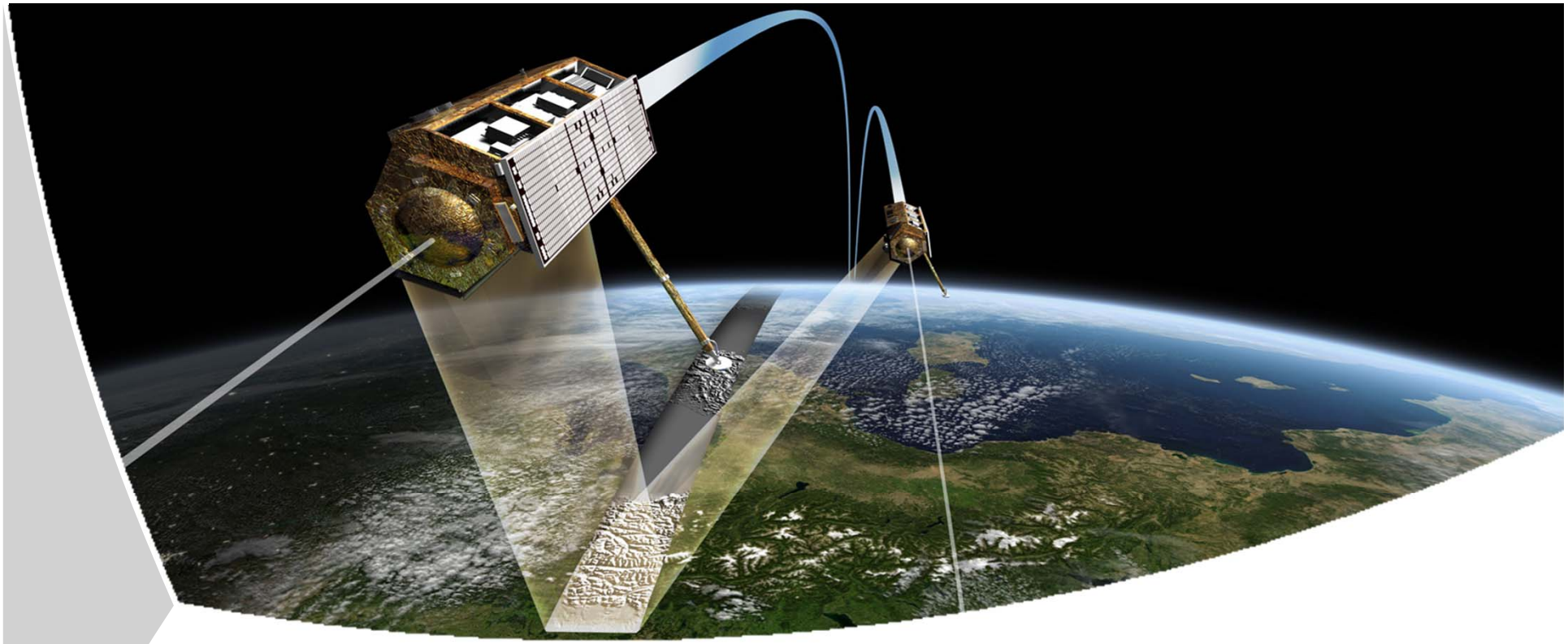
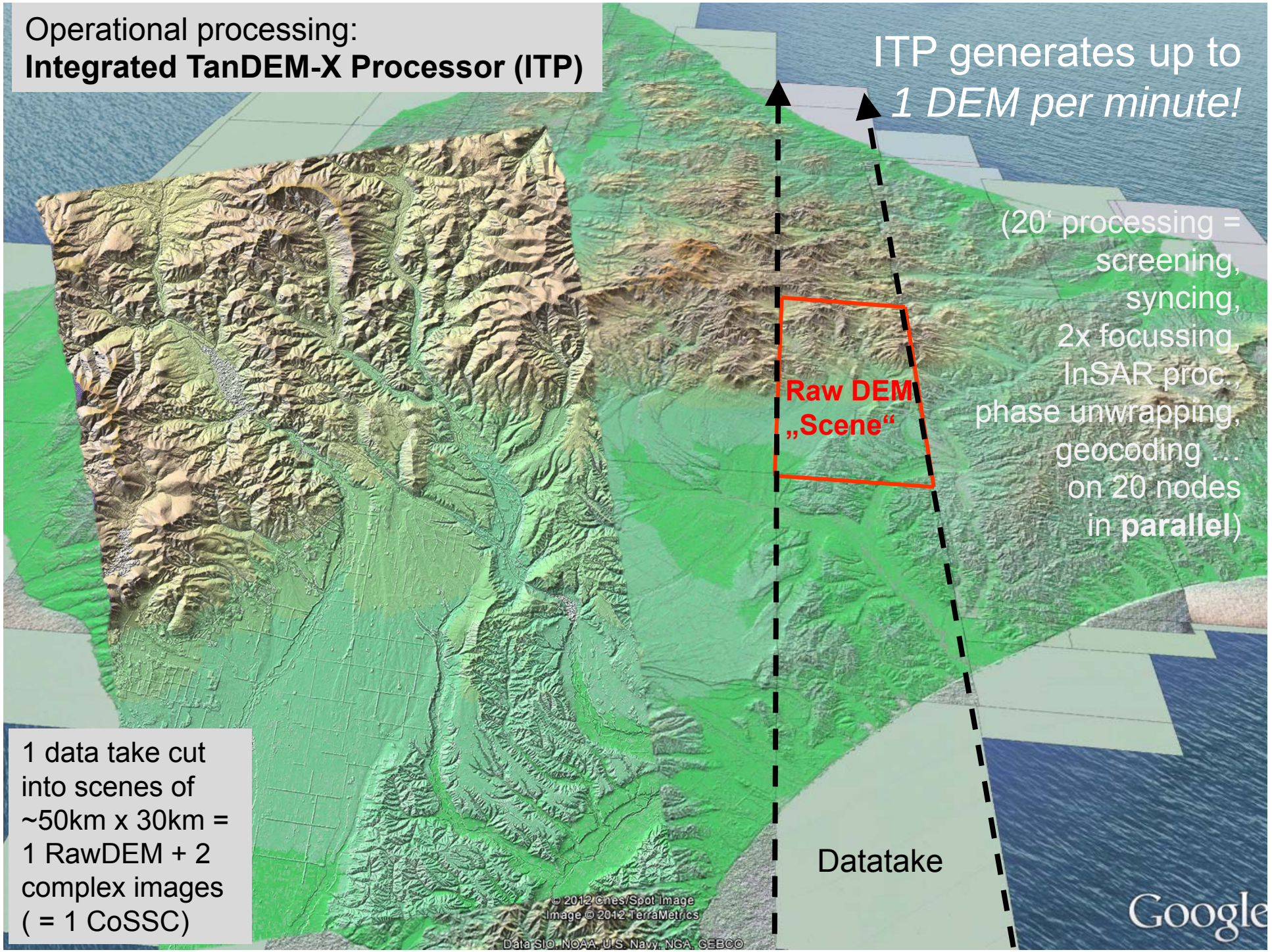


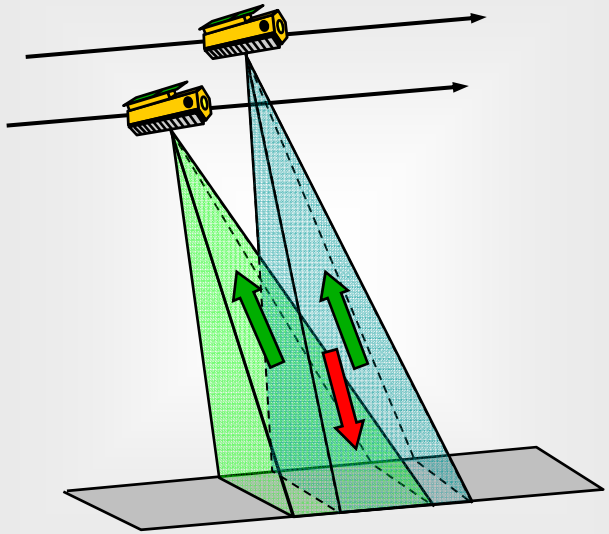
Interferometric Processing

T. Fritz, H. Breit, M. Lachaise, S. Duque, C. Rossi, U. Balss, N. Yague-Martinez + *ITP- & G/S-Teams*

Deutsches Zentrum für Luft- und Raumfahrt e.V.
in der Helmholtz-Gemeinschaft

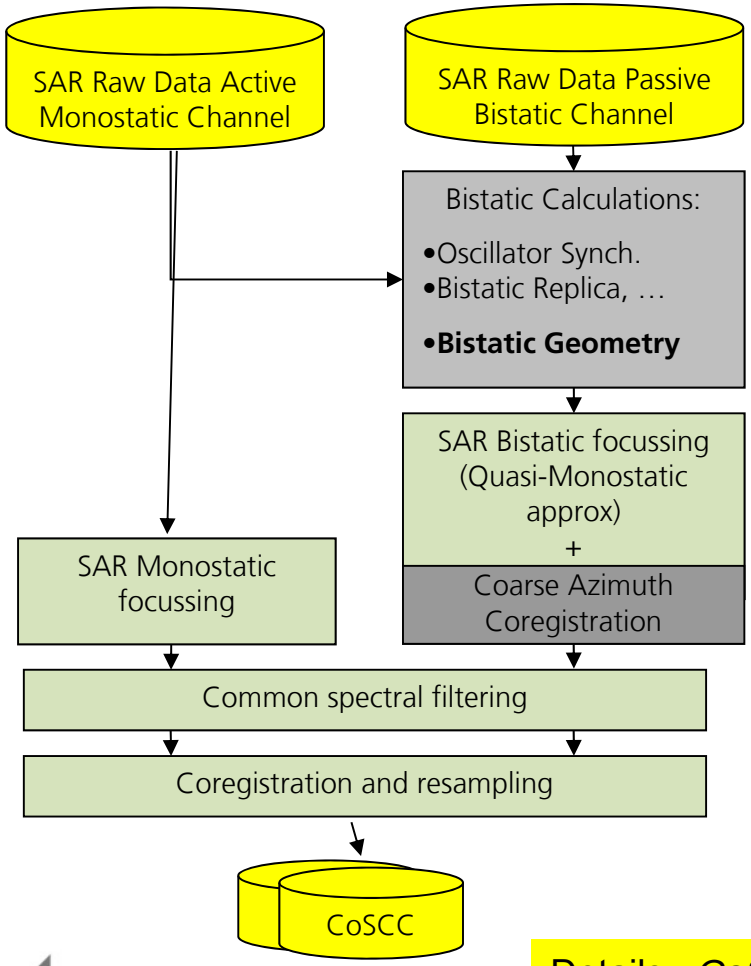

Operational processing:
Integrated TanDEM-X Processor (ITP)
ITP generates up to
1 DEM per minute!
(20‘ processing =
screening,
syncing,
2x focussing,
InSAR proc.,
phase unwrapping,
geocoding …
on 20 nodes
in **parallel**)
Raw DEM
„Scene“
1 data take cut
into scenes of
~50km x 30km =
1 RawDEM + 2
complex images
(= 1 CoSSC)
Datatake
© 2012 Cnes/Spot Image
Image © 2012 TerraMetrics
Data SIO, NOAA, U.S. Navy, NGA, GEBCO
Google

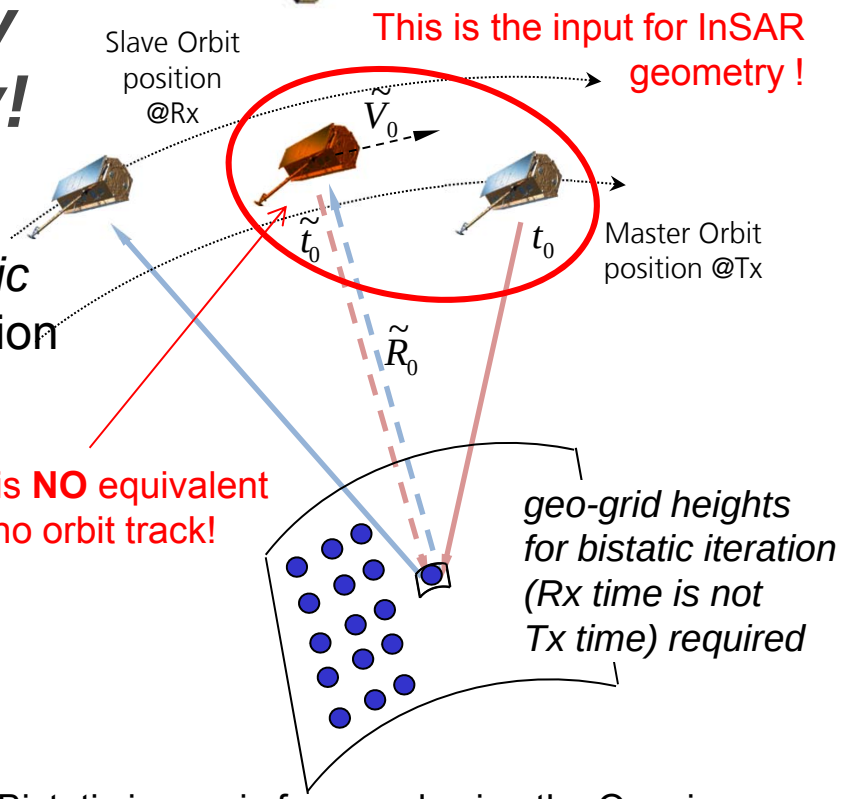
TanDEM-X Data Acquisition Modes Processed by ITP

Pursuit Monostatic	Bistatic	Alternating Bistatic
		

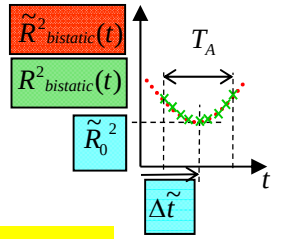
- one satellite transmits and both satellites **receive simultaneously**
- **dual use** of signal energy
- requires **synchronisation**

CoSSC Bistatic Geometry – very accurate but tricky!



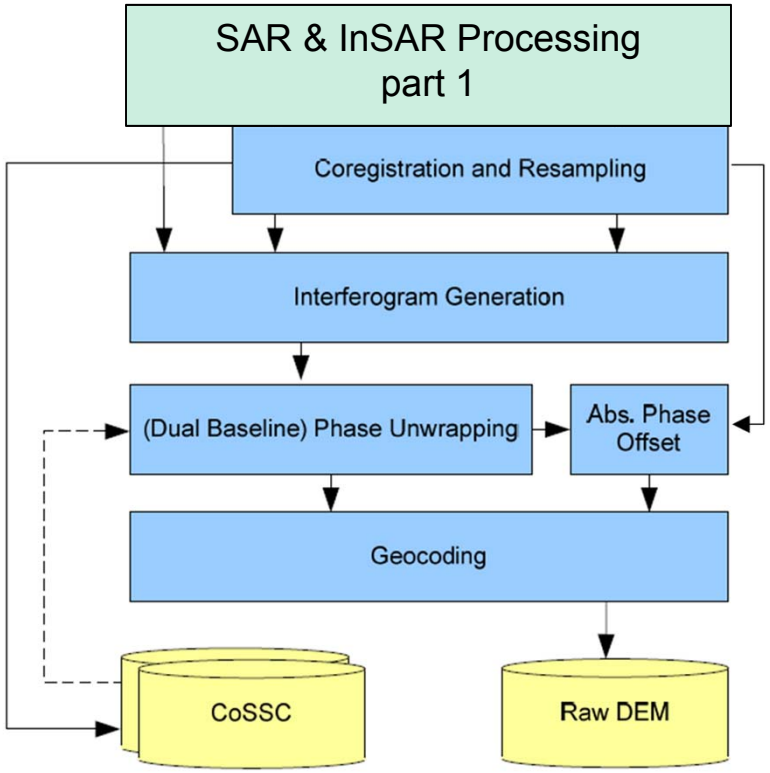


- The Bistatic image is focussed using the Quasi-monostatic approximation → ***Monostatic equivalent***.
- *Three parameters* to be found
  - The equivalent sat *velocity*, $\tilde{V}_0$
  - The *azimuth time* at the apex, $\tilde{t}_0$
  - The *range* at the apex, $\tilde{R}_0$



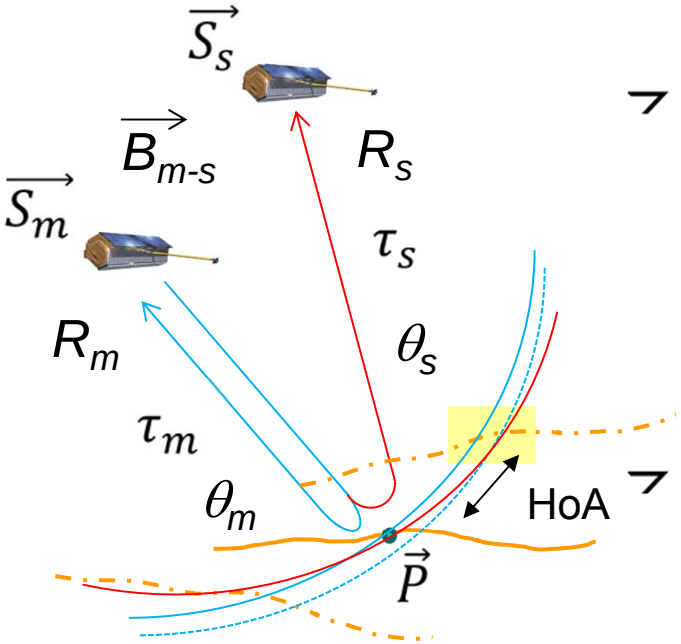
Details: „*CoSSC Generation & Interferometric Considerations*“ document by S. Duque (on science web server)

ITP Interferometric Processing Sequence

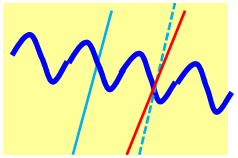


- *bistatic synchronization, calibration & focusing performed by ITP part 1*
- **Signal based high-resolution coregistration** (no reference DEM required)
- "Byproduct": **Radargrammetric** shifts used for
  - **absolute phase offset** determination = absolute height "pre-" calibration
  - fully automatic phase unwrapping (PU) **quality control**
- **Dual Baseline PU** uses both coverages to unwrap the problematic (large baseline) data

SAR Interferometry and Radargrammetry



$\Delta\theta_{wrap} = \Delta\theta$ $+/- 2\pi$



- The determination of the differential delay time $\Delta\tau = \tau_m - \tau_s$ for a given point on ground enables 3D-reconstruction.
- An **unambigiuous** but **coarse** estimate $\Delta\tau_{coarse}$ is determined by means of correlation in co-registration step, reaching sub-wavelength accuracy (but too coarse for accurate terrain reconstruction).
  => **Radargrammetry**
- The interferometric phase $\theta = \left(\frac{2\pi \cdot \Delta\tau \cdot c}{\lambda}\right) mod\ 2\pi$ provides an highly **accurate** but **ambiguous** estimate $\Delta\tau_{wrapped} = \Delta\tau\ mod\ \left(\frac{\lambda}{c}\right) = \Delta\tau - n\frac{\lambda}{c}$
  => **Interferometry**
- The performance of both methods depends on coherence

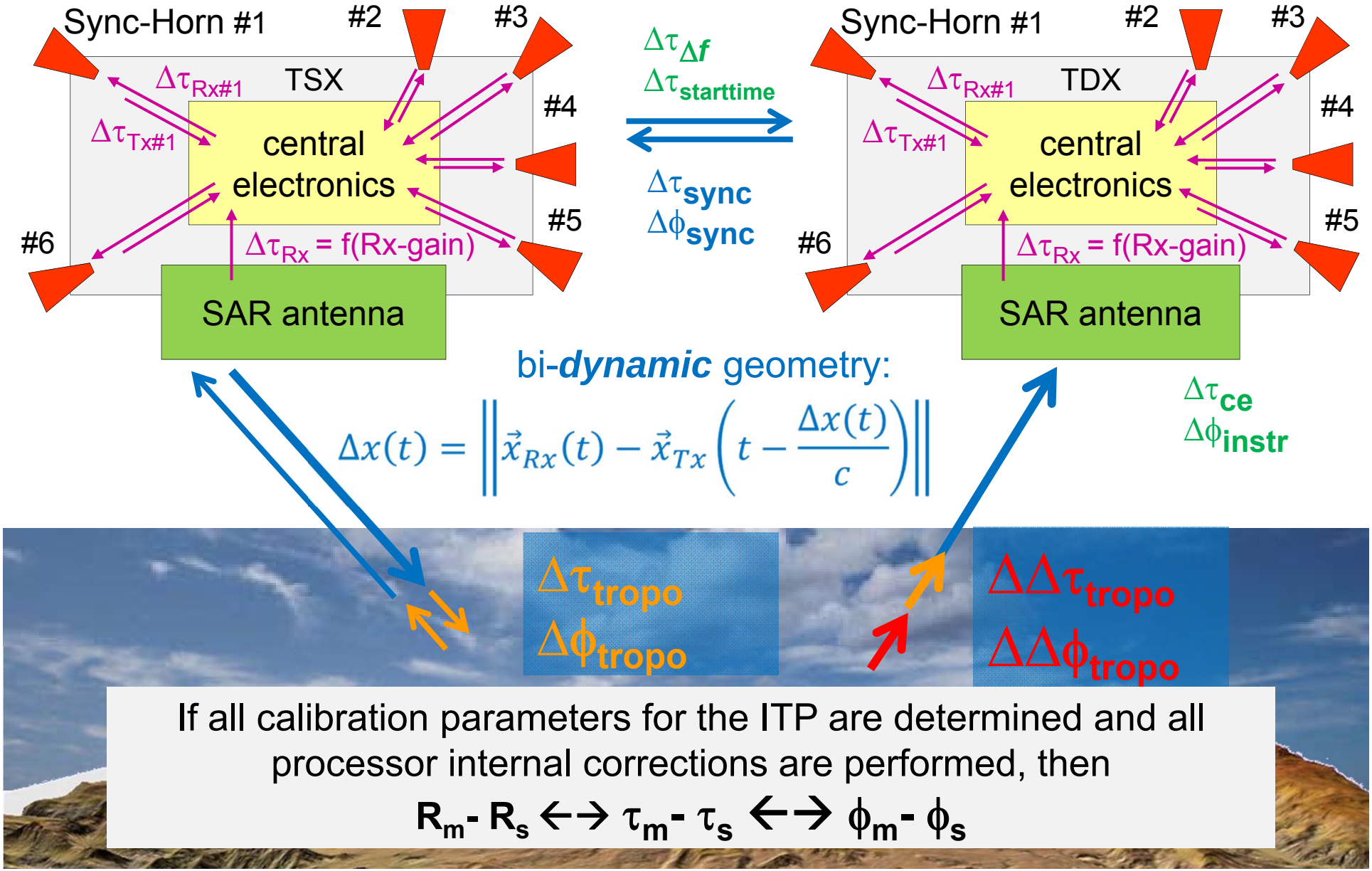
TanDEM-X DEM-Processing: Interferometry + ***Radargrammetry***
(with *very small* angular separation)
➔ coarse but ***absolute*** „**Stereo-DEM**“
used for absolute height determination
of ambiguous InSAR-DEM (2π=HoA)

requires ***mm*** relative
system accuracy

Terra Sar X & Tandem X, 28 Nov 2010, 17:01:22.30 - 17:01:32.35 UTC
Canon EOS 450D + EF 50/2.5 Macro @ F2.8, 800 ISO, 10.05s
Marco Langbroek, SatTrackCam Leiden (Cospar 4353)

RawDEM-processing is completely independent from any reference data!

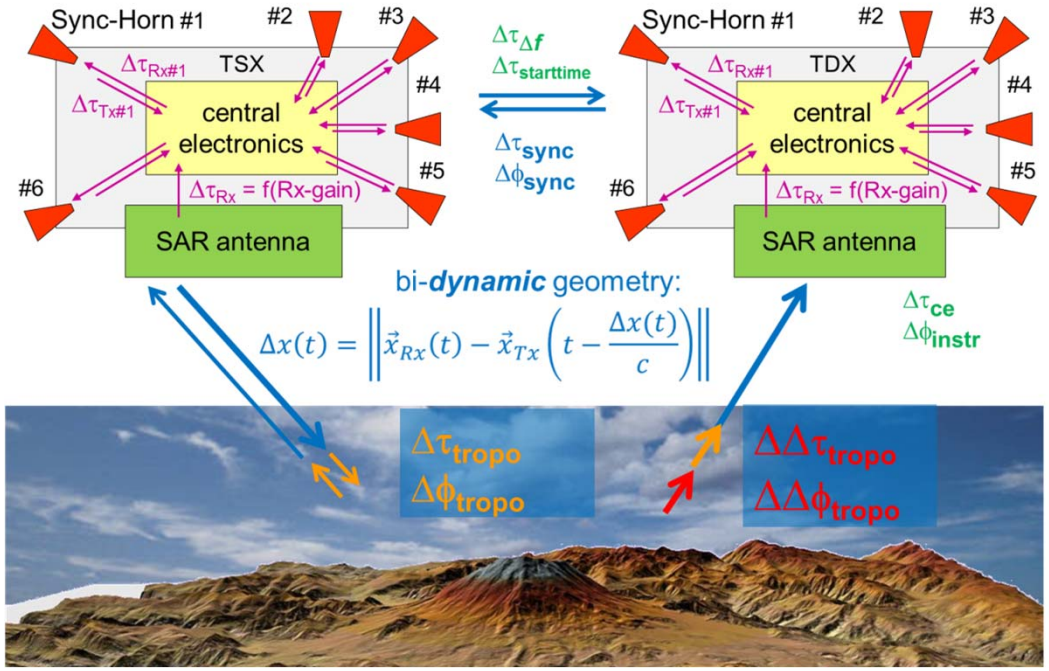
Phase & Delay Corrections in Processing



If all calibration parameters for the ITP are determined and all processor internal corrections are performed, then

$$R_m - R_s \leftrightarrow \tau_m - \tau_s \leftrightarrow \phi_m - \phi_s$$

Phase & Delay Corrections in ITP Products



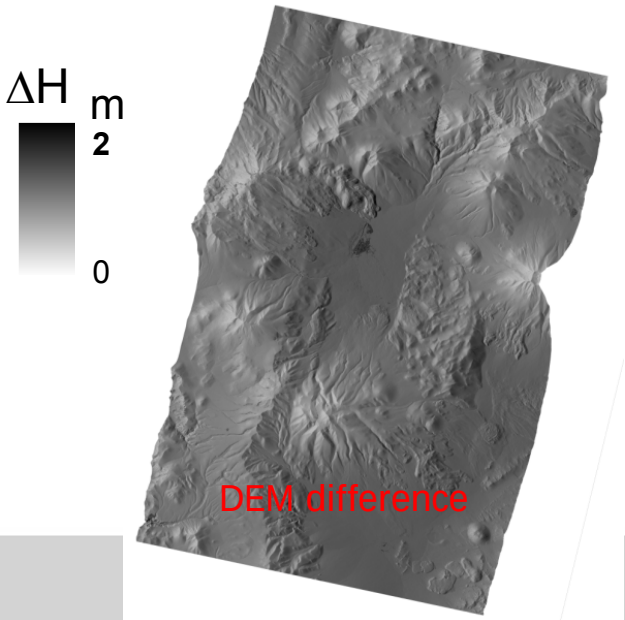
applied for all CoSSCs

performed during geocoding to RawDEM (since height dependent).

Atmospheric (+ ionospheric) delay correction – Impact on DEM:

$$\Delta R^{Z}_{tropo}(h) = \frac{ZPD}{\cos(i)} \cdot e^{\left(\frac{-h}{H}\right)}$$

$$ZPD = 2.3m; H = 6000m$$

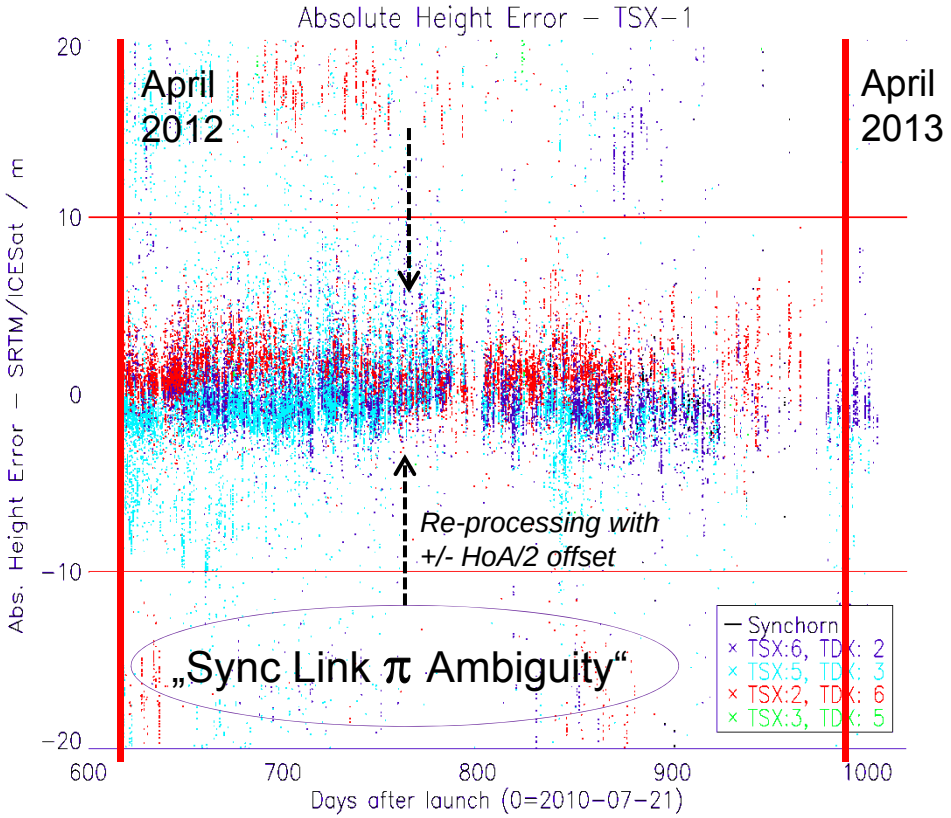


Absolute Height “Error” to Reference Data (IceSAT & SRTM)

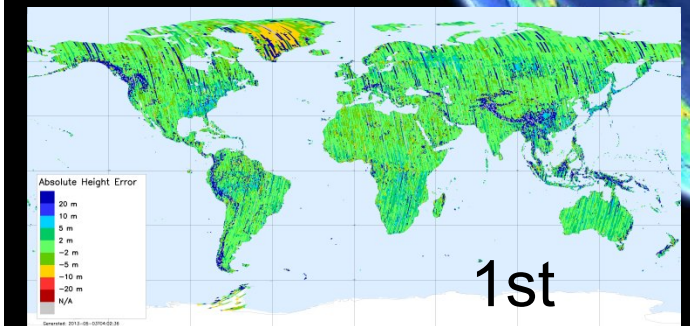
by courtesy of MCP & M. Bachmann

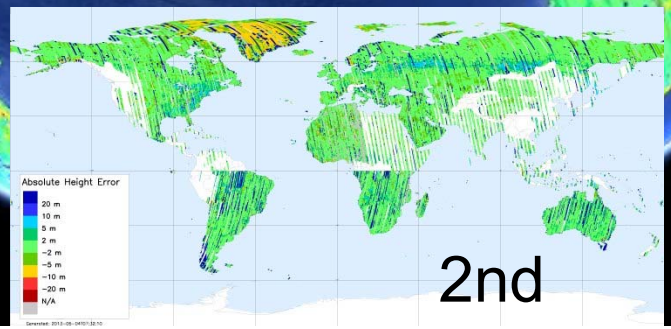
RawDEM scene height offsets ***before*** calibration/mosaicking in MCP:

IDEM Region (examples)	*uncorrected* H differences	
	mean [m]	std.dev. [m]
Saudi Arabia	-0.6	2.0
Mexico	-1.0	2.2
Italy	-0.7	2.6
UK	0.0	2.0
Iceland	0.6	1.8
Hokkaido	0.7	2.5
MacKenzie/ CAN	-1.0	1.7
Greenland-Russel Glc.	-2.2	**5.0**



Absolute Height Offsets of *Raw*DEMs

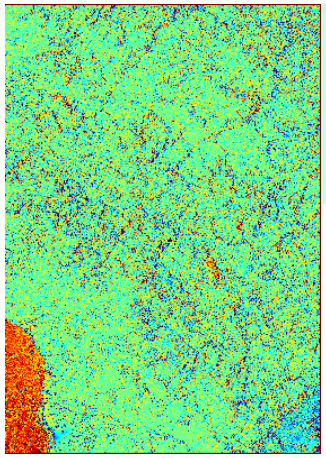




„Error“: presumably dominated by X-band penetration & scattering in ice volume / vegetation.

Radargrammetry for PU Quality Control & Phase Offset

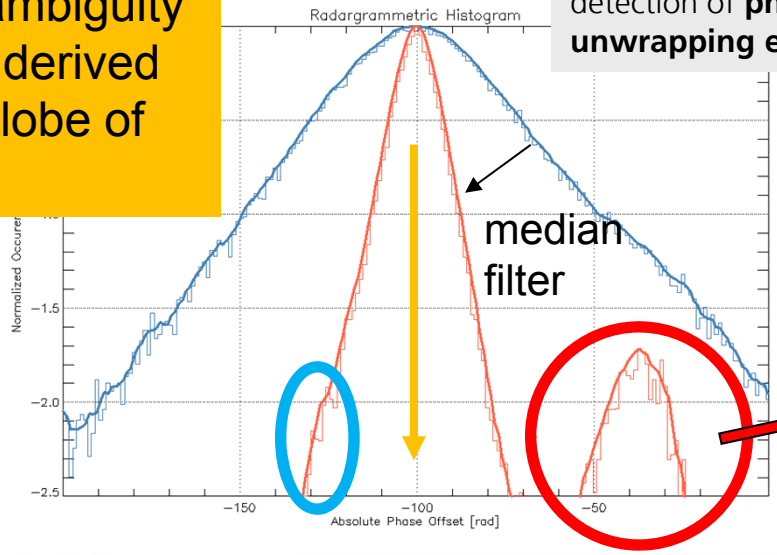
Master Channel SAR Amplitude, Cordillera Central Mountains, Peru, 11/04/2011



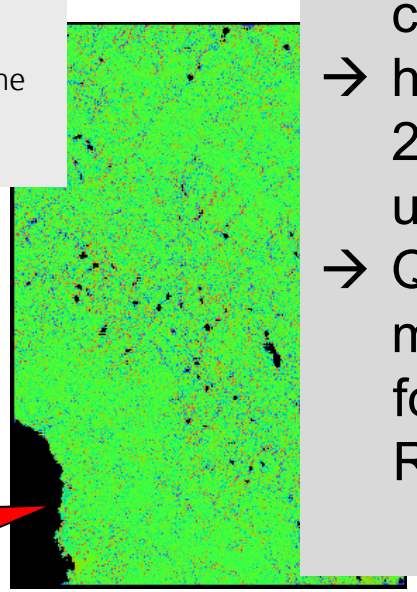
Phase Differences

Radargrammetric Phase – unwrapped InSAR Phase

Integer π-ambiguity number *m* derived from main lobe of histogram



Phase Difference Histogram. The median filtered version allows the detection of **phase unwrapping errors.**



PU Control Map

- → Absolute phase offset (integer π)
- → Fractional offset for system calibration
- → heights for 2BL phase unwrapping
- → Quality mask &flag for each RawDEM

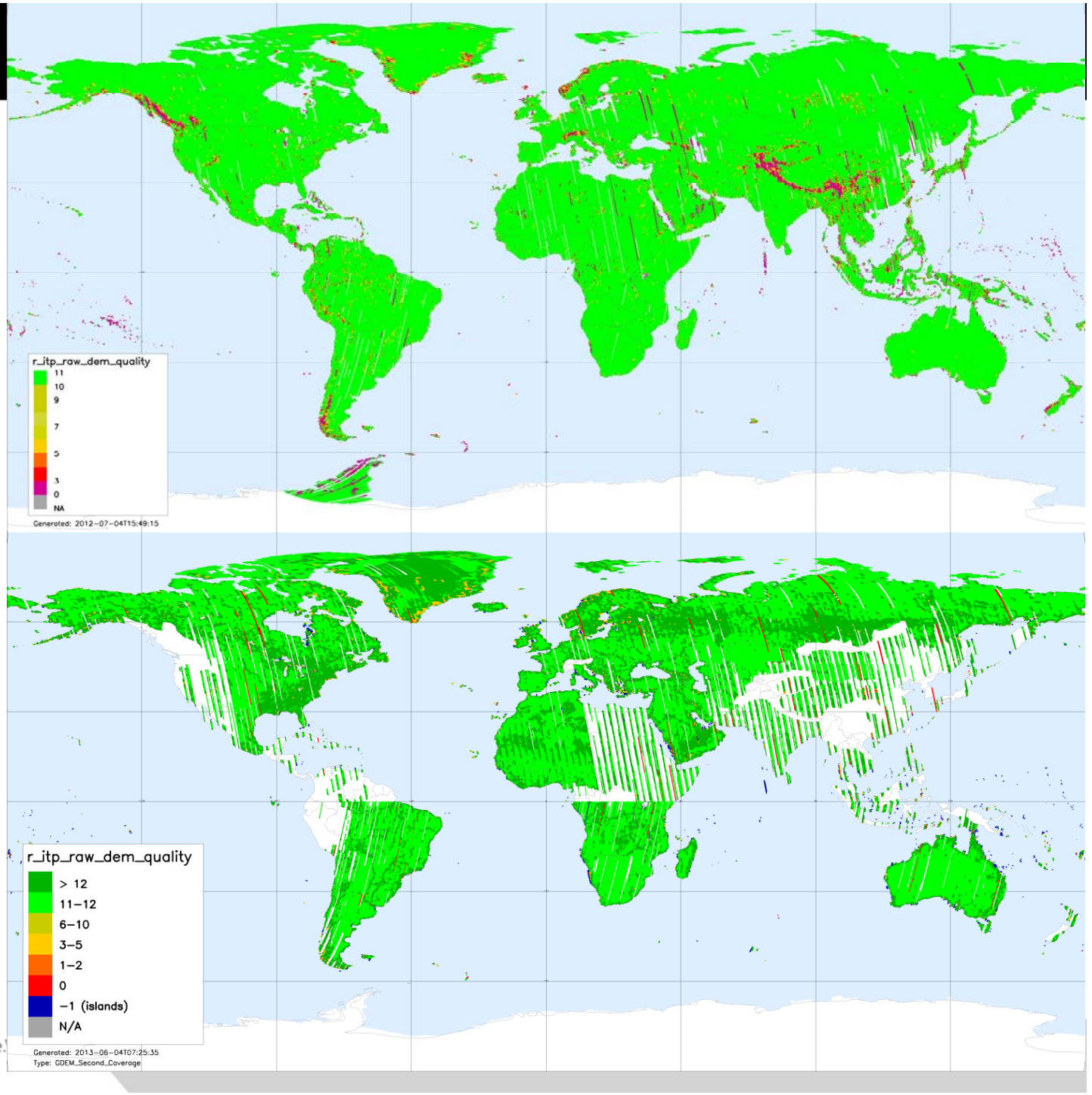
Processed

1st Coverage

ITP **quality flag** on radargram consistency (PU errors & USO anomalies)

2nd Coverage

dark green = ***dual-baseline*** PU check & correction performed

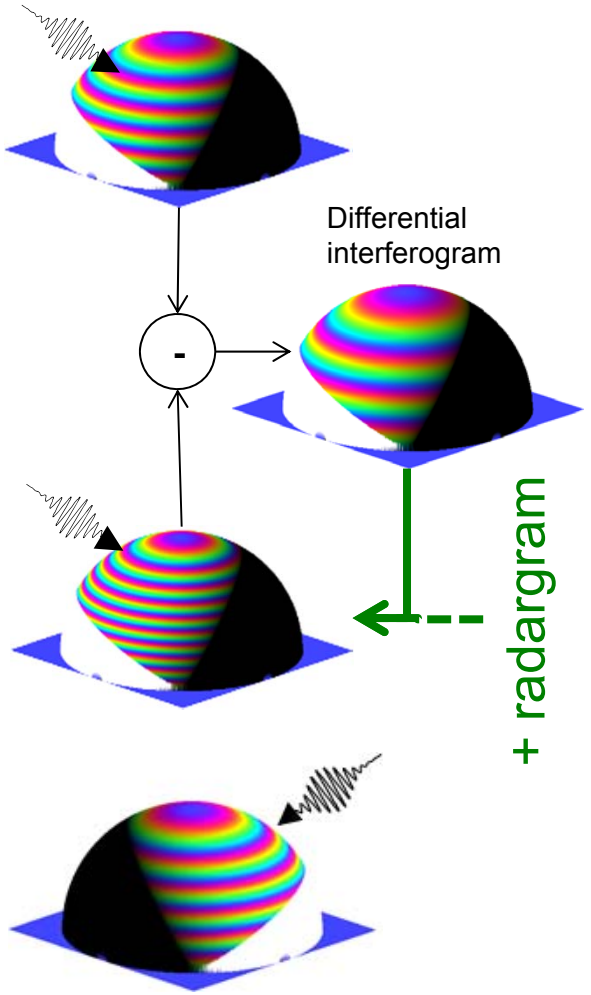


TanDEM-X Acquisition & Processing concepts

- Year 1: full coverage with smaller baseline
  - height ambiguity > 45 m good for moderate terrain
  - phase unwrapping problems in steep terrain
- Year 2: repeat with larger baseline
  - height ambiguity ~ 35 m gives full accuracy
  - robust **phase unwrapping by combining with first year**

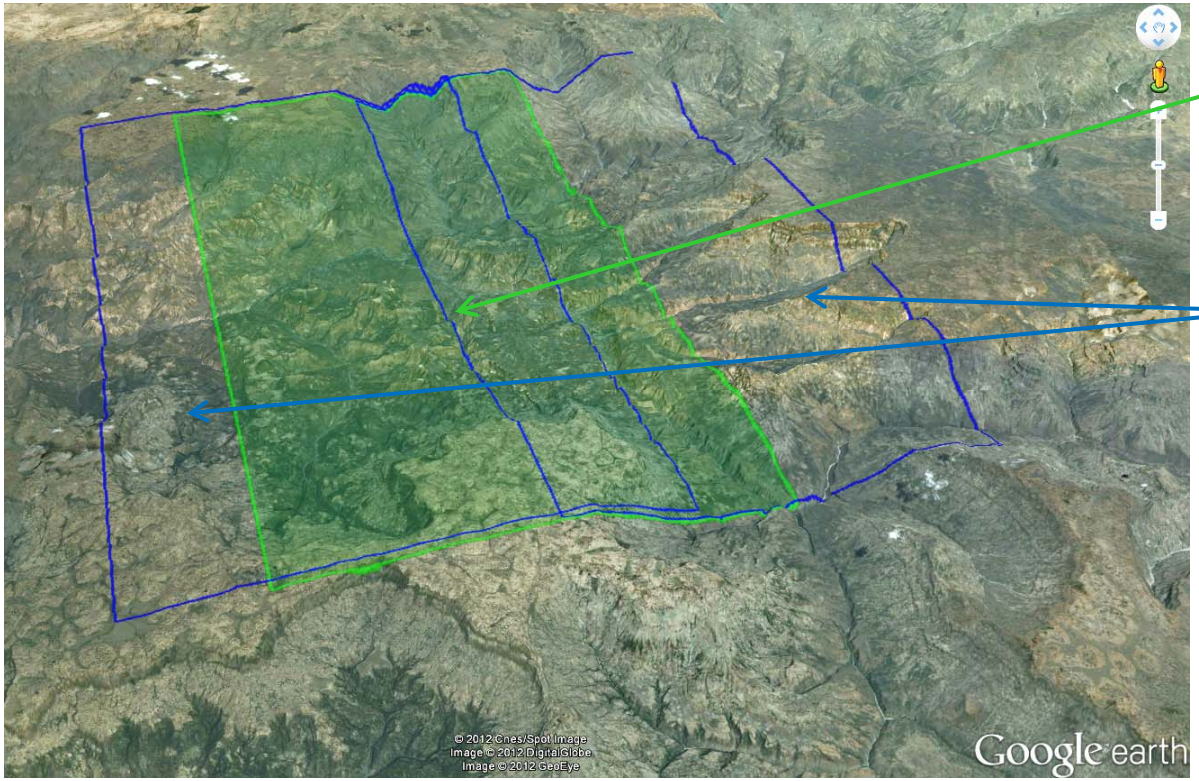
    ⇒ "*dual-baseline phase unwrapping*"

    ⇒ **correction of 1st year phase unwrapping errors**
- Year 3: more baselines & angles
  - fill shadow and layover regions
  - support phase unwrapping of difficult areas



For more details on the algorithms, see papers from **Marie Lachaise** *(e.g. IGARSS 2012)*

Dual-baseline phase unwrapping error correction principle



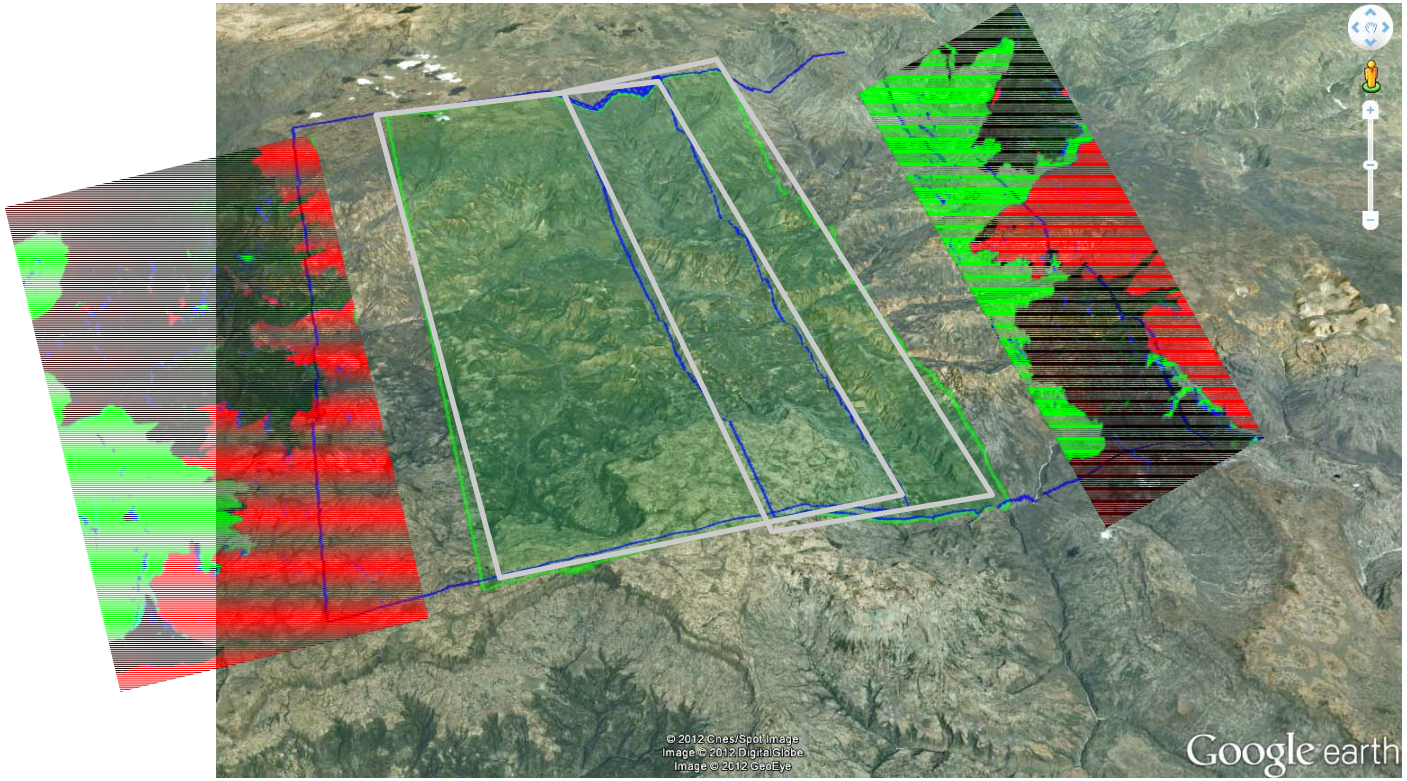
Scene from 2nd year

Supporting scenes from 1st year

Every 2nd year scene is checked <u>operationally</u> in a <u>fully automatic</u> approach

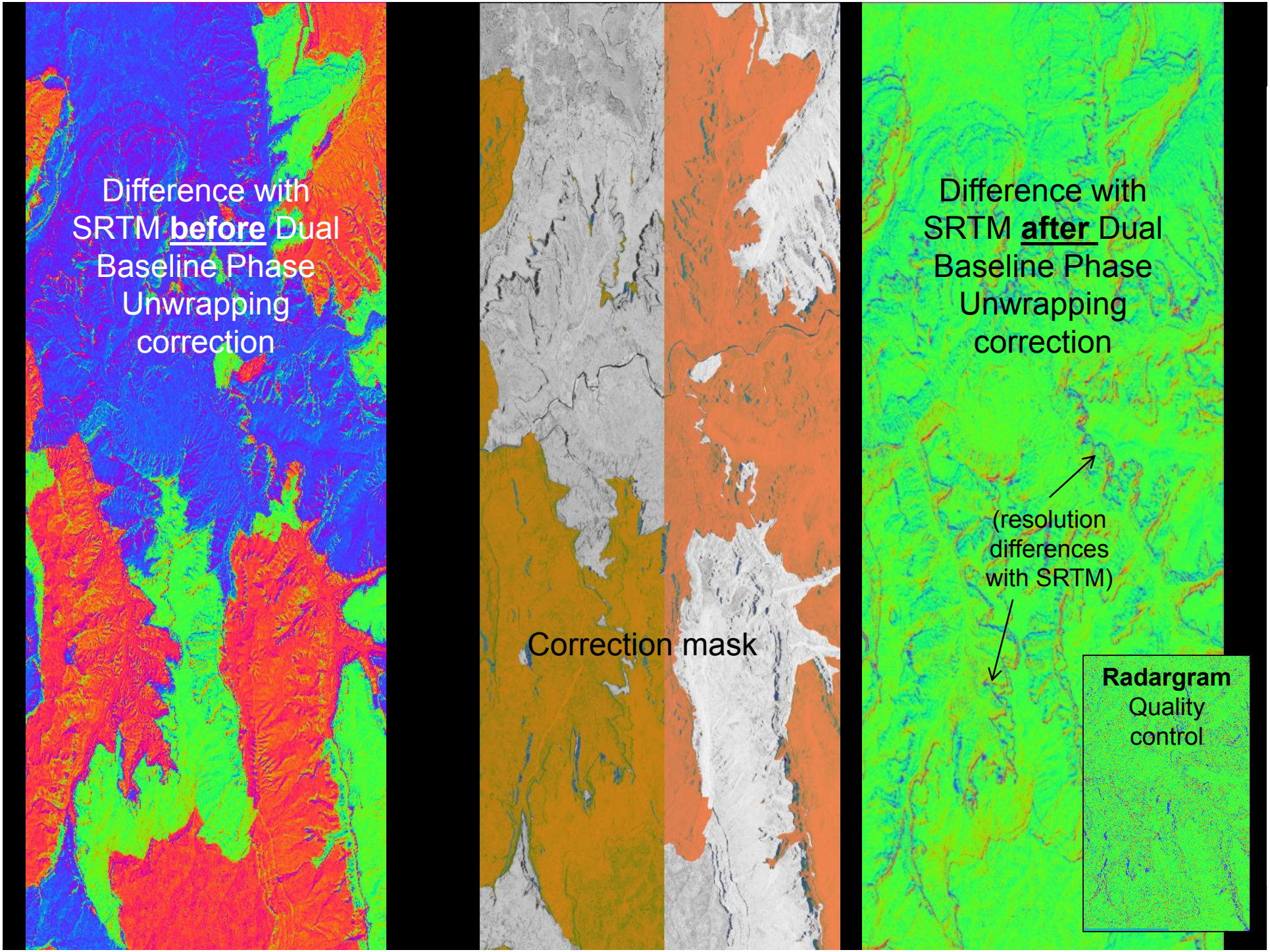
For more details on the algorithms, see papers from **Marie Lachaise** *(e.g. IGARSS 2012)*

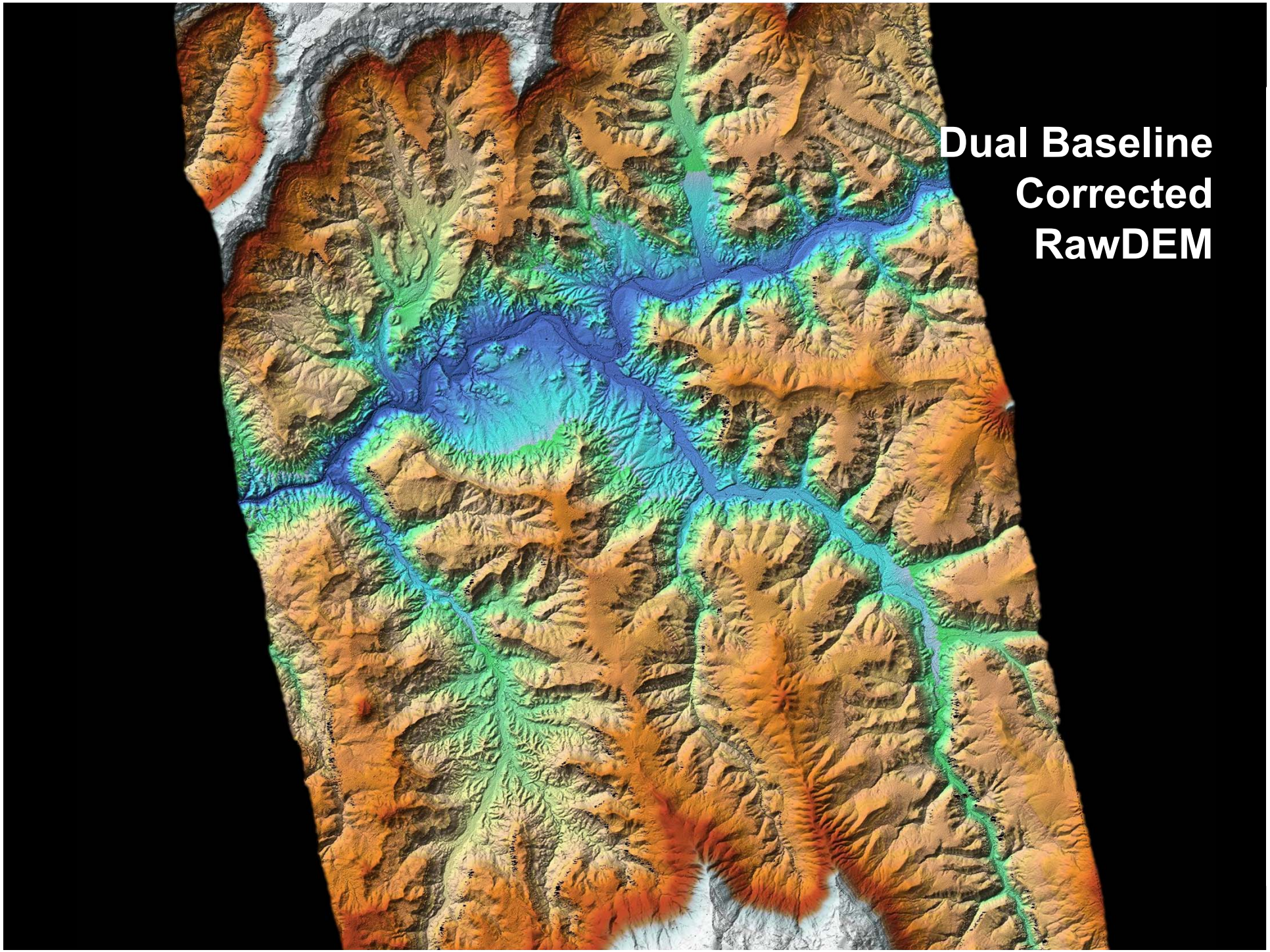
Dual-baseline phase unwrapping error correction principle (II)



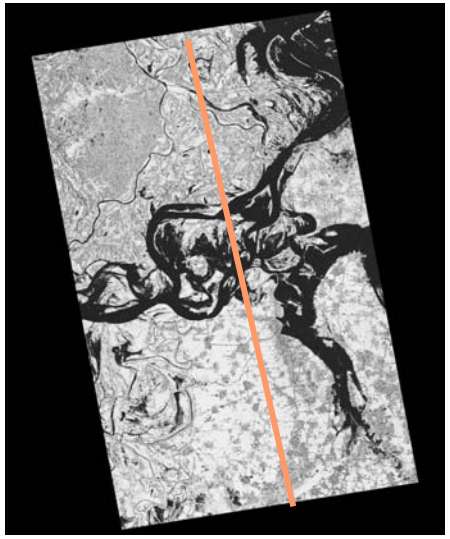
1. Look for height discrepancies in every overlap with the 1st year scenes
2. Correct these discrepancies with the scenes combination

For more details on the algorithms, see papers from **Marie Lachaise** *(e.g. IGARSS 2012)*


Difference with SRTM **before** Dual Baseline Phase Unwrapping correction
Correction mask
Difference with SRTM **after** Dual Baseline Phase Unwrapping correction
(resolution differences with SRTM)
Radargram Quality control


Dual Baseline
Corrected
RawDEM

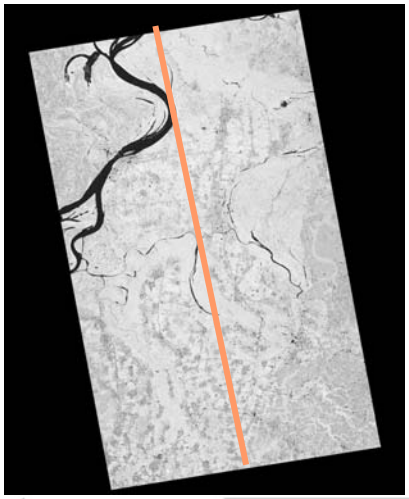
Coherence & Compatibility – Temporal Changes

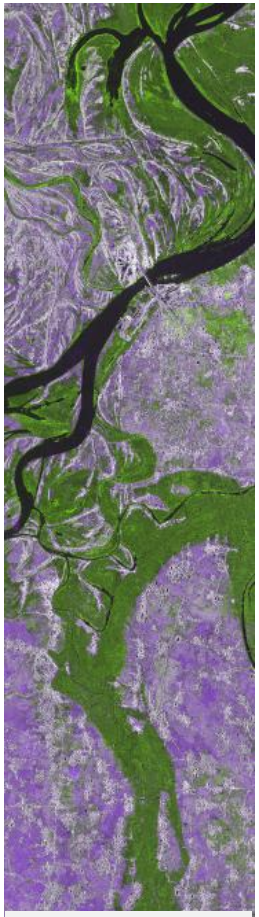


example: flooded „master“

coherence

supporting CoSSC

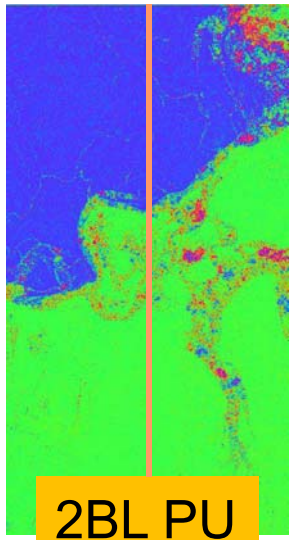




master-master amplitude change (R G)

master-master (1yr) coherence

compatibility (differential coh. combination)



2BL PU

2BL only possible where „compatible“, rest may be „void“

ITP Operational Dual Baseline Processing Success Rate

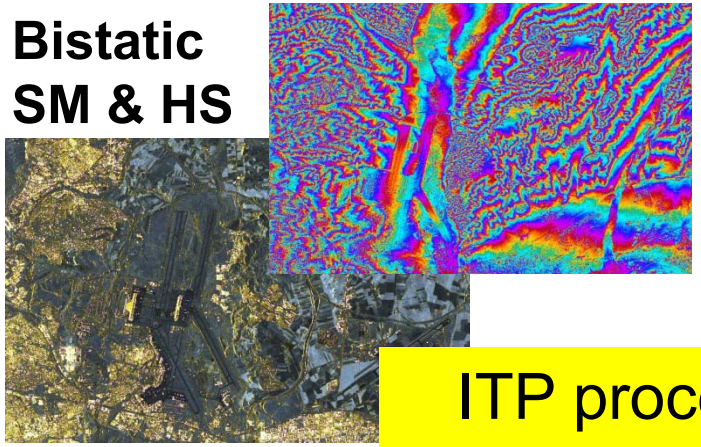
	Number of scenes	Supporting CoSSCs	Single-baseline	Dual-Baseline	Success rate*
August 2012	9389	16961	75,6%	24,4%	**96,9%**
Sept. 2012	9993	14477	78,1%	21,9%	**96,4%**
October 2012	11451	26657	67,3%	32,7%	**97.5%**
November 2012	7701	21770	62,0%	38,0%	**97,4%**
December 2012	6650	17401	65,6%	34,4%	**97,2%**
January 2013	10185	27551	63,0%	37,0%	**97,1%**
February 2013	9289	19065	74,1%	25,9%	**97,4%**
March 2013	15080	26134	76,3%	23,7%	**97,2%**
April 2013	13440	31840	69,8%	30,2%	**99,0%**
May 2013	13392	32143	67,0%	33,0%	**97,1%**

- **Success rate* > 97%**
- About 70% of the data are already of (very) good quality and do not need any dual-baseline phase unwrapping correction
- Remaining erroneous RawDEMs will be reprocessed with dual-baseline and possibly further additional data
- Extreme terrain (e.g. Himalaya, Alps) is not yet processed. Further acquisitions are required here.

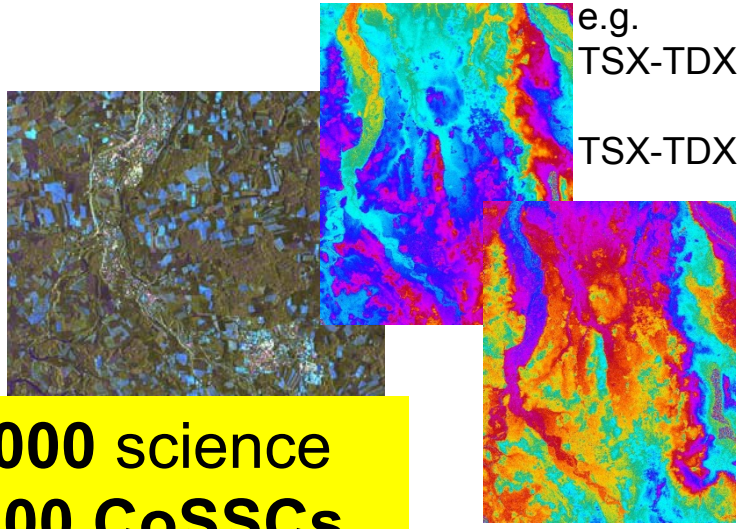
* = Highest quality score in radargrammetric consistency check after processing

TanDEM-X Scientific Products *operationally* generated by the ITP:

Bistatic SM & HS



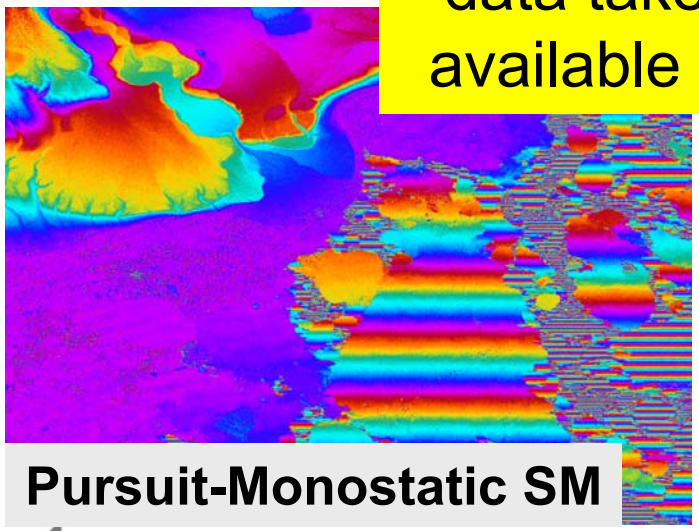
Dual-Pol. Bistatic SM



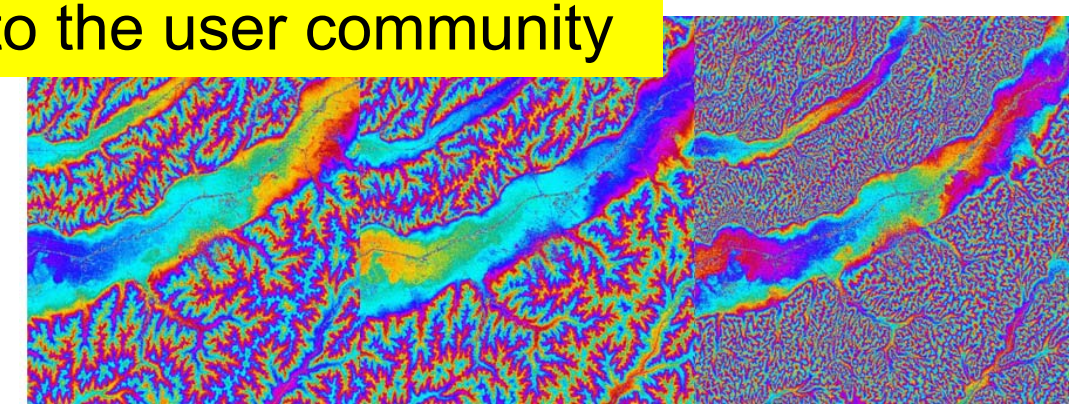
e.g.
TSX-TDX **VV**

TSX-TDX **VH**

ITP processed **>8000** science data takes to **>26000 CoSSCs** available to the user community



Pursuit-Monostatic SM

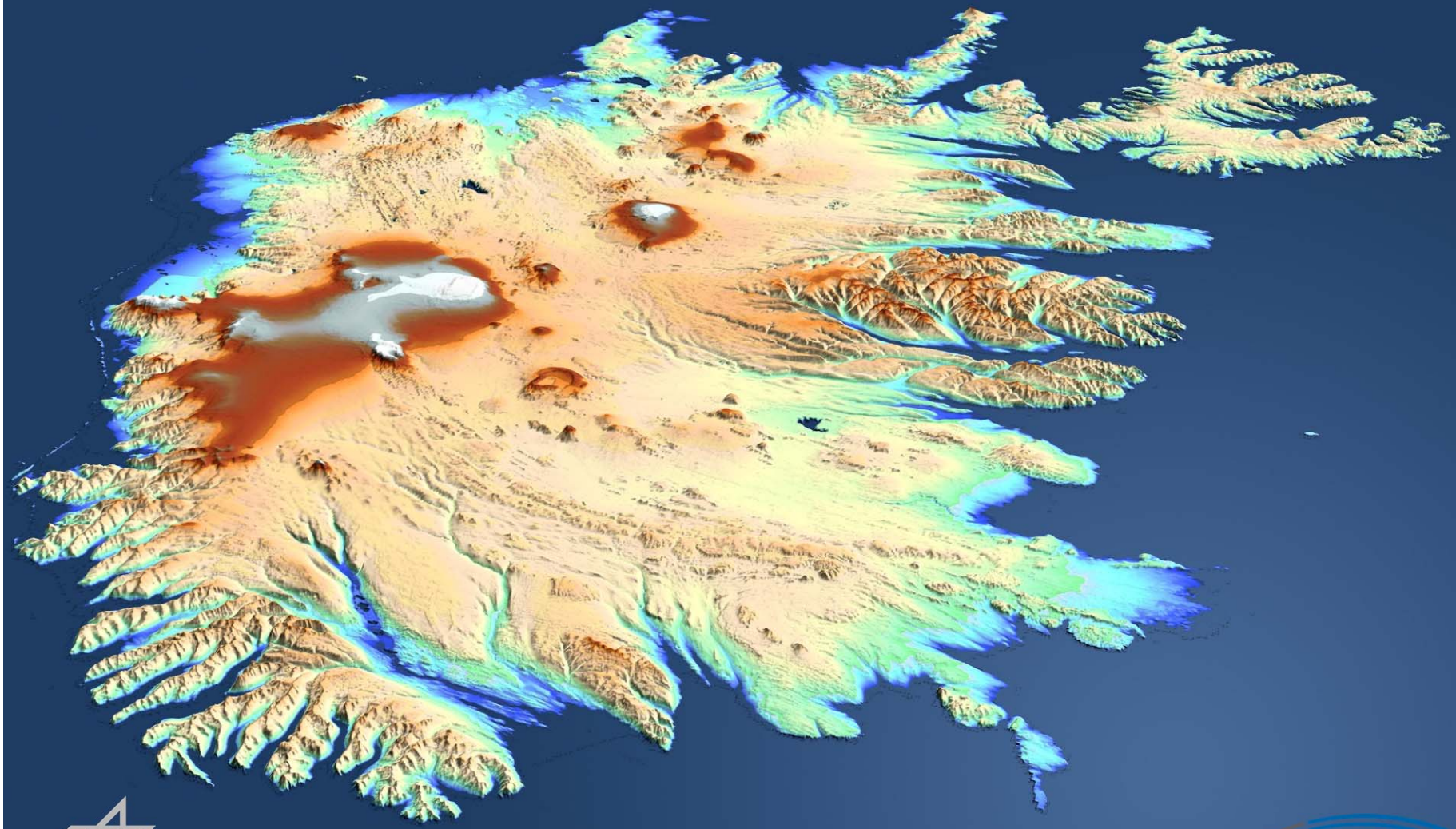


Alternating Bistatic SM TSX-TDX **Bi** TDX-TSX **Bi** + **MONO**

+ additional modes ITP products

Thank you for your attention!

www.dlr.de



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TanDEM