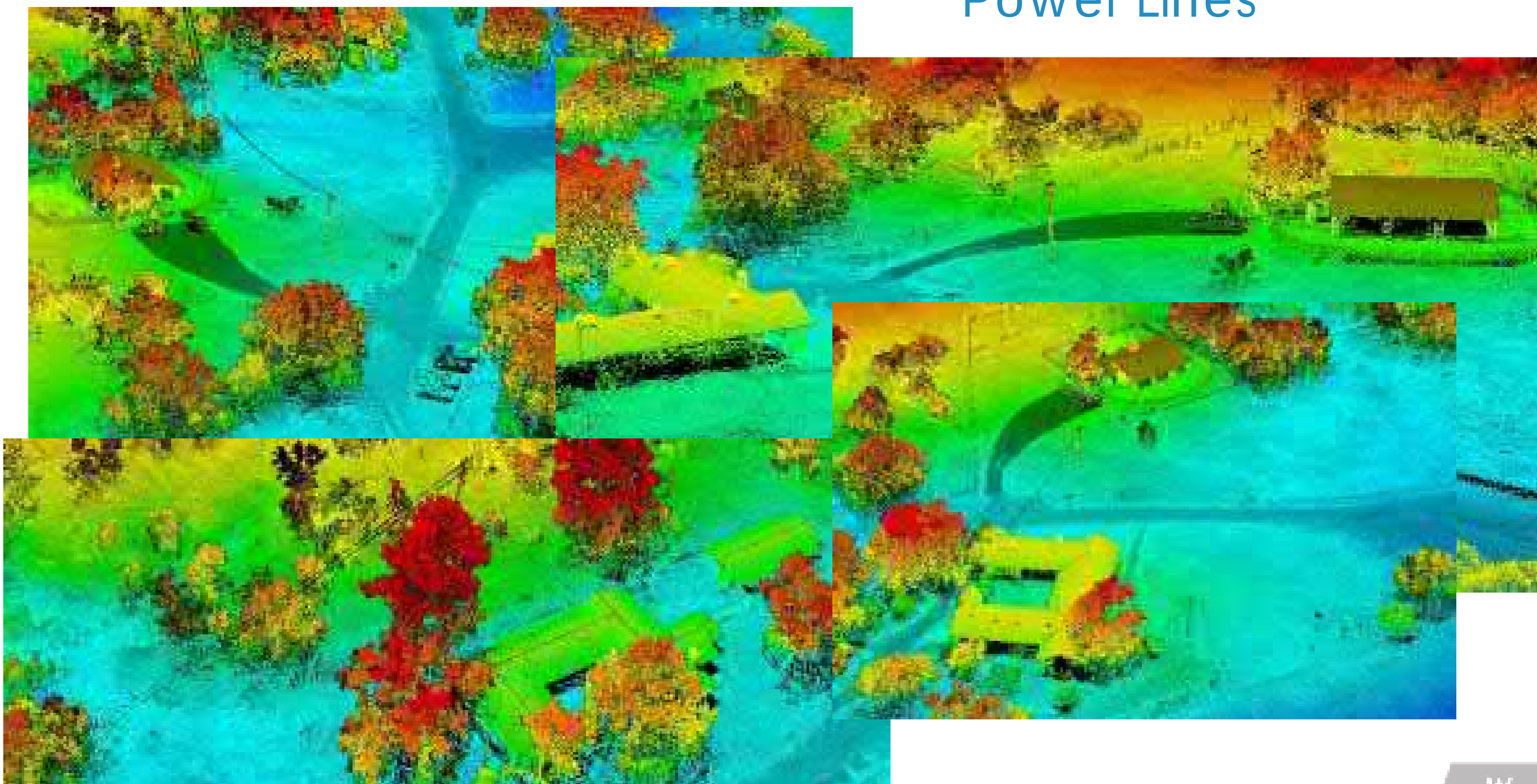


Roofs

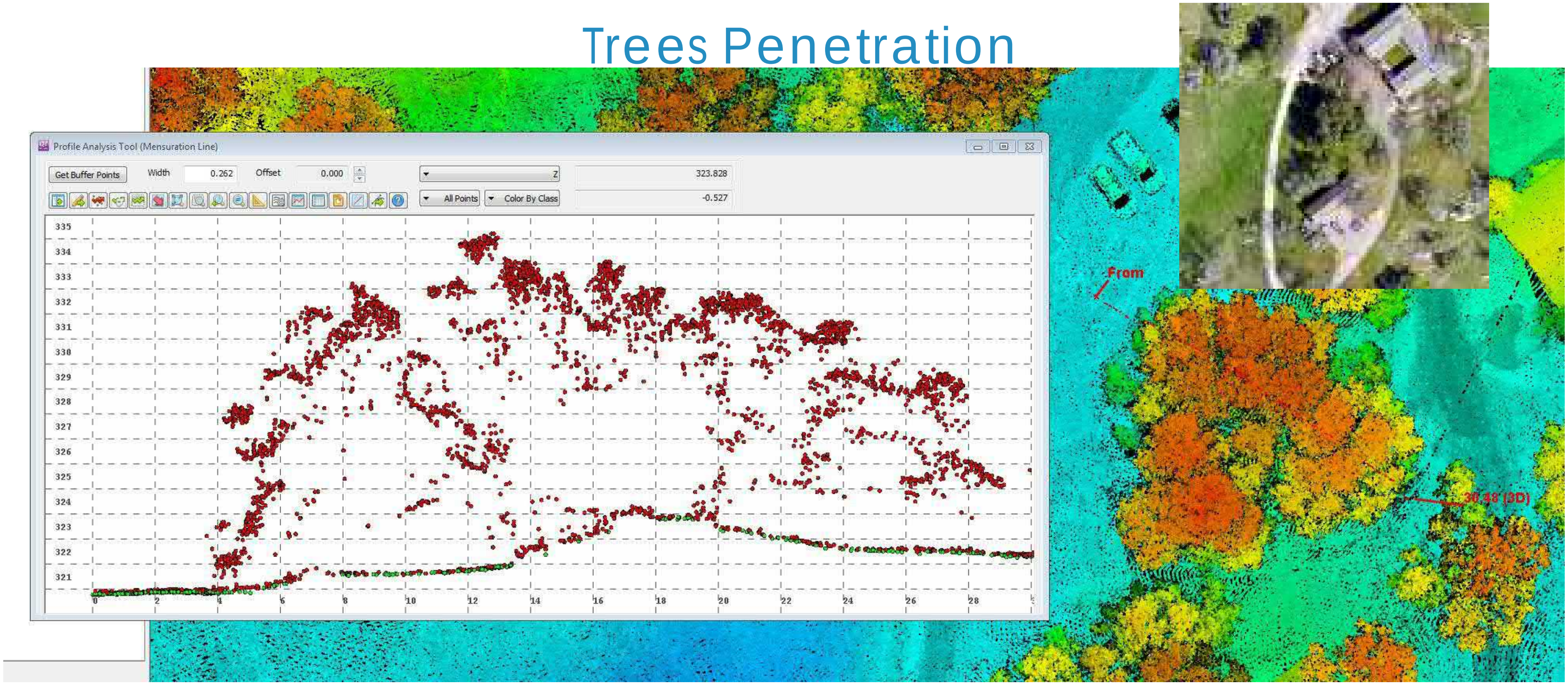




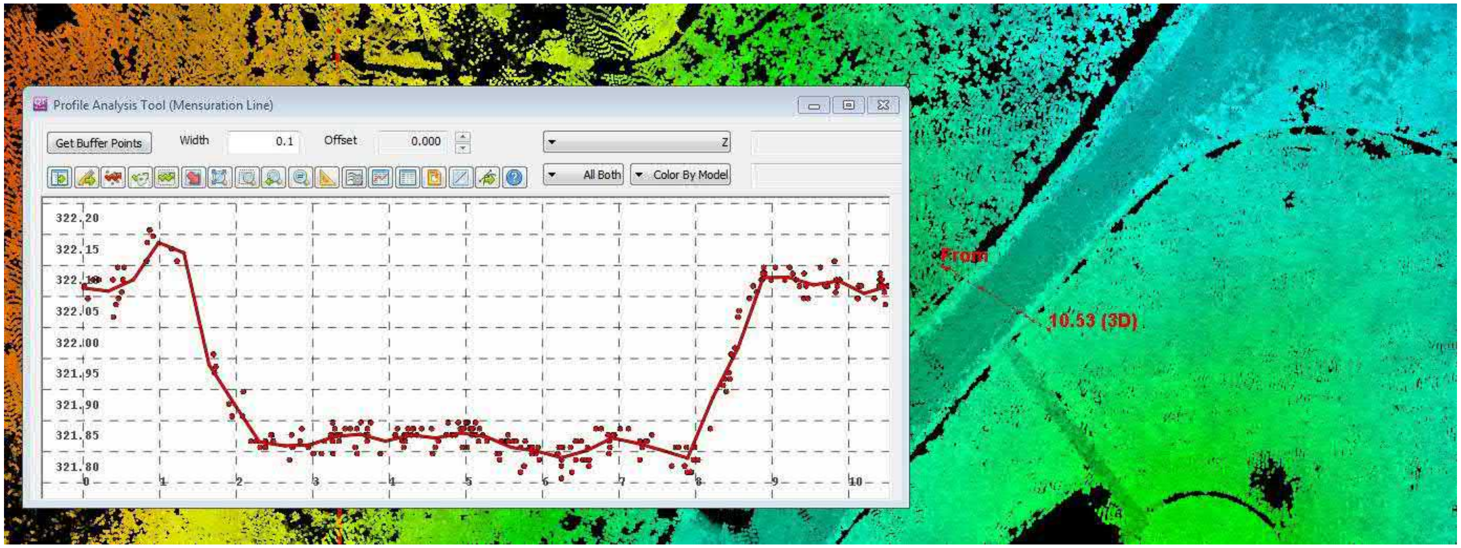
Power Lines

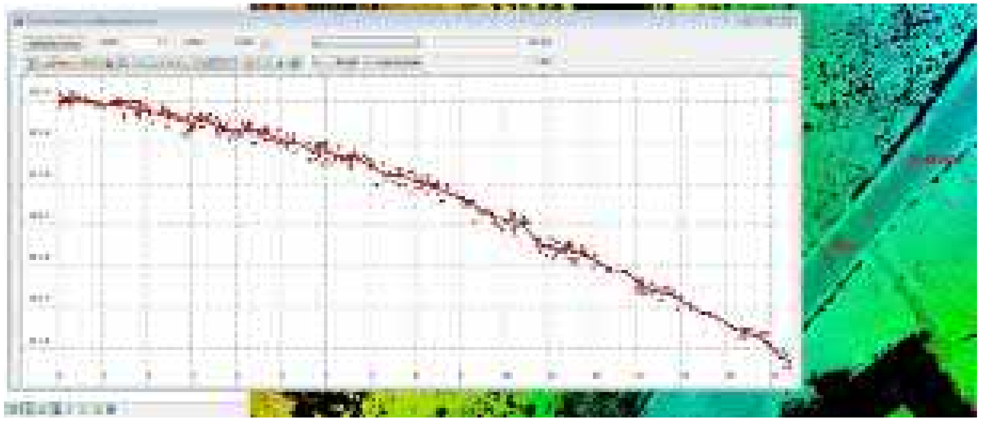


Trees Penetration

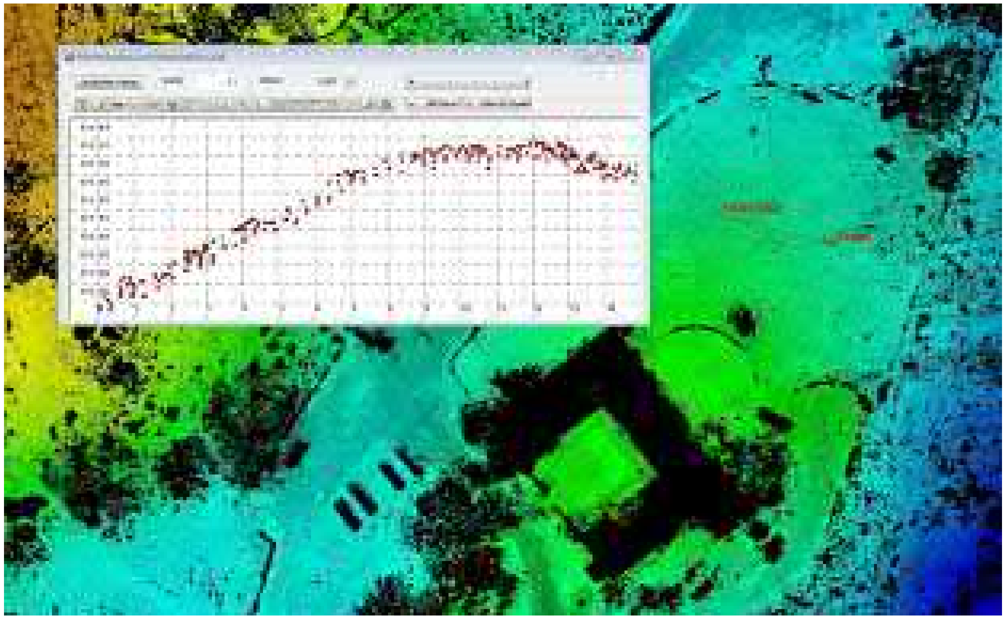


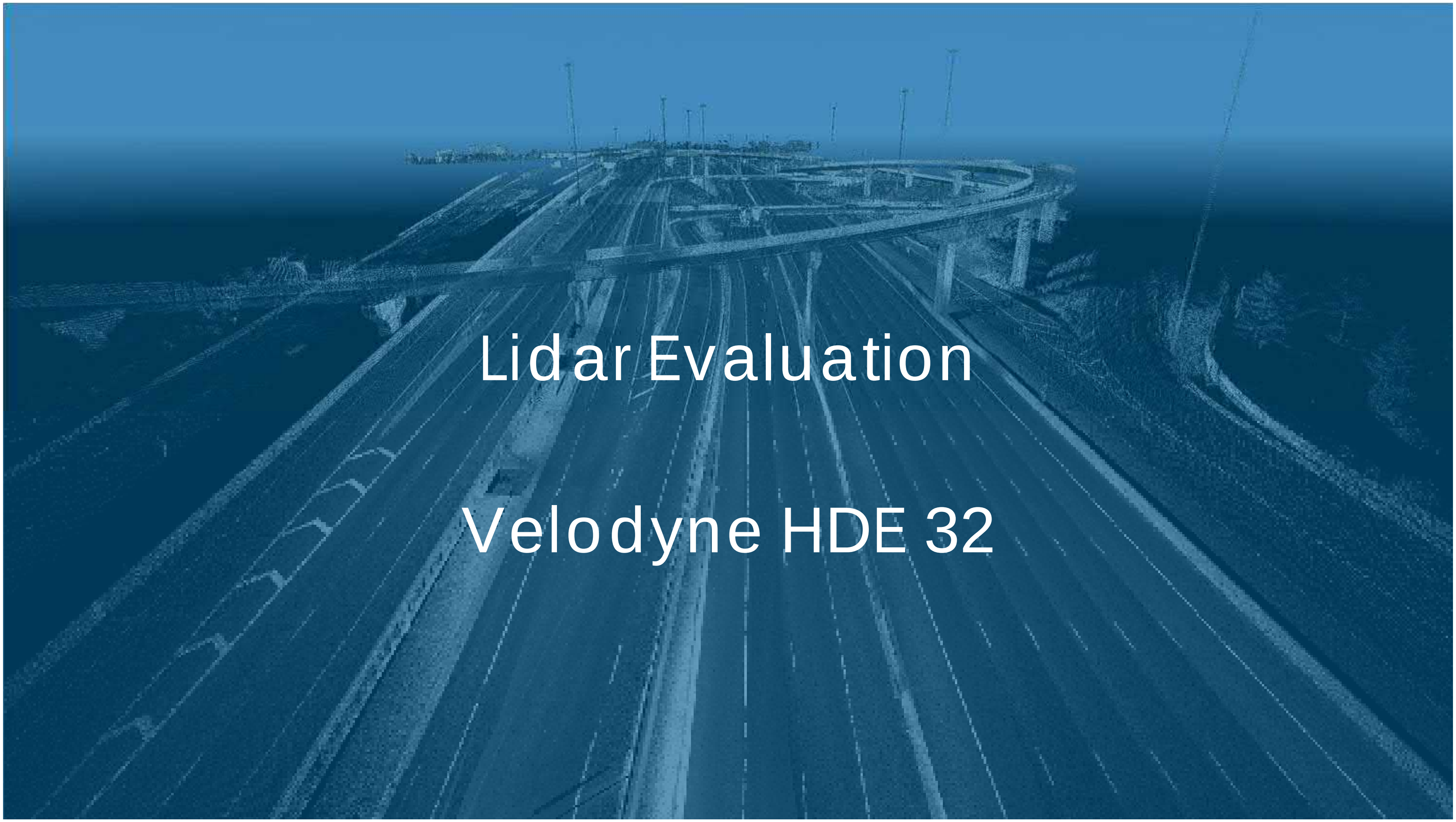
Road Profiles



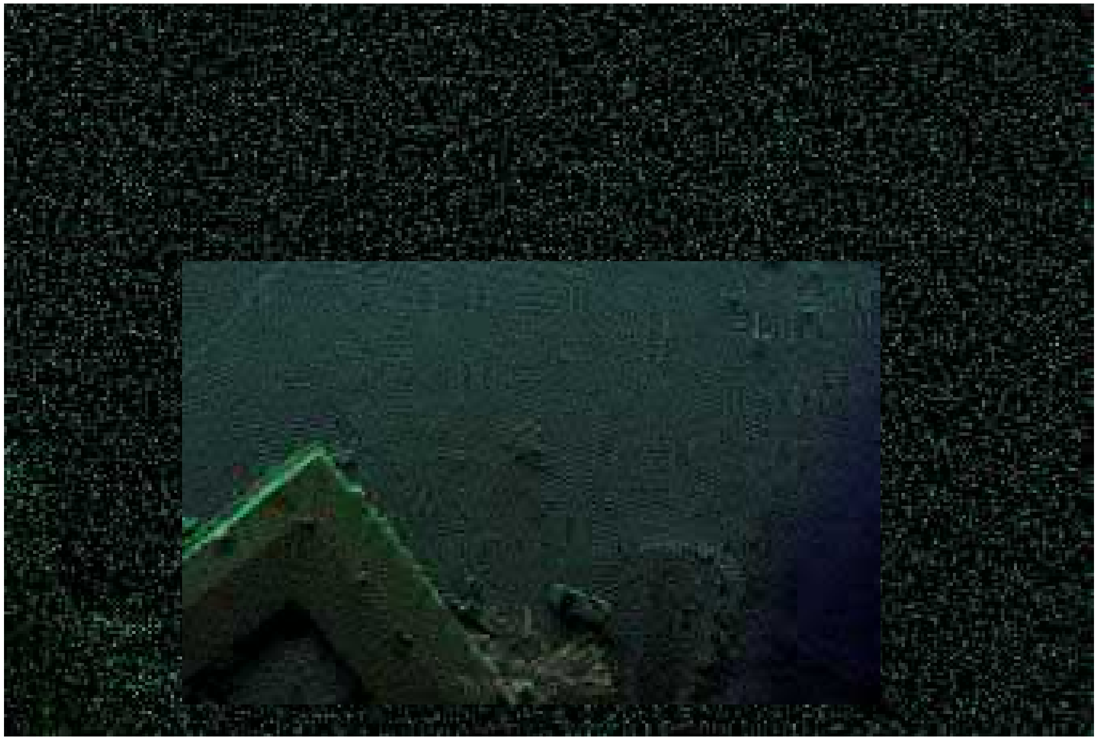


Grassy Ground



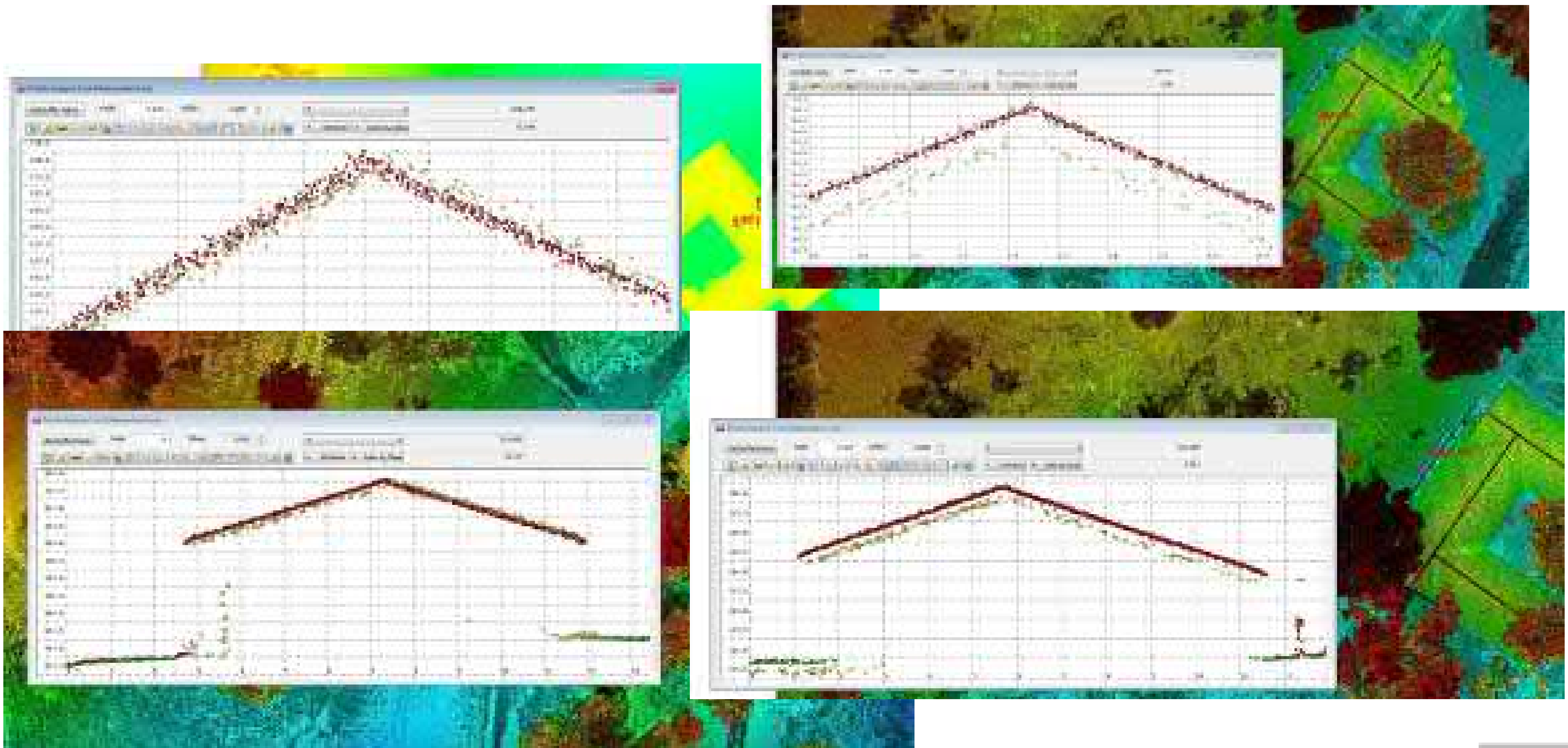

Lidar Evaluation
Velodyne HDE 32

Scan Pattern

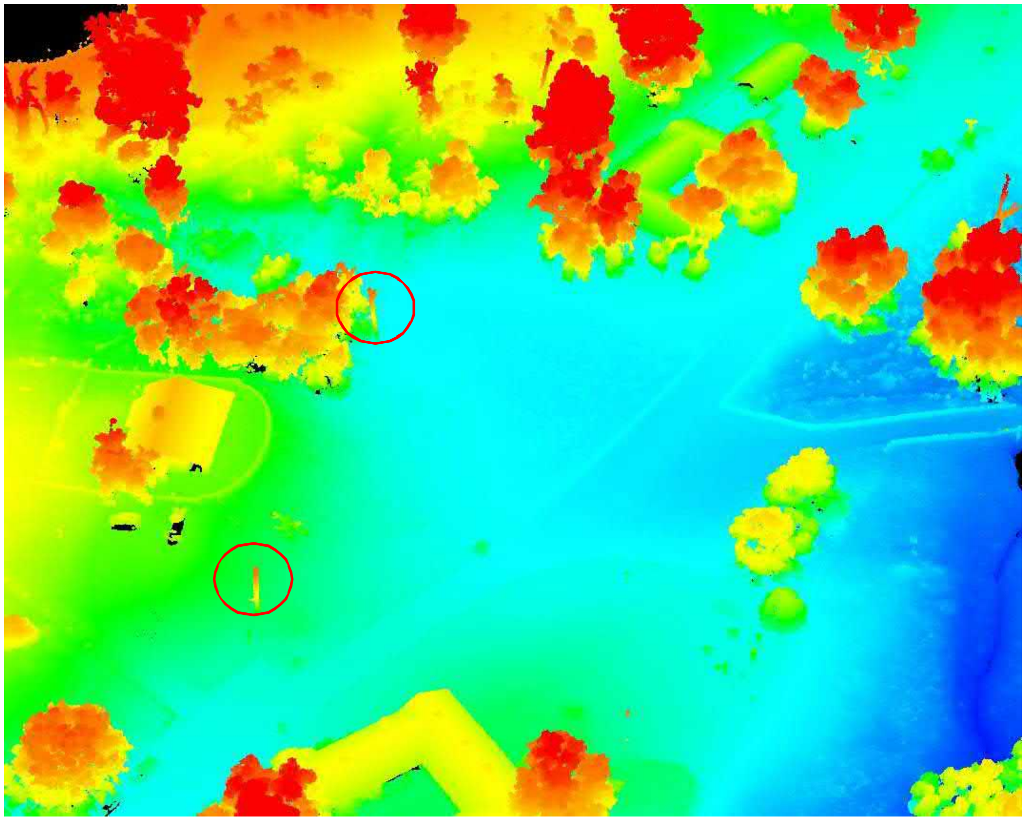


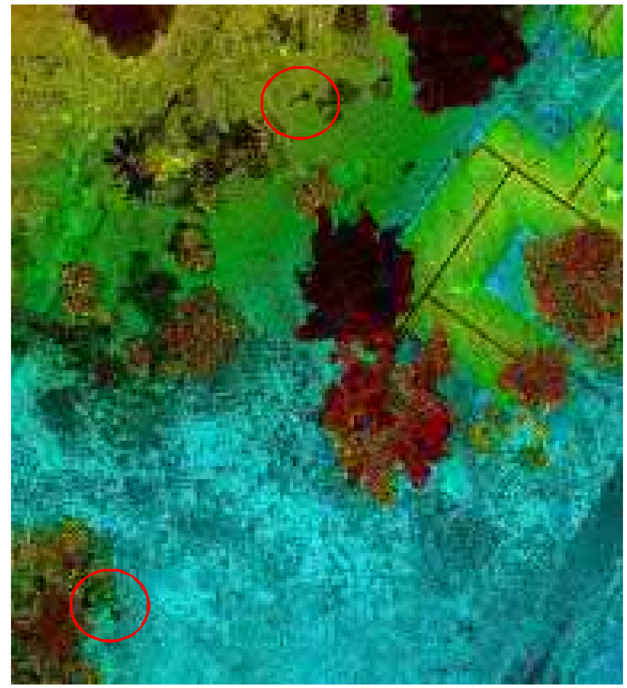
Intensity Quality

Roofs

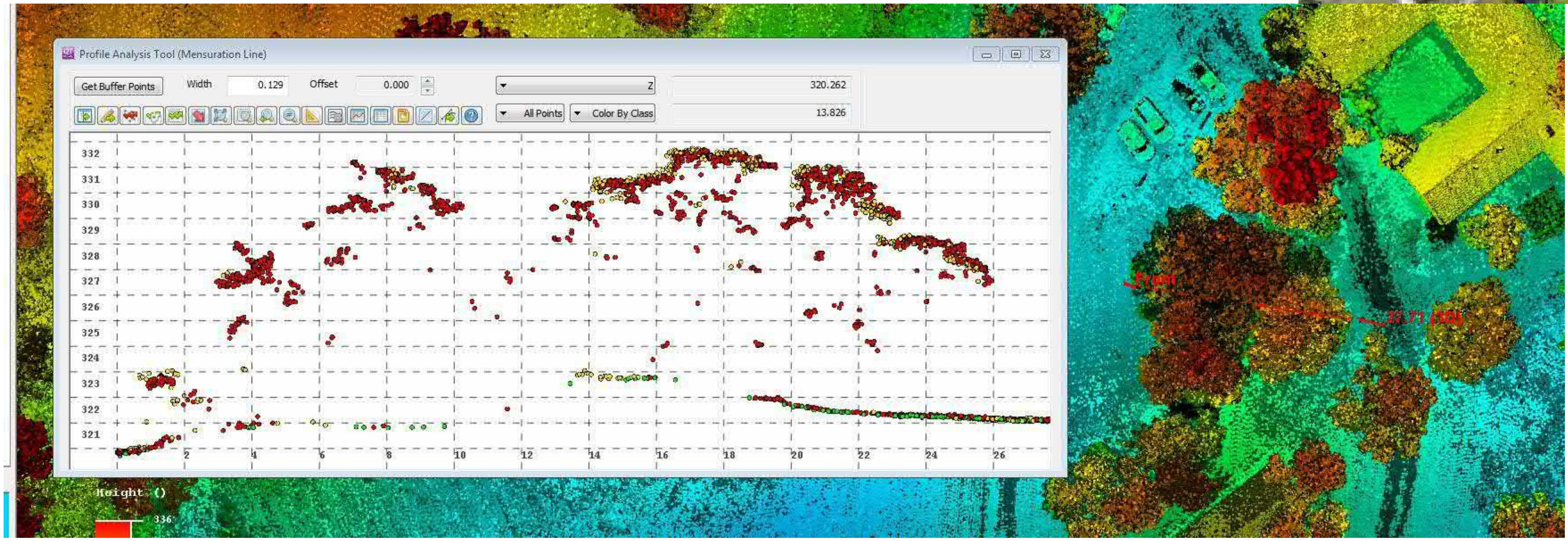


Missing Power Lines

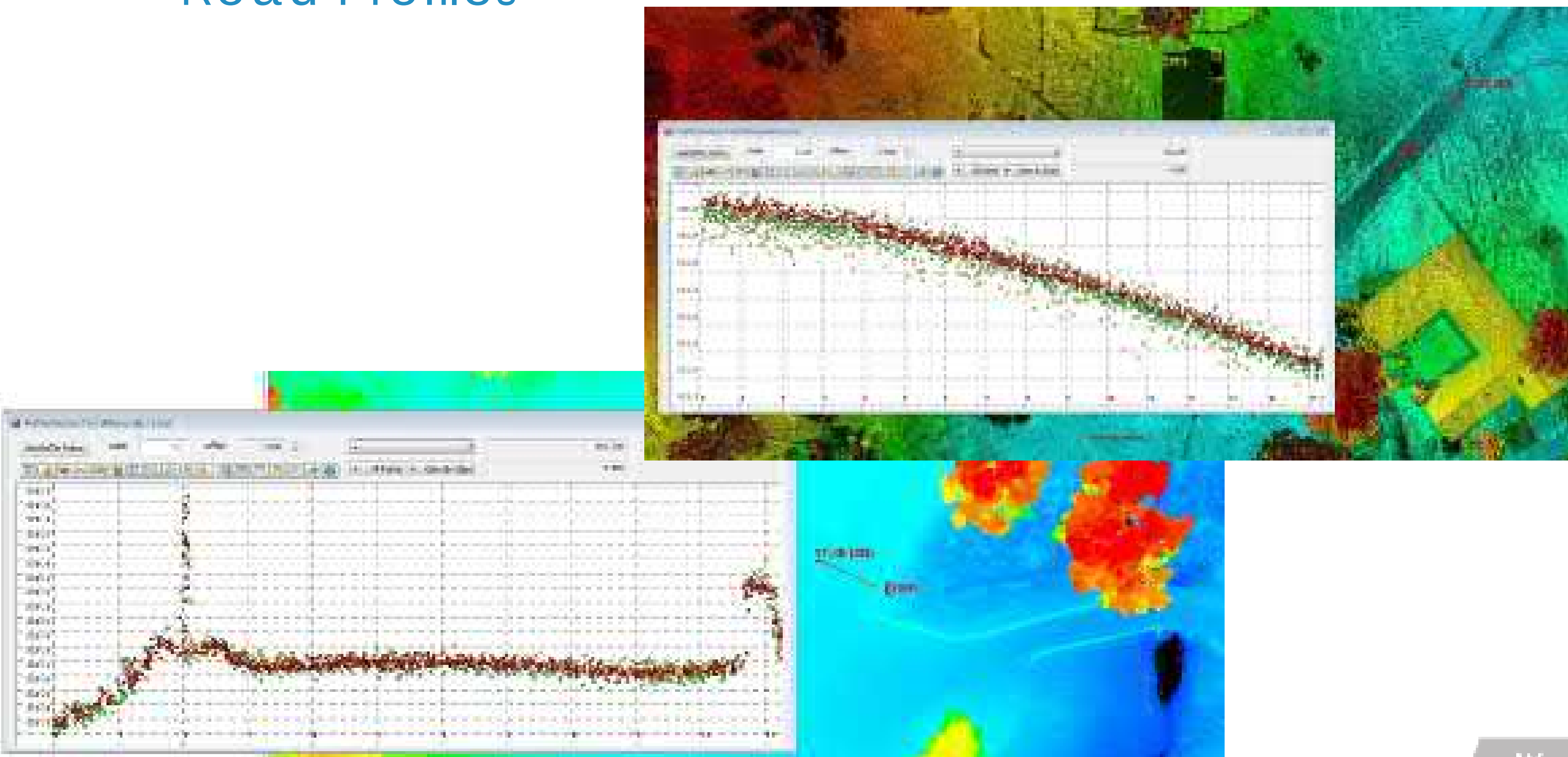




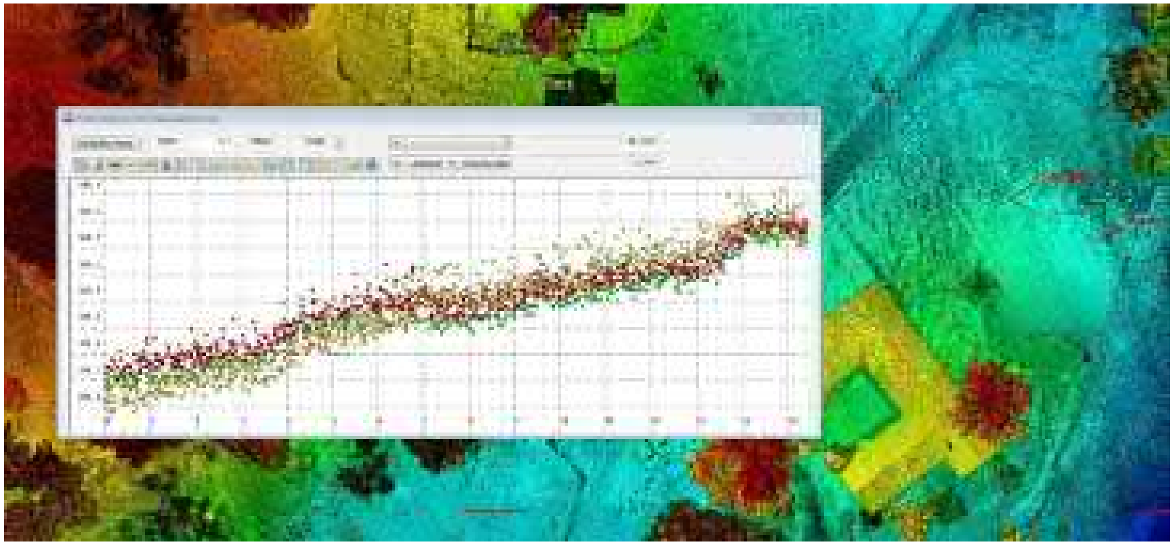
Trees Penetration

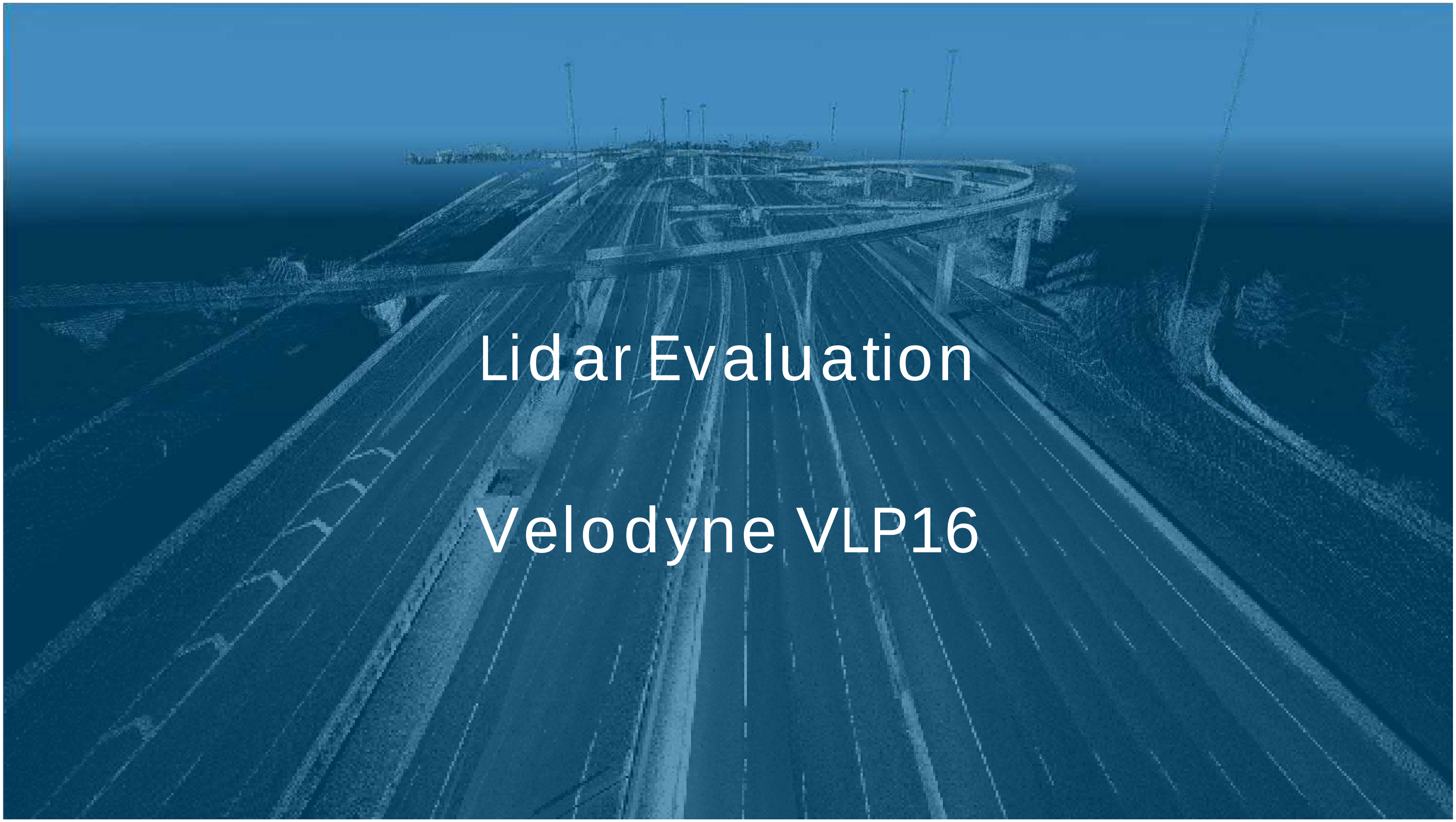


Road Profiles



Grassy Ground

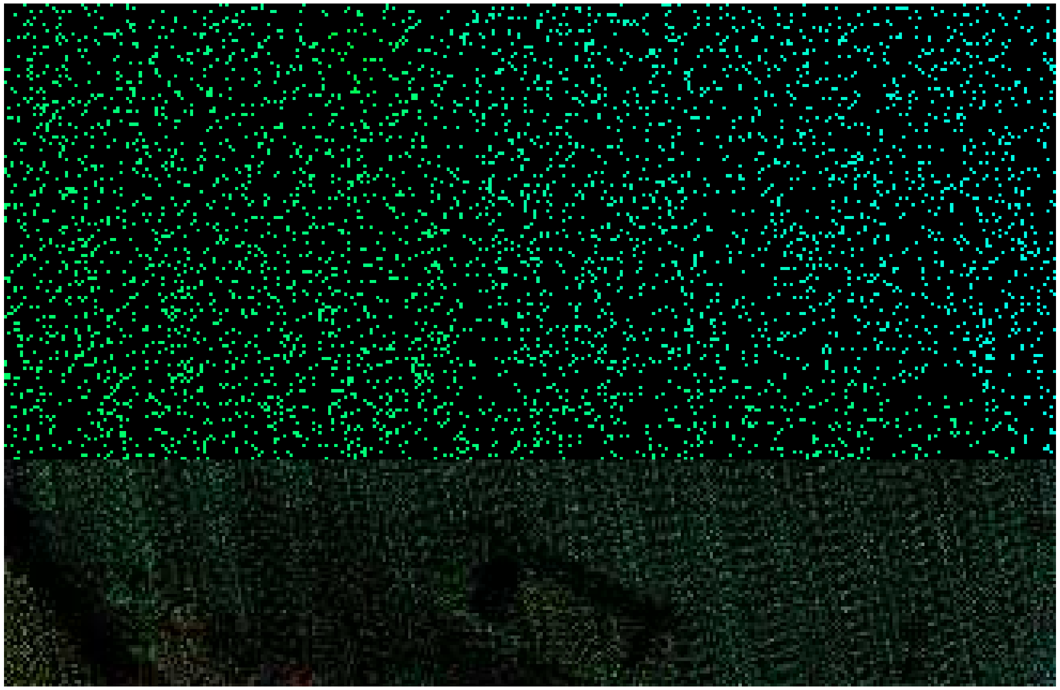




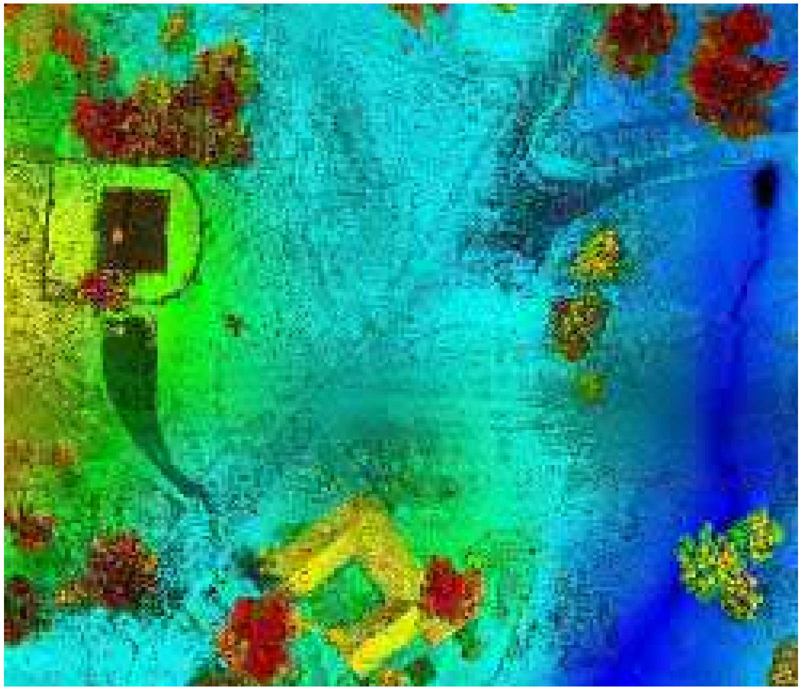
Lidar Evaluation

Velodyne VLP16

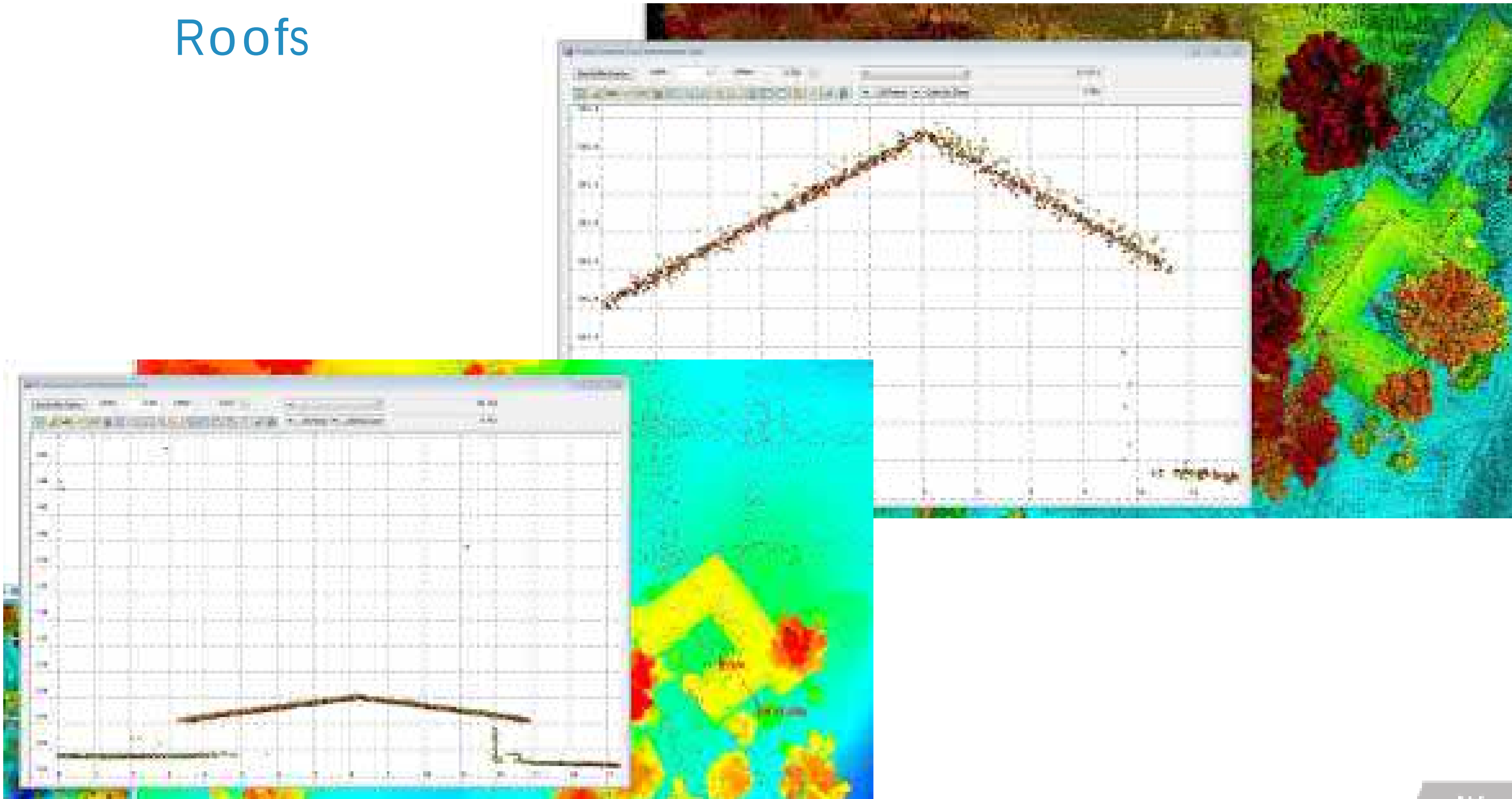
Scan Pattern



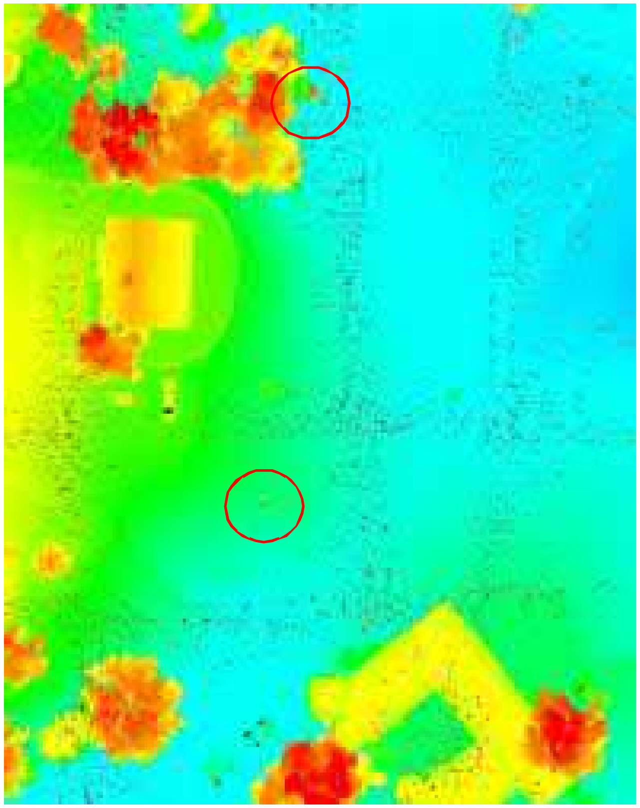
Intensity Quality



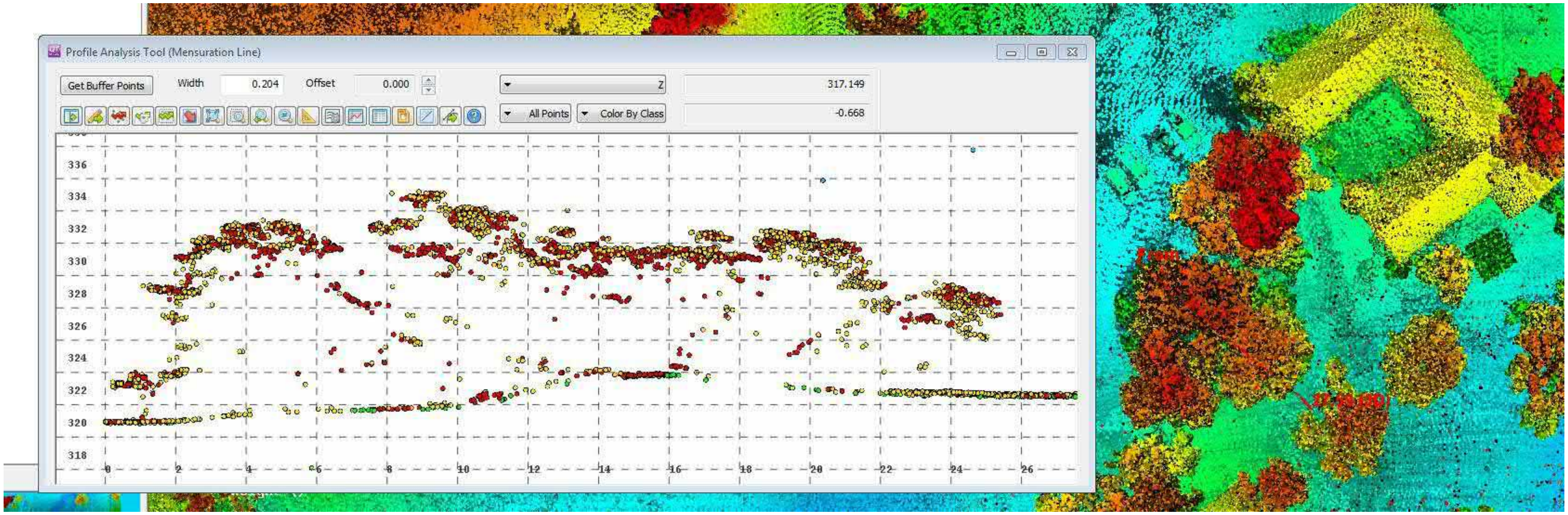
Roofs



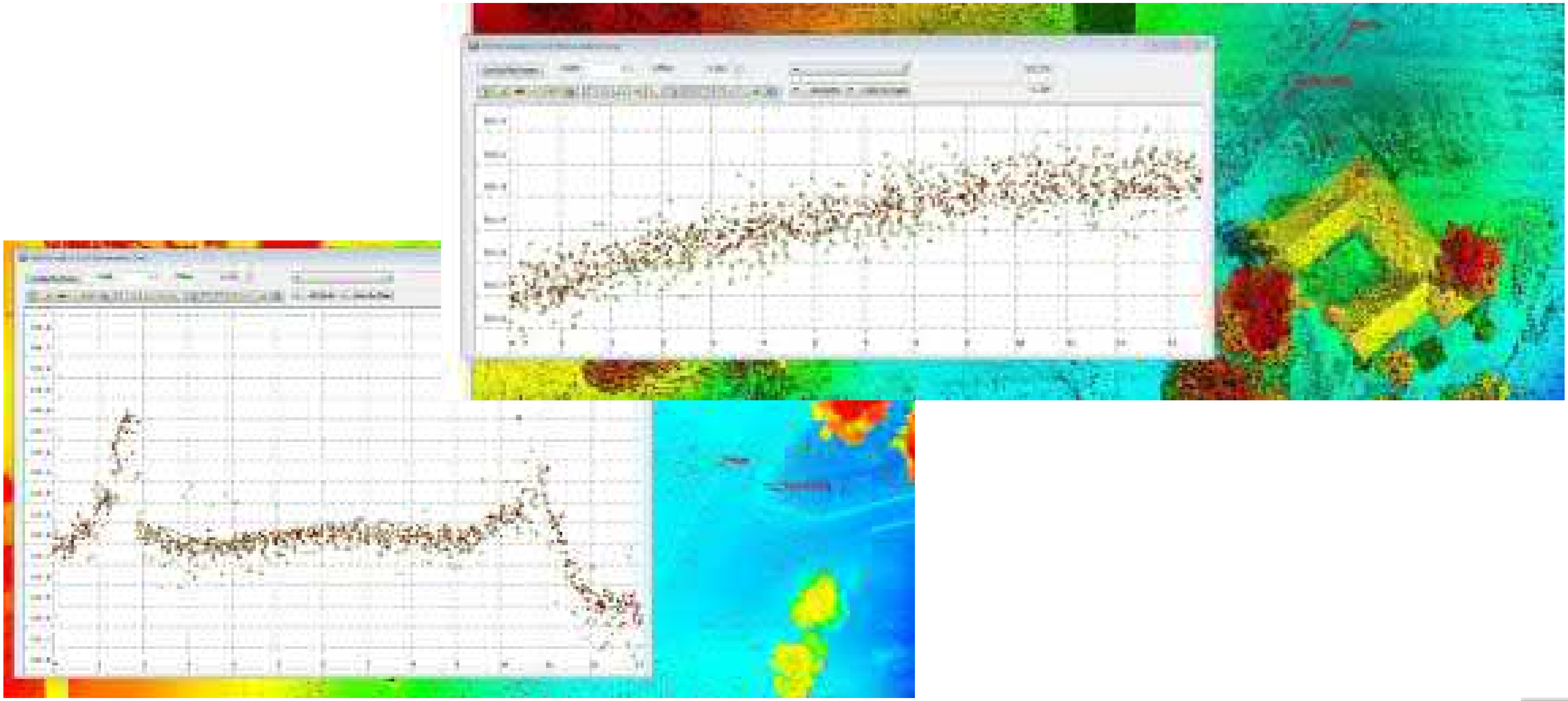
Missing Power Lines



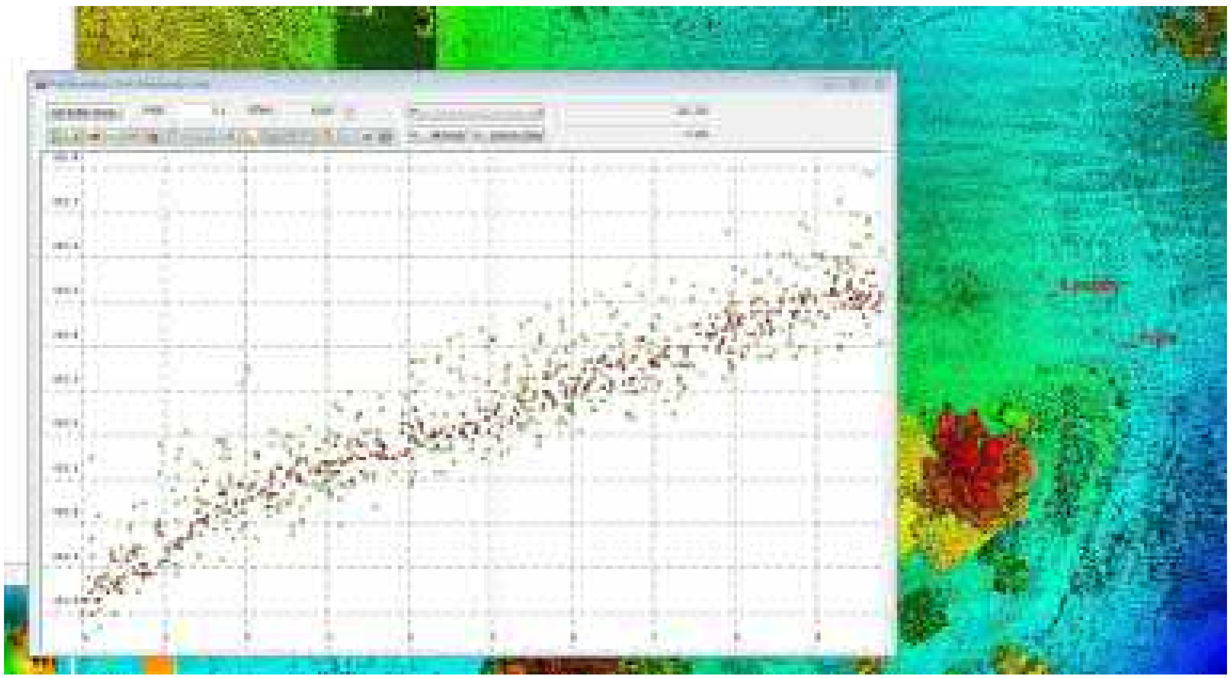
Trees Penetration



Road Profiles



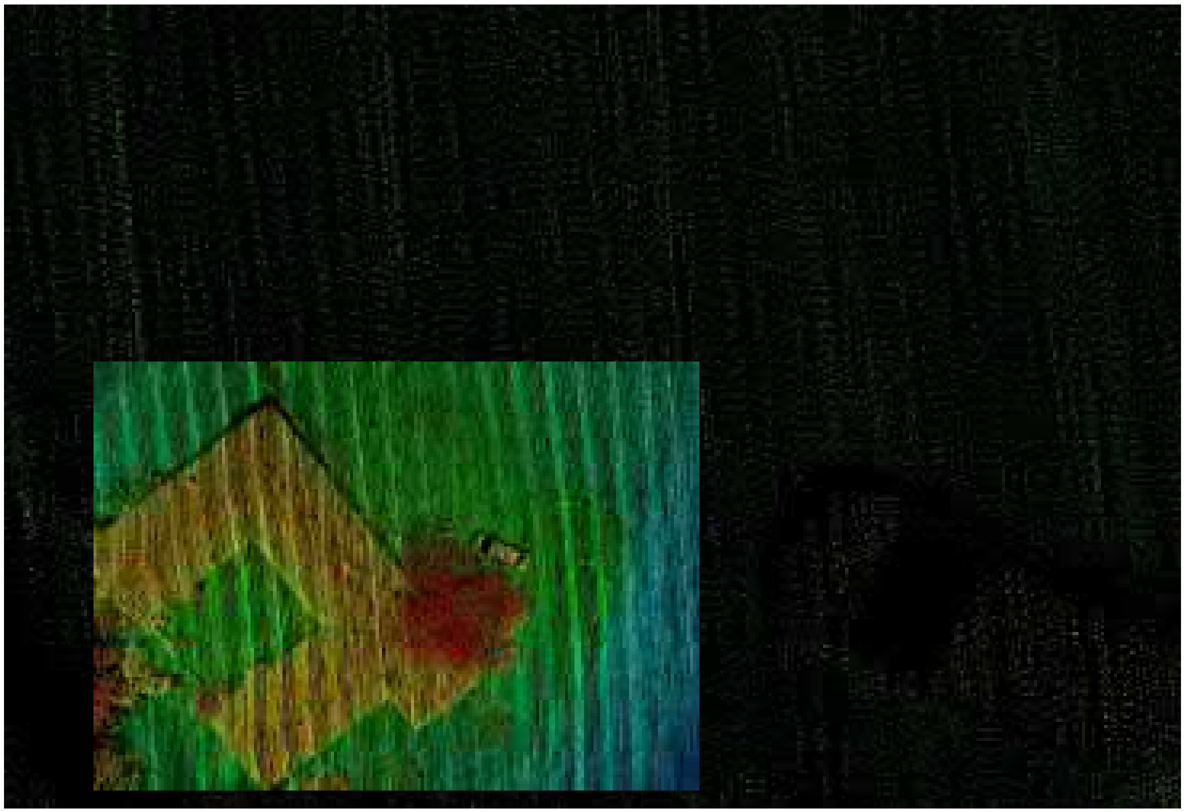
Grassy Ground



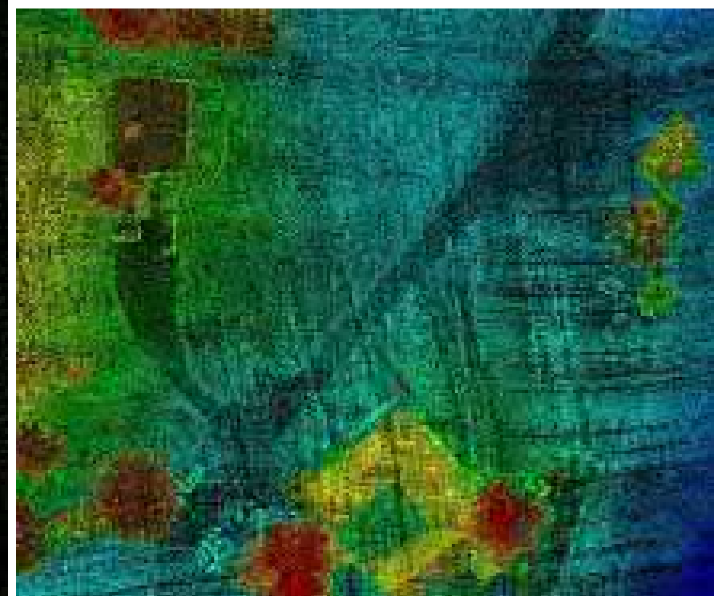
Lidar Evaluation

Quenergy M8

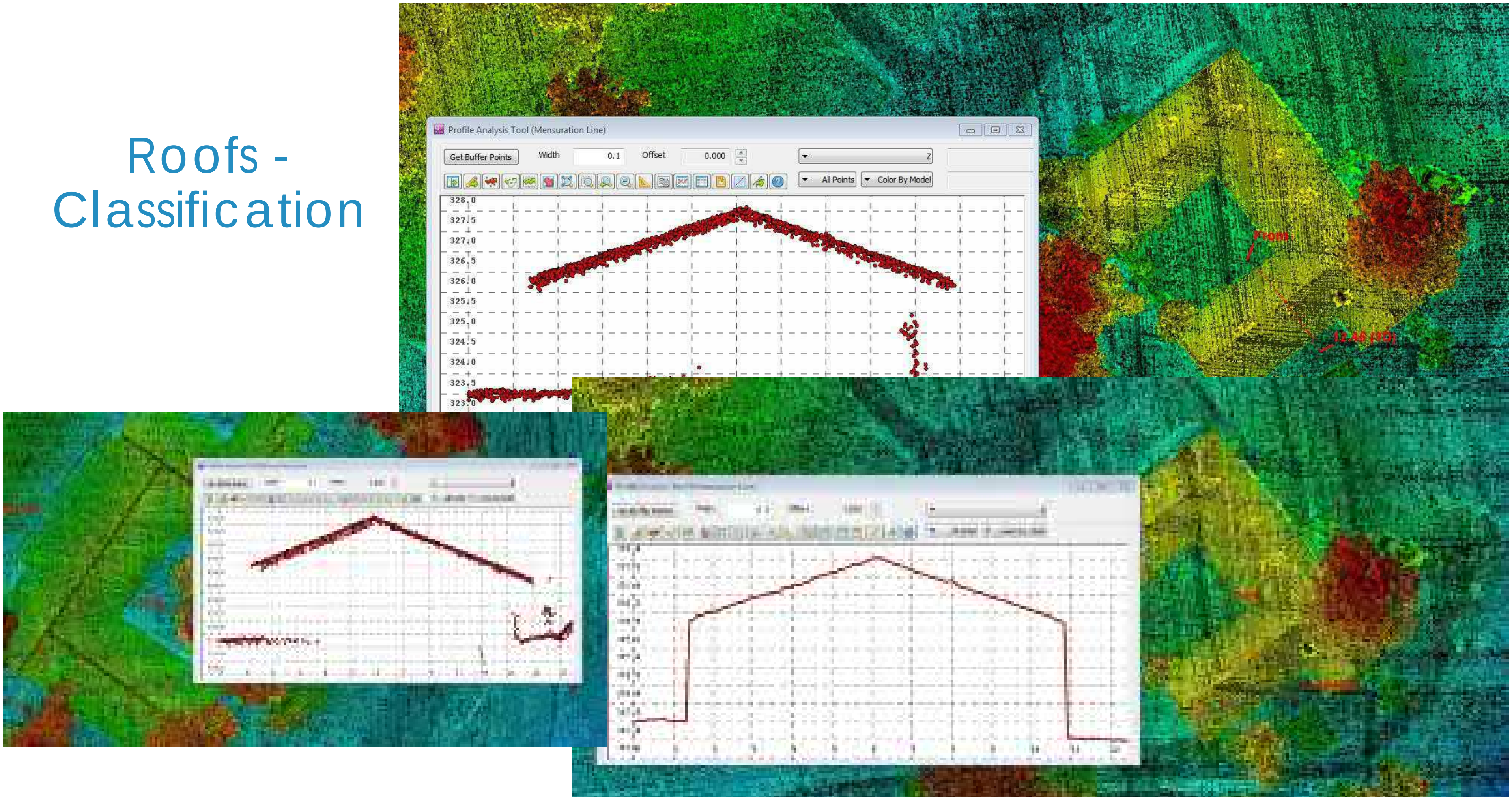
Scan Pattern



Intensity Quality

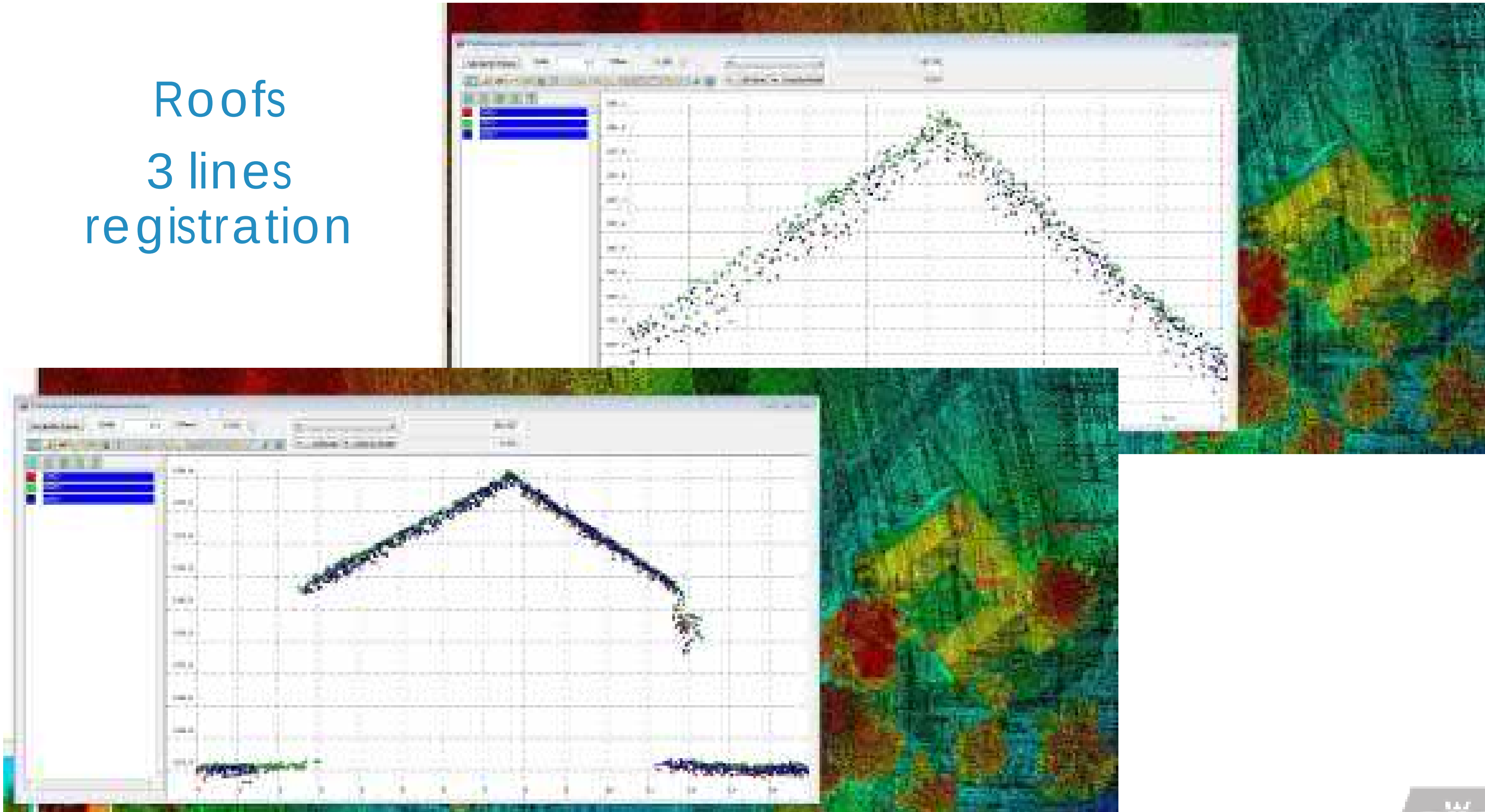


Roofs - Classification

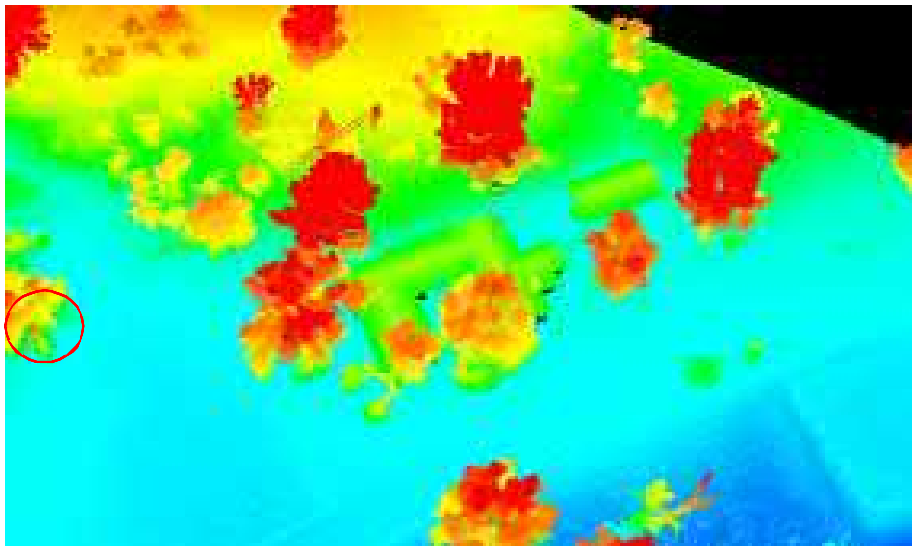


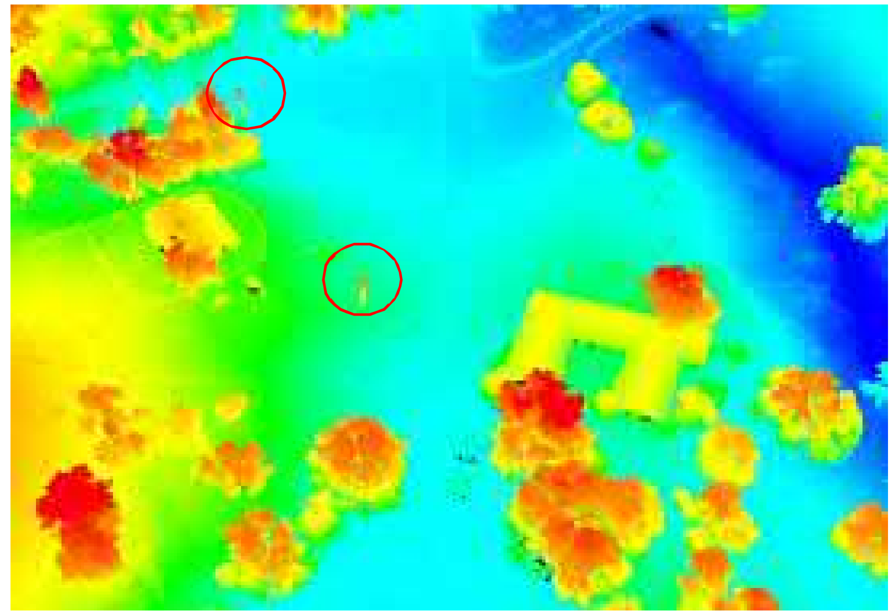
Roofs

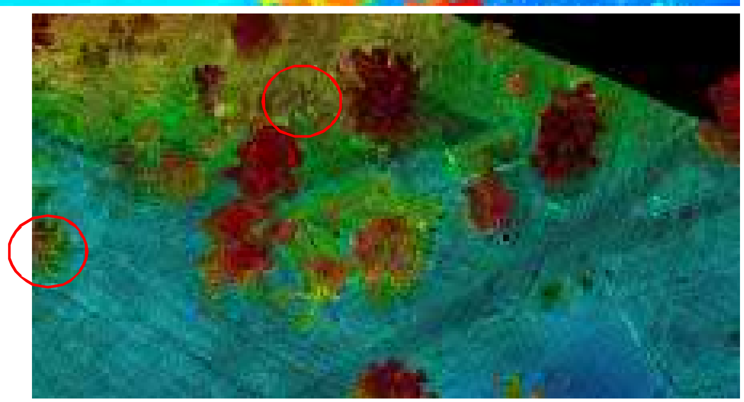
3 lines registration



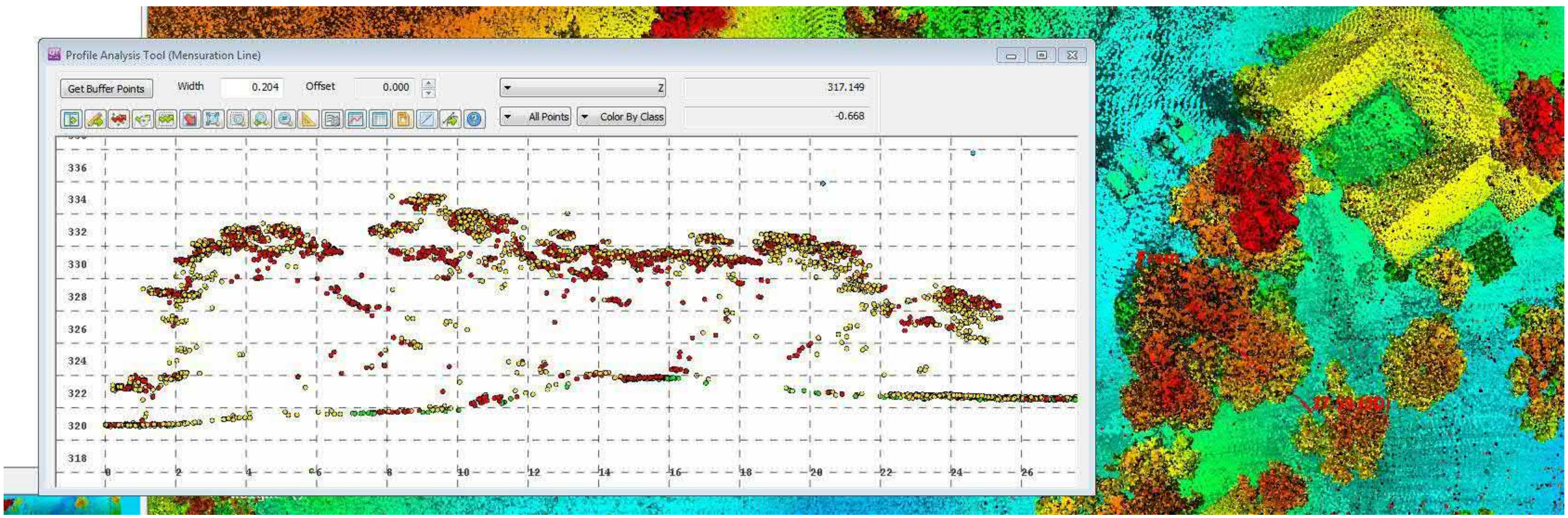
Missing Power Lines



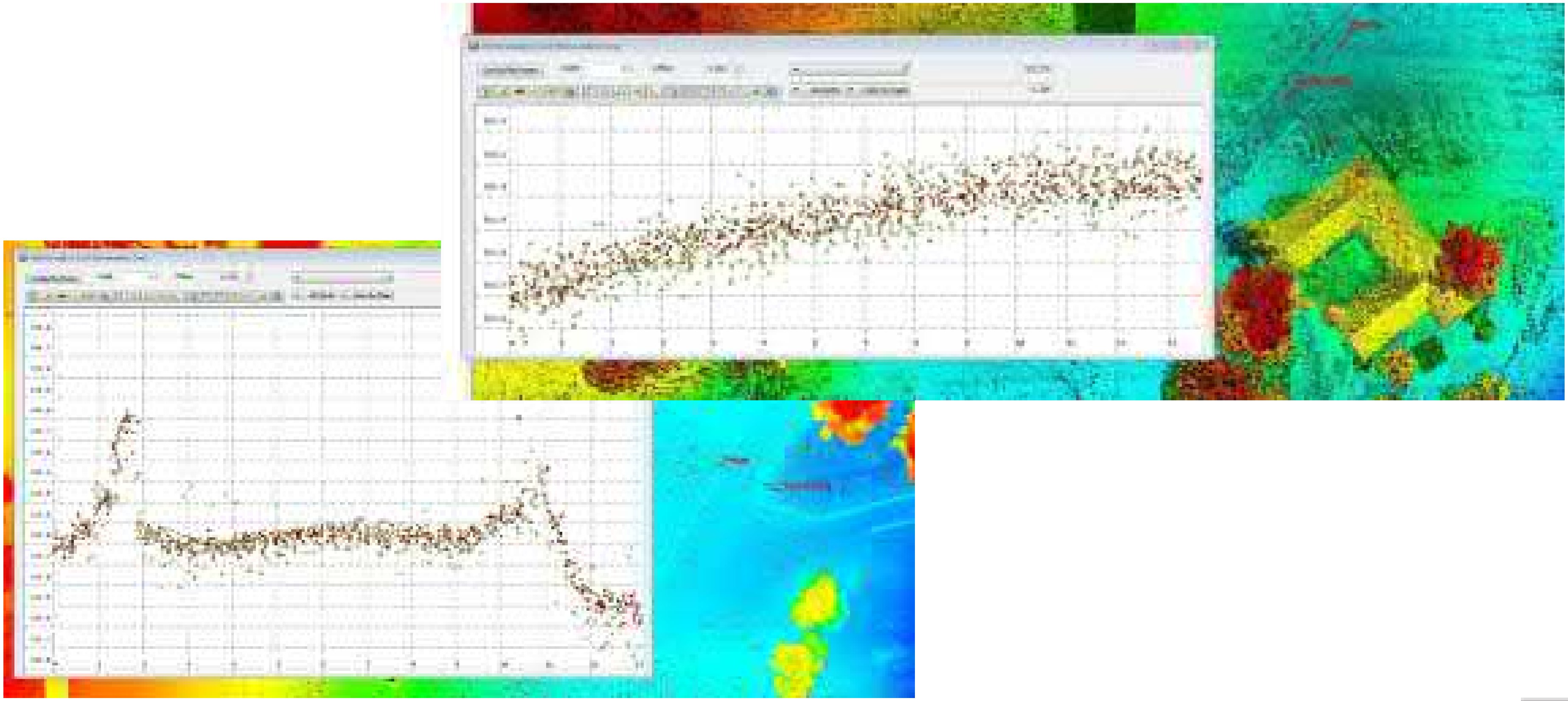




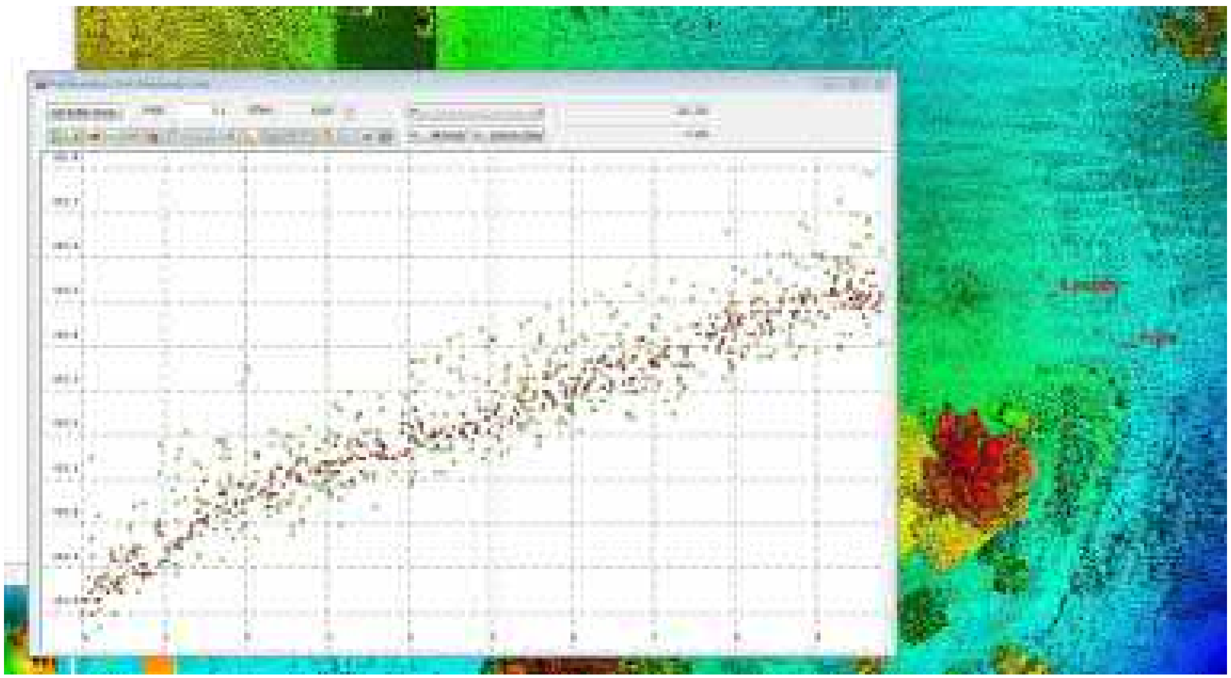
Trees Penetration

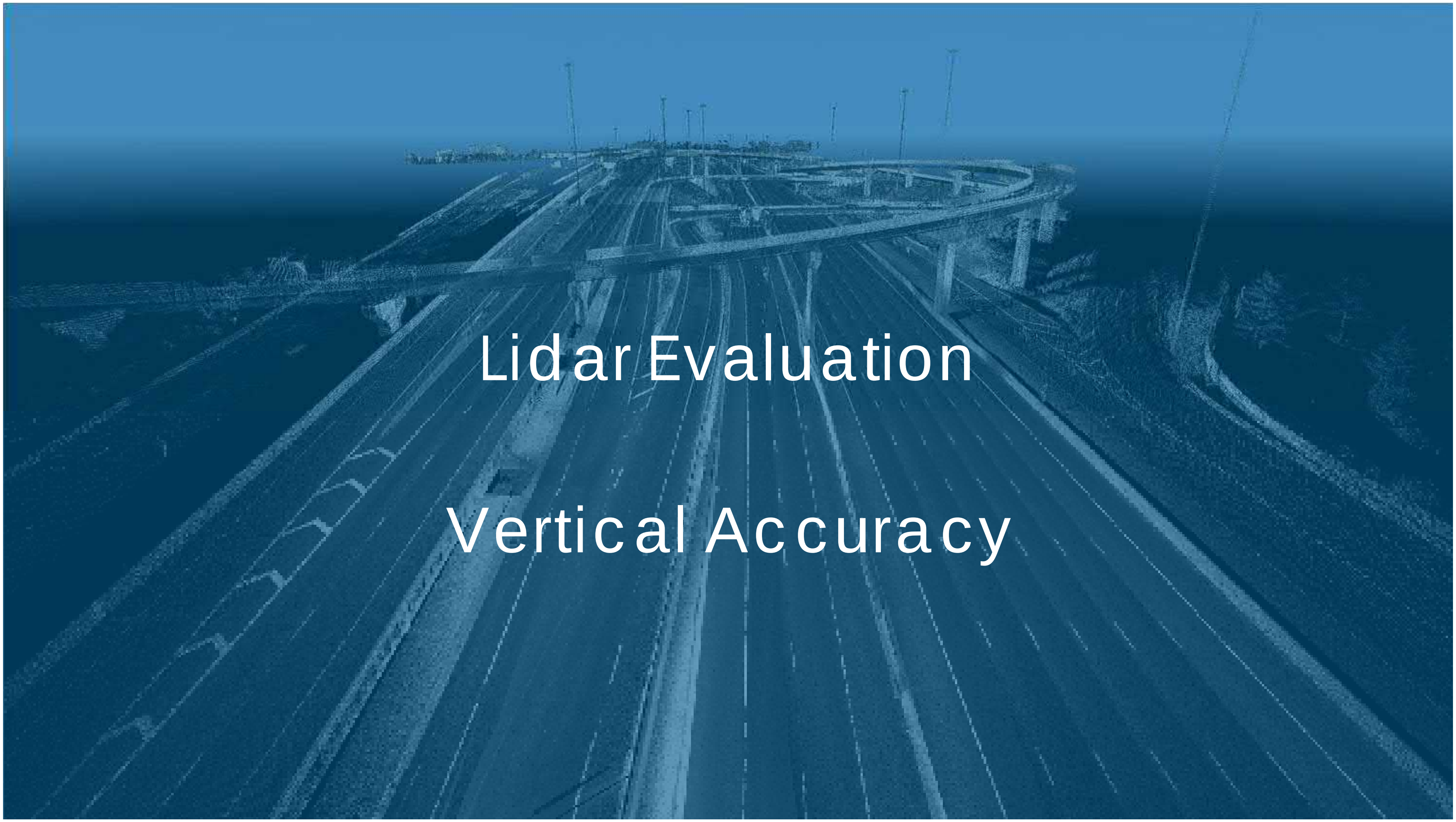


Road Profiles



Grassy Ground





Lidar Evaluation

Vertical Accuracy

AQ1

Accuracy Evaluation using 40 check points

Accuracy Term	Velodyne HDL 32E	Velodyne HDL VLP16	Riegl MiniVUX	Quenergy M8
Average (m)	0.000	0.000	0.000	0.000
Minimum (m)	-0.162	-0.138	-0.093	-0.128
Maximum (m)	0.149	0.100	0.071	0.052
StDEV (m)	0.082	0.054	0.038	0.042
$RMSE_v$ (m)	0.081	0.054	0.038	0.042
Accuracy at 95% (m)	0.159	0.105	0.074	0.082

AQ1 Abdullah, Qassim, 7/21/2019

The Wrong and Right Practices In Geospatial Data Accuracy Verification

Statement of the problem:

- We quantify products accuracy ignoring the errors in the surveyed check points
- Our surveying techniques are approximating the datum, i.e. producing pseudo datum
- Currently, we are evaluation the closeness of data to the pseudo datum and not the datum

Current practice:

Product accuracy = Errors in fitting products to check points

Correct practice:

Product accuracy = Errors in fitting products to check points + check points accuracy

Why So

Long ago, geospatial products and mapping technologies were less accurate:

- Ortho imagery produced with low resolution, DOQQ is 1 meter GSD
- Maps were produced with small scale
- Therefore, errors in control/check points were usually ignored as it was considered negligible

Why Now

- Geospatial products today are very accurate
- We are heading toward more accurate datum in 2022
- Drone are collecting imagery with 1-cm GSD and producing highly accurate products
- Lidar is providing accuracy in the range of 1.5 to 10 cm
- ASPRS standards support high accuracy
- We just can not continue our wrongful practice

How should we express product accuracy?

<u>Photogrammetry:</u>

Aerial Triangulation Accuracy = The fit to the GCPs + the accuracy of the GCPs

Ortho Accuracy = The fit to check points + the accuracy of the GCPs

<u>Lidar:</u>

Lidar Accuracy = The fit to check points + the accuracy of the GCPs

Example

- Surveyed check points are used to verify ortho and DSM accuracy.
- The check points was surveyed using RTK techniques with horizontal accuracy of RMSE = 2-cm and vertical accuracy of RMSE = 3-cm

Ortho QC using the check points resulted in $RMSE_{xy}$ = 2.5-cm

DSM QC resulted in $RMSE_z$ = 2.7-cm

Final Ortho Accuracy = 2.5-cm + 2-cm (vectors arithmetic should be used here)

Final DSM Accuracy = 2.7-cm + 3-cm (vectors arithmetic should be used here)

Currently, the ortho is labeled with 2.5-cm accuracy and the DSM with 2.7-cm accuracy


Thank you!
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The Best of All Worlds:
Data Fusion and the Hybrid DSM

Aerial Lidar + MMS + UAS

Aerial Lidar:

Points Density: up to 30 pts/m^2

Accuracy(v) RMSE = 6 to 15 cm

MMS:

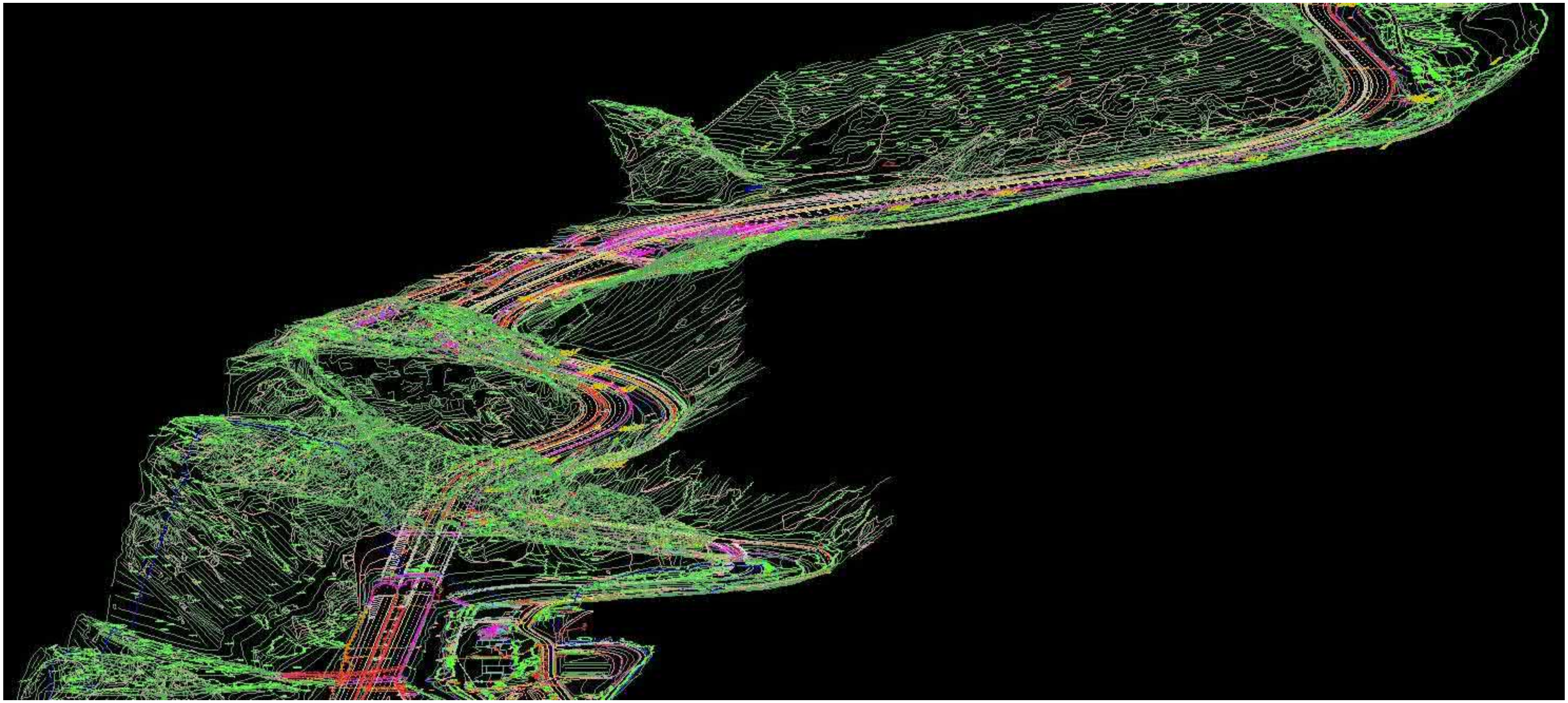
Points Density: 2,000 to 6,000 pts/m^2

Accuracy(v) RMSE = 1.5 cm

UAS:

Points Density: 40 to 1000 pts/m^2

Accuracy(v) RMSE = 5 to 15 cm



Integrated Surfaces

Collect, digitize and attribute all elements of the project

Advantages of Point Clouds from UAS Imagery

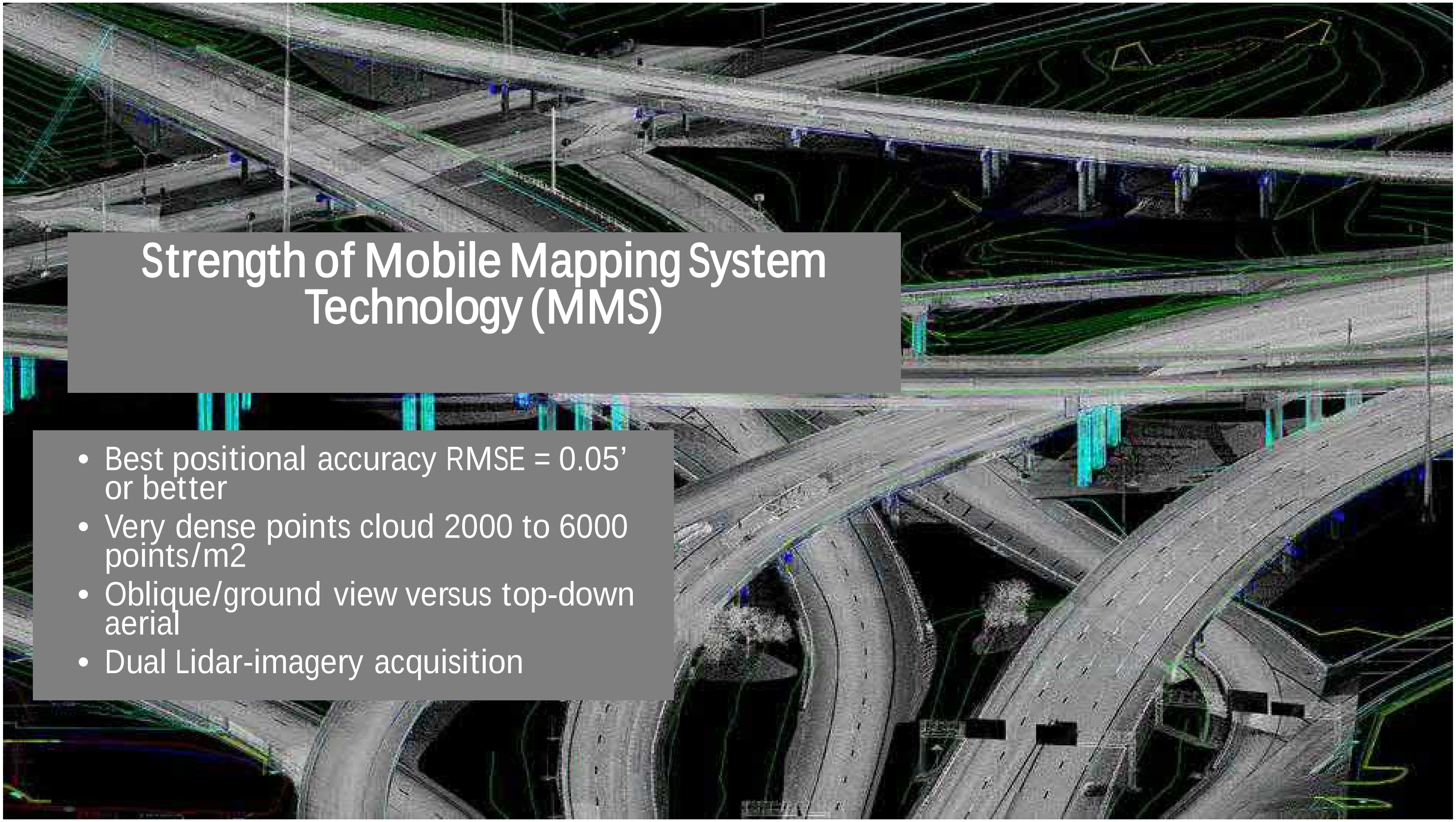
- Birds Eye View, i.e. beyond MMS coverage
- Affordable approach
- Easy to deploy
- Easy to process
- Excessive overlap

Limitations of Point Clouds from Imagery

- Less accurate than LiDAR
- No tree penetration
- FAA Regulations

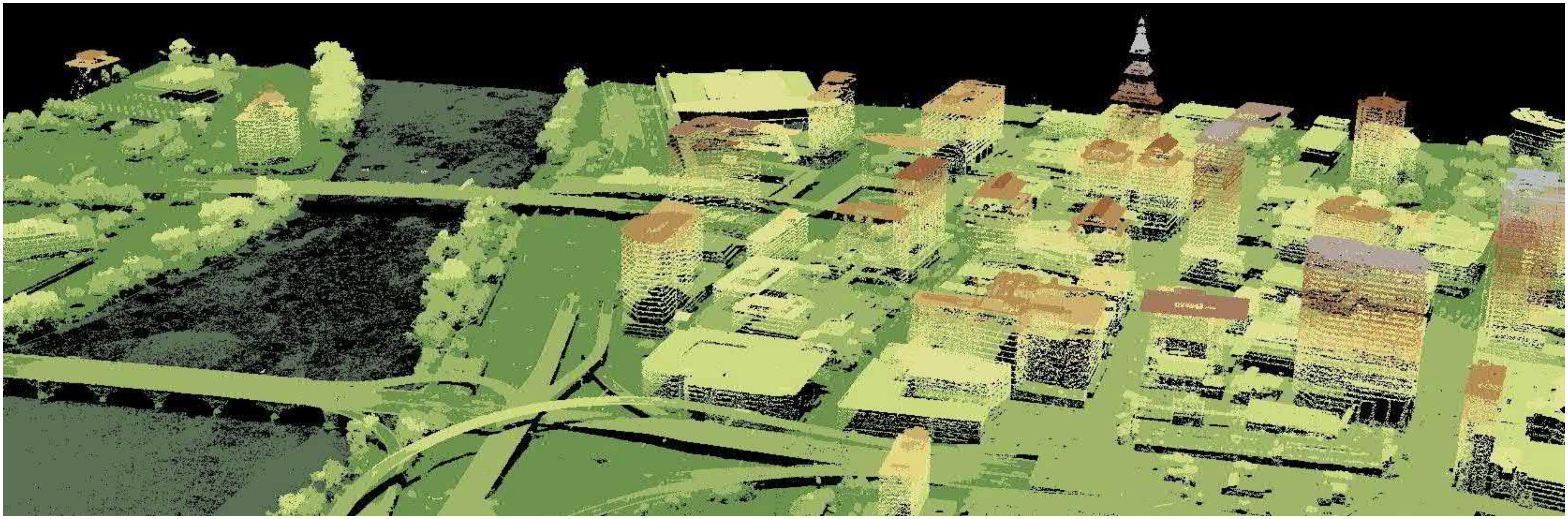
Strength of Mobile Mapping System Technology (MMS)

- Best positional accuracy RMSE = 0.05’ or better
- Very dense points cloud 2000 to 6000 points/m2
- Oblique/ground view versus top-down aerial
- Dual Lidar-imagery acquisition



Limitations of Mobile Mapping Systems (MMS)

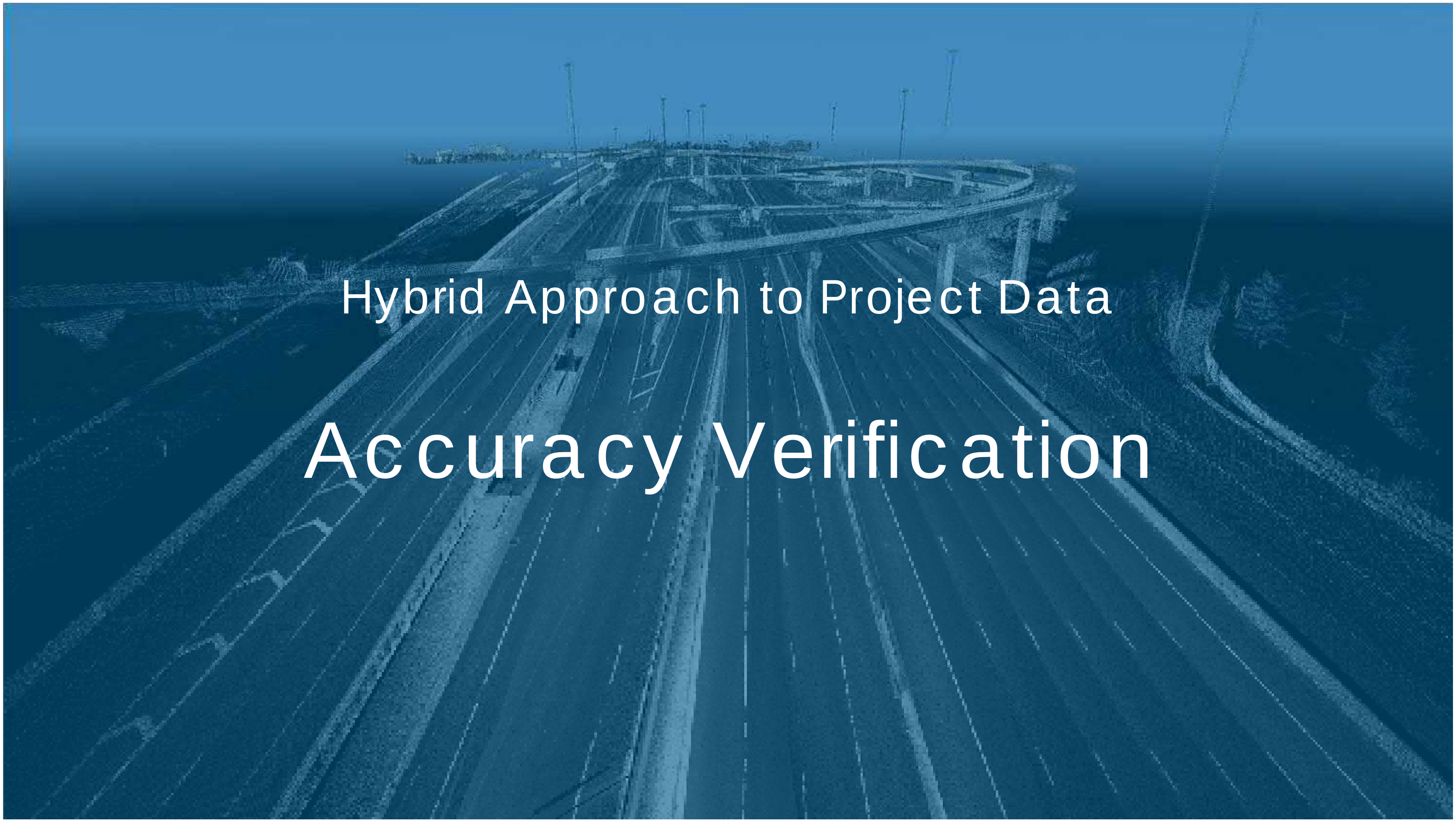
- Only on driven roads
- Limited range
- Not suitable for rural environments



Limitations of Aerial LiDAR

- Lower point cloud density as compared to MMS
- Limited positional accuracy for DOT's road design projects
- Not suitable for small projects
- Obscured areas

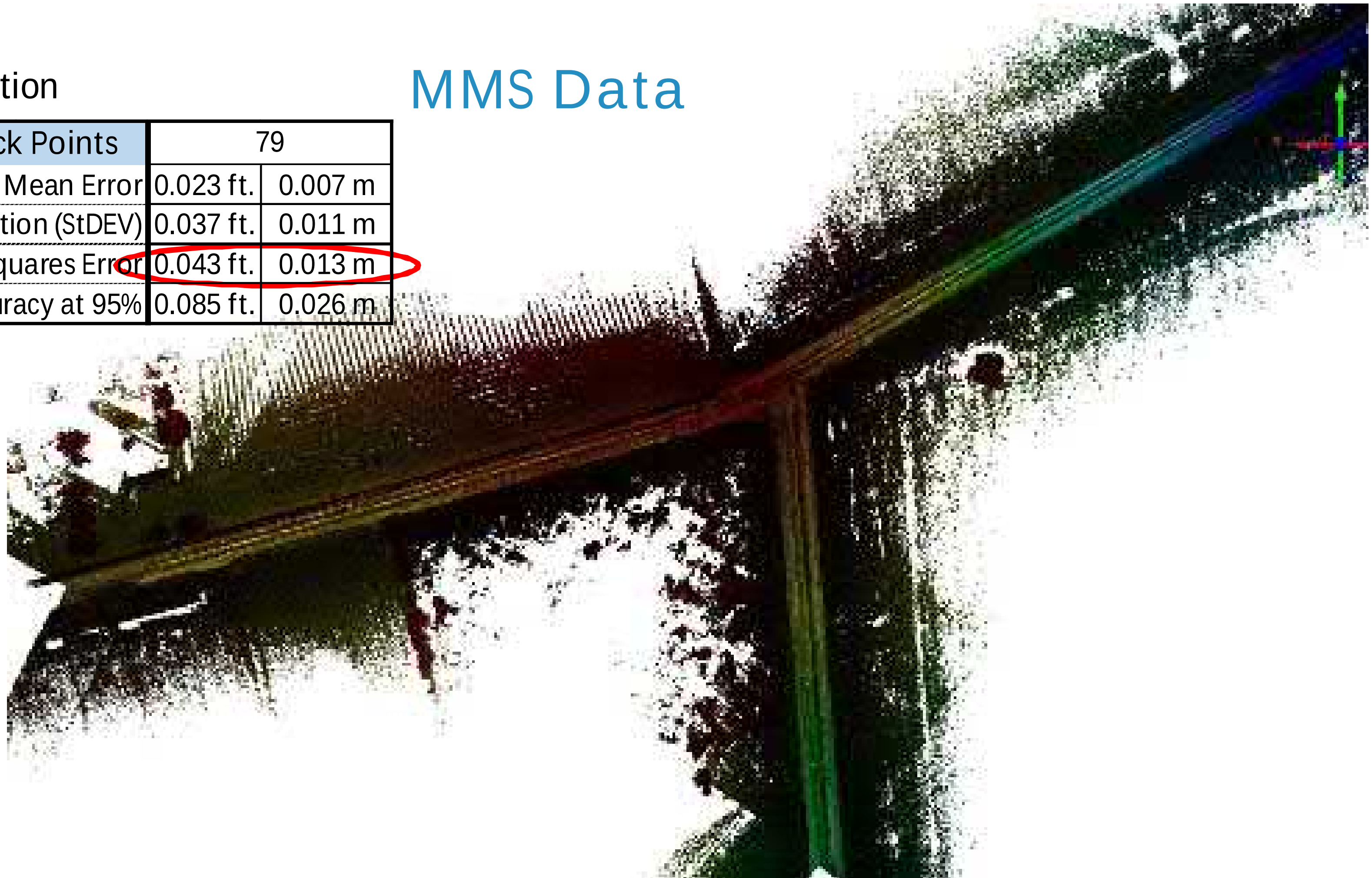
Data Fusion
The Petersburg/Overman Roads Intersection Improvement


Hybrid Approach to Project Data
Accuracy Verification

Accuracy Validation

MMS Data

Number of Check Points	79	
Mean Error	0.023 ft.	0.007 m
Standard Deviation (StDEV)	0.037 ft.	0.011 m
Root Mean Squares Error	0.043 ft.	0.013 m
NSSDA Vert Accuracy at 95%	0.085 ft.	0.026 m

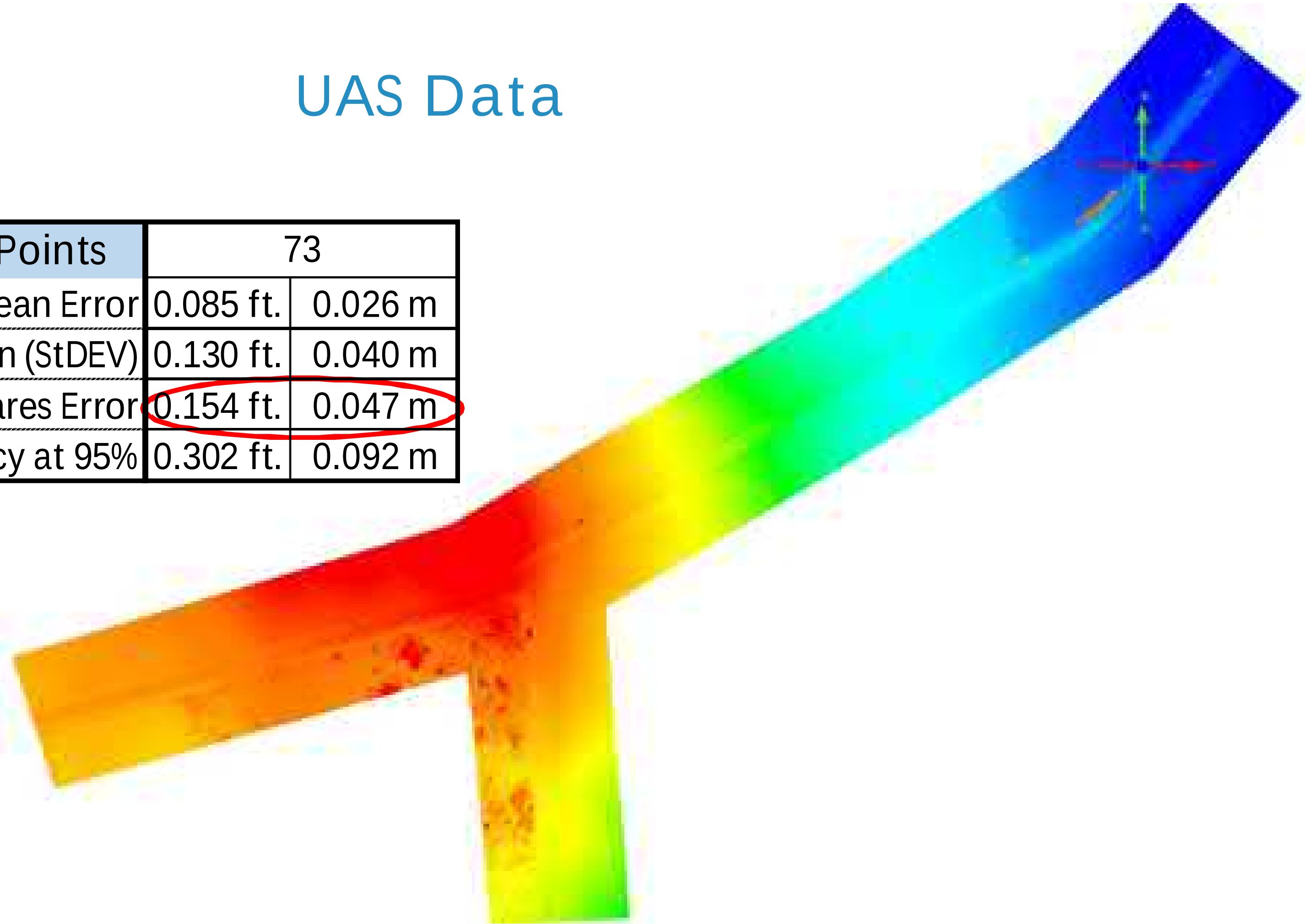


UAS Data

UAS Data

Accuracy Validation

Number of Check Points	73	
Mean Error	0.085 ft.	0.026 m
Standard Deviation (StDEV)	0.130 ft.	0.040 m
Root Mean Squares Error	0.154 ft.	0.047 m
NSSDA Vert Accuracy at 95%	0.302 ft.	0.092 m

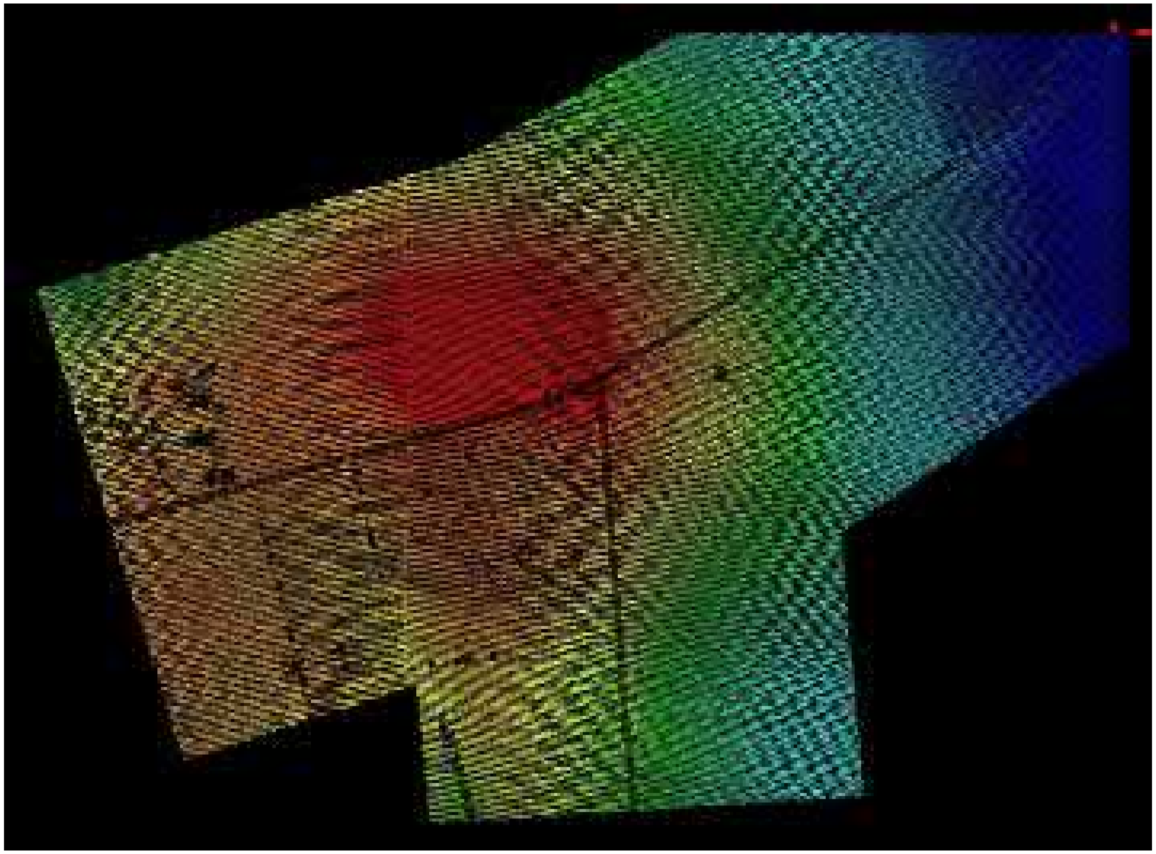


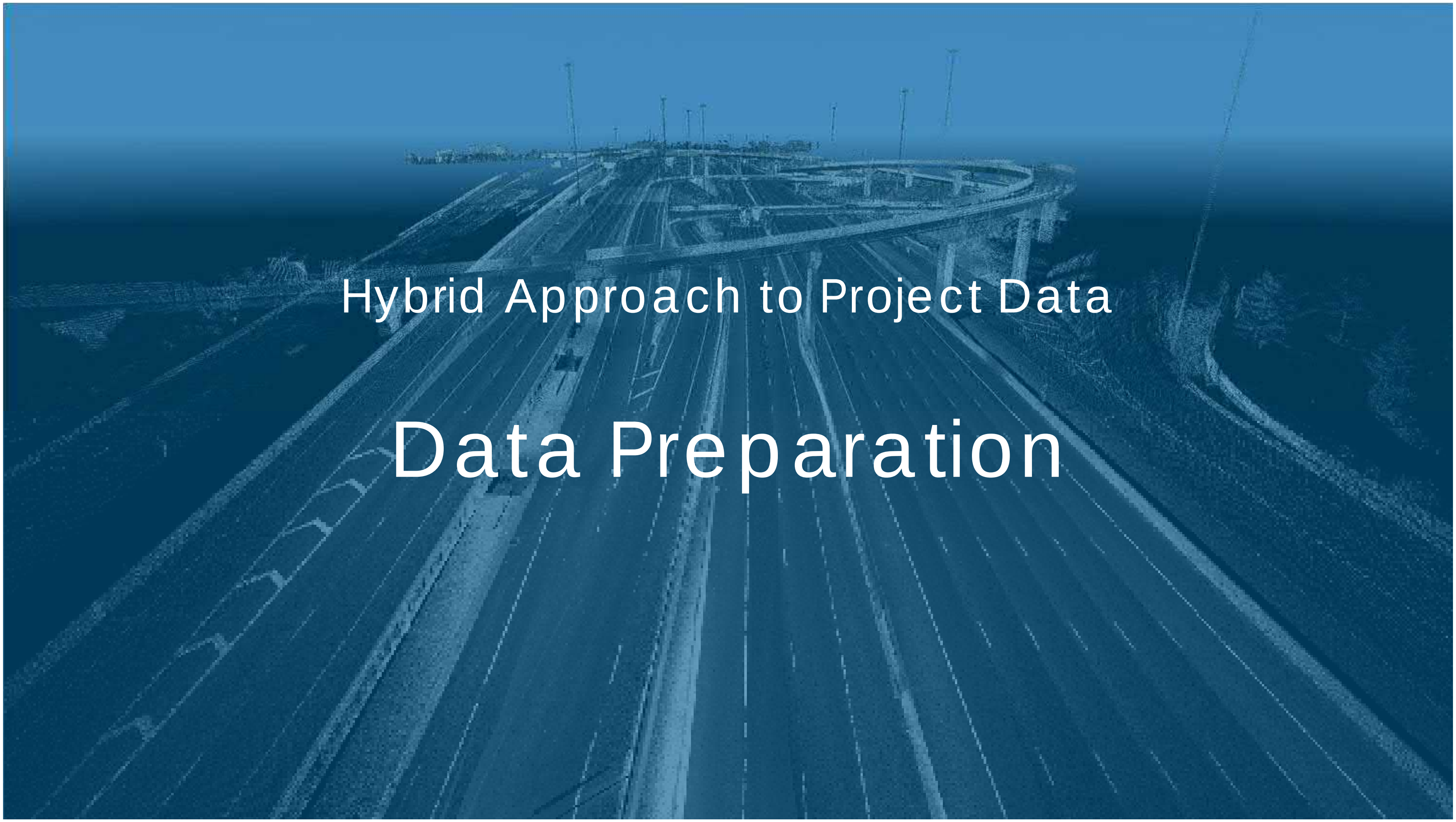
Aerial LiDAR: Existing Ohio Statewide Imagery Program (OSIP)

Accuracy Validation

Number of Check Points	197	
Mean Error	0.47 ft.	14.39 cm
Standard Deviation (StDEV)	0.16 ft.	4.90 cm
Root Mean Squares Error (RMSEz)	0.50 ft.	15.19 cm
NSSDA Vert Accuracy at 95% Confidence Level	0.98 ft.	29.79 cm

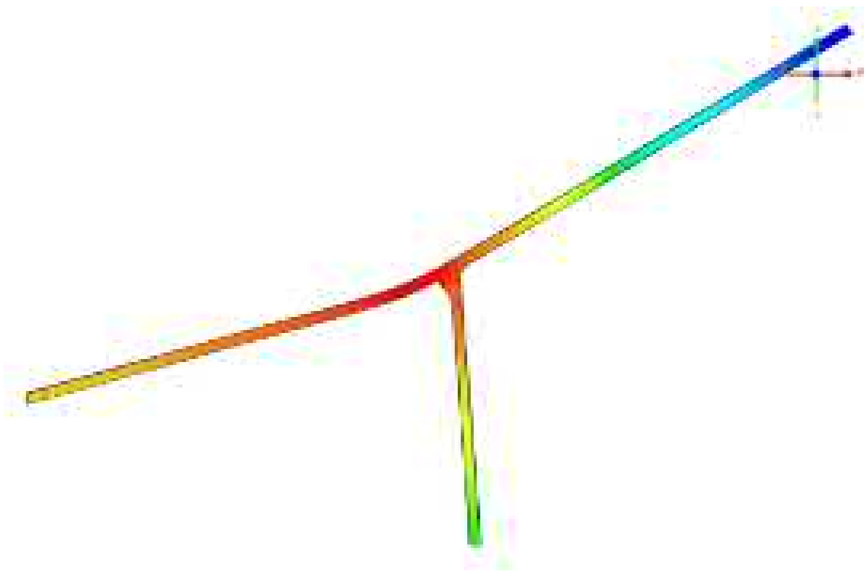
Aerial LiDAR Data




Hybrid Approach to Project Data
Data Preparation

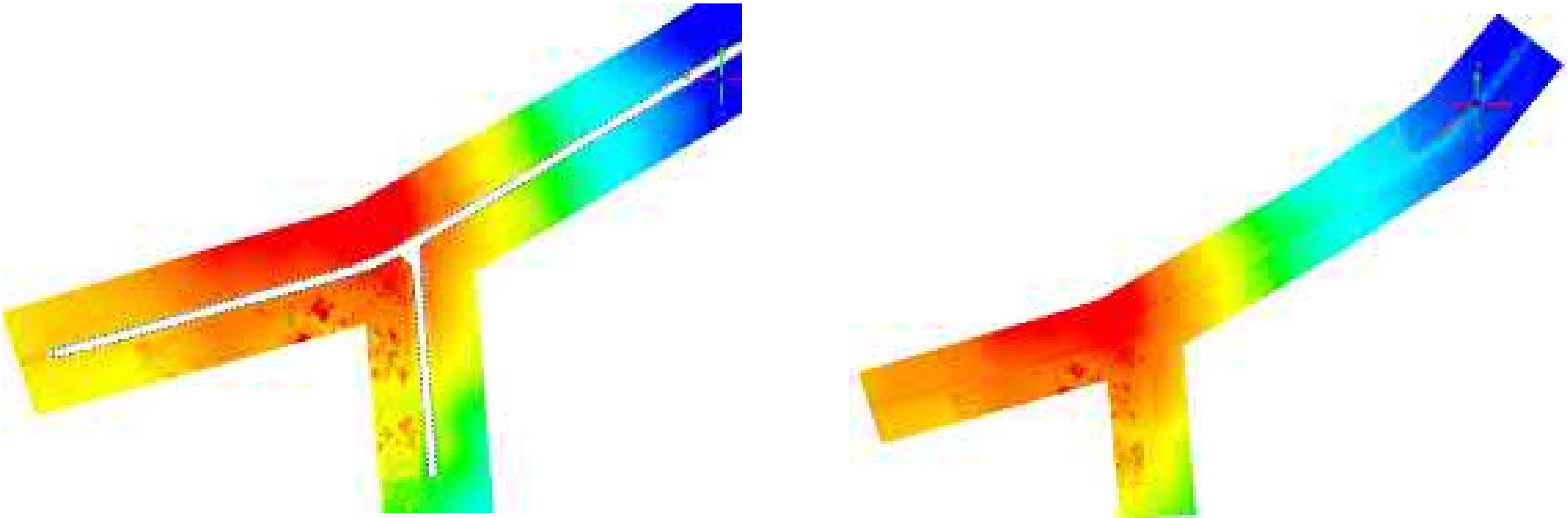
STEP 1: Preparing MMS Data

Only good around driven roads



MMS Data

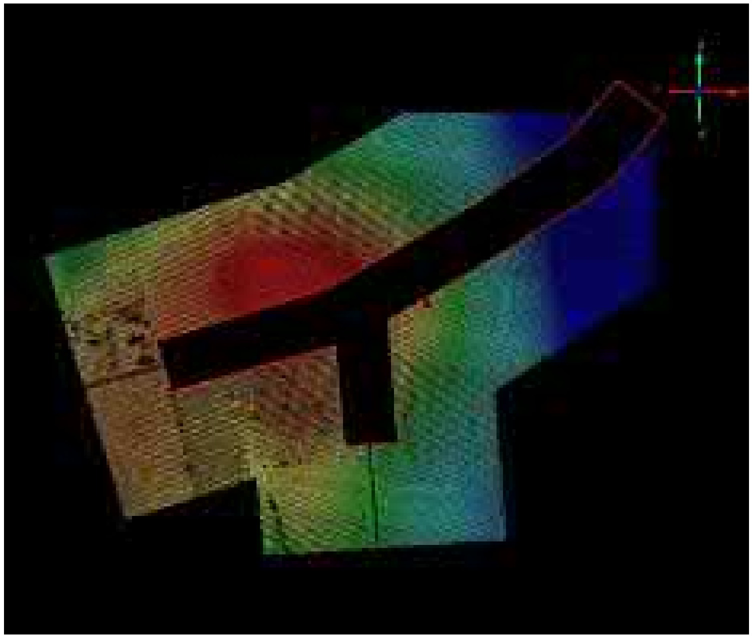
STEP 2: Preparing UAS Data

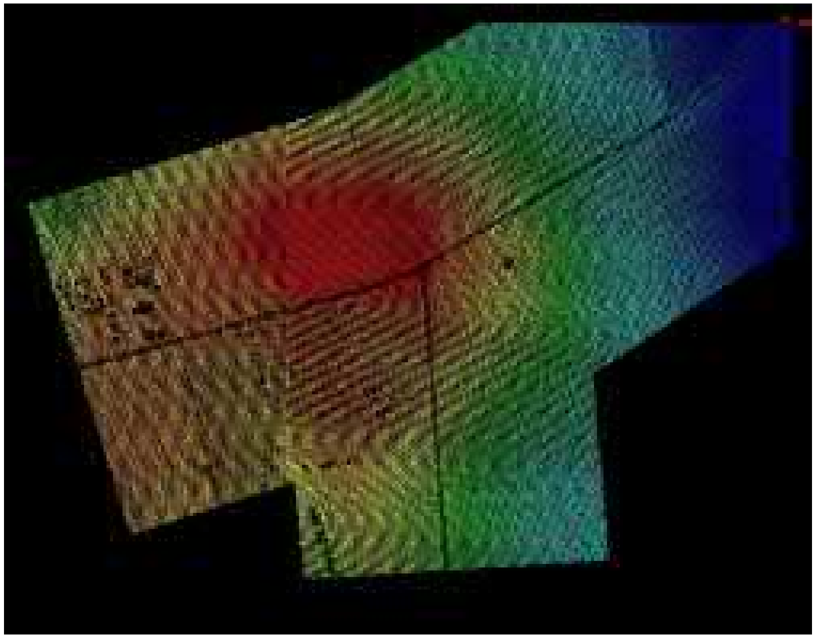


Drone-based DSM

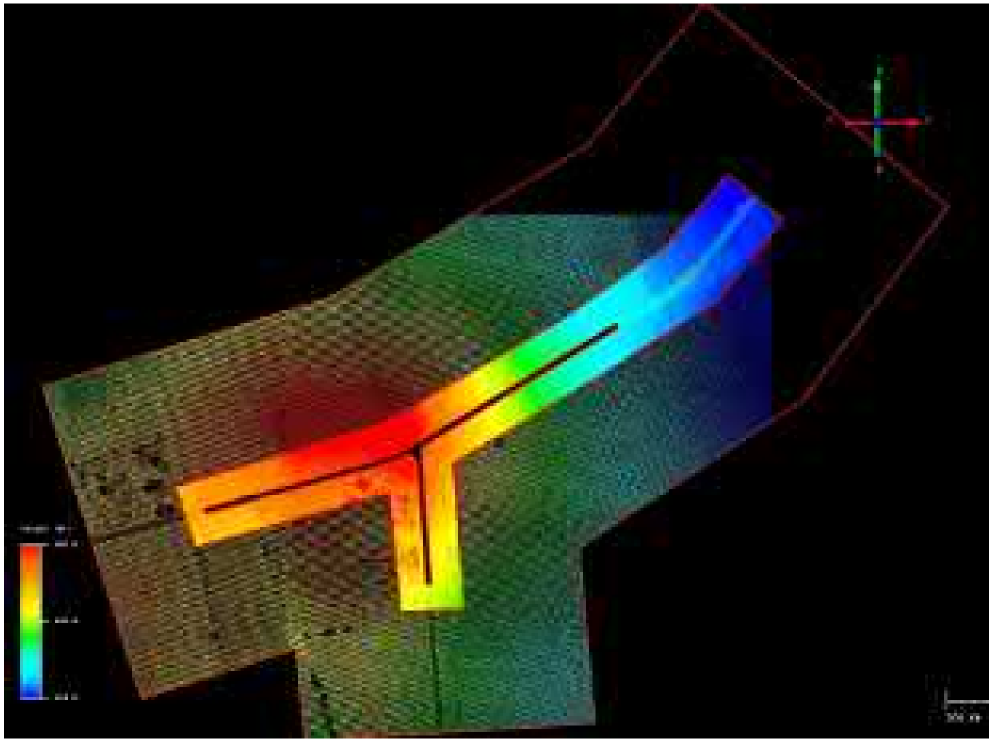
STEP 3: Preparing Aerial Lidar Data

Aerial LiDAR from OSIP

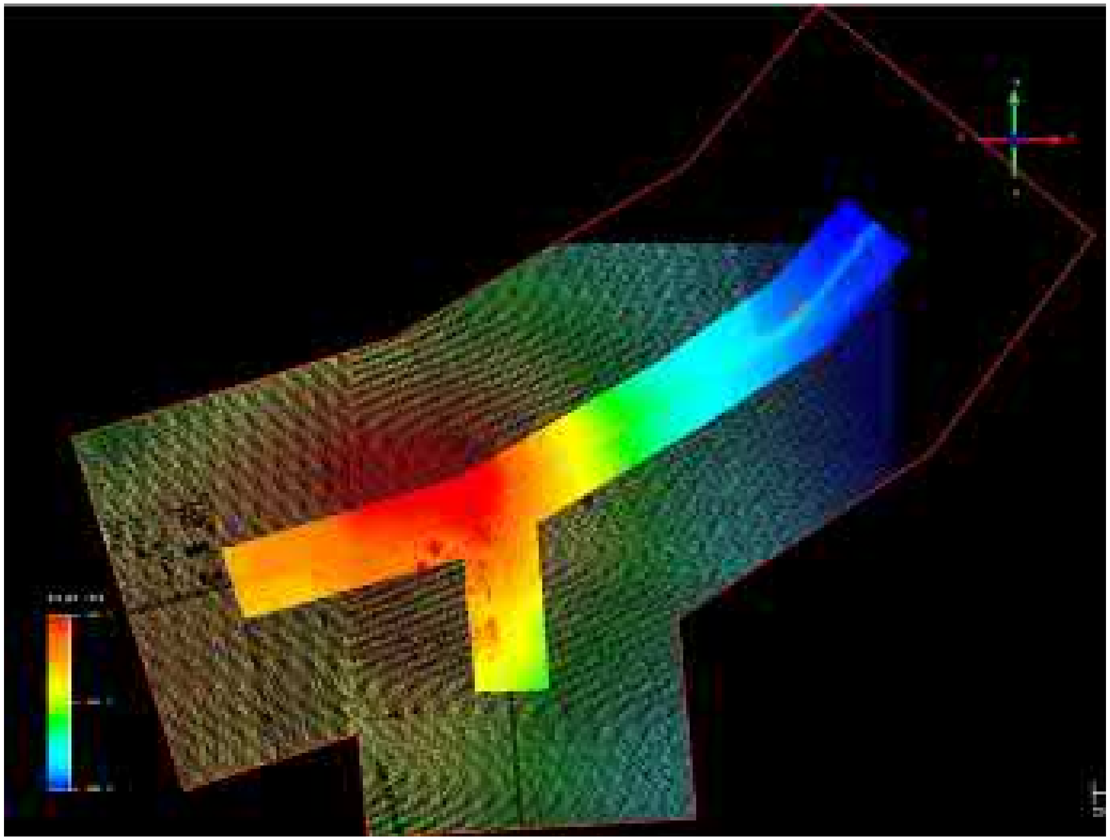


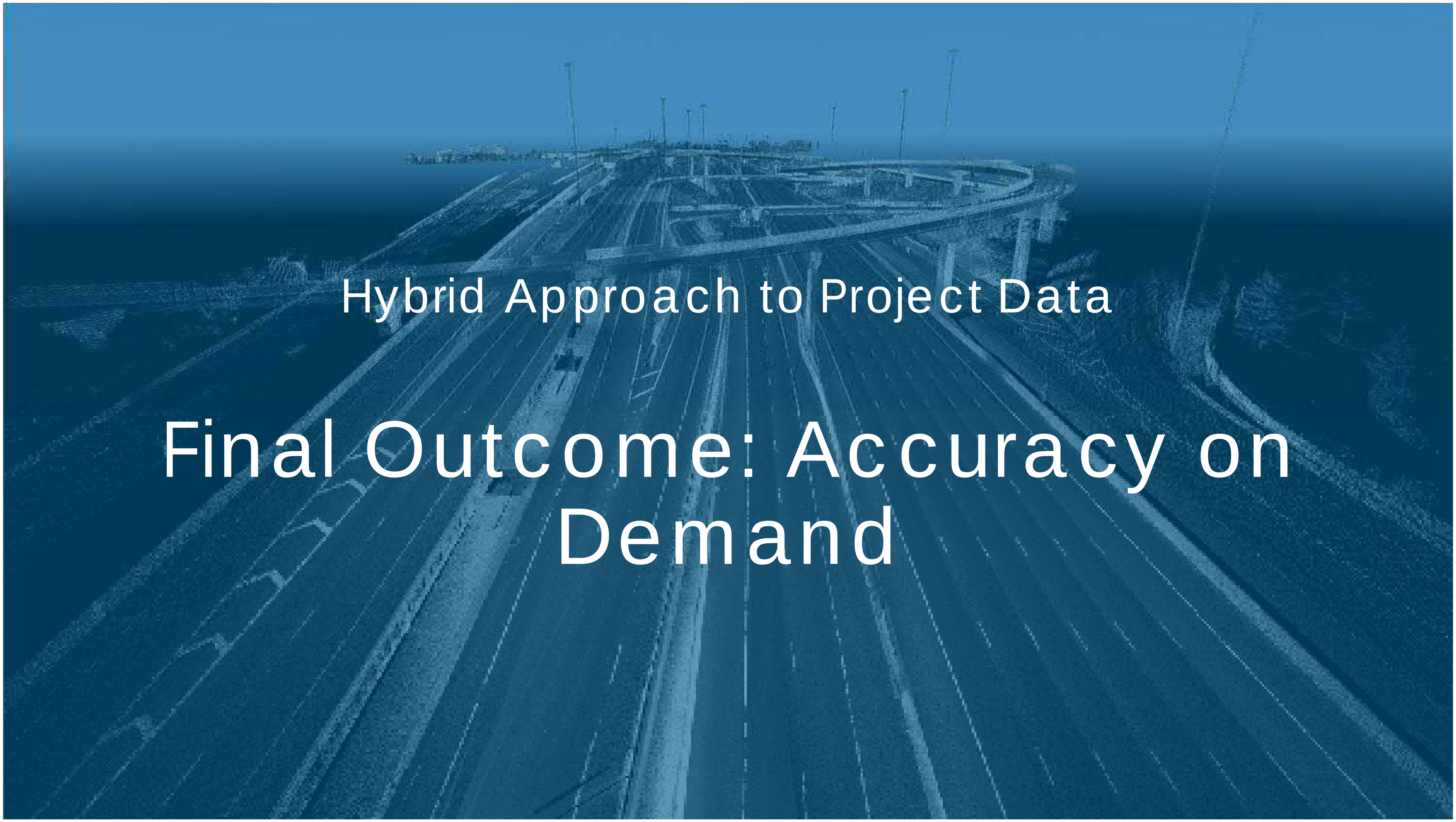


STEP 4: Merging Aerial LiDAR + UAS DSM



STEP 5: Merging Aerial LiDAR + UAS DSM + MMS DSM
(The Hybrid DSM)

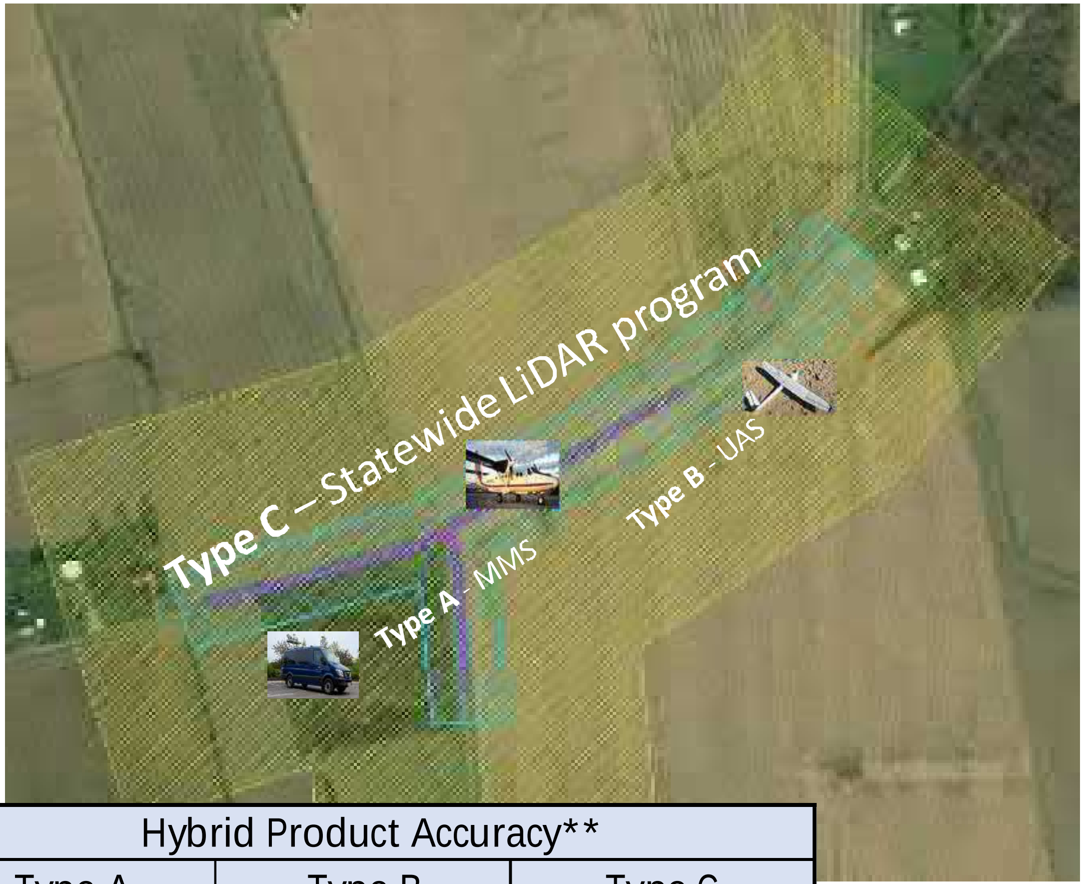




Hybrid Approach to Project Data

Final Outcome: Accuracy on Demand

Data Fusion provides accuracy where you need it most!



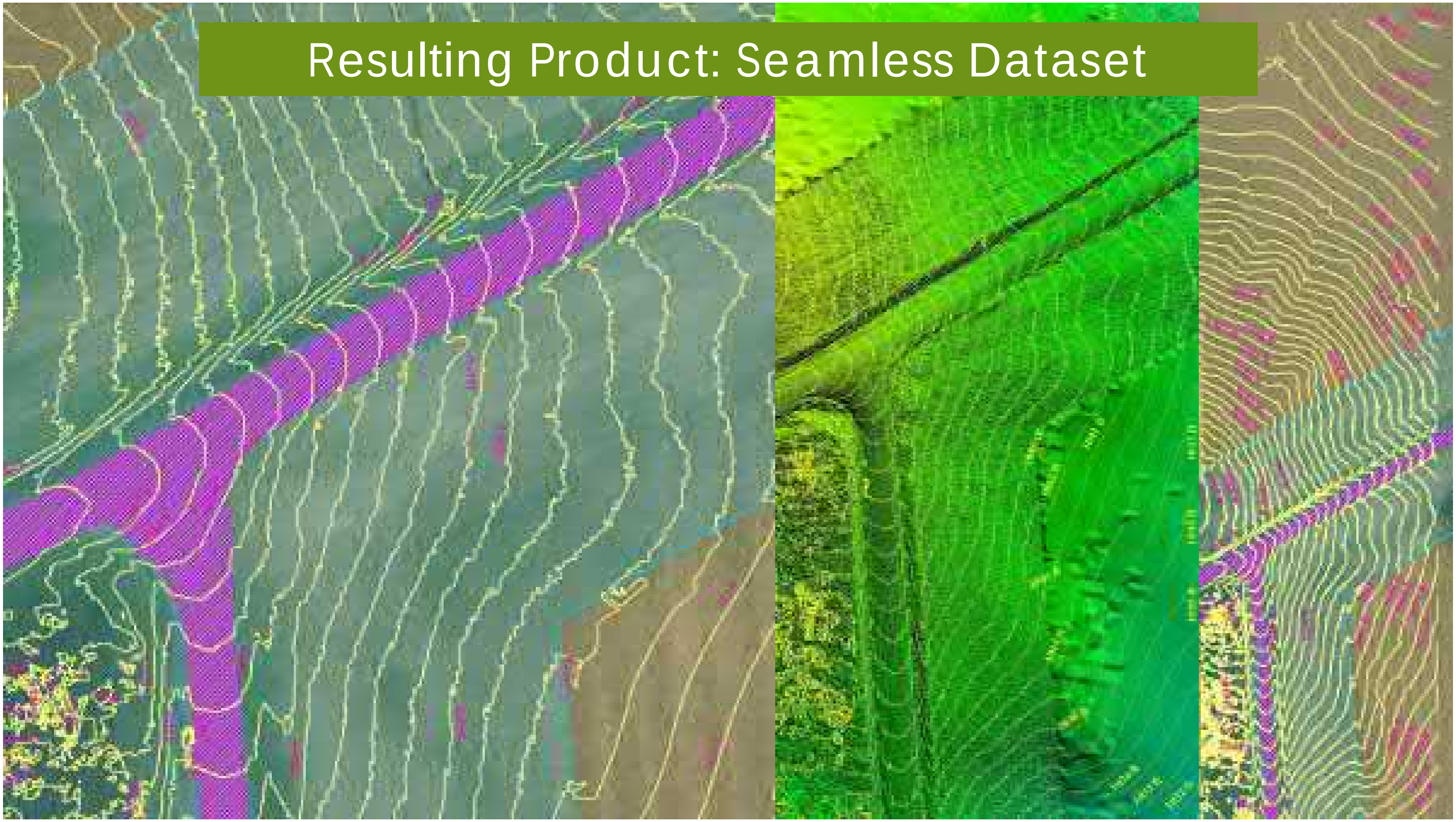
Product Specification	Hybrid Product Accuracy**		
	Type A	Type B	Type C
Terrain surface accuracy as verified using independent check points	$RMSE_v \leq 0.06$ ft.	$RMSE_v \leq 0.10$ ft.	$RMSE_v \leq 0.50$ ft.

** Type A = MMS lidar , Type B = UAS imagery-based points cloud, Type C = State wide lidar program

Hybrid Approach to Project Data

Products Development and Final Deliverables

Resulting Product: Seamless Dataset




Thank you!
WOOLPERT
ARCHITECTURE | ENGINEERING | GEOSPATIAL