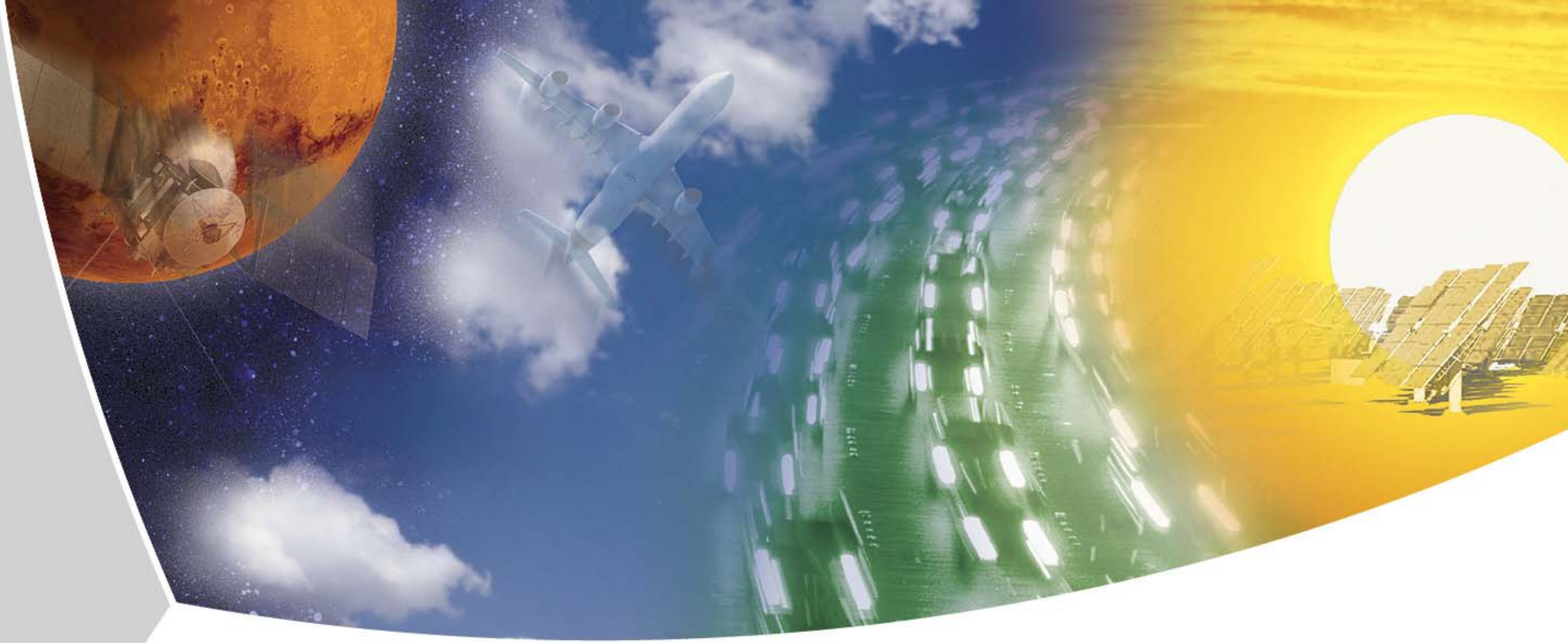

TanDEM-X DEM Calibration Concept and Height References

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TANDEM CALIBRATION

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

Microwaves and Radar Institute

- EUSAR 2008, Friedrichshafen –

06.06.2008

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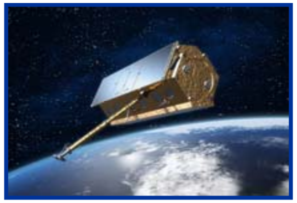
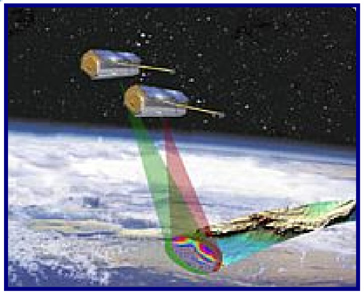
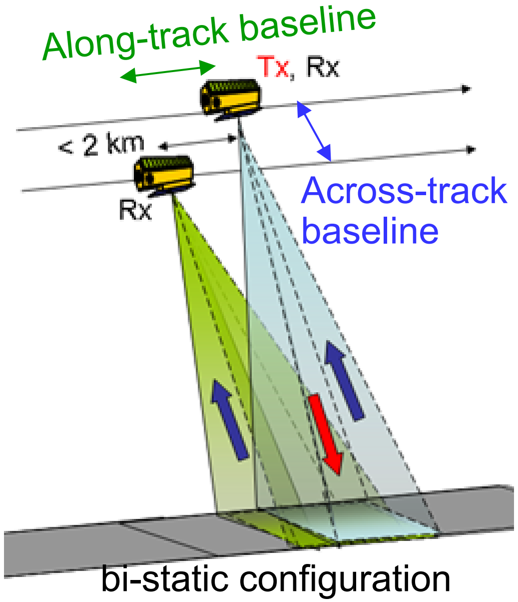
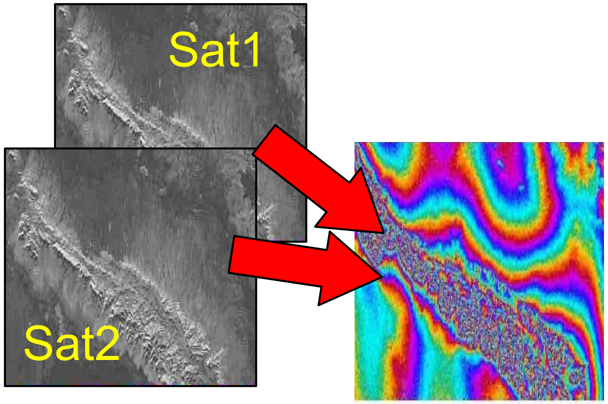
1. Introduction







- Bi-static satellite operation:
  TerraSAR-X (launched June 2007) and TanDEM-X (previewed for September 2009)
- SAR-DataTake → Sat 1: Tx+Rx
  Sat 2: Rx
- Synchronisation required

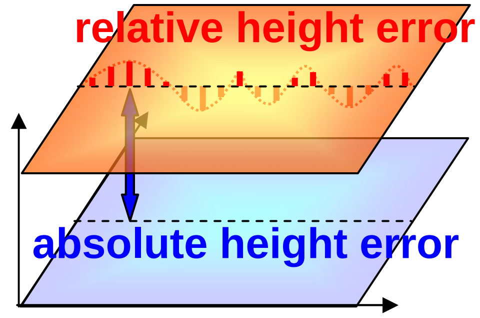


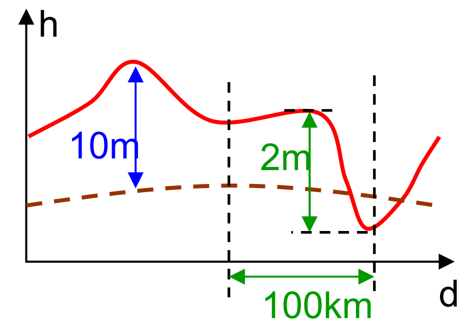
- Processing of both images
- Calculation of an interferometric image via phase difference of images
- Derivation of DEM
- Remaining errors after instrument calibration: baseline and phase errors → Height errors

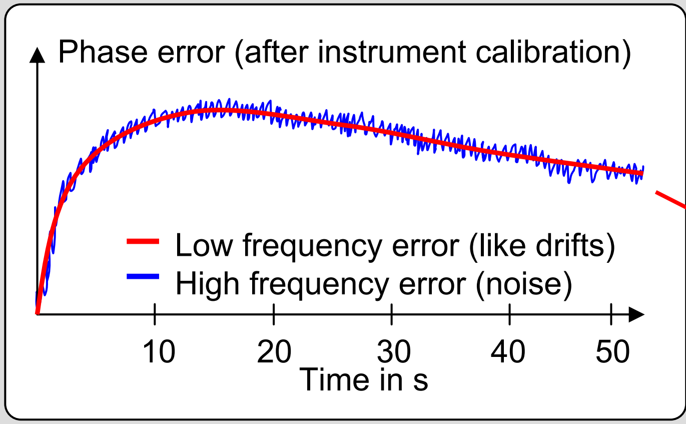
2. Objectives – DEM Calibration

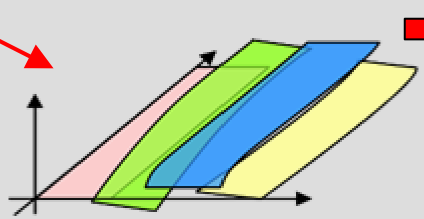
- Global DEM HRTI-3-"like" within mission time (3 years)

Requirement HRTI-3	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







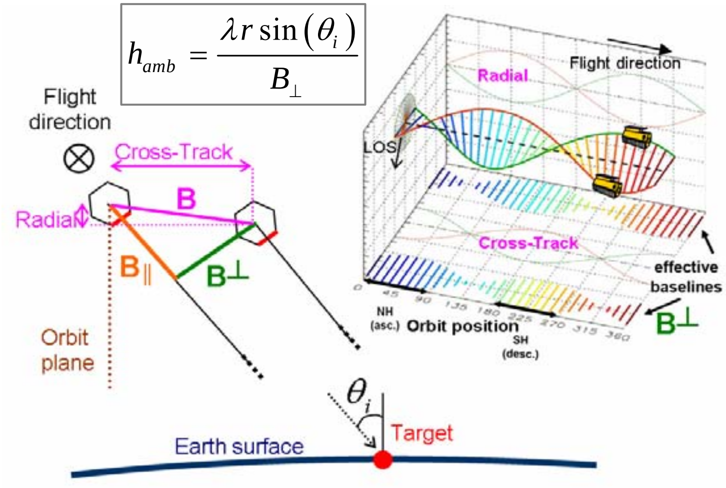


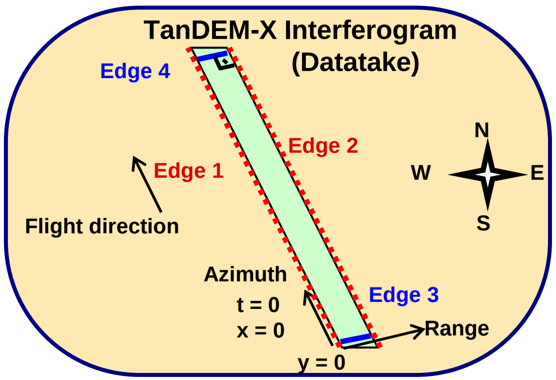
DEM Calibration Concept
- Adjustment methods
- Height references

3. Phase and Baseline Errors to Height Errors

- Baseline errors ($\Delta B_{\|}$)
  - Azimuth modulation: $\Delta h = \frac{h_{amb}}{\lambda} \cdot \Delta B_{\|}$
  - Elevation tilt: $\varphi_{tilt} = \frac{\Delta h}{\Delta s} = \frac{\Delta B_{\|}}{B_{\perp}}$
- Instrument errors → Azimuth modulation: $\Delta h = \frac{h_{amb}}{2\pi} \cdot \Delta\varphi$

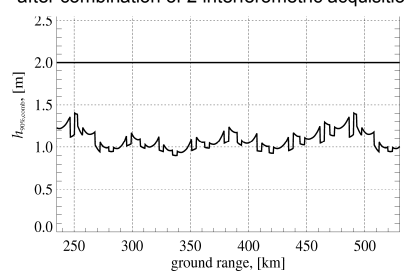
$$h_{amb} = \frac{\lambda r \sin(\theta_i)}{B_{\perp}}$$

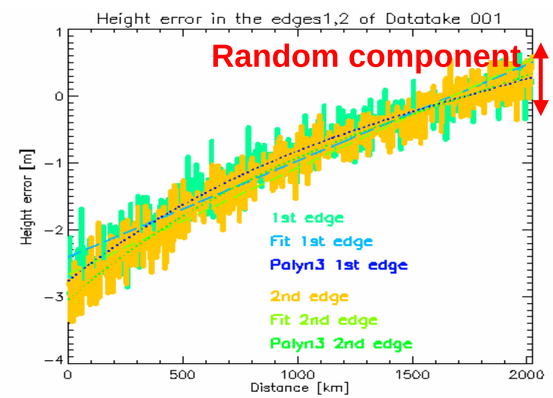




- "Slow-changing" errors → drifts, slow/periodical changes
- "Fast" random errors → thermal noise/performance

90% height error for soil and rock
after combination of 2 interferometric acquisitions





3. Phase and Baseline Errors to Height Errors (cted.)

- Random errors (1.5m) almost exhaust all the relative height error specification (2m)
- Assumptions:
  - DEM is calibrated in absolute height (**Height references**)
  - Processing solves most of the phase unwrapping errors
- Rest of the remaining errors have a systematic nature
- Example:

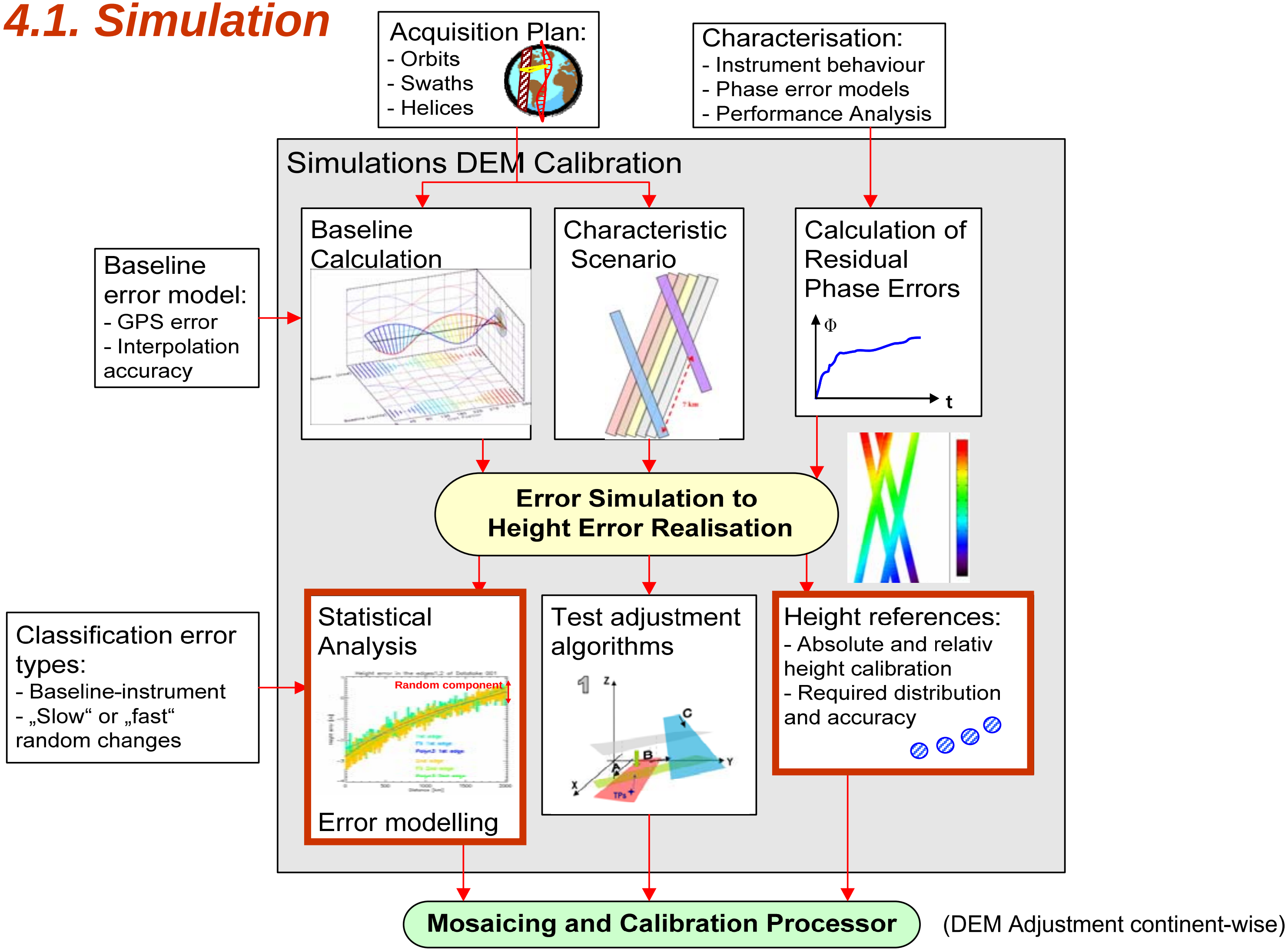
Incident Angle	Normal Baseline (h_{amb}=35m)	Height Errors (for h_{amb}=35m)		
		$\Delta B_{\parallel}$ = 1mm		$\Delta B_{\perp}$ = 1mm
		Δh	$\Delta h/\Delta s$ (tilt)	Δh (h=9km)
30°	260 m	1.1 m	3.8 mm/km	3.5 cm
45°	439 m		2.3 mm/km	2.1 cm

  - 1 mm $\Delta B_{\parallel}$ → height offset of 1.1 m in the datatake
    Translated to specification region (100 km × 100 km) → potential non-compliance
  - The vertical displacement and the tilt in range would also directly follow the time evolution of the parallel baseline error

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

4. DEM Calibration Concept

4.1. Simulation



4. DEM Calibration Concept

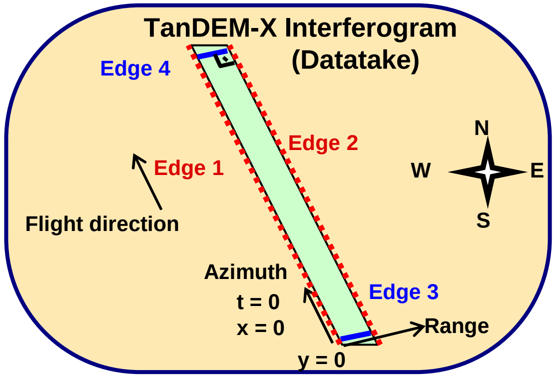
4.2. Error Modeling

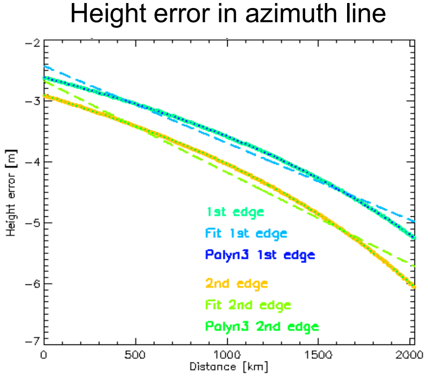
- Statistical study of the **systematic** height error behaviour in different zones (latitudes)
- Confirmed assumptions regarding height error evolution (see table)
- Therefore→ 2D height error evolution can be approximated by functional descriptions
- Statistical analysis → derive coefficients of the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

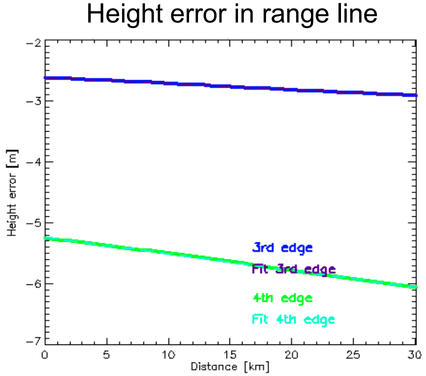
$$g(x,y) = a_0 + a_1 \cdot x + a_2 \cdot x^2 + a_3 \cdot x^3 + b_1 \cdot y + k \cdot x \cdot y$$

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

- Least-squares adjustment with constraints
- Principle: heights in overlapping areas should be nearly identical after correction → correction parameters can be found independent from terrain types

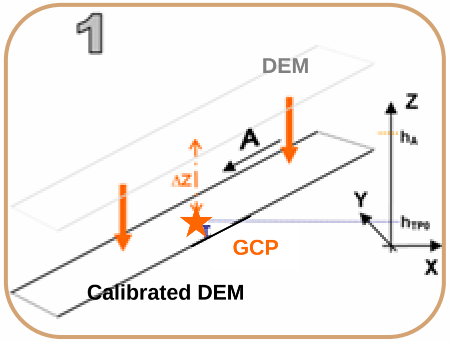






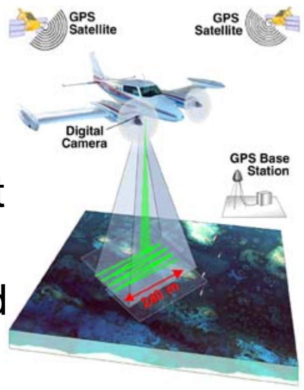
5. Height References

5.1. Types



- Absolute and relative height calibration requires accurate height references:
  - Adequate distribution depending on data take scenario
  - Coverage on all significant isolated land masses
  - Controlled accuracy are pursued
  - Independent from sources used for validation

- Global data sets
  - Good coverage for hooking in the DEM
  - GPS stations, ICESat…: very useful in regions of the planet where local height data are limited/unreliable/unavailable
  - Open terrain height references preferable: uncertainties between terrain and surface models do not need to be considered



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

5. Height References

5.2. ICESat

- Satellite with a laser altimeter (GLAS) , Launched in January 2003 performing global elevation measurements of land, sea and ice
- Elliptical footprints of 60 m diameter, 170 m in along track distance, 80 km across track separation; 91 day repeat cycle
- Good absolute **accuracy**: < 0.5 m (slope < 3 m)
  < 1.0 m (slope < 10 m)
  Slopes determinable from ICESat products

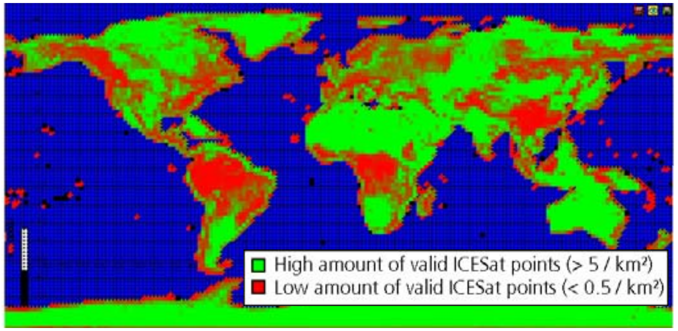
Bibliography:

J. Abshire, et al. "Geoscience Laser Altimeter System (GLAS) on the ICESat Mission: On-orbit measurement performance", Geophysical Research Letters, Vol. 32, 2005.

E. Rodriguez, et al. "An assessment of the SRTM topographic products", Technical Report JPL D-31639, Jet Propulsion Laboratory, Pasadena, California, 143 pp.

- Improved DEM accuracy as a secondary mission goal (HRTI-4 standard)
  → ICESat database can be applied

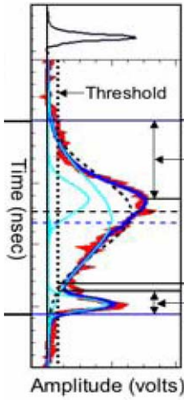
- **Global coverage**
  (actually over 1 billion measurement points)

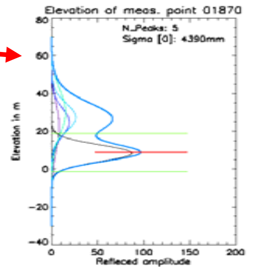


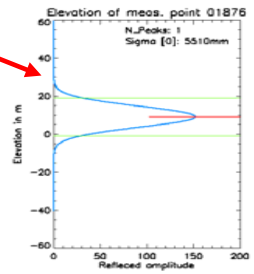
5. Height References

5.3. ICESat Data Application

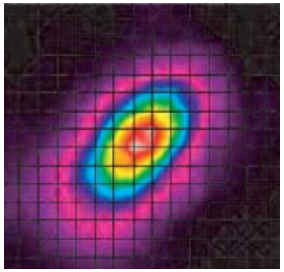
- Main height reference source for TanDEM-X
- Elliptical footprints of 60 m diameter
- Pulse characteristics
  - Decomposed in 6 Gaussians
  - 1 peak (flat ground)
  - More peaks (trees, slope, scattering)

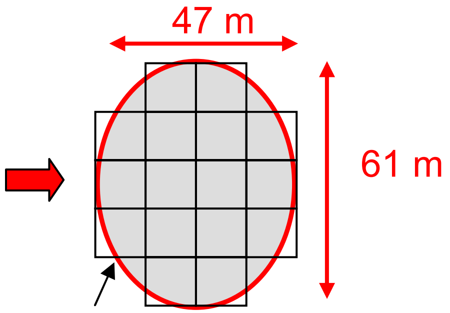






- ICESat **Data Packet Parameters**: Evaluation and classification information for each measurement point
  - DEM height
  - SRTM height
  - N. Peaks
  - Sigma width/saturation
  - Slope
  - Cloud layers
  - Surface properties
  - Region type
- Additionally MODIS vegetation coverage data

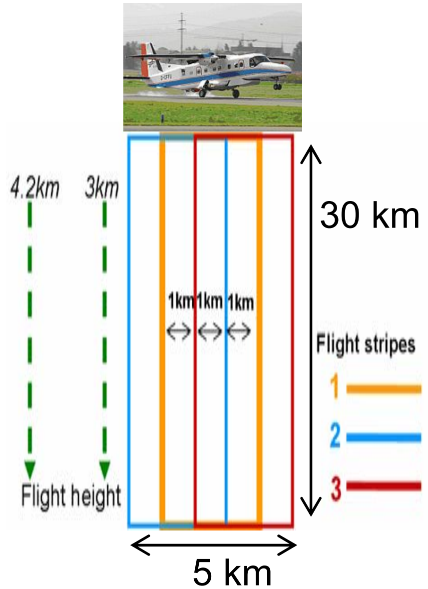




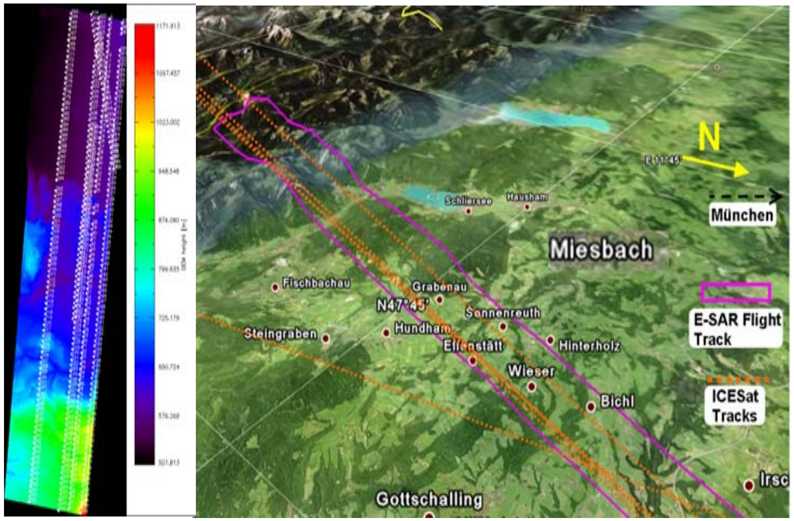
5. Height References

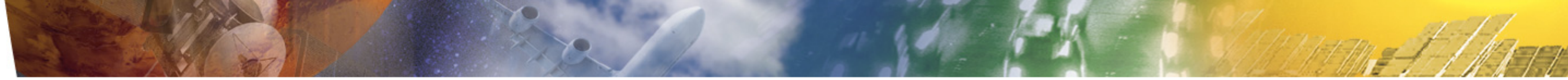
5.4. ESAR Campaign Miesbach

- Flight campaign of the Experimental Airborne Radar System (E-SAR) close to Miesbach, Munich
- Acquisition region: flat land, forests and mountainous areas
- Three parallel overlapping stripes of 3 km width and 30 km length (two acquisitions/strip, with different flight heights)
- ICESat height references available over this area (several tracks)



- Goals of this campaign:
  - Assess the accuracy of ICESat data
  - Precision over different terrain types
  - Dual baseline phase unwrapping
  - Averaging of the ICESat footprint pattern
  - Averaging of E-SAR/TDX DEMs around tie/control points
  - Height calibration/mosaicing/trend identification
  - Identify highly forested regions with MODIS vegetation coverage data

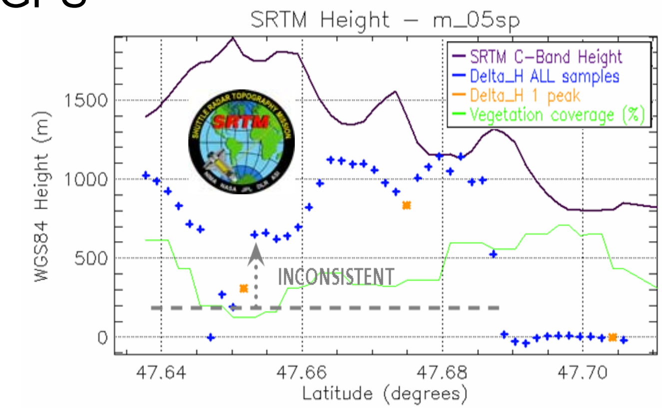




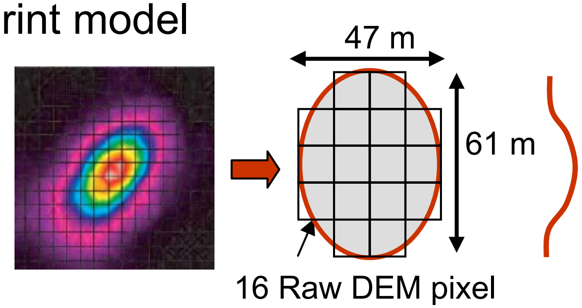
5. Height References

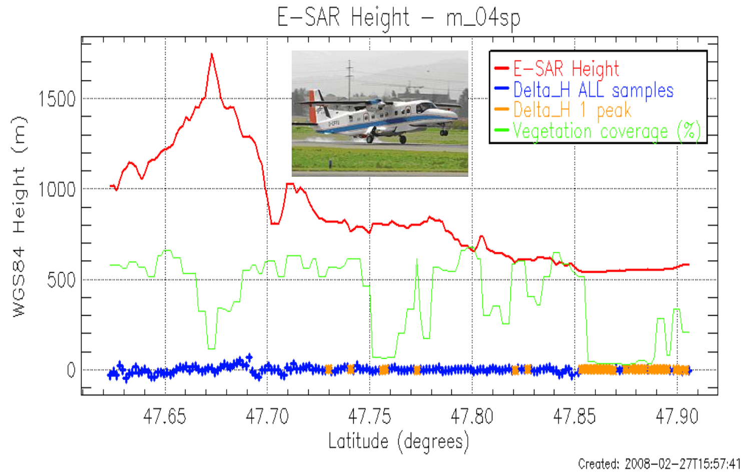
5.5. ICESat – ESAR – SRTM Comparison

- E-SAR DEMs calibrated in absolute height by means of several corner reflector ground control points measured with differential GPS
- First check with SRTM C-band DEM data
  (90 m resolution and ±8.5 m vertical accuracy at 90%)
  - Inconsistence of several ICESat points
  - Possible cloud reflections. But NO flag



- Height difference ICESat – ESAR/SRTM after averaging ESAR samples with the ICESat footprint model

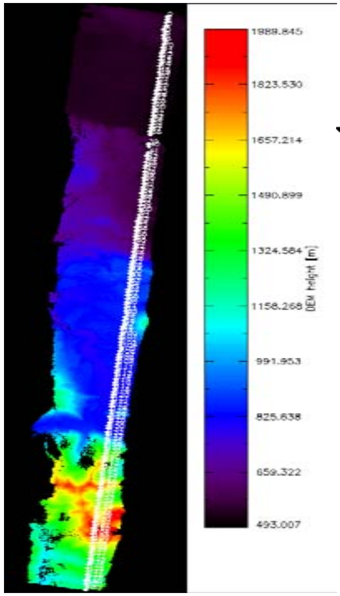




- Comparison plots with difference points
  - Orange points: "good quality"
  - Blue points: scattered echo

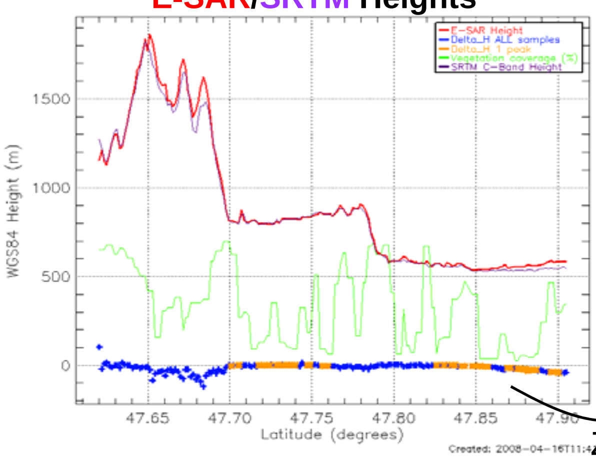
5. Height References

5.5. ICESat – ESAR – SRTM Comparison (cted.)

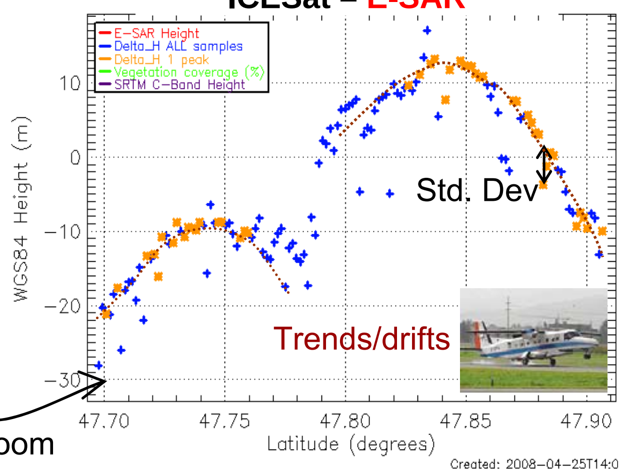


- Results ICESat (track Autumn 2005) – ESAR / – SRTM comparison :
  - Drift in the E-SAR DEM, due to plane motion compensation methods
  - SRTM DEM mean differences are ≈ 0 (shows no trends)
  - However stddev of I-ESAR differences (~2m) < I-SRTM (~10m)
  - If drifts solved, accuracy of ESAR is higher, more suitable for ICESat accuracy study

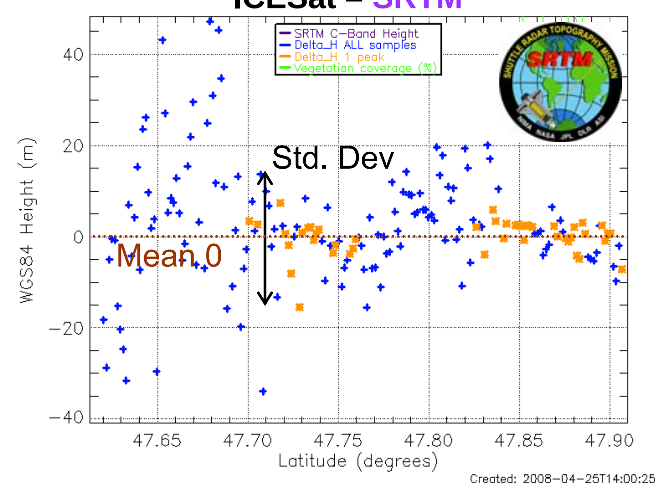
E-SAR/SRTM Heights



ICESat – E-SAR



ICESat – SRTM



5. Height References

5.5. ICESat – ESAR – SRTM Comparison (cted. 2)

- Statistic SRTM Differences
  - “Good” points have much better results than scattered
  - Better than accuracy specifications
  - Validates ICESat height values, but not exact accuracy

	Δ ICESat – SRTM C-Band Heights (m)			
	Reliable points (1pk)		All points	
Track	Mean	StdDev (1σ)	Mean	StdDev (1σ)
All	**-0.002**	**3.5**	**-0.061**	**10.0**

- Selection criteria for ICESat Data:

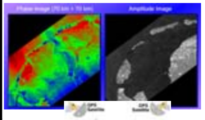
1. Inconsistencies pre-selection with SRTM C-Band; threshold : 200m difference
   (Web SRTM Database is more accurate than the parameter in ICESat data package)
2. Only good echoes with 1 peak and narrow sigma (threshold)
3. If not enough “good” ICESat height samples available in a certain region: the best “scattered” samples can be extracted by relaxing the *n.peaks* and *sigma* thresholds
4. *Vegetation*, *terrain type*, *saturation*, *cloud layer* parameters as a quality selection criteria (work ongoing)

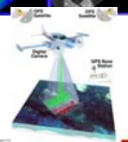
6. Conclusions Height References

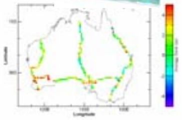
6.1. Summary and Fall-back solutions

- SRTM (C-Band, X-Band) for coarse absolute height offset calibration of the TanDEM-X DEM
- Main source of height references in the fine DEM Calibration: ICESat
- Fall-back: Ocean-land Transitions, local Lidar DEMs
- Validation: GPS Tracks

Function	GCP source	Coverage	Accuracy	Quality parameters
PRELIMINARY absolute height calibration	SRTM	C-Band: almost Global (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 along-track distance and no ocean 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



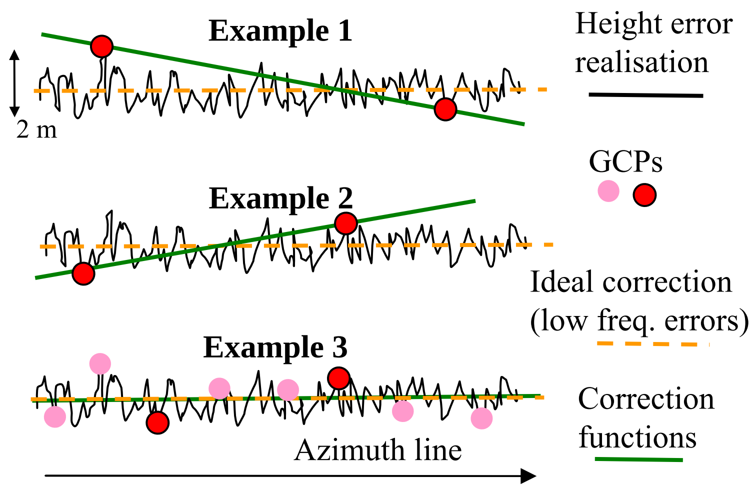




6. Conclusions Height References

6.2. Other recommendations

- Max distance between GCPs: 200 km
  Regions with lower density of high quality height references: crossing orbits
- Averaging of GCP height values: increase their stability minimizing the random height error

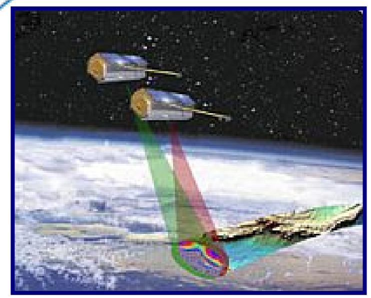


- Flat areas: TanDEM-X heights can be averaged with neighbouring pixels to compare its height with ICESat
  (implicitly done: ICESat footprint has a bigger surface than the TanDEM-X DEM resolution)

7. Outlook

- Improvement in the ESAR DEM: more reliable ICESat accuracy study
- ESAR analysis → ICESat selection criteria
- Other validation activities related to the ESAR experiment:
  - Test multi-baseline PU
  - Mosaicing
  - Test Mosaicing and Calibration Processor execution chain (functional correction model)
  - Assessment of the X-Band height accuracy over forests.
- Laser DEM

End of the presentation



Questions?

Suggestions?