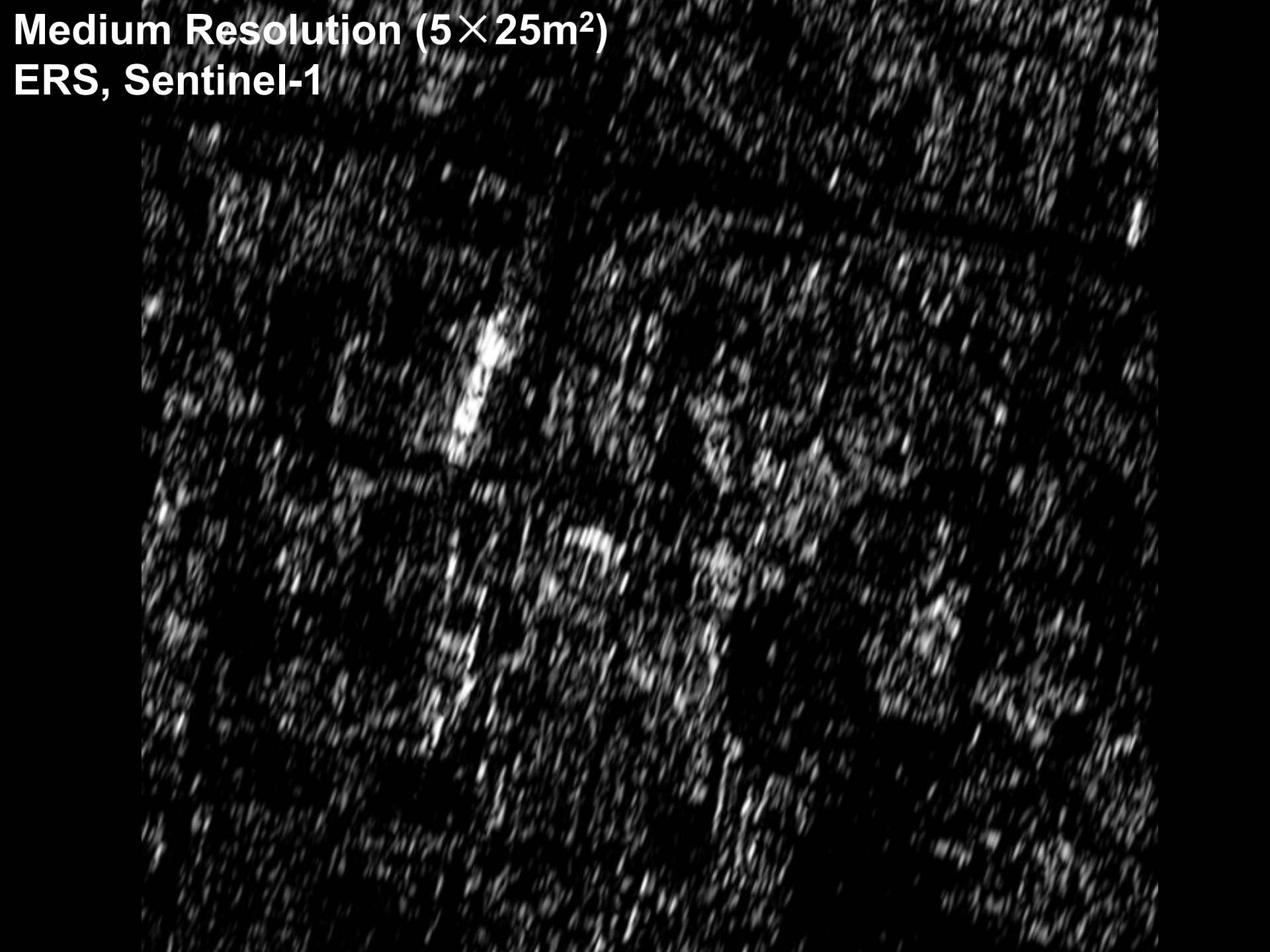
Multi-temporal High-Resolution SAR for Geometric Measurements and for Ground Deformation Monitoring

Michael Eineder & SAR teams
Remote Sensing Technology Institute, DLR &
Technische Universität München

DLR


Medium Resolution (5×25m²)
ERS, Sentinel-1

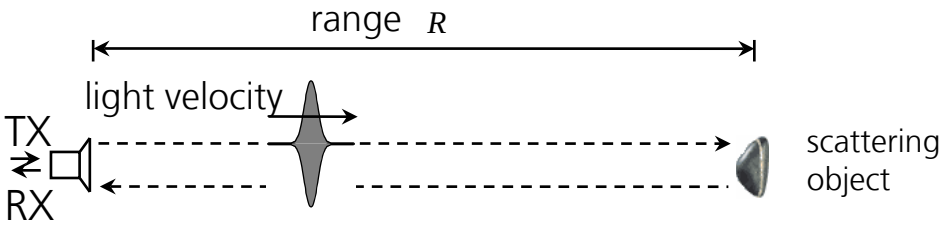

Very High Resolution (1.1×0.6 m²)
TerraSAR-X

Outline

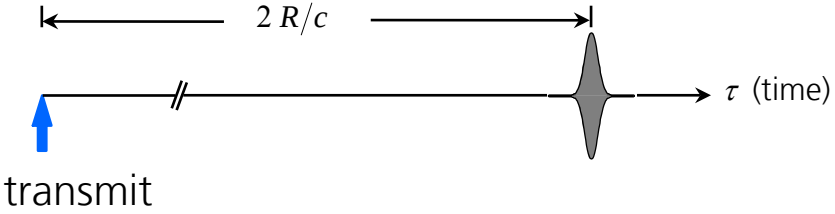
- Short tutorial *Accuracy of SAR geometry*
  - Methods for error reduction
  - Range & azimuth measurements
  - Exploitation of accurate geometry

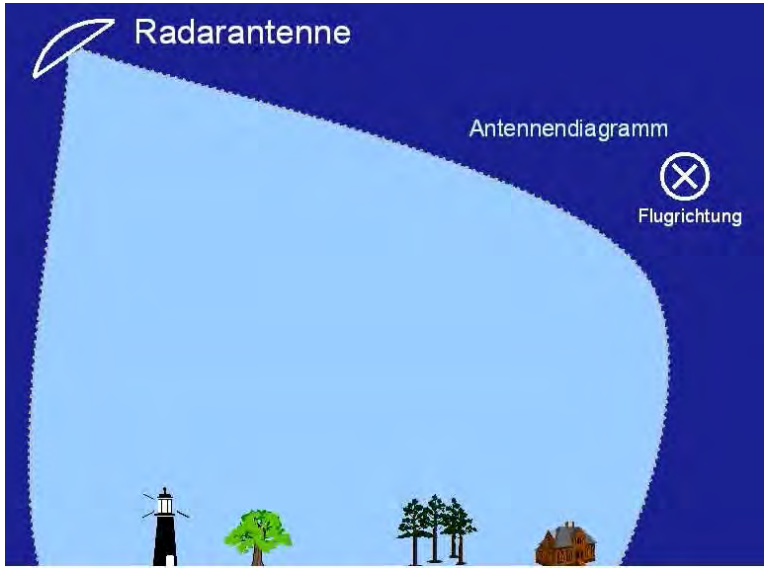
- Some recent examples from TerraSAR-X and TanDEM-X

“Range” Measurements with SAR: How Accurate?



received echo:



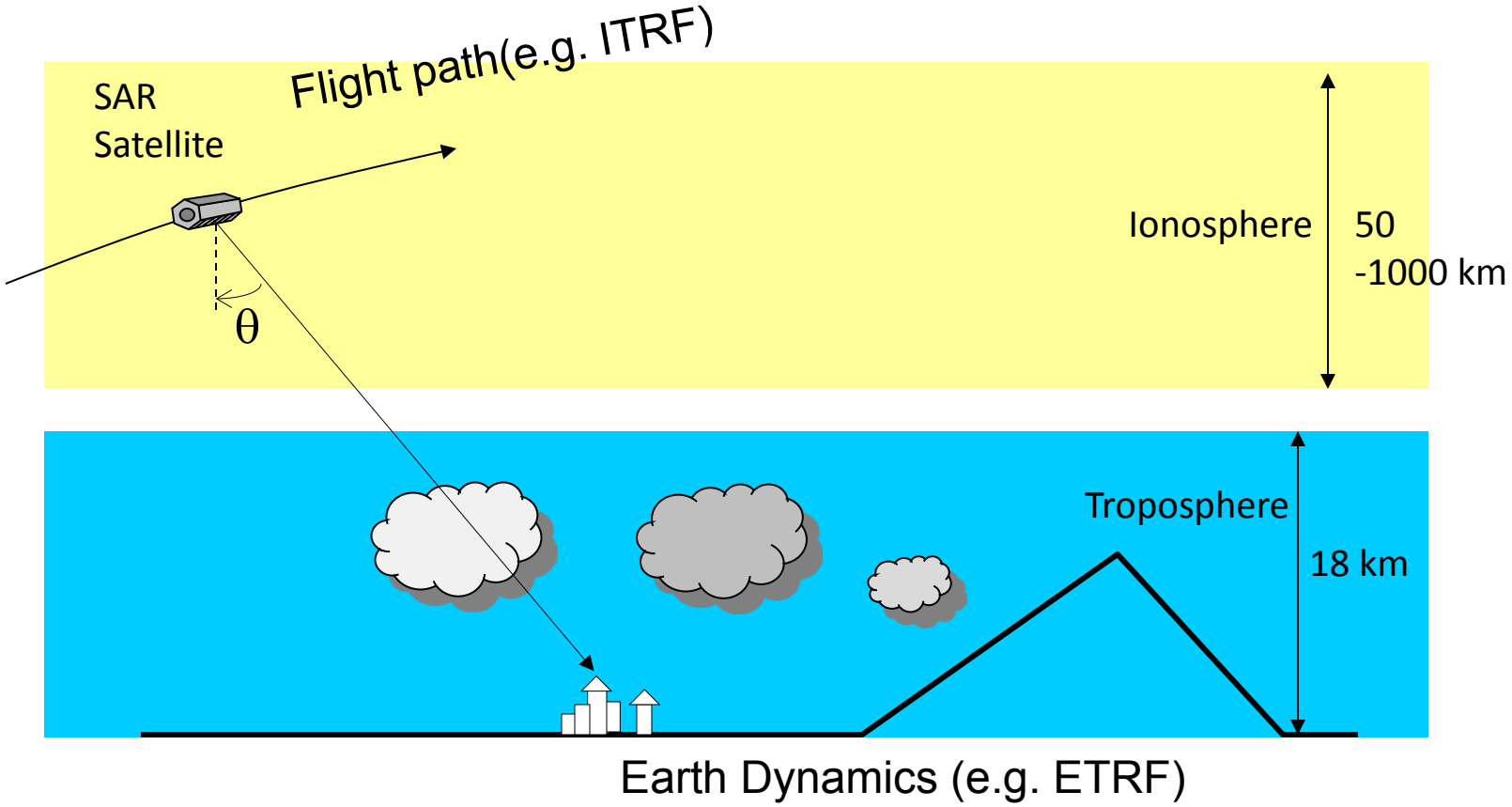


$$R = \frac{\tau c'}{2}$$

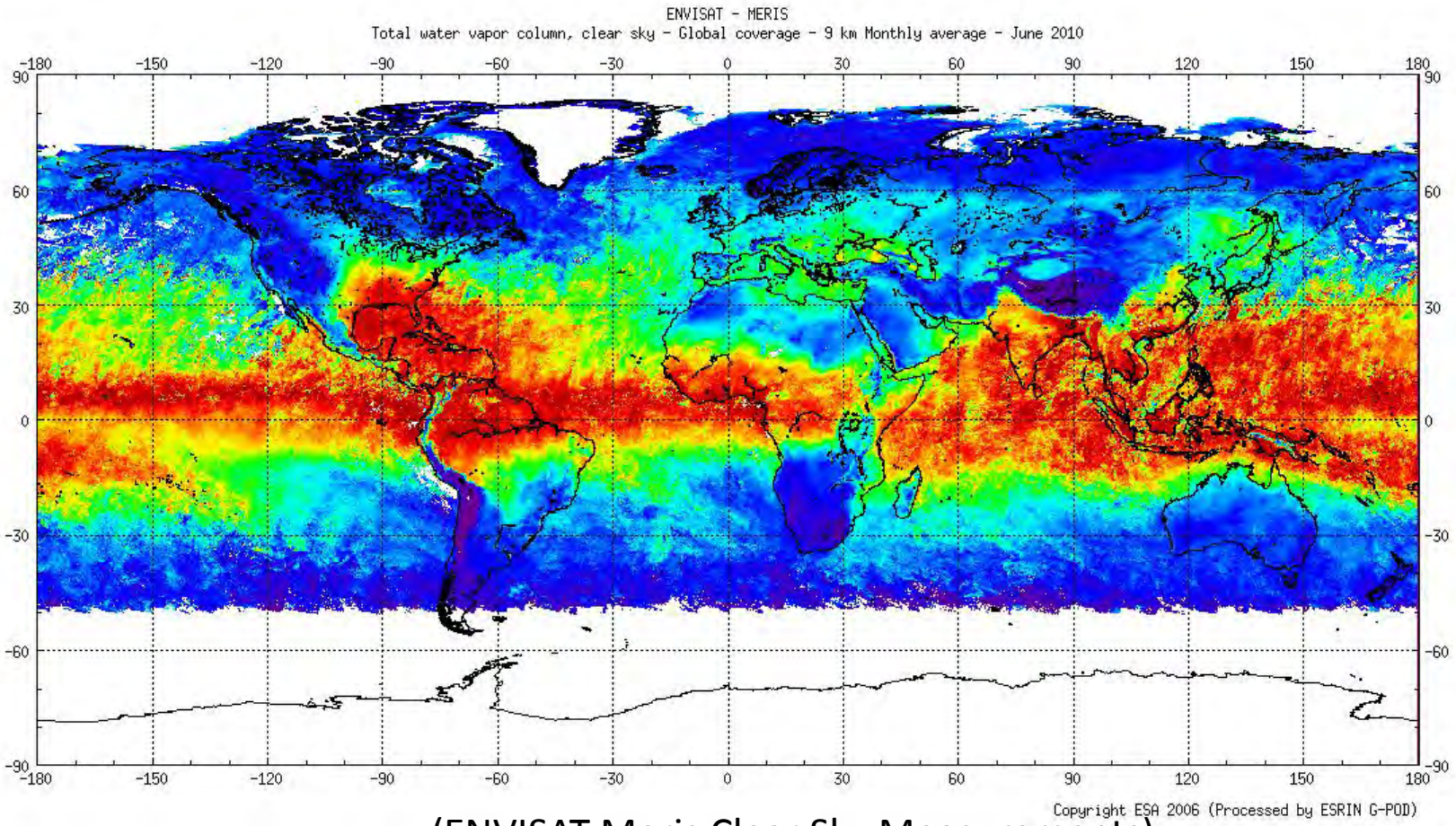
$$\varphi = 2\pi \; f\tau \approx 4\pi \frac{R}{\lambda}$$

R?
c´?

SAR Signal Propagation and Coordinate Systems



Water Vapor: Spatio-Temporal Distribution



33 cm delay

(ENVISAT Meris Clear Sky Measurements)

➔ Error of 2.5 m ± 20 cm; seasons, stratification

Tropospheric Delay Correction Methods

• PSI: temporal averaging	expensive, slow
• Local GNSS measurements: σ < 2-4 mm	simple, location restricted, 0D
• 3D ECMWF reanalysis models: σ ≈13 mm	simple, global, low res., 3D
• 3D numerical model, e.g. WRF : σ < 13 mm?	comp. expensive, global
• Empirical model fit	1D, assumes uncorr. h / Δr

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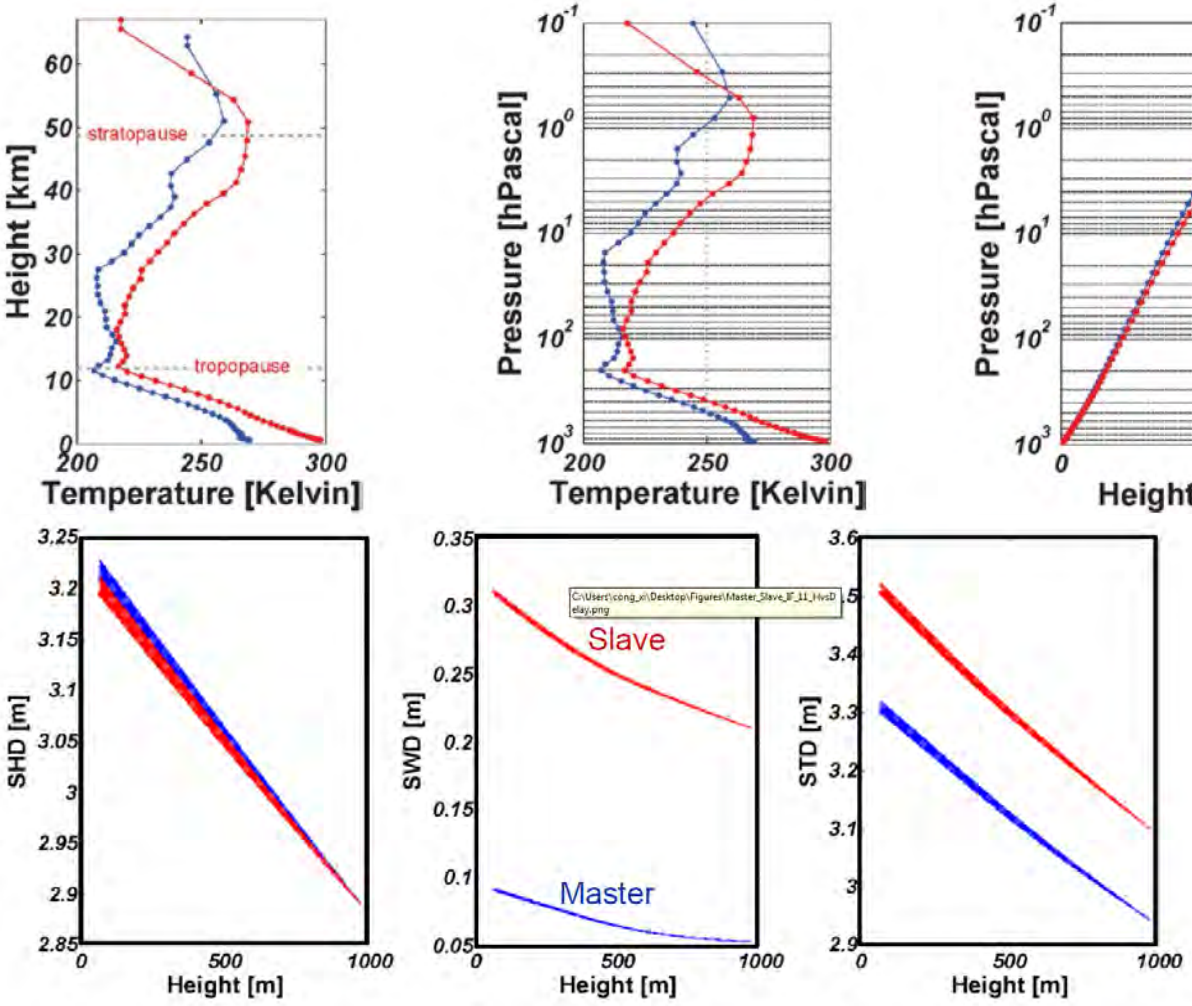
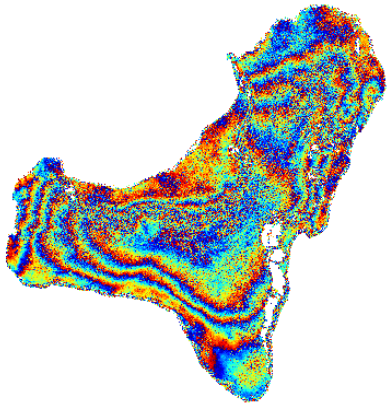
MultiTemporal Tropospheric Stratification from ECMWF



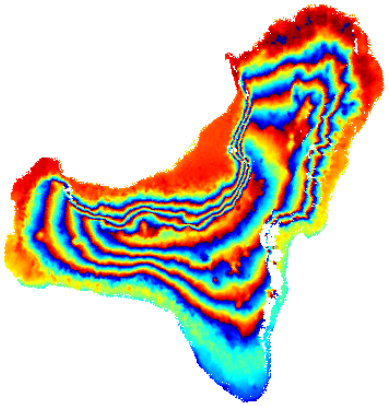
X. Cong, TUM/IMF

Mitigation of Atmospheric Delay Using ERA-Interim Data

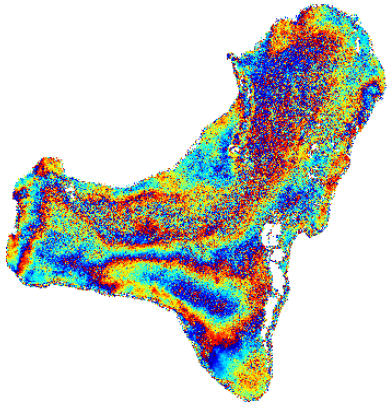
Original Phase



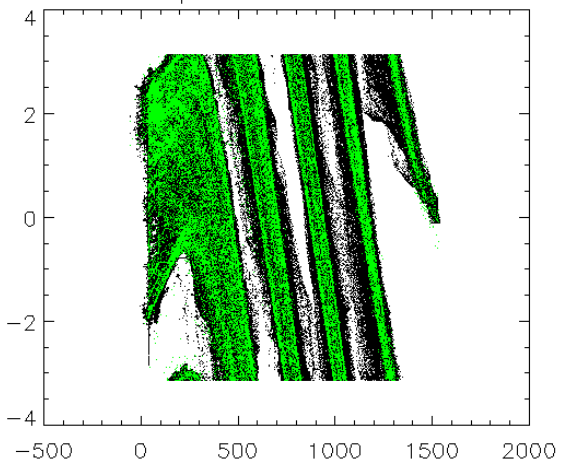
Atmospheric Phase



Corrected Phase



Atmospheric Phase vs. DEM



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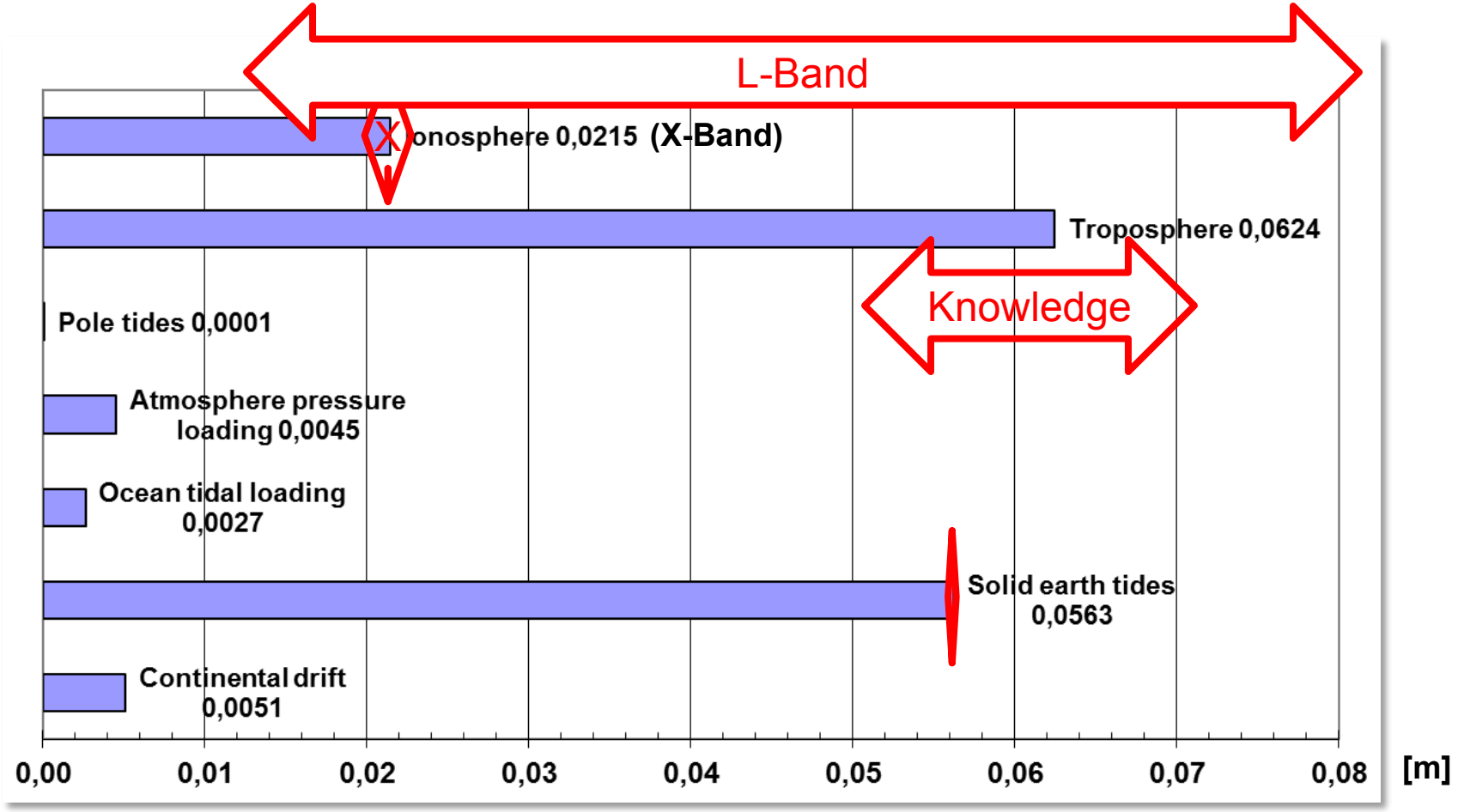
Summary: Geophysical Range Error Contributions



SAR Azimuth Positioning Errors

- Typical error sources
  - Not: Attittude
  - Timing synchronization between SAR and orbit metrology (GNSS)
  - SAR processor approximations (start-stop, …)
  - …
  - Calibration errors
  - Ionospheric gradients (C/L-Band)
  - Orbit angle error

- ➔ 1-2 cm achievable in X-Band

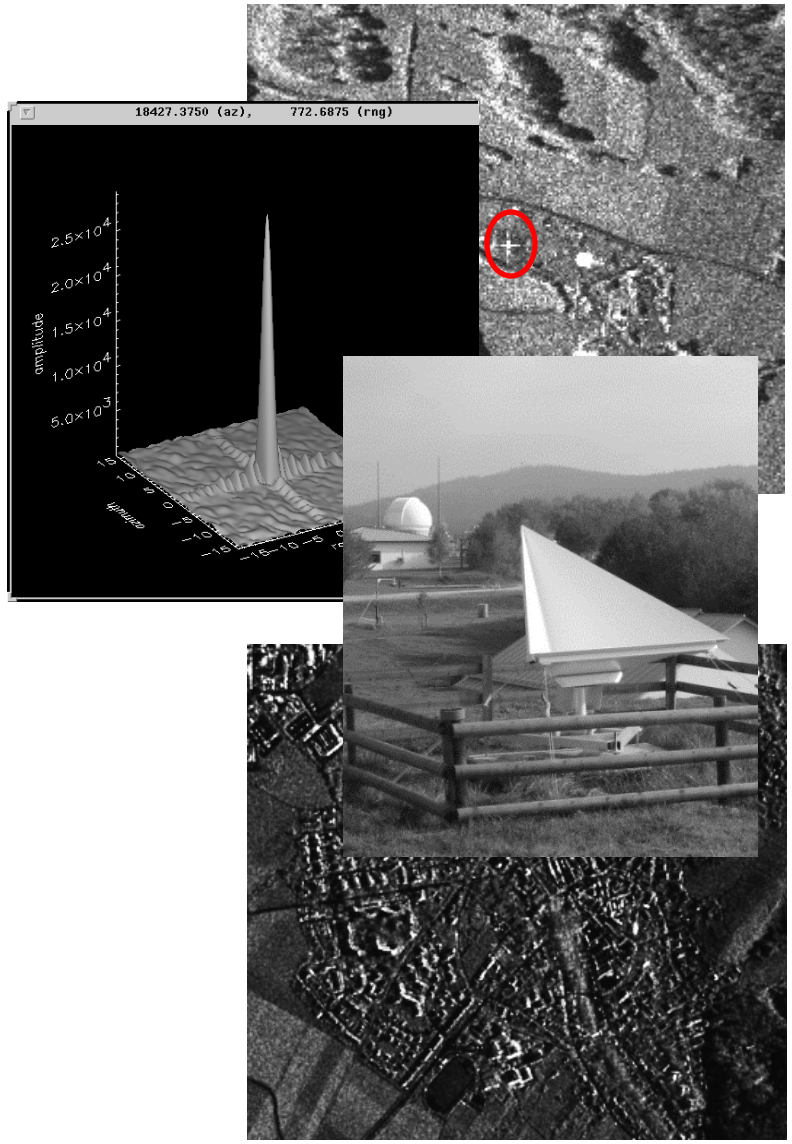
Localizationof Points in Images

- Corner reflector: < 1/100 pixel accuracy achievable with point target analysis, e.g.

$$\sigma_{\text{point}} = \frac{\sqrt{3}}{\pi}\frac{1}{\sqrt{SCR}} \approx \frac{0.55}{\sqrt{SCR}} \quad [\text{res. elem.}]$$

- E.g. 1.5 m CR, 1m resolution → 2 mm error

- Persistent Scatterers: modified point target analysis
  - < 1/100 pixel accuracy (SCR)

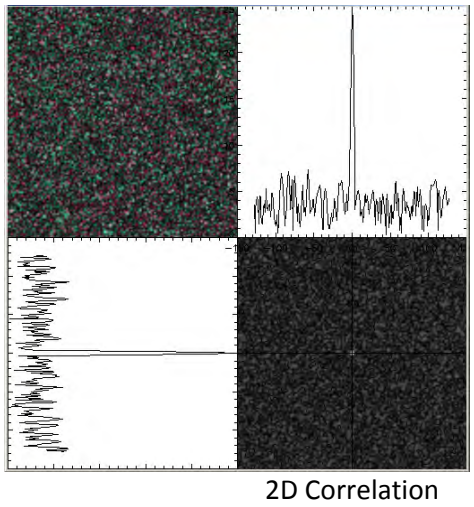


Localizationof Features in Images

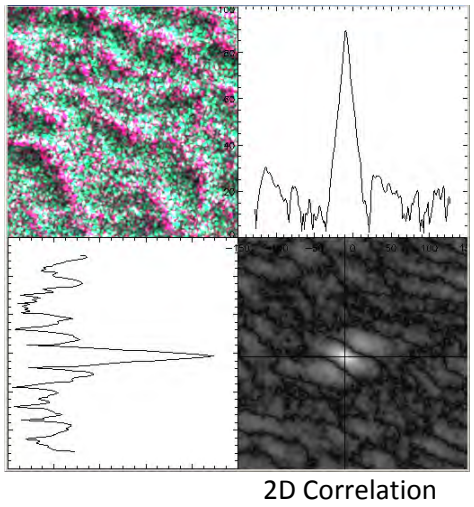
- Contrast / Texture: (in)coherent correlation
  - < 1/100 pixel accuracy (SNR)

$$\sigma_{area} = \sqrt{\frac{3}{2\,N}}\,\frac{\sqrt{1-\gamma^2}}{\pi\,\gamma}$$

Speckle



E.g. coherent snow

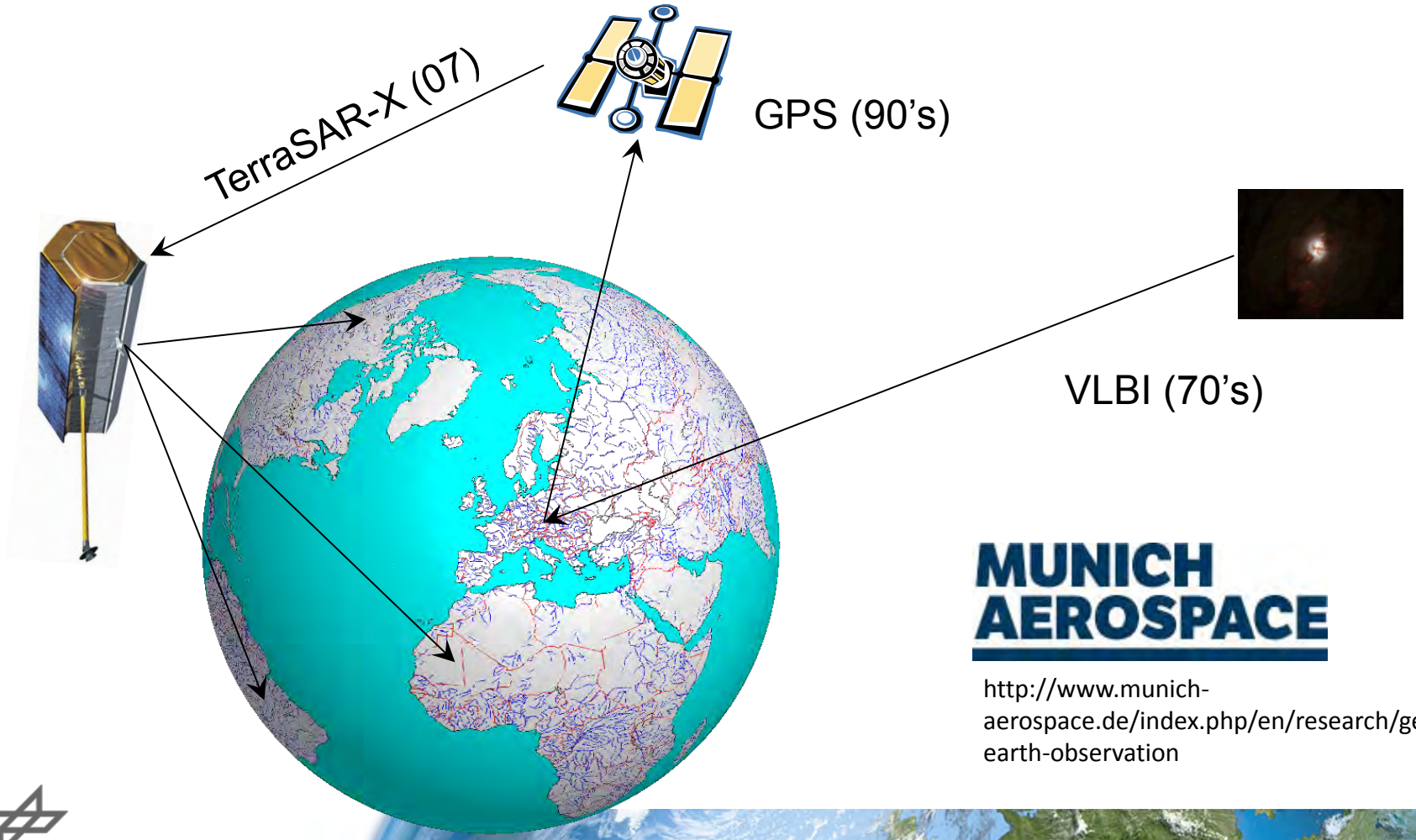


Feature

E.g. glacier crevasses

VLBI → GPS →SAR Imaging Geodesy

“SAR as a next generation positioning method?”



MUNICH AEROSPACE

http://www.munich-aerospace.de/index.php/en/research/geodetic-earth-observation

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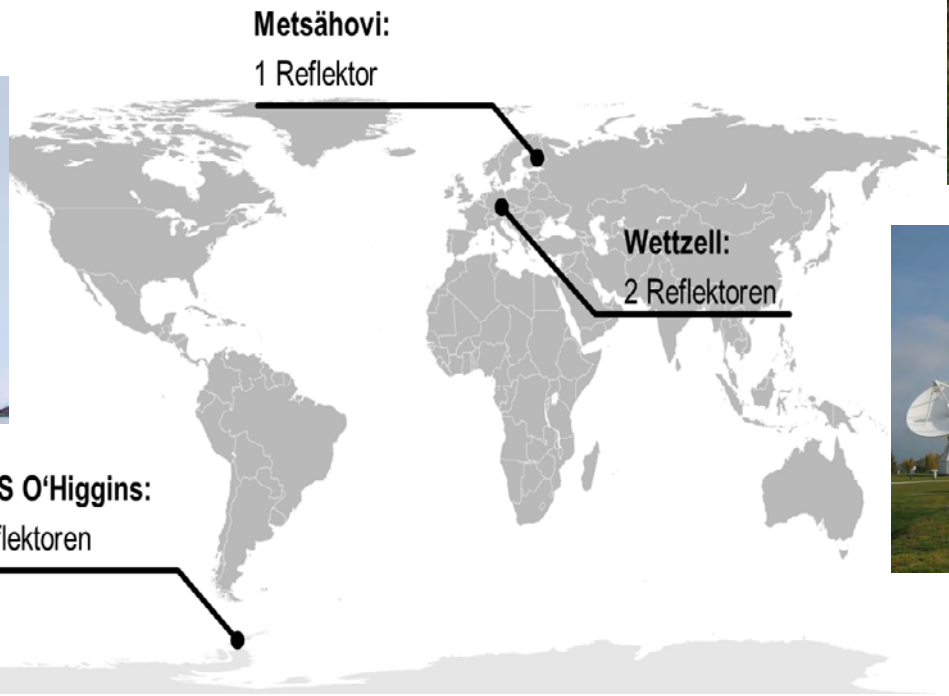
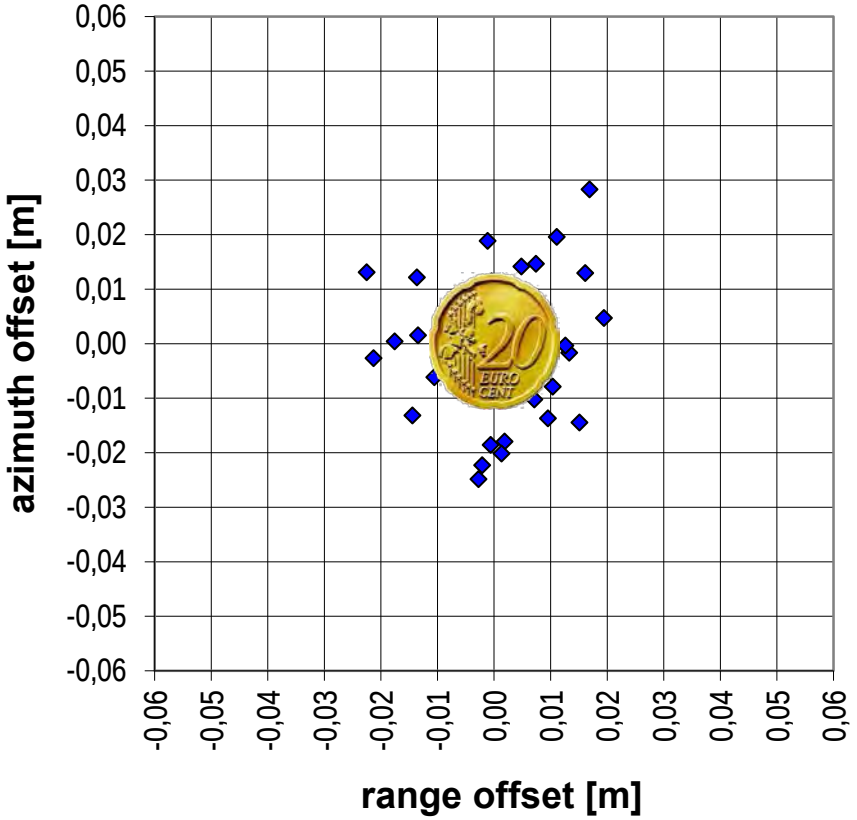
DLR‘s Geodetic SAR-Calibration Network



TerraSAR-X Slant Range Localization Accuracy

Reflector Wettzell

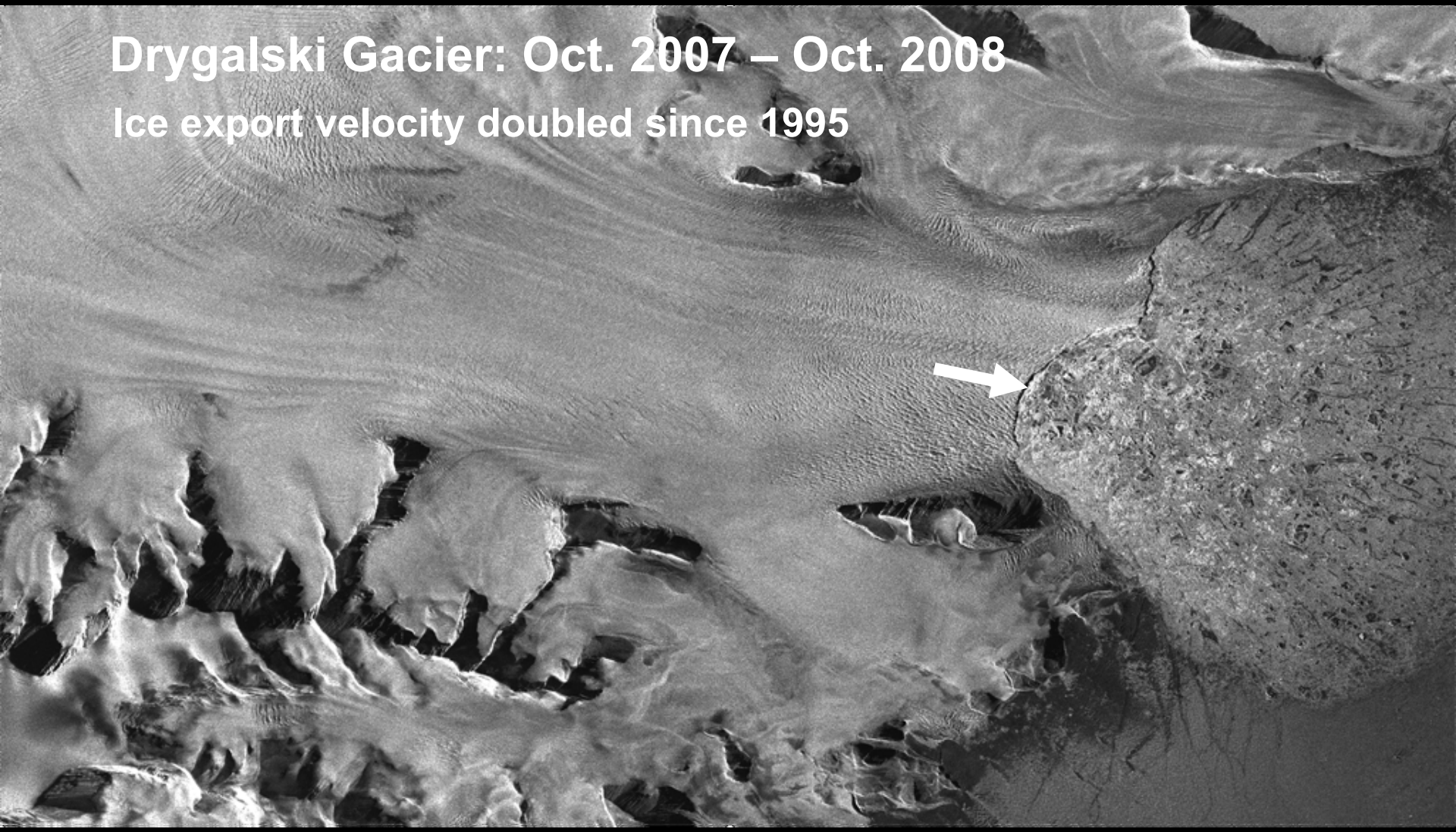


After corrections of solid earth tides, atmospheric refraction (H_2O, TEC), pole tides etc.

- **Range error: σ=10.8 mm**
- **Az. error: σ=13.0 mm**

Imaging Geodesy Application Examples

Velocity Measurements without GCPs

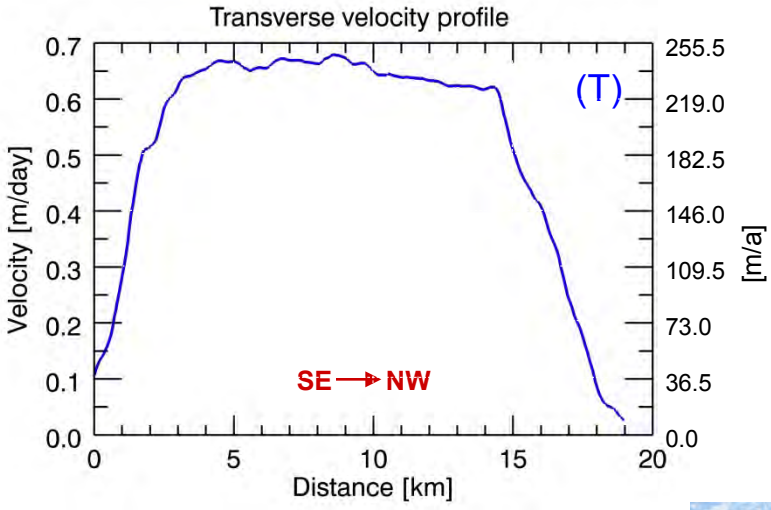


Video: M. Eineder

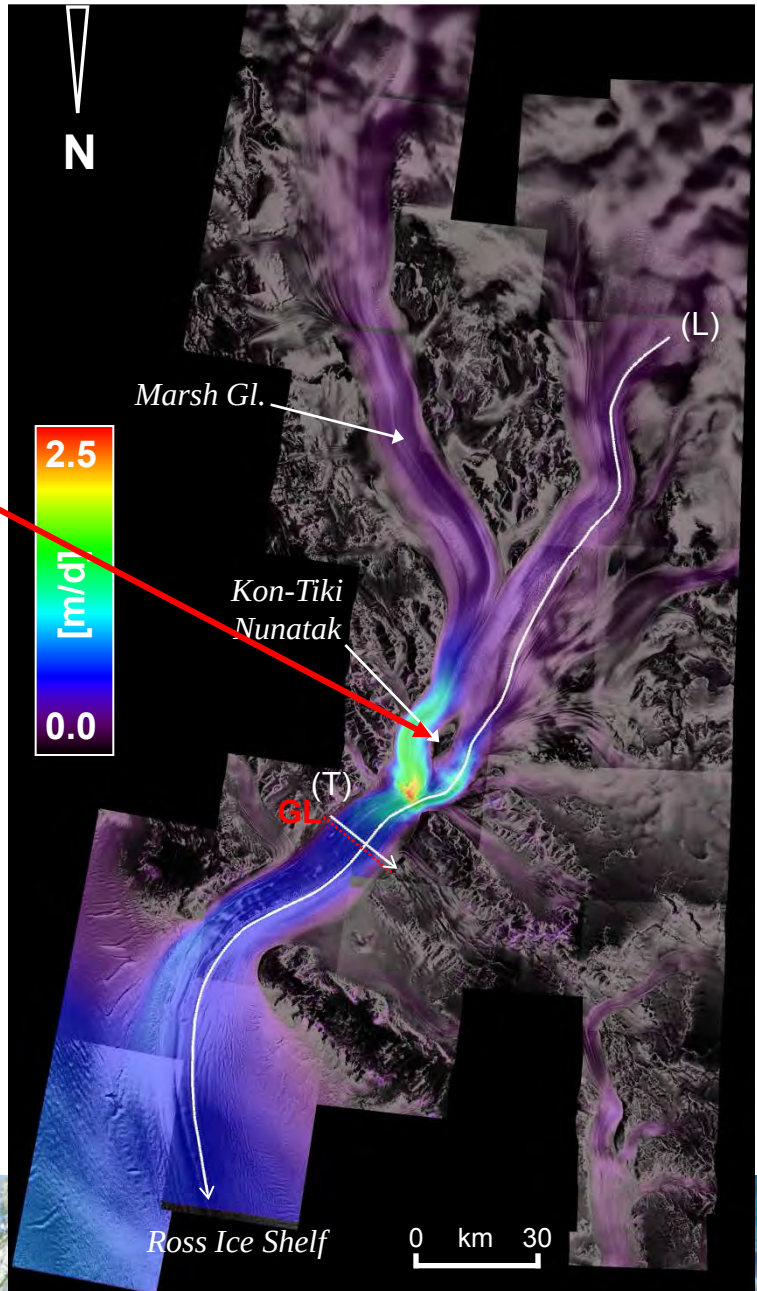
Mass changes of outlet glaciers along the Nordensjköld Coast, northern Antarctic Peninsula, based on TanDEM-X satellite measurements, H. Rott et al, Geophysical Research Letters, 2014.

Ice Surface Velocity from TerraSAR-X

Nimrod Glacier

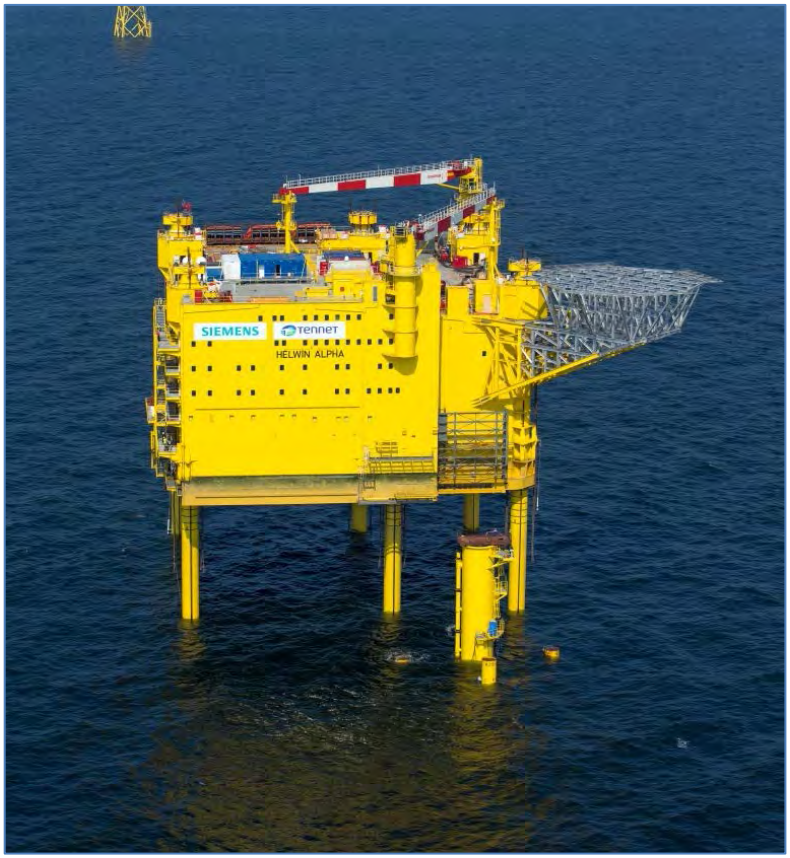


Plug-like shape: strong side drag



W. Abdel Jaber,
D. Floricioiu, DLR-IMF

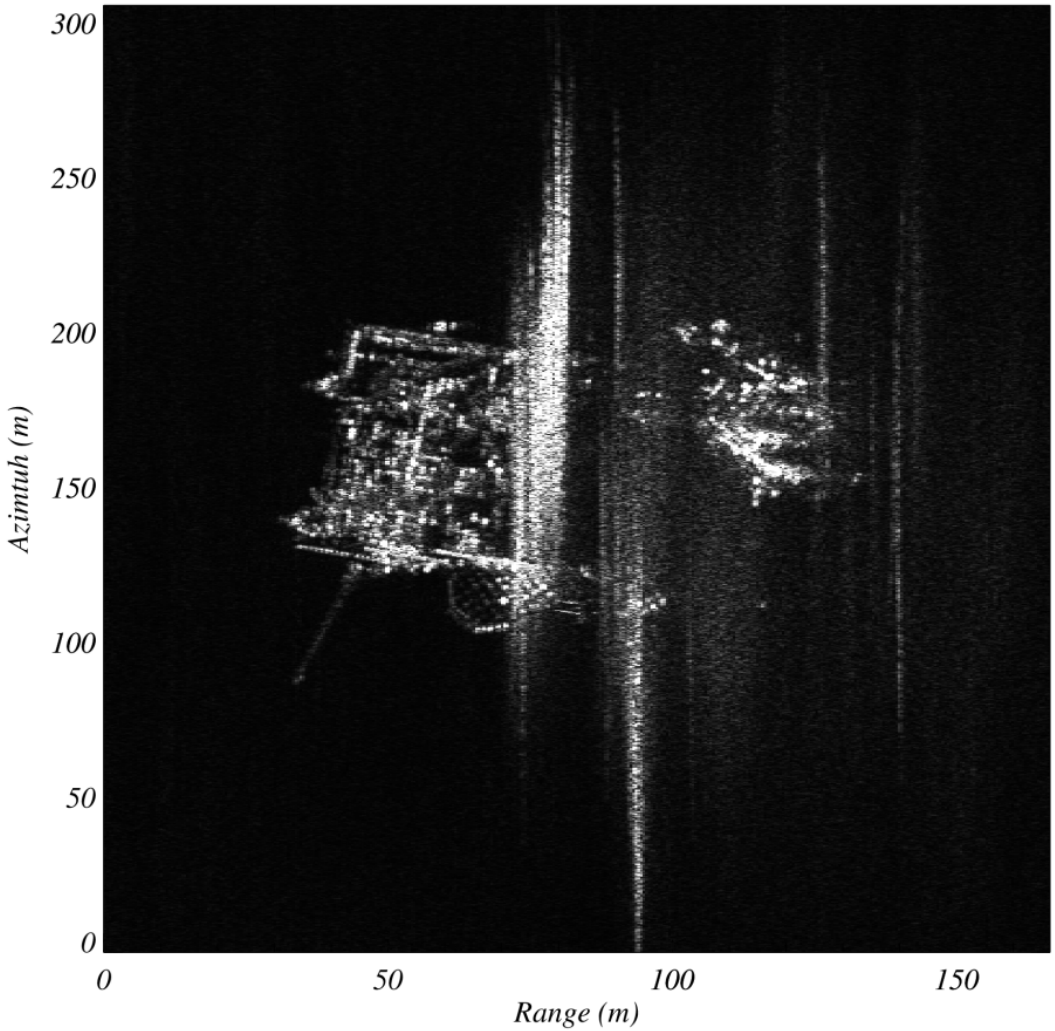
Applications: Offshore Platform Monitoring. Test site



- Helwin1: seabed attached platform installed by Siemens in the North Sea in 2013
- Converts AC power generated by wind farms into low-loss DC for transmission to land
- Closest land more than 40 km away

Duque S. et al., Accurate Measurements Using TerraSAR-X And TanDEM-X Data Without Any Reference, IGARSS 2014, DLR-IMF

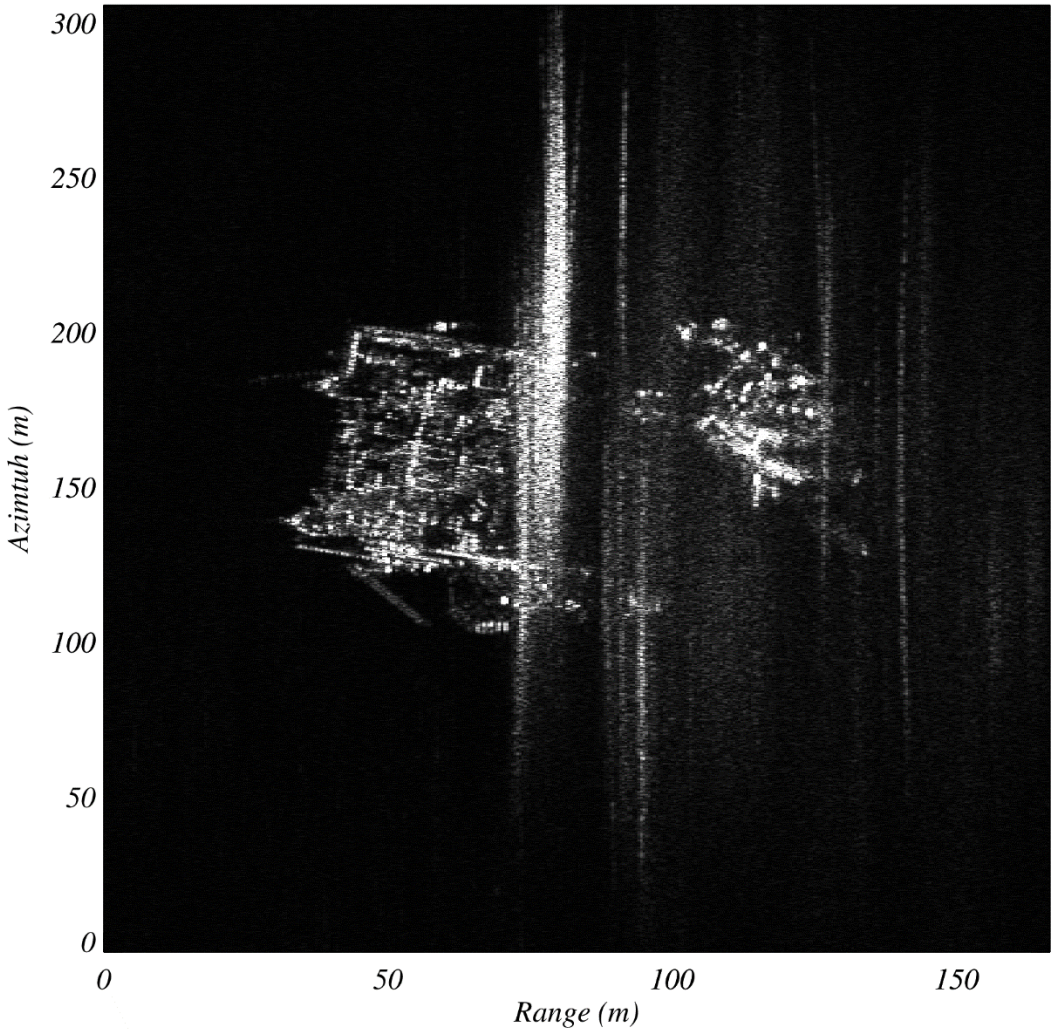
Master Image



TerraSAR-X
Staring
Spotlight
4.11.2013

DLR

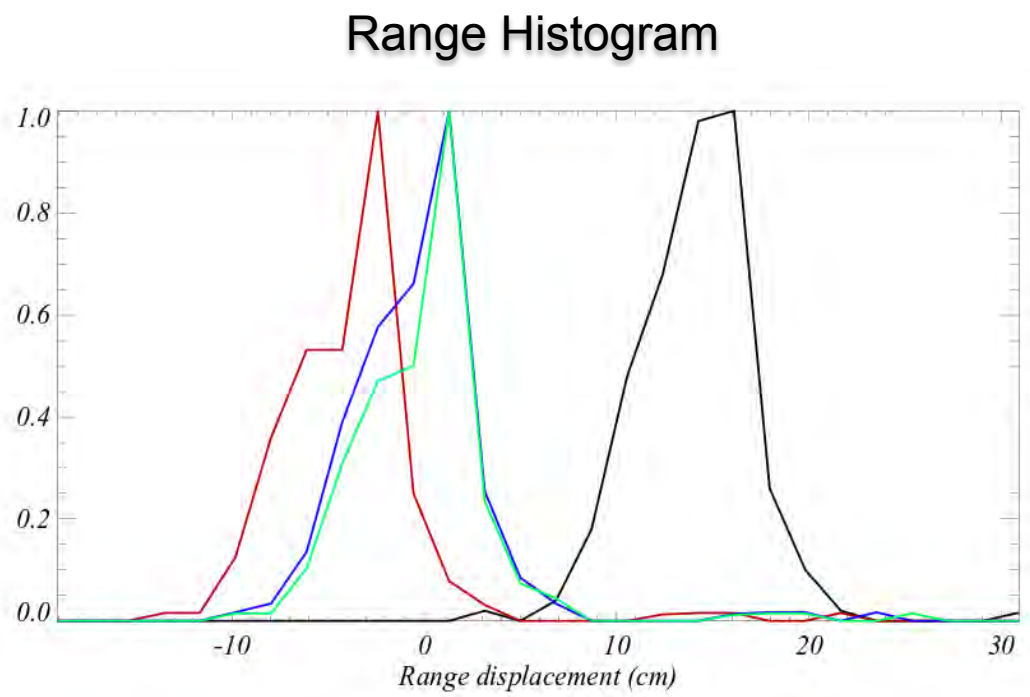
Slave Image



TerraSAR-X
Staring
Spotlight
15.11.2013

DLR

Applications: Offshore Platform Monitoring



Incoherent Cross Correlation (ICC)

ICC + tropo

ICC + tropo + SET

ICC + tropo + SET + TOL

$\mu_{rg} = 0.7\ cm$

$\sigma_{rg} = 1.1\ cm$

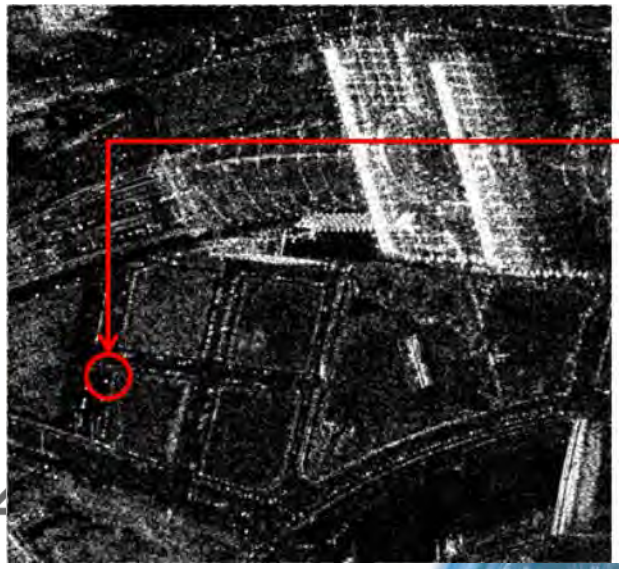
Duque S. et al., Accurate Measurements Using TerraSAR-X And TanDEM-X Data Without Any Reference, IGARSS 2014, DLR-IMF

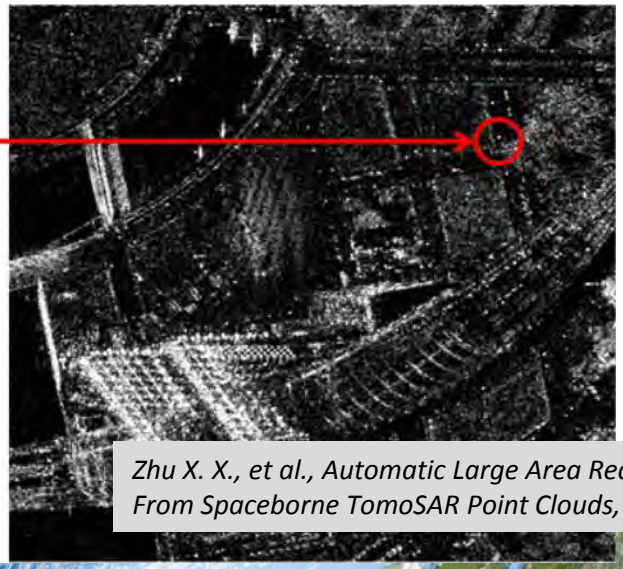
3D Localization of Reflectors using Stereo-SAR

A lamp pole near the central railway station
Coordinates in the ITRF 2008 reference frame:

$$x = 3783630.014 \pm 0.010\text{m};$$
$$y = 899035.0040 \pm 0.010\text{m};$$
$$z = 5038487.589 \pm 0.011\text{m}.$$

Diameter of ca. 20cm → systematic bias, still to be considered!

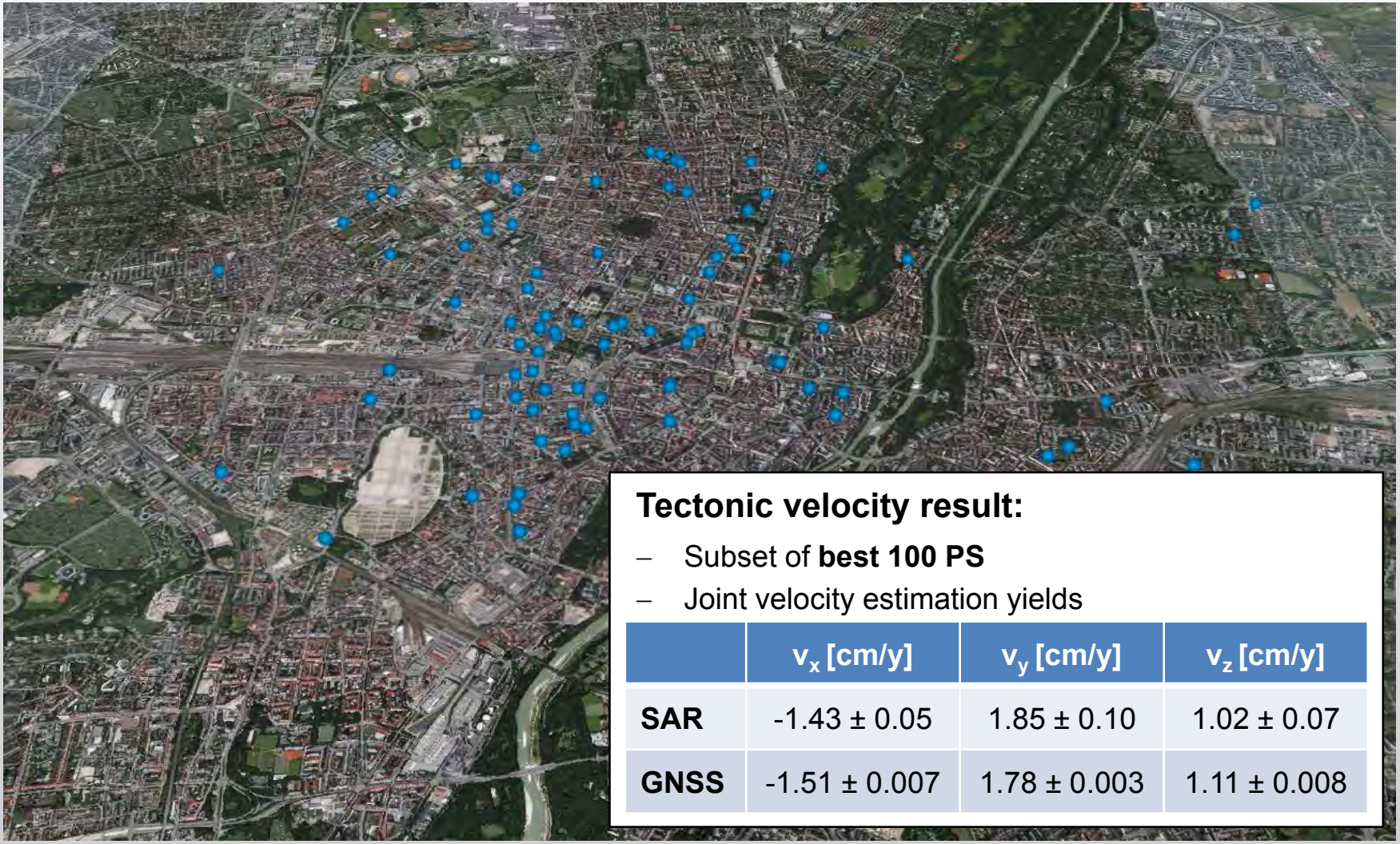




Zhu X. X., et al., Automatic Large Area Reconstruction Of Building Façades From Spaceborne TomoSAR Point Clouds, IGARSS 2014, DLR-IMF

Automated Munich processing

- Geodetic Stereo SAR for about **1200 PS** in the city of Munich (0.2 m)



Tectonic velocity result:

- Subset of **best 100 PS**
- Joint velocity estimation yields

	v_x [cm/y]	v_y [cm/y]	v_z [cm/y]
SAR	-1.43 ± 0.05	1.85 ± 0.10	1.02 ± 0.07
GNSS	-1.51 ± 0.007	1.78 ± 0.003	1.11 ± 0.008

Erdbeben in Nepal: Satelliten...

www.spiegel.de/wissenschaft/natur/erdbeben-in-nepal-satellitenbild-zeigt-bodenbewegung-a-1031575.html

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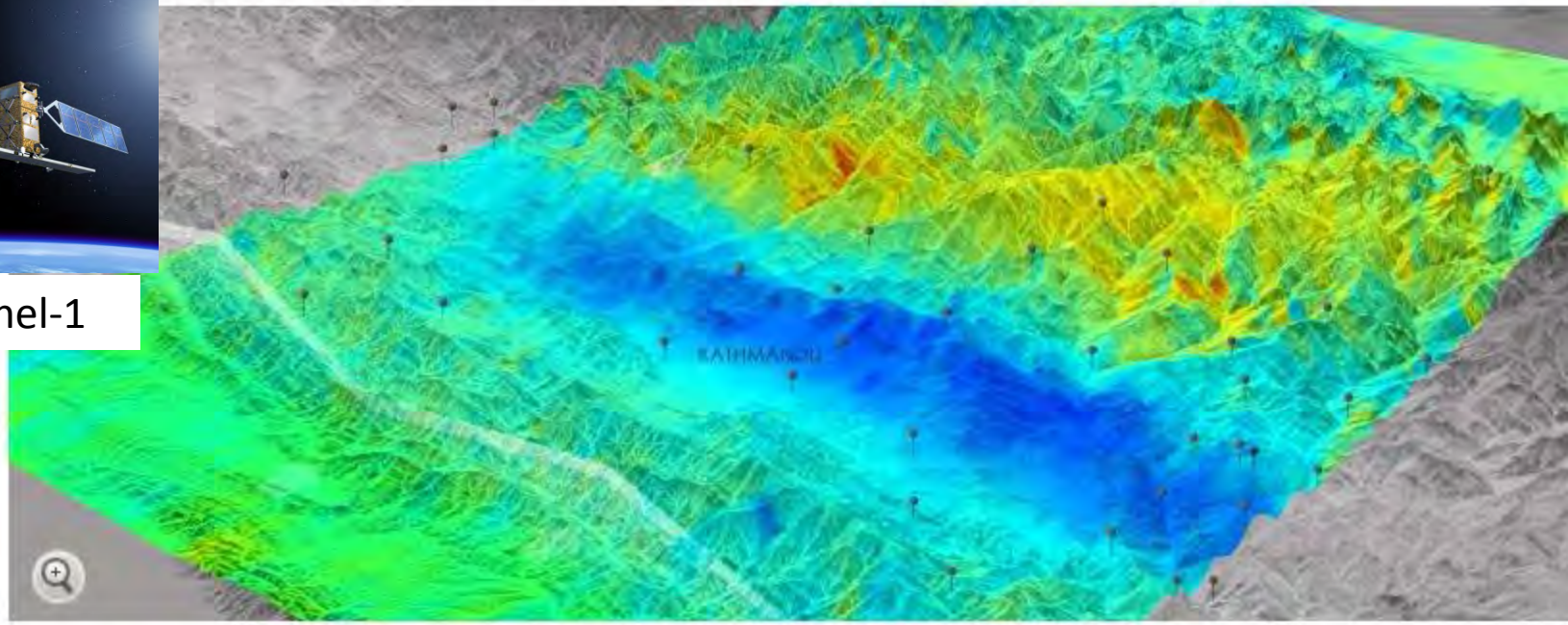
Nachrichten > Wissenschaft > Natur > Satellitenbild der Woche > Erdbeben in Nepal: Satellitenbild zeigt Bodenbewegung

Satellitenbild der Woche: Wie das Erdbeben Nepal verändert

Data: Sentinel-1



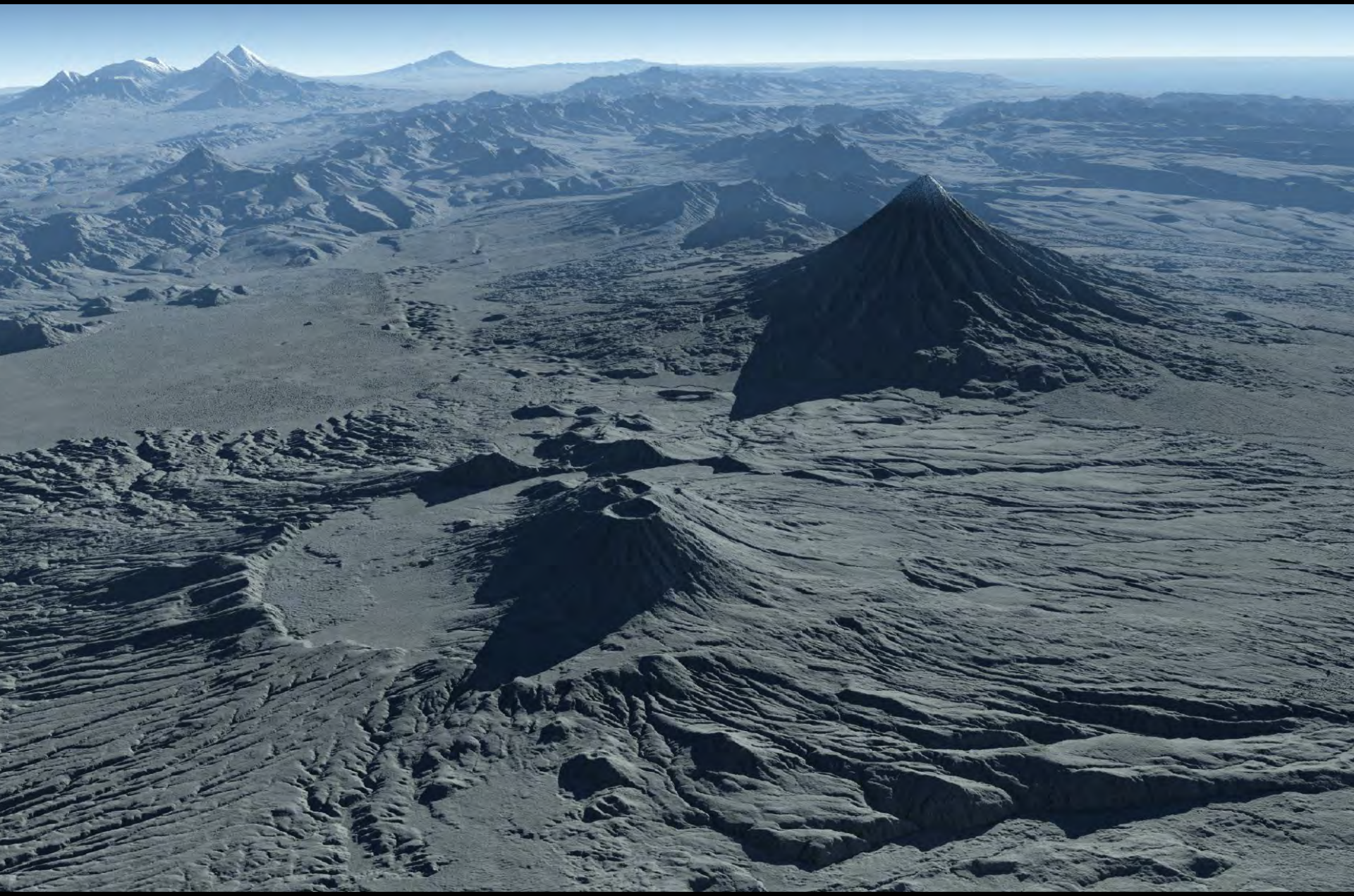
Bodenveränderung nach Erdbeben: Blau zeigt Hebung, Gelb und Rot Senkung

Rodriguez

Das schwere Erdbeben hat katastrophale Folgen für Nepal - und das Land gravierend verändert. Ganze Landstriche wurden höher und tiefer gelegt.

TanDEM-X DEMs

TanDEM-X DEM Kamtchatka

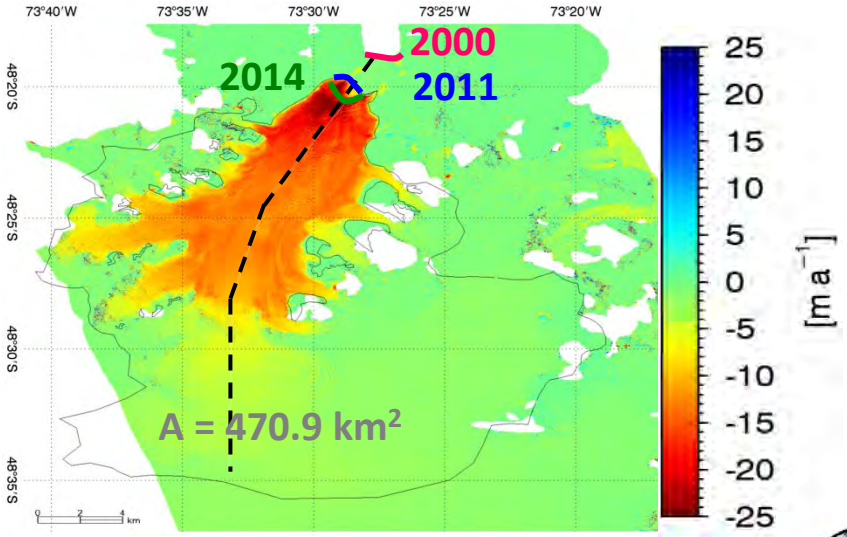


Mass balance of glaciers from DEM differencing

$$\frac{dM}{dt} = \int_A \rho \frac{\Delta h}{\Delta t} dA$$

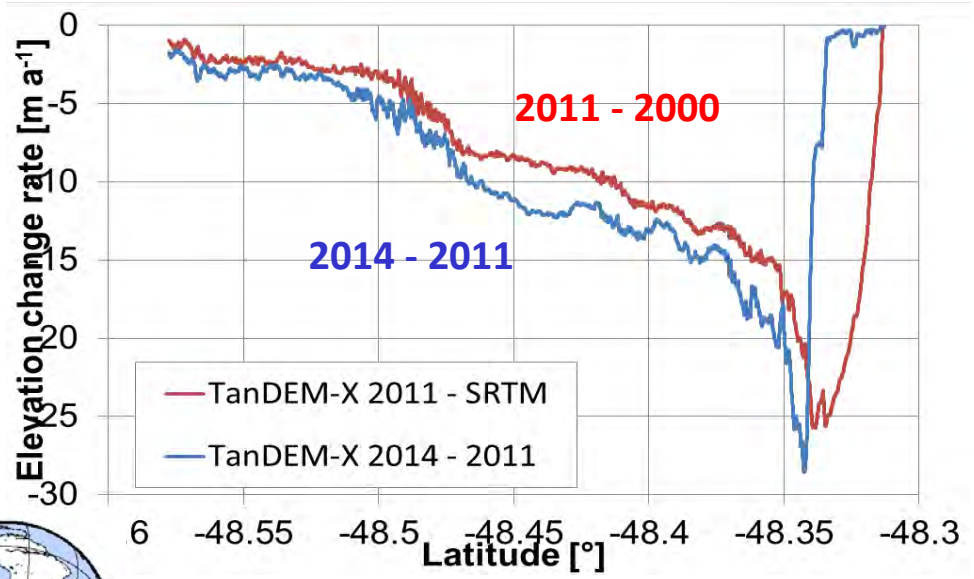
Surface elevation change rate

TanDEM-X 21.04.2014 - 9.05.2011



J. Montt, South Patagonia Icefield

Acceleration of surface lowering



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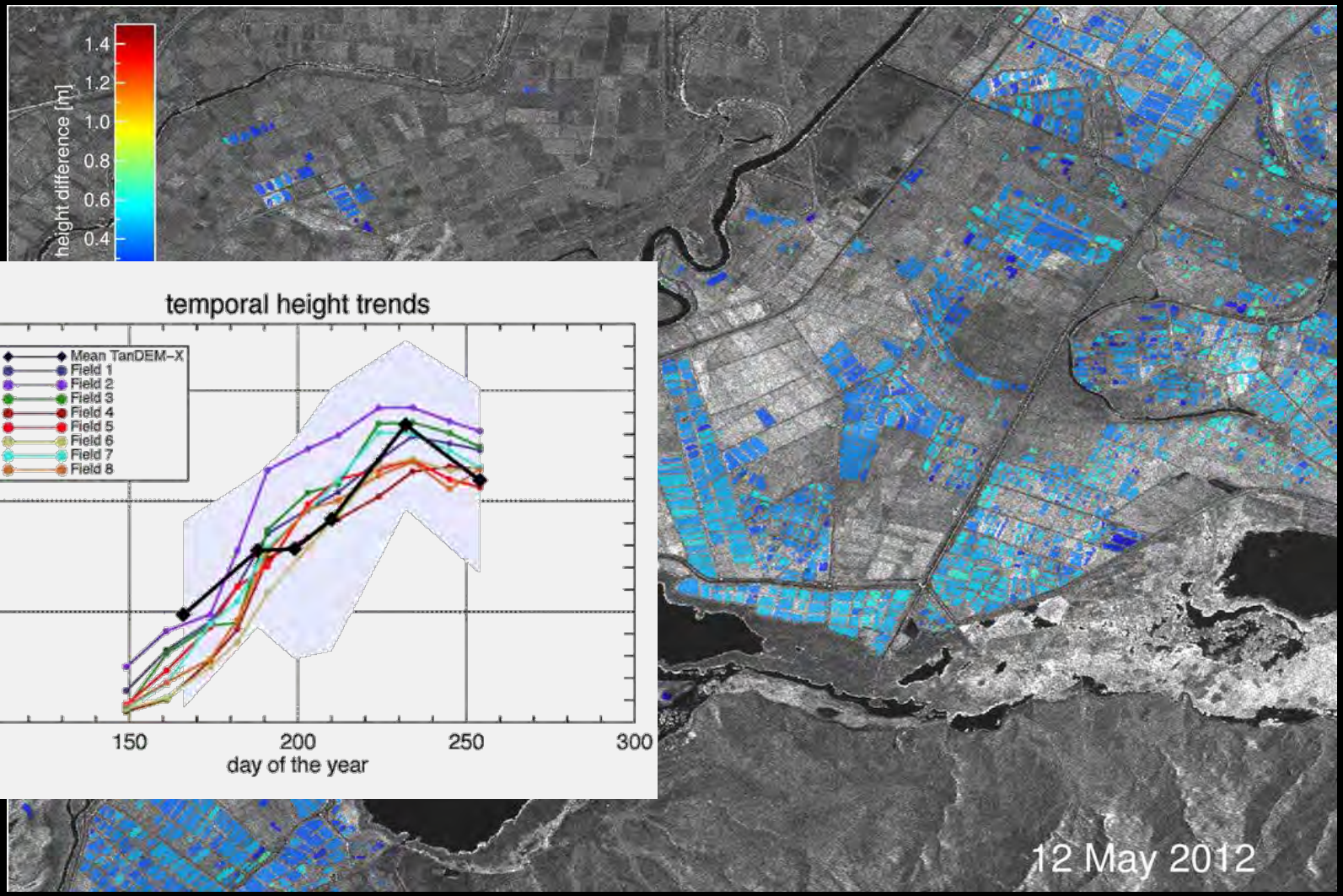
TanDEM

Rice Growth Monitoring using MultiTemporal DEMs



Rossi, C.; Erten, E., Paddy-Rice Monitoring Using TanDEM-X,, IEEE TGRS 2015

High Resolution SAR Interferometry

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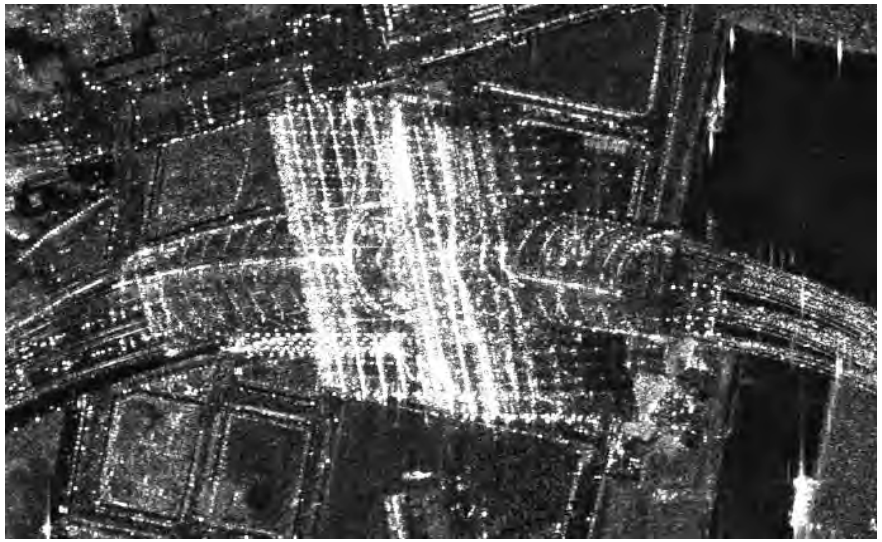
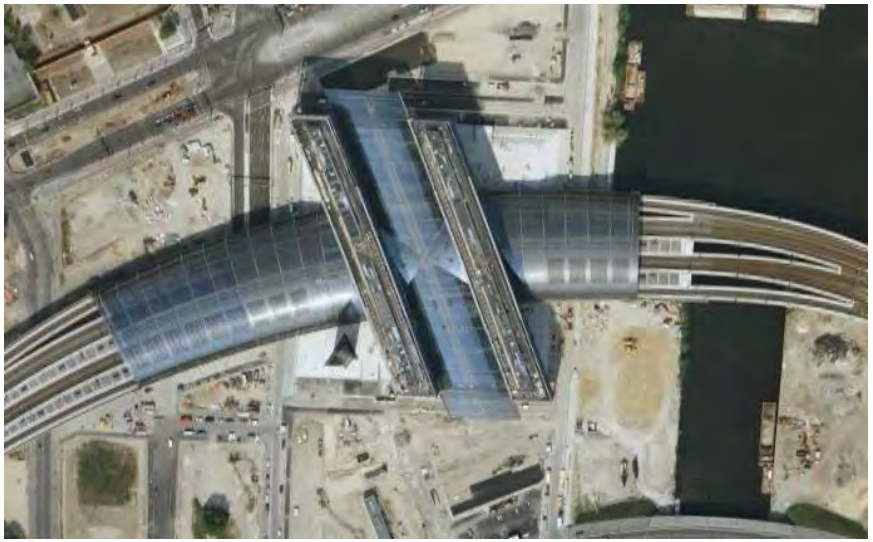
Case Study: Berlin, Central Railway Station

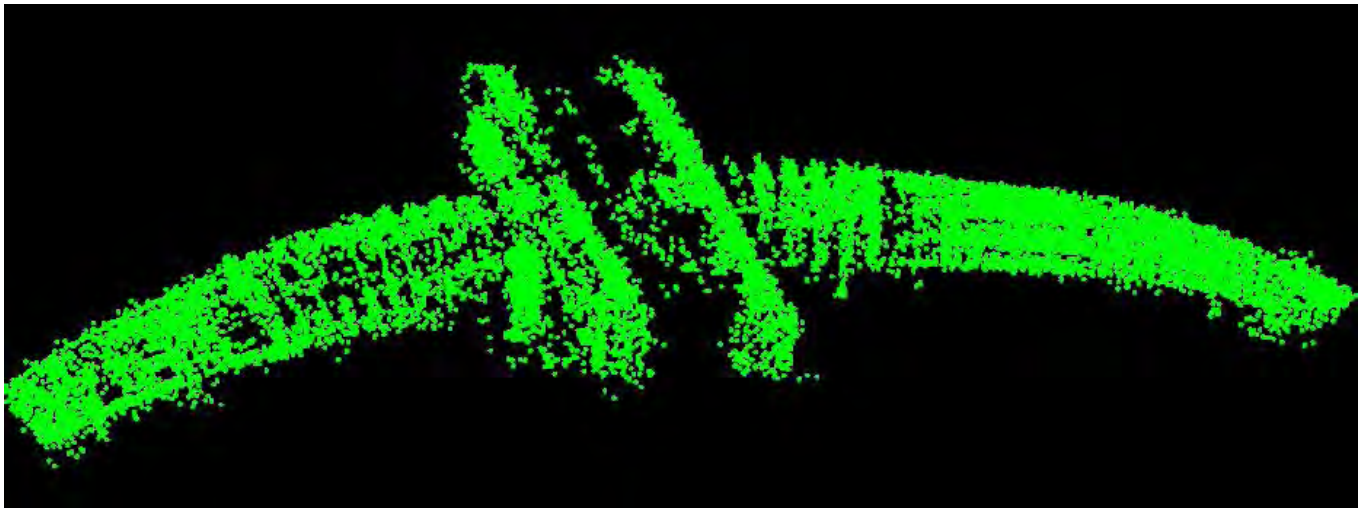


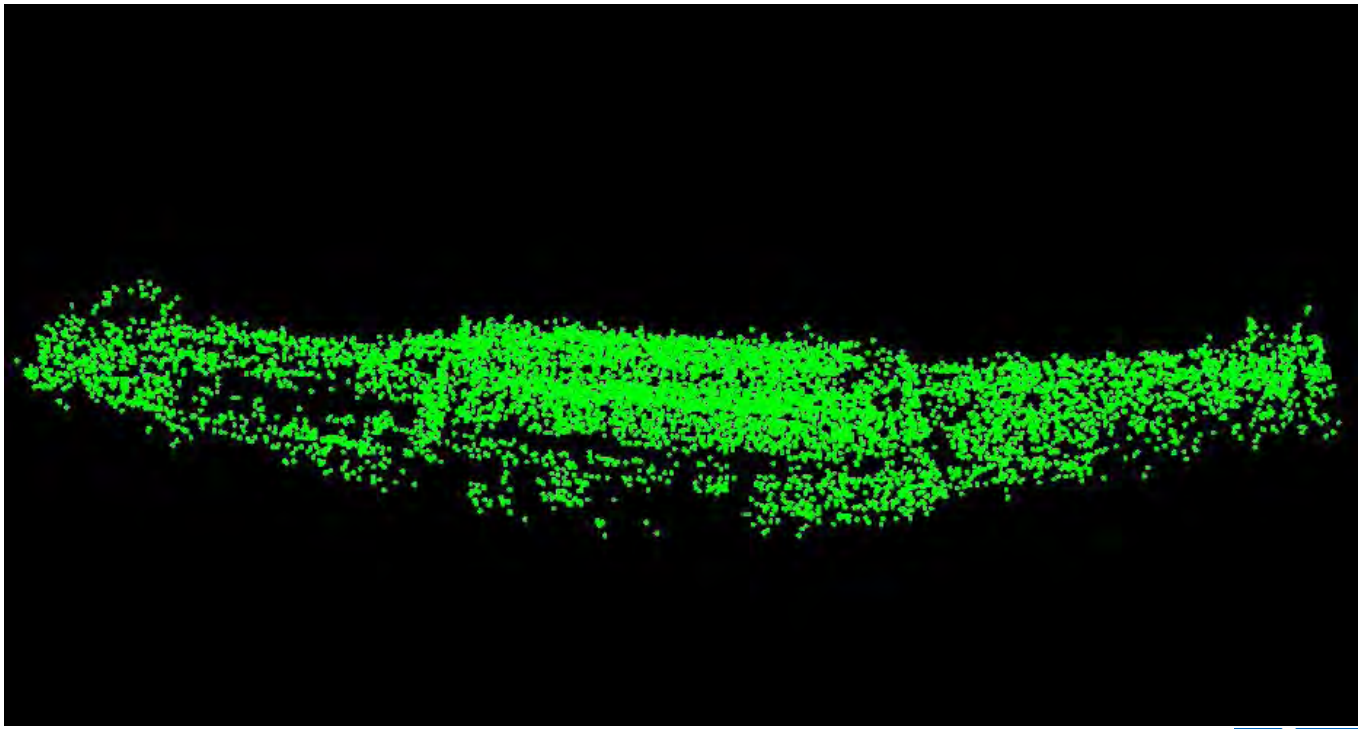
TerraSAR-X



Google Earth

DLR





S. Gernhardt TUM

Height Dependent Motion on Buildings (I)

SV Verlagsgebäude, Munich

- Recently built steel-concrete building
- Height dependent linear motion

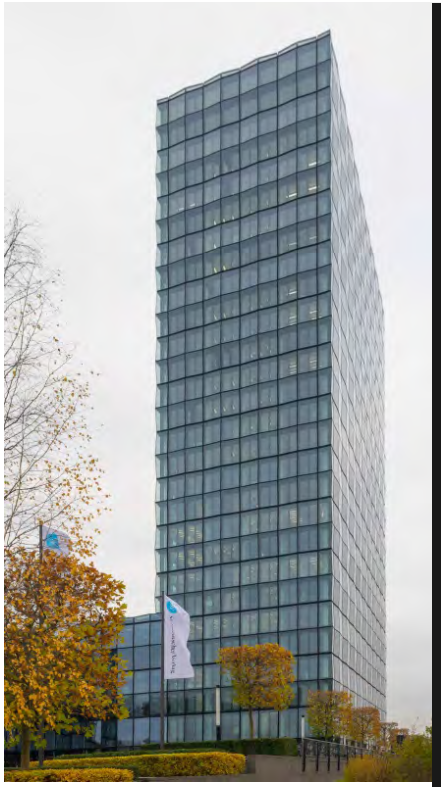
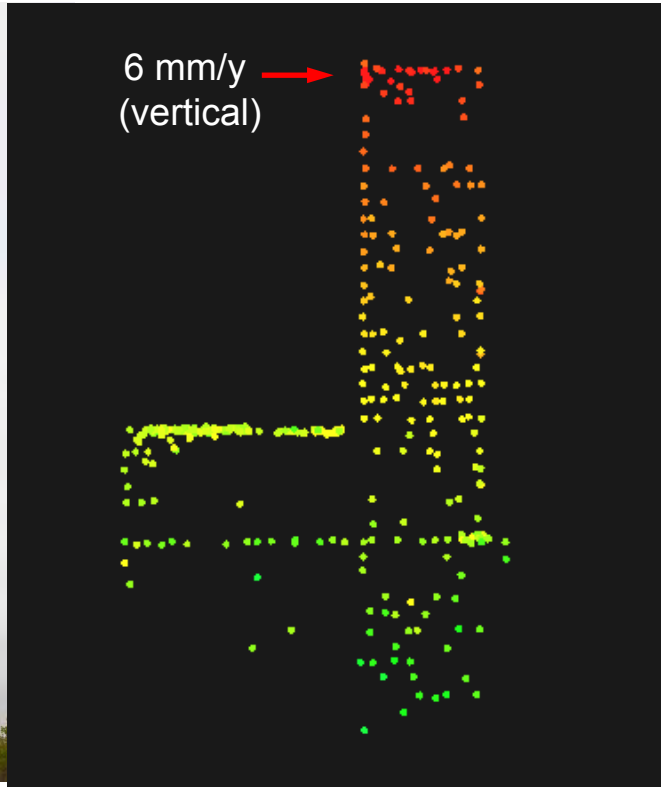


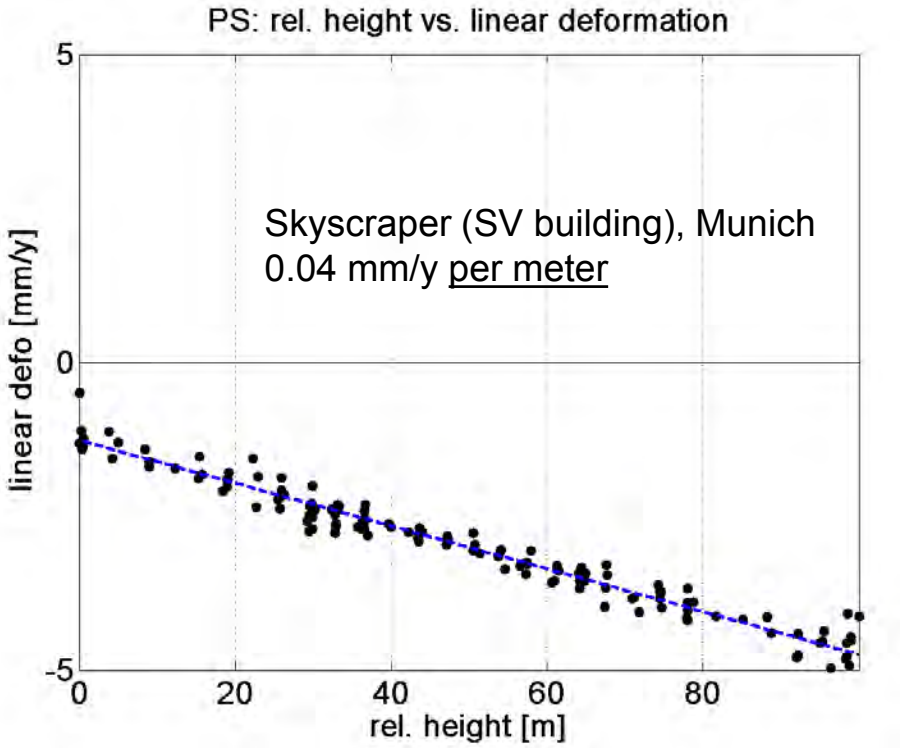
Photo: M. Eineder



Color: Linear deformation

S. Gernhardt, TUM (2014)

Height Dependent Motion on Buildings (II)



Reason: compaction of concrete (dehydration & creeping) !

Gernhardt G, Bamler R (2015) Structural Deformation and Non-seasonal Motion of Single Buildings in Urban Areas Revealed by PSI. Proc. Joint Urban Remote Sensing Event, Lausanne, submitted.

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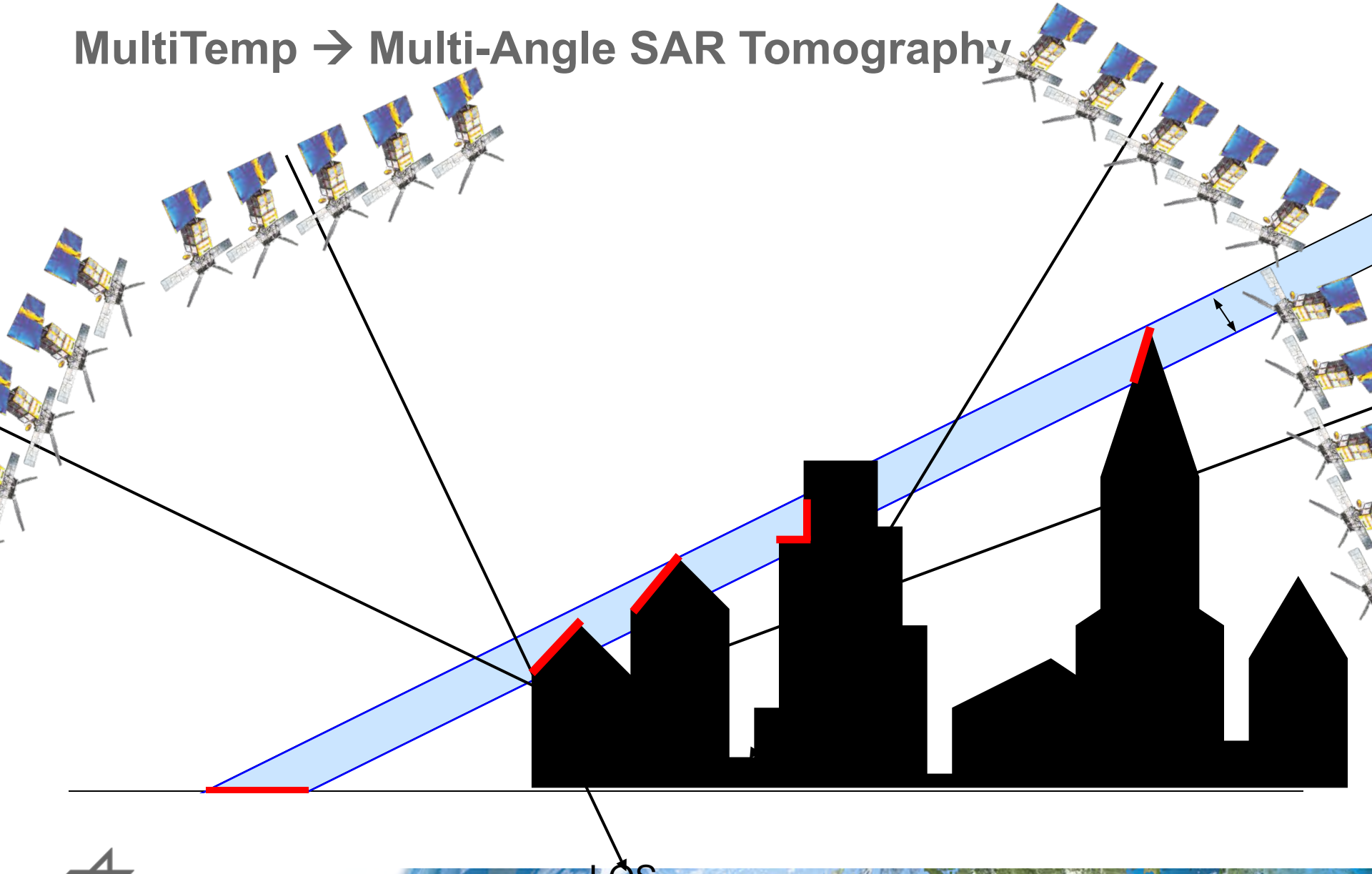
SAR Tomography

MultiTemp → Multi-Angle SAR Tomography



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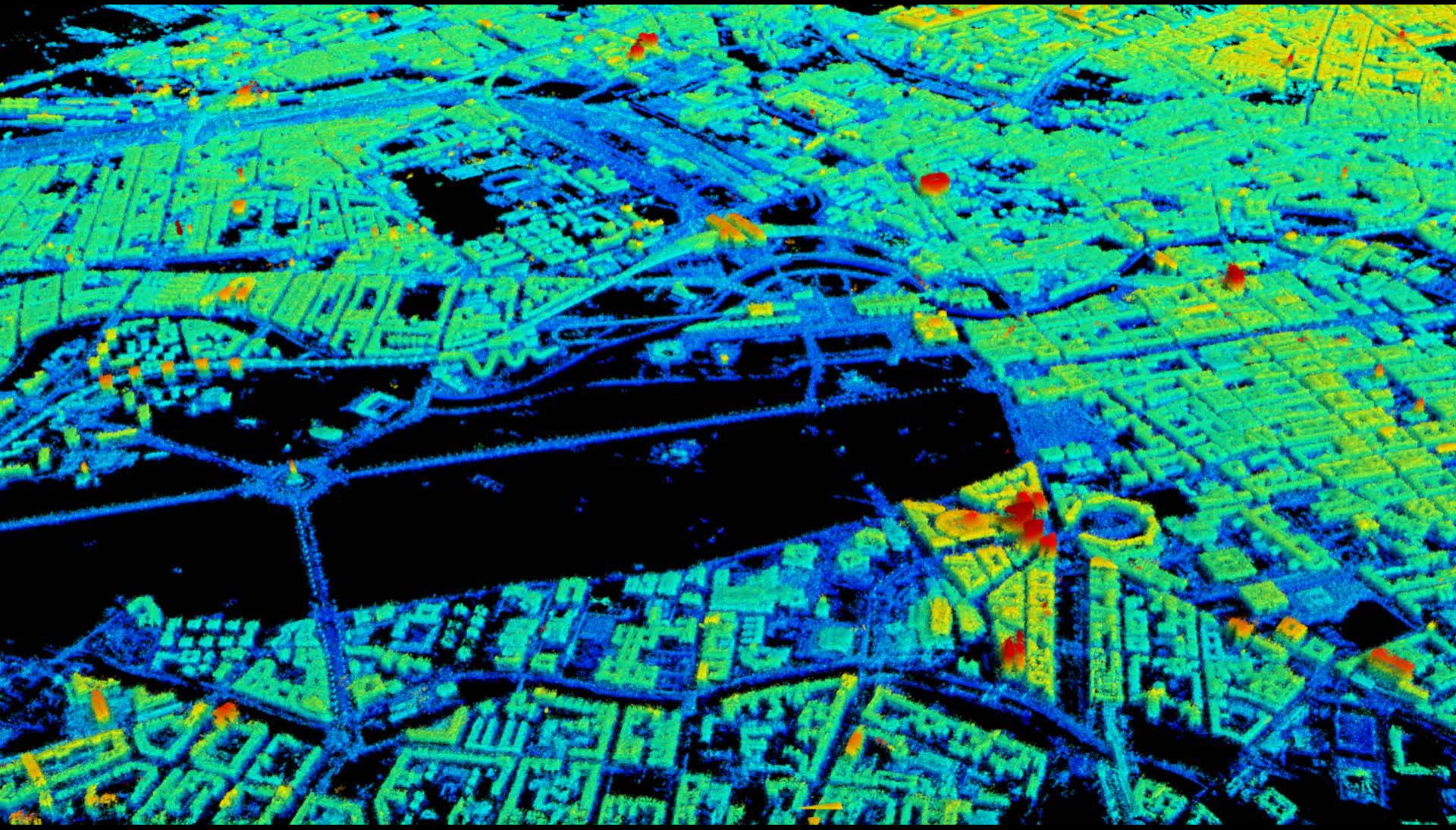
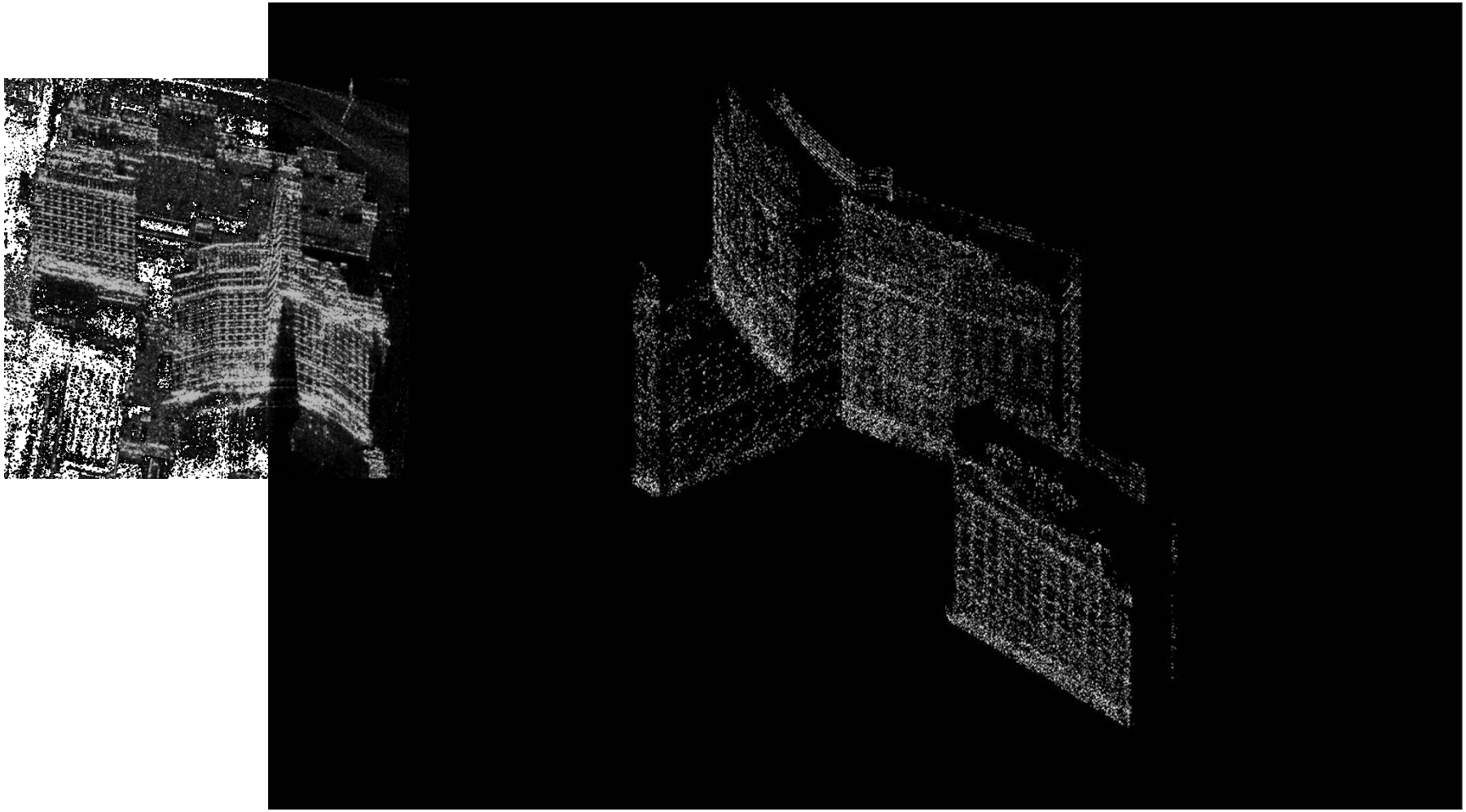
Tomographic SAR Imaging of Urban Areas (>600 img.)



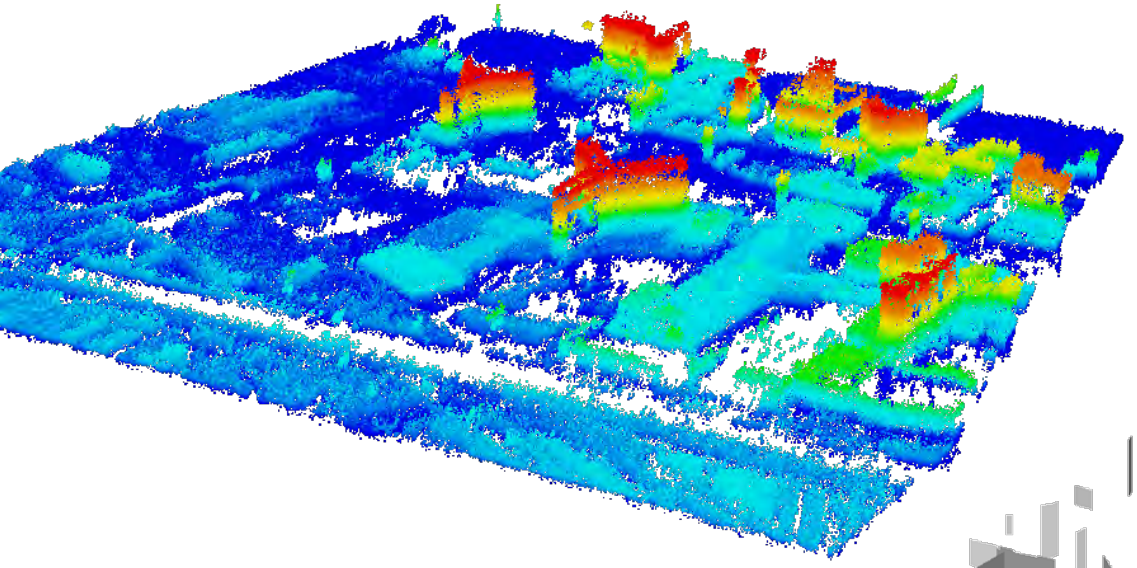
Gernhardt, Zhu DLR/TUM

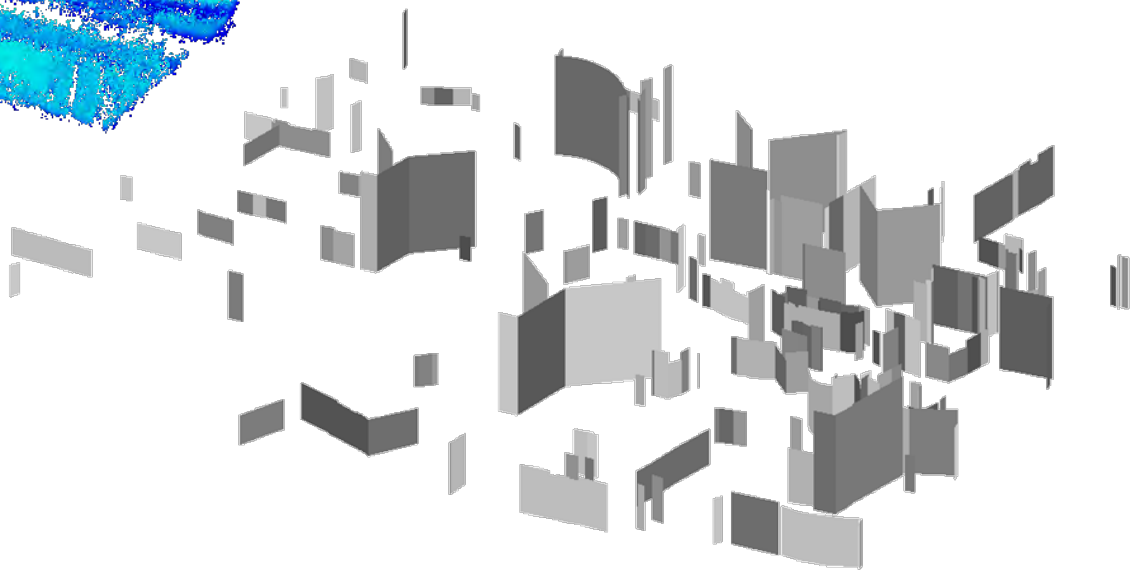
2D → 3D SAR: Separation of Wall / Ground Reflection



Shahzad/Zhu TUM/DLR-IMF

From TomoSAR Point Clouds to Objects – Façade

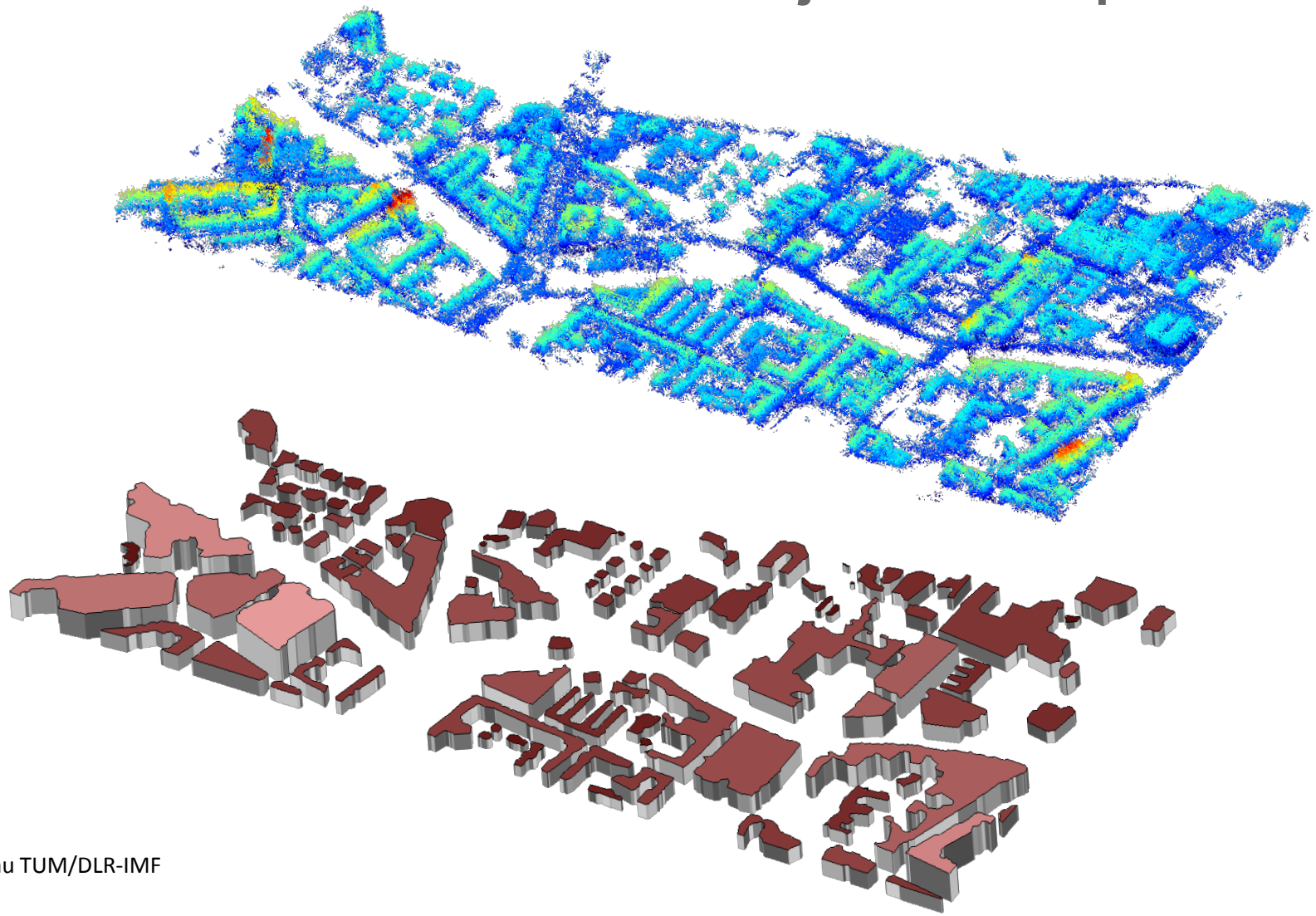




Shahzad/Zhu TUM/DLR-IMF

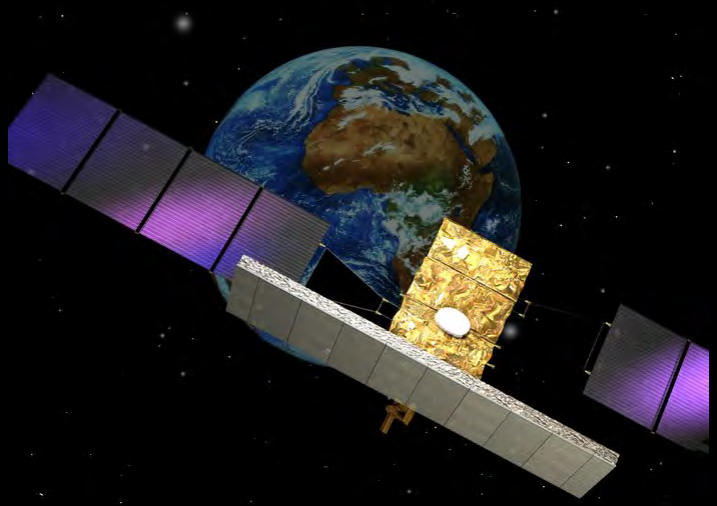
DLR

From TomoSAR Point Clouds to Objects – Footprint



Shahzad/Zhu TUM/DLR-IMF

Sentinel-1A



Cosmo-SkyMed

What comes next?
MultiSensoral?

ALOS-2

TerraSAR-X/TanDEM-X