Potentials of the TanDEM-X mission in the generation of urban DEMs

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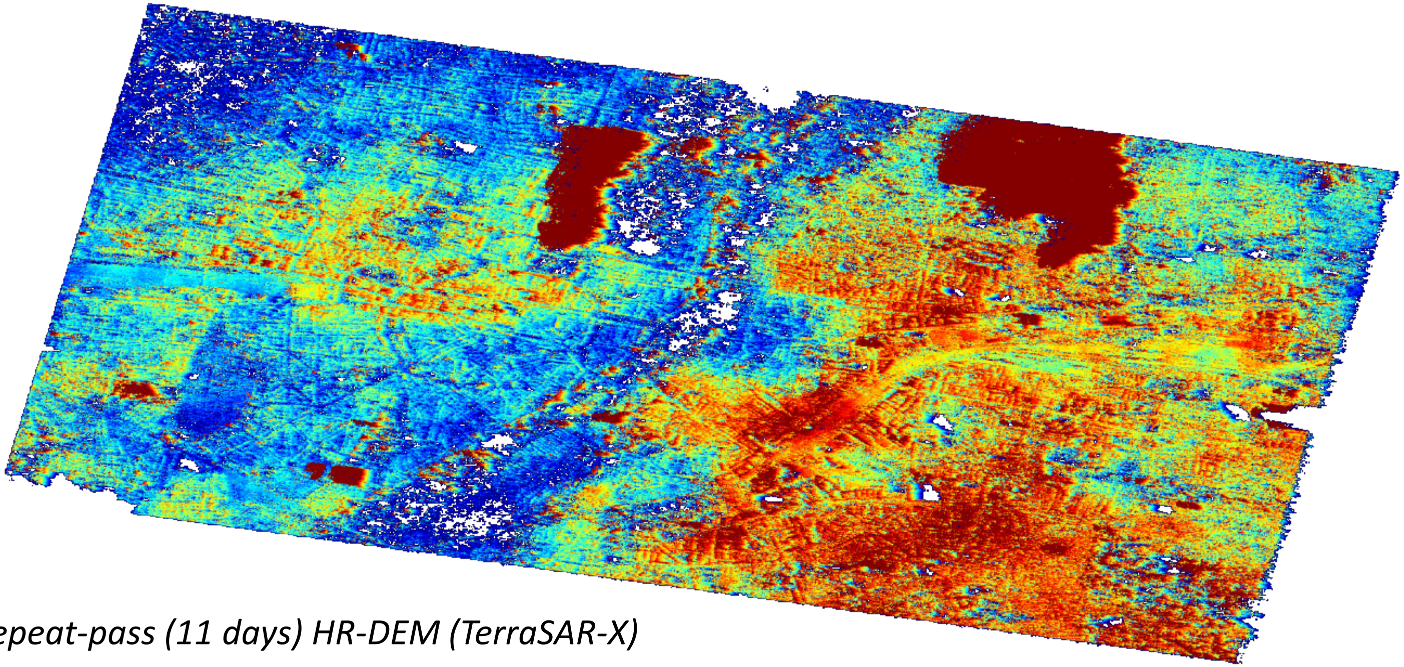
Motivations

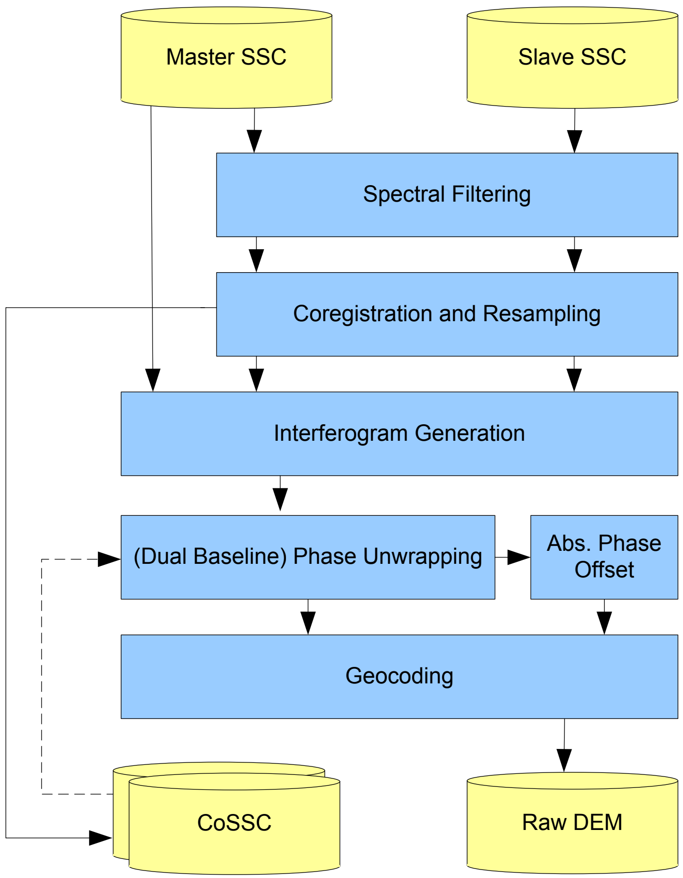
- TanDEM-X mission offers two important pre-requisites for the exploitation of SAR in the generation of urban DEMs
  1) High-resolution
  2) Absence of temporal decorrelations (*single-pass interferometry*)



repeat-pass (11 days) HR-DEM (TerraSAR-X)

- TanDEM-X is a global mission: **all the cities all over the world are mapped** → how?

TanDEM-X Interferometric Processing (ITP)



- The operational spatial resolution (12x12 m) is not sufficient for a (dense) urban mapping
- DEMs with 3 meters resolution are experimentally generated with TanDEM-X HRS data
  → suitable for urban mapping
- **Deviations** from the operational ITP algorithms may be useful for the generation of urban DEMs:

  - spectral shift filtering configuration (OFF)
  - coregistration configuration (window size/subs.)
  - interferogram generation (Nlooks / adaptive)
  - phase unwrapping (cost function, ON/OFF)
  - geocoding (layover management)

Interferogram Generation

- *Complex multilooking:* a number of *L* neighboring pixels are averaged to yield an estimate of the interferometric phase and coherence. In ITP a moving average window is set to the purpose.

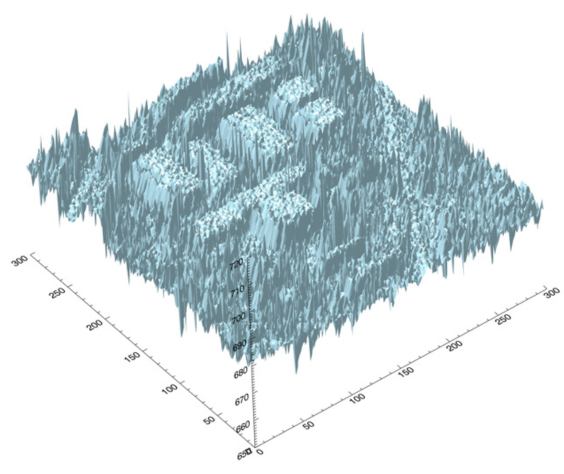
- The theoretical interferogram resolution depends on the number of looks *L* used in the processing:

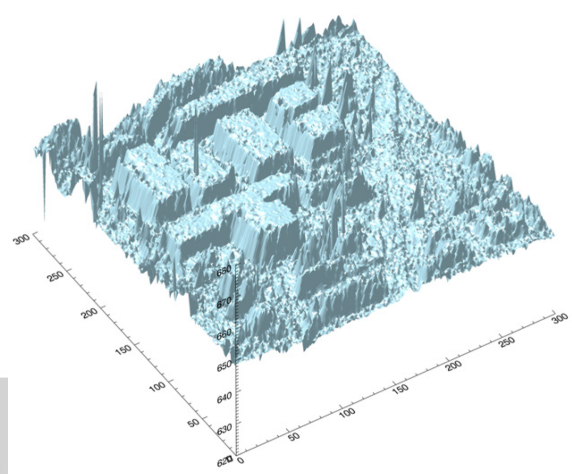
$$r_{az} = \frac{PBW}{PRF}\Delta g_{az} L_{az}$$
➢ *ground azimuth resolution*

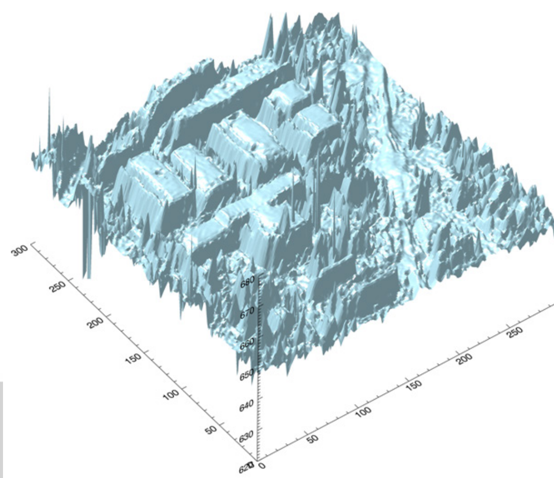
$$r_{rg} = \frac{RBW}{RSF}\Delta g_{rg} L_{rg}$$
➢ *ground range resolution*

- Adaptive techniques mix *"radiometrically close"* pixels instead of all the pixels inside a window to increase the final precision ➔ more accurate phase unwrapping ➔ better DEM, better performances, better application results (i.e. edge detection)

1. "*General Adaptive-Neighborhood Technique for Improving SAR Interferometric Coherence Estimation*", Vasile et al, 2004.
2. "*NL-InSAR, Non Local Interferogram Estimation*", Deladalle et al. 2011.



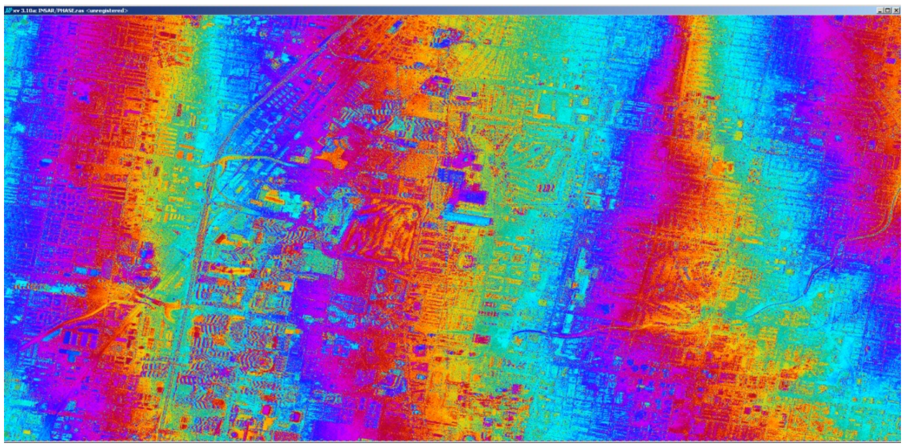


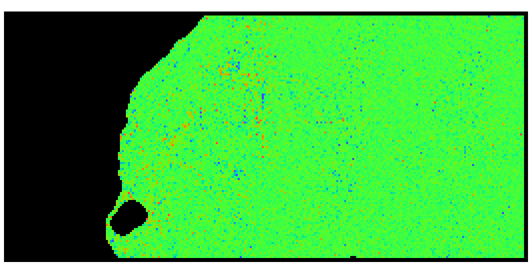


Phase Unwrapping Error Detection

- *Radargrammetric Control Map*: ITP tool for PU errors detection *

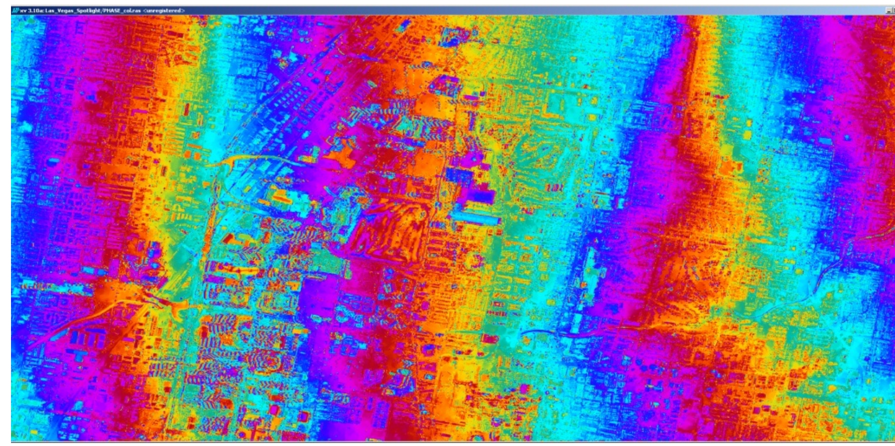
Non-Adaptively Filtered

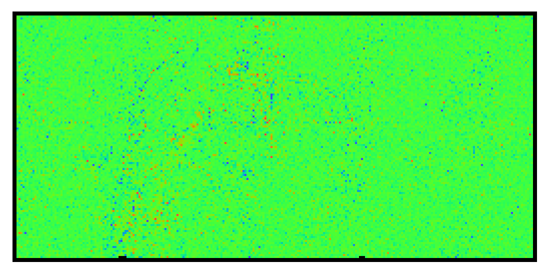




q_{ratio} = 76%

Adaptively Filtered





q_{ratio} = 99.9%

→ adaptive filter recommended

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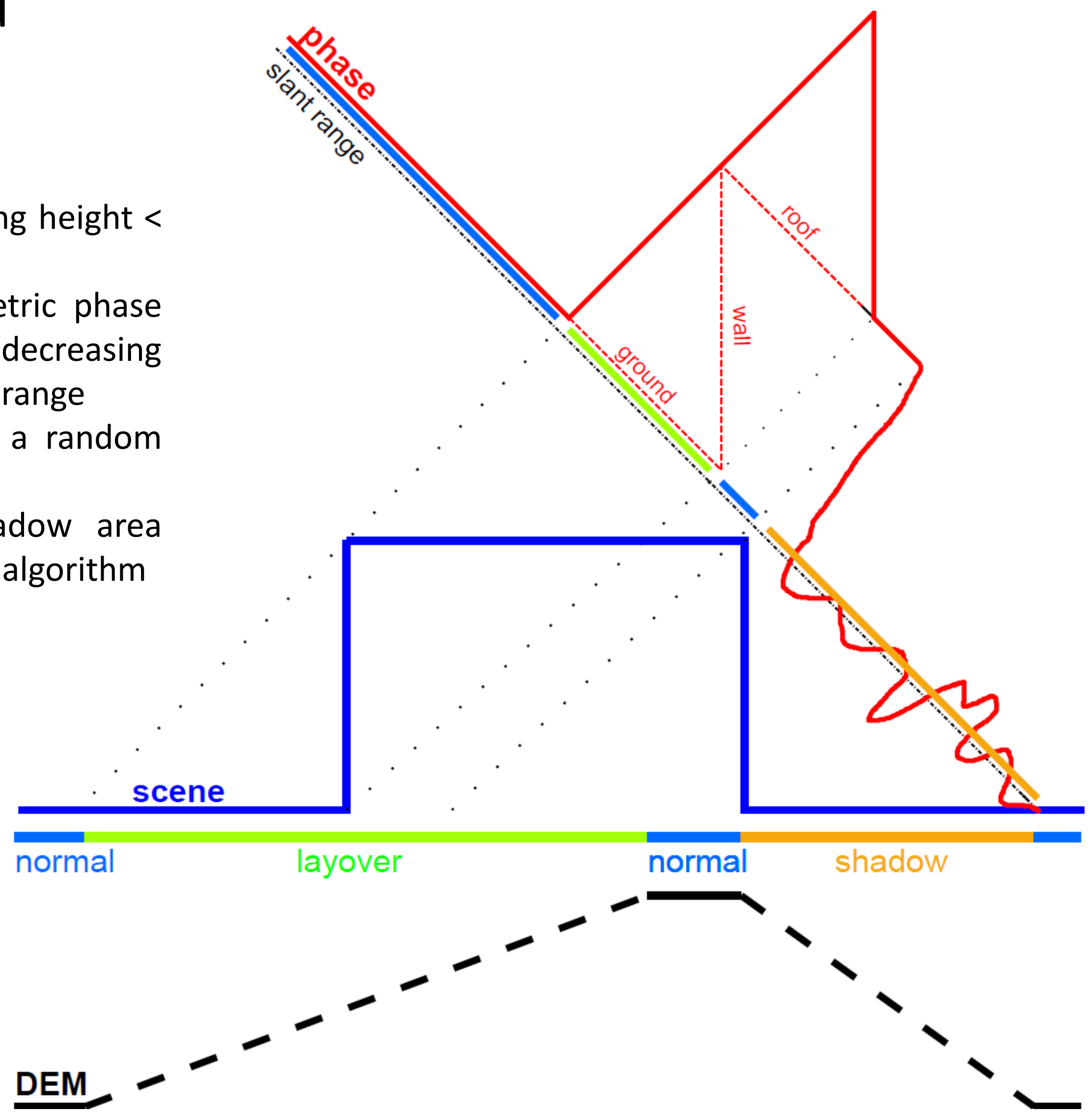
* *TanDEM-X Calibrated Raw DEM Generation*, Rossi et al, ISPRS J, 2012

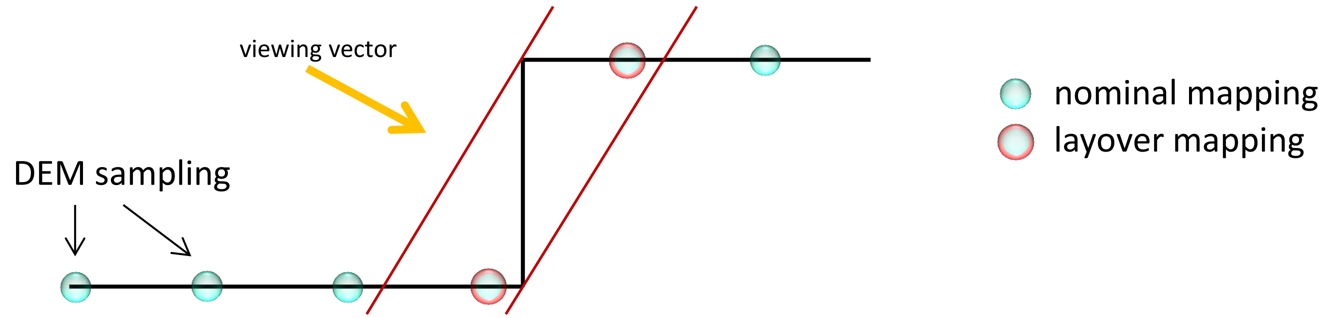
Theoretical Phase Trend

- Correct unwrapping assumed (building height < HoA/2)
- In the layover area the interferometric phase has a downtrend profile due to the decreasing height of the wall for increasing slant range
- In the shadow area the phase has a random profile
- The DEM in the layover and shadow area depends on the employed geocoding algorithm

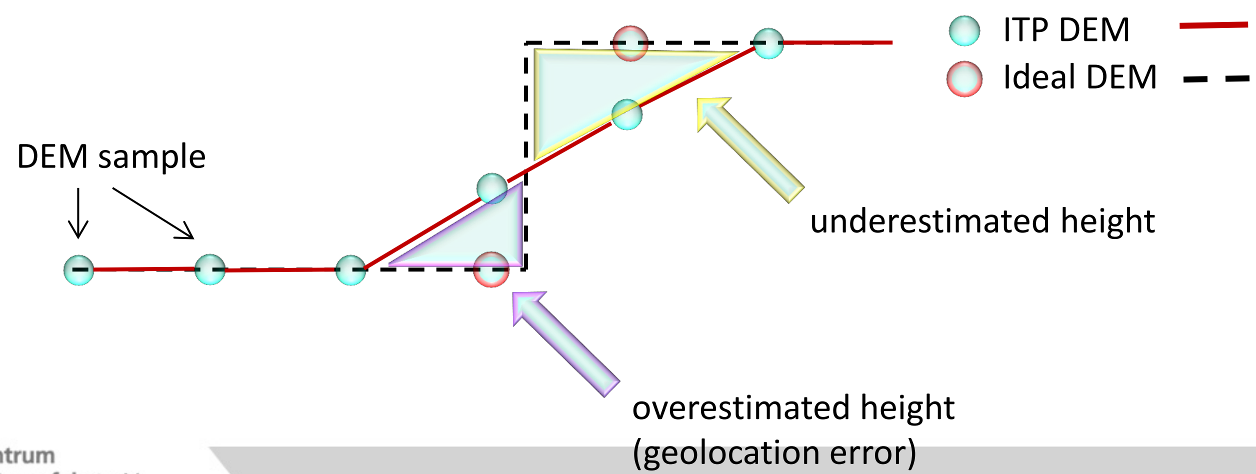


SAR Geocoding on Buildings

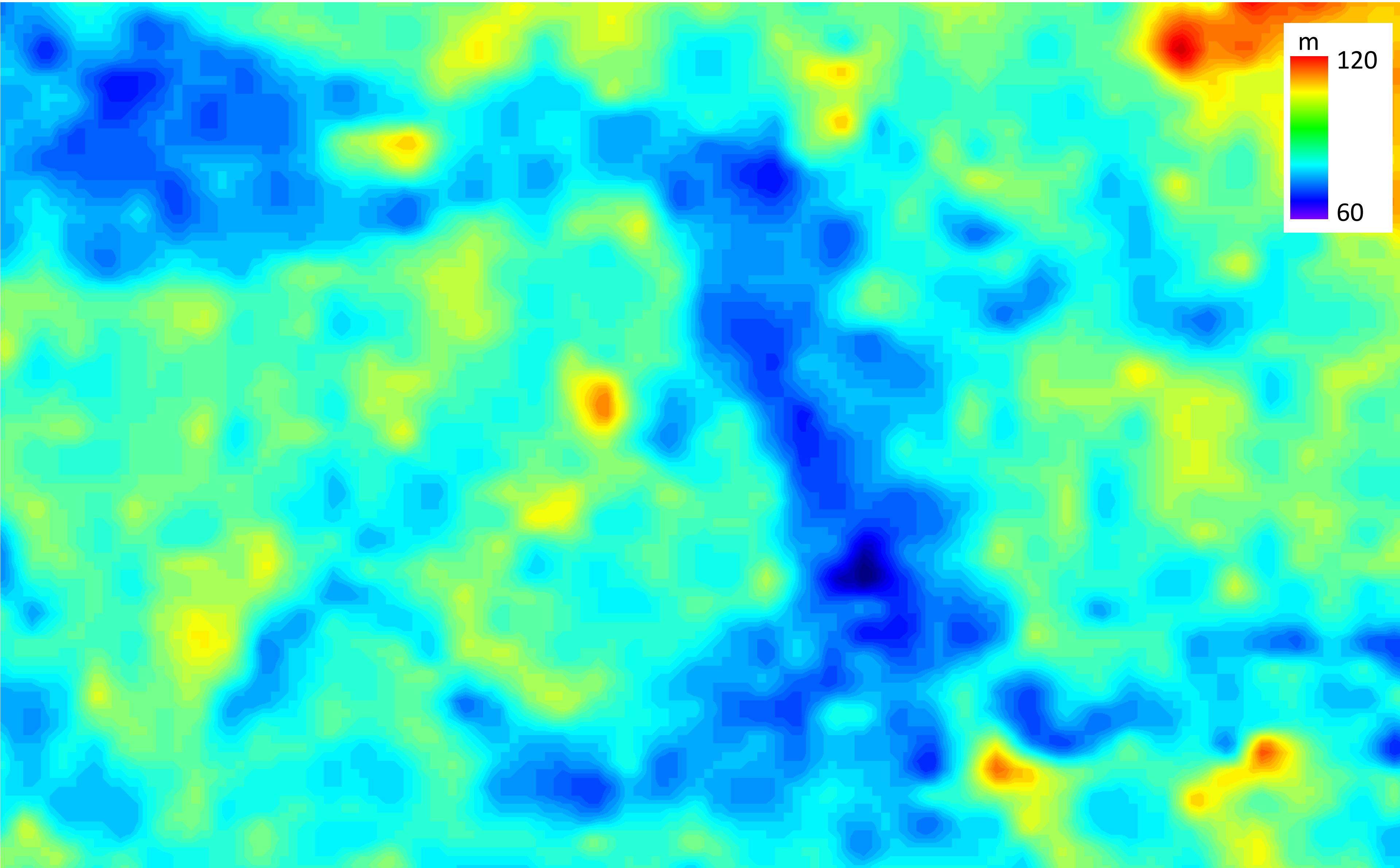
- Due to the SAR side-looking geometry, layover cannot be directly solved in single-pass DEMs (=TanDEM-X)



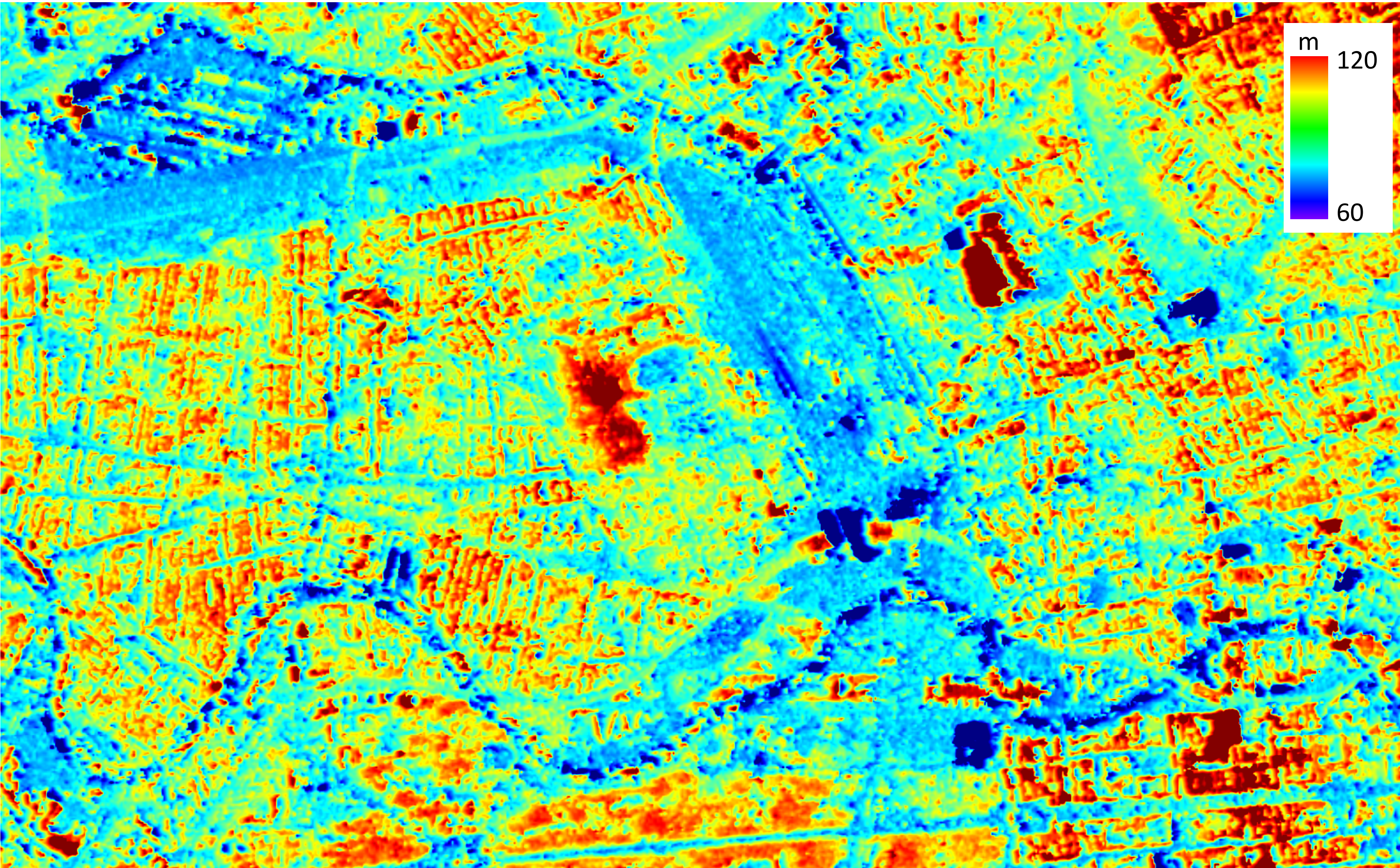
- The geocoding algorithm “connects” the first and last unlayovered samples creating a geolocation error and a building height underestimation



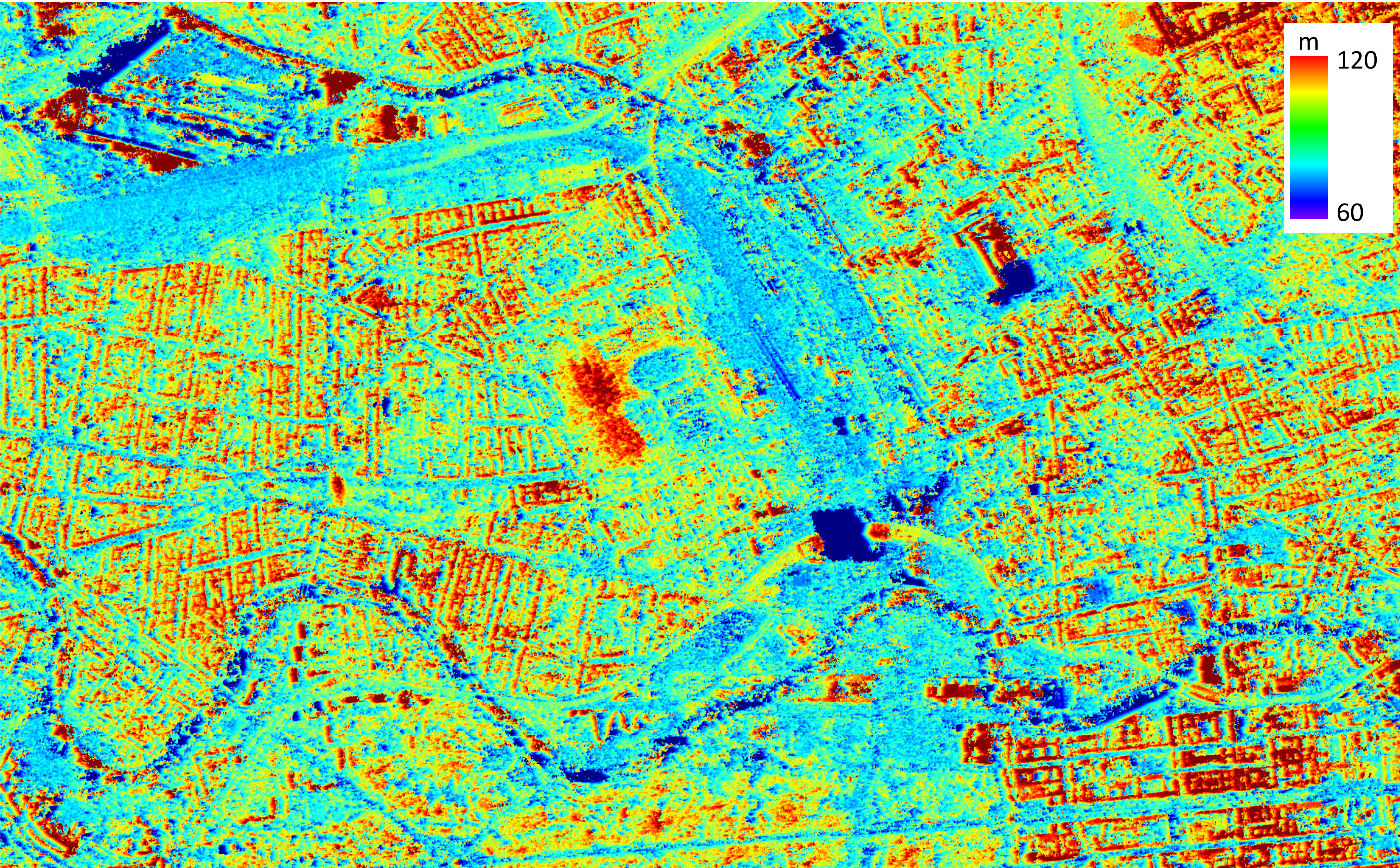
SRTM (2.5 m posting – interpolated)



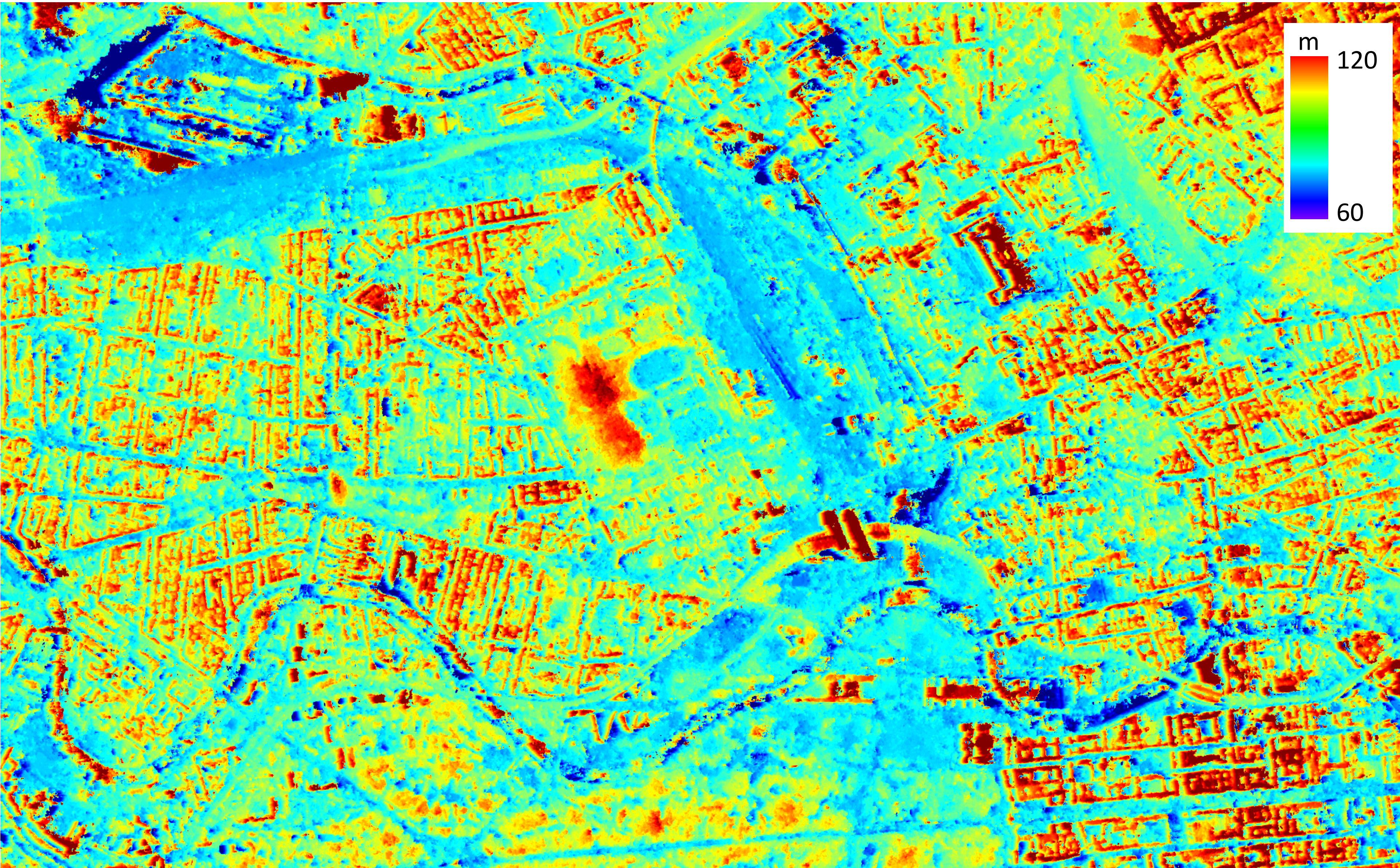
TanDEM-X Operational Stripmap (2.5 m posting – interpolated)



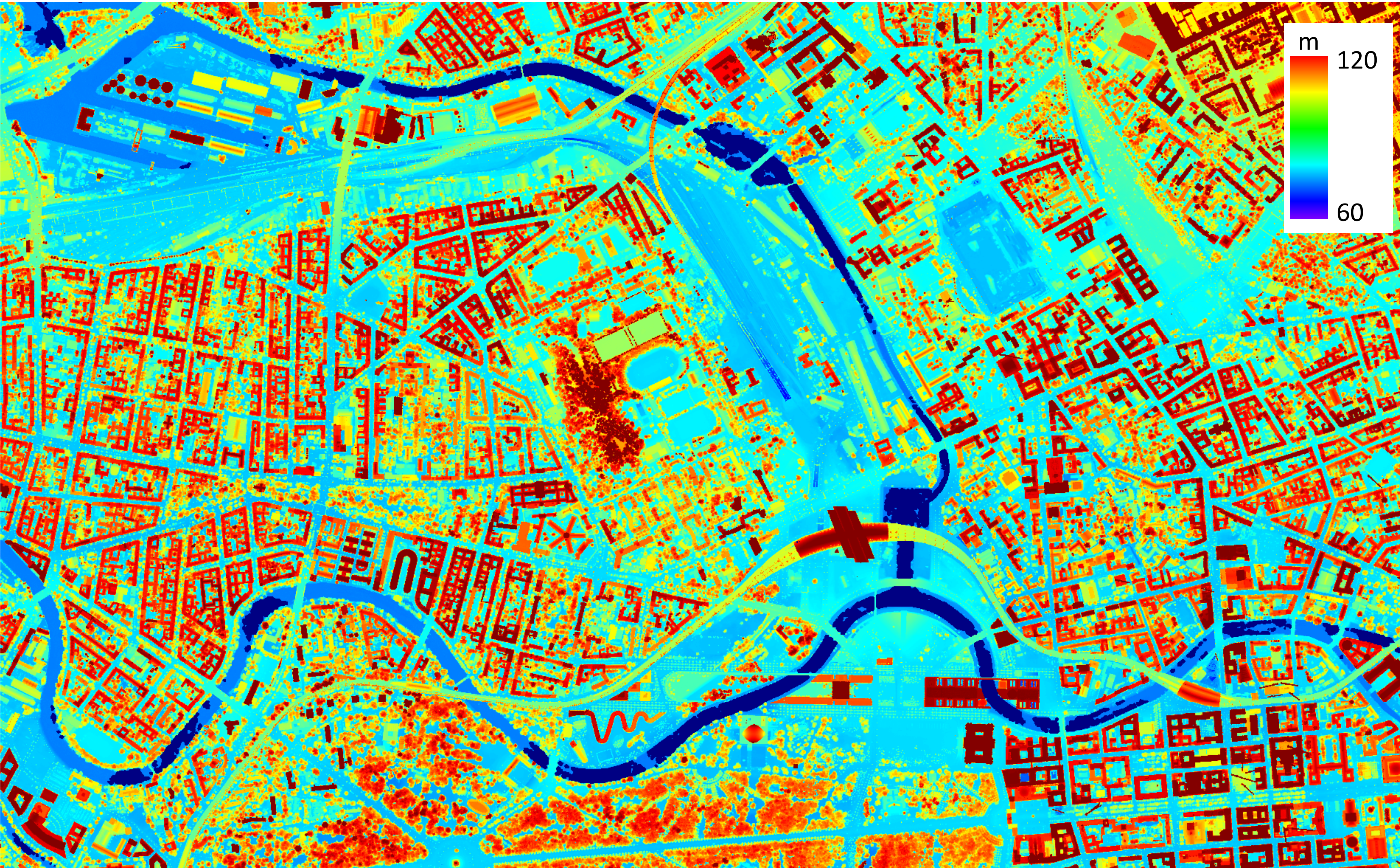
TanDEM-X Operational Spotlight (2.5 m posting)



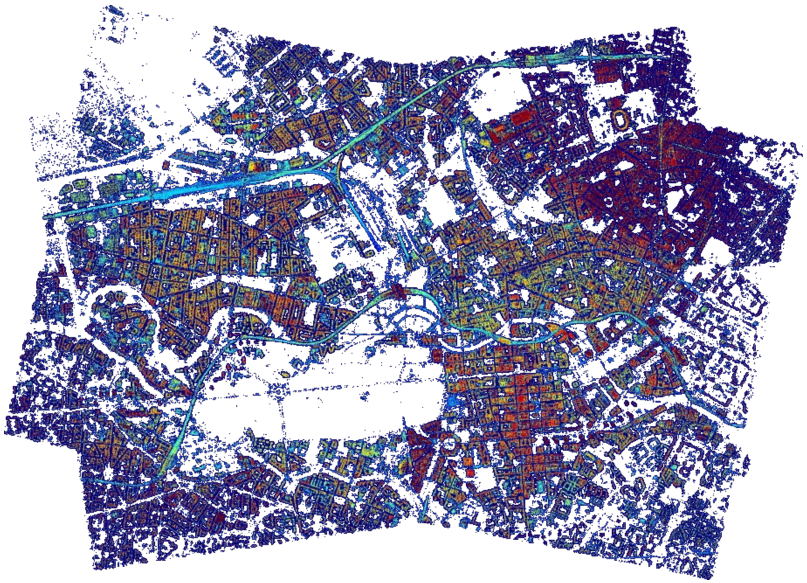
TanDEM-X Experimental Spotlight (2.5 m posting)



LiDAR (2.5 m posting – interpolated)

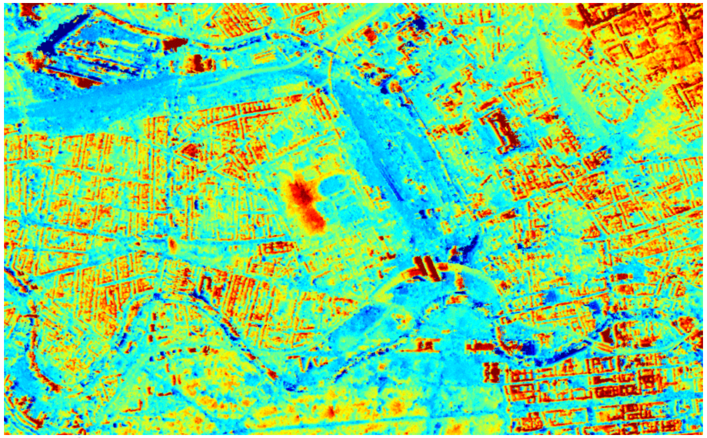


Fusion of PSI and TanDEM-X : inputs



PSI-DEM

- 2.5m raster
- derived from 4 stacks (2 asc+2desc) ~ 120 images
- valid heights represent (mainly) the structures
- non valid heights represent the rest
- geocoded PS point cloud (*) rasterized at 2.5m with a façade detection (PCA) (maximum value), gaps filling (median), and ground removal

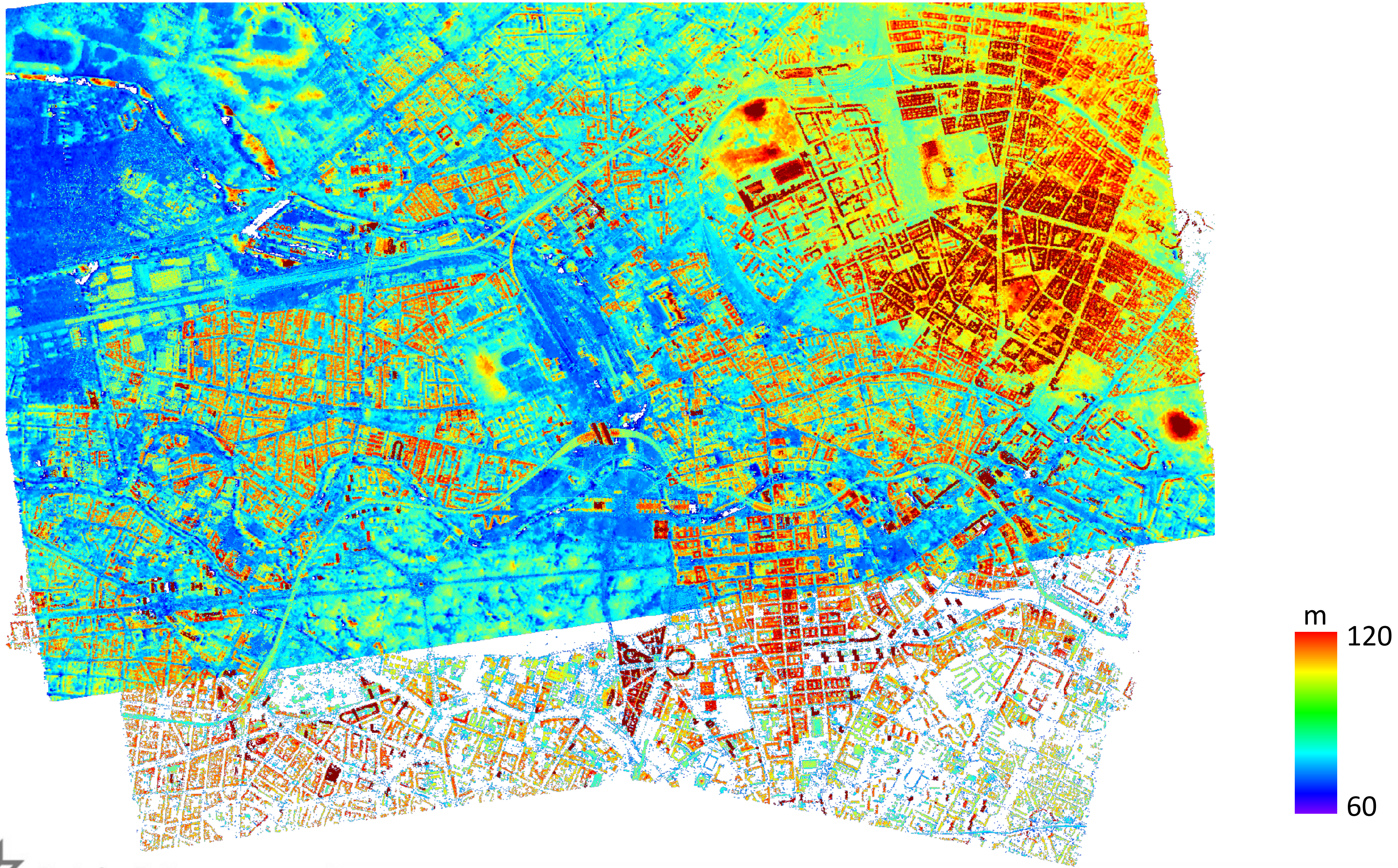


TanDEM-X DEM

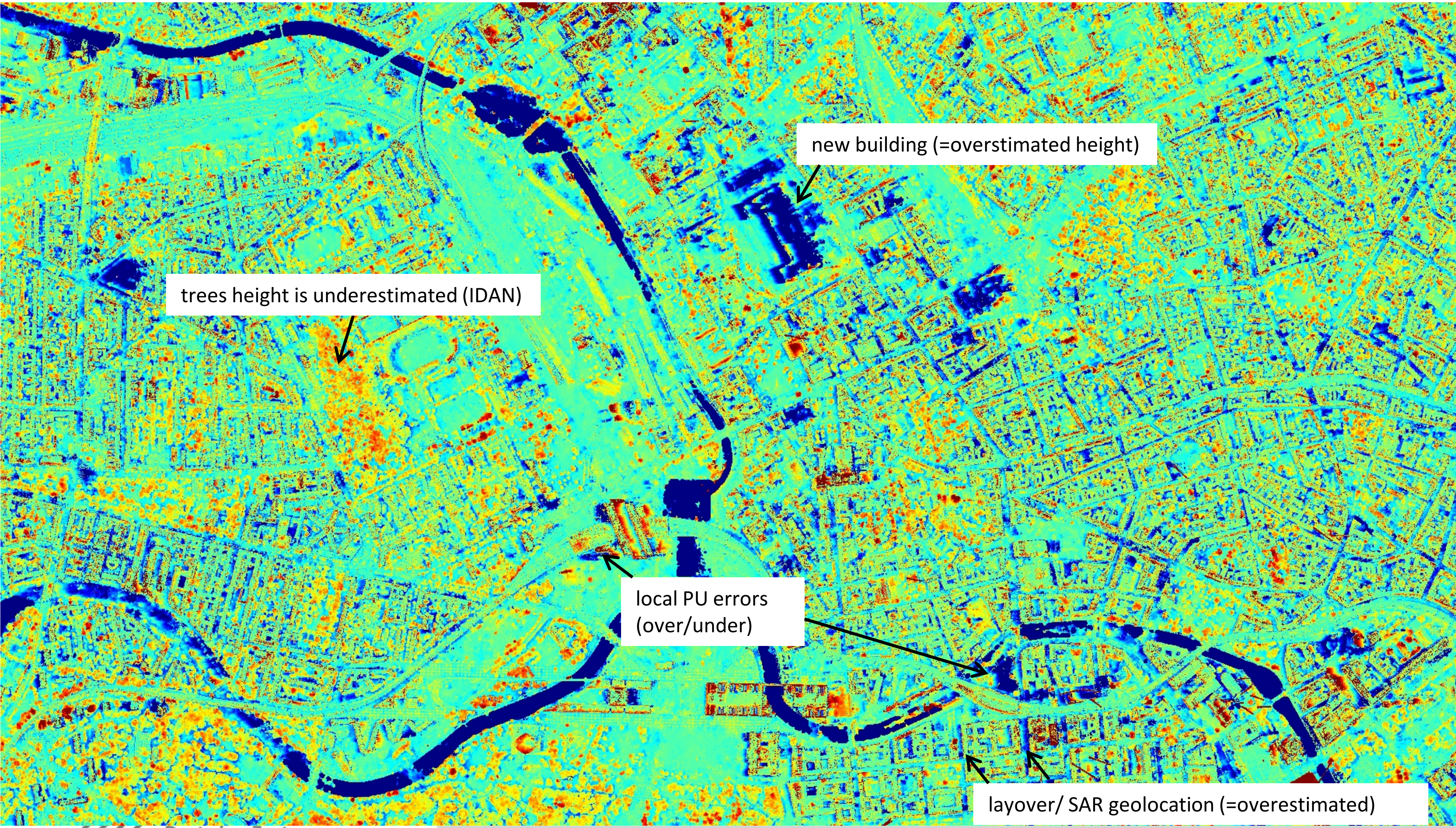
- 2.5m raster
- derived from one single pass HRS acquisition (04.01.2012)
- HoA: 65.4 meters
- adaptively filtered to a 2.5 m resolution with the IDAN filter
- no invalid point in the DEM

* *Deformation Monitoring of Single Buildings Using Meter-Resolution SAR in PSI*, Gernhardt-Bamler , ISPRS J, 2012

TanDEM-X DEM fused with PSI DEM



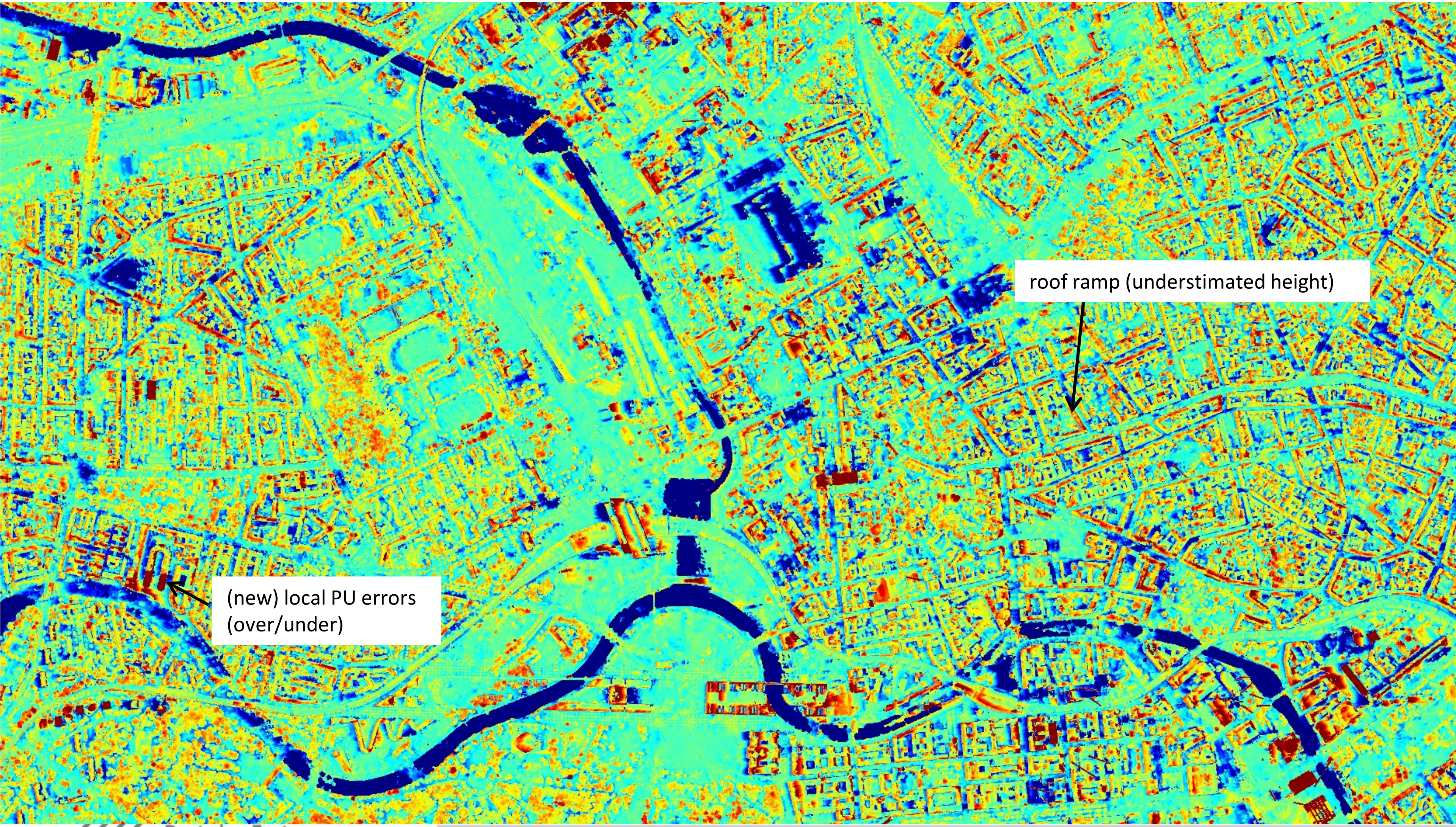
Difference Analysis – (LiDAR – Fused DEM)



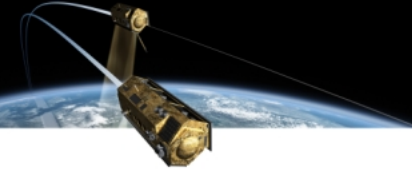
general good matching for structures and roads

-20 m 20

Difference Analysis – (LiDAR – TanDEM-X)

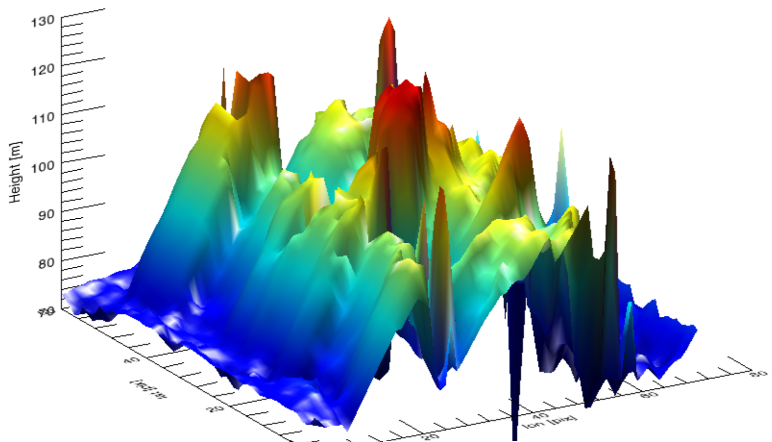


evident building underestimation (ramp effect)

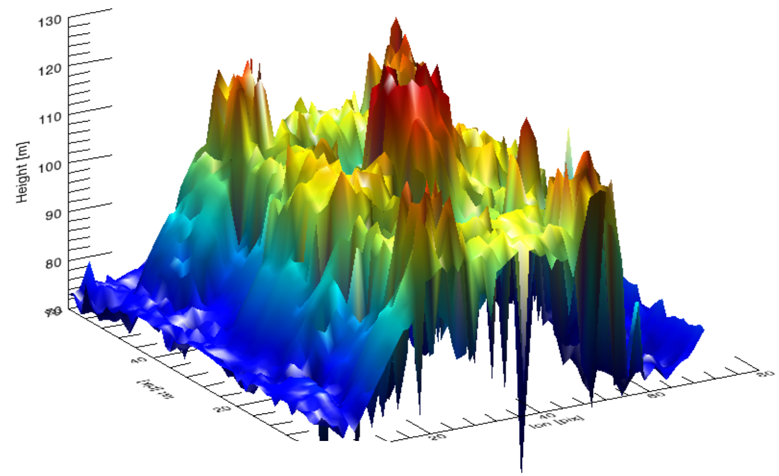


Visual comparison: Bundestag in the Reichstagsgebäude

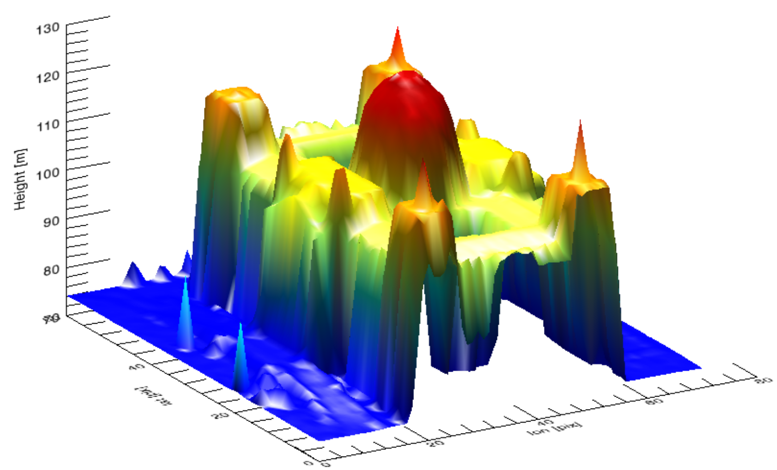
Bundestag - TanDEM-X

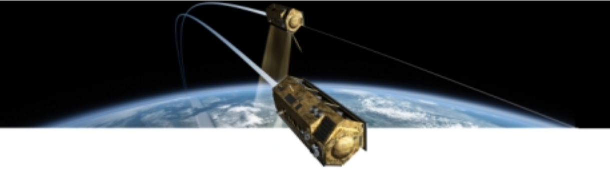


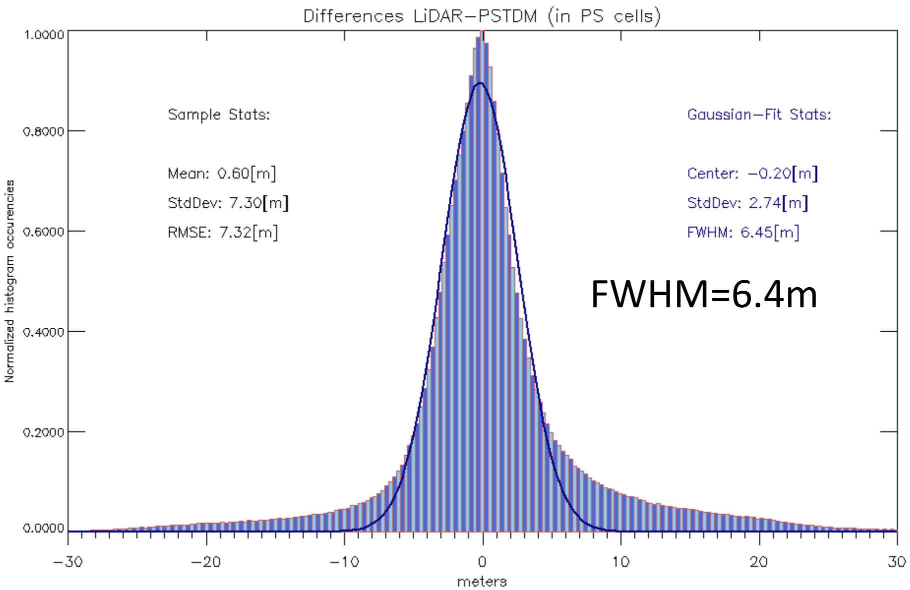
Bundestag - Fused DEM

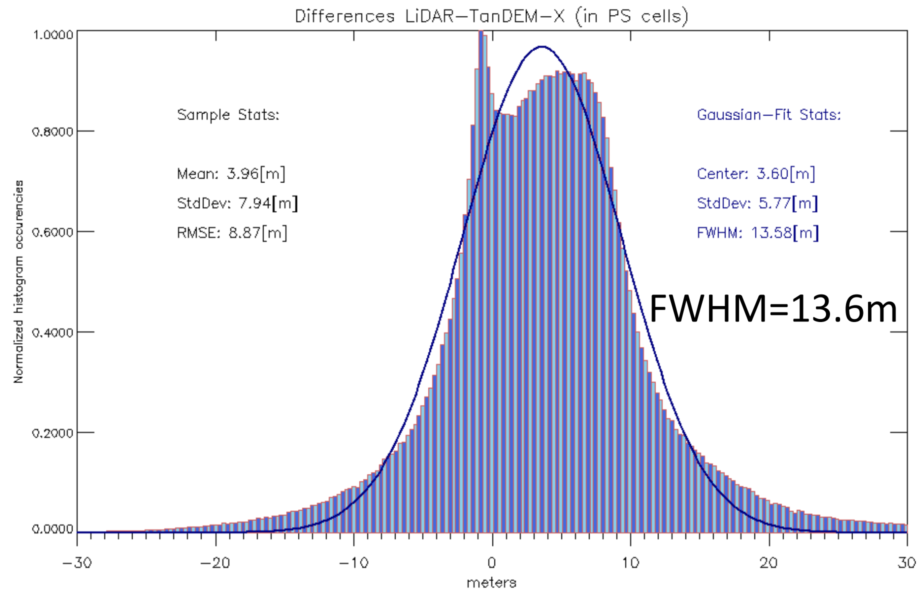


Bundestag - LiDAR

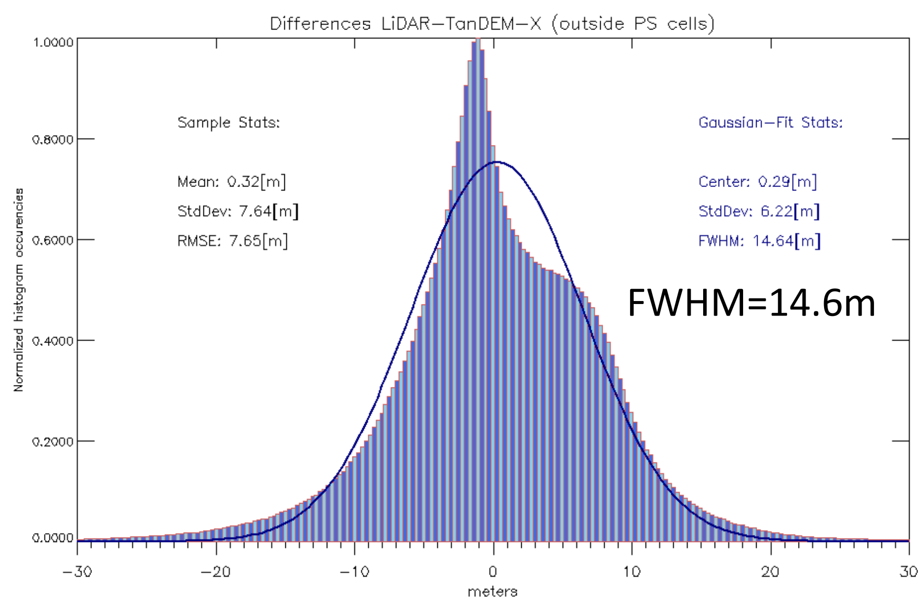


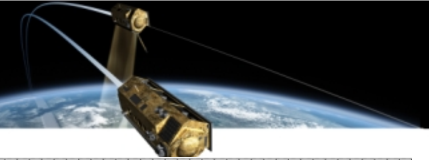




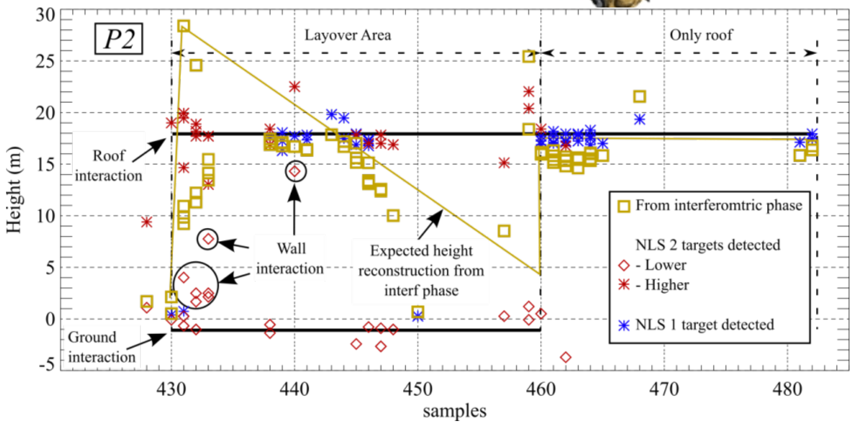


- The improvements in the PS cells are quantitatively demonstrated with the differences with the reference
- The large peak in the differences outside the PS cells is due to “layover height” next to every building
- Generally, the RMSE is below 8 meters



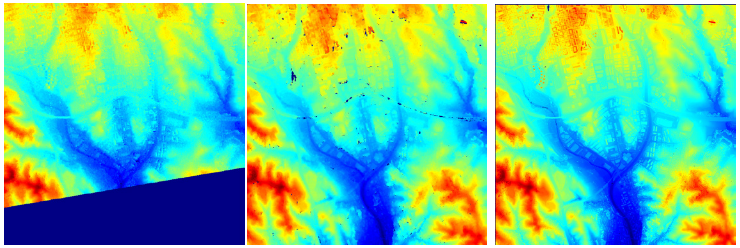


Ongoing research..

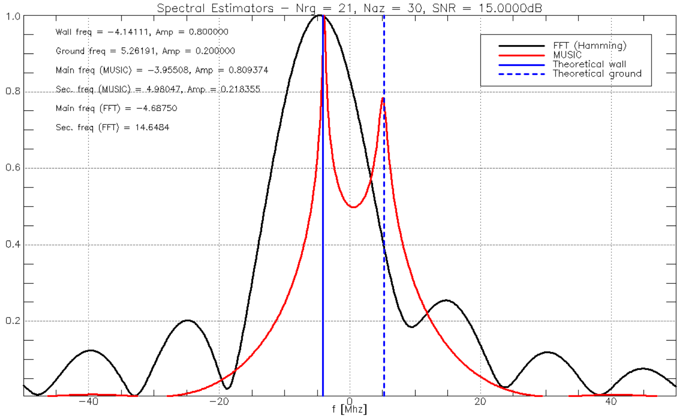


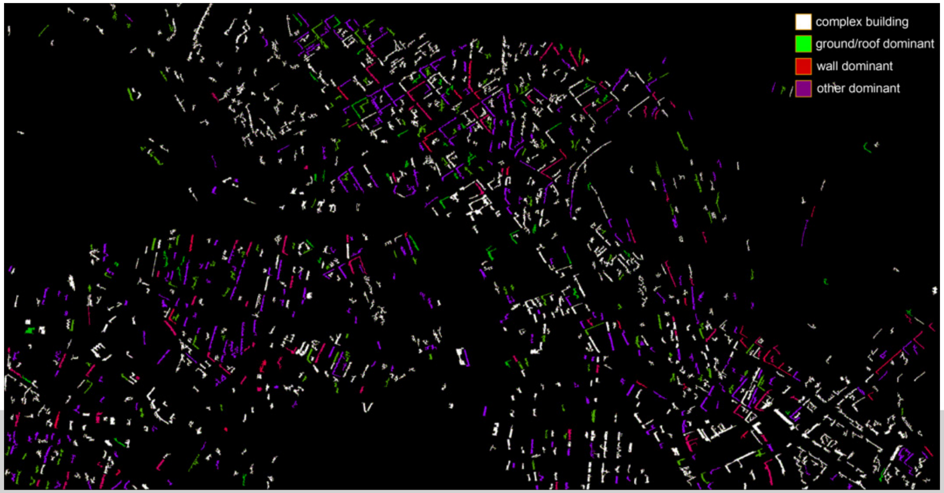
- Alternating Bistatic tomography

- Optical/radar DEM fusion



- In-processing layover detection and fringe frequency estimation





Conclusions

- TanDEM-X mission opens new perspectives in urban DEM generation from satellite's SAR interferometry

  1. no temporal decorrelation
  2. high resolution

- A global accuracy of about 8 meters was retrieved for both structures and non-structures in the DEM

- Layover creates trends in the DEM. A general roof's height underestimation is noticeable, especially in HR data. Note: cities with skylines (i.e. New York) can't be correctly mapped with single-pass data!

- PSI and experimental TanDEM-X data can be fused to obtain an accurate InSAR urban DEM

- InSAR processing tricks were suggested. For the correction of local phase unwrapping errors is of fundamental importance a fringe adaptive filter

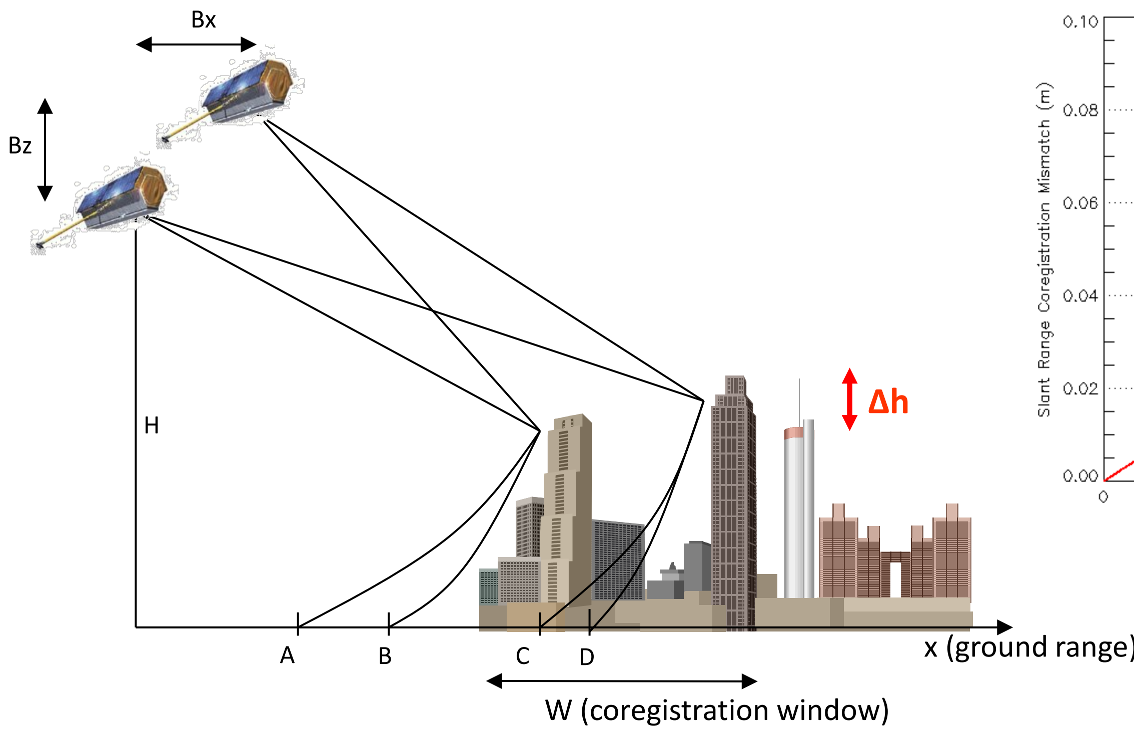
- Current work is dedicated to in-processing solutions of layover, fusion/comparison with more optical sensors and "cheap tomography"

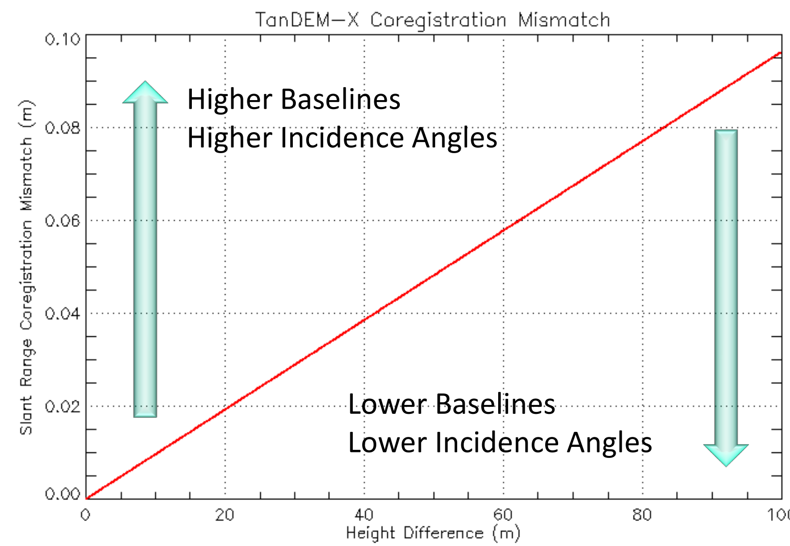
Thank you for your attention!

EXTRA MATERIAL

SAR Coregistration

- ITP coregistration strategy already well optimized
- Window size: 32x32 pix – Spacing 64x64 pix
- Urban Issue: coregistration mismatch due to different heights: **Δp = AB-CD**





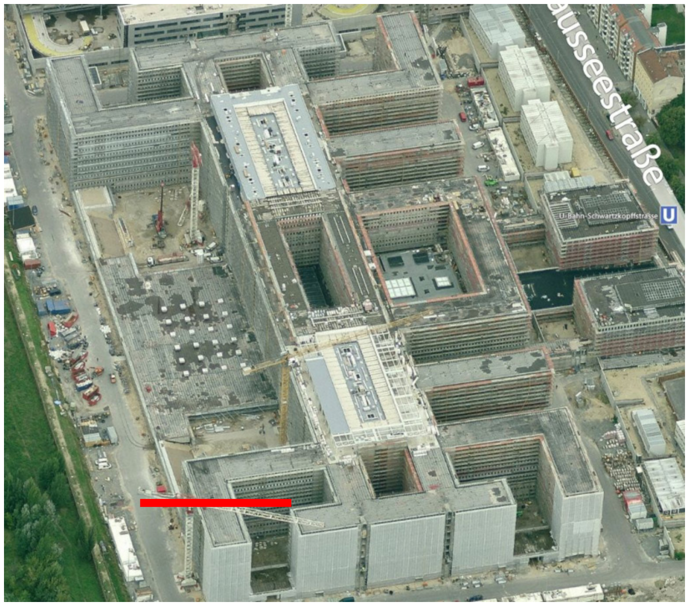
~ 1cm every 10 m of Δh

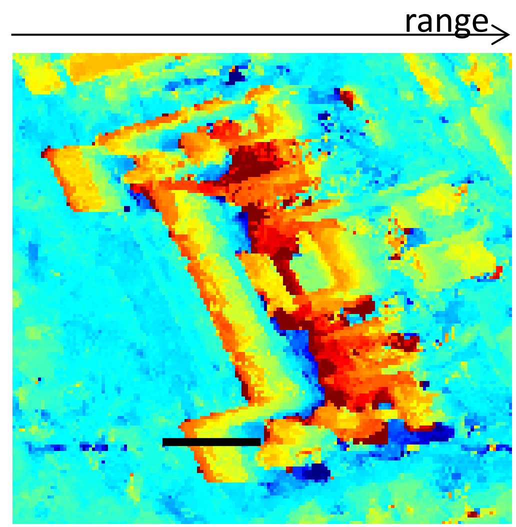
= 1/50 HRS resolution cell

✓ Small coherence loss

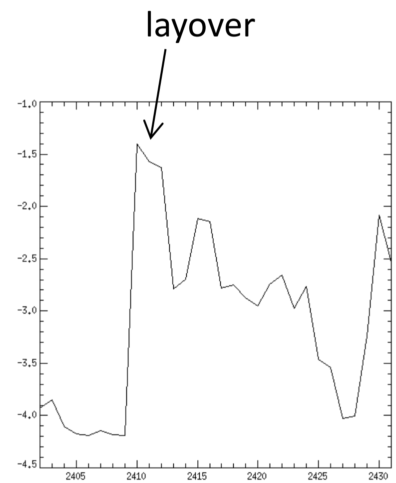
$$p = \sqrt{x^2 + (H-h)^2 - H^2} - \sqrt{(x-B_x)^2 + (H+B_z-h)^2 - (H+B_z)^2} - B_x$$

Real Example





Interferometric phase



➔ The layover peak is evident through all the front façade of the building

➔ How is the DEM in the layover areas?
= how does the geocoding algorithm behave?

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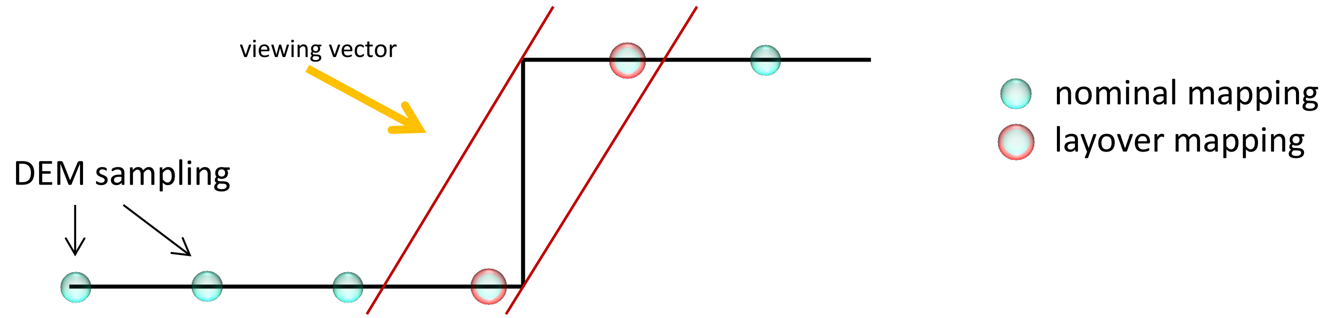
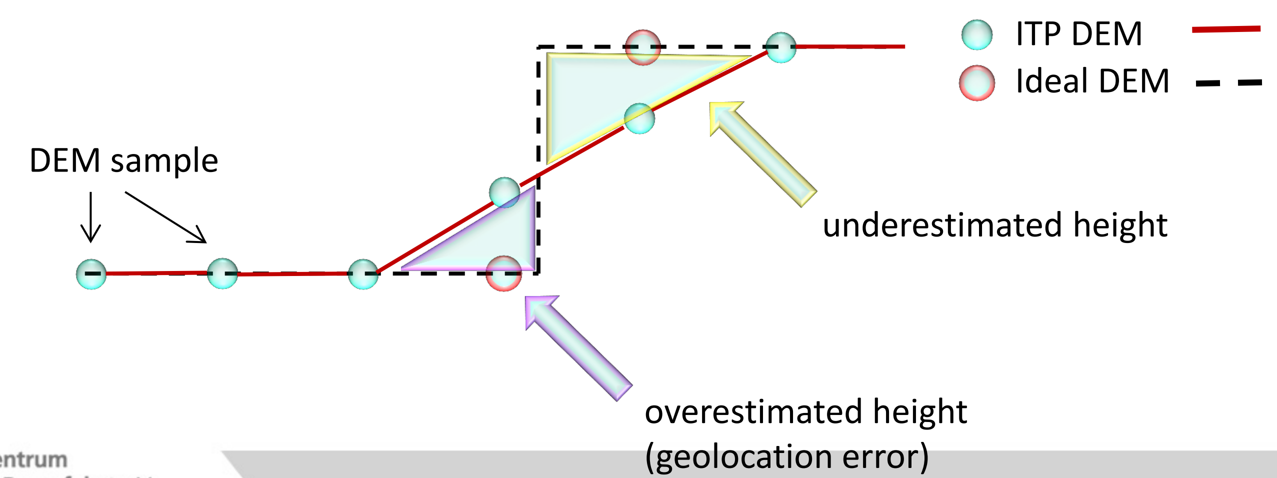
SAR Geocoding on Buildings

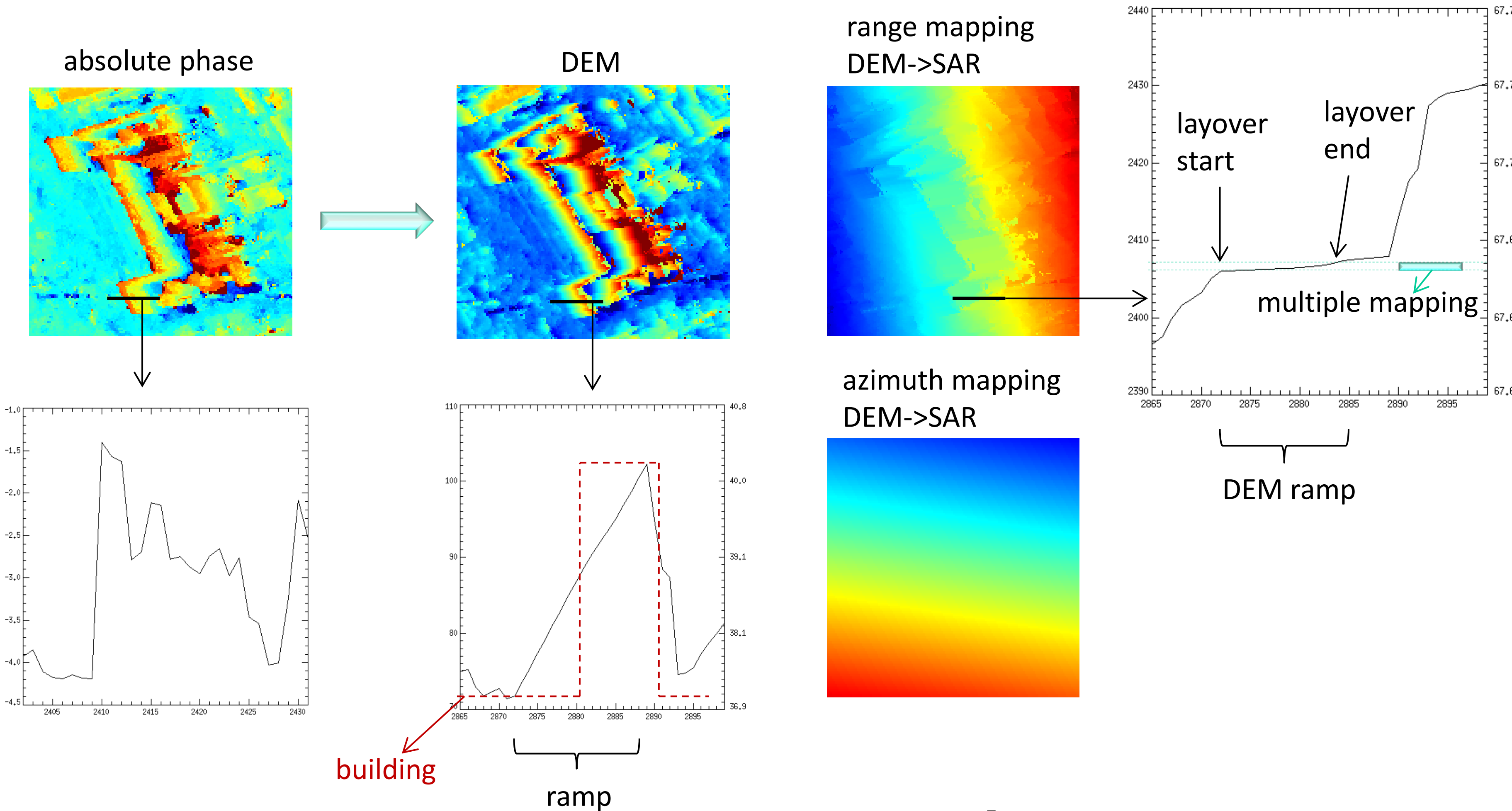
- Due to the SAR side-looking geometry, layover cannot be directly solved in single-pass DEMs (=TanDEM-X)



- The geocoding algorithm “connects” the first and last unlayovered samples creating a geolocation error and a building height underestimation

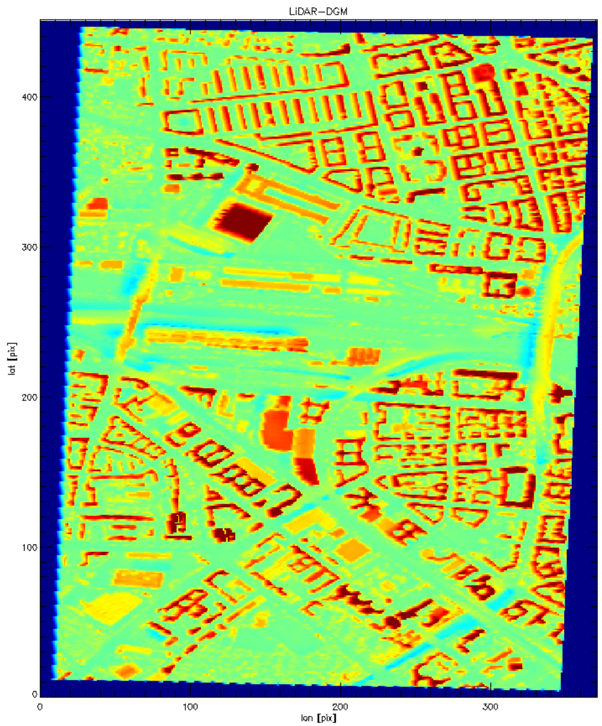


Real Example

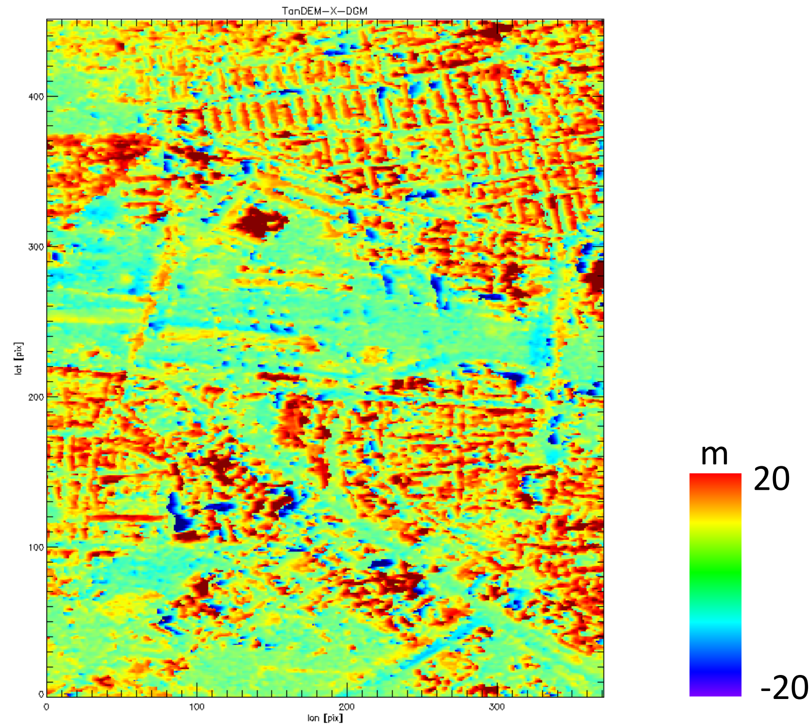


➔ is layover easily detectable? (see later)

Operational Urban DEM Analysis: Inputs and Strategy



LiDAR – 1m resolution

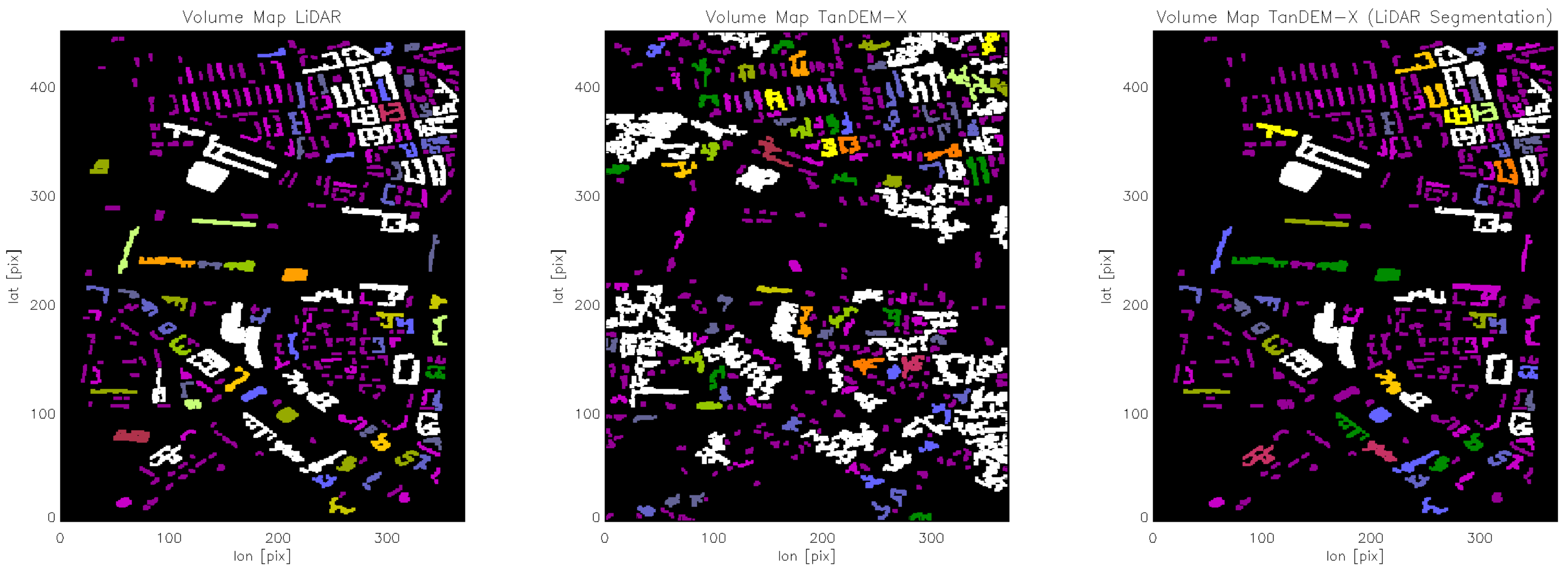


TanDEM-X – 12m resolution

- Comparison strategy: extract the buildings from LiDAR and commonly segment the TanDEM-X *
- Sub-product: volume map

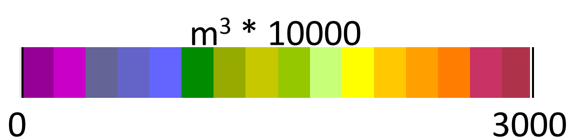
** algorithm details described in the ISPRS12 paper*

Operational Urban DEM Analysis: Volume Maps



#buildings: 403

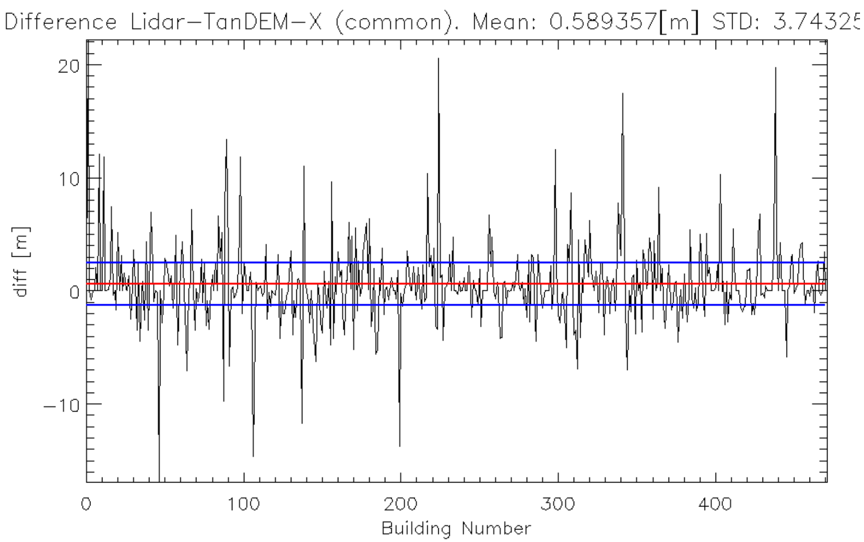
#buildings: 437



- +8% buildings detected in TDM → PU errors, noise
- TanDEM-X total volume is underestimated

Operational Urban DEM Analysis: Differences

	Difference Mean [m]	Difference STD [m]	RMSE [m]
LiDAR Segmentation	4.536	4.334	8.205
Common Segmentation	0.589	3.743	4.824



- "LiDAR segmentation" includes ground components due to building geolocalization errors
- "Common segmentation" provides an absolute difference below the meter
- As expected from the theoretical trends, TanDEM-X underestimates the building heights