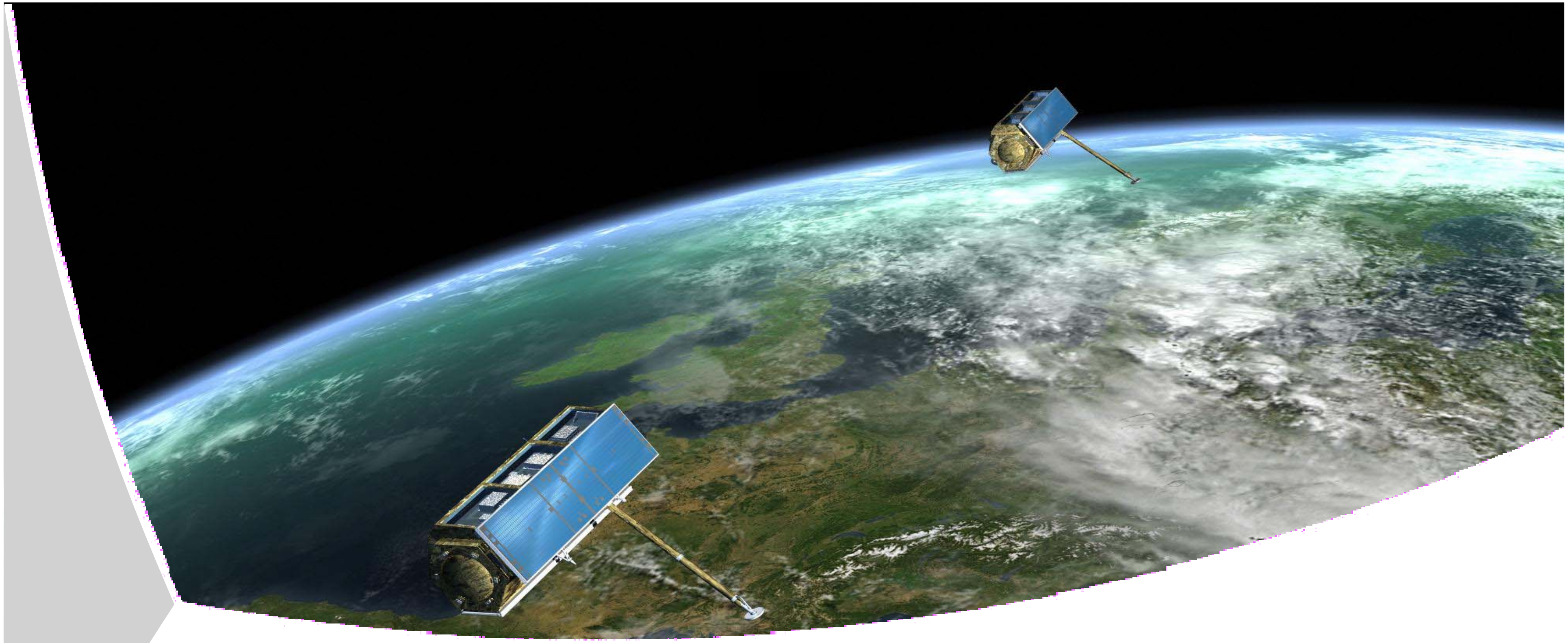

TanDEM-X DEM Calibration Status and Commissioning Phase

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TanDEM CALIBRATION

Deutsches Zentrum für Luft- und Raumfahrt e.V.
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Microwaves and Radar Institute

- CEOS 2008, DLR-OP, Germany -

28/11/2008

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6. Commissioning Phase
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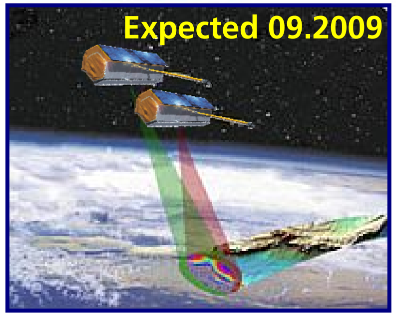
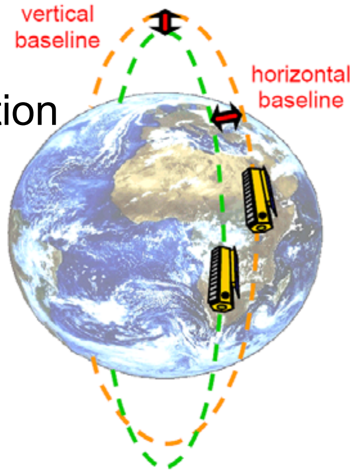
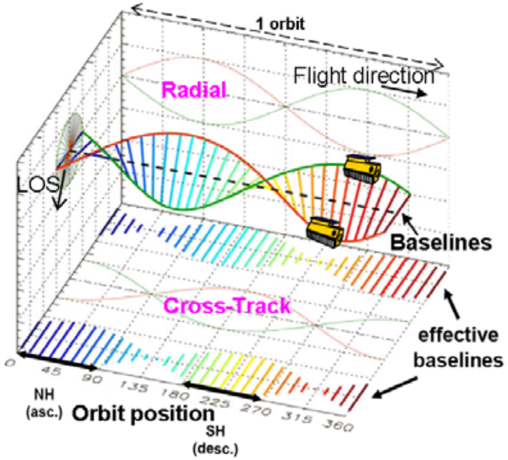
1. TanDEM-X Mission



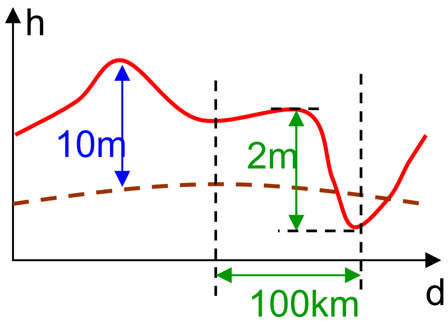
- Two almost identical satellites in helix formation
- Typical baseline lengths between 250-500m
- Bi-static acquisitions: Sat 1: Tx+Rx
  Sat 2: Rx





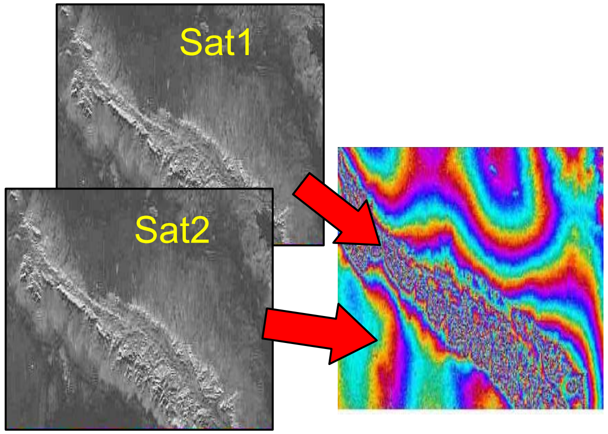
- OBJECTIVE: HRTI-3-”like” global DEM within mission time (3 years)

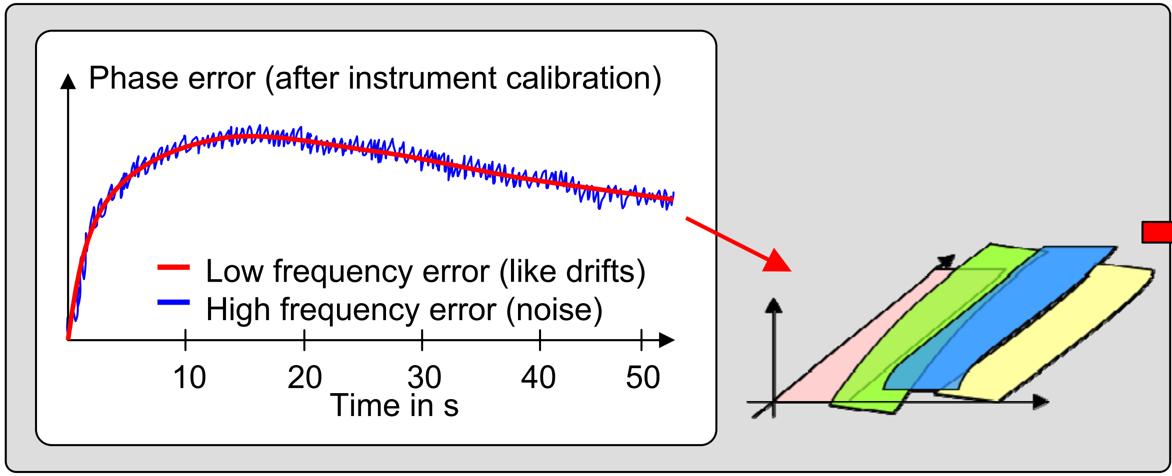
Requirement	Specification	HRTI-3
Absolute vertical accuracy (global)	90% linear error	10m
Relative vertical accuracy (100 km x 100 km)	90% linear point-to-point error	2m (slope<20%) 4m (slope>20%)
Horizontal accuracy	90% circular error	10m
Post spacing	Independent pixels	12m



2. Interferogram and Errors

- Processing of both images
- Calculation of an interferometric image
- Baseline geometry determines the phase resolution
- Derivation of DEM
- Remaining errors after instrument calibration: **baseline** and **phase** errors → Height errors



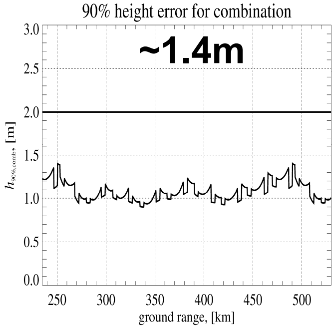


DEM Calibration Concept
- Adjustment methods
- Height references

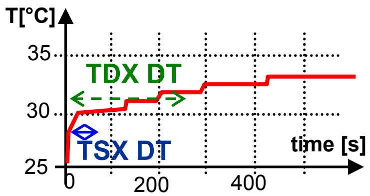
3. Nature DEM Errors

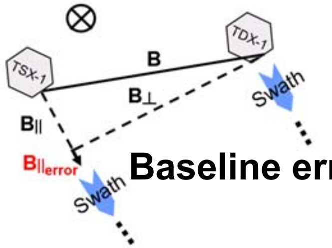
Error Sources | Magnitude | Correction methods

- **Phase Noise** and **Performance**
  Residual errors of ICAL, Baseline and Sync — ~1.4m

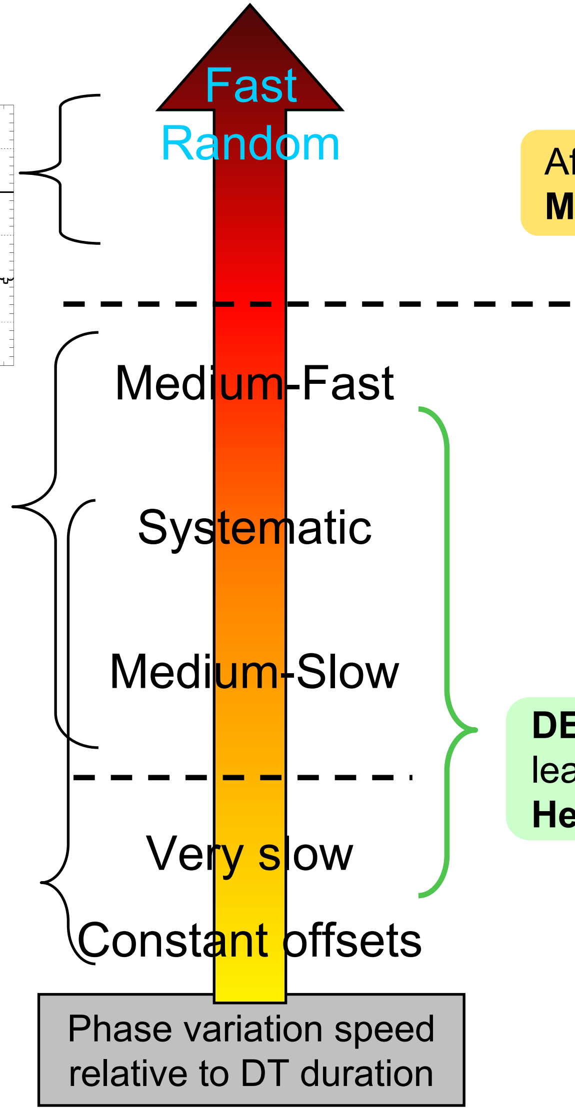


- **Instrument drifts** — ~dm





- **Baseline errors** — ~m



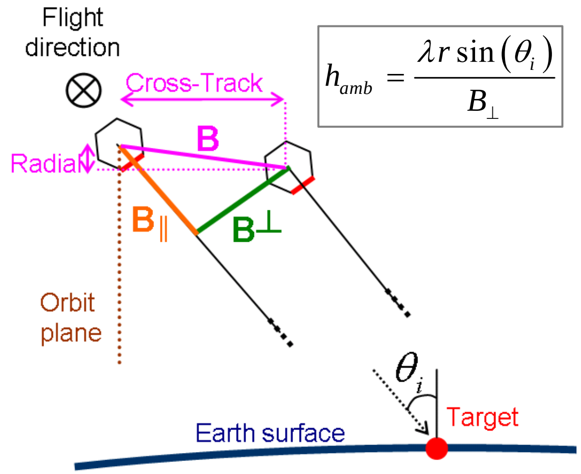
After **averaging** pixels and DTs
Multilooking

DEM Calibration→
least-squares adjustment model
Height references

4. Phase and Baseline Errors to Height Errors

- Baseline errors ($\Delta B_{\|}$)
  - Azimuth modulation: $\Delta h = \frac{h_{amb}}{\lambda} \cdot \Delta B_{\|}$
  - Elevation tilt: $\varphi_{tilt} = \frac{\Delta h}{\Delta s} = \frac{\Delta B_{\|}}{B_{\perp}}$

- Phase errors → instrument, coherence losses
  - Azimuth modulation: $\Delta h = \frac{h_{amb}}{2\pi} \cdot \Delta\varphi$



$$h_{amb} = \frac{\lambda r \sin(\theta_i)}{B_{\perp}}$$

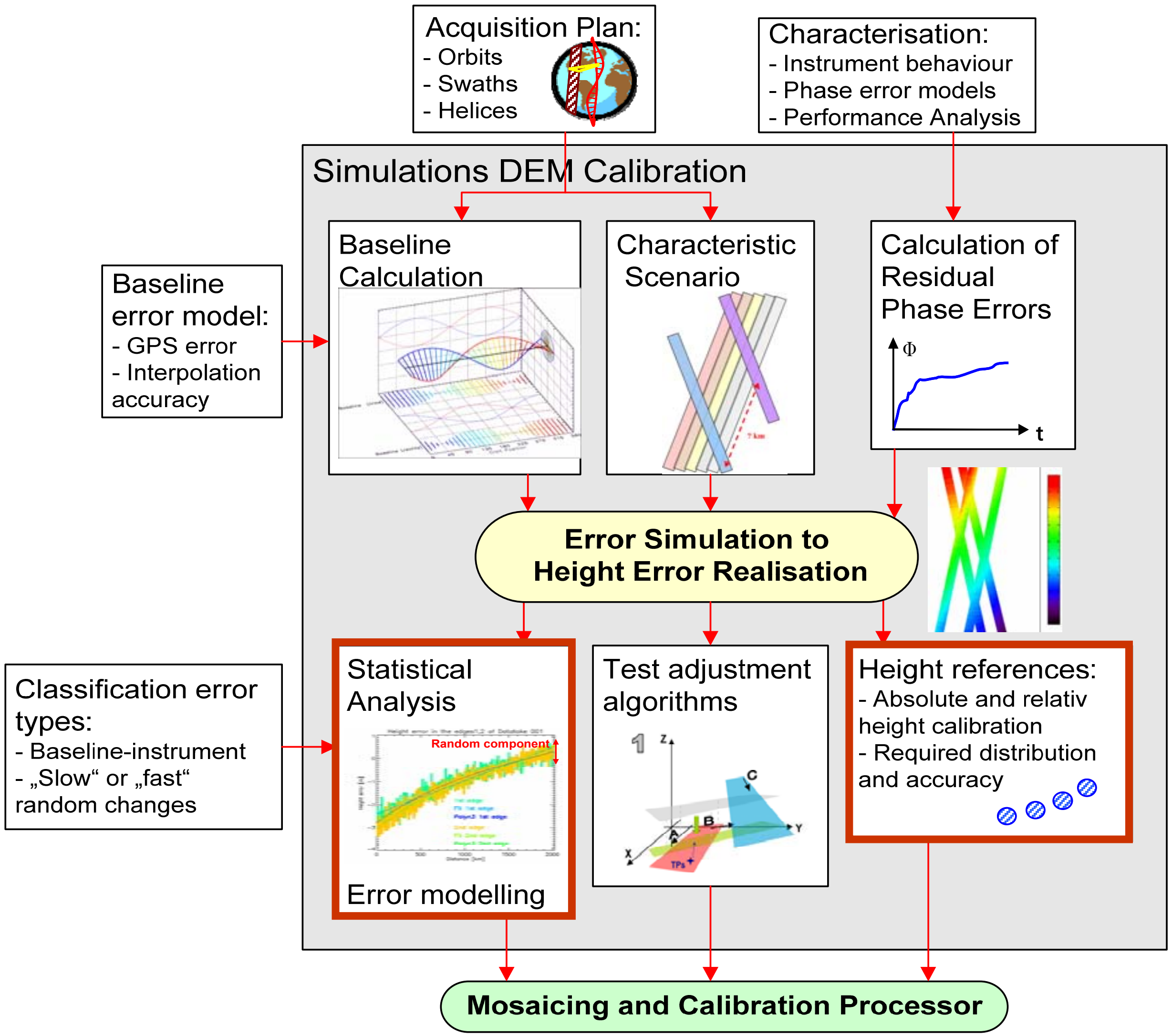
Incident Angle	Normal Baseline (h_{amb}=35m)	Height Errors (for h_{amb}=35m)	
		$\Delta B_{\|}$ = 1mm	
		Δh	Δh/Δs (tilt)
30°	260 m	1.1 m	3.8 mm/km
45°	439 m		2.3 mm/km

Relative height error requirement	2m (90%)
Performance losses	~1.8m (90%)
DEM adjustment	0.53m (σ)

height references accuracy < 0.4m (σ)

- Necessity of DEM Calibration → absolute : height references
  → relative : overlapping regions of DEMs

5. DEM Calibration Concept

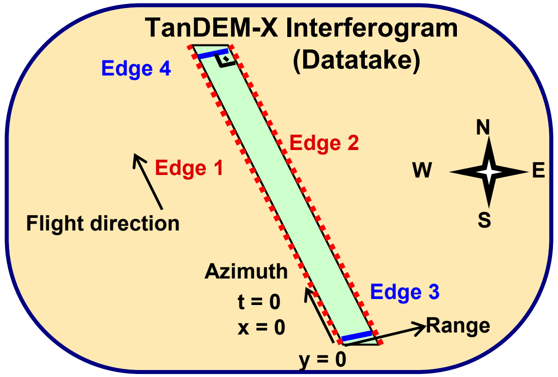


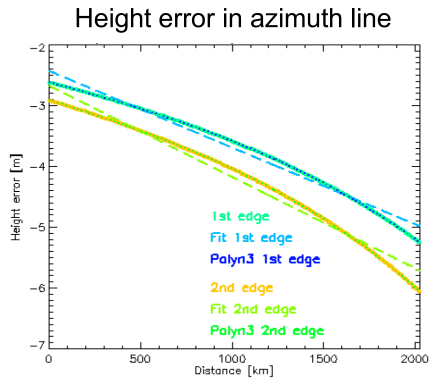
5.1. Error Modeling

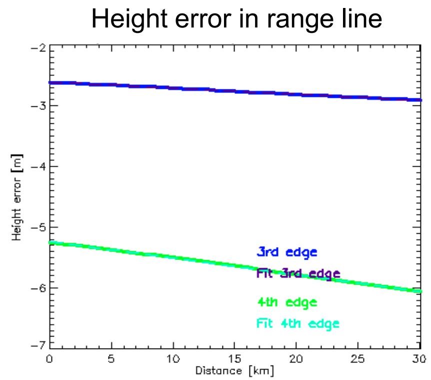
- Statistical study of the **systematic** height error behaviour
- Confirmed assumptions regarding height error evolution (see table)
- 2D height error evolution modelled by functional descriptions
- Statistical analysis → derive coefficients of the **functional model** to be implemented in the MCP

$$g(x,y) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + b_1 \cdot y + k \cdot x \cdot y$$

Height error evolution	Azimuth	Range
Fitting function	3[rd] order polynomial	linear

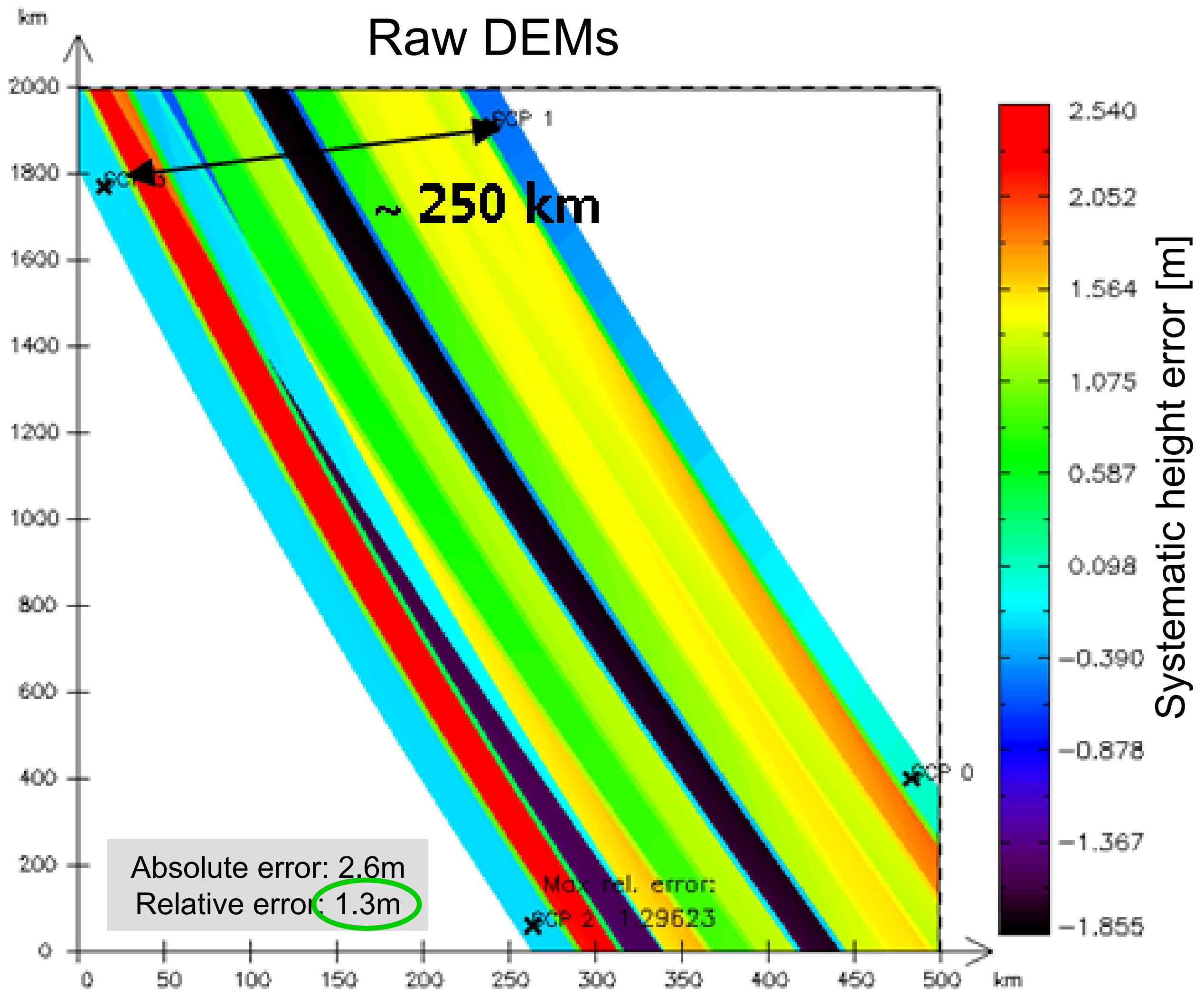






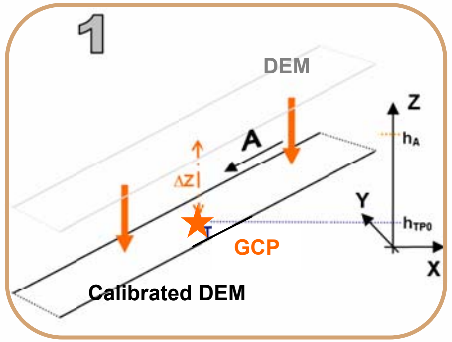
- Least-squares adjustment with constraints
- Principle: heights in overlapping regions of DTs and height references will be used to determine the coefficients for the adjustment

5.1 Adjustment Method

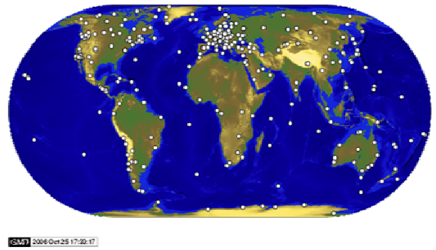


5.2. Height References

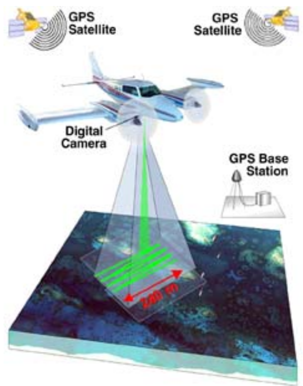
- DEM calibration requires accurate height references:
  - Adequate distribution
  - Coverage on all significant isolated land masses
  - Controlled accuracy



- Global data sets
  - Good coverage for hooking in the DEM
  - GPS stations, ICESat…: very useful in regions of the planet with few local height data

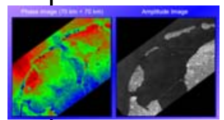


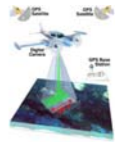
- Local DEMs and references
  - Airborne Lidar DEMs, GPS tracks…: more accurate, but more cost
  - Limited coverage
  - Certain interest regions: fulfil a HRTI-4 standard – secondary mission goal

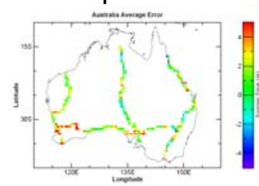


5.2. Summary Height References

Function	GCP source	Coverage	Accuracy	Quality parameters
PRELIMINARY absolute height calibration	SRTM	C-Band: (56°S-60°N) X-Band: 56°S-60°N, but big gaps	8.5 m ~ surface slope and roughness	Height specifications
MAIN absolute and relative height calibration	ICESat	Global	0.1 m - 1 m (weather/ terrain)	Accuracy info/sample HRTI-3 (even HRTI-4) – after pre-selection
SECONDARY absolute and relative height calibration	Ocean-land	Global (theory); restricted to optimal AT-distance and no currents	0.5 m	TBD
	Lidar/Airborne DEM	Local	0.1 m – 0.5 m	HRTI-4
VALIDATION	GPS tracks	SRTM campaigns; selected regions	0.5 m	Height specifications HRTI-3

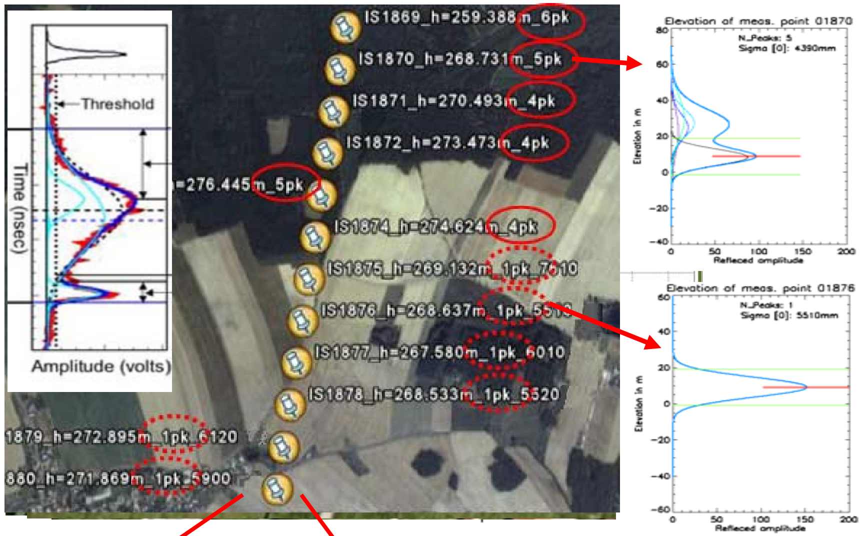




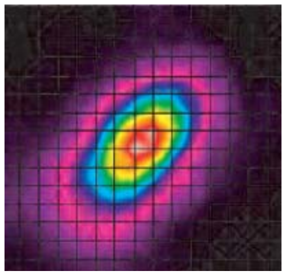


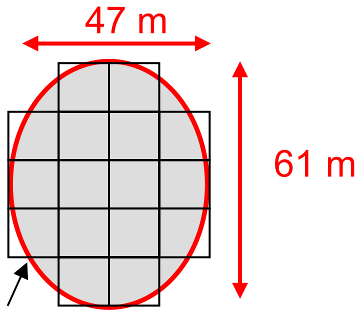
5.2. ICESat Data Application

- Main height reference source for TanDEM-X
- Elliptical footprints of 60 m diameter
- Pulse characteristics
  - Decomposed in 6 Gaussians
  - 1 peak (flat ground)
  - More peaks (trees, slope…)



- ICESat **Data Packet Parameters**:
  Evaluation and classification information
  for each measurement point
  - **DEM height**
  - **SRTM height**
  - **N. Peaks**
  - **Sigma width/saturation**
  - **Slope**
  - **Cloud layers**
  - **Surface properties**
  - **Region type**
- Additionally MODIS vegetation coverage data

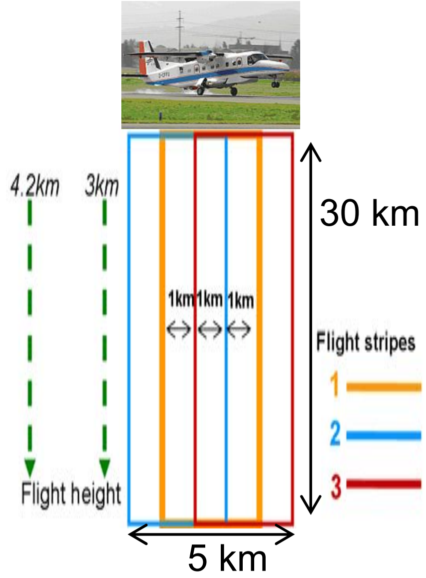


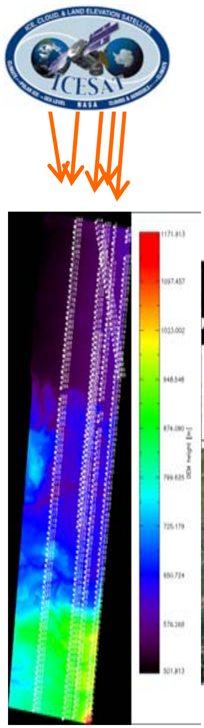


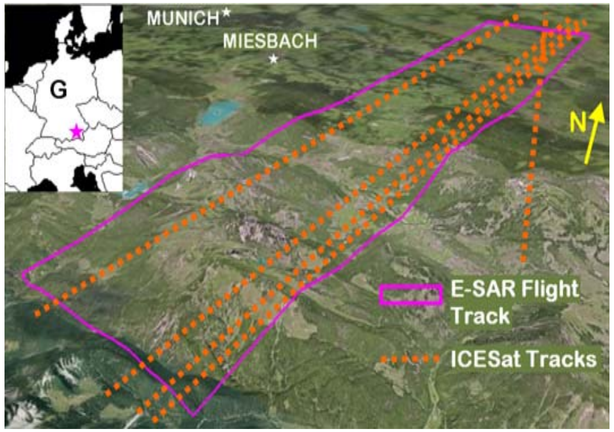
16 Raw DEM pixel

5.2. Campaign Miesbach and Selection Criteria

- Flight campaign Experimental Airborne Radar System (E-SAR)
- Acquisition region Miesbach: flat land, forests and mountainous areas
- 2 interferometric acquisitions/strip, with different flight heights
- ICESat height references available over this area – several tracks



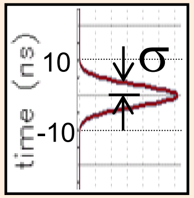




ICESat Selection Criteria for TDX mission: **< 0.4m**

1. Outliers pre-selection with SRTM C-Band
2. Echoes with 1 peak
3. Echoes with narrow σ →

Thresholds	BASIC	EXTREME	OPTIMAL
σ (ns)	8	3.2	4.9
Selected points	30%	5%	15%



4. Threshold vegetation coverage MODIS
   < 20% OPTIMAL

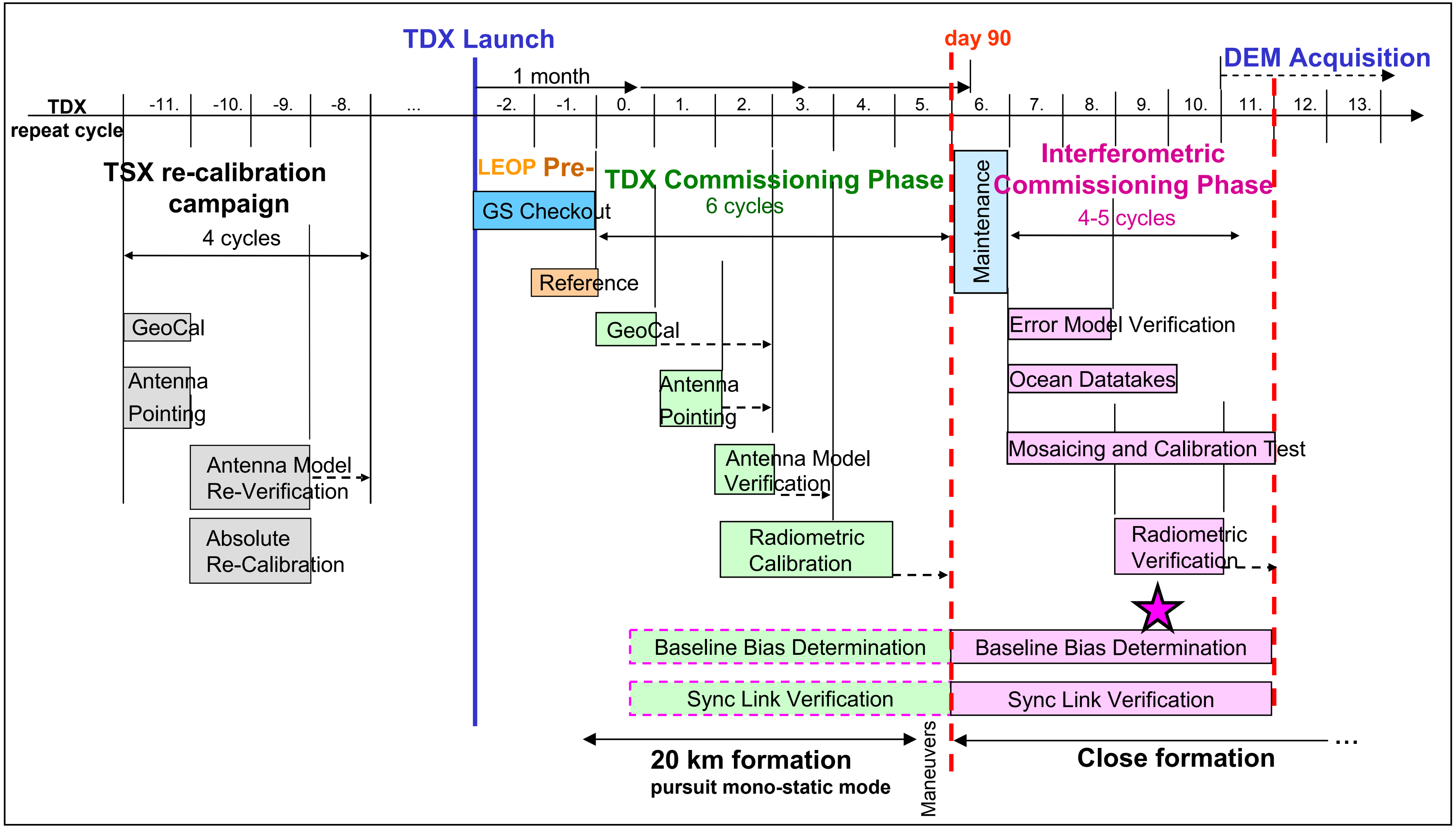
6. TDX Calibration Schedule

- On-ground Characterisation
- TSX re-calibration . . . . 3-4 cycles
- **Launch**

Commissioning Phase

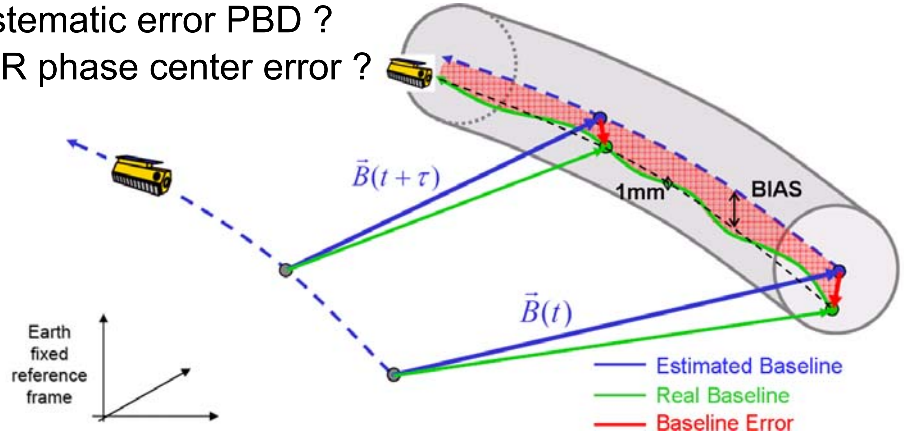
- Mono-static calibration: ready for **TSX operation** . . Pursuit Mono-static Mode 20km along-track . . 6 cycles
  - Geometric Calibration
  - Pointing
  - Antenna Model
  - Radiometric Calibration
- Bi-static calibration: ready for **DEM acquisition** . . Close formation . 4-5 cycles
  - Error model verification
  - Mosaicing and Calibration Processor Test
  - Radiometric check
  - Baseline bias determination
  - Sync Link verification
  - Start DEM acquisition before end of the phase

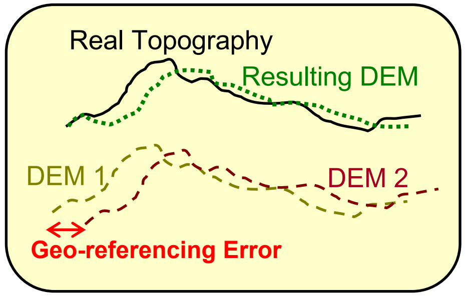
6. TDX In-Orbit Calibration Plan



7. TanDEM-X Baseline Error

- Baseline knowledge is critical to the DEM accuracy
- Baseline determination expected:
  - relative accuracy of 1mm (1σ)
  - slow periodical variation ~ TDX DT length
- However unknown bias (0-6mm) could be present
  - systematic error PBD ?
  - SAR phase center error ?

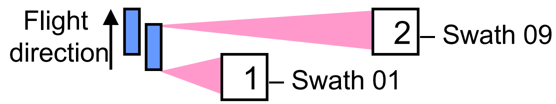


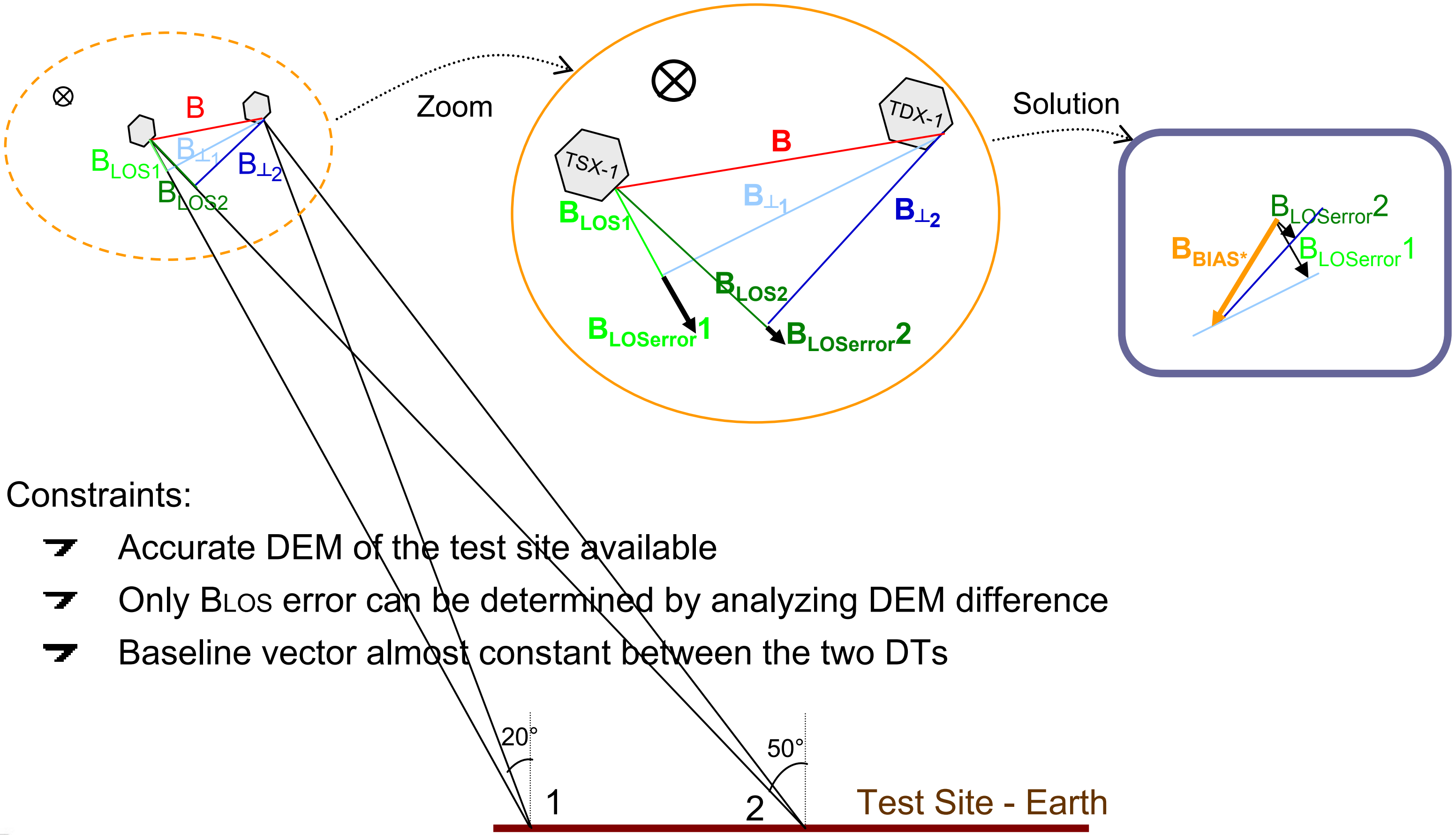


- Consequences of this hypothetical case
  - Not critical for DEM Calibration → height offset could be corrected
  - Error in geo-referencing → different DTs geo-referenced to different positions error when comparing heights
- During Commissioning Phase: - **Test sites** with known DEMs
  - Determine Line Of Sight (LOS) from interferogram difference
  → accurate known DEM – TDX DEM

7. Determination Baseline Bias in LOS

- Acquisition strategy for each test site:
  - Two short DTs are acquired consecutively – different incidence angles
  - Bias vector B_{BIAS}* - perpendicular to the flight direction

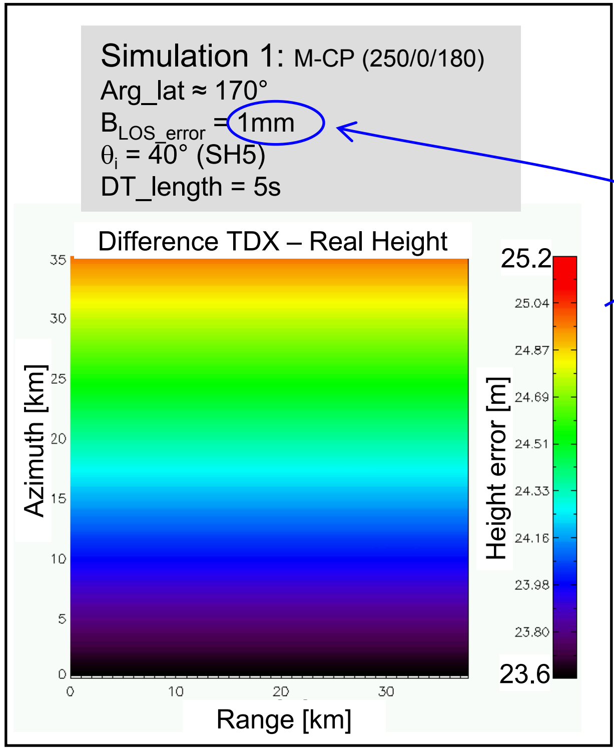




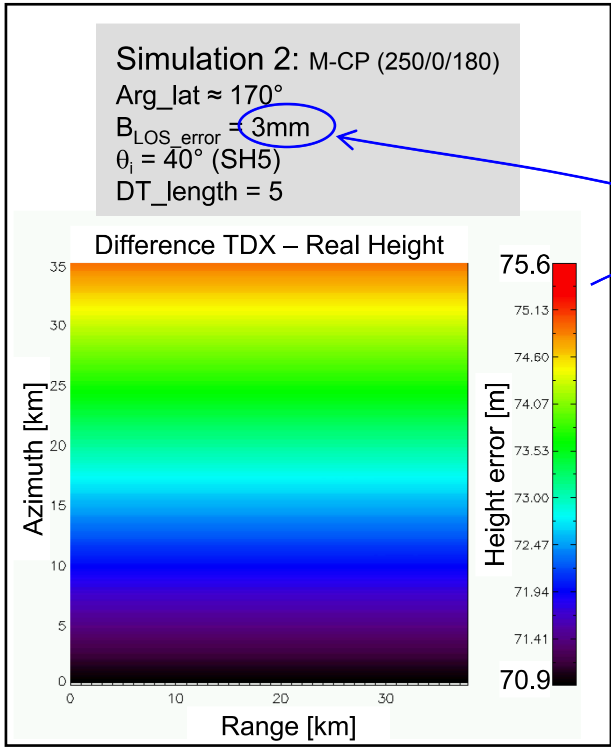
- Constraints:
  - Accurate DEM of the test site available
  - Only B_{LOS} error can be determined by analyzing DEM difference
  - Baseline vector almost constant between the two DTs

7. Derivation of B_{LOS} error ($\Delta B_{\parallel}$) from DEM error

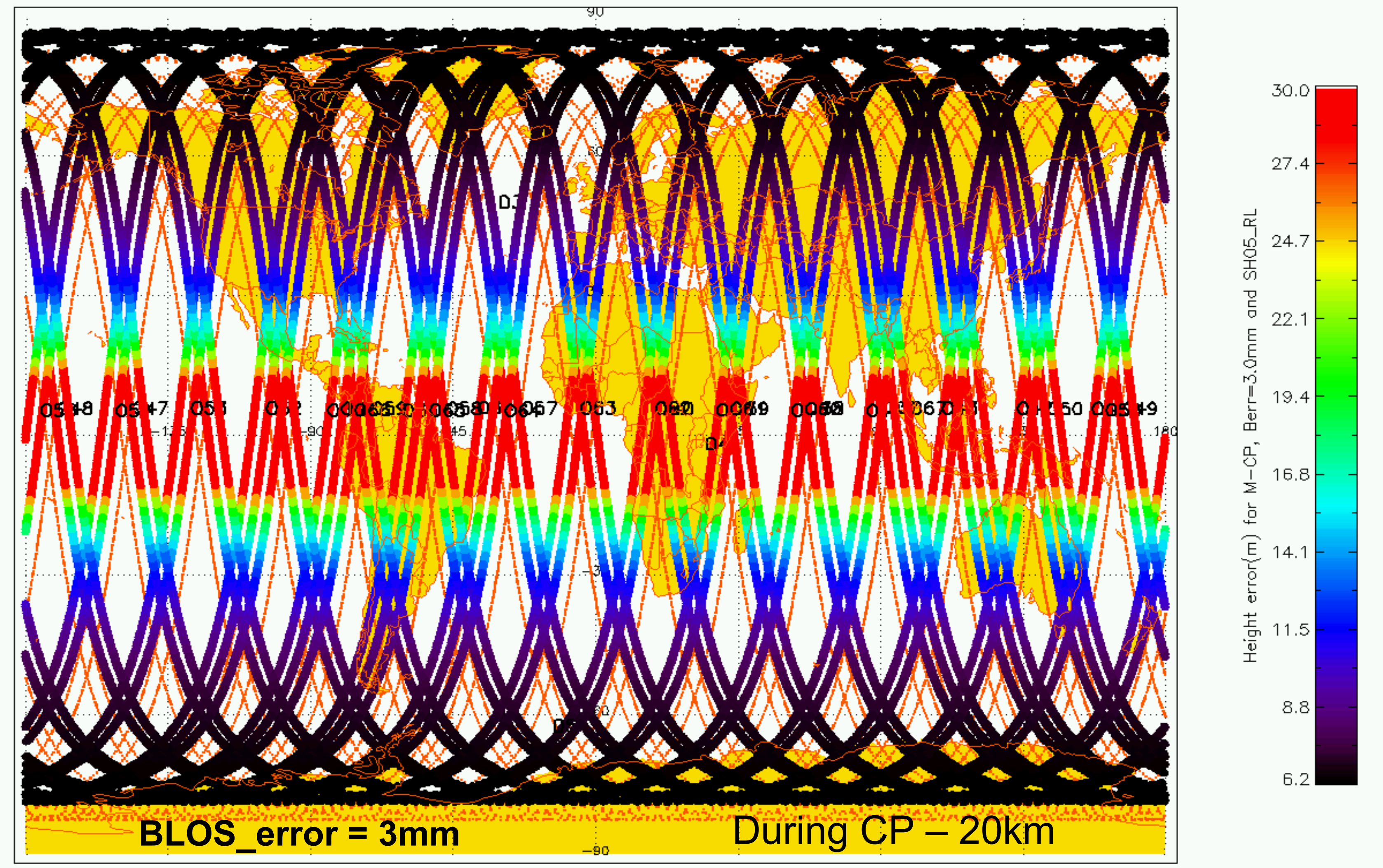
- Helix and baseline geometry known → h_{amb}
- For a given B_{LOS} error → height error realisation
- Baseline error has the strongest effect on the DEM height error
- Several acquisitions over the same test site to cancel rest of errors



$$\Delta B_{\parallel} = \Delta h \cdot \frac{\lambda}{h_{amb}}$$



7. Potential Baseline Bias Test Regions



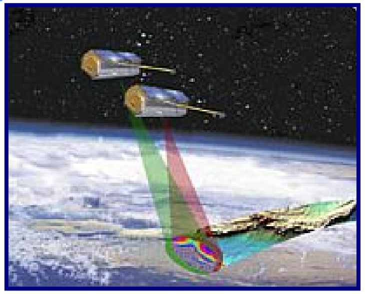
7. Outlook

- Results
  1. Height error simulator: functional model for MCP
  2. DEM adjustment simulations: height error < 0.4m
  3. ICESat selection criteria
  4. Commissioning Phase Plan
  5. Proposal baseline bias determination

- Next steps
  1. Implementation MCP
  2. ICESat investigation
     - Pulse form
     - Density and penetration depth in forests
  3. ICESat investigation
  4. GPS tracks
  5. Choice test sites baseline bias determination

End of the presentation

TanDEM



Questions?

Suggestions?