# TanDEM-X: A Global Mapping Mission

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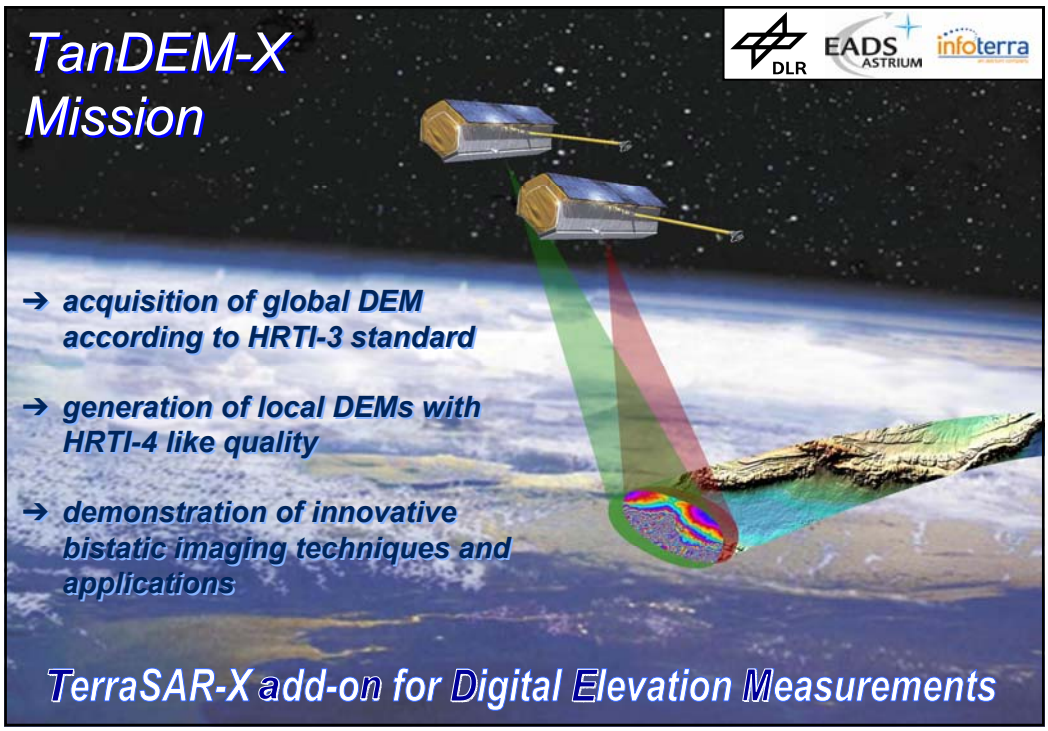
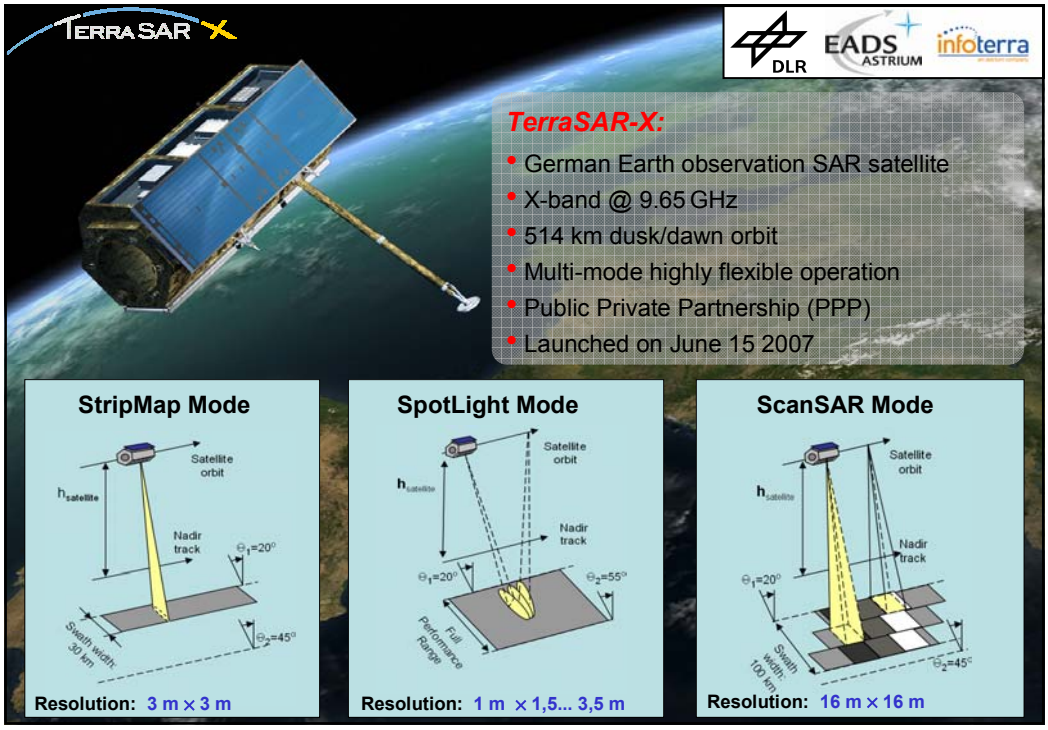
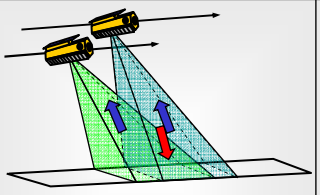
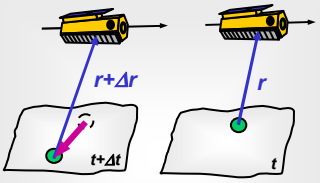
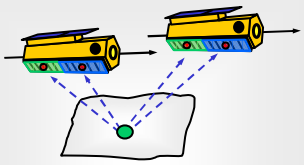
## Outline

- Introduction
  - TanDEM-X mission
  - TerraSAR-X mission
- Capabilities of TanDEM-X
- Orbit Configuration
- Data Acquisition Concept and Mission Planning
- Bistatic Synchronization
- DEM specification and format
- Baseline Estimation and Calibration
- Global DEM Performance Prediction
- Conclusion


TanDEM-X Mission
DLR
EADS ASTRIUM
infoterra
➔ 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


TERRA SAR X
DLR
EADS ASTRIUM
infoterra
TerraSAR-X:
• German Earth observation SAR satellite
• X-band @ 9.65 GHz
• 514 km dusk/dawn orbit
• Multi-mode highly flexible operation
• Public Private Partnership (PPP)
• Launched on June 15 2007
StripMap Mode
Satellite orbit
Nadir track
Swath width: 30 km
Resolution: 3 m × 3 m
SpotLight Mode
Satellite orbit
Nadir track
Full Performance Range
Resolution: 1 m × 1,5... 3,5 m
ScanSAR Mode
Satellite orbit
Nadir track
Swath width: 100 km
Resolution: 16 m × 16 m

## Capabilities of TanDEM-X

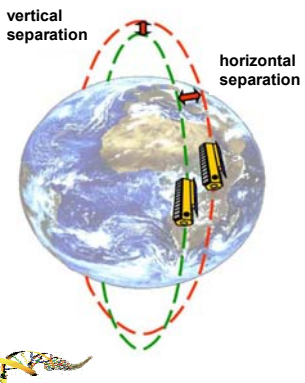
| Cross-Track Interferometry | Along-Track Interferometry | New Techniques |
|---|---|---|
|  |  |  |
| → **Digital Elevation Models**<br>→ **Spatial Coherence** (forest, ...)<br>→ **Double DInSAR** (change maps, ..)<br>→ **High Resolution SAR Images** | → **Large Scale Velocity Fields** (ocean currents,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

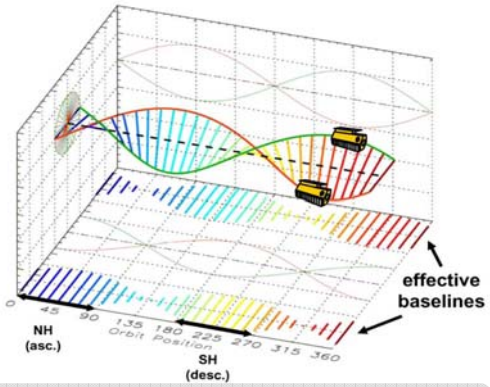
**TanDEM-X is a highly flexible sensor which enables multiple imaging modes**

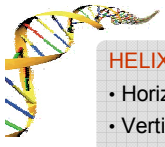
| | | | |
|---|---|---|---|
| ▪cross-track baselines (0 km to several km) | ▪interferometric modes (bistatic, alternating, monostatic) | ▪bandwidth / resolution (0 ... 150/300 MHz) | ▪polarisations (single, dual, quad) |
| ▪along-track baselines (0 km to several 100 km) | ▪SAR modes (ScanSAR, Stripmap,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



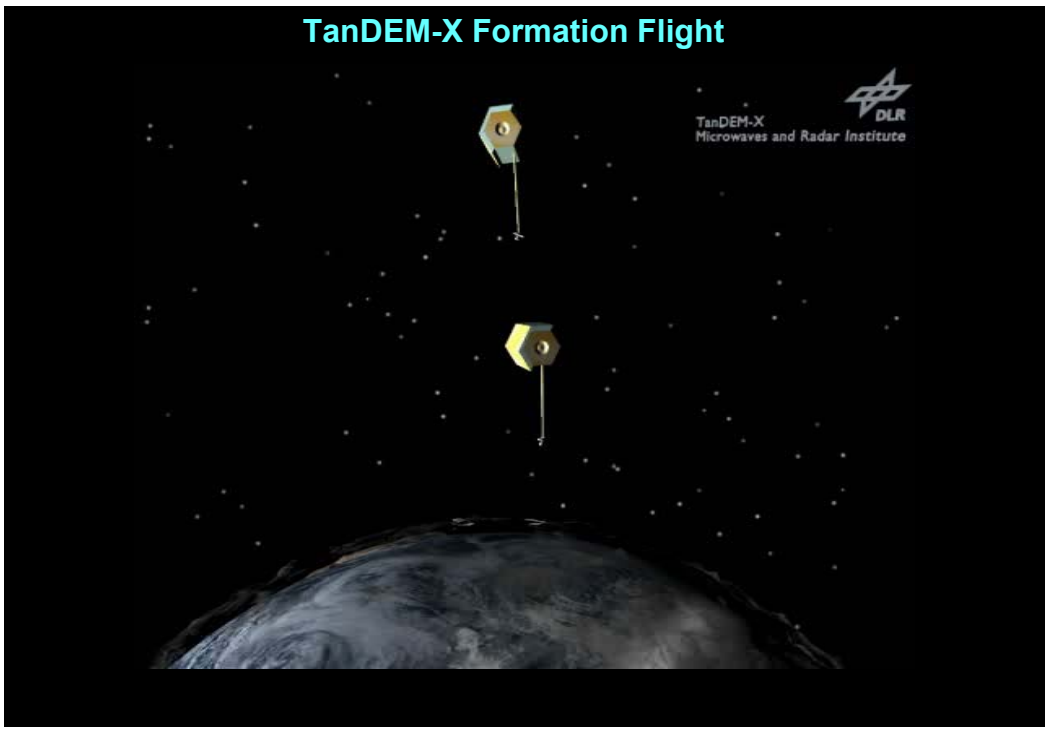
## Orbit Configuration



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




## Data Acquisition Concept

| 3m | 1 year | 1 year | 6 months | ≥ 3 months |
|---|---|---|---|---|
| Comissioning Phase | 1 global DEM acquisition with small baselines | 1 global DEM acquisition with scaled baselines + acquisition of scientific radar data products | additional DEM data takes for difficult terrain and filling-in of possible gaps + radar data products | radar data products and customized DEMs with large interferometric baselines |

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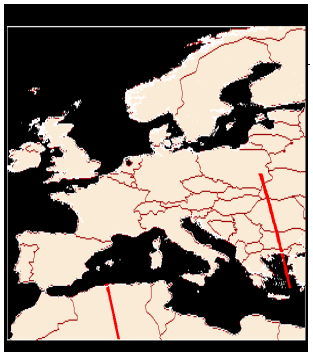
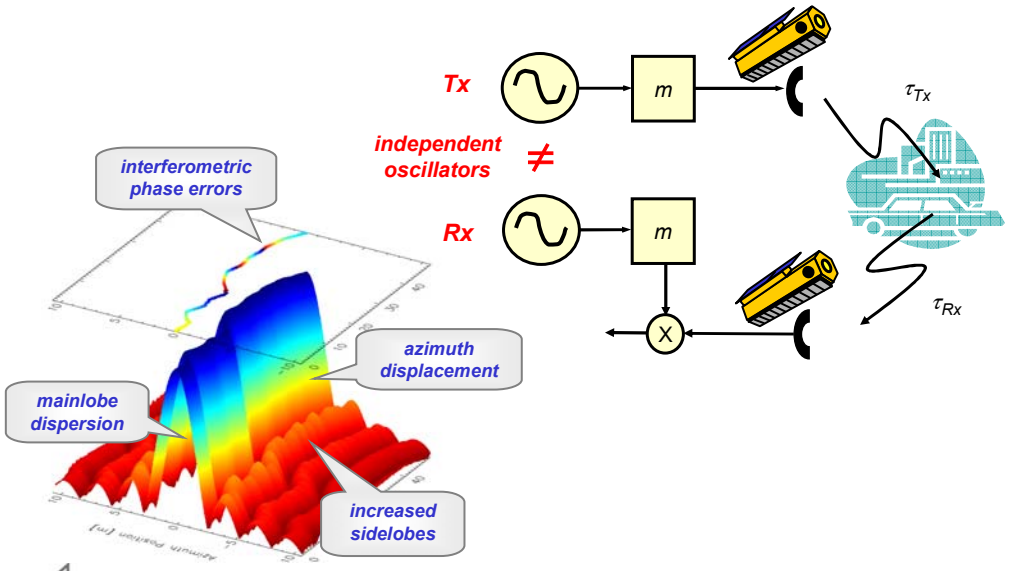
## Mission Planning

- Combined planning of single TerraSAR-X requests and global mapping requests for TanDEM-X
- Systematic acquisition of DEM data in long strips of typically 1000km
- Constraints:
  - Minimize impact on TerraSAR-X mission
  - Data storage and downlink scenario
  - Instrument and system constraints
  - Datatake priority

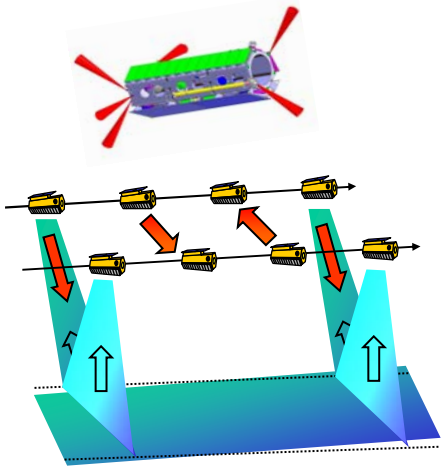


## Impact of Oscillator Noise and Drifts

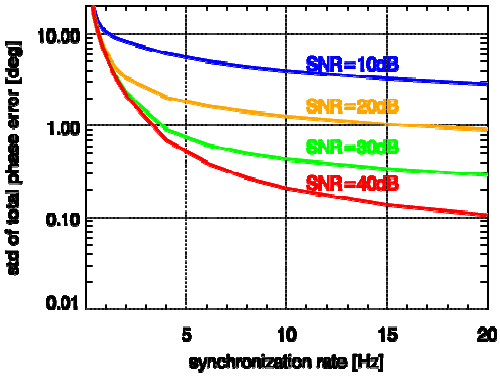


## Phase Referencing

Synchronisation Link



Analysis of Residual Errors

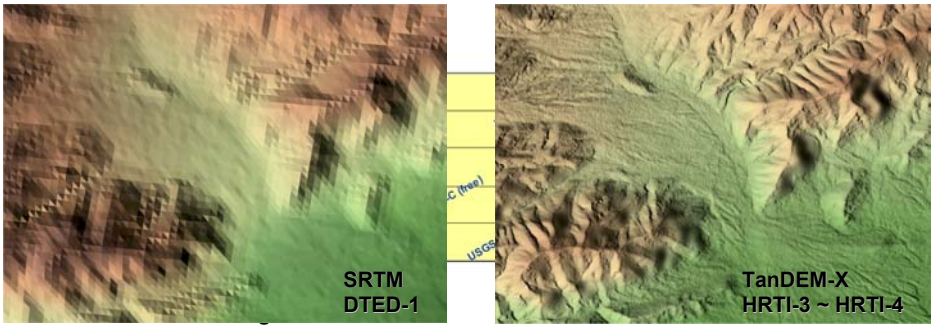



→ phase referencing can achieve short term rmse below 1°



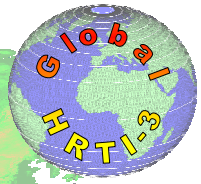
## HRTI Specification

| | 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 |



## Global HRTI-3 DEM - Characteristics

- Data stored and delivered in tiles
- Terrain elevation given as WGS84 ellipsoidal height [m]
- Optional delivery of SAR amplitude data
- Latitude-dependent pixel spacing (zones)
- Raw DEM mosaicking on continent level
- Quality control and post-processing incl. flattening of water bodies
- Final DEM available 4 years after launch (intermediate DEM earlier)

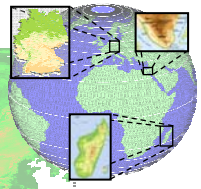



| Zone | Latitude (North/ South) | Latitude pixel spacing | Longitude pixel spacing | Tile size (Latitude x Longitude) | Tile size (example, MB) |
|---|---|---|---|---|---|
| I | 0° – 50° | 0.4'' | 0.4'' | 1° x 1° | 891 |
| II | 50° – 60° | | 0.6'' | 1° x 1° | 595 |
| III | 60° – 70° | | 0.8'' | 1° x 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 |



## Local DEM products - Characteristics

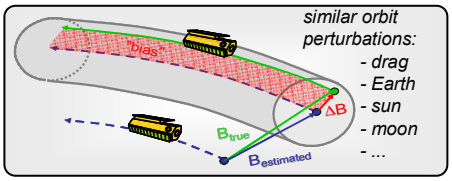
- Customized DEMs generated on request
- For areas of limited size only
- Sub-meter resolution (e.g. HRTI-4)
- Multiple data acquisitions with large and small baselines



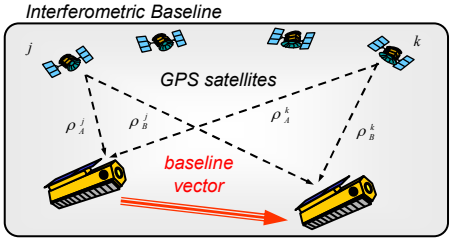
## Inter-satellite Baseline Estimation

- **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
- **Several studies predict a 3-D accuracy in the order of 1-2 mm**

*Relative Orbit Model*



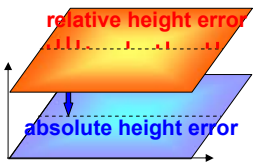

*Interferometric Baseline*

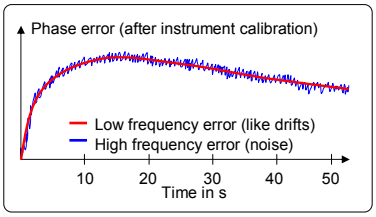


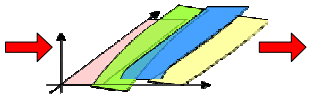



## Need for DEM Calibration

- 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)

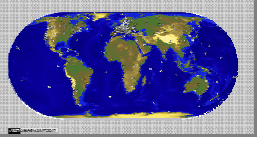
## DEM Calibration Aspects

**Height Reference Data:**

*GLOBAL:*
- ICESat Laser Altimeter

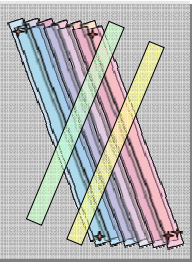
*LOCAL:*
- Airborne LIDAR data
- GPS tracks (for validation)
- Radar point targets (corner reflectors, transponders)

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

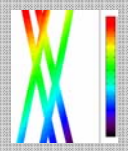


**Multiple Ground Coverage:**

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



**Error Modelling and Adjustment:**



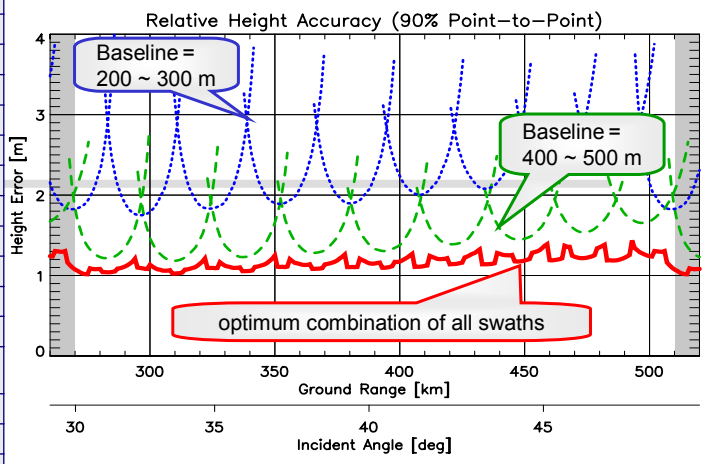
- Systematic errors modelled by polynomials
- Coefficients determined by statistical analysis
- Least-squares adjustment with constraints
- Principle: heights in overlapping areas should be nearly identical after correction



## 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**

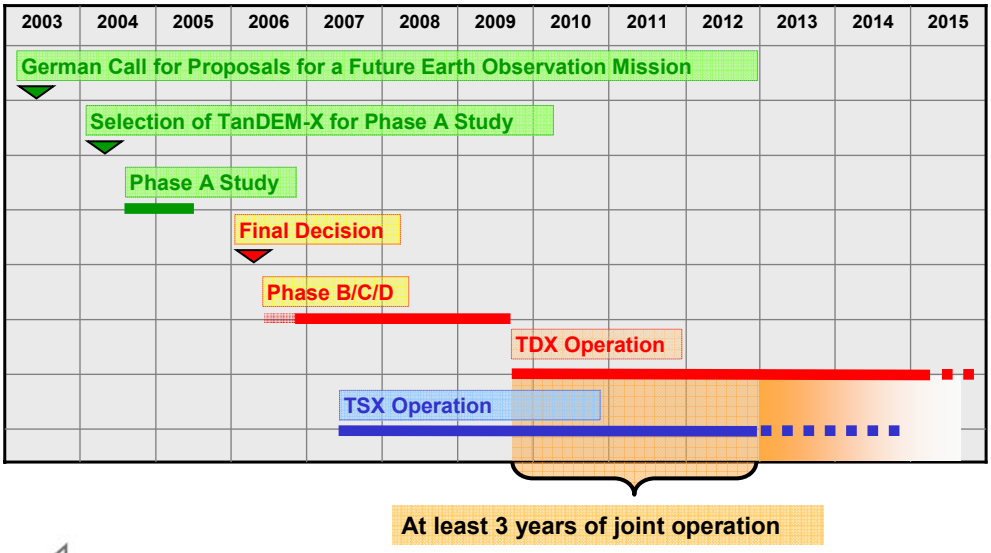


## Conclusion

- TanDEM-X has outstanding scientific and commercial potentials
- TanDEM-X is based on the successful TerraSAR-X mission
- TanDEM-X key technologies are:
  - close formation flying capability
  - bistatic radar operation and phase synchronisation
  - precise baseline determination
  - new algorithms for interferometric processing
- TanDEM-X plays a key role in the development of next generation bistatic and multistatic SAR missions and applications
- Launch of TanDEM-X add-on satellite scheduled for end of 2009



## TanDEM-X Timeline





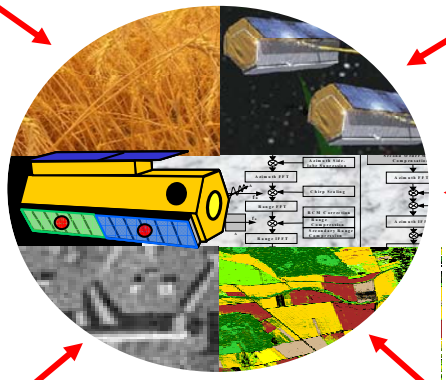

## Data Circulation & Processing

- 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
- Global (level-3) product
- In total 1500 TB to be processed and archived (additional archive required for interferometric processing)

## Secondary Mission Goals & New Techniques

***Pol-InSAR***
(fully polarimetric !)

***Along-Track Interferometry***
(HELIX formation !)



***Digital Beamforming***
(4 phase centres !)

***Multi Baseline InSAR***
(flexible baselines !)

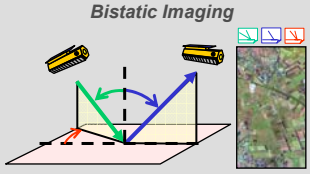
***Super Resolution***
(large bandwidth !)

***Bistatic Observations***
(bistatic angle !)

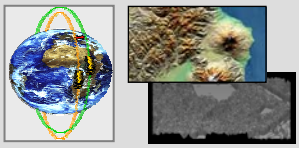


## Potentials of Bistatic and Multistatic SAR Systems

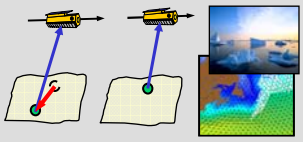
***Bistatic Imaging***



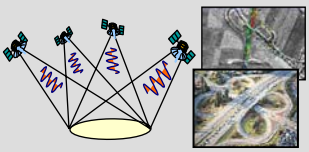
***Cross-Track Interferometry***



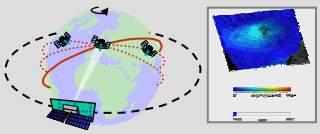
***Along-Track Interferometry***



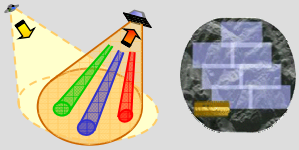
***Moving Target Indication***



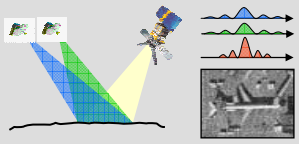
***Frequent Monitoring***



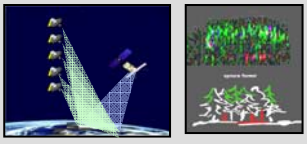
***Digital Beamforming***



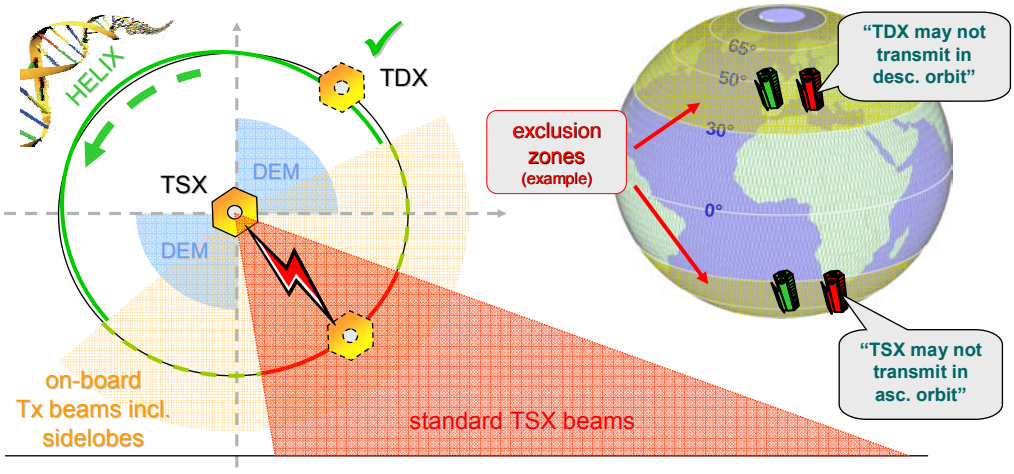
***Resolution Enhancement***



***SAR Tomography***



## Transmit Exclusion Zones







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