VIENNA UNIVERSITY OF TECHNOLOGY
INSTITUTE OF PHOTOGRAMMETRY AND REMOTE SENSING

Comparison of ALS Strip Adjustment with and without Trajectory Data

Camillo Ressl, Norbert Pfeifer, Helmut Kager
{car,np,hk}@ipf.tuwien.ac.at

Institute of Photogrammetry and Remote Sensing (I.P.F.),
TU Vienna, www.ipf.tuwien.ac.at

Mathematical model for ALS (direct georeferencing)

$$\mathbf{X} = \mathbf{X}_{GNSS} + \mathbf{R}_{IMU} \cdot \left(\mathbf{m} - \mathbf{R}_{M} \cdot \begin{pmatrix} 0 \\ \rho \cdot \sin\theta \\ \rho \cdot \cos\theta \end{pmatrix} \right)$$

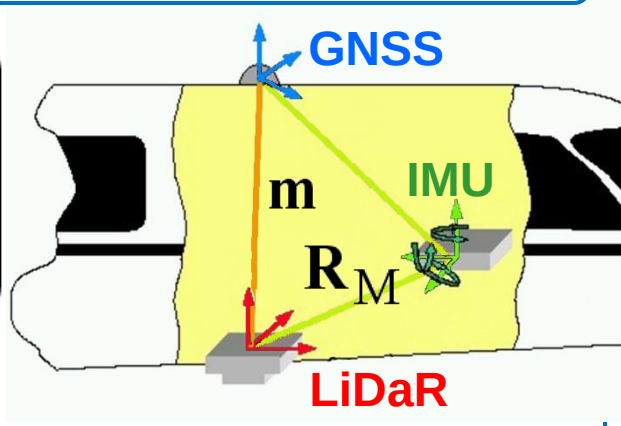


Fig. adapted from Cramer 2001

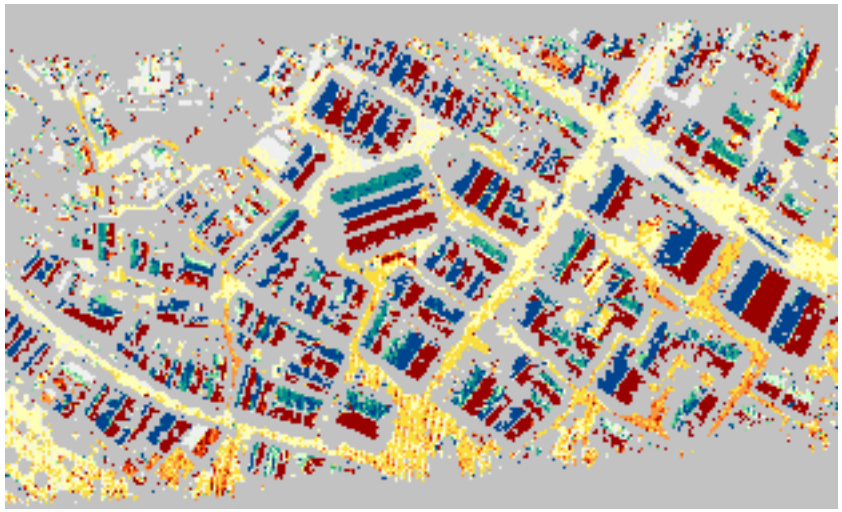
$\mathbf{X}$	Surface point (in the reference system)
$\mathbf{X}_{GNSS}$	GNSS antenna: phase centre
$\mathbf{R}_{IMU}$	Rotation from "sensor body frame" to reference system
ρ, θ	Range and deflection angle of the laser beam
$\mathbf{m}$	Mounting offset vector ('lever arm')
$\mathbf{R}_M$	Mounting rotation bias ('misalignment')

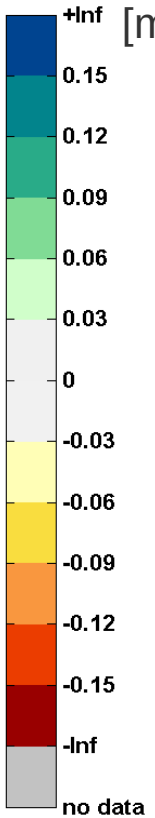
Involved sensors (GNSS, IMU, LiDaR) have systematic errors (constant over a certain period of time; e.g. minutes or days), which generate errors in **X.**

Especially the **mounting calibration** is often not known accurately enough.

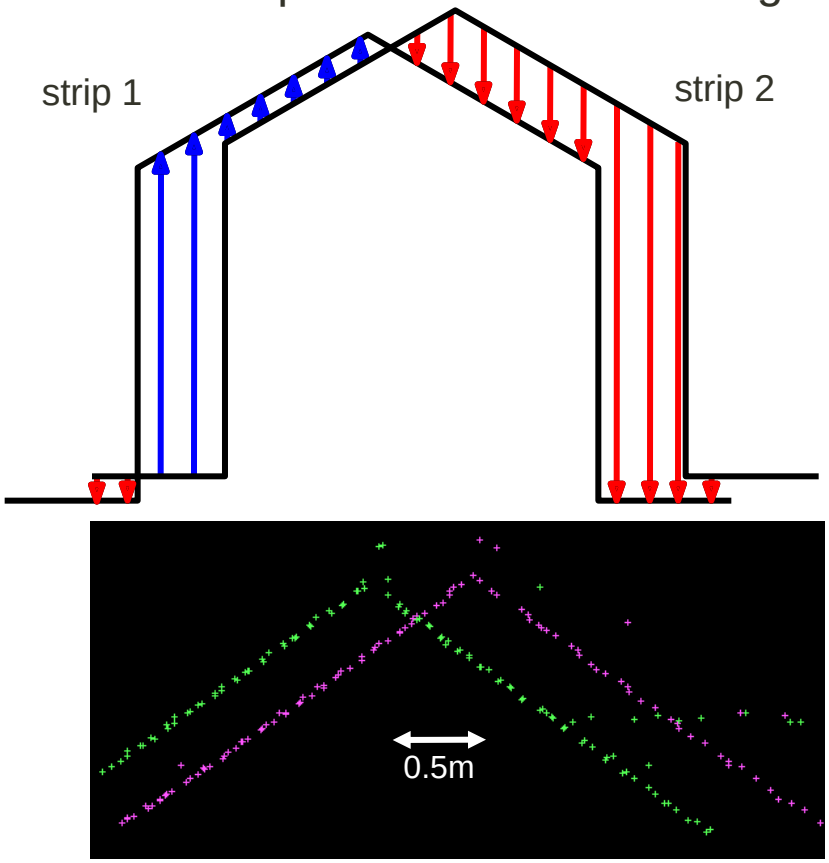
Strip difference: Appearance of buildings

Color-coded strip difference:





effect of strip differences at buildings:

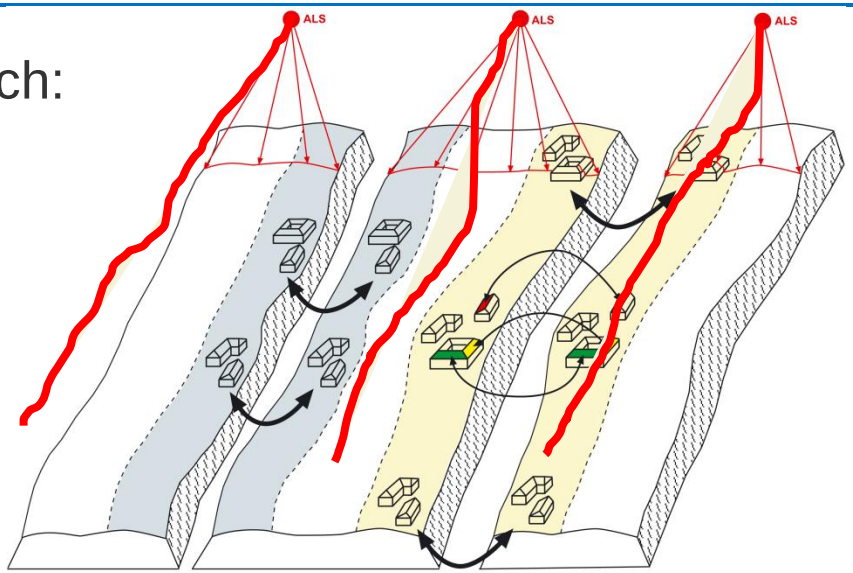


- mainly planar errors (caused by wrong georeferencing; mainly due to errors of the **mounting calibration**)

Schönbrunn 2004 Str 8/9

ALS strip adjustment with GNSS-INS-Traj.

The rigorous approach:



→ Corrections $\Delta\mathbf{X}$ of the measured points **X:**

$$\Delta \boldsymbol{X} = \Delta \boldsymbol{X}(\boldsymbol{X}(t), \boldsymbol{X}_{GNSS}(t), \mathbf{R}_{IMU}(t), \Delta\mathbf{R}_M \cdot \mathbf{R}_M, \boldsymbol{m} + \Delta\boldsymbol{m}, \Delta\boldsymbol{i})$$

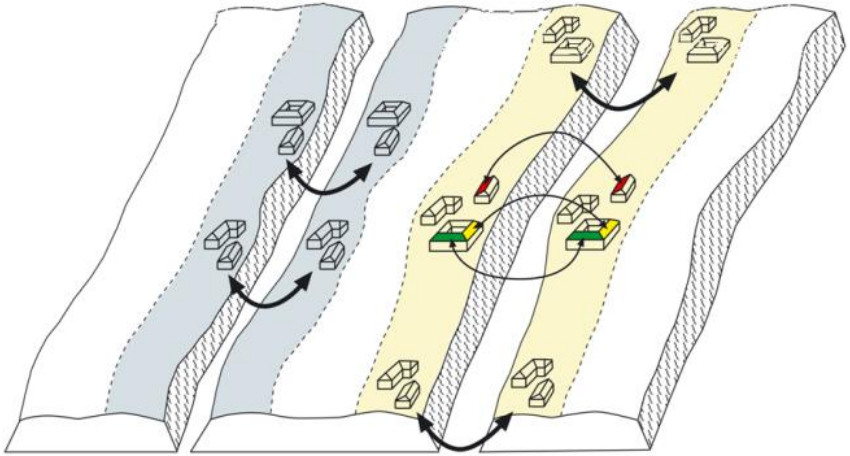
H. Kager: "Discrepancies Between Overlapping Laser Scanning Strips-Simultaneous Fitting of Aerial Laser Scanner Strips"; ISPRS XXth Congress, Istanbul; 2004; implemented in software ORIENT

Requirement: GNSS-IMU-trajectory $\mathbf{X}_{\mathbf{GNSS}}(t)$, $\mathbf{R}_{\mathbf{IMU}}(t)$ must be known.

What method if the trajectory is not given? (e.g. historic projects)

ALS strip adjustment without GNSS-INS-Traj.

The approximate approach:



→ Approximate corrections $\overline{\Delta \boldsymbol{X}}$ of the measured points **X:**

$$\overline{\Delta \boldsymbol{X}} = \overline{\Delta \boldsymbol{X}}(\boldsymbol{X}, a_i)$$

Motivation for correction function:

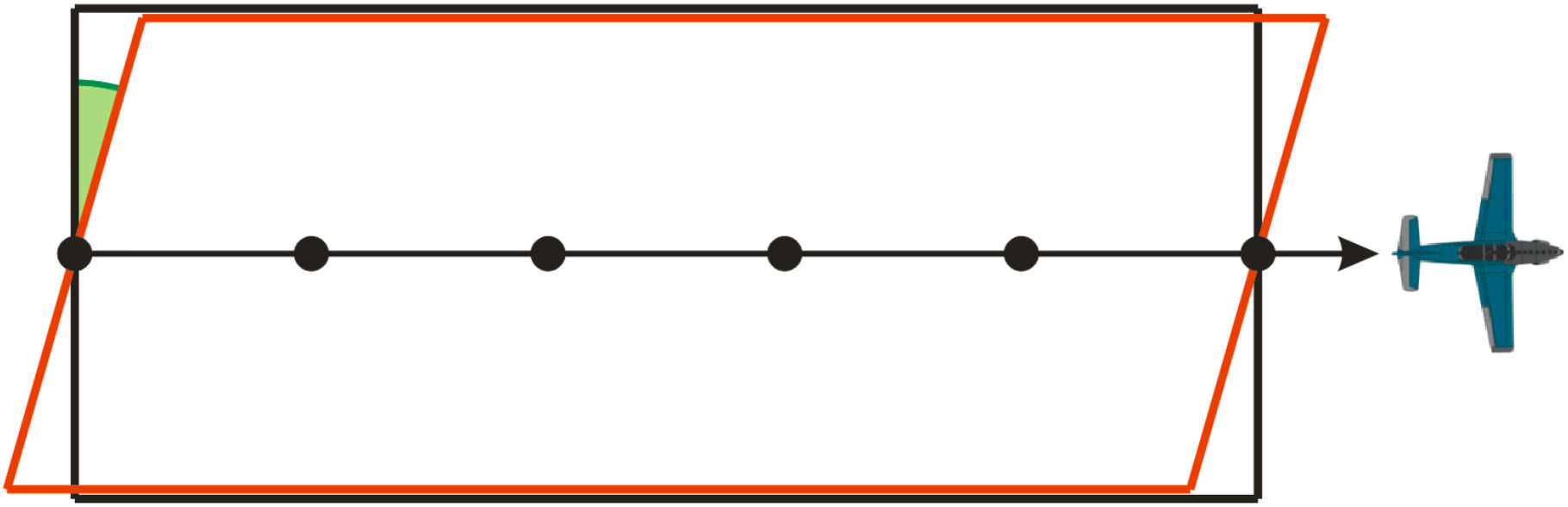
Linear approximation of trajectory based correction function & mounting errors.

→ **3D affine transformation** of each strip: $\boldsymbol{X} + \overline{\Delta \boldsymbol{X}} = \mathbf{B} \cdot (\boldsymbol{X} - \boldsymbol{S}) + \boldsymbol{b} + \boldsymbol{S}$

$\mathbf{B}$	unknown 3x3 matrix
$\boldsymbol{b}$	unknown 3x1 shift
$\boldsymbol{S}$	known reduction point (for numeric. reasons)

Why affine?

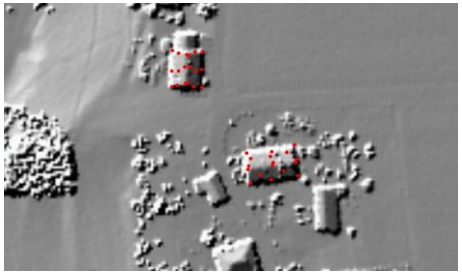
- Effect of yaw error of misalignment



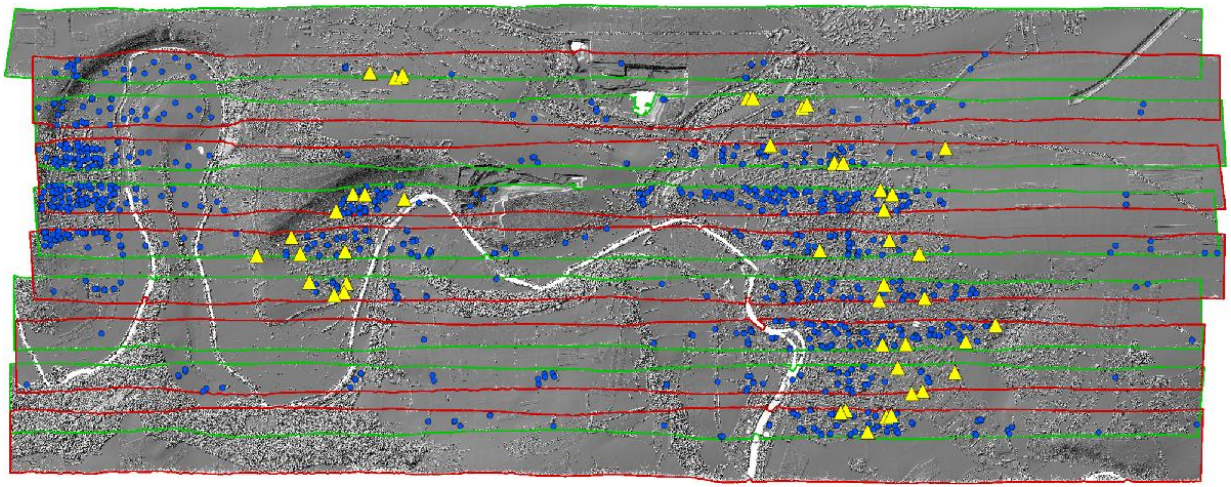
Similar relation holds for effect of pitch error.

Choice of tie features

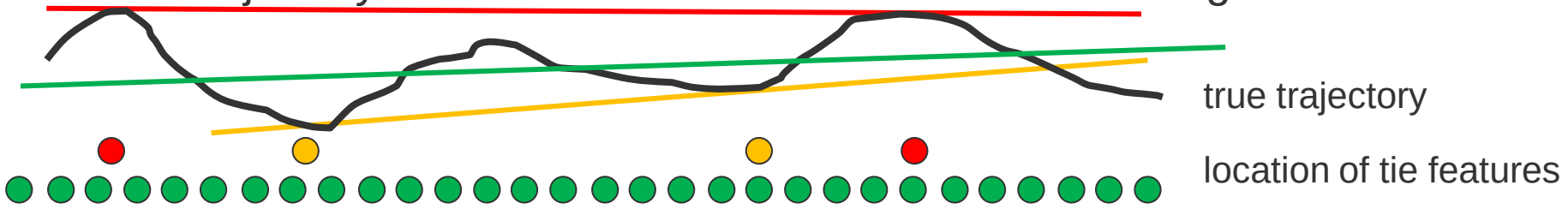
- Usually (roof) planes



- … but their distri-butation can be very inhomogenous

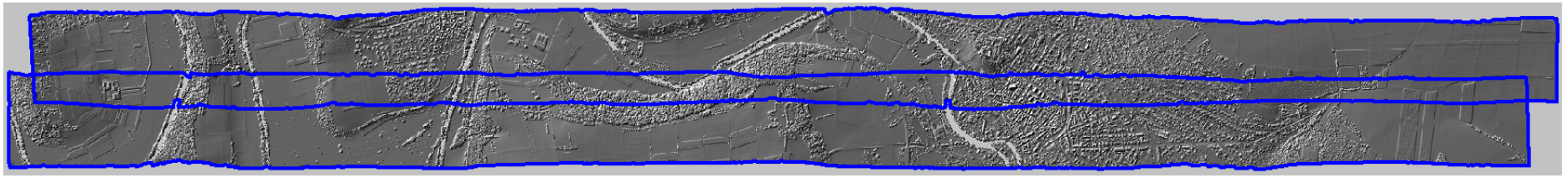


- Here: Trajectory not considered → effects of non-linear flight variations?



Tie features: entire overlap of strip pairs

2 overlapping strips



Interpolate grid DSM for each strip and use overlap as one big window for LSM.

Rough, shadow and extrapolation cells are removed using a mask.

ALS strip adjustment without GNSS-INS-Traj.

Computation of **absolute** affine transformation $\{A, a\}_j$ for each strip **j** using the following two major steps:

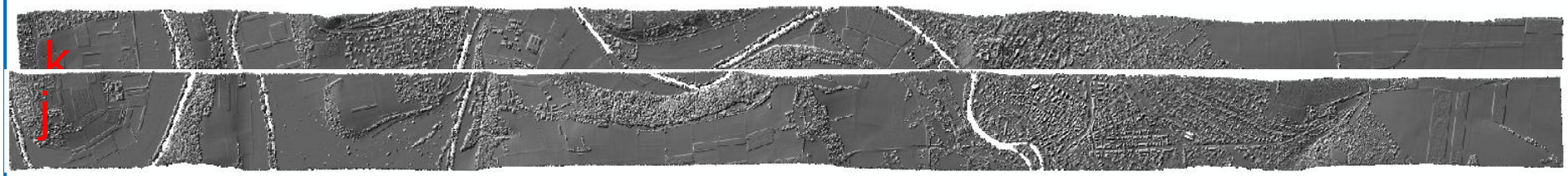
- Compute **relative** affine trafo $\{R, r\}^k_j$ for each **pair** of overlapping strips; i.e. from strip **j** to strip **k** using LSM (least squares matching):

$$X^k = R^k_j \cdot X^j + r^k_j$$

- Use computed $\{R, r\}^k_j$ between all overlapping strips in the **block** to derive the **absolute** affine transformation $\{A, a\}_j$ for each strip **j**.

Step 1: Relative affine transformations $\{R, r\}^k_j$ from strip j to strip k using LSM

2 overlapping strips k and j:
Overlap emphazised with color coded height differences:



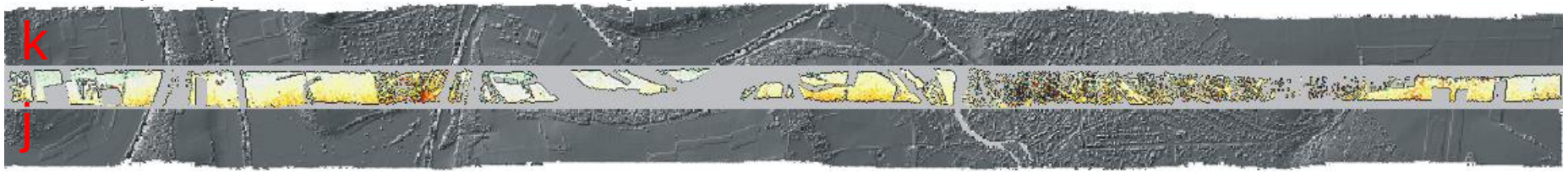
Step 1: Relative affine transformations $\{R, r\}^k_j$ from strip j to strip k using LSM

2 overlapping strips k and j:

Overlap emphazised with color coded height differences:

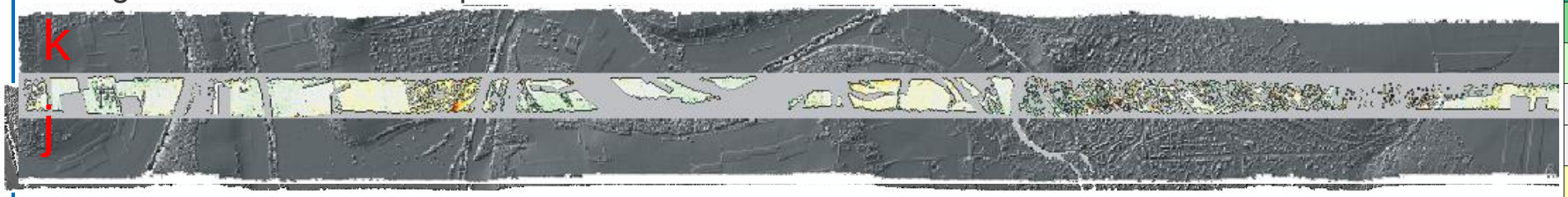
Step 1: Relative affine transformations $\{R, r\}^k_j$ from strip j to strip k using LSM

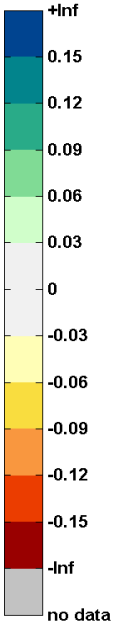
2 overlapping strips k and j:
Overlap emphazised with color coded height differences:



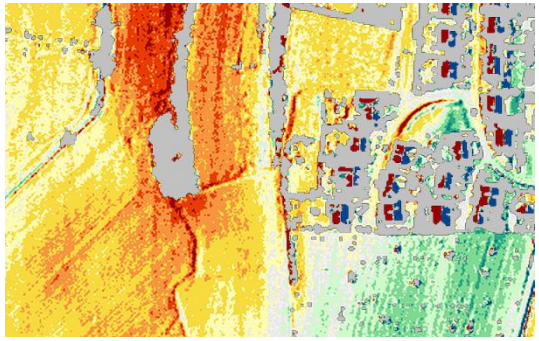
Idea of 3D LSM: keep strip k fixed and apply an affine transformation on strip j such that the masked height differences in the overlap are minimized.

Height differences in overlap after LSM:





Zoom in: before LSM:



after LSM:

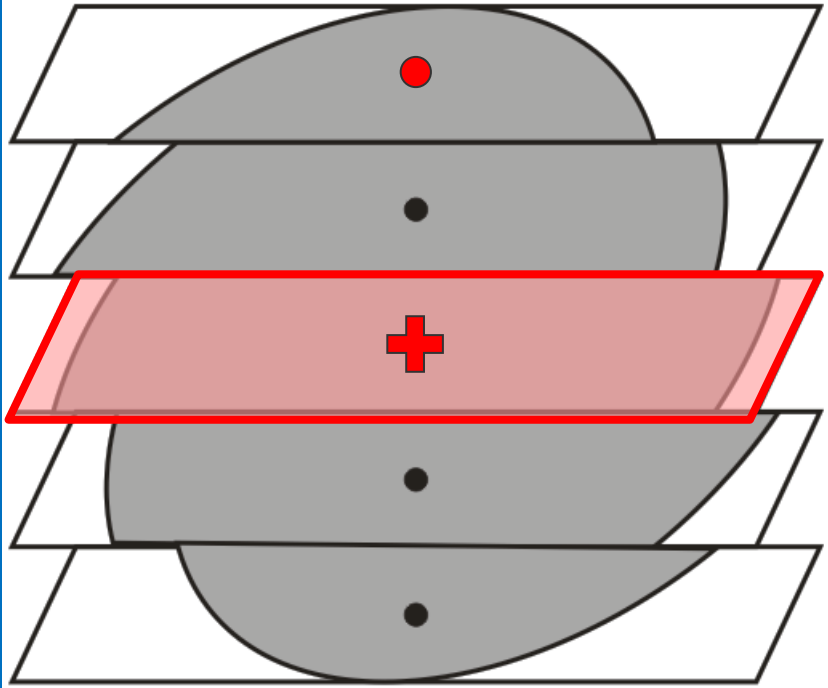
Step 2: Strip adjustment

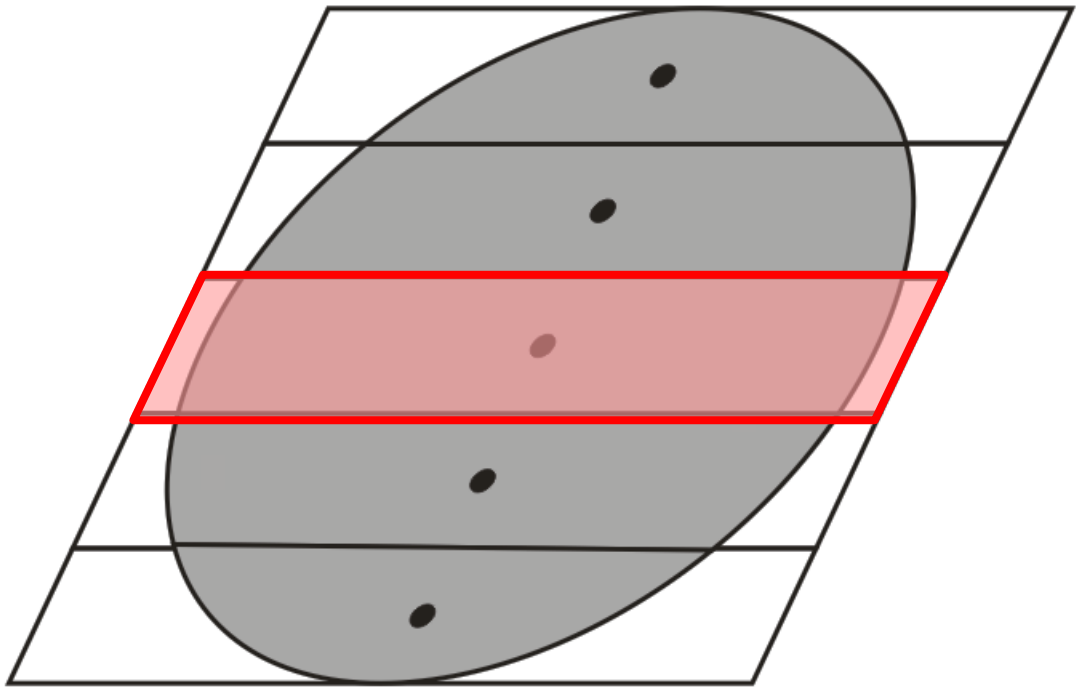
Simultaneous adjustment of **all relative affine** transformations: **datum of block** needs to be defined by fixing 12 proper coefficients.

Example: 5 strips with yaw mounting error

datum a) fix all 12 coef. of central strip

datum b) fix 9 coef. of central strip + 3 of border

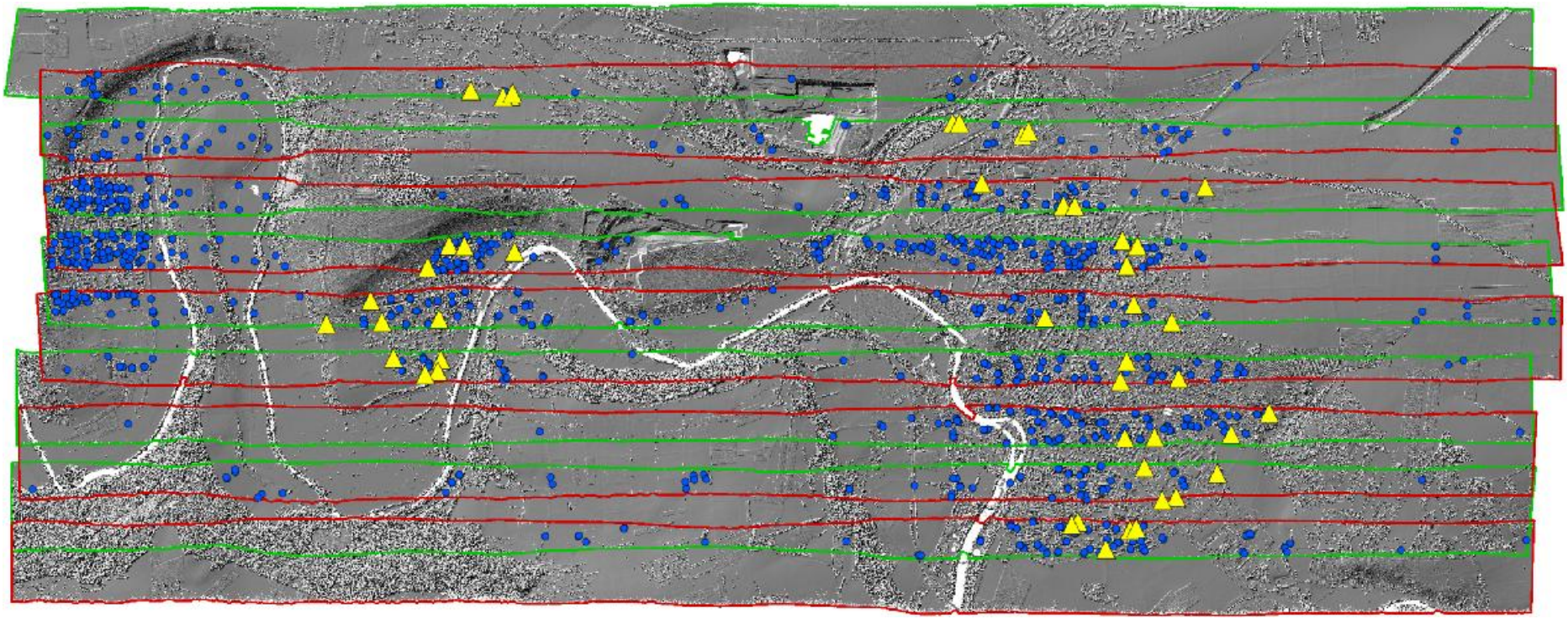




- **Absolute orientation** with respect to **map system** can be improved afterwards using **ground control information** (e.g. roof planes) and 3D LSM.

Example: ALS-Vaihingen 2008

Leica ALS 50, 10 strips, point density >3 pts/m², side overlap 30%



[data provided by DGPF]

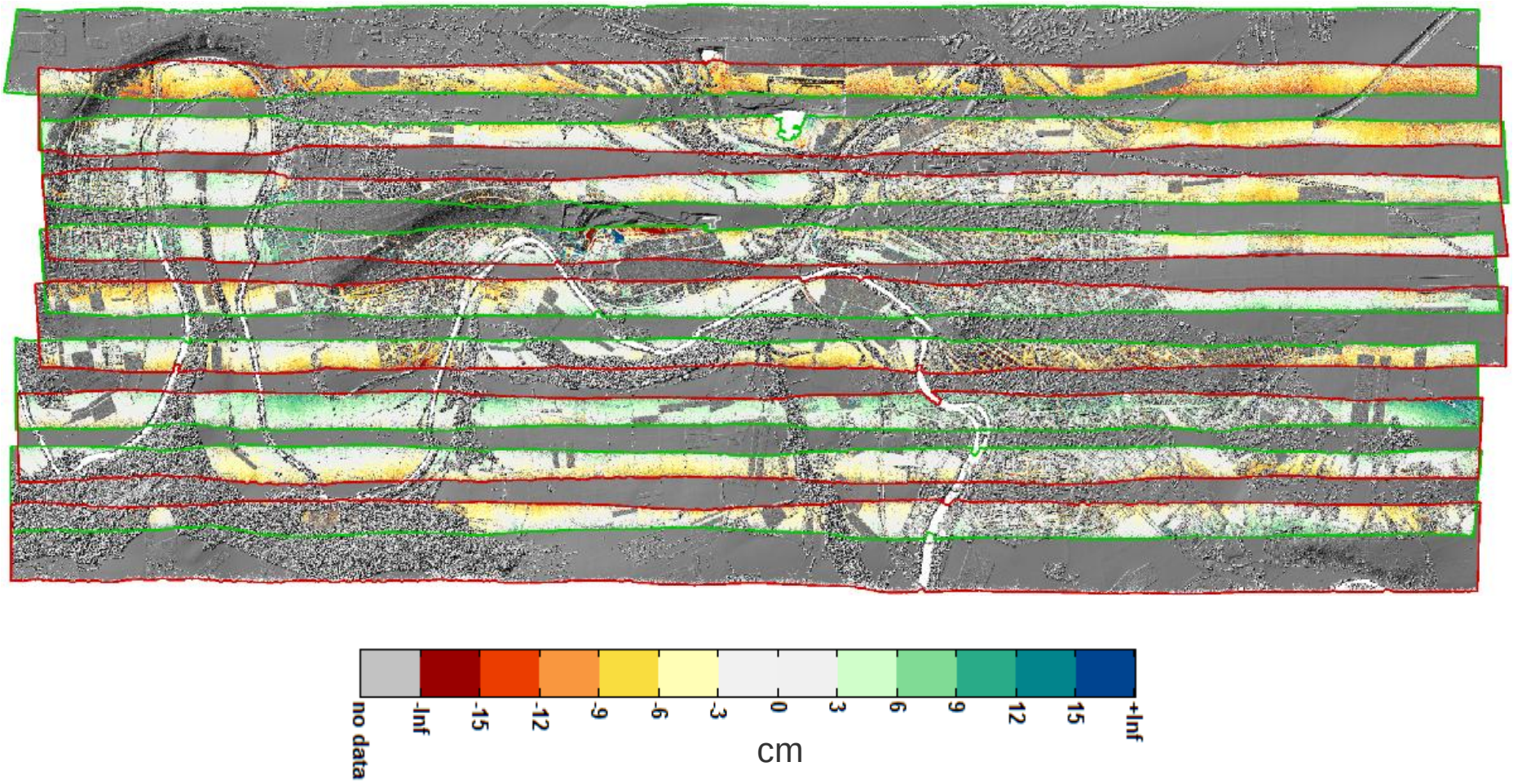
Strip adjustment with GNSS/INS trajectory computed with software Orient:

1110 Tie planes

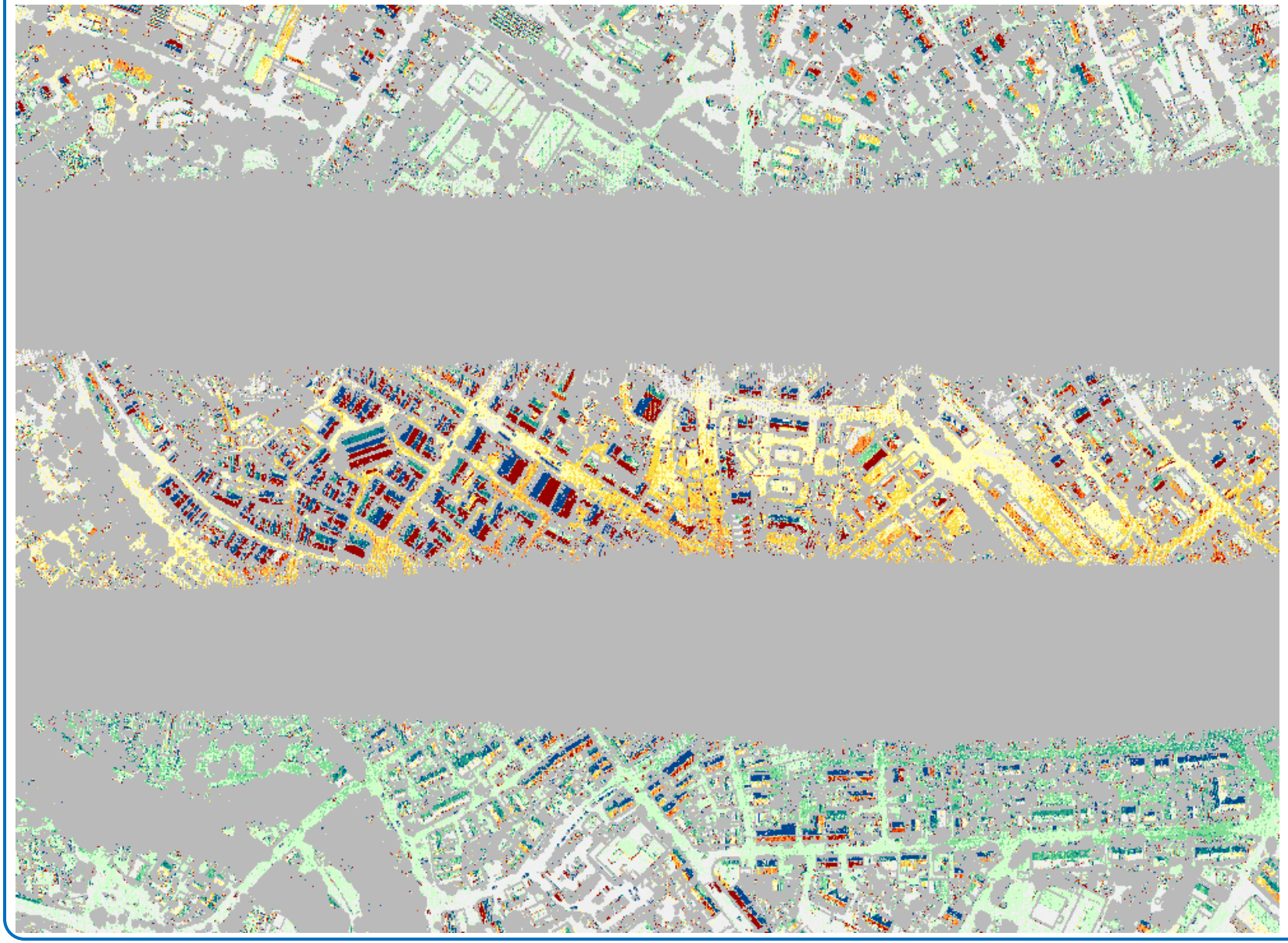
49 Control planes

unknown sensor parameters: misalig., lever, scale for angles and range, range offset

Strip differences



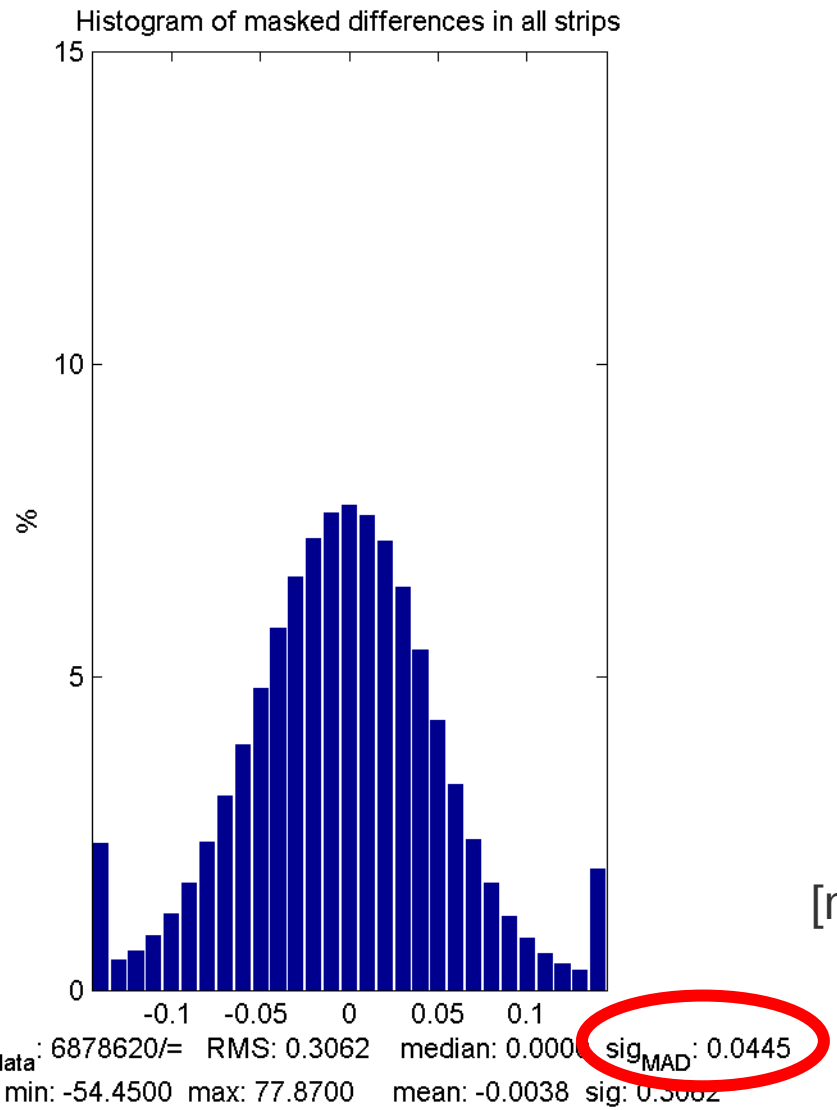
Strip differences: before adjustment



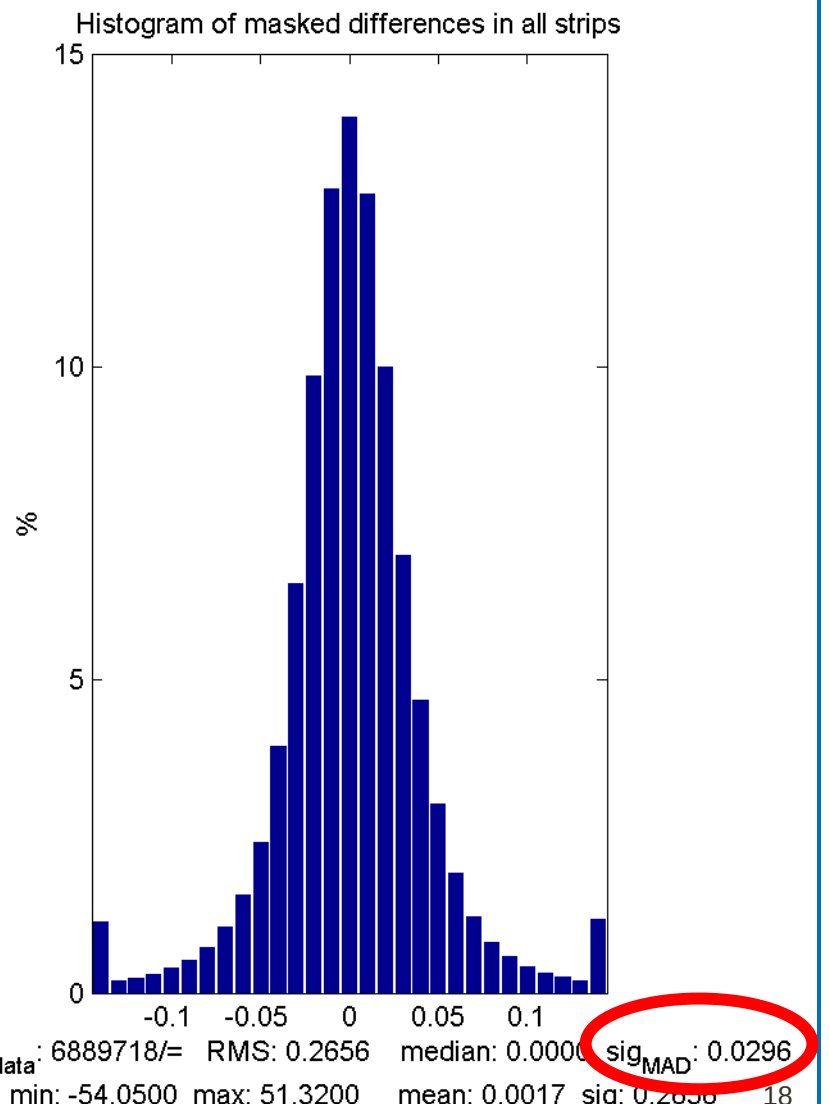
Strip differences: after adjustment with traj.

Statistics of all masked strip differences (6.6 mill. vals.)

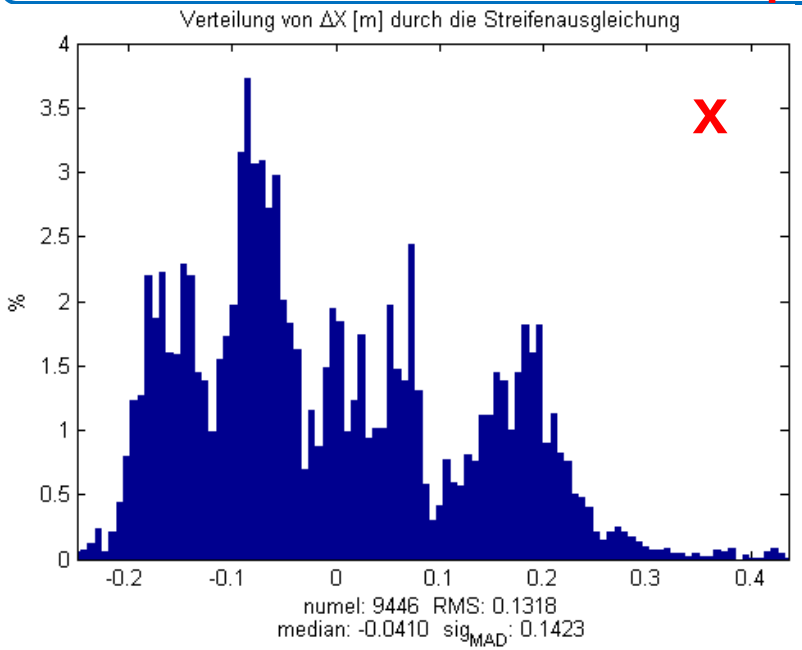
before strip adjustment

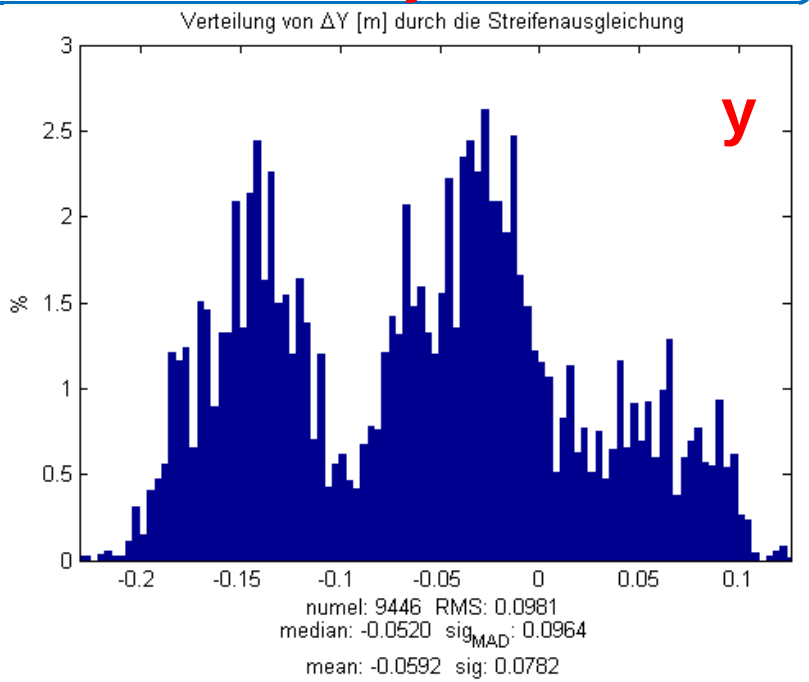


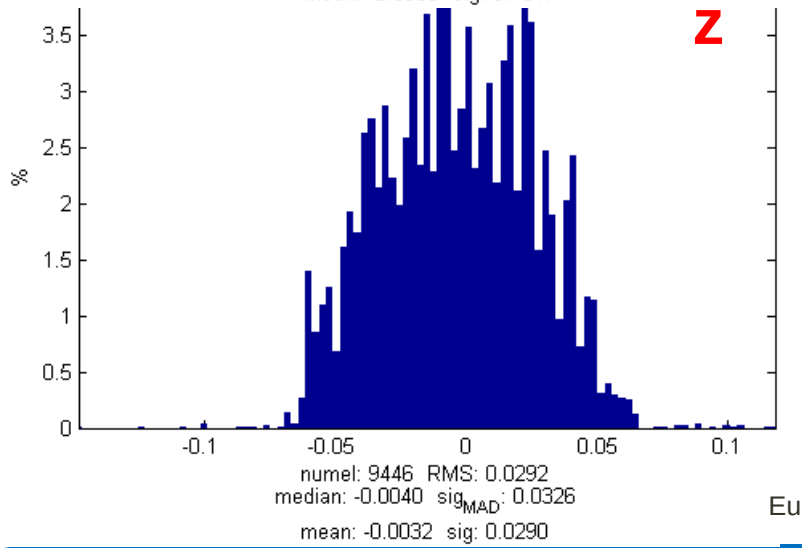
after strip adjustment (**with** GNSS-INS traj.)



Corrections of the original points after the strip adjustment with traj.

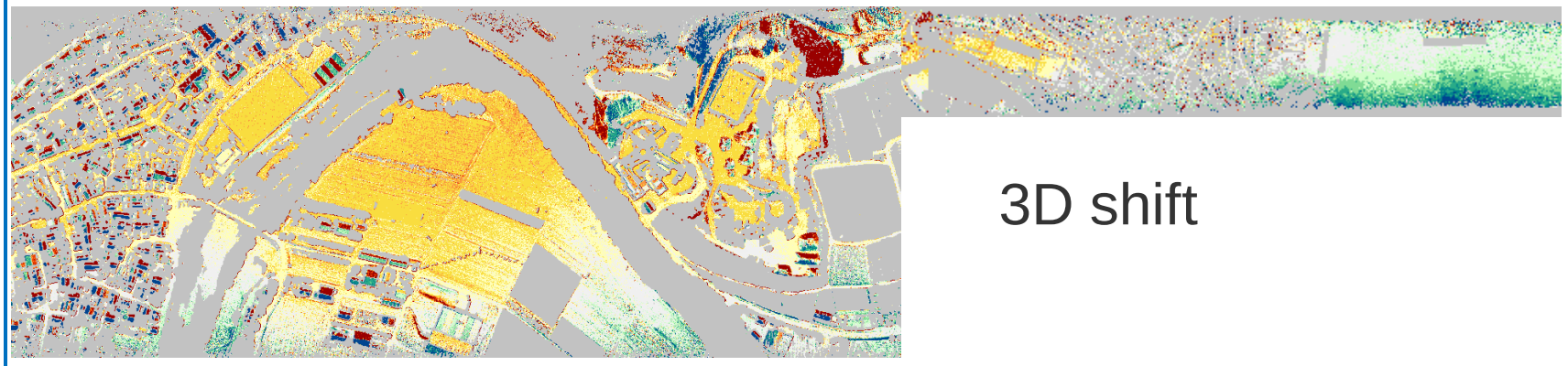




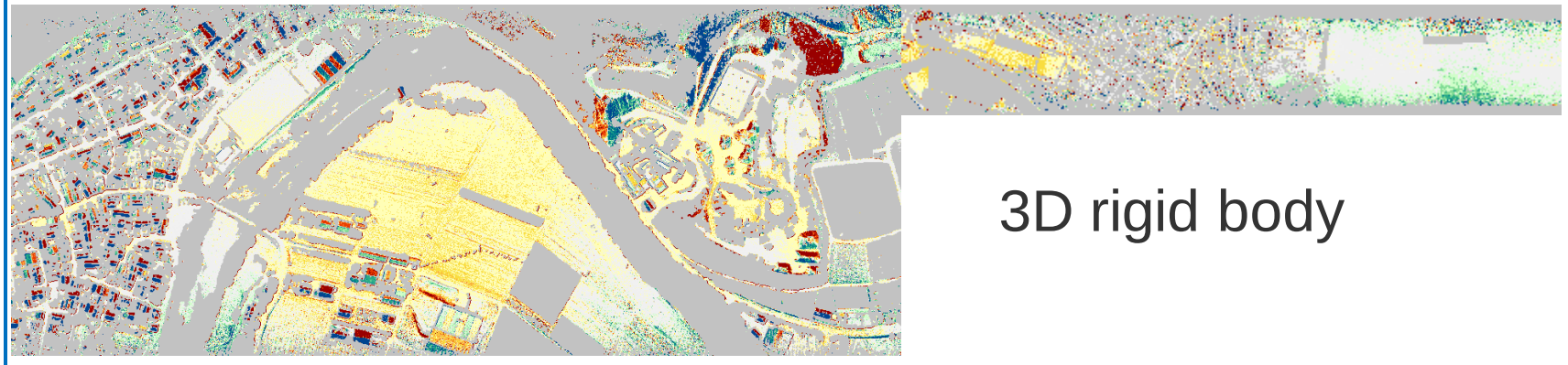


#	mean	RMS	max	[m]
9446 x:	-0.007	0.132	0.436	
9446 y:	-0.059	0.098	-0.231	
9446 z:	-0.003	0.029	-0.148	

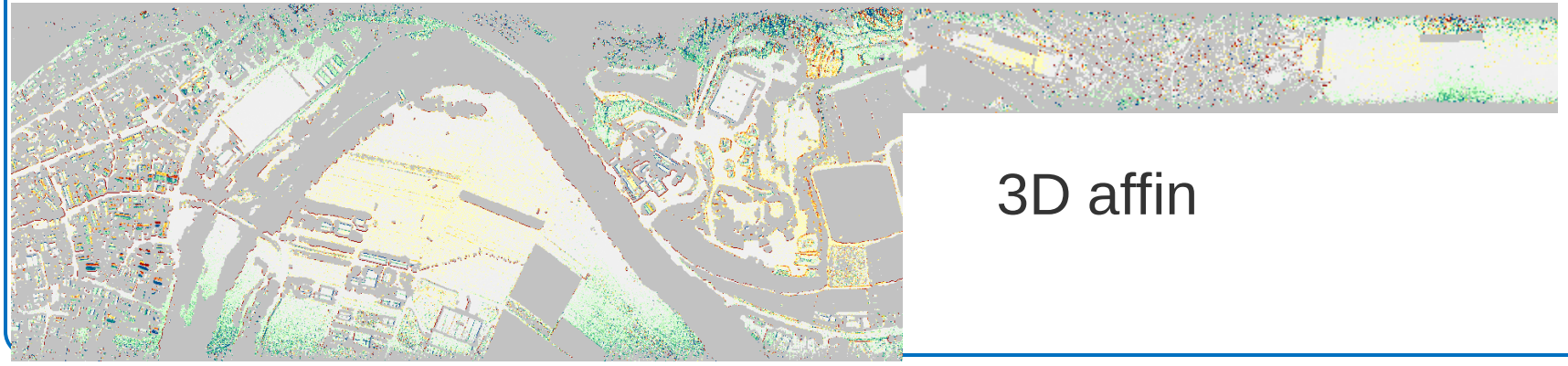
Without Traj.: Choice of Transformation Model → difference to strip after adj. with traj.



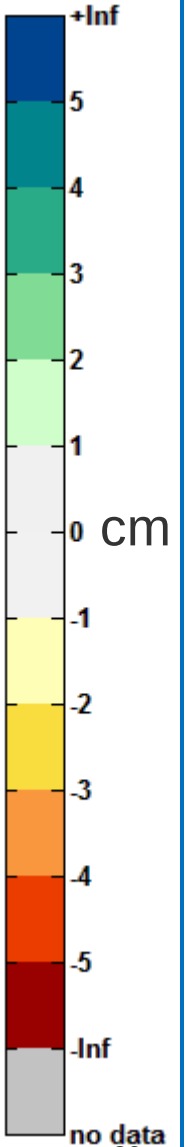
3D shift



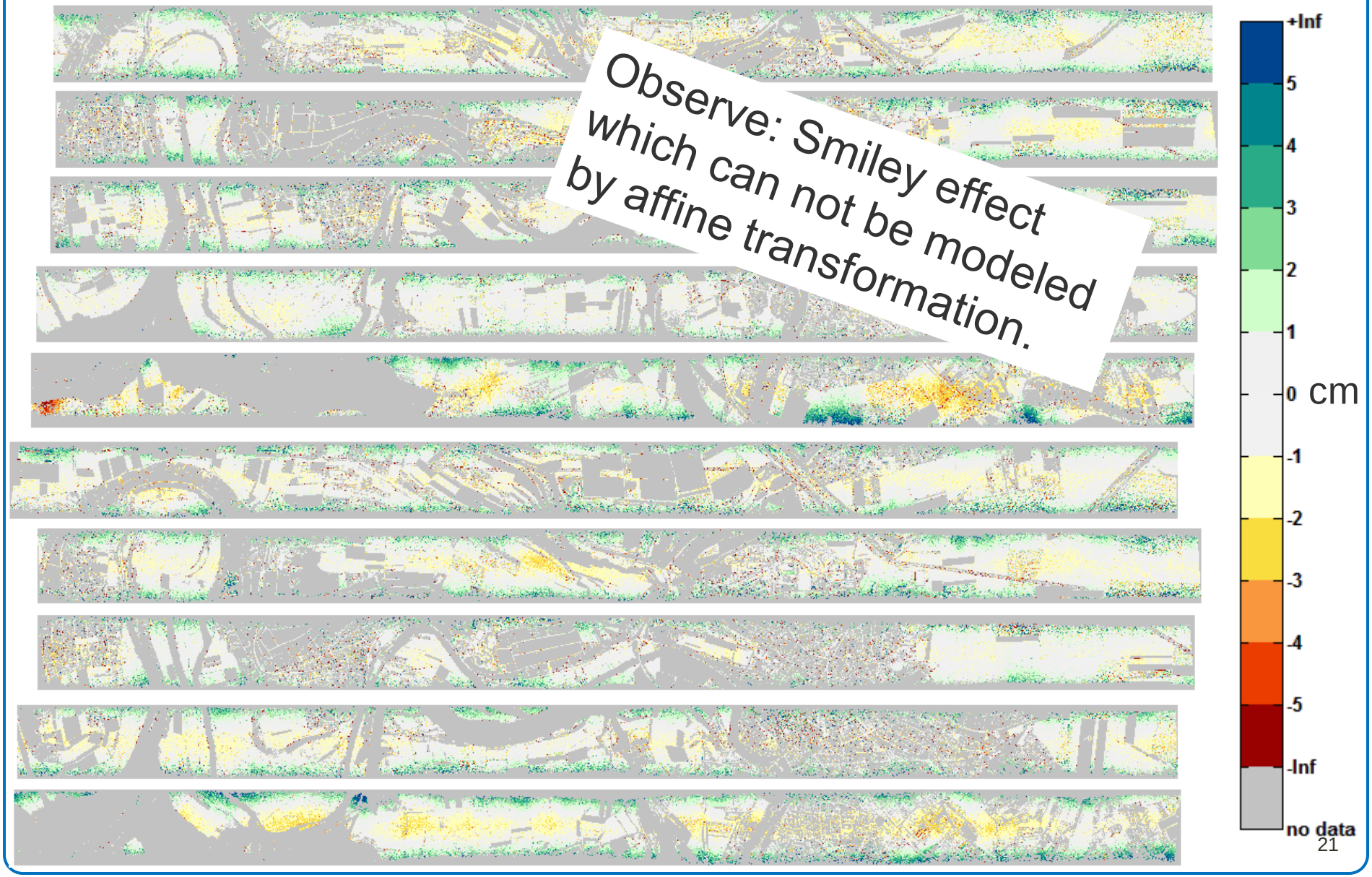
3D rigid body



3D affin

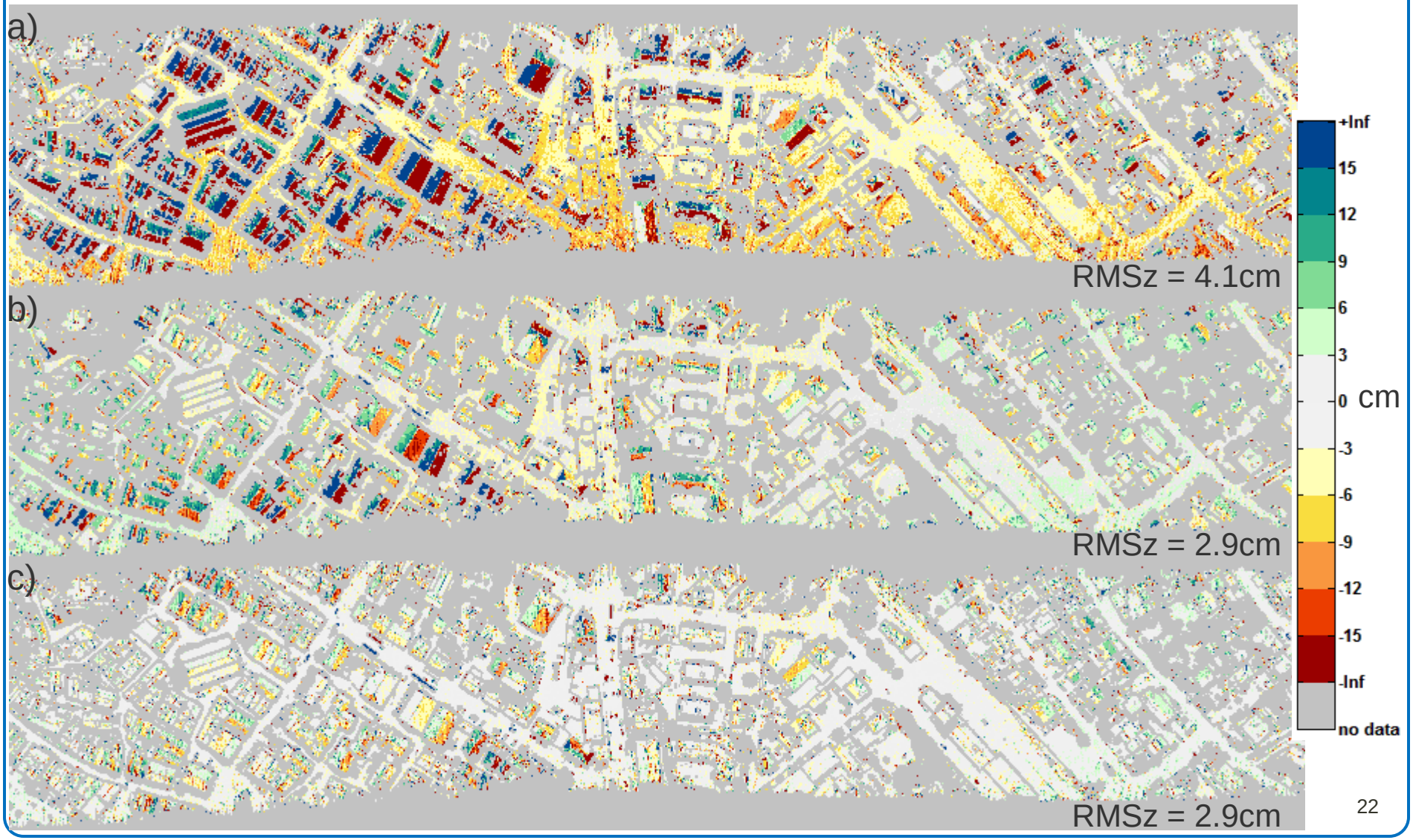


Without Traj.: Choose Affine Transformation Model



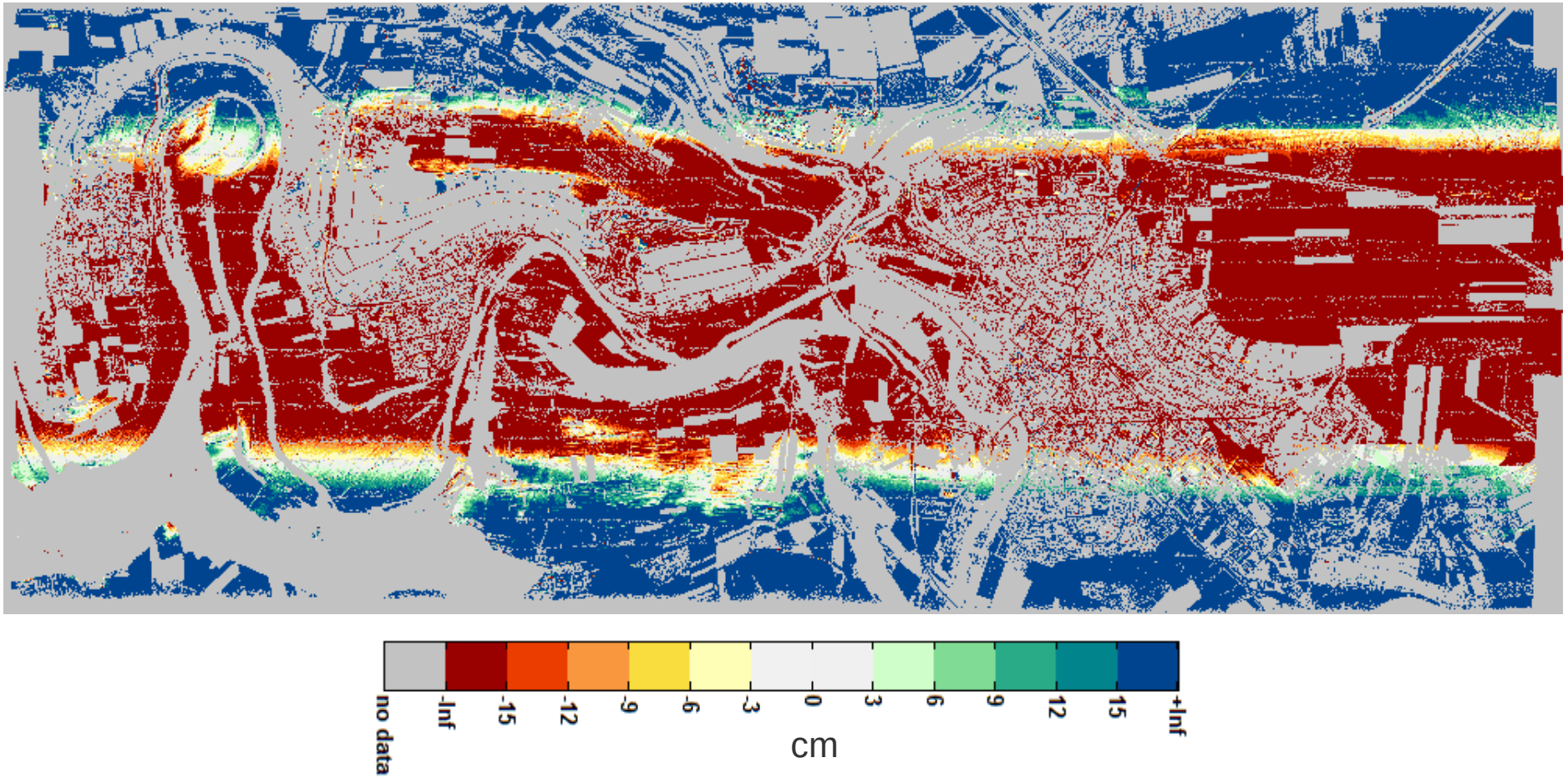
Without Traj.: Quality of relative orientation

Vaihingen: a) “original“, b) “affine 3D-LSM“, c) “with trajectory“



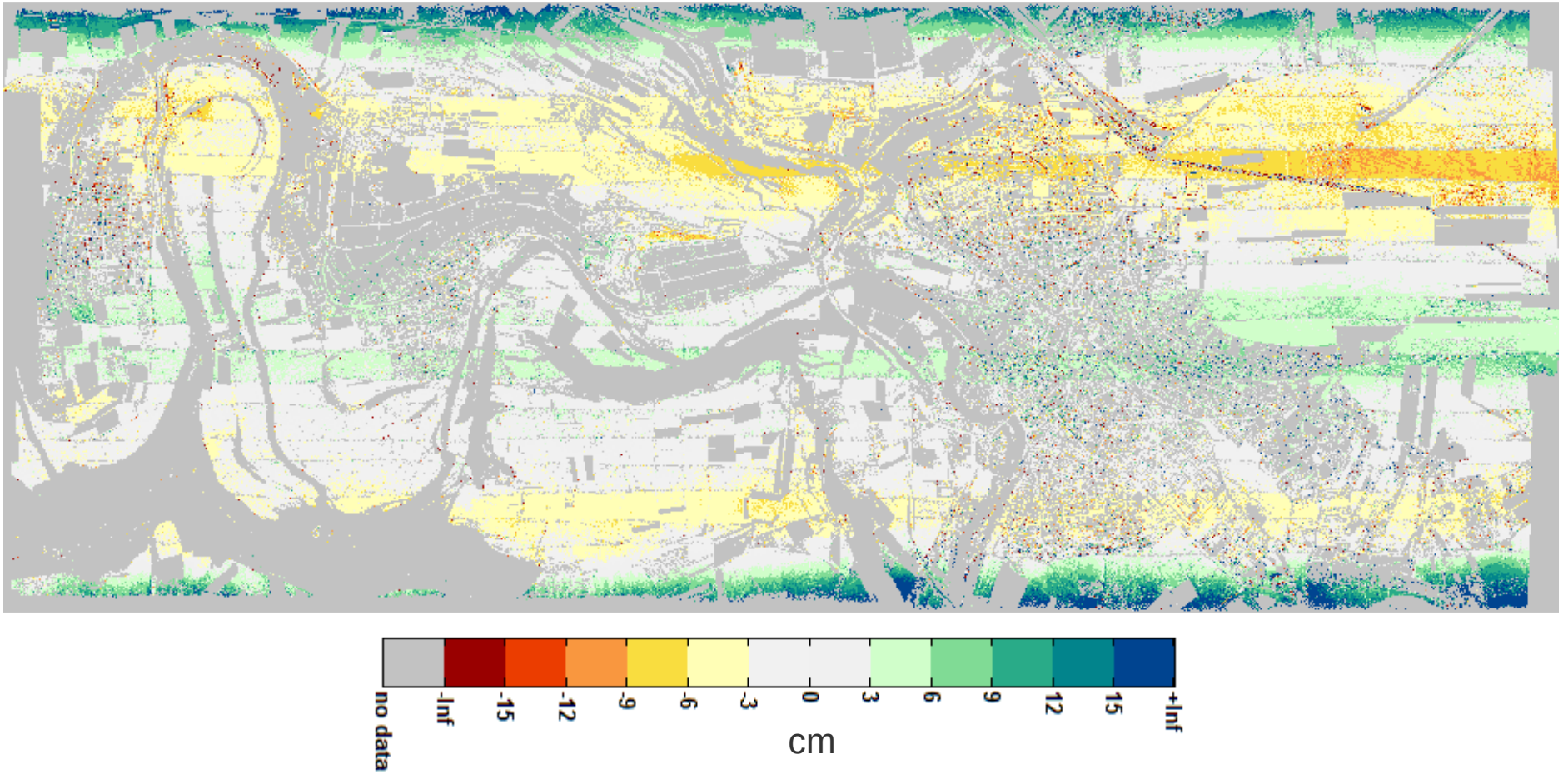
Without Traj.: Quality of absolute orientation

Simultaneous adjustment of relative affine transformations: bad weighting



Without Traj.: Quality of absolute orientation

Simultaneous adjustment of relative affine transformations: better weighting



Summary

- ALS strip adjustment without trajectory data is only approximate, with trajectory is more rigorous → recommended method
- No trajectory? → Transformation model: 3D affine trafo. for each strip
- **Strip adjustment** without trajectory in two steps:
  - **3D LSM** for **each pair** of overlapping strips → relative transformations
  - simultaneous **adjustment of all relative** transformations → block of adjusted strips in relative datum (examples show room for improvement)
  - (optional) **absolute** datum afterwards: 3D LSM between relative block and ground control points
  - Current problem: proper weighting and constraints in the simultaneous adjustment of the relative transformations

Software: opals http://www.ipf.tuwien.ac.at/opals

Literature

- C. Ressl, N. Pfeifer, G. Mandlburger:
  "Applying 3D Affine Transformation And Least Squares Matching For Airborne Laser Scanning Strips Adjustment Without Gnss/imu Trajectory Data"; Talk: ISPRS Workshop Laser Scanning 2011, Calgary, Canada.
- C. Ressl, G. Mandlburger, N. Pfeifer:
  "Investigating Adjustment Of Airborne Laser Scanning Strips Without Usage Of GNSS/IMU Trajectory Data„ in: "ISPRS Workshop Laserscanning `09", IAPRS, Vol. XXXVIII, 2009, 195 - 200.
- C. Ressl, H. Kager, G. Mandlburger:
  "Quality Checking Of ALS Projects Using Statistics Of Strip Differences„
  in: "Proceedings of International Society for Photogrammetry and Remote Sensing XXIst Congress, Beijing, China", Vol. XXXVII., 2008, 253 - 260.
- H. Kager:
  "Discrepancies Between Overlapping Laser Scanning Strips- Simultaneous Fitting of Aerial Laser Scanner Strips"; in : "Proceedings of International Society for Photogrammetry and Remote Sensing XXIst Congress, Istanbul„; Vol XXXV, 2004, 555 - 560.