Global Digital Elevation Model from TanDEM-X and the Calibration/Validation with worldwide kinematic GPS-Tracks

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• TanDEM-X Mission
• Global DEM Processing
• Kinematic GPS Measurements
• FIG Cooperation
• Conclusions and Outlook

TanDEM-X
TerraSAR add-on for Digital Elevation Measurements

TerraSAR-X/TanDEM-X:
• German Earth observation SAR satellites
• Public Private Partnership (PPP)
• X-band @ 9.65 GHz
• 514 km dusk/dawn orbit
• Ground resolution: 1 – 16 m
• Multi-mode highly flexible operation
• Launch on June 15, 2007/2010
• Generation of a global DEM (HRTI-3)
• Generation of local DEMs (HRTI-4)
• Demonstration of new bistatic SAR
### Primary Mission Goal:
Generation of a global HRTI-3 DEM

<table>
<thead>
<tr>
<th>Spacing: 12m x 12m</th>
<th>abs. dh &lt; 10 m</th>
<th>abs. dl &lt; 10 m</th>
<th>rel. dh &lt; 2 m (4m, slope &gt; 20 %)</th>
</tr>
</thead>
<tbody>
<tr>
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</tbody>
</table>

**HRTI 3 - HRE-GP**

### Helix Orbit Configuration

- Vertical baseline: 300m – 600m
- Horizontal baseline: Error = 1 mm
Interferometric System (Bistatic Mode)

Radar advantages:
- allweather capability
- active
- various frequencies

Overview of DEM Mosaicking and Calibration Processor

Global TanDEM-X DEM

Mosaicking and Calibration Processor

raw single InSAR DEM:
- Elevation
- Height Error Map
- Amplitude
- Flag Mask

DEM generation
- Preparation
- Calibration
- Validation
- Mosaicking

mosaicked DEM:
- Elevation
- Height Error Map
- Amplitude Mosaic
- Flag Mask
Mosaicking / Fusion

- Applies estimated systematic corrections to raw DEMs
- Mosaic generation: Averages all available raw DEMs to minimize random error
- Followed by operator-conducted quality control
- 1. year: Mosaicked DEM -> intermediate TanDEM-X DEM, 2 years after launch
- 2.+3. year: TanDEM-X DEM -> 4 years after launch (Sep. 2014)

Digital Elevation Models Accuracy

- Goal of the TanDEM-X Mission:
  Global, consistent Digital Elevation Model

- Accuracy Requirements:
  - ~12 m spatial posting
  - <10 m absolute height accuracy
  - <10 m absolute horizontal accuracy
  - <2 m relative height accuracy
DEM Calibration and Validation

Error Modelling and Adjustment:
- Systematic errors modelled (spacecraft, sensor, orbit, SAR-processor, etc.)
- Least-squares adjustment
- Tie-pointing
- Principle: heights in overlapping areas should be nearly identical after correction

Multiple Ground Coverage:
- Swath overlap (~4 km)
- Land surface covered twice (at least)
- Crossing orbits (3rd year)

Height Reference Data:
- **GLOBAL:** ICESat (Laser Altimeter)
- **LOCAL:** Airborne LIDAR, Radar point targets (corner reflectors), kinematic GPS tracks (for validation)

Precise Point Positioning

Why PPP?
- No reference station
- No additional data
- Worldwide possible
- "Easy-to-use"?
- Postprocessing "at home"

Feasibility study and test in Germany
- Quality Study (University Stuttgart)
  - Result: Height RMS ~ 0.5 m
- GIPSY and CSRS online Service
- Roundtrip measurements
- Fix and virtual reference stations
- SAPOS
Worlwide GPS Tracks

Europe
Munich - Ukraine
Munich - Sao Marinho (Portugal)
Dovhanets - Tisa (Ukraine)

Russia
Krasnojarsk – Belgorod (Russia)

Asia
Beijing – Gaoquan (China)
Kolkata - Surat (India)

South America
Vina Del Mar – Mar Del Plata (Chile-Argentina)
Laguna Verde – Punta de Choros (Chile)
Recife – Porto Velho (Brasil)

Africa
Dar es Salaam – Skeleton Coast (Namibia)
Conakry - Ife (Niger)

USA/Canada
Los Angeles – Inuvik (Canada)
Vancouver – Nova Scotia (Canada)

Australia
Sydney – Perth

Saudi Arabia
Dammam – Khamis Mushayt (planned)

Requirements for Track Acquisition

- **Dual frequency** receiver with 10 Hz
- Leica GPS1200 is preferred as GPS system (Trimble, Sokkia was also used)
- GPS antenna high as possible
- Speed maximum 100km/h
- Output format RINEX
- Planning regarding visibility of GPS satellites
- Cut off elevation angle 0 – 10 degree
- DOP > 10
- Satellite visibility check
- PPP initialization at start (30 minutes)
- Data take only in dynamic mode
- Track section length 2 hours
- Maximum single data take 2 hours ( 30 minutes initialization, 90 measurement of raw data)
- 30 minutes synchronisation at the end of the day
- Online data quality check
- The track should be in east-west or vice versa direction
- Measurement of 2 large intersections (if possible)
- Integration of available international GPS reference stations in a distance of 20 km and driving with a reduced speed or a stop of about 10 minutes
Problems and Quality of the Tracks

Andean

Problem: Signal lost, Buildings
Problem: Forest and ?

Validation of GPS tracks

- Validation with two independent post-processing approaches (GIPSY, National Resources Canada) processed at Uni Stuttgart
- IGS Information

<table>
<thead>
<tr>
<th>Reference Station</th>
<th>Mean dh (m)</th>
<th>RMS dh (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Urum (China)</td>
<td>-0.03</td>
<td>0.39</td>
</tr>
<tr>
<td>SANT (Chile)</td>
<td>0.37</td>
<td>0.79 (large dist. to station)</td>
</tr>
<tr>
<td>NVSK (Russia)</td>
<td>0.39</td>
<td>0.15</td>
</tr>
<tr>
<td>OBE3 (Germany)</td>
<td>0.21</td>
<td>0.5</td>
</tr>
<tr>
<td>SALA (Spain)</td>
<td>0.18</td>
<td>0.37</td>
</tr>
<tr>
<td>BRLAZ (Brazil)</td>
<td>-0.16</td>
<td>0.24</td>
</tr>
</tbody>
</table>
Track Statistics (March 2010)

<table>
<thead>
<tr>
<th>Track</th>
<th>Track Length (km)</th>
<th>Valid track</th>
<th>RMS dh (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chile-Argentina</td>
<td>1714</td>
<td>87%</td>
<td>0.51/0.57</td>
</tr>
<tr>
<td>Chile</td>
<td>566</td>
<td>58%</td>
<td>0.5/0.49</td>
</tr>
<tr>
<td>China</td>
<td>3991</td>
<td>71%</td>
<td>0.52</td>
</tr>
<tr>
<td>Europe</td>
<td>900</td>
<td>61%</td>
<td>0.48</td>
</tr>
<tr>
<td>Europe</td>
<td>2400</td>
<td>59%</td>
<td>0.48/0.48</td>
</tr>
<tr>
<td>Russia</td>
<td>4585</td>
<td>59%</td>
<td>0.46</td>
</tr>
<tr>
<td>Brazil</td>
<td>4984</td>
<td>36%</td>
<td>0.53</td>
</tr>
<tr>
<td>SUM: 19140</td>
<td>~ 56%</td>
<td>~ 0.49</td>
<td></td>
</tr>
</tbody>
</table>

Cooperation with FIG

FIG Newsletter 2008:
Kinematic GNSS for Evaluation of TanDEM-X Digital Elevation Model

Feedback:
More than 20 interested groups from all over the world
Selection of 8 partners (scientific and commercial)

Further cooperation:
TanDEM-X Science team at DLR
Science Coordinator: Irena Hajnsek (Irena.Hajnsek @dlr.de)
Validation of DEMs with access to TanDEM-X products (DEM, Radar)
Scientific usage of GPS Tracks
### TanDEM-X Product Classes

**DEM Products**
- Intermediate DEM (2 years after launch)
- Standard global DEMs (4 years)
  - \( \Delta h = 2 \text{m} @ 12 \text{m posting} \) (HRTI-3)
  - also: 1 \text{m} @ 25 \text{m} and 0.5 \text{m} @ 50 \text{m}
  - 4\text{m} @ 6\text{m} (on special request)
- global access

**Customised DEMs**
- improved resolution (e.g. 1\text{m} @ 6\text{m} – HRTI-4)
- multiple DEMs (different seasons/years)
- only on local/regional basis

**Supporting information**
- coherence maps
- geocoded SAR products
- height error maps

**Radar Data Products**
- Deliverables for scientific User
  - SLC SAR images
  - auxiliary data (baselines, …)
  - interferograms (if applicable)
  - SAR raw data (on special request)
  - Geocoded products
  - Optional amplitude mosaic

- Commercial products support by Infoterra

### Conclusions and Outlook

- Kinematic PPP is a suitable calibration approach
- Height accuracy better than 0.5\text{m}
- Postprocessing is very important and time consuming
- TanDEM satellite is at the cosmodrom Baikonur
- Lauch date summer 2010
- First intermediate DEM “two years after launch
- Access for scientific user via DLR

Acknowledgements:
The TanDEM-X project is partly funded by the German Federal Ministry for Economics and Technology (Förderkennzeichen 50 EE 0601):
From Sensor to Digital Elevation Model

Process of DEM Generation from SAR

**Radarhologram**

**Radarimage**

**Interferogramm**

**DEM-Product**

**Application**

Preparation Quality Control

Visual inspection of **visual potential water bodies** regarding the right parameter settings for different areas

Height discrepancy Detection

Assessing matching quality and distribution between **tie-points** or image chips
## TanDEM-X Data Acquisition Strategy

<table>
<thead>
<tr>
<th>Terrain Type</th>
<th>Percentage of Total Landmass</th>
<th>Number of Acquisitions</th>
<th>Required Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Moderately Sloped Areas</td>
<td>50%</td>
<td>1</td>
<td>~ 7 months</td>
</tr>
<tr>
<td>(h_a &lt; 35 m)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hilly Areas, Tall Forests</td>
<td>30%</td>
<td>2</td>
<td>~ 8 months</td>
</tr>
<tr>
<td>(+ different h_max)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Mountainous Areas</td>
<td>&lt; 20%</td>
<td>4</td>
<td>~ 11 months</td>
</tr>
<tr>
<td>(+ asc. / desc.)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>1 - 4</td>
<td>~ 26 months</td>
</tr>
</tbody>
</table>

### TanDEM-X Mission Scenario for 3 Years

- **Global HRTI-3 DEM**
  - (incl. multiple acquisitions for difficult terrain)
  - ~ 70%

- **Additional Applications**
  - (local HRTI-4, ATI, new techniques, ...)
  - ~ 30%

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### HRTI-3 Specification

<table>
<thead>
<tr>
<th>Spatial Resolution</th>
<th>Absolute Horizontal Accuracy (90%)</th>
<th>Absolute Vertical Accuracy (90%)</th>
<th>Relative Vertical Accuracy (90%)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>DTED-1</strong></td>
<td>90m x 90m</td>
<td>&lt; 50 m</td>
<td>&lt; 20 m</td>
</tr>
<tr>
<td><strong>DTED-2</strong></td>
<td>30m x 30m</td>
<td>&lt; 23 m</td>
<td></td>
</tr>
<tr>
<td><strong>HRTI-3</strong></td>
<td>12m x 12m</td>
<td>&lt; 10 m</td>
<td>&lt; 2 m (15m, slope &gt; 20%)</td>
</tr>
<tr>
<td><strong>HRTI-4</strong></td>
<td>6m x 6m</td>
<td>&lt; 10 m</td>
<td>&lt; 0.8 m (1m, slope &gt; 20%)</td>
</tr>
</tbody>
</table>
TanDEM-X Data Acquisition Modes

<table>
<thead>
<tr>
<th>Pursuit Monostatic</th>
<th>Bistatic</th>
<th>Alternating Bistatic</th>
</tr>
</thead>
<tbody>
<tr>
<td>both satellites transmit and receive independently</td>
<td>one satellite transmits and both satellites receive simultaneously</td>
<td>transmitter alternates between PRF pulses</td>
</tr>
<tr>
<td>susceptible to temporal decorrelation and atmospheric disturbances</td>
<td>small along-track displacement required for Doppler spectra overlap</td>
<td>provides three inter-ferograms with two baselines in a single pass</td>
</tr>
<tr>
<td></td>
<td></td>
<td>enables precise phase synchronisation, calibration &amp; verification</td>
</tr>
</tbody>
</table>