Point Clouds
From Calibration to Classification

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Contributions
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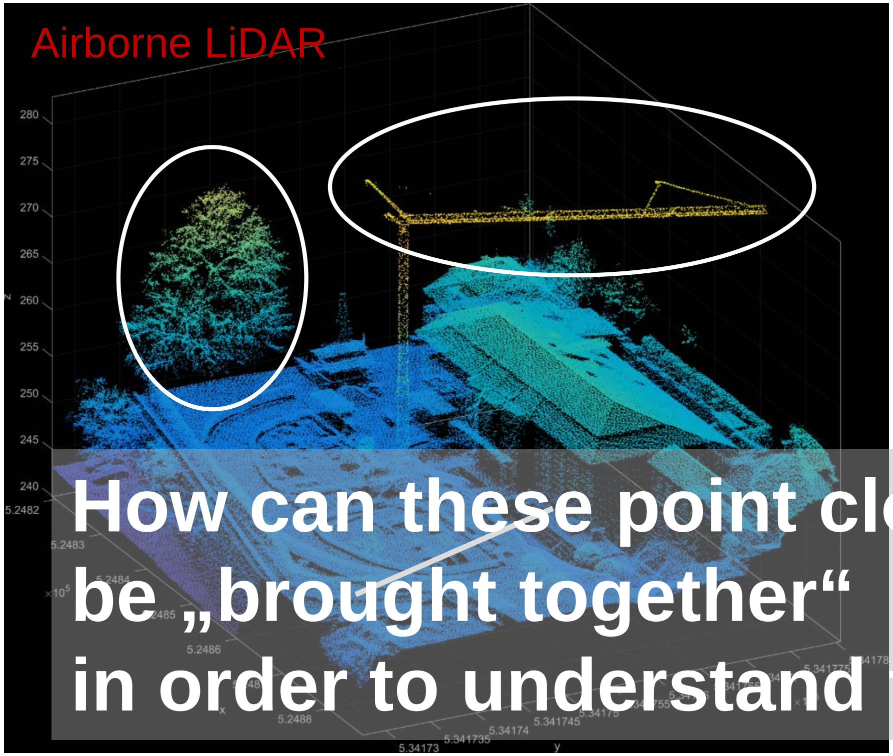
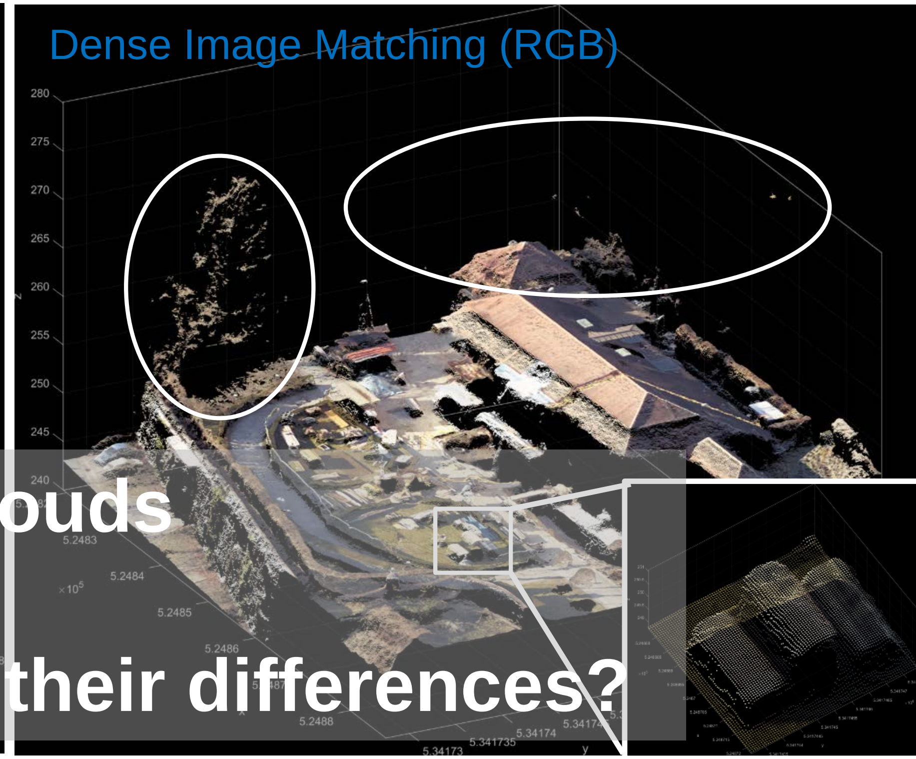
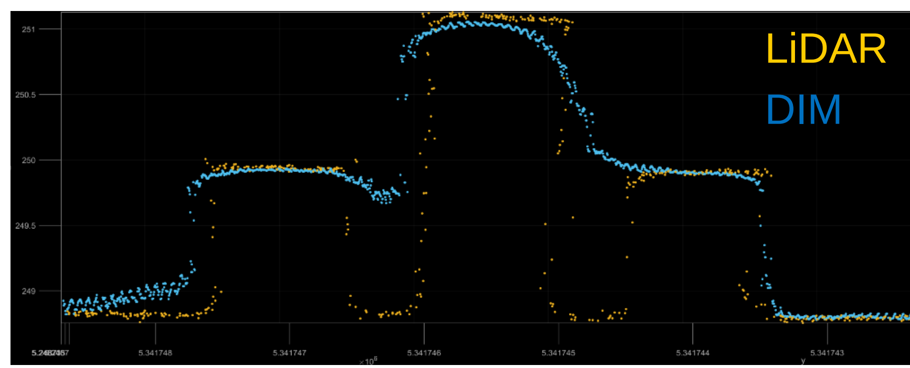
Point Cloud Calibration and Orientation





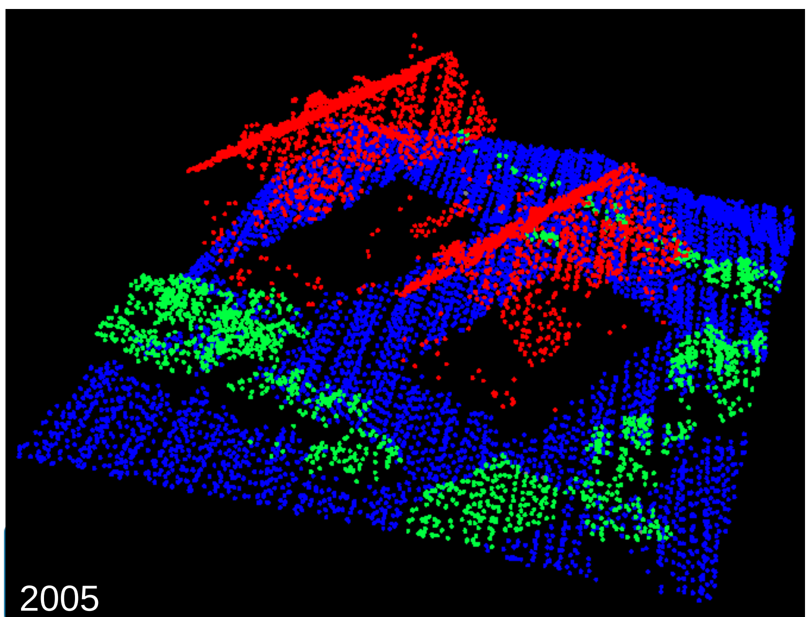
How can these point clouds be „brought together“ in order to understand their differences?

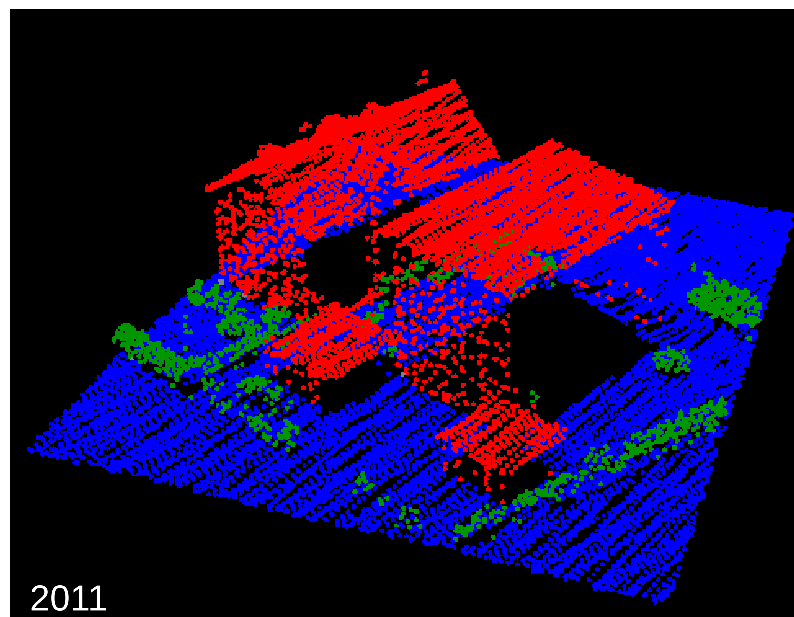
- 3D color vs. mainly geometry
- Differences: vegetation, crane
- Piles of construction material
- DIM: stereo occlucion
- LiDAR: points between piles available



Point Cloud Change Detection

- 4 data sets taken at 4 different times
- Different modality
  RGB, nIR, photo/lidar, GSD,
  point density, shadow, …
- Classified Lidar point clouds
  ground, building, vegetation





Computational Geometry – Point Cloud Legacy

- Design Process
  - Given: Point cloud $\mathbf{p}_i \in \mathrm{R}^3$, $i = 1, \ldots n$
  - Find: surface $\mathbf{s}(u,v)$ closely interpolating $\mathbf{p}_i$, i.e. minimize $f\,(\,\mathbf{s}(u_i,v_i) - \mathbf{p}_i\,)$
  - NURBS (...) surface, patch layout based on curvature, curvature defined in each point

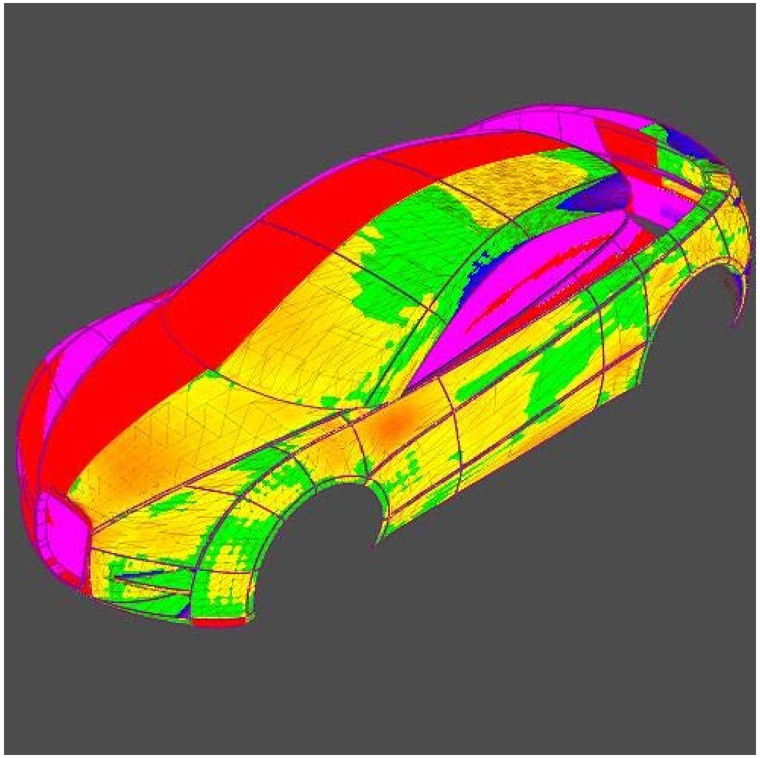


Image: learning alias

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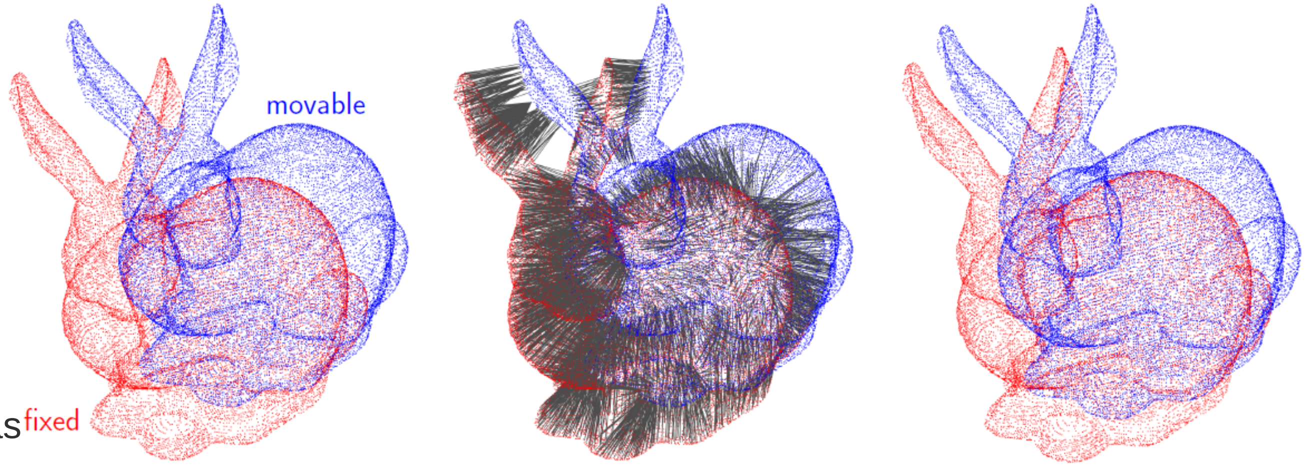
  - NURBS (…) surface, patch layout based on curvature, <u>curvature defined in each point</u>
- Quality Inspection
  - Given: CAD model of a object, discretized as points $\mathbf{m}_i$
  - Given: point cloud of the manufactured object, data points $\mathbf{d}_j$
  - Find: transformation of $\mathbf{d}_j$ onto $\mathbf{m}_i$, but no exact correspondence
  - Replace exact with approximate, <u>iteratively determined correspondence</u>: ICP



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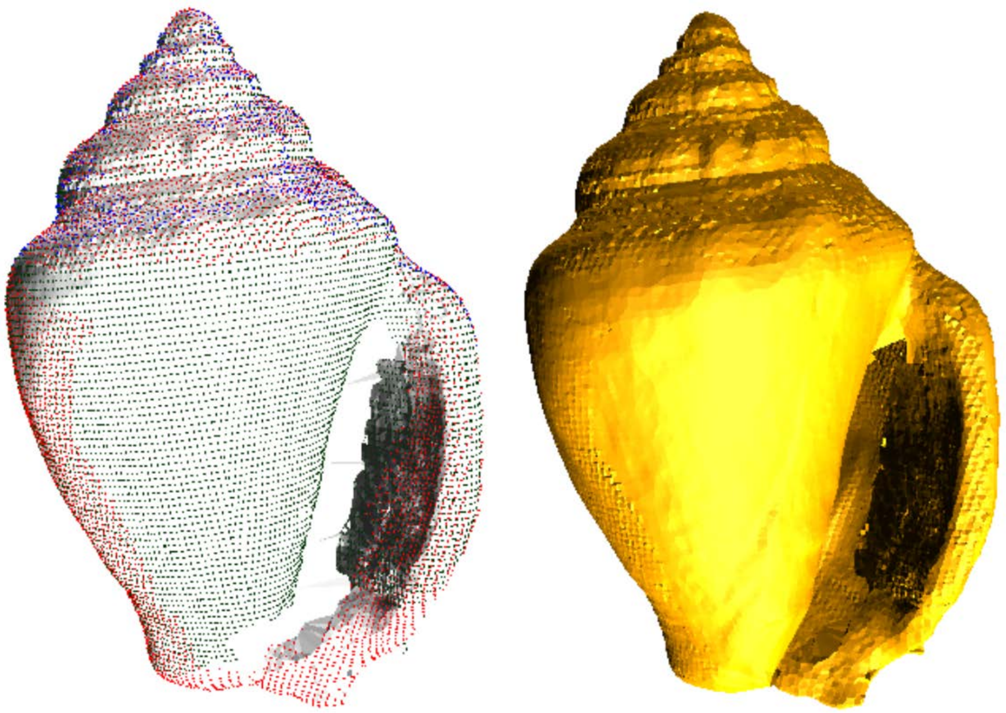
  - Given: point cloud of the manufa
  - Find: transformation of $\mathbf{d}_j$ onto $\mathbf{m}$
  - Replace exact with approximate, .
- Visualization
  - Given: Point cloud $\mathbf{p}_i$
  - Find TIN with vertices $\mathbf{p}_i$ that follows surface of object
  - No 2D solution, e.g. Delaunay criterion,
    but <u>localized processing</u> independent of overall shape



Point clouds

Computational Geometry

- Object centered (often)
- Point $\mathbf{p}_i\,(\,x_i\,,\,y_i\,,\,z_i\,)$
- Cartesian coordinate system
- No datum
- No attributes
- Error free (negligible errors)
- No measurement process

Geodesy and Geoinformation

- Billions of points
- Projected CS
- Random (0.5-30cm), systematic (up to meter), and many gross errors
- Attributes: color, accuracy, echo ID, FWF information, time, etc.
- Measurement process known
- Measurement along optical line of sight

Point cloud research domain

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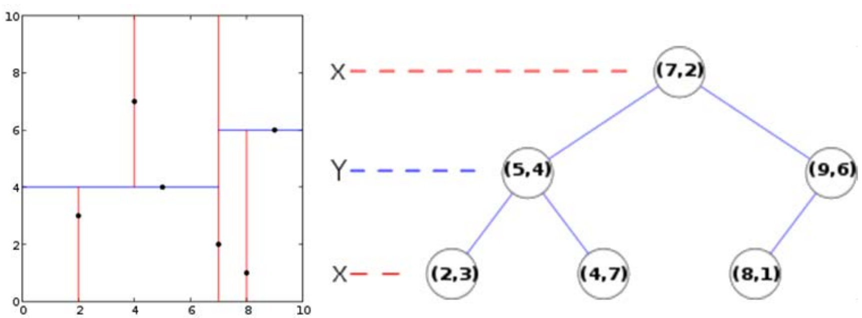

Data structures

- kD-tree
  appropriate for processing, nearest neighbor search, etc.
- octree
  appropriate for visualization (e.g. potree)
- Data structure for manuel editing, processing and visualization of point clouds?

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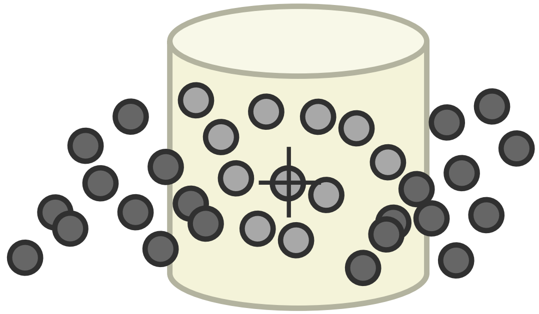

Data structures

- kD-tree
  appropriate for processing, nearest neighbor search, etc.
- octree
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- Data structure for manuel editing, processing and visualization of point clouds?
- Processing strategies
  parallelization
  tile wise processing
- Neighborhood
  optimal neighborhoods, parameter selection, etc.

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Calibration and orientation

- sensor modeling
- measurement process modeling sensor + medium/media + object
- observation error models

$$\boxed{\mathbf{x}^e(t) = \mathbf{g}^e(t) + R^e_n(t)\, R^n_i(t)(\mathbf{a}^i + R^i_s\, \mathbf{x}^s(t))}$$

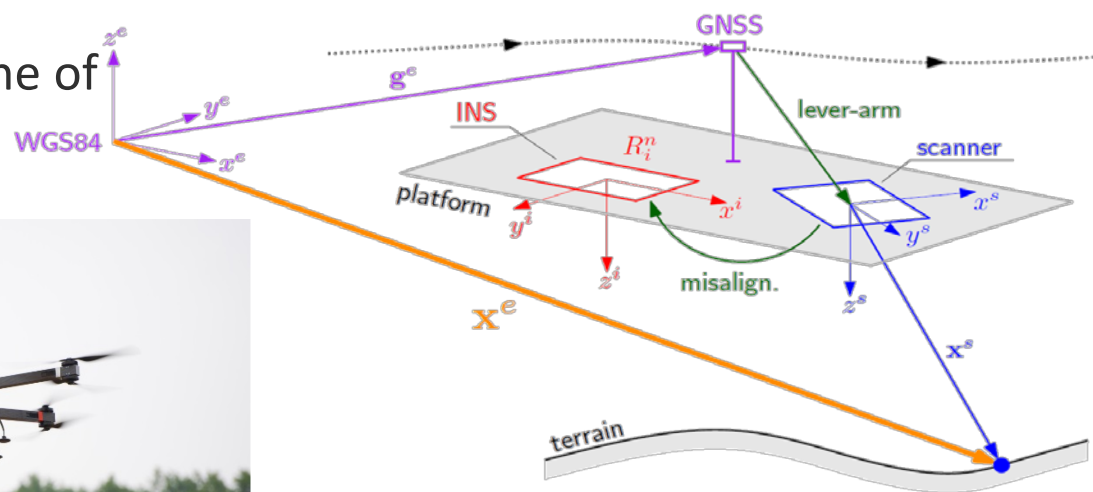

Image: Riegl

Glira et al.

Point cloud research domain

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Applications

- land cover mapping
- topographic modeling
- indoor modeling
- engineering surveying
- deformation analysis
- change detection

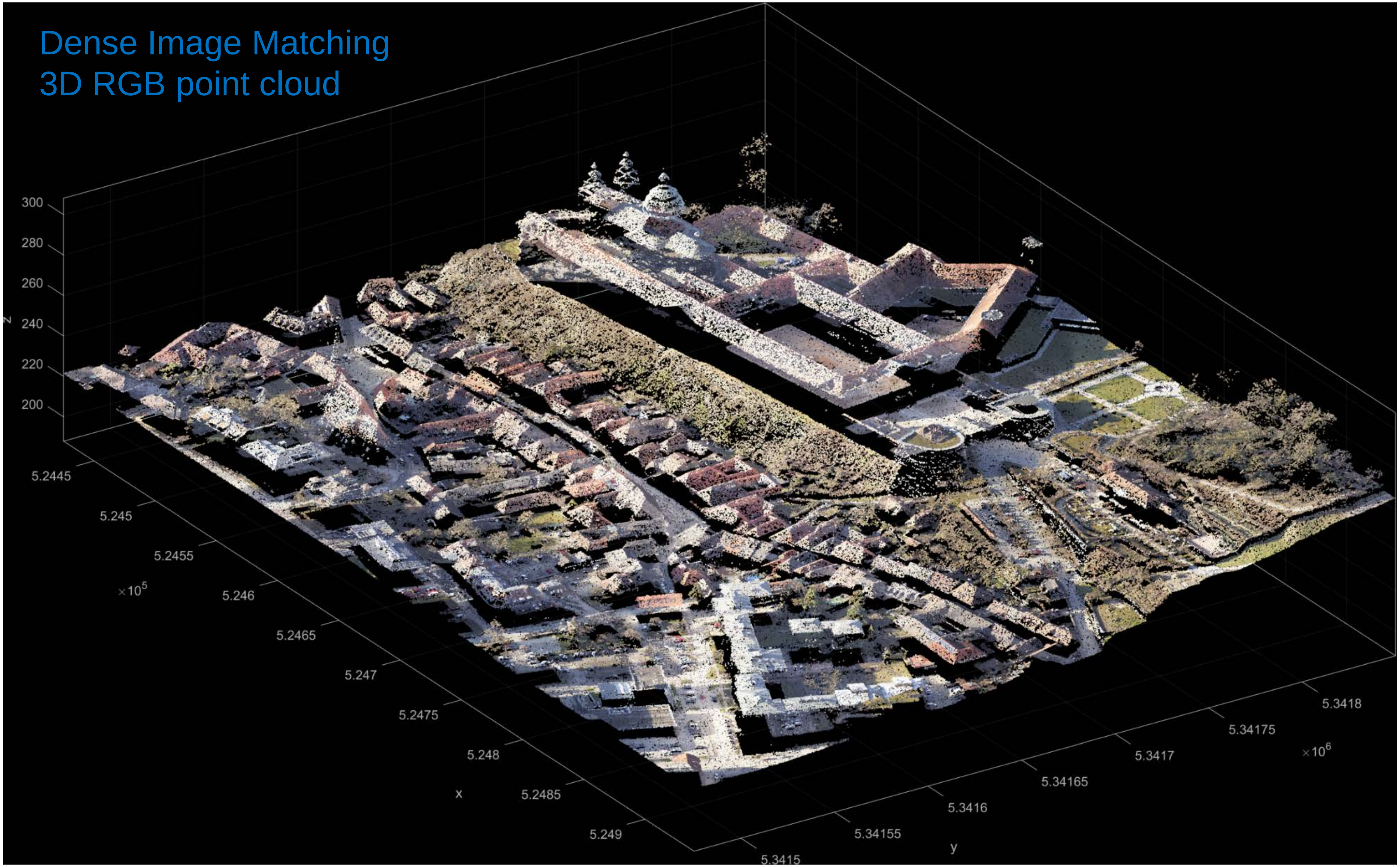
Calibration of point clouds

Integrated calibration and orientation of lidar and image matching point clouds

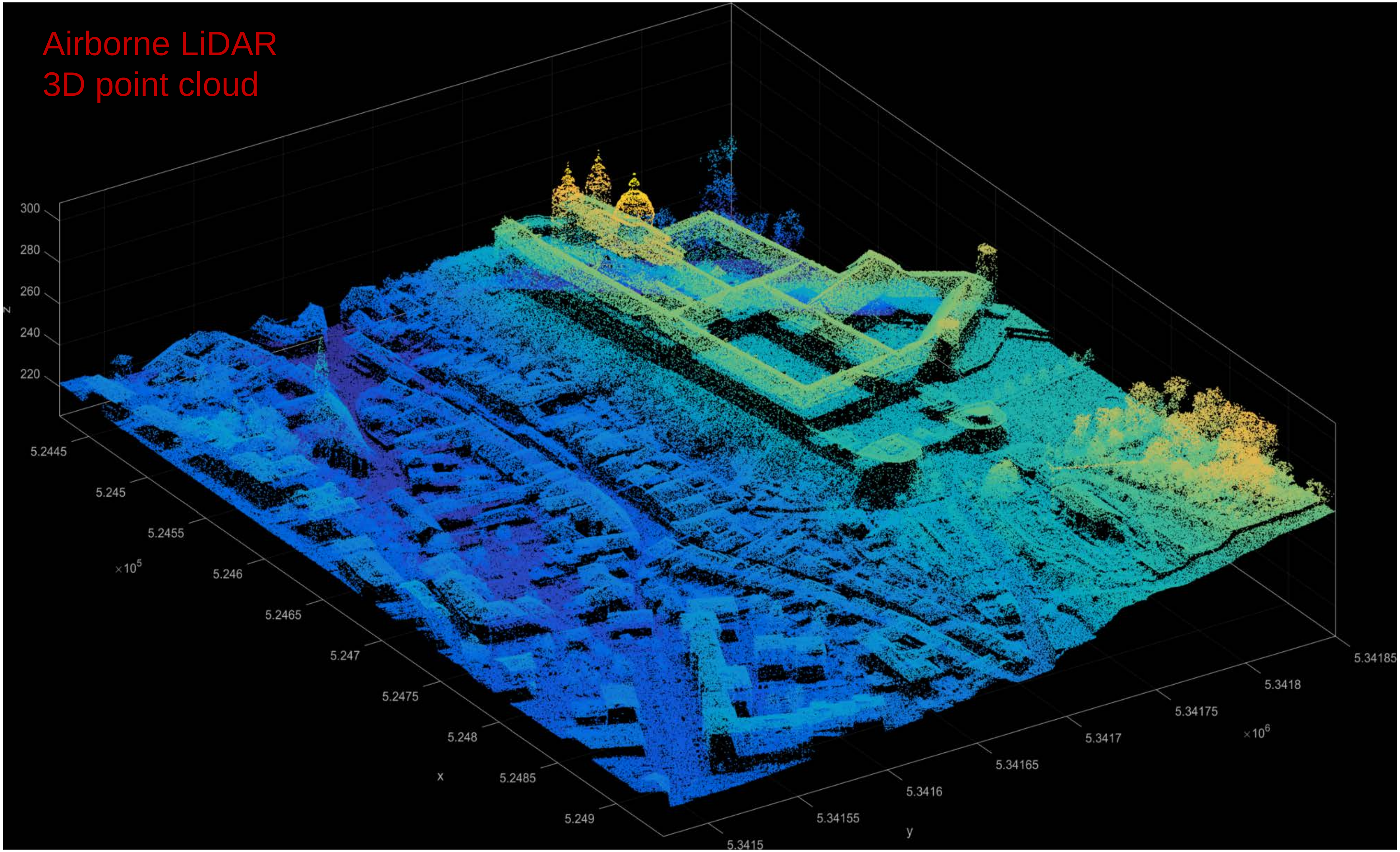
- Where‘s the problem?
- Lidar point clouds are good within surfaces and for vegetation,
  not influenced by (sun) shadows
- Image matching point clouds are good on edges and have high resolution
  physical explanation:
  aperture size of current laser scanners vs. photogrammetric cameras
- Aim
  combine the advantages and exploit the differences
- Requirement
  precise geo-referencing
- Standard method
  independent bundle block adjustment and laser scanning strip adjustment

Flight block Melk (Austria)

Results: data acquisition Melk

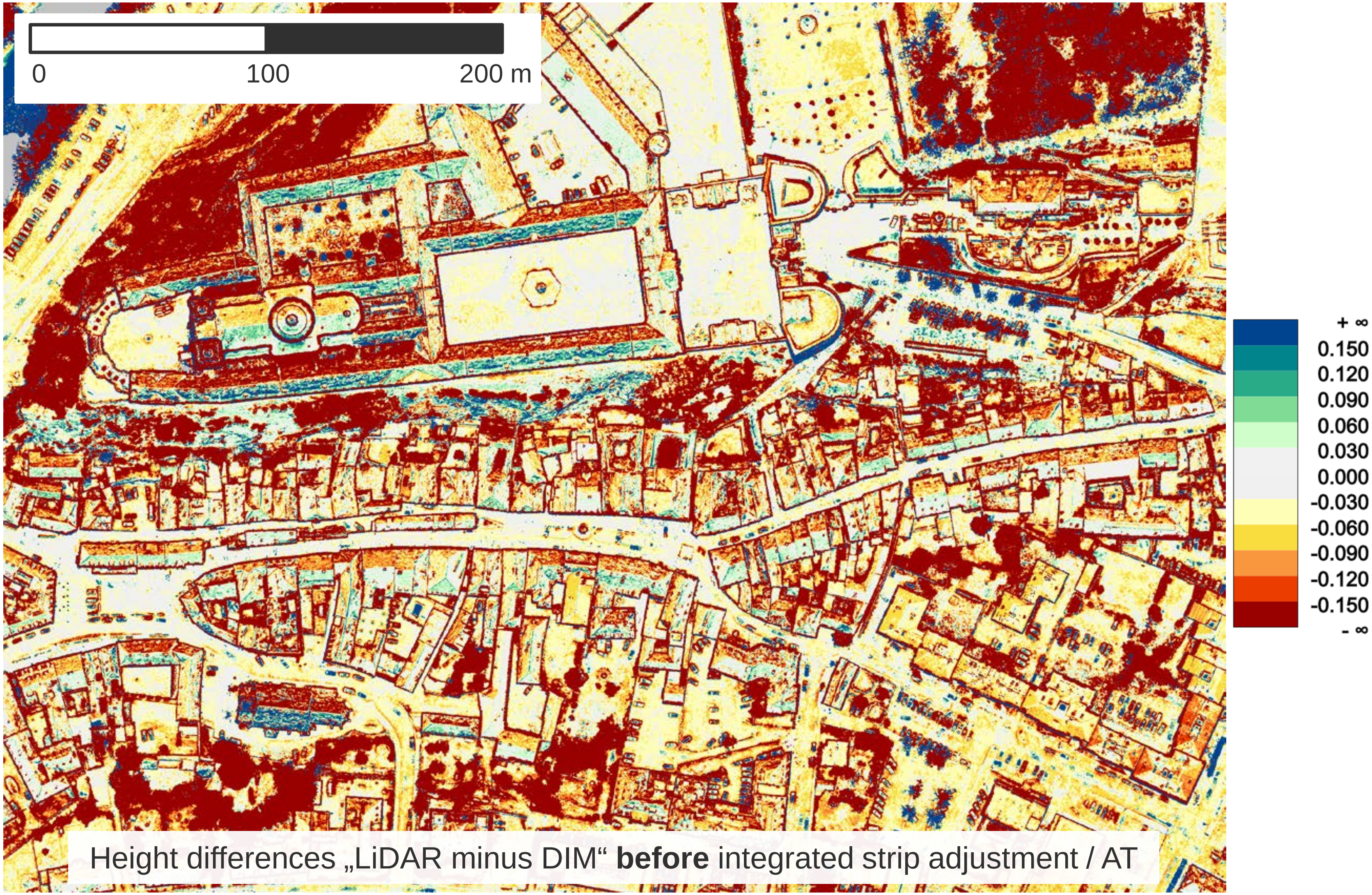


Results: data acquisition Melk



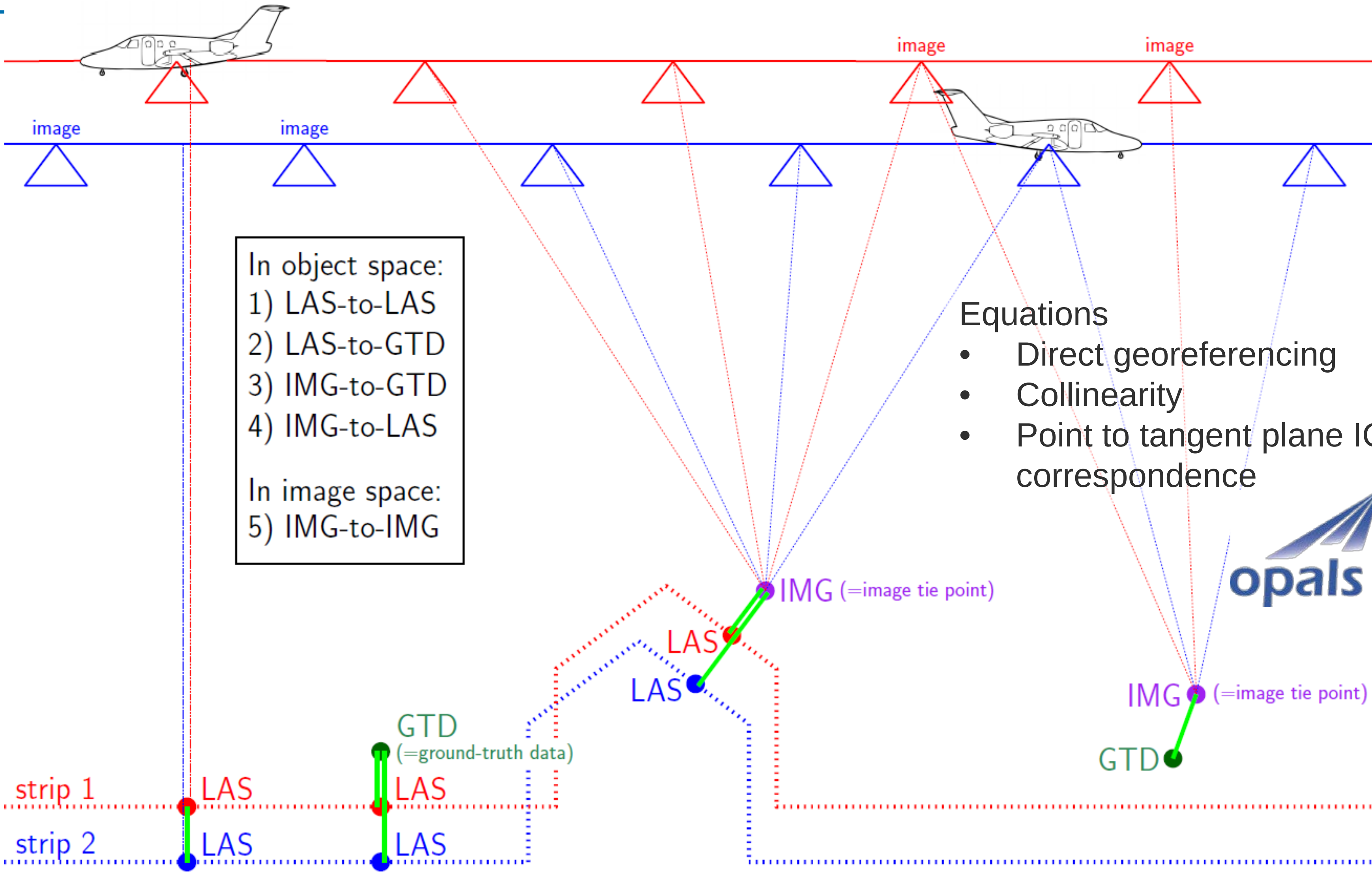
Riegl

Elevation differences with standard method



Height differences „LiDAR minus DIM“ **before** integrated strip adjustment / AT

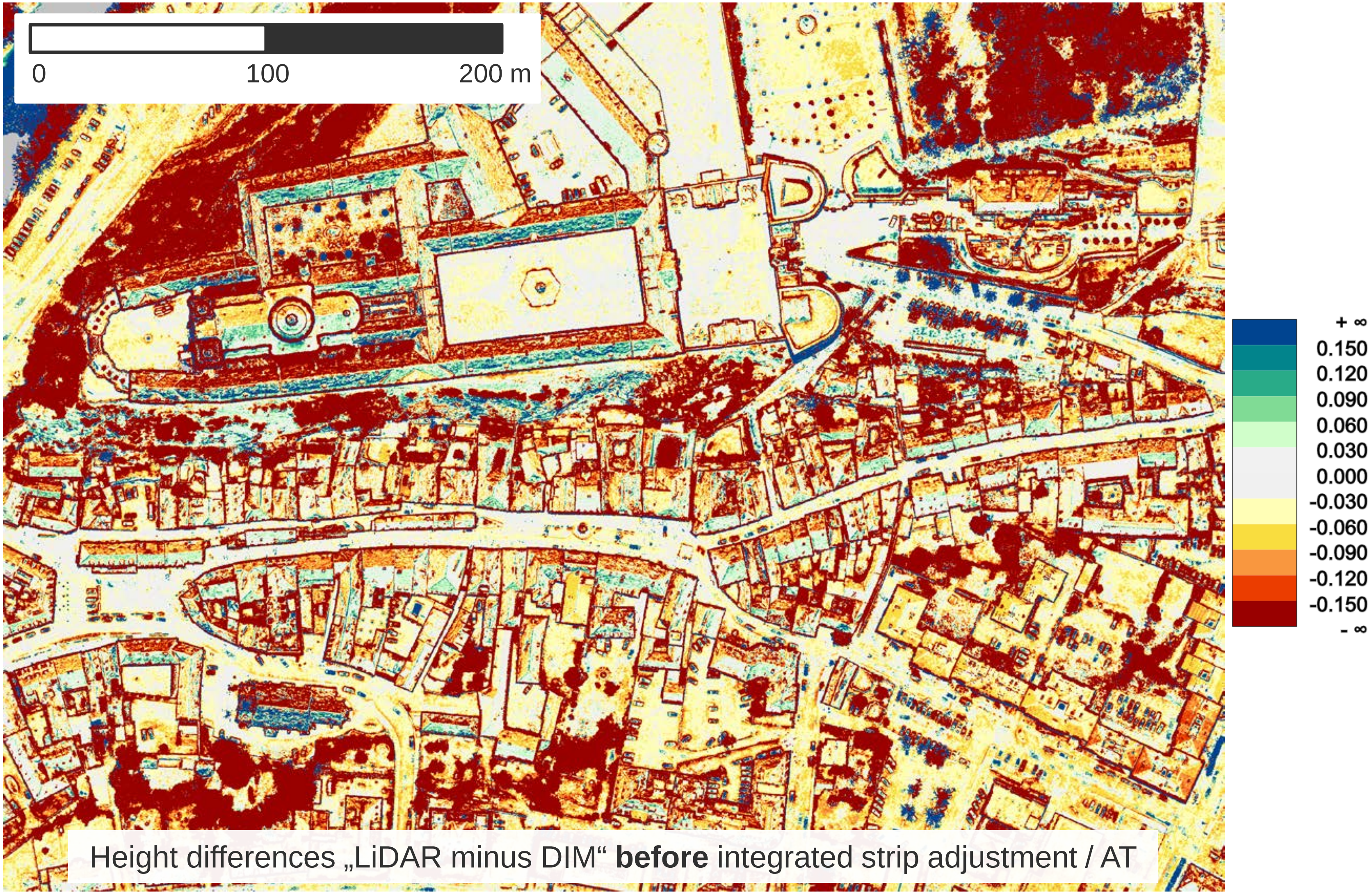
Integration of LiDAR strip adjustment and aerotriangulation



Equations
- Direct georeferencing
- Collinearity
- Point to tangent plane ICP correspondence

Glira et al.

Results: data acquisition Melk



Results: data acquisition Melk

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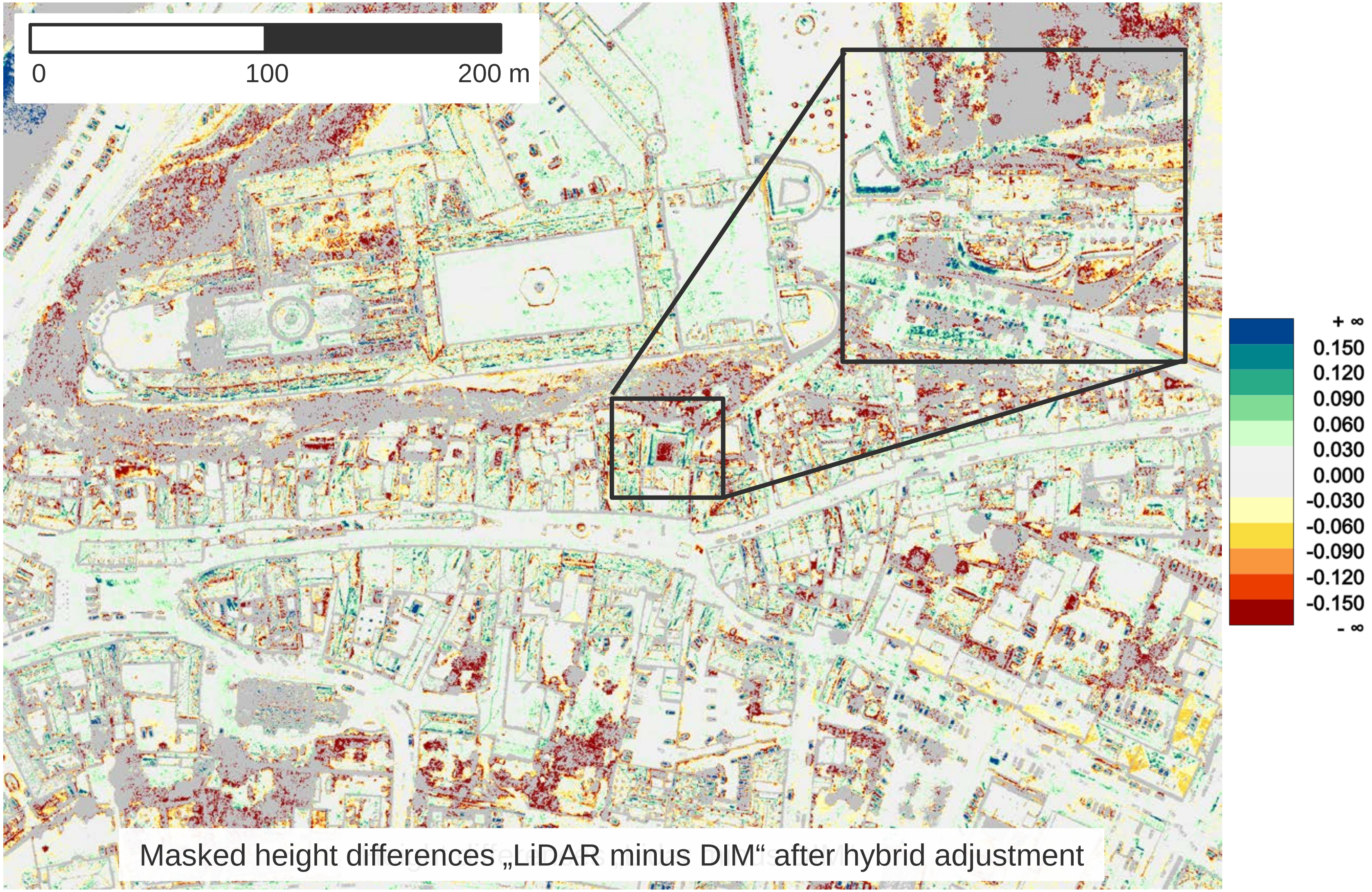
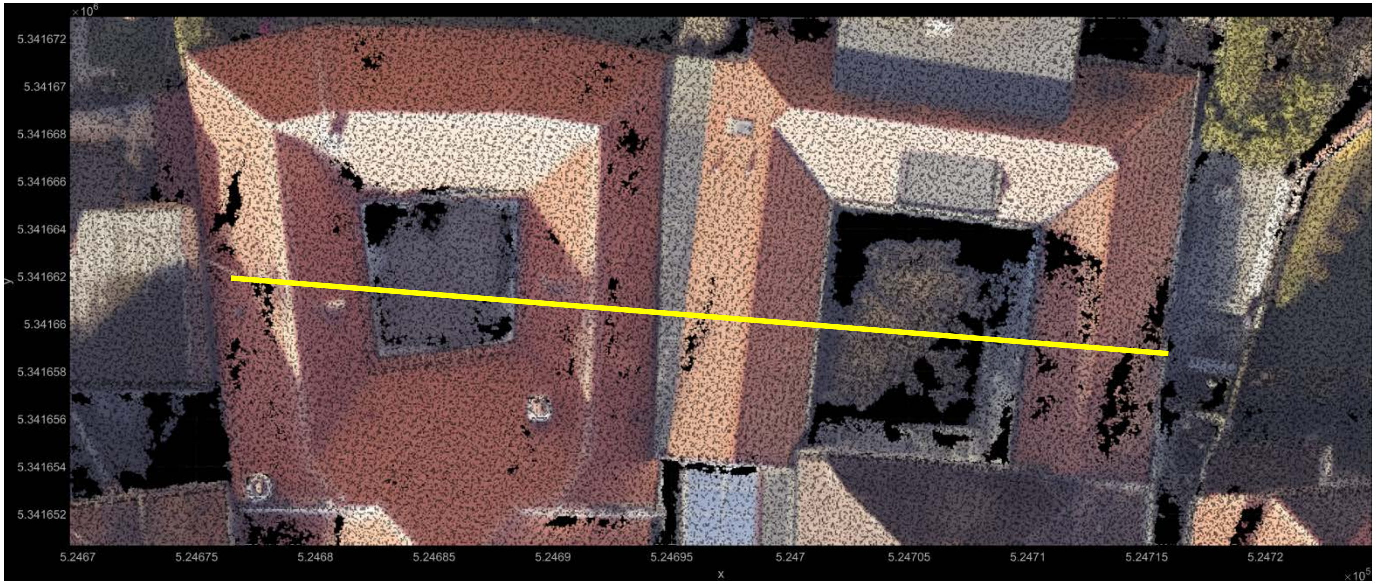
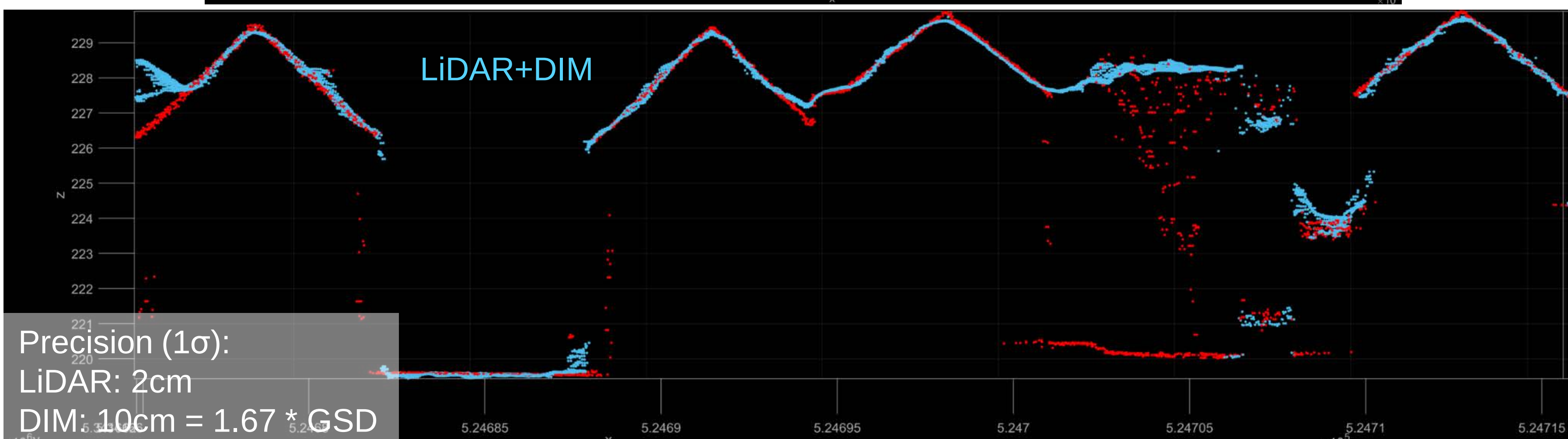


Masked height differences „LiDAR minus DIM“ after hybrid adjustment

DSM generation from LiDAR and DIM





Precision (1σ):
LiDAR: 2cm
DIM: 10cm = 1.67 * GSD

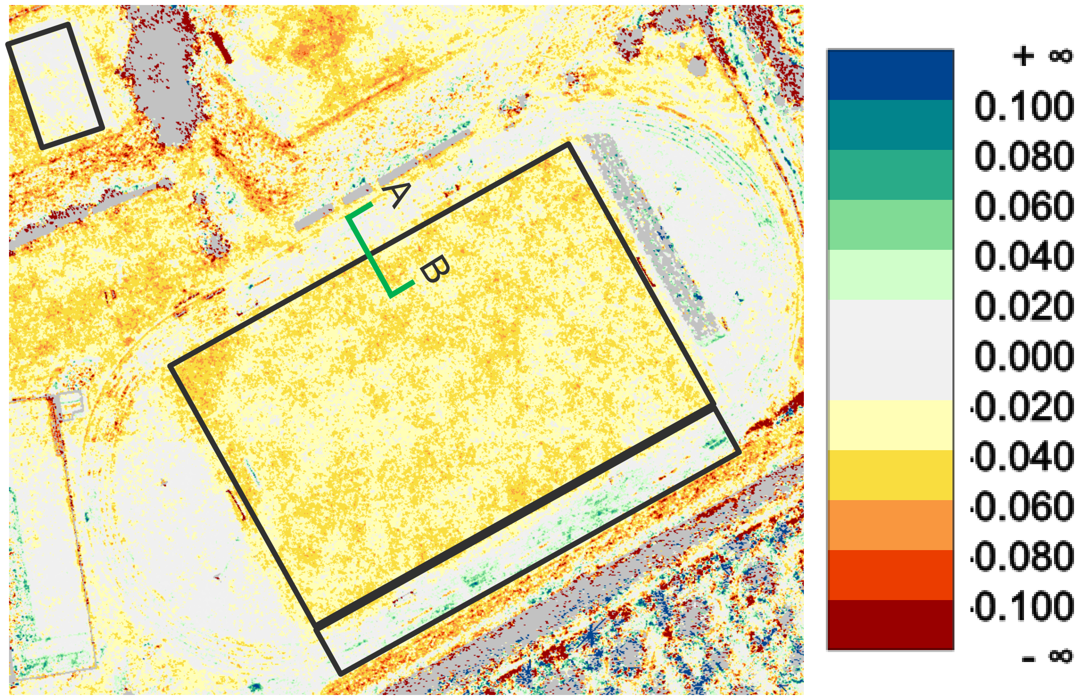
Mandlburger et al.

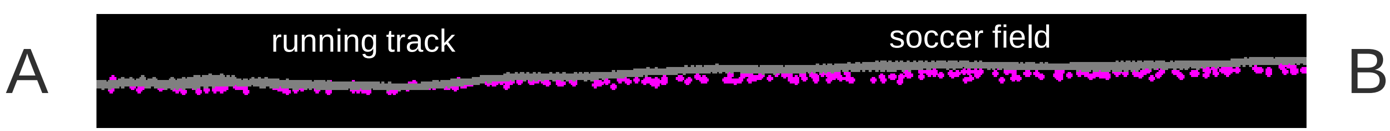
LiDAR/DIM data properties: vegetation penetration

- Vegetation: DIM=top of grass surface, LiDAR=penetrates grass layer
- Impenetrable surfaces: negligible height differences between DIM and ALS

colorized DIM point cloud

height difference: LiDAR-DIM

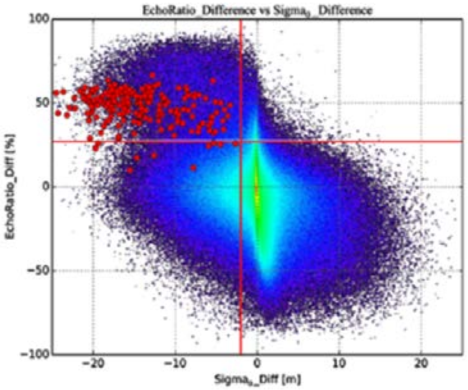


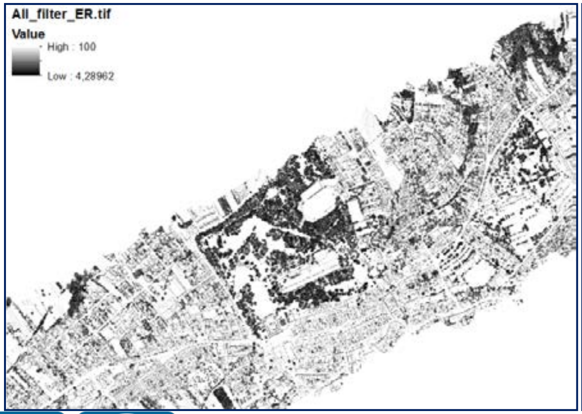


Classification of point clouds

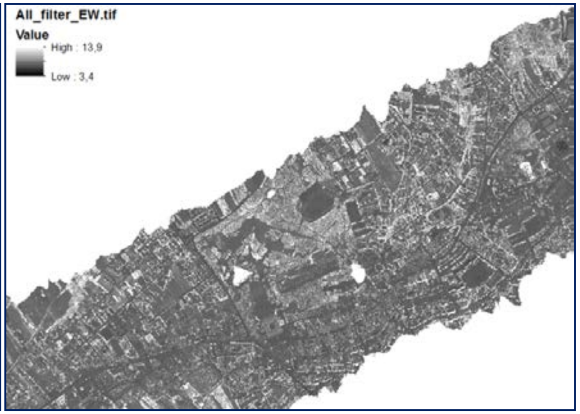
Point cloud classification

- Principle: use measured and computed features to infer, which class a point belongs to (features selection?)

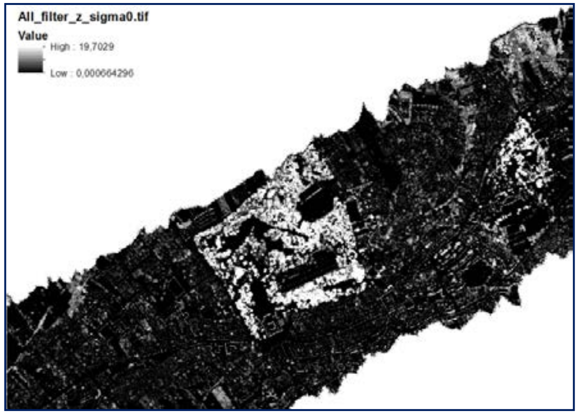




EchoRatio



Echo width



Sigma0

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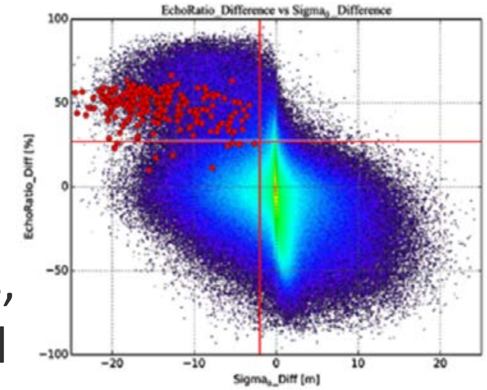
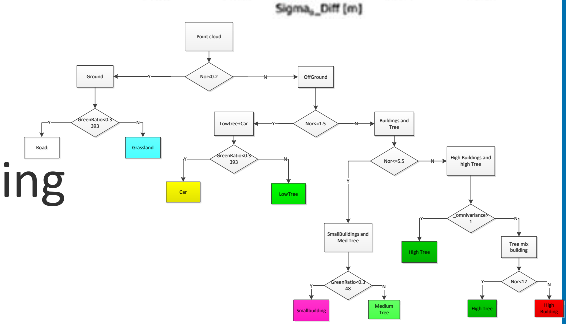
Classification of point clouds

Point cloud classification

- Principle: use measured and computed features to infer, which class a point belongs to (features selection?)
- Methods: manual decision trees, support vector machines, random forests, Markov chains, deep convolutional neural networks
- Considerations: transferability of rules (across missions, scales, etc.), number of classes, run time, amout of training data, representation of rarely occuring classes, classification accuracy





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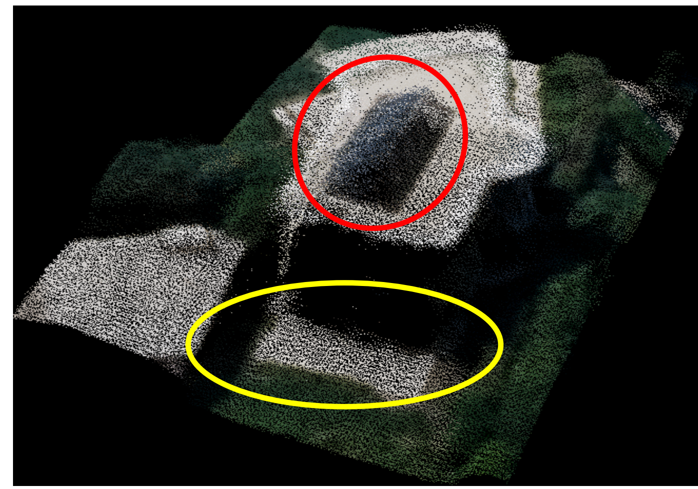
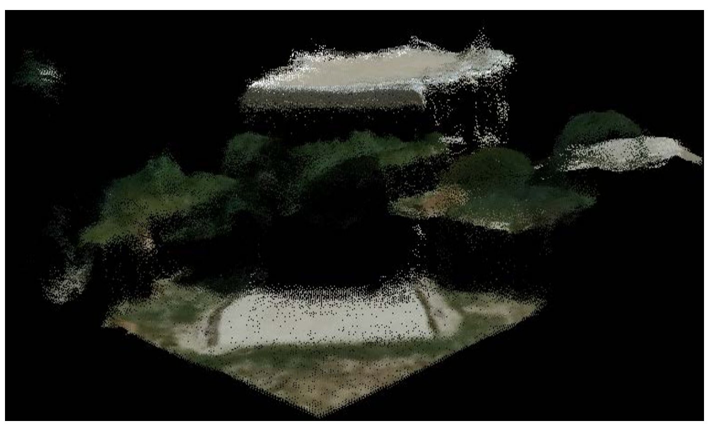
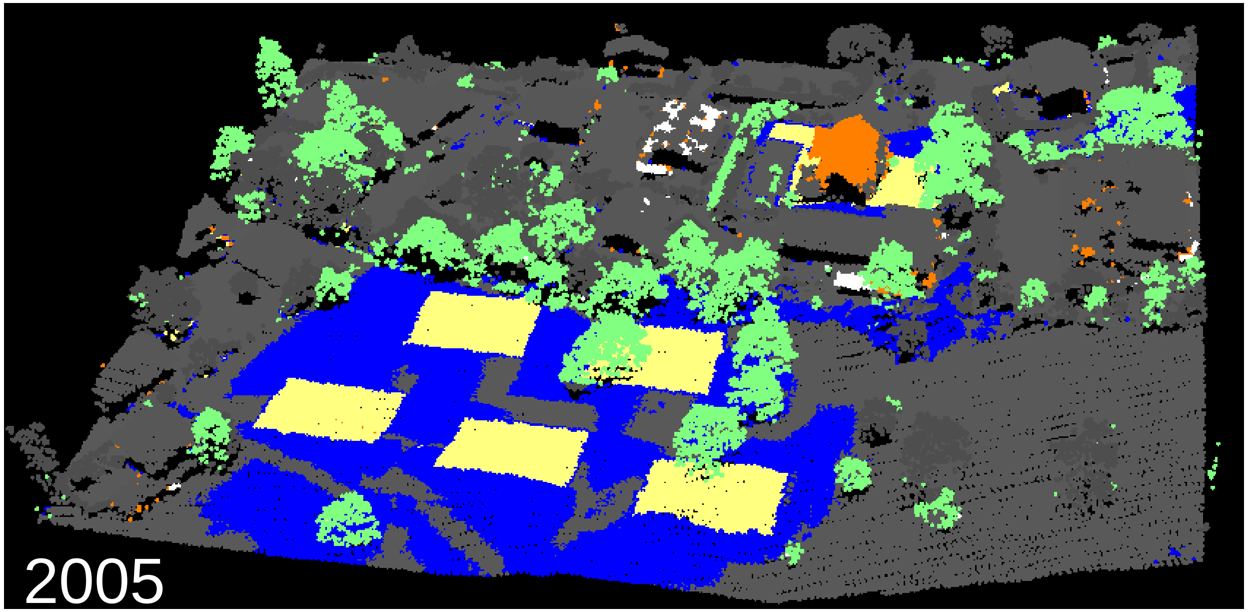
High building Small building Vegetation Grassland Cars Sealed surface

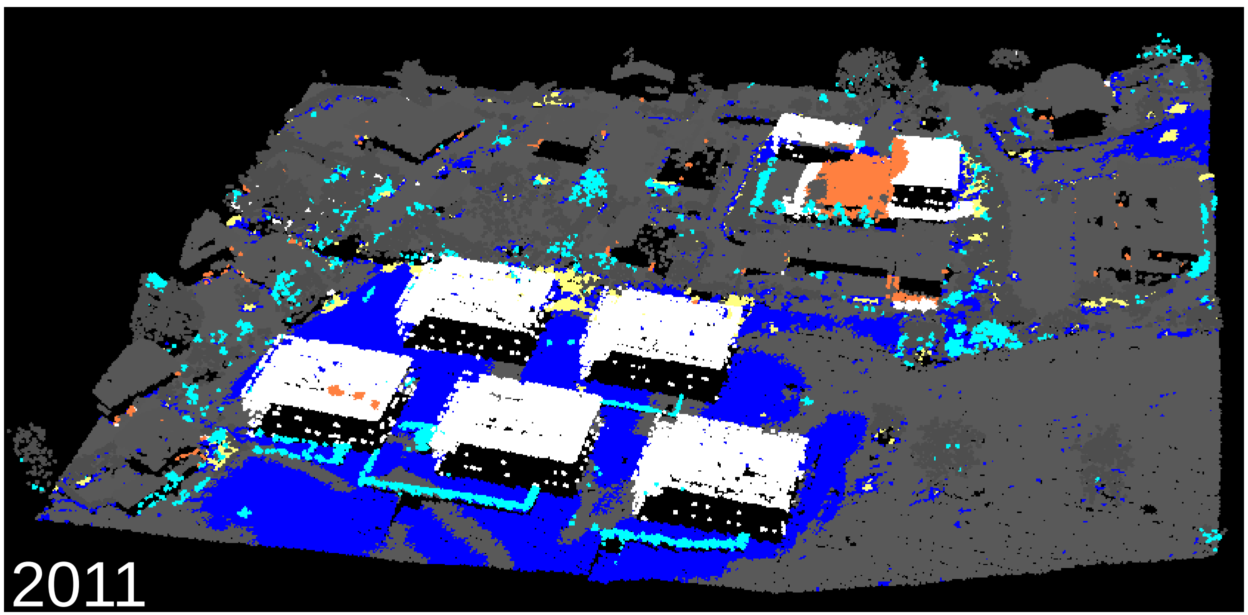
Change detection in point clouds

- A1: classify point clouds of different epochs + compare labels (proximity?)
- A2: compute geometric point cloud difference + classify changed points
- Problem 1
  change in class and change in geometry can be independent
- Problem 2
  different data properties
- Problem 3
  3D changes


PC CD envisaged result





- Cut tree
- New tree
- Ground to another landuse
- Ground change in height >0.5m
- Reconstructed building
- New buildings
- Unchange

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PC CD Method

- Exploit the power of machine learning
- Features for class and features for change

1. measurement process: echo ID, waveform attribute, etc.
2. local neighborhood: normal vector, roughness, etc.
3. approximate height (simple terrain model)
4. change indicators
   - distance to nearest point in PC of other epoch
   - point distribution feature
     evaluated at location of epoch 1 points
     with points of epoch 2

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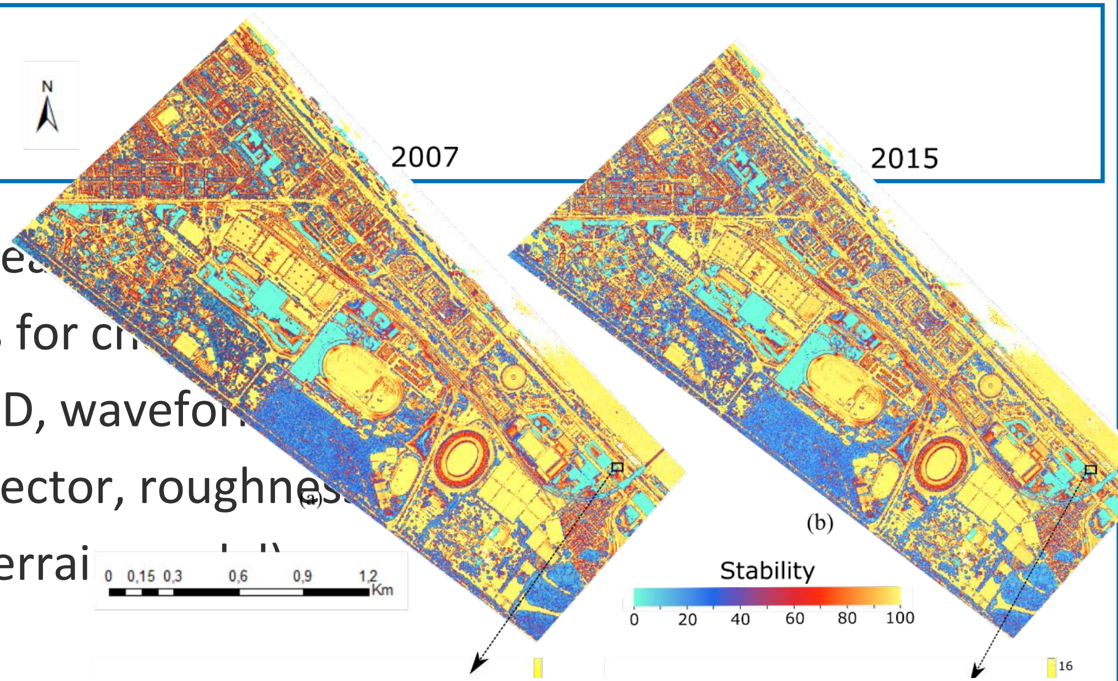
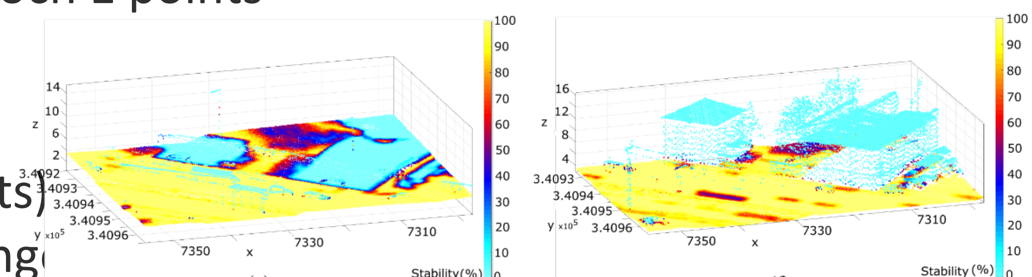


- Sample training data,

  learn model (e.g. random forests)

  apply model to detect all chang

  done (?)



(e) (f)

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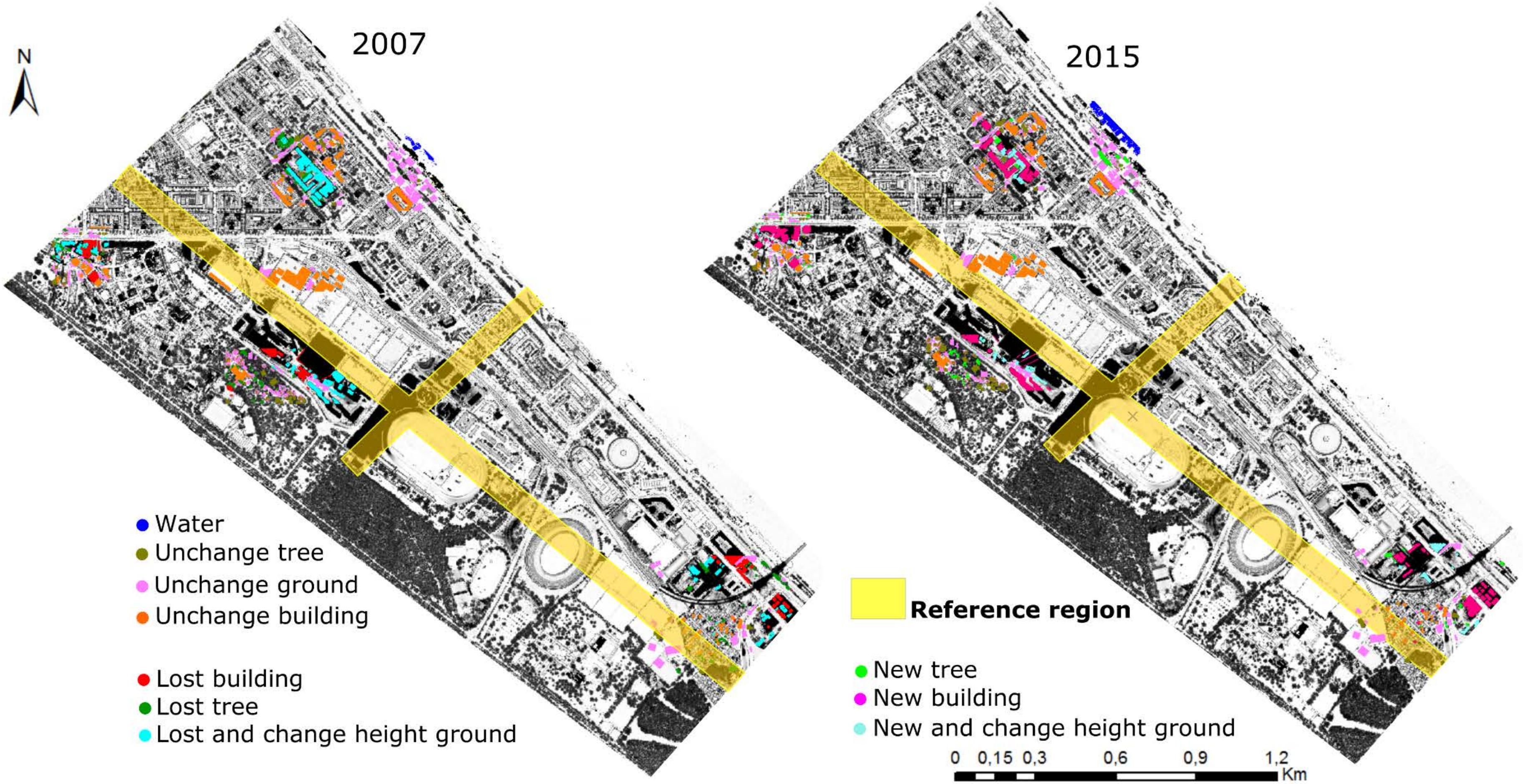
PC CD ML



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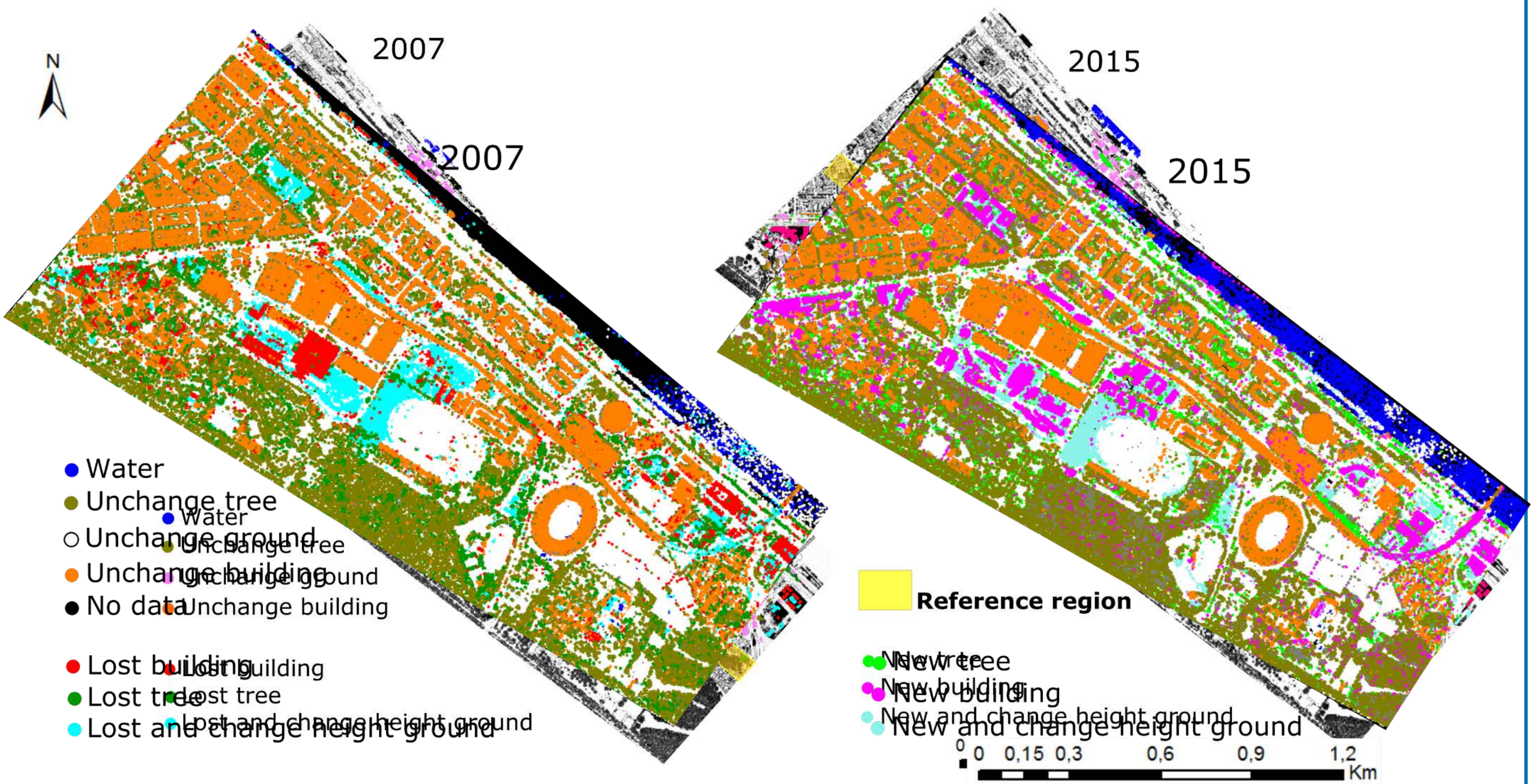
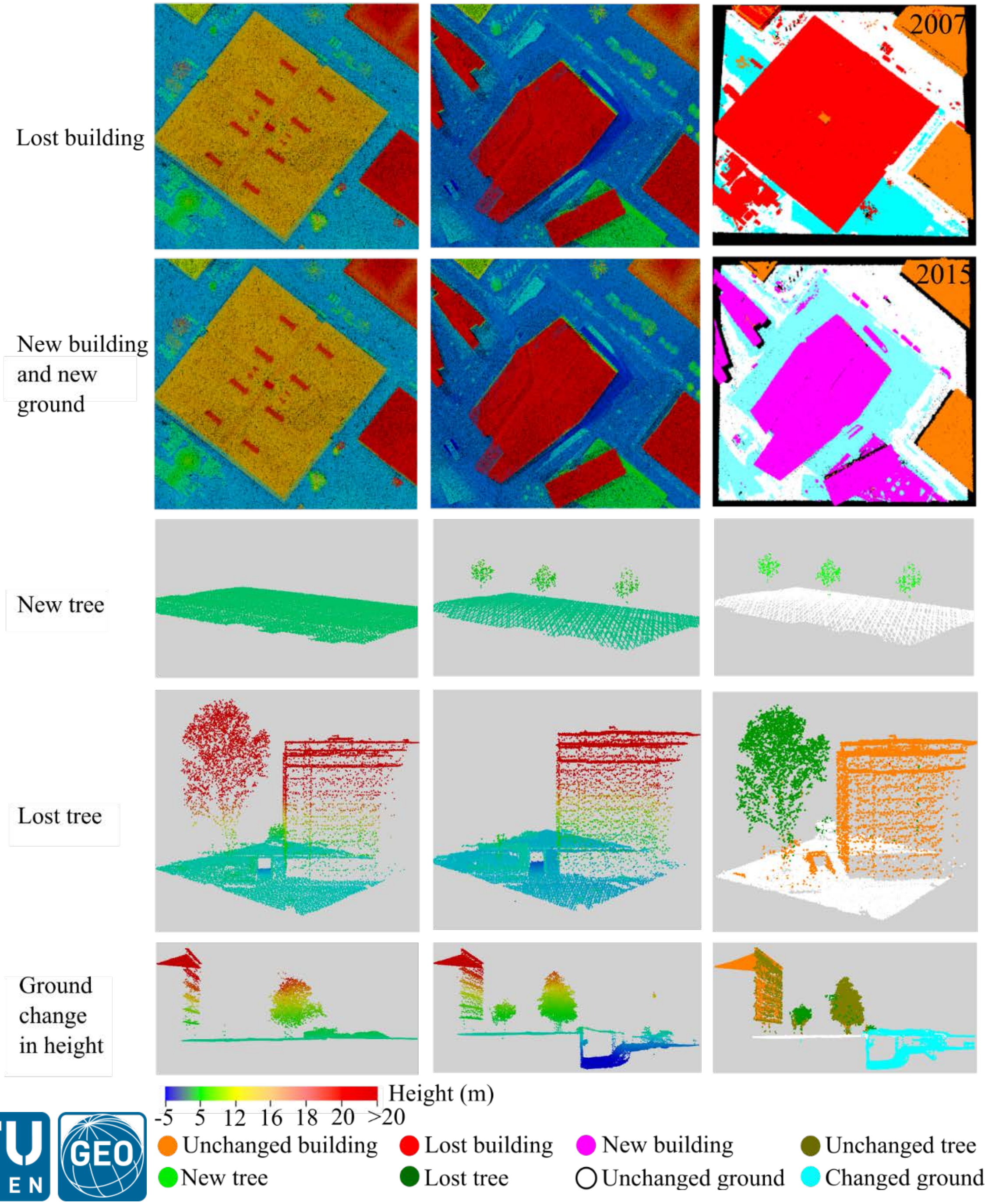
PC CD ML


N
2007
2015
Water
Unchange tree
Unchange ground
Unchange building
No data
Lost building
Lost tree
Lost and change height ground
Reference region
New tree
New building
New and change height ground
0 0,15 0,3 0,6 0,9 1,2
Km



2015	**UG**	**CG**	**UB**	**NB**	**UT**	**NT**
Ref_UG	48.3	0.5	0.1	0	0	0
Ref_CG	0.9	10	0.1	0.1	0	0
Ref_UB	0	0	16.5	0.2	0.9	0
Ref_NB	0	0.2	0.1	4.6	0.1	0
Ref_UT	0	0	0.3	0.2	11.1	1.1
Ref_NT	0	0	0.1	0.1	1.1	1.6
Sum	49.2	10.8	17.1	5.3	13.2	2.7
EOC	1.8	6.9	3.6	12.4	15.9	42
Corr	98.2	93.1	96.4	87.6	84.1	58.0
Overall Accuracy: 92.05						
Total number of points: 8,636,900						

Tran et al.

Conclusions

Many open point cloud research questions

References

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