Evaluation and Comparison of Global DSMs

JACIE Workshop 2018

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Objective

• Internal, Maxar wide, need to understand:
  • Which DEM to use.
  • Accuracy of different DSMs.
  • Applicability of different DSMs.

• Several versions of SRTM available.

• Latest DSMs:
  • TFRM v4
  • GDEM v3
  • TanDEM-x
DSMs, Release Dates, and Sources

• SRTM
  • SRTMGL1 (~2006) – USGS
  • NASADEM (2018) – JPL/Caltech
  • TFRMv4 (2018) – NGA
    • TERRain Adjusted For ORthoMosaics (TERRAFORM)
    • Includes more than SRTM.
  • DG_SRTM - void filled from SRTMGL1, limited DG editing < 1%.

• AW3D30 v2.1 (4/2018) - ALOS PRISM, JAXA
  • Additional void fill and partial in-swath variation correction relative to v1.1 (2017).

• GDEMv2 (2011) - ASTER, METI/NASA
  • Improved GDEMv3 available late 2018.

• ArcticDEM release 6 (2017) - WorldView, NGA-NSF-UMN PGC
  • Reprojected from Polar Stereographic and averaged from 5 m.
  • Converted to MSL using EGM2008.

• Reference Elevation Model of Antarctica (REMA) - WorldView, NGA-NSF-UMN PGC
VRICON DSM Used as Reference

• VRICON DSM (2015-present) - Worldview
  • Not a global DSM yet.
  • Completely independent from other DSMs and their control.
  • Reprojected from UTM and averaged from 50 cm.
  • Converted to MSL using EGM2008.
ICESat GLAS Used as Reference

- Ice, Cloud, and land Elevation Satellite (ICESat)
- the Geoscience Laser Altimeter System (GLAS)
  - Laser pulses 40 times a second.
  - Illuminates a 70 meter spot.
  - 170 meter intervals along the orbit path.
- GLAS measurements used were selected land elevations ($d_{elev}$) without clouds/cloud contamination, and pass other validity tests.
  - $d_{elev}$ is the surface elevation after instrument corrections, atmospheric delays and tides have been applied.
  - 162m valid points were subset from the 427m land elevation measurements.
  - The selected points were nearest gridded at 10 arcsec, ~300m, a little coarser than the along track interval.
- GLAS $d_{elev}$ may be closer to the ground than elevations derived from optical or InSAR.
Source Data Currency

• DSM currency can be an issue in these areas:
  • Surface mines and other earth moving.
  • Man made structures: either new or demolished.
  • Land slides.
  • De/Re-forestation.
  • Ice/glaciers.

• DSM source dates:
  • VRICON - 2007 to present.
  • ArcticDEM -2010 to present.
  • GDEM - 2000 to 2011.
  • SRTM - 2/2000 (oldest).
  • TFRM - SRTM and other sources.
  • ICESat GLAS - 2003 to 2009.
  • REMA - 2010 to present.
Elevation Differences

• Different canopy and vegetation penetration of laser, radar, optical.

• Different methods:
  • Stereophotogrammetry
    • ALOS PRISM AW3D
    • ASTER GDEM
    • ArcticDEM
    • REMA
    • VRICON
  • InSAR
    • SRTM both C and X band.
    • TanDEM-X.
  • Laser-ranging
    • ICESat GDEM
DSMs for Different Applications

- TFRM is specifically optimized for orthorectification.
- Different processing and filtering may be required for different applications.
- Absolute accuracy may be more important than other factors for some applications.
- Drainage monotonicity is a requirement for hydrologic analysis.
  - DTM is required.
  - Non of these DSMs are acceptable.
- Terrain analysis:
  - Requires DTM.
  - Can be approximated with DSM.
½ Arcmin Interpolated ICESat GLAS
Absolute Accuracy

Compared to ICESat GLAS
SRTMGL1-GLAS, 10 Arcsecond Resolution
Statistic Sample Locations

- Greenland
- Antarctica
- Globe including >±60°
- North America >60°
- Europe/Asia >60°
- N60 to S60
- Central Russia
- Himalayas
- Midwestern US
- Amazon
- Northern Africa (arid)
- Central Africa (Congo)
- Eastern Europe

AW3D.tif, GDEMv2.tif, NASADEM.tif, TFRMv4.tif
Mean Elevation Difference by Region Relative to GLAS

- Antarctica
- Greenland
- Globe
- Amazon
- North Africa
- Central Africa
- N60° to S60°
- Central US
- Himalayas
- Northern Russia
- Eastern Europe
- Central Australia
- North America +60°
- Europe and Asia +60°

Meters Mean Error Relative to GLAS

ArcticDEM
AW3D
GDEMv2
NASADEM
TFRMv4
Elevation RMSE by Region Relative to GLAS (log scale)

Meters RMSE Relative to GLAS (log scale)

Antarctica  Greenland  Globe  Europe and Asia +60°  Himalayas  North America +60°  North Africa  Central Africa  N60° to S60°  Northern Russia  Amazon  Eastern Europe  Central US  Central Australia
Elevation RMSE by Region Relative to GLAS

- **ArcticDEM**
- **AW3D**
- **GDEMv2**
- **NASADEM**
- **TFRMv4**

Comparison of Global DSMs

- **Meters RMSE Relative to GLAS (log scale)**
- **Antarctica**
- **Greenland**
- **Globe**
- **Europe and Asia +60°**
- **Himalayas**
- **North America +60°**
- **North Africa**
- **Central Africa**
- **N60° to S60°**
- **Northern Russia**
- **Amazon**
- **Eastern Europe**
- **Central US**
- **Central Australia**

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Number of Samples

• Does number of samples significantly affect the statistics?

• Central Africa
  • Fewer GLAS observations as a result of:
    • Predominantly clouded area.
    • Widest orbit separation at the Equator.
  • The mean-error-graph may show an inconsistency.

<table>
<thead>
<tr>
<th>Minimum # of Samples</th>
<th>Region</th>
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<tbody>
<tr>
<td>5642</td>
<td>Central Africa</td>
</tr>
<tr>
<td>57076</td>
<td>Eastern Europe</td>
</tr>
<tr>
<td>62734</td>
<td>Amazon</td>
</tr>
<tr>
<td>107725</td>
<td>North Africa</td>
</tr>
<tr>
<td>110822</td>
<td>Central US</td>
</tr>
<tr>
<td>111245</td>
<td>Himalayas</td>
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<tr>
<td>137147</td>
<td>Northern Russia</td>
</tr>
<tr>
<td>227315</td>
<td>Central Australia</td>
</tr>
<tr>
<td>289705</td>
<td>Antarctica</td>
</tr>
<tr>
<td>675667</td>
<td>North America +60°</td>
</tr>
<tr>
<td>845519</td>
<td>Greenland</td>
</tr>
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<td>1243748</td>
<td>Europe and Asia +60°</td>
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<tr>
<td>8152502</td>
<td>N60° to S60°</td>
</tr>
<tr>
<td>13162730</td>
<td>Globe</td>
</tr>
</tbody>
</table>
DSM Artifacts
Comparison of Global DSMs

TFRM and AW3D30 Elevation Artifact 59° & 60° North

GLAS Delta

AW3D

DSM Data

GDEM Delta

<6m jump

59° North

60° North

AW3D-TFRM

<8m jump

59° North

60° North
Comparison of Global DSMs

One Degree Latitude Zones (65k to 107k samples per zone)
SRTMGL1 and DG_SRTM identical to TFRM <60°

- Mean Error by Latitude, Eastern Hemisphere

ArcticDEM
AW3D
GDEMv2
NASADEM
TFRMv4
Comparison of Global DSMs

One Degree Latitude Zones

SRTMGL1 and DG_SRTM identical to TFRM <60°
Comparison of Global DSMs

One Degree Latitude Zones (65k to 107k samples per zone)

SRTMGL1 and DG_SRTM identical to TFRM <60°
GDEM Elevation Variation, Northern Australia

- Red transect: Low frequency orbit track elevation oscillation, ~12 m amplitude, ~1053 arcsec frequency.
- Green transect: Track to track elevation variation, ~30m max.
- Blue rectangle: Subscene for next slide.
GDEM Elevation Variation, Northern Australia

Higher frequency orbit path elevation oscillation: 
~8 m amplitude 
~142 arcsec frequency 
Elevation transect for the red line below.
GDEM Shifted Latitude Band

GDEM-TFRM. or other DSM, shows a latitude band 2.5°N to 4°N with ~<20 m discontinuity.
• ~4m amplitude within swath variation.

• Elevation profile for the red line normal to the swath/orbit is shown below.

• AW3D30 version 2.1 has corrected Northwestern Eurasia and parts of Africa for this artifact. JAXA continues to work on other areas for future releases.
NASADEM Swath Striping, Northwest Africa

NASADEM - AW3D30
Shows SRTM path striping.

SRTMGL1 - AW3D30
Does not show SRTM path striping.

NASADEM - SRTMGL1
Shows SRTM path striping. Largest shift ~5m.
Comparison of Global DSMs

<table>
<thead>
<tr>
<th>Dataset Combination</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>NASADEM - AW3D30</td>
<td>Shows SRTM swath striping.</td>
</tr>
<tr>
<td>SRTMGL1 - AW3D30</td>
<td>Does not show SRTM swath striping.</td>
</tr>
<tr>
<td>NASADEM - SRTMGL1</td>
<td>Shows SRTM swath striping. Largest shift ~3m.</td>
</tr>
</tbody>
</table>
TFRM-NASADEM, Antenna Oscillation Correction
Low frequency orbit related patterns removed.
Low-frequency orbit related patterns removed. Some antenna oscillations remain.
Comparison of Global DSMs

- TFRM Fill from GDEM Shifted ~-30 m

All dark patches are areas filled with GDEM.

TFRM Elevations

<table>
<thead>
<tr>
<th>TFRM Elevations</th>
<th>ArcticDEM Elevations</th>
</tr>
</thead>
<tbody>
<tr>
<td>North America &gt;60°</td>
<td></td>
</tr>
<tr>
<td>North Asia &gt;60°</td>
<td></td>
</tr>
</tbody>
</table>
Comparison of Global DSMs

TFRM Geocell N27E085 Inconsistent

- TFRM - AW3D30
- TFRM - NASADEM
- TFRM - GLAS
Resolution
DEM Comparison

VRICON

AW3D30

GDEM

TFRM

NASADEM

SRTMGL1
AW3D30 Reduced from 5 m
VRICON Reduced from 50 cm
Mountainous Void Areas

N 29° 25’ E 96° 17’
Mountainous Void Areas

N 27° 50’ E 92° 36’
NASADEM No Void Fill
Conclusions

• GDEM
  • Largest absolute error.
  • Largest systematic errors.
  • Contains some holes >±60°.

• AW3D30
  • Second largest systematic errors: ~4m within swath variation.
  • Better resolution than SRTM or GDEM.
  • May be the best global DSM after removal of systematic errors.
  • Plan to use ArcticDEM >60° North.

• NASADEM
  • Best absolute accuracy <±60°.
  • Minimized voids with new InSAR processing.
  • Somewhat better SRTM void fill using adjusted GDEMV3.
  • Introduces <5m orbit to orbit inconsistencies.
  • Only partial correction of antenna oscillation.
  • Do not use n60*.hgt tiles. These tiles are inconsistent with those south of 60° North.

• TFRM
  • Only complete global coverage.
  • uniform global dataset.
  • Alaska and North of 60°, have some large errors <30m.

• ArcticDEM
  • Best quality, accuracy, and resolution for Greenland, Alaska, Kamchatka, and North of 60°.
  • Many holes remain.
  • SRTMGL1 and DG_SRTM are ~equivalent, somewhat poorer subsets of TFRM.
Recommendations

• Use TFRM:
  • Globally for orthorectification.
  • Particularly for moderate resolution products.
  • Use ArcticDEM where available in future TFRM versions.
  • Correct GDEM fill elevation offset.

• Use ArcticDEM:
  • Where available for small AOIs.
  • Avoid hole areas or delta surface fill with:
    • AW3D30 south of 82° where available?
    • GDEM/TFRM elsewhere.

• Use AW3D30:
  • Only south of +59° to -60°.
  • For small AOIs that can benefit from slightly higher resolution in more rugged terrain.

• Use NASADEM:
  • When absolute accuracy is most critical.
  • To replace existing SRTM, GDEM, and AW3D30 cloud/void fill in mountainous areas (Himalayas and Andes, minimum).
Future Work and Improvement

• Include GDEMv3 and TanDEM.
• Work at 5 arcsec resolution. ~150m resolution is closer to GLAS sampling.
• Eliminate GDALwarp average downsampling, source tile boundary issue. Some products have subtle grids.
• Eliminate subpixel shift. Subpixel shift has increased the RMSE, and appears as increased texture in rough topography areas.
• Attempt to identify source of contour-like patterns on AW3D30 difference images. Integer rounding or an elevation control adjustment?