Rigorous Scan Data Adjustment for Mobile and Airborne LIDAR Systems

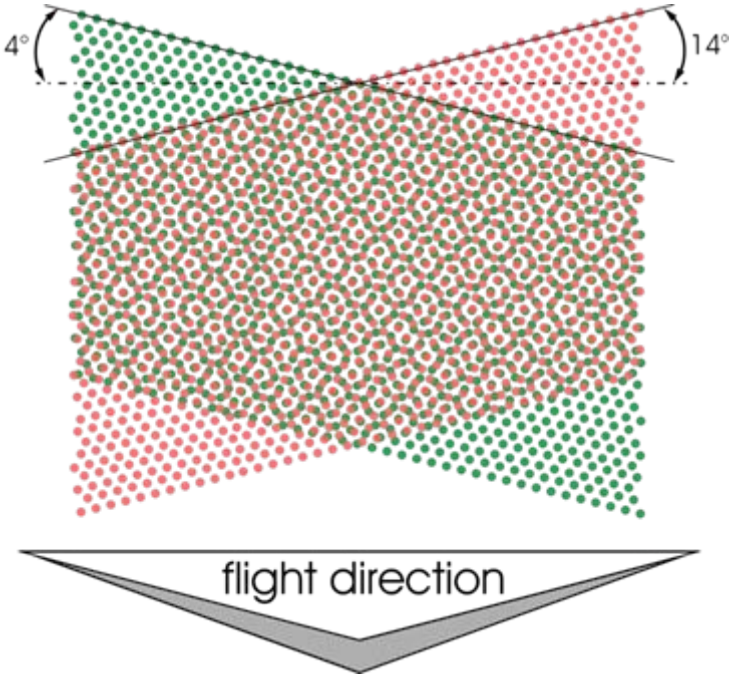
Paul Swatschina
Andreas Ullrich
RIEGL LMS GmbH

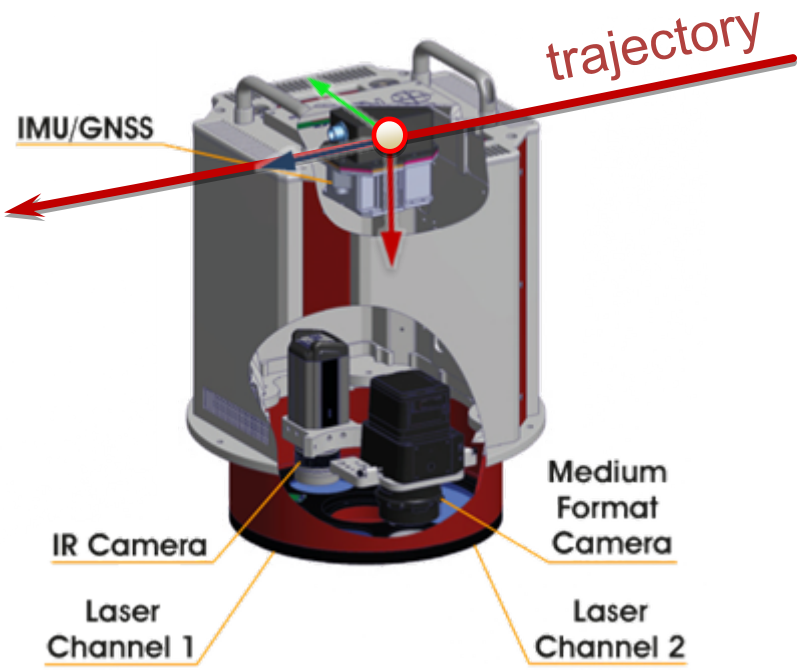
EuroCOW 2014
February 13th , 2014
Castelldefels, Spain

RIEGL®
LASER MEASUREMENT SYSTEMS


RIEGL
VMX-450
RIEGL
VMX-450

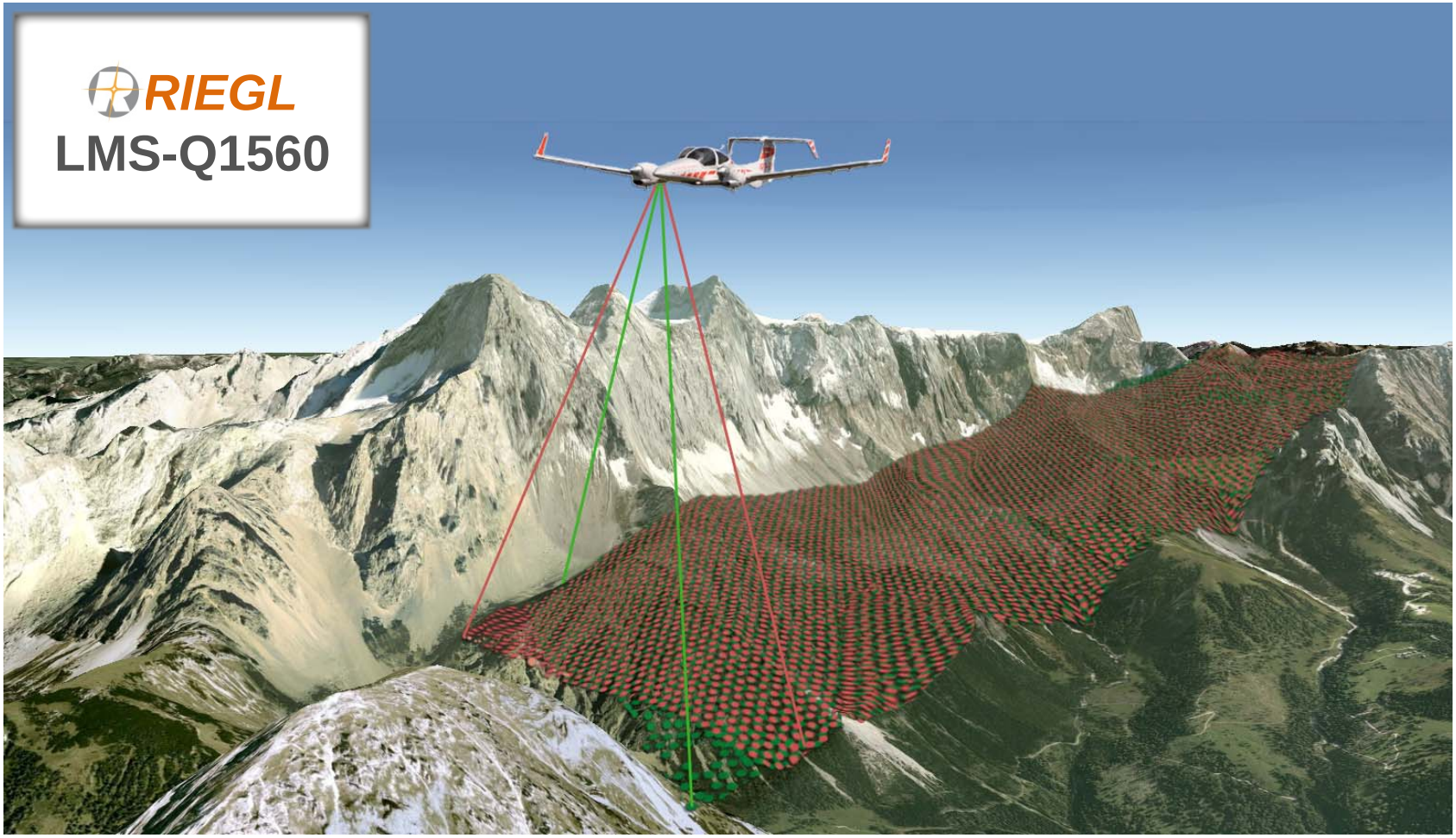
Airborne Laser Scanning



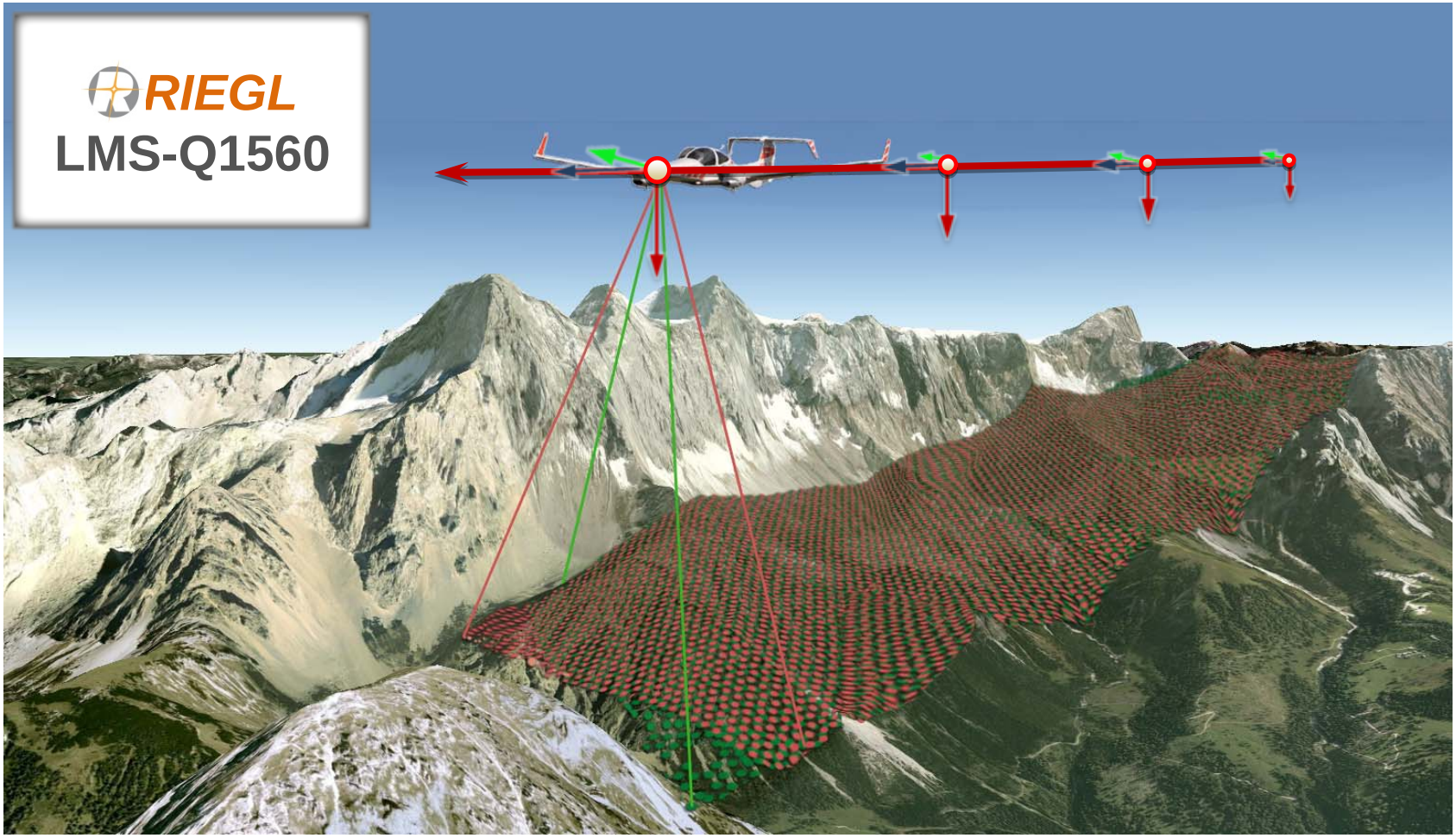


RIEGL
LMS-Q1560

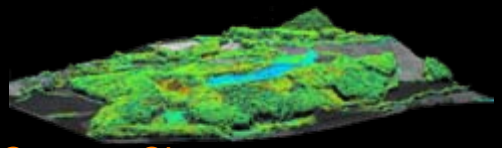
Airborne Laser Scanning



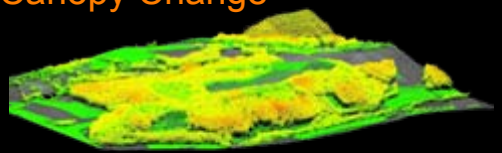
Airborne Laser Scanning



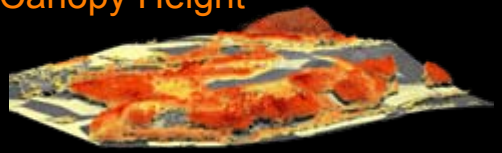
Layers of Information



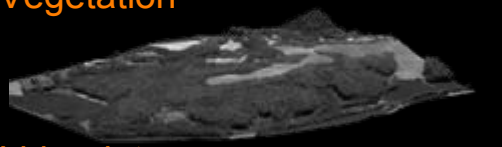
Canopy Change



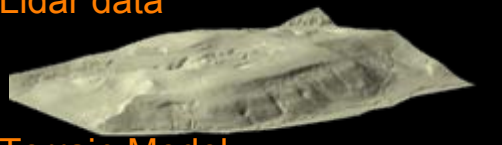
Canopy Height



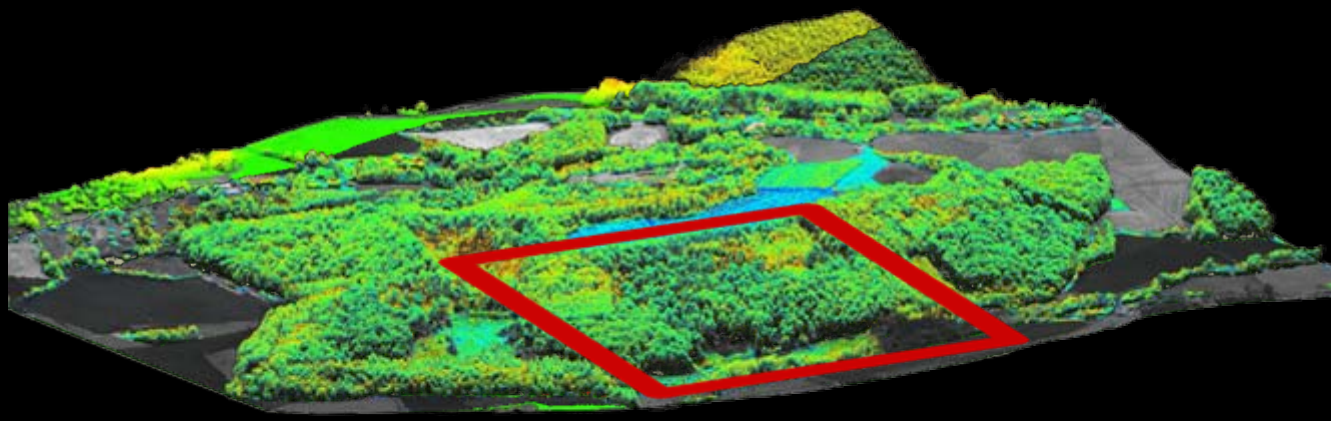
Vegetation



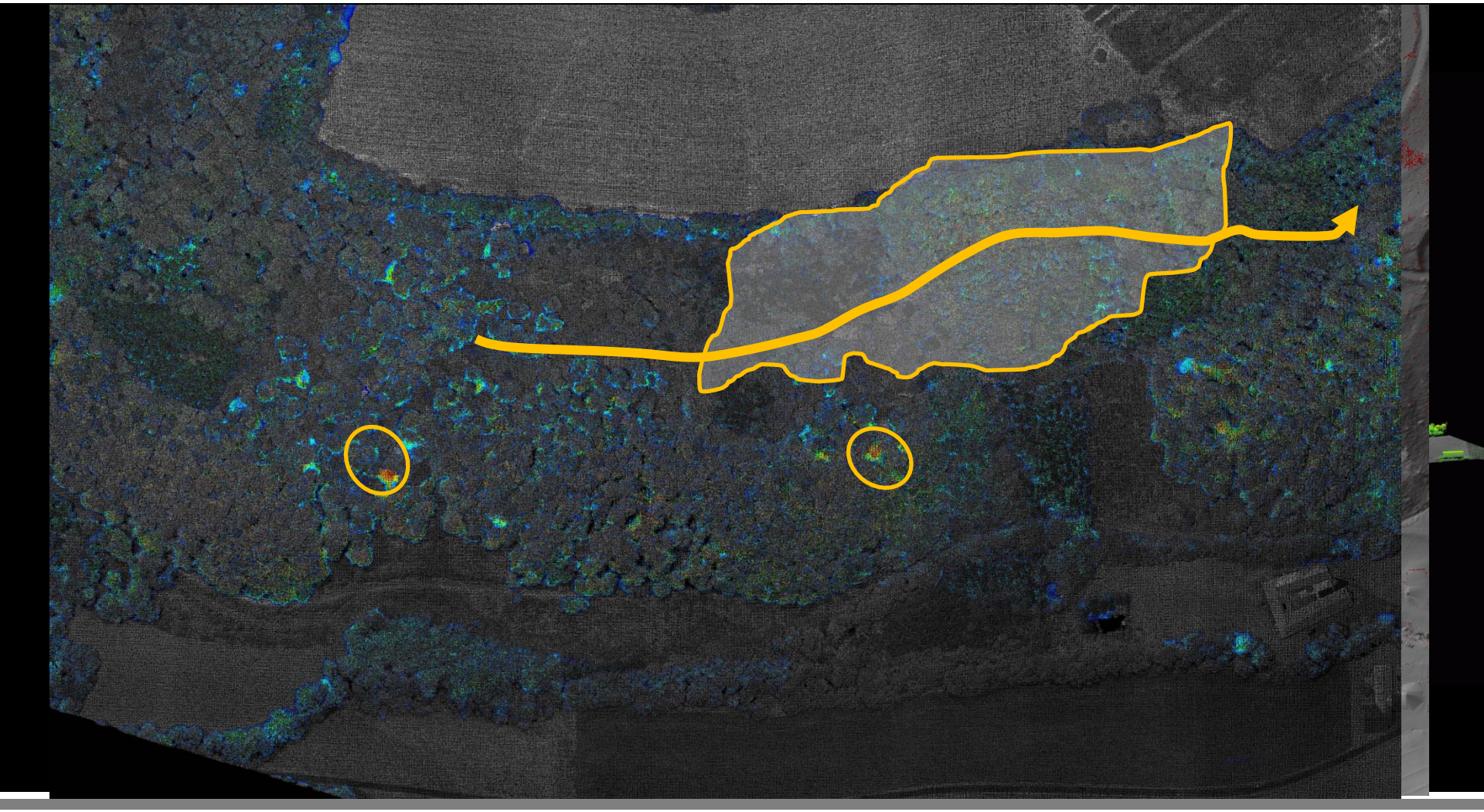
Lidar data



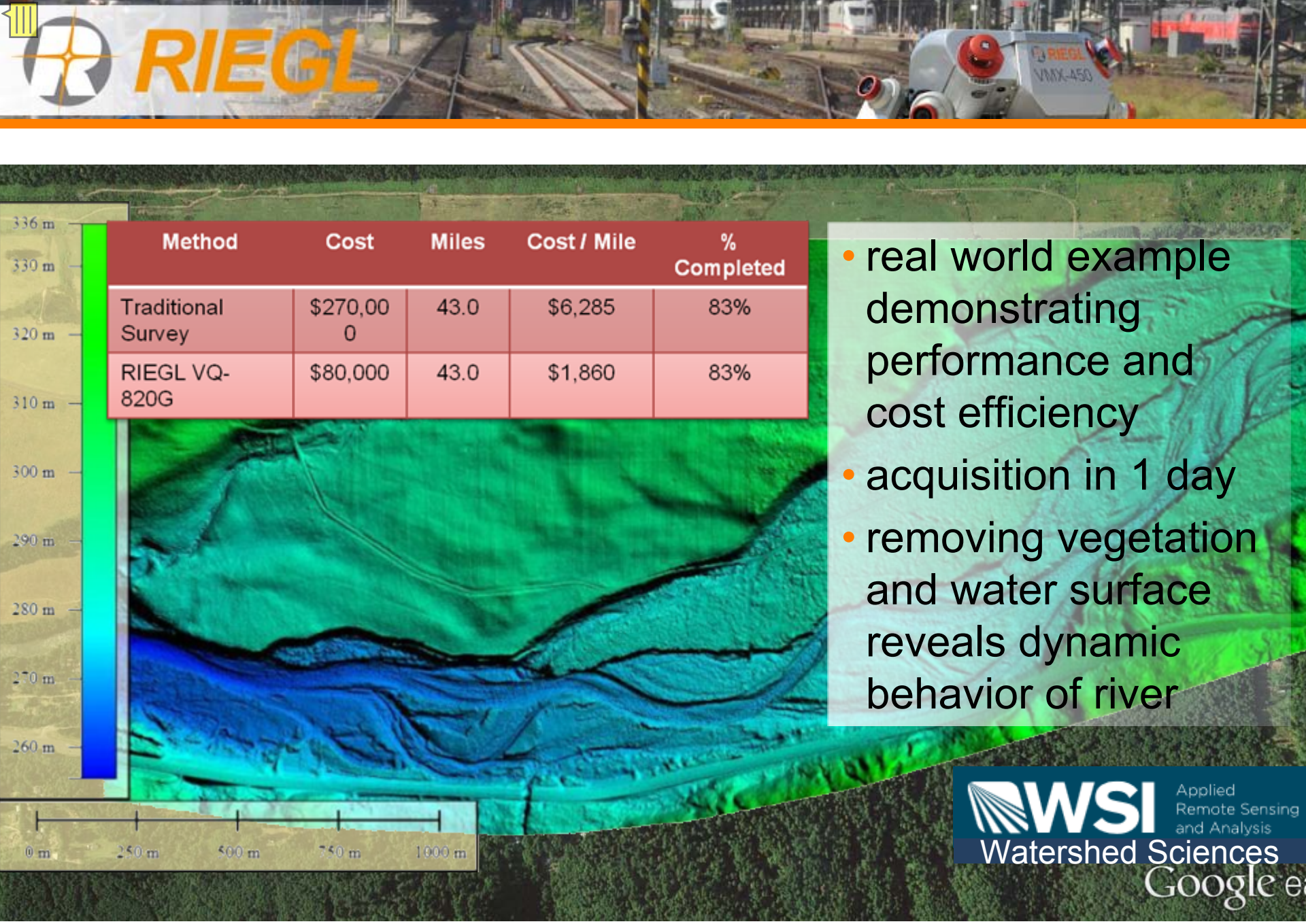
Terrain Model



Environmental Monitoring



Look closer…



Method	Cost	Miles	Cost / Mile	% Completed
Traditional Survey	$270,000	43.0	$6,285	83%
RIEGL VQ-820G	$80,000	43.0	$1,860	83%

- real world example demonstrating performance and cost efficiency
- acquisition in 1 day
- removing vegetation and water surface reveals dynamic behavior of river

WSI Applied Remote Sensing and Analysis
Watershed Sciences

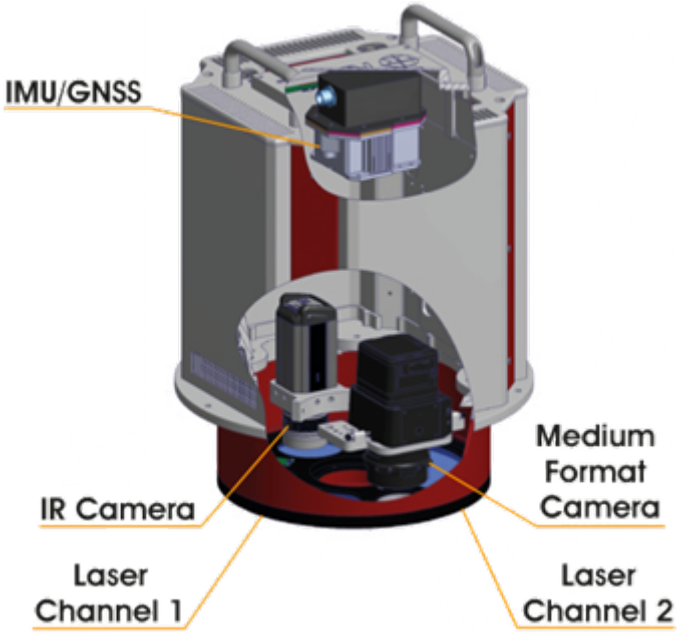
Google

Snake River, Oregon

Airborne Laser Scanning

The world´s first survey-grade LiDAR sensor for UAS!

RIEGL VUX-1
- echo digitization
- online waveform processing
- ranging up to 600 m
- up to 550 000 meas./sec
- mm-accuracy levels
- optional integrated IMU/GNSS
- weight less than 4 kg



RIEGL
LMS-Q1560

Survey-grade Lidar Sensor for UAS 07/02/2014

RIEGL Laser Measurement Systems has been developing their first survey-grade UAS Lidar sensor, the VUX-1, and the company will be presenting it later this month. The VUX-1 will be presented for the first time at the official launch event, ILMF, which will be held in Denver, USA, from 17 to 19 February.

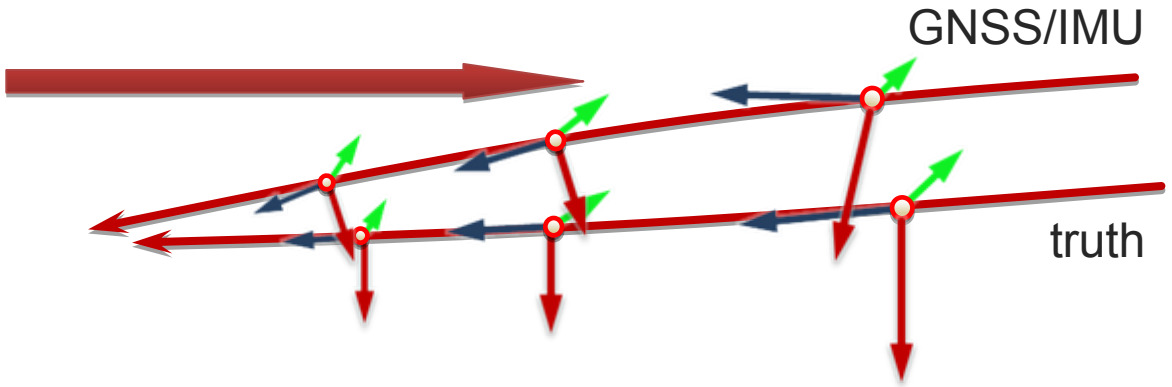
The innovative sensor was designed to meet the challenges of emerging surveying solutions by UAS, gyrocopters, and ultra-light aircraft, both in measurement performance and in system integration. The VUX-1 is an ultra lightweight Lidar sensor with less than 4 kilograms (less than 9 pounds) overall weight, that can easily be mounted onto professional UAS/RPAS.

It has a 300 degree field of view and produces the extremely high quality Lidar data users expect from a RIEGL product. Internal storage offers the ability to collect data for several hours at altitudes/ ranges up to more than 1,000 ft. Scanner applications include, but are not limited to: agricultural and forestry, defence, wide area mapping, flood zone mapping, glacier and snowfield mapping, topography and mining, and the academic markets.

By introducing the VUX-1, RIEGL now offers a Lidar sensor that has been especially developed for the UAS and RPAS markets. The Austrian company expects tremendous growth in these fields and is proud to support these with the breakthrough VUX-1, said Dr. Johannes Riegl, RIEGL's CEO.

This VUX-1 will be on display during ILMF 2014 at the RIEGL USA booth (booth 36).

Kinematic Laser Scanning

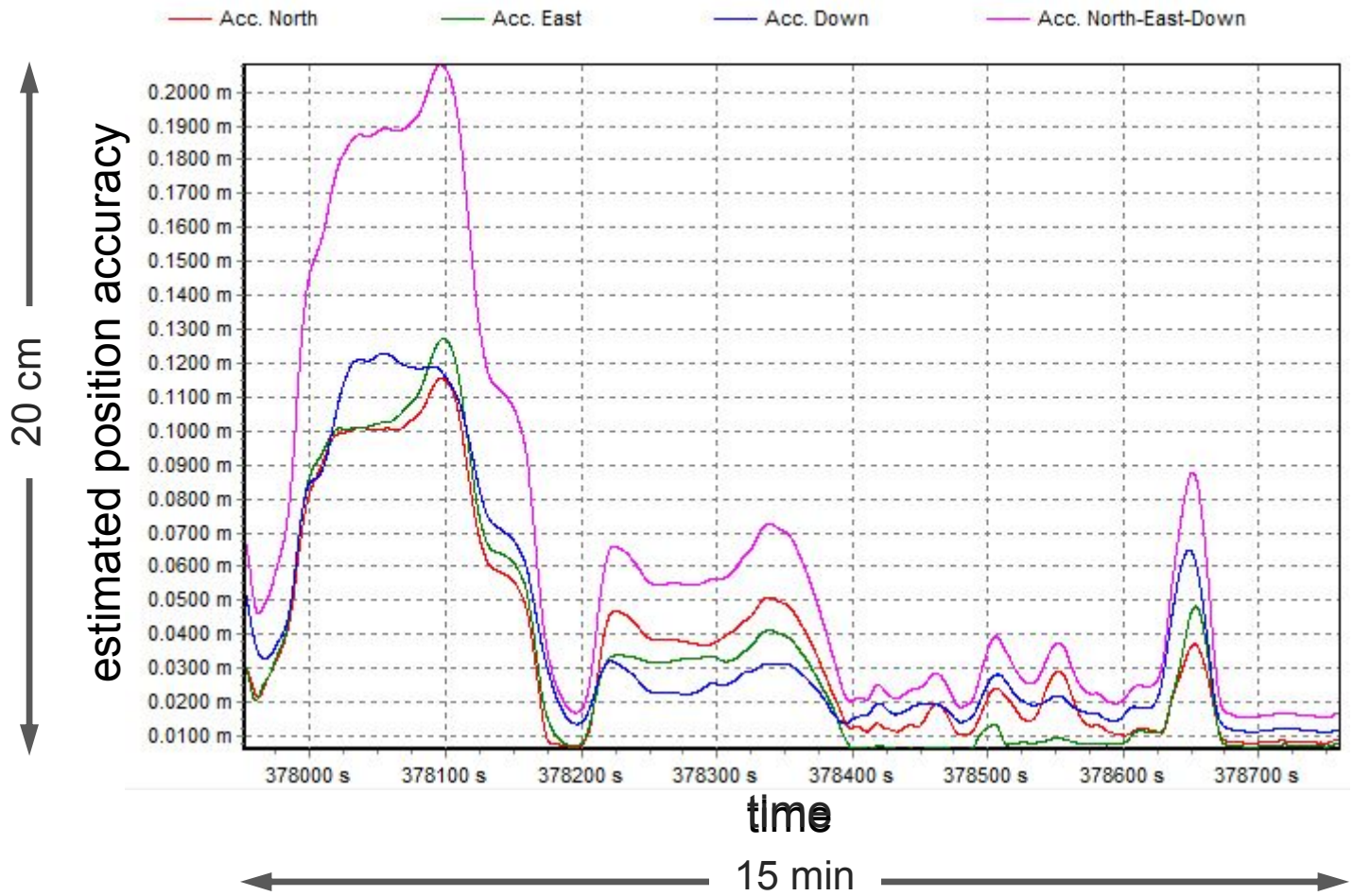


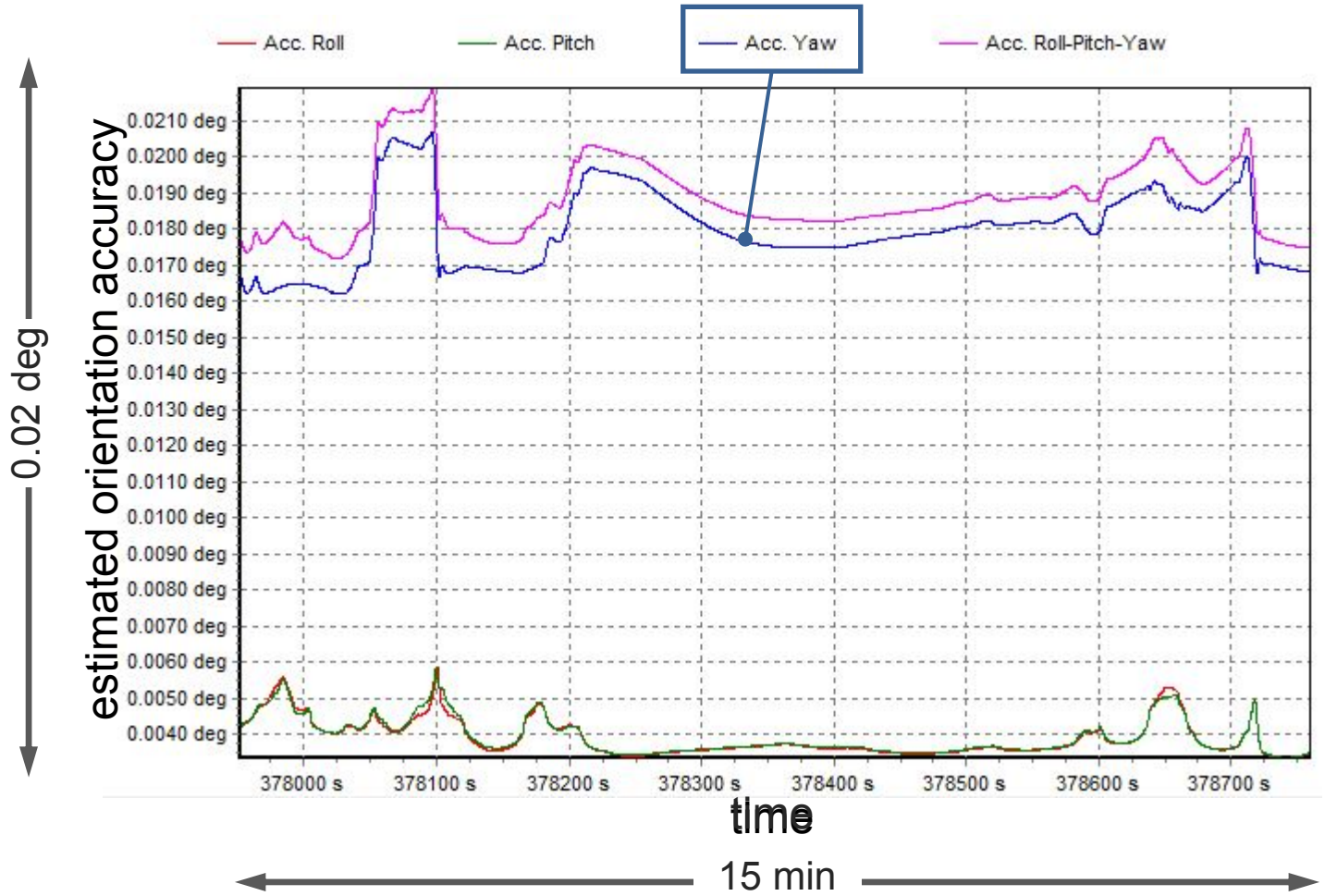
Laser Scanners	System Calibration	Platform Trajectory
scanner coordinate systems	lever arms and orientation	from GNSS/IMU
highly accurate and precise	highly accurate and precise	comparably low accuracy
~ some mm	~ mm ~ mdeg	~ some cm — m ~ several mdeg

Platform Trajectory Errors

GNSS/IMU trajectory error sources:

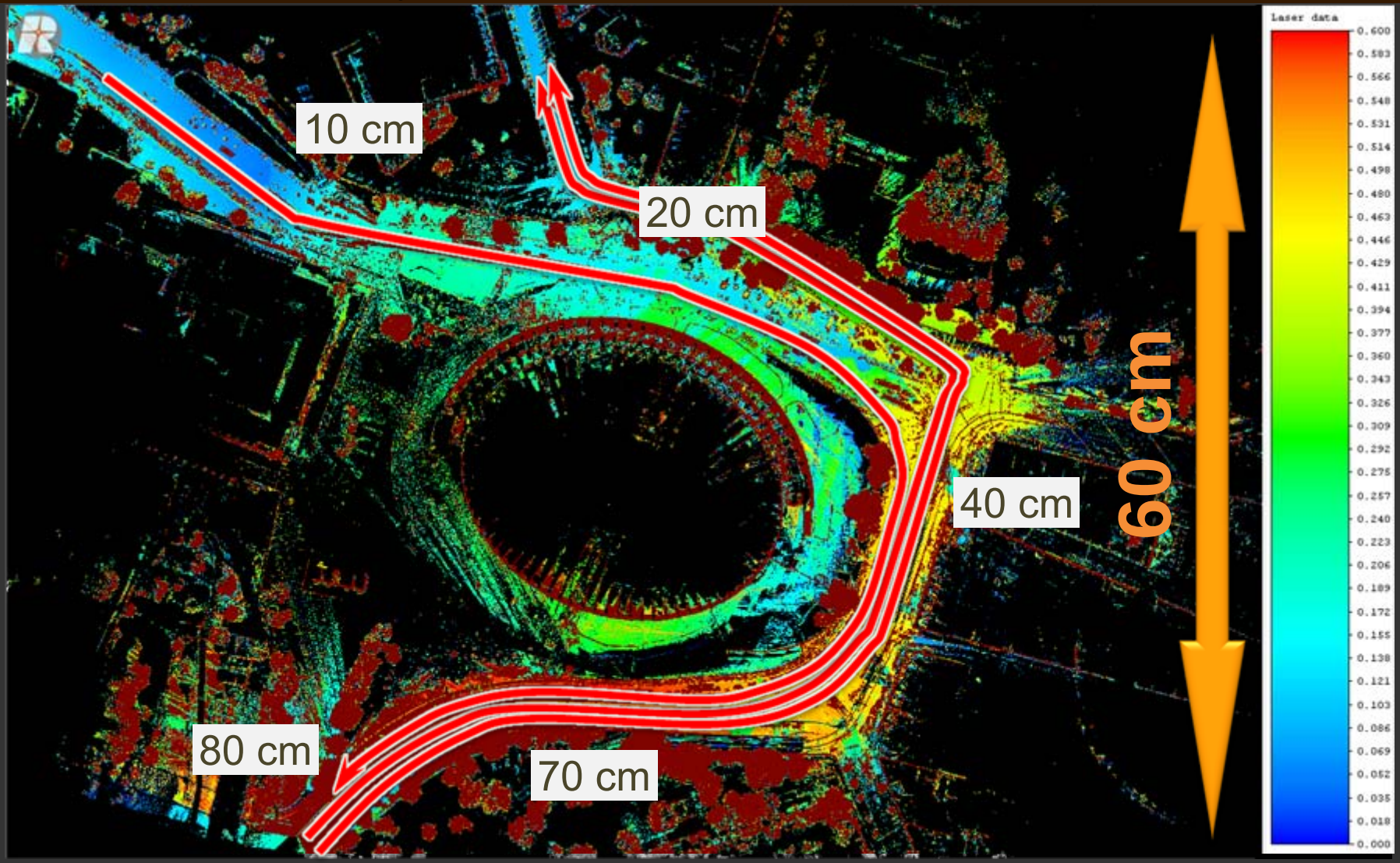
- IMU inertial measurements
  - biases
  - noise
  - drifts
- GNSS pseudo range measurements
  - biases
  - noise
- GNSS satellite visibility condition (esp. for MLS)
  - rapidly changing field of view (FOV)
  - number of tracked satellites
  - multipath effects
  - cycle slips

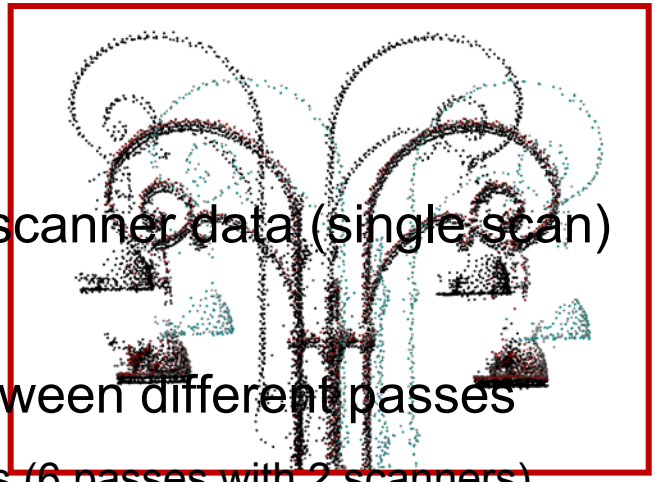

Acc. North
Acc. East
Acc. Down
Acc. North-East-Down
20 cm
estimated position accuracy
0.2000 m
0.1900 m
0.1800 m
0.1700 m
0.1600 m
0.1500 m
0.1400 m
0.1300 m
0.1200 m
0.1100 m
0.1000 m
0.0900 m
0.0800 m
0.0700 m
0.0600 m
0.0500 m
0.0400 m
0.0300 m
0.0200 m
0.0100 m
378000 s
378100 s
378200 s
378300 s
378400 s
378500 s
378600 s
378700 s
time
15 min


Acc. Roll
Acc. Pitch
Acc. Yaw
Acc. Roll-Pitch-Yaw
0.02 deg
estimated orientation accuracy
0.0210 deg
0.0200 deg
0.0190 deg
0.0180 deg
0.0170 deg
0.0160 deg
0.0150 deg
0.0140 deg
0.0130 deg
0.0120 deg
0.0110 deg
0.0100 deg
0.0090 deg
0.0080 deg
0.0070 deg
0.0060 deg
0.0050 deg
0.0040 deg
378000 s
378100 s
378200 s
378300 s
378400 s
378500 s
378600 s
378700 s
time
15 min

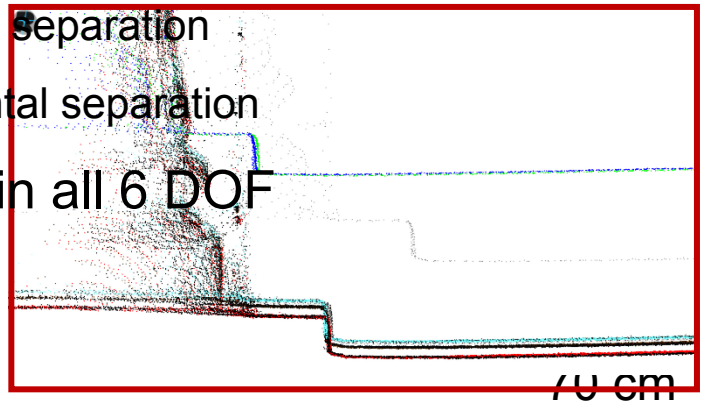
Colosseum
Rome, Italy

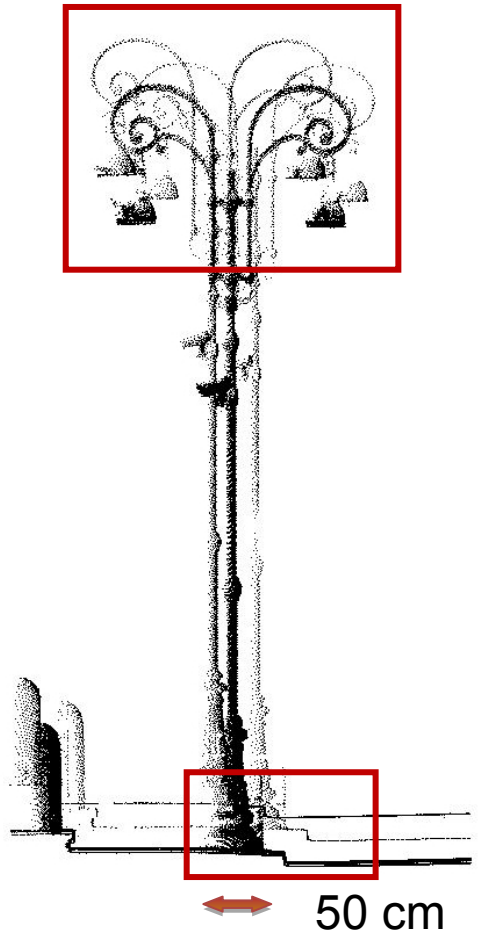
maximum height differences between all point cloud data





- precise laser scanner data (single scan)
- deviations between different passes
  - …12 scans (6 passes with 2 scanners)
  - 70 cm vertical separation
  - 50 cm horizontal separation
- trajectory errors in all 6 DOF
- errors are time-varying





strategies for a better trajectory solution

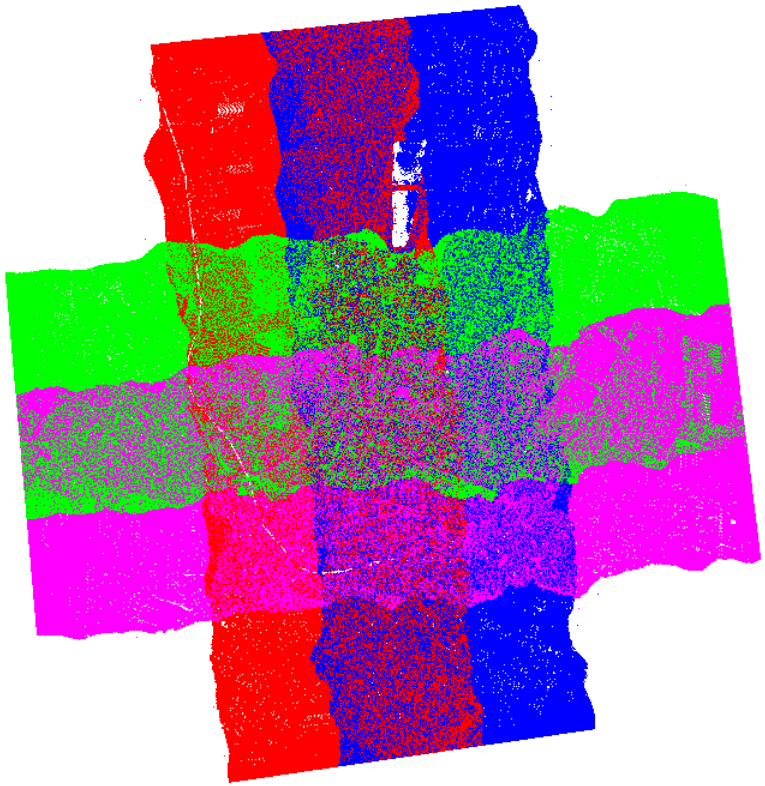
- use measurements from additional sensors
  - laser scanners
    - points of point cloud
    - geometrical point cloud features
    - amplitude, reflectance, deviation
  - cameras
    - image correlation
    - matching image features

measuring disparities of point clouds

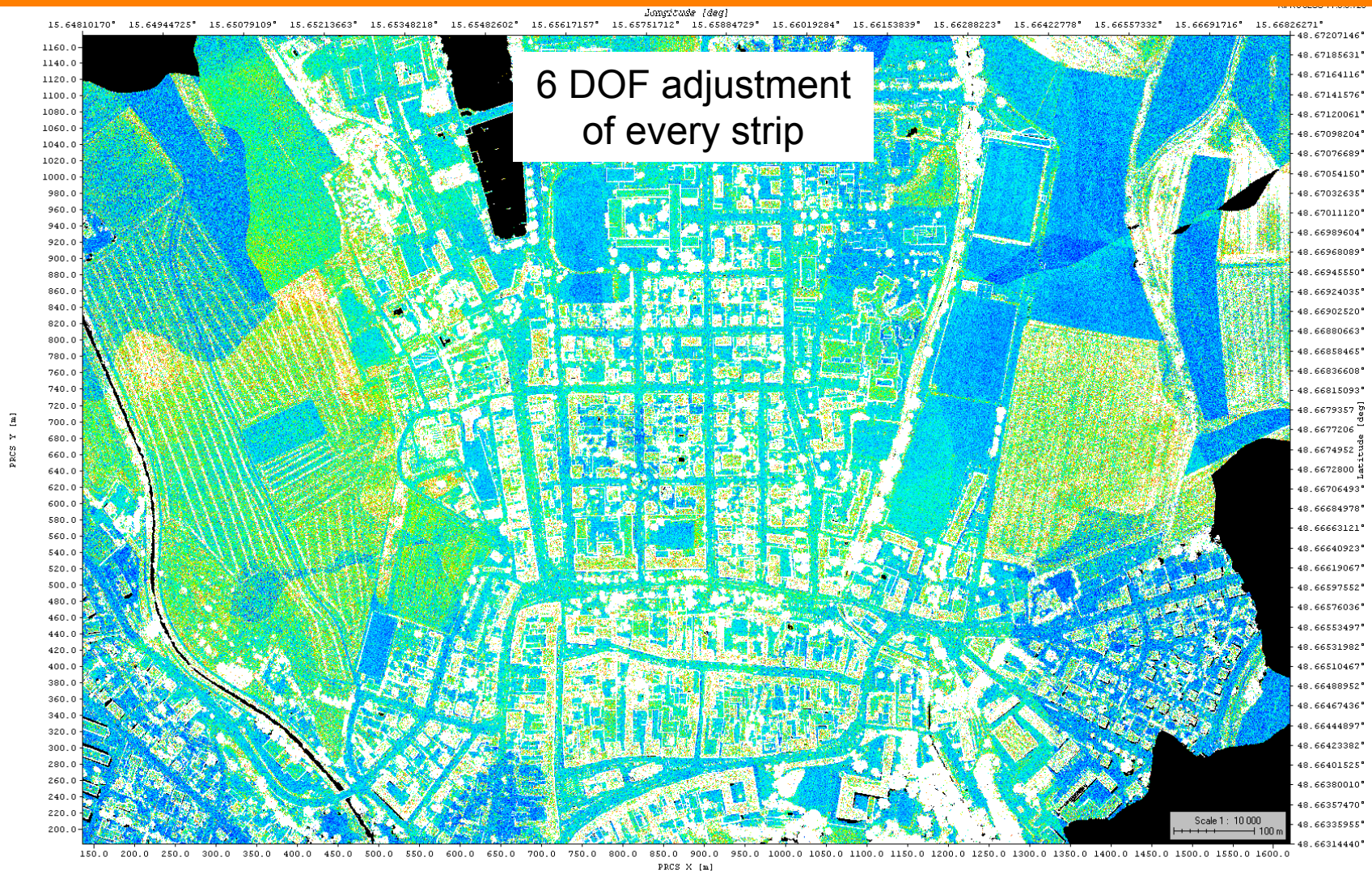
- point-to-point distance
  - ICP (Iterative Closest Points)
- point-to-local plane distance
  - modified ICP
- feature-to-feature distance
  - planes, spheres, cubes, cylinders, edges, corners, ...
  - requires feature extraction as pre-processing step
  - additional radiometrical features as “markers” on geometrical features

time-invariant adjustment of each scan/strip

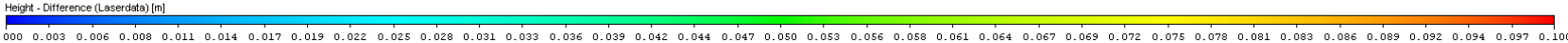
- suitable for airborne laser data
- 6 DOF for every strip
  - rigid shift by 3 offsets / improvements to trajectory positions
  - 3 offsets / improvements to trajectory orientations




RIEGL
VMX-450

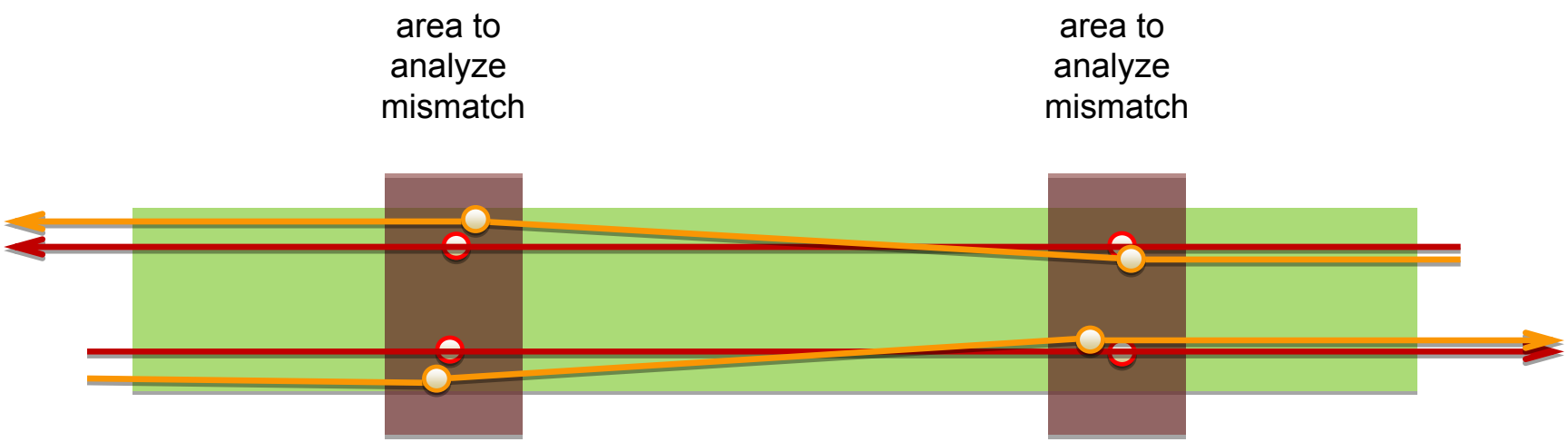

6 DOF adjustment
of every strip
Longitude [deg]
PRCS Y [m]
PRCS X [m]
Latitude [deg]
Scale 1 : 10 000
100 m

0 cm


Height - Difference (Laserdata) [m]

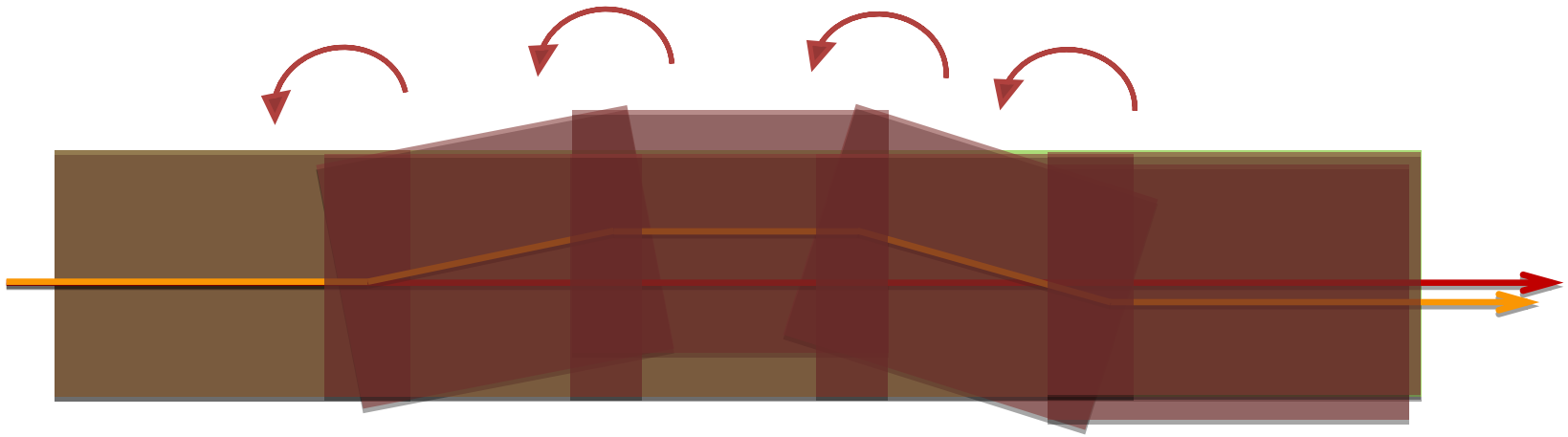
10 cm

sparse locally time-invariant approach



- determination of 6 DOF correction for minimizing discrepancies in each local region
- interpolation in between

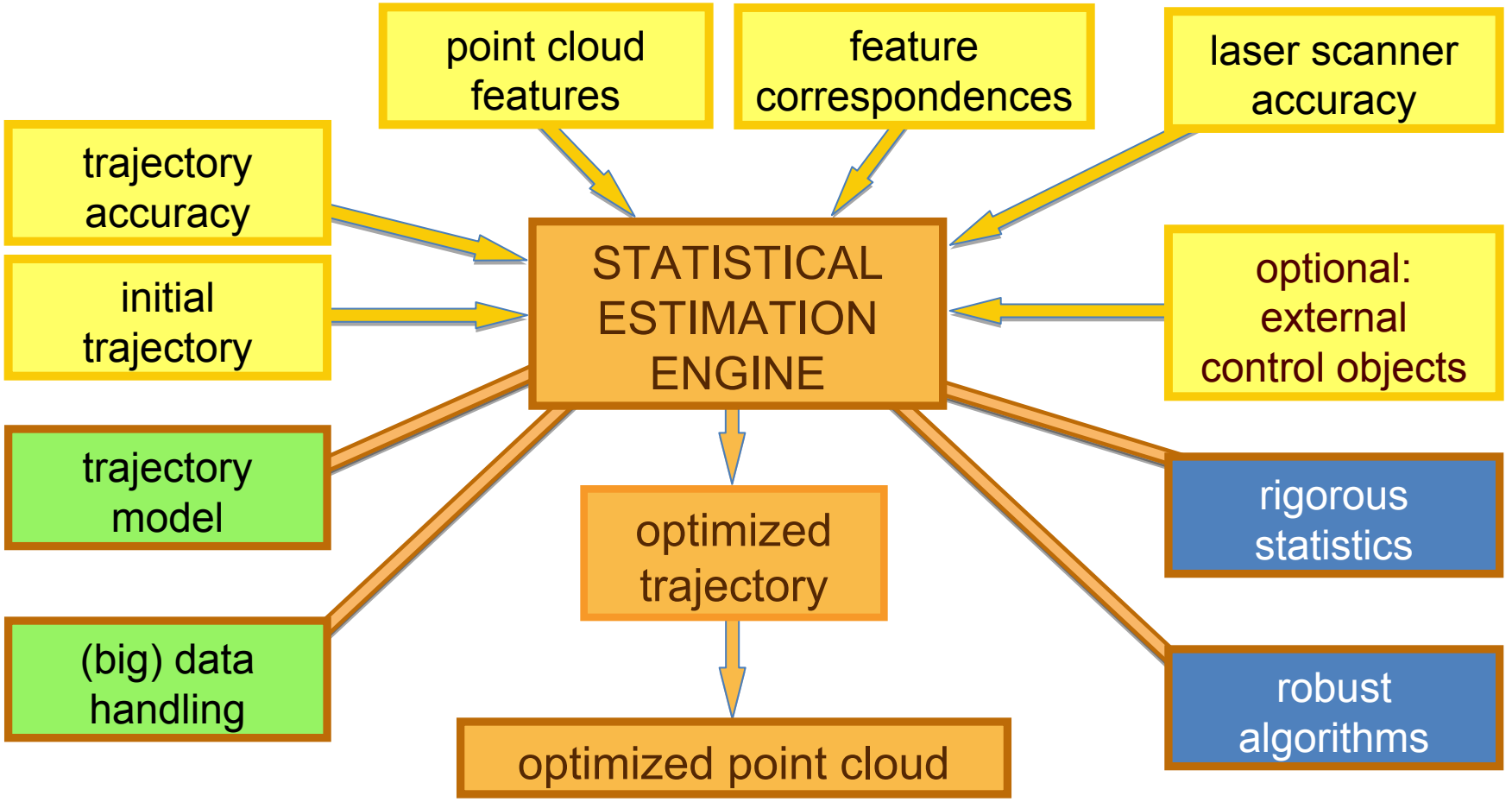
dense locally time-invariant adjustment approach (semi-rigid approach)

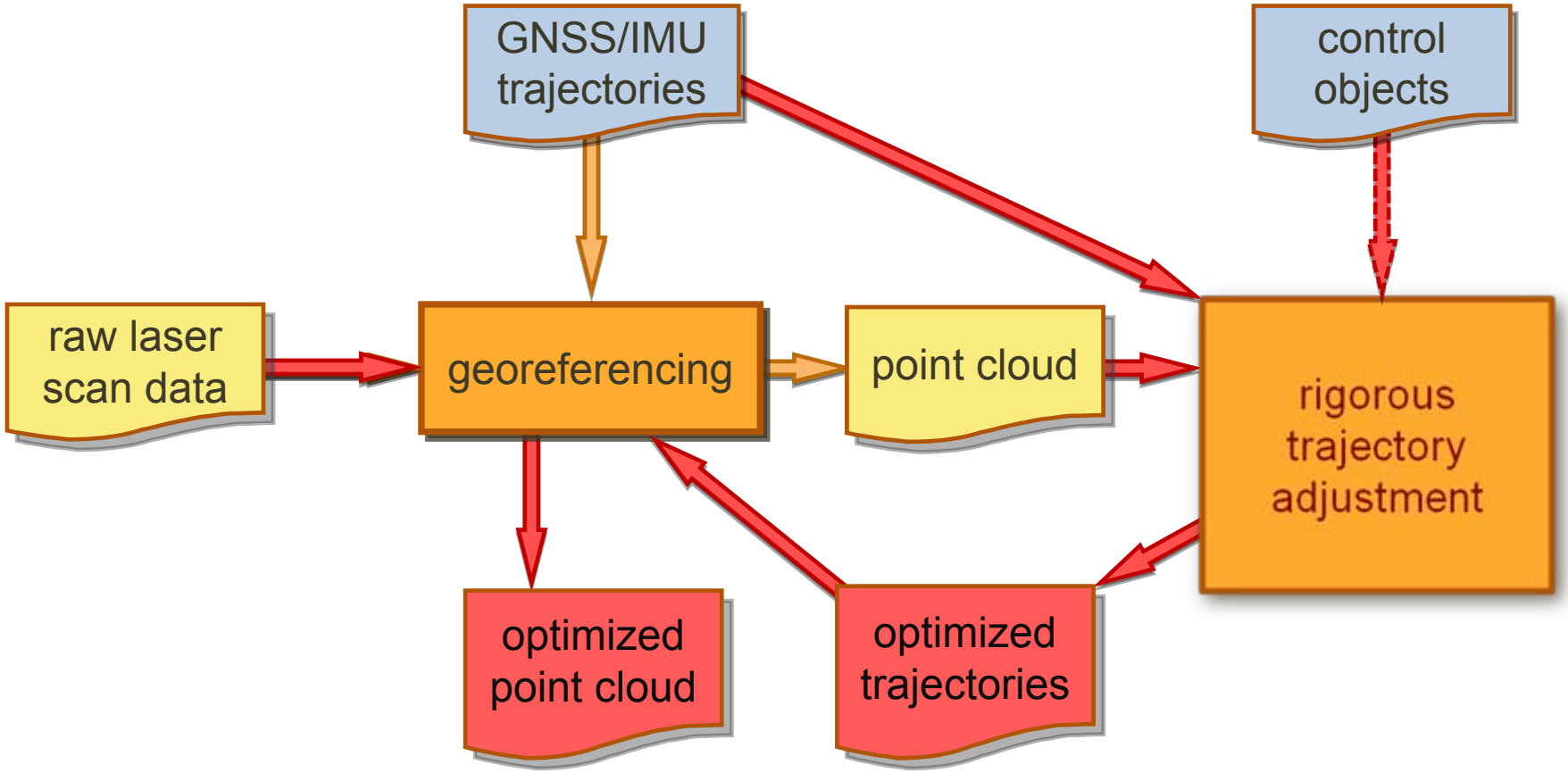


- determination of 6 DOF correction for minimizing discrepancies in overlapping local regions
- previous block serves as reference
- adding-up / integration of corrections

time variant rigorous adjustment strategy

- thorough modeling of all system components
  - appropriate error models
  - propagation of raw sensor data quality to final data product
  - incorporation of all available information
  - statistically most rigorous
- flexible trajectory adjustment
  - no rigid or semi-rigid treatment
  - continuous and seamless
- adjustment strategy
  - floating adjustment possible (control scans/points as reference optional)
  - simultaneous adjustment (no recursive filtering)

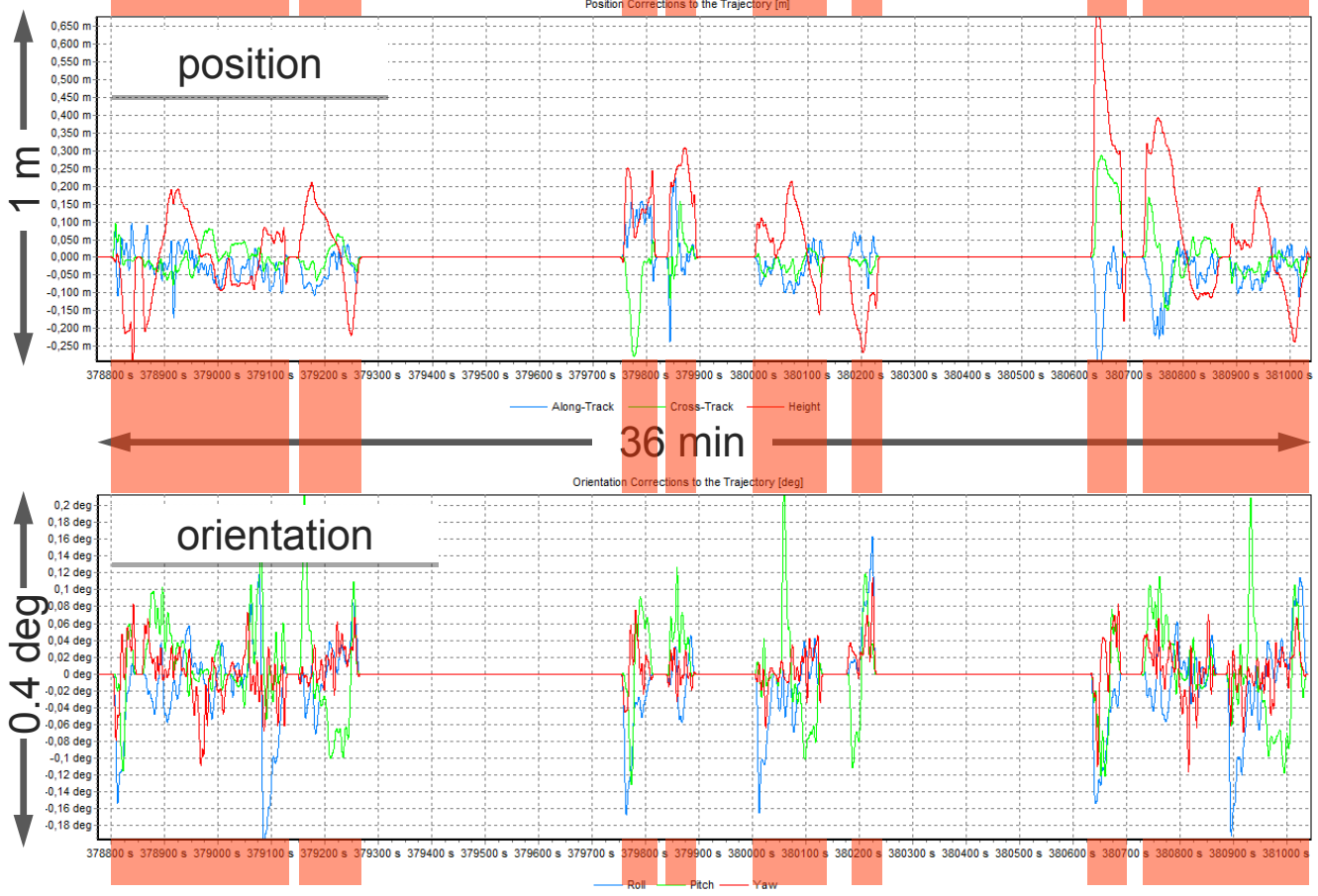

point cloud features
feature correspondences
laser scanner accuracy
trajectory accuracy
initial trajectory
STATISTICAL ESTIMATION ENGINE
optional: external control objects
trajectory model
optimized trajectory
rigorous statistics
(big) data handling
robust algorithms
optimized point cloud


GNSS/IMU trajectories
control objects
raw laser scan data
georeferencing
point cloud
rigorous trajectory adjustment
optimized point cloud
optimized trajectories

RIEGL RiPRECISION - adjustment software for kinematic LIDAR data

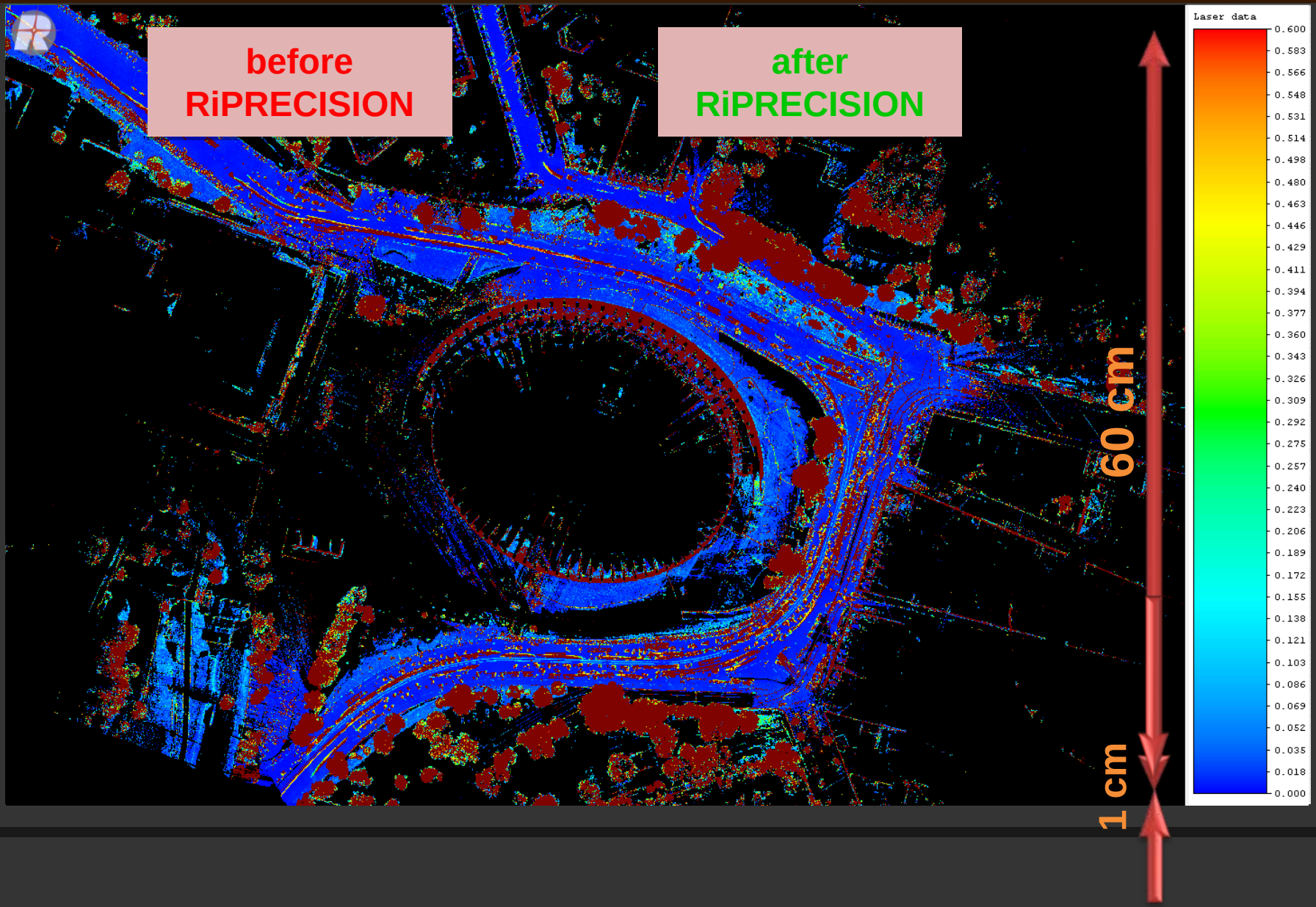
- embedded in kinematic data handling/processing software product *RIEGL* RiPROCESS
- user tasks
  - select scans
  - select trajectories
  - select control objects / scans
  - start adjustment
- fully automatic processing

observations from scan data



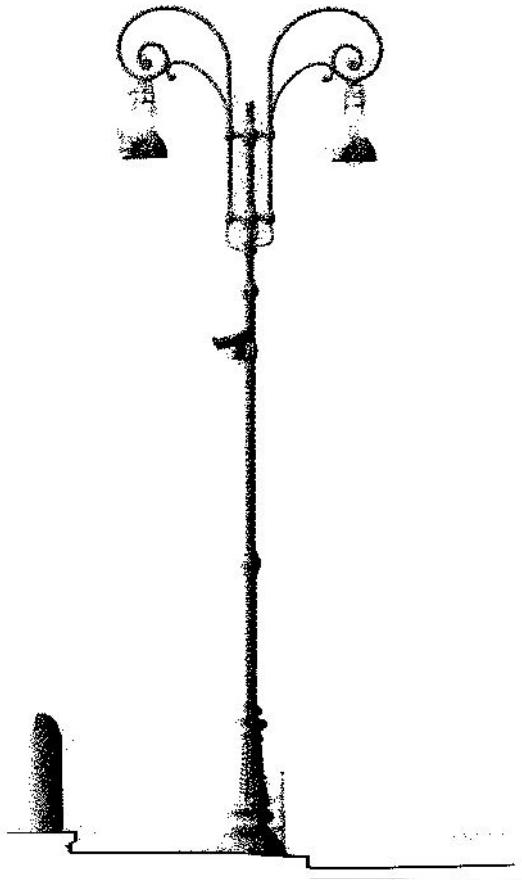
Position	RMS	max
along [cm]	7	33
side [cm]	6	29
up [cm]	16	80

Orientation	RMS	max
roll [mdeg]	54	208
pitch [mdeg]	56	220
yaw [mdeg]	83	116

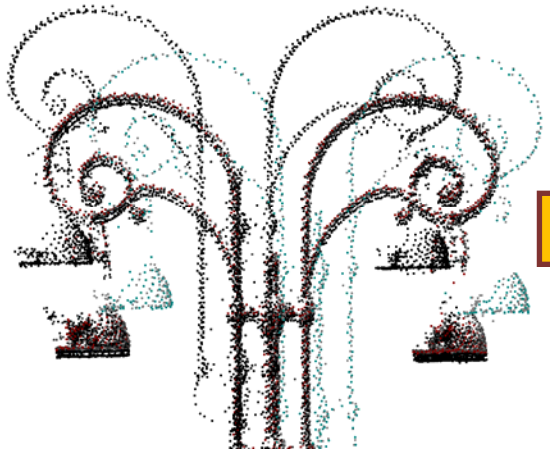

before
RiPRECISION
after
RiPRECISION
60 cm
1 cm
Laser data
0.600
0.583
0.566
0.548
0.531
0.514
0.498
0.480
0.463
0.446
0.429
0.411
0.394
0.377
0.360
0.343
0.326
0.309
0.292
0.275
0.257
0.240
0.223
0.206
0.189
0.172
0.155
0.138
0.121
0.103
0.086
0.069
0.052
0.035
0.018
0.000

Adjusted Point Cloud

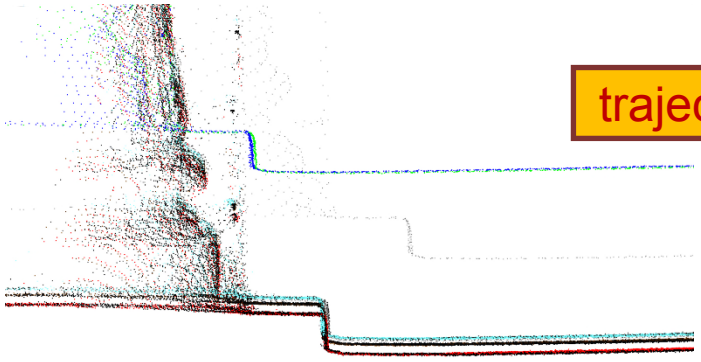
before adjustment



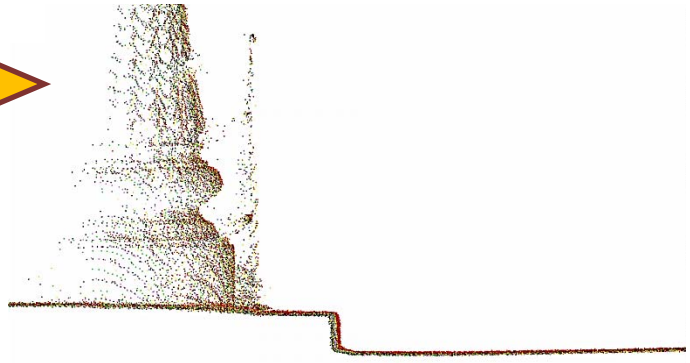
after adjustment

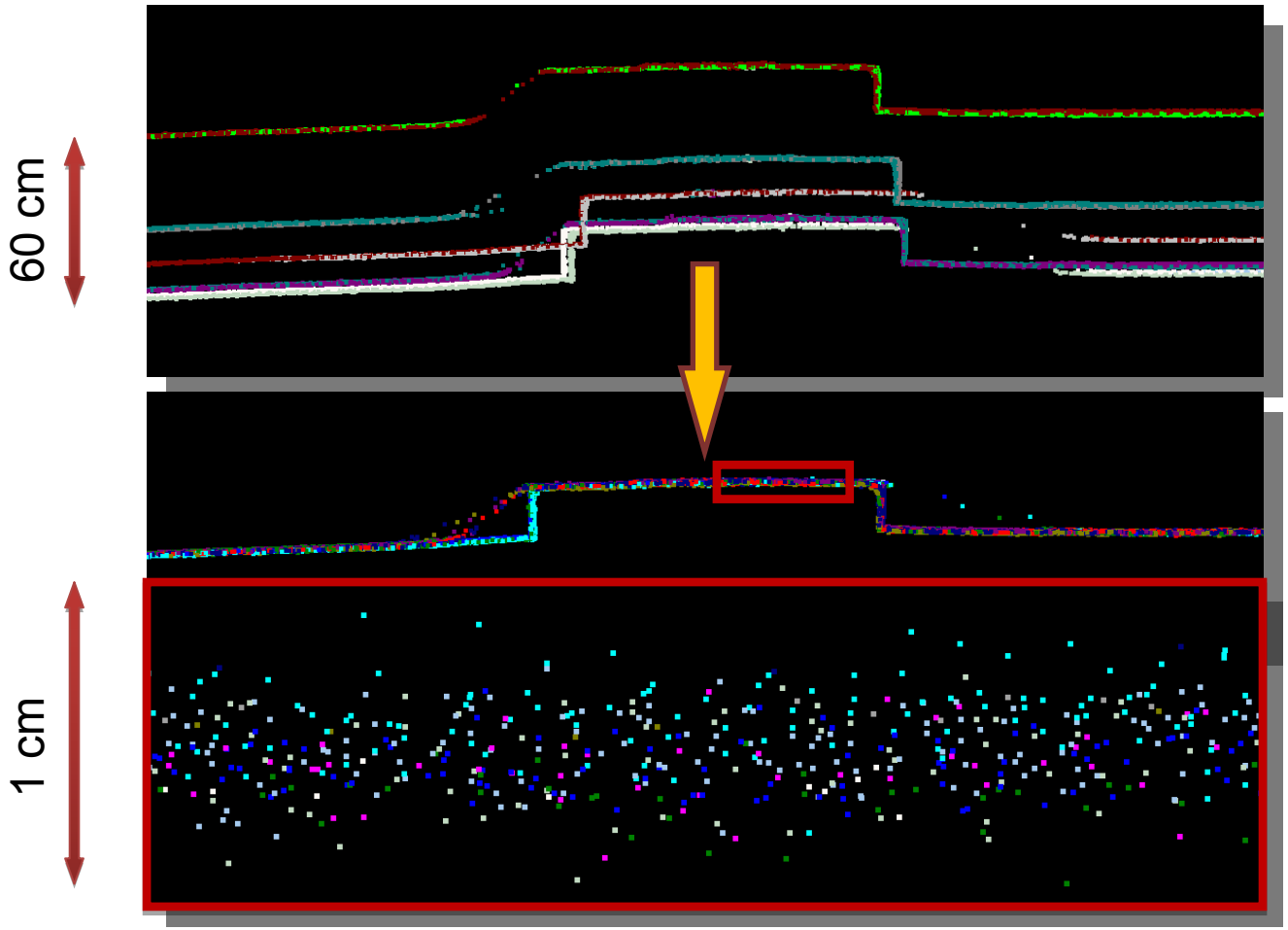


trajectory adjustment



trajectory adjustment





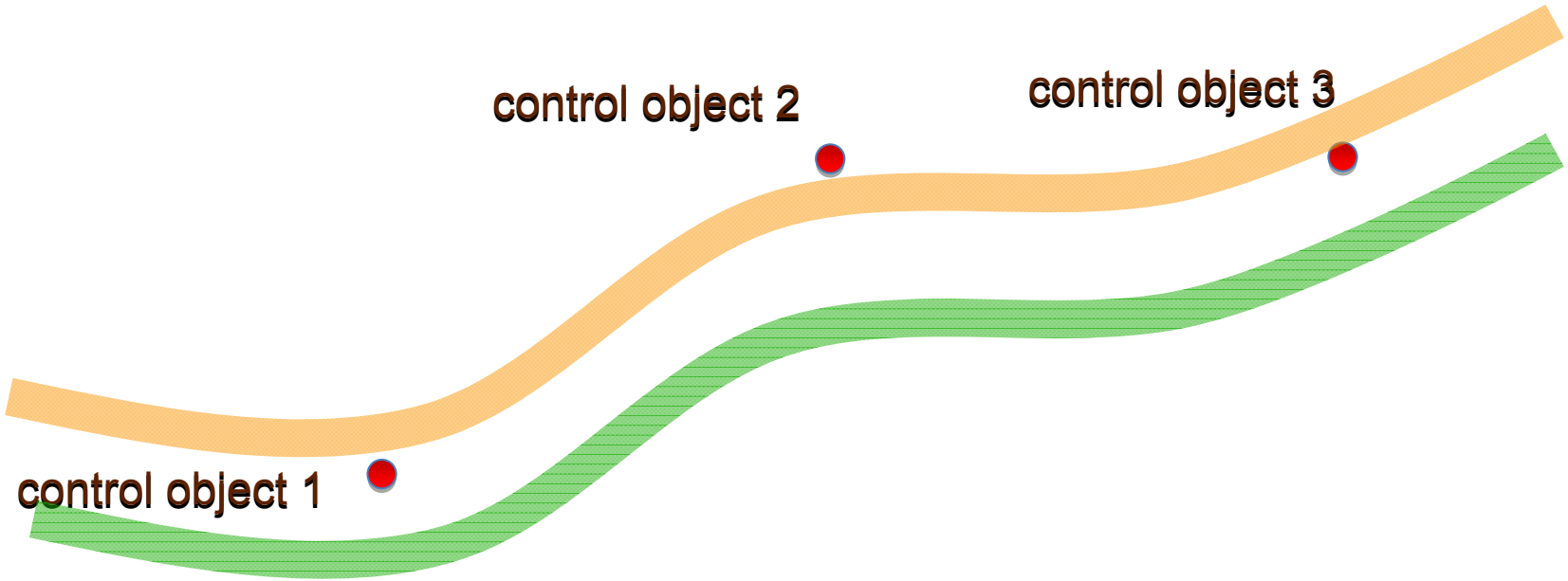
12 scans
(6 passes)

- project
  - number of points 670 millions
  - size of project 100 GB
  - up to 18 overlapping scans
- adjustment performance
  - point cloud feature extraction
    (5 million feature correspondences) 15 min
  - RiPRECISION **4.5 min**
  - georeferencing, generating search tree structures 20 min
  - total time **40 min**

→ residual deviations down to a few cm

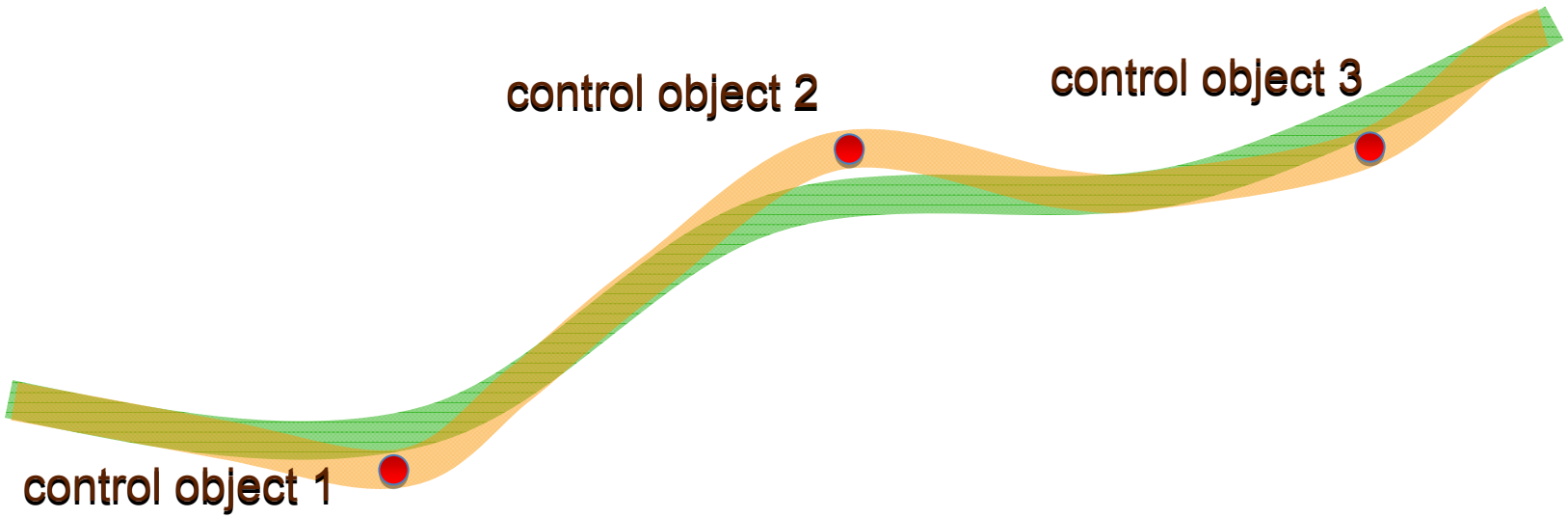
→ no user interaction

- rigid frame translation only



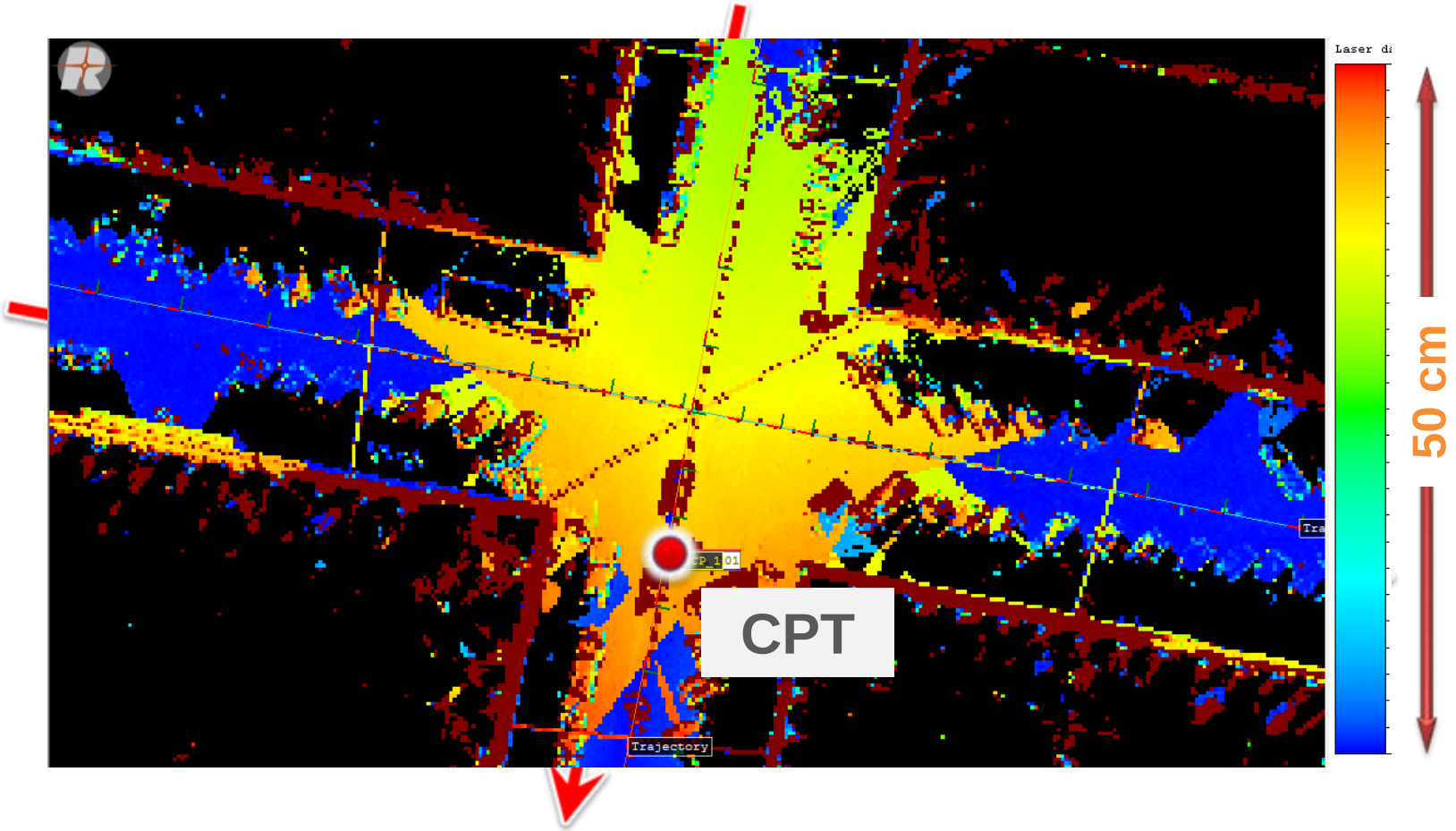
- global shift only

- non-rigid mode



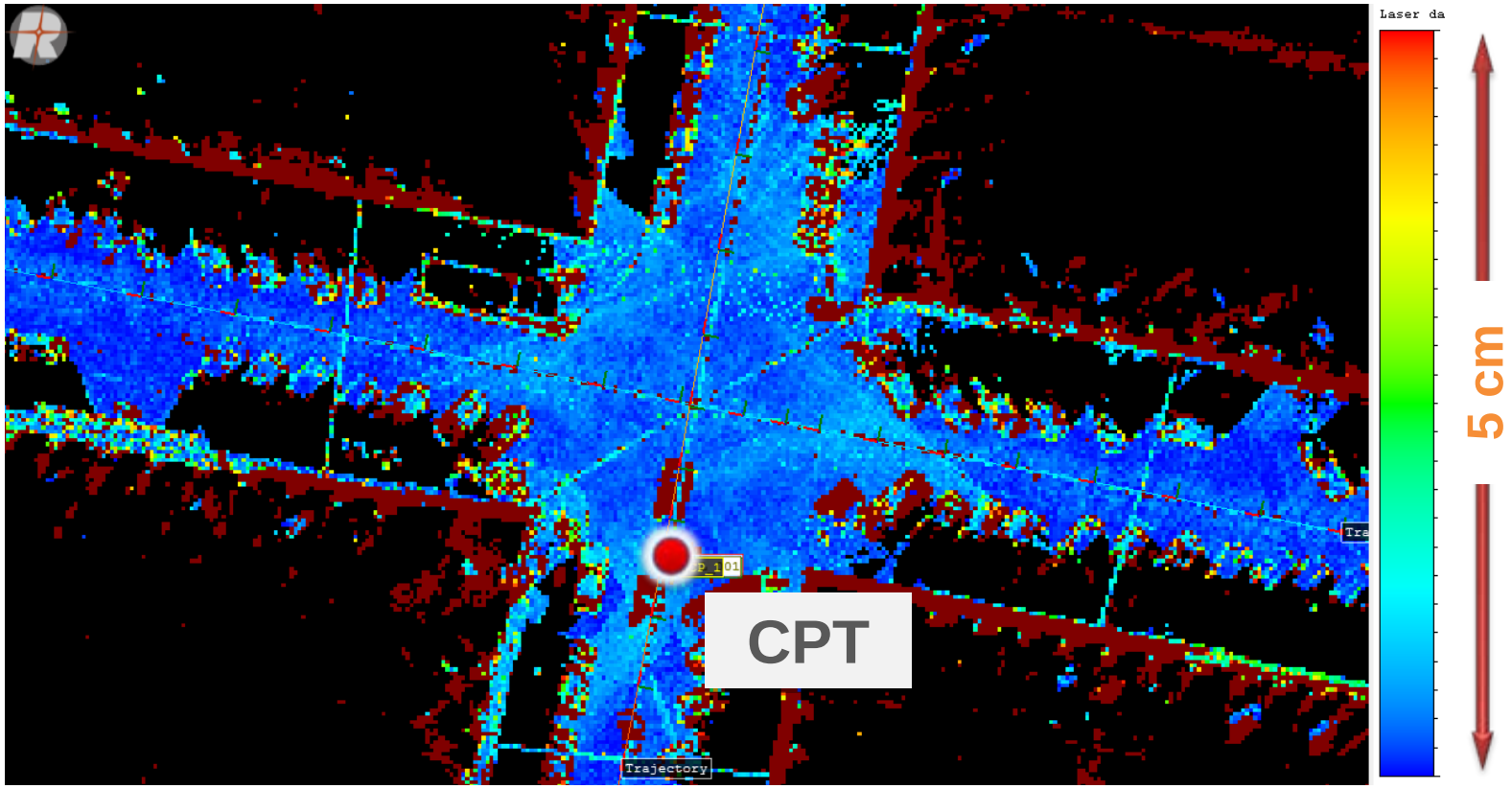
- local adjustments

before adjustment

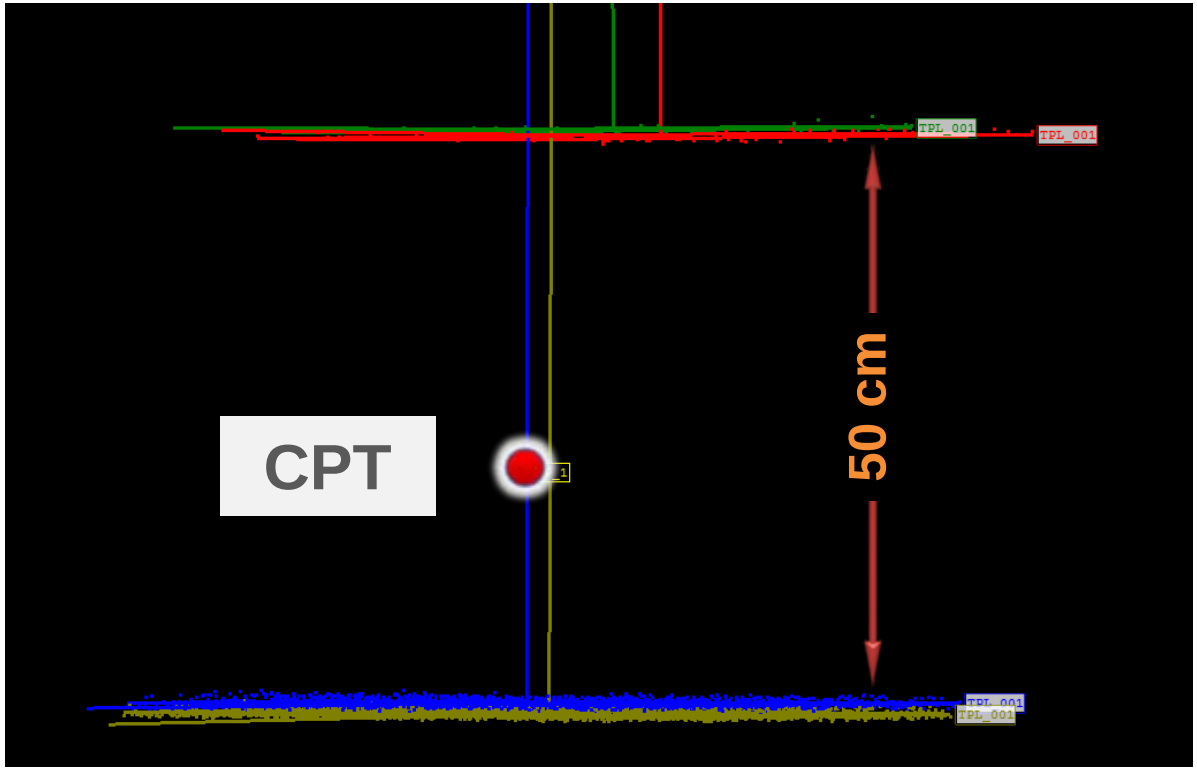


example for absolute adjustment

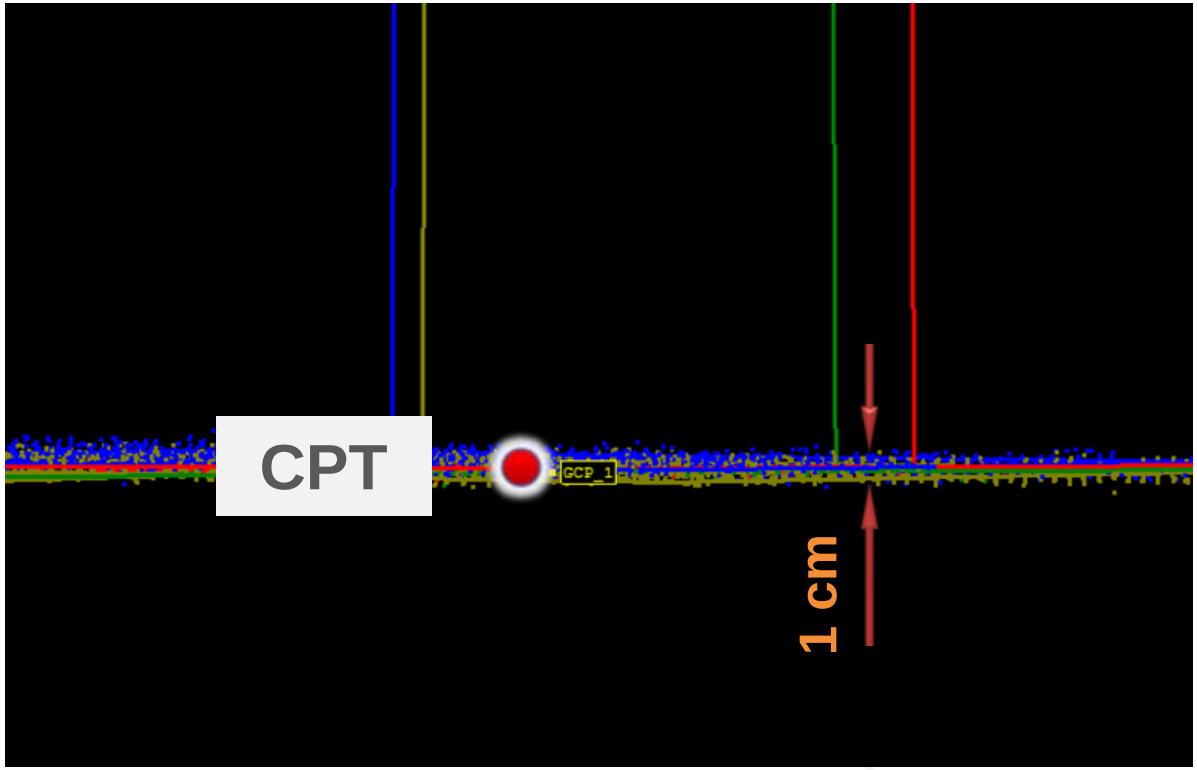
after adjustment



before adjustment



after adjustment



example for absolute adjustment

rigorous trajectory adjustment yields

- significantly better point cloud quality
  - realistic modeling → very precise and consistent
  - rigorous statistics → highly accurate and reliable
- time savings
  - automatic processing → almost no manual labor time
  - efficient processor → very short processing times
  - control objects → less time for reference field setup