



# *Advances in RIEGL's Waveform-LiDAR technology and Waveform-LiDAR products*

*Andreas Ullrich  
RIEGL LMS, CTO*

*PhoWo 2017  
September 11<sup>th</sup>, 2017  
Stuttgart, Germany*



## RIEGL VZ-400i

Ultra High Performance  
3D Terrestrial Laser Scanner



## RIEGL VMX-1HA

High Speed, High Performance  
Dual Scanner Mobile Mapping System



## RICOPTER

Fully integrated UAV-based  
Airborne LiDAR Scanning System



## RIEGL VQ-1560i

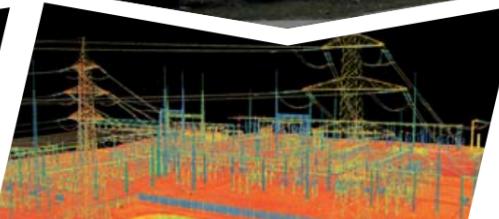
Dual Channel Waveform Processing  
Airborne LiDAR Mapping System



TERRESTRIAL



MOBILE



UAS/UAV



AIRBORNE

RIEGL 2017



RIEGL®

2017



LASER SCANNERS for TLS



LiDAR SYSTEMS  
for MLS



LiDAR ENGINES for ALS & MLS



LiDAR ENGINES &  
SYSTEMS for ULS



LiDAR SYSTEMS  
for ALS & BLS



LASER SCANNERS  
for ILS

# CORE Technologies

PURE DIGITAL LiDAR  
SIGNAL PROCESSING

CALIBRATED  
AMPLITUDES &  
REFLECTANCE  
ESTIMATES

OPTIMUM DISTRIBUTION  
OF MEASUREMENTS

UNIQUE APPROACH  
FOR RESOLVING  
AMBIGUITIES IN  
RANGING

SEAMLESS  
INTEGRATION  
AND  
CALIBRATION



# CORE Technologies

**PURE DIGITAL LiDAR  
SIGNAL PROCESSING**

CALIBRATED  
AMPLITUDES &  
REFLECTANCE  
ESTIMATES

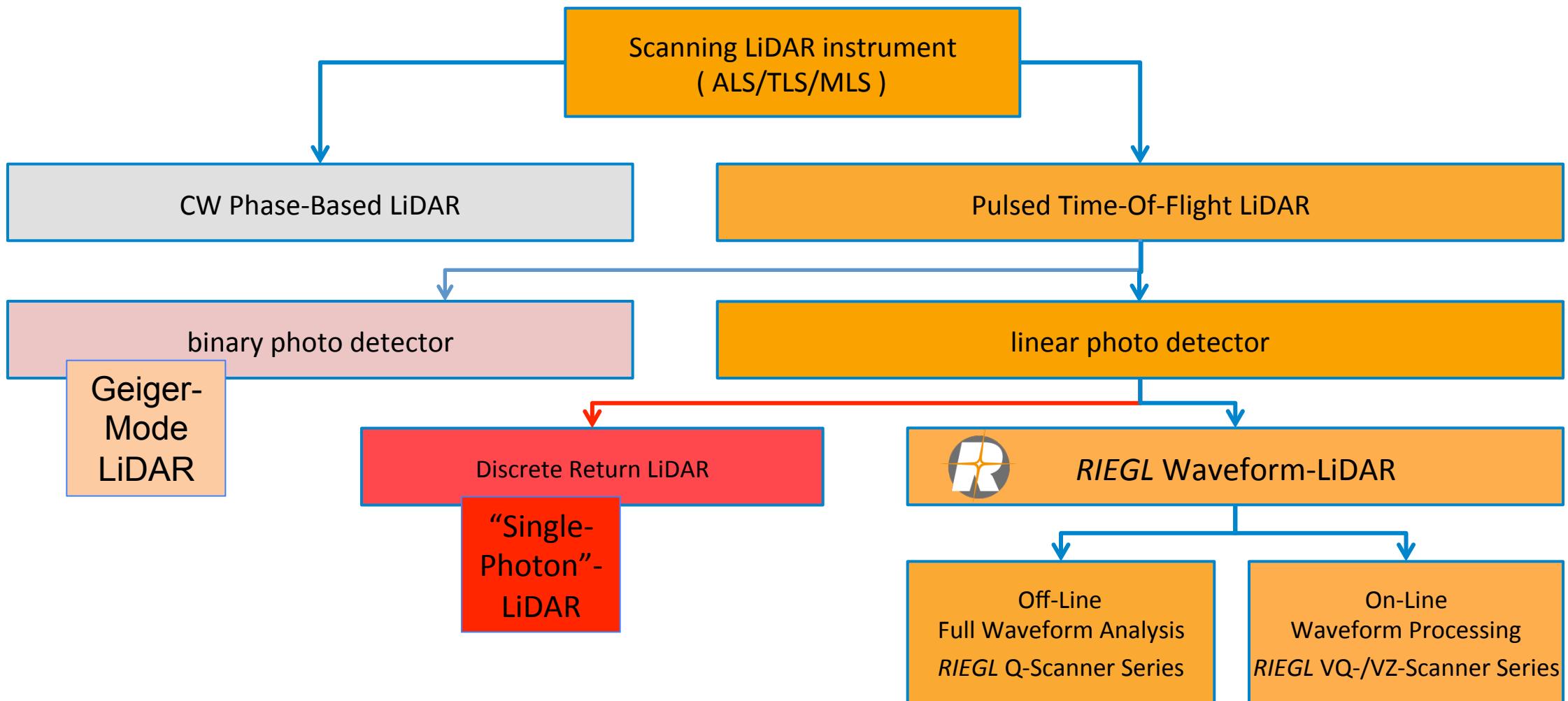
OPTIMUM DISTRIBUTION  
OF MEASUREMENTS

UNIQUE APPROACH  
FOR RESOLVING  
AMBIGUITIES IN  
RANGING

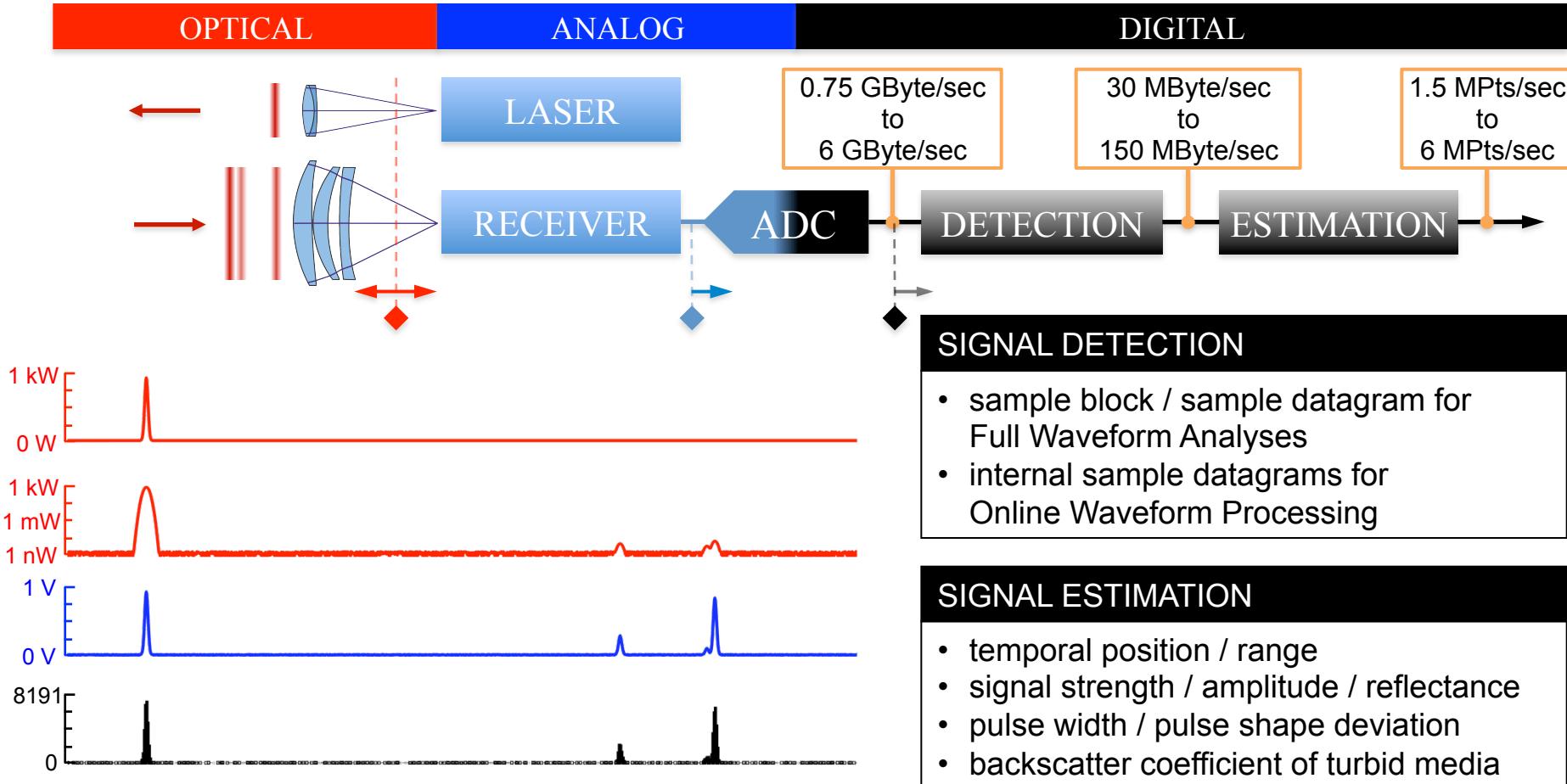
SEAMLESS  
INTEGRATION  
AND  
CALIBRATION



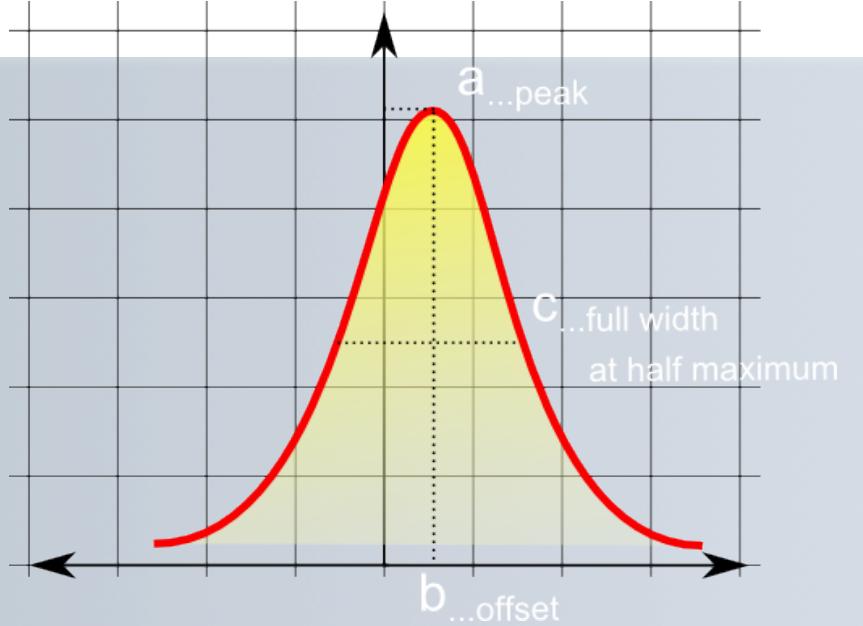
## Waveform LiDAR



# Waveform LiDAR



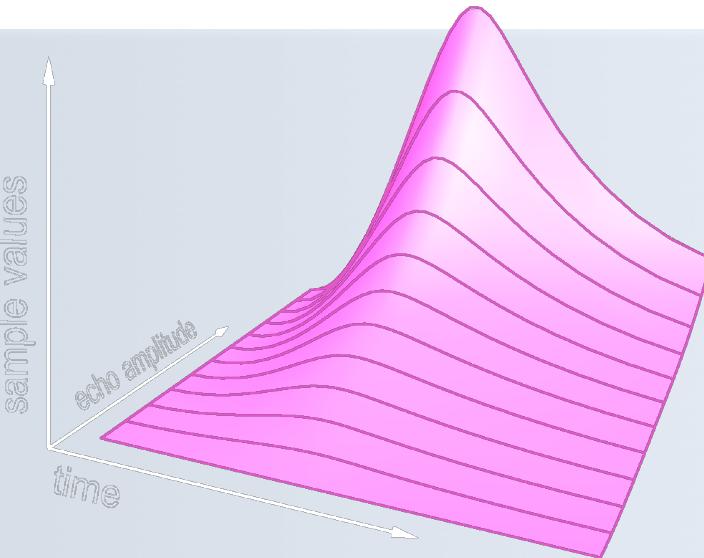
## Waveform LiDAR



### Full Waveform Analysis

#### Gaussian decomposition

- pulse width attribute
- post-processing
- robust and fast



### Online Waveform Processing

#### System response fitting

- pulse shape deviation
- real-time processing
- up to 6 million echoes/sec



# Waveform LiDAR

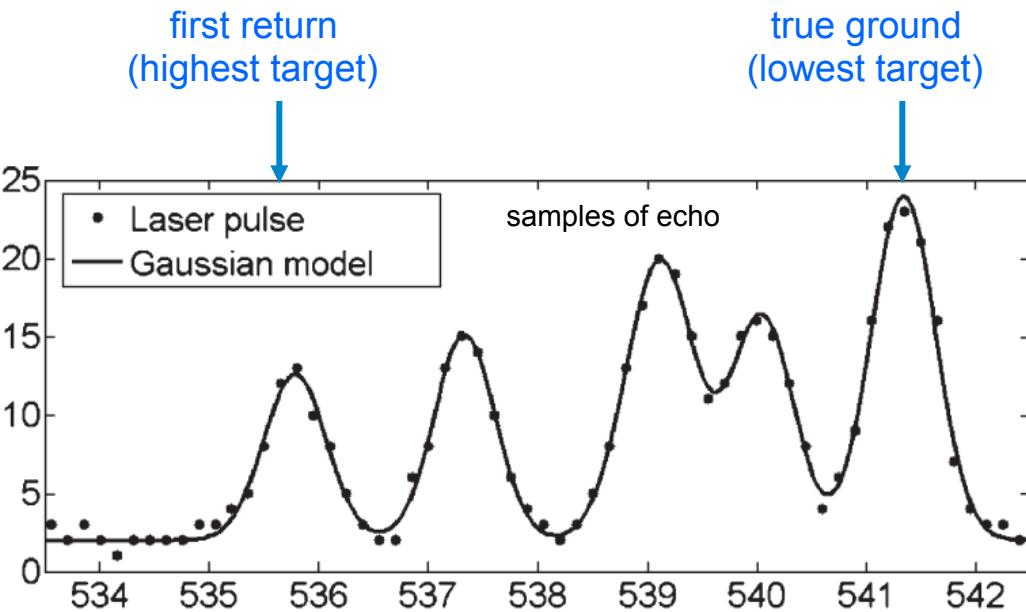
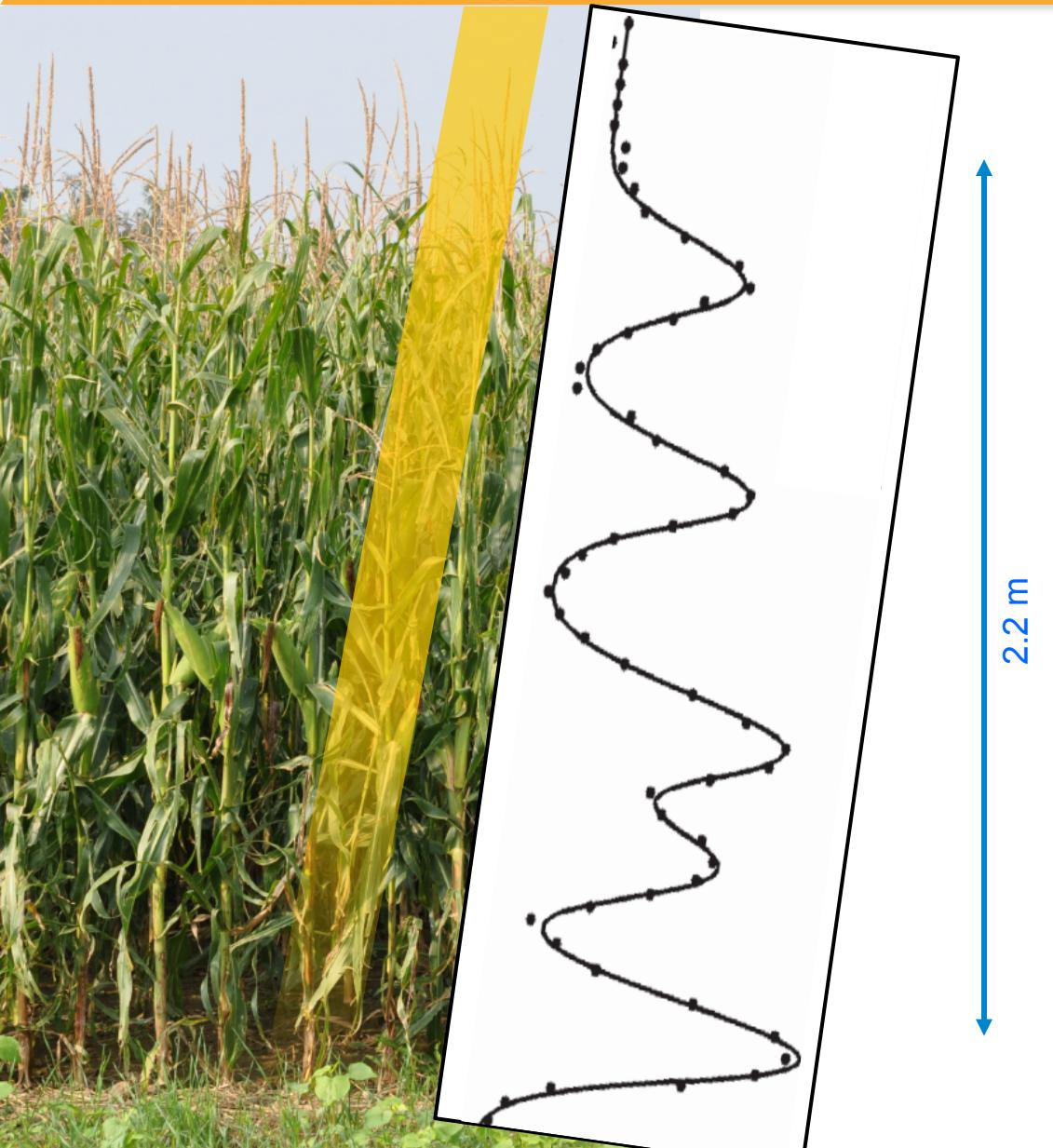


**RIEGL®**



- precision 10 mm typ
- relative accuracy 15 mm typ
- absolute accuracy 25 mm typ
- spatial resolution 15 cm typically (AGL 600 m)

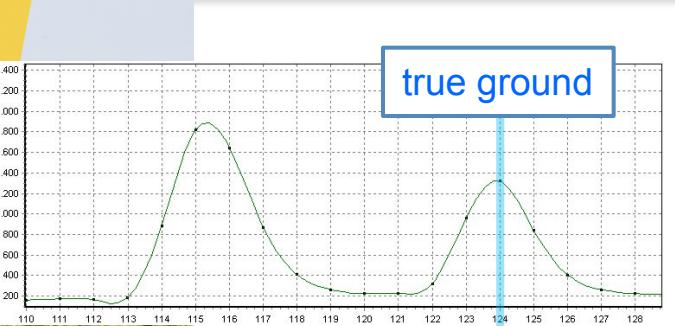
## Waveform LiDAR



### Gaussian decomposition

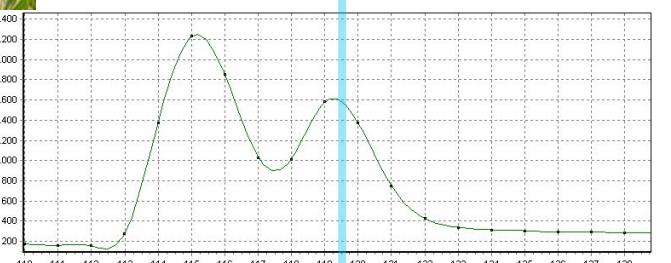
- fits Gaussian system response
- estimates pulse width
- estimates target's depth (width)
- robust and fast
- RIEGL RiANALYZE

## Waveform LiDAR



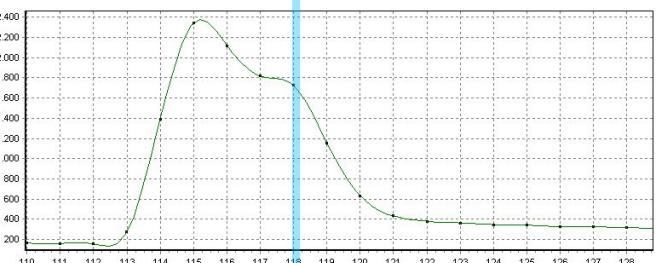
clear separation of target returns

FWA: perfect result  
OWP: perfect result



merging of target returns

FWA: perfect result  
OWP: satisfying result



severe merging of target returns

FWA: nearly perfect result  
OWP: just one target,  
but clear indication of pulse shape deviation

**FWA** .. Full Waveform Analysis

**OWP** .. Online Waveform Processing

## Waveform LiDAR advantages


RIEGL
DIFER

### **RIEGL VQ-1560i**



	Waveform LIDAR	Single Photon LIDAR	Geiger Mode LIDAR	Dense Image Matching
acquisition speed for 8 meas/m <sup>2</sup>	450 km <sup>2</sup> /h	640 km <sup>2</sup> /h	2100 km <sup>2</sup> /h	~ 1000 km <sup>2</sup> /h
day and night operation	YES	~	~	NO
small objects & DTM simultaneously	YES	YES	NO	NO
penetration of dense foliage	YES	YES	NO	NO
radiometric calibration capability	YES	NO	NO	YES
multiple wavelengths	YES	NO	~	YES
real time data	YES	~	NO	NO
accuracy	+	~	~	~



# CORE Technologies

PURE DIGITAL LiDAR  
SIGNAL PROCESSING

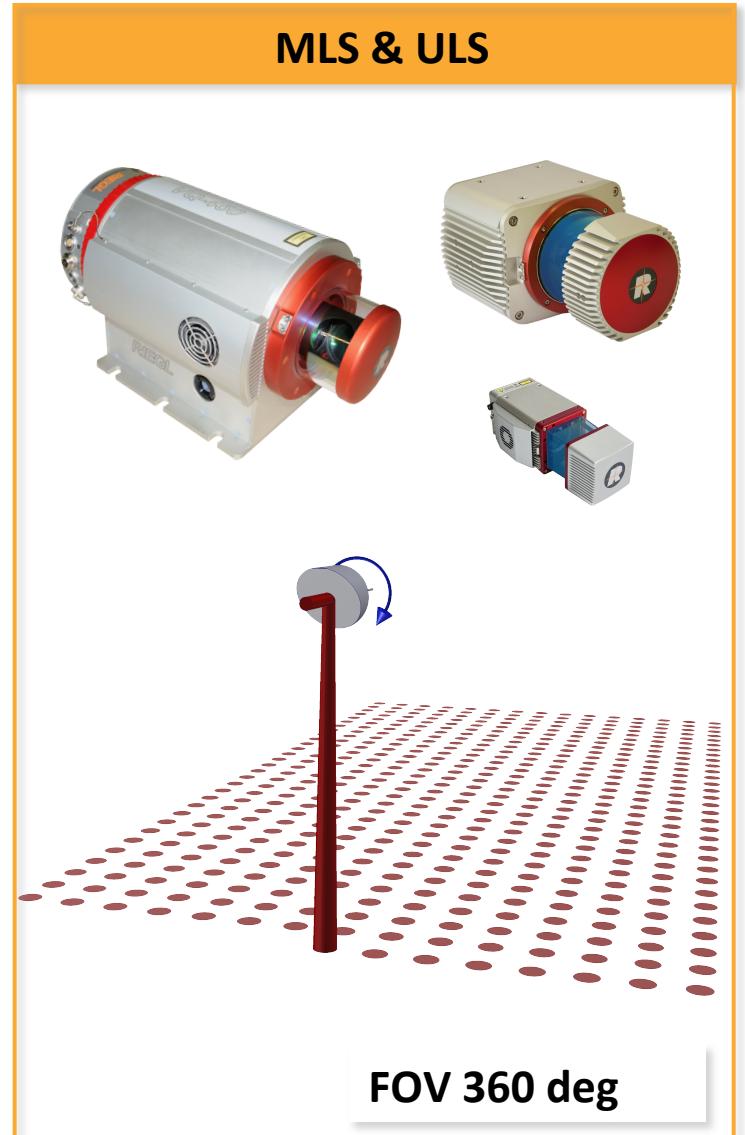
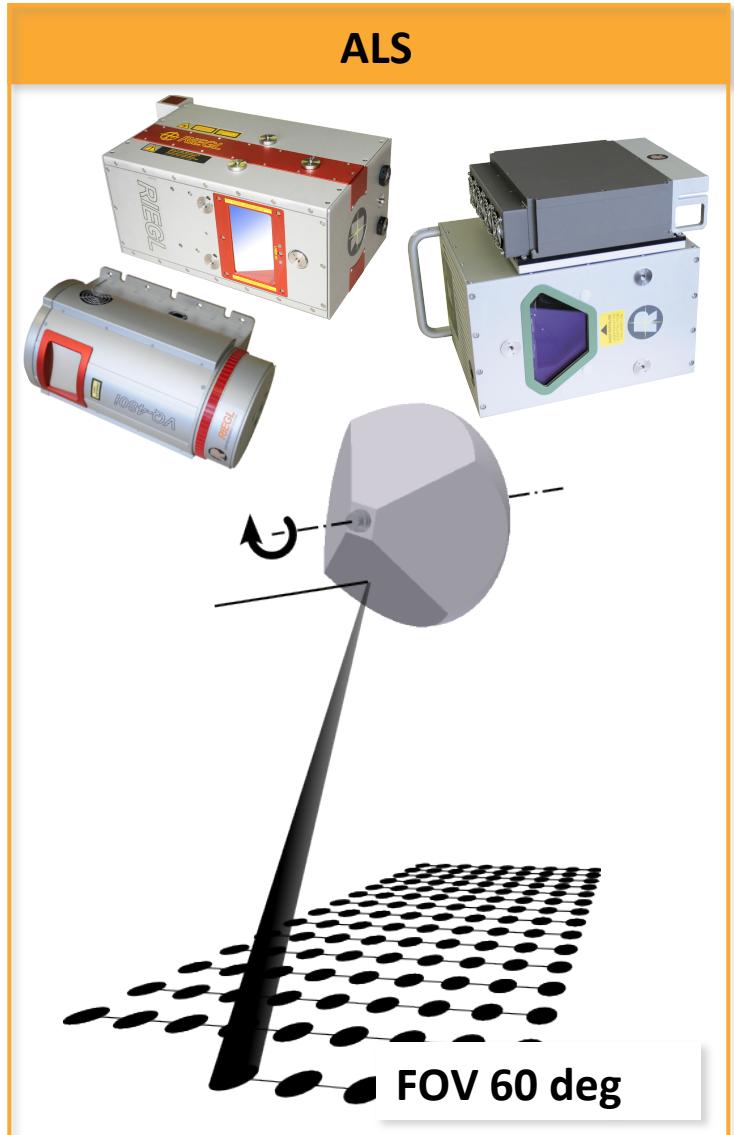
CALIBRATED  
AMPLITUDES &  
REFLECTANCE  
ESTIMATES

**OPTIMUM DISTRIBUTION  
OF MEASUREMENTS**

UNIQUE APPROACH  
FOR RESOLVING  
AMBIGUITIES IN  
RANGING

SEAMLESS  
INTEGRATION  
AND  
CALIBRATION

## Distribution of measurements

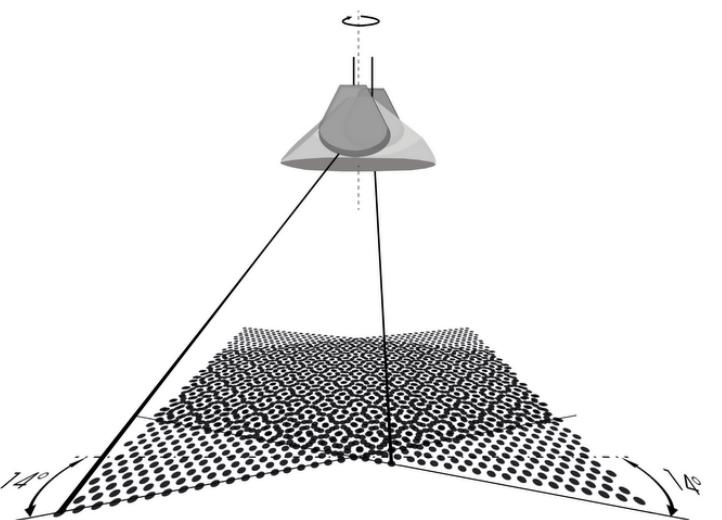


## Distribution of measurements

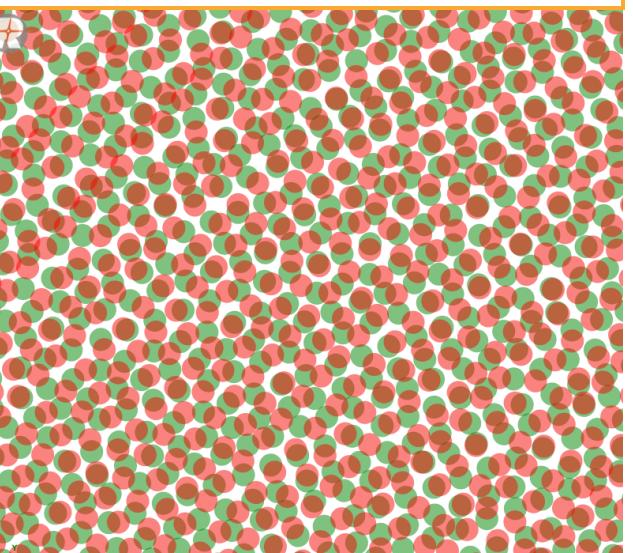


### RIEGL LMS-Q1560

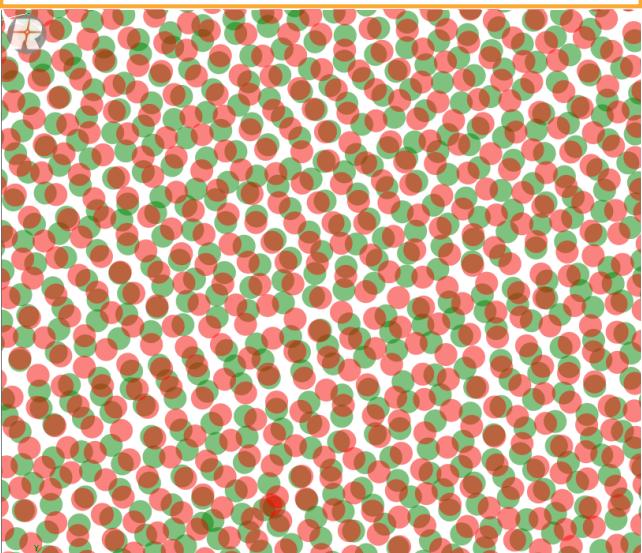
- AGL 2000 m
- speed 100 knots
- PRR 2 x 400 kHz
- levelling no



channel 1 - channel 2



channel 1 - channel 2





# CORE Technologies

PURE DIGITAL LiDAR  
SIGNAL PROCESSING

**CALIBRATED  
AMPLITUDES &  
REFLECTANCE  
ESTIMATES**

OPTIMUM DISTRIBUTION  
OF MEASUREMENTS

UNIQUE APPROACH  
FOR RESOLVING  
AMBIGUITIES IN  
RANGING

SEAMLESS  
INTEGRATION  
AND  
CALIBRATION

## Waveform LiDAR point attributes

Geometry	Native Attributes	External Attributes
Discrete Return point cloud	<p>X, Y, Z</p>  <p>timestamp, intensity return number 1 to 4</p>  <p>colour, classification ...</p>	
Waveform point cloud	<p>X, Y, Z</p>  <p>timestamp, return number 1 to n calibrated amplitude calibrated reflectance pulse width / pulse shape deviation</p>  <p>colour, classification ...</p>	



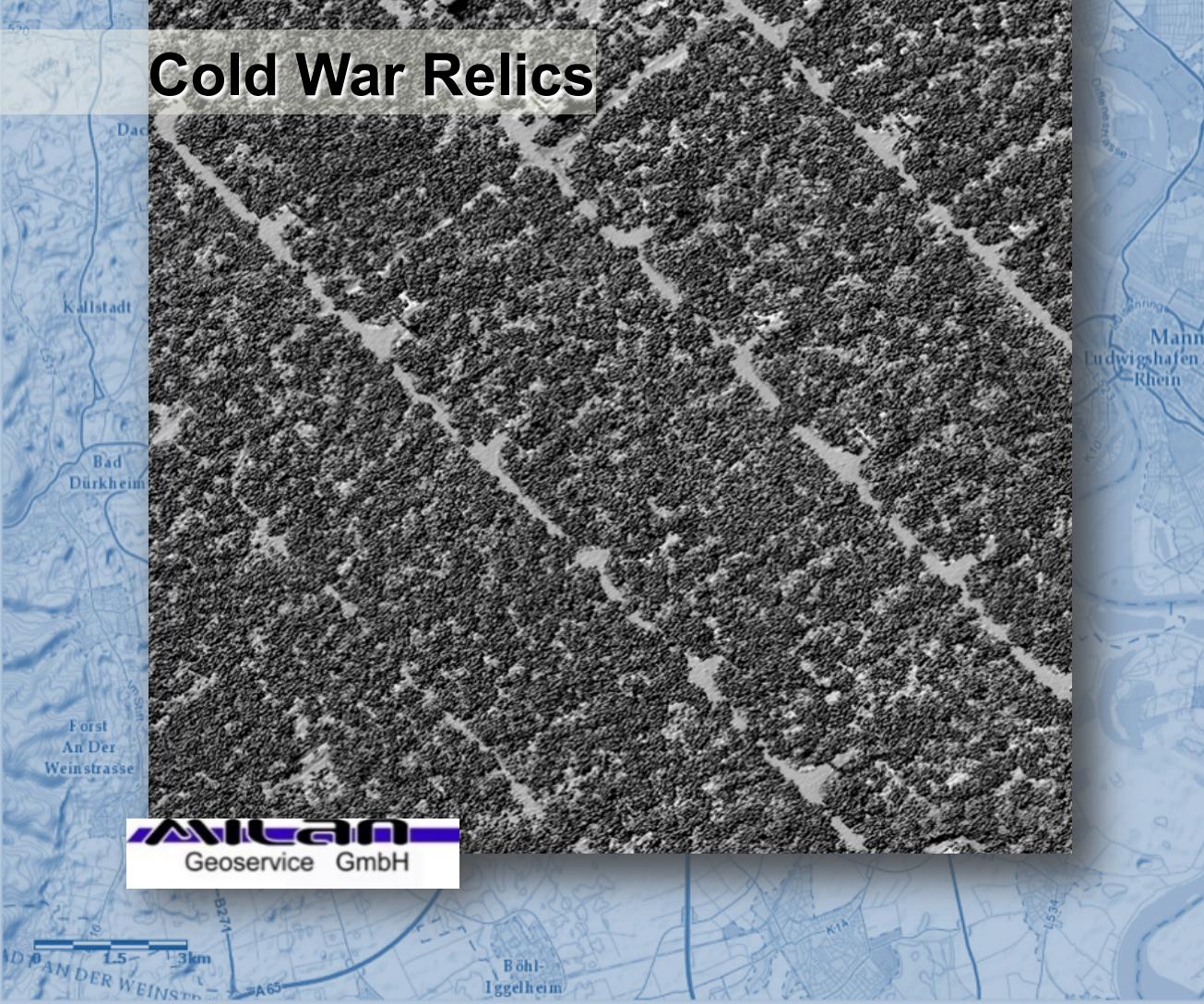
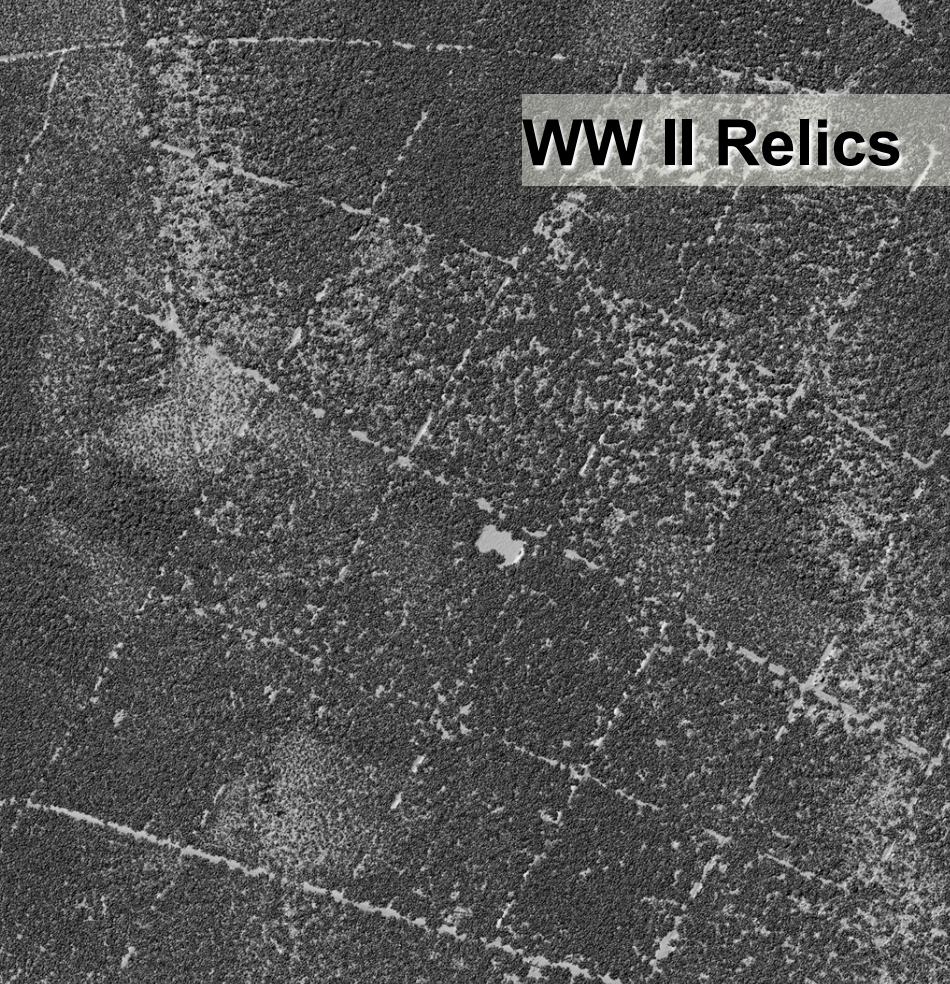
RIEGL

LiDAR

## Waveform LiDAR point attributes

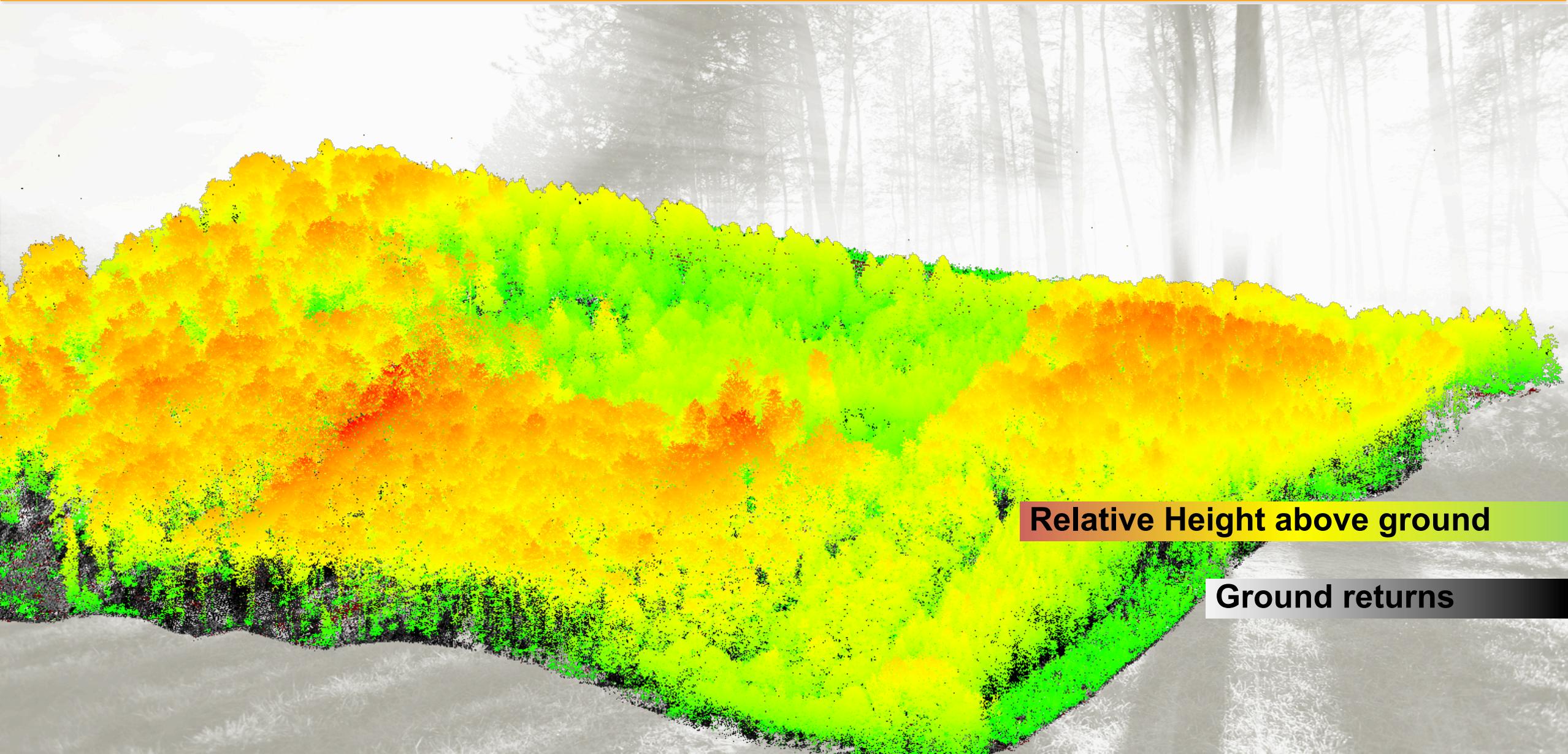


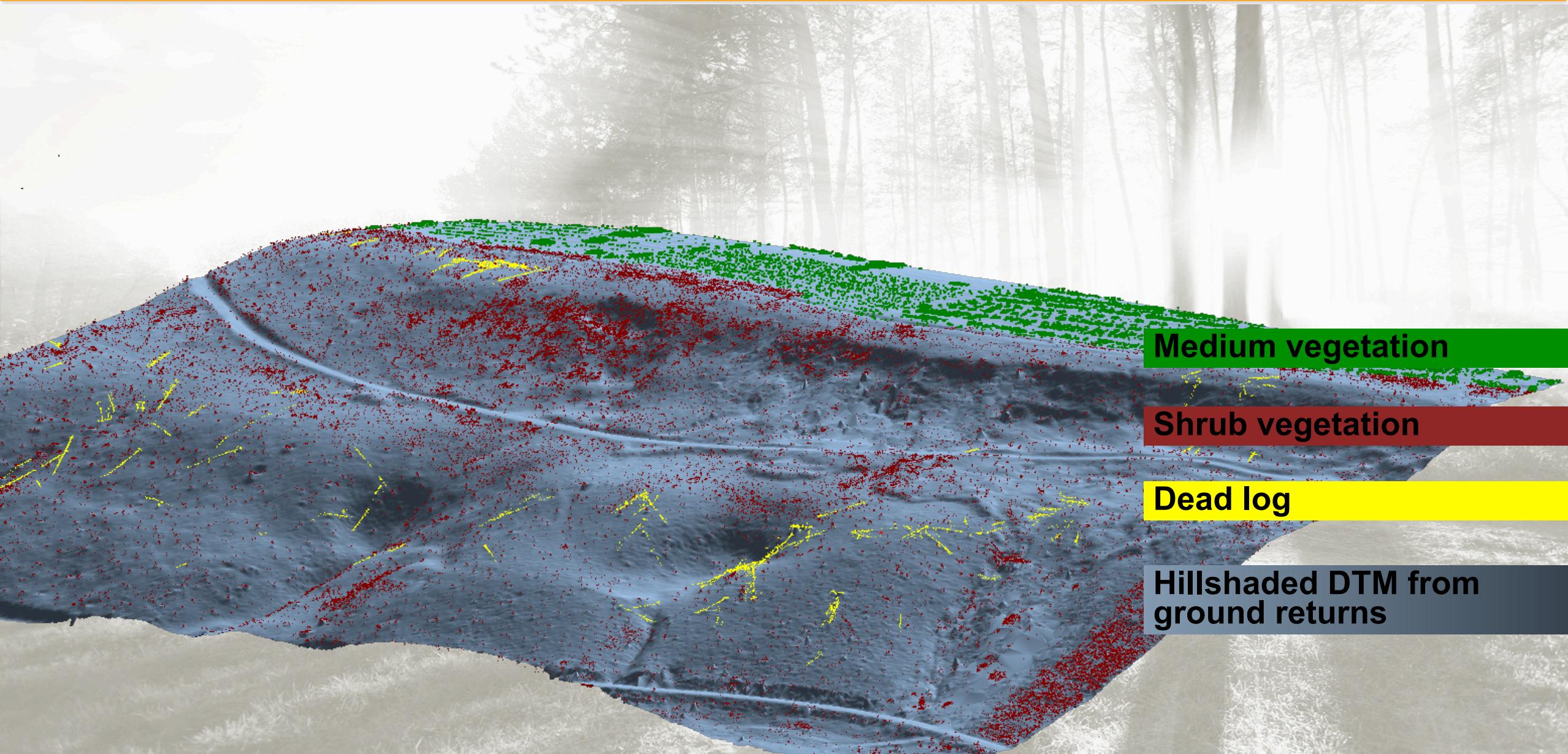
RIEGL

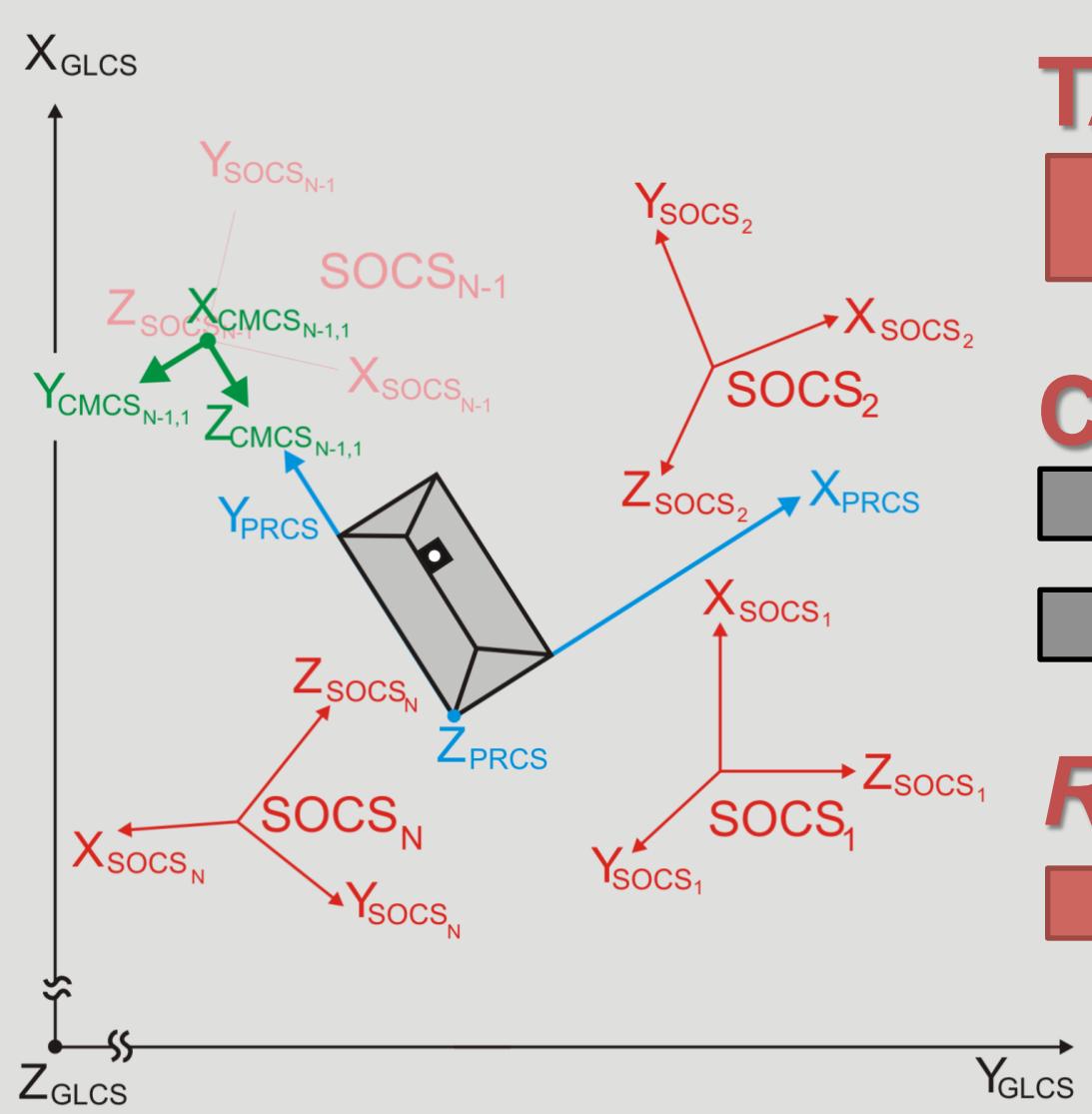


POWERED BY

esri







## TASK:

calculate orientation & position matrix for each scan position

## Conventional approach:

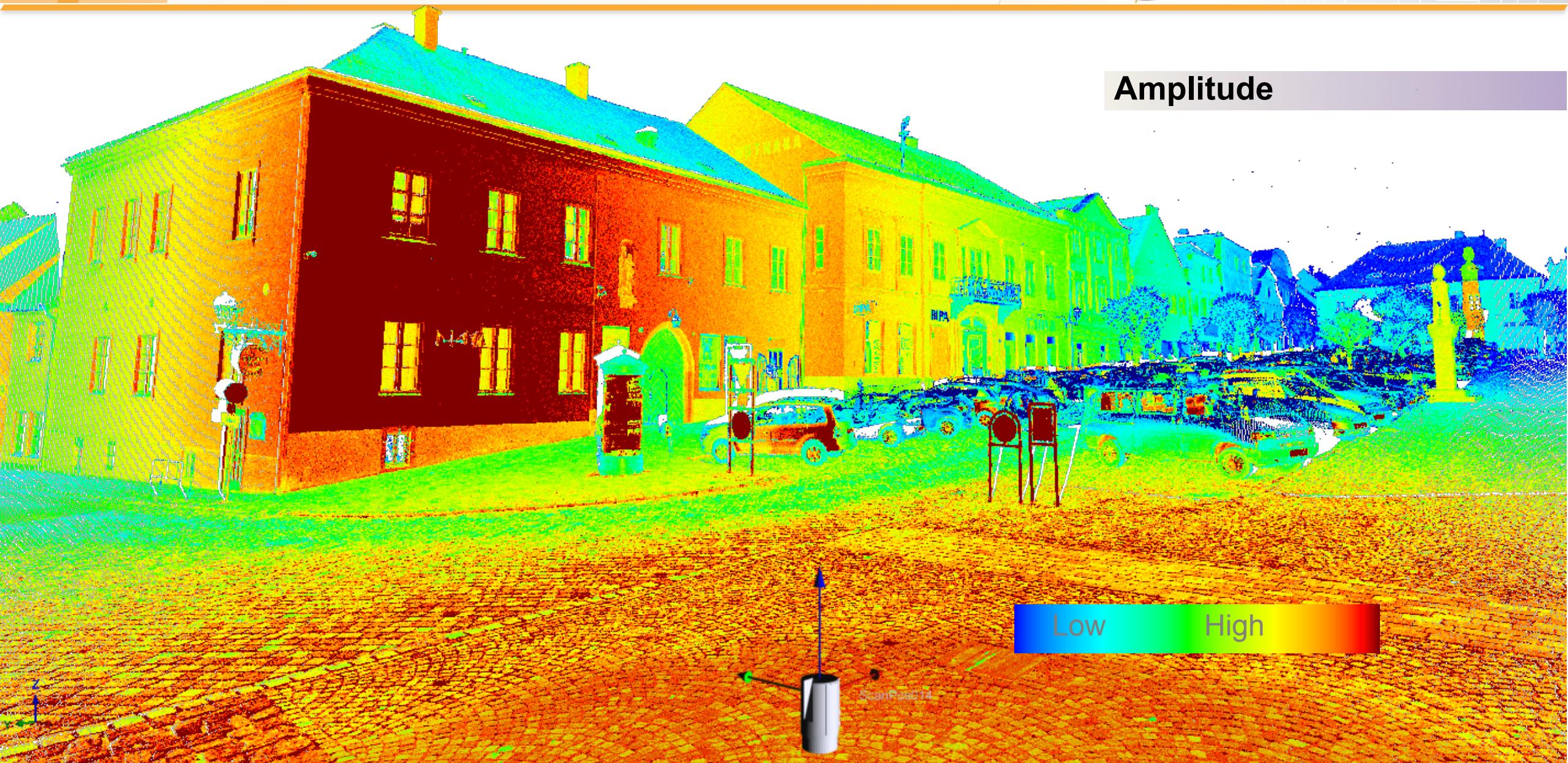
Match tieobjects (markers, cylinders, spheres)

Match pointclouds (ICP algorithms)

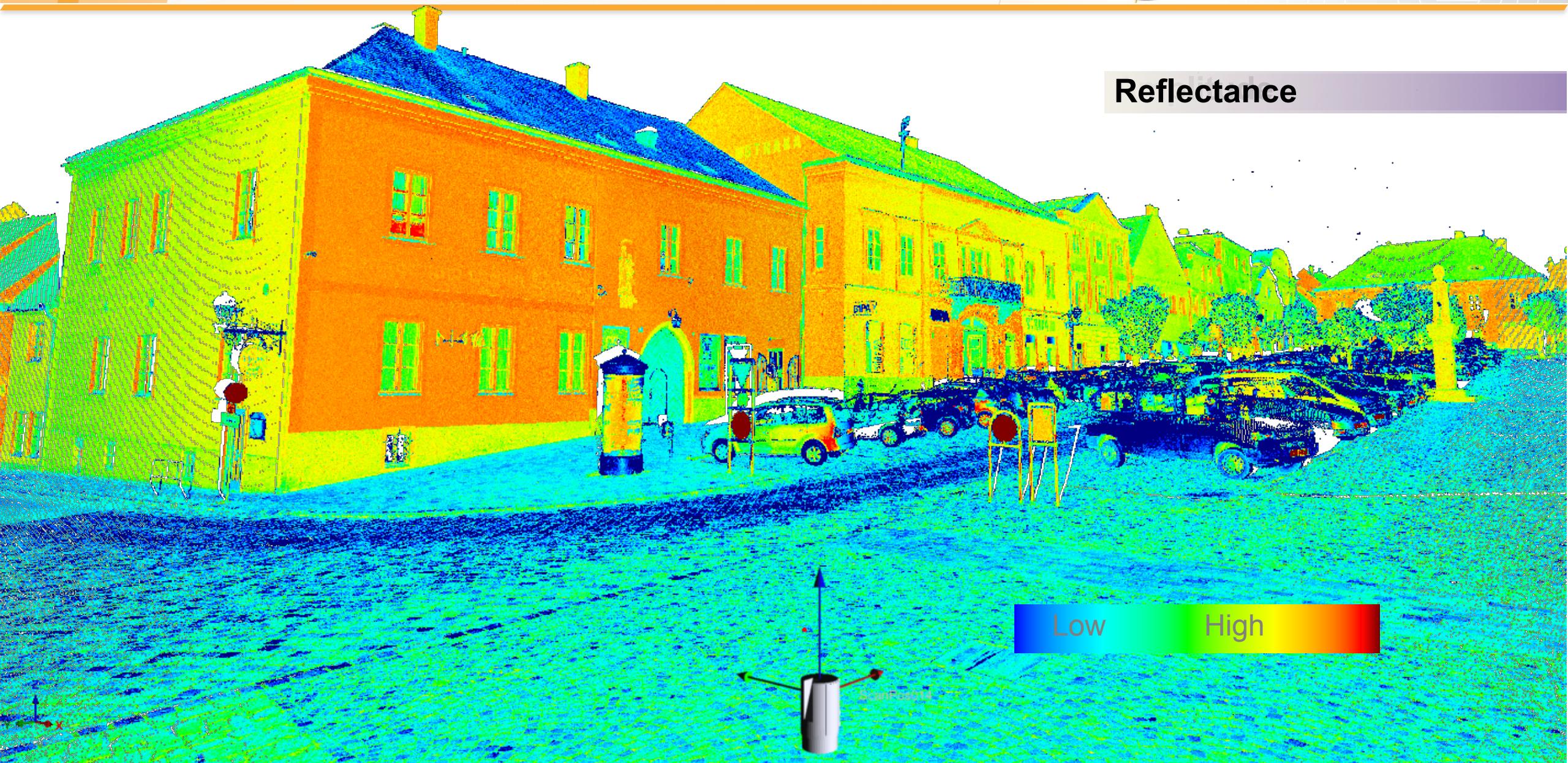
## RIEGL registration 2.0:

Phase-only matched filtering

## Amplitude vs Reflectance



## Amplitude vs Reflectance



## Pointcloud with reflectance encoding

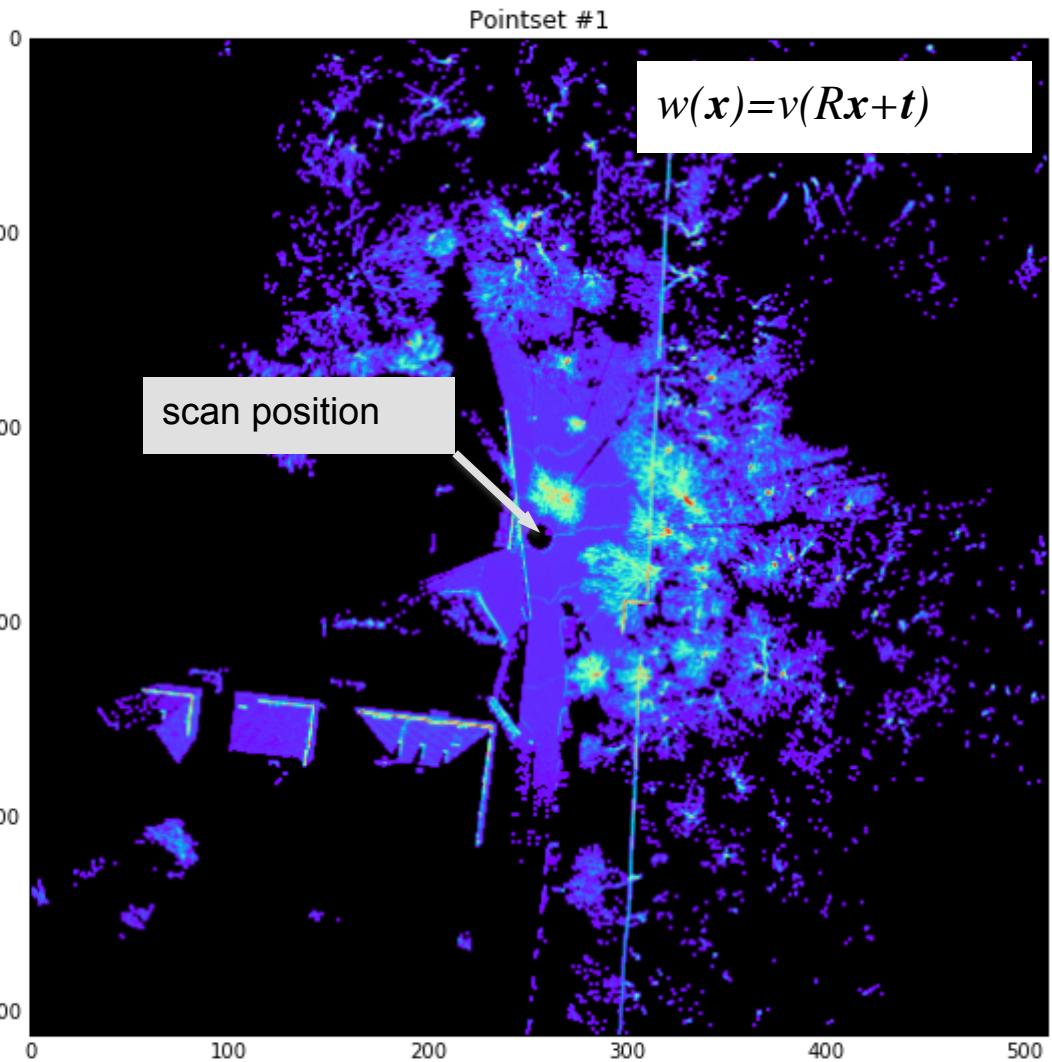
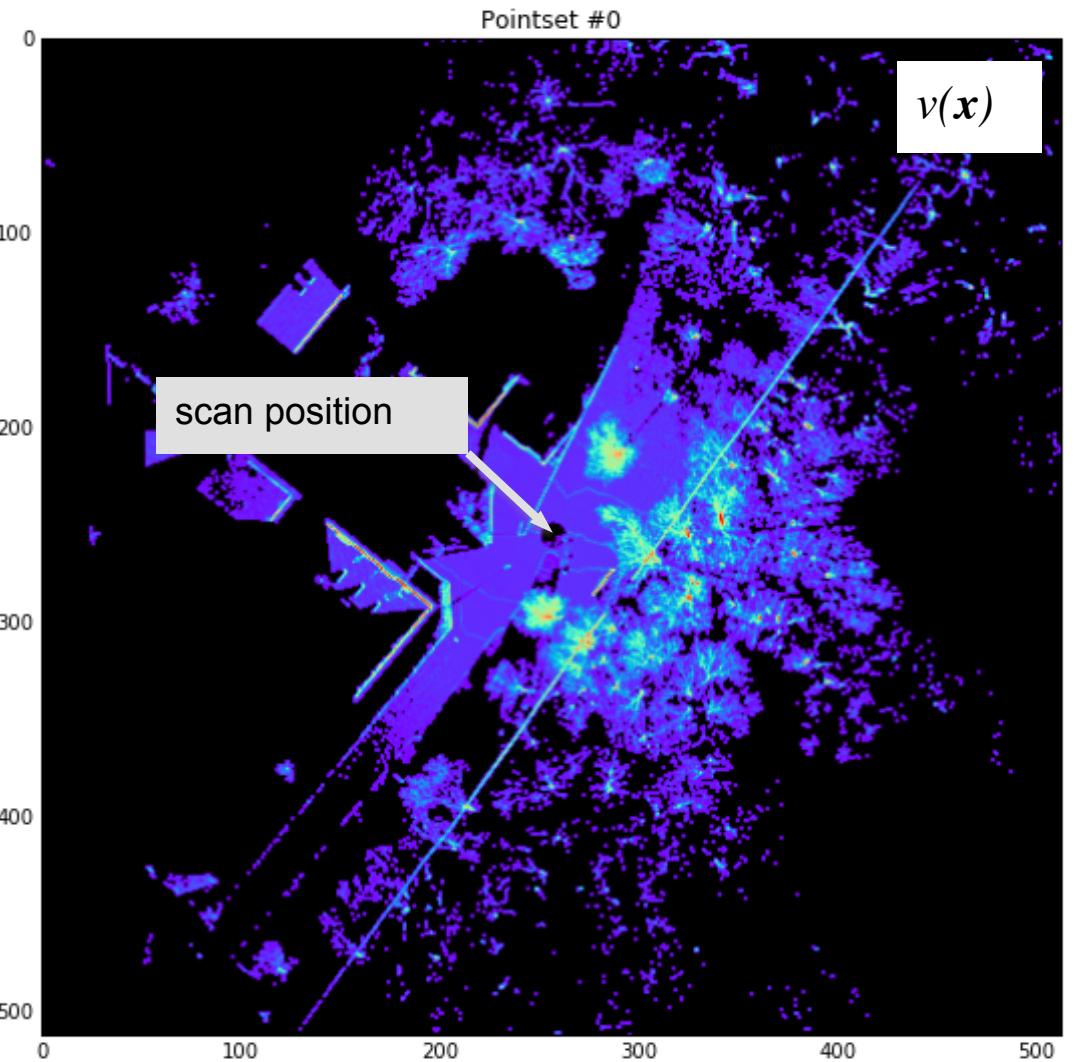


## Voxels with reflectance encoding



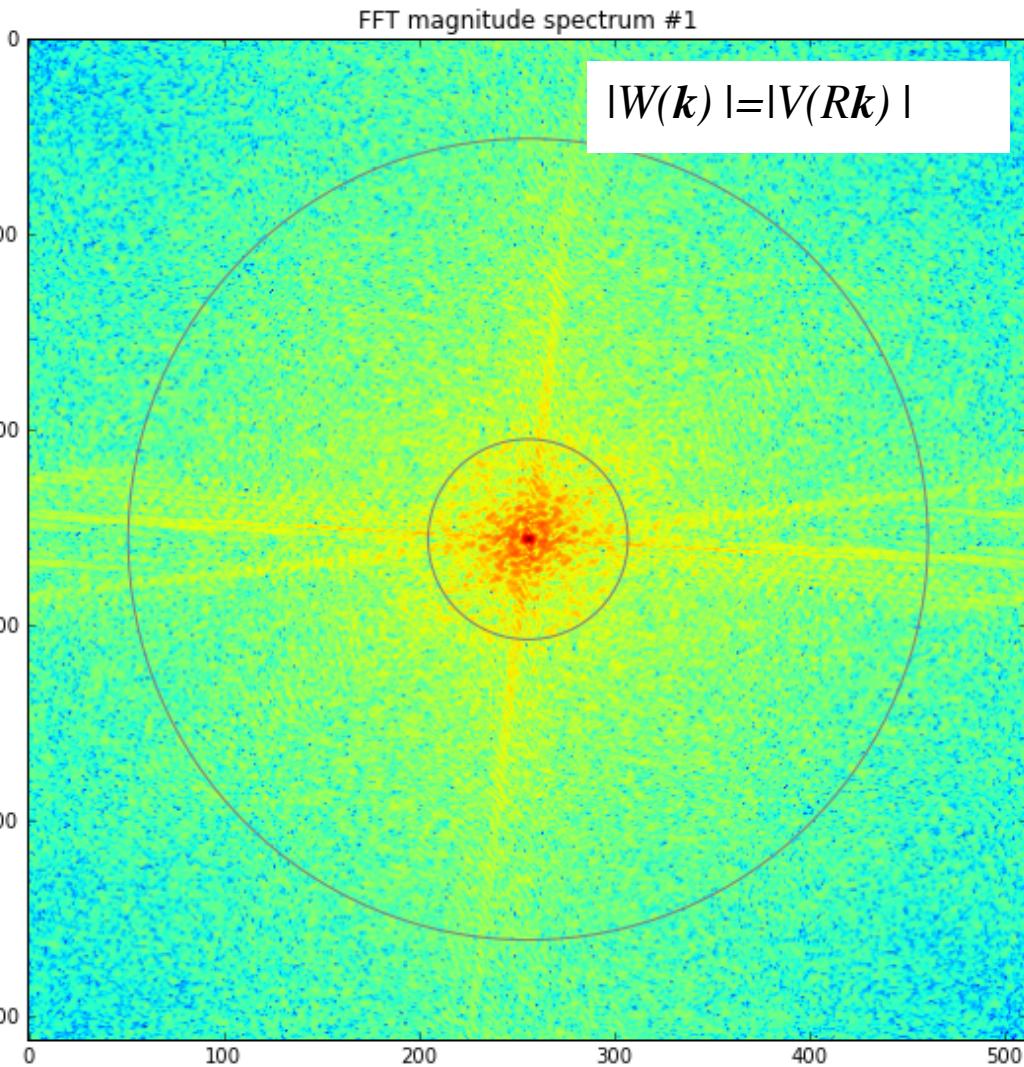
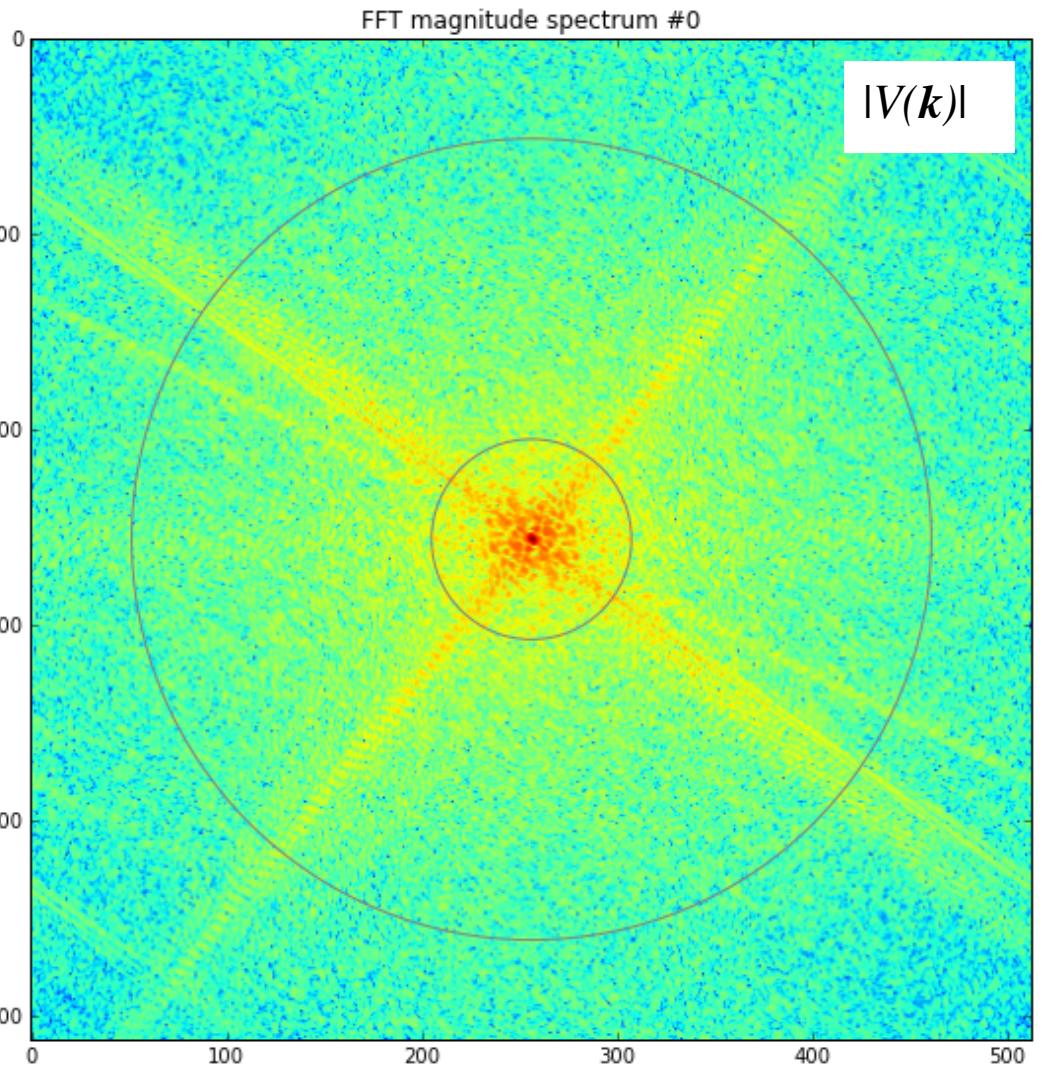


## Voxel data of two scan positions





## Magnitude of spectra

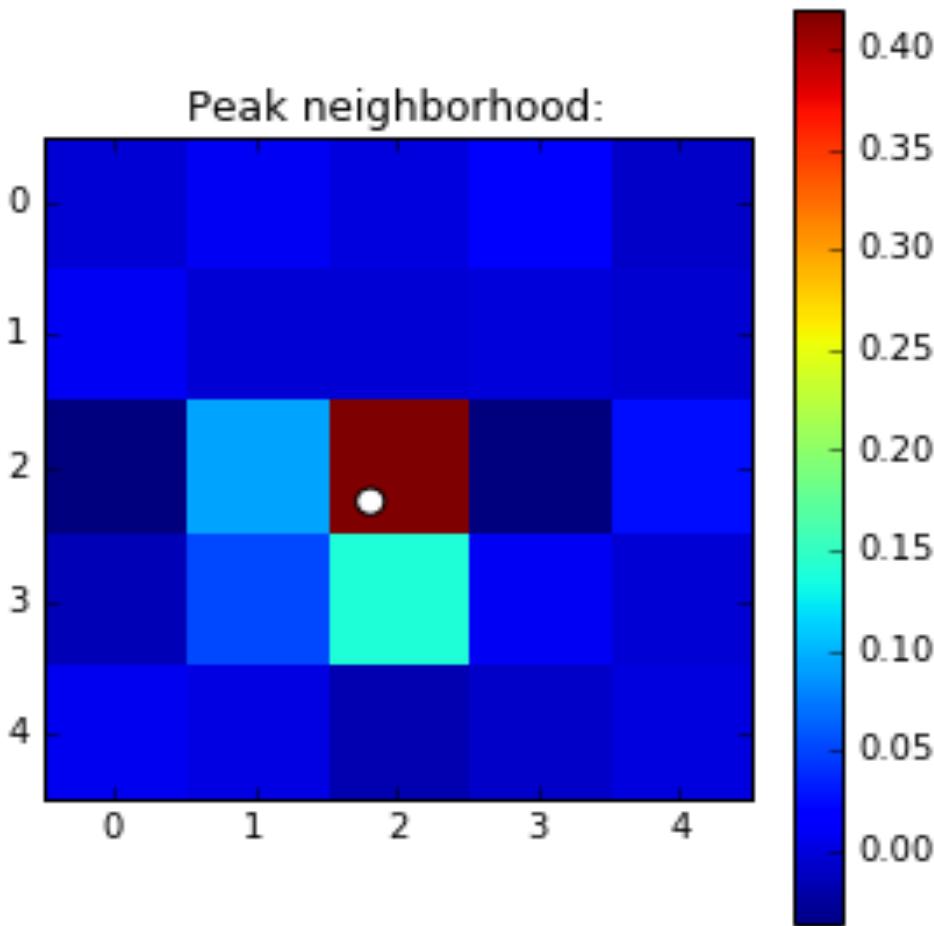
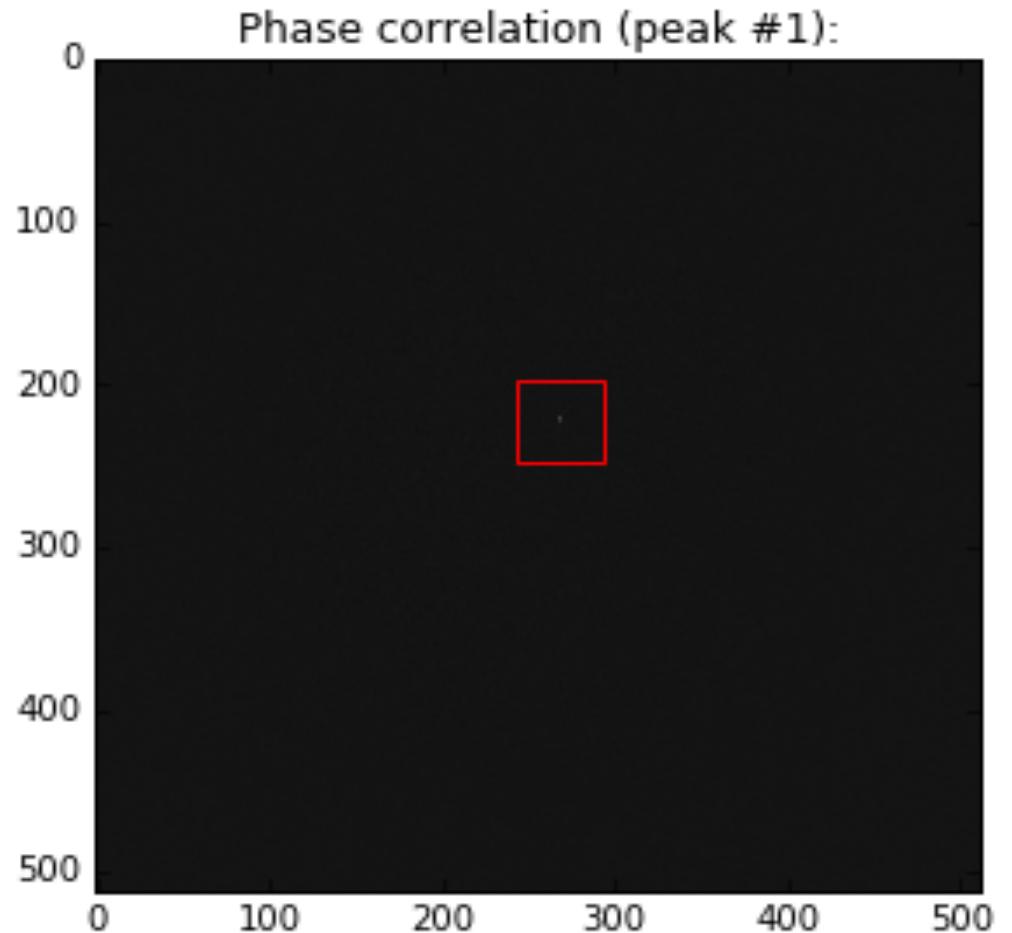




## POMF for estimating translation



$$W(\mathbf{k}) = V(\mathbf{k}) \exp(i2\pi \mathbf{k}^T \mathbf{t})$$





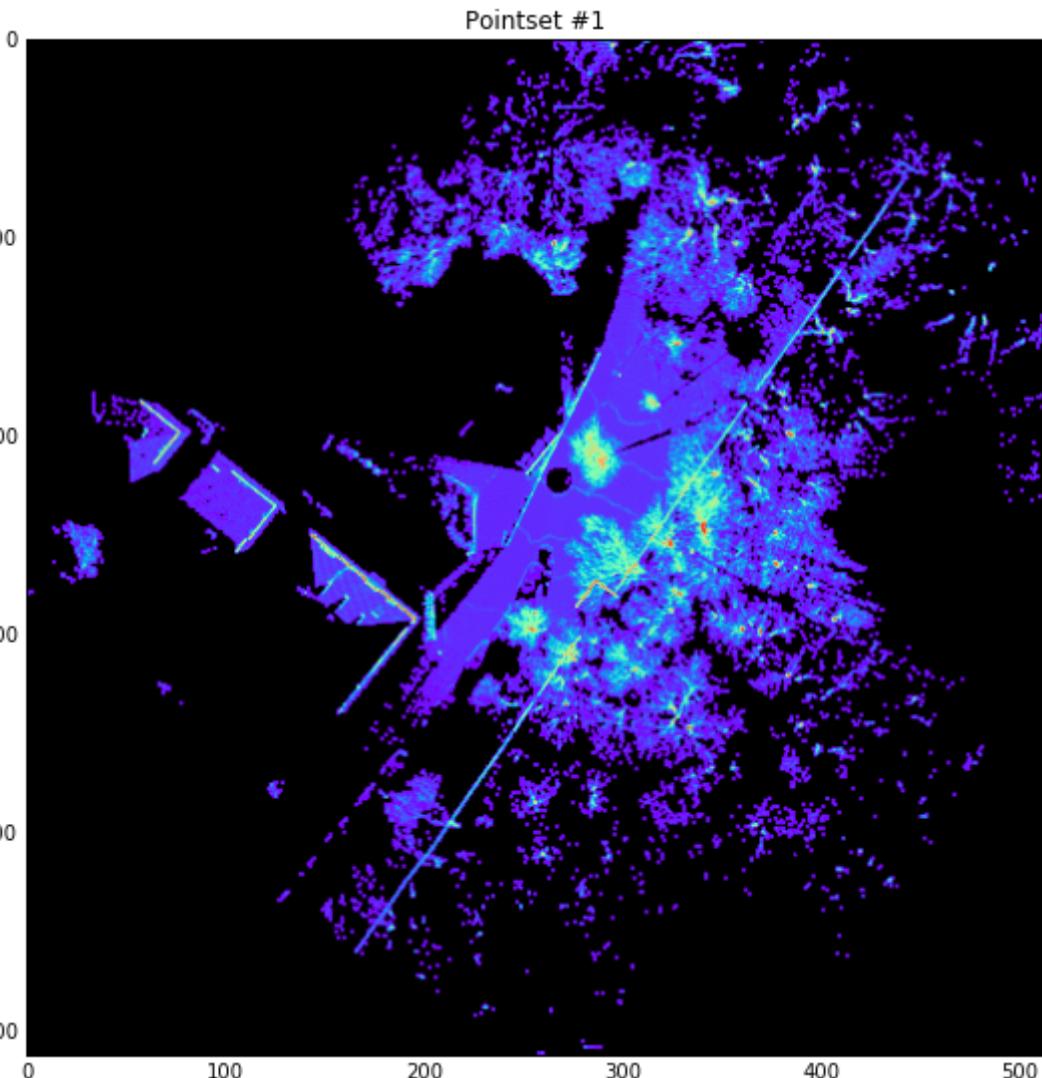
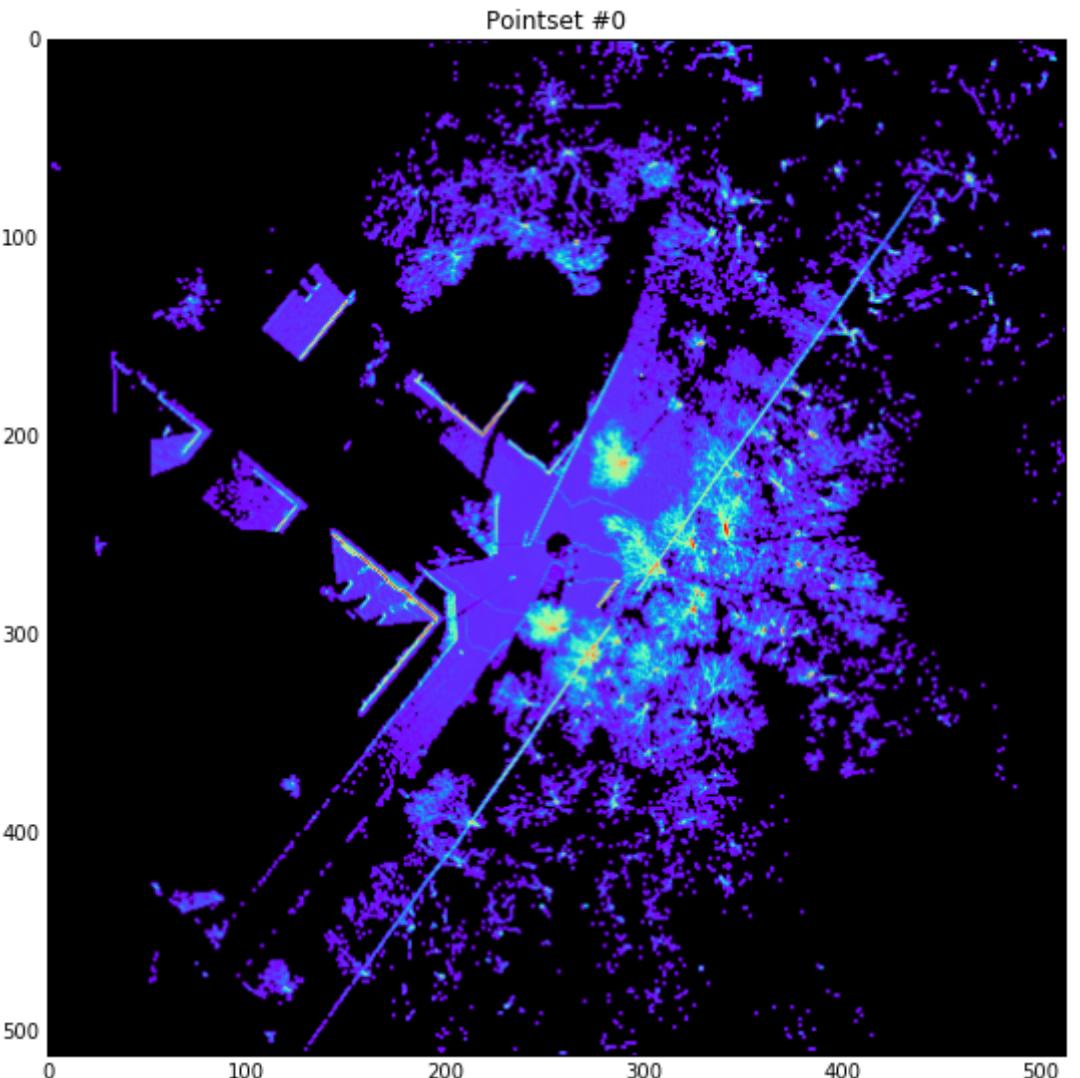
RIEGL

DIM

## Spatial domain – yaw & translation applied



RIEGL®



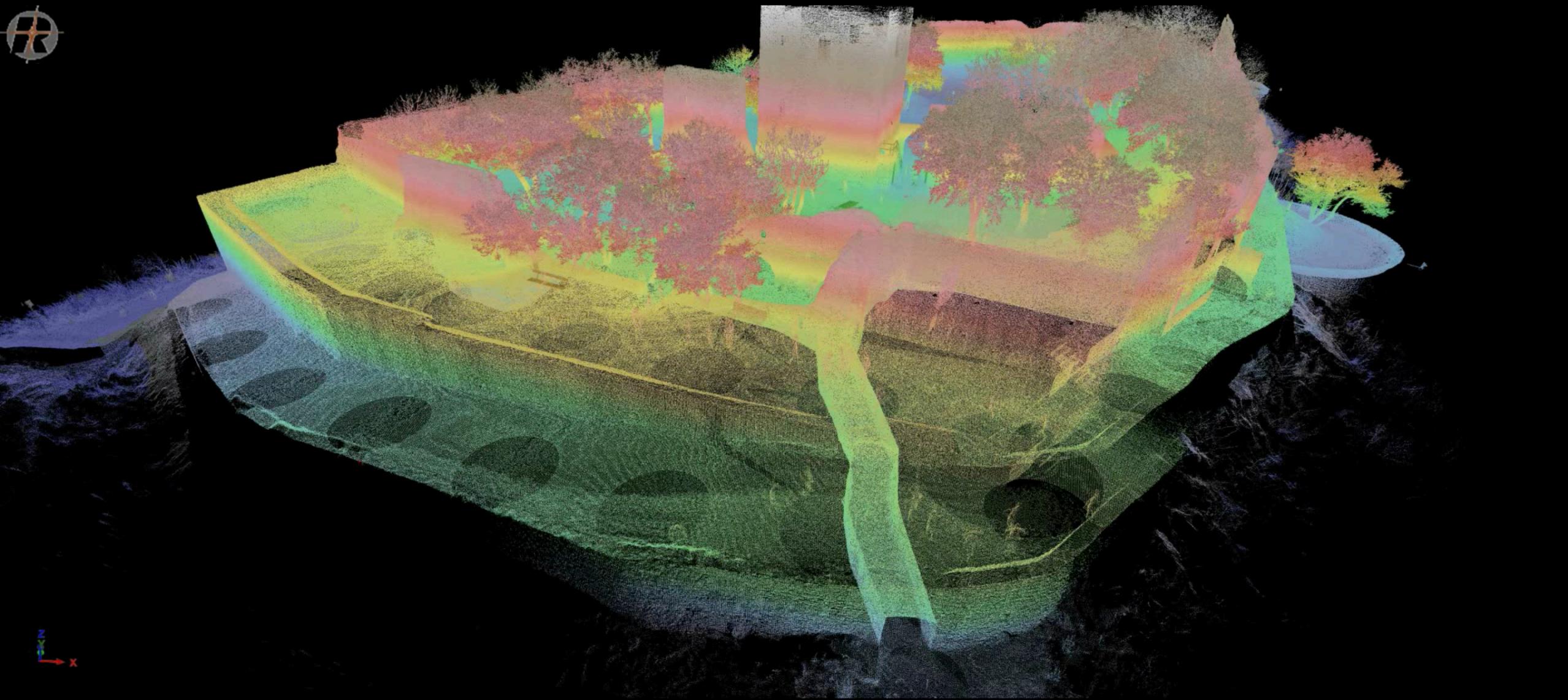


## automatic registration example



**RIEGL®**

**RIEGL®**





**RIEGL®**

# APPLICATIONS

## Applications

Vienna State Opera  
53 Scans

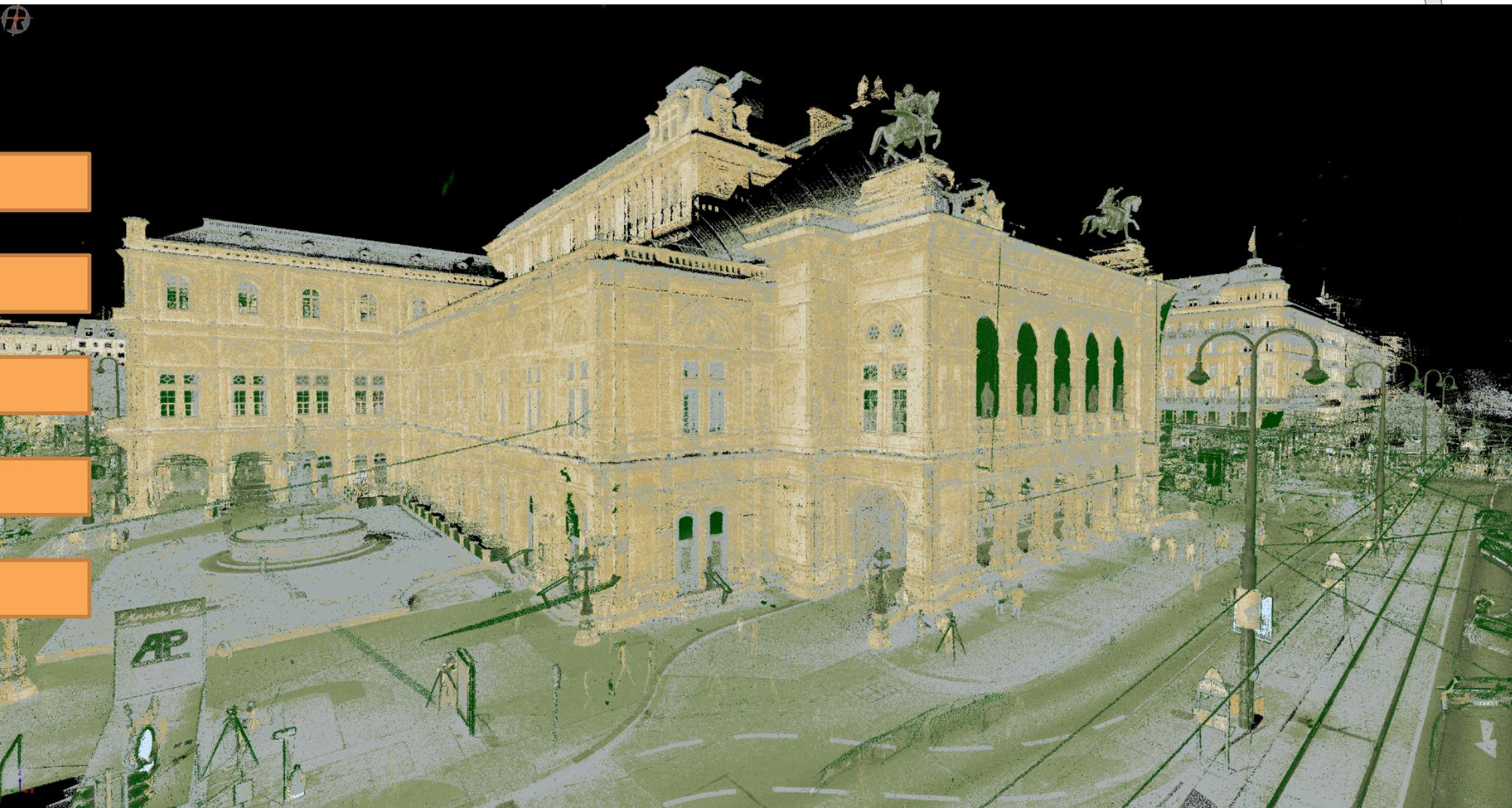
Architecture

Cultural heritage

Archaeology

Civil construction

Crash Site / Forensic



## Applications

Vienna State Opera  
53 Scans



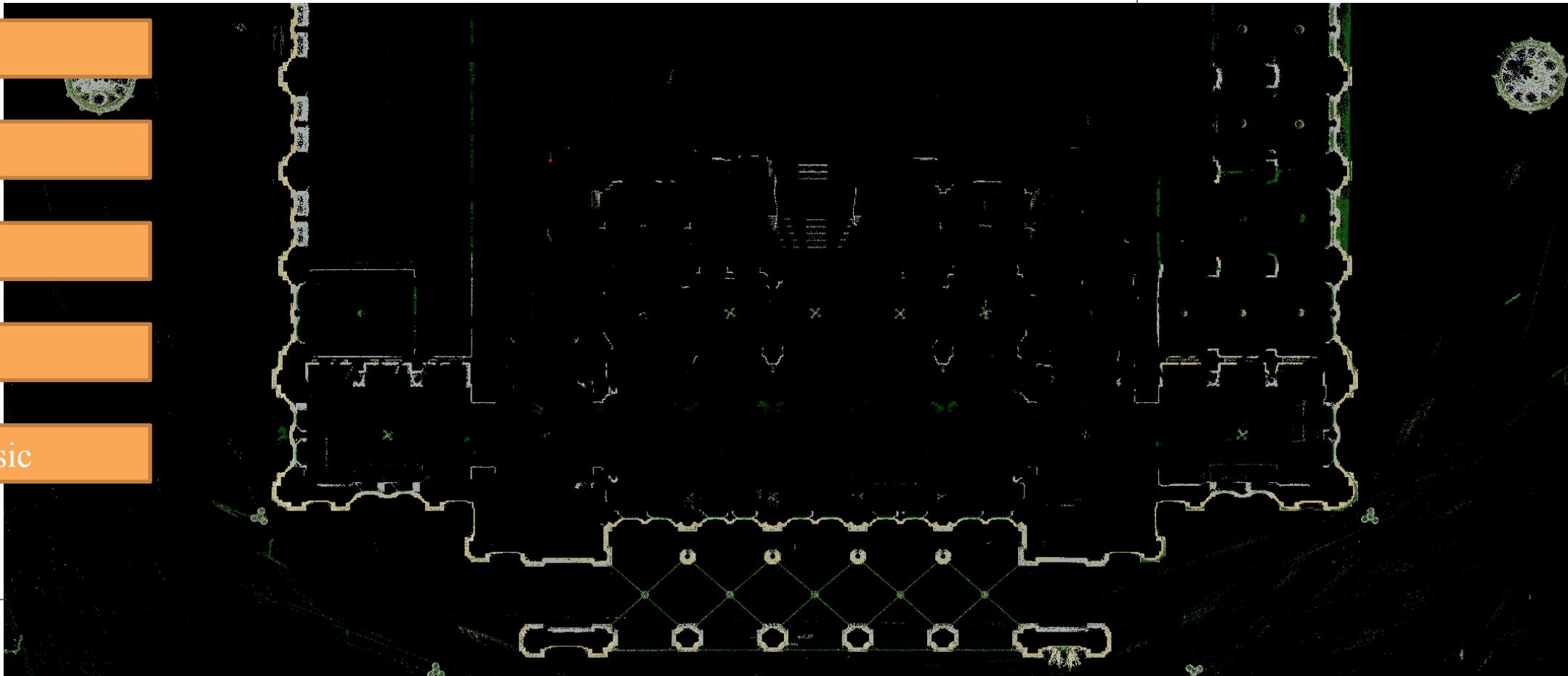
Architecture

Cultural heritage

Archaeology

Civil construction

Crash Site / Forensic



## Applications

Vienna State Opera  
53 Scans



Architecture



Cultural heritage



Archaeology



Civil construction



Crash Site / Forensic



# Applications

Vienna State Opera  
53 Scans

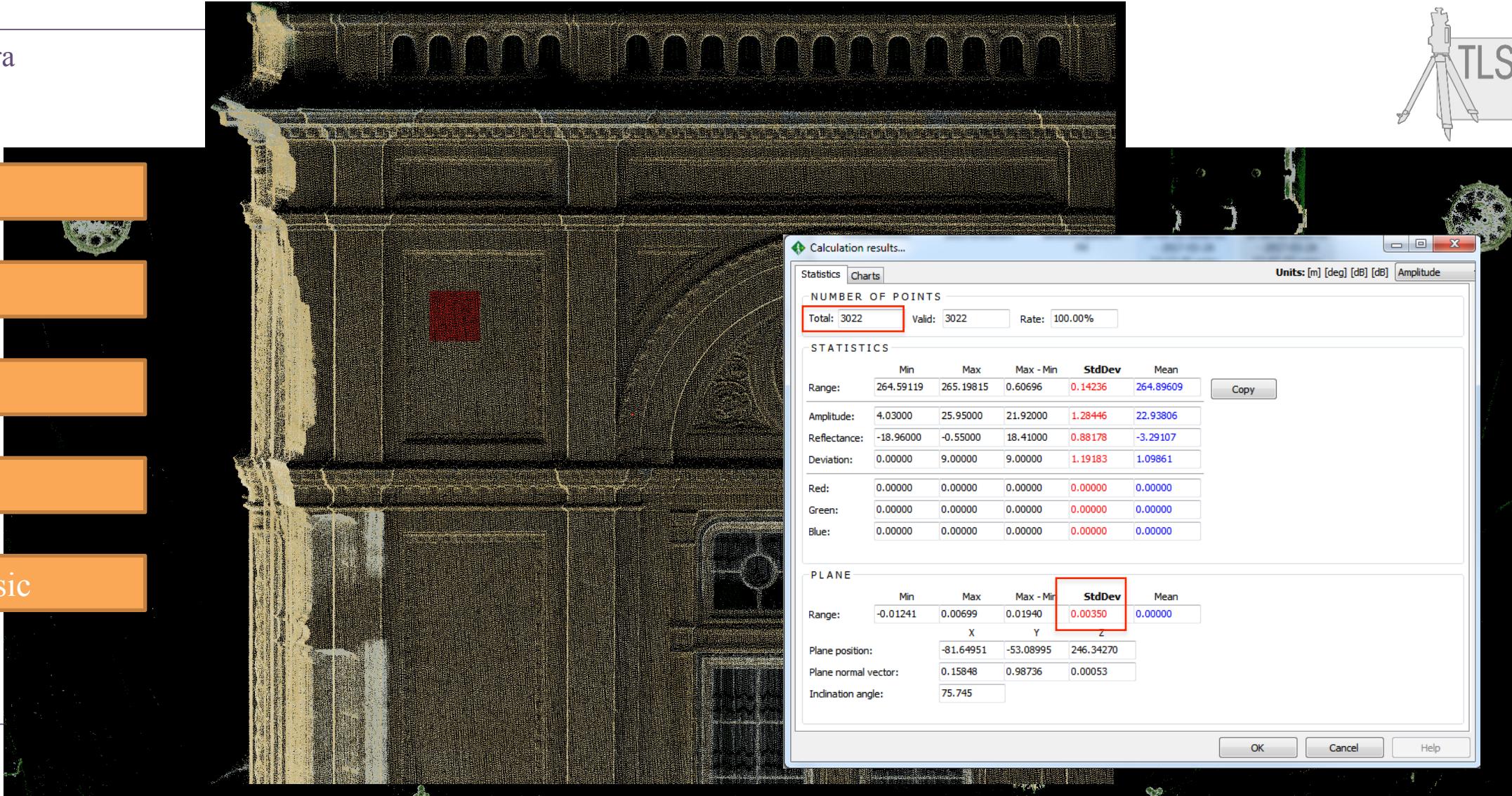
Architecture

Cultural heritage

Archaeology

Civil construction

Crash Site / Forensic



## Applications

UK crash site

Architecture

Cultural heritage

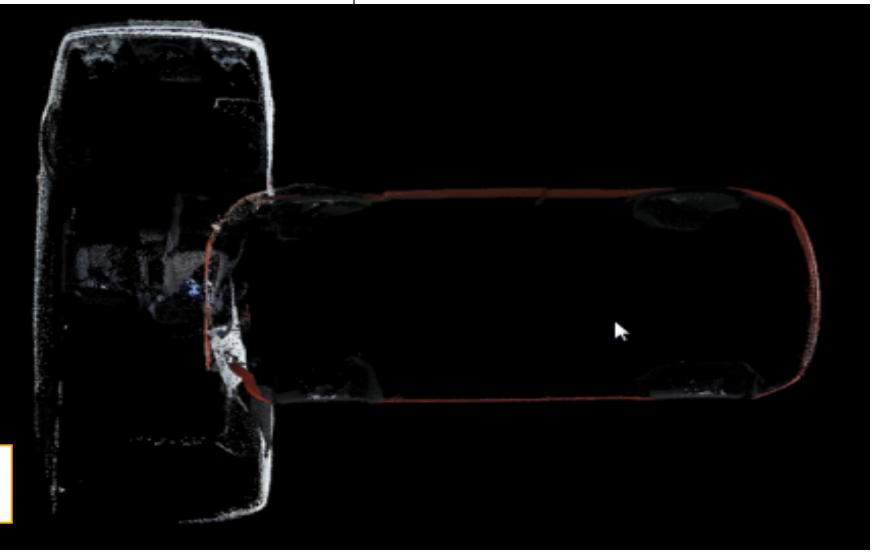
Archaeology

Civil construction

Crash Site / Forensic

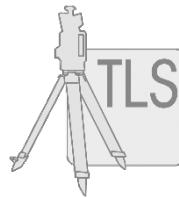
Crash site documentation

Impact reconstruction



## Applications

Fortress Hochosterwitz



Architecture

profiles

Cultural heritage

floor

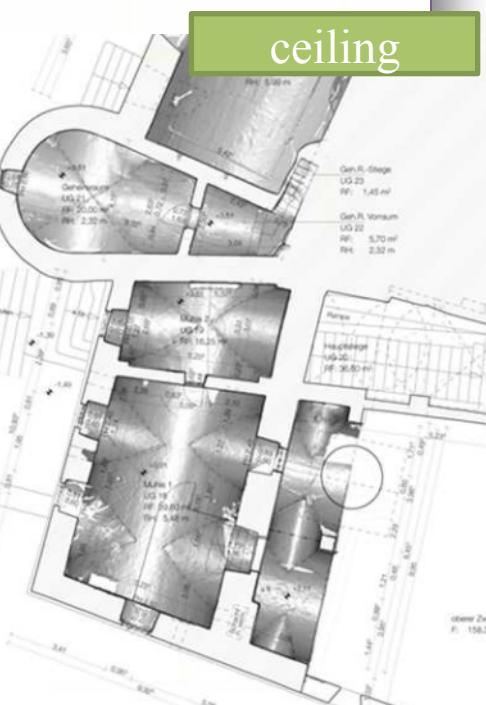
Archaeology

ceiling

Civil construction

CAD

Crash Site / Forensic



## Applications

Chemical processing plant,  
Germany



Crop monitoring

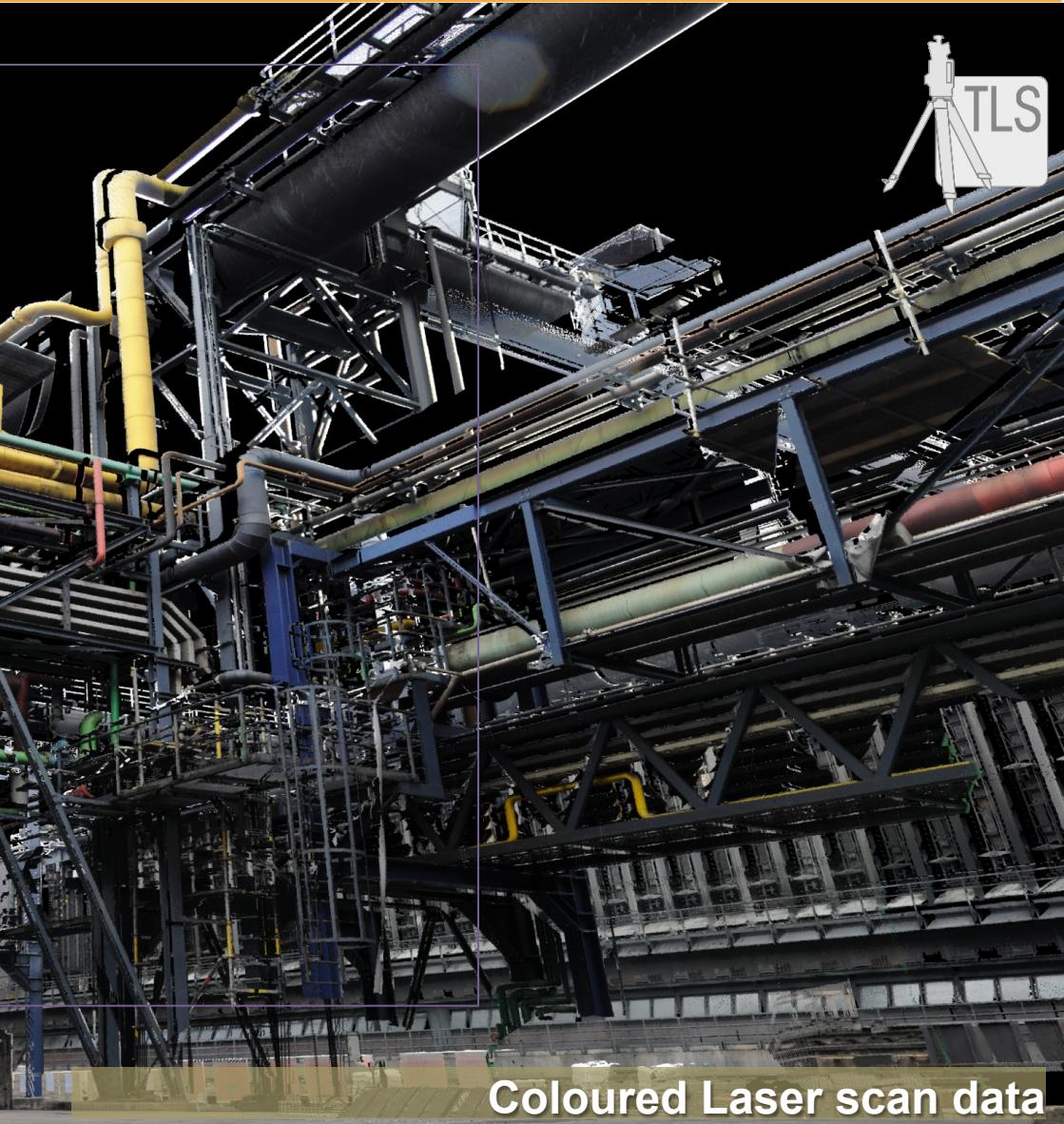
Landslide documentation

Snow field / glacier

Open pit mining

Open pit mining

Laser scan data by Reflectance



Coloured Laser scan data

## Applications

Chemical processing plant,  
Germany

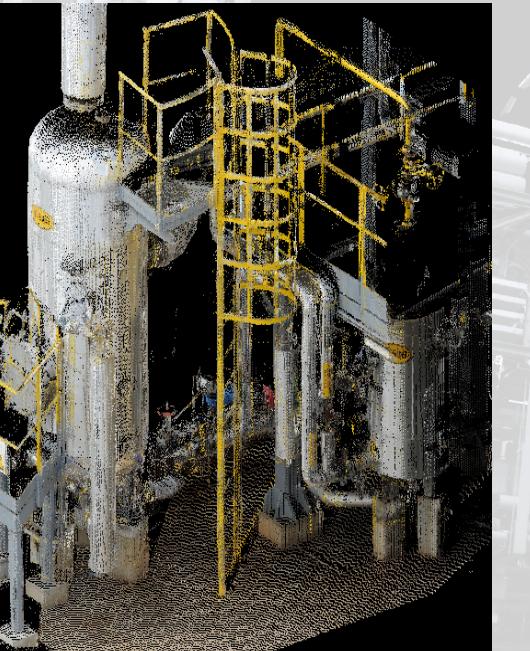
Crop monitoring

Landslide documentation

Snow field / glacier

Open pit mining

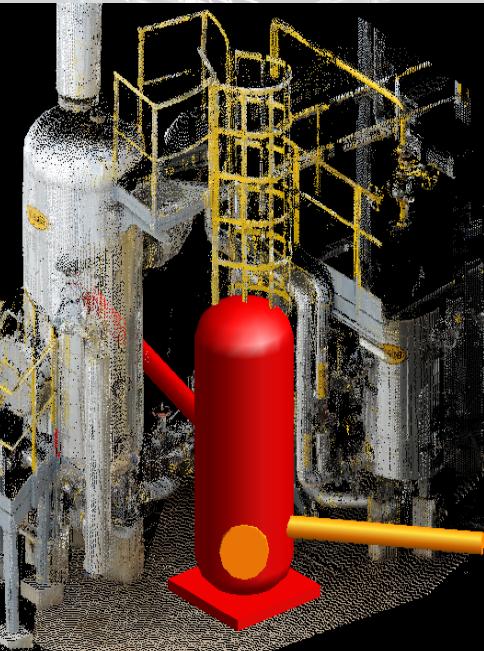
Open pit mining



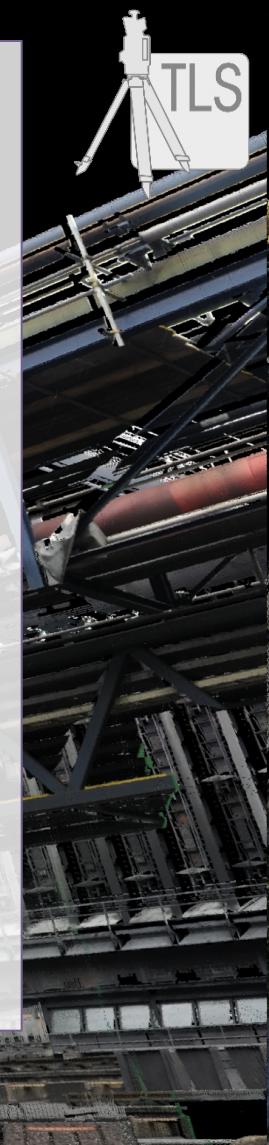
As-built



Design Model



Clash detection



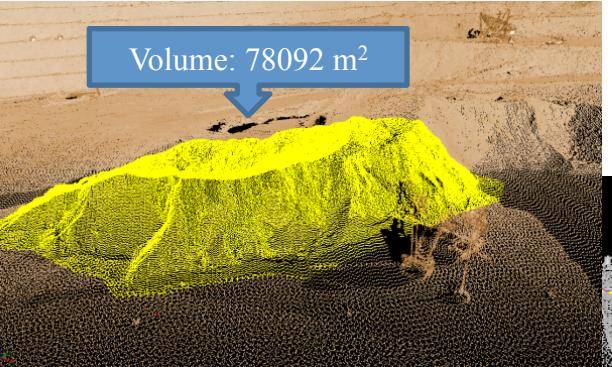
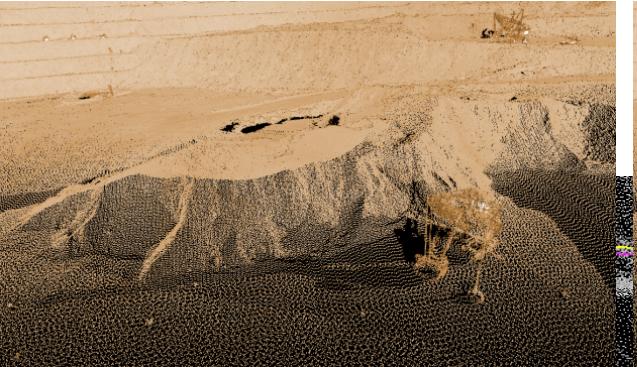


# Applications



RIEGL®

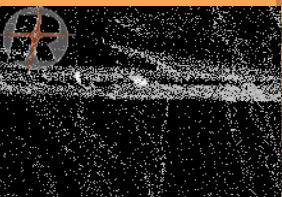
Open pit mine,  
Australia



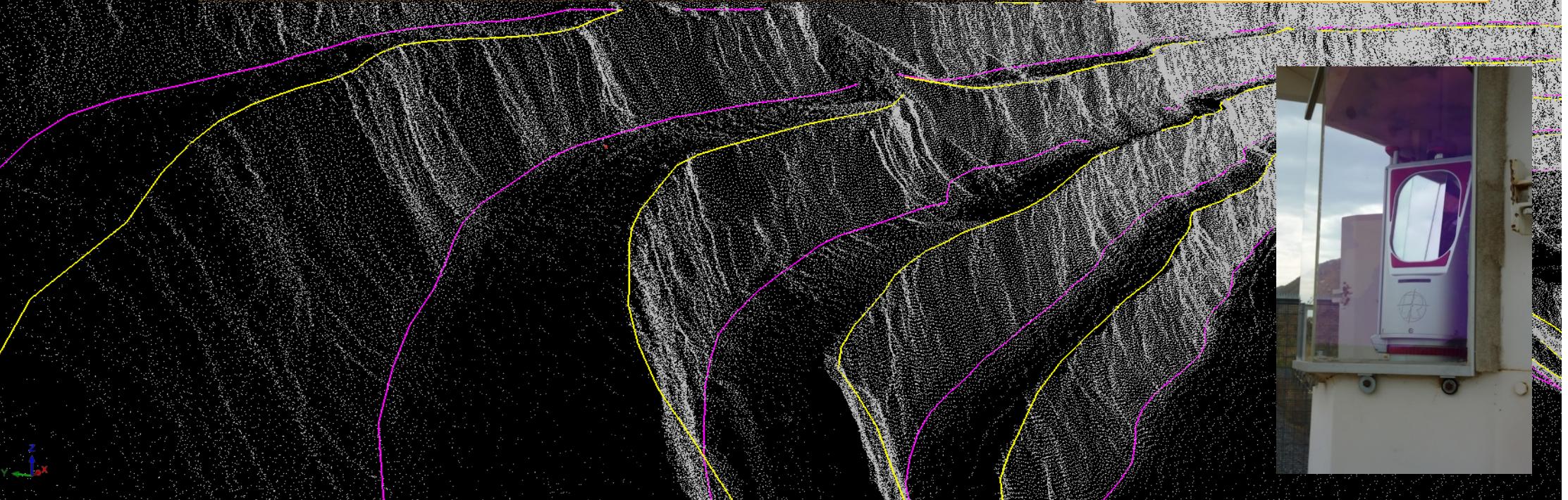
Mining  
Volume calculation  
Stockpile measurement  
Monitoring



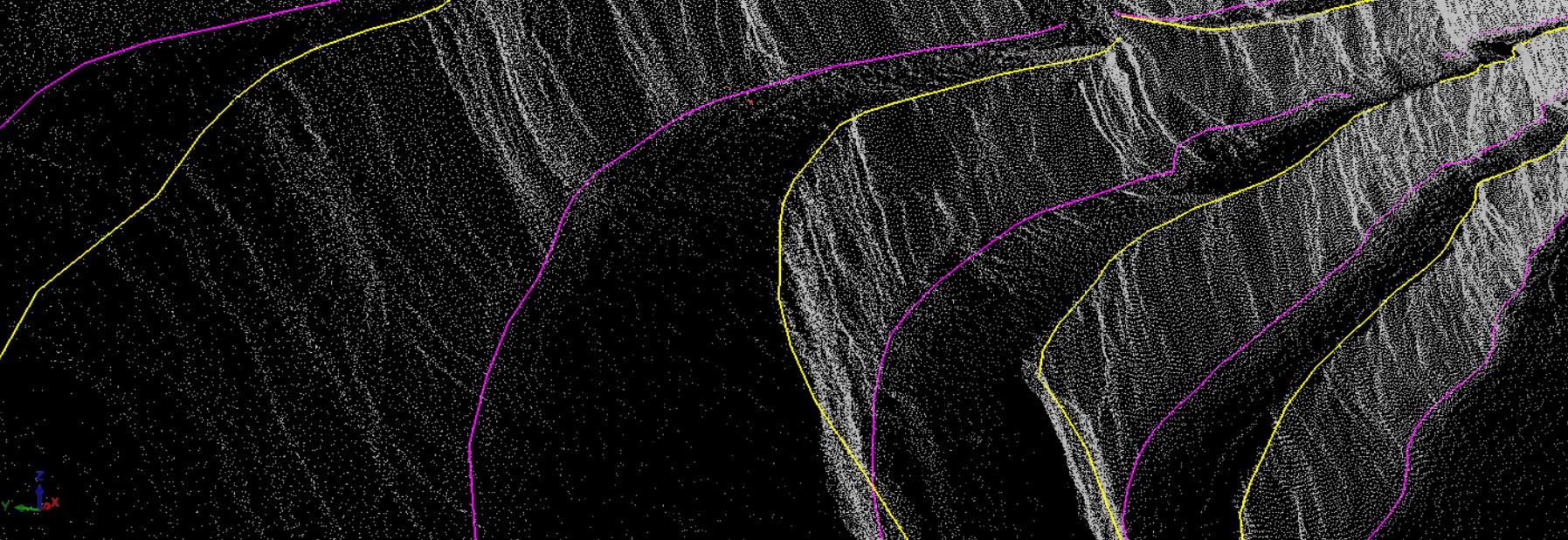
Crop monitoring



Landslide docu



Snow field / gl



Open pit minin



Open pit minin

## Applications

Corn field, Austria



Crop monitoring

Landslide documentation

Snow field / glacier

Open pit mining

Open pit mining



## Applications

Corn field, Austria

Crop monitoring

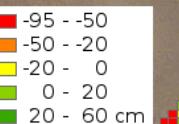
Glacier monitoring

Cultural heritage

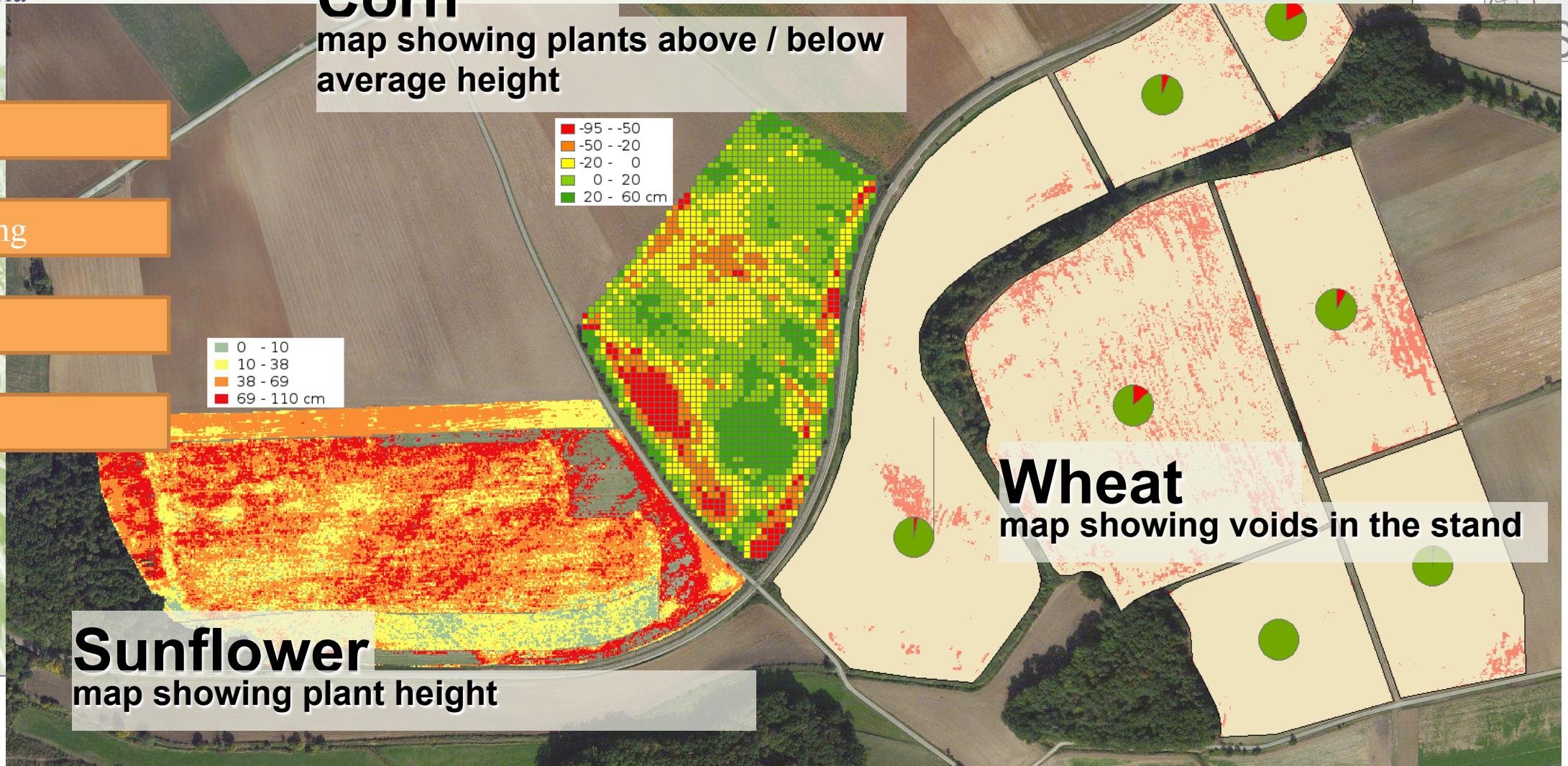
Open pit mining



**Corn**  
map showing plants above / below average height



**Sunflower**  
map showing plant height



## Applications

Goettweig monastery,  
Austria

Crop monitoring

Glacier monitoring

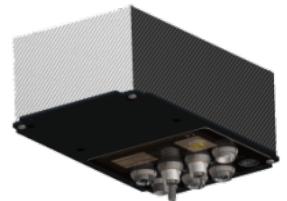
Cultural heritage

Open pit mining



## Applications

trajectory

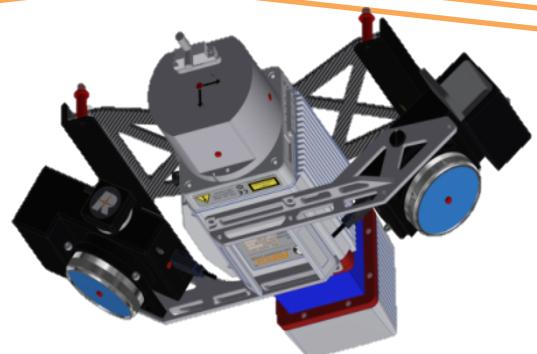


VUX-SYS-CU (control unit)  
GPS receiver, camera electronics

aerial vehicle



survey sensors



## Applications

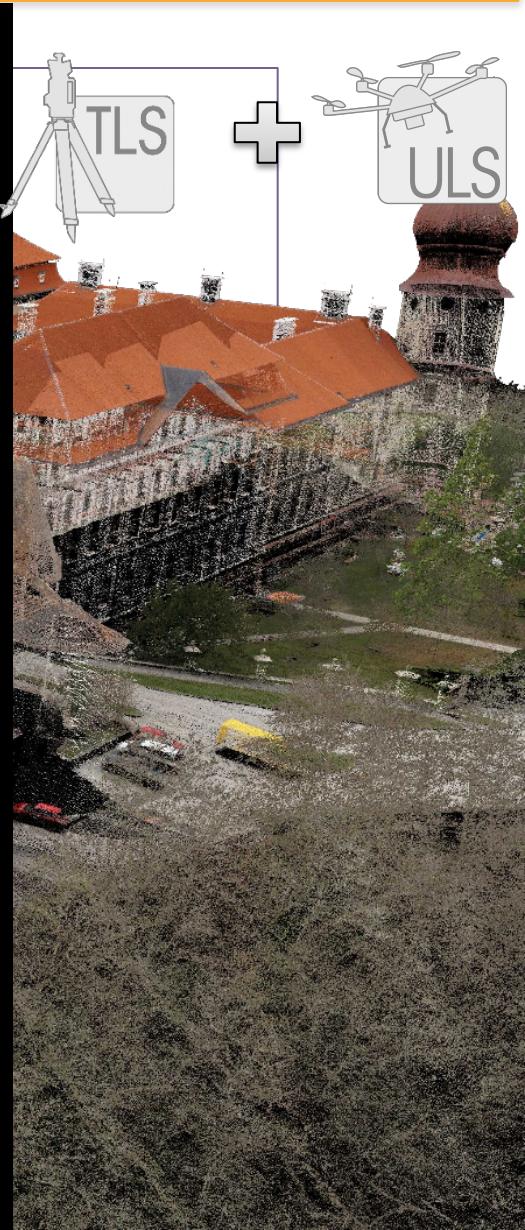
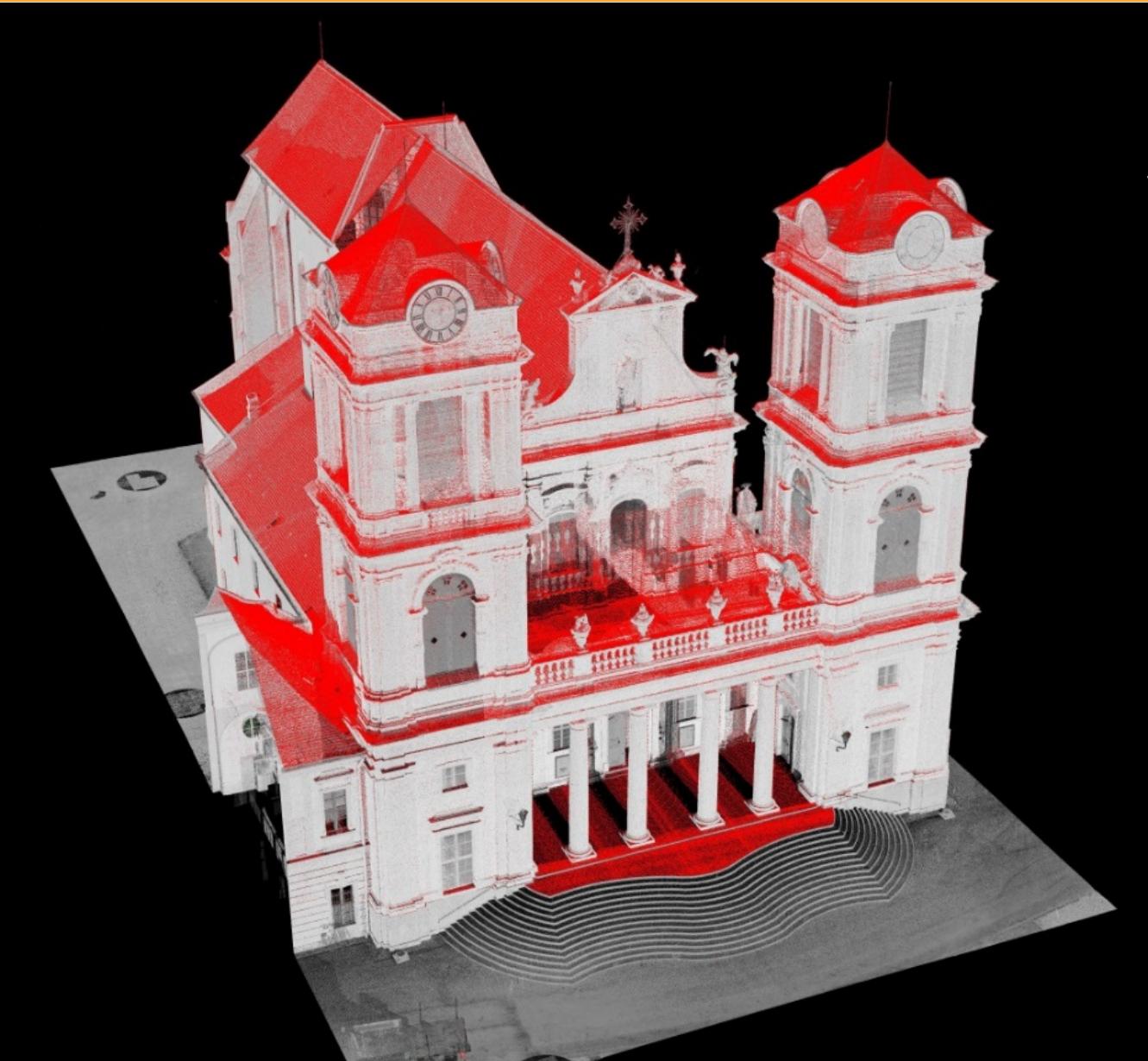
Goettweig monastery,  
Austria

Crop monitoring

Glacier monitoring

Cultural heritage

Open pit mining



## Applications

Vegetation mapping



Mapping / Cartography

Forestry



**RGB COMPOSITE**

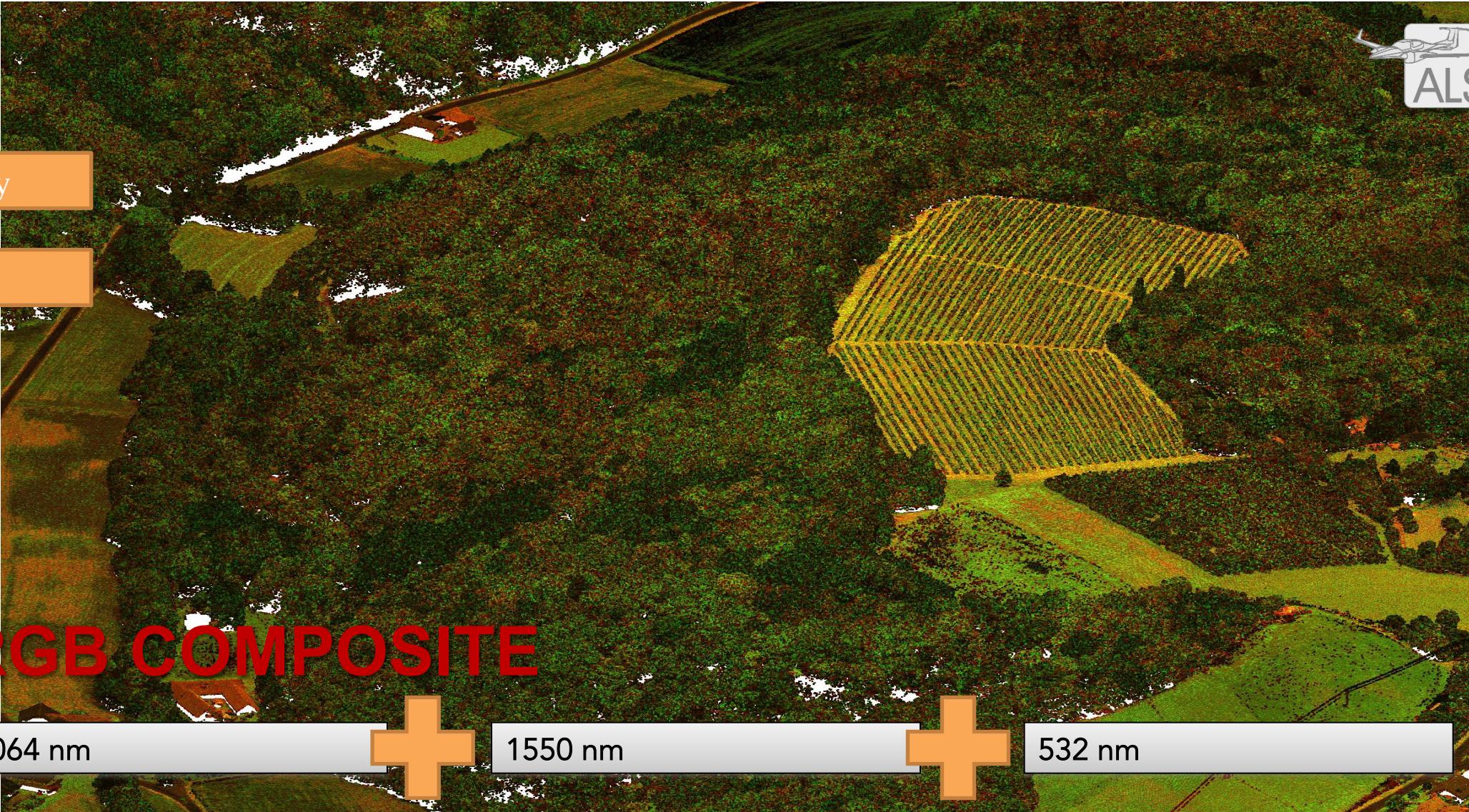
1064 nm



1550 nm



532 nm



## Applications

Vegetation mapping



Mapping / Cartography



Forestry



Normalized Difference Water Index (NDWI)



Green Normalized Difference Vegetation Index (GNDVI)



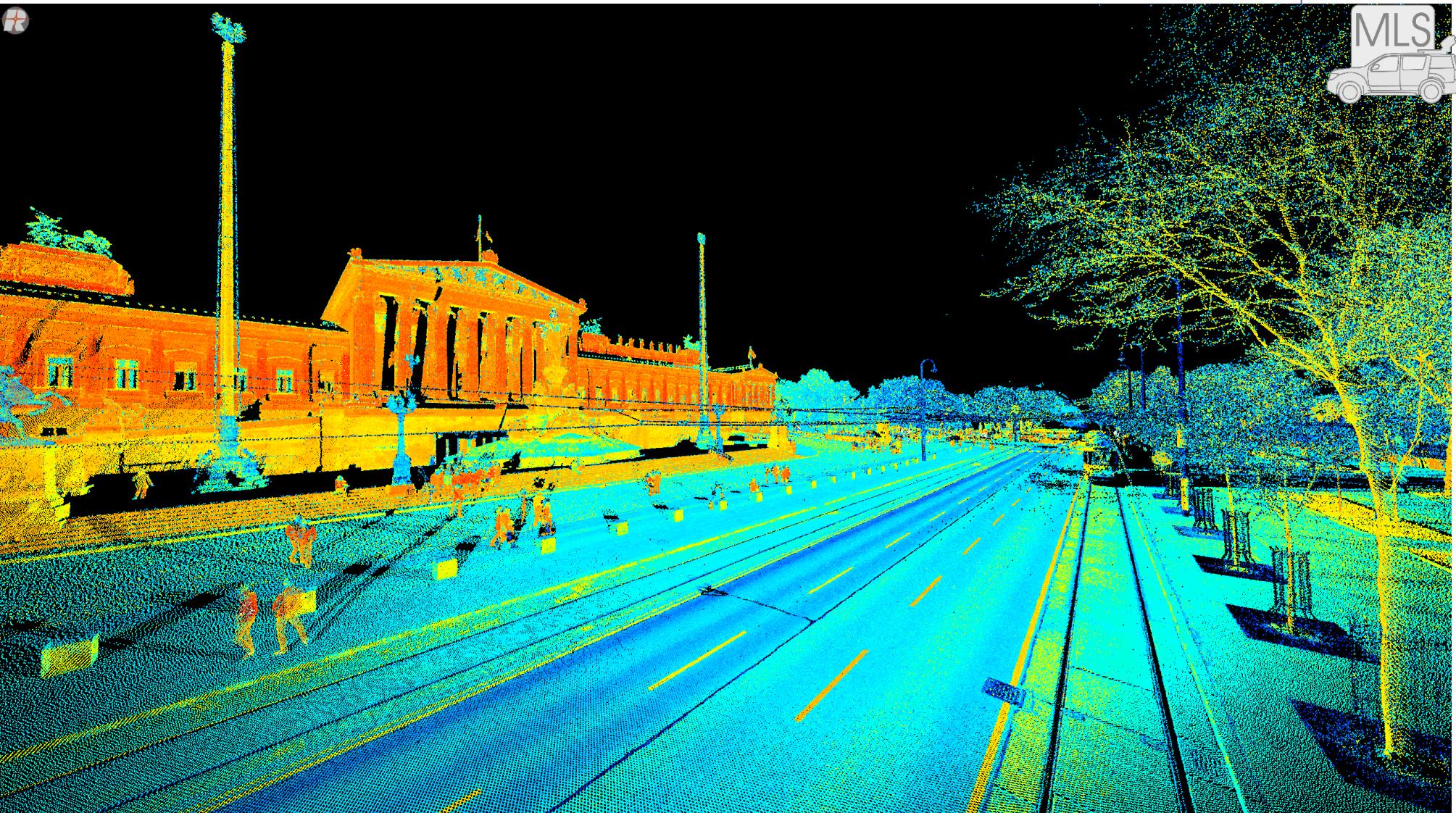
## Applications

Street asset collection



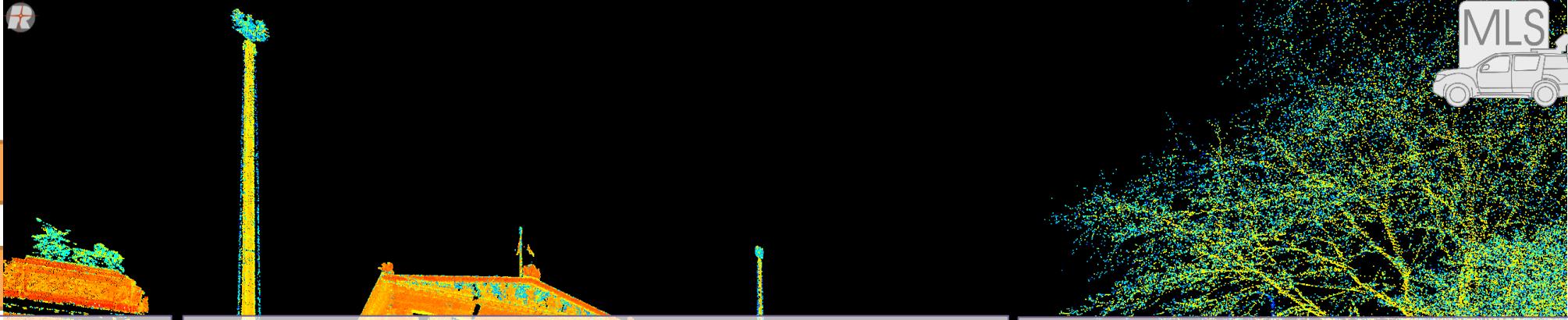
City modelling

Infrastructure mapping



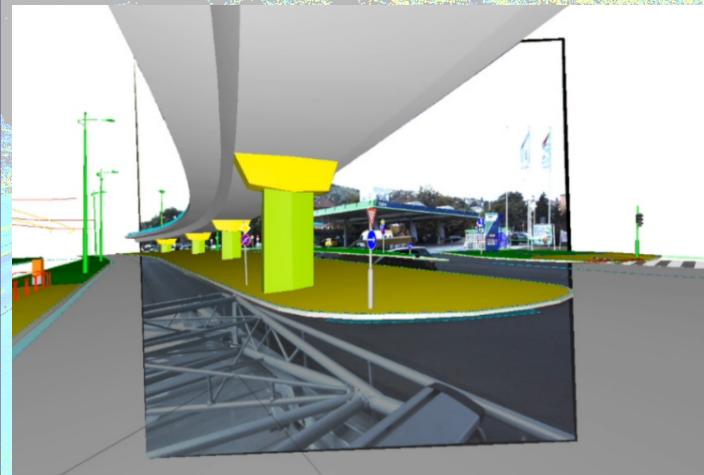
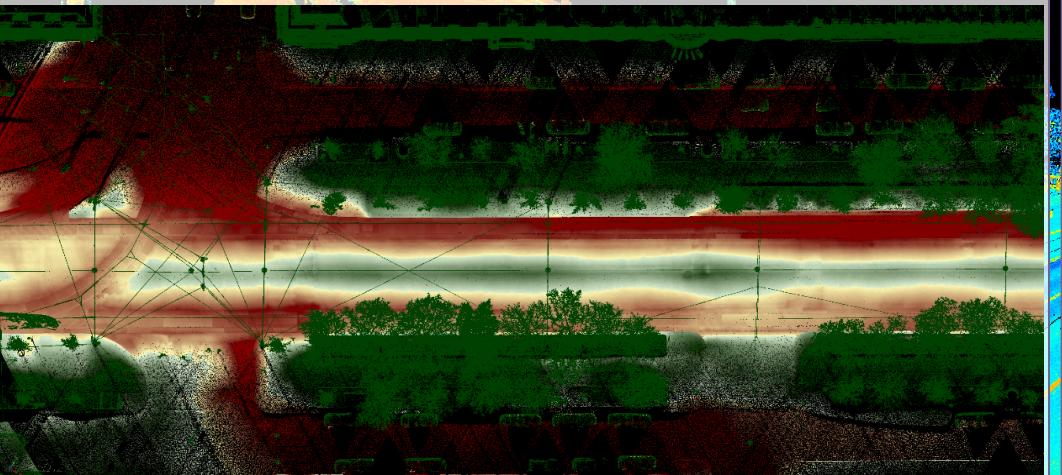
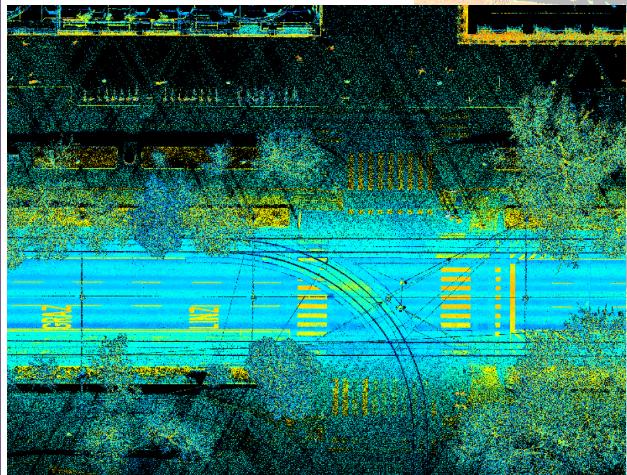
## Applications

Street asset collection



City modelling

Infrastructure mapping



Roadmarkings,  
Traffic signs, etc

Drainage, rutting, road conditions

Bridge clearance