SEARCHING FOR THE POTENTIAL OF SINGLE PHOTON TECHNOLOGIES – TOWARDS MULTISPECTRAL SINGLE PHOTON LIDAR: FGI CASES STUDIES ON SINGLE PHOTON LIDAR

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NLS
FINNISH GEOSPATIAL RESEARCH INSTITUTE
FGI

Basic Motivation

Multispectral Laser Scanning

- output of the laser scanner: including the intensity
- several active channels at different wavelengths -> multispectral laser scanner.
- fundamental for fully using the intensity data, and their applications with ALS intensities were presented by Coren and Sterzai (2006), Ahokas et al. (2006), Wagner et al. (2006), and Höfle and Pfeifer (2007).

Single Photon

- Single photon technologies permits about 100 times higher pulse rates and data densities; limitations such as low signal to noise ratio, noisy data, and cloud cover permitting operations
- If single photon techniques can be combined with active multispectral laser scanning, then automatic 3D object recognition would be more accurate and faster, allowing completely new possibilities for various mapping and monitoring tasks

The presentation is our attempt and story towards multispectral single-photon lidar since Anttoni Jaakkola's discovery (2016), that it is possible – with some success and with disappointments.

Single Photon/Geiger in General

Remarks (e.g. Jutzi 2017)

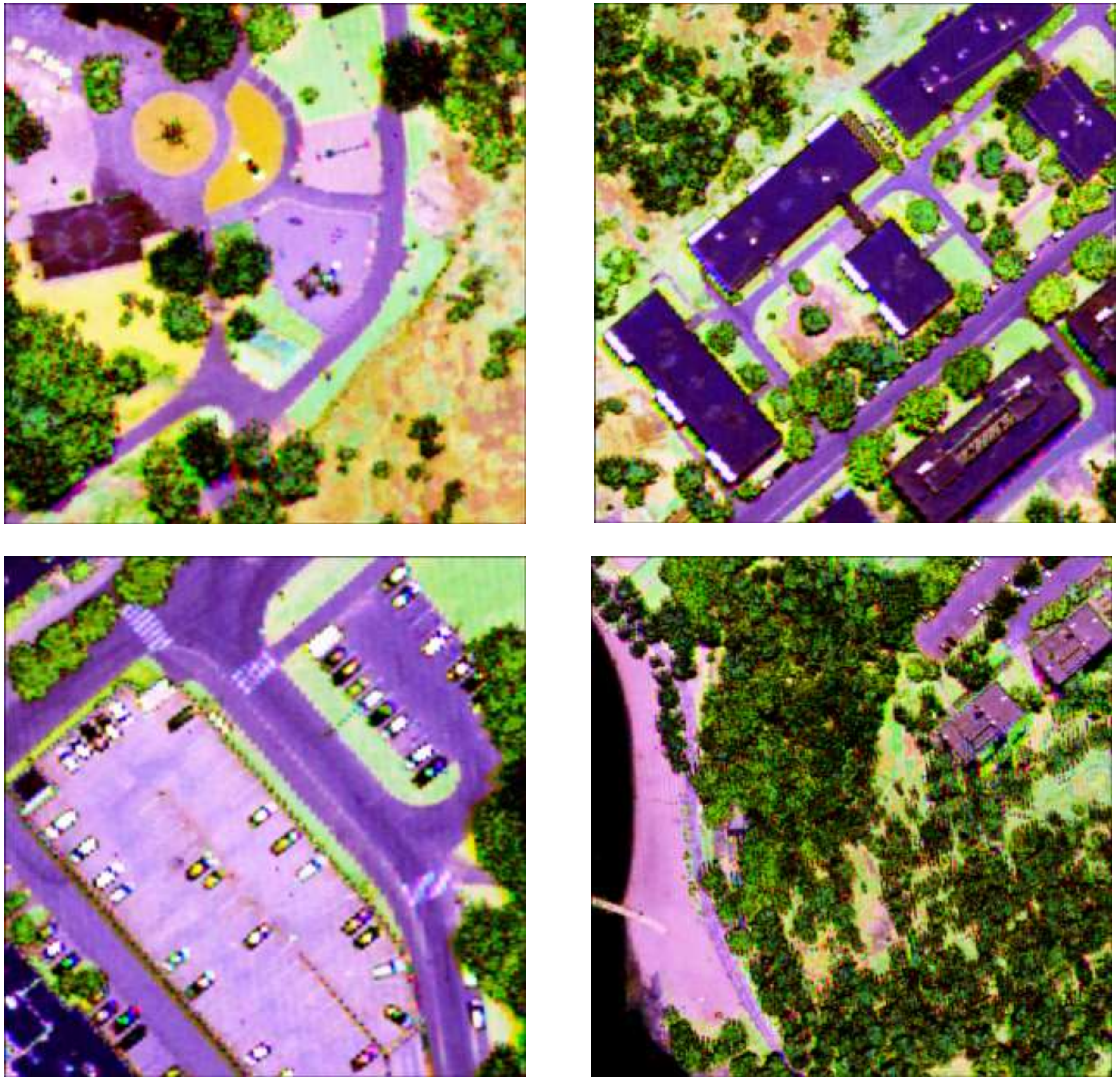
- **Wavelength and intensity** - visible domain (532 nm) is excellent for bathymetry, generally low reflectances from natural surfaces. Optical components are inexpensive, the detector arrays high efficiency. Near-infrared wavelength with 1064 nm (lower solar background, generally high reflectances from natural surfaces). Multi-spectral LiDAR is challenging. Surface reflectance capabilities require reasonable radiometry. The sum of photons collected by the full 10x10 array is comparable to the sum of photons collected with a conventional Multi-Photon LiDAR (MPL).
- **DTM** – SPL/SS: recovery time with 1.6 ns (respectively 24 cm in range). In GM the penetration capabilities are limited, DTM generation might be difficult. Blanking loss appears after a photon event is triggered (respectively 7.5 to 240 m in range). DSMs can be well determined, but generating DTMs might be challenging
- **Point density** – SPL/SS: a 10x10 regular array; GM: array of APDs with 128x32 elements in total in GM. The aerial coverage with up to 2100 km2/h (@ 8 pts/m2) correspond to Maximum Flying Height of 11000 m AGL. High altitude is more sensitive to atmospheric influences and effects caused by weather conditions.
- **Scanning Geometry** - Facades of buildings.
- **Noise in data** - smoothing

Why Multispectral?

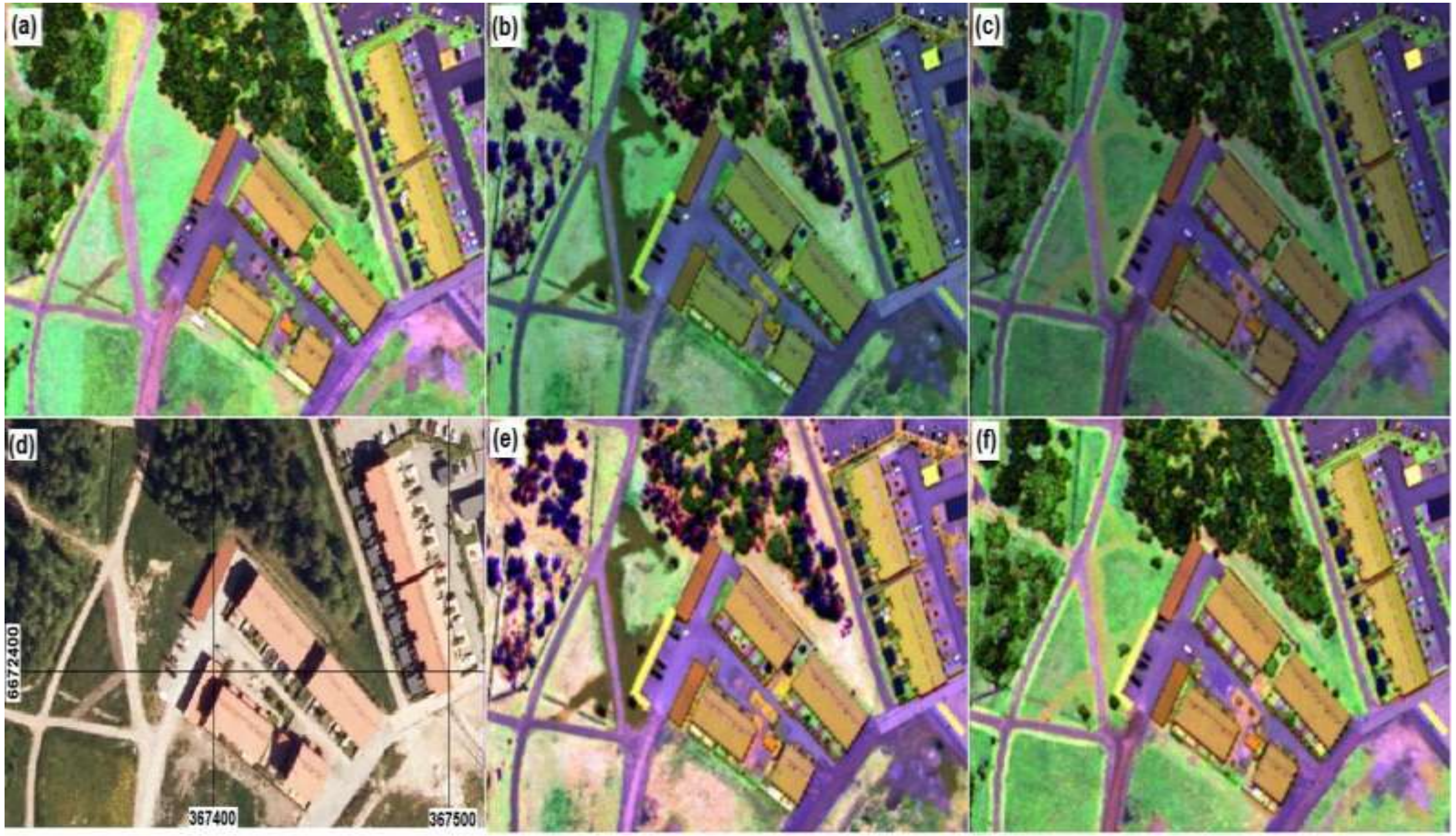
Leena Matikainen, Xioawei Yu, Kirsi Karila, Juha Hyyppä
Centre of Excellence in Laser scanning Research

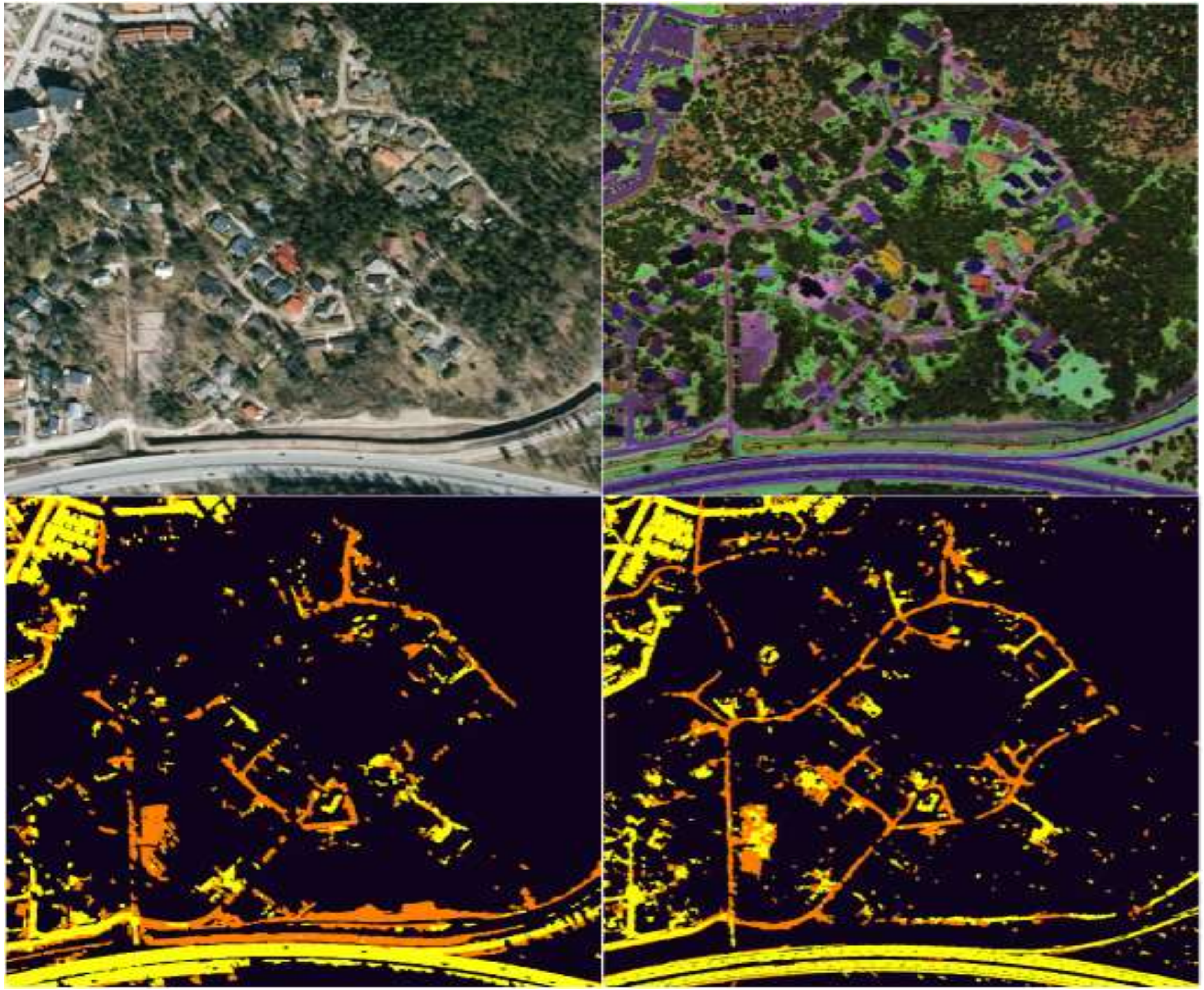
FGI Multispectral LS examples

- Matikainen, L., Karila, K., Hyyppä, J., Litkey P., Puttonen, E., Ahokas, E., 2017. Object-based analysis of multispectral airborne laser scanner data for land cover classification and map updating. ISPRS Journal of Photogrammetry and Remote Sensing, 128: 298-313.
- Karila, K, Matikainen, L., Puttonen, E., Hyyppä, J. 2016. Feasibility of Multispectral Airborne Laser Scanning Data for Road Mapping, IEEE Geoscience and Remote Sensing Letters PP(99):1-5 http://ieeexplore.ieee.org/document/7829363/
- Yu, X., Hyyppä, J., Litkey, P., Kaartinen, H., Vastaranta, M., Holopainen, M. Single-sensor solution to tree species classification using multispectral airborne laser scanning. Remote Sensing 2017, *9*(2), 108; doi:[10.3390/rs9020108](https://doi.org/10.3390/rs9020108)



Adjustment of intensities





Tree Species Classification

Confusion matrix based on intensity features

		Predicted			producer
		Pine	Spruce	Birch	
Reference	Pine	623	12	16	95.70
	Spruce	32	180	27	75.31
	Birch	47	18	197	75.19
user		88.75	85.71	82.08	Overall = 86.81%

Confusion matrix based on point cloud and intensity features

		Predicted			producer
		Pine	Spruce	Birch	
Reference	Pine	622	14	15	95,55
	Spruce	18	201	20	84,10
	Birch	46	21	195	74,43
user		90.67	85.17	84.78	Overall = 88.36%

FGI Single Photon System

Anttoni Jaakkola, Antero Kukko, Teemu Hakala, Matti Lehtomäki, Xinlian Liang, Juha Hyyppä

Centre of Excellence in Laser scanning Research

Experiment and case study

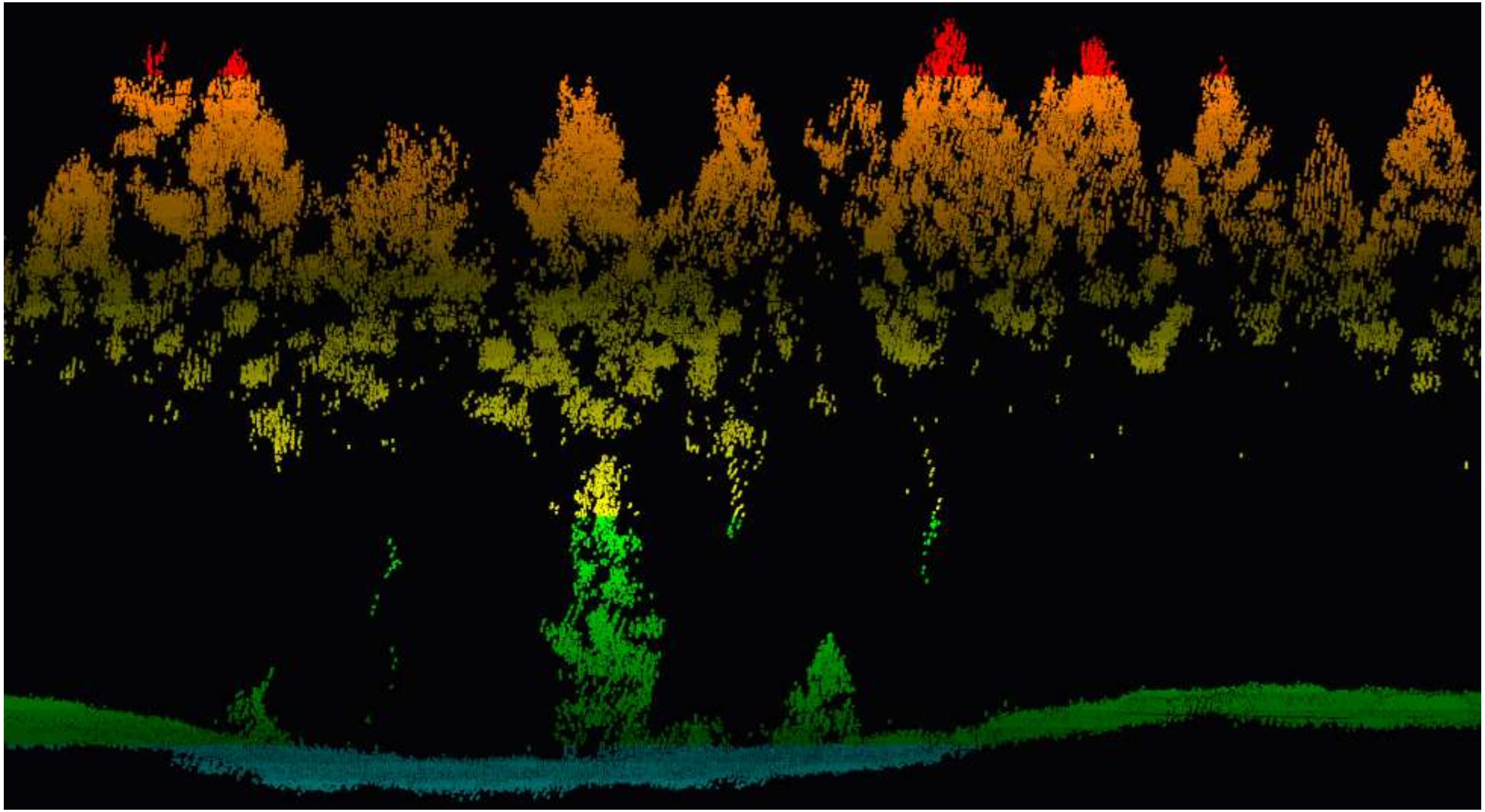
System Setup

- Range gating: 3x5 ns gate
- Size of one image is 64 pixels x 32 pixels
- Fligth altitude: 100 m AGL
- 2 sequences per second:
  - 3x500 frames per seq.
  - 70m field of depth in total
- 16 cm pixel size on the ground

Bell 206 JetRanger

Experiment and case study

Point density appr. 500/m^2



Tests with SPL100

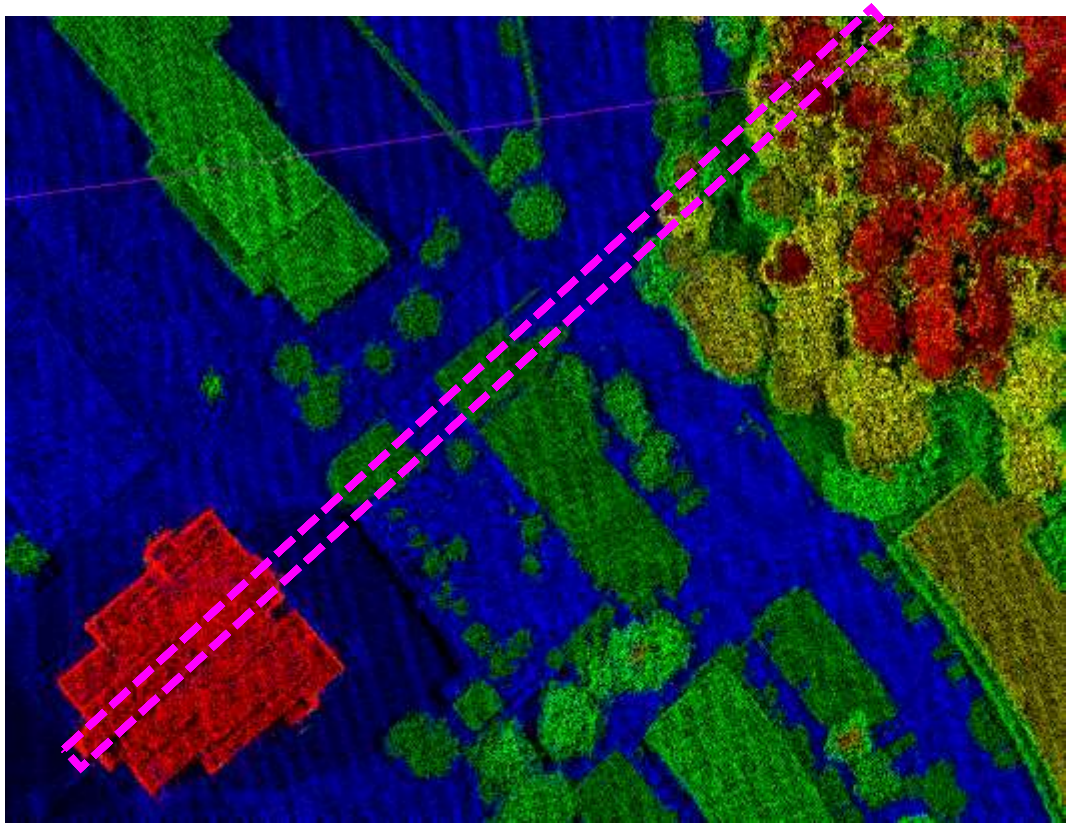
Eero Ahokas, Juha Hyyppä

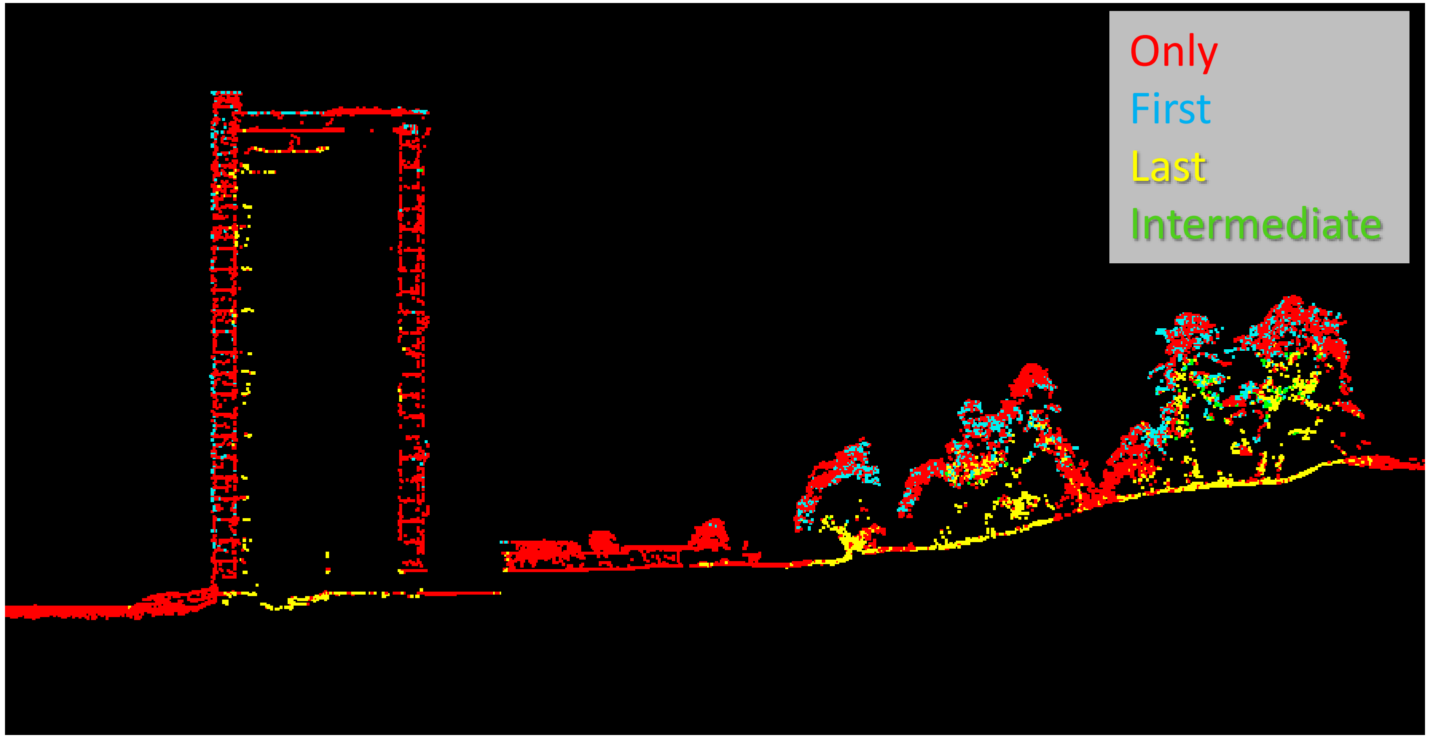
Centre of Excellence in Laser scanning Research

Applied SPL and ALS Data

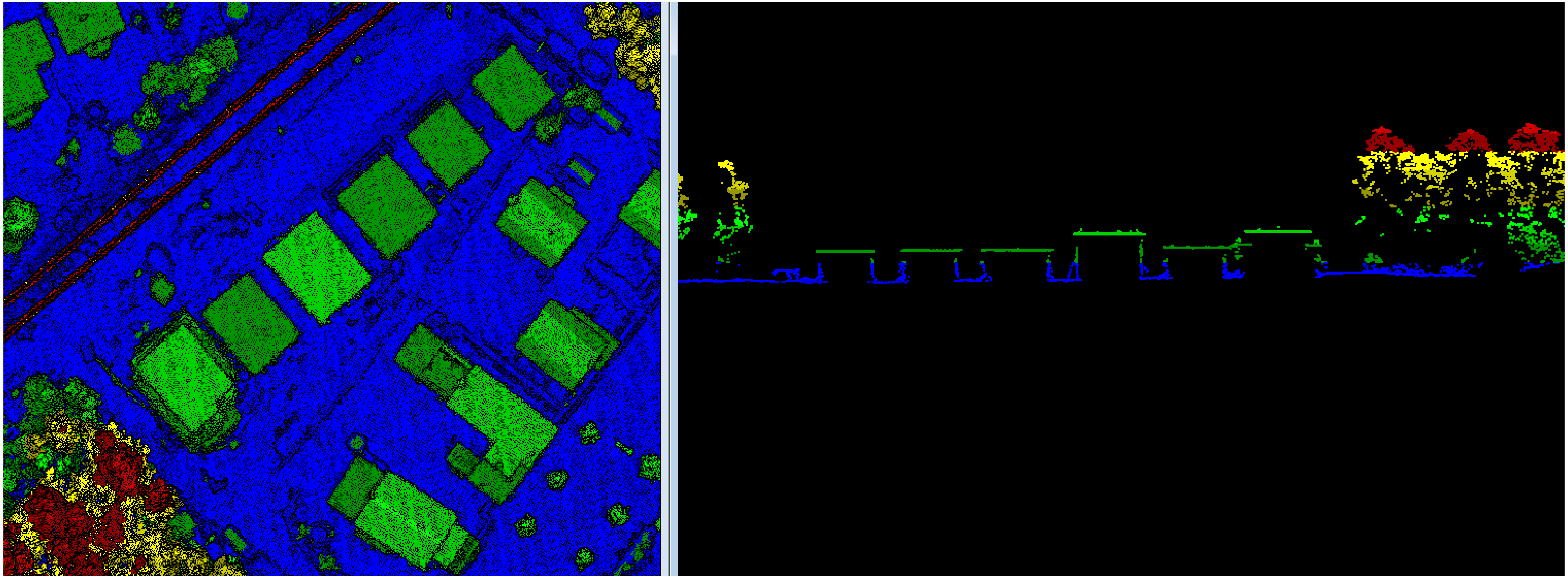
	SPL65	SPL120	Titan
Date	19 Aug.2018	19.Aug.2018	13-14. Jun. 2018
flight lines	7	5	37
flight altitude AGL (m)			1644-1736 ft
wavelength (nm)	532	532	532/1064/1550
FOV			30
laser pulse rate (kHz)	60		250
scan frequency (Hz)	up to 25		53
point density (pts/m2)	67.4	22.4	41.7
stripe wide (m)	1030	2060	214
divergence (mrad)	0.08 (1/e2)	0.08 (1/e2)	Channel 1,2: 0.35 (1/e), Channel 3: 0.7 (1/e)

Data from walls/balconies





Data from walls/balconies

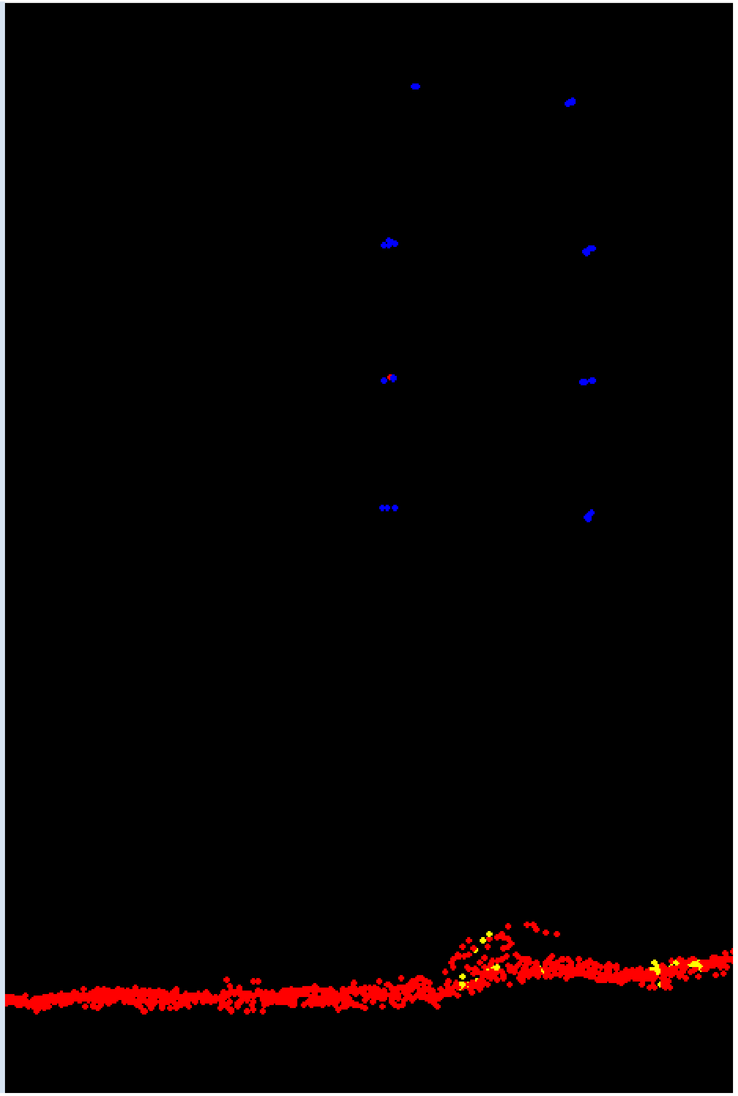


Data from walls/balconies

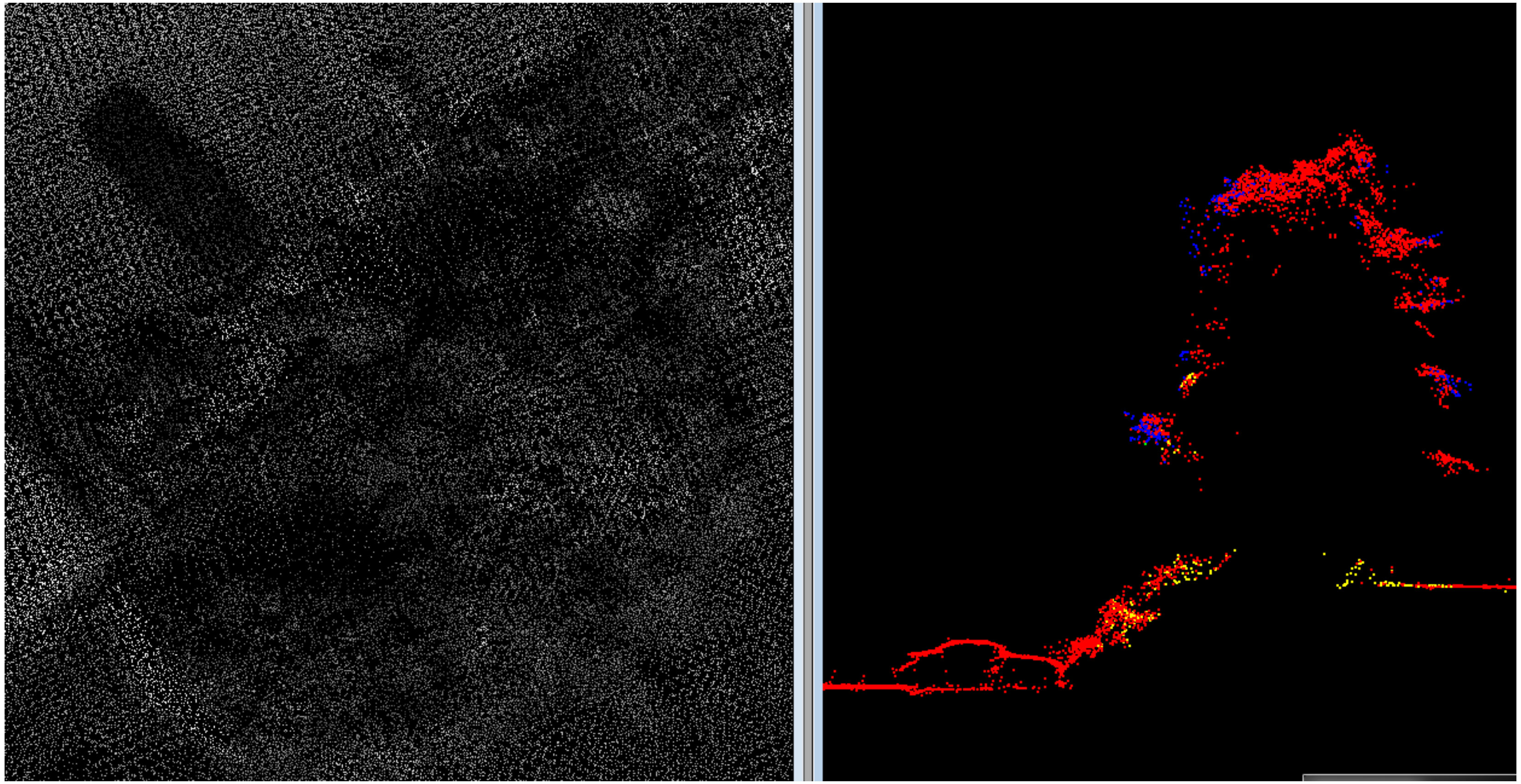
Point count (pixel size 20 cm)

Standard deviation of height

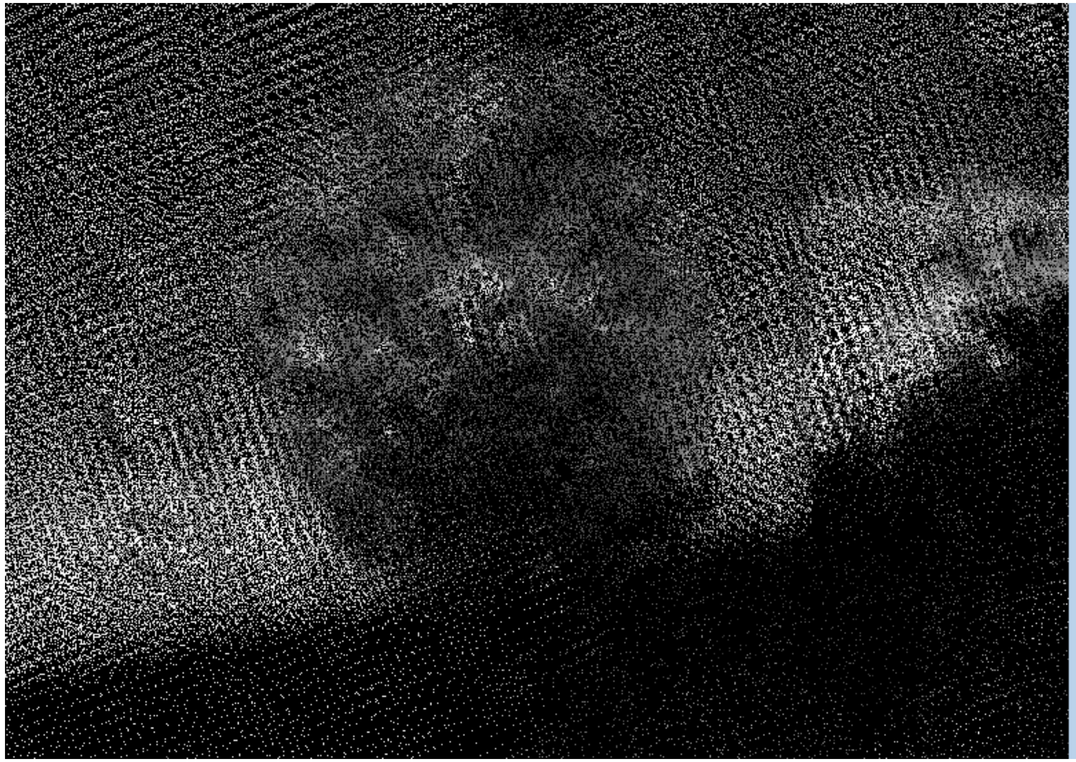
Use of pulse information, blue =1. pulse, red=only pulse

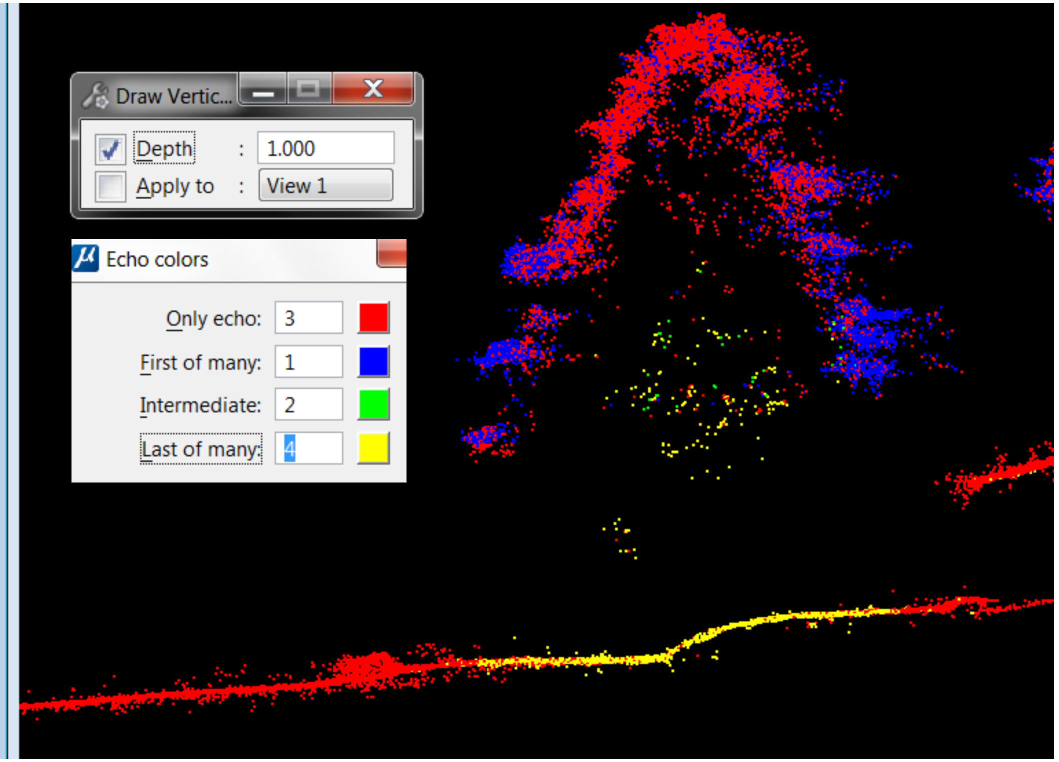


Car and deciduous tree – penetration in deciduous canopies

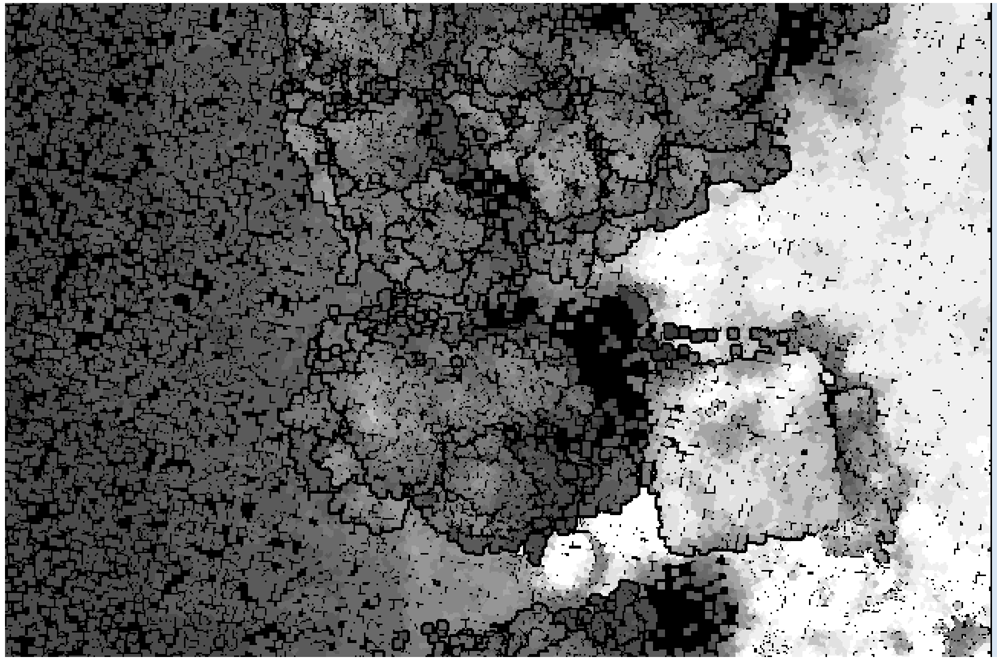


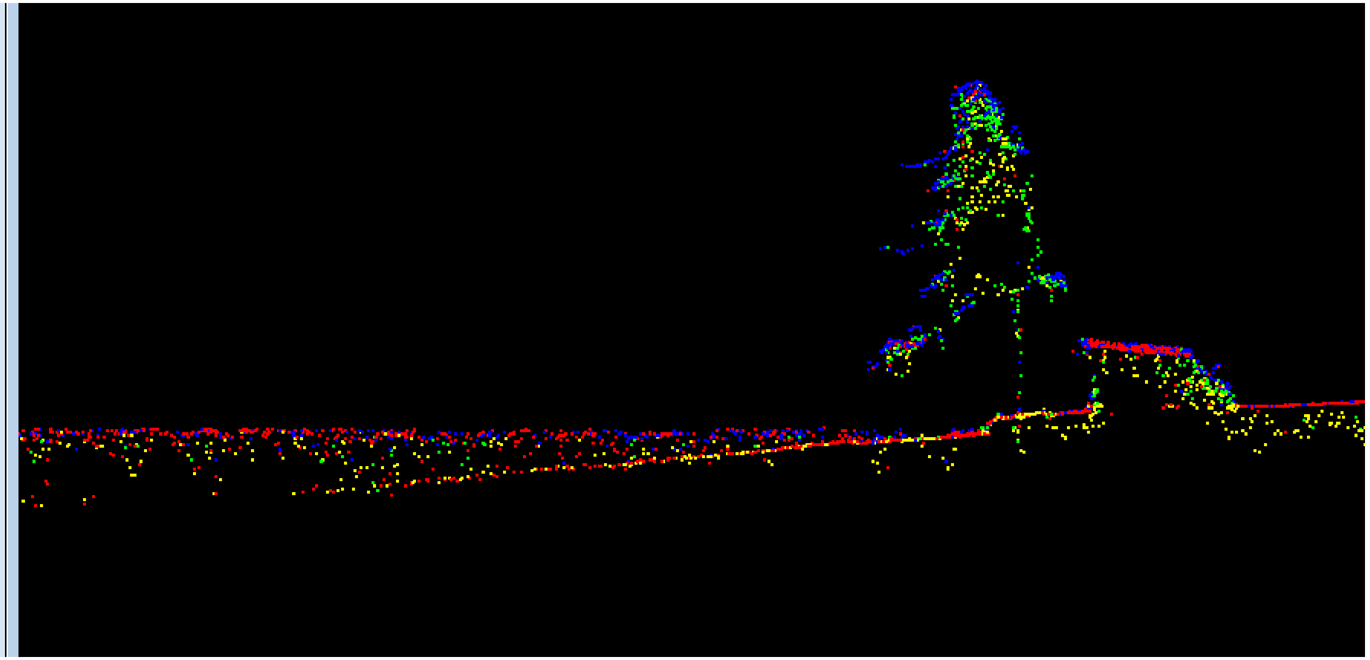
Sometimes good penetration with deciduous trees



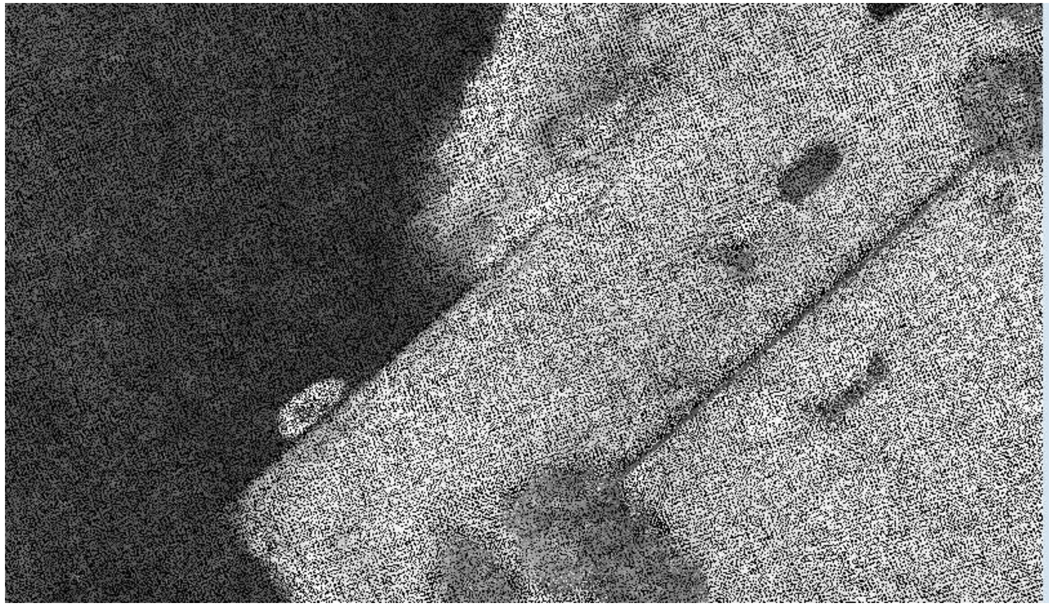


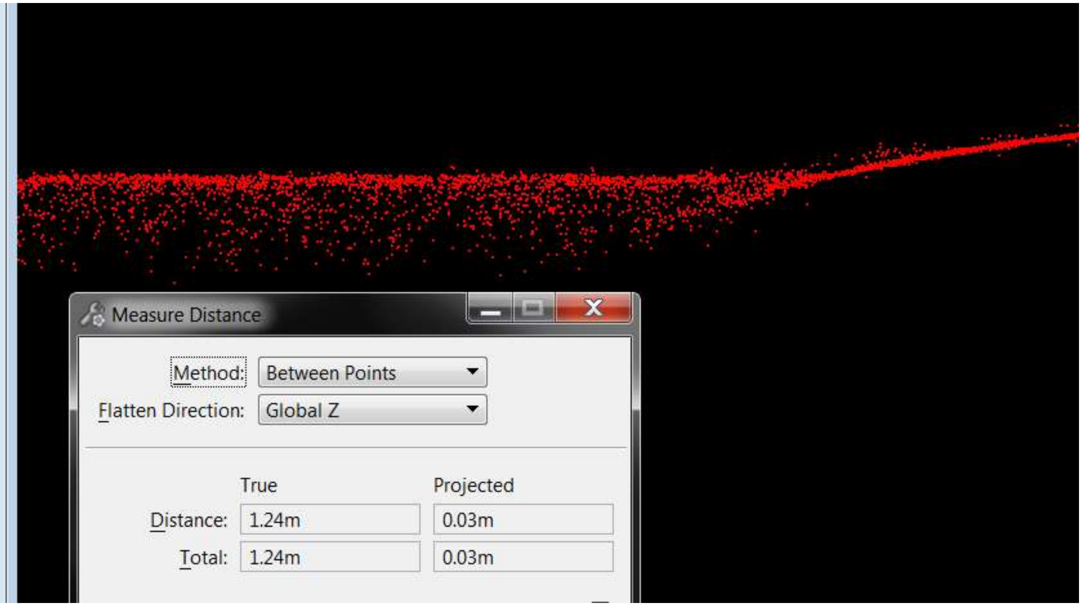
Penetration into water, large number of underground points



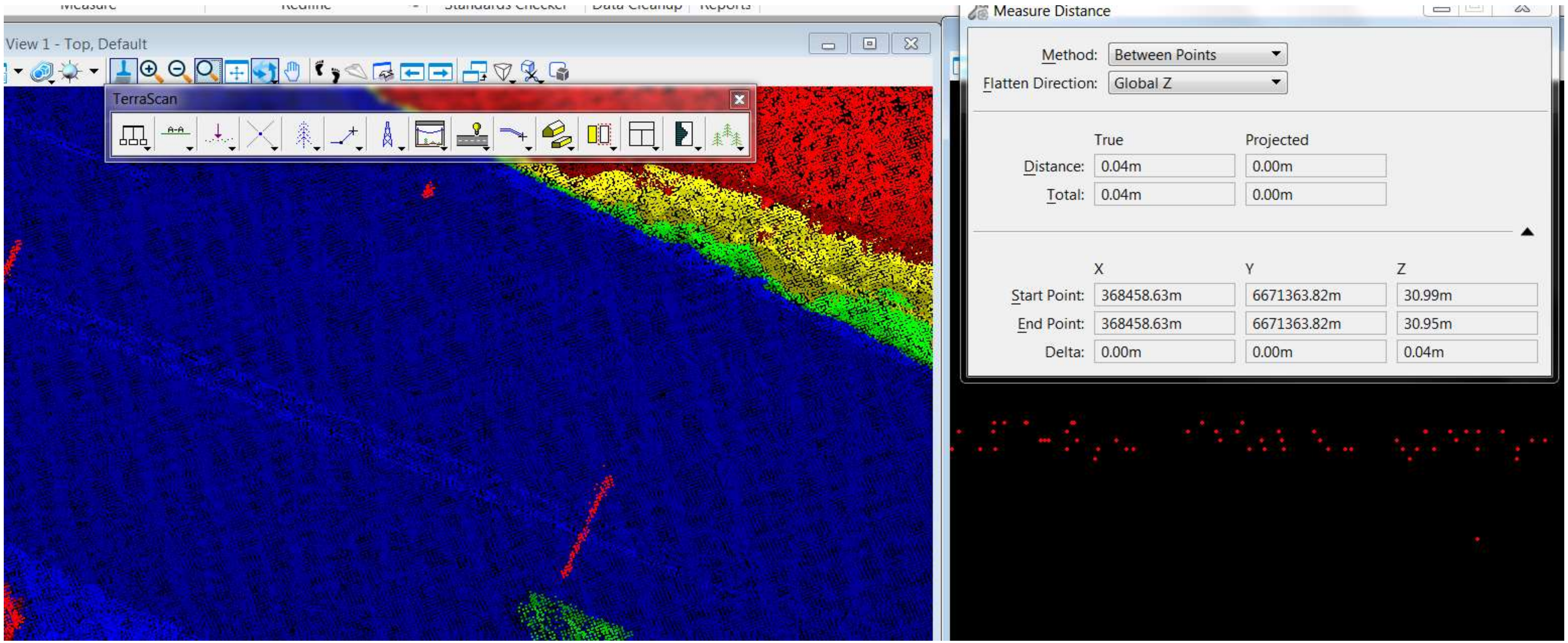


Dirty Water, Espoo, max penetration 1.24 m

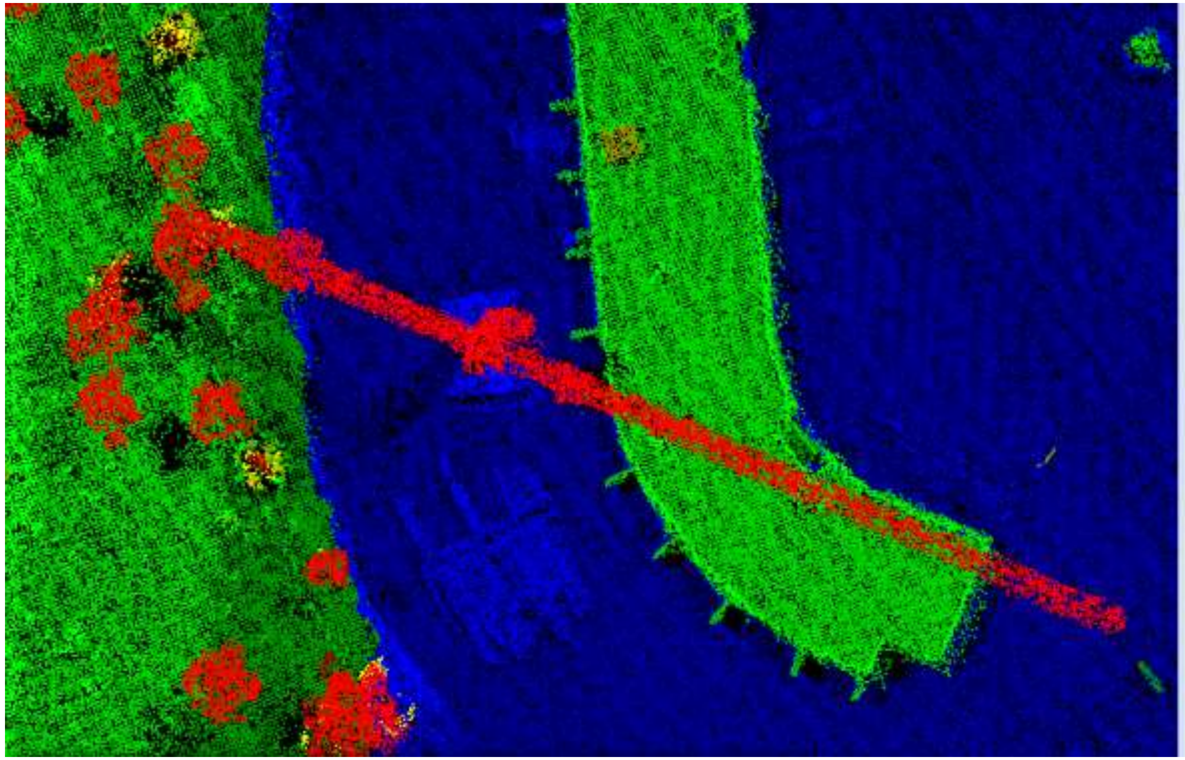


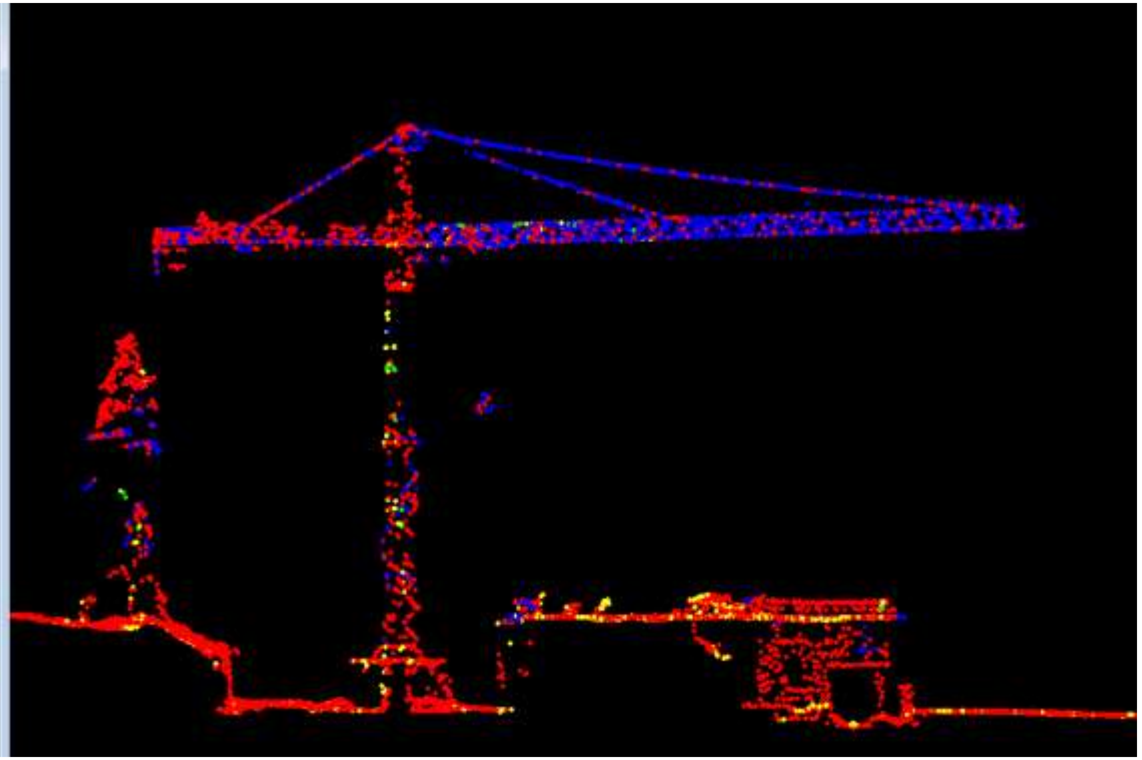


Asphalt road – elevation std 4 cm

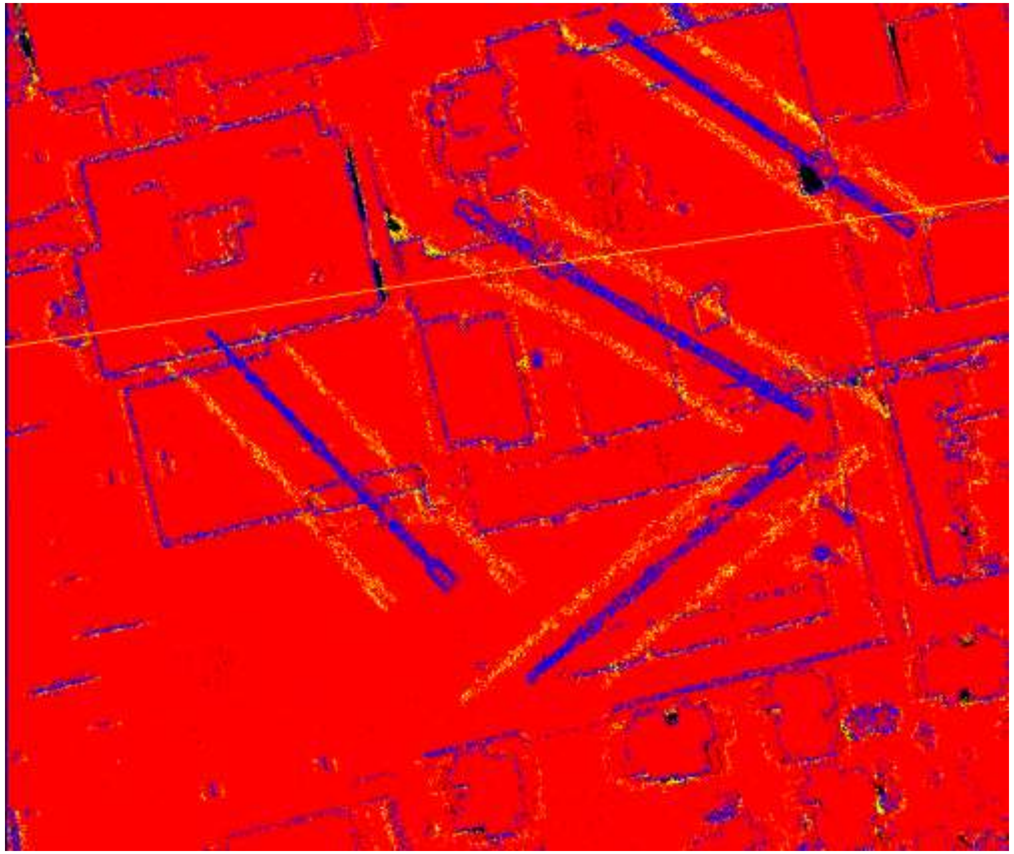


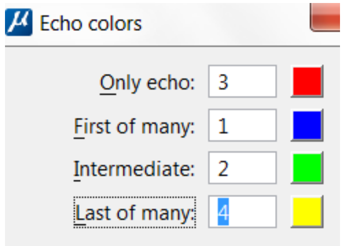
Details and different pulses in built environment



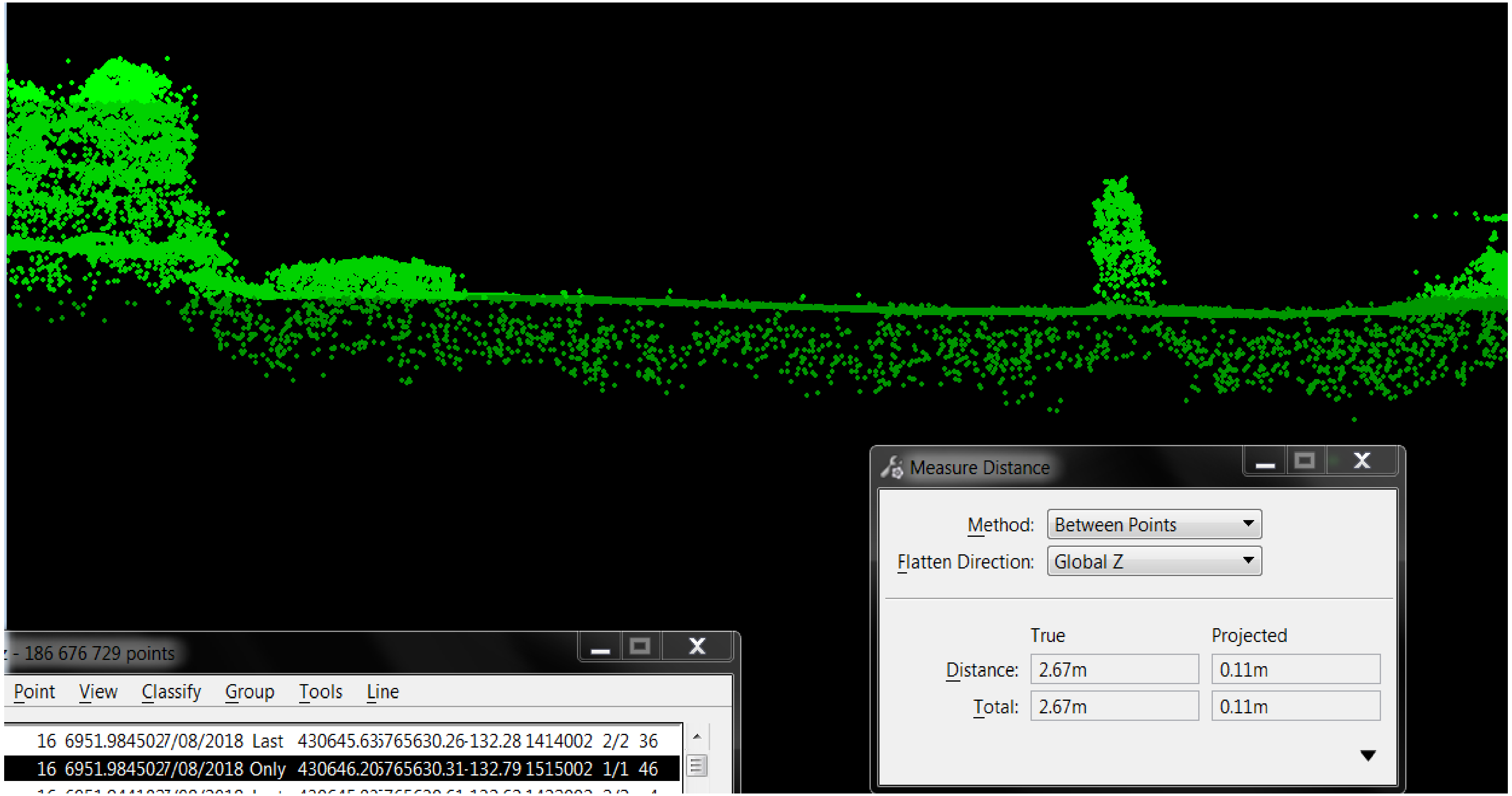


Shadows in the data using pulse information

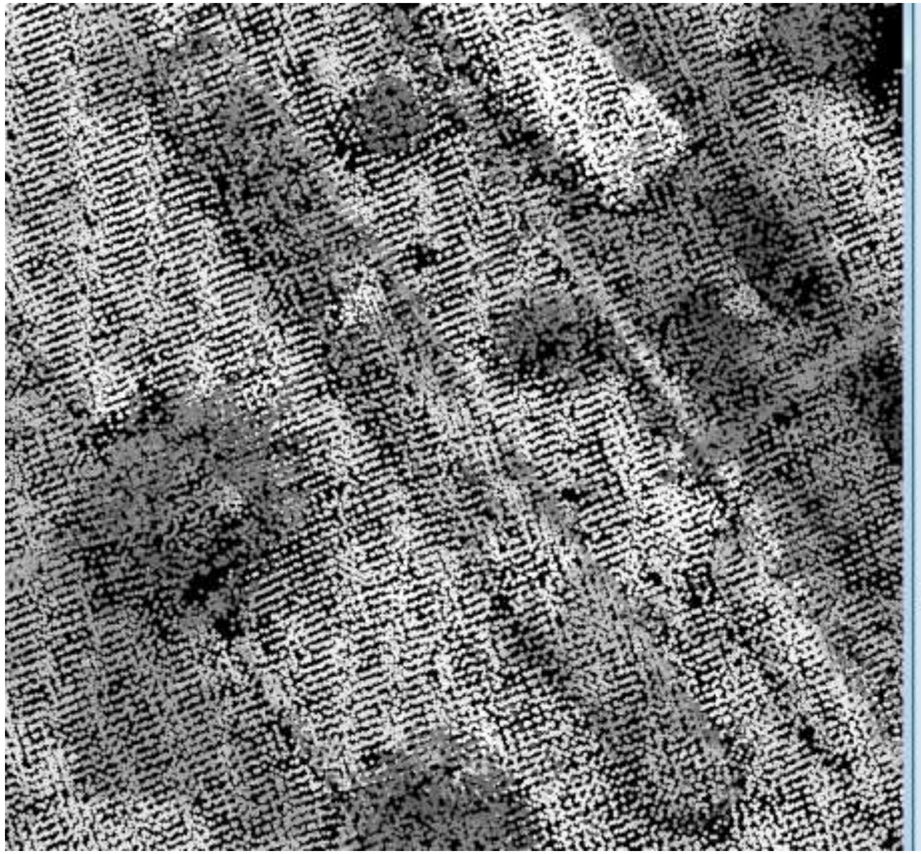


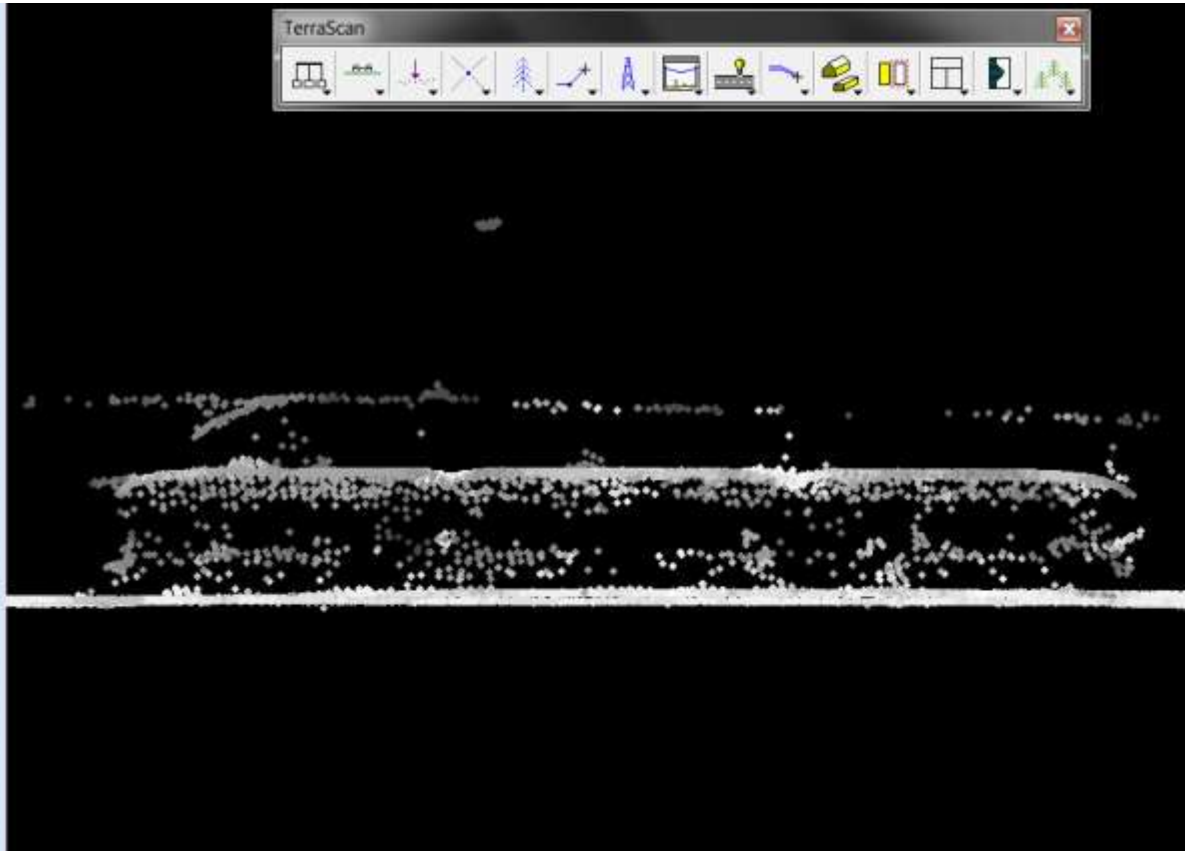


Ground points even 2m below ground level – filtering problem

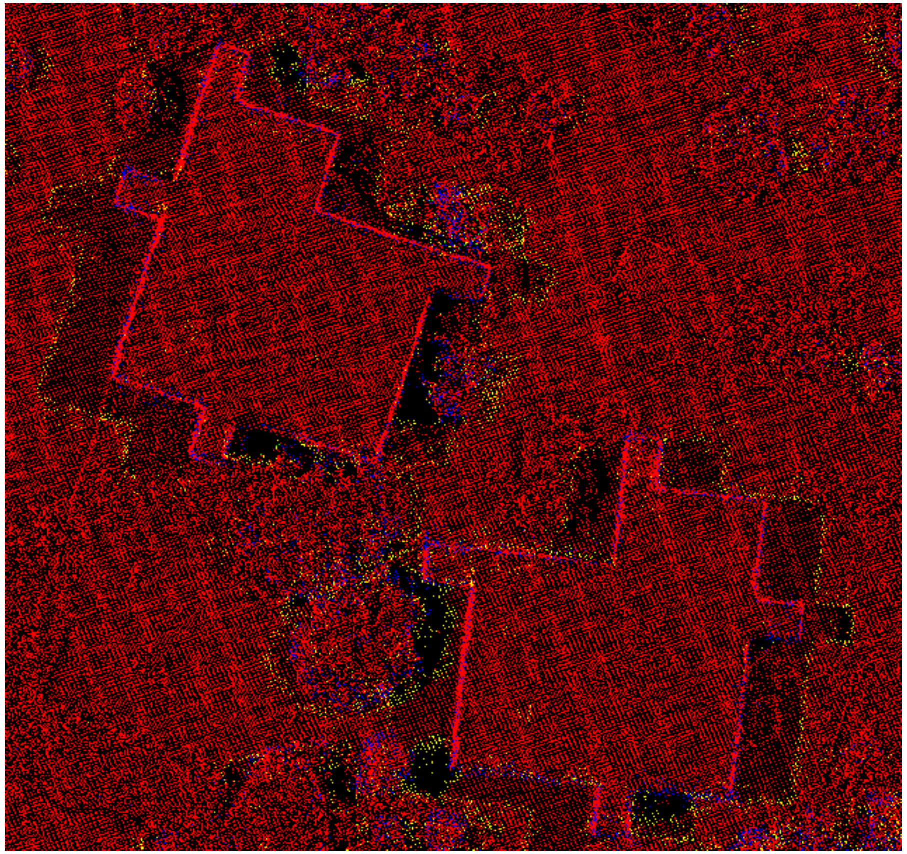


Tram – electric wires are visible

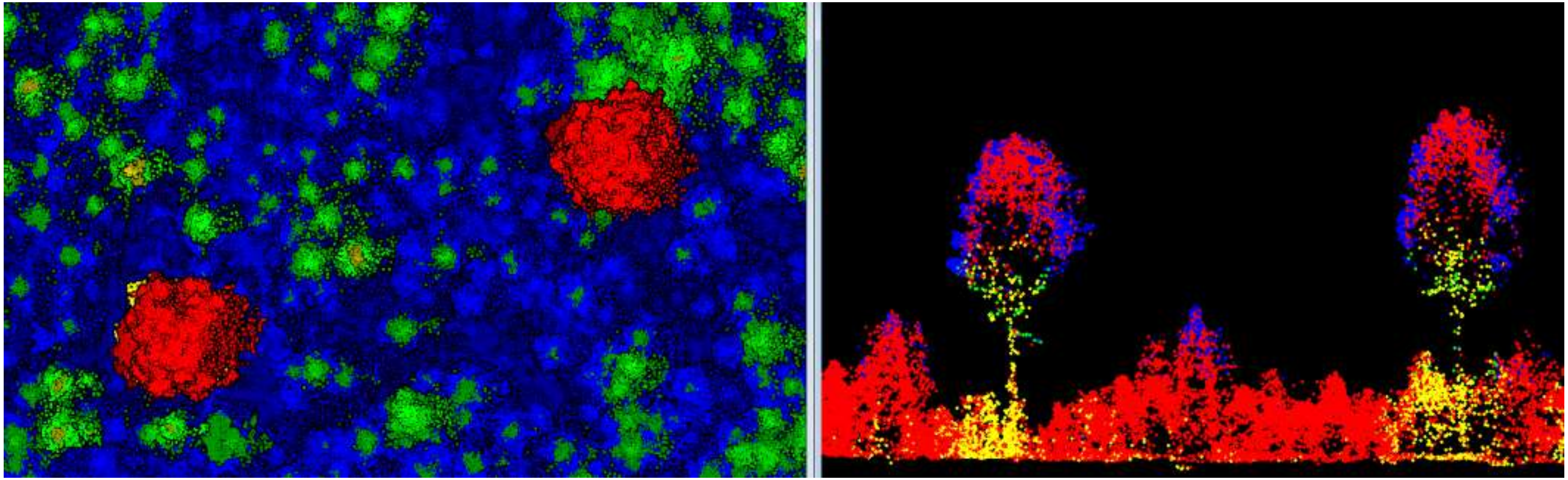




Shadows in building area



Pulse mode sometimes gives the storey numbering



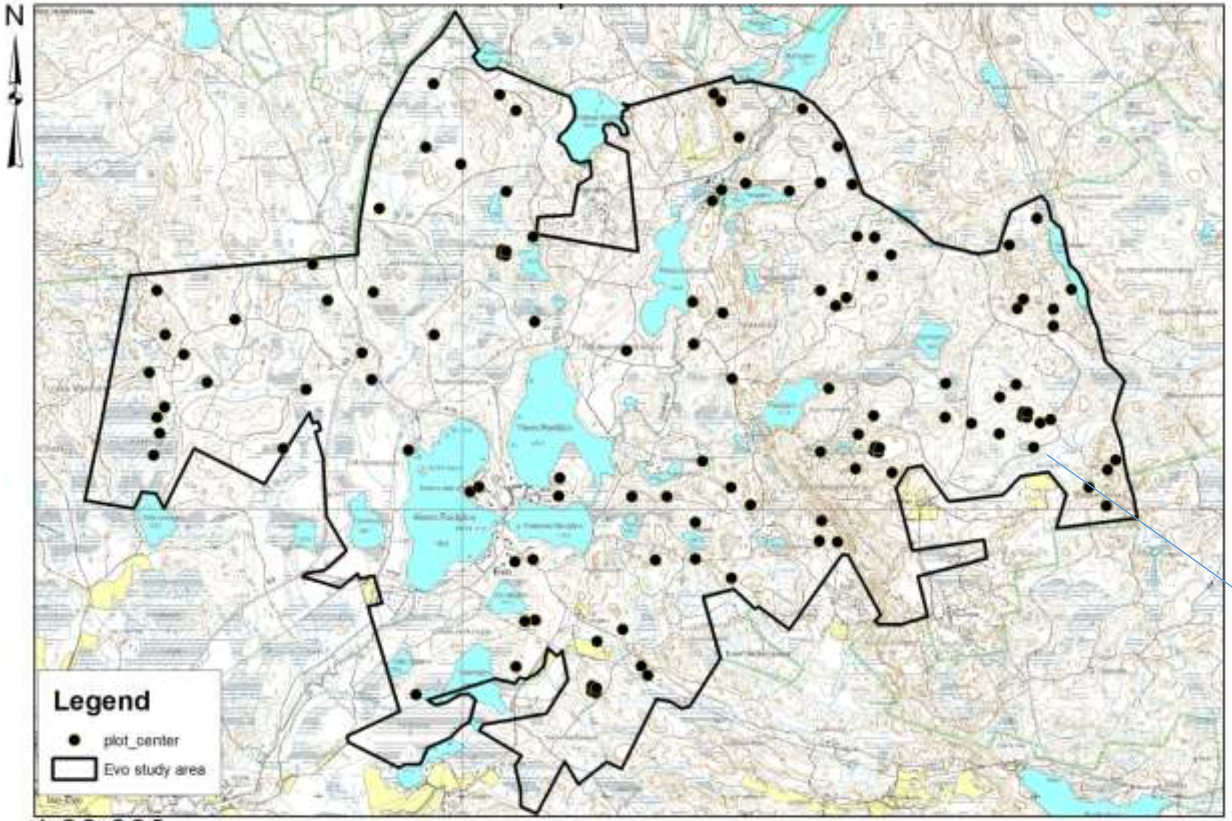
Tests with SPL100 for forests and DTM

Xiaowei Yu, Juha Hyyppä

Centre of Excellence in Laser scanning Research

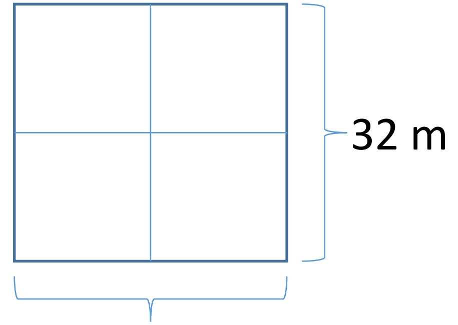
Study area and reference data

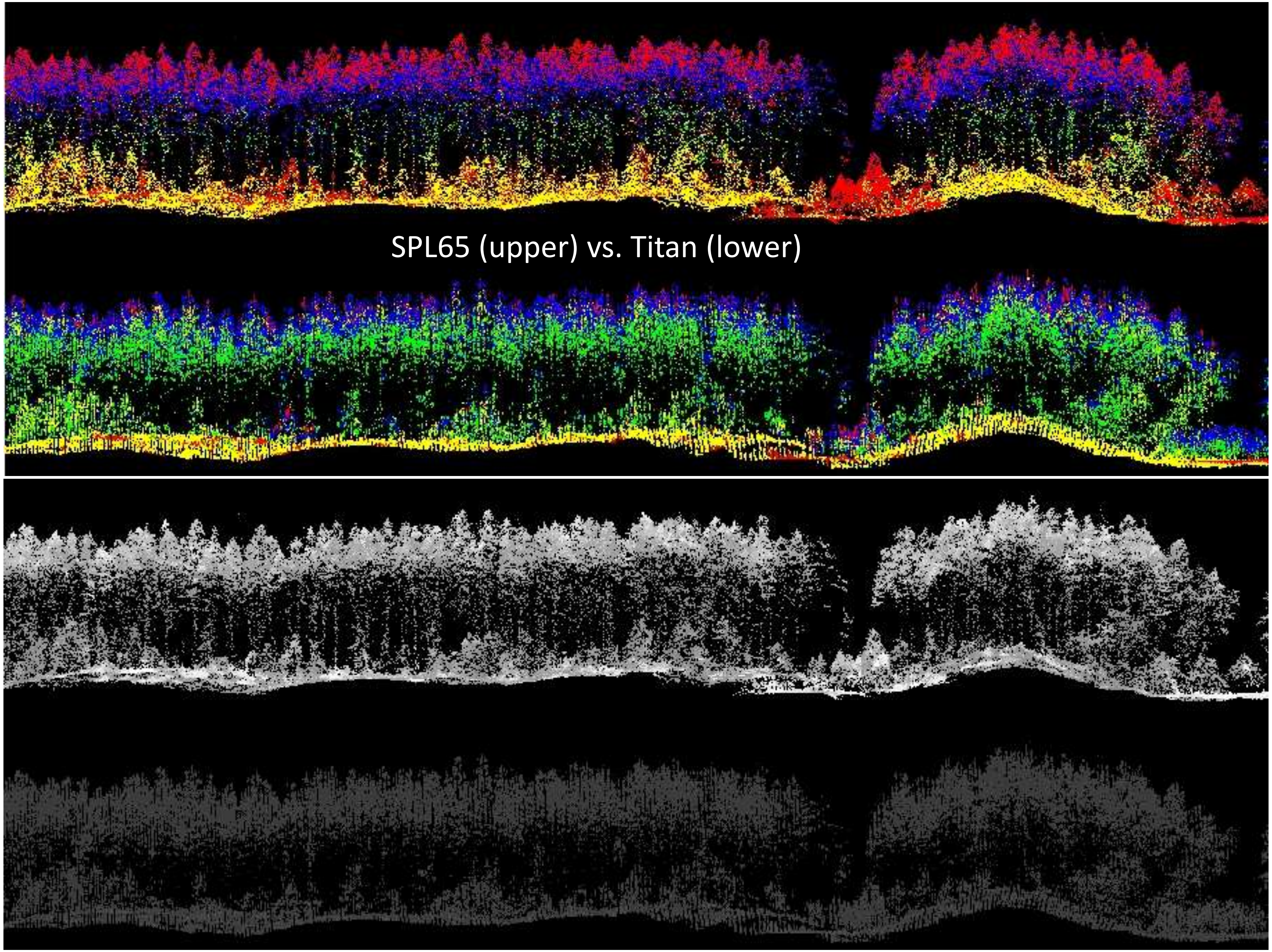
EVO test site and sample plots



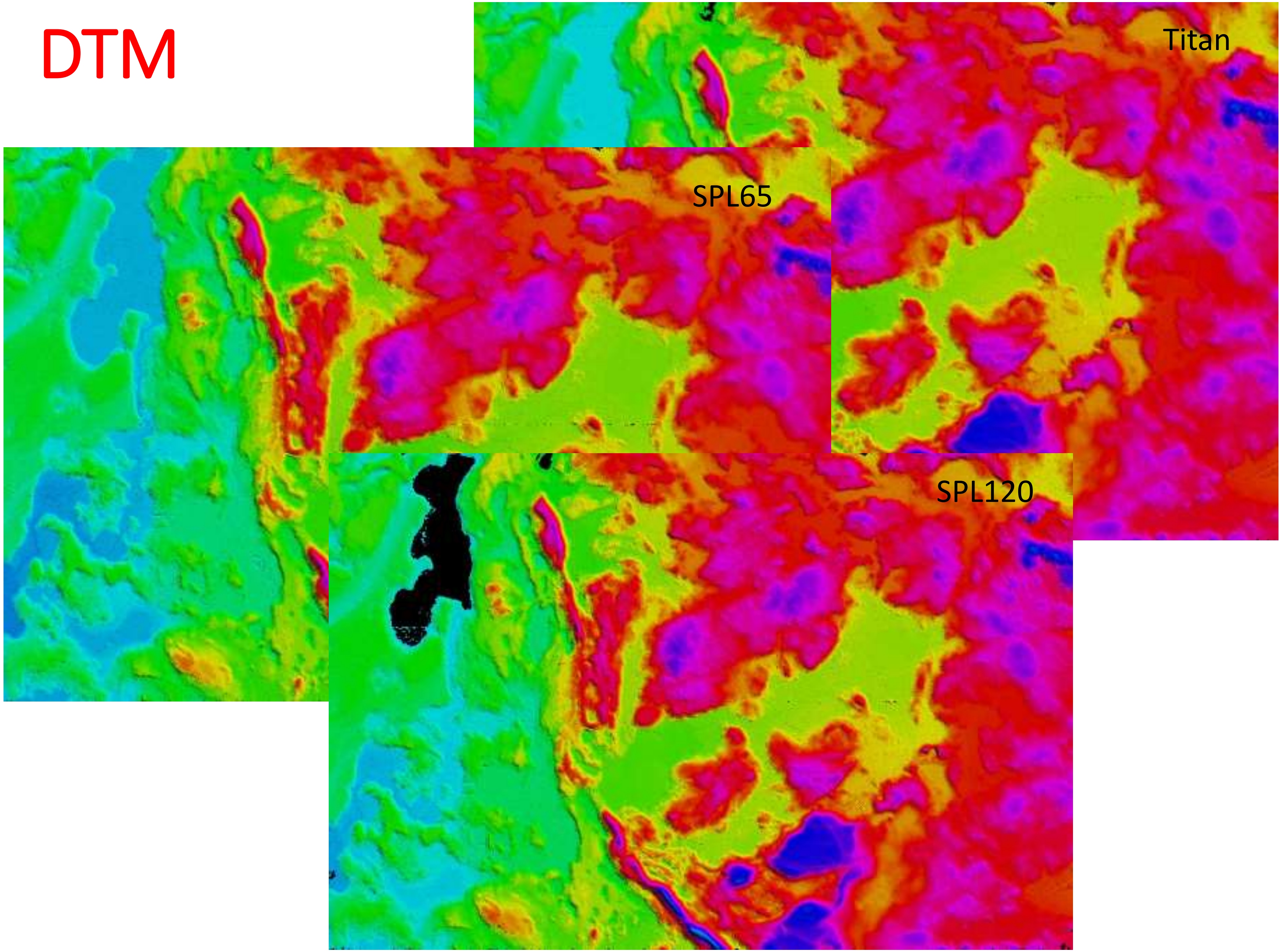
1:30 000

- <u>Reference data</u>
  - 91 sample plots of 32 m x 32 m
  - Dominant species:
    - Scots pine, Norway spruce, birch
  - Measurements:
    - tree height, DBH, tree species.

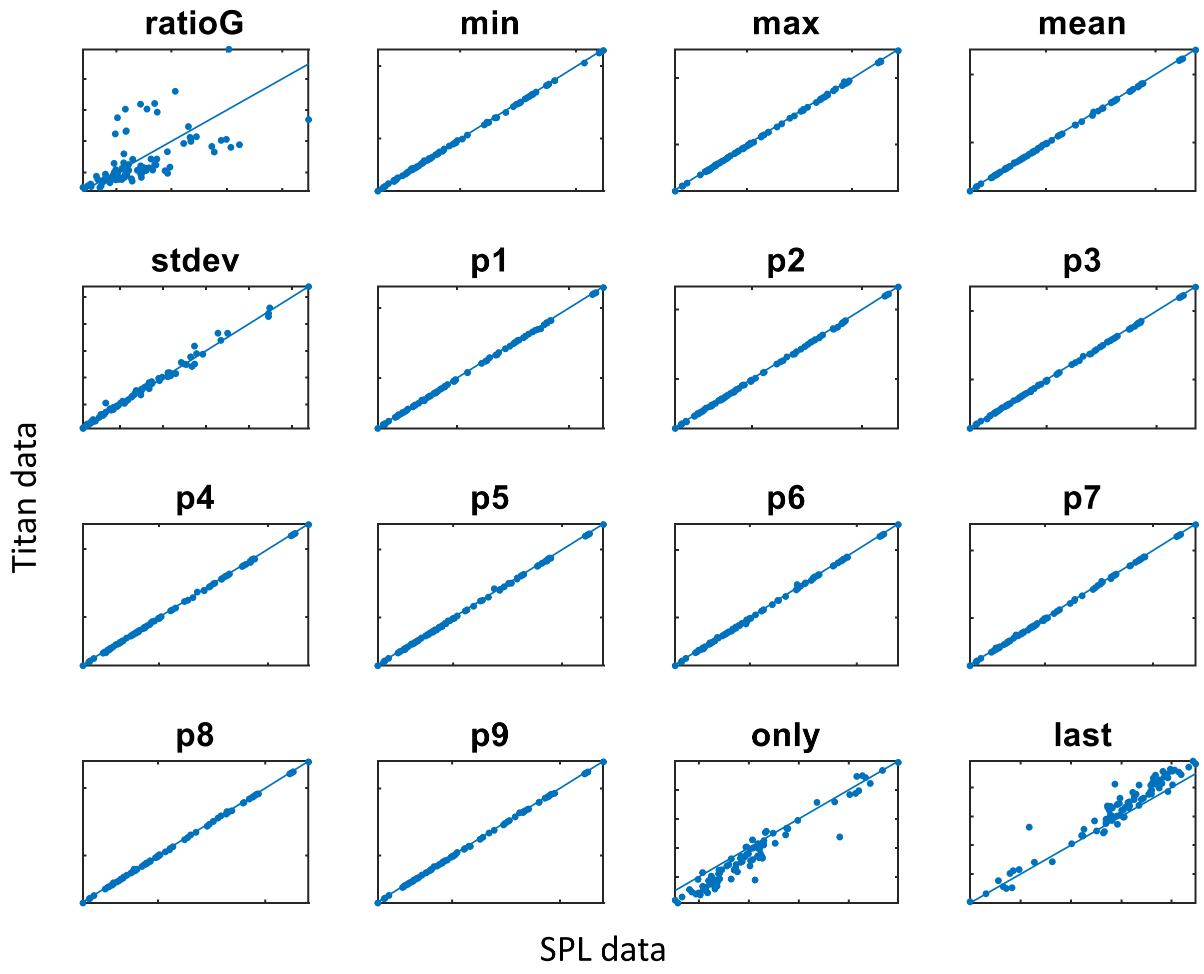



SPL65 (upper) vs. Titan (lower)

DTM



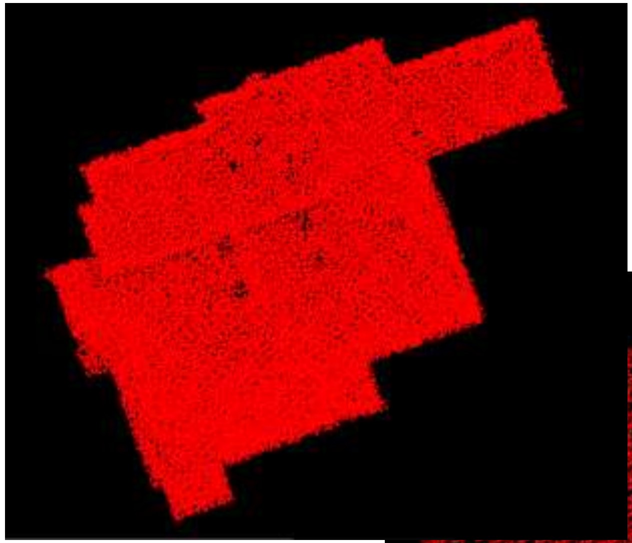
Features of ground points



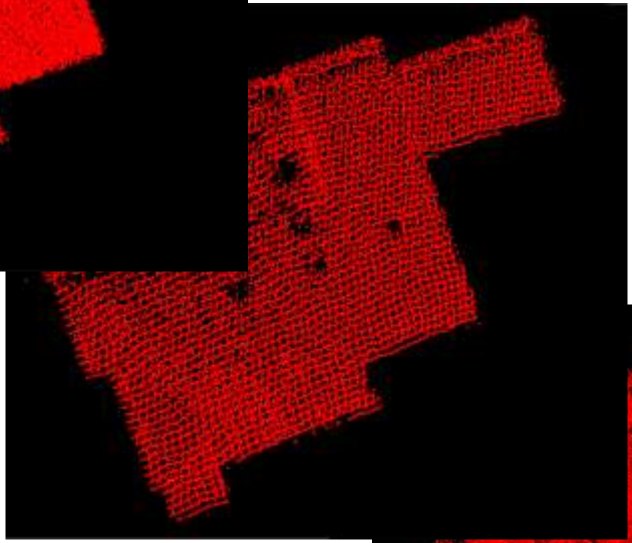
Tests with SPL100 for building mapping

Arttu Järvinen, Antero Kukko, Harri Kaartinen, Juha Hyyppä

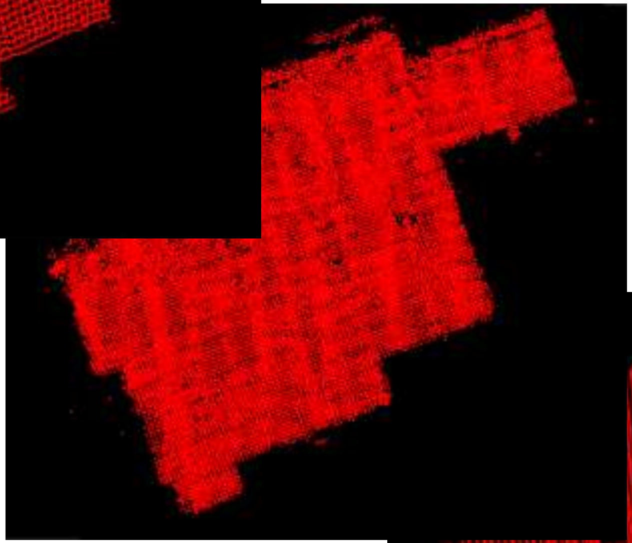
Centre of Excellence in Laser scanning Research



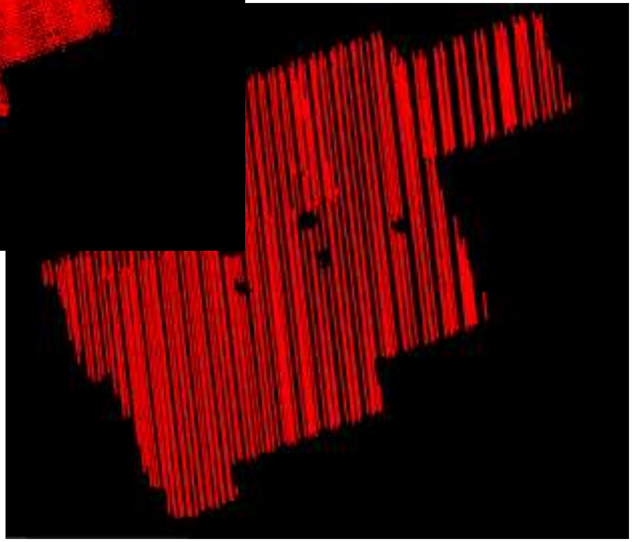
VUX



MiniVUX

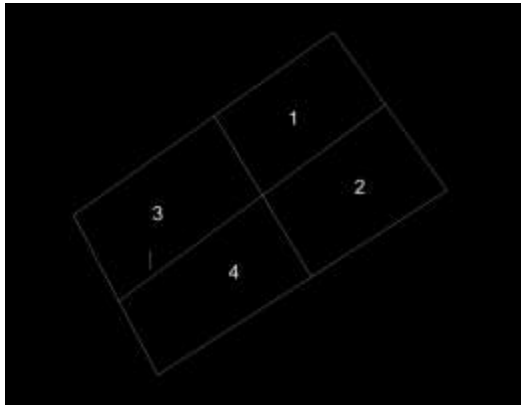


SPL-100



Titan

Testsite: Espoonlahti



~ 265 ha

Surface area differences (m2)

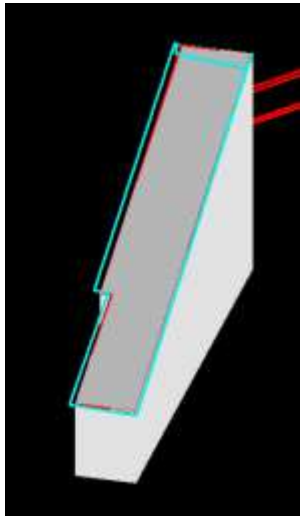
	Block of flats 1
VUX	**773,03**
miniVUX	+4,47
SPL-100_1	+19,25
SPL-100_2	--1,15
Titan	+36,68
Titan Ch1	+3,09
Titan Ch2	+15,09
Titan Ch3	+45,80

	Trash shelter
VUX	**33,69**
miniVUX	-3,93
SPL-100_1	+1,50
SPL-100_2	+3,19
Titan	+2,75
Titan Ch1	-0,46
Titan Ch2	-1,49
Titan Ch3	+4,05

	Car shelter
VUX	**130,22**
miniVUX	-6,36
SPL-100_1	+7,62
SPL-100_2	+0,70
Titan	-0,99
Titan Ch1	-5,57
Titan Ch2	-2,67
Titan Ch3	+13,17

	Warehouse
VUX	**567,20**
miniVUX	-7,39
SPL-100_1	+10,59
SPL-100_2	+32,54
Titan	+44,15
Titan Ch1	+5,59
Titan Ch2	+14,92
Titan Ch3	+59,27

	Block of flats 2
VUX	**854,75**
miniVUX	+33,77
SPL-100_1	+107,30
SPL-100_2	+31,98
Titan	+33,18
Titan Ch1	-4,61
Titan Ch2	+0,16
Titan Ch3	+52,71

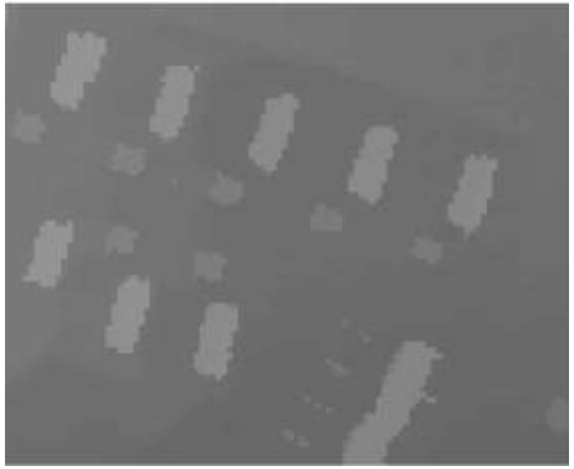


Simulation of multispectral single photon data for mapping/land cover classification

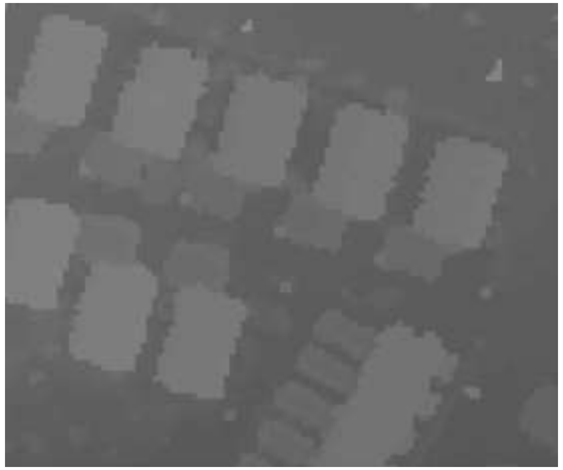
Leena Matikainen, Paula Litkey, Kirsi Karila, Eero Ahokas
Juha Hyyppä

Centre of Excellence in Laser scanning Research

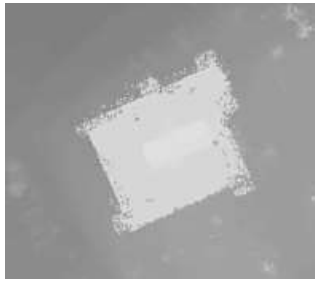
Some DSM experiments



SPL, Min height, 100 cm

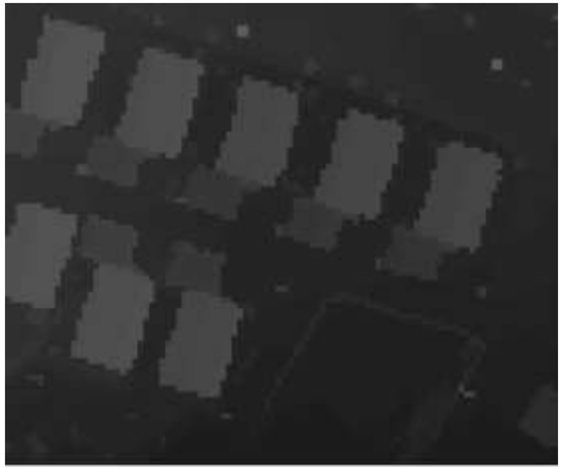


SPL, Max height, 100 cm



SPL, Min height, 100 cm / 20 cm

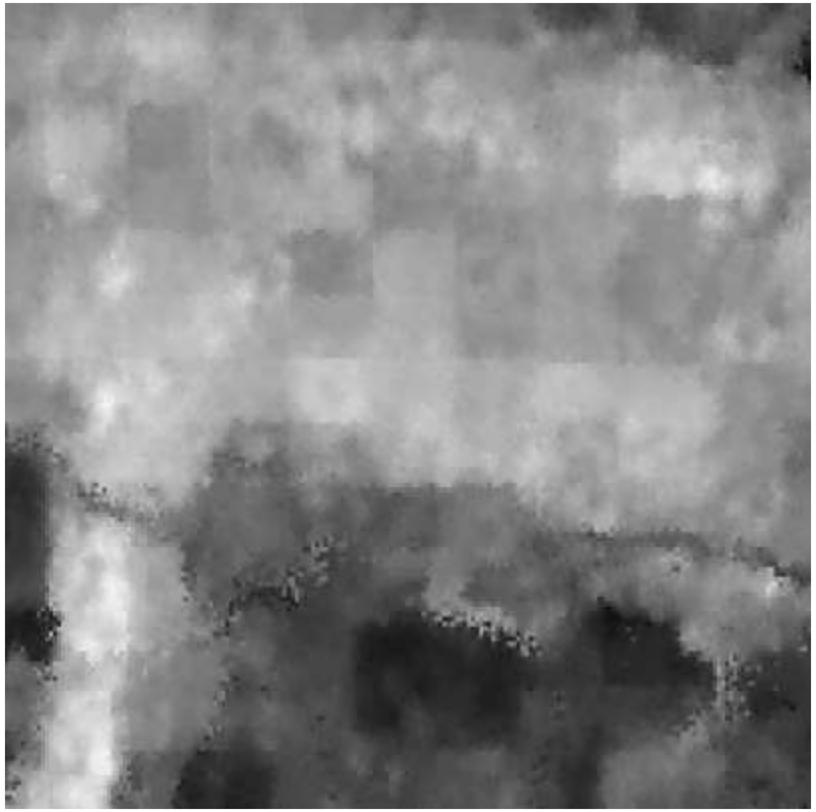
Another laser dataset, Min height, 100 cm

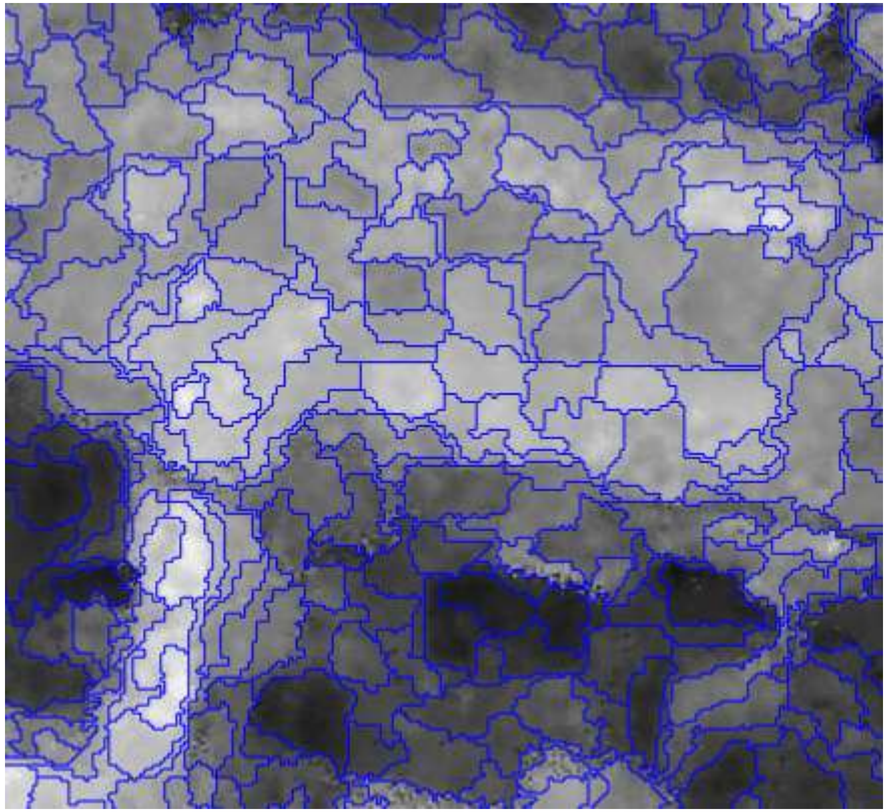


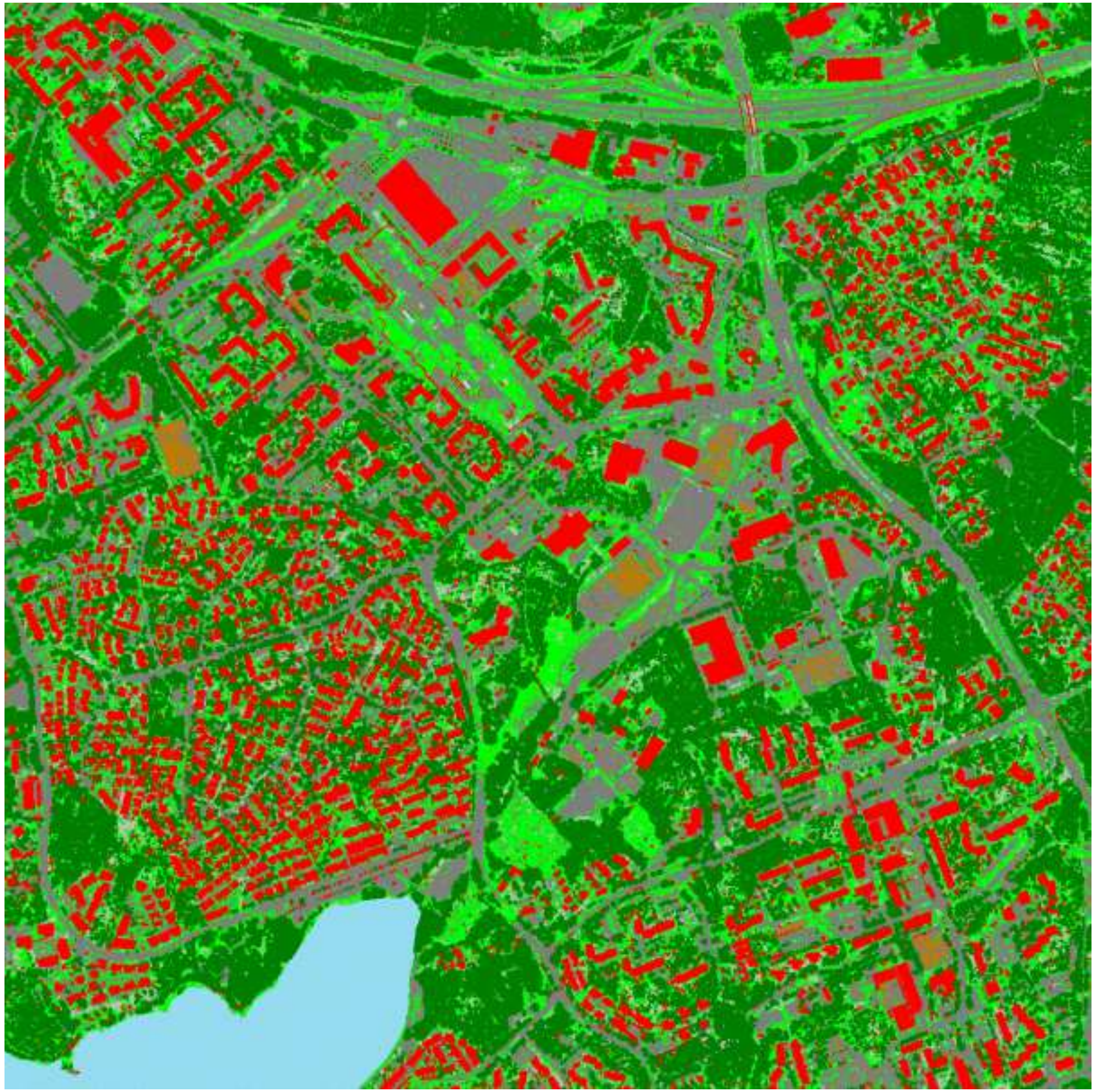
Another laser dataset, Max height, 100 cm

- Processing methods used for other laser scanner datasets are not necessarily directly applicable to SPL data
- More experiments are needed

Intensity has some block structure

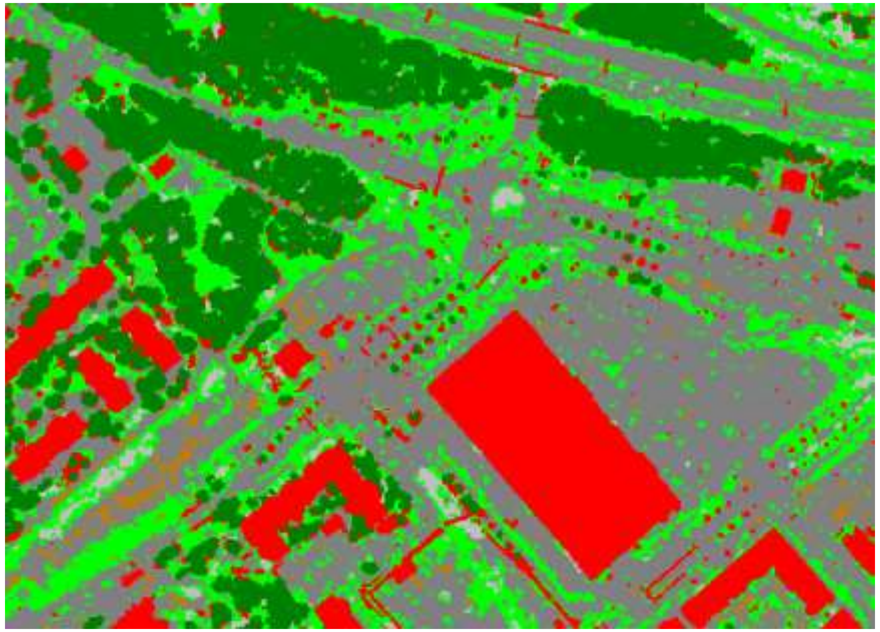






Automatic classification of SPL data into 6 land cover classes

- Results are acceptable on a coarse level
- Details such as narrow roads are not accurately detected



Towards Autonomous Single Photon System

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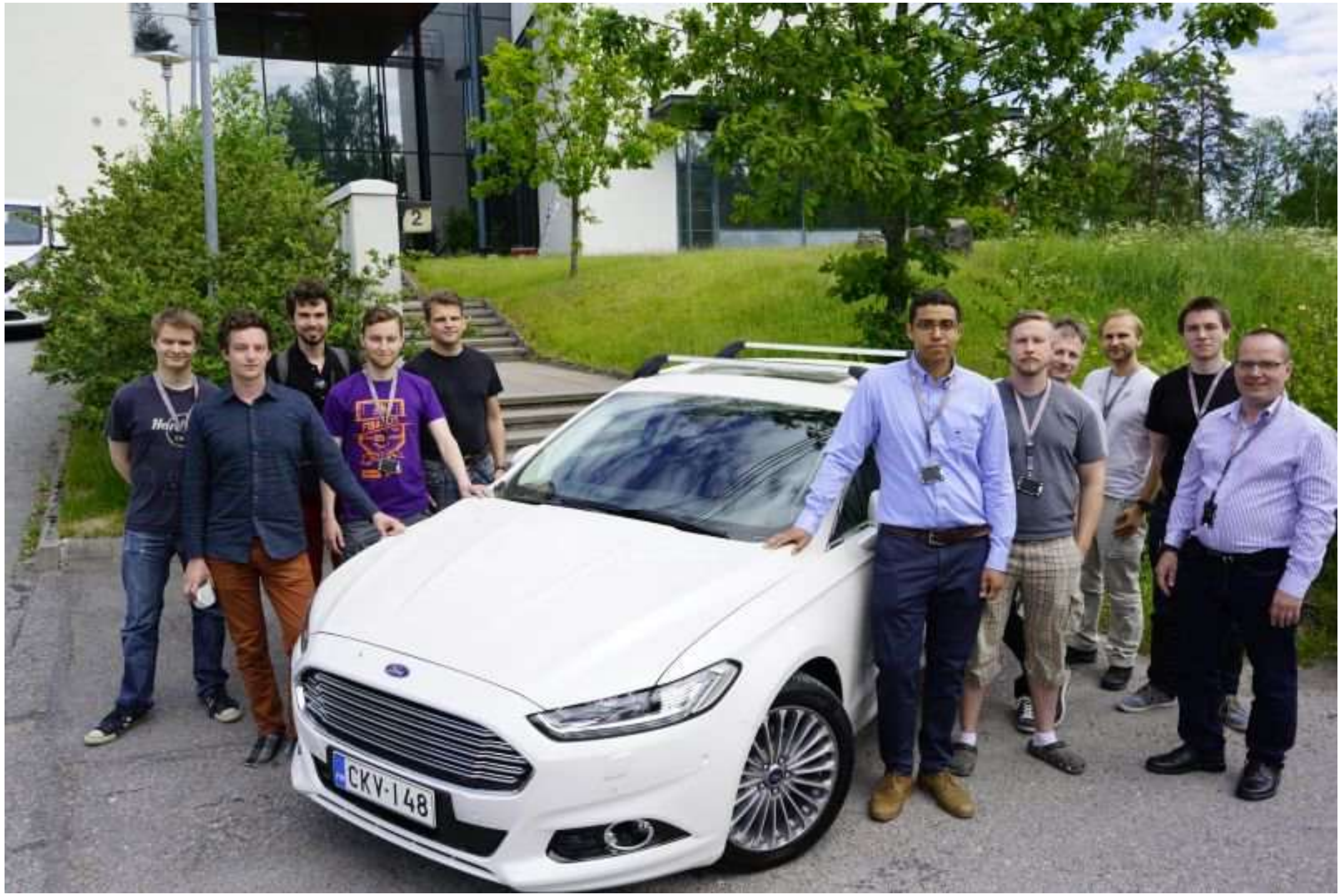
Centre of Excellence in Laser scanning Research

FGI Autonomous Driving Research Team



Longest range flash LiDAR

Developed in 6 months in 2018

Created in collaboration between FGI and industry

Inventors and creators FGI researchers Dr. Anttoni Jaakkola and Tero Heinonen