Quality of the TanDEM-X DEM

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Tokyo Denki University, Japan
TerraSAR-X-add-on for Digital Elevation Measurements
Launched: 21-Jun-2010

- acquisition of a global DEM according to Level-3 standard
- generation of local DEMs with Level-4 like quality
- demonstration of innovative bistatic imaging techniques and applications
Standards for Digital Elevation Models

<table>
<thead>
<tr>
<th>Spatial Resolution</th>
<th>Absolute Vertical Accuracy (90%)</th>
<th>Relative Vertical Accuracy (point-to-point in 1° cell, 90%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DTED-1</td>
<td>90 m x 90 m</td>
<td>&lt; 30 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 20 m</td>
</tr>
<tr>
<td>DTED-2</td>
<td>30 m x 30 m</td>
<td>&lt; 18 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 12 m</td>
</tr>
<tr>
<td>TanDEM-X</td>
<td>12 m x 12 m</td>
<td>&lt; 10 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 2 m / 4 m *</td>
</tr>
<tr>
<td>Level-4</td>
<td>6 m x 6 m</td>
<td>&lt; 5 m</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&lt; 0.8 m</td>
</tr>
</tbody>
</table>

Definition of 90% point-to-point errors:

\[
\Delta h^{90\%} \approx 2.33 \cdot \sigma_h
\]

* slopes below/above 20%
Key Capabilities of TanDEM-X

- Close Formation Flight
- Synchronisation
- Calibration
- Precise Baseline Determination

- Highly accurate and powerful processing chains

3D baseline at mm accuracies
Helix Formation
Bi-static Operation - Synchronisation

- Bi-static operation of TSX and TDX requires synchronisation of independent oscillators
- Phase referencing by exchange of pulses via synchronization link
- Leap PRIs compensate drift of Echo Window
- *Sync Warning for mutual health check*
- *Picosecond accuracies achieved*
TanDEM-X Global DEM Acquisition Plan

**1st Global Coverage**
- Small baseline (~200 m)
- Height of Ambiguity ~ 50 m

**2nd Global Coverage**
- Increased baseline (~300 m)
- Height of Ambiguity ~ 35 m

Combination:
- Dual Baseline Phase Unwrapping
- Improved relative height accuracy

**3rd Year**
- Antarctica
- Difficult terrain to account for shadow & layover
  → Different viewing geometry
- Deserts

**4th Year & Beyond**
- TanDEM-X Science Phase
- Local High-Resolution DEMs
- Global DEM improvement &
- Complementary products

Timeline:
- 2010: Comm. Phase
- 2011: 1st Global Coverage
- 2012: 2nd Global Coverage
- 2013: Difficult Terrain & Antarctica & Gap Filling
- 2014: Science Phase
Acquisition Sequence - Relative Height Error

First Coverage

(Acquisition started: Dec 12, 2010)
1 data take cut into scenes of ~50km x 30km = 1 RawDEM + 2 complex images (= 1 CoSSC)

Operational processing:
Integrated TanDEM-X Processor (ITP)
Radargrammetry to Resolve Phase Ambiguity Band

→ requires delay calibration of the system to mm accuracies

- parallactic angles → time delays in SAR = phases in InSAR
- $t_{\text{sl}} / 2$, $t_{\text{ma}} / 2$
- especially important in regions > 60 deg latitude where no SRTM is available
- becoming globally independent of SRTM as reference DEM for phase unwrapping
Calibration of the Interferometric System

• Baseline calibration to mm accuracy achieved

• Accurate calibration of differential delays and correction of relativistic effects enables use of radargrammetry for resolving ambiguities
  → works for 99% of all RawDEMs

• Global phase constant adjusted to minimize offset w.r.t. ICESat corrected SRTM

• Correction of differential tropospheric path delay
  → 90% of all data within ±10 m (w.r.t. to SRTM + ICESat)
Absolute Height Error of Scene-Based RawDEMs

![Graph showing absolute height error for two coverage areas]

- First Coverage
- Second Coverage

**Argument of Latitude / deg**

- Abs. Height Error – SRTM/ICESat / m
Final DEM Adjustment using ICESat Altimeter Data

- Filtering of ICESat points (flat areas, no or low vegetation)
- Selected set of ca. 100 ICESat points per geocell are used for absolute calibration
- Remaining majority of points (> 15 Mio.) are used for validation

Errors Corrected:
- Offsets
- Gradient in azimuth
- Tilt in range
DEM Product Layer Overview
96.4% of Final DEMs Achieve Relative Height Accuracy Specification
Absolute Height Accuracy

90% Accuracy: Tile Pot.

- Less than 2 m: 68.38%
- Less than 5 m: 21.0%
- Less than 8 m: 4.63%
- Less than 10 m: 0.81%
- Greater than 10 m: 1.14%
- Not Applicable: 4.04%

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<tr>
<th>Parameter</th>
<th>Statistic</th>
</tr>
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<tbody>
<tr>
<td>Number of Available DEM Tiles</td>
<td>18,630</td>
</tr>
<tr>
<td>Accumulated Number of Validation Points</td>
<td>15,021,838</td>
</tr>
<tr>
<td>Mean Height Deviation of Validation Points</td>
<td>-0.3086 m</td>
</tr>
<tr>
<td>Linear Error for Absolute Height Accuracy of 10 m</td>
<td>99.48%</td>
</tr>
<tr>
<td>Accumulated Absolute Height Accuracy with 90% LE</td>
<td>3.23 m</td>
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Penetration Depth - Greenland Ice Sheet

Penetration Depth

Difference: TDX DEM - ICESat

<table>
<thead>
<tr>
<th>Facies</th>
<th>Penetration depth</th>
<th>TDX DEM - ICESat</th>
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<tbody>
<tr>
<td></td>
<td>Mean [m]</td>
<td>Std. Dev. [m]</td>
</tr>
<tr>
<td>Dry snow</td>
<td>7.7</td>
<td>1.0</td>
</tr>
<tr>
<td>Percolation</td>
<td>5.8</td>
<td>0.8</td>
</tr>
<tr>
<td>Wet snow</td>
<td>4.2</td>
<td>0.8</td>
</tr>
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### Absolute Height Accuracy

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Accumulated Absolute Height Accuracy (without Greenland & Antarctica): **1.13 m**
Data Coverage: Comparison with SRTM Rev. 1.0

Percent Invalid per Tile

SRTM: 3.9%  TanDEM-X: 0%

N29W003: Algeria

Percent Invalid per Tile

SRTM: 21%  TanDEM-X: 0.06%

N20E051: Saudi Arabia
Data Coverage: Comparison with SRTM Rev. 1.0

TanDEM-X Data Set shows significantly less voids
Data Coverage TanDEM-X (Analysis ongoing)

15,292 Tiles have been analyzed covering approx 83% of Earth's land mass
The TanDEM-X DEM has a 99.89% global data coverage
From Coherence to Forest/Non-Forest

Deforestation in Amazon rainforest, Brazil [10°S, 67°W]

Coherence map

Forest map
TerraSAR-X/TanDEM-X Mission Status

- Stable operations since 2007, in close formation since Oct-2010
- Outstanding calibration of the interferometric system
- Global TanDEM-X DEM just completed
- Data well within specifications
- Absolute height error one order of magnitude better than requirement
- AO for global DEM issued: https://tandemx-science.dlr.de/
- Both satellites fully functioning, fuel resources for several additional years
Questions?