Sampling the World in 3D by Airborne LIDAR –

Assessing the Efficiency of LIDAR Systems for Large-Scale Surveying

Geospatial World Forum 2014
May 09th, 2014
Geneve, Germany

Peter Rieger
RIEGL LMS GmbH

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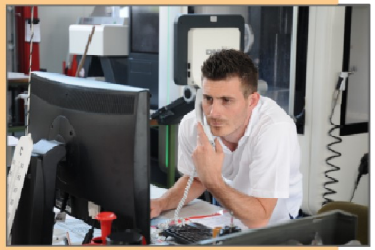
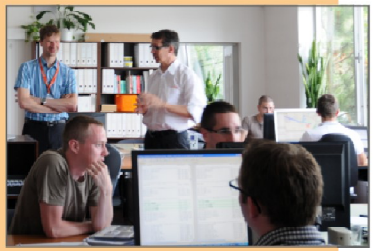
LASER MEASUREMENT SYSTEMS

About RIEGL





With more than 30 years experience in the research, development and production of laser rangefinders, distancemeters and scanners, ***RIEGL*** delivers proven innovations in 3D.

Dedicated to designing, developing, and producing the best possible laser sensors for the desired application, in order to perfectly fulfil measurement tasks and therefore fully satisfy the customer's expectations world-wide.

As a primarily technology-orientated company, ***RIEGL*** successfully cooperates with renowned system integrators, resulting in powerful turnkey solutions for multiple fields of application.

RIEGL has always been committed to delivering the highest performance, quality, reliability and longevity of all its products and services and strict adherence to applicable international standards is a priority.

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About RIEGL

The ***RIEGL*** staff in Austria comprises more than 140 highly skilled and motivated engineers, technicians, and other qualified employees.

Dr. Andreas Ullrich, CTO

Dr. Johannes Riegl, CEO

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About RIEGL

Located in Horn, an attractive small town in Lower Austria, around 85 km northwest of the Austrian capital Vienna, the ***RIEGL*** headquarters is right in the heart of the European Union, with good transport connections in all directions.

Worldwide sales, training, support and services are delivered from ***RIEGL*‘s** Austrian headquarters and its offices in Vienna and Salzburg, main offices in USA and in Japan, and by a worldwide network of representatives covering Europe, North and South America, Asia, Australia and Africa.

About RIEGL

The ***RIEGL*** headquarters provides more than 40,000 square feet work space for research, development, production as well as for marketing, sales, training and administration.

Another 200,000 square feet of open air ground is used for product testing.

Marketing, Sales, Training & Administration

Research, Development & Production

Outdoor 3D-Test Range

CNC Production

RIEGL®
LASER MEASUREMENT SYSTEMS

Explore Products

TLS Terrestrial Laser Scanning

ALS Airborne Laser Scanning

MLS Mobile Laser Scanning

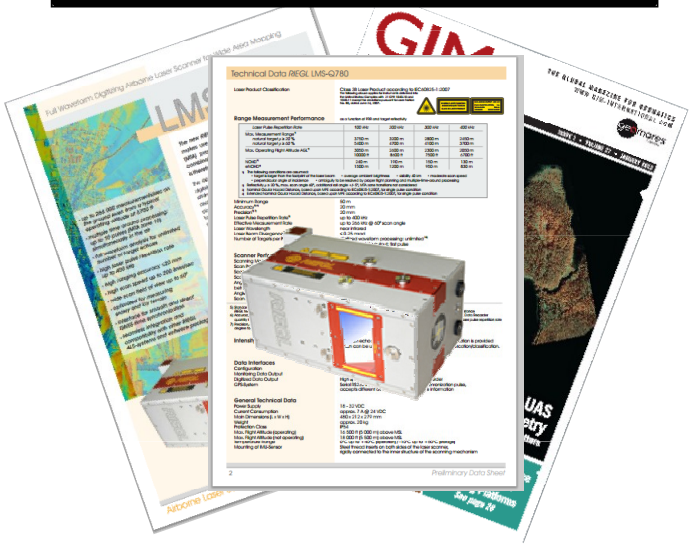
ILS Industrial Laser Scanning

RIEGL®
LASER MEASUREMENT SYSTEMS

Explore Products

ALS Airborne Laser Scanning

[redacted]



density and spacing

LIDAR spec

performance envelope

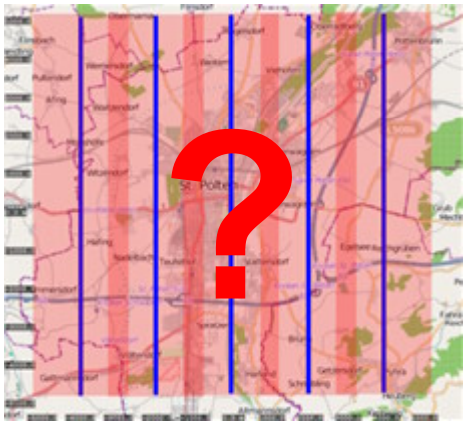
scanner performance

impact of terrain

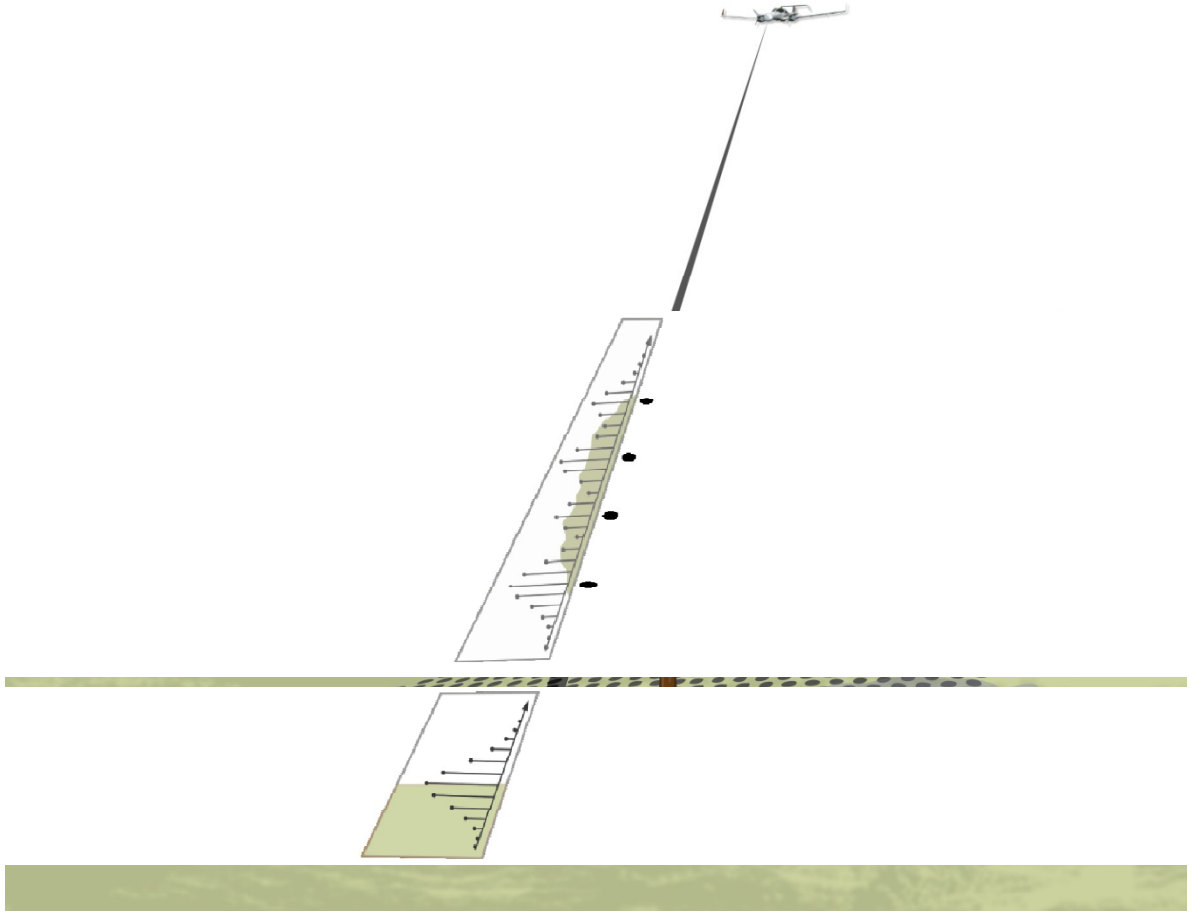
example on 3D sampling

acquisition time

How long does the acquisition actually take?



What will be the point cloud's sampling quality?



- sequential data acquisition
- surface sampling at laser footprints
- “sampling” footprint ← → single point of point cloud (PC)
- organizing measurements in scan lines
  - intra-line spacing
  - inter-line spacing
- “2D” resolution limited by footprint size
- sampling density impacts information content of PC
- resolution in 3rd dimension
- echo-digitization with full waveform analysis → best multi-target resolution

LIDAR density and spacing specification
(ASPRS Version 1.0, Draft 2)

LDSS point spacing	LDSS point density
1-dimensional metric	2-dimensional metric
point-to-point distance	points in a given area
unit: meters (feet, yards, cm …)	unit: points per m² (ft², …)

LIDAR Guidelines and Base Specification → **Nominal Point Spacing (NPS)**
(U.S. Geological Survey, National Geospatial Program,Version 13)

spatial sampling frequency	point density
1-dimensional metric	2-dimensional metric
inverse of point spacing (1/NPS)	average points in a given area
unit: points per meters (feet, yards, …)	unit: points per m² (ft², …)

LIDAR density and spacing specification
(ASPRS Version 1.0, Draft 2)

Unbiased LiDAR Data Measurement (Draft)

Ty Naus, Fugro Horizons, Inc.

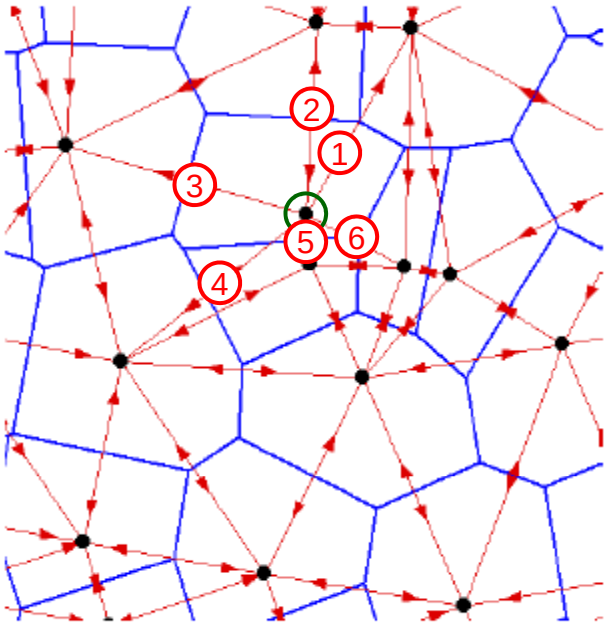
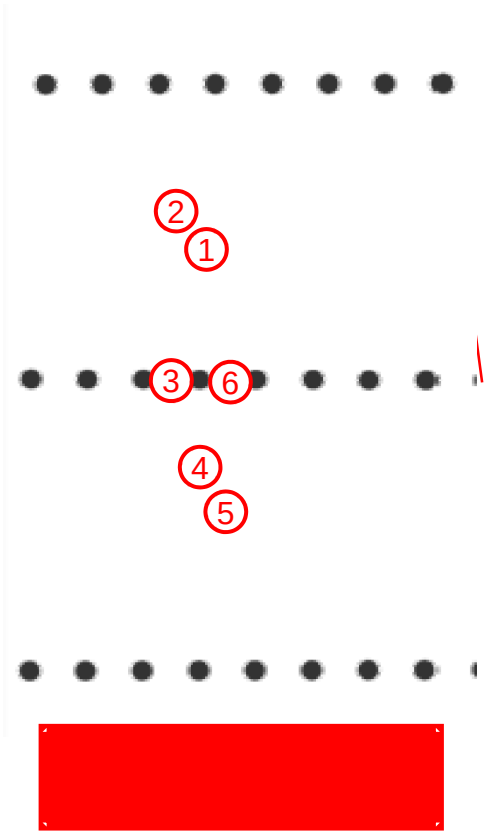


Figure 7b: Voronoi polygons shown in blue for actual LiDAR point distributions – the triangulation edges are shown in red.

$$d_{p-p} = \frac{1}{N}\sum_{i=1}^{N} d_i$$



average or maximum?

	Instrument A	Instrument B	Instrument C
scan mechanism	rotating polygon	oscillating mirror	oscillating mirror
number of channels	single channel	dual laser output	dual laser output
flight altitude, AGL [1)]	50 m - 3500 m	150 m - 3500 m	150 m – 5000 m
laser pulse rate	100 kHz - 400 kHz	2 x 40 kHz – 2 x 250 kHz	2 x 50 kHz – 2 x 250 kHz
measurement rate	66 kHz - 266 kHz	80 kHz - 500 kHz	100 kHz - 500 kHz
pulses in the air	up to 12	2 x up to 2	not disclosed
field of view	0 deg - 60 deg	0 deg - 75 deg	0 deg - 75 deg
scan rate	10 LPS – 200 LPS	0 LPS- 2 x 200 LPS	0 LPS- 2 x 280 LPS

	Instrument A	Instrument B	Instrument C
scan mechanism	rotating polygon	oscillating mirror	oscillating mirror
number of channels	single channel	dual laser output	dual laser output
flight altitude, AGL [1)]	50 m - 3500 m	150 m - 3500 m	150 m – 5000 m
laser pulse rate	100 kHz - 400 kHz	2 x 40 kHz – 2 x 250 kHz	2 x 50 kHz – 2 x 250 kHz
measurement rate	66 kHz - 266 kHz	80 kHz - 500 kHz	100 kHz - 500 kHz
pulses in the air	up to 12	2 x up to 2	not disclosed
field of view	0 deg - 60 deg	0 deg - 75 deg	0 deg - 75 deg
scan rate	10 LPS – 200 LPS	0 LPS- 2 x 200 LPS	0 LPS- 2 x 280 LPS

	Instrument A	Instrument A2
scan mechanism	rotating polygon	rotating polygon
number of channels	single channel	dual channel
flight altitude, AGL [1)]	50 m - 3500 m	50 m – 3500 m
laser pulse rate	100 kHz - 400 kHz	2 x 100 kHz – 2 x 400 kHz
measurement rate	66 kHz - 266 kHz	123 kHz – 532 kHz
pulses in the air	up to 12	2 x up to 12
field of view	0 deg - 60 deg	0 deg – 60 deg
scan rate	10 LPS – 200 LPS	2 x 10 LPS- 2 x 200 LPS

Instrument A
***RIEGL* LMS-Q780**

Instrument A2
***RIEGL* LMS-Q1560**

instrument A

instrument B

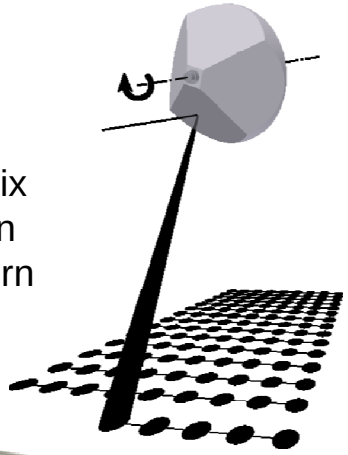
instrument C

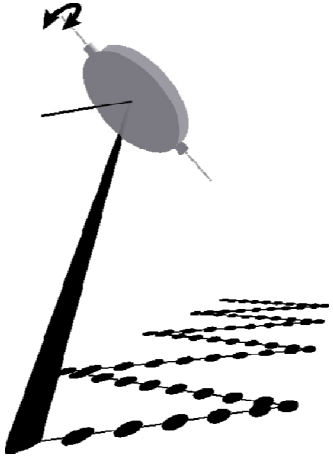
rotating polygon, single channel

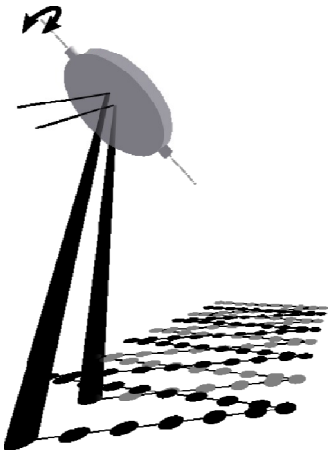
oscillating mirror, single channel

oscillating mirror, dual laser output

matrix scan pattern







***RIEGL* LMS-Q780**

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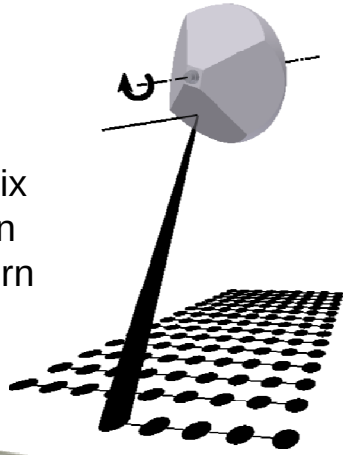
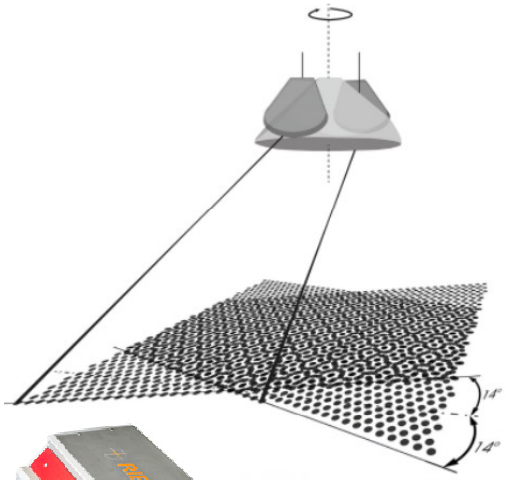
instrument A	instrument A2	instrument B instrument C
rotating polygon, single channel	rotating polygon, dual channel	oscillating mirror, dual laser output

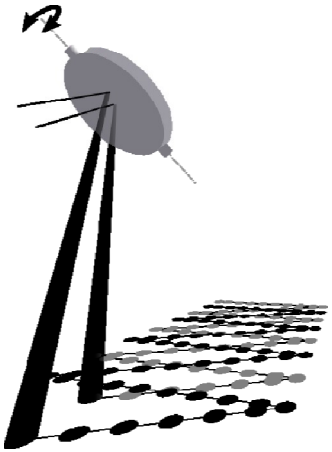
matrix scan pattern



***RIEGL* LMS-Q780**



***RIEGL* LMS-Q1560**



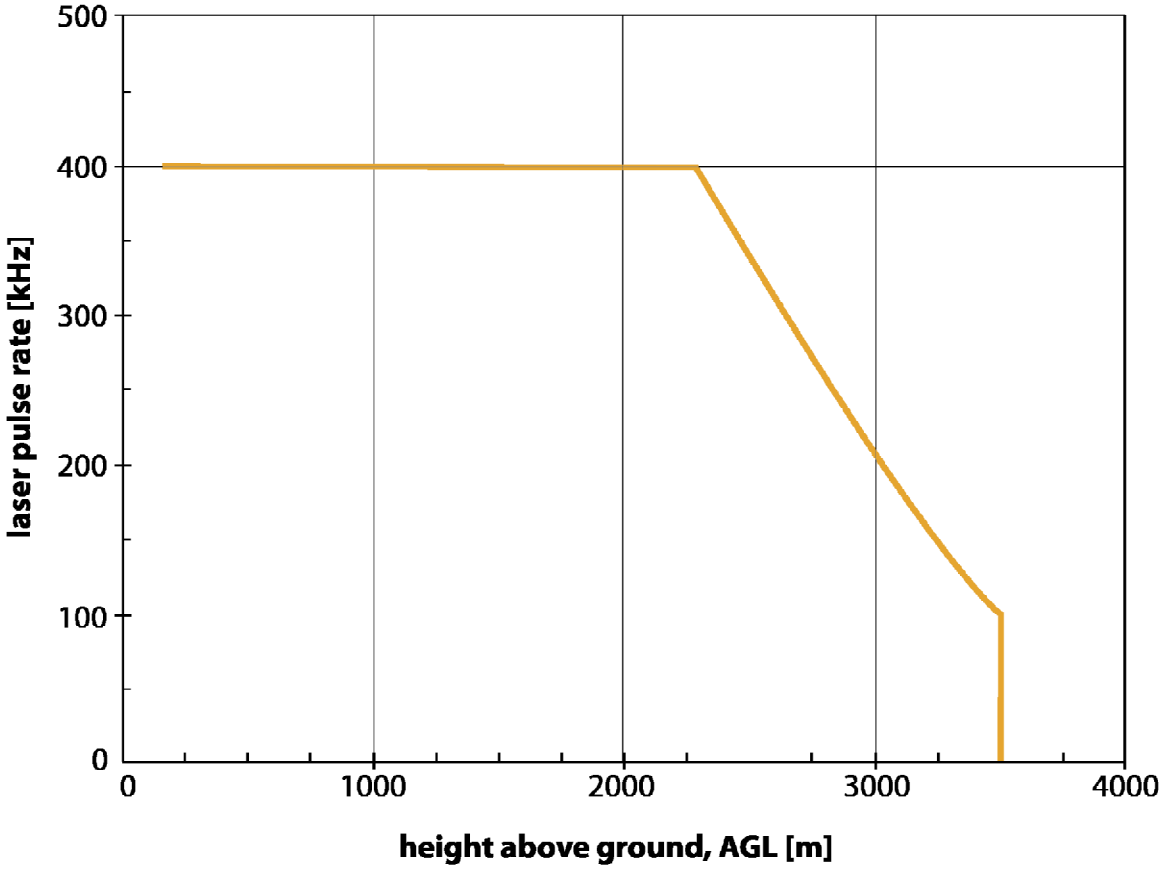
	Instrument A	Instrument B	Instrument C
scan mechanism	[redacted]		
number of channels			
flight altitude, AGL [1)]			
laser pulse rate			
measurement rate			
pulses in the air			
field of view			
scan rate			

performance envelope

scan speed vs FOV

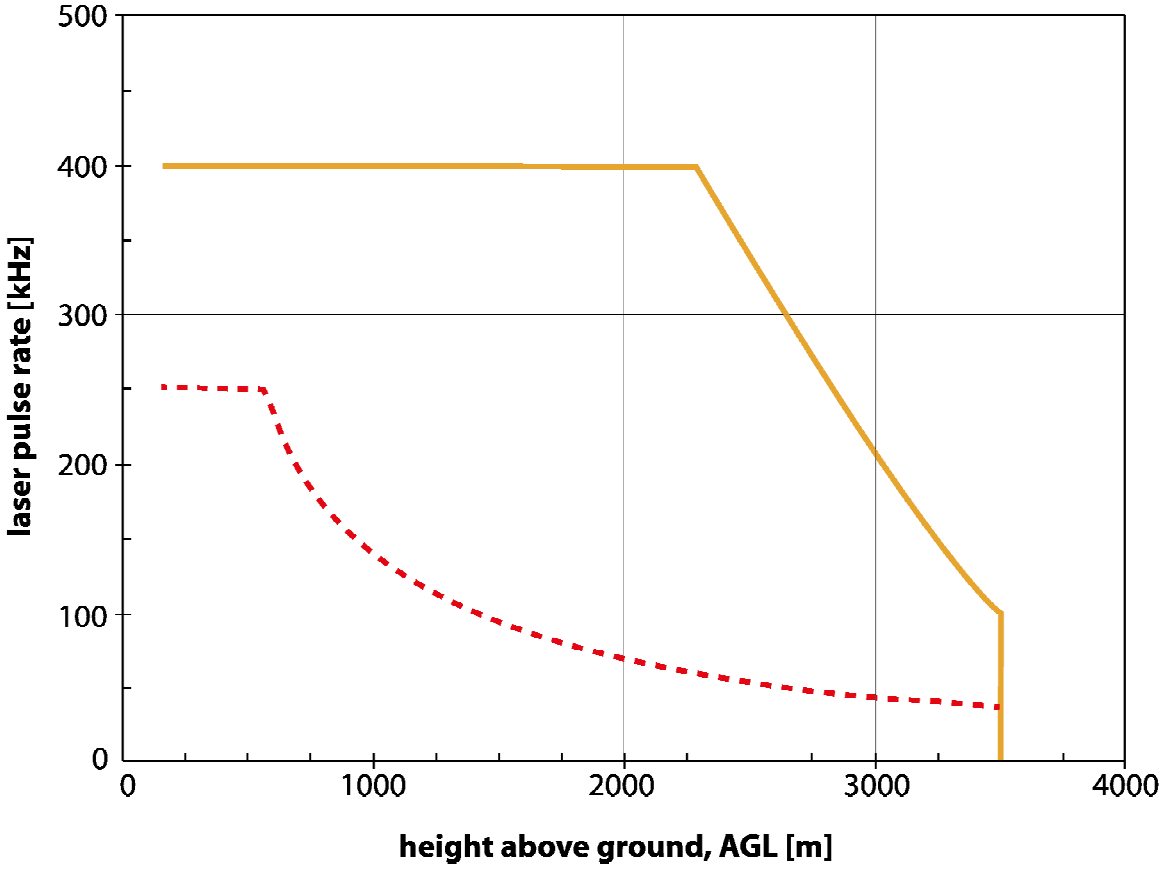
[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility

[redacted]

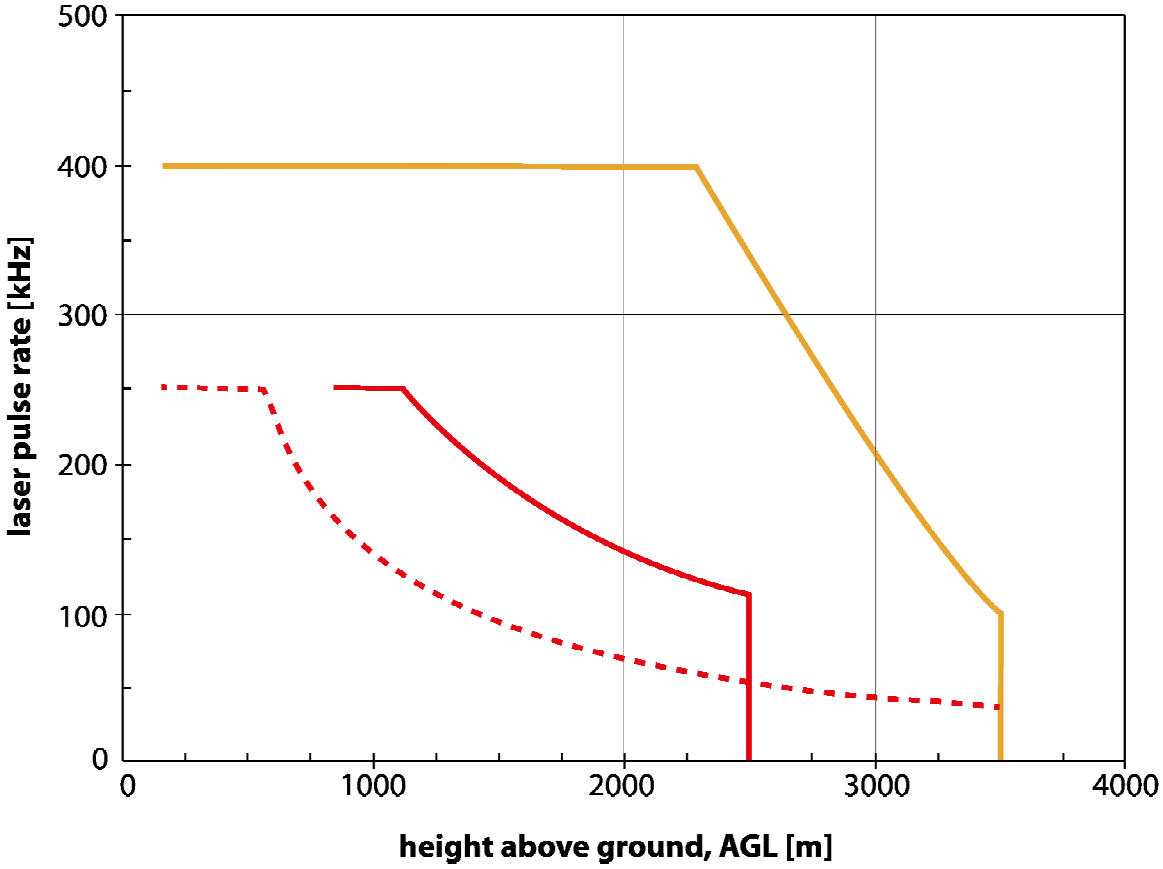


instrument A, *RIEGL* LMS-Q780

[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility



[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility



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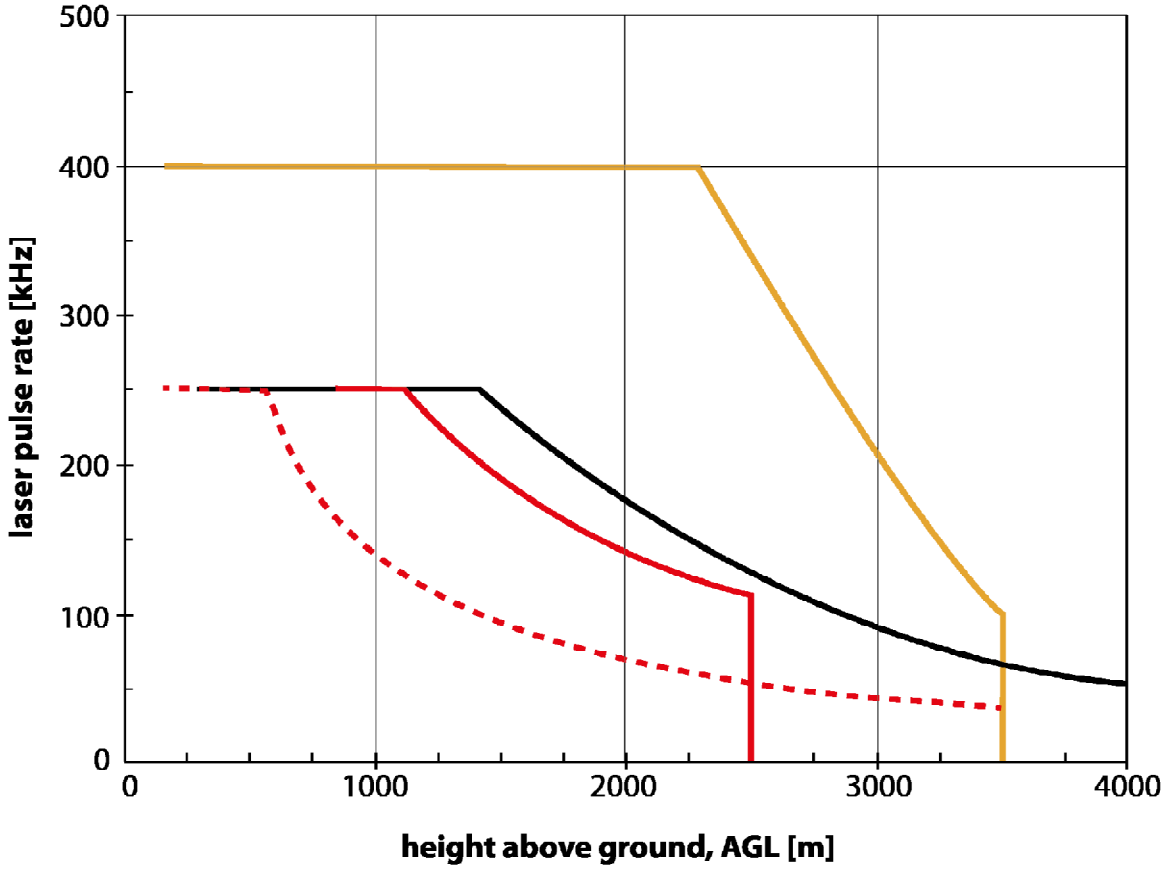
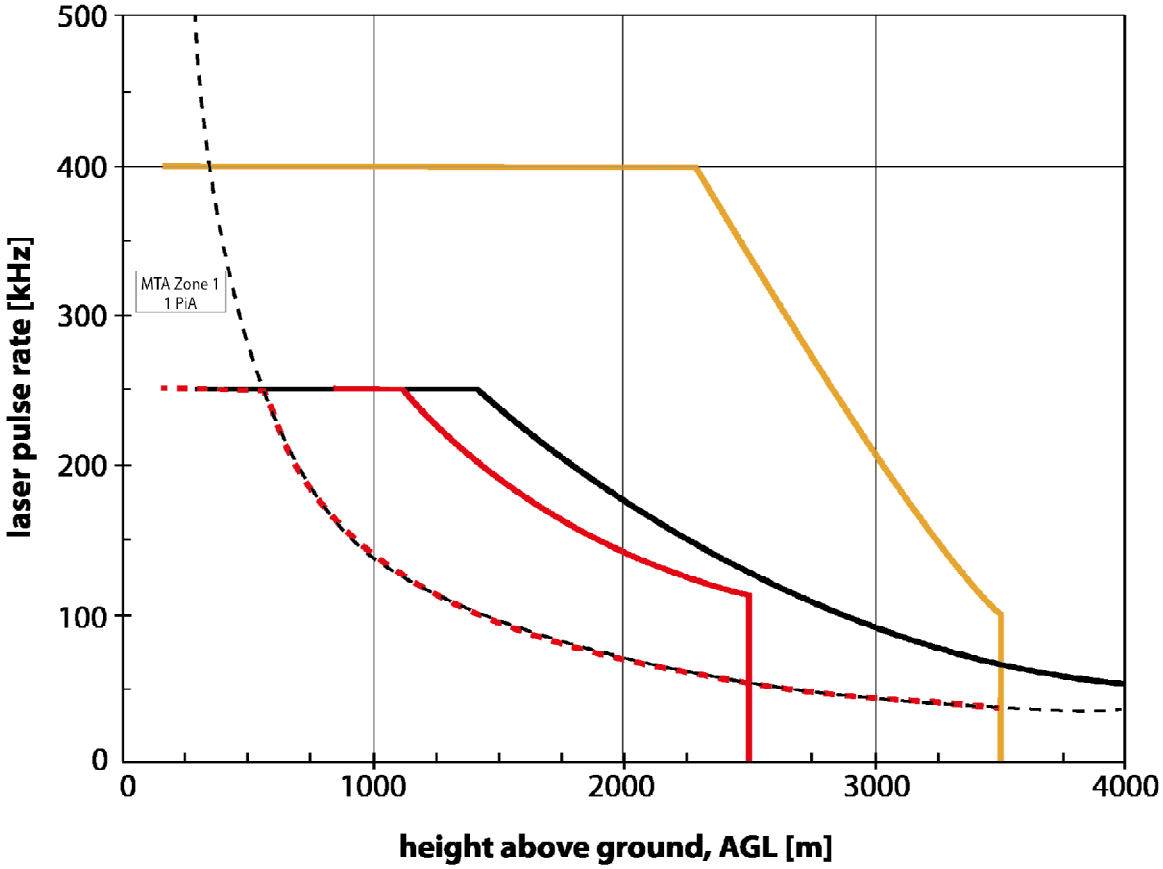
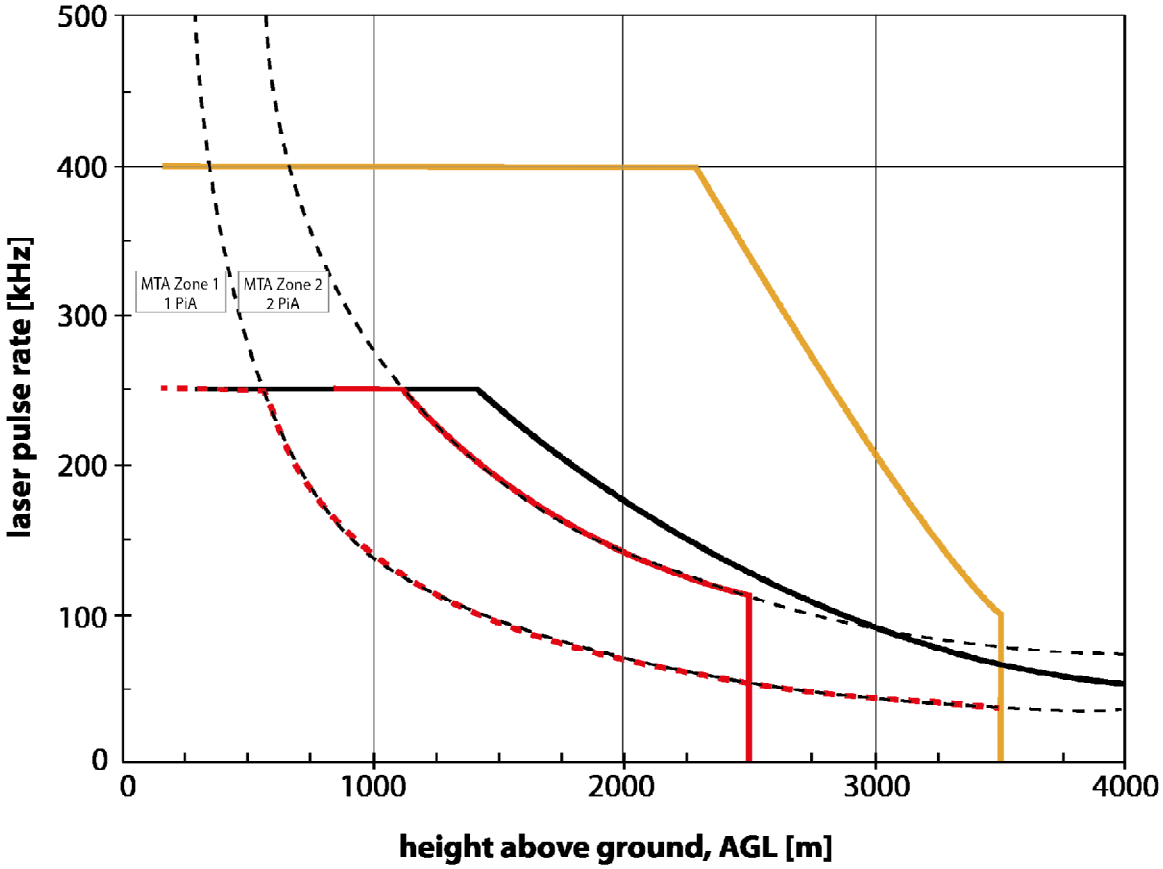


[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility

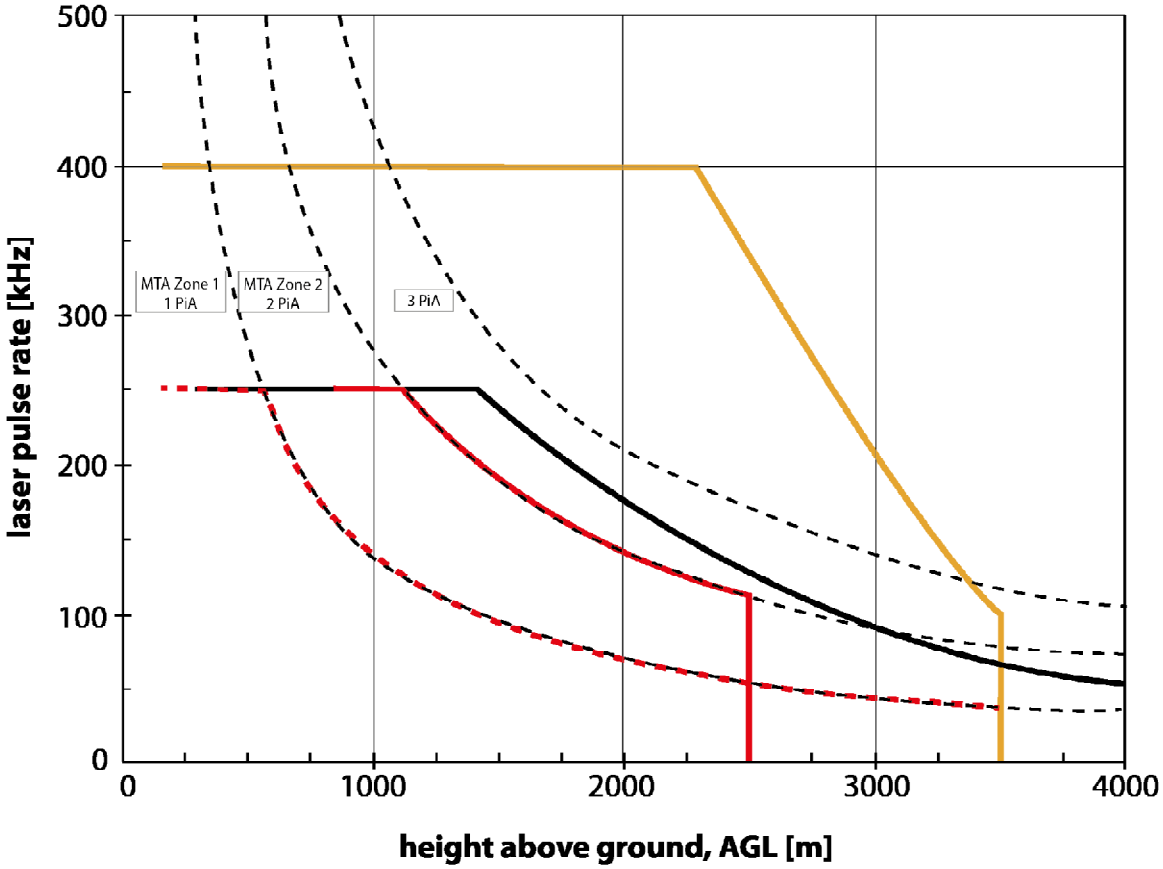


[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility



instrument A, *RIEGL* LMS-Q780
instrument B, 1 PiA
instrument B, 2 PiA
instrument C

[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility



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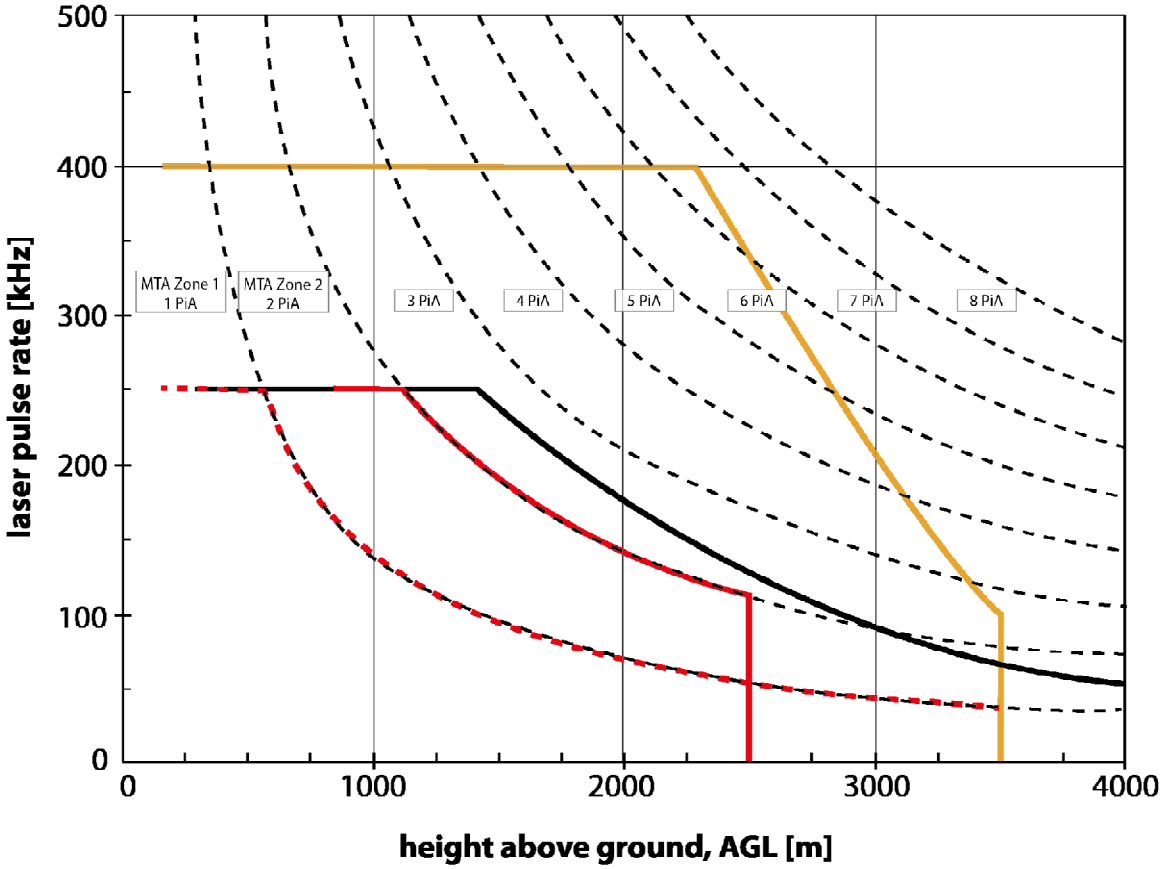
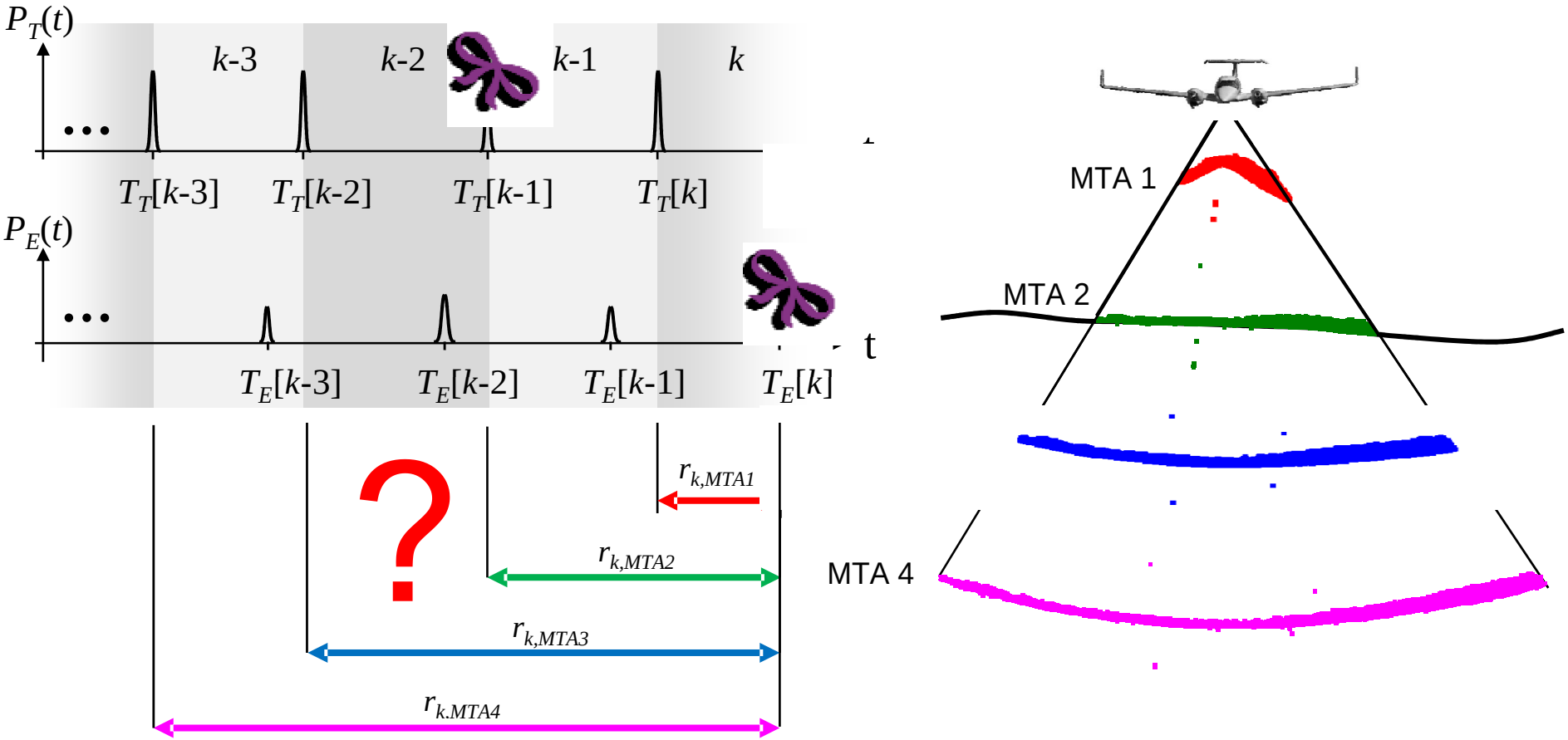


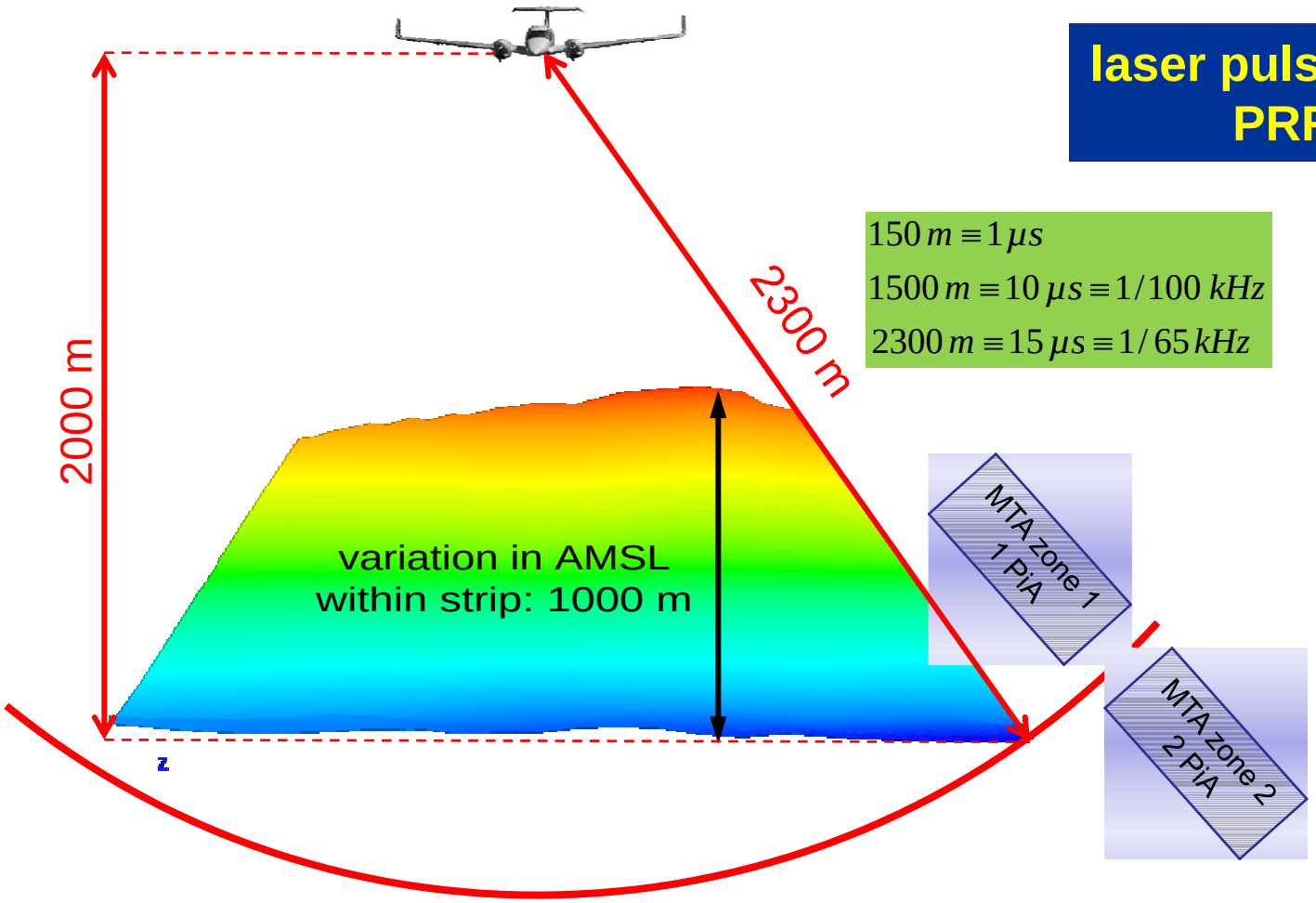
instrument A, *RIEGL* LMS-Q780
instrument B, 1 PiA
instrument B, 2 PiA
instrument C

[1)] 10% reflectance, 90% detection probability, 40 deg FOV, 23 km visibility



MTA-Zone 1, 2, 3 or 4 ?

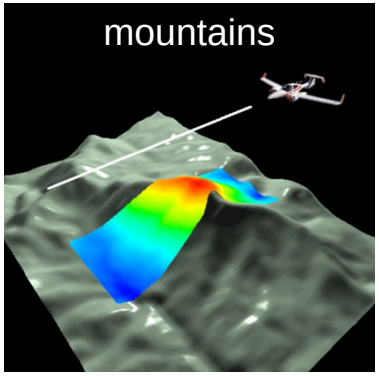
laser pulse repetition rate
PRR = 65 kHz



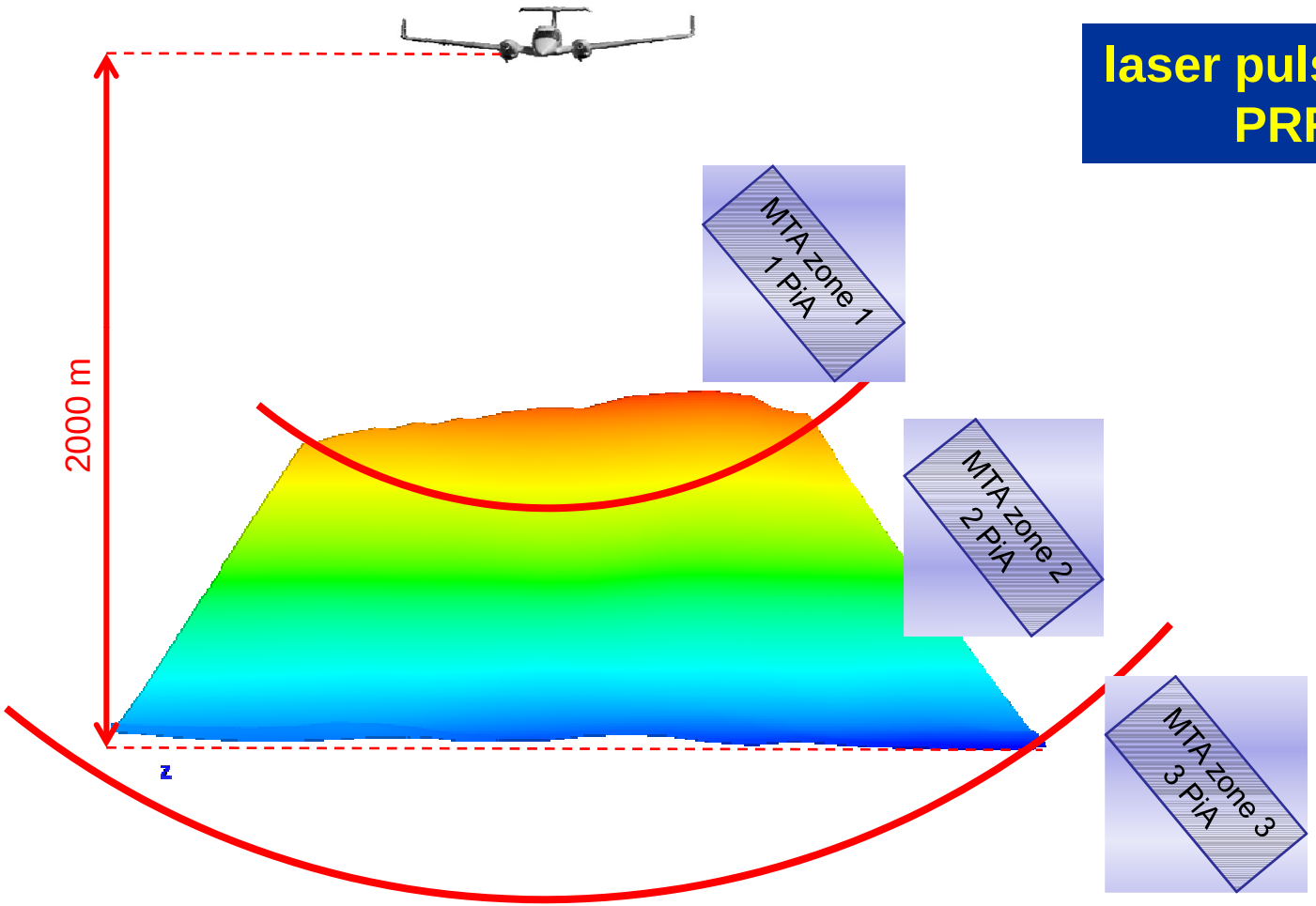
$150\,m \equiv 1\,\mu s$

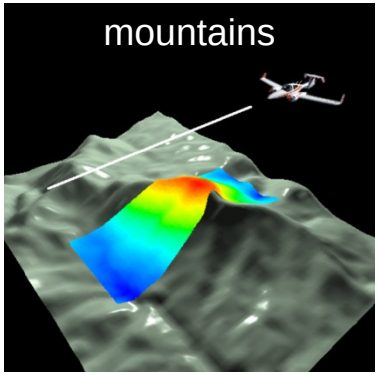
$1500\,m \equiv 10\,\mu s \equiv 1/100\,kHz$

$2300\,m \equiv 15\,\mu s \equiv 1/65\,kHz$

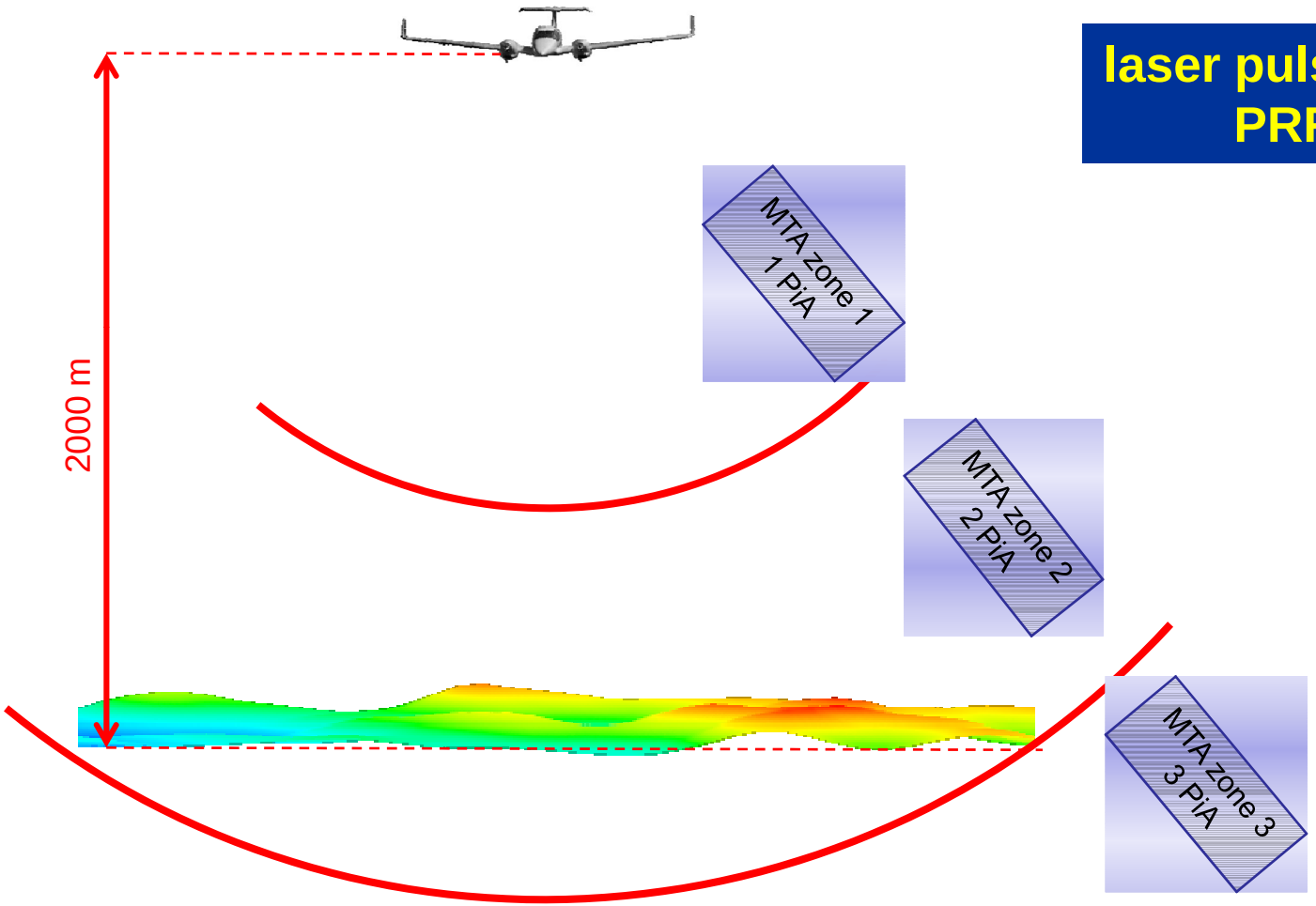


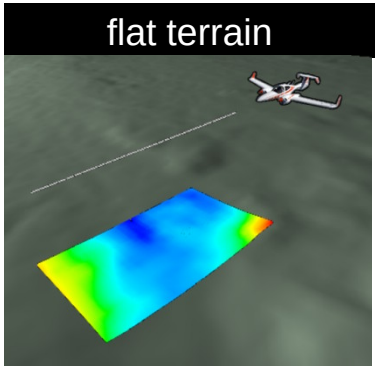
laser pulse repetition rate
PRR = 130 kHz

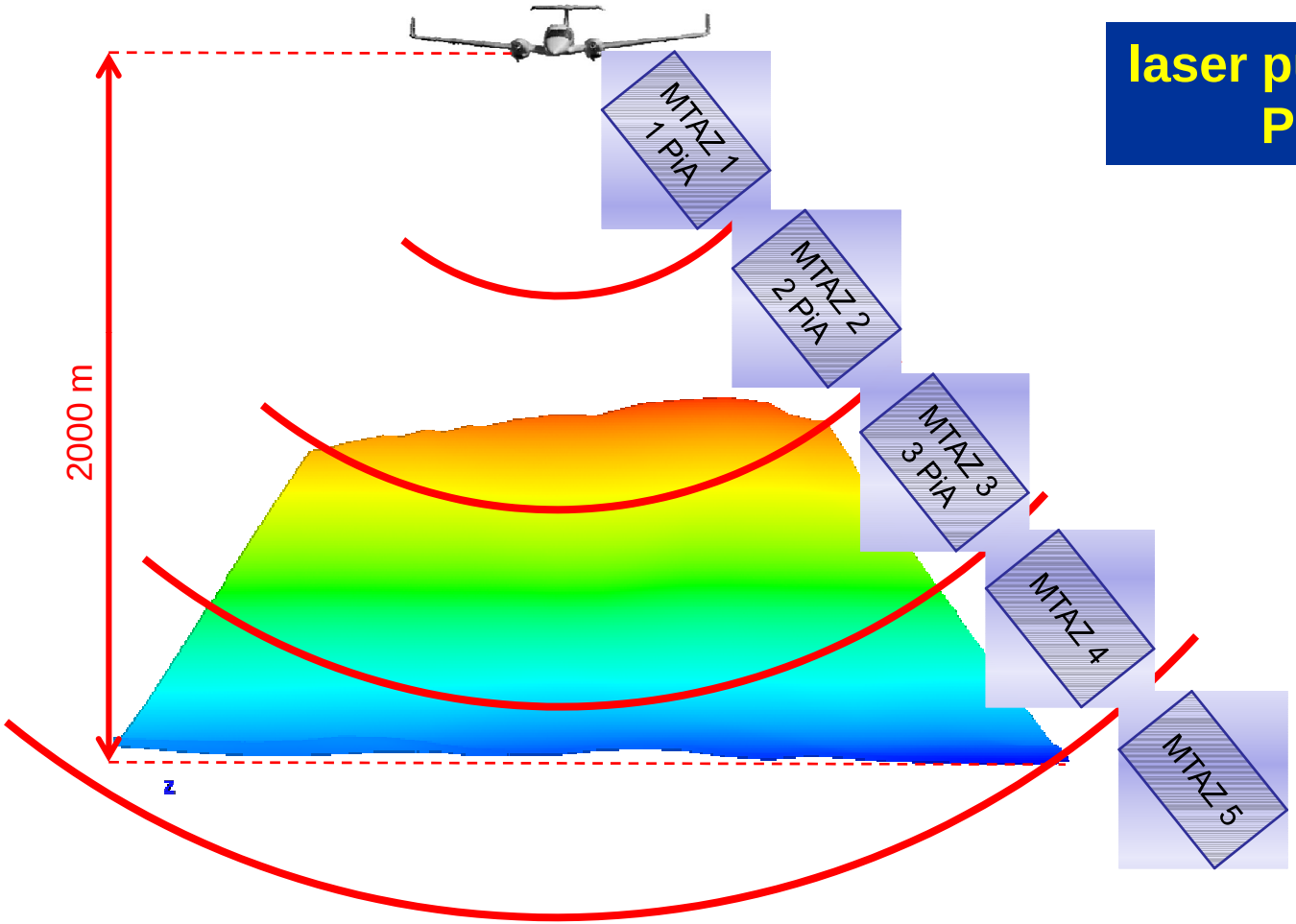




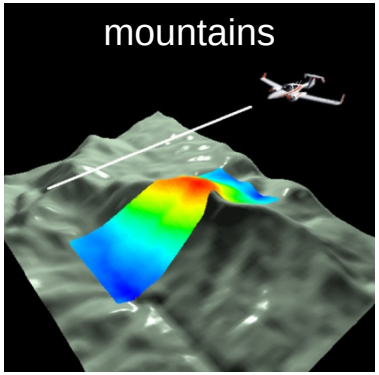
laser pulse repetition rate
PRR = 130 kHz

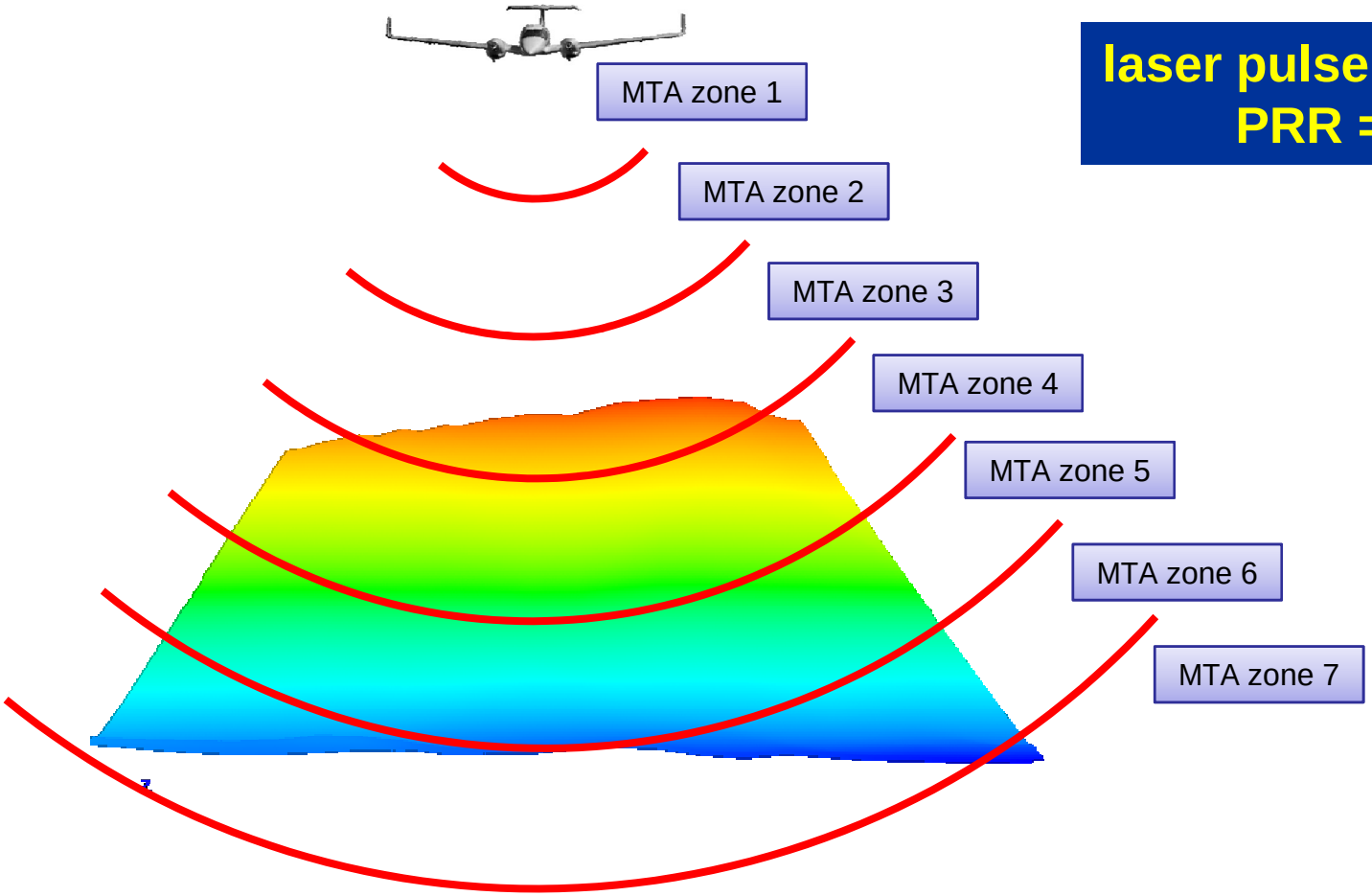




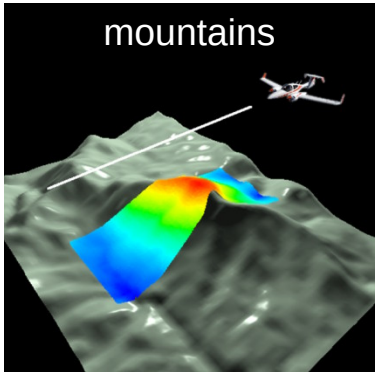


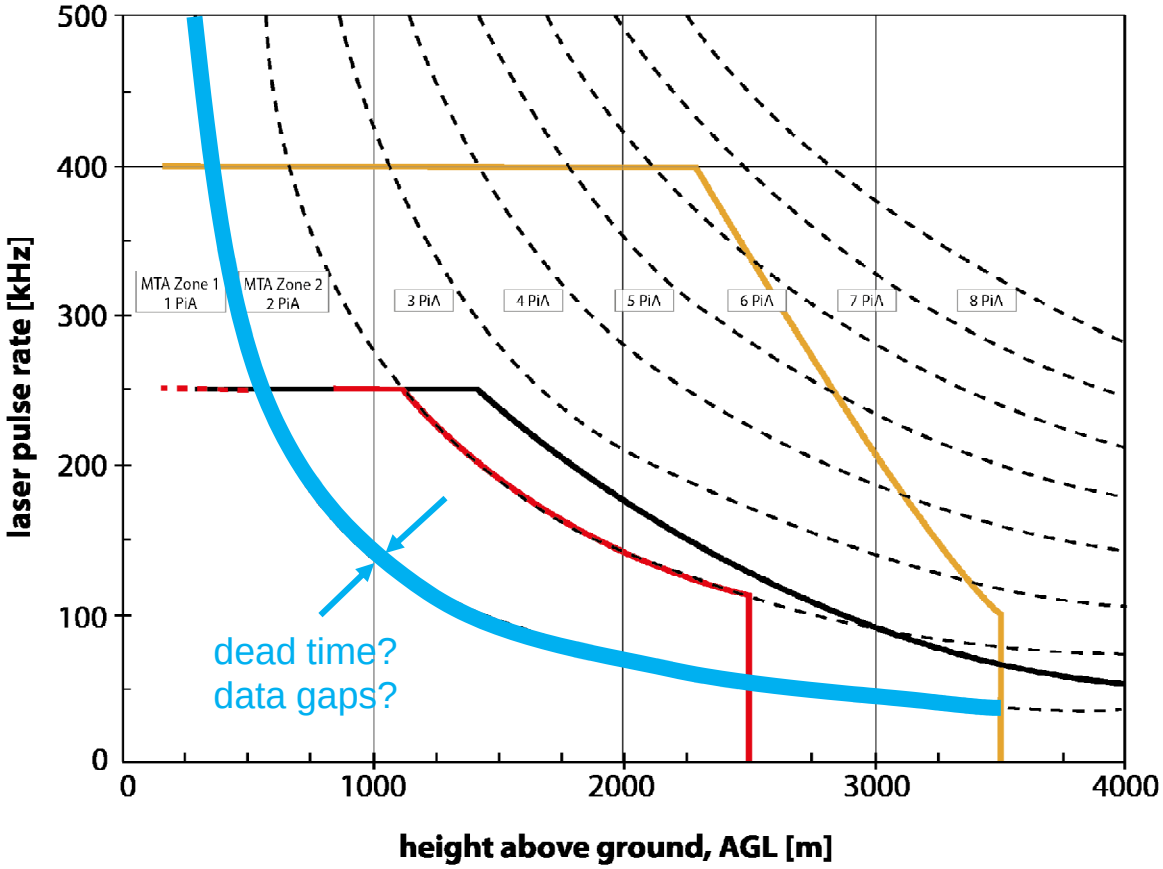
laser pulse repetition rate
PRR = 250 kHz





laser pulse repetition rate
PRR = 400 kHz





- instrument A, *RIEGL* LMS-Q780
- instrument B, 1 PiA
- instrument B, 2 PiA
- instrument C

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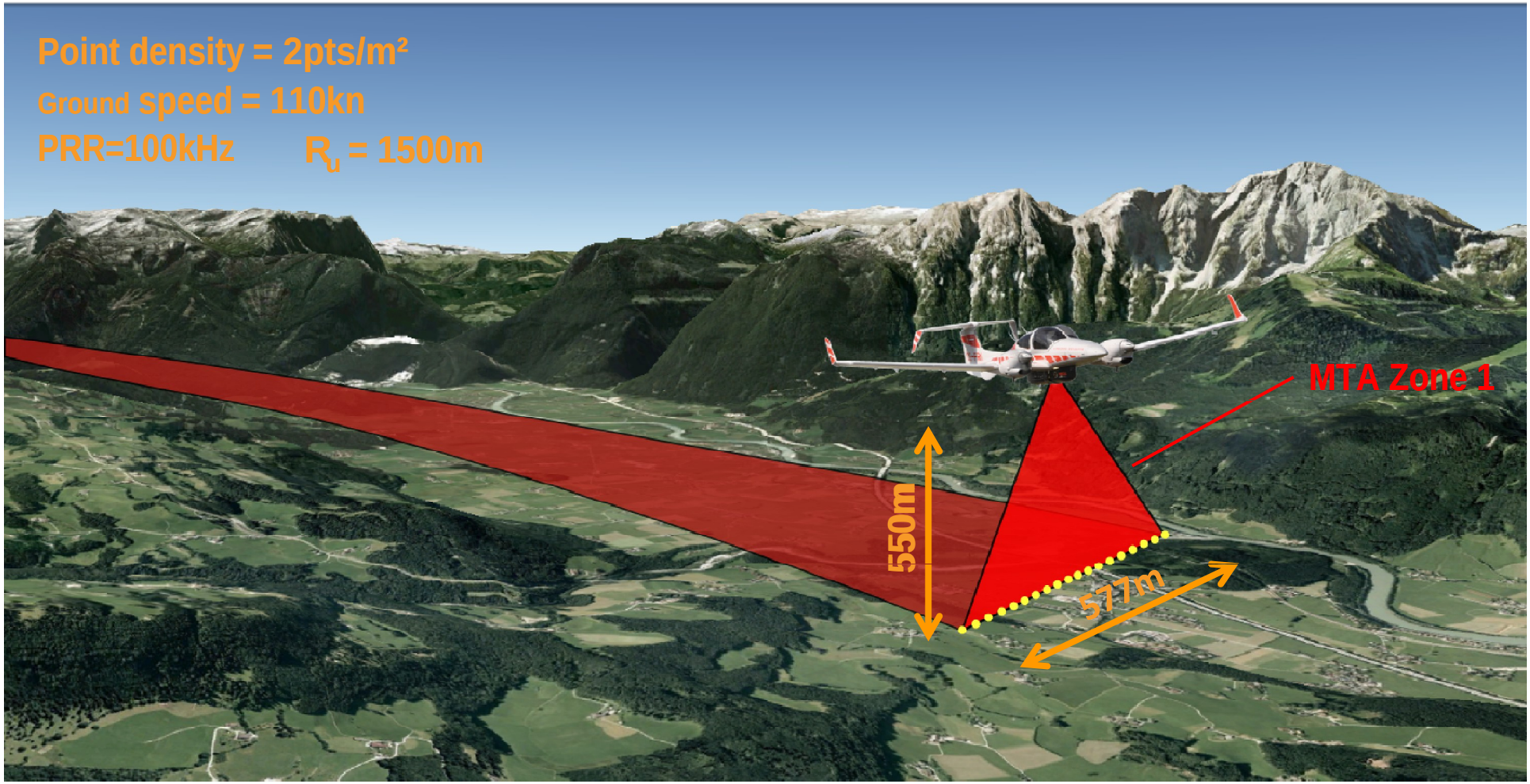

Single pulse in the air…

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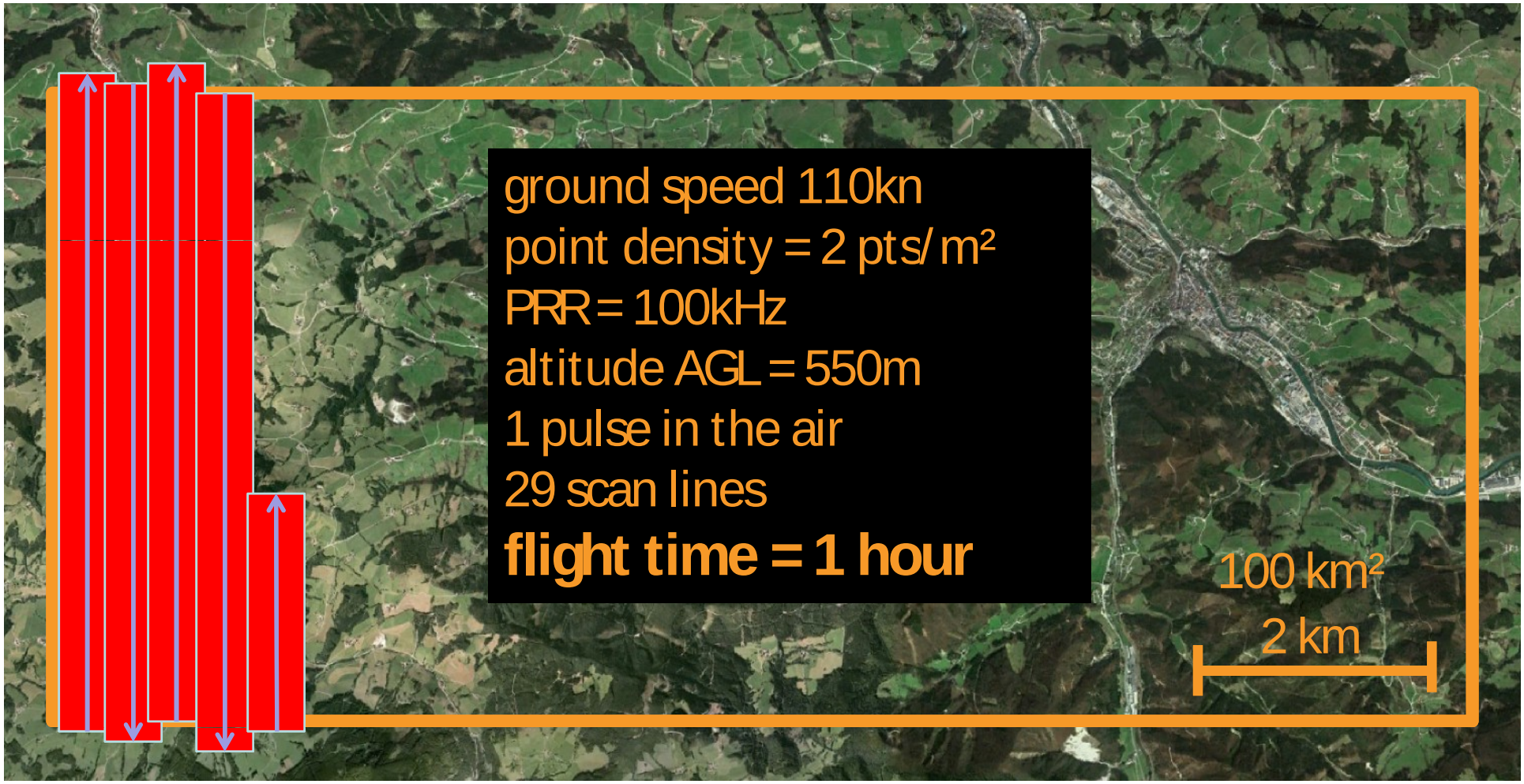

..long flights

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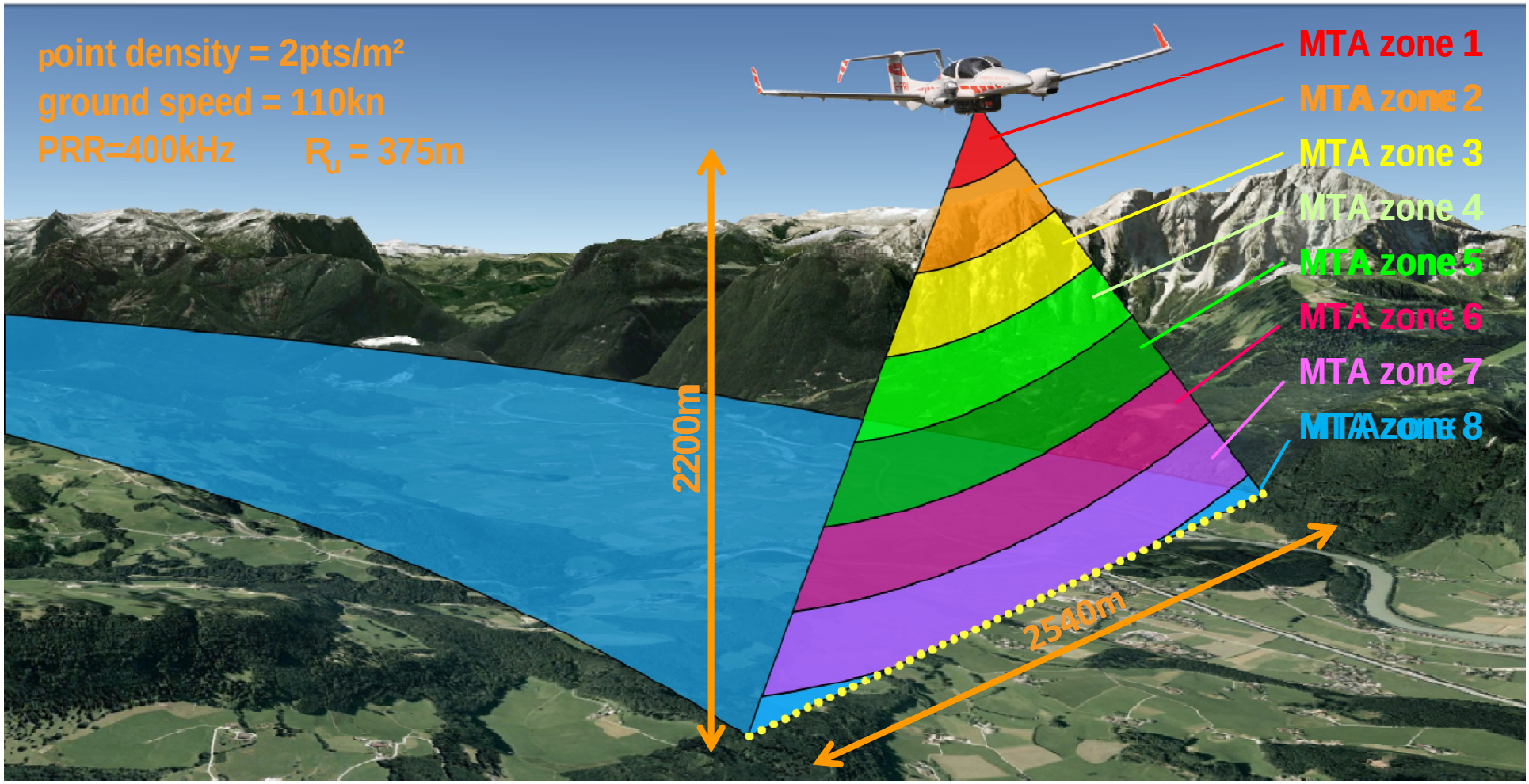

Multiple pulses in the air…

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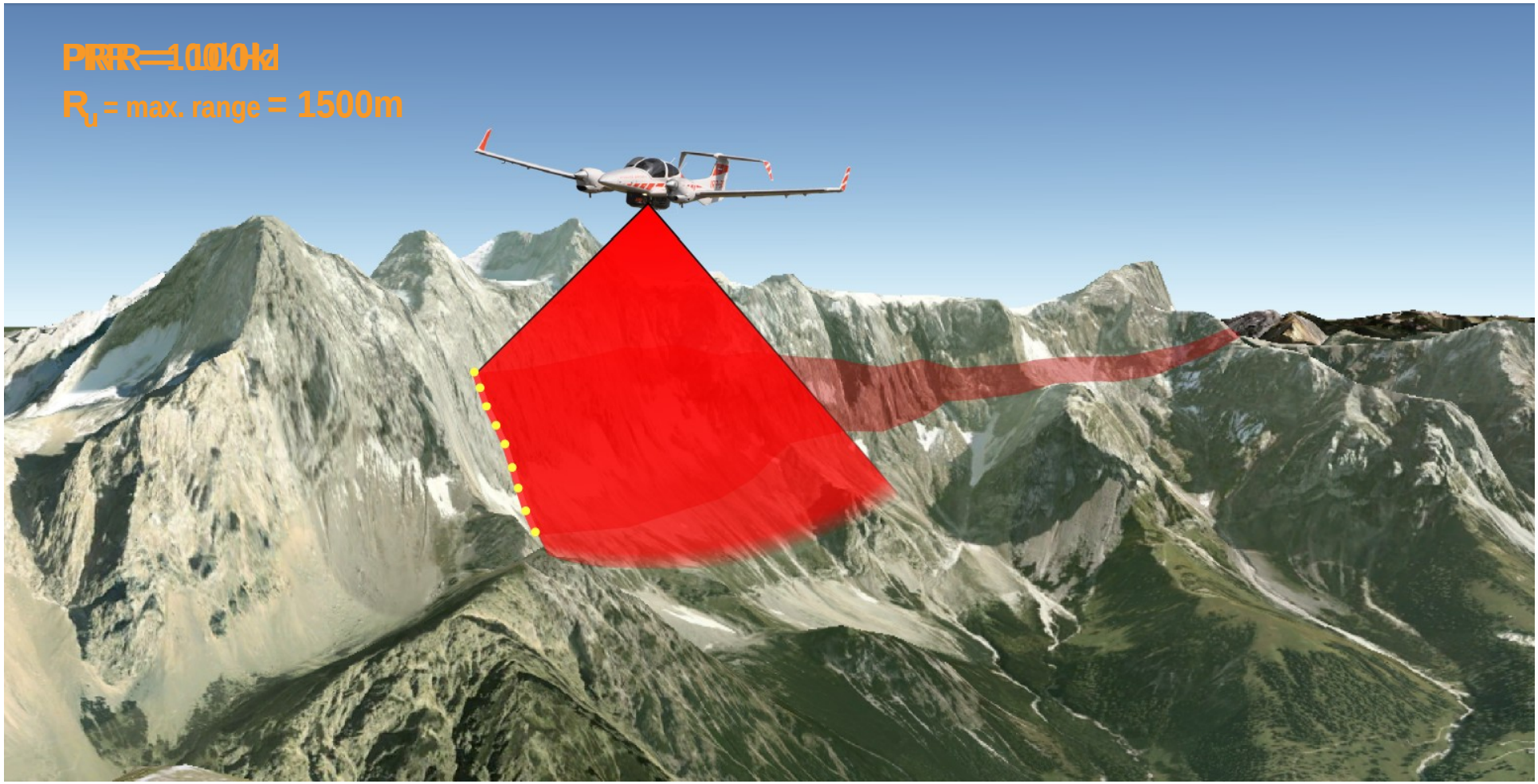
..efficient flights



Single pulse in the air…

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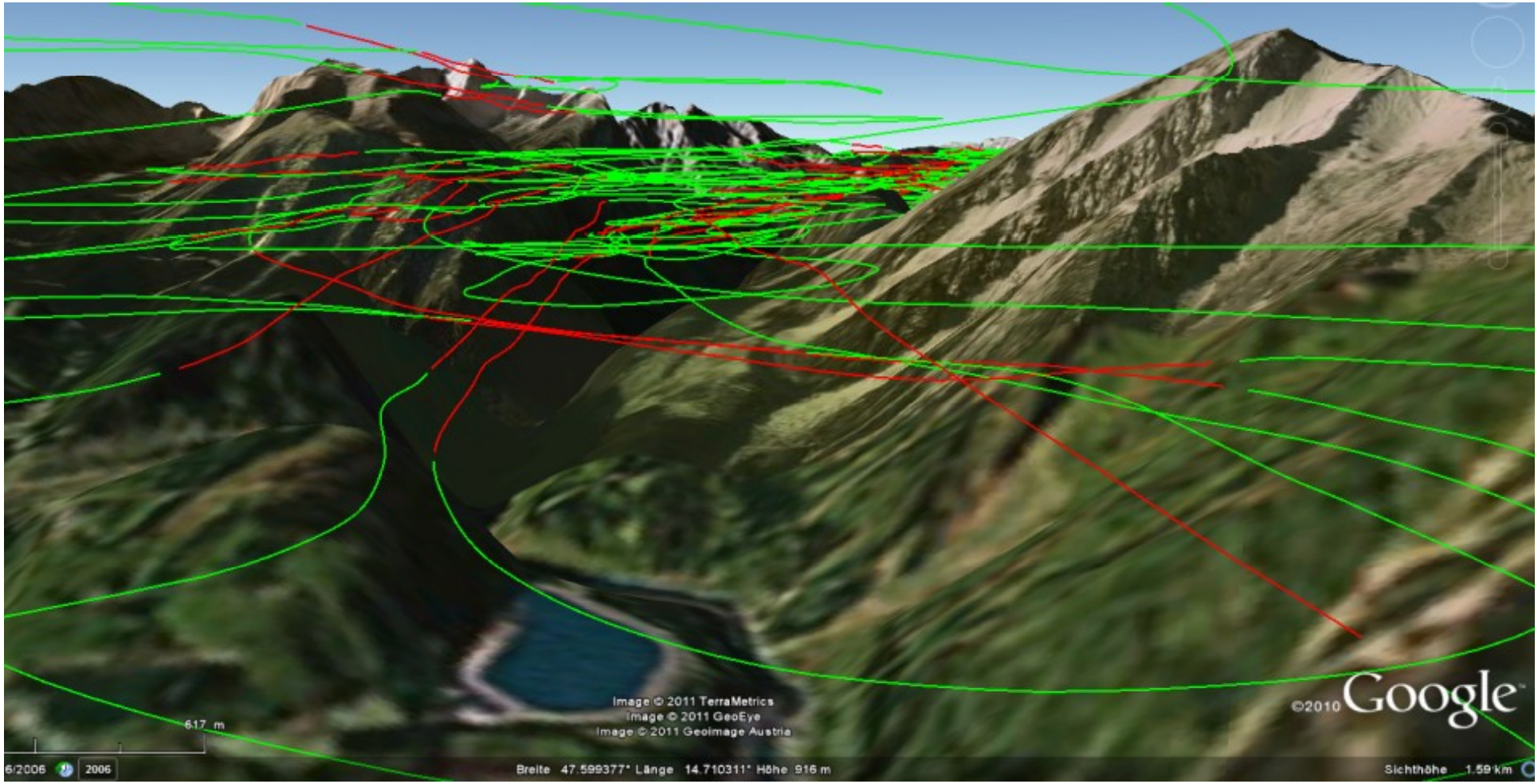

..difficult flights

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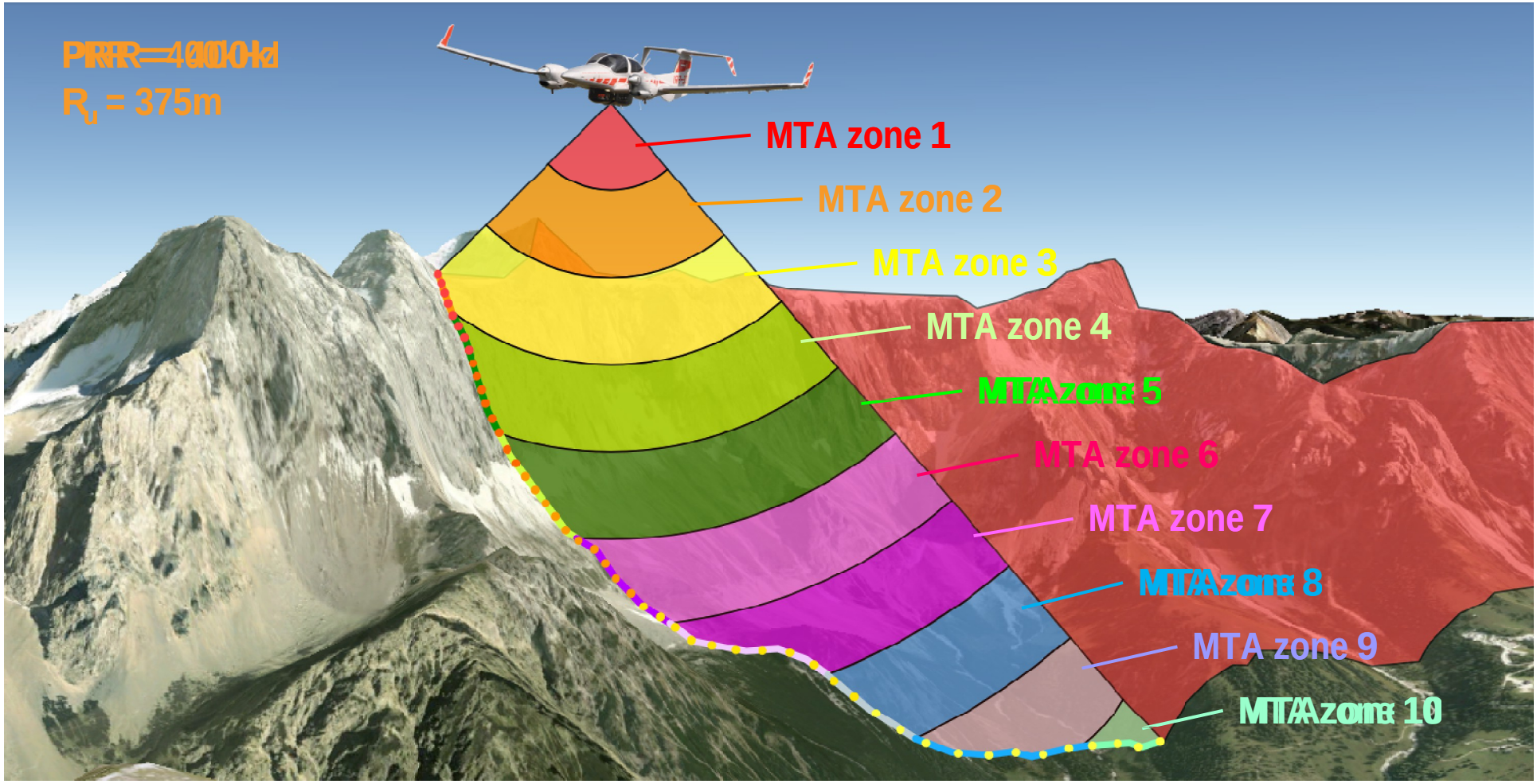

multiple pulses in the air

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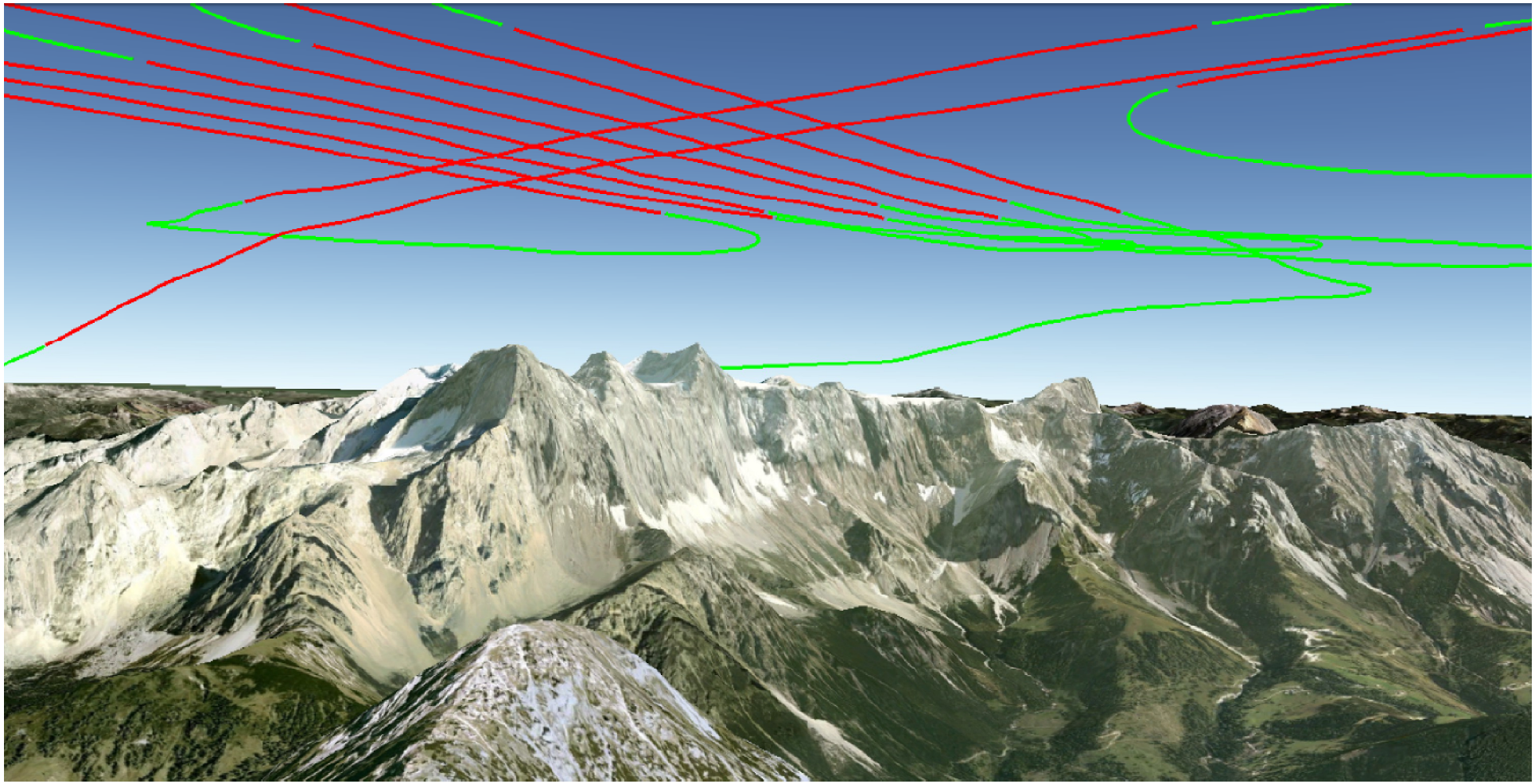
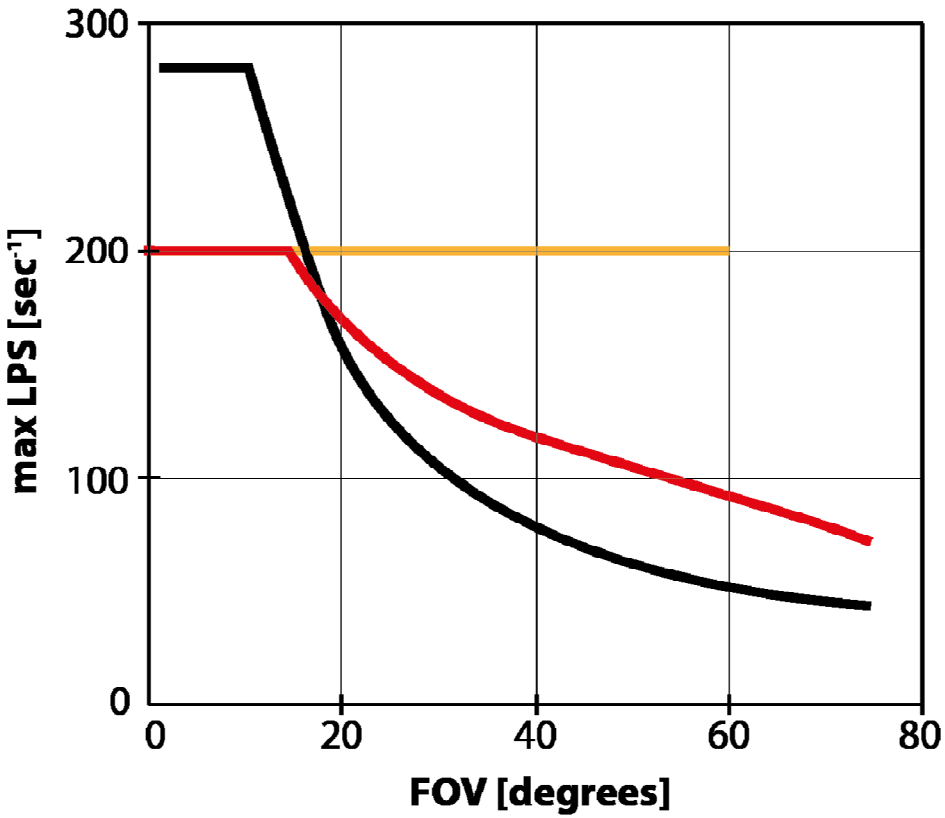
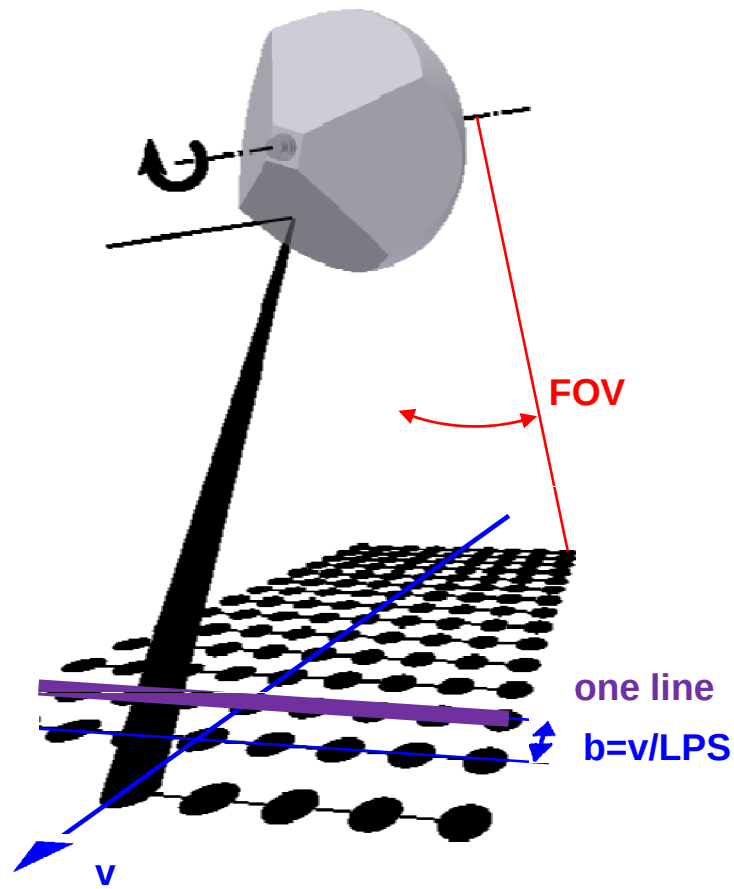


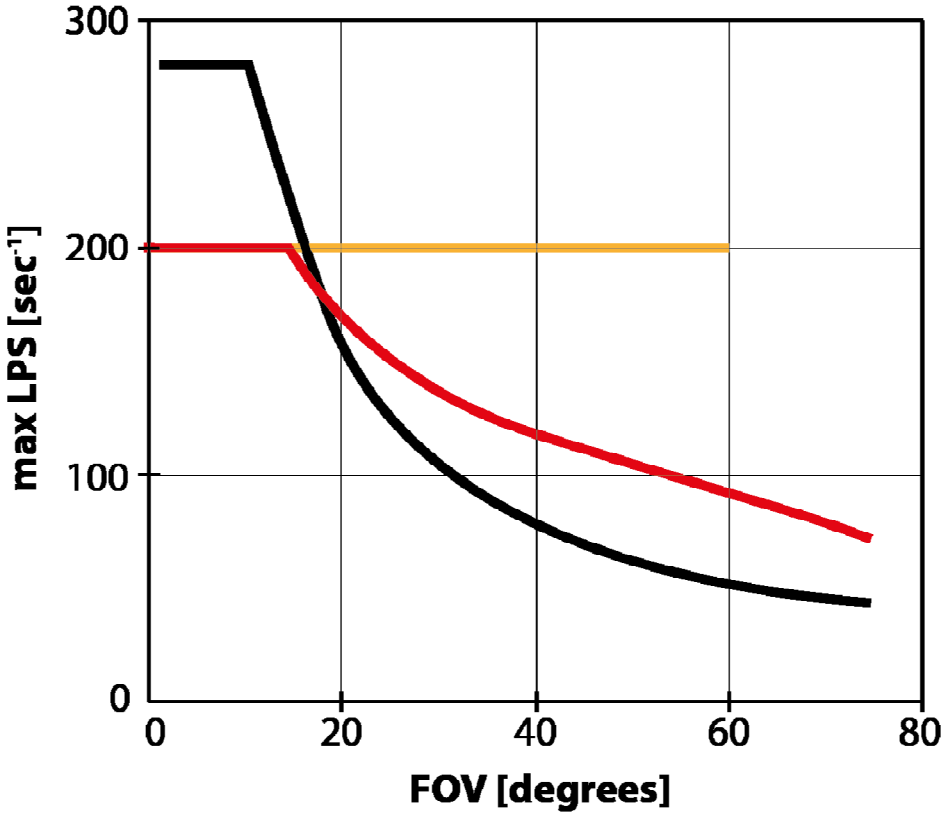
..safe flights

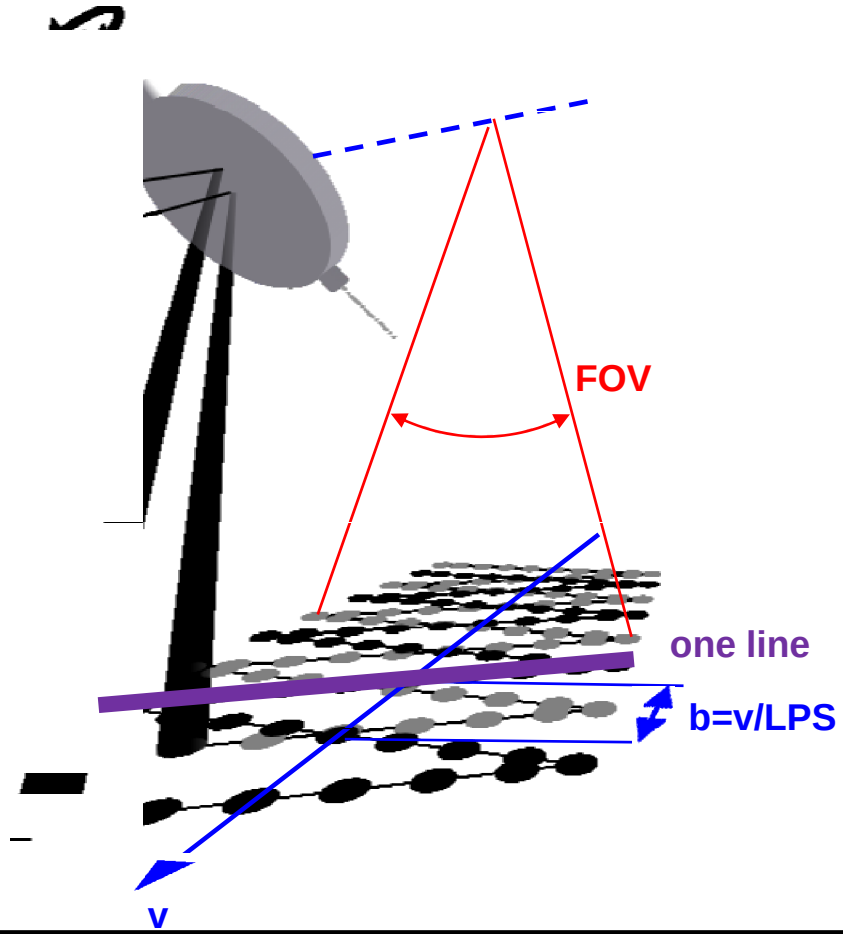


instrument A, *RIEGL* LMS-Q780
instrument B (single channel)
instrument C (single channel)

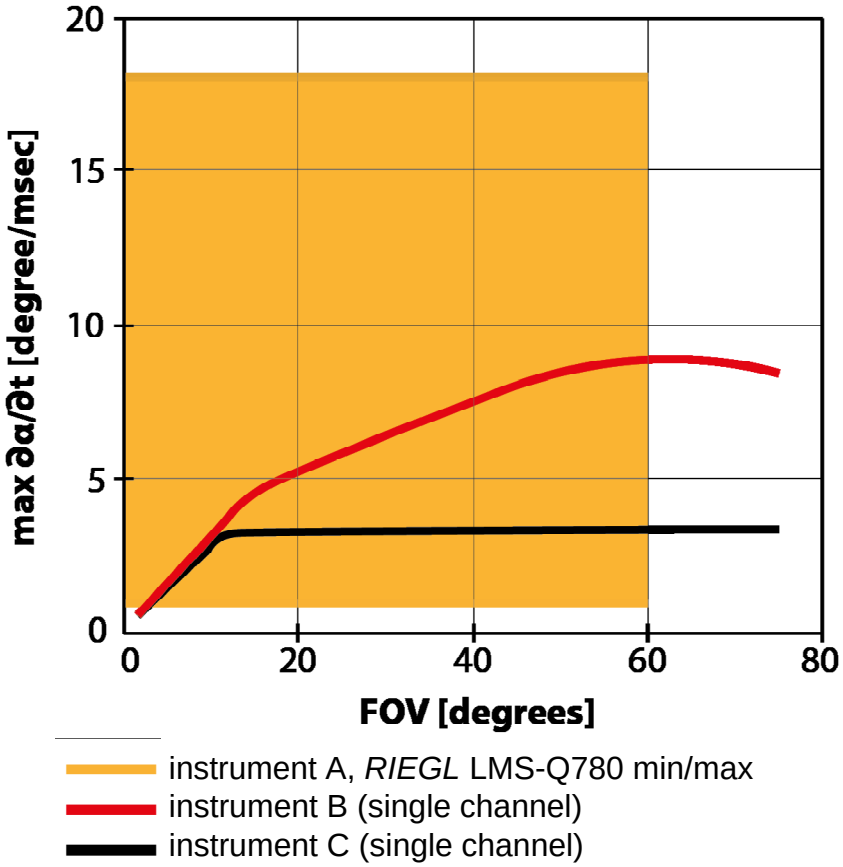


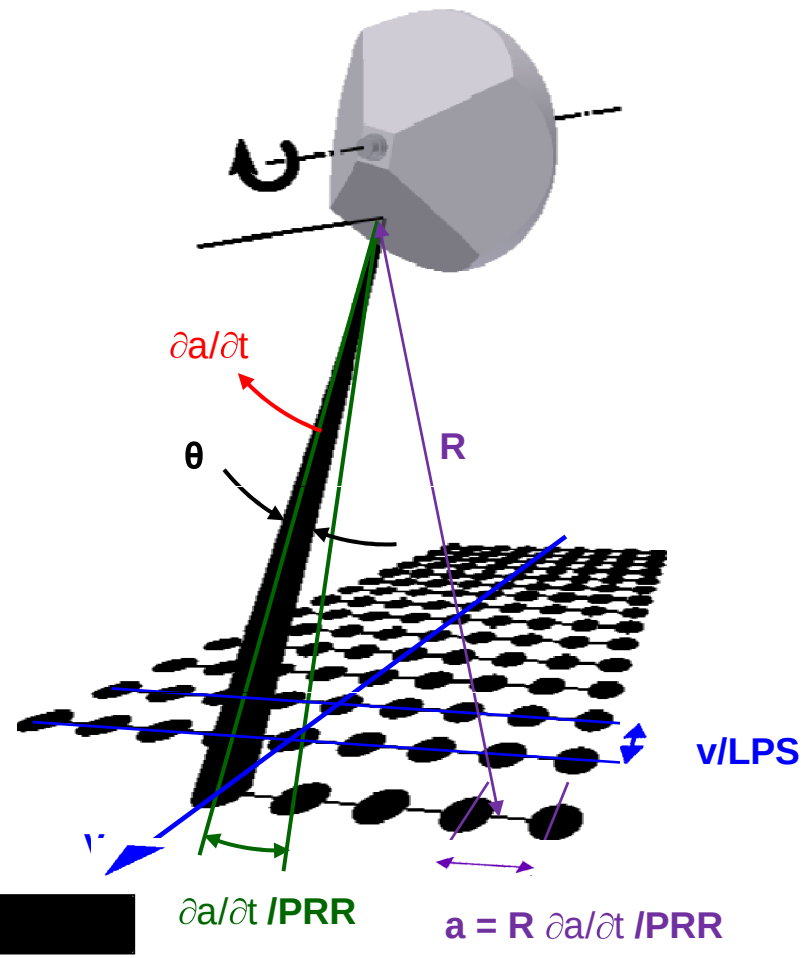
scan speed (lines per second) vs FOV





scan speed (lines per second) vs FOV

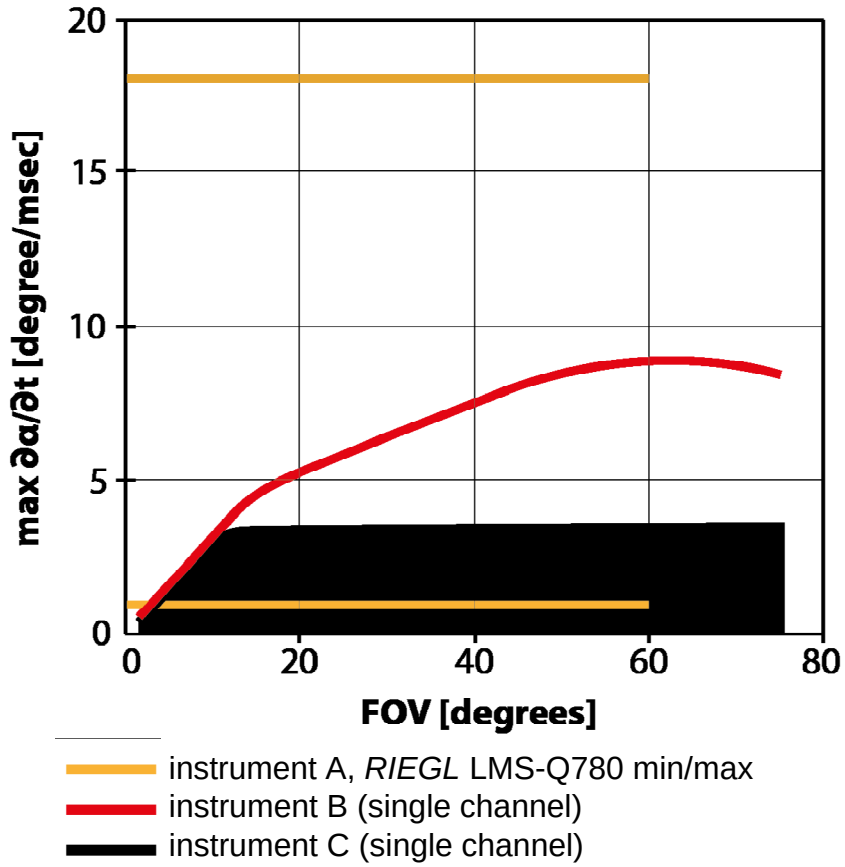


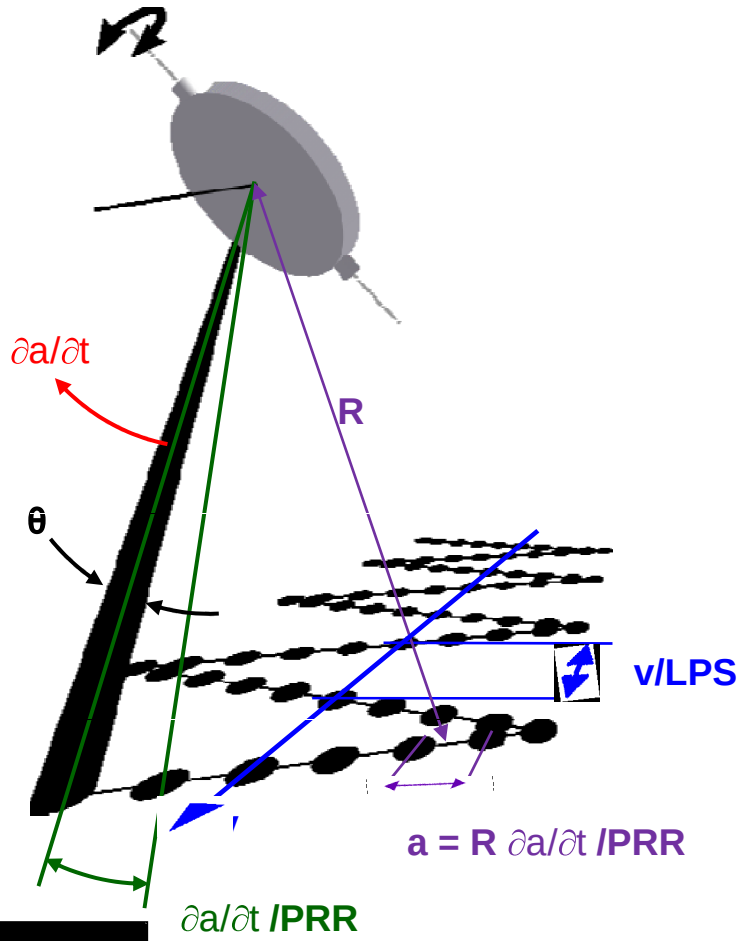


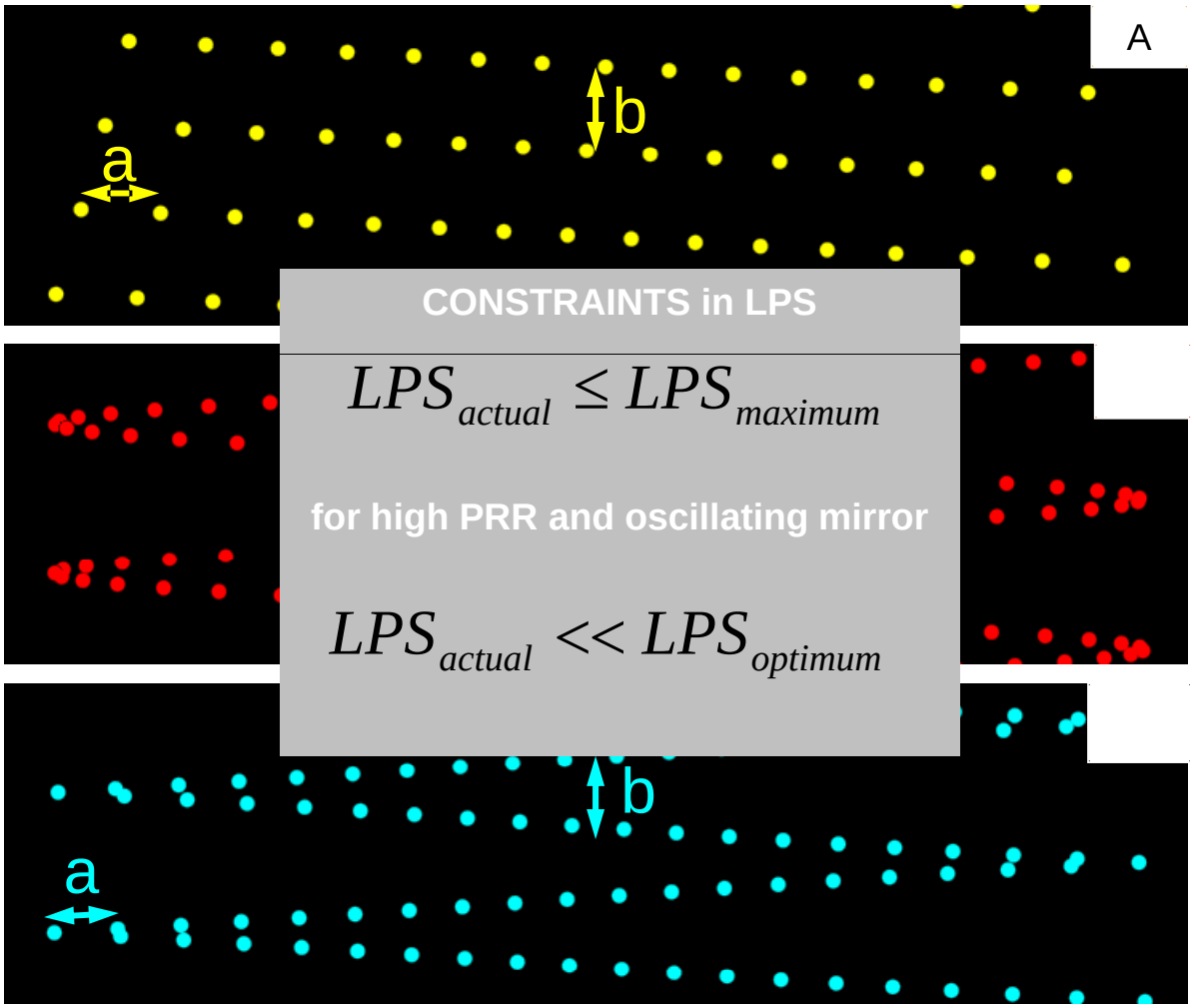
[redacted]

scan speed (degrees per millisecond) vs FOV


RIEGL
LASER MEASUREMENT SYSTEMS


max ∂α/∂t [degree/msec]
20
15
10
5
0
0
20
40
60
80
FOV [degrees]
instrument A, *RIEGL* LMS-Q780 min/max
instrument B (single channel)
instrument C (single channel)


∂a/∂t
R
θ
v/LPS
a = R ∂a/∂t /PRR
∂a/∂t /PRR



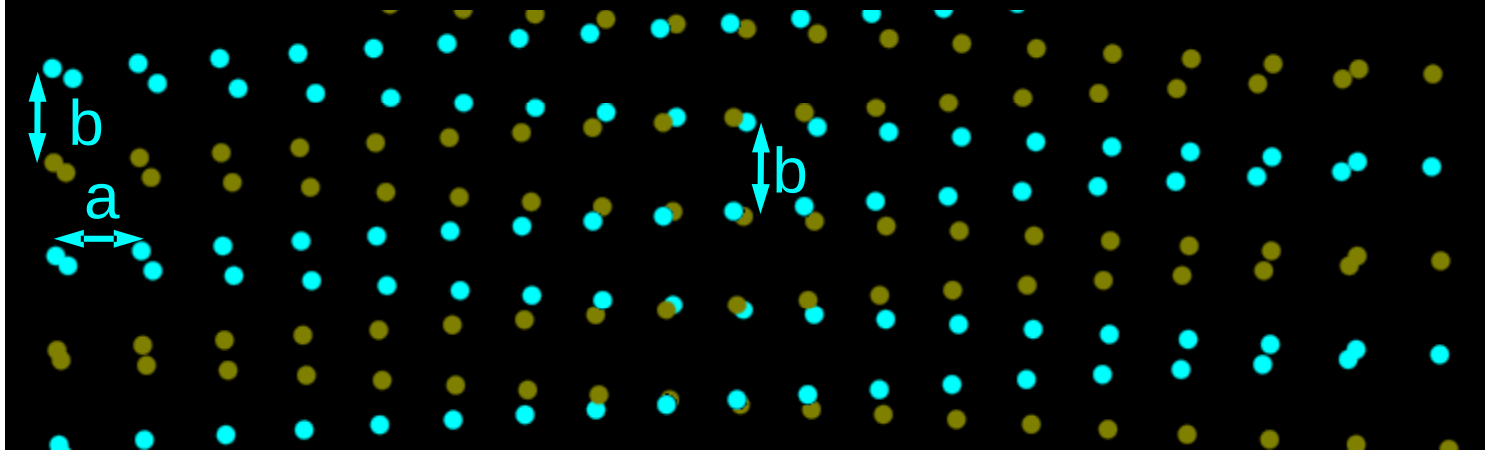
CONSTRAINTS in LPS

$$LPS_{actual} \leq LPS_{maximum}$$

for high PRR and oscillating mirror

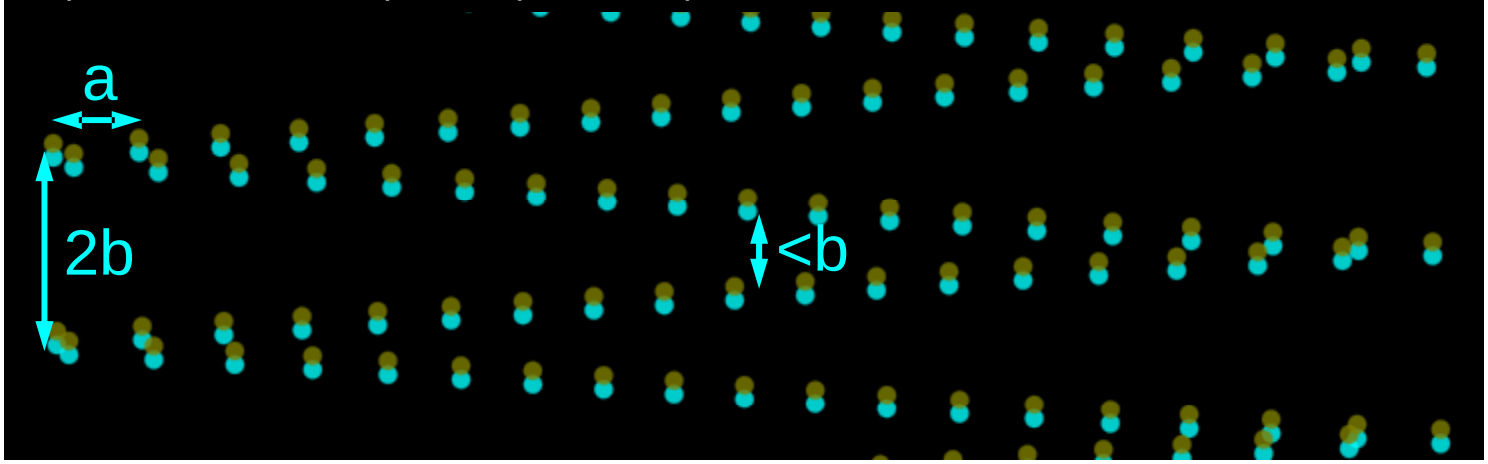
$$LPS_{actual} << LPS_{optimum}$$

out-of-phase interference pattern (desired)



phase depends on
- speed
- AGL
- LPS

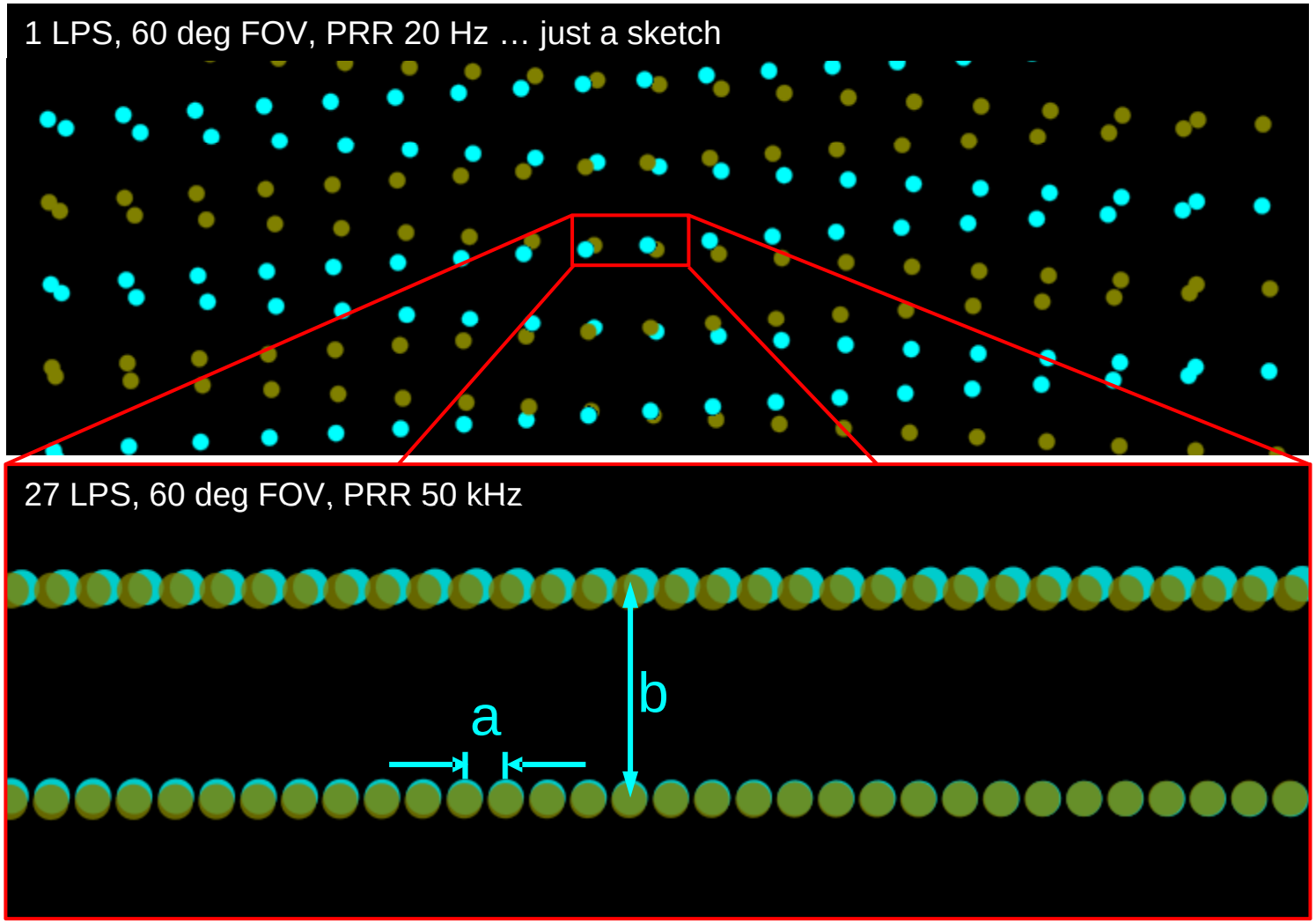
in-phase interference pattern (undesired)

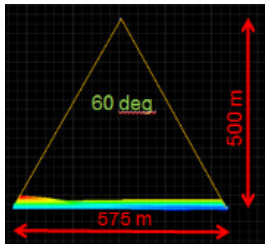
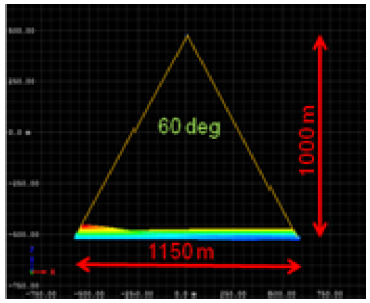
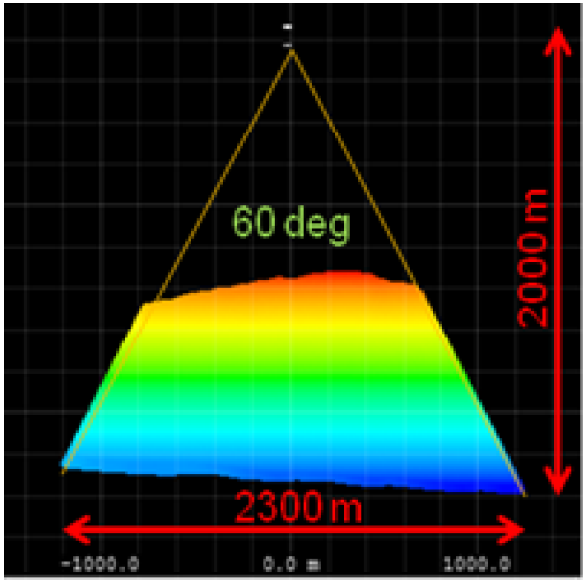


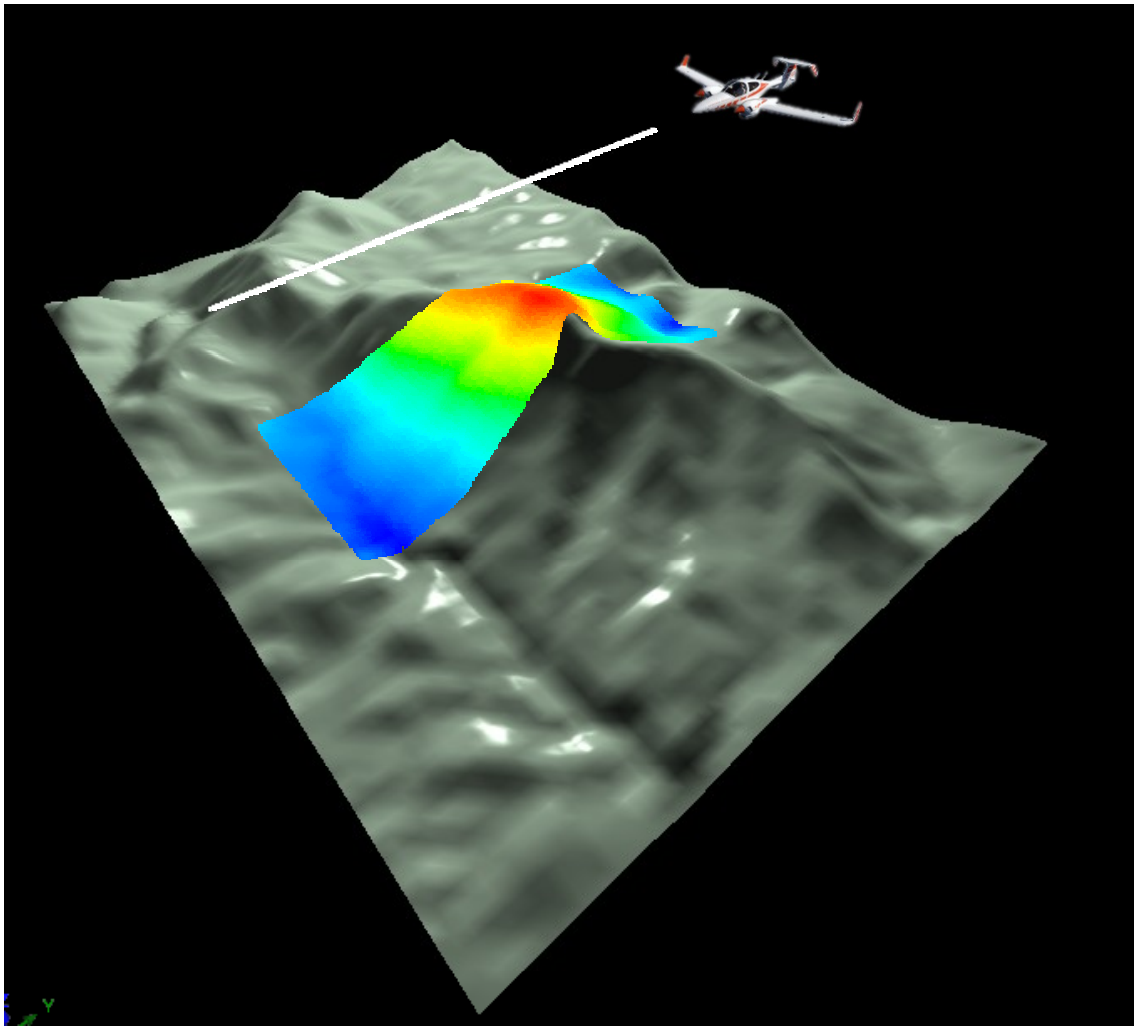
in any case:

2x “point density”

but:
“point spacing” ?


1 LPS, 60 deg FOV, PRR 20 Hz … just a sketch
27 LPS, 60 deg FOV, PRR 50 kHz
a
b

	scenario 1	scenario 2	scenario 3
application	corridor mapping	high density survey	wide area mapping
terrain	flat	flat	mountainous
AGL	500 m	1000 m	2000 m – 1000 m
speed	60 kn	120 kn	140 kn
FOV	60 deg	60 deg	60 deg
			

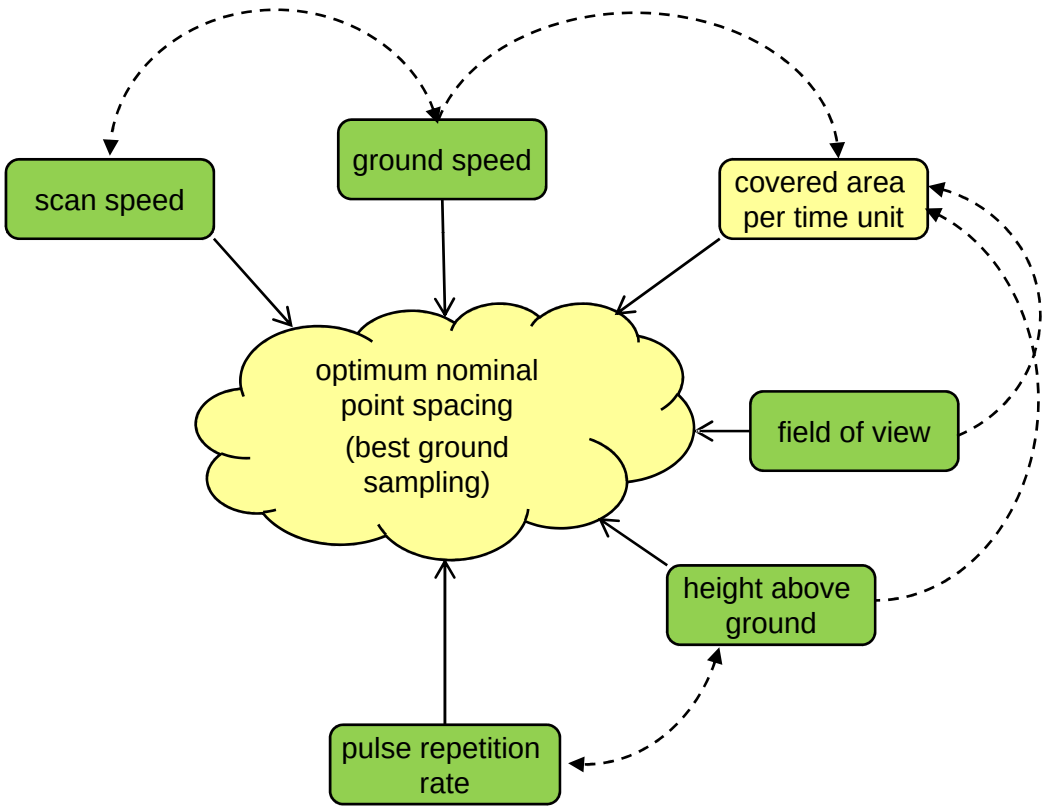


mountainous terrain

- variation in AMSL 1000 m
- scenario 3

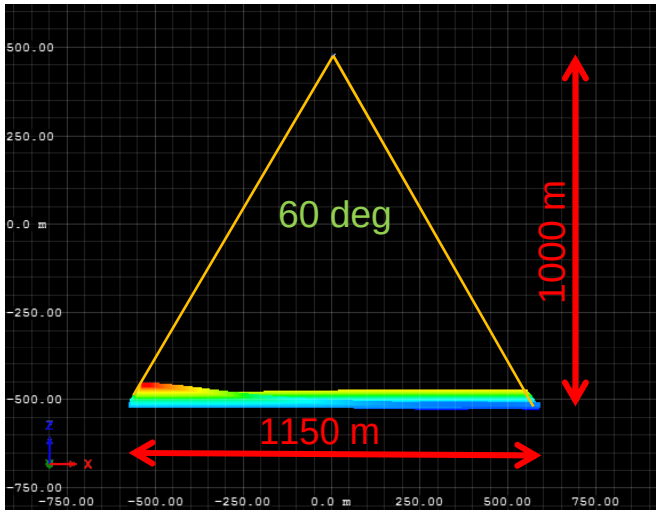
simulation of point distribution on terrain

- defining test area (scenarios 1 – 3)
- choosing optimum flight parameters
  - performance envelope → PRR_{max}
  - calculating $LPS_{optimum}$ → LPS_{actual}
- generating trajectory
- “mounting” LIDAR & generating “pulses”
- intersecting beams with terrain
- analyzing / visualizing point clouds



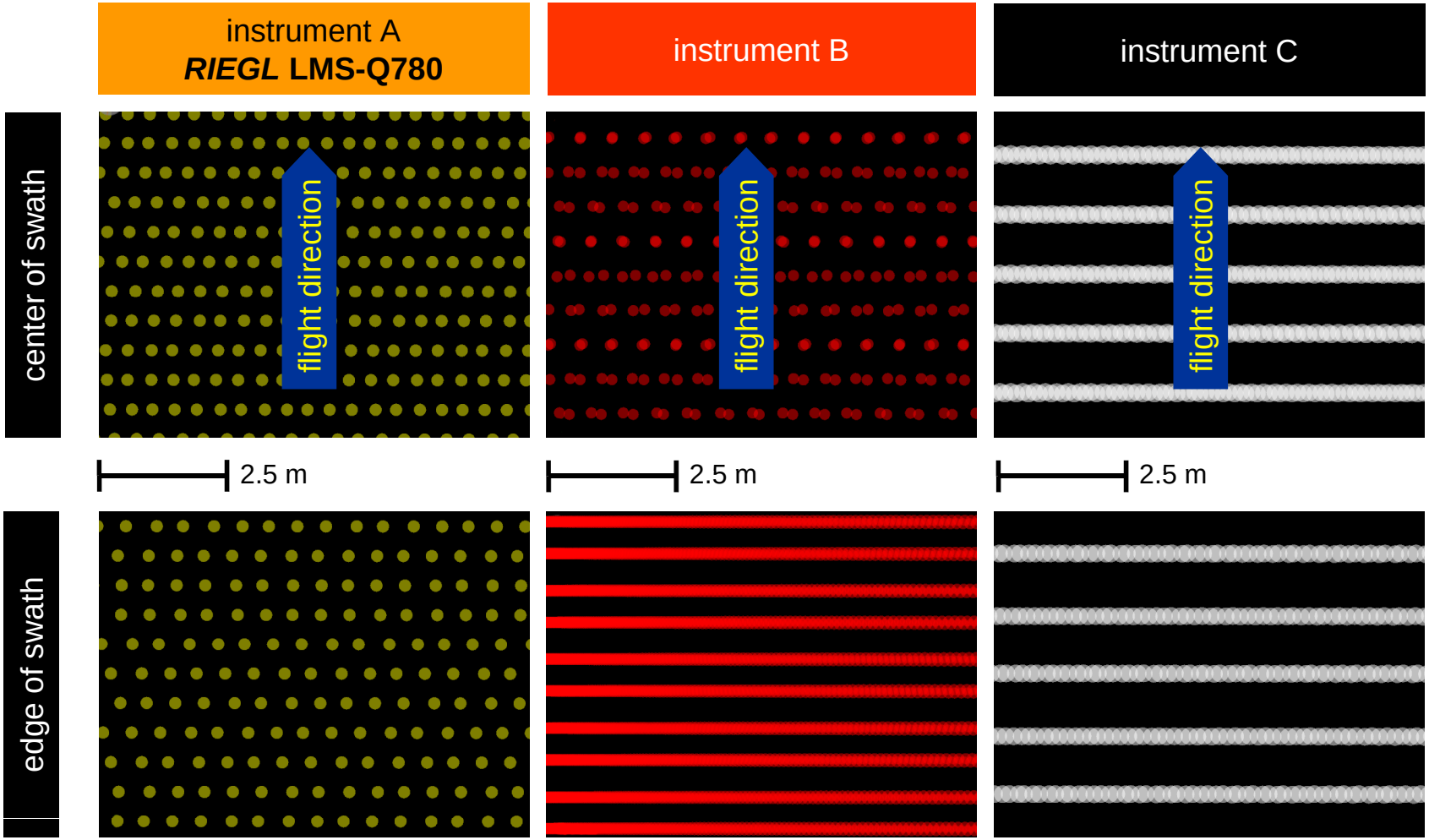
Performance on flat terrain

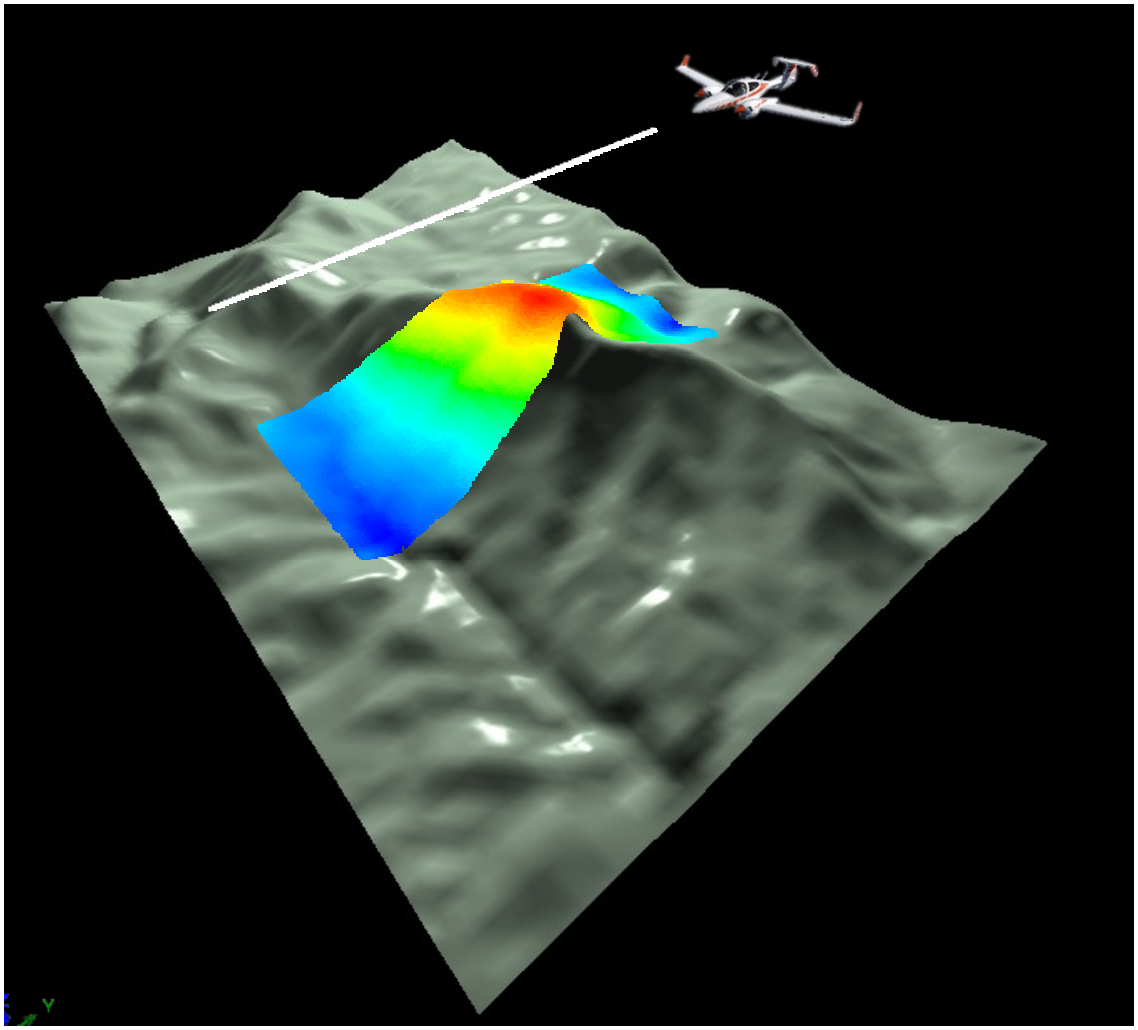
- AGL at 1000 m
- speed over ground 120 kn
- FOV of 60 degrees
- optimum operating parameters for all instruments



	AGL	FOV	MR	LPS	across spacing	along spacing	point density
instrument A	1000 m	60 deg	1x 266 kHz	1x 108 LPS	0.57 m	0.57 m	4.1 p/m²
instrument B	1000 m	60 deg	2x 250 kHz	2x 93 LPS	0.61 m	0.66 m	7.7 p/m²
instrument C	1000 m	60 deg	2x 250 kHz	2x **53 LPS**	0.30 m	**1.16 m**	7.7 p/m²


RIEGL
LASER MEASUREMENT SYSTEMS


instrument A
RIEGL LMS-Q780
instrument B
instrument C
center of swath
edge of swath
flight direction
flight direction
flight direction
2.5 m
2.5 m
2.5 m



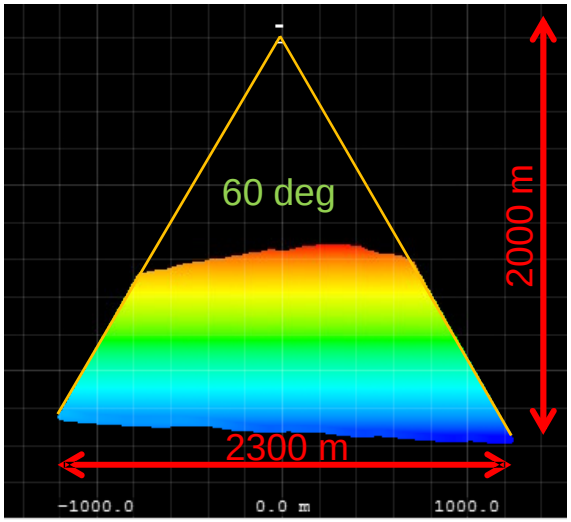
mountainous terrain

- variation in AMSL 1000 m
- scenario 3

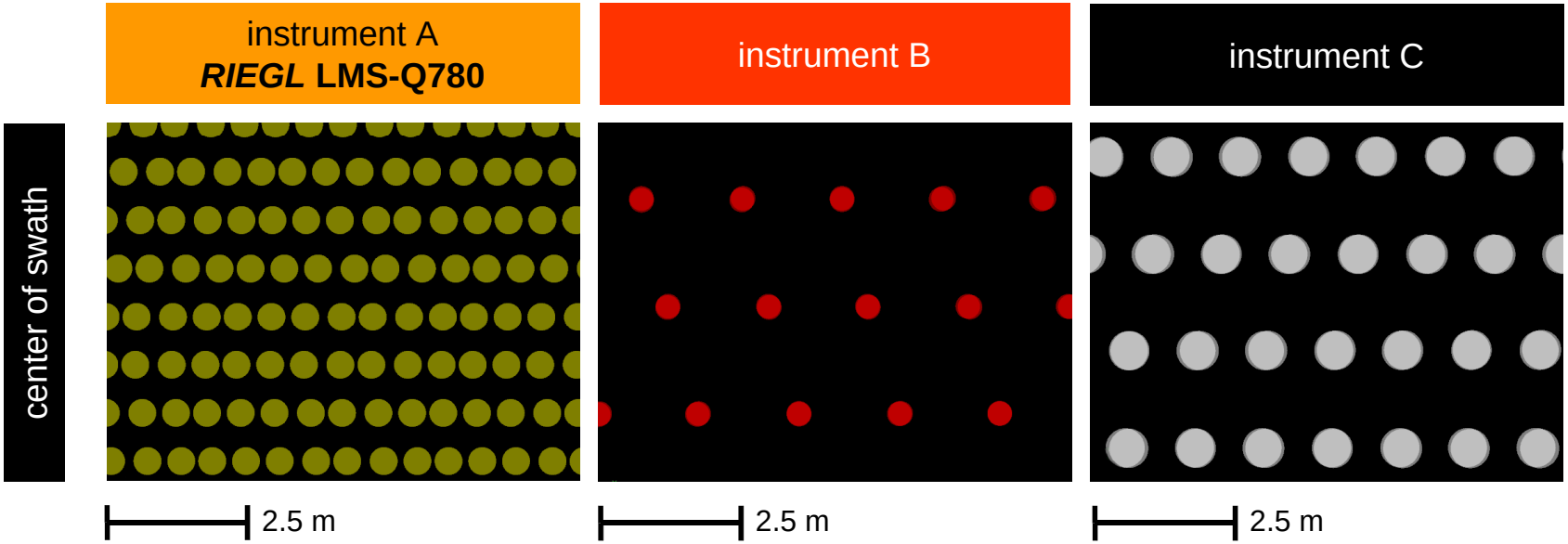
simulation of point distribution on terrain

Performance on mountainous terrain

- AGL from 1000 m to 2000 m
- speed over ground 140 kn
- FOV of 60 degrees
- optimum operating parameters for all instruments

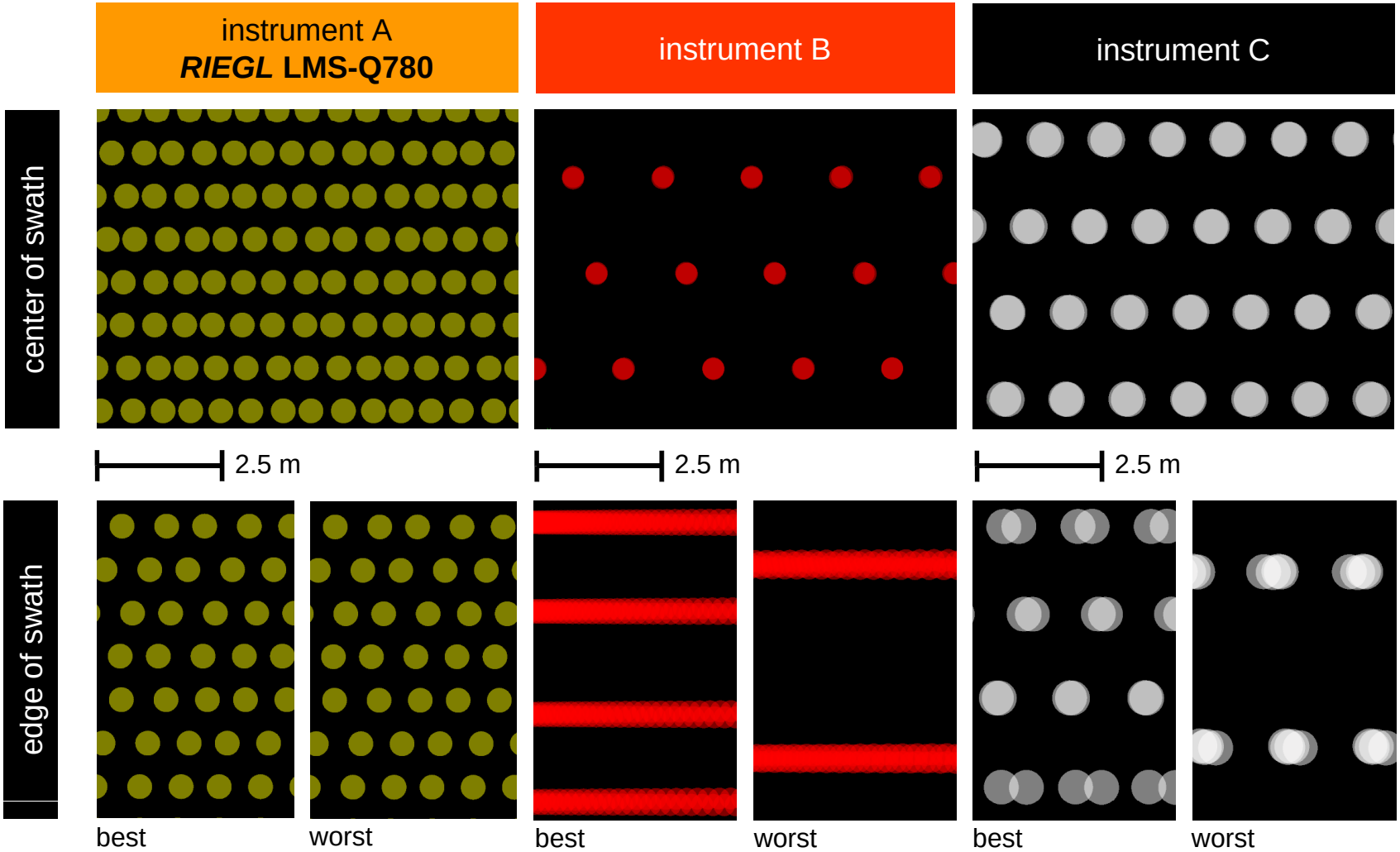


	maximum AGL	FOV	meas. rate	LPS	across spacing	along spacing	avg. point density
instrument A	2000 m	60 deg	1x 266 kHz	1x 83 LPS	0.87 m	0.87 m	1.3 - 3.5 p/m²
instrument B	2000 m	60 deg	2x 63 kHz	2x 37 LPS	1.94 m	4.32 m	0.53 - 1.9 p/m²
instrument C	2000 m	60 deg	2x 66 kHz	2x 41 LPS	1.74 m	3.50 m	0.9 - 2.6 p/m²



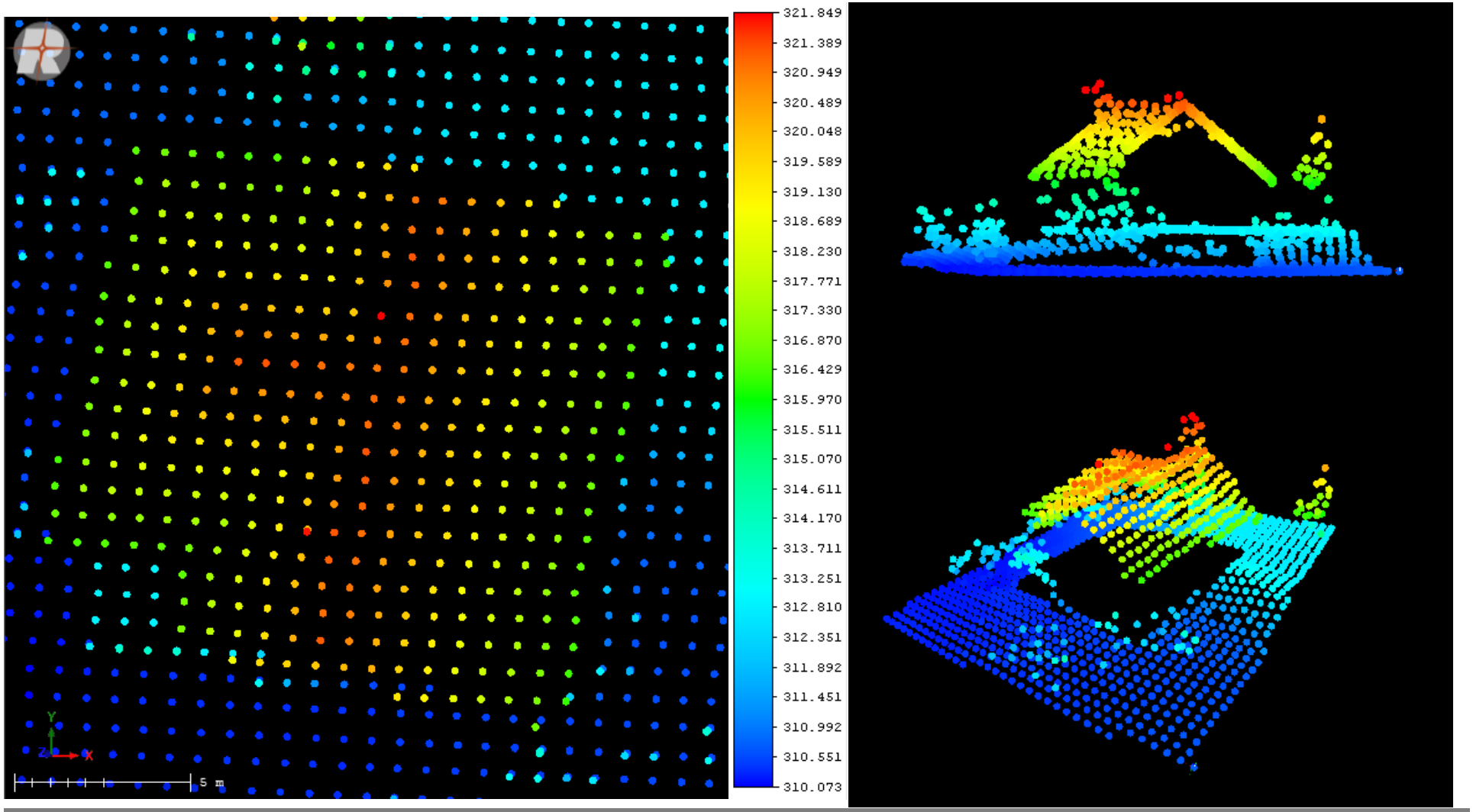
- variation in terrain height permits only acquisition in MTA zone 1 (1 pulse in the air)
- dead time between zones reduces measurement rate even further

Next >>

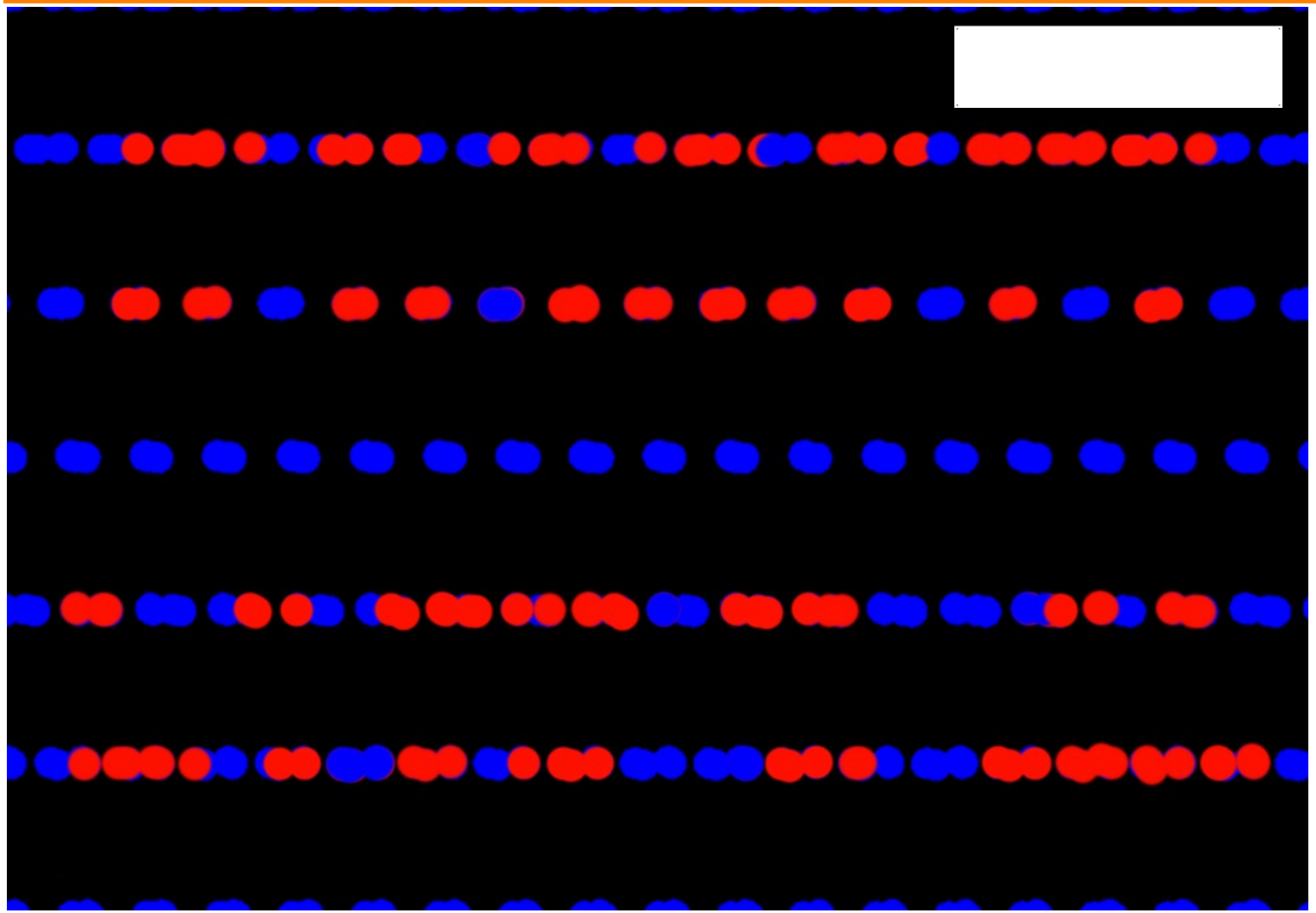


scenario 3, mountainous terrain

Next >>

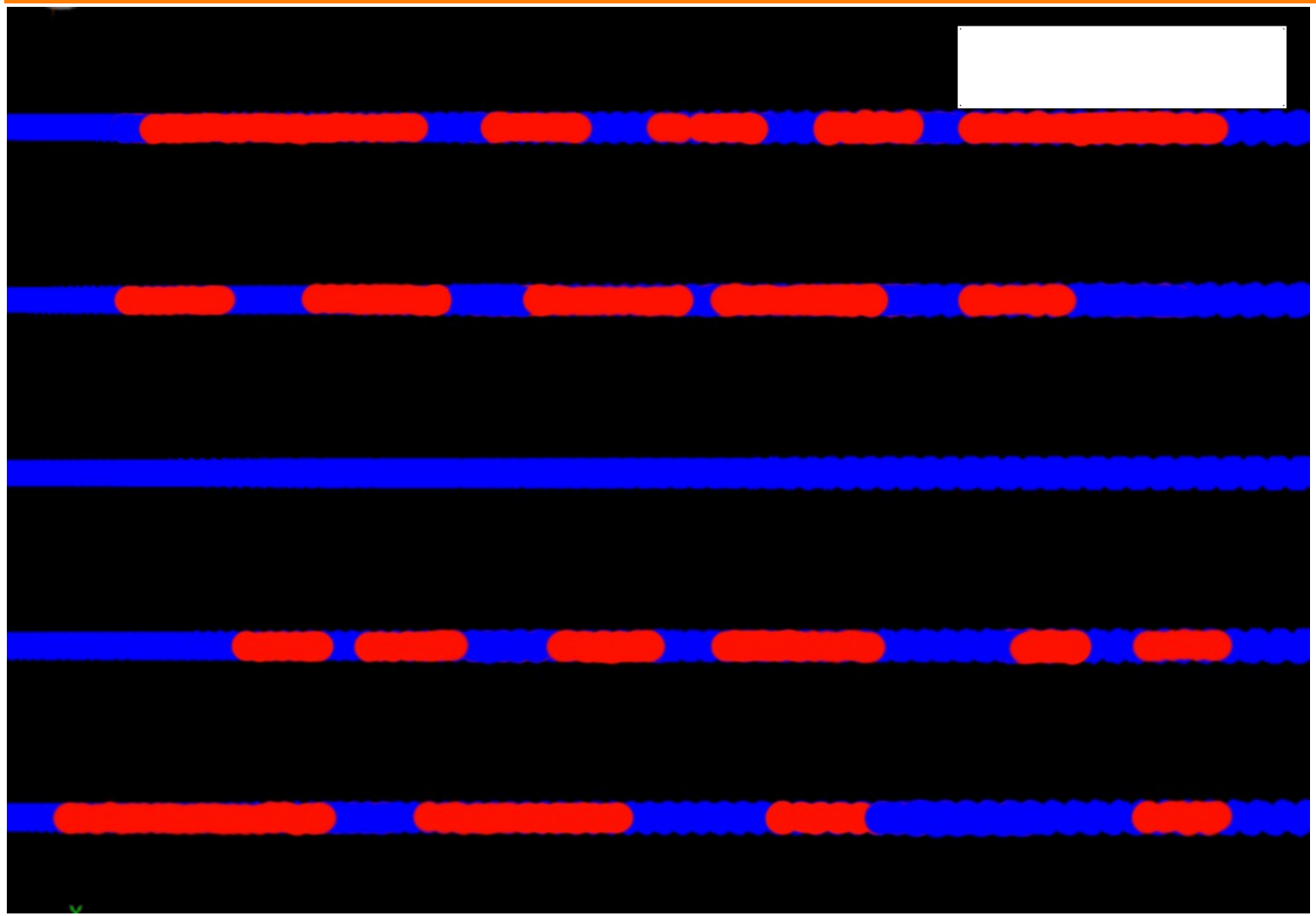


sampling objects – point spacing & spatial sampling frequency



2000 m AGL
140 kn GSP
60 deg FOV

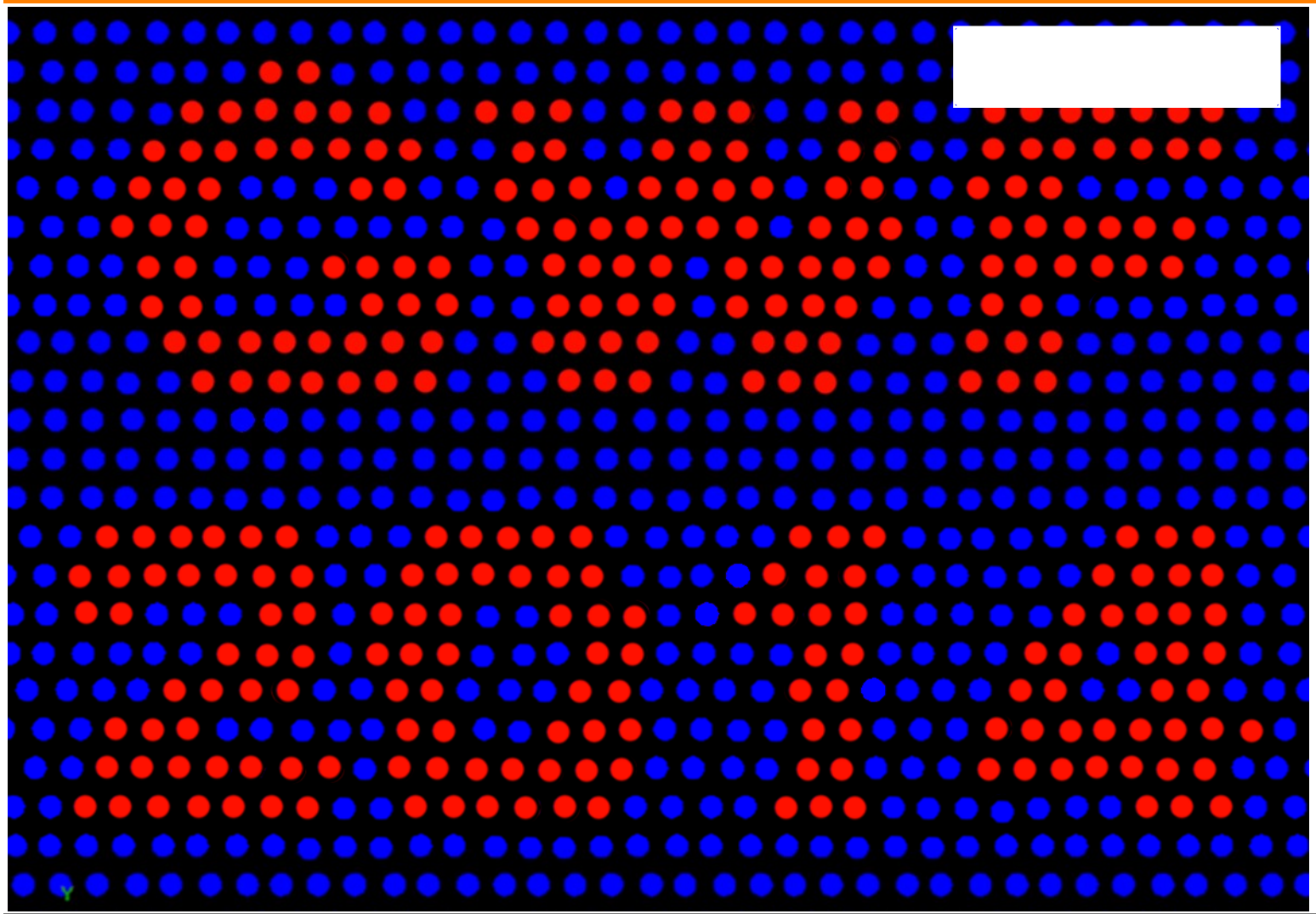
mountainous terrain
near edge of swath



2000 m AGL
140 kn GSP
60 deg FOV

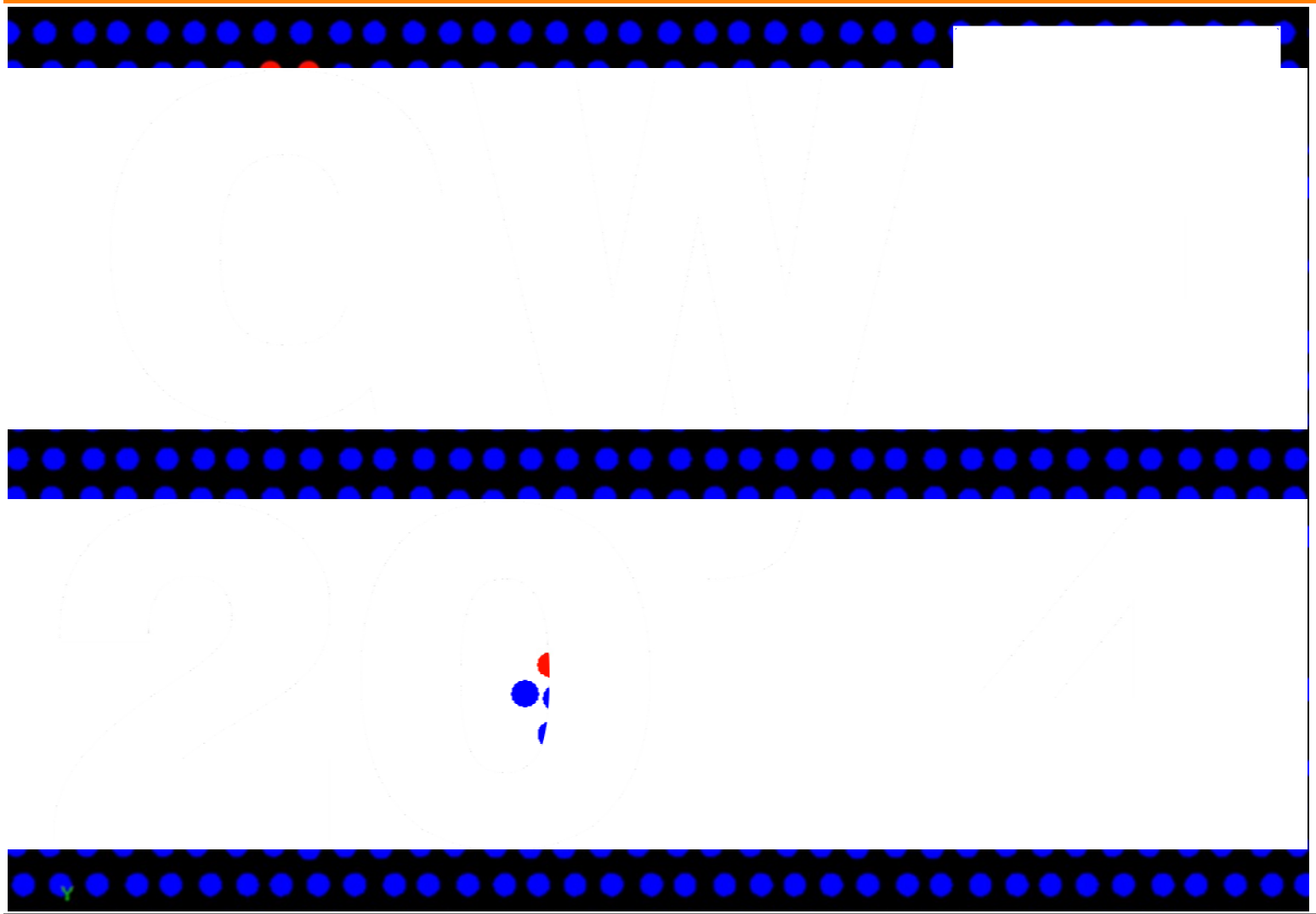
mountainous terrain
near edge of swath

sampling objects – point spacing & spatial sampling frequency



2000 m AGL
140 kn GSP
60 deg FOV

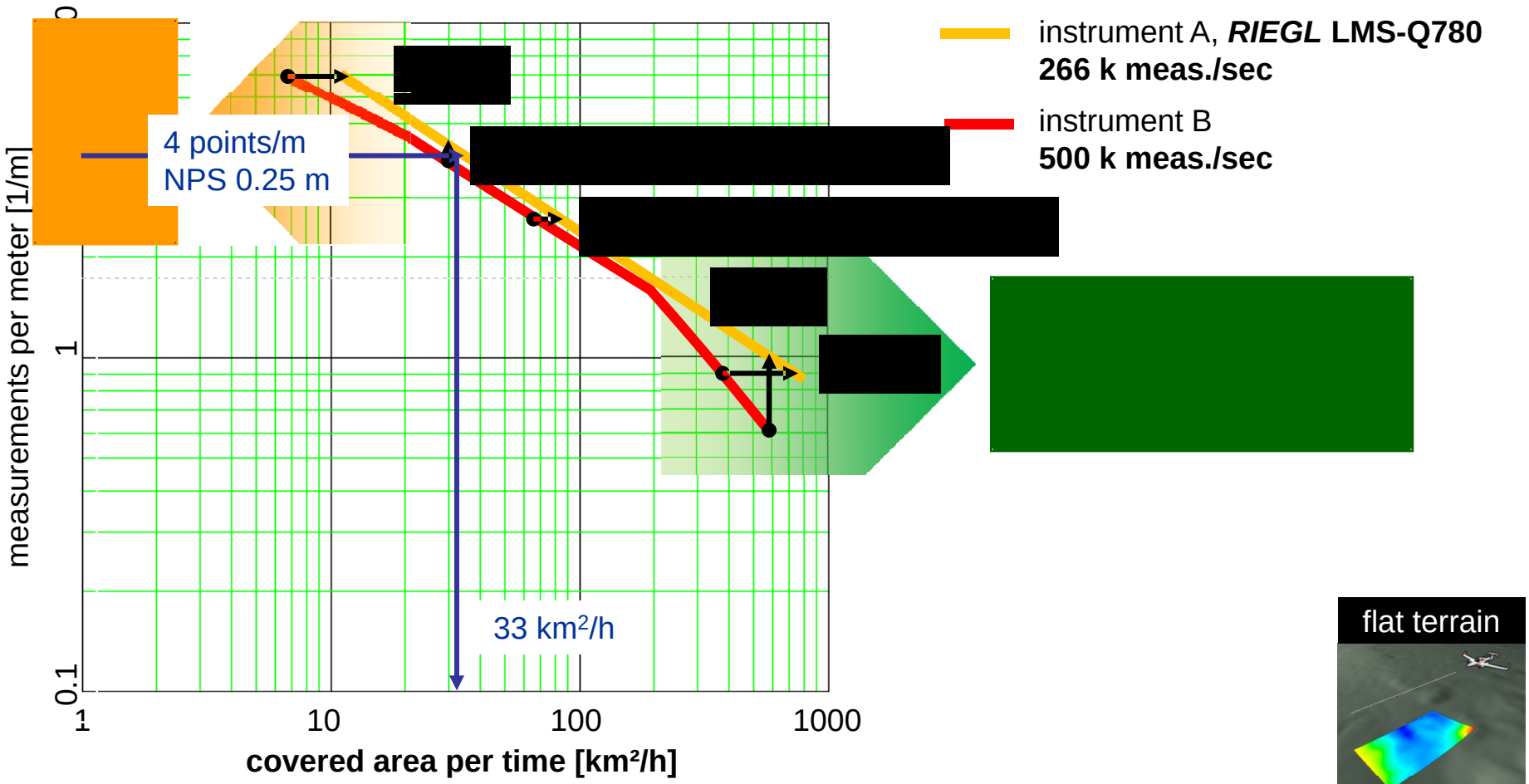
mountainous terrain
near edge of swath

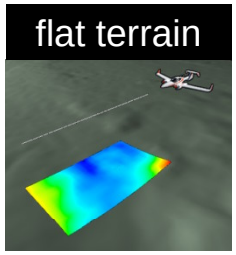


2000 m AGL
140 kn GSP
60 deg FOV

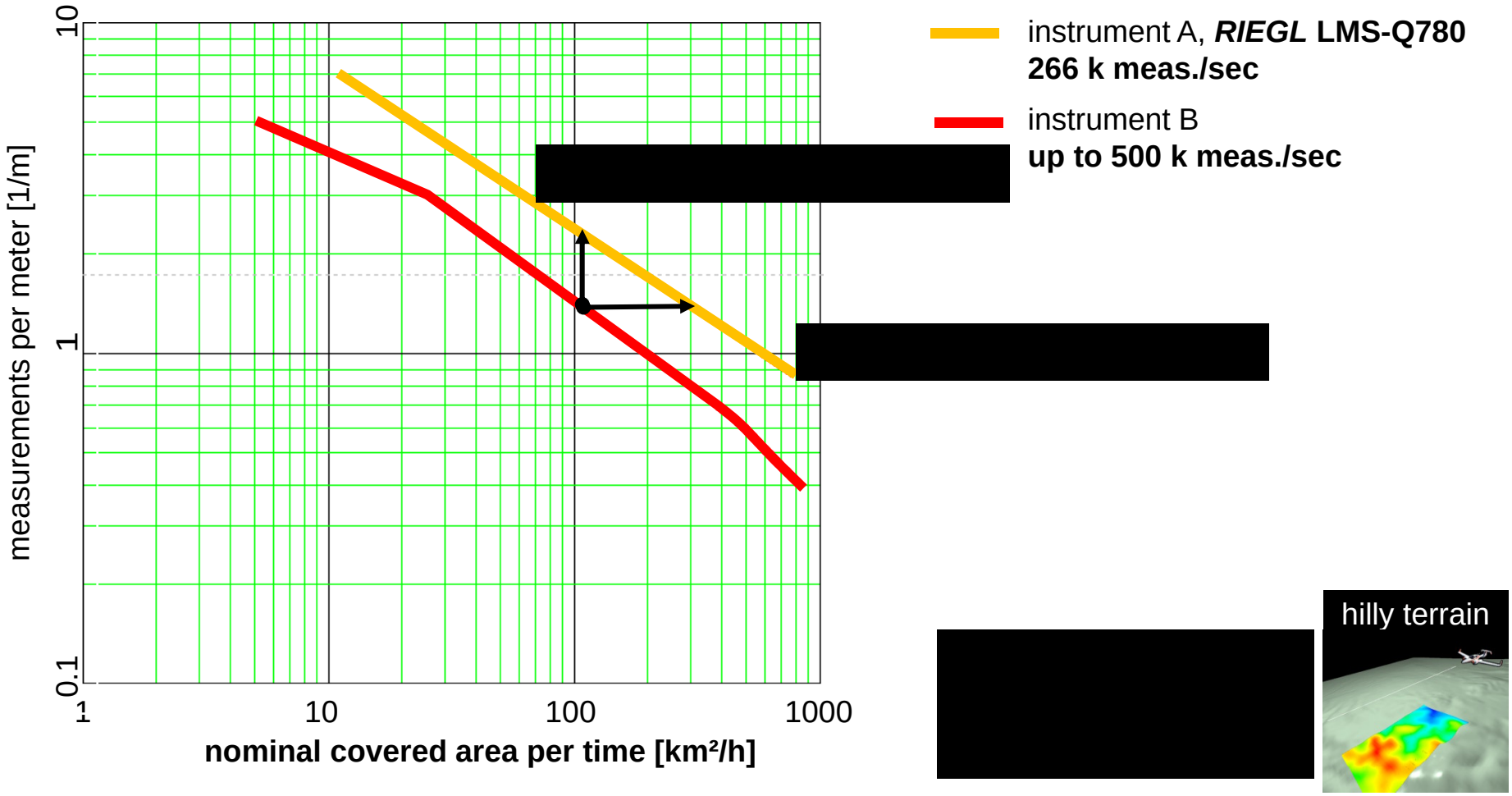
mountainous terrain
near edge of swath

sampling objects – point spacing & spatial sampling frequency

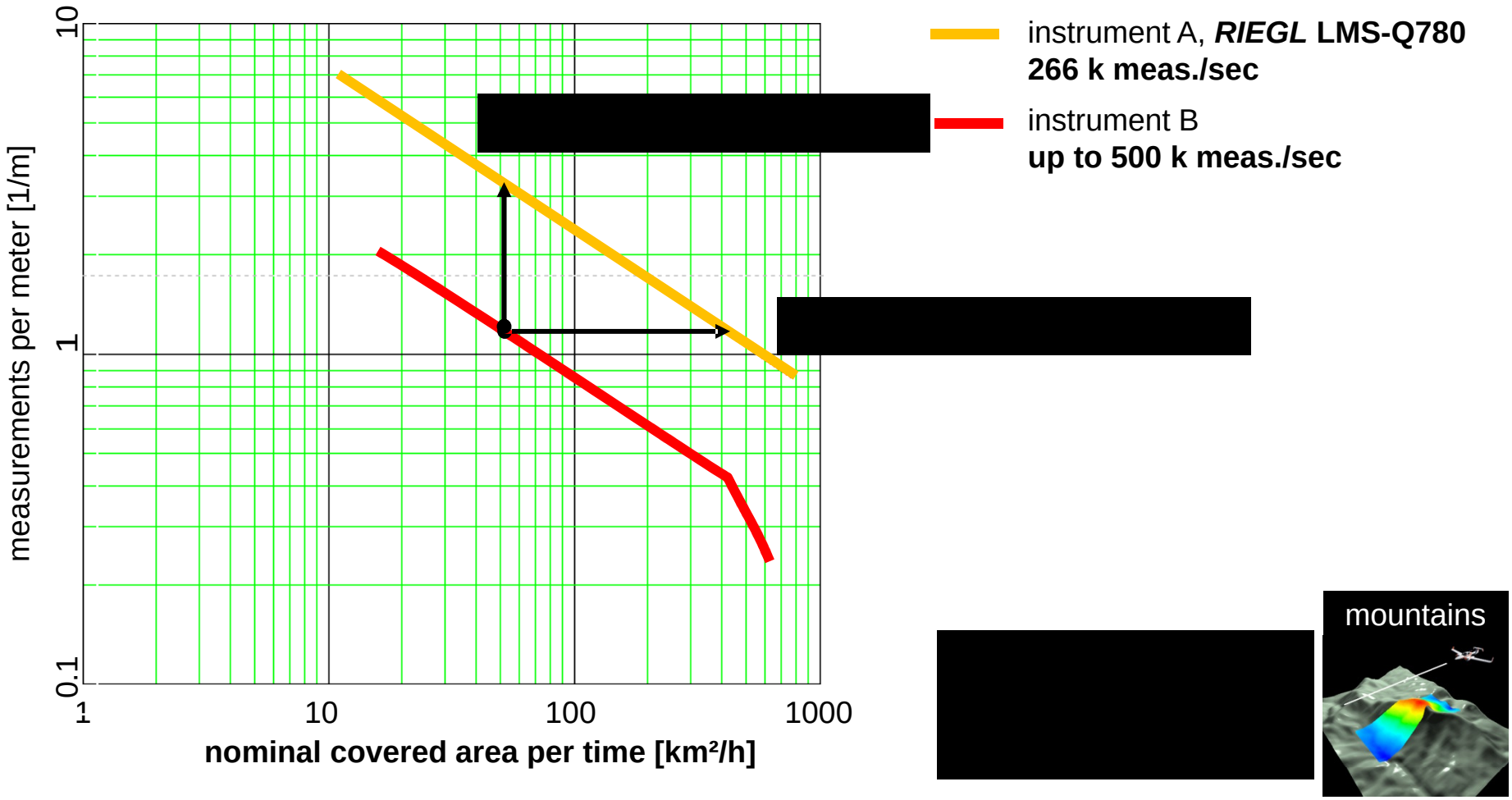




sampling frequency (1/NPS) vs acquisition speed



sampling frequency (1/NPS) vs acquisition speed


measurements per meter [1/m]
10
1
0.1
1
10
100
1000
nominal covered area per time [km²/h]
instrument A, *RIEGL* **LMS-Q780**
266 k meas./sec
instrument B
up to 500 k meas./sec
[redacted]
[redacted]
[redacted]
mountains

high ground sampling frequency
low nominal point spacing

AND

high acquisition speed

- fast scan at high FOV (polygon mirror)
- no interference problems (single channel or sophisticated dual channel scanner design)
- wide performance envelope
- high pulse repetition rate at high AGL (high-MTA-zone processing capability)

“it is the point spacing, not the number of measurements on the ground”

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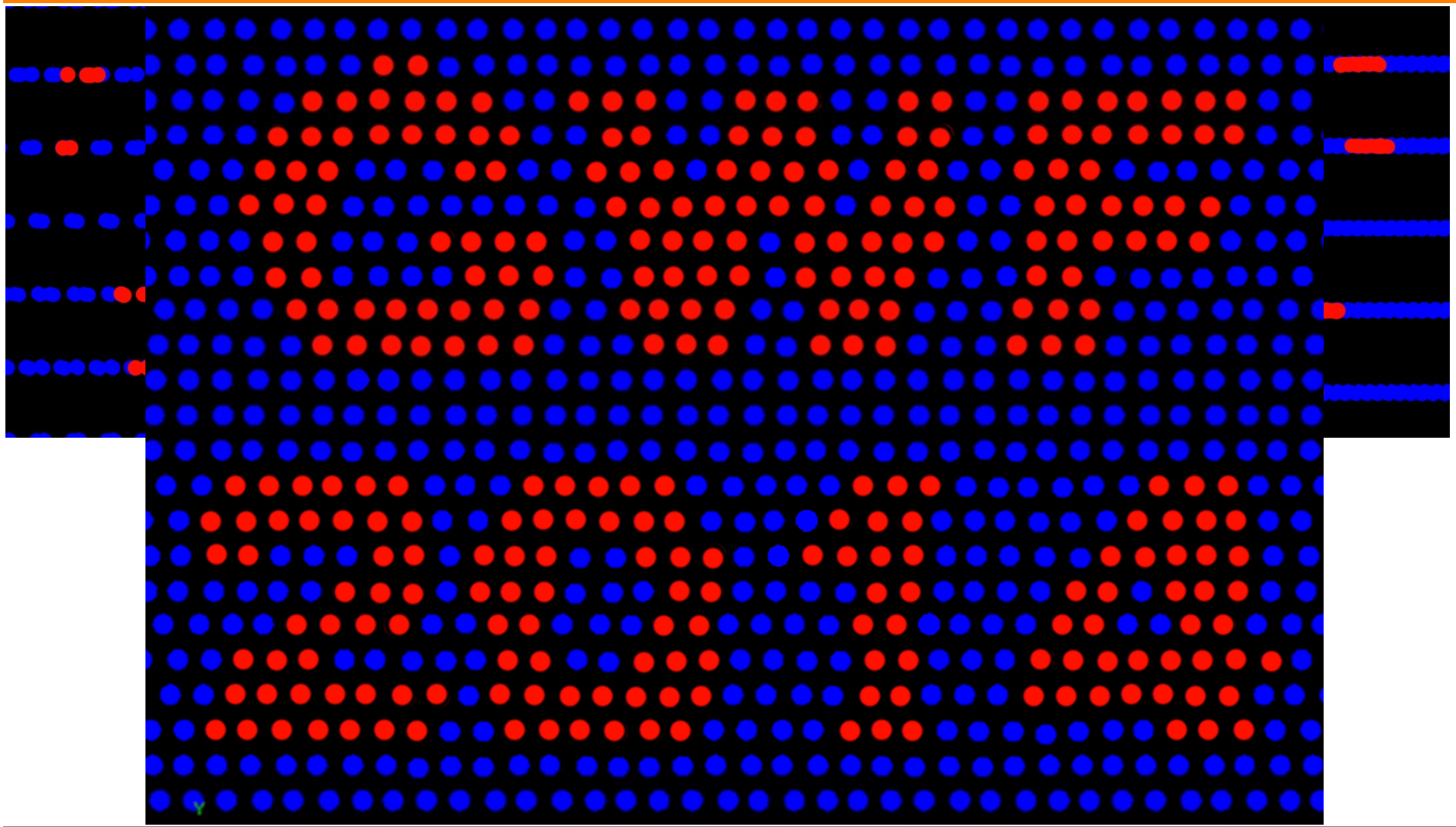
LASER MEASUREMENT SYSTEMS



Thank you!