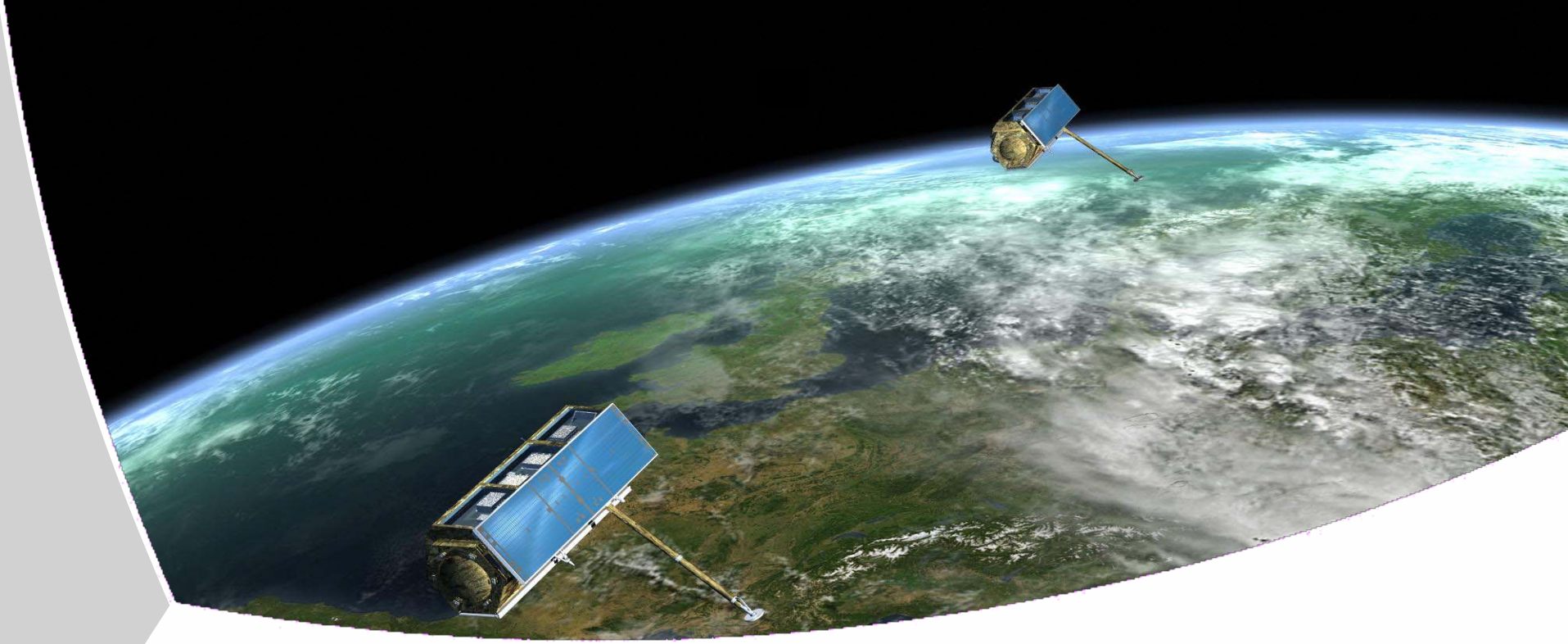


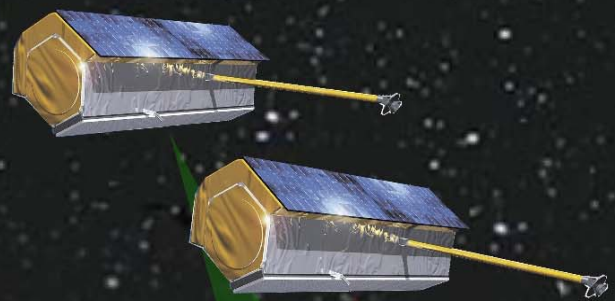
TanDEM-X

TerraSAR-X add-on for Digital Elevation Measurements

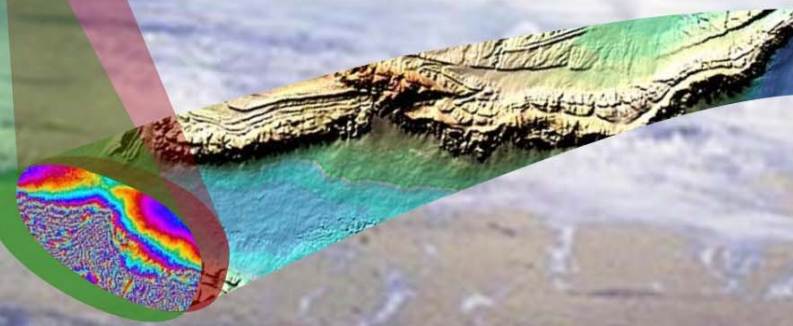
D. Schulze, M. Zink, G. Krieger, H. Fiedler, J. Böer, A. Moreira

DLR - Microwaves and Radar Institute

TanDEM-X Mission

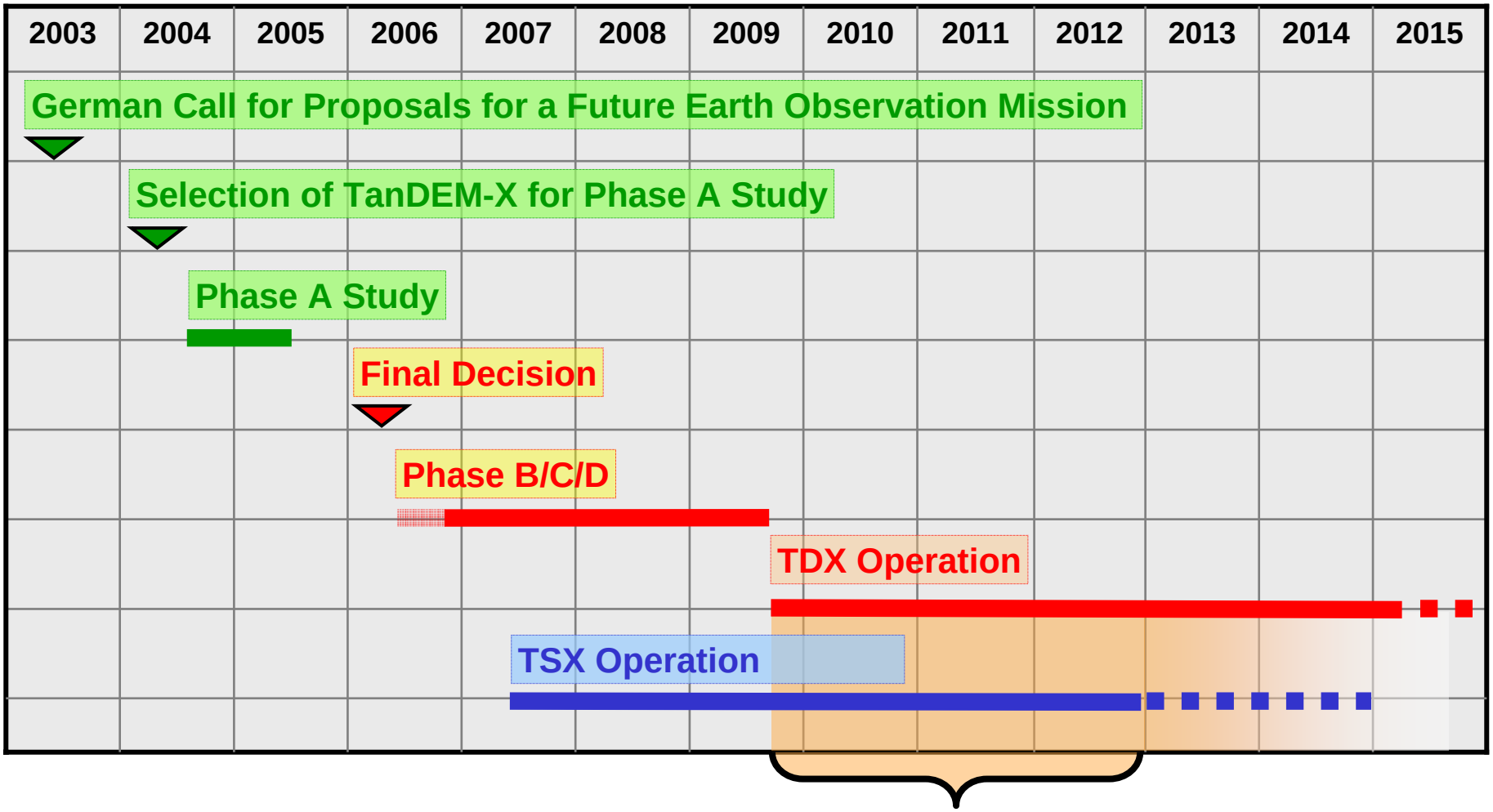


- acquisition of global DEM according to HRTI-3 standard
- generation of local DEMs with HRTI-4 like quality
- demonstration of innovative bistatic imaging techniques and applications

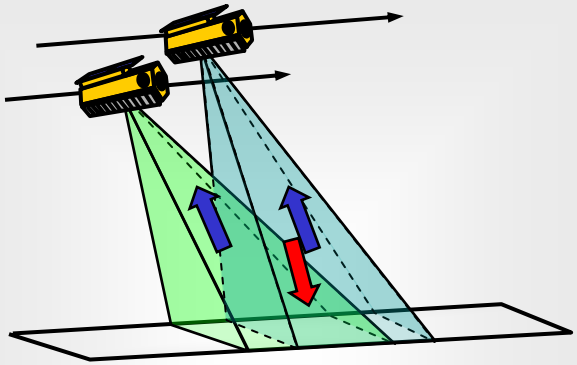
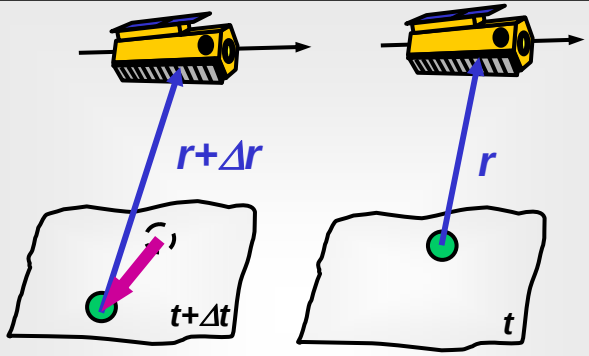
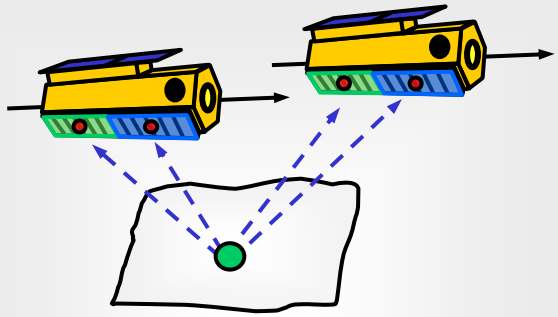


TerraSAR-X add-on for Digital Elevation Measurements

TanDEM-X Timeline



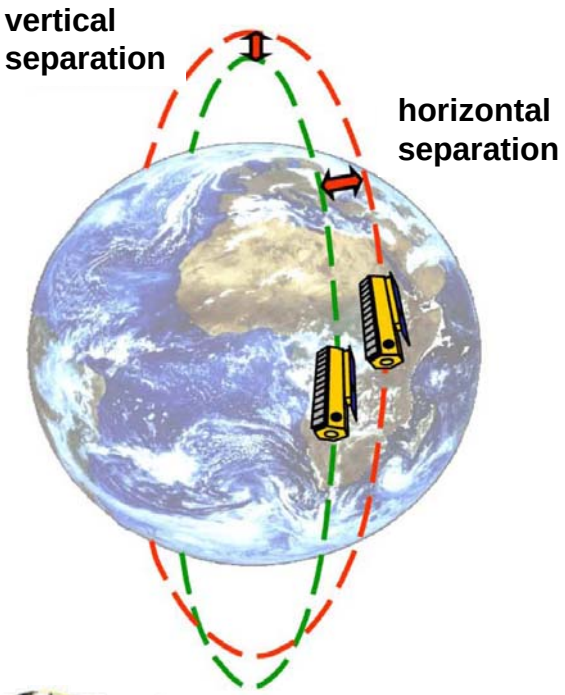
Capabilities of TanDEM-X

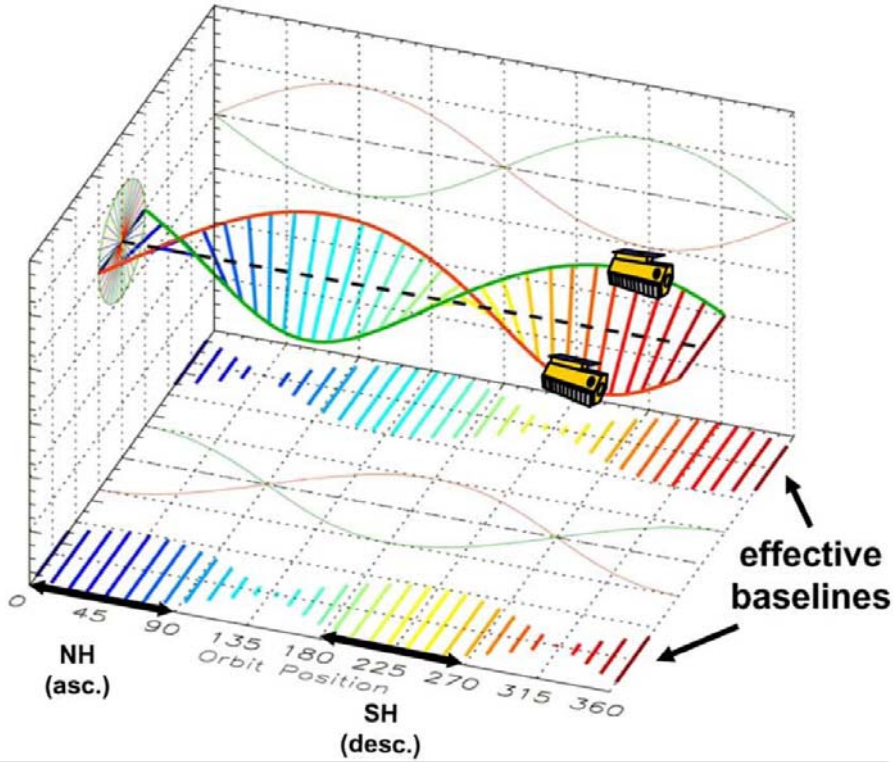
Cross-Track Interferometry	Along-Track Interferometry	New Techniques
		
→ **Digital Elevation Models** → **Spatial Coherence** (forest, ...) → **Double DInSAR** (change maps, ..) → **High Resolution SAR Images**	→ **Large Scale Velocity Fields** (ocean currents, ice drift, ...) → **Moving Object Detection** → **Temporal Coherence Maps**	→ **4 Phase Center MTI** (traffic, ...) → **PolInSAR** (vegetation height, ...) → **Digital Beamforming** (HRWS, ...) → **Bistatic Imaging** (classification, ..)

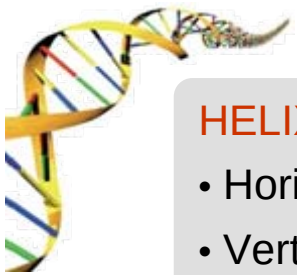
TanDEM-X is a highly flexible sensor which enables multiple imaging modes

- cross-track baselines (0 km to several km)
- along-track baselines (0 km to several 100 km)
- interferometric modes (bistatic, alternating, monostatic)
- SAR modes (ScanSAR, Stripmap, ...)
- bandwidth / resolution (0 ... 150/300 MHz)
- incident angles (20° ... 55°)
- polarisations (single, dual, quad)
- ...

Orbit Configuration



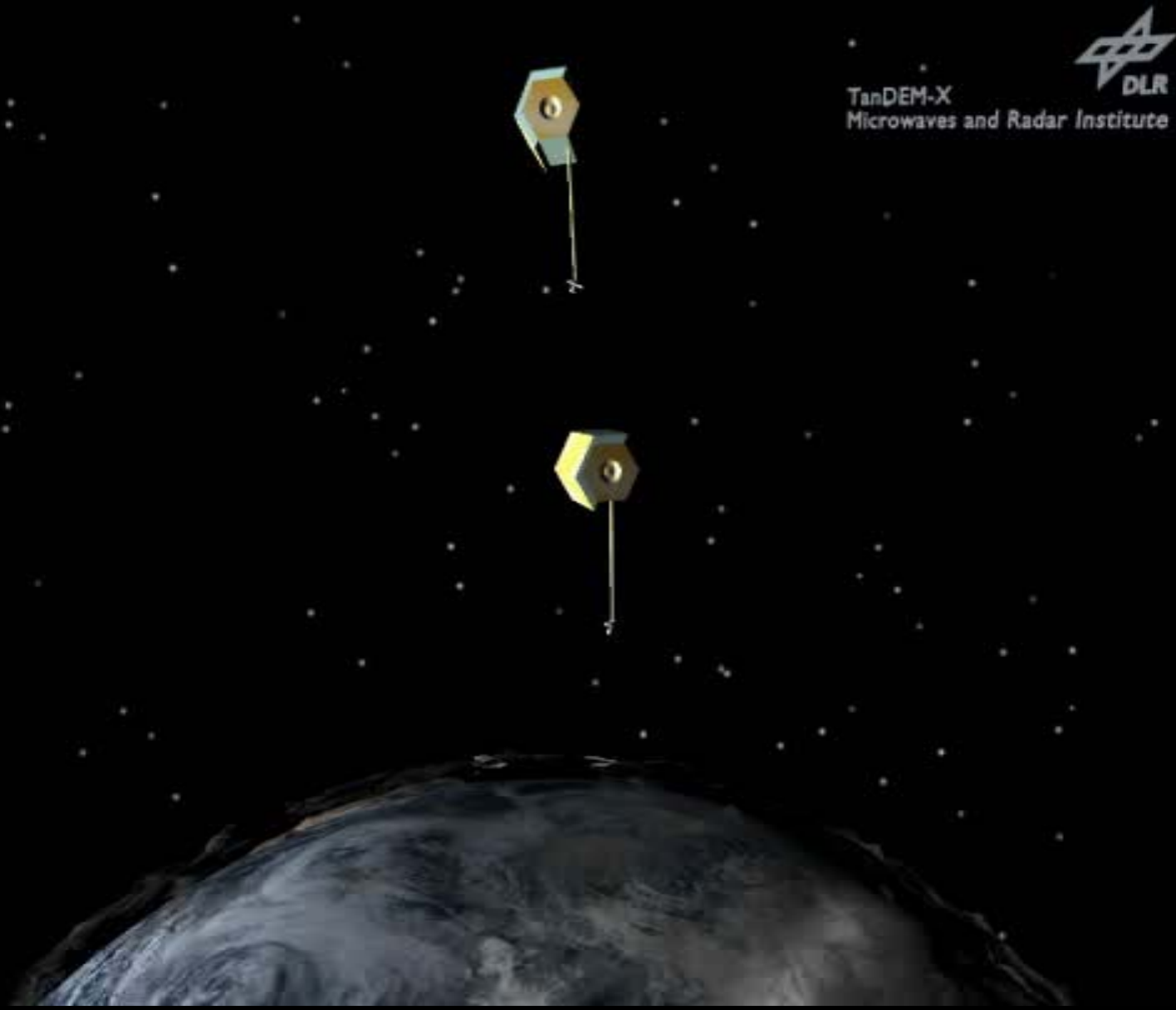




HELIX satellite formation allows safe operation

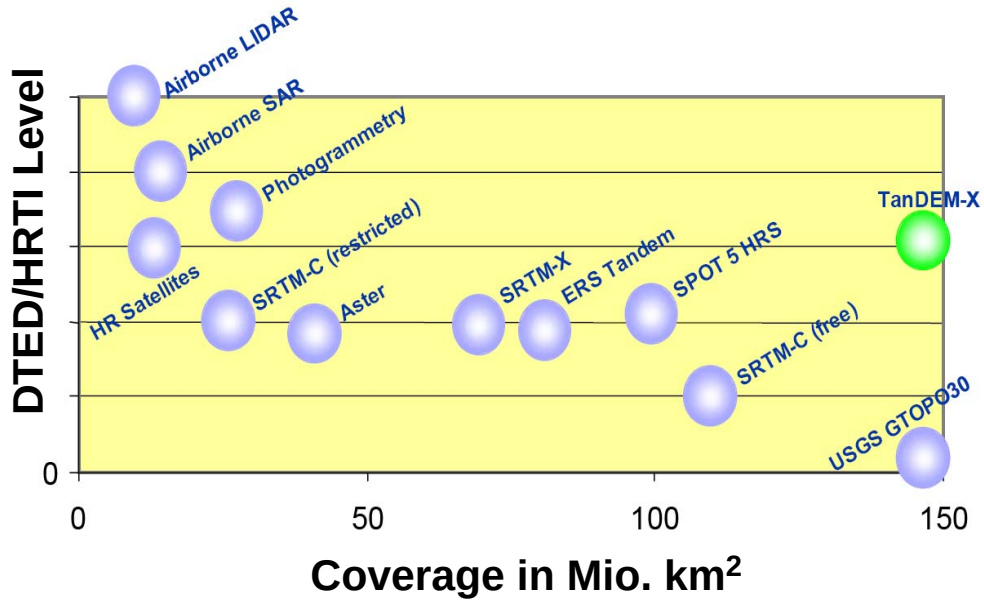
- Horizontal cross-track separation at equator by different ascending nodes
- Vertical separation at poles by orbits with different eccentricity vectors
- No crossing of single orbits
- Variation of baselines in cross-track and along-track easily achievable

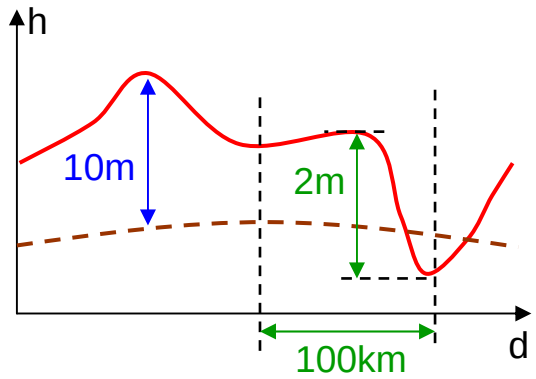
TanDEM-X Formation Flight



Primary Goal: *Global HRTI-3 DEM*

	Spatial Resolution	Absolute Vertical Accuracy (90%)	Relative Vertical Accuracy (point-to-point in 1° cell, 90%)
DTED-1	90 m x 90 m	< 30 m	< 20 m
DTED-2	30 m x 30 m	< 18 m	< 12 m
HRTI-3	12 m x 12 m	< 10 m	< 2 m
HRTI-4	6 m x 6 m	< 5 m	< 0.8 m





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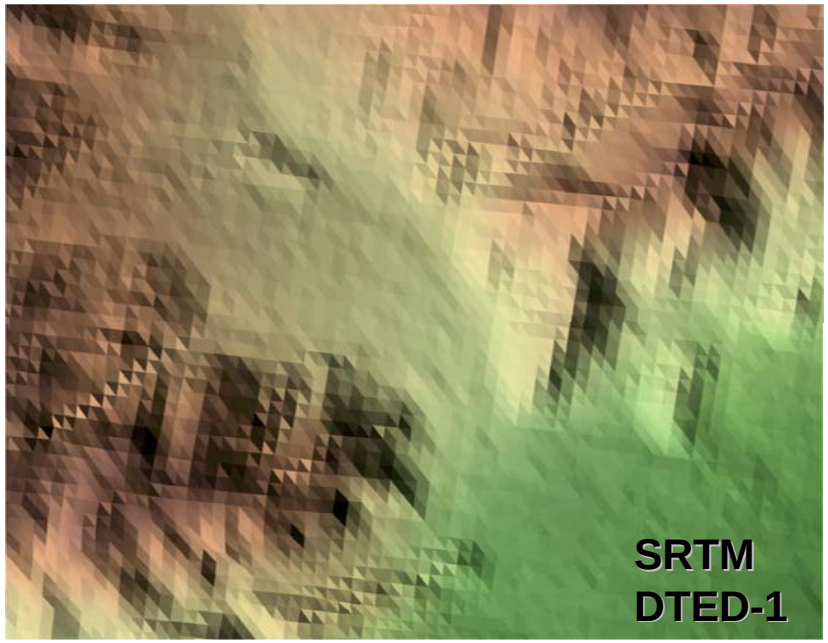
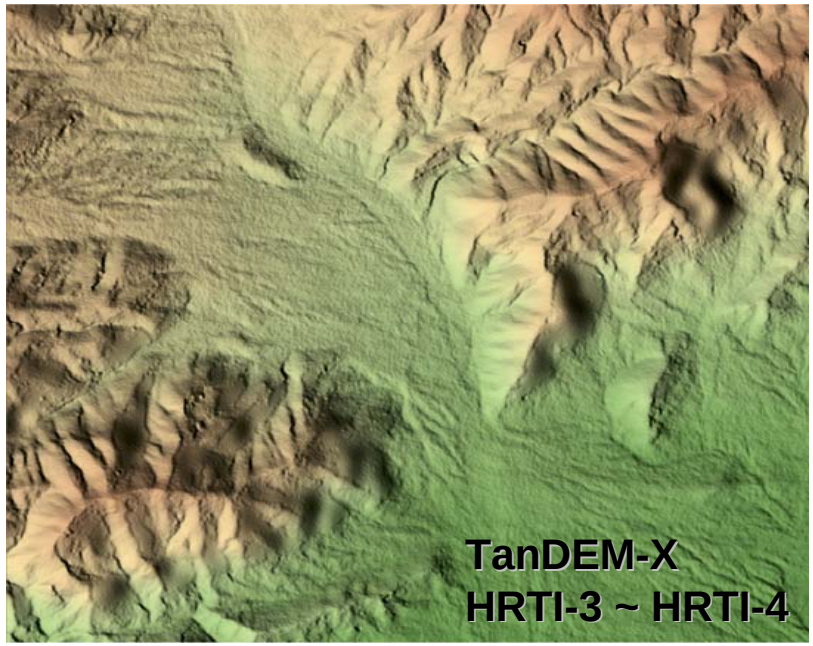
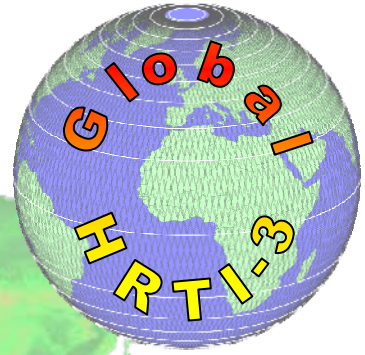




TanDEM-X DEM - Characteristics



- Data stored and delivered in tiles
- Terrain elevation given as ICRF-2005 ellipsoidal height [m]
- Optional delivery of SAR amplitude data
- Latitude-dependent pixel spacing (zones)
- Raw DEM mosaicking performed on continent level
- DEM quality control and post-processing
- Final DEM available 4 years after launch (intermediate DEM earlier)

Zone	Latitude (North/ South)	Latitude pixel spacing	Longitude pixel spacing	Tile size (Latitude x Longitude)	Tile size (example, MB)
I	0° – 50°	0.4''	0.4''	1° x 1°	891
II	50° – 60°		0.6''	1° x 1°	595
III	60° – 70°		0.8''	1° x 2°	890
IV	70° – 80°		1.2''	1° x 2°	596
V	80° – 85°		2.0''	1° x 4°	712
VI	85° – 90°		4.0''	1° x 4°	356

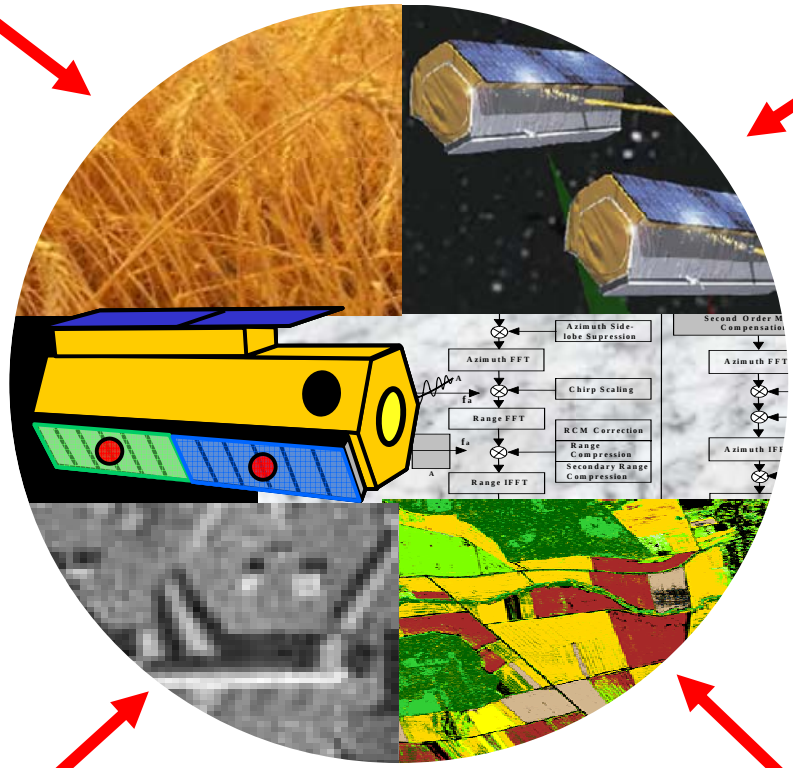
Secondary Mission Goals & New Techniques

Pol-InSAR

(fully polarimetric !)

Along-Track Interferometry

(HELIX formation !)



Digital Beamforming

(4 phase centres !)

Multi Baseline InSAR

(flexible baselines !)

Super Resolution

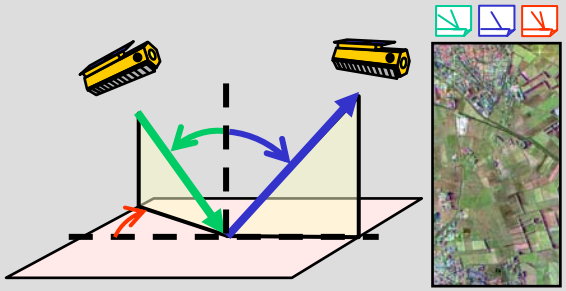
(large bandwidth !)

Bistatic Observations

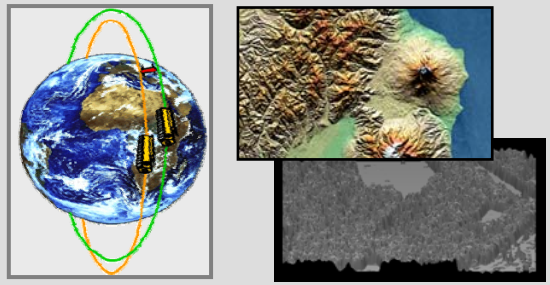
(bistatic angle !)

Potentials of Bistatic and Multistatic SAR Systems

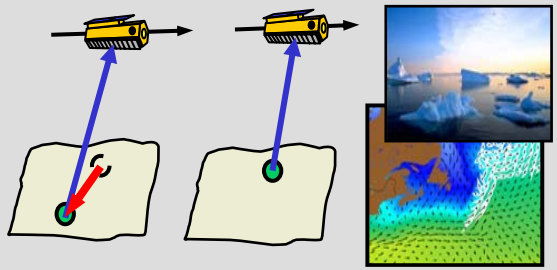
Bistatic Imaging



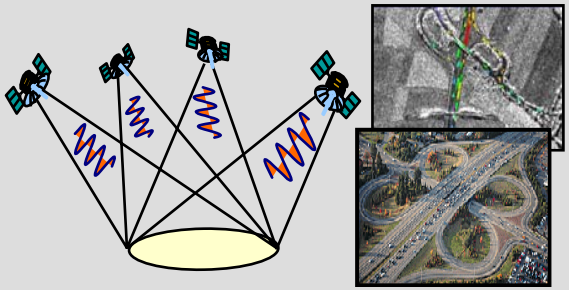
Cross-Track Interferometry



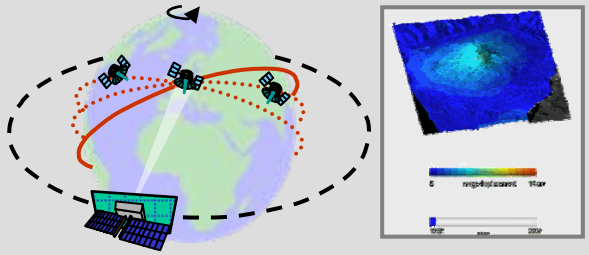
Along-Track Interferometry



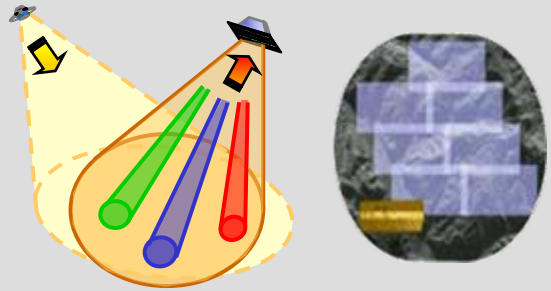
Moving Target Indication



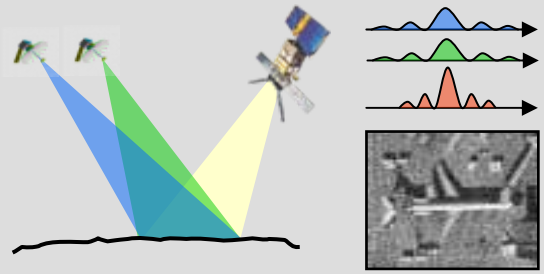
Frequent Monitoring



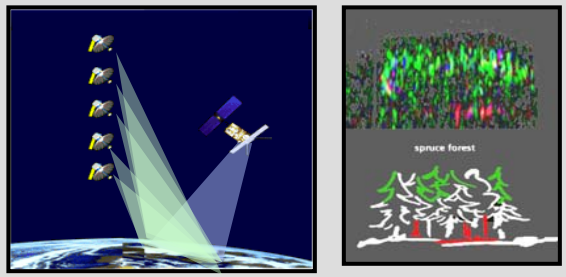
Digital Beamforming



Resolution Enhancement

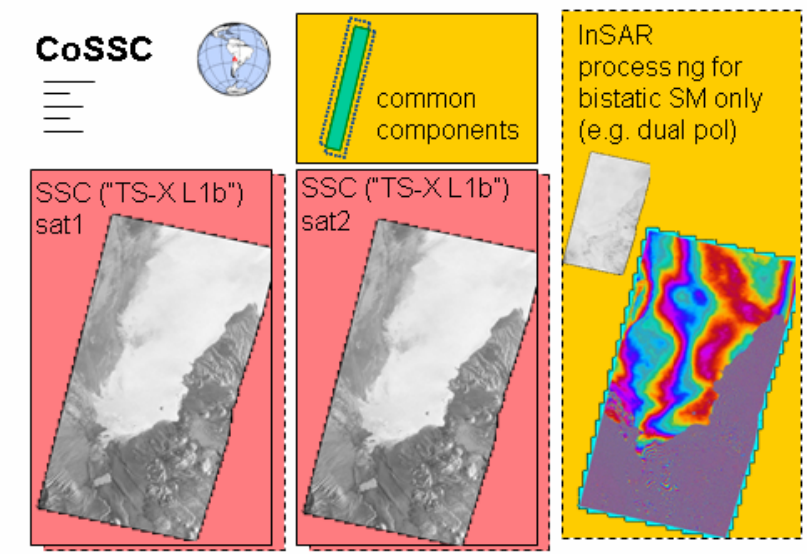


SAR Tomography

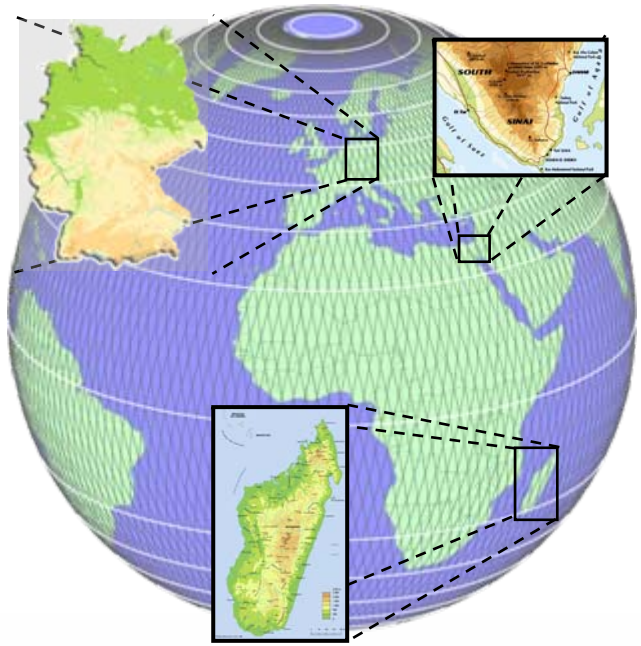


Secondary Mission Goal Products

- Co-Registered Single-Look Complex Images for Science Users

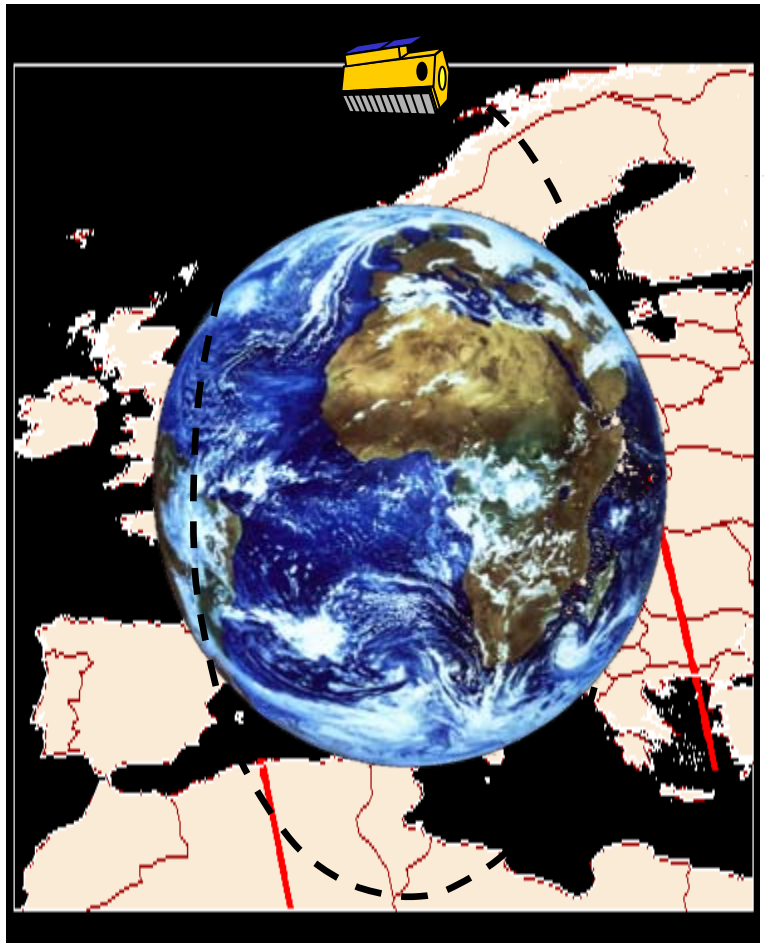


- Customized DEMs generated on request
  - For areas of limited size only
  - Sub-meter resolution (e.g. HRTI-4)



DEM Acquistion

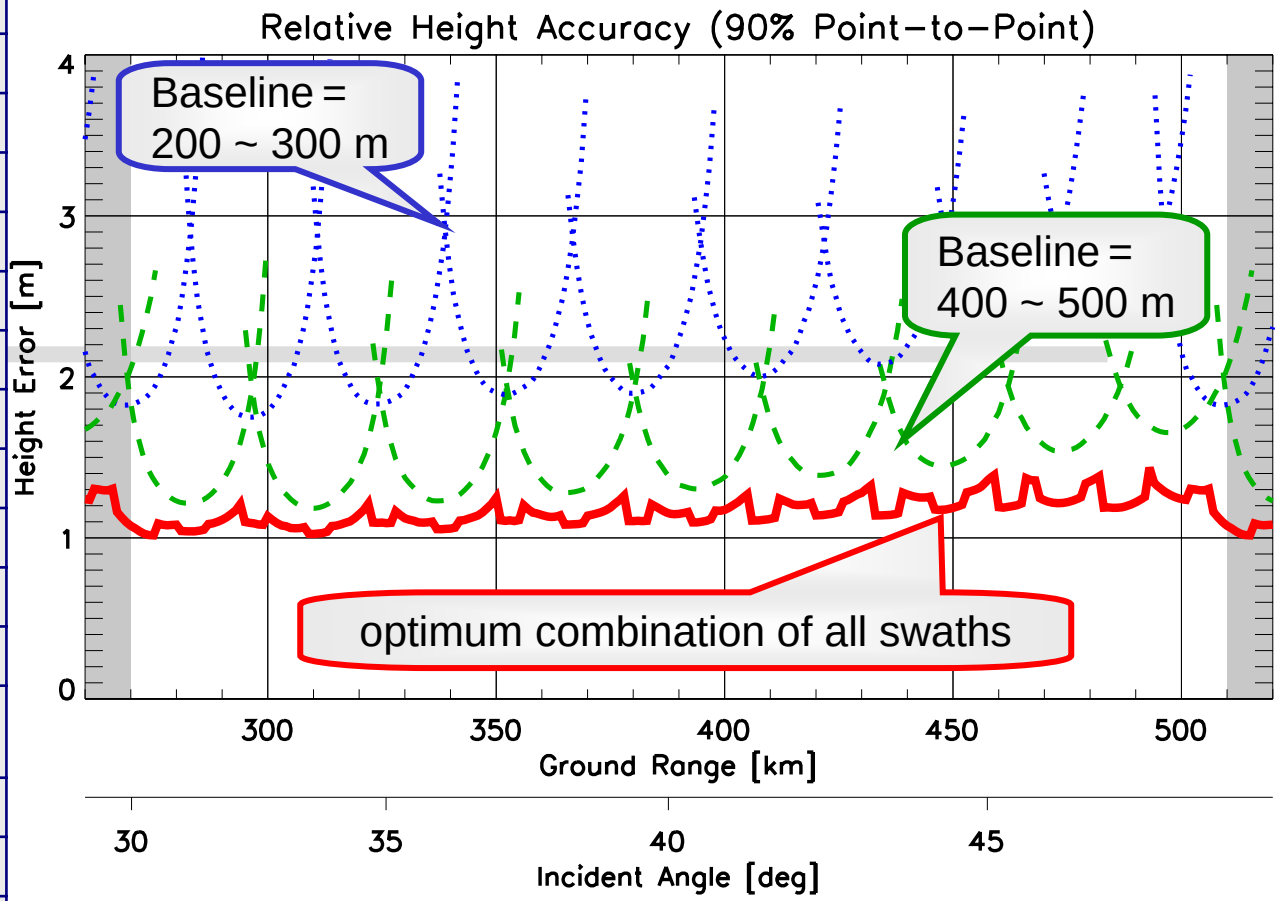
- Combined planning of single TerraSAR-X requests
  and global mapping requests for TanDEM-X
- Constraints:
  - Minimize impact on TerraSAR-X mission
  - Satellite data storage and downlink
  - Instrument and system constraints
  - Maximize length of Datatakes (typically 1000 km)
- Data volume (raw data) of 328 TB (3 years)
- Total ground station contact time of 110000s in 11-day repeat-cycle required
- Minimum network of 3 ground stations
- In total 1500 TB to be processed and archived
- ***Complex Mission Planning***



DEM Performance Prediction

Parameter	Value
Wavelength	0.031 m
Chirp Bandwidth	≤150 MHz
Peak Transmit Power	2260 W
Duty Cycle	18 %
Noise Figure TRM	4.3 dB
Losses (rad., atm.,..)	4.1 dB
Antenna Size (Tx, Rx)	4.8 m x 0.7 m
Antenna Tapering	linear phase
PRF (swath variant)	~3500 Hz
Processed Bandwidth	2266 Hz
Mis-Registration	1/10 pixel
Quantization	4 bit (BAQ)
Sigma Nought Model (90% occurence)	Ulaby (X-Band, VV, Soil)
Along-Track Displacem.	< 1 km
Swath Width	30 km
Post Spacing	12 m x 12 m

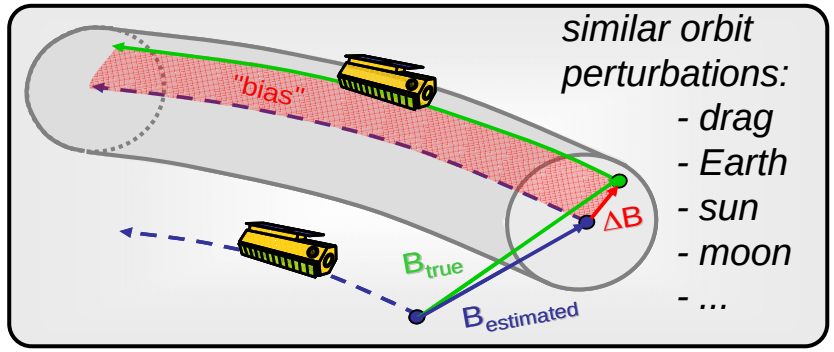
Relative Height Accuracy



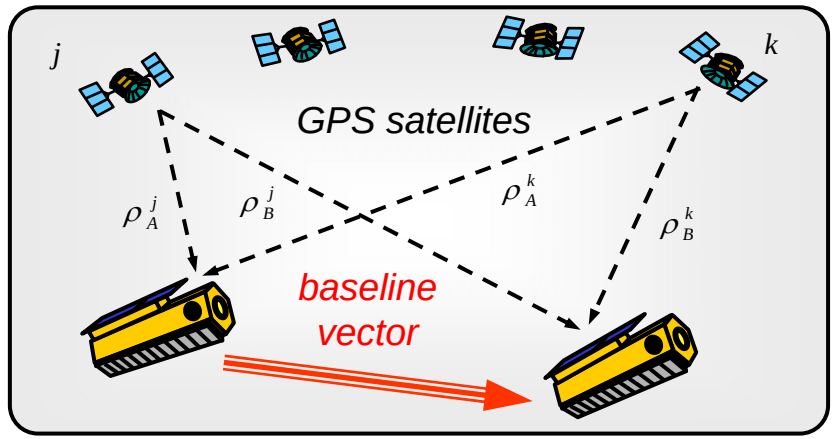
Inter-satellite Baseline Estimation

- **Very accurate Baseline Vector with a 3-D accuracy of 1 mm required for DEM**
- **Both satellites are exposed to almost identical orbit perturbations**
  - negligible azimuth modulation / twisting of DEM swath
  - vertical bias and tilt of raw DEM swaths due to initial baseline estimation errors
- **Precise baseline estimation by**
  - double-difference GPS carrier-phase measurements
  - accurate orbit propagation model
- **Different studies prove feasibility**

Relative Orbit Model

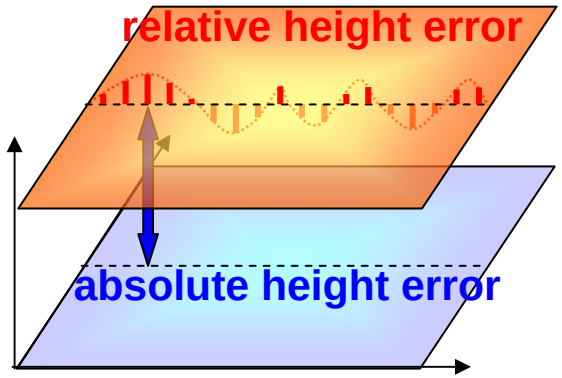


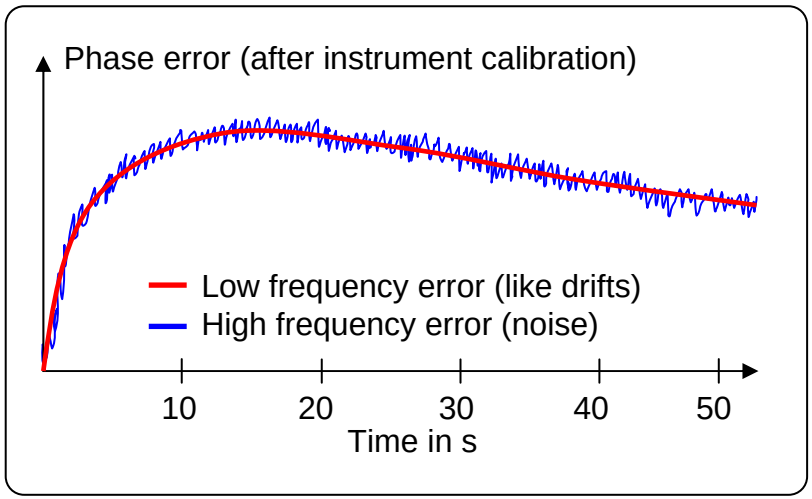
Interferometric Baseline

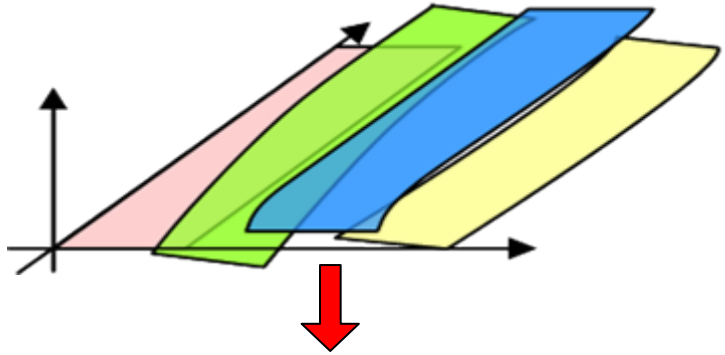


DEM Calibration I

- Inaccurracies of interferometric phase:
  - Baseline determination errors
  - Instrument phase errors
  - Image co-registration / processing errors (e.g. interferogram phase-unwrapping errors)
- Phase errors directly translate into height errors
- Error model: Drifts and noise-like errors







DEM Calibration Concept
- Adjustment methods
- Height references

- DEM calibration aims at removal of systematic errors (tilt, bias, modulation)

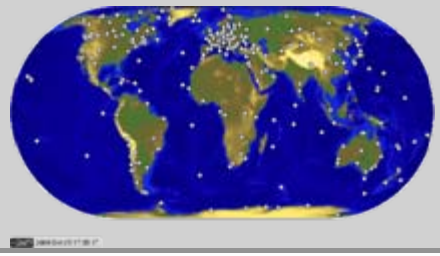
DEM Calibration II

Height Reference Data:

GLOBAL:
- ICESat Laser Altimeter

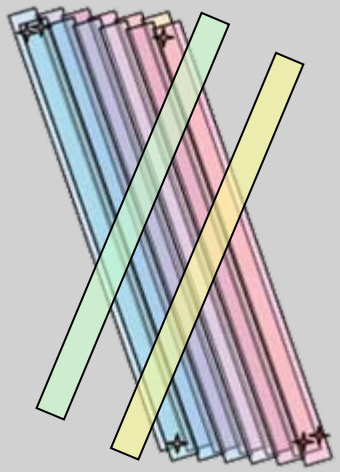
LOCAL:
- Airborne LIDAR data
- GPS tracks (for validation)
- Radar point targets (corner reflectors, transponders)

→ Coverage on all significant isolated land masses
→ Controlled accuracy
→ Independent from sources used for validation

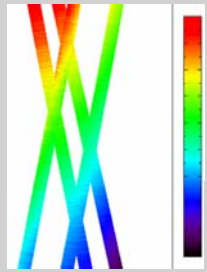


Multiple Ground Coverage:

- Swath Overlap (~4km)
- Land surface covered twice (at least)
- Crossing Orbits (3rd year)

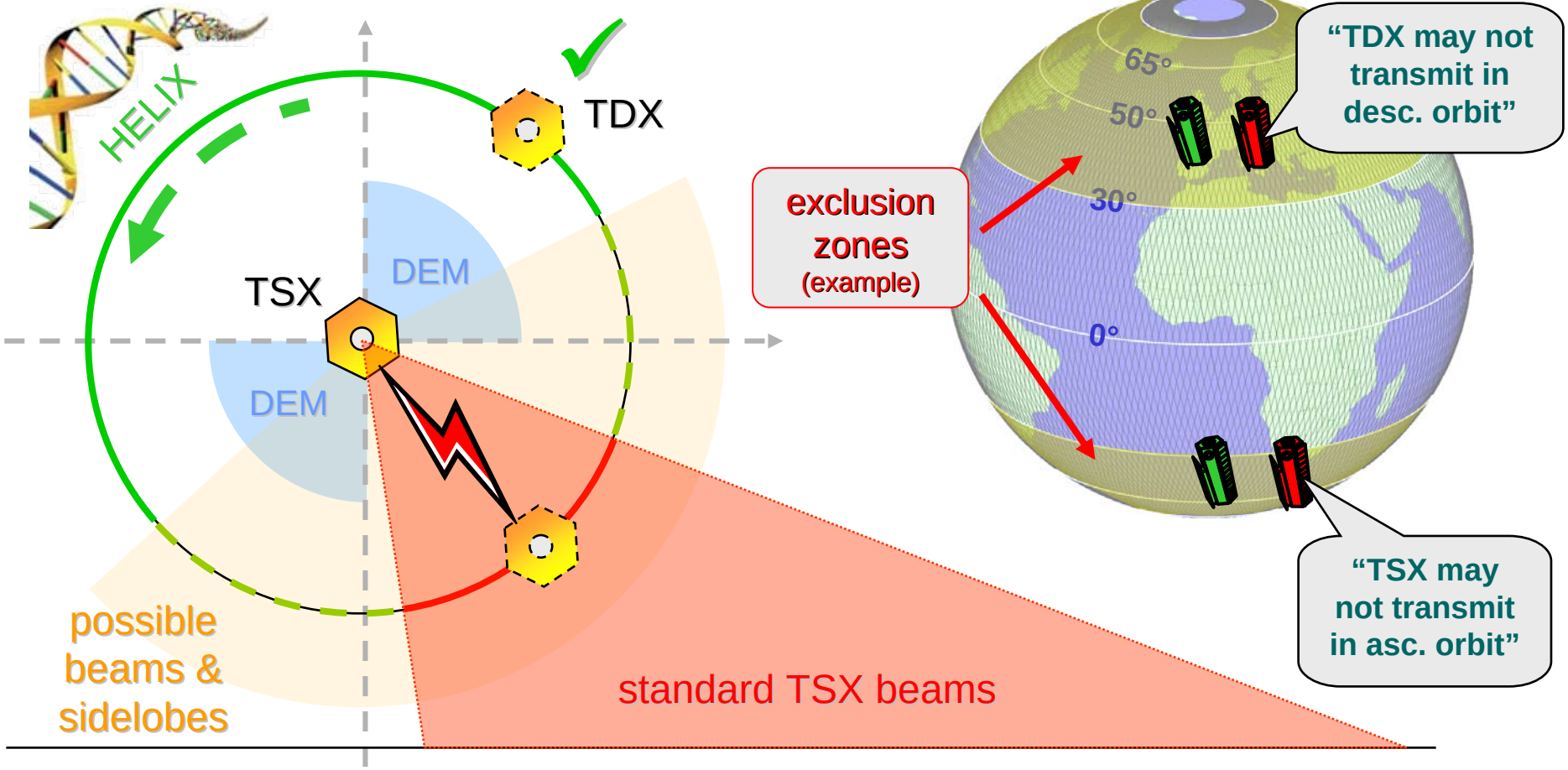


Error Modelling and Adjustment:



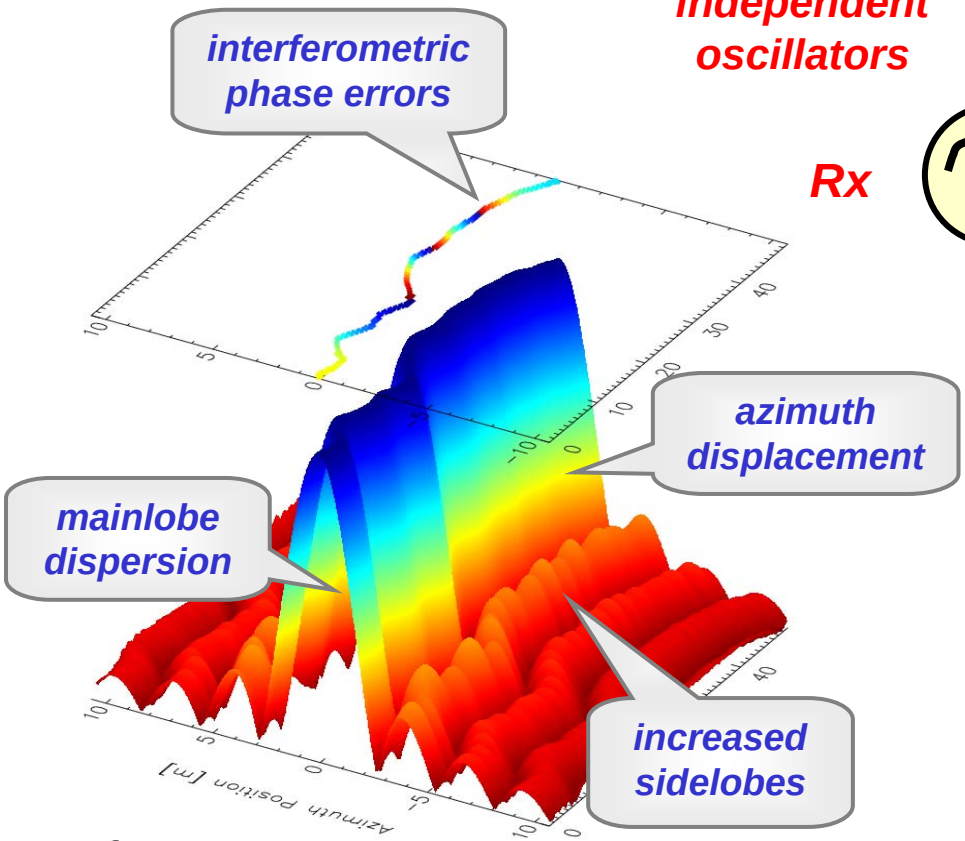
- Systematic errors modelled by polynomials
- Coefficients determined by statistical analysis
- Least-squares adjustment with constraints
- Principle: heights in overlapping areas should be nearly identical after correction

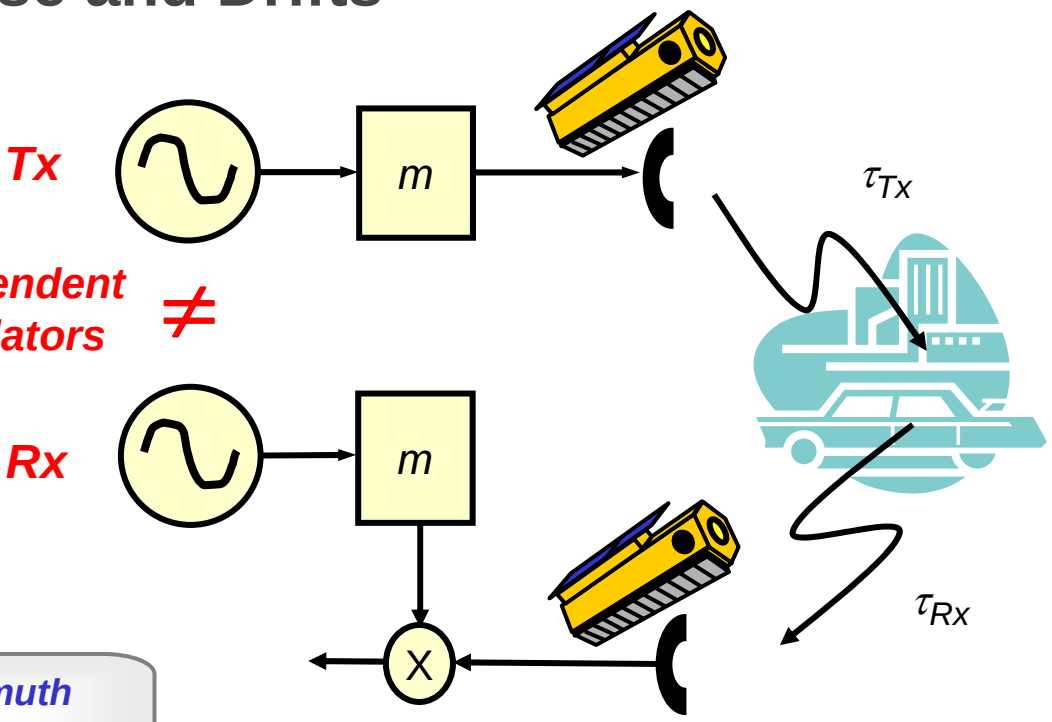
Radar Transmit Exclusion Zones



Definition of exclusion zones for TSX & TDX based on beam table.
Different exclusion zones in case of left-looking operation !

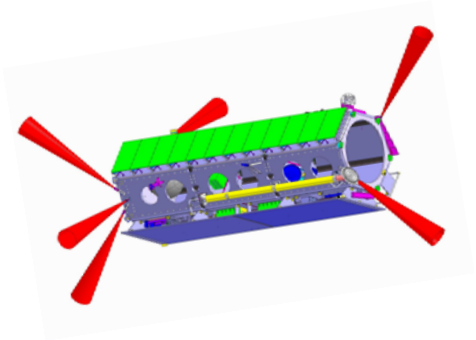
Impact of Oscillator Noise and Drifts

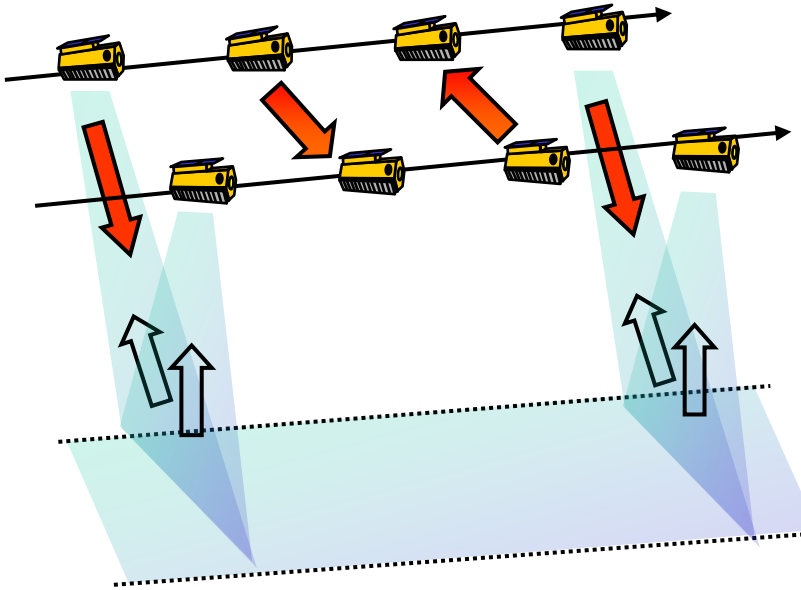




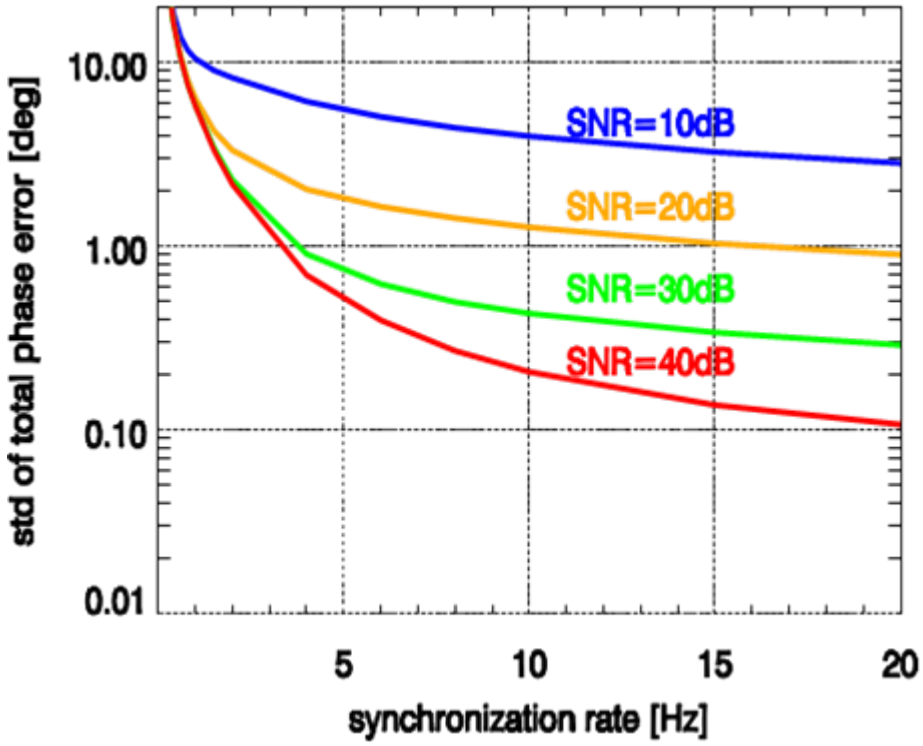
Phase Referencing

Synchronisation Link





Analysis of Residual Errors



→ **phase referencing can achieve short term rmse below 1°**

TanDEM-X Summary

- TanDEM-X is the next German Earth Observation Mission to be launched in 2009
- TanDEM-X has outstanding scientific and commercial potentials
- TanDEM-X key technologies are:
  - bistatic radar operation and phase synchronisation
  - precise baseline determination
  - close formation flying capability
  - new algorithms for interferometric processing
- TanDEM-X plays a key role in the development of next generation bistatic and multistatic SAR missions and applications