TerraSAR-X and TanDEM-X: Mission Status and Outlook

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TanDEM-X / TerraSAR-X Mission Status

TerraSAR-X (launch 15 June 2007):

- Operational phase since 07.01.2008
- Provision of high-resolution SAR data to science and commercial users
- Arbitrary ordering of acquisitions with different imaging modes and polarizations of individually chosen regions of interest
- Either TSX or TDX is used for TerraSAR-X acquisitions

TanDEM-X (launch 21 June 2010):

- *__T__erraSAR-X __a__dd-o__n__ for __D__igital __E__levation __M__easurement* acquisition of raw data for a global DEM within 3 years
- Acquisition of raw data for a high resolution global DEM within 3 years
- Close formation flight to establish a bi-static SAR interferometer
- Global DEM acquisition since 12.12.2010
- Preplanned acquisitions for the global DEM

➔ *Manifold technical and operational challenges…*

DLR

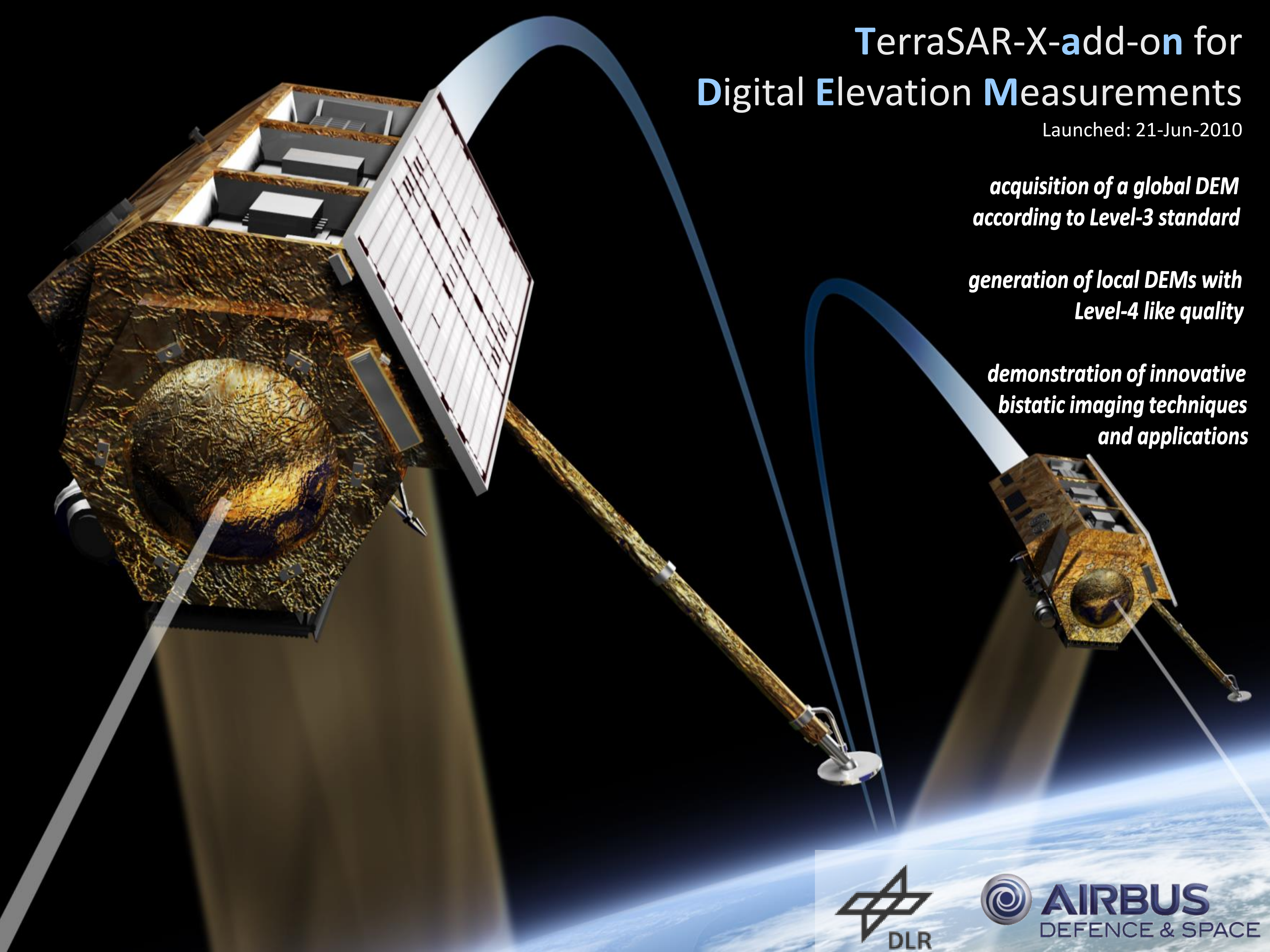
TerraSAR-X-add-on for Digital Elevation Measurements

Launched: 21-Jun-2010

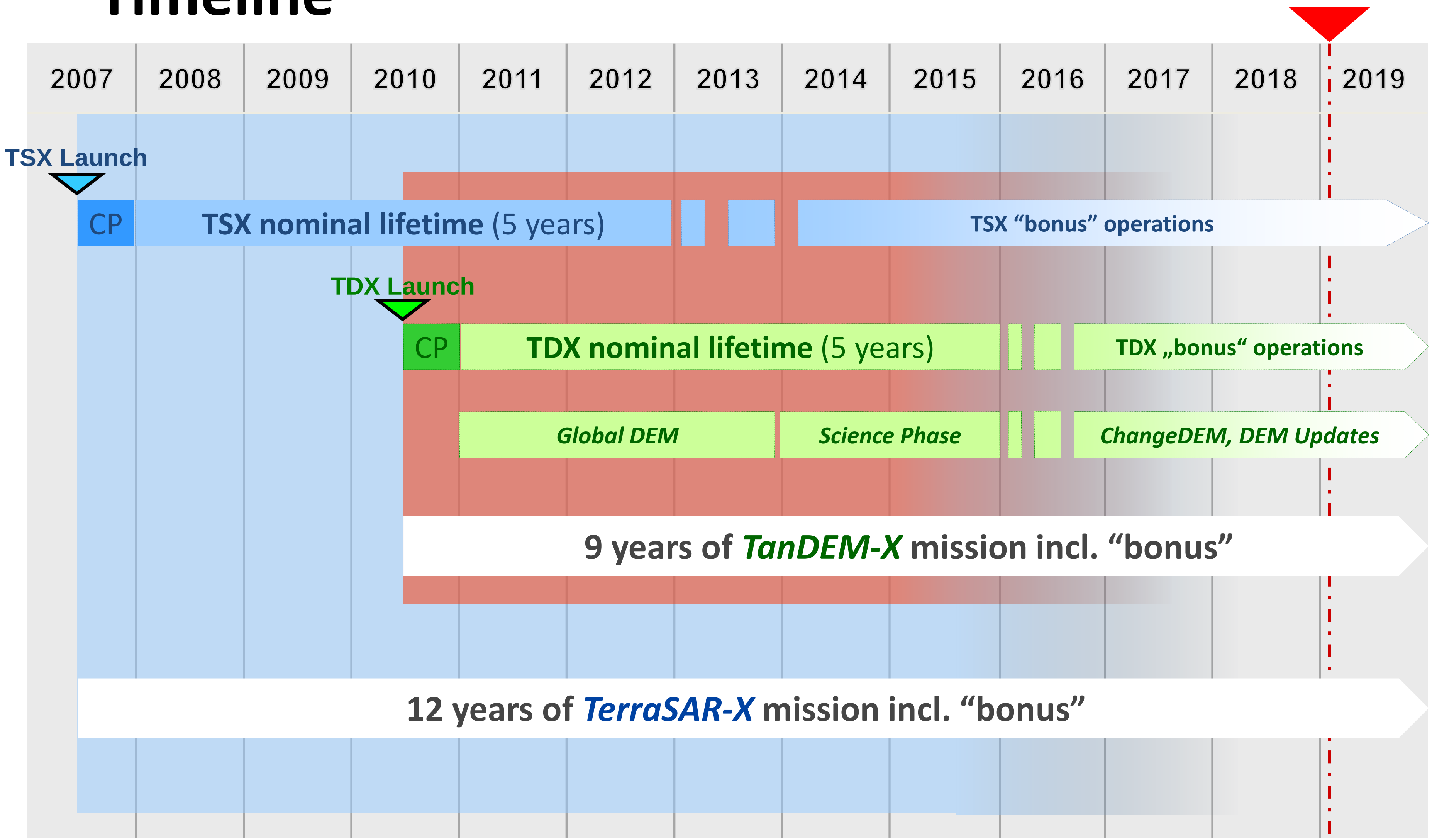
acquisition of a global DEM according to Level-3 standard

generation of local DEMs with Level-4 like quality

demonstration of innovative bistatic imaging techniques and applications

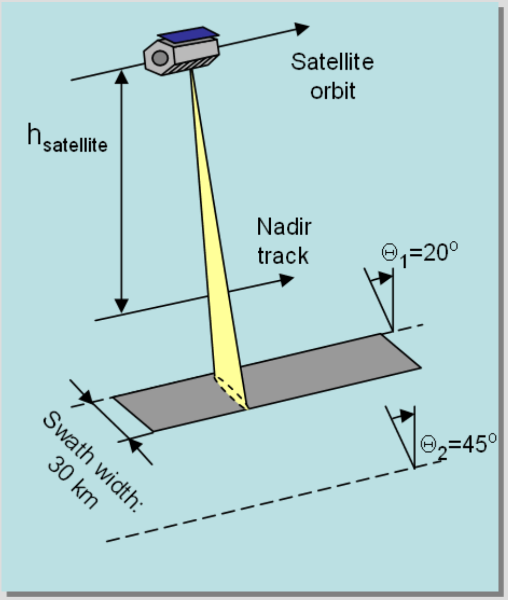


Timeline



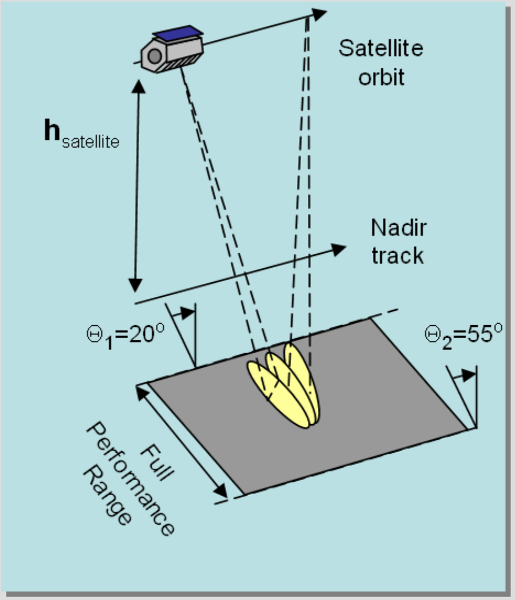
2007
2008
2009
2010
2011
2012
2013
2014
2015
2016
2017
2018
2019
TSX Launch
CP
TSX nominal lifetime (5 years)
TSX "bonus" operations
TDX Launch
CP
TDX nominal lifetime (5 years)
TDX „bonus" operations
Global DEM
Science Phase
ChangeDEM, DEM Updates
9 years of TanDEM-X mission incl. "bonus"
12 years of TerraSAR-X mission incl. "bonus"

TerraSAR-X Nominal Imaging Modes



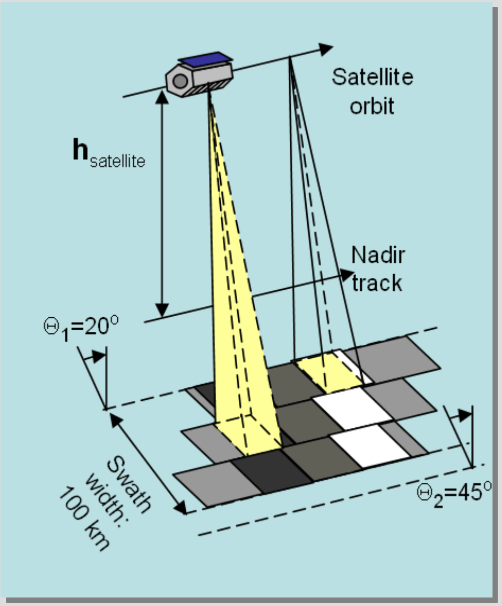
StripMap Mode

Resolution: 3 m × 3 m
Scene Size: 30 km × 50 km
[Range × Azimuth]



SpotLight Mode

Resolution: 1 m × 1,5... 3,5 m
Scene Size: 10 km × 5...10 km
[Range × Azimuth]



ScanSAR Mode

Resolution: 16 m × 16 m
Scene Size: 100 km × 150 km
[Range × Azimuth]

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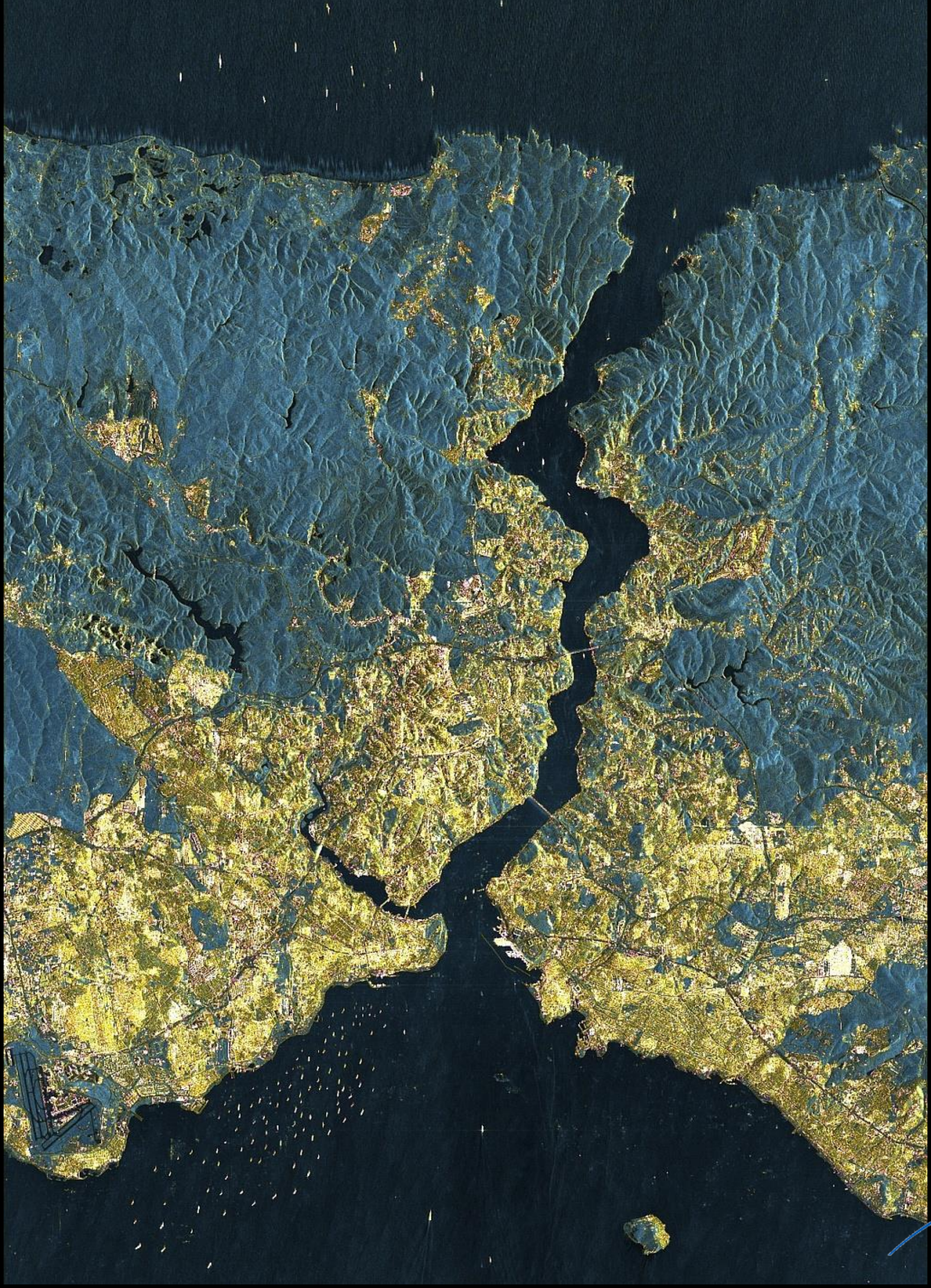
Urban Planning

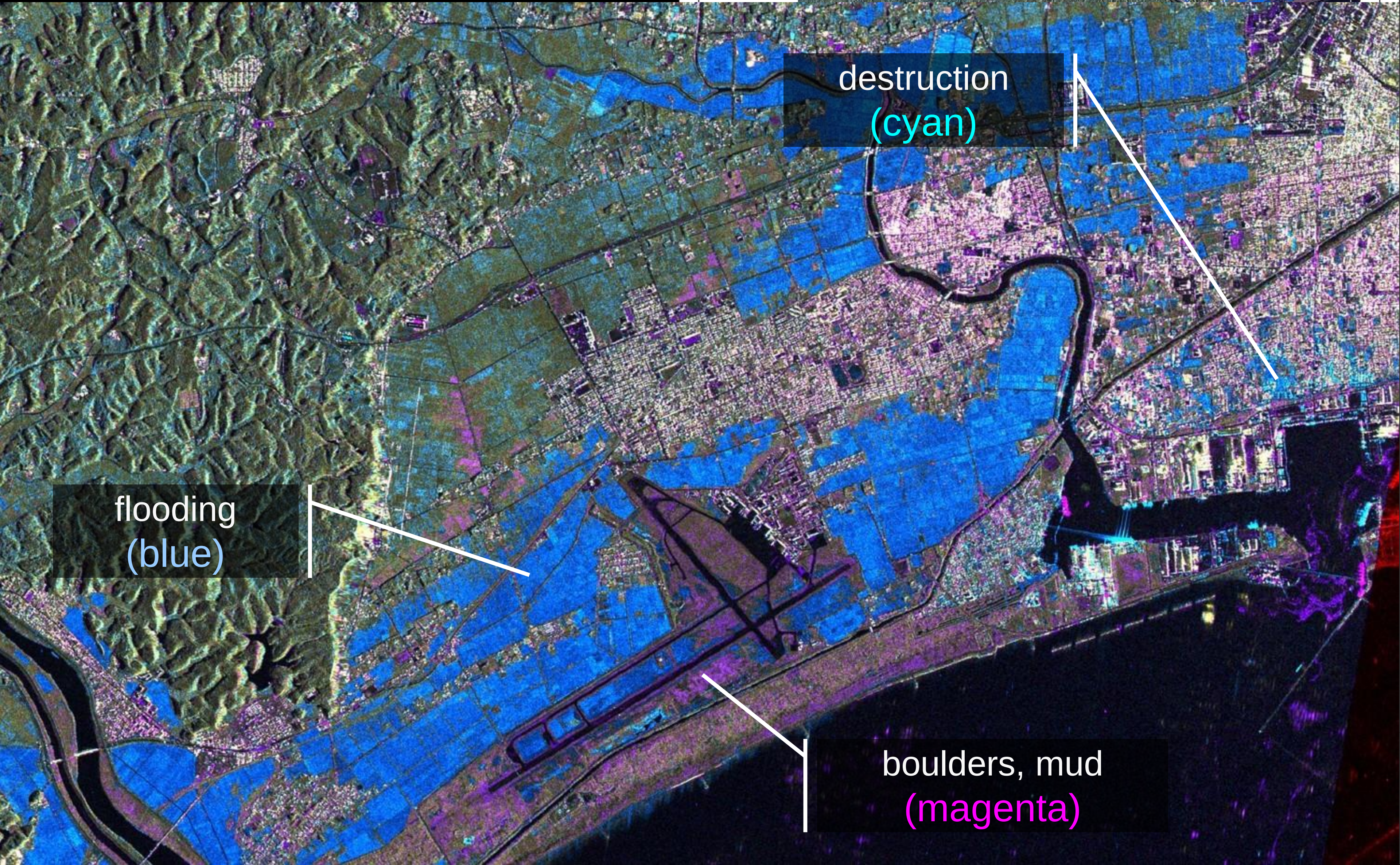
Istanbul



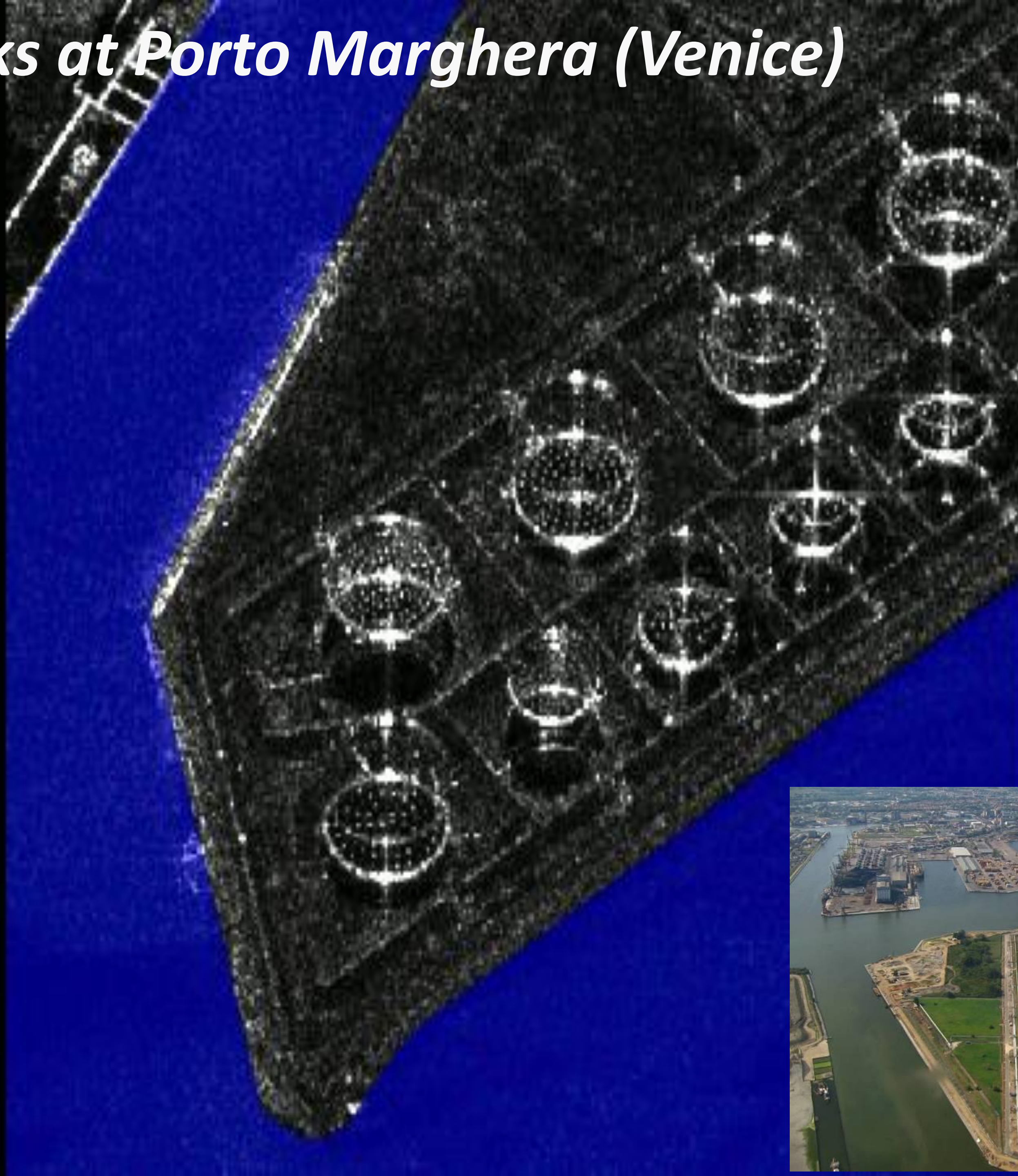
Desaster-Monitoring

Sendai Area, Japan

12.03.2011 + 15.03.2011



Gas Tanks at Porto Marghera (Venice)



TerraSAR-X Experimental vs extended to Operational Modes

- **Wide Swath** 200 km swath width, 32 m resolution (az)
- **TOPS Mode** 100 km swath width, 16 m resolution (az)
- **Staring Spotlight** ~2.7 km swath width, 0.24 m resolution (az)
- **Bi-directional SAR** grating lobes pointing in forward and backward direction → simultaneous acquisition of two azimuth shifted images

- Dual Receive Antenna (DRA) Mode
    - **Quad Polarization**
    - **Along Track Interferometry**

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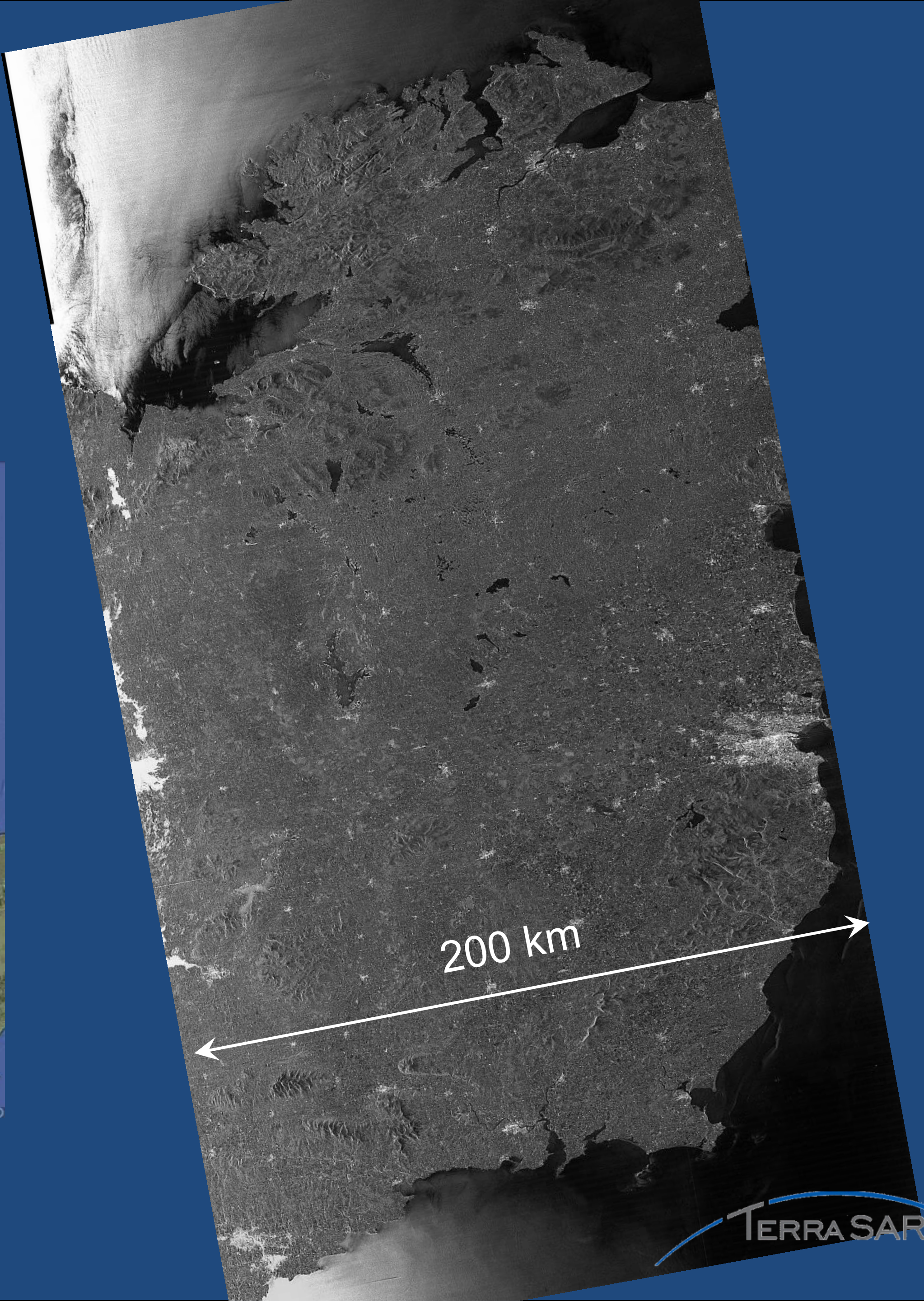
8-Beam ScanSAR
Swath width: 200 km
Ireland



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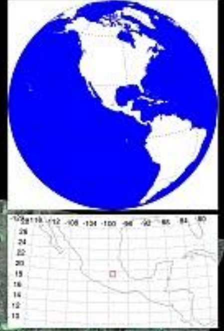
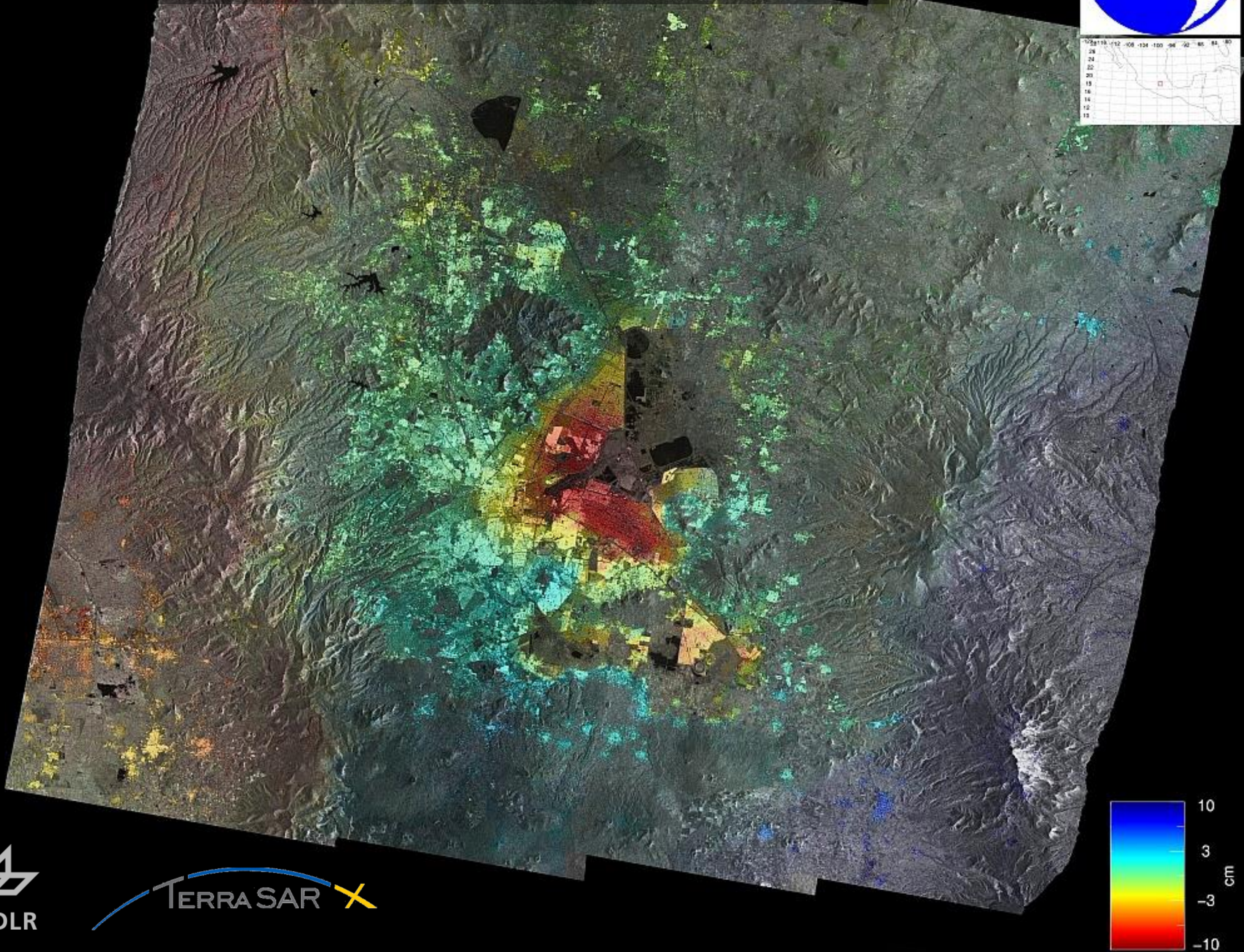
TerraSAR X

TOPS Mode Acquisition

Flevoland – Netherlands

Differencial Interferometry (Tops Mode) Mexico City
Subsidence due to ground water extraction





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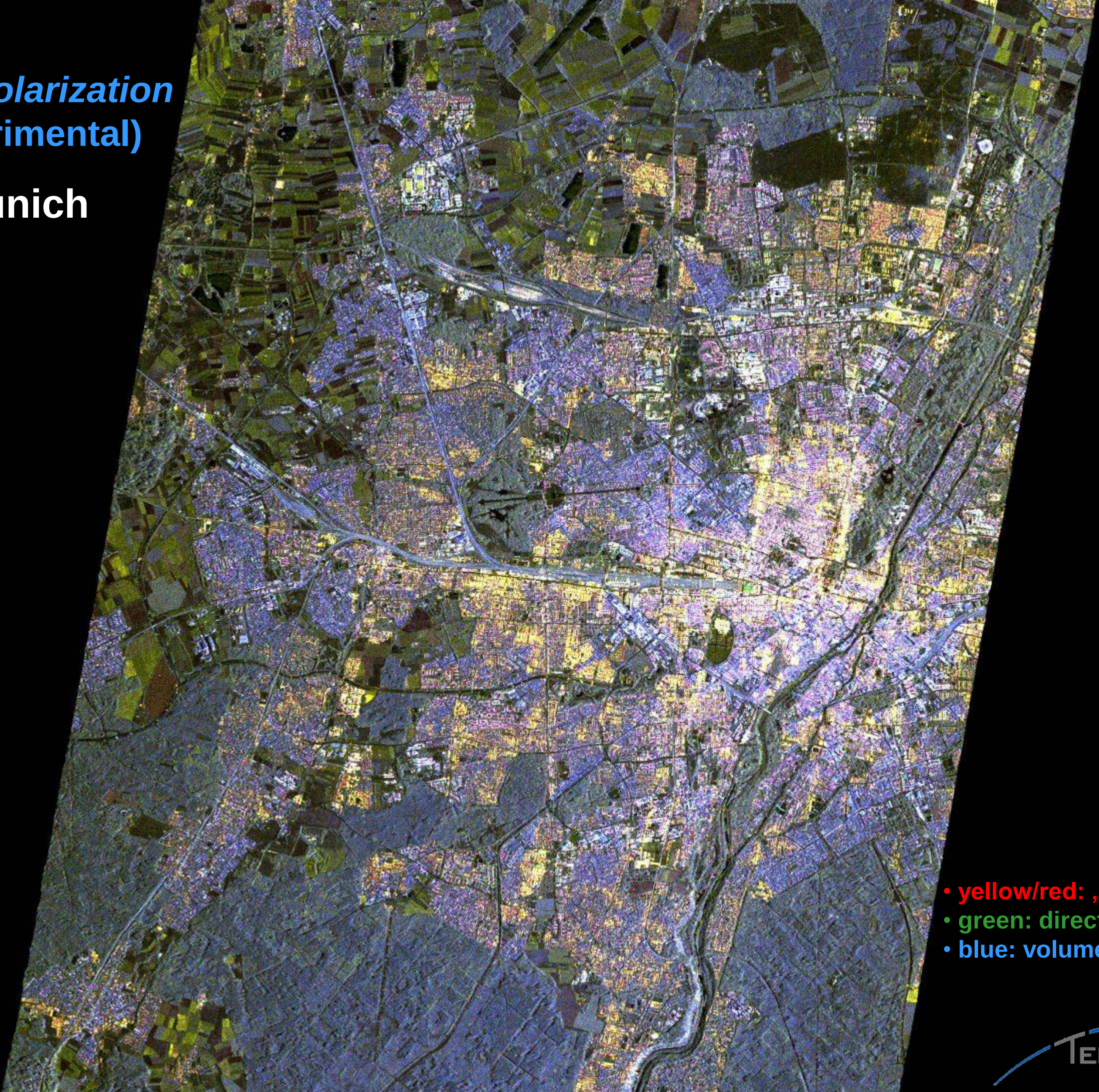
TERRASAR-X

Quad-Polarization (experimental)

Munich

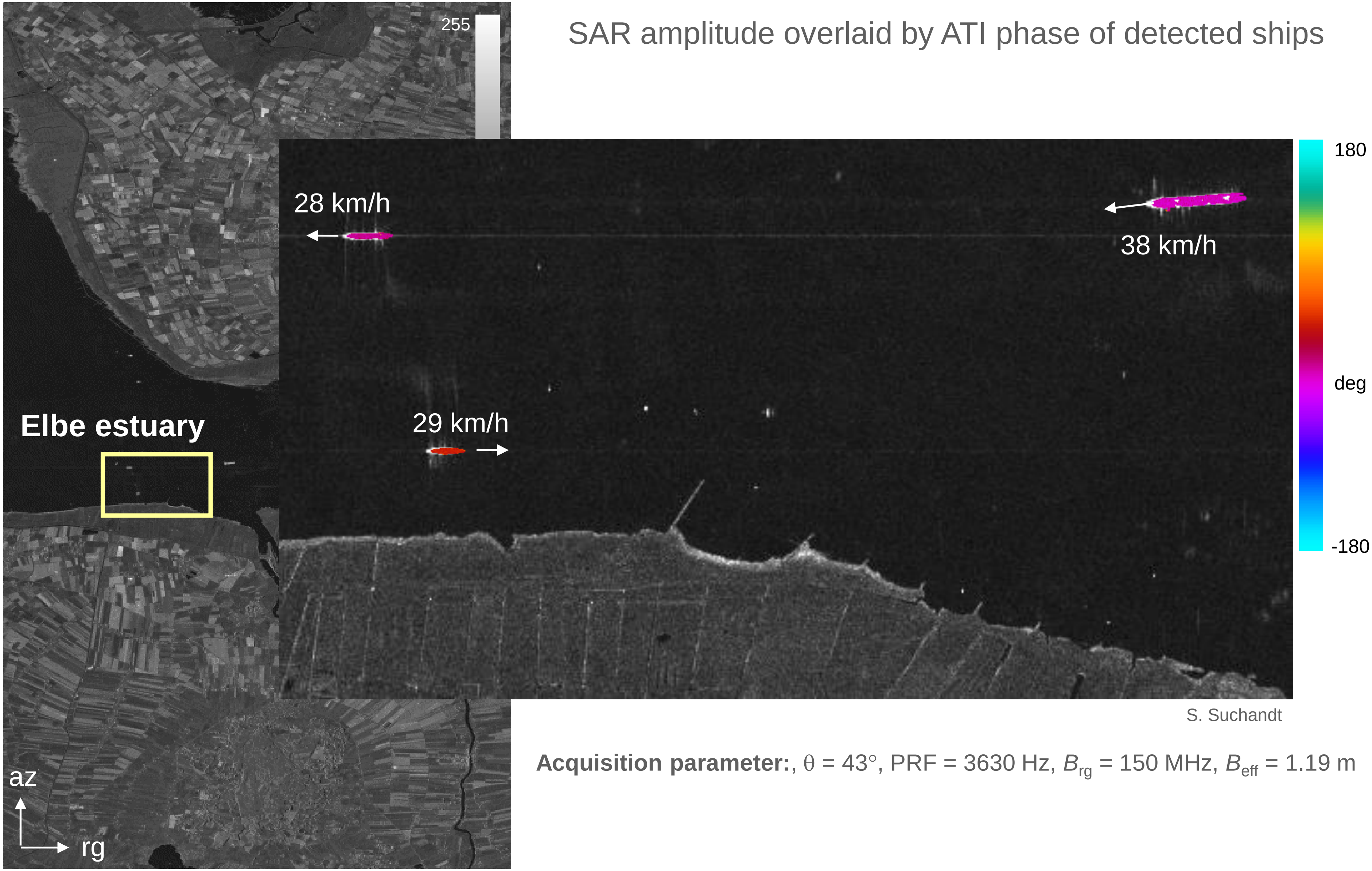


- yellow/red: „double bounce“
- green: direct reflection
- blue: volume scattering

TERRASAR X

Ship Detection & Measurement with DRA Mode (29.4.2009)

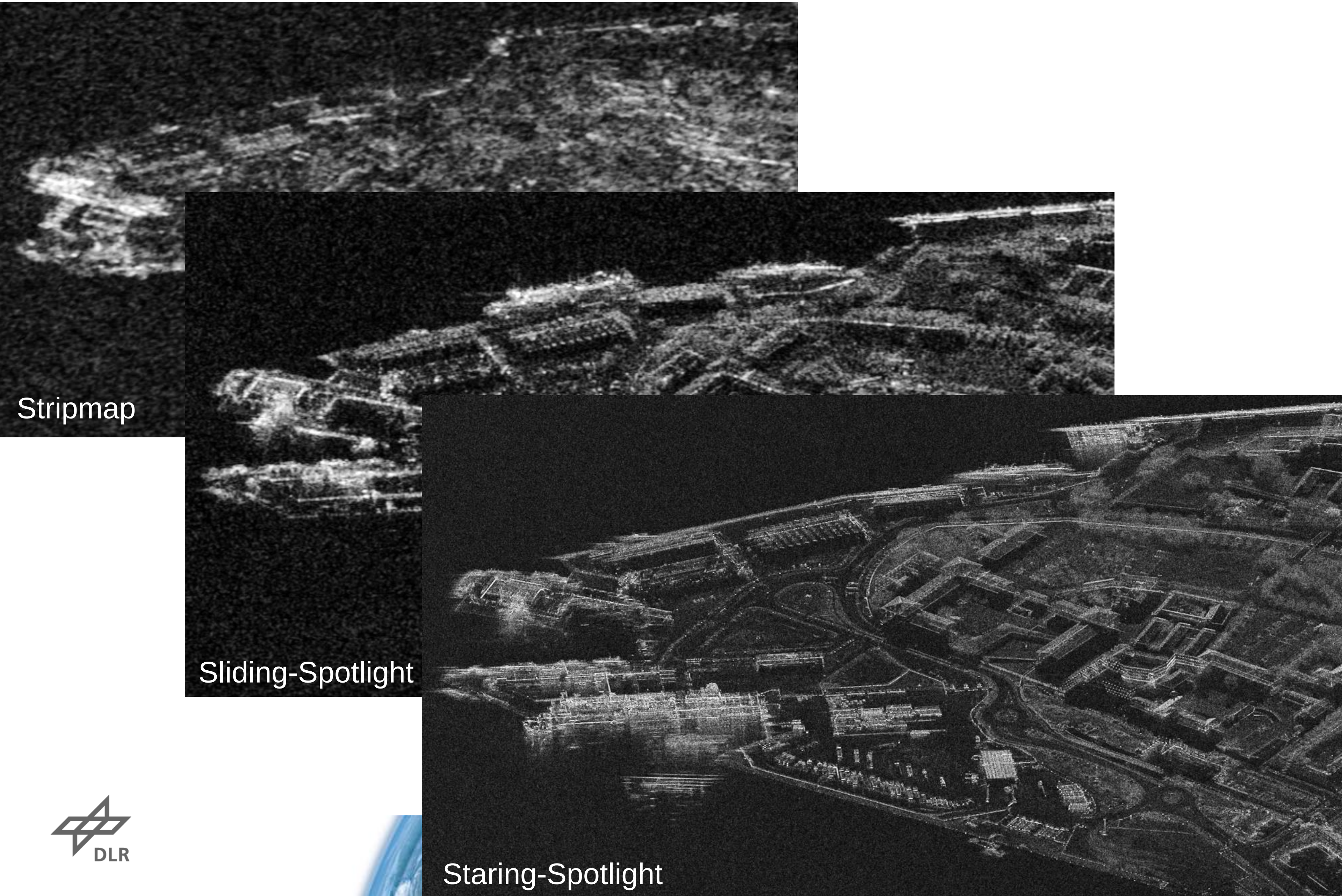
SAR amplitude overlaid by ATI phase of detected ships



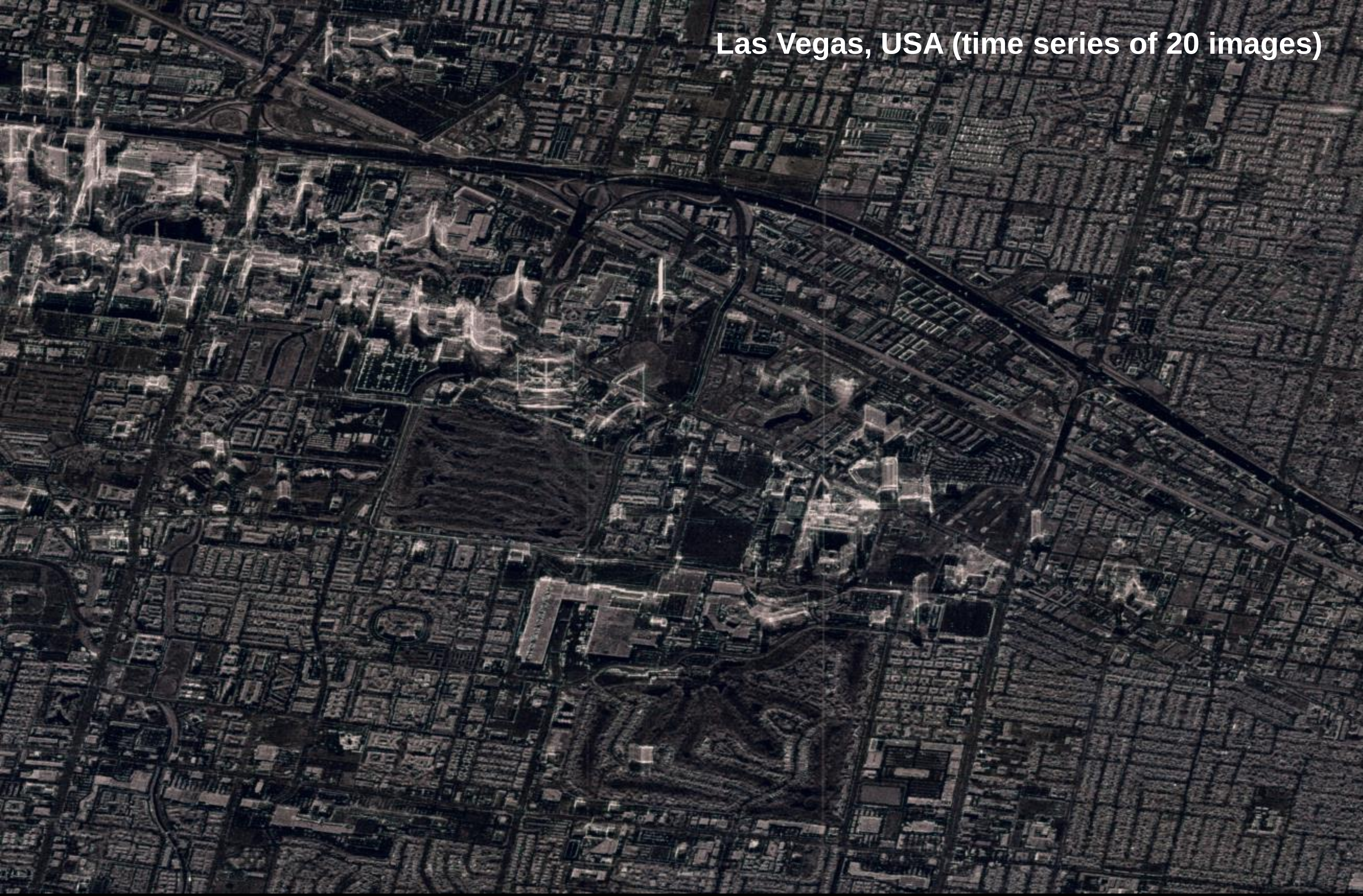
S. Suchandt

Acquisition parameter:, θ = 43°, PRF = 3630 Hz, B_{rg} = 150 MHz, B_{eff} = 1.19 m

High Resolution SAR Imaging with TerraSAR-X

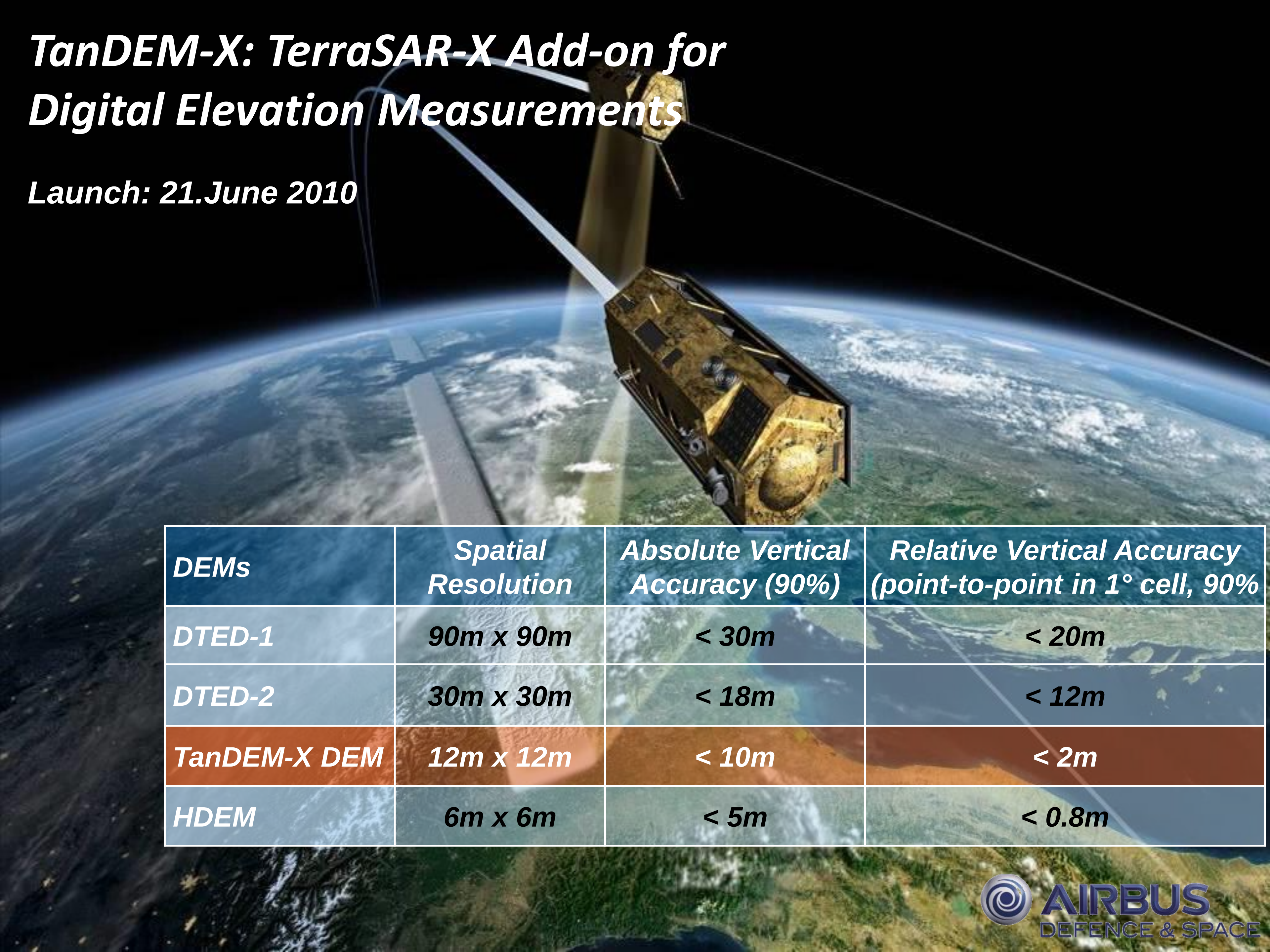


Las Vegas, USA (time series of 20 images)



TanDEM-X: TerraSAR-X Add-on for Digital Elevation Measurements

Launch: 21.June 2010



DEMs	*Spatial Resolution*	*Absolute Vertical Accuracy (90%)*	*Relative Vertical Accuracy (point-to-point in 1° cell, 90%*
DTED-1	*90m x 90m*	*< 30m*	*< 20m*
DTED-2	*30m x 30m*	*< 18m*	*< 12m*
TanDEM-X DEM	*12m x 12m*	*< 10m*	*< 2m*
HDEM	*6m x 6m*	*< 5m*	*< 0.8m*

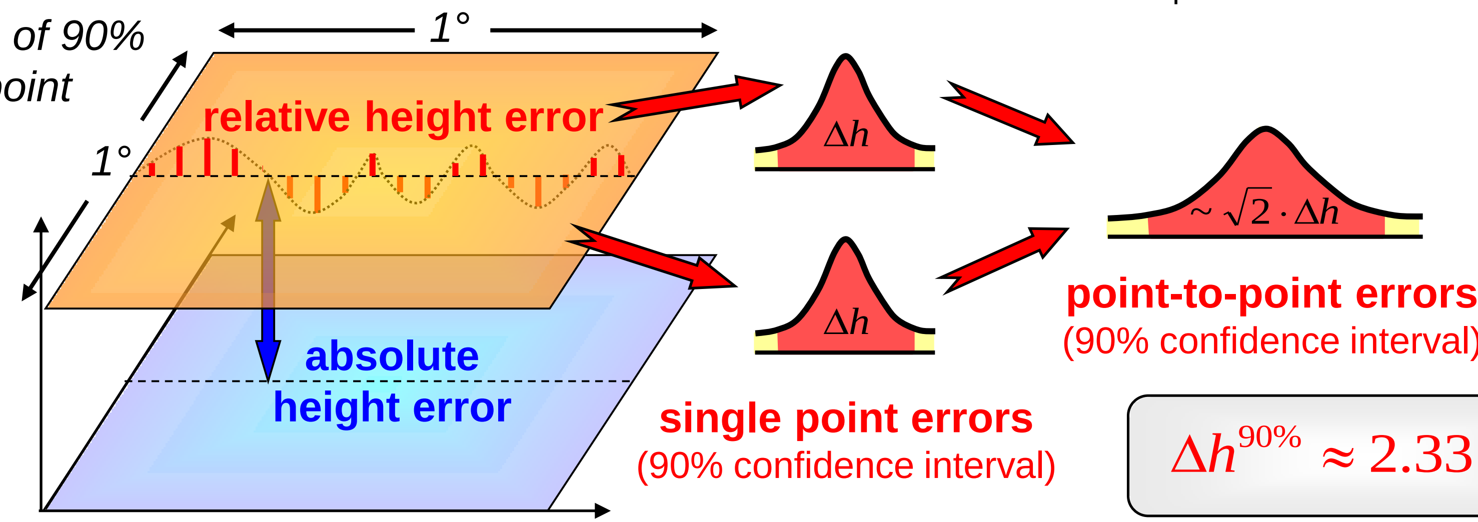
AIRBUS DEFENCE & SPACE

Standards for Digital Elevation Models

	Spatial Resolution	Absolute Vertical Accuracy (90%)	Relative Vertical Accuracy (point-to-point in 1° cell, 90%)
DTED-1	90 m × 90 m	< 30 m	< 20 m
DTED-2	30 m × 30 m	< 18 m	< 12 m
TanDEM-X	12 m × 12 m	< 10 m	< 2 m / 4 m *
Level-4	6 m × 6 m	< 5 m	< 0.8 m

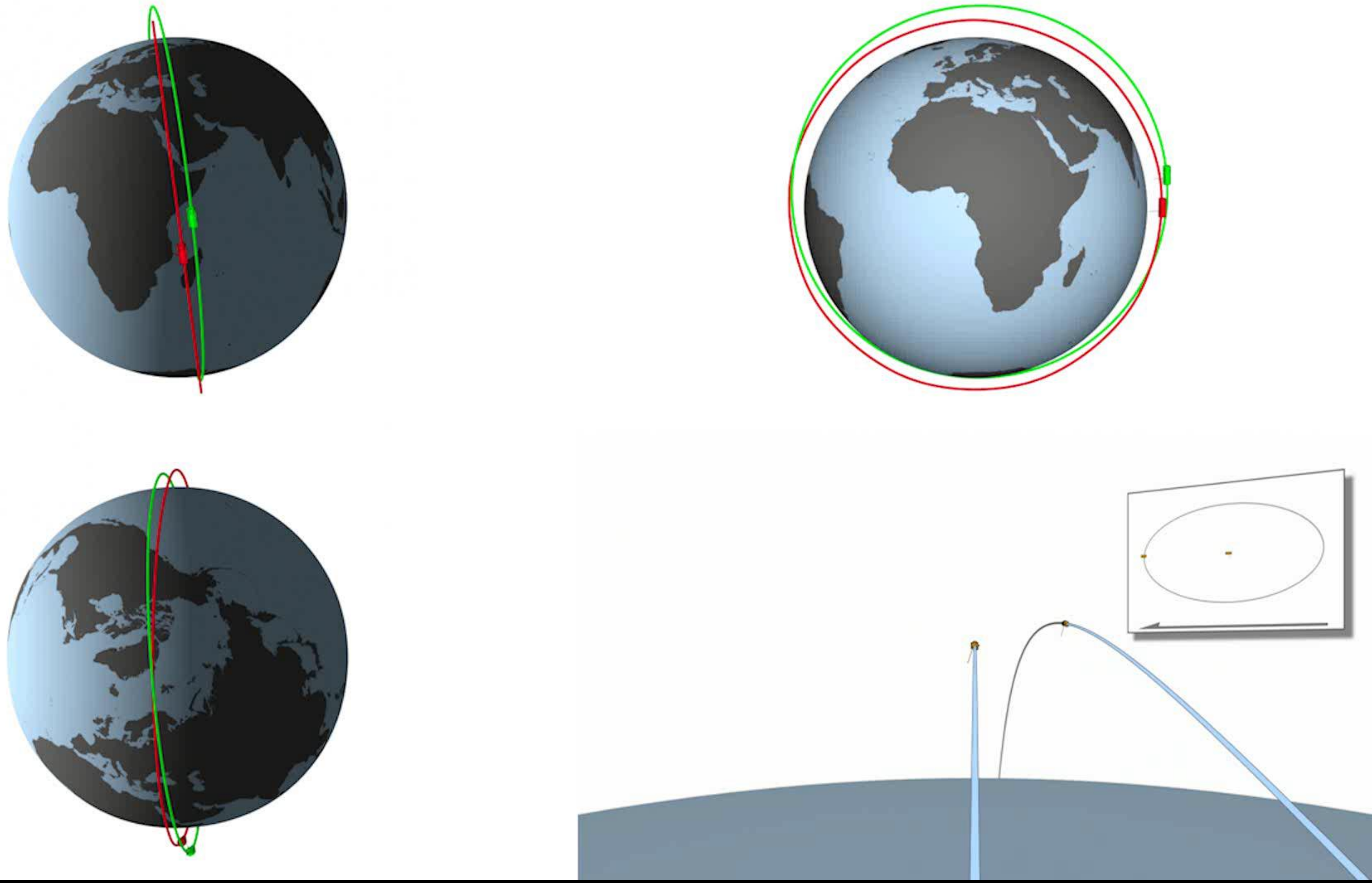
* slopes below/above 20%

Definition of 90% point-to-point errors:

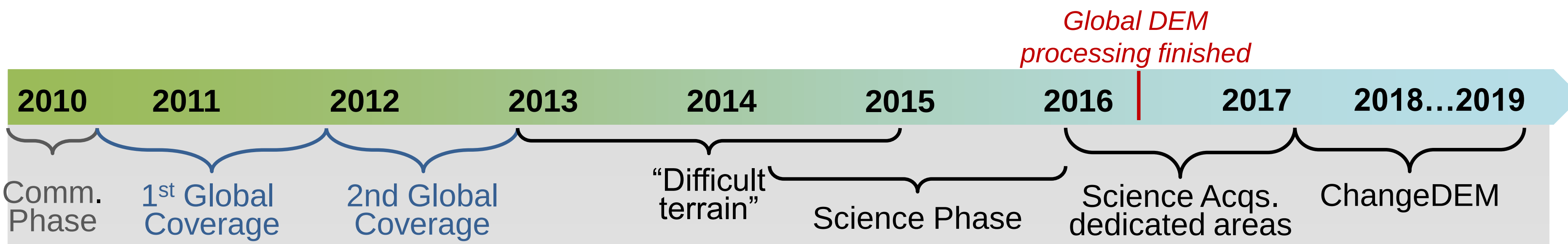


$$\Delta h^{90\%} \approx 2.33 \cdot \sigma_h$$

Helix Formation



TanDEM-X Global DEM & Science Acquisition Plan



1st Global Coverage (2011-2012)

- Small baseline (~200 m), HoA* ~ 50 m

2nd Global Coverage (2012-2013)

- Increased baseline (~300 m), HoA* ~ 35 m
- Combination:
  - Dual Baseline Phase Unwrapping
  - Improved Height Accuracy

Additional Global DEM Acqs. (2013-2015)

- “Difficult Terrain” to account for shadow & layover
  → Different viewing geometry
- Antarctica, deserts, filling of gaps

Science Phase (2014-2016)

- Acquisitions with special formations
- ATI, multistatic, PolInSAR,digital beamforming, etc.
- Higher resolution DEMs with local extend

Science Acquisitions (2016-2017)

- Areas of high dynamics w.r.t. local height changes
- Antarctica costal regions
- Greenland and permafrost
- Forest

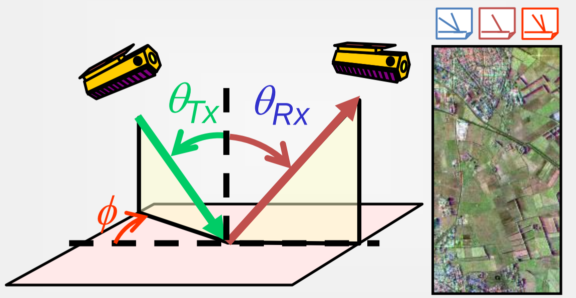
ChangeDEM Acquisitions (2017-2019)

- Topographic changes on a global scale
- Quality improvements of the global DEM

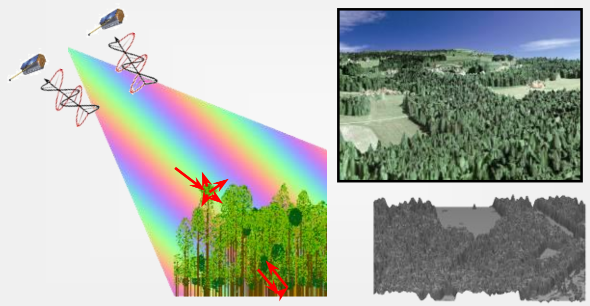
*HoA: Height of Ambiguity ↔ 2π Interferometric Phase

Secondary Mission Objectives: New Techniques Demonstration

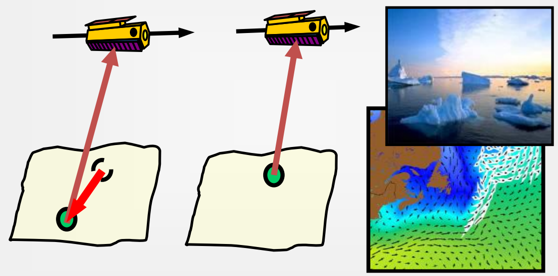
Bistatic SAR Imaging



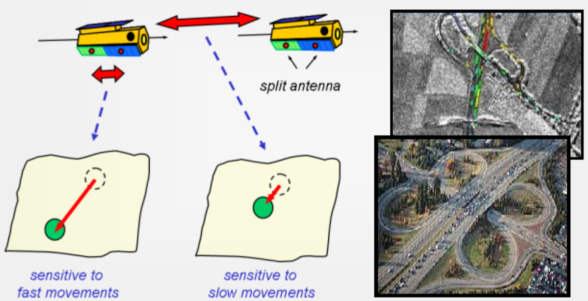
Polarimetric SAR Interferometry



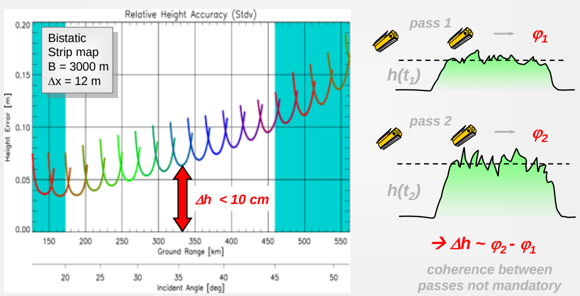
Along-Track Interferometry



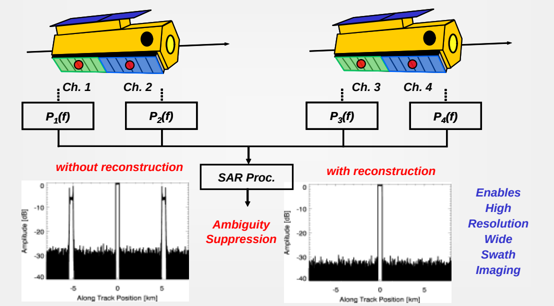
Ground Moving Target Indication



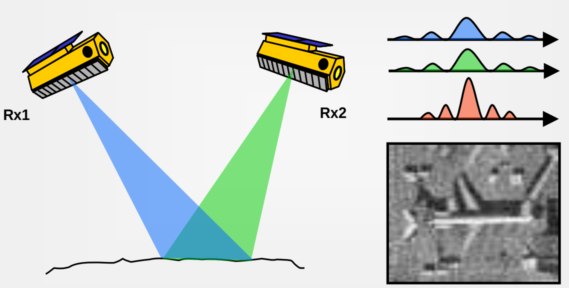
Double Differential Interferometry



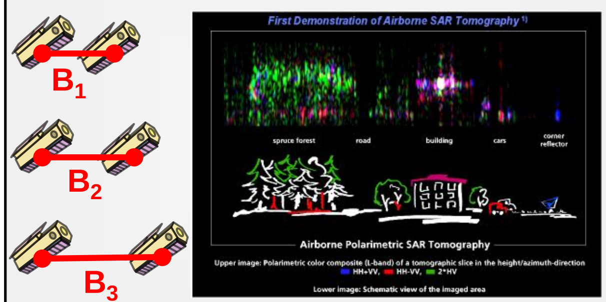
Digital Beamforming



Super Resolution



SAR Tomography



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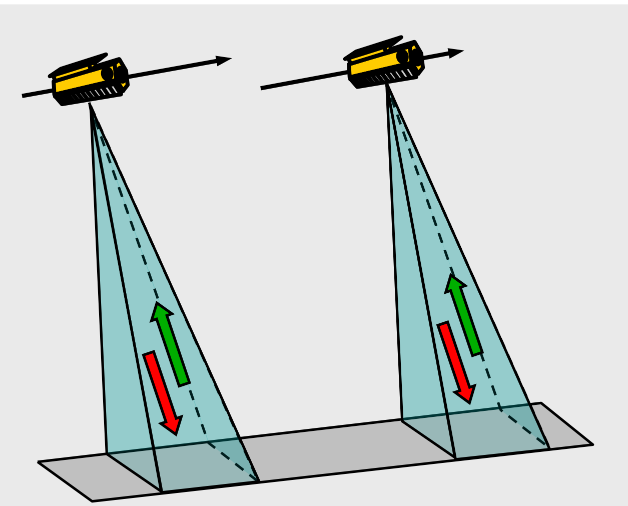
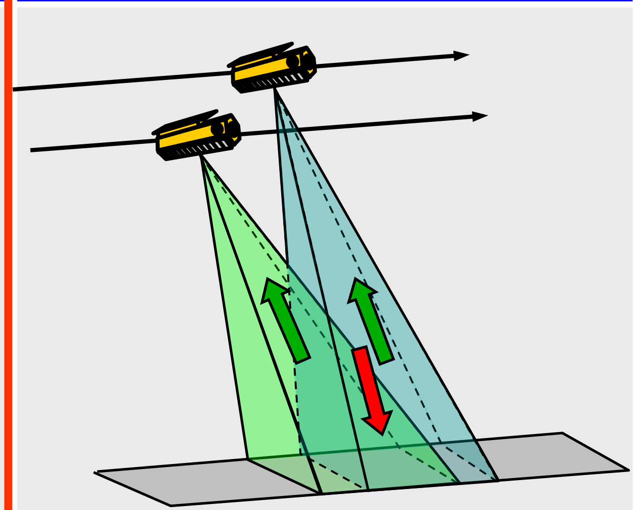
TanDEM-X Data Acquisition Modes

Pursuit Monostatic



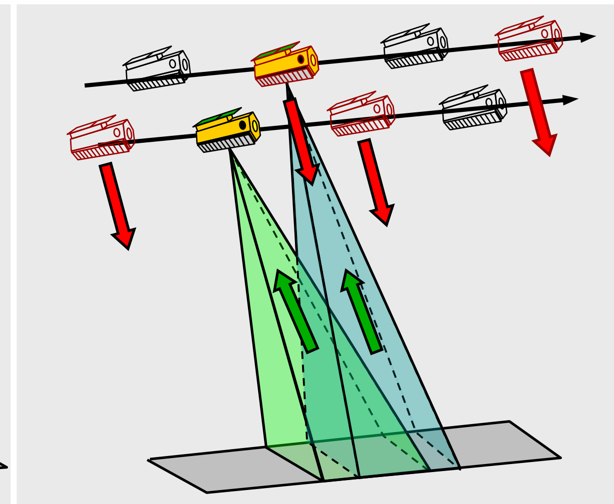
- **both satellites transmit and receive independently**
- susceptible to temporal decorrelation and atmospheric disturbances
- no PRF and phase synchronisation required (backup solution)

Bistatic



- **one satellite transmits and both satellites receive simultaneously**
- small along-track displacement required for Doppler spectra overlap
- requires PRF and phase synchronisation

Alternating Bistatic



- **transmitter alternates between PRF pulses**
- provides three interferograms with two baselines in a single pass
- enables precise phase synchronisation, calibration & verification

First Pol-InSAR Data Takes

Dual-Pol HH-VV Spotlight

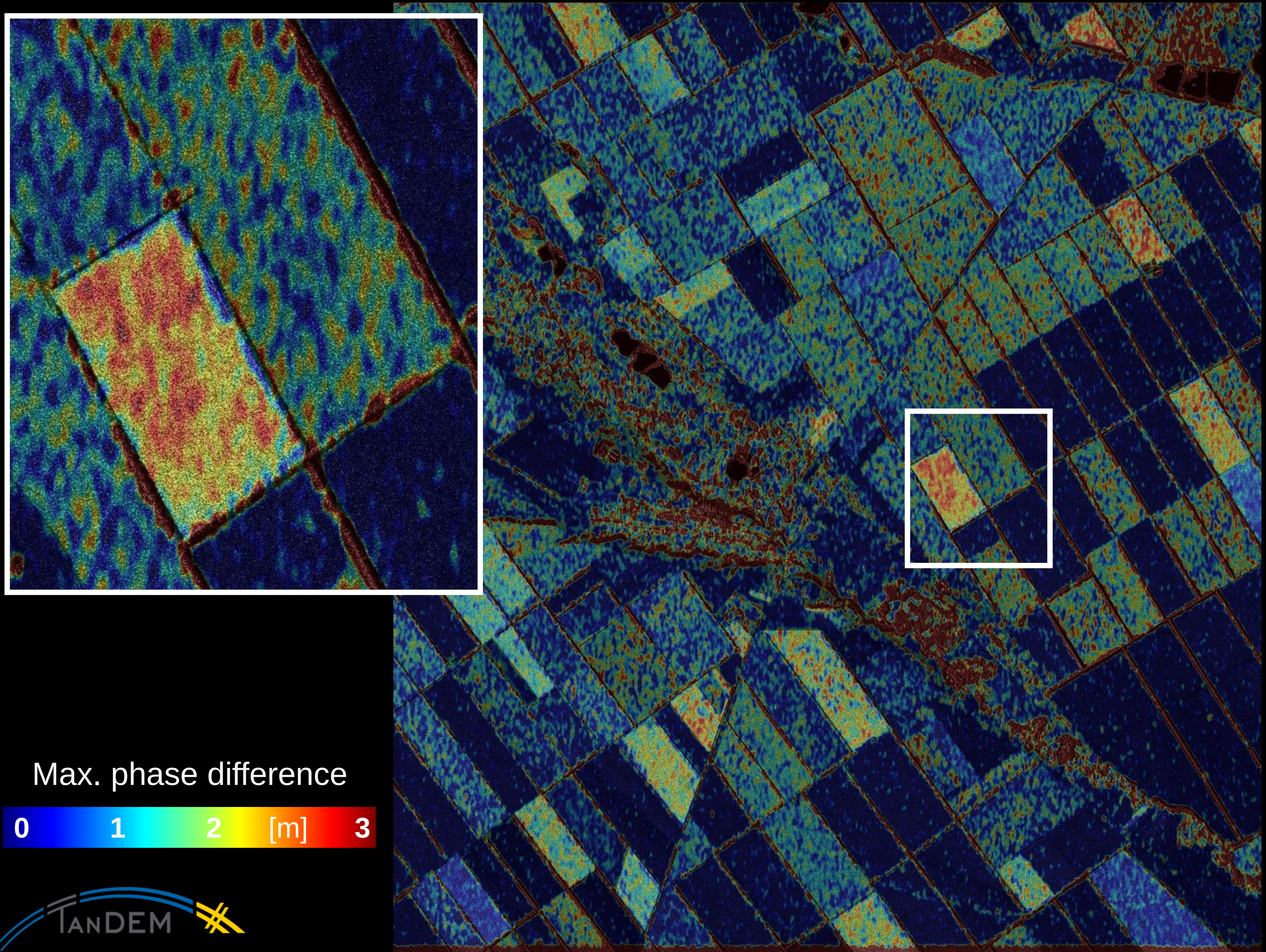
Test Site Location: Russia

InSAR Mode: Monostatic

Temporal Baseline: 3sec

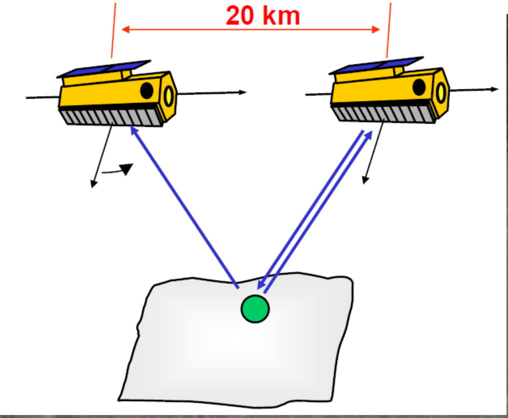
Spatial Baseline (┴): 275m

TanDEM


Max. phase difference
0 1 2 [m] 3

First Bistatic Experiments with TanDEM-X: Brasilia

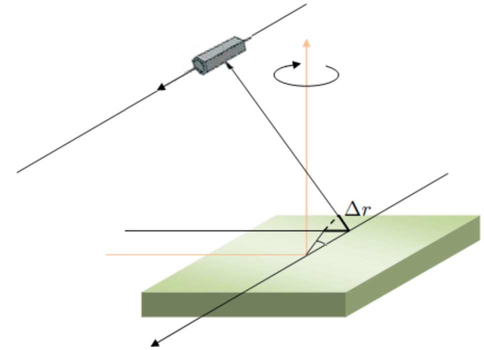
- Performed during the TDX pursuit monostatic phase
- Innovative acquisitions with non-nominal set-ups

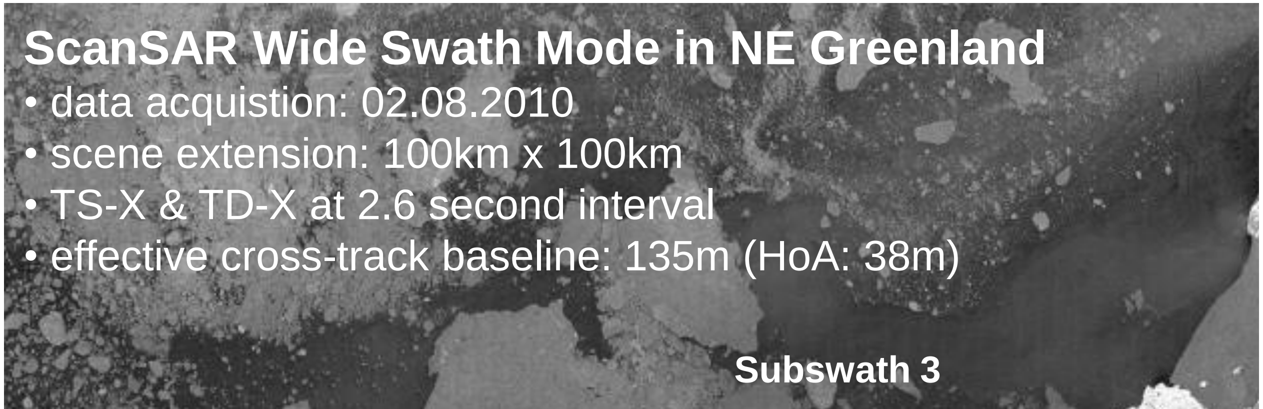


Interferometric Sea-Ice Mapping with TanDEM-X

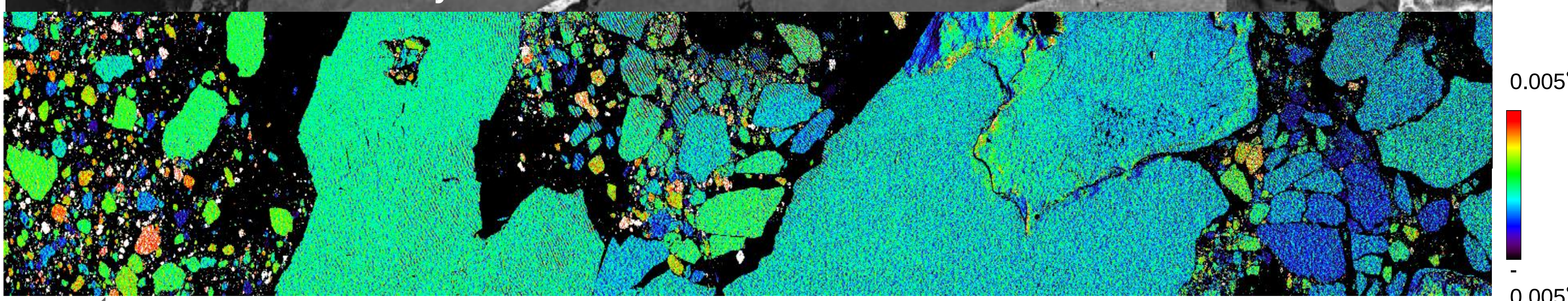
ScanSAR Wide Swath Mode in NE Greenland

- data acquistion: 02.08.2010
- scene extension: 100km x 100km
- TS-X & TD-X at 2.6 second interval
- effective cross-track baseline: 135m (HoA: 38m)





Sea ice blocks rotation analysis



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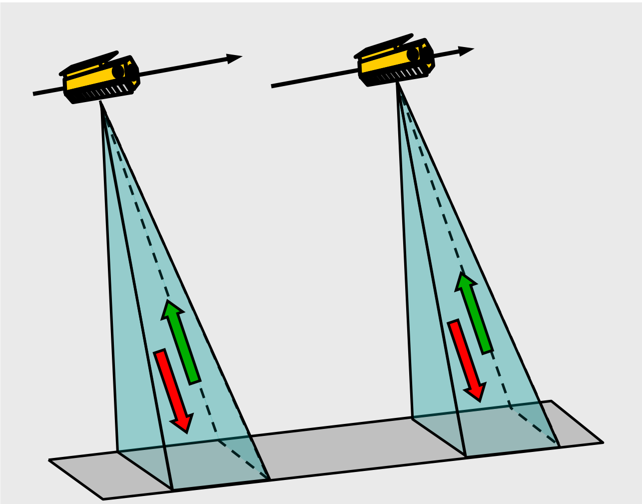
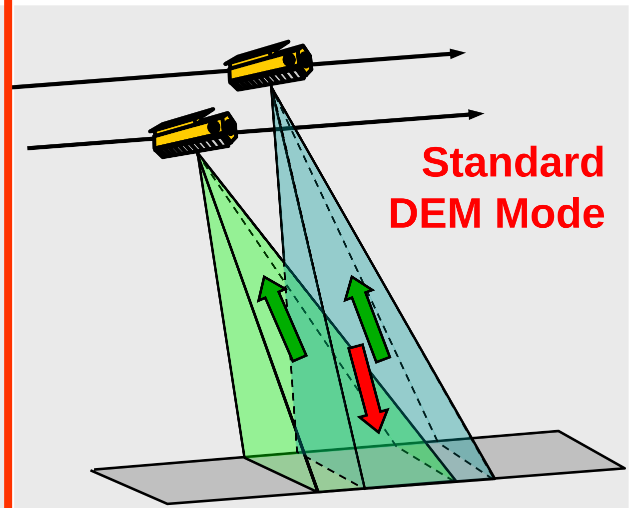
TanDEM-X Data Acquisition Modes

Pursuit Monostatic



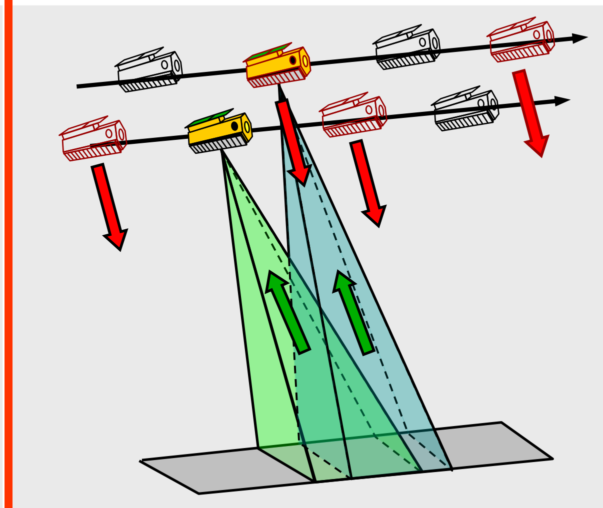
- **both satellites transmit and receive independently**
- susceptible to temporal decorrelation and atmospheric disturbances
- no PRF and phase synchronisation required (backup solution)

Bistatic



- **one satellite transmits and both satellites receive simultaneously**
- small along-track displacement required for Doppler spectra overlap
- requires PRF and phase synchronisation

Alternating Bistatic



- **transmitter alternates between PRF pulses**
- provides three interferograms with two baselines in a single pass
- enables precise phase synchronisation, calibration & verification

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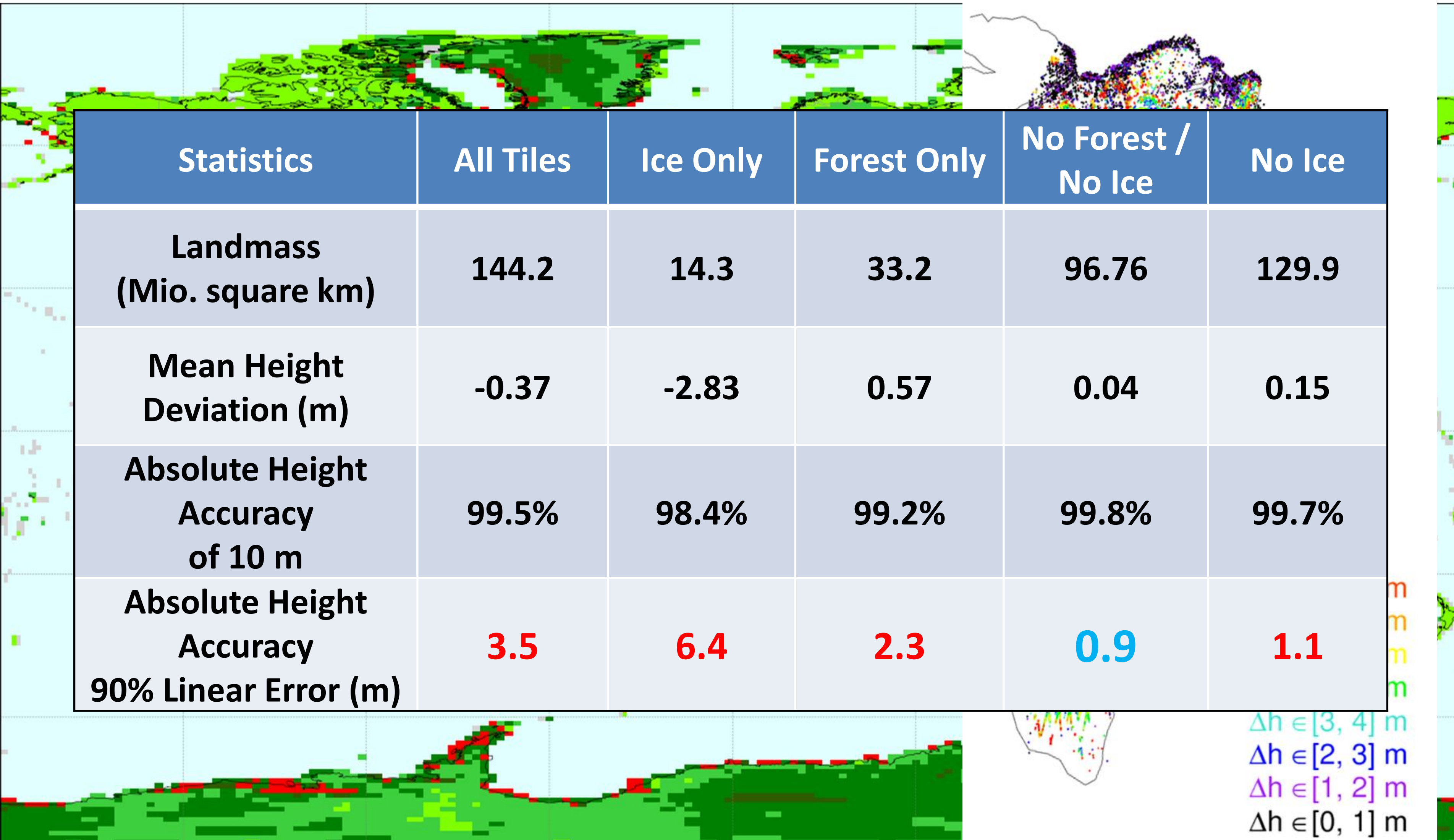
Relative Height Error – Evolution over Time

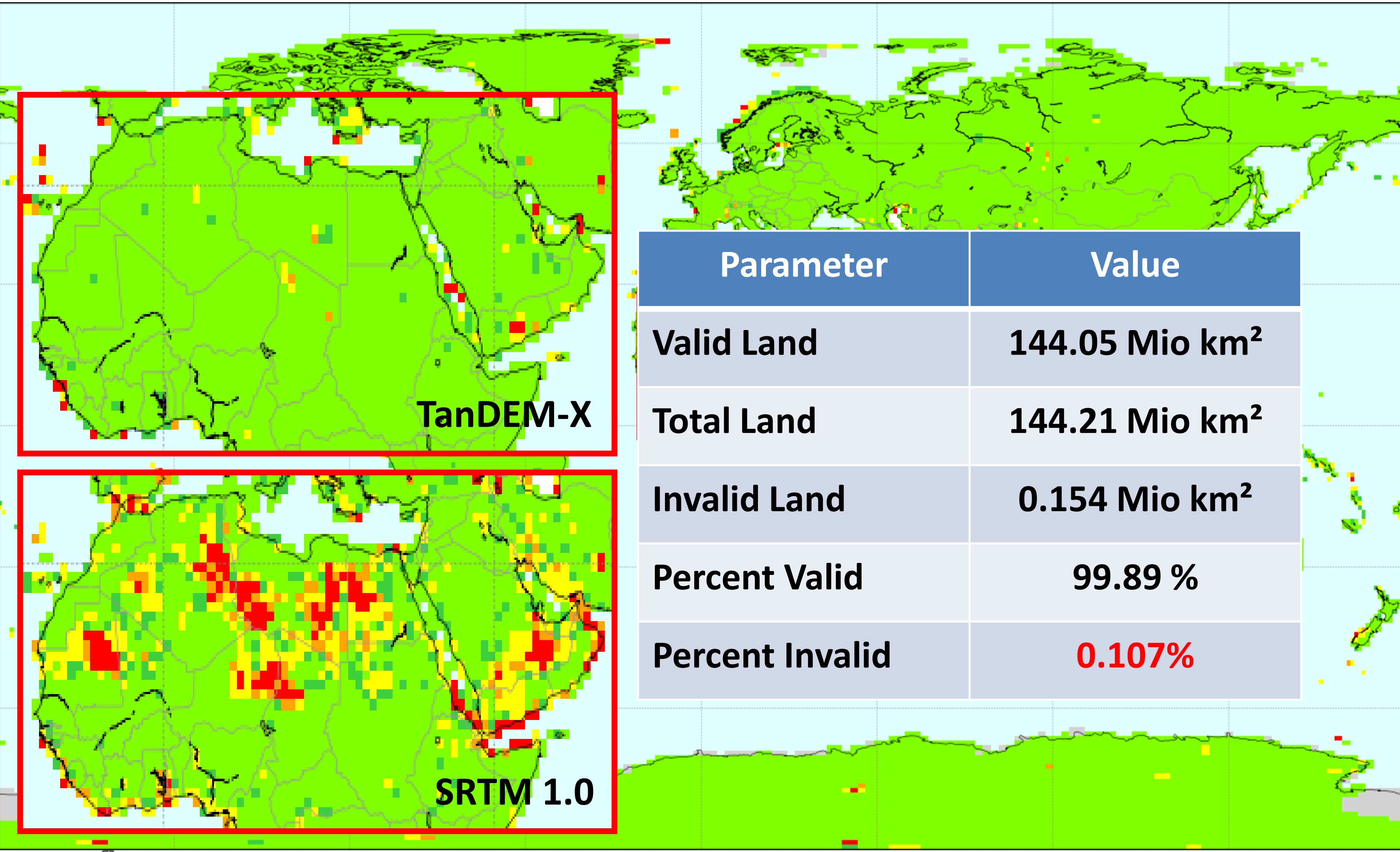
Absolute Height Accuracy

TanDEM-X DEM – ICESat (specification: < 10 m global, 90% confidence level)



Statistics	All Tiles	Ice Only	Forest Only	No Forest / No Ice	No Ice
Landmass (Mio. square km)	144.2	14.3	33.2	96.76	129.9
Mean Height Deviation (m)	-0.37	-2.83	0.57	0.04	0.15
Absolute Height Accuracy of 10 m	99.5%	98.4%	99.2%	99.8%	99.7%
Absolute Height Accuracy 90% Linear Error (m)	3.5	6.4	2.3	0.9	1.1

TanDEM-X Data Coverage – Global Voids Performance



Parameter	Value
Valid Land	144.05 Mio km²
Total Land	144.21 Mio km²
Invalid Land	0.154 Mio km²
Percent Valid	99.89 %
Percent Invalid	0.107%

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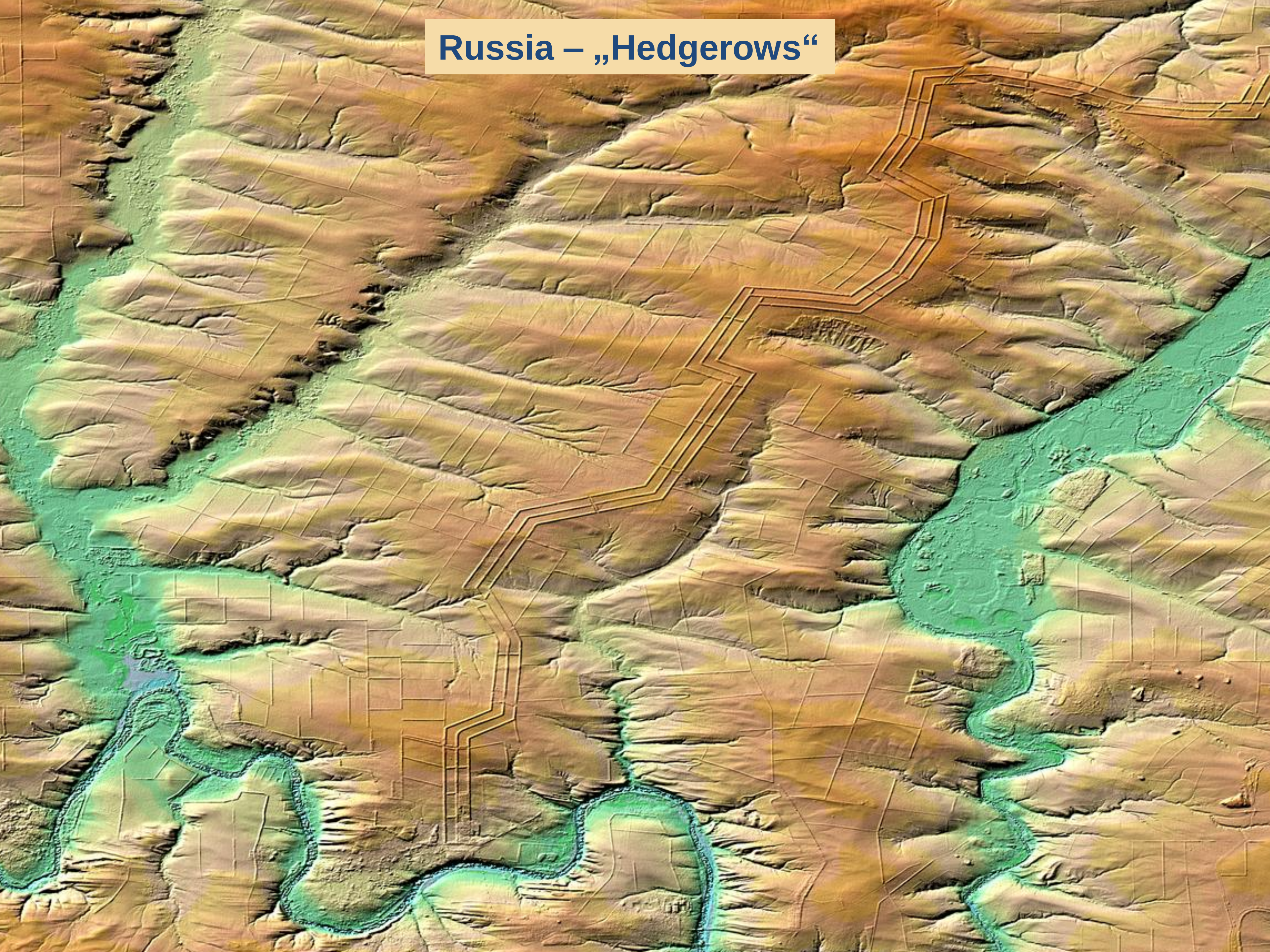
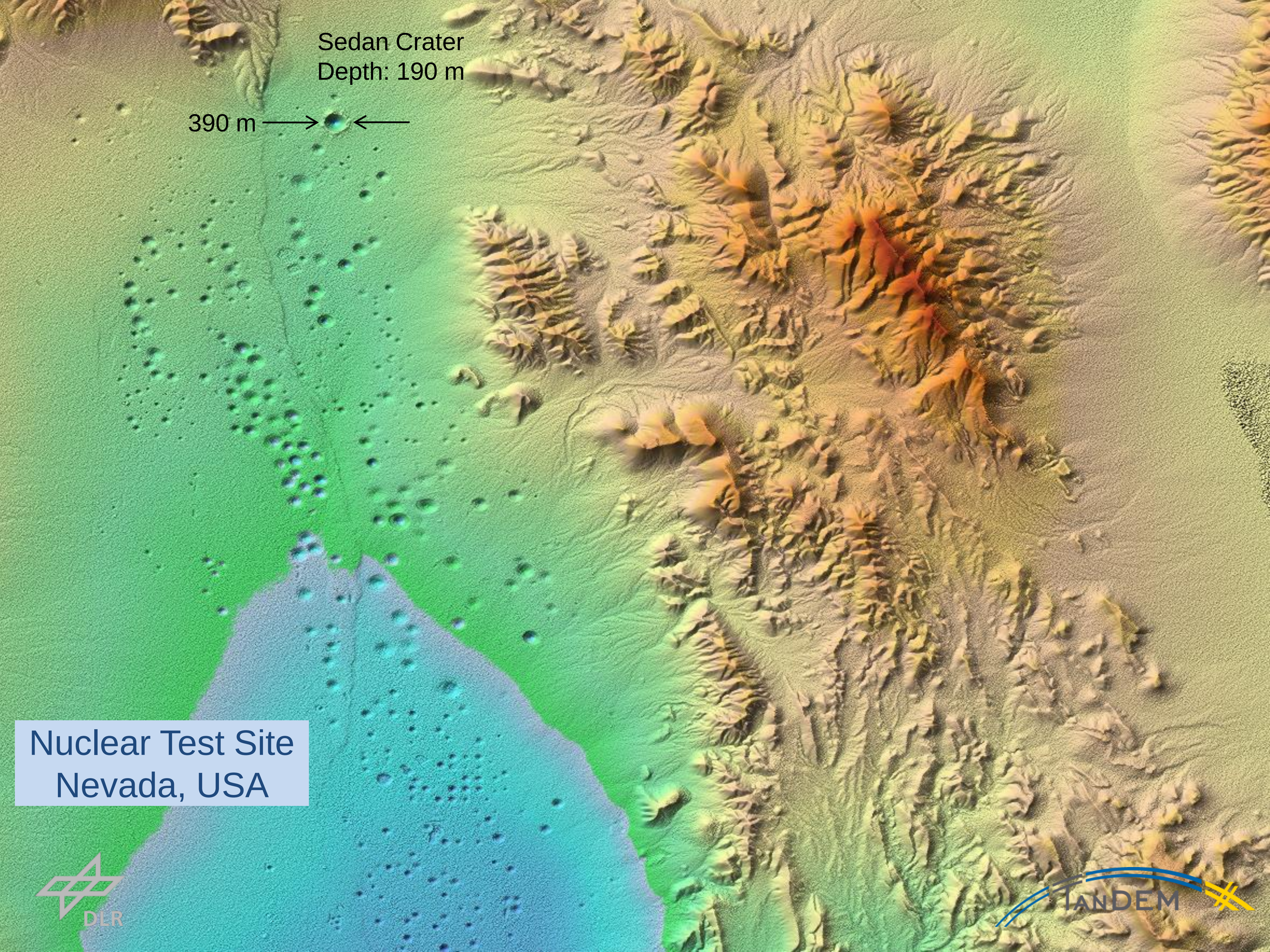
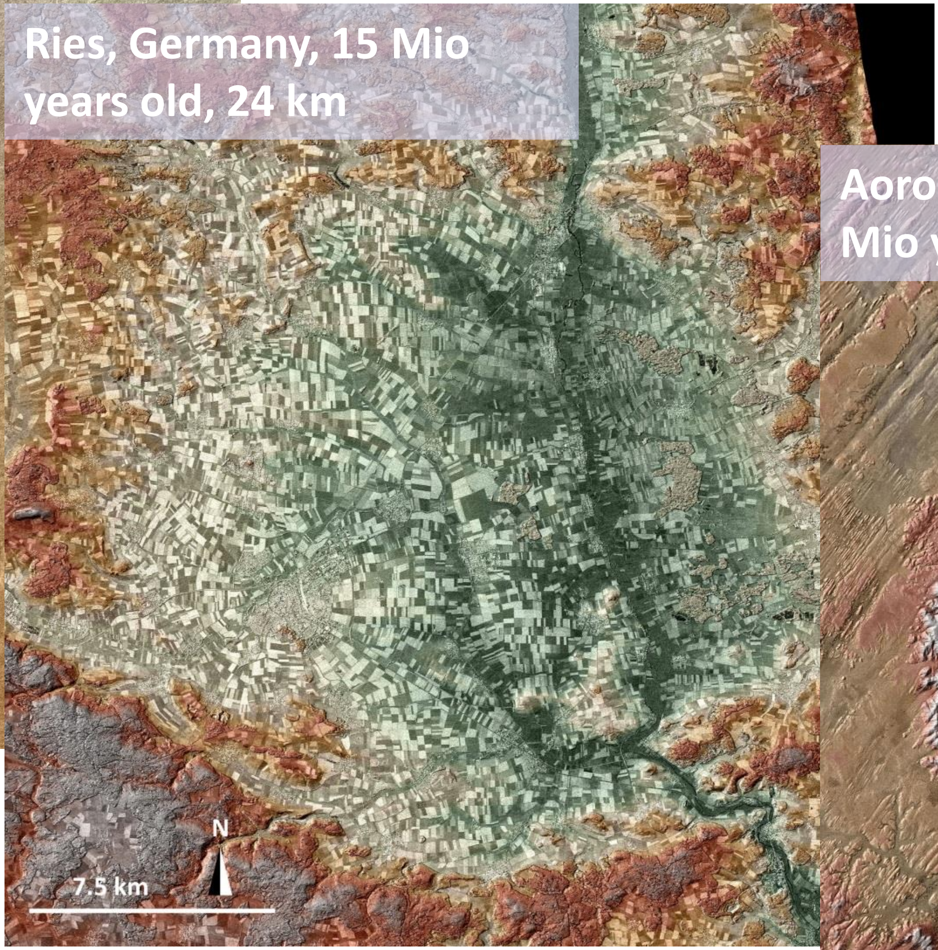

Russia – „Hedgerows“


Sedan Crater
Depth: 190 m
390 m
Nuclear Test Site
Nevada, USA
DLR
TanDEM

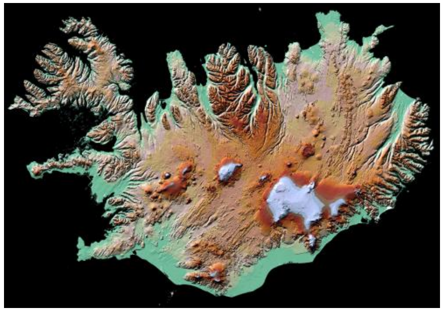
Impact Craters: TanDEM-X DEMs



DLR

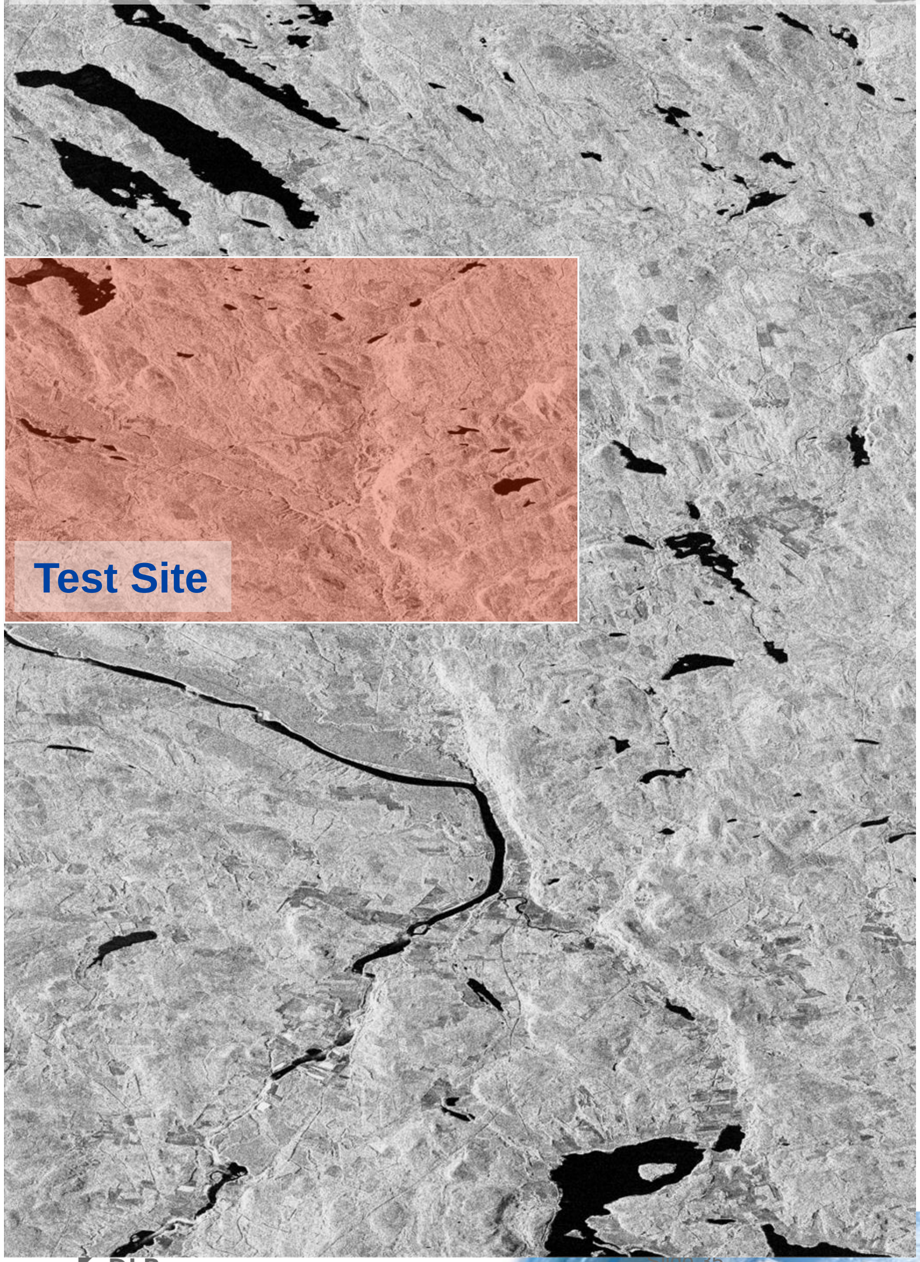
Gottwald, M. et al., "Mapping terrestrial impact craters with the TanDEM-X digital elevation model", in "Large Meteorite Impacts and Planetary Evolution V", GSA Special Paper, in print, 2015

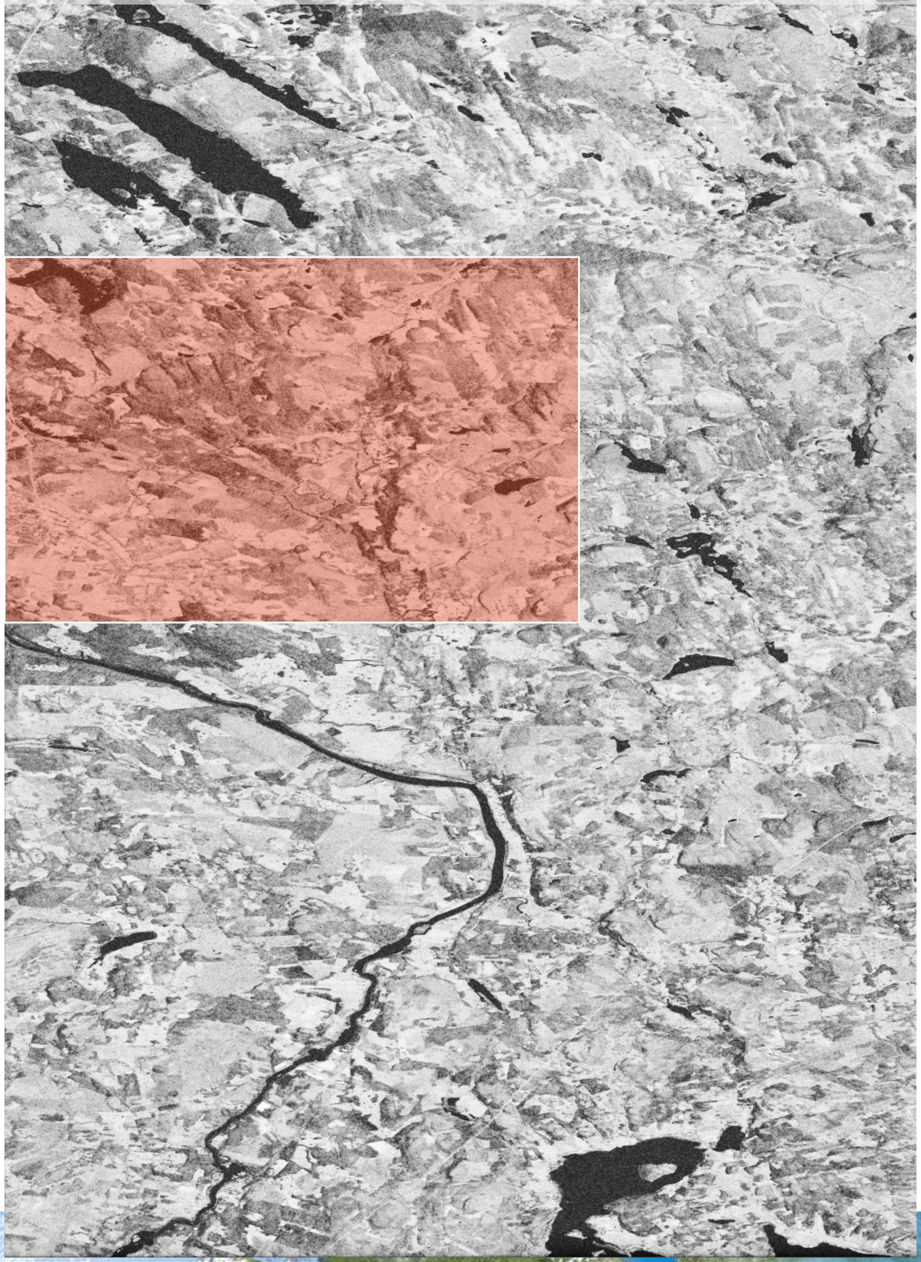
DEM Products for Scientific Use
TanDEM-X DEM



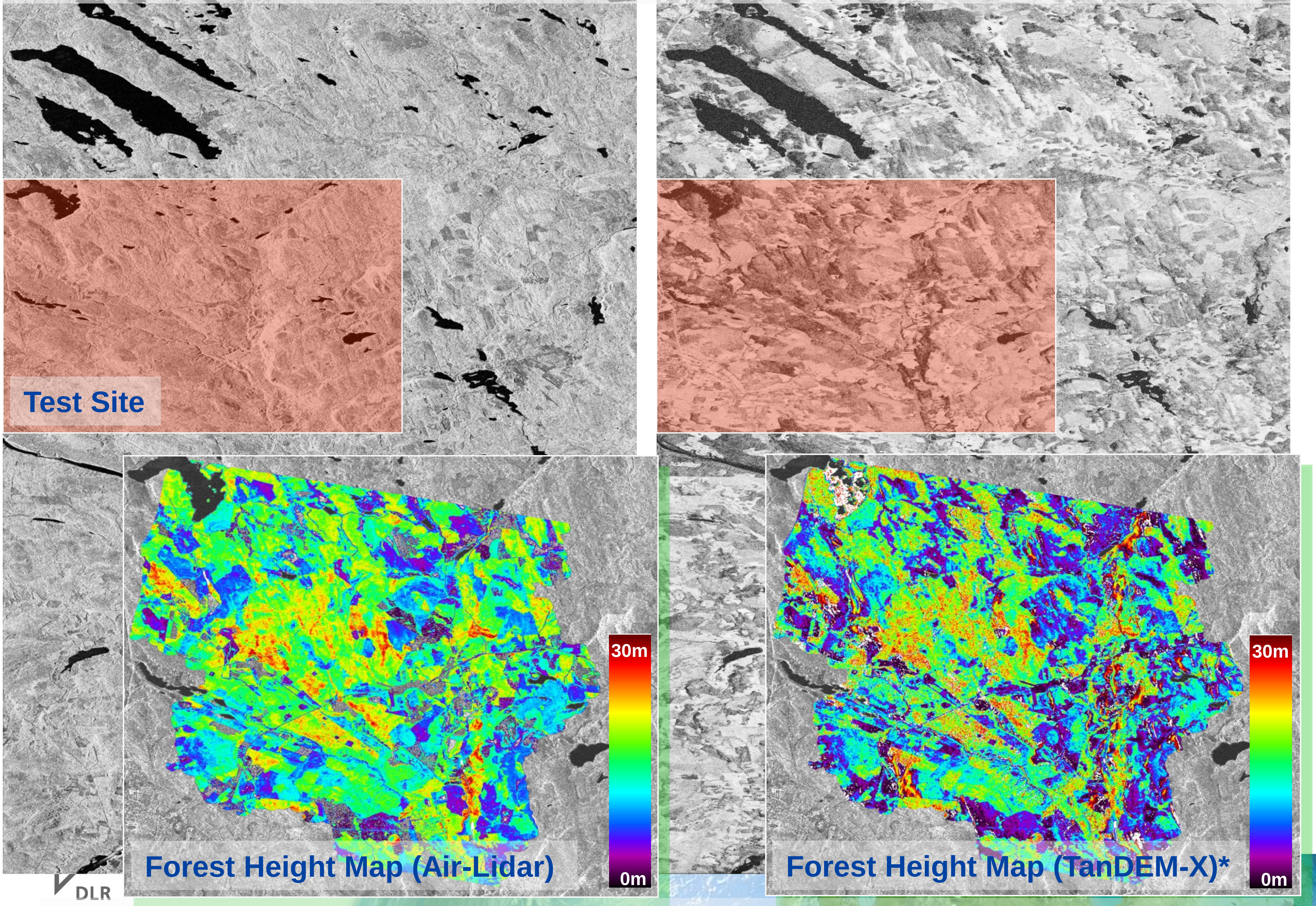
DEM Product	Spatial Resolution Absolute	Horizontal Accuracy CE90	Absolute Vertical Accuracy LE90	Relative Vertical Accuracy
TanDEM-X DEM (standard product 0.4 arcsec)	~12 m (0.4 arcsec @ equator)	<10 m	<10 m	< 2 m (slope @ 20%) < 4 m (slope > 20%) 90% linear point-to-point error within an area of 1°x1°
TanDEM-X DEM (1 arcsec)	~30 m (1 arcsec @ equator)	<10 m	<10 m	Not specified
TanDEM-X DEM (3 arcsec)	~90 m (3 arcsec @ equator)	<10 m	<10 m	Not specified

TanDEM-X: Kryckland Test Site, Sweden





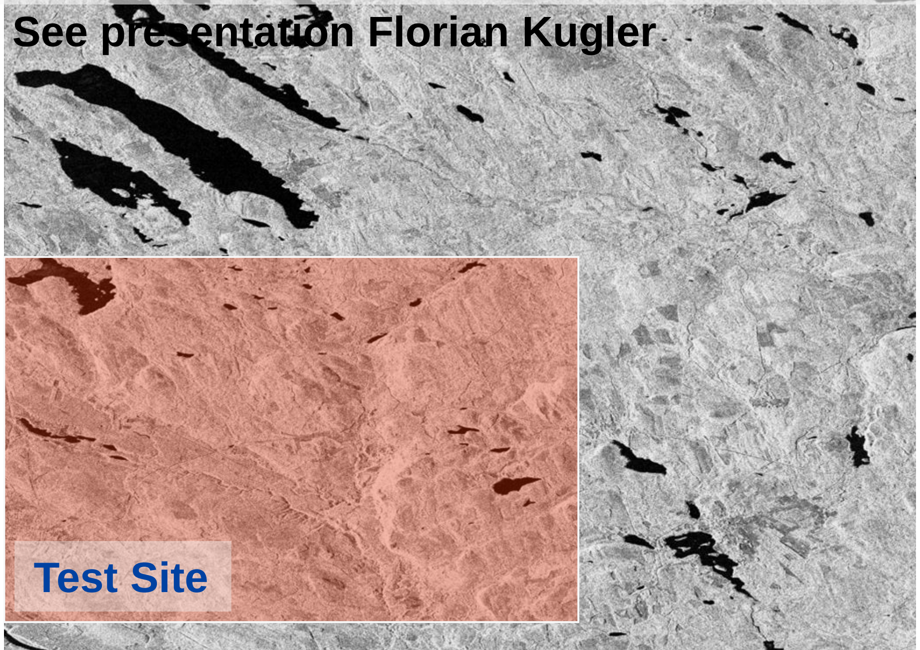
TanDEM-X: Kryckland Test Site, Sweden

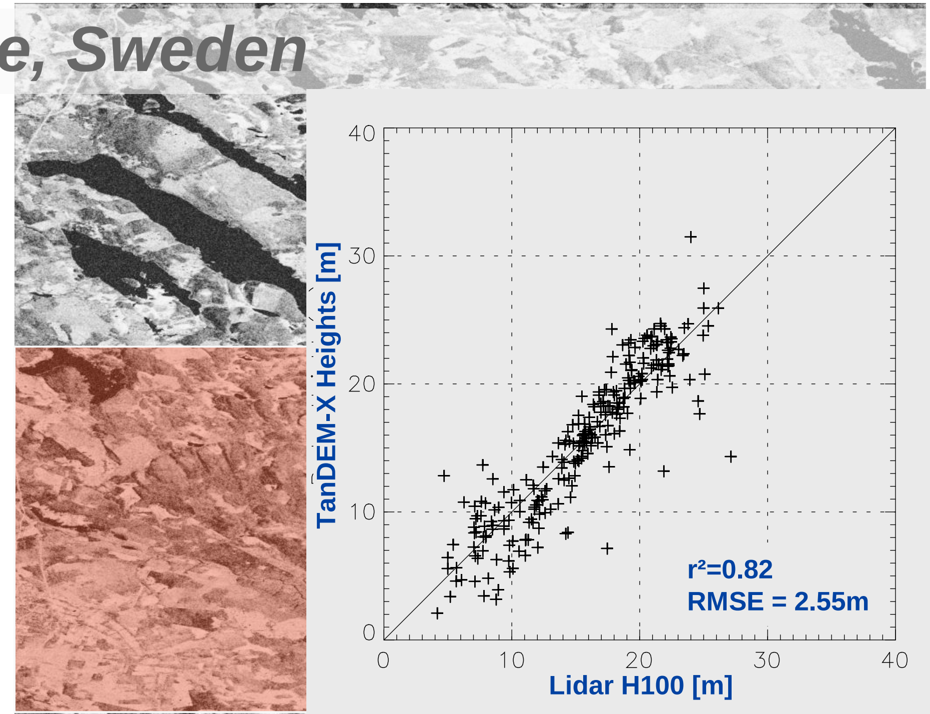


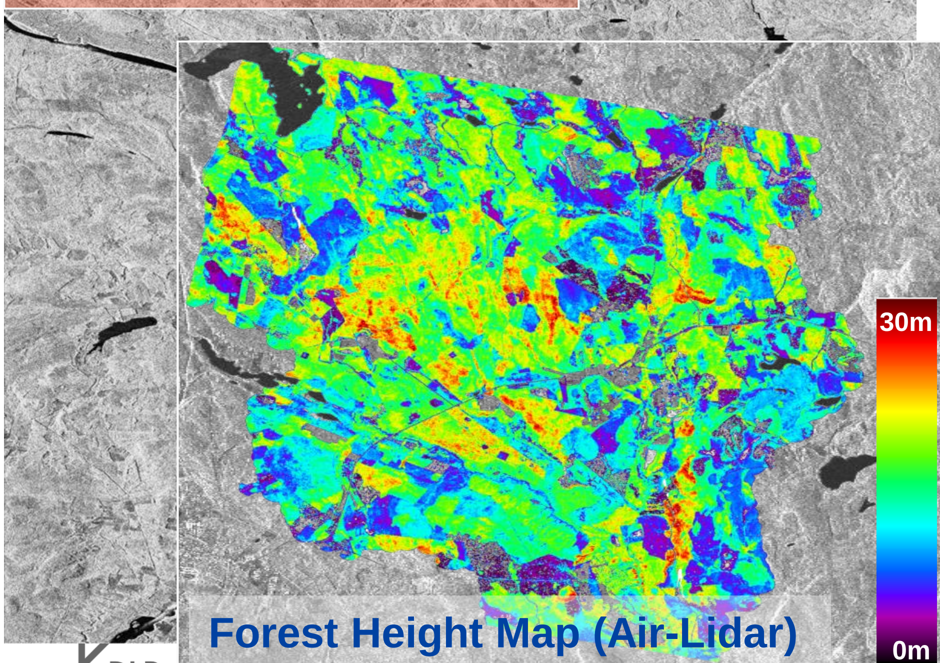
* Derived from the inversion of the TanDEM-X VV coherence by using the Lidar derived ground topography as input.

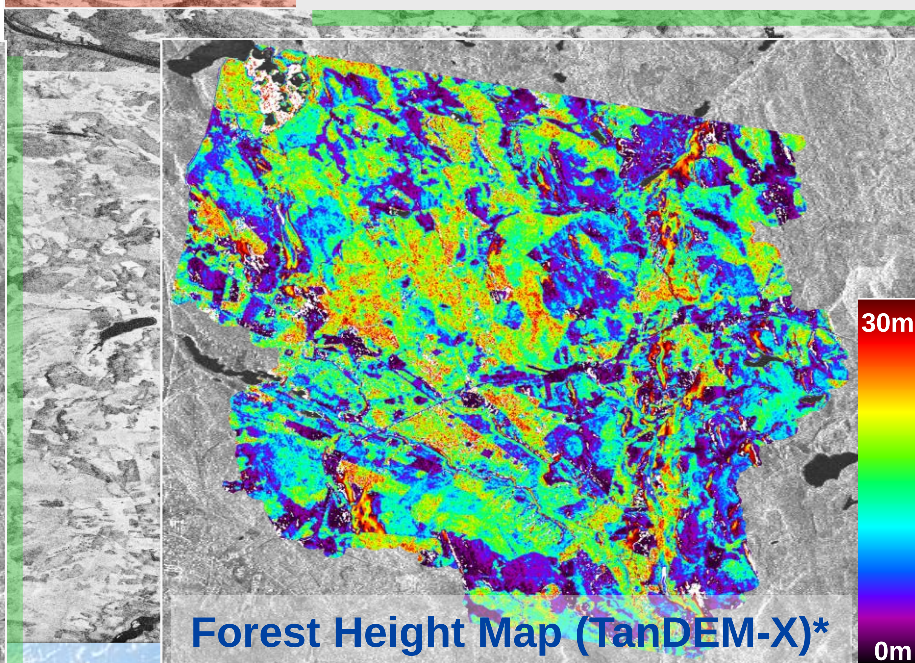
TanDEM-X: Kryckland Test Site, Sweden

See presentation Florian Kugler





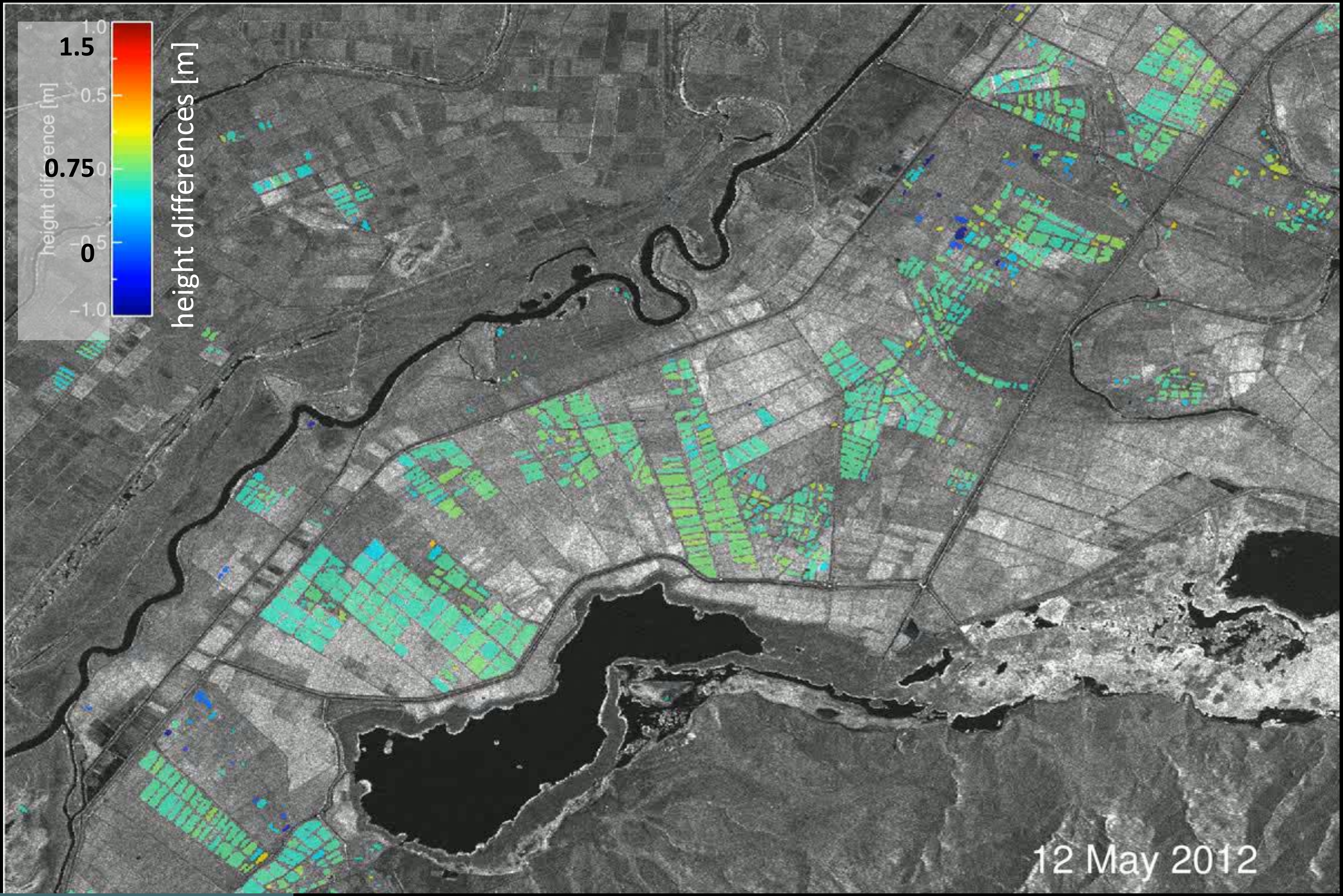




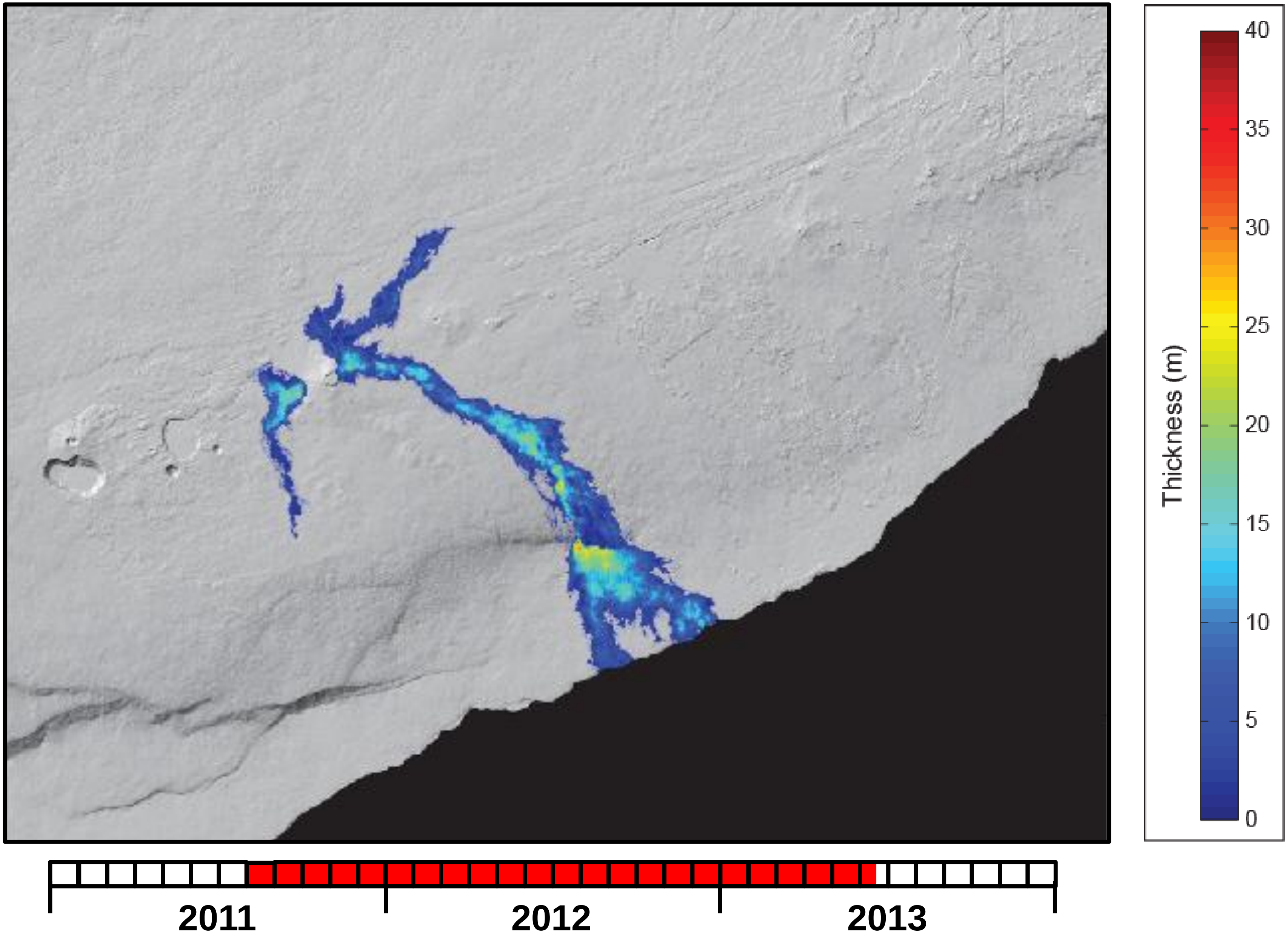
DLR

* Derived from the inversion of the TanDEM-X VV coherence by using the Lidar derived ground topography as input.

Experimental paddy-rice monitoring

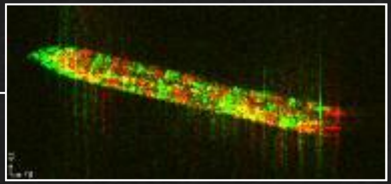



Poland, M., Lava discharge rates determined from TanDEM-X imagery from Kīlauea Volcano, Hawai‘I
August 3–15, 2011

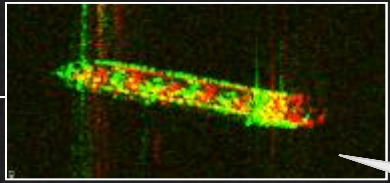


Thickness (m)
40
35
30
25
20
15
10
5
0
2011
2012
2013

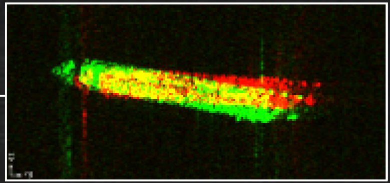
Ships @ the Straight of Gibraltar



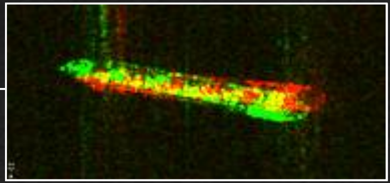
Coordinate: 35.949 N, -5.712 O
Velocity: 16.7 kn
Direction: 280.9°
Ship-ID: 3



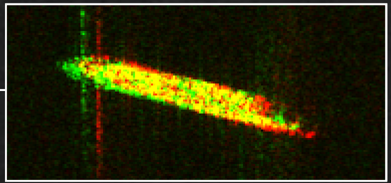
Coordinate: 35.953 N, -5.704 O
Velocity: 9.5 kn
Direction: 276.9°
ShipID: 4



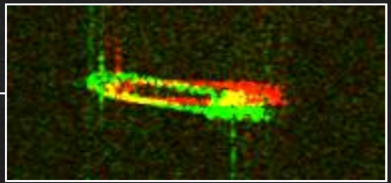
Coordinate: 35.960 N, -5.694 O
Velocity: 12.7 kn
Direction: 250.0°
Ship-ID: 6



Coordinate: 35.964 N, -5.700 O
Velocity: 8.9 kn
Direction: 264.9°
Ship-ID: 7



Coordinate: 35.951 N, -5.659 O
Velocity: 8.8 kn
Direction: 273.5°
Ship-ID: 2

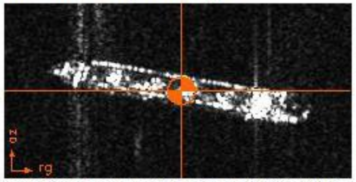


Coordinate: 35.963 N, -5.657 O
Velocity: 9.8 kn
Direction: 273.8°
Ship-ID: 5

Measured SAR-GMTI Data

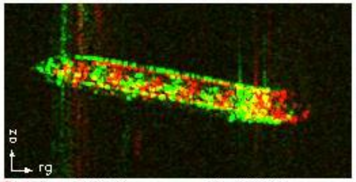
Target ID:	4
Latitude:	35.9530°
Longitude:	-5.7040°
Speed:	9.5 kn
Acceleration:	0.00 m/s²
Heading:	276.9°
Detected At:	2010-09-07T18:23:04.41Z

Detected Original Image



TerraSAR-X image, patch size (rg x az): 203 x 102 px.
The circle markes the pixel considered for geocoding.

Color Composite of Both Images



Red: TerraSAR-X image; green: TanDEM-X image.

Diff. to Closest AIS Reference Data

Absolute Position Difference:	55.8 m
Easting Position Difference:	-55.7 m
Northing Position Difference:	2.9 m
Speed Difference:	0.2 kn
Heading Difference:	4.9°
Observation Time Difference:	9.0 s

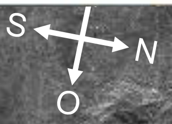
AIS Reference Data

Name:	Alabama Belle
MMSI:	548752000
IMO Number:	8412144
Callsign:	DYPD
Latitude:	35.9530°
Longitude:	-5.7030°
Speed:	9.3 kn
Heading:	272.0°
Vessel Type:	Cargo
Length:	184.0 m
Beam:	30.0 m
Draught:	6.5 m
Destination:	Termisa Brazil
ETA:	2010-09-17T18:00:00.00Z
Status:	Under way using engine
Extra Info:	N/A
AIS Last Seen At:	2010-09-07T18:22:55.00Z
AIS Retrieved:	2010-09-07T18:23:02.00Z
Web Info:	MMSI 548752000

Additionaly Measured SAR-GMTI Data

Along-Track Speed:	2.7 kn
Across-Track Speed:	-9.1 kn
Azimuth Displacement:	-317.1 m
Strip Heading:	350.5°
Target Heading With Respect to the Azimuth Direction:	-73.7°
Incidence Angle:	46.60°
Azimuth Displacement Difference:	2.00 samples
Range Displacement Difference:	-9.50 samples
Correlation Coefficient:	0.81
Rotation Angle:	0.0°

Deutsches Zentrum für Luft- und Raumfahrt
DLR



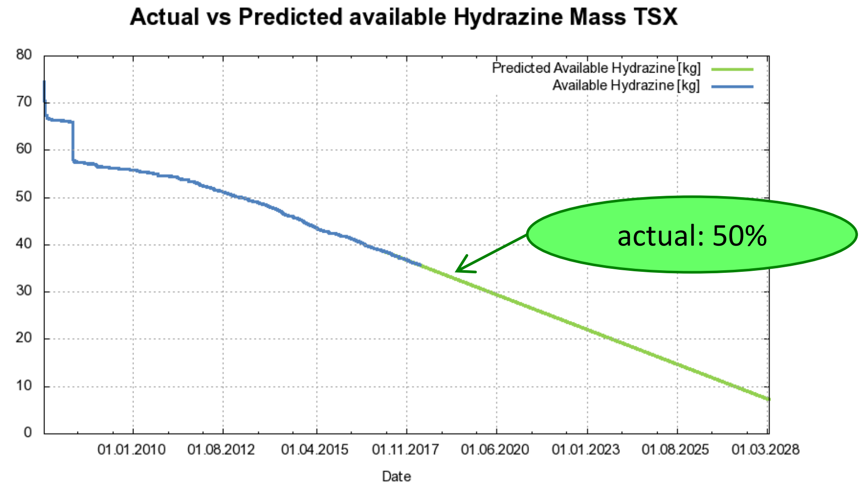
Resources Status – Hydrazine (March 2018)

TerraSAR-X Satellite

Hydrazine filling level

11 years after launch:

ca. 50%

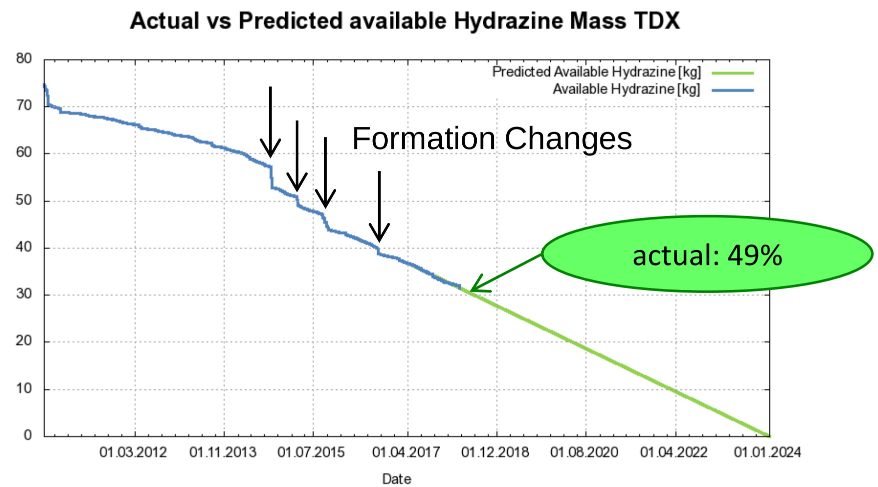


TanDEM-X Satellite

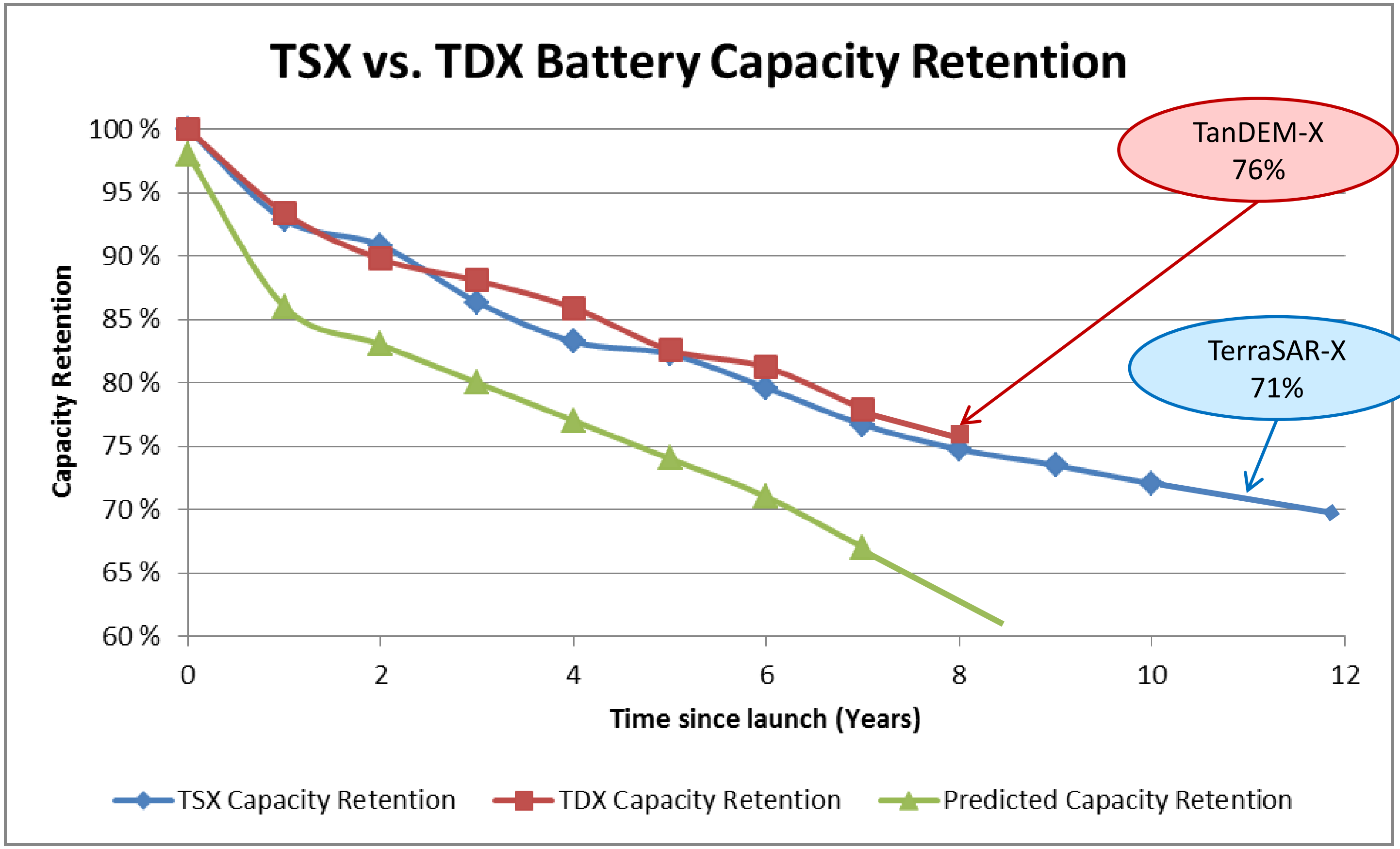
Hydrazine filling level

8 years after launch:

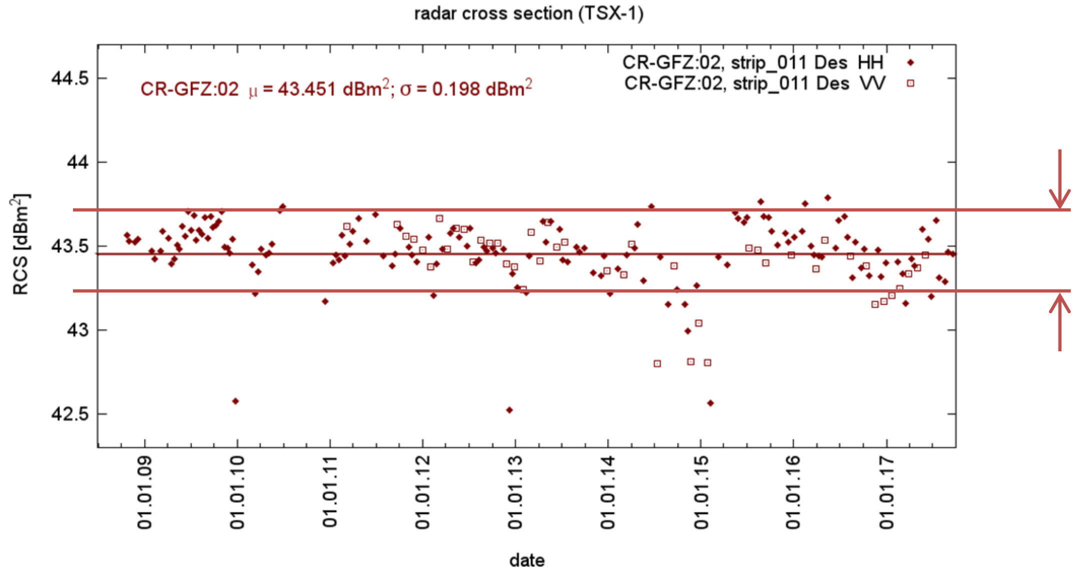
ca. 49%



Resources Status - Battery

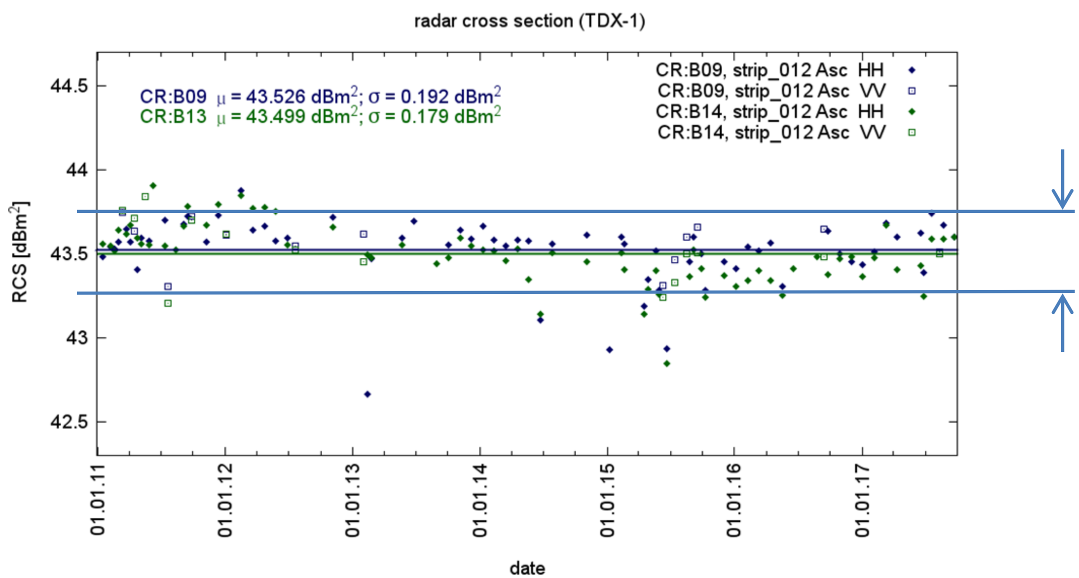


Long-Term System Monitoring - RCS Measurement Example



Satellite TSX

$\sigma \approx 0.2$ dBm²
(9 years)



Satellite TDX

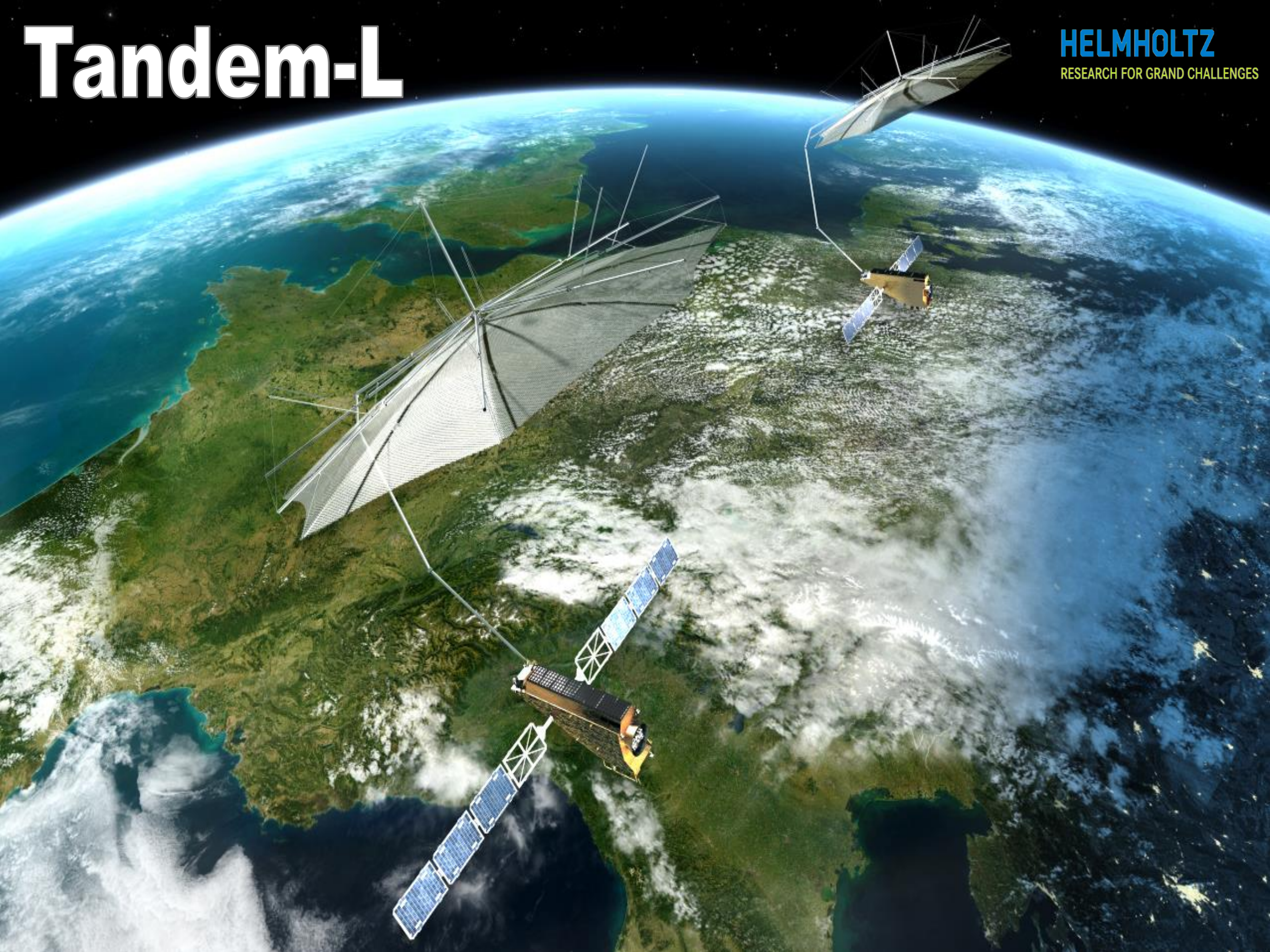
$\sigma \approx 0.2$ dBm²
(7 years)

DLR

TerraSAR-X / TanDEM-X Mission Status

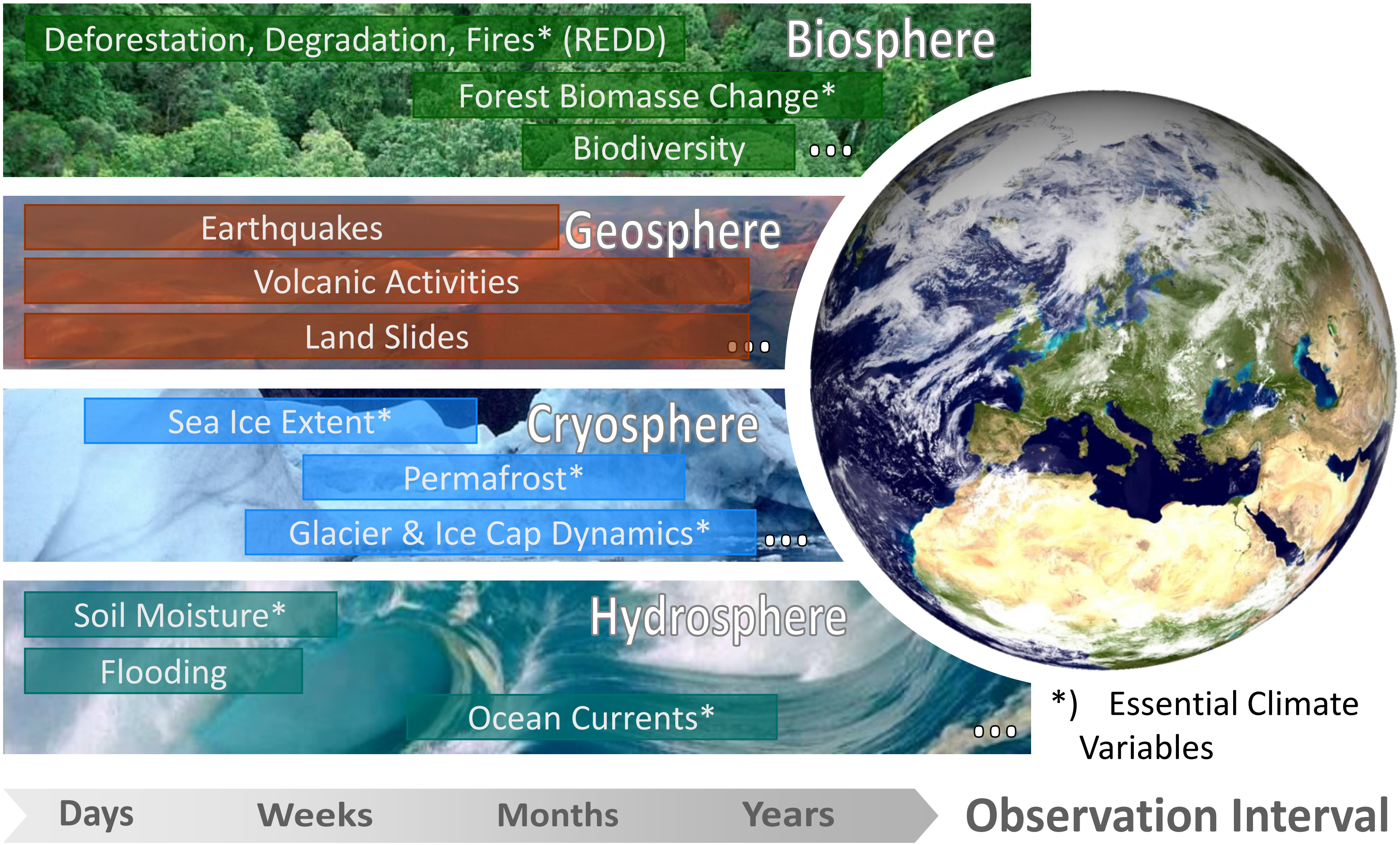
- TerraSAR-X / TanDEM-X Mission will be continued
- Stable operations in close formation since October 2010
- Precise calibration of the interferometric system
- Global TanDEM-X DEM completed in September 2016
- Available data well within specifications (outstanding absolute height accuracy and less than 0.3% voids)
- Ongoing: Bistatic acquisitions in order to fill gaps in the global DEM and to acquire updates in dedicated areas
- 90m TanDEM-X DEM available for scientific use

Tandem-L



HELMHOLTZ
RESEARCH FOR GRAND CHALLENGES

Dynamic Processes on the Earth Surface



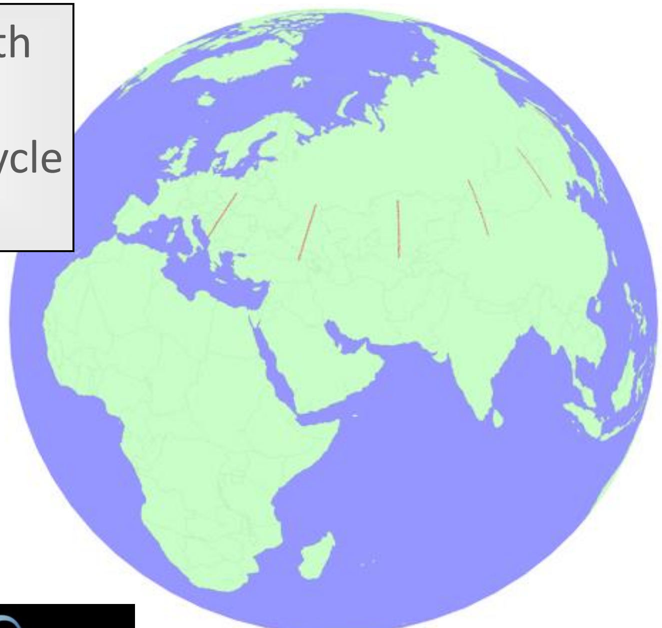
DLR

Comparison of Imaging Capacity

TerraSAR-X/TanDEM-X

1 global coverage / year

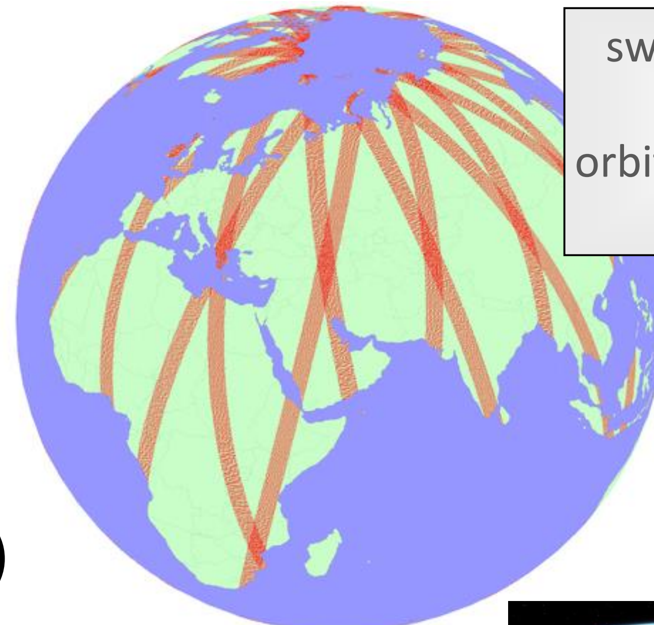
swath width
30 km
orbit duty cycle
3 min



Tandem-L

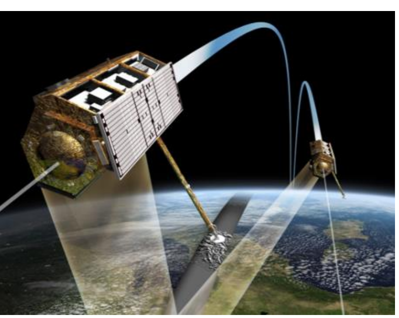
2 global coverages / week

swath width
350 km
orbit duty cycle
30 min



1

Days



DLR