

Modern LIDAR Sensor Technologies - an Overview

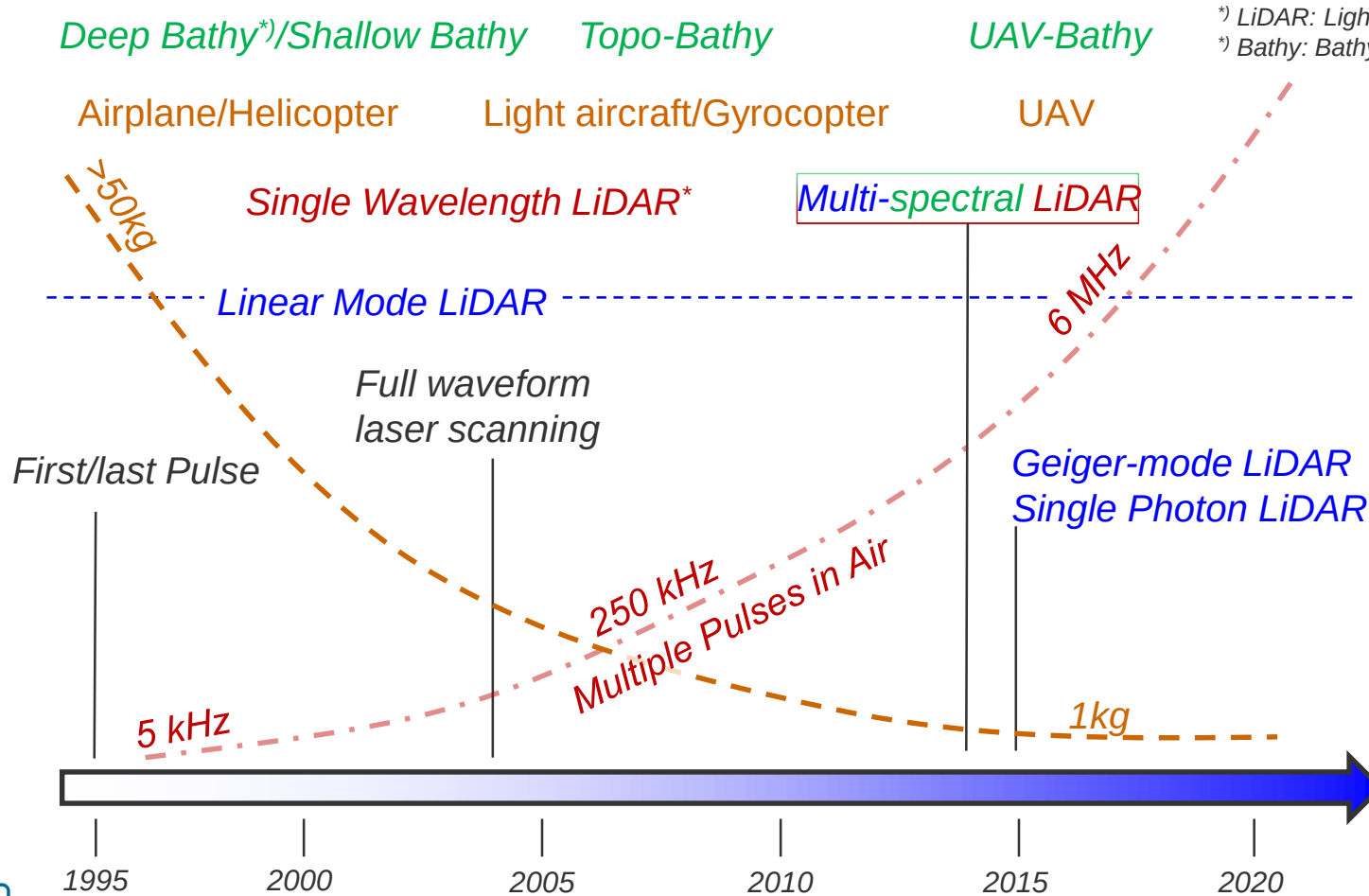
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University of Stuttgart, Institute for Photogrammetry

Timeline Airborne Laser Scanning



^{*)} LiDAR: Light Detection And Ranging

^{*)} Bathy: BathymetryHydrographie

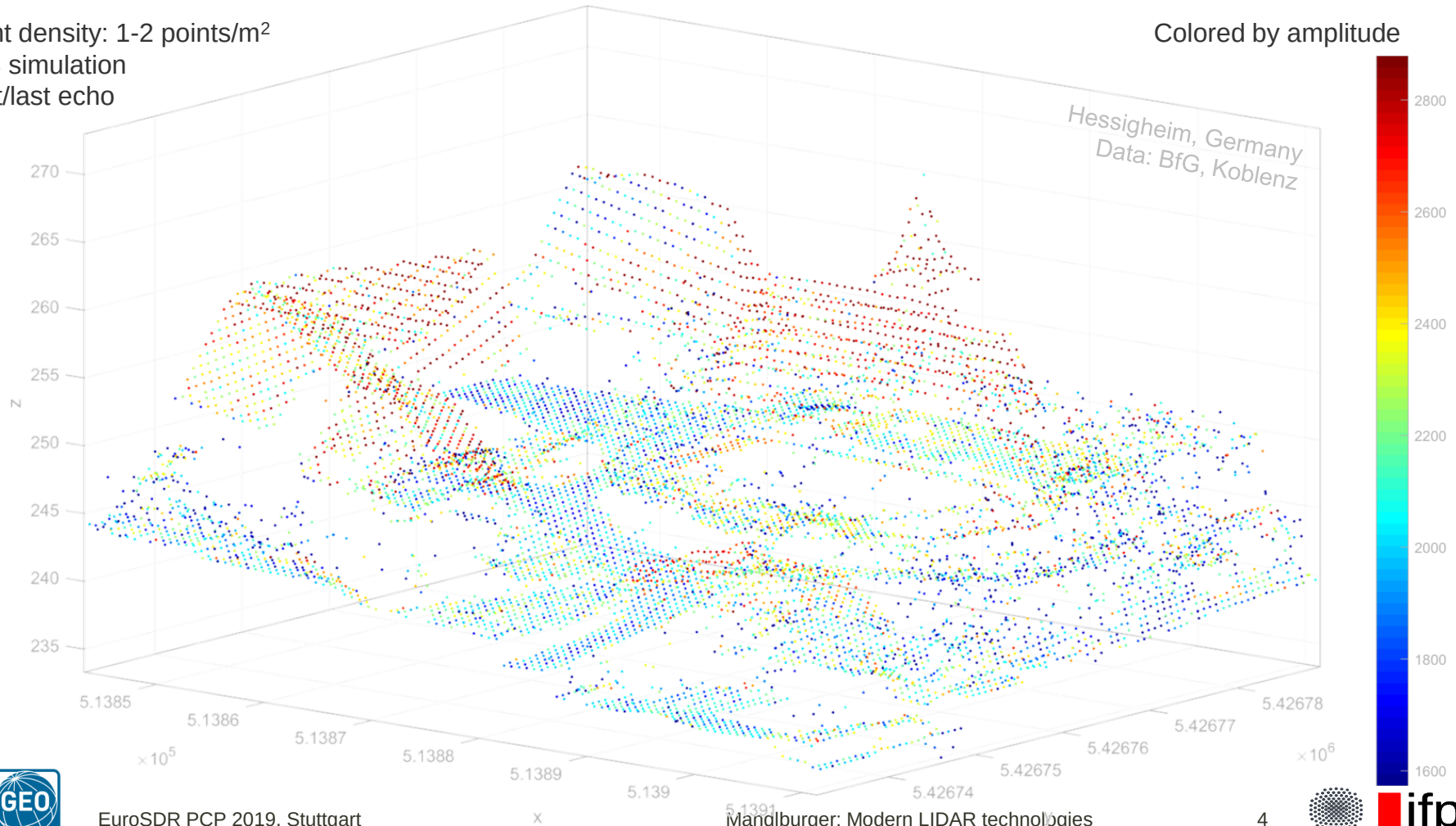
Timeline Airborne Laser Scanning – 1997

Point density: 1-2 points/m²

ALS simulation

First/last echo

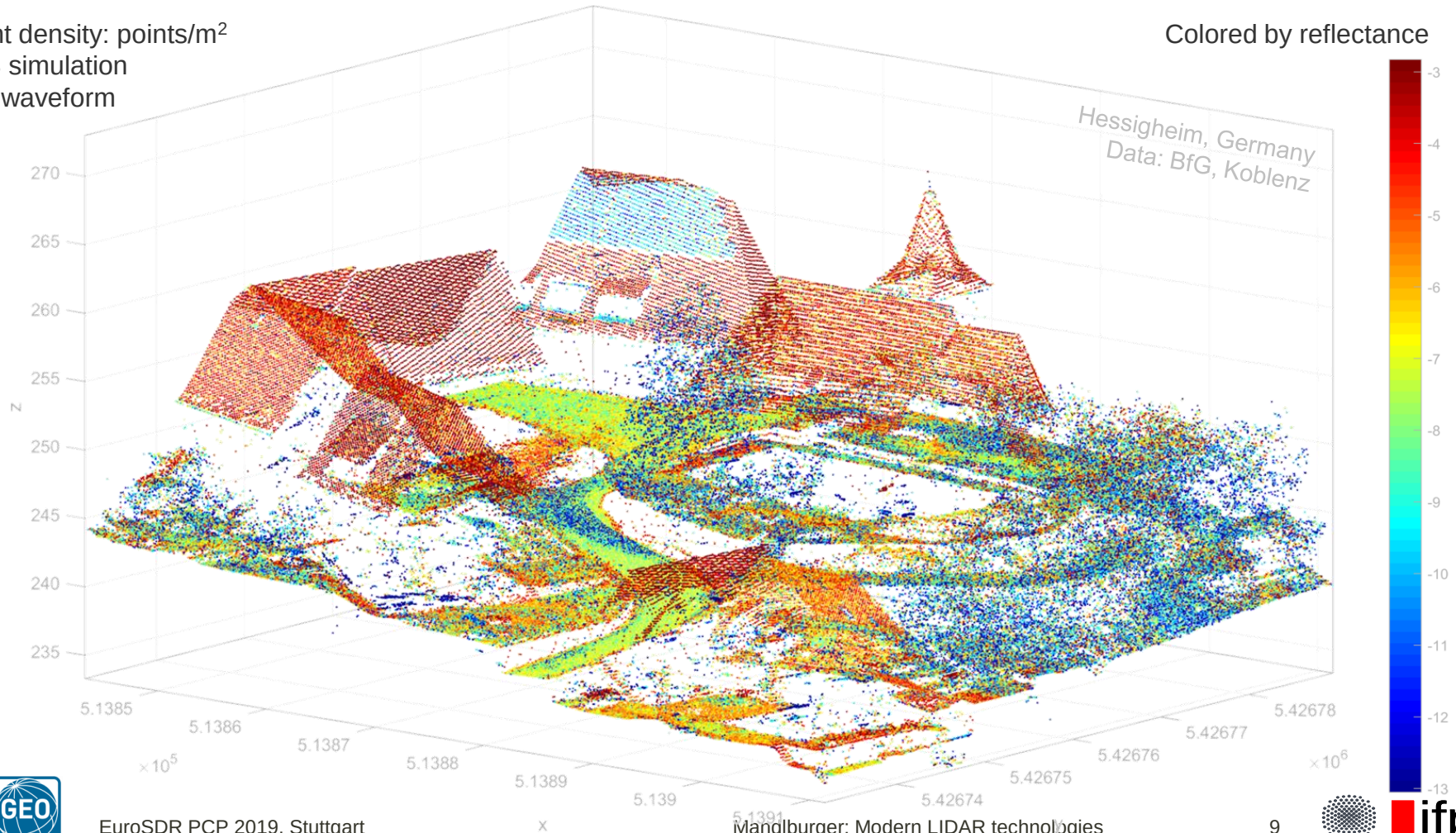
Colored by amplitude



Timeline Airborne Laser Scanning – 2015

Point density: points/m²
ALS simulation
Full waveform

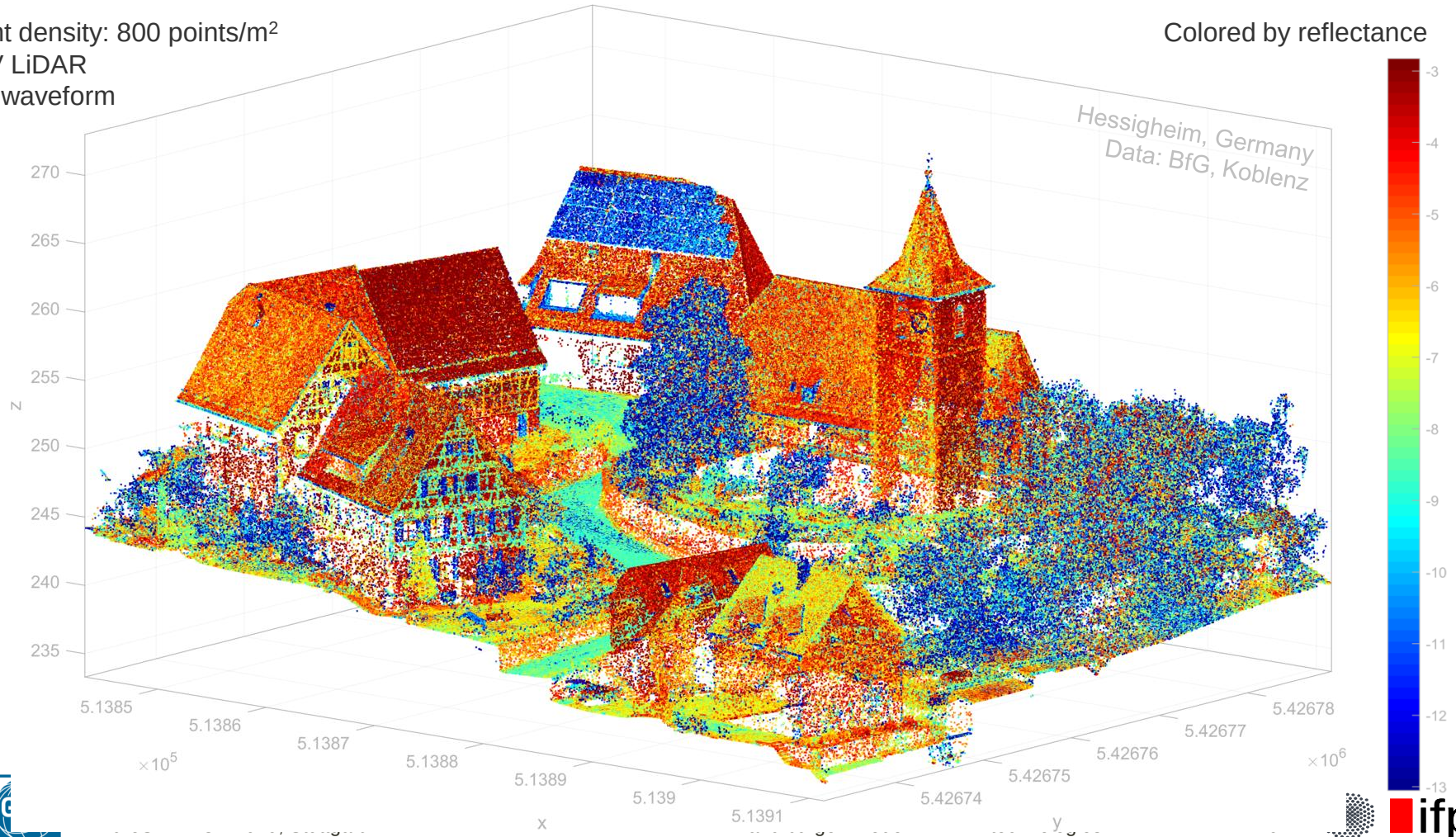
Colored by reflectance



Timeline Airborne Laser Scanning – 2019

Point density: 800 points/m²
UAV LiDAR
Full waveform

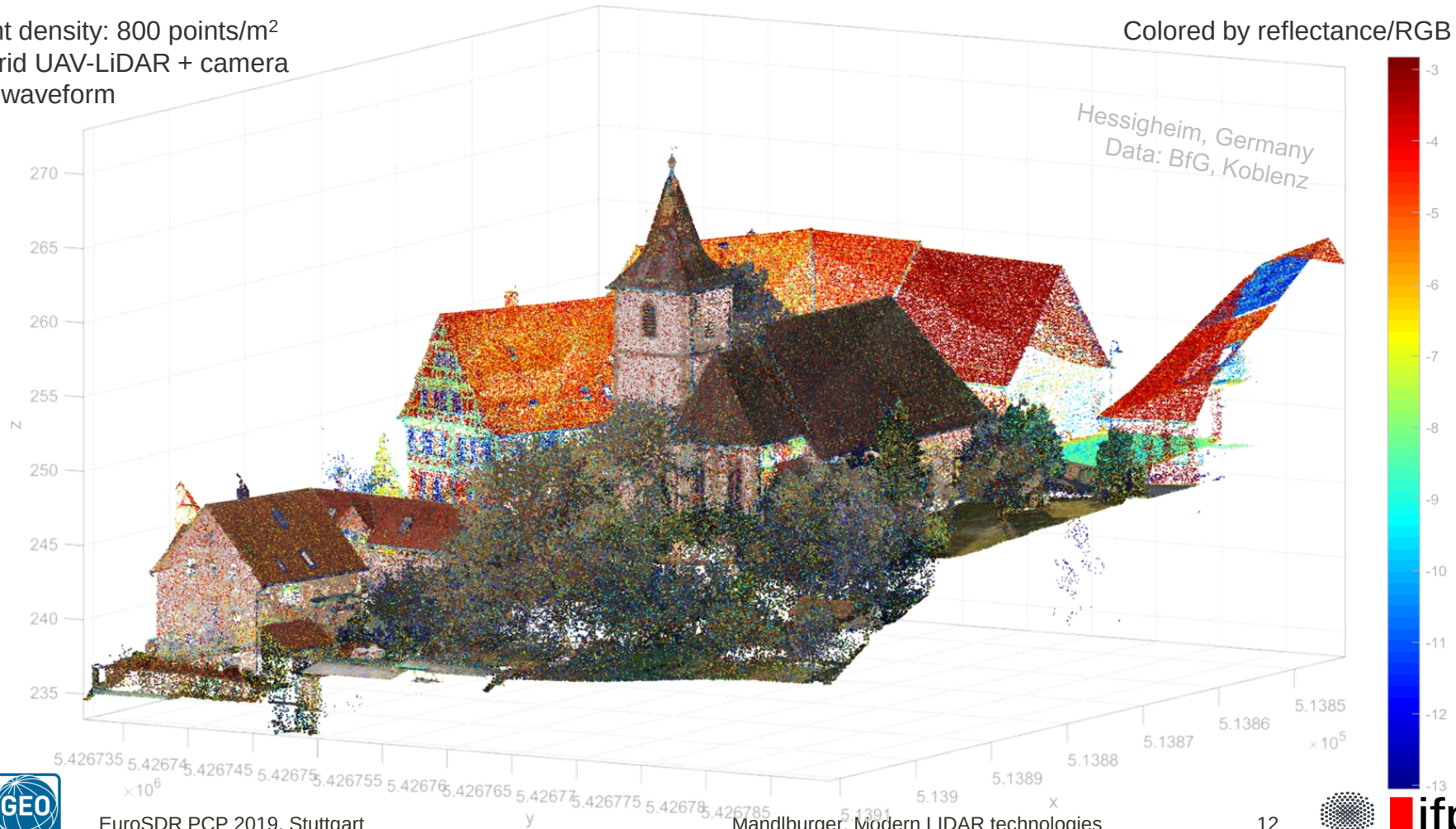
Colored by reflectance



Timeline Airborne Laser Scanning – 2019

Point density: 800 points/m²
Hybrid UAV-LiDAR + camera
Full waveform

Colored by reflectance/RGB



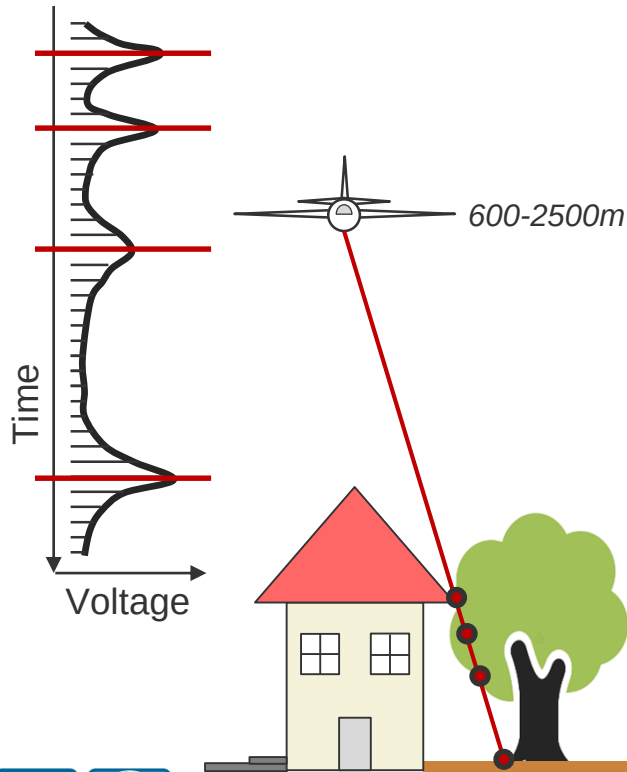
Contents

- LiDAR basics: Geometry and radiometry
- Target detection: From discrete to returns to full waveform LiDAR
- Laser wavelengths: From single wavelength to multispectral LiDAR
- Below water: From topography to bathymetry
- Detector technology: From linear-mode to Single Photon LiDAR
- Sensor systems: From single purpose scanners to hybrid sensor systems
- Platforms: From manned platforms to UAV LiDAR (Topo+Bathy)

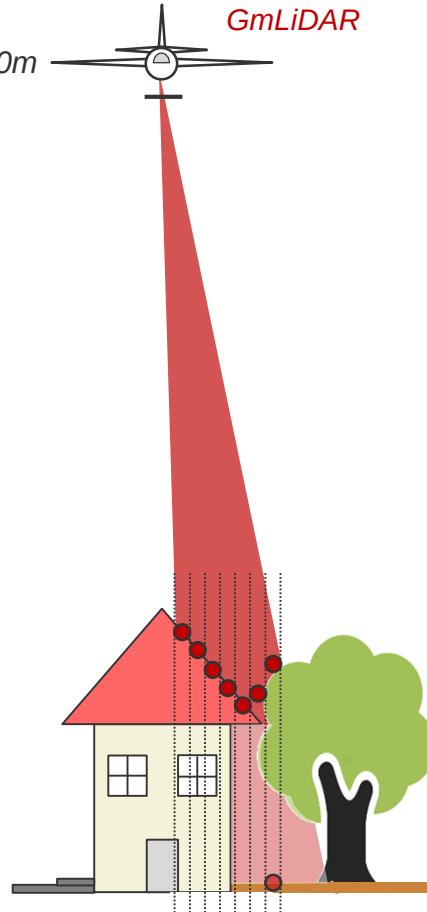
Linear mode– Geiger mode – Single Photon

Comparison: single laser pulse

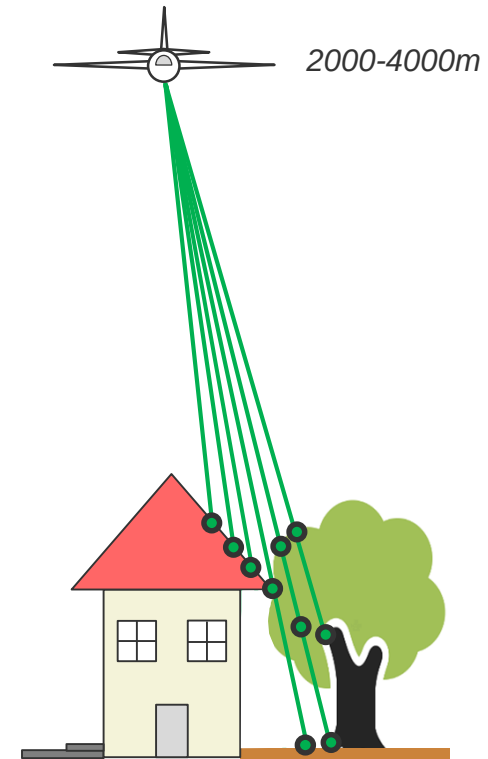
Linear-mode waveform LiDAR



4000-10000m **GmLiDAR**

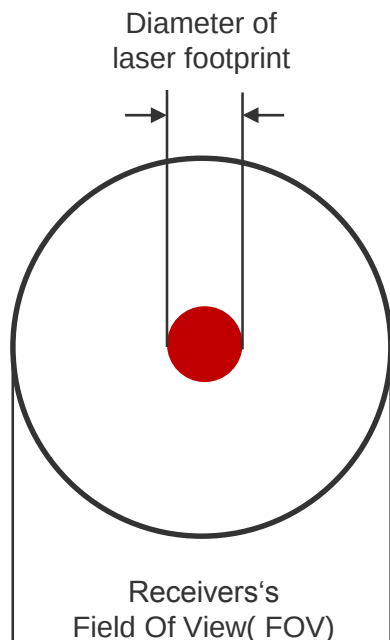


Single Photon LiDAR



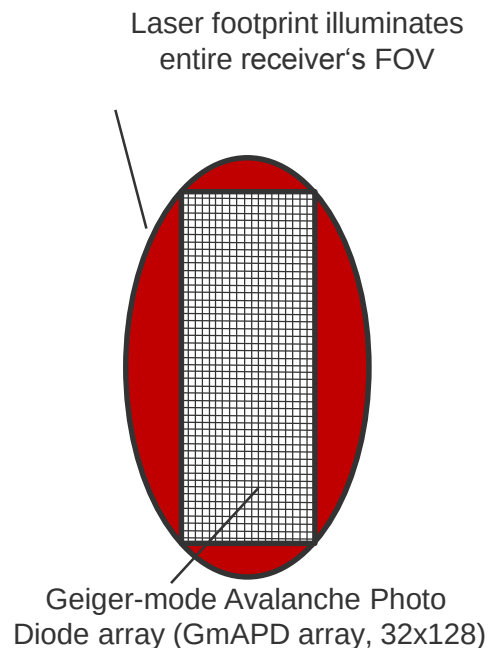
Linear-mode vs Single Photon LiDAR

Conventional LiDAR Linear-mode LiDAR



1 transmitter → 1 receiver
(full waveform)

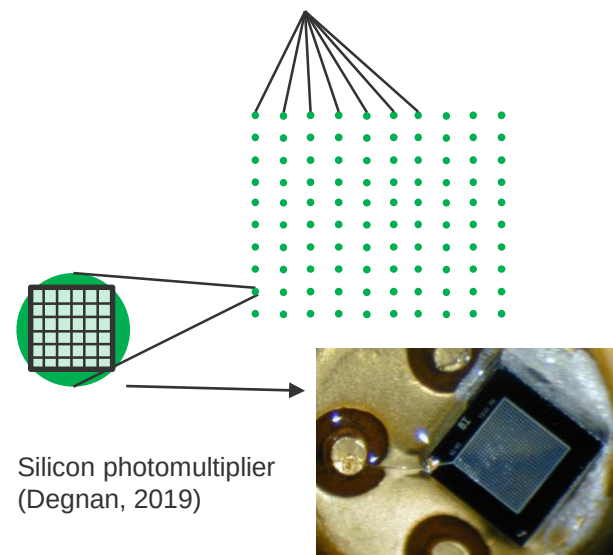
Geiger-mode LiDAR



1 transmitter → 4096 receivers
(binary detectors)

Single Photon LiDAR

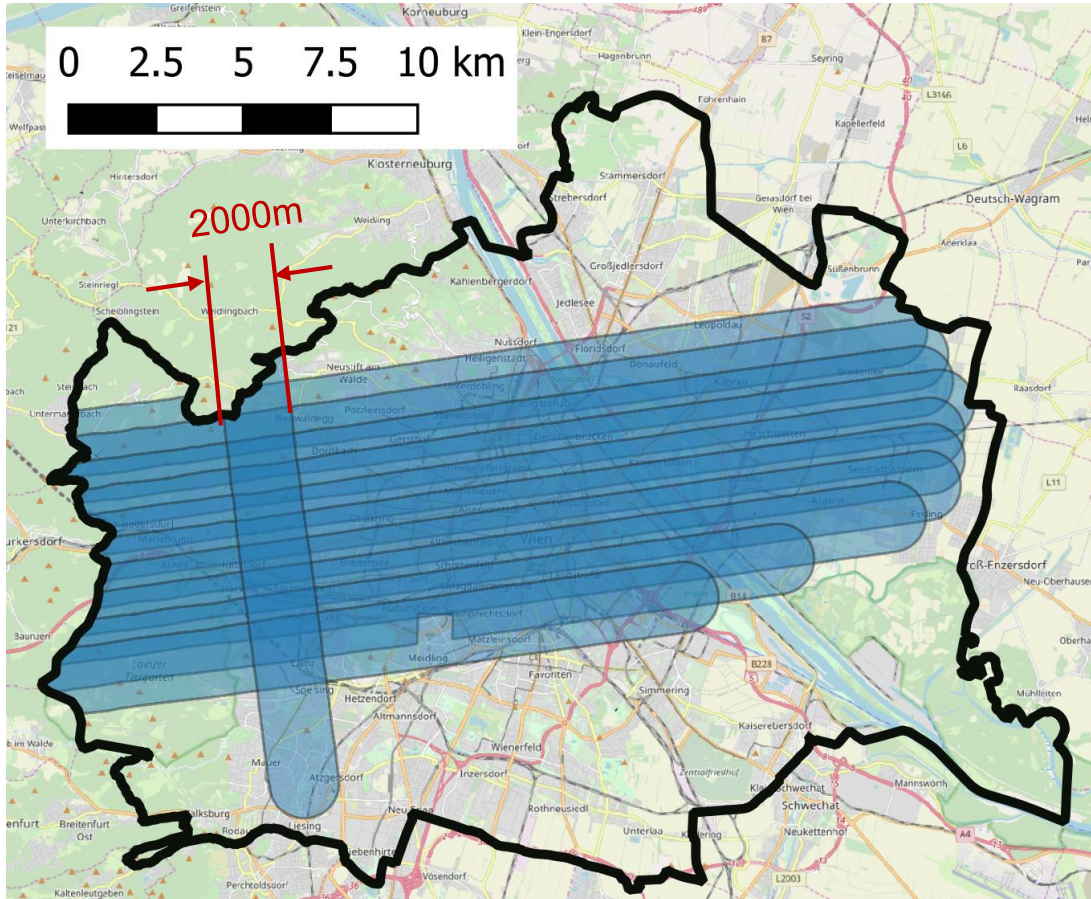
10x10 partial beams (beamlets)
derived from single laser pulse
via Diffractive Optical Element (DOE)



en.wikipedia.org/wiki/Silicon_photomultiplier

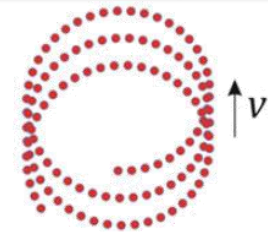
1 transmitter → 100 receivers
(discrete echo detection)

Data acquisition Single Photon LiDAR (SPL 100)

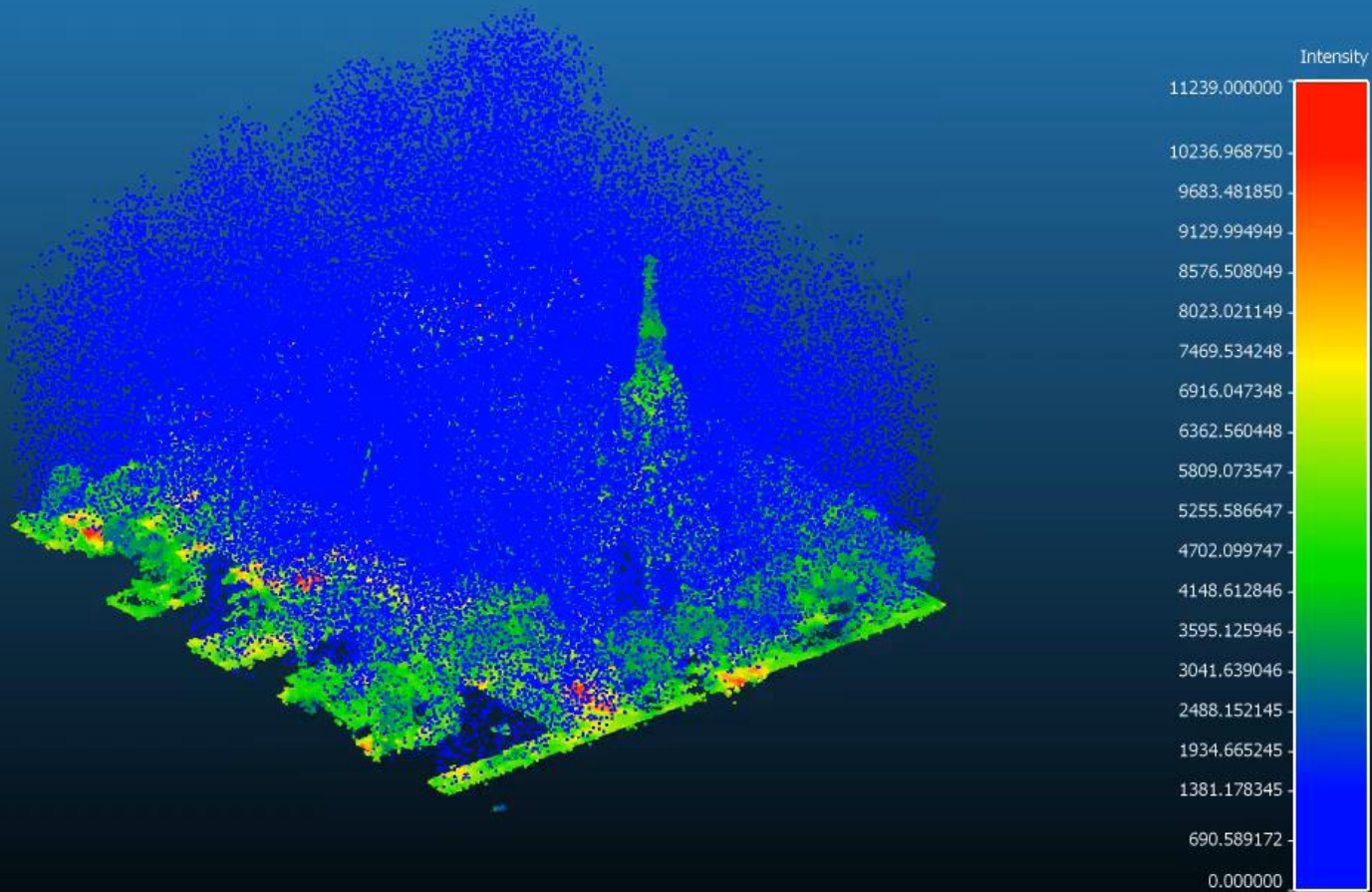


Flight mission parameters

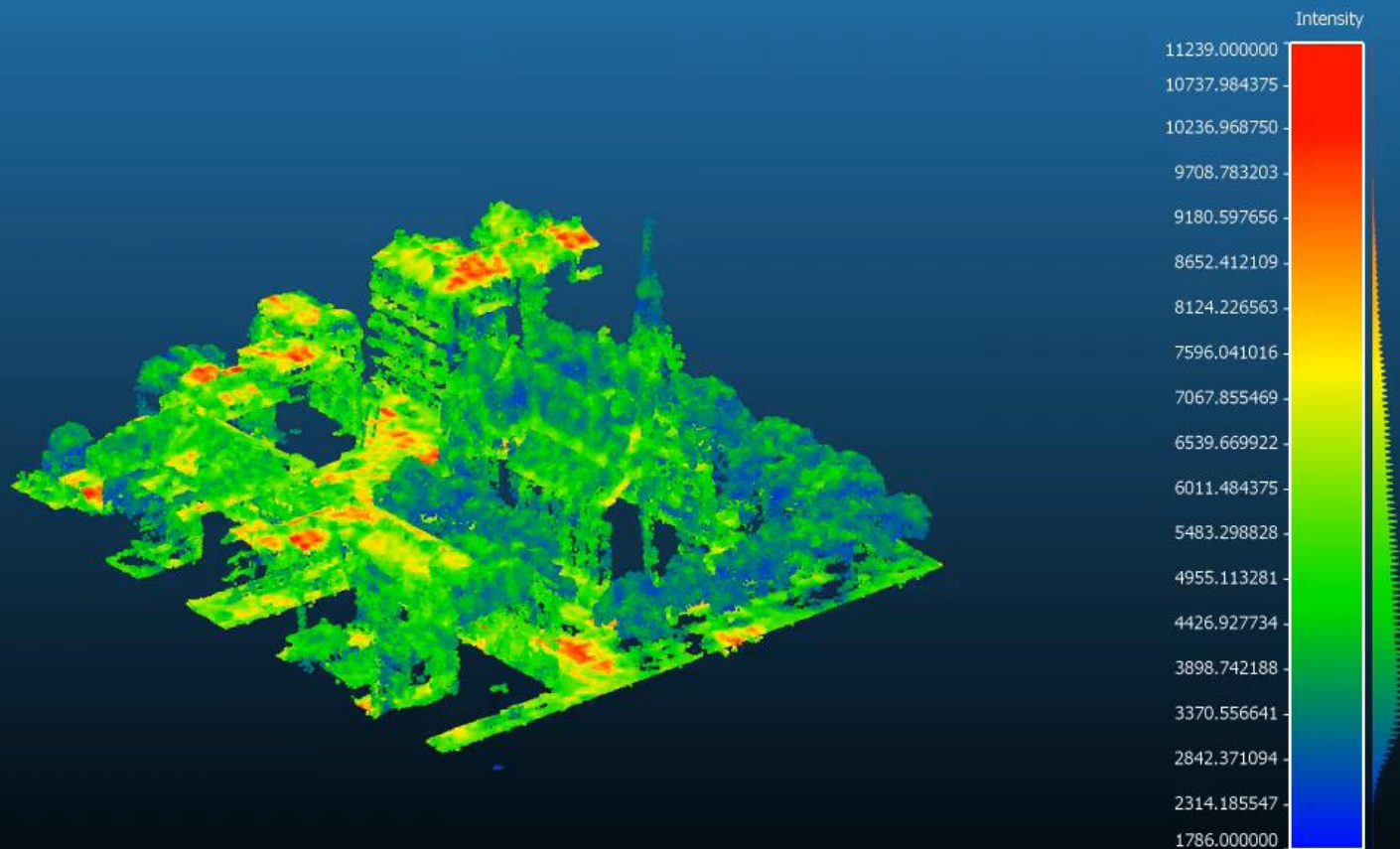
Flight date	29.07.2018
Scan rate	5 MHz
Flying altitude	4000m
Swath width	2000m
Scan pattern	circular (Palmer)
Field-of-View	30°
Overlap	>50%
Nom. pt. density	20 Pkt/m ²
Nr. of strips	10



Single Photon LiDAR (SPL): Unfiltered 3D point cloud

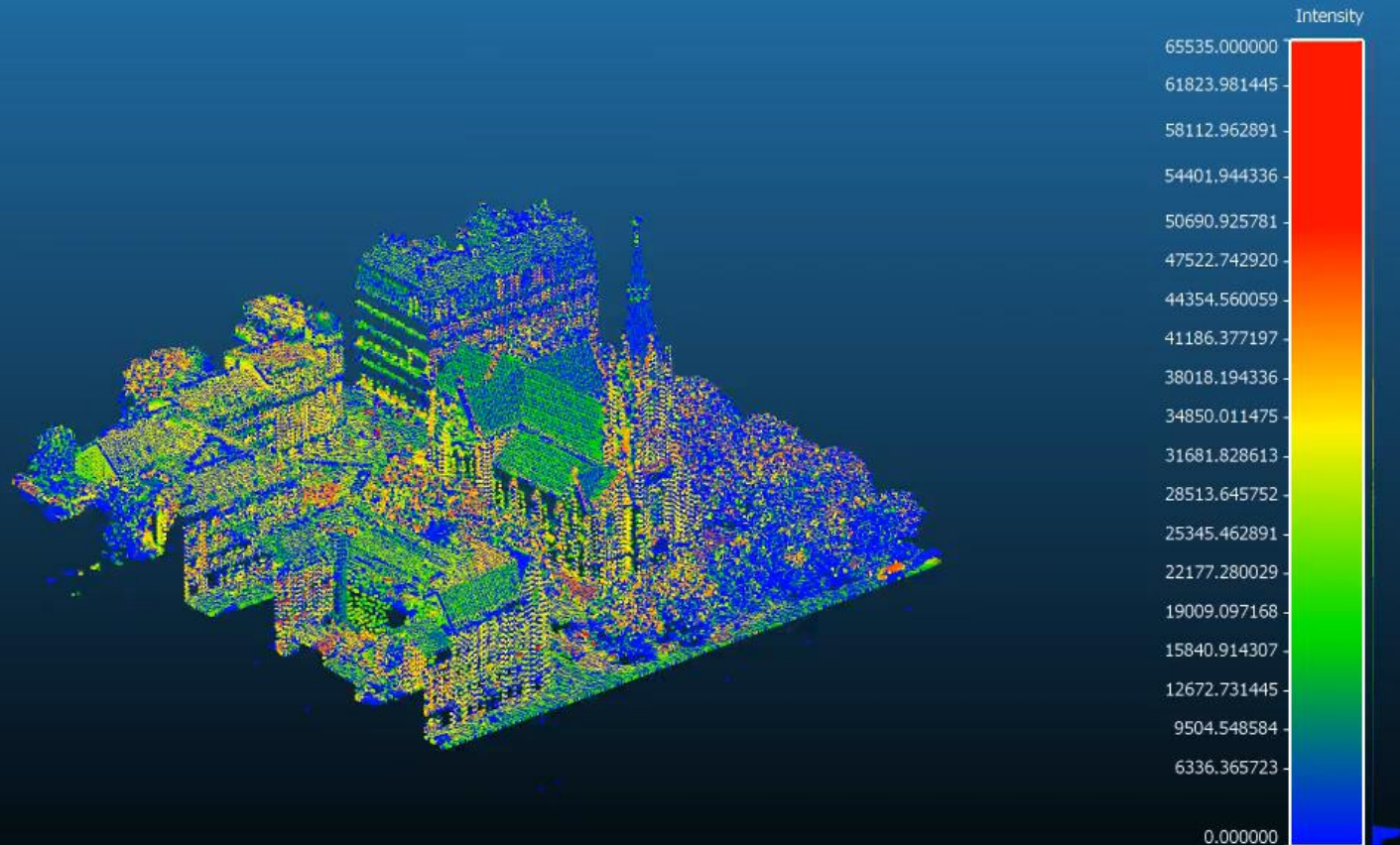


Single Photon LiDAR (SPL): Postproc. 3D point cloud



City of Vienna, 3rd district, Scanner: Leica SPL100

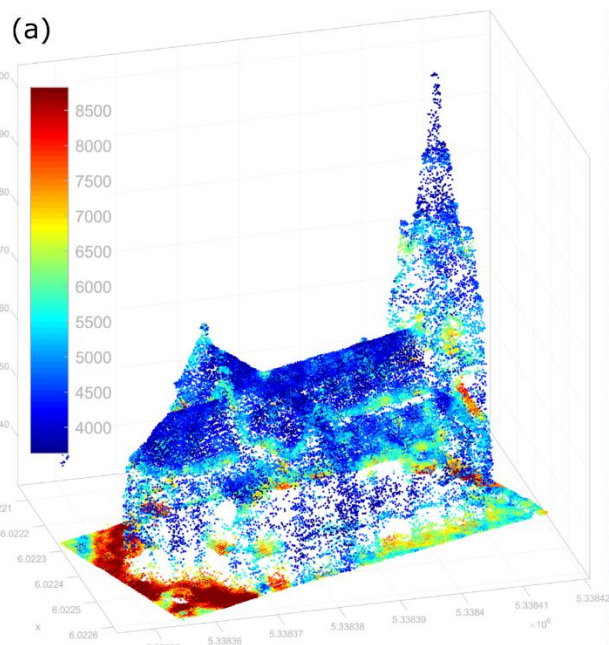
Full Waveform LiDAR: 3D point cloud



City of Vienna, 3rd district, Scanner: *RIEGL* VQ-1560i

Visual comparison of 3D point clouds

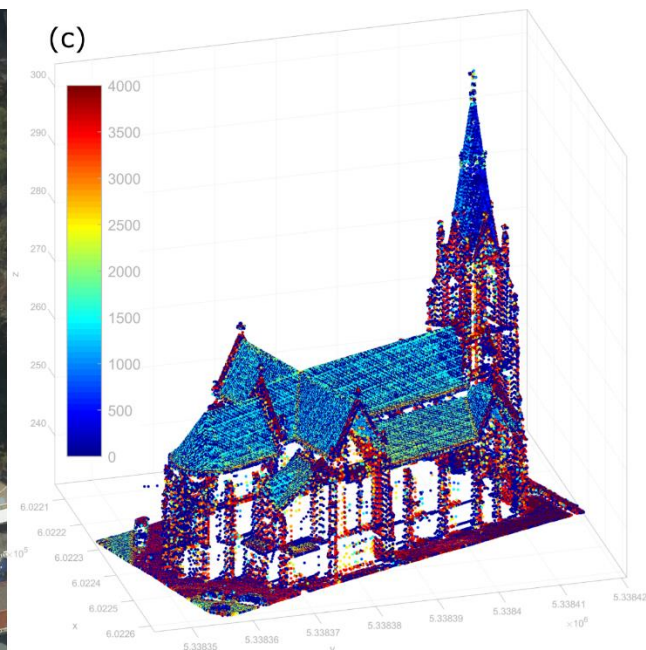
SPL



Aerial image (RGB)



Waveform LiDAR



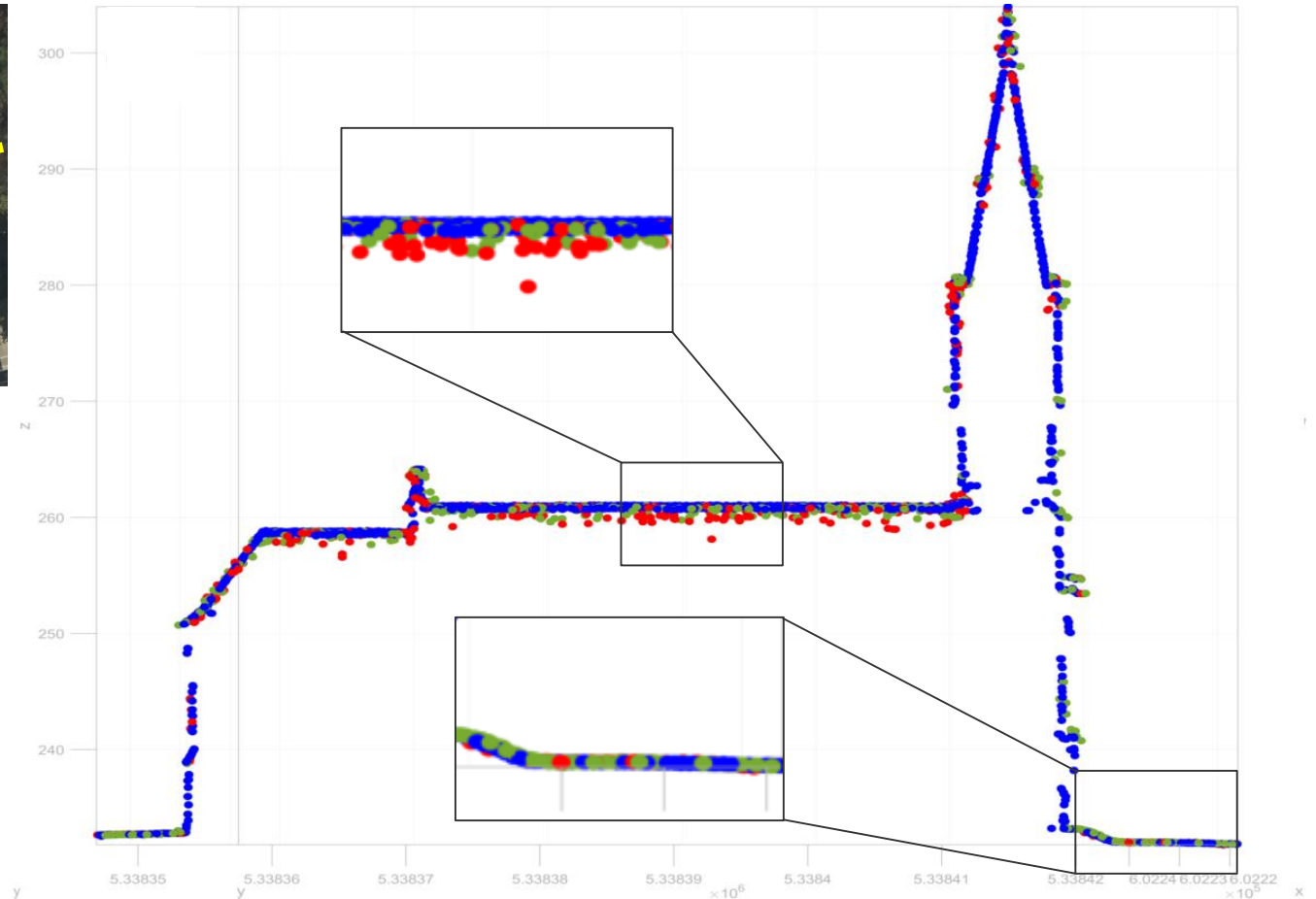
Signal intensity [DN]

Comparison: longitudinal section



Legend:

- SPL unfiltert
- SPL postprocessed
- Waveform LiDAR



Sensor systems

From range finders to integrated multi-purpose sensors

Hybrid Aerial Sensors

Produkt	Laser channels [nm]	Scan rate [kHz]	Camera	Type	Pixel size [μm]
Optech Titan	532/1064/1550	3 x 300	CM-10000	80 MP, RGB	5.2
Optech Galaxy	1064	1000	CM-10000	80 MP, RGB	5.2
Riegl VQ-1560-DW	532/1064	2 x 666	PhaseOne	100 MP, RGB	4.6
Leica TerrainMapper	1064	2000	RCD30	80 MP, RGBI	5.2
Leica CityMapper	1064	700	5 x RCD30	80 MP, RGB(I)	5.2

Titan



Galaxy



VQ-1560i-DW



TerrainMapper

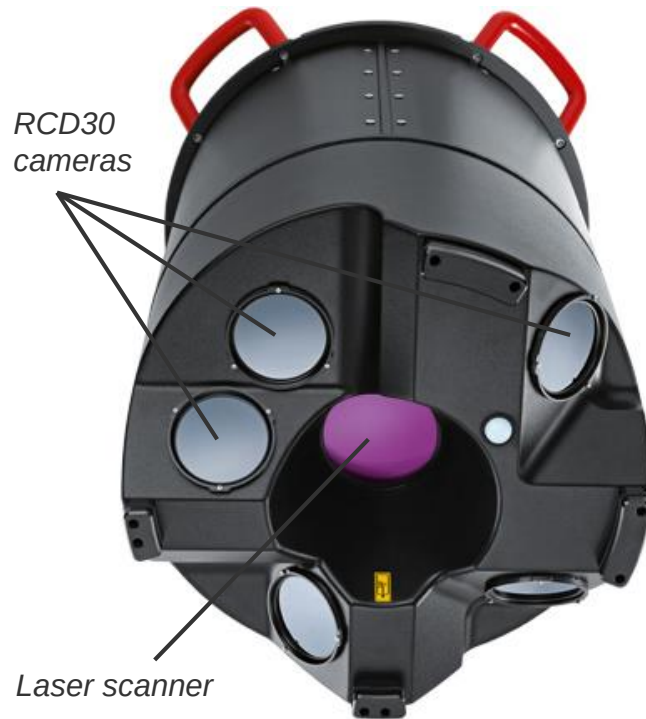


CityMapper-2

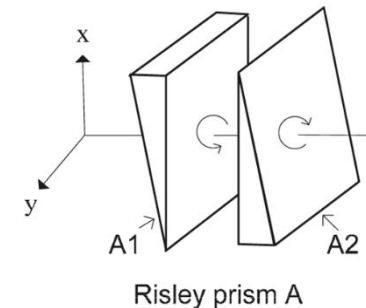


Hybrid sensor systems, Leica CityMapper-2

*Leica CityMapper-2
Airborne Hybrid Sensor*



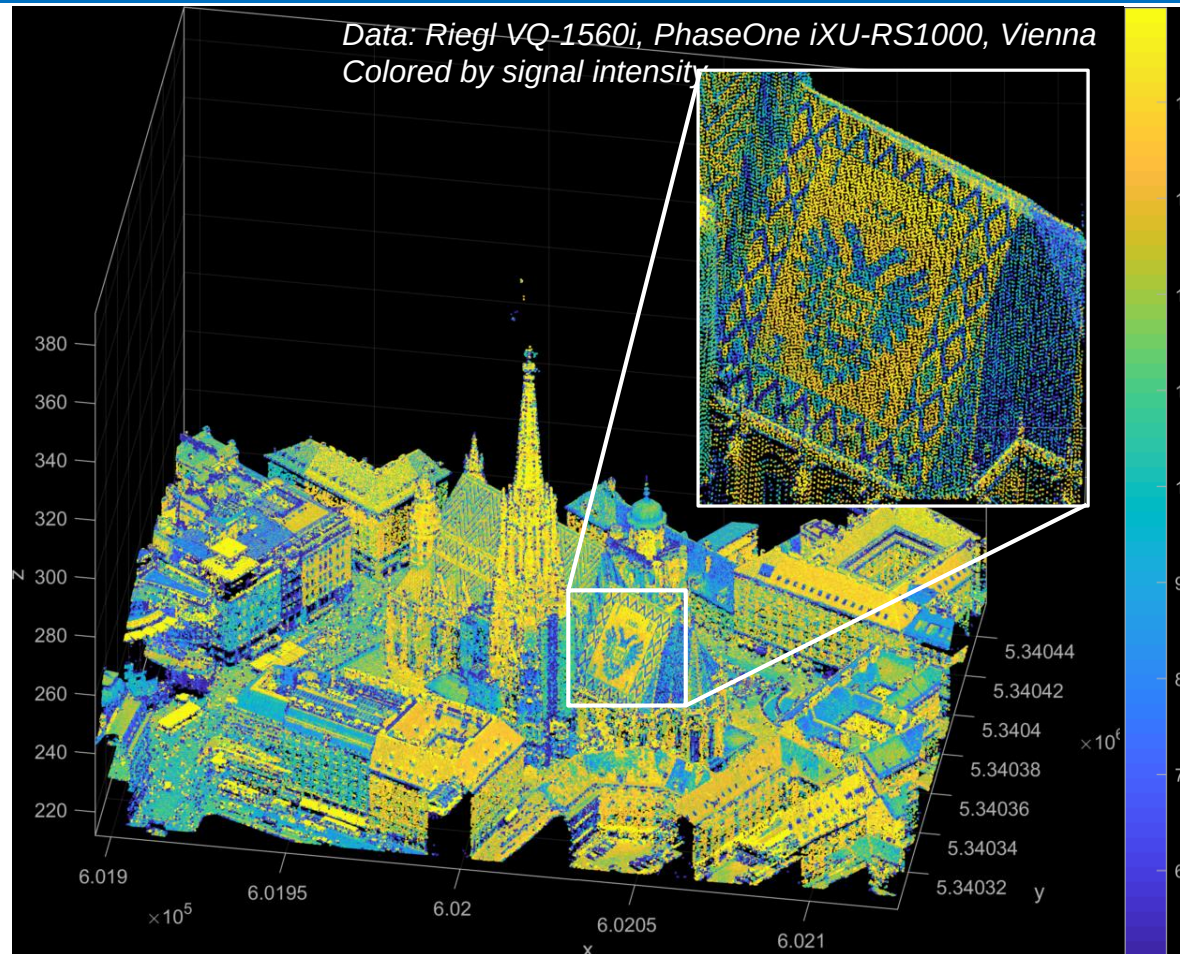
Laser scanner	1064 nm
Pulse repetition rate	2000 kHz
Beam divergence ($1/e^2$)	0.25 mrad
Flying altitude	300 – 2500 m
Scan mechanism	Risley Prisma
4 x oblique cameras	RCD30, RGBI, 150 Mpix
1 x nadir camera	RCD30, RGBI, 150 Mpix



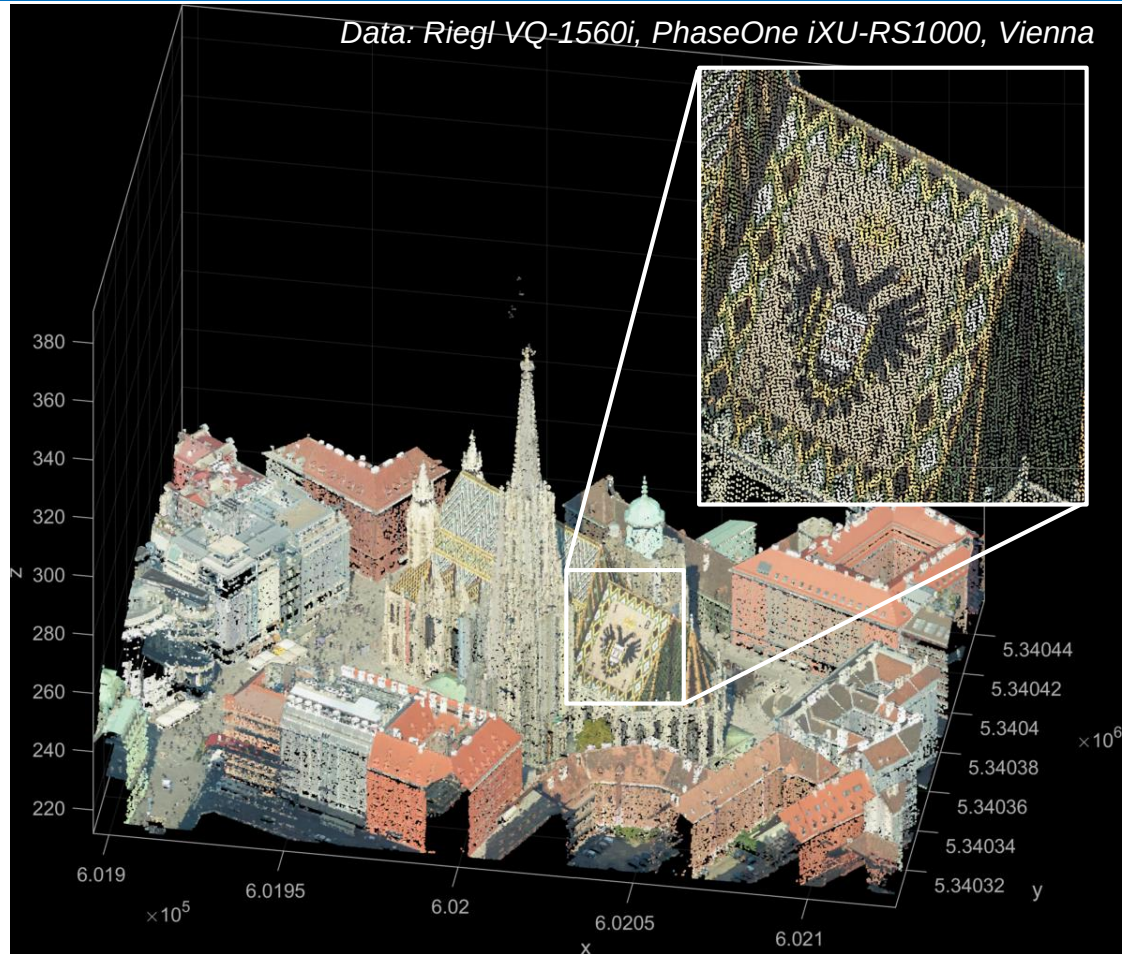
*Arbitrary scan patterns by coupling
of two rotating prisms (Risley prism)*

Source: <https://leica-geosystems.com/en-in/products/airborne-systems/leica-citymapper>

Fusion of LiDAR and Images

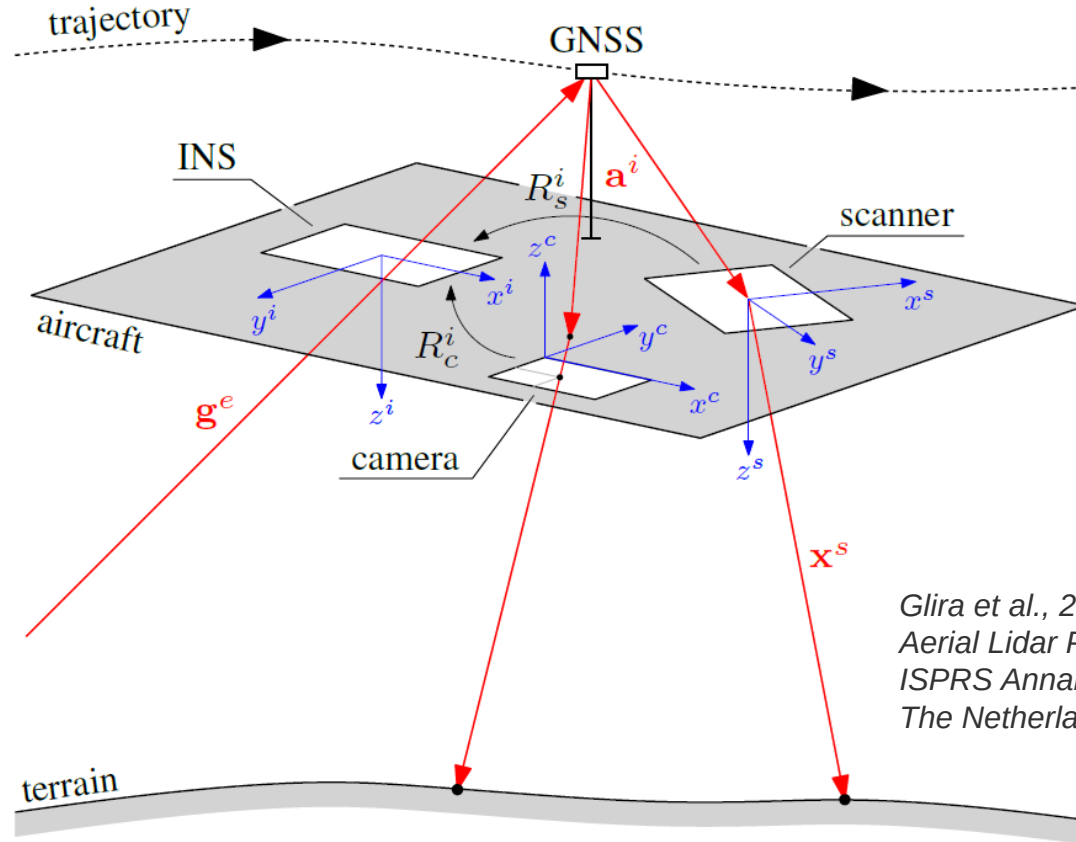


Fusion of LiDAR and Images



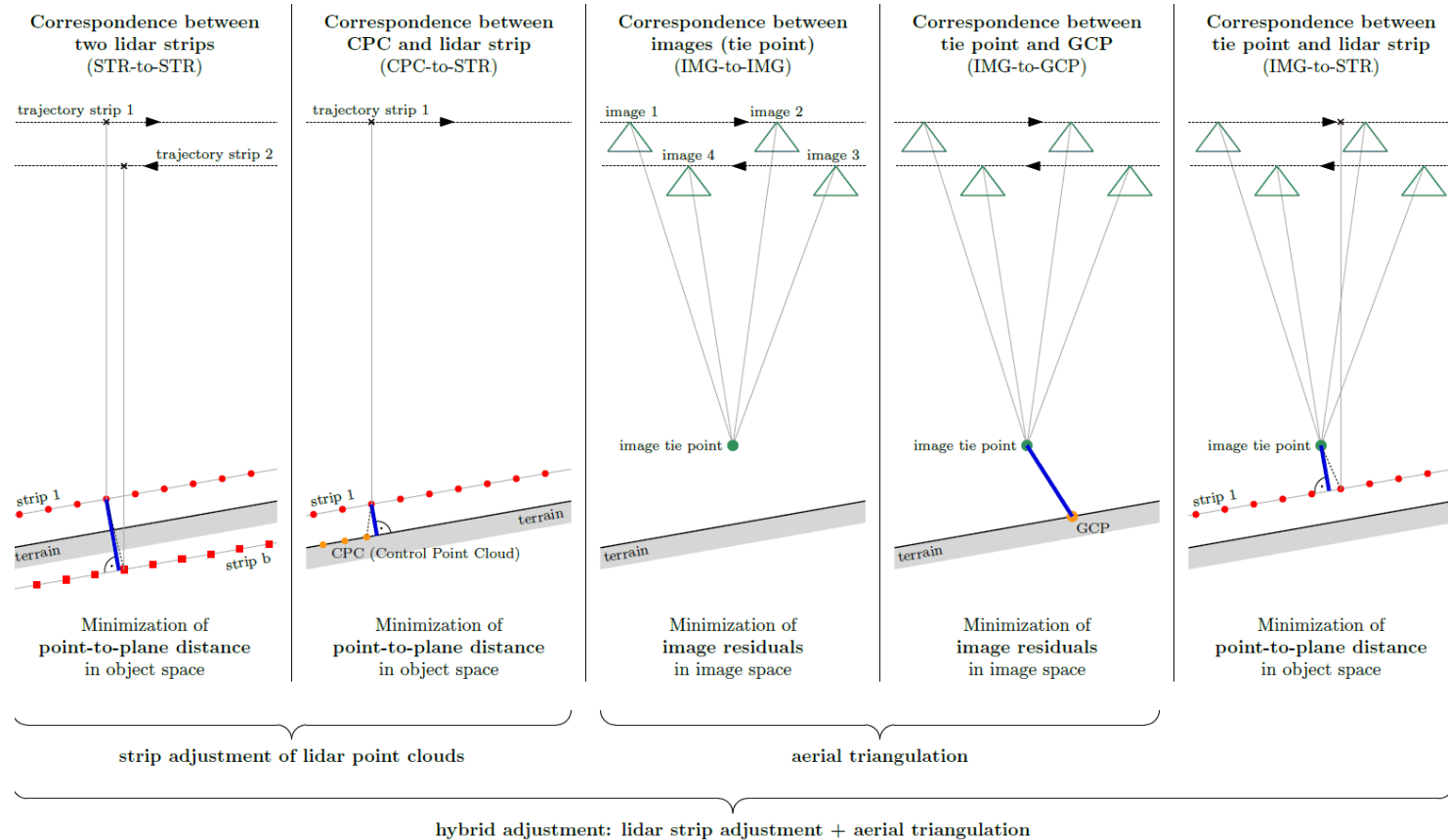
Hybrid sensor orientation (Glira, 2019)

Schematic representation of laser/camera sensors on an airborne platform



Glira et al., 2019, Hybrid Orientation of Aerial Lidar Point Clouds and Aerial Images. ISPRS Annals, Geospatial Week, Enschede, The Netherlands

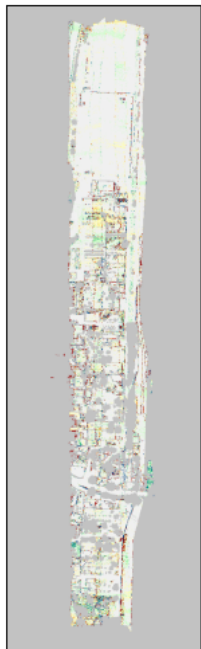
Hybrid sensor orientation (Glira, 2019)



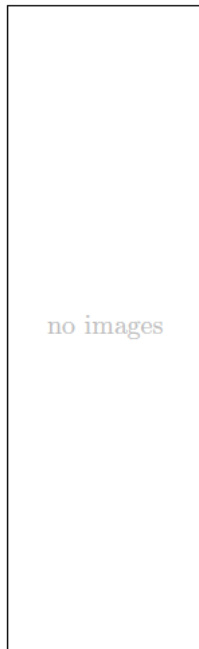
Height differences LiDAR – Dense Image Matching

Laser only orientation

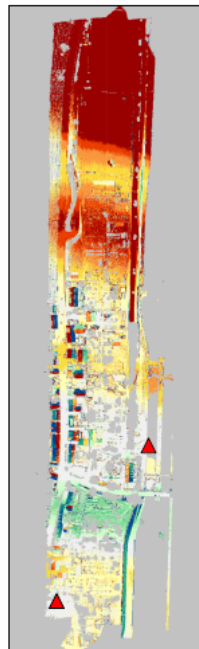
Relative Orientation: strips-to-strips



Relative Orientation: strips-to-images



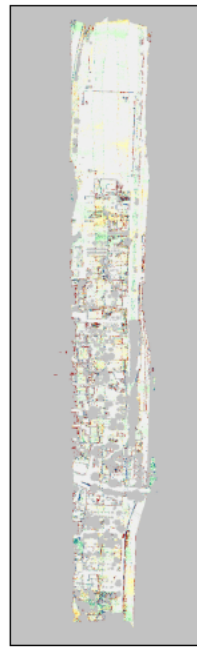
Deviation: laser block vs. optimum orientation



Data: Hessigheim, BfG, Koblenz

Hybrid sensor orientation

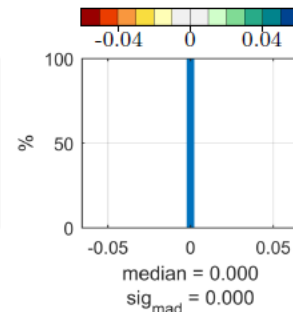
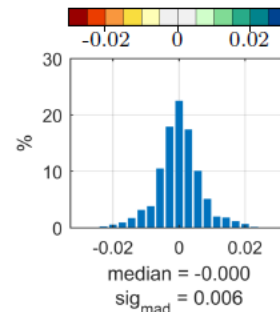
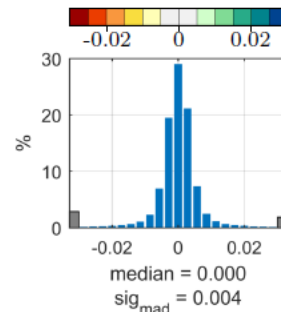
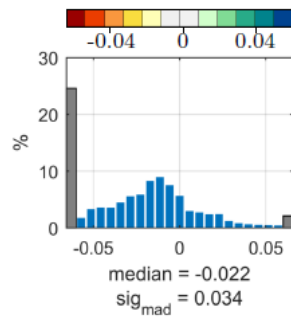
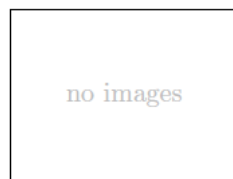
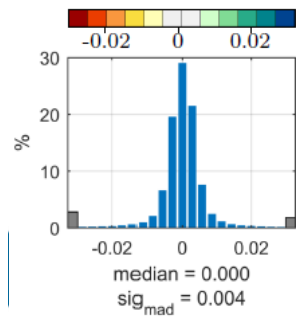
Relative Orientation: strips-to-strips



Relative Orientation: strips-to-images



Deviation: laser block vs. optimum orientation



Platforms

From manned aircrafts to Unmanned Aerial Vehicles

Manned and unmanned platforms

Transport aircraft (Source: Wiki)



Light aircraft (Source: Diamond aircraft)



Helicopter (Source: SPAR3D)



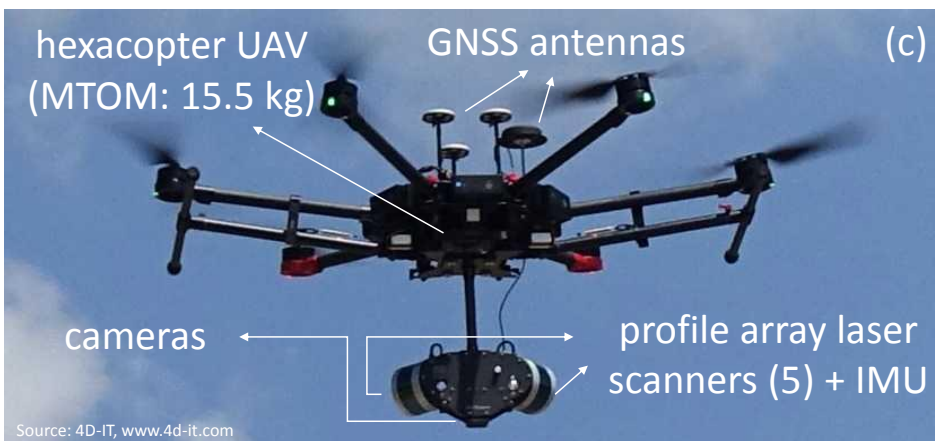
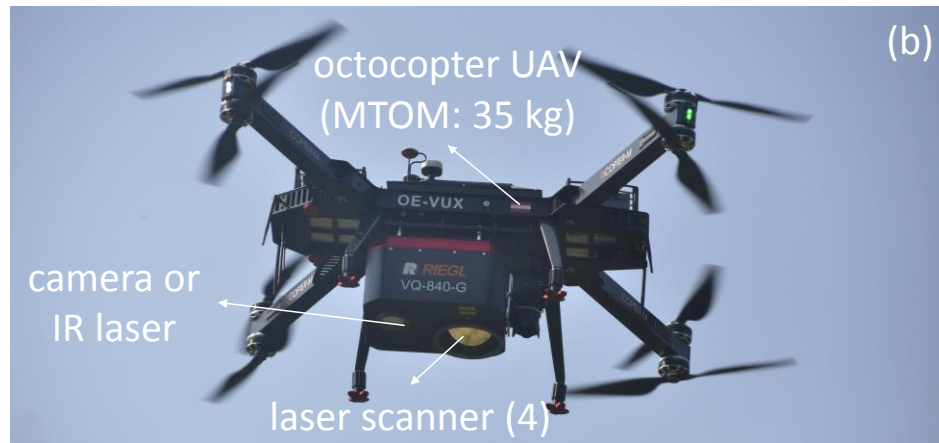
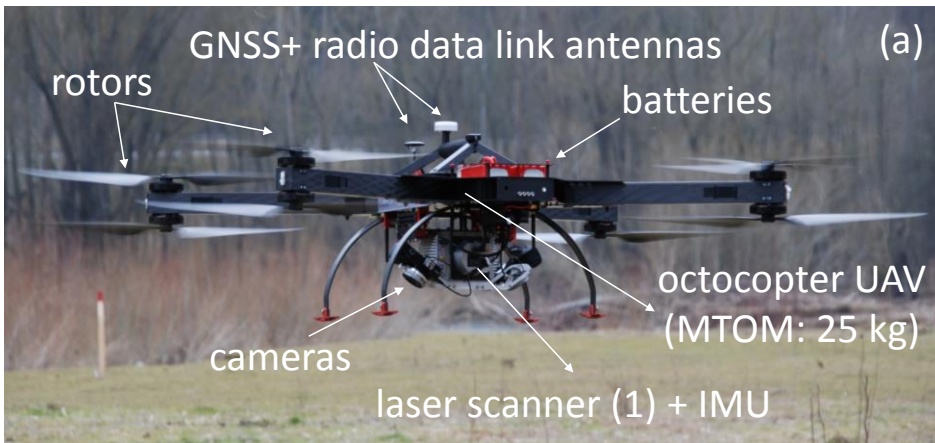
UAV (Source: Wallace et al. Forests)



Gyrocopter (Source: IGI systems)



Unmanned platforms

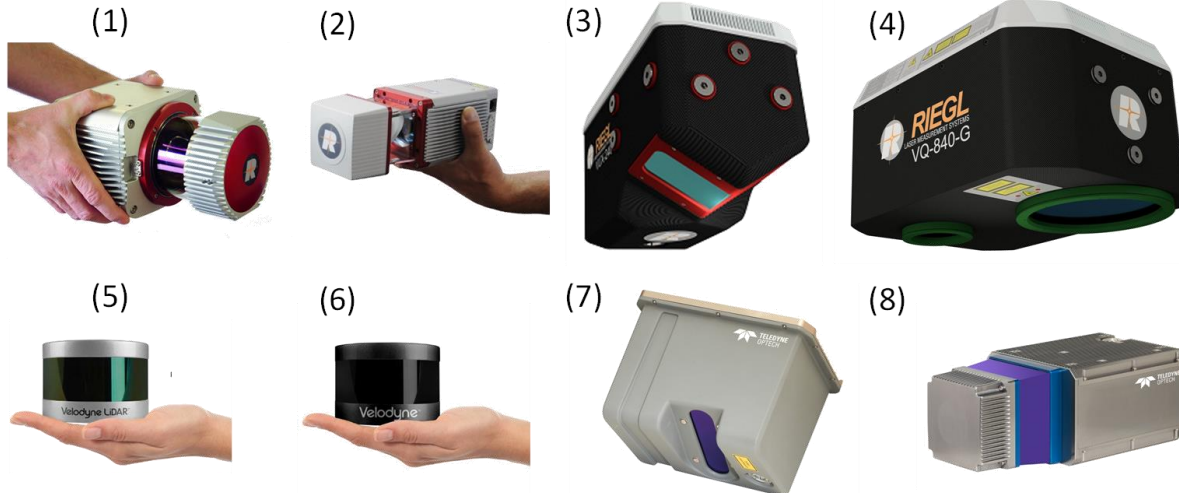


Source: 4D-IT, www.4d-it.com

Source: Quantum systems, <https://www.quantum-systems.com>; YellowScan, <https://www.yellowscan-lidar.com/>

UAV LiDAR – Sensor overview

ID	sensor	mass	wavelength	max range	prec/ acc	meas. rate	meam div.	footprint @50m agl	FOV	channels
		[kg]	[nm]	[m]	[mm]	[kHz]	[mrad]	[mm]	°	
1	VUX1-UAV	3.75	1550	300	5/10	500	0.5	25	330	1
2	miniVUX-2UAV	1.60	905	250	10/15	200	1.6 x 0.5	80 x 25	360	1
3	VUX-240	4.10	1064	650	15/20	1500	0.35	18	75	1
4	VQ-840-G	12.00	532	---	15/20	200	1.0 - 6.0	50 - 300	40	1
5	Puck LITE	0.59	903	100	--/30	300	3.0 x 1.2	150 x 60	360	32
6	Alpha Puck	3.50	903	300	--/30	2400	3.0 x 1.5	150 x 75	360	128
7	CL-90	3.85	1550	175	5/10	500	0.3	15	90	1
8	CL-360	3.50	1550	300	5/10	500	0.3	15	360	1



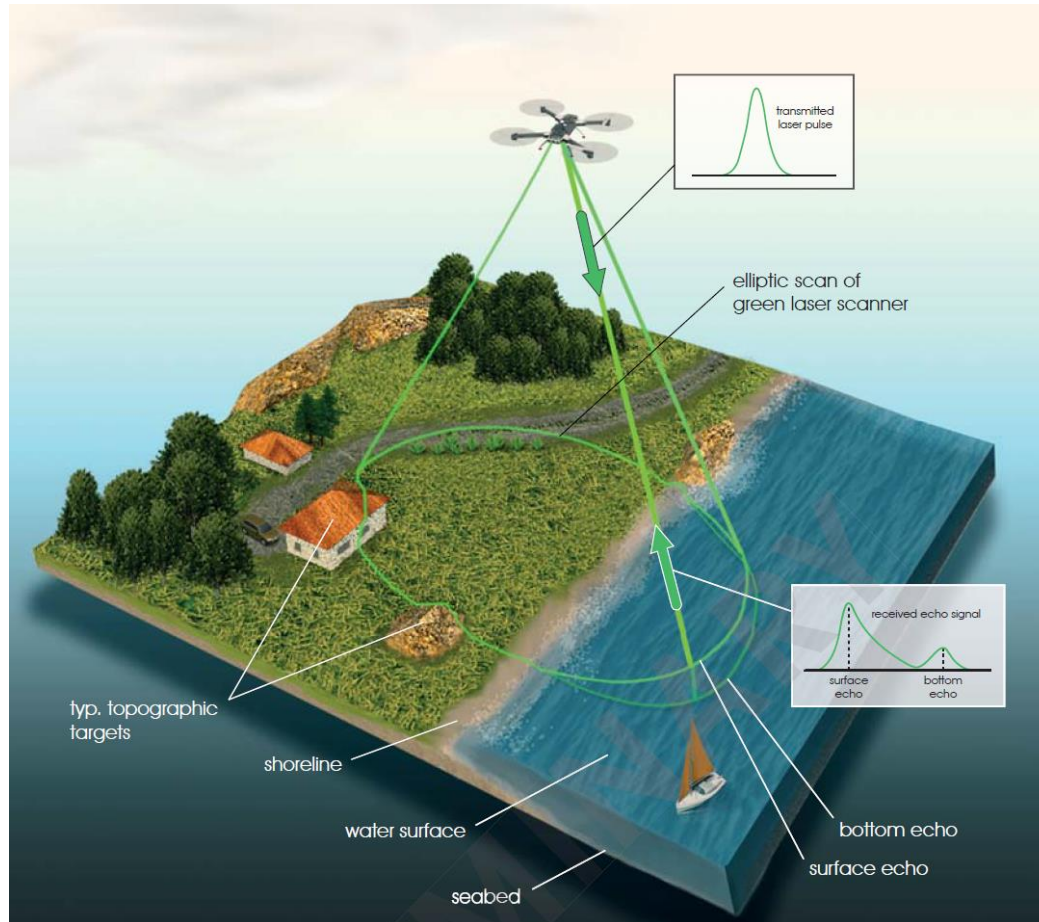
UAV-LiDAR Hessigheim



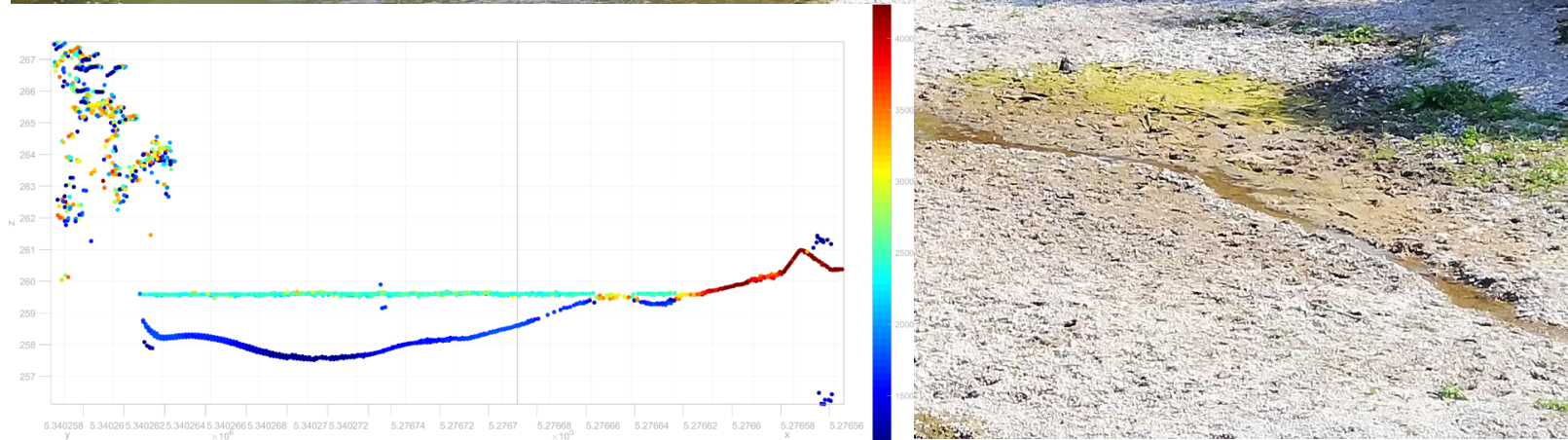
*LiDAR point cloud colorised
with oblique imagery*

Data: Hessigheim, BfG, Koblenz
Sensor: Riegl VUX1-UAV+2xSony A6000

Bathymetric UAV Laser Scanning: Riegl VQ-840-G



Data capturing, Neubacher Au, Pielach, Aug 27th 2019



Landing of RiCopter-M carrying VQ-840-G bathymetric laser scanner after surveying a 500m section of Pielach River

Summary

- Constant progress in lidar technology
 - Echo detection:
 - Discrete echo → full waveform capture → online waveform processing
 - Measurement rate:
 - Increased measurement range and scan rate → multiple pulses in the air
 - Multiple wavelengths:
 - Single wavelength → multispectral laser scanning
 - Receiver sensitivity:
 - Linear-mode LiDAR → Single Photon LiDAR
 - Comprehensive systems:
 - Scanner only → Hybride sensor system (scanner + cameras)
 - Miniaturization:
 - Manned platforms → UAV LiDAR → small footprint → high spatial resolution