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REVEALING INSIGHTS

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

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- 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

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- 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

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- 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.
  - AW3D30 - 1/2006 to 4/2011 (filled with SRTM).
  - GDEM - 2000 to 2011.
  - SRTM - 2/2000 (oldest).
  - TFRM - SRTM and other sources.
  - ICESat GLAS - 2003 to 2009.
  - REMA - 2010 to present

Elevation Differences

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- 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

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- 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.

ArcticDEM

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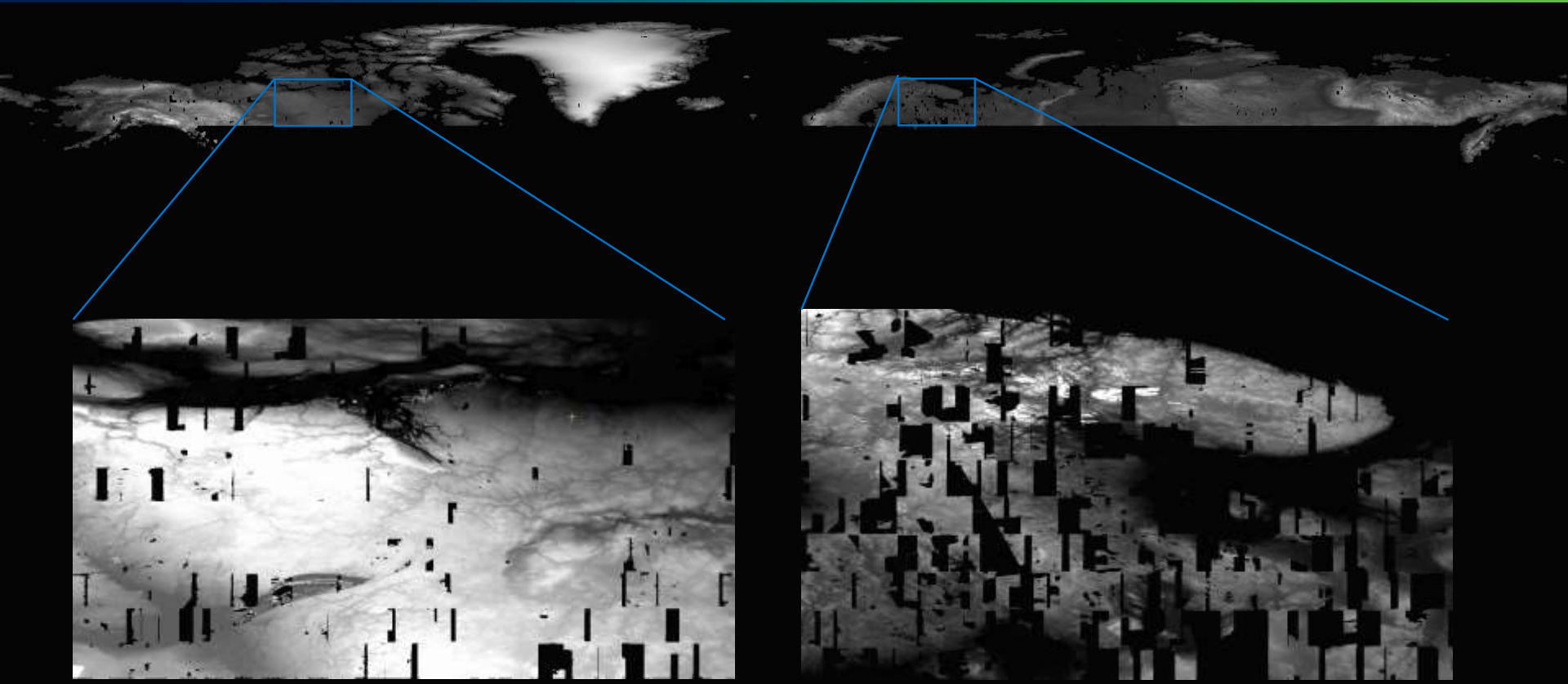
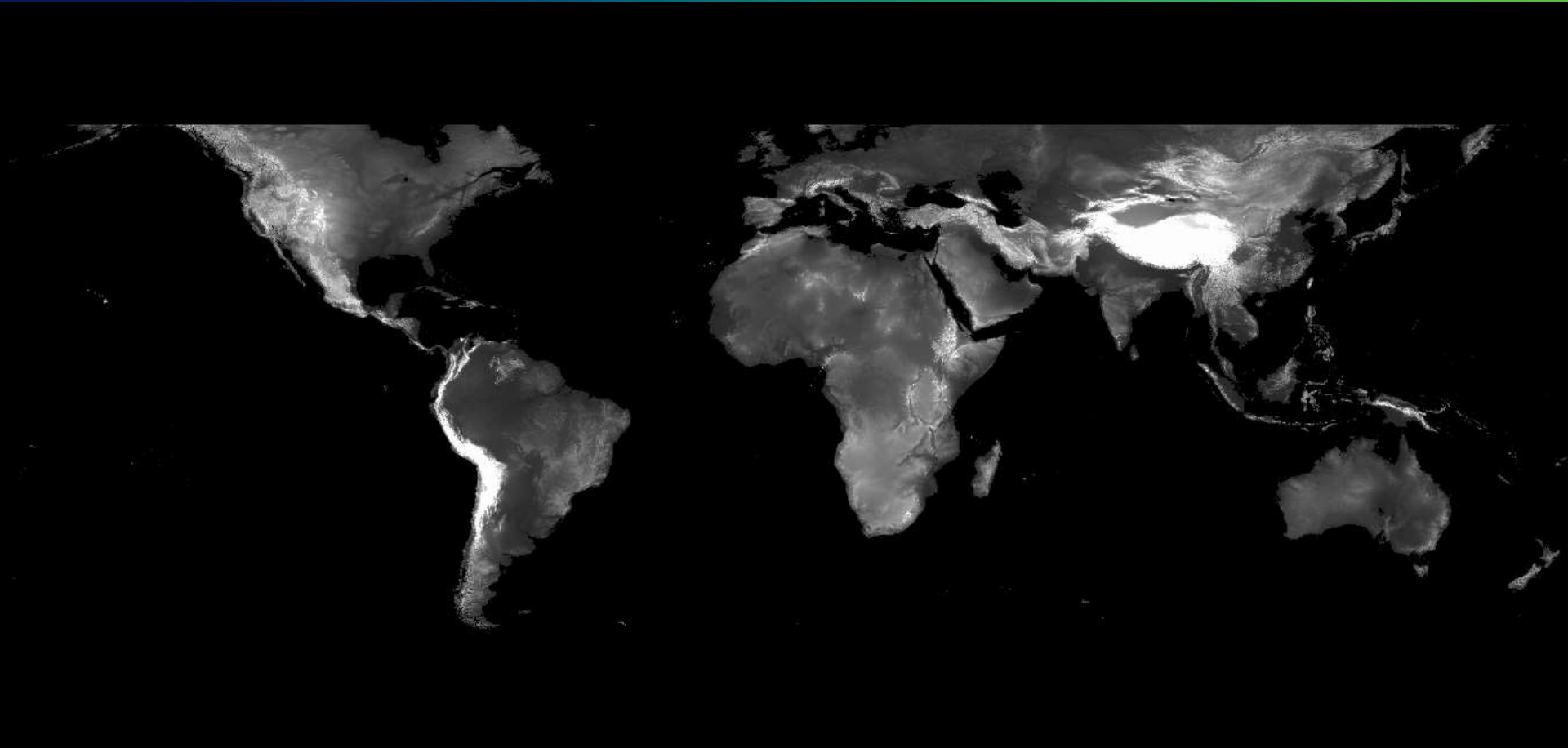
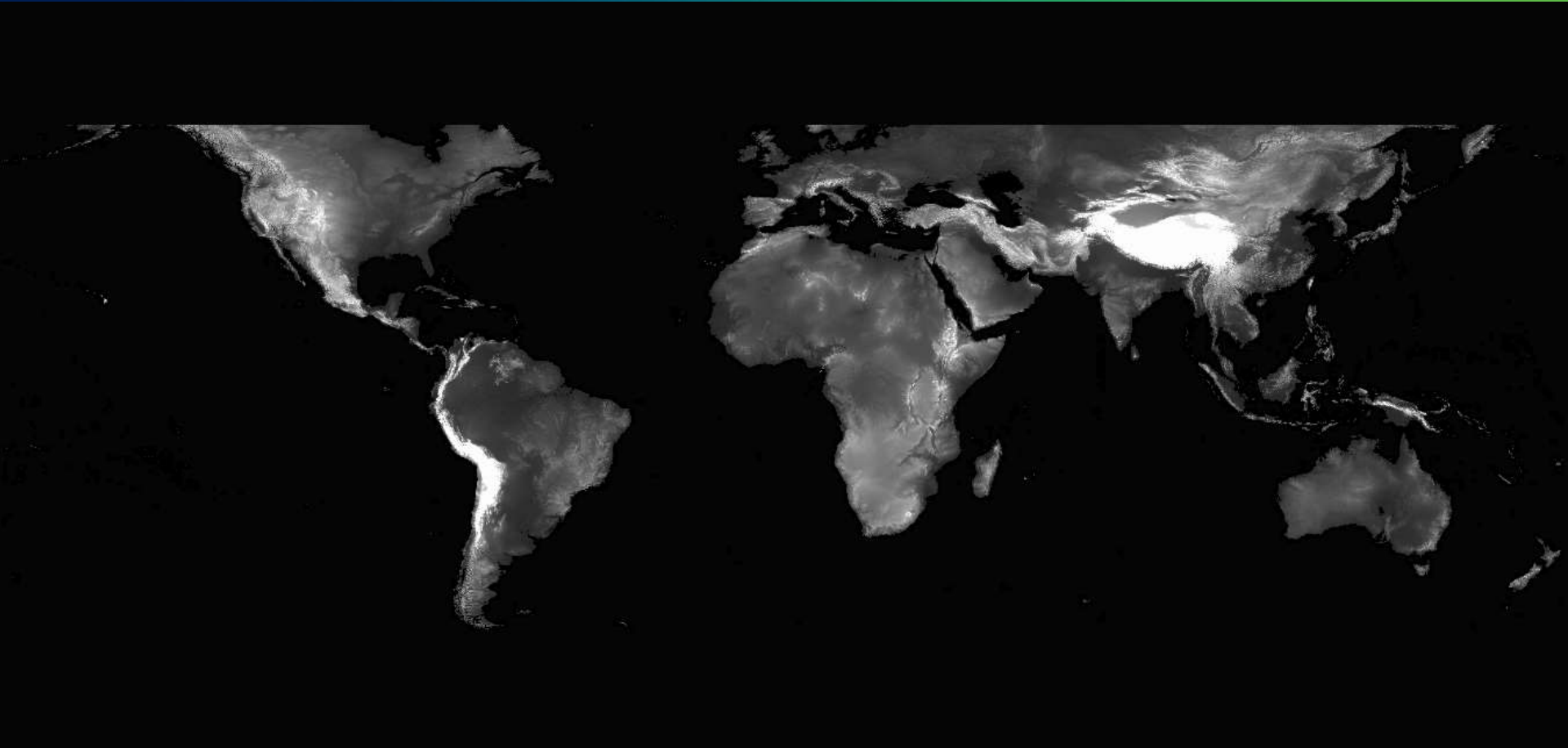


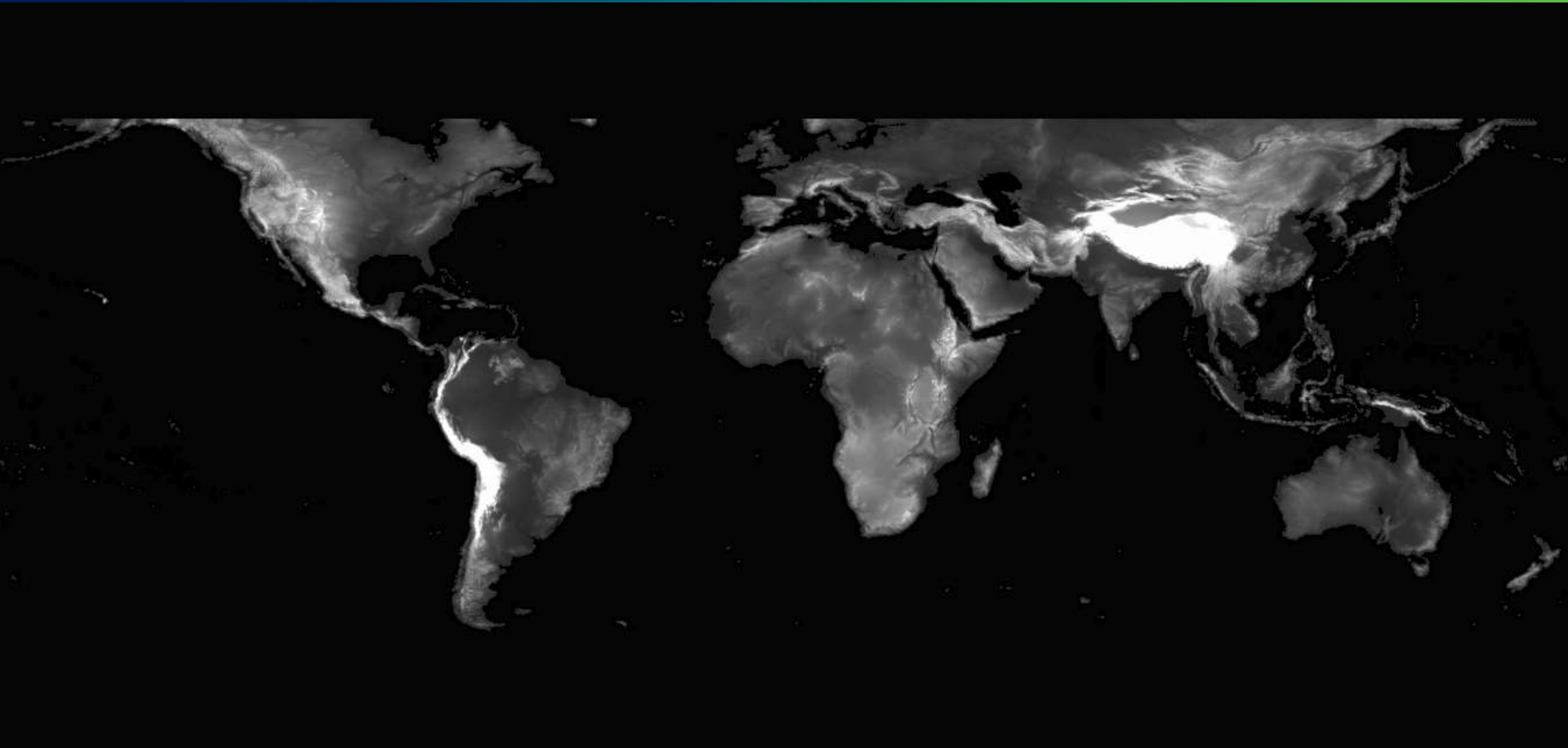
SRTMGL1



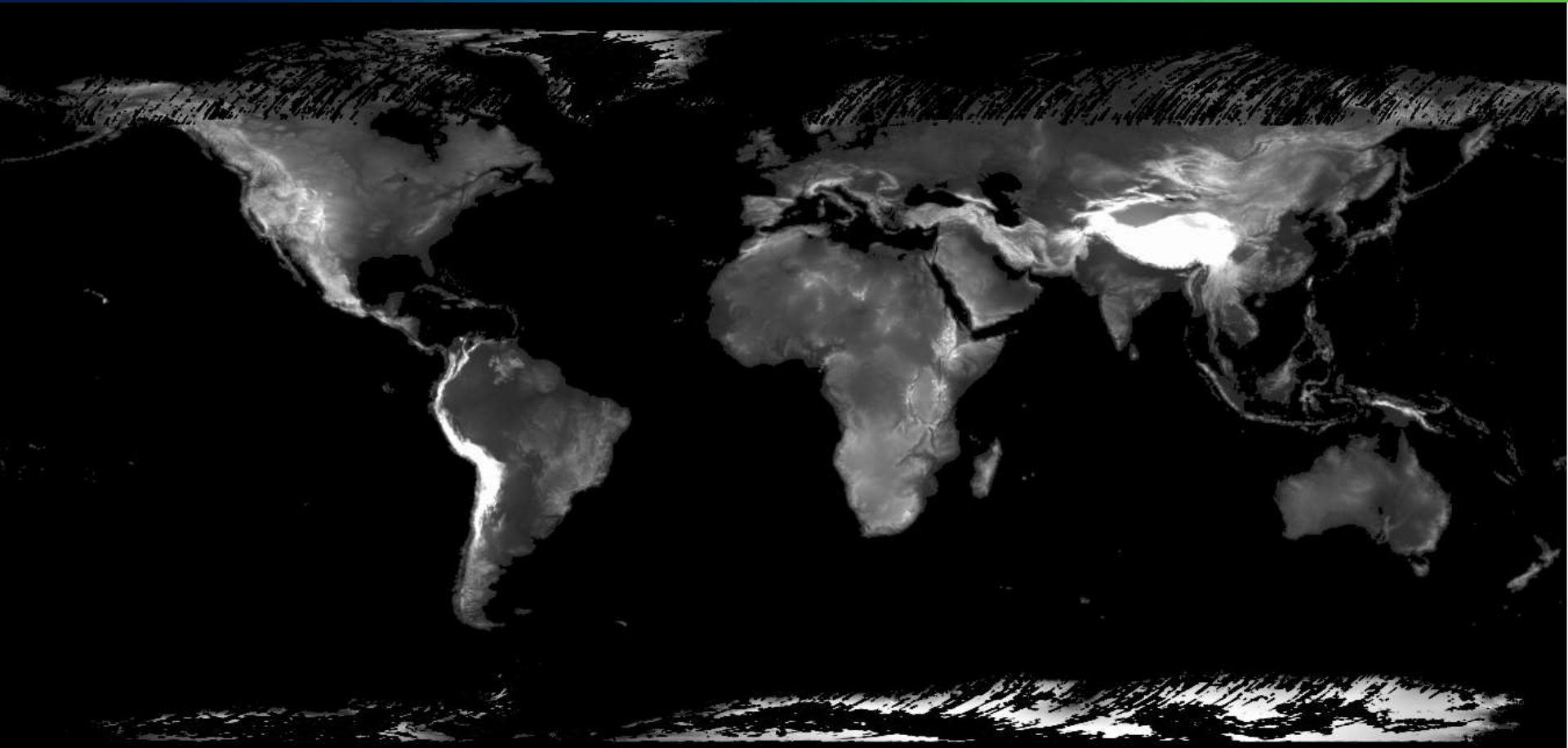
DG_SRTM



NASADEM



AW3D30



GDEM

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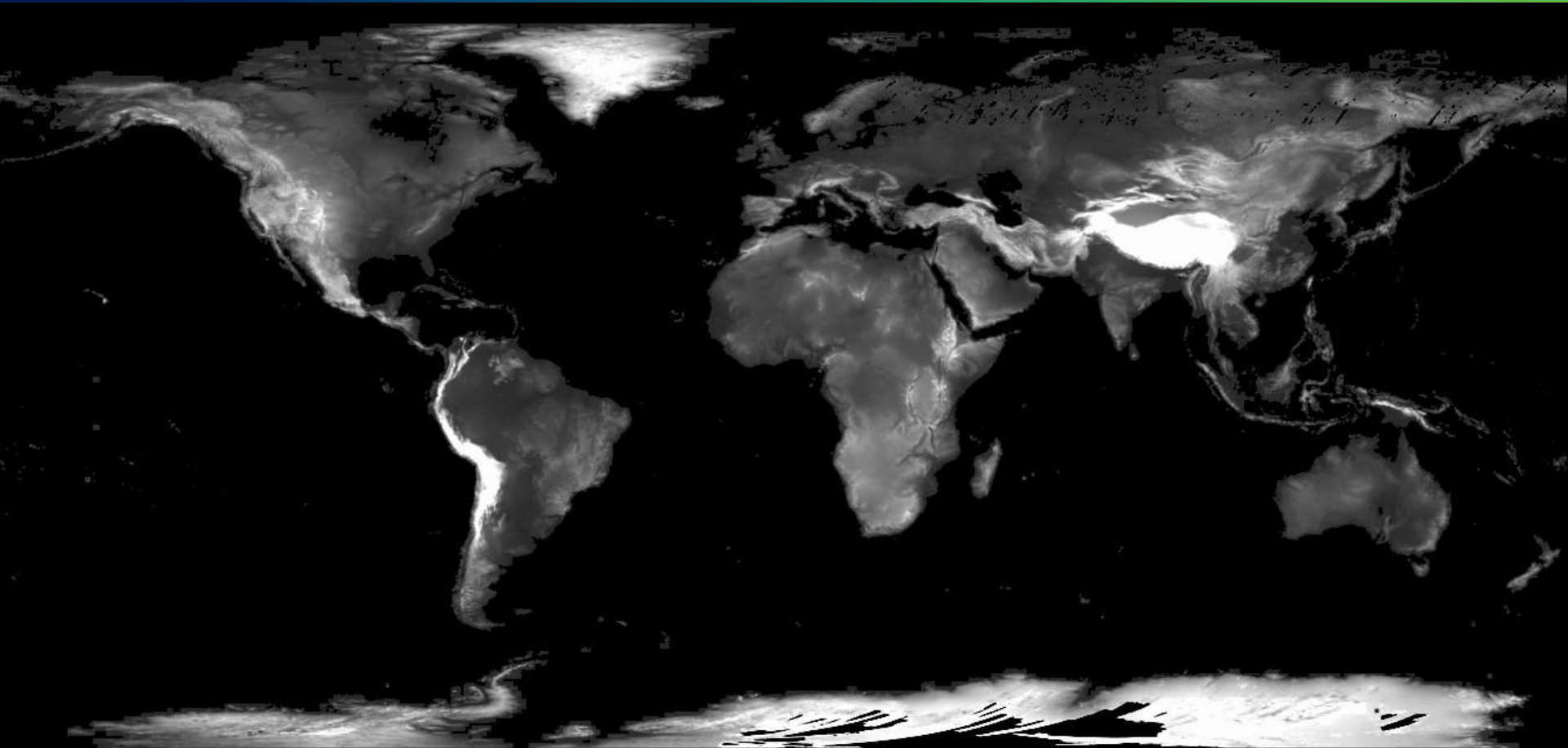

TFRM

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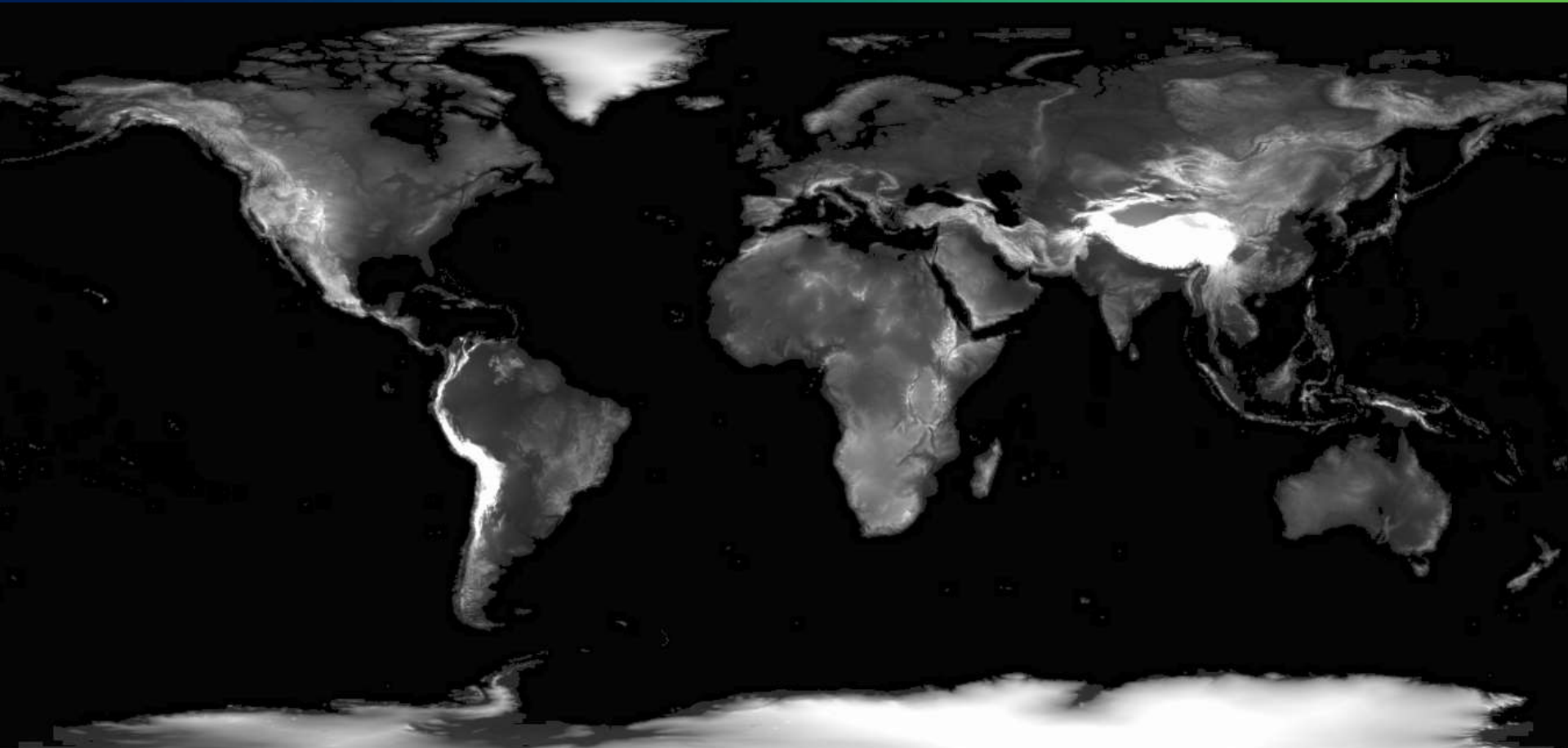

½ Arcmin Interpolated ICESat GLAS

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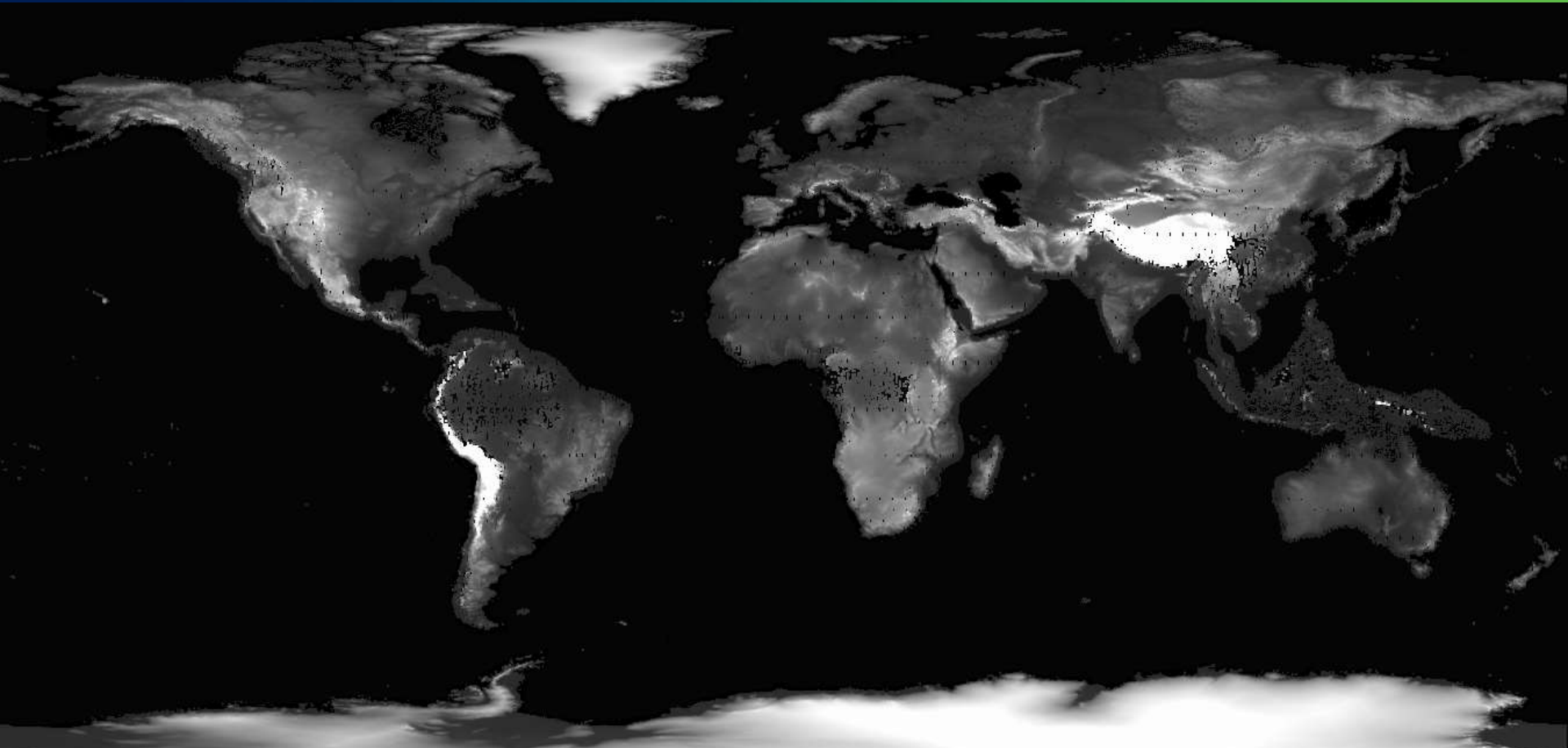
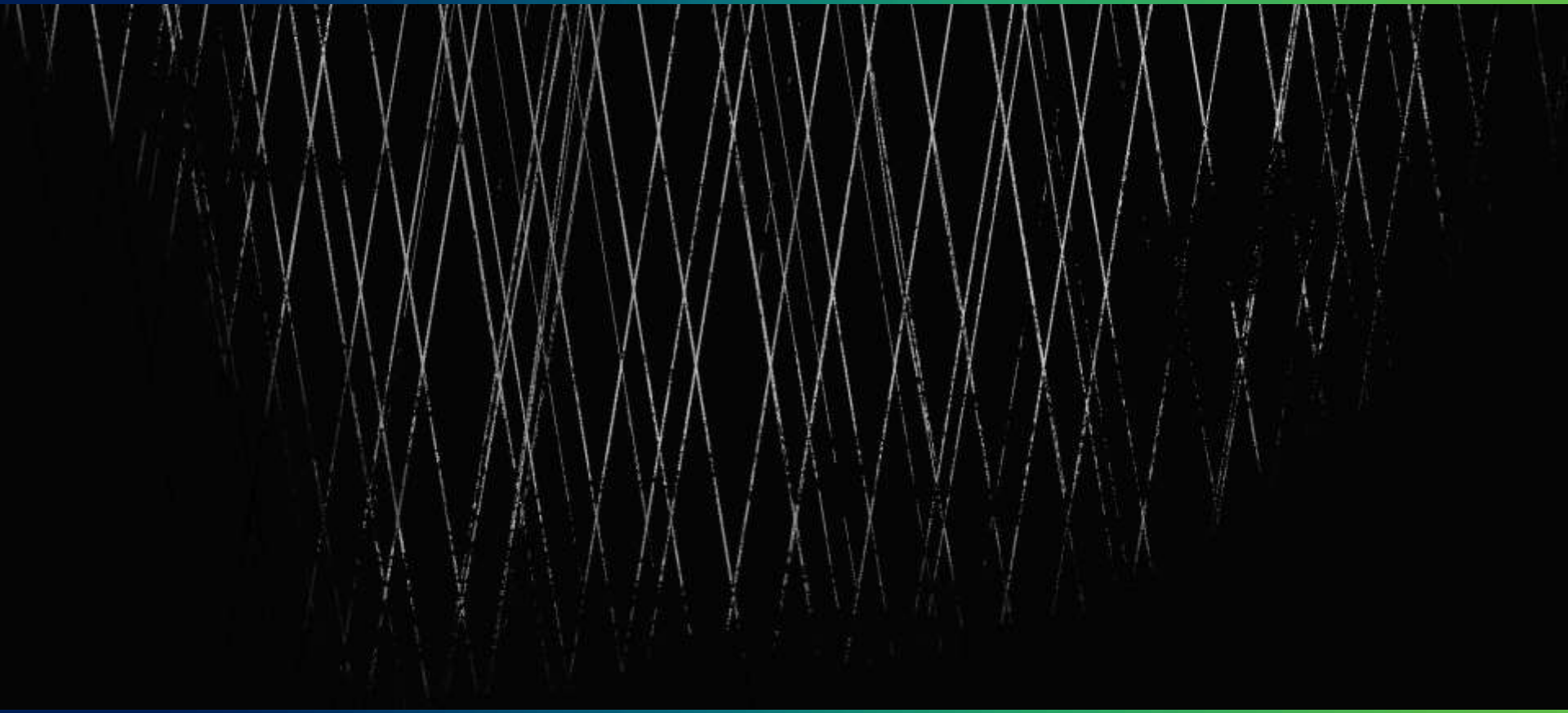


10 Arcsec Gridded ICESat GLAS, South Africa



Absolute Accuracy

Compared to ICESat GLAS

SRTMGL1-GLAS, 10 Arcsecond Resolution

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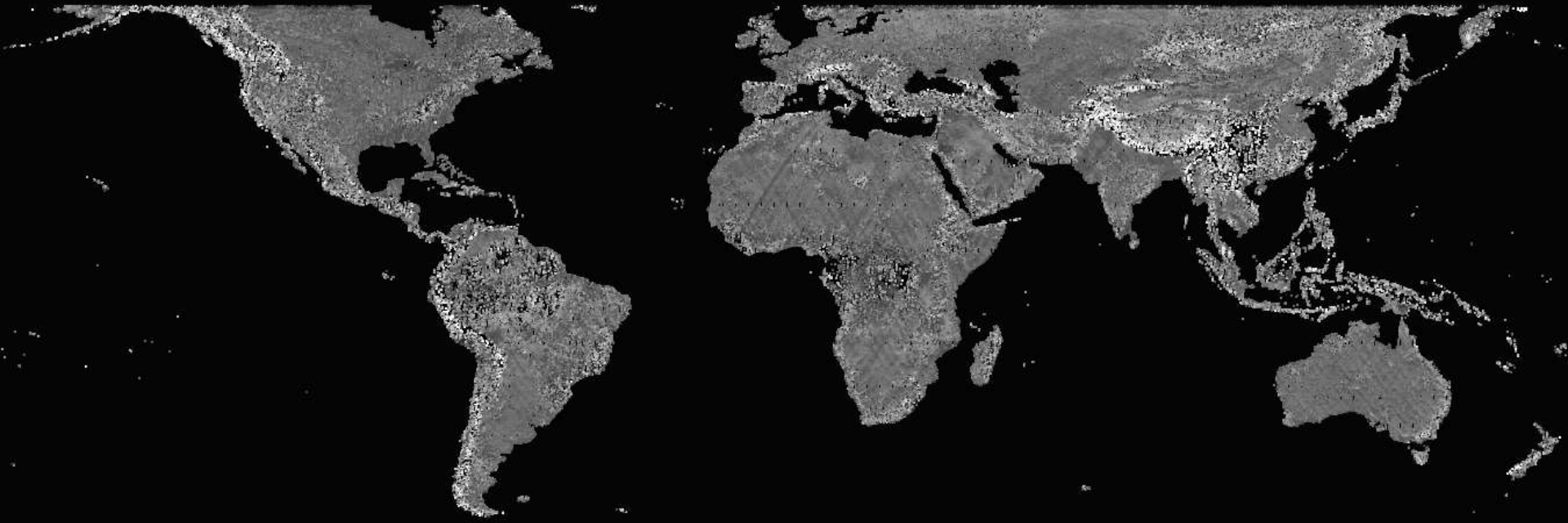
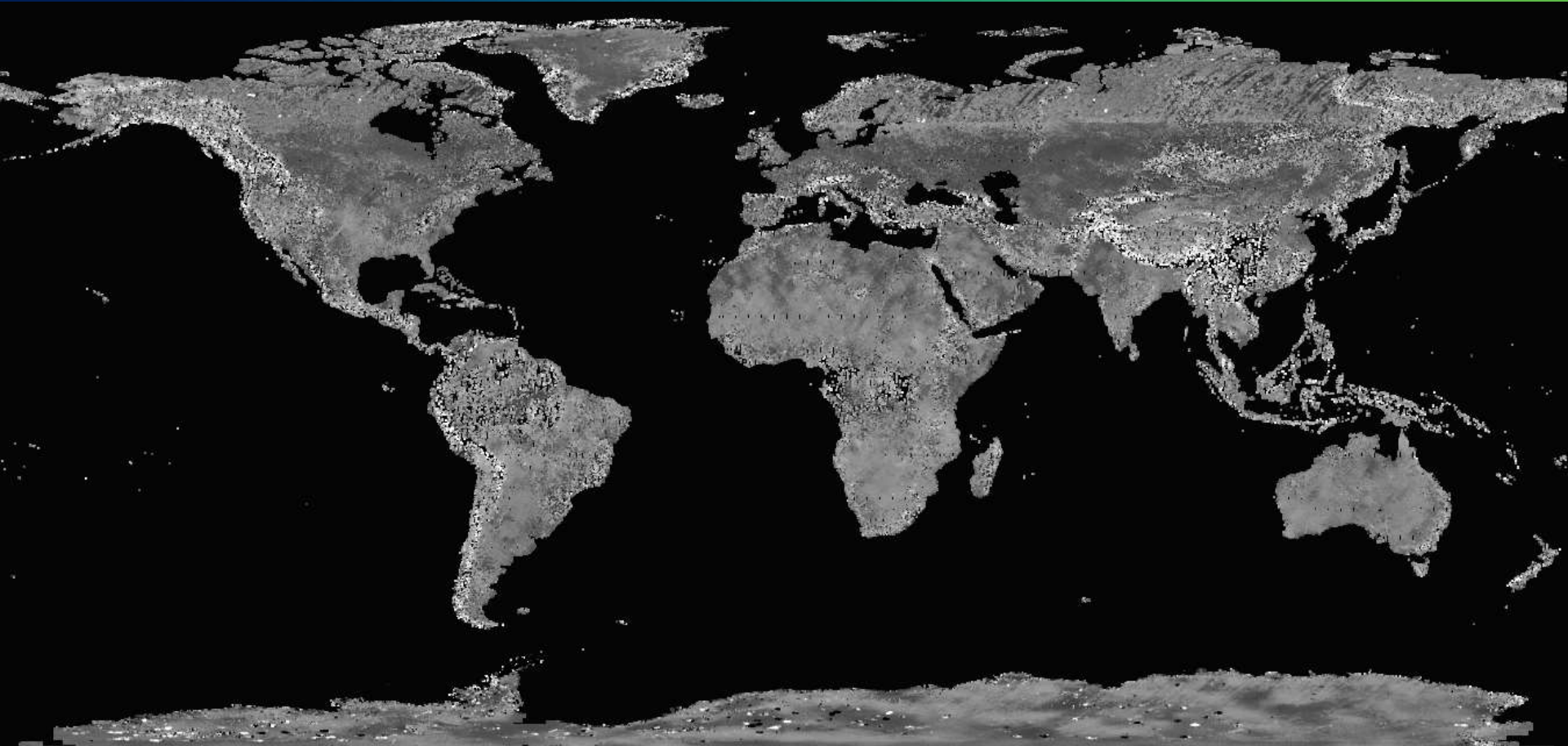
NASADEM-GLAS



TFRM-GLAS

radiant SOLUTIONS



AW3D30-GLAS

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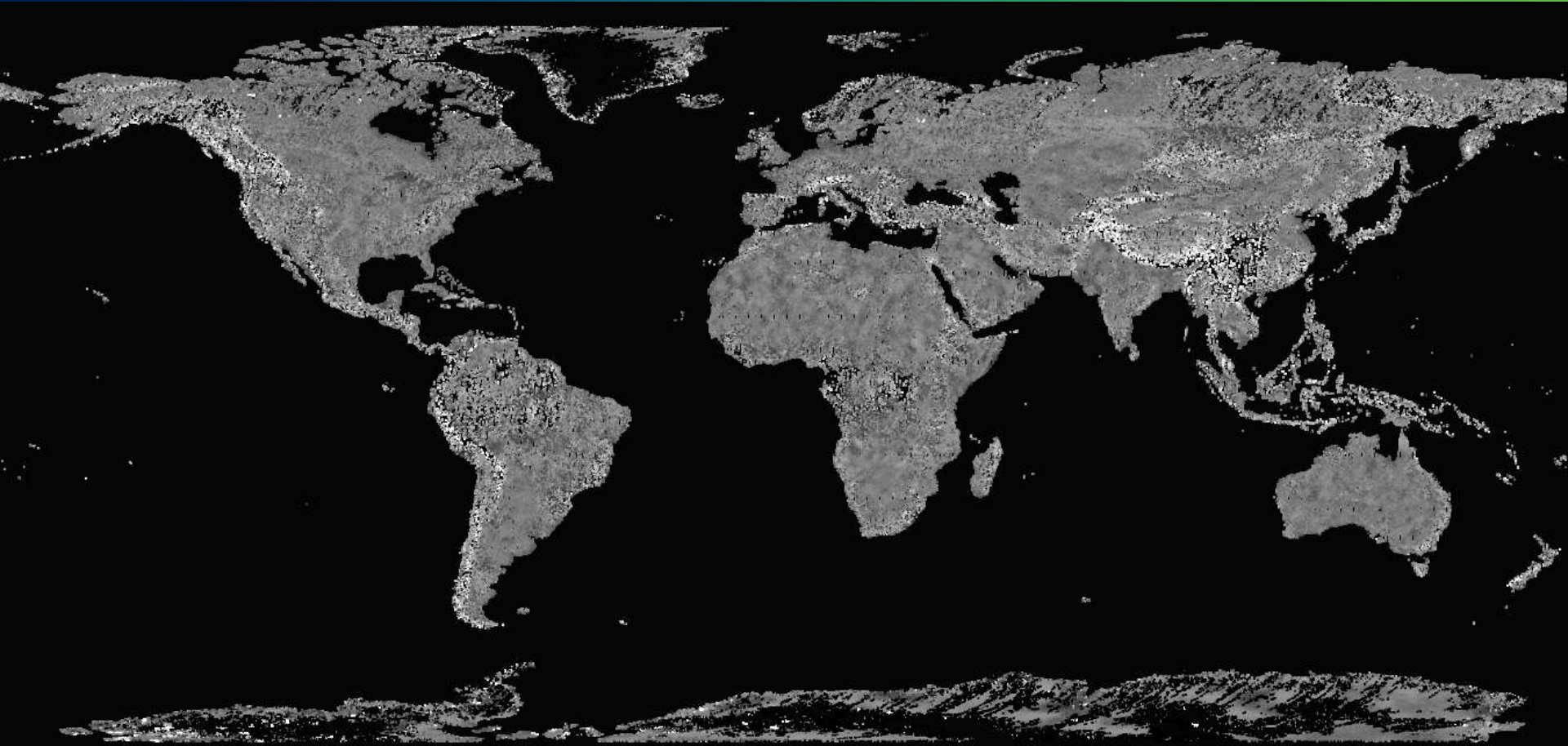
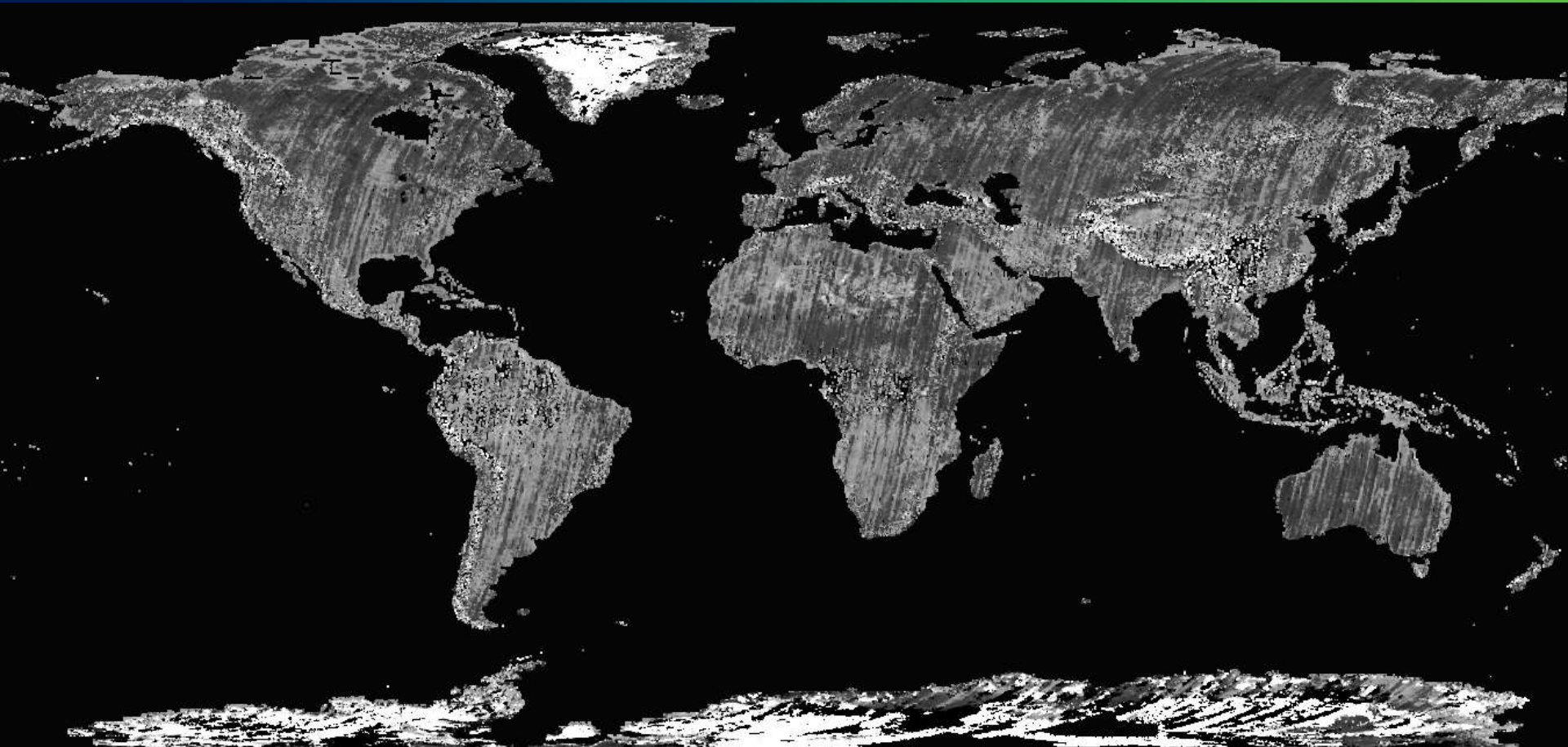


GDEM-GLAS

radiant SOLUTIONS



ArcticDEM-GLAS

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Statistic Sample Locations

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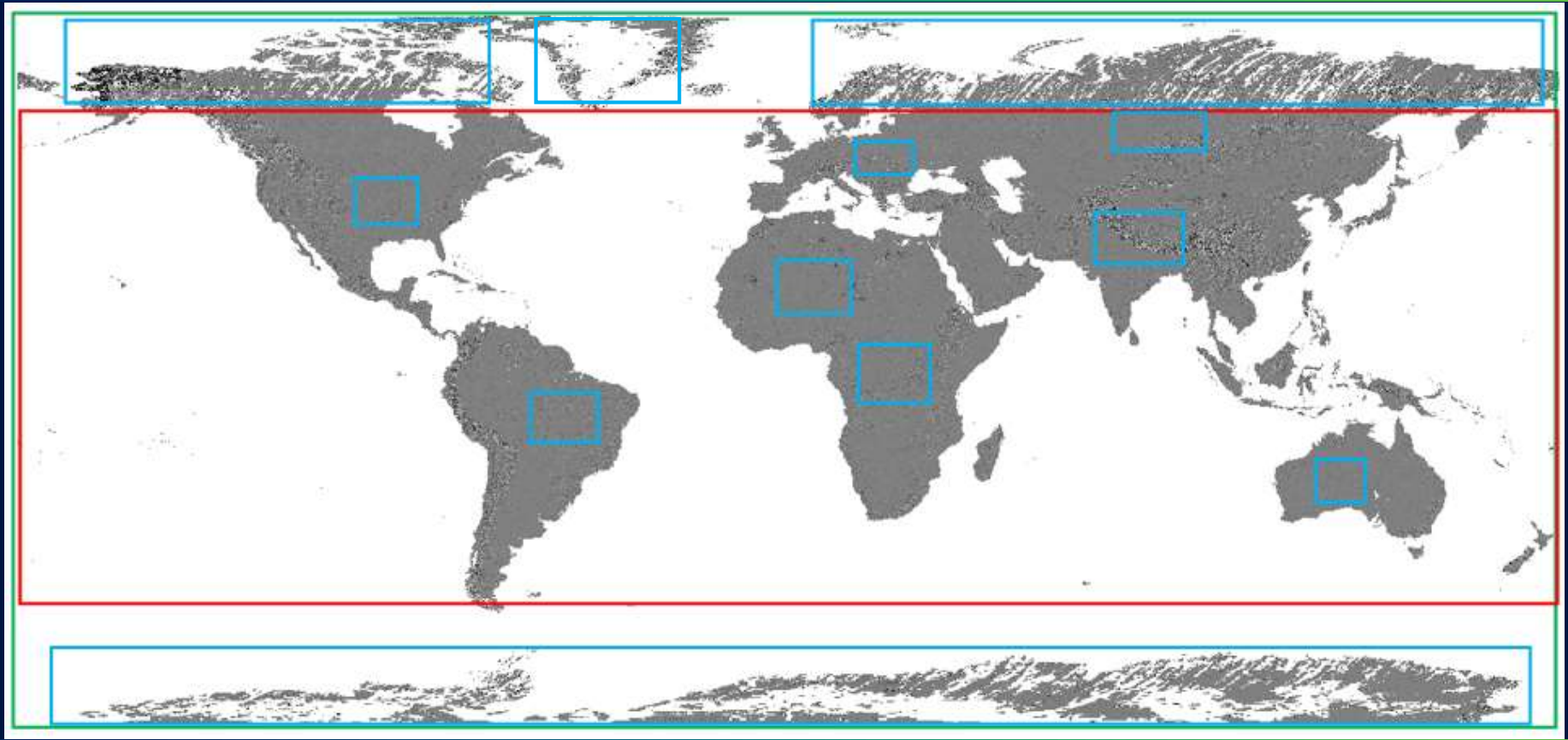
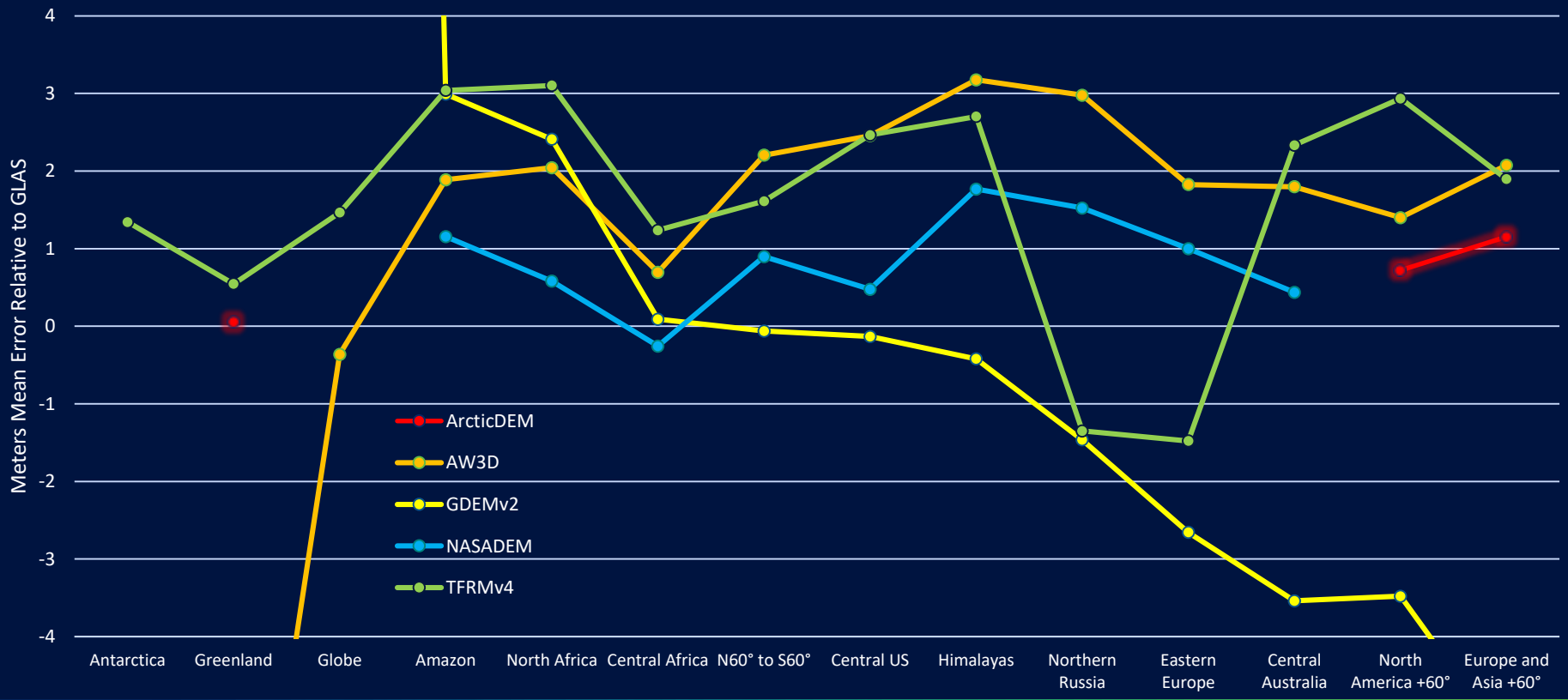
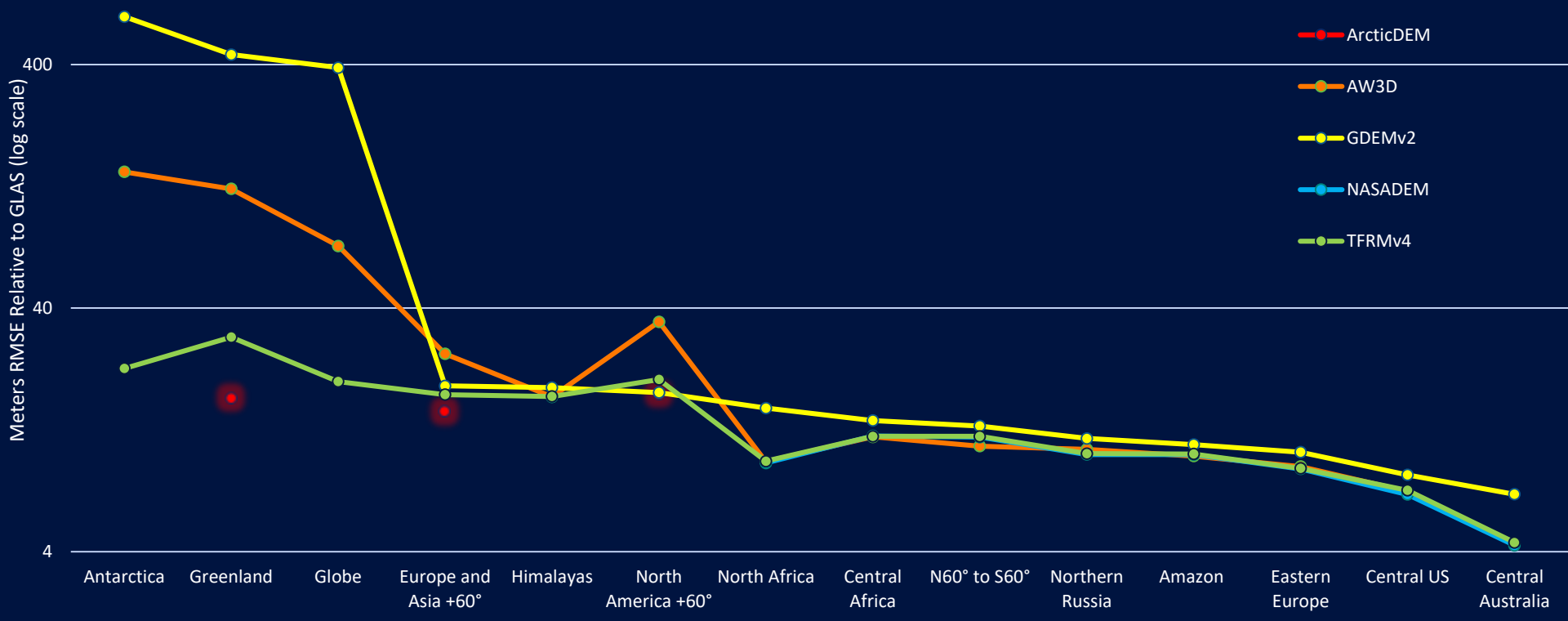


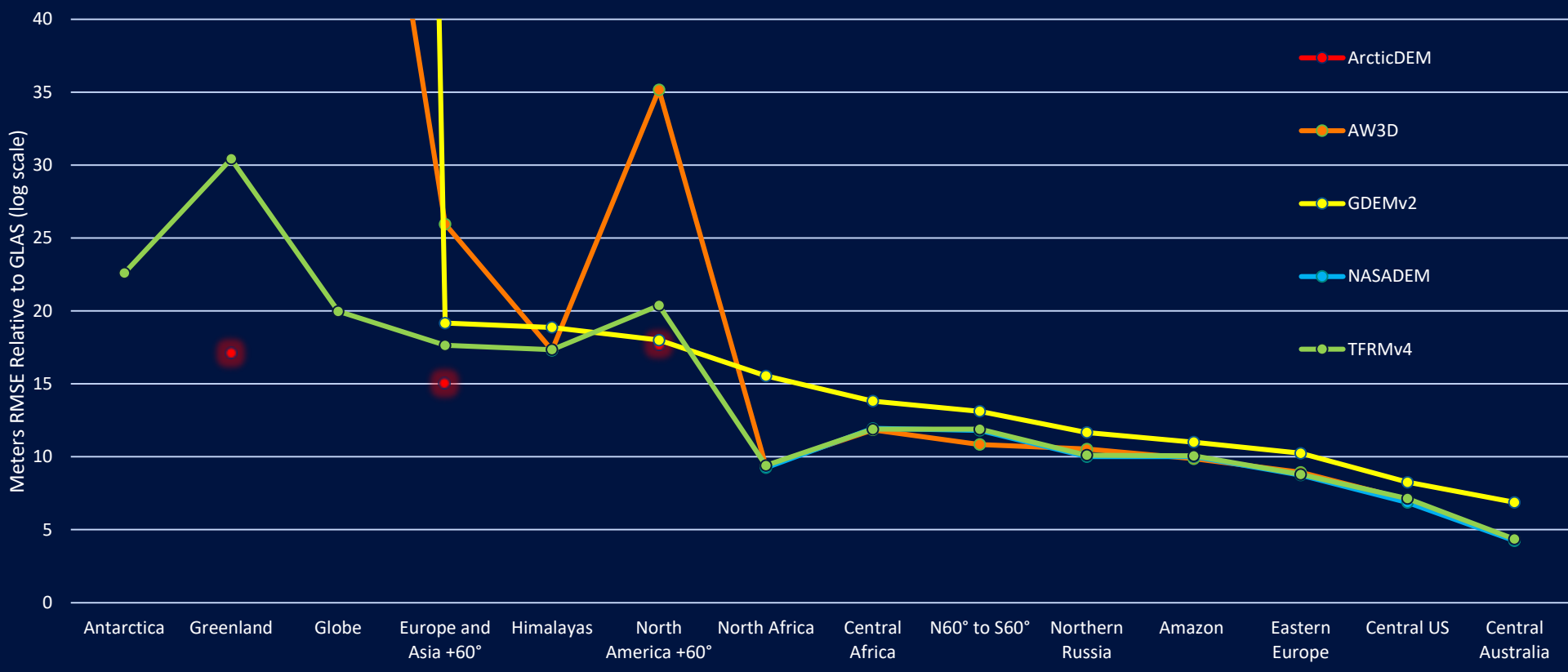
Mean Elevation Difference by Region Relative to GLAS



Elevation RMSE by Region Relative to GLAS (log scale)



Elevation RMSE by Region Relative to GLAS



Number of Samples

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- 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.

Minimum # of Samples	Region
5642	Central Africa
57076	Eastern Europe
62734	Amazon
107725	North Africa
110822	Central US
111245	Himalayas
137147	Northern Russia
227315	Central Australia
289705	Antarctica
675667	North America +60°
845519	Greenland
1243748	Europe and Asia +60°
8152502	N60° to S60°
13162730	Globe

DSM Artifacts

TFRM and AW3D30 Elevation Artifact 59° & 60° North

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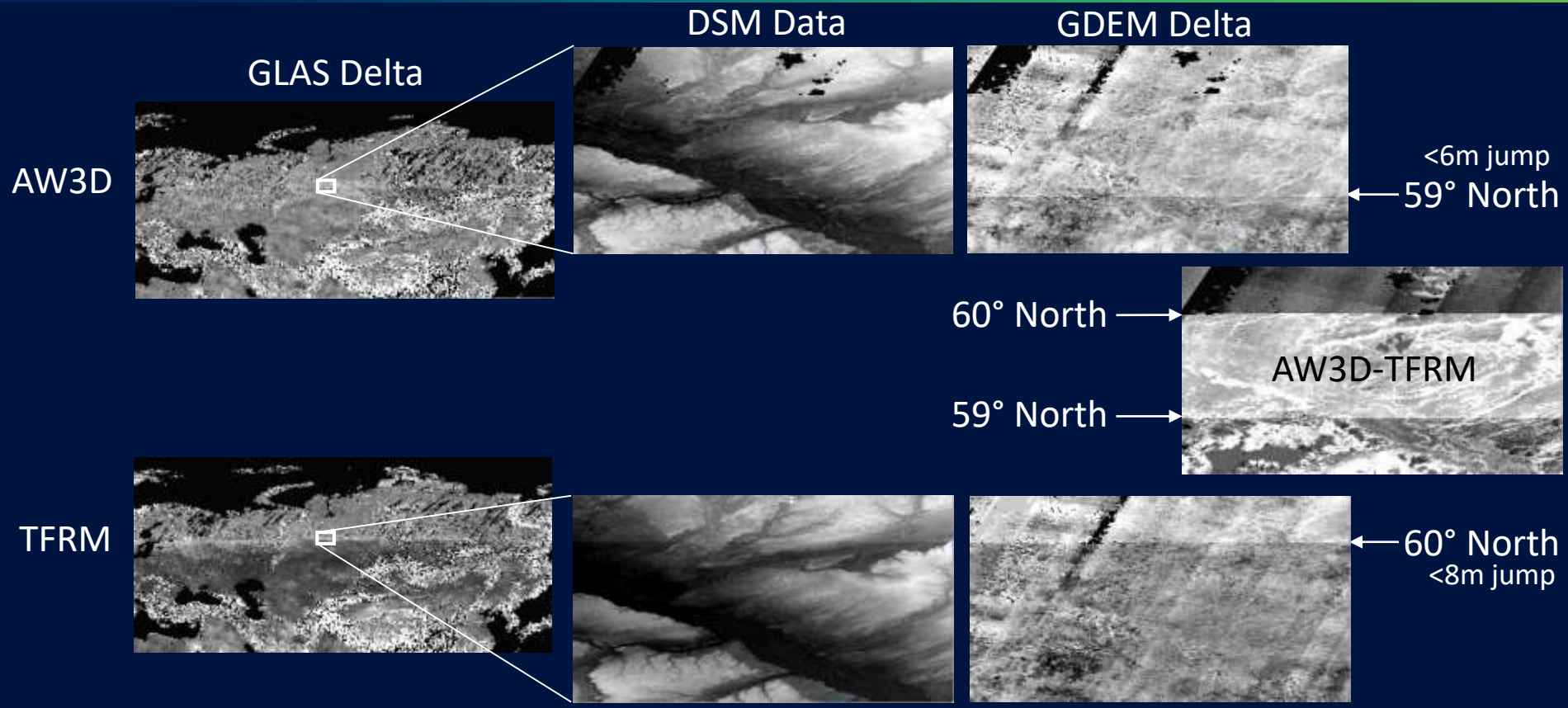
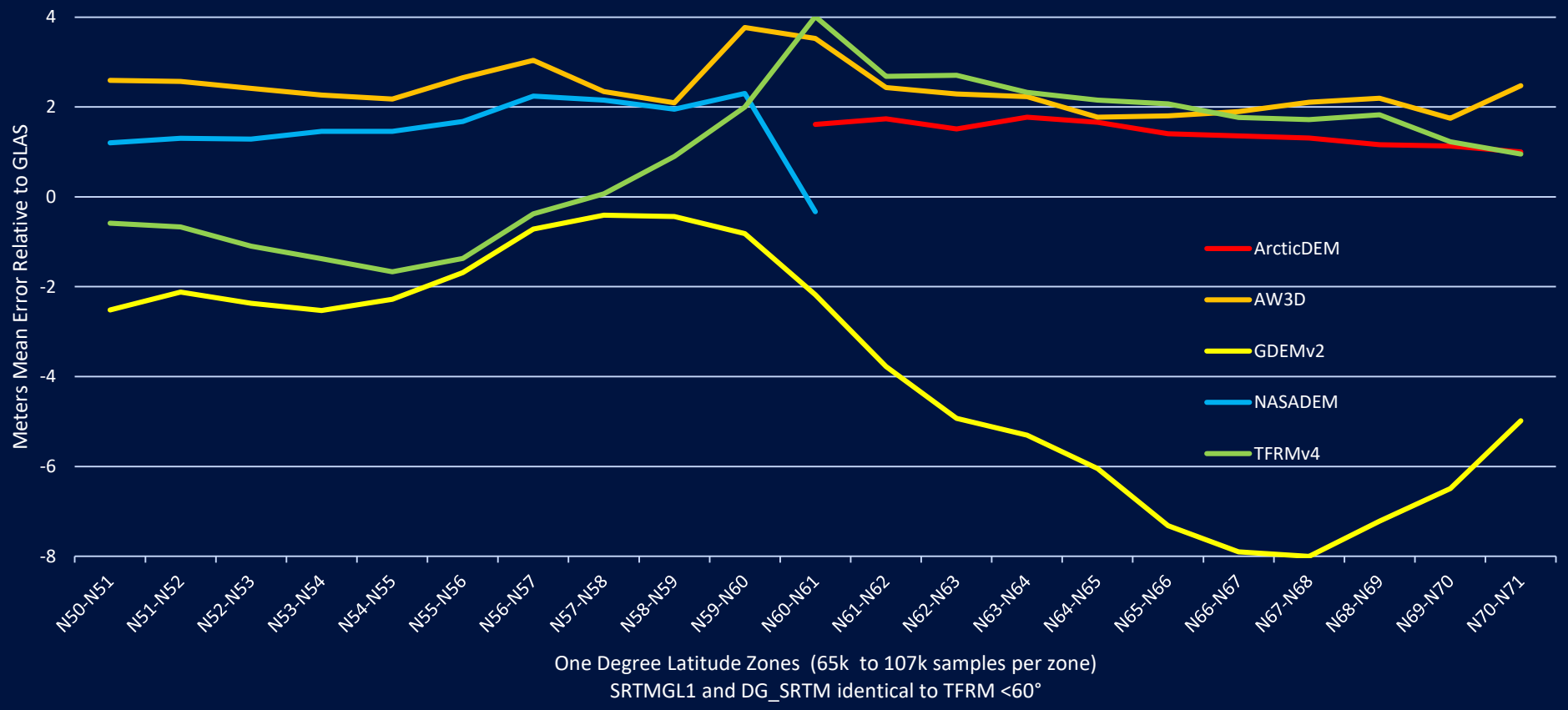


DSM Mean Error by Latitude, Eastern Hemisphere



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

DSM Mean Error by Latitude, Northern Russia

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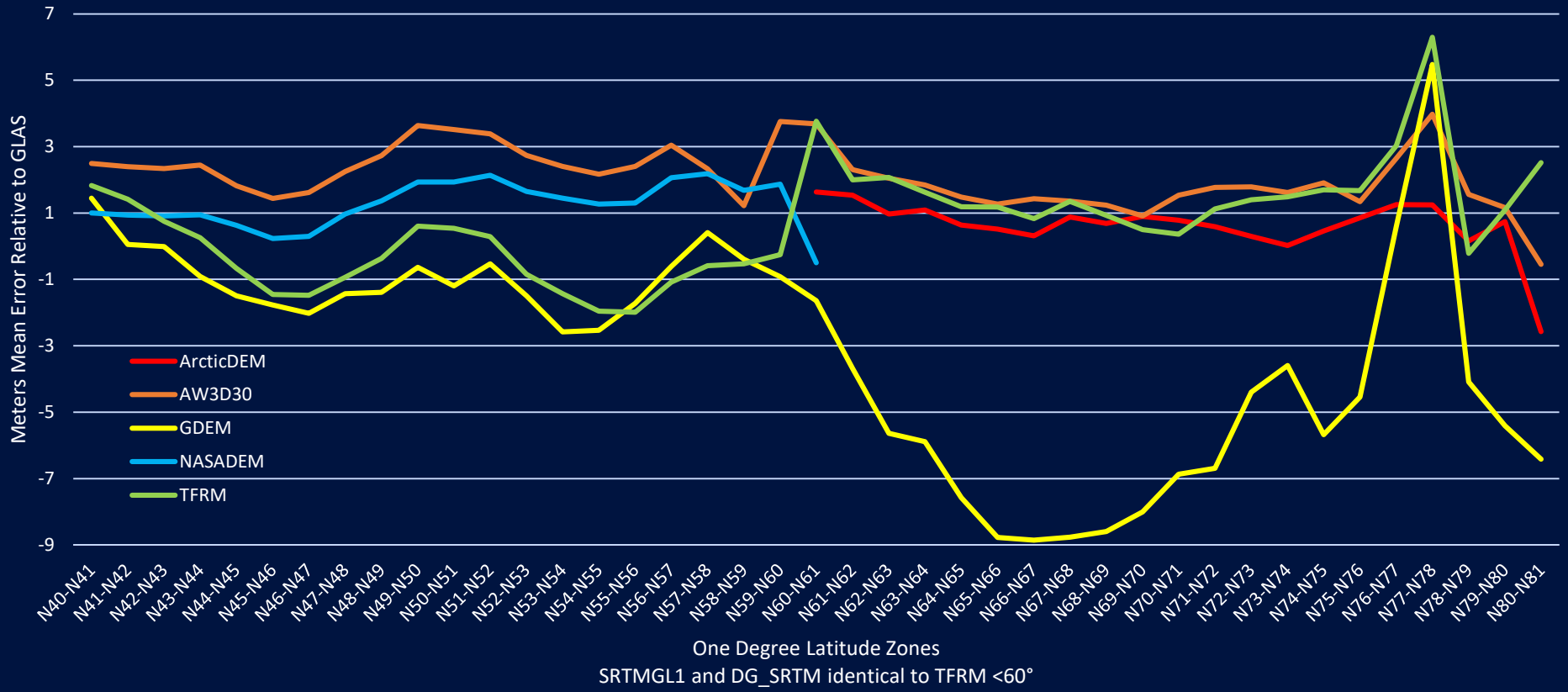
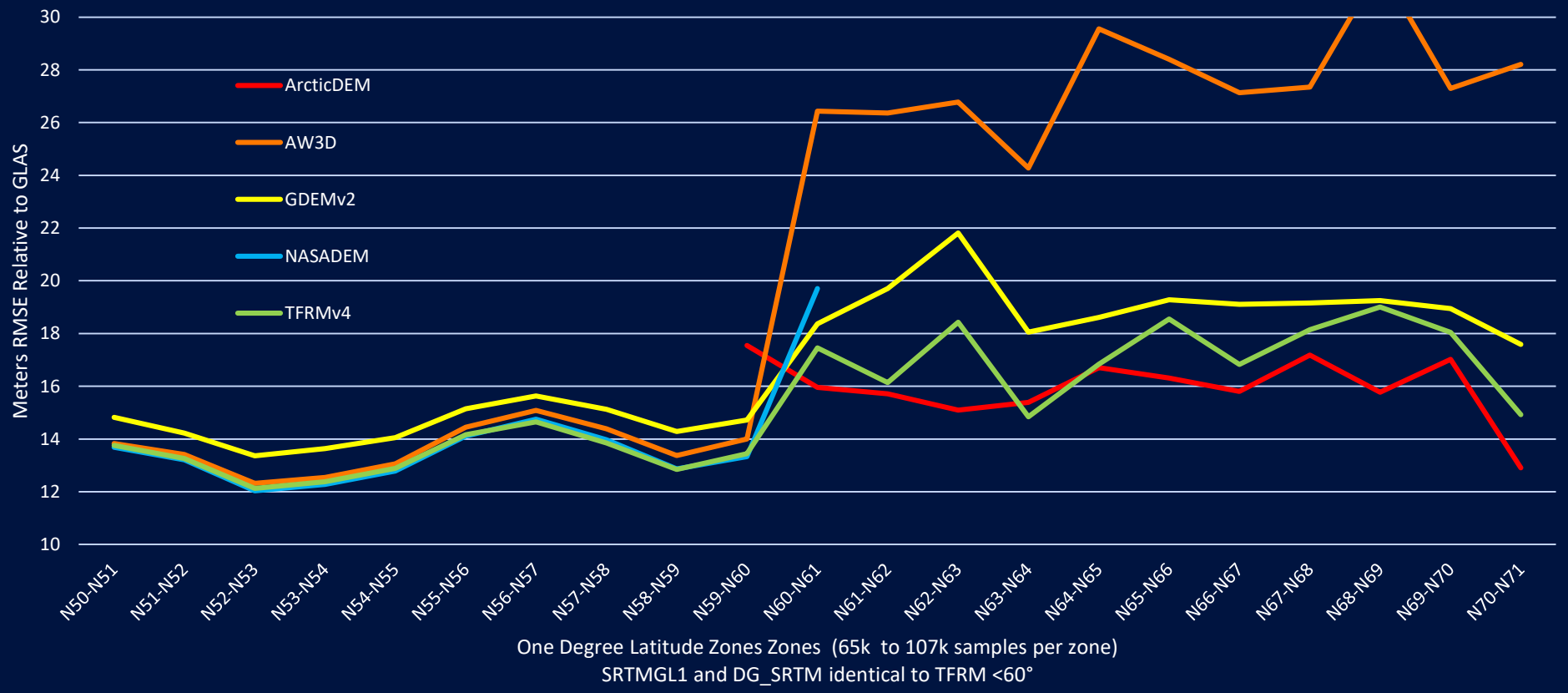
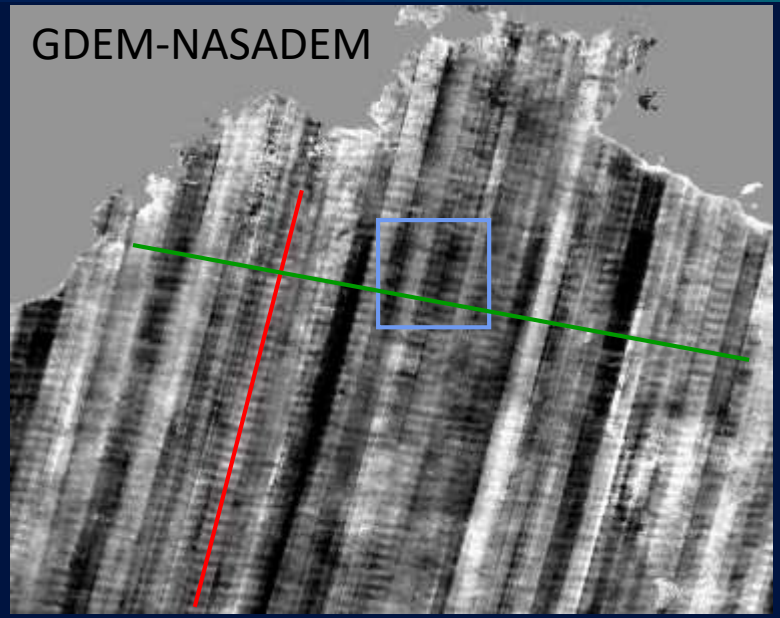


DSM RMSE by Latitude, Eastern Hemisphere

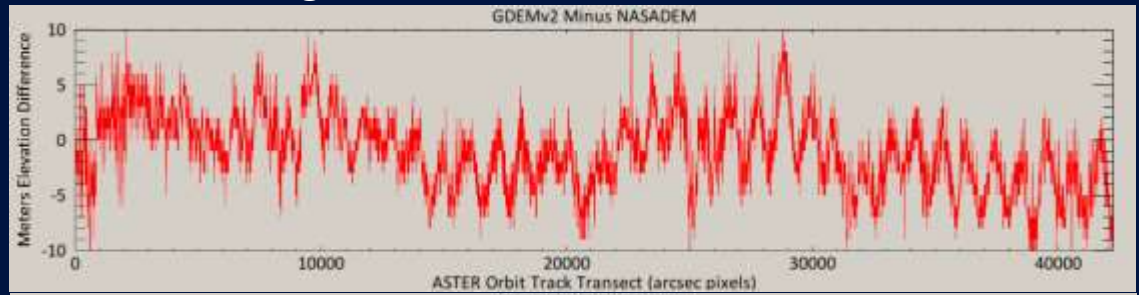


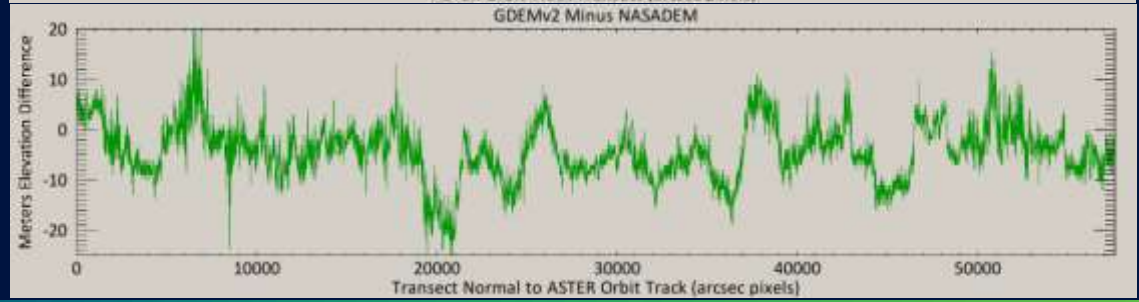
One Degree Latitude Zones Zones (65k to 107k samples per zone)
SRTMGL1 and DG_SRTM identical to TFRM <60°

GDEM Elevation Variation, Northern Australia

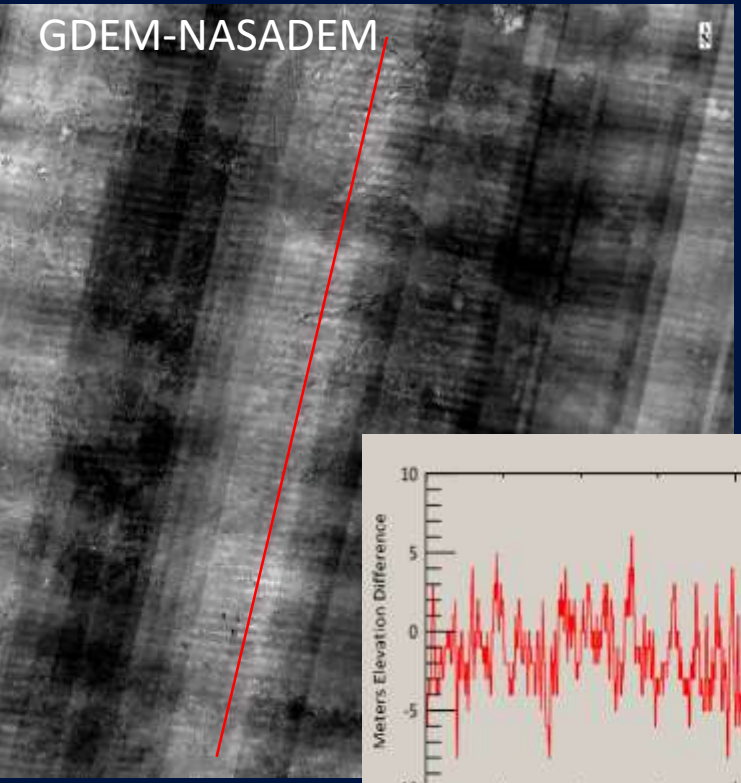


- Red transect: Low frequency orbit track elevation oscillation, ~12 m amplitude, ~1053 arcsec frequency.
- Green transect: Track to track elevation variation, ~30m max.
- Blue rectangle: Subscene for next slide.





GDEM Elevation Variation, Northern Australia

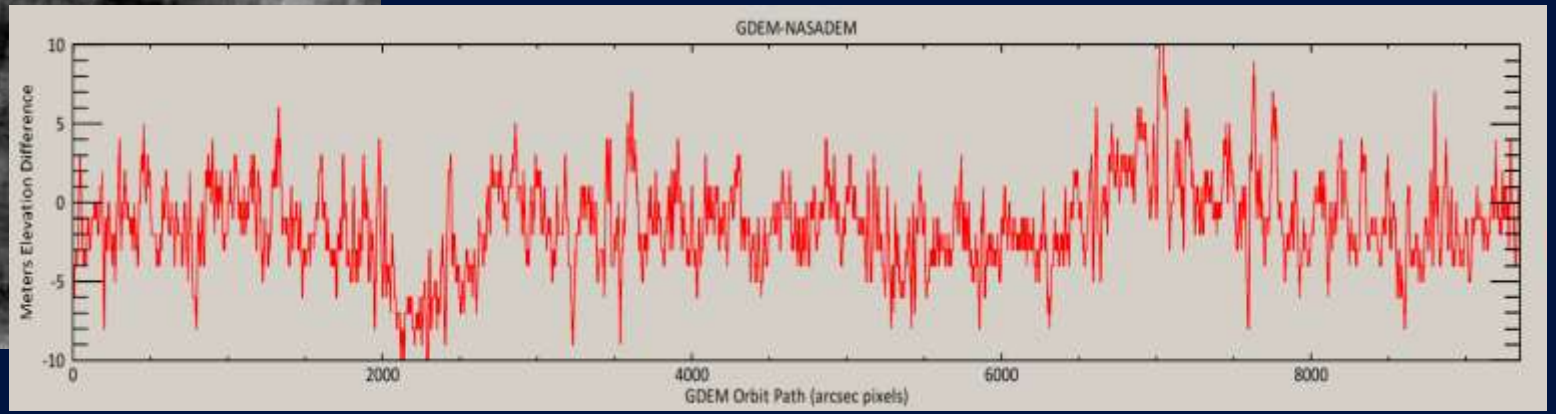


Higher frequency orbit path elevation oscillation:

~8 m amplitude

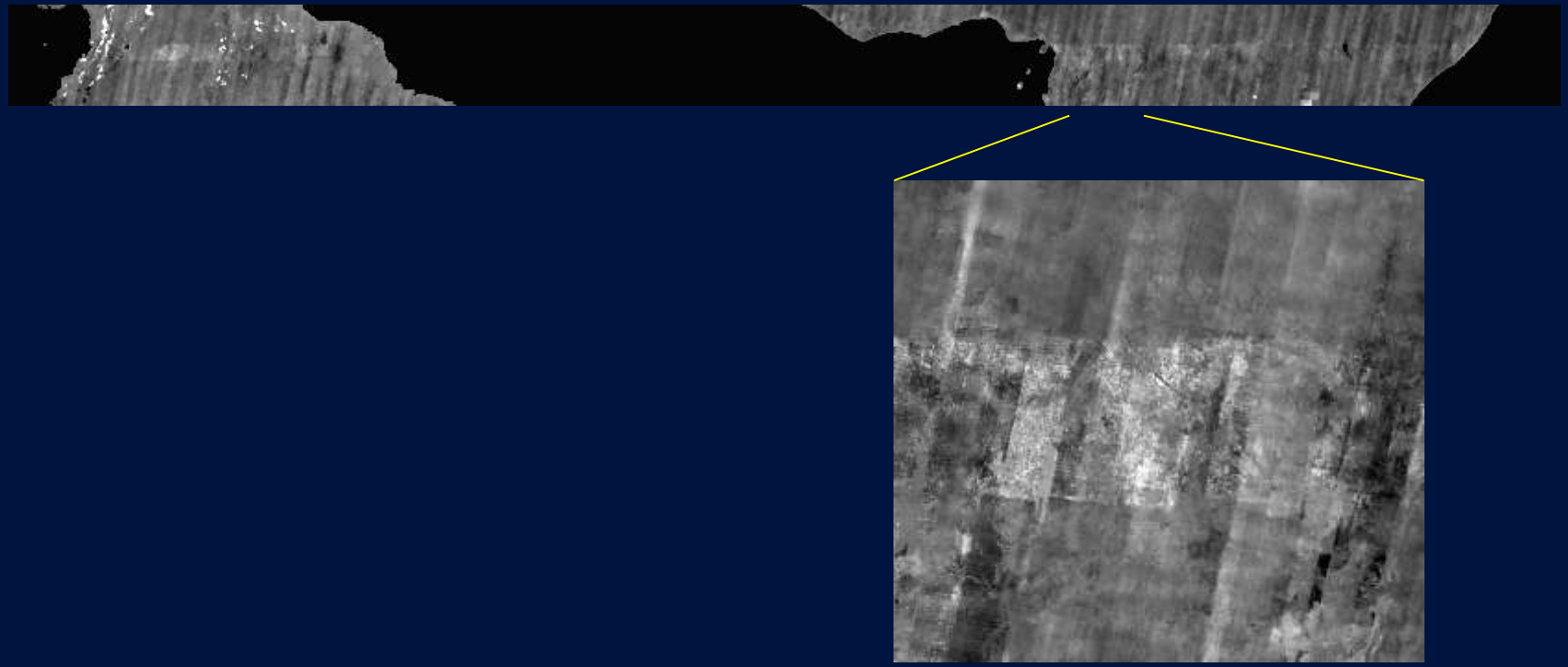
~142 arcsec frequency

Elevation transect for the red line below.

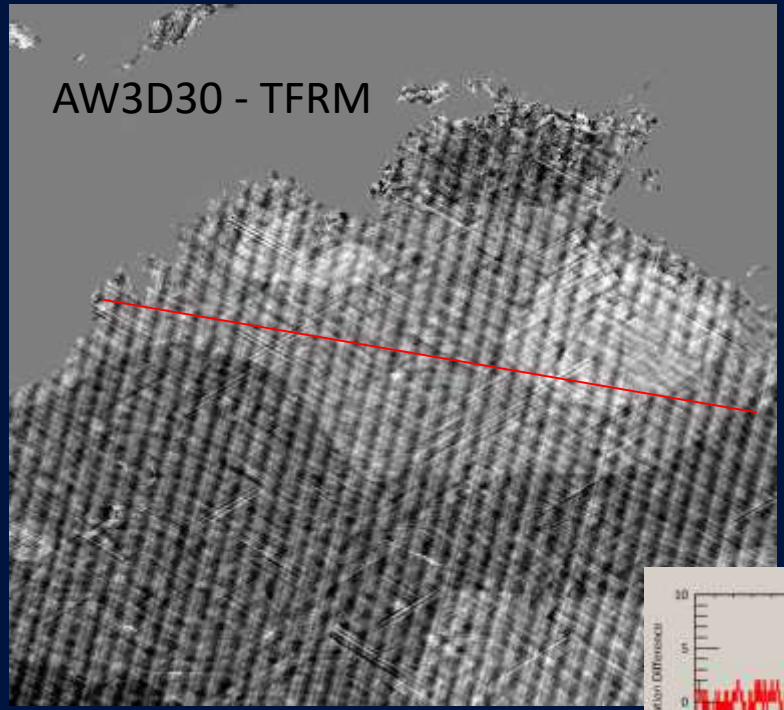


GDEM Shifted Latitude Band

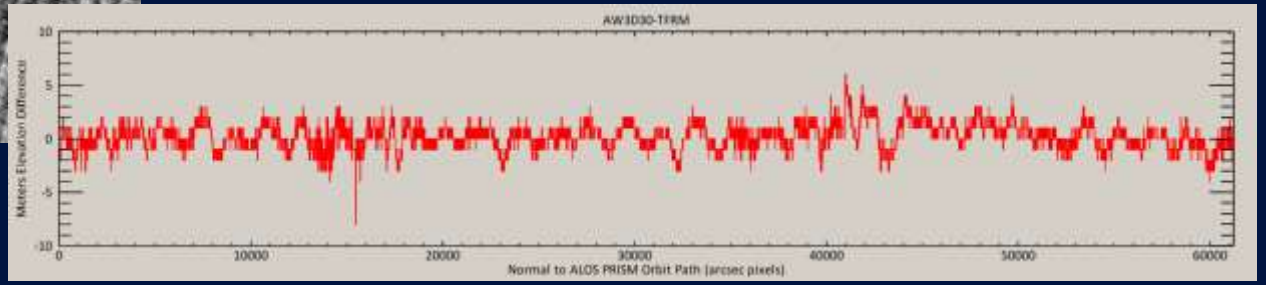
GDEM-TFRM. or other DSM, shows a latitude band 2.5°N to 4°N with ~<20 m discontinuity.



AW3D30 In-Swath Variation, Northern Australia



- ~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

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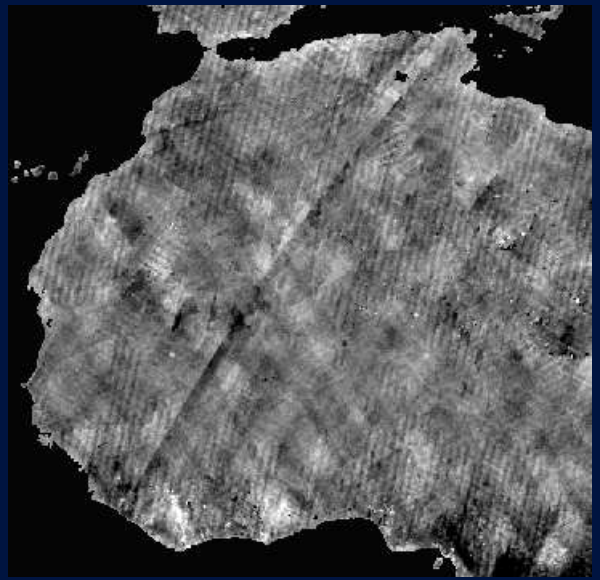
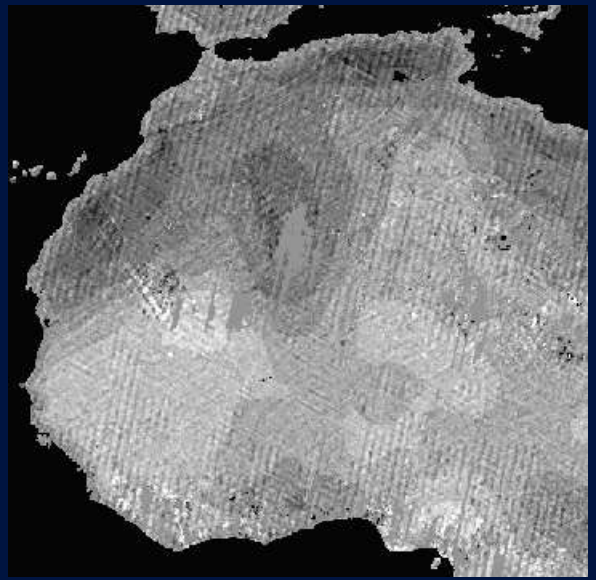
NASADEM - AW3D30



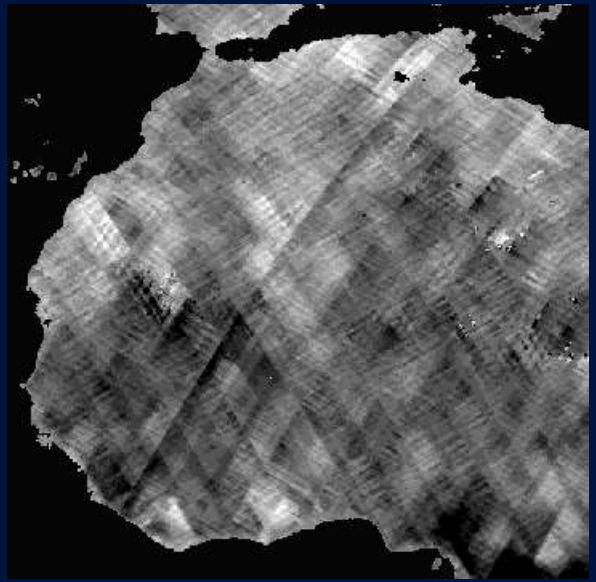
Shows SRTM path striping.

SRTMGL1 - AW3D30



Does not show SRTM path striping.

NASADEM - SRTMGL1



Shows SRTM path striping. Largest shift ~5m.

NASADEM Swath Striping, Australia , 10 Arcsec Res.

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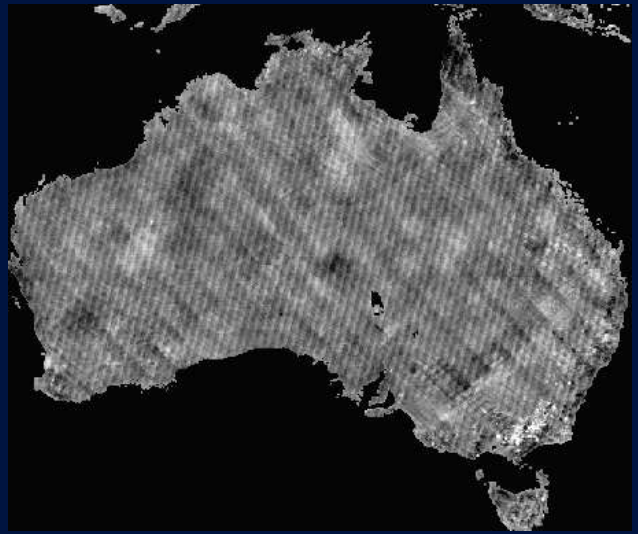
NASADEM - AW3D30

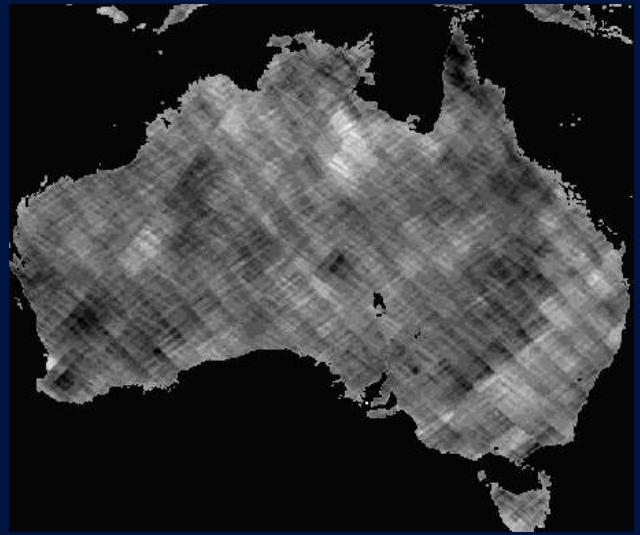


Shows SRTM swath striping.

SRTMGL1 - AW3D30

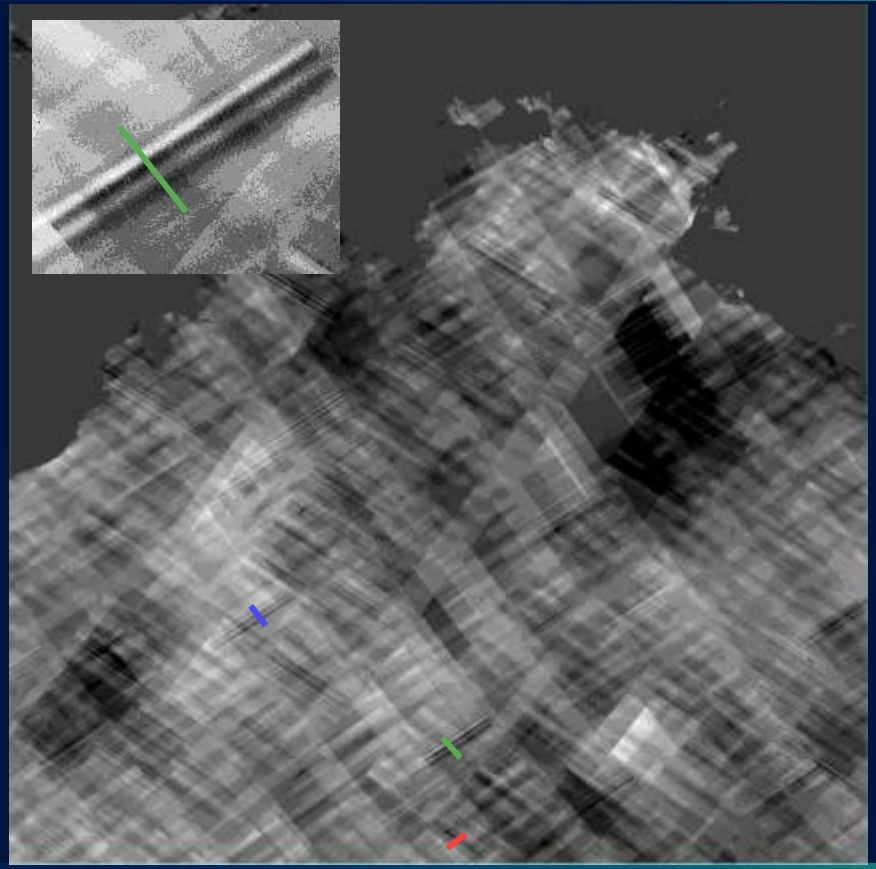
Does not show SRTM swath striping.

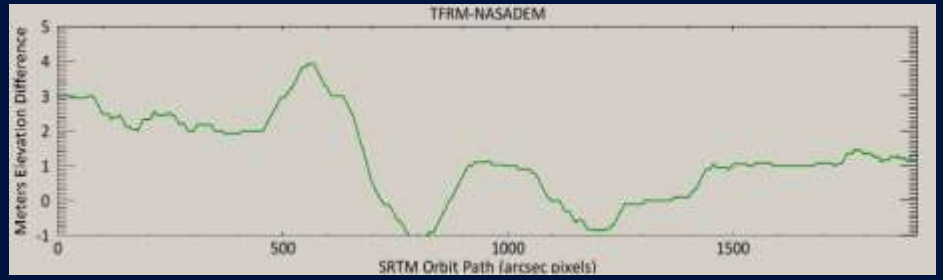
NASADEM - SRTMGL1

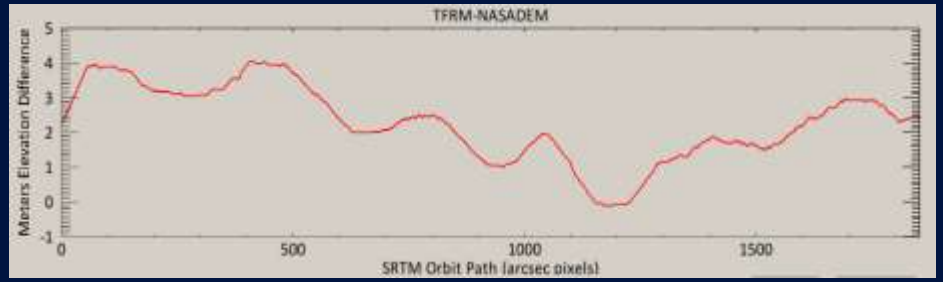


Shows SRTM swath striping. Largest shift ~3m.

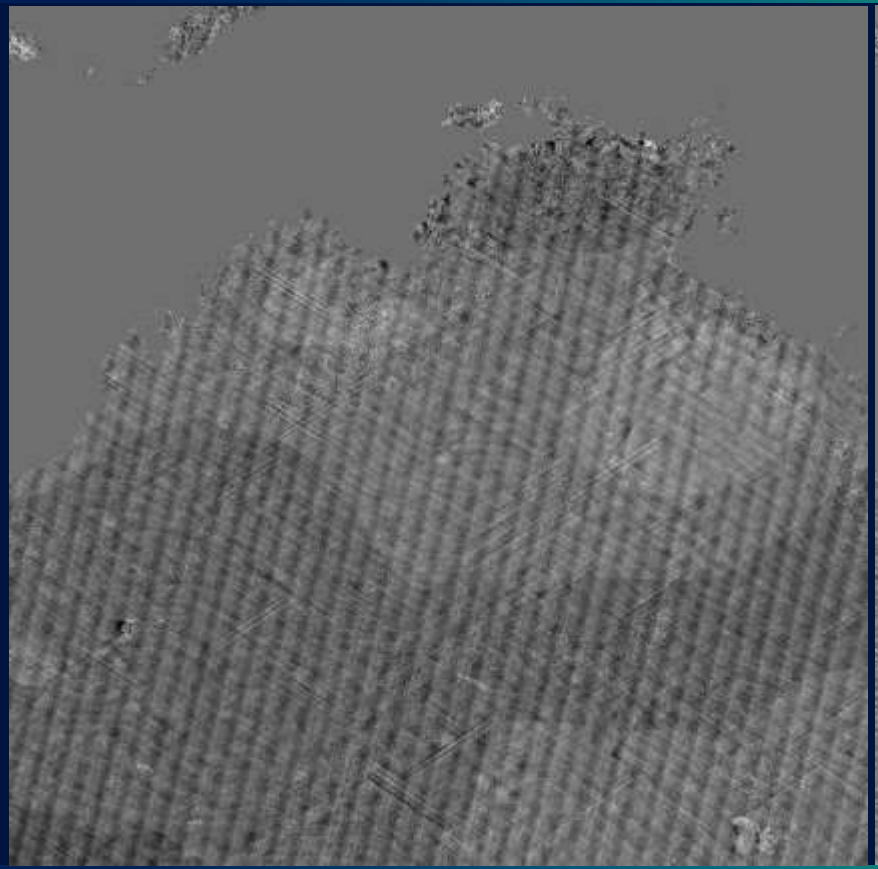
TFRM-NASADEM, Antenna Oscillation Correction

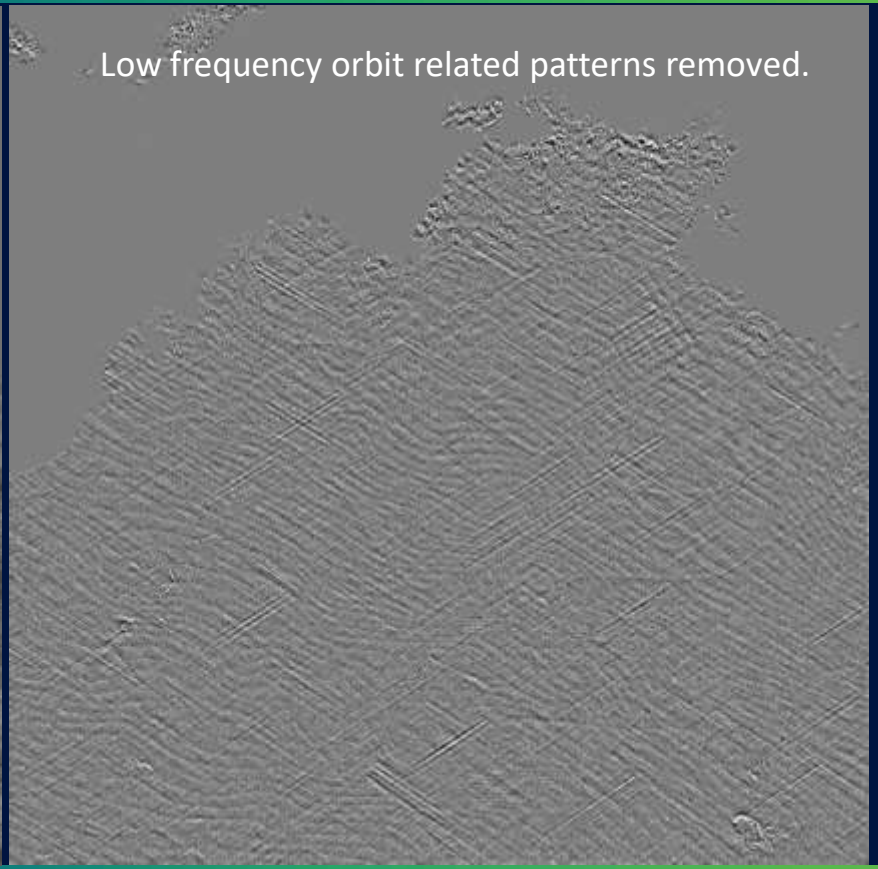




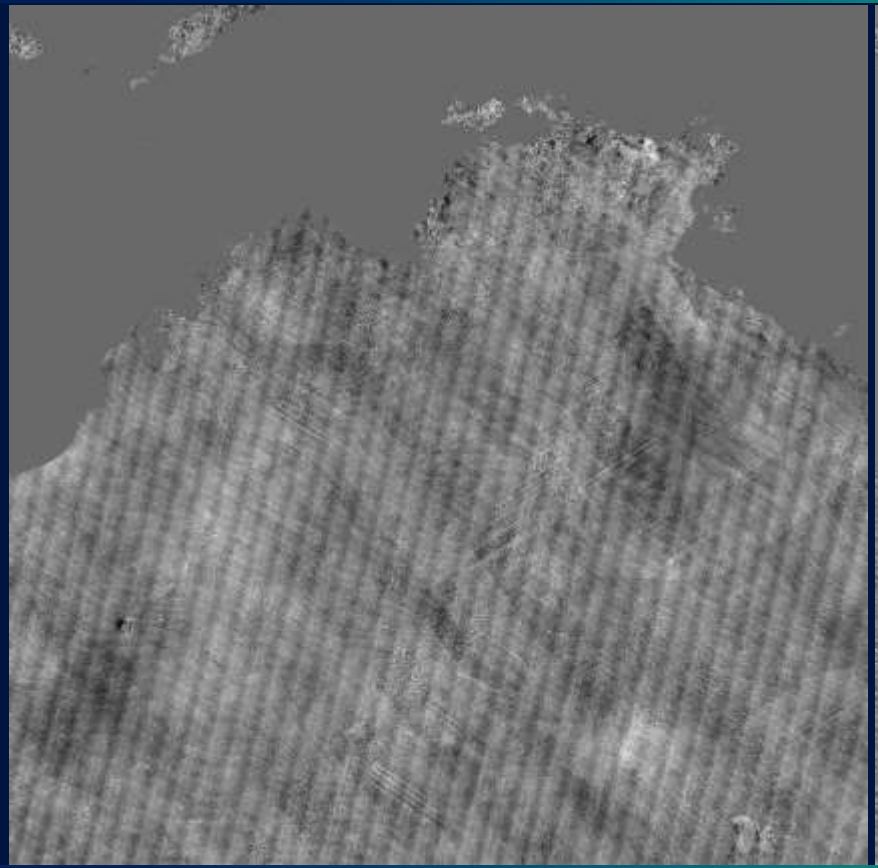


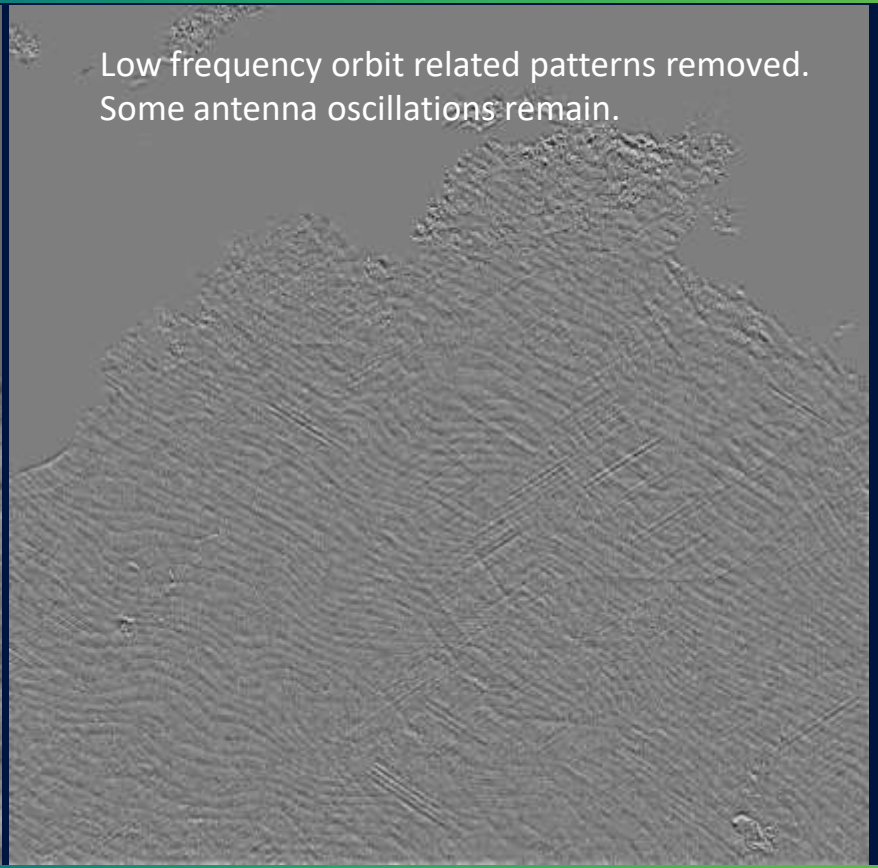
AW3D30-TFRM, Pre Antenna Oscillation Correction





AW3D30-NASADEM, Post Antenna Oscillation Correction





TFRM Fill from GDEM Shifted ~-30 m

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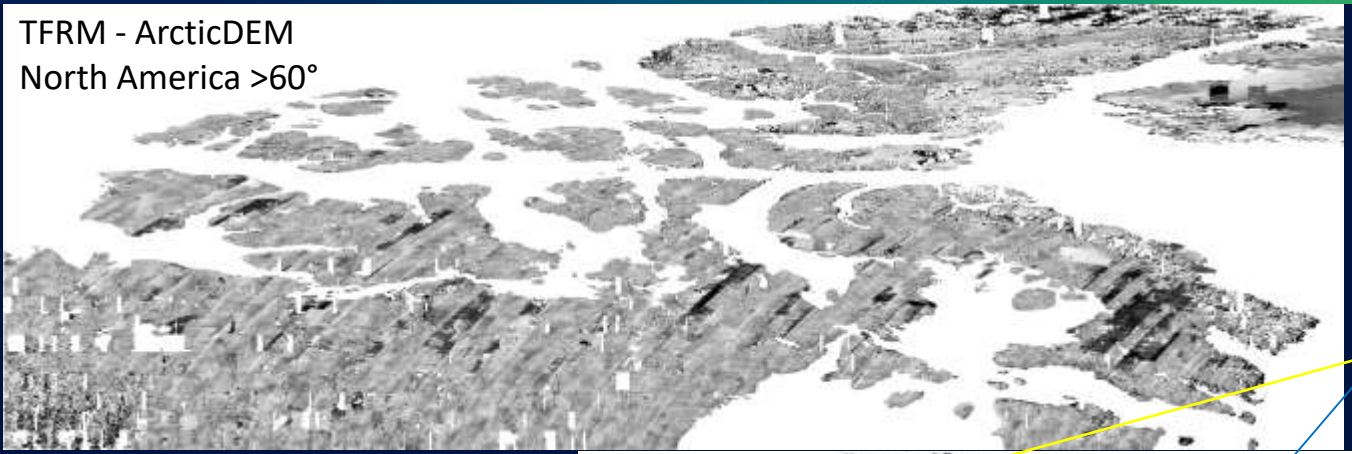
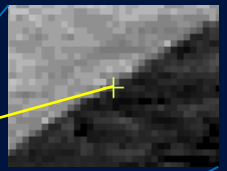
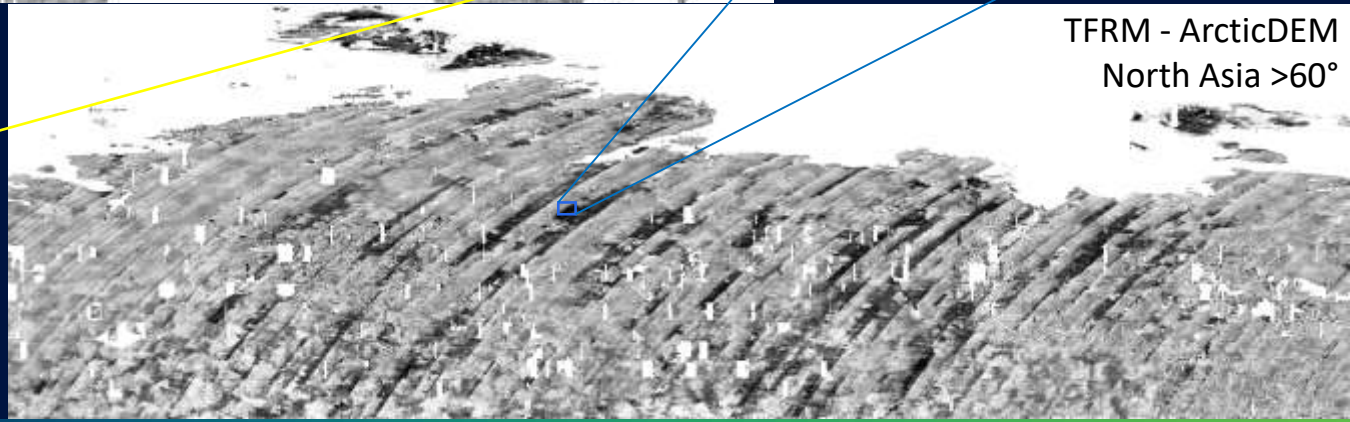


All dark patches are areas filled with GDEM.



TFRM Elevations

435	438	440	438	436
423	420	417	405	404
405	393	384	382	386
384	378	377	373	373
392	384	382	385	387



TFRM Geocell N27E085 Inconsistent

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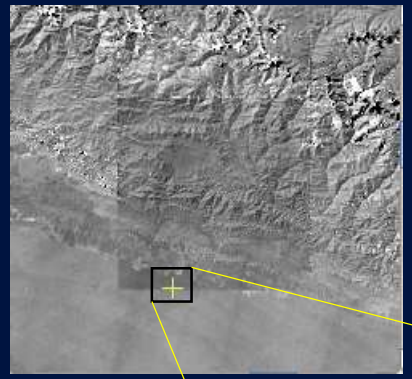
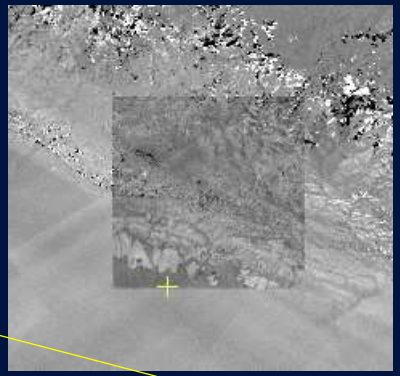
TFRM - AW3D30



TFRM - NASADEM



TFRM - GLAS

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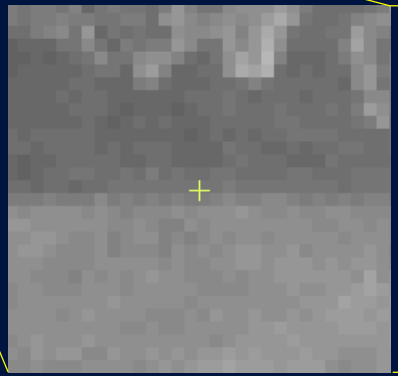
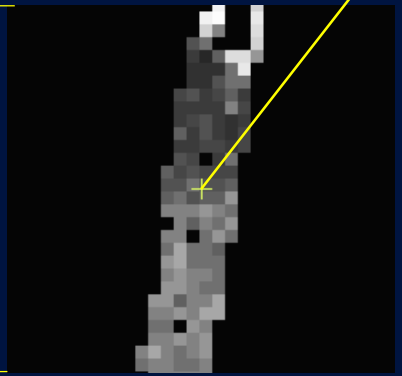


TFRM - GLAS



TFRM Alaska

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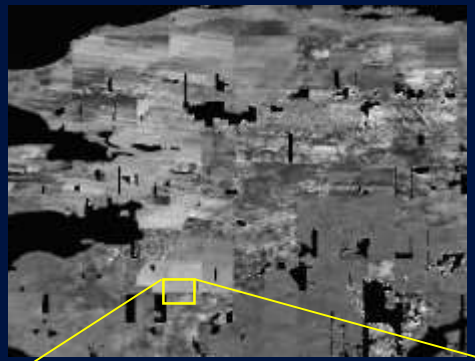
TFRM - ArcticDEM



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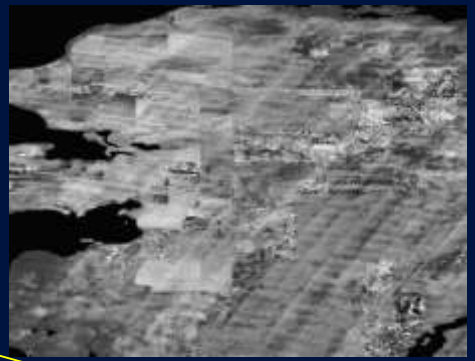
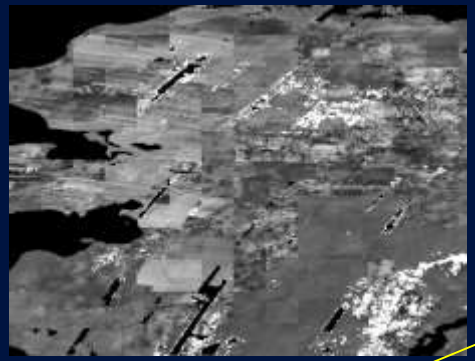


TFRM - AW3D30



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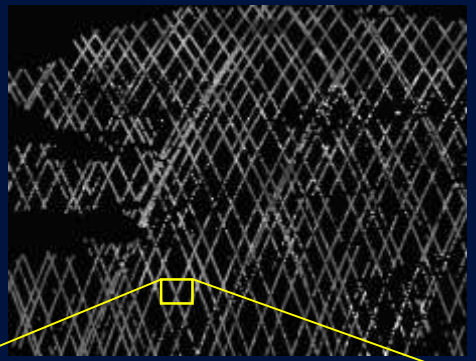

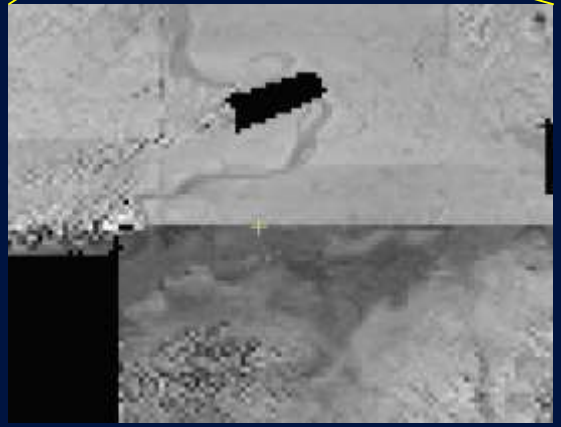

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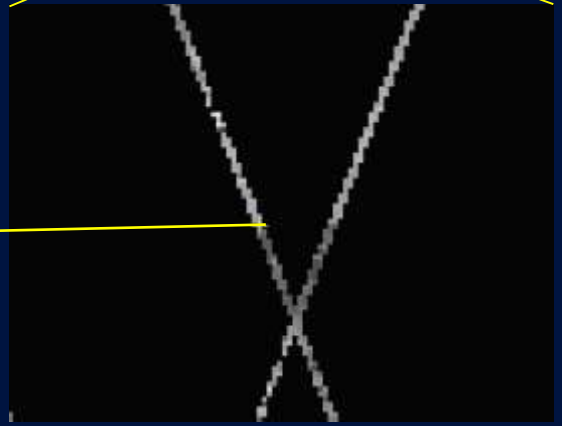


Resolution

DEM Comparison

VRICON

AW3D30

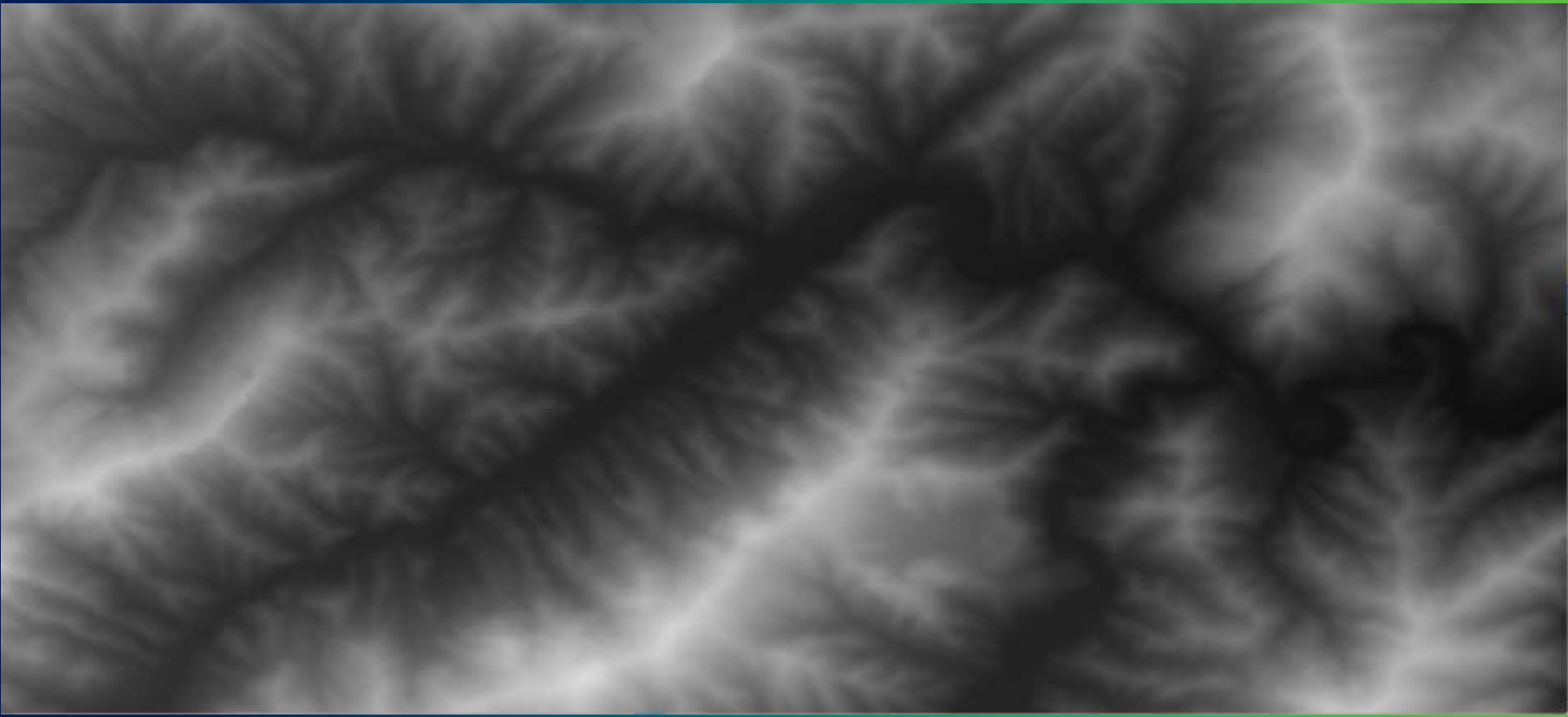
GDEM

TFRM

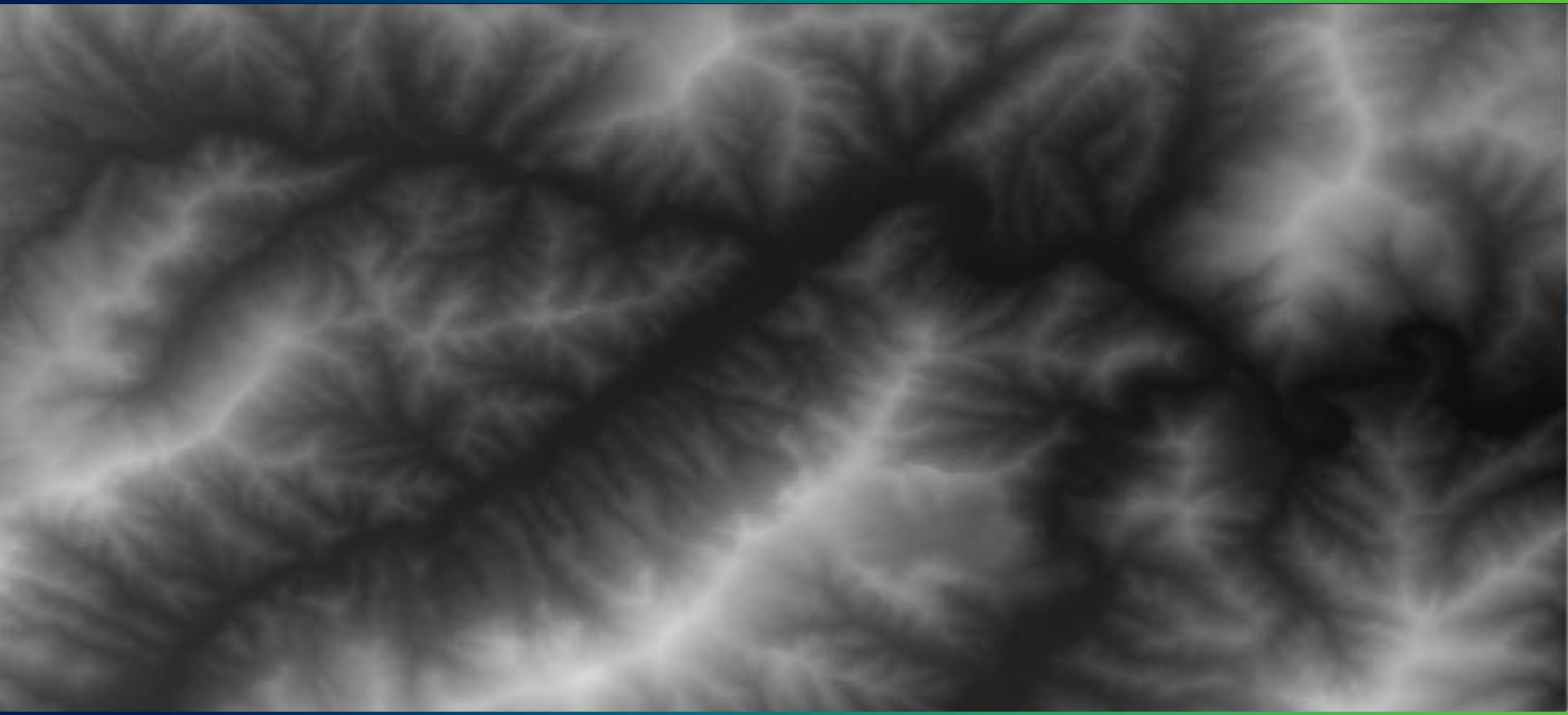
NASADEM

SRTMGL1

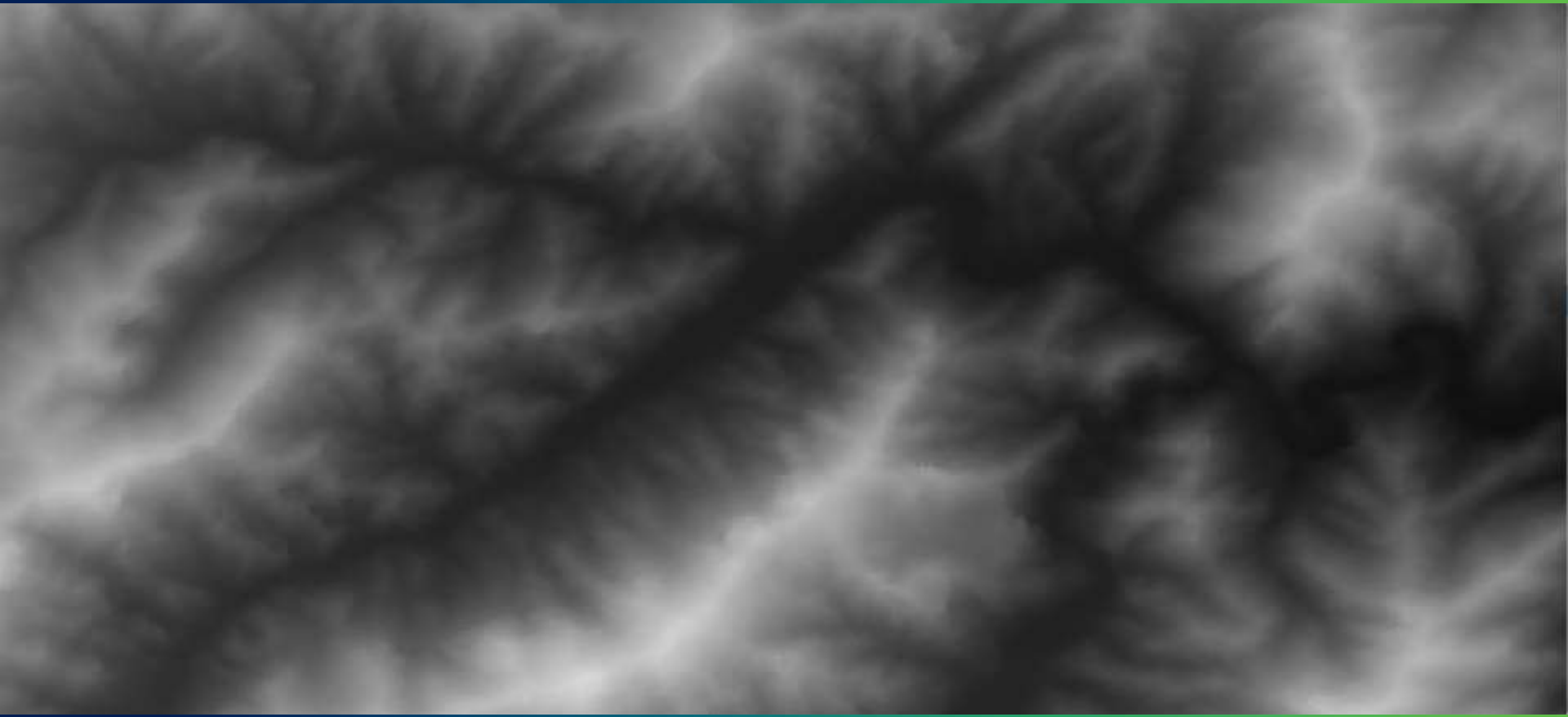
AW3D30 Reduced from 5 m



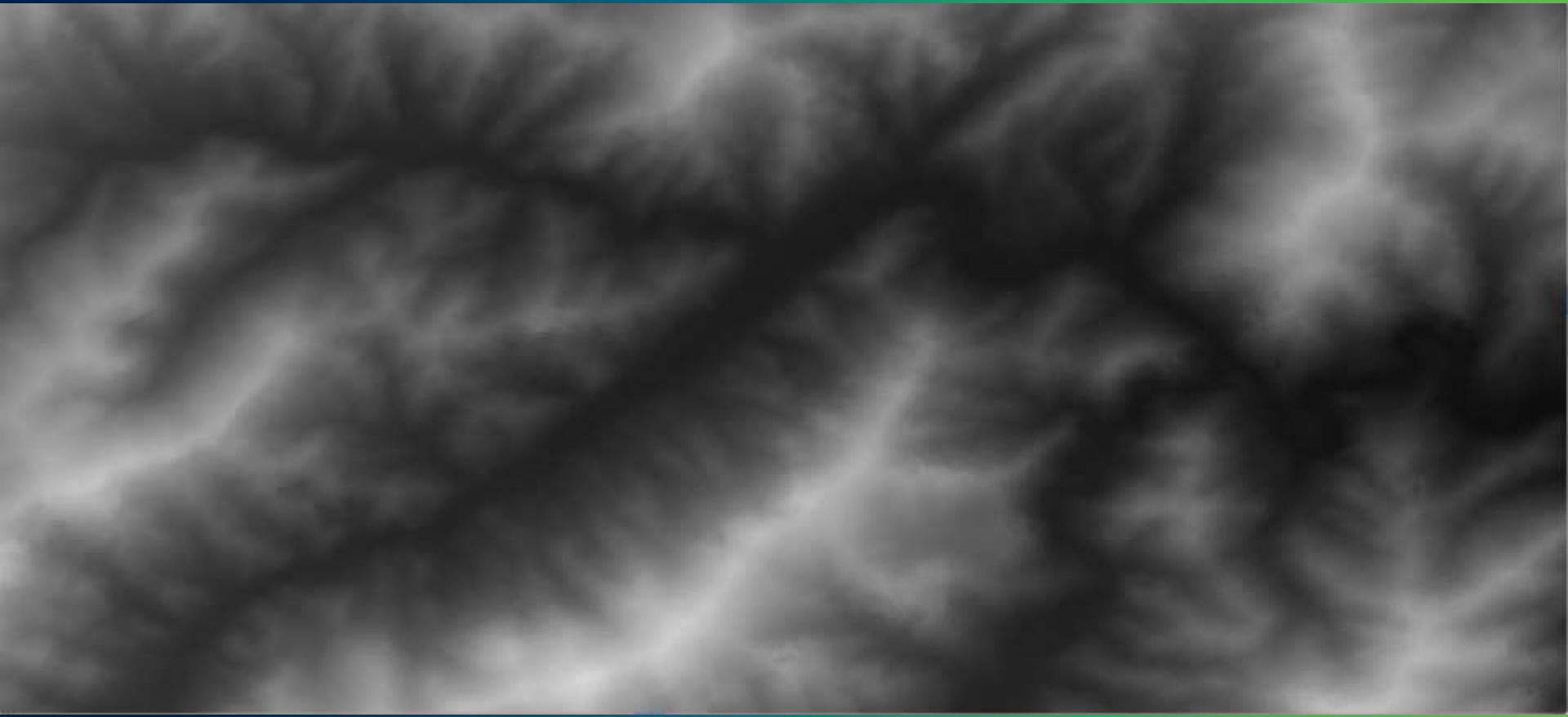
VRICON Reduced from 50 cm



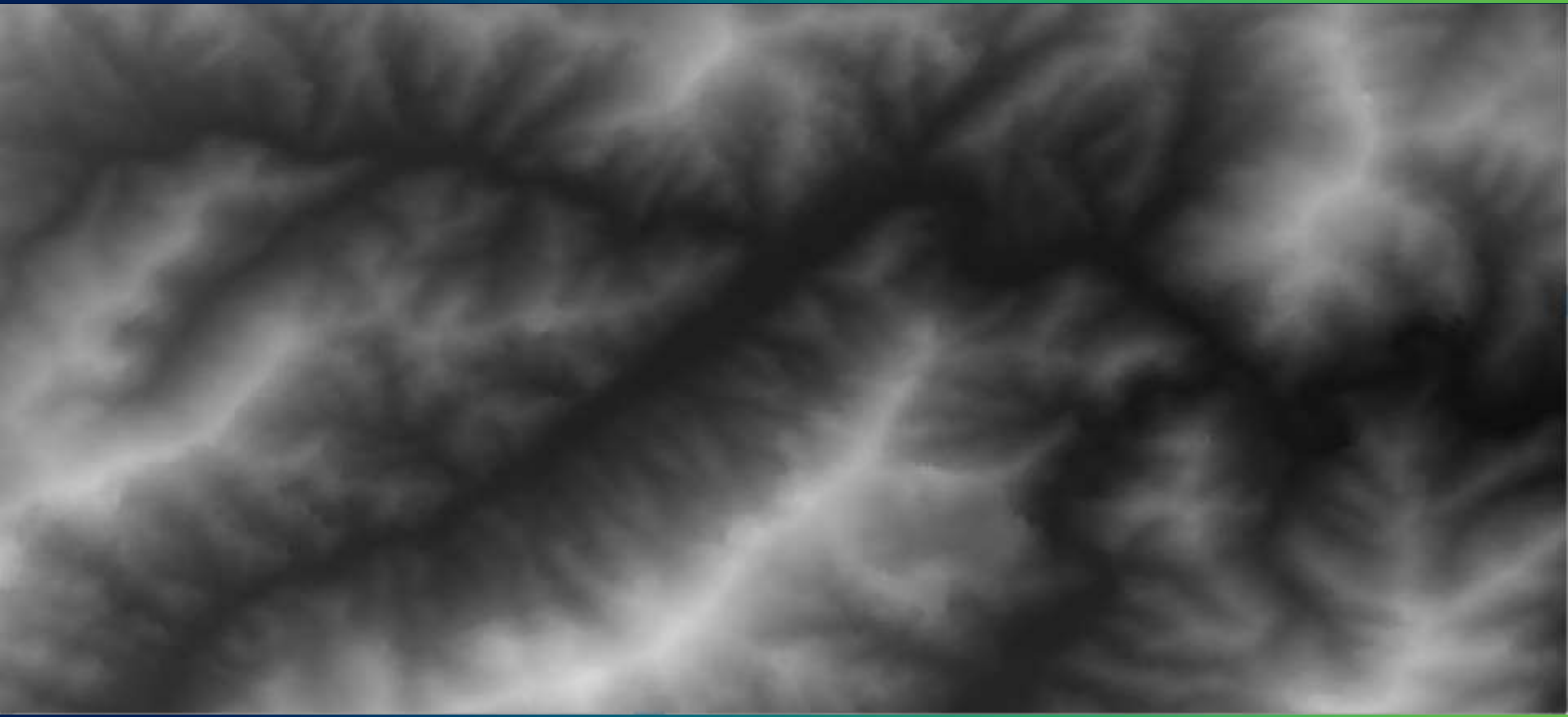
TFRM



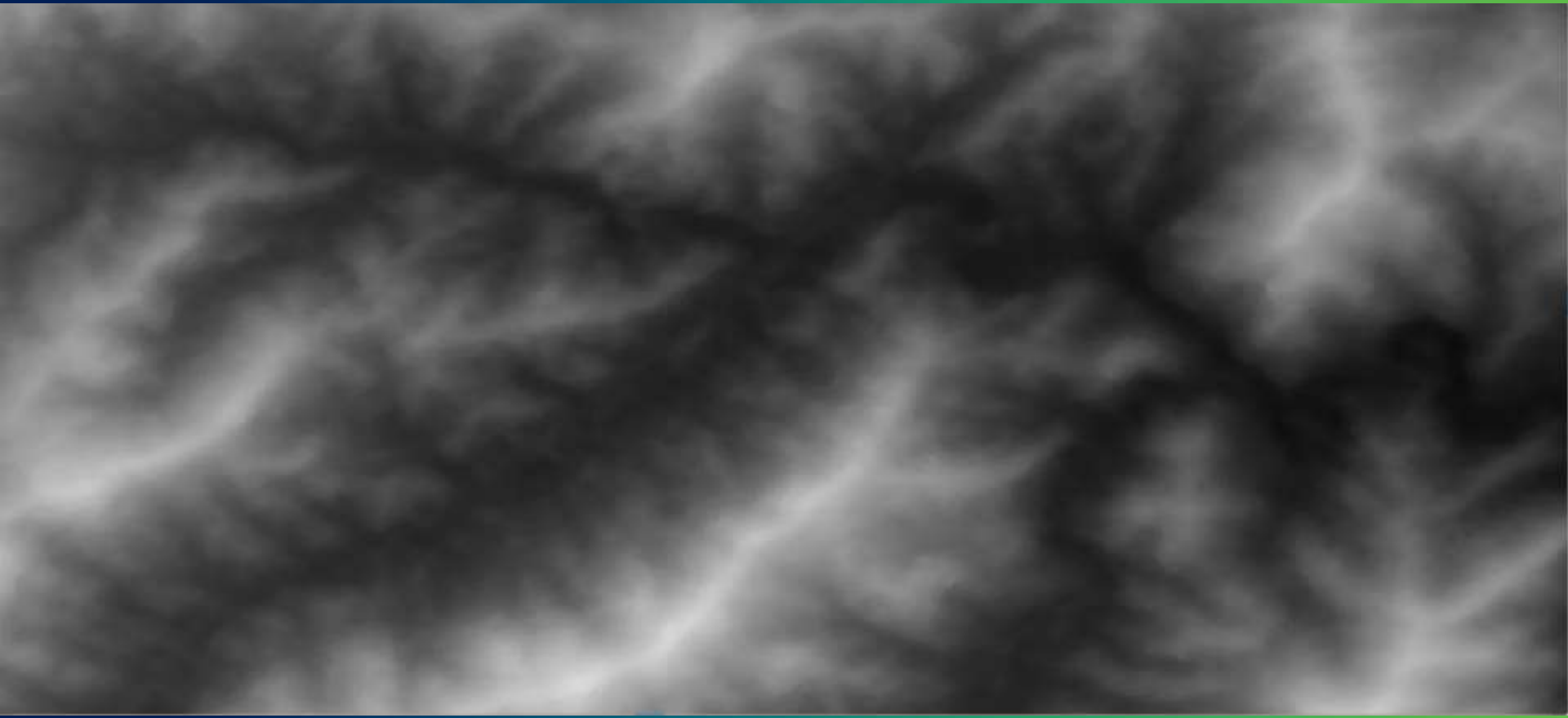
NASADEM



SRTMGL1



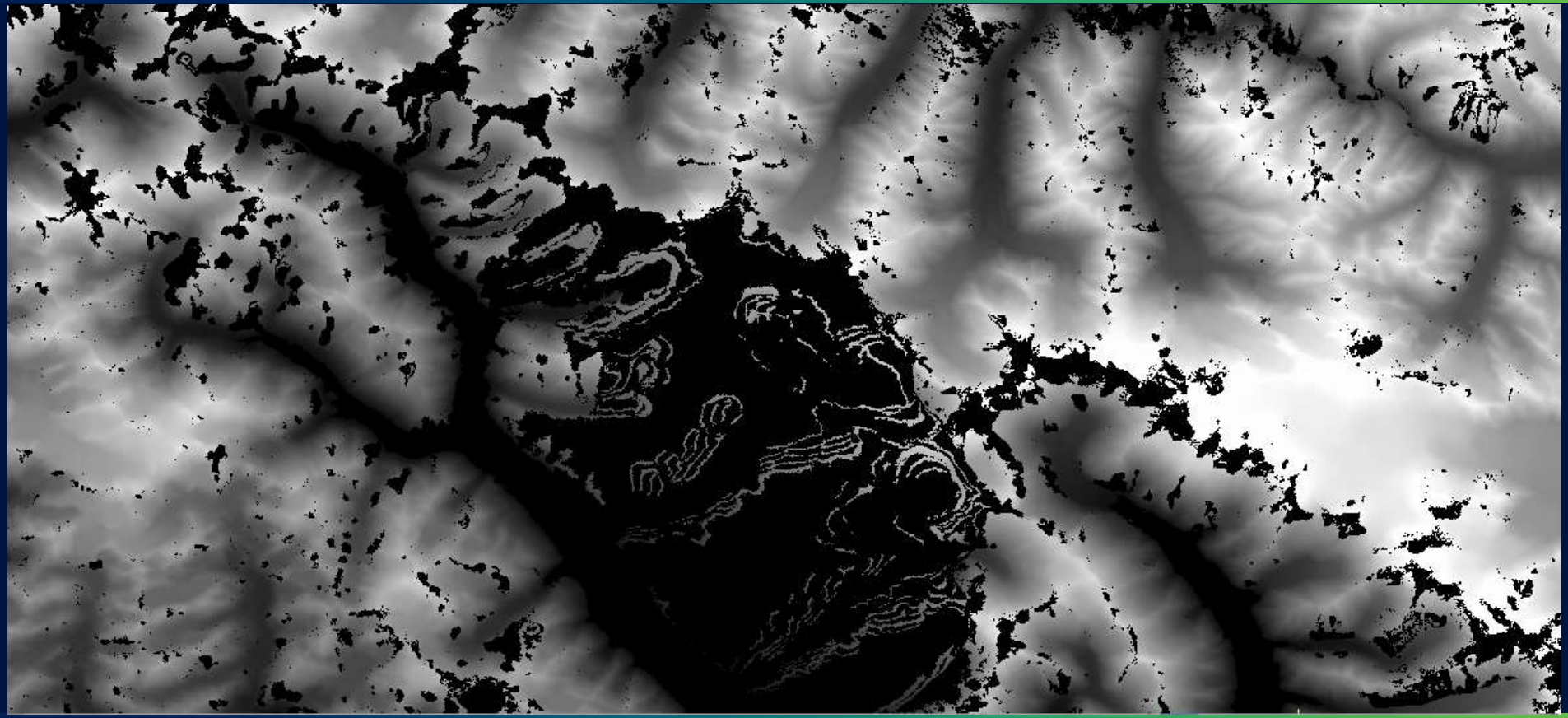
GDEM



Mountainous Void Areas

N 29° 25’ E 96° 17’

NASADEM No Void Fill



SRTMGL1

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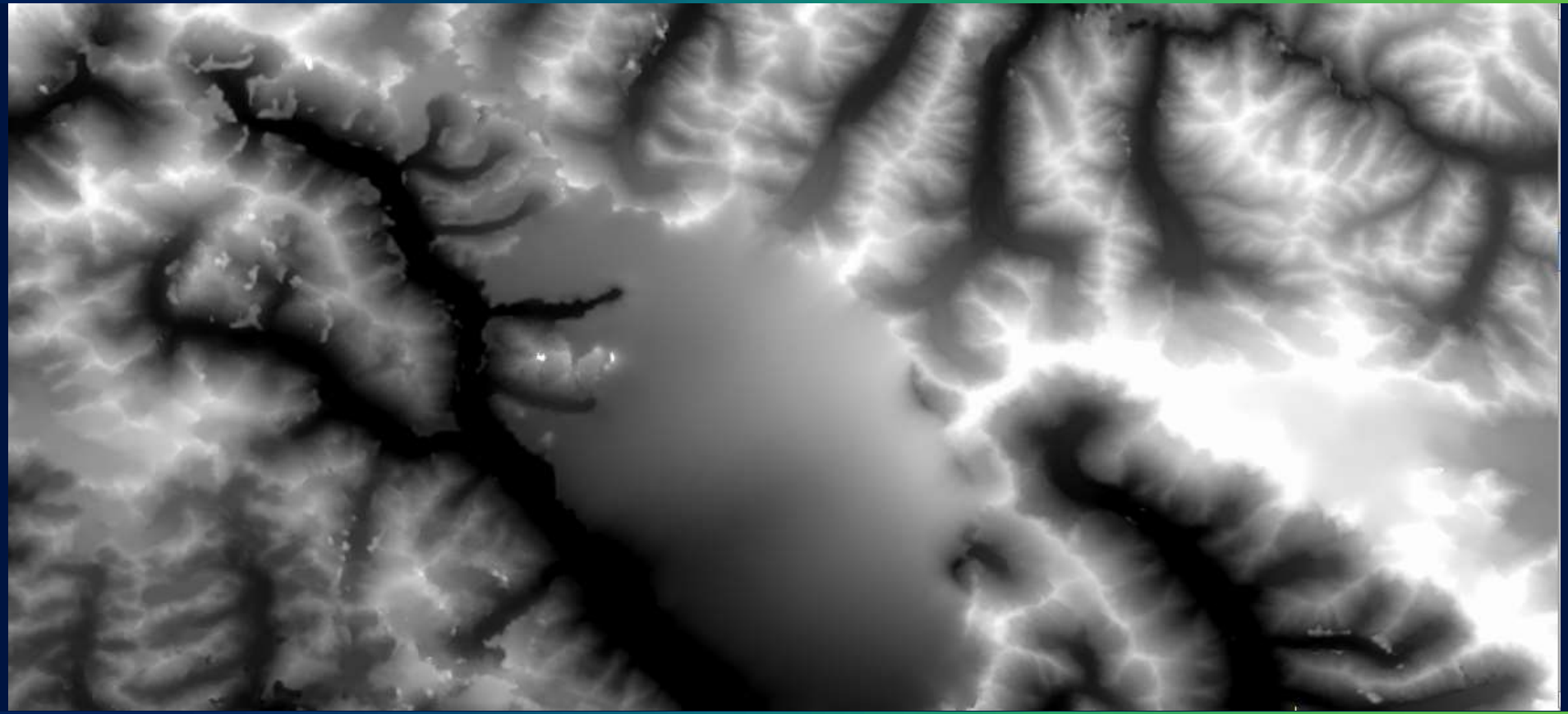
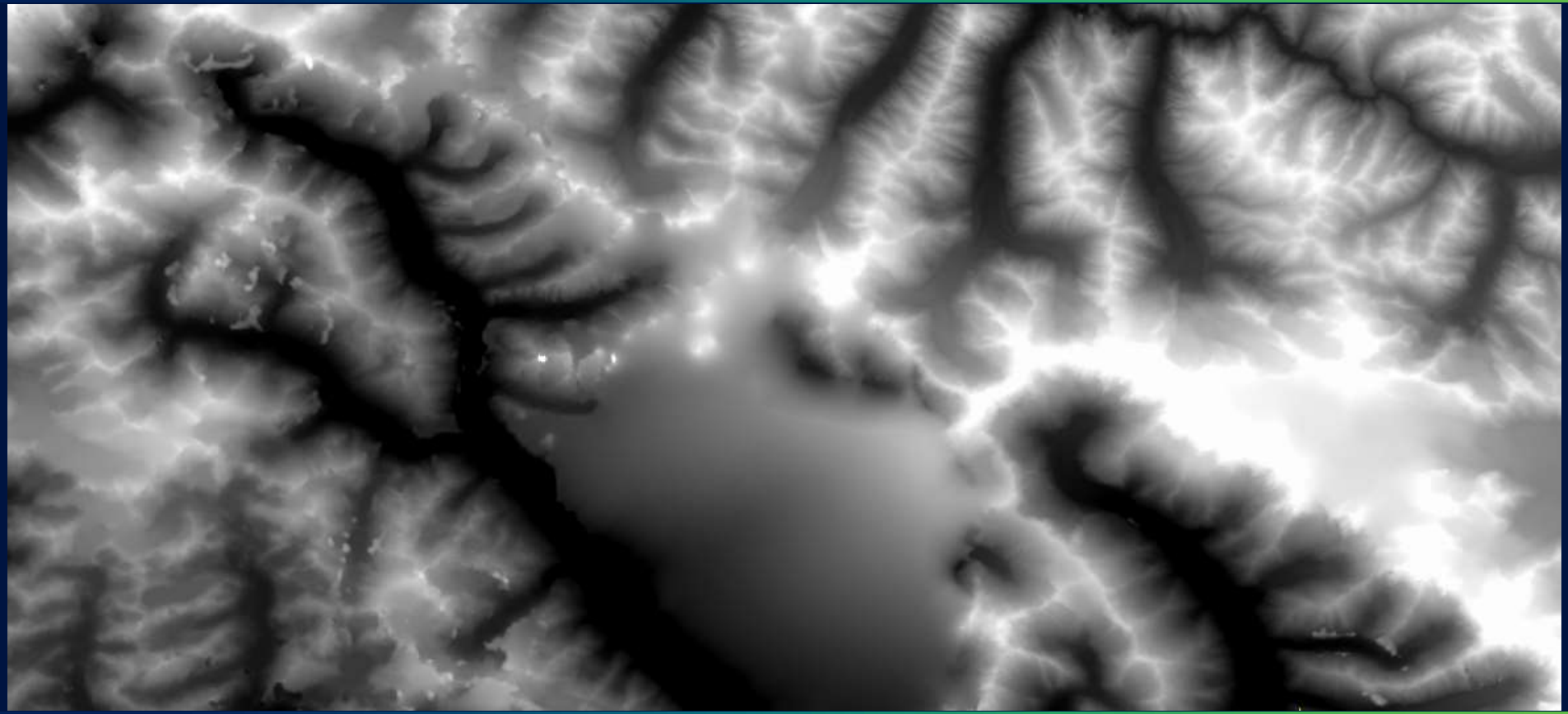


AW3D30



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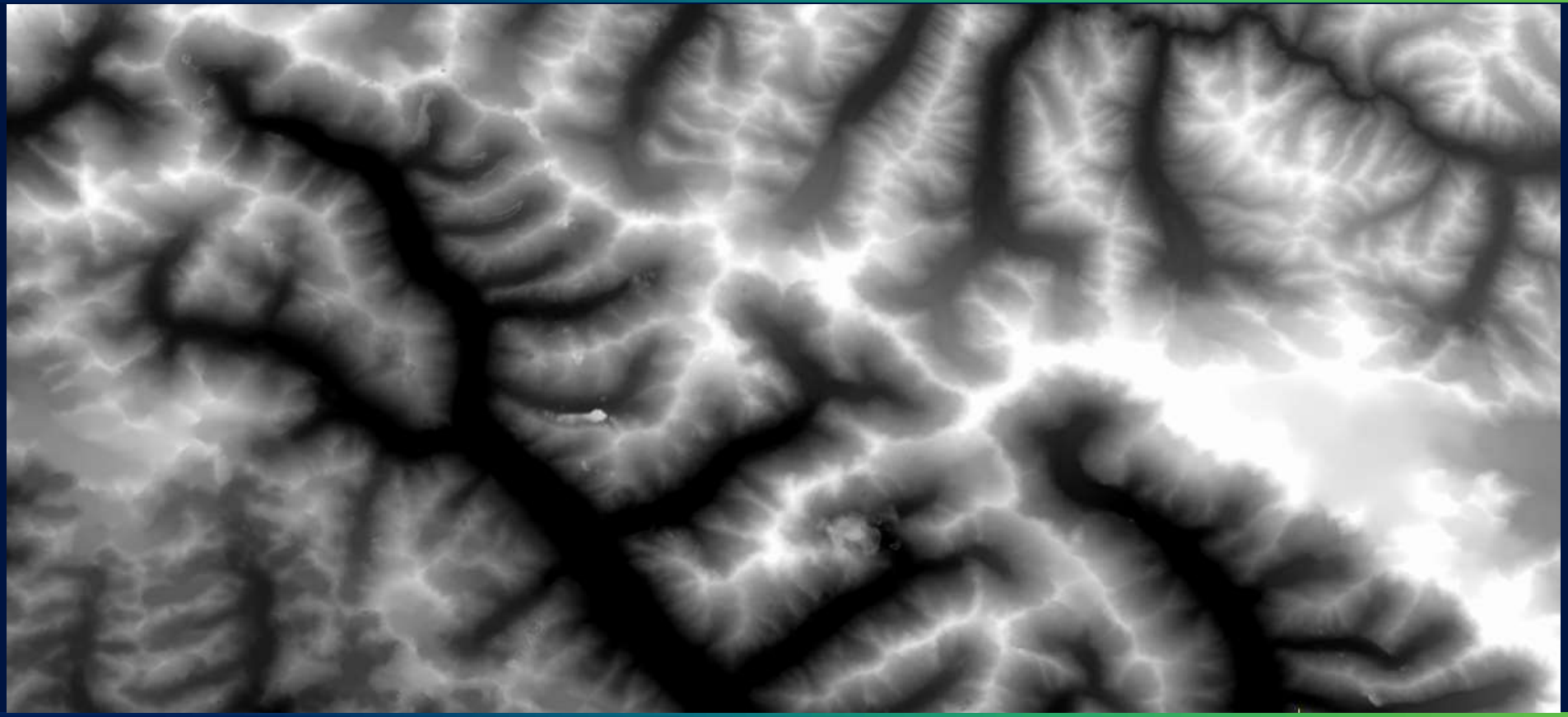
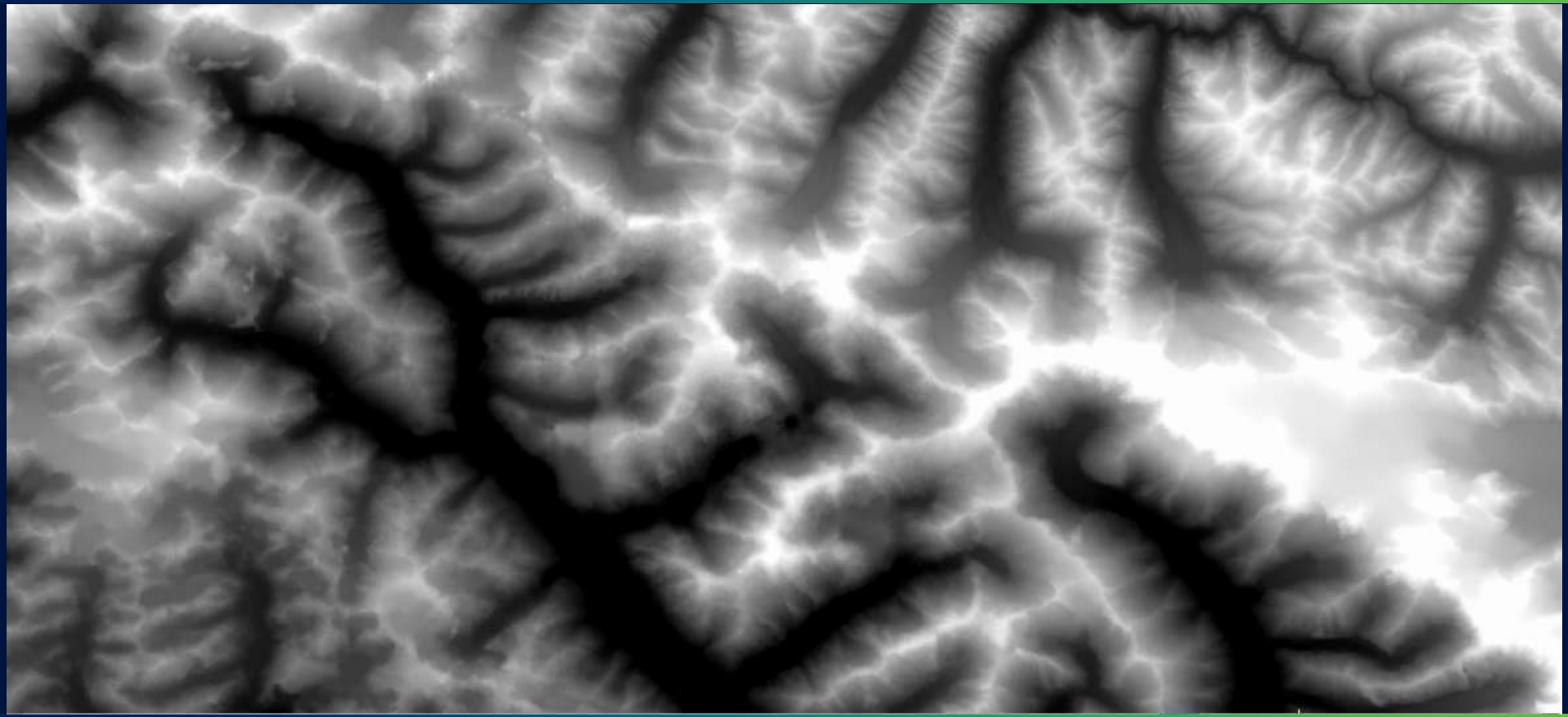
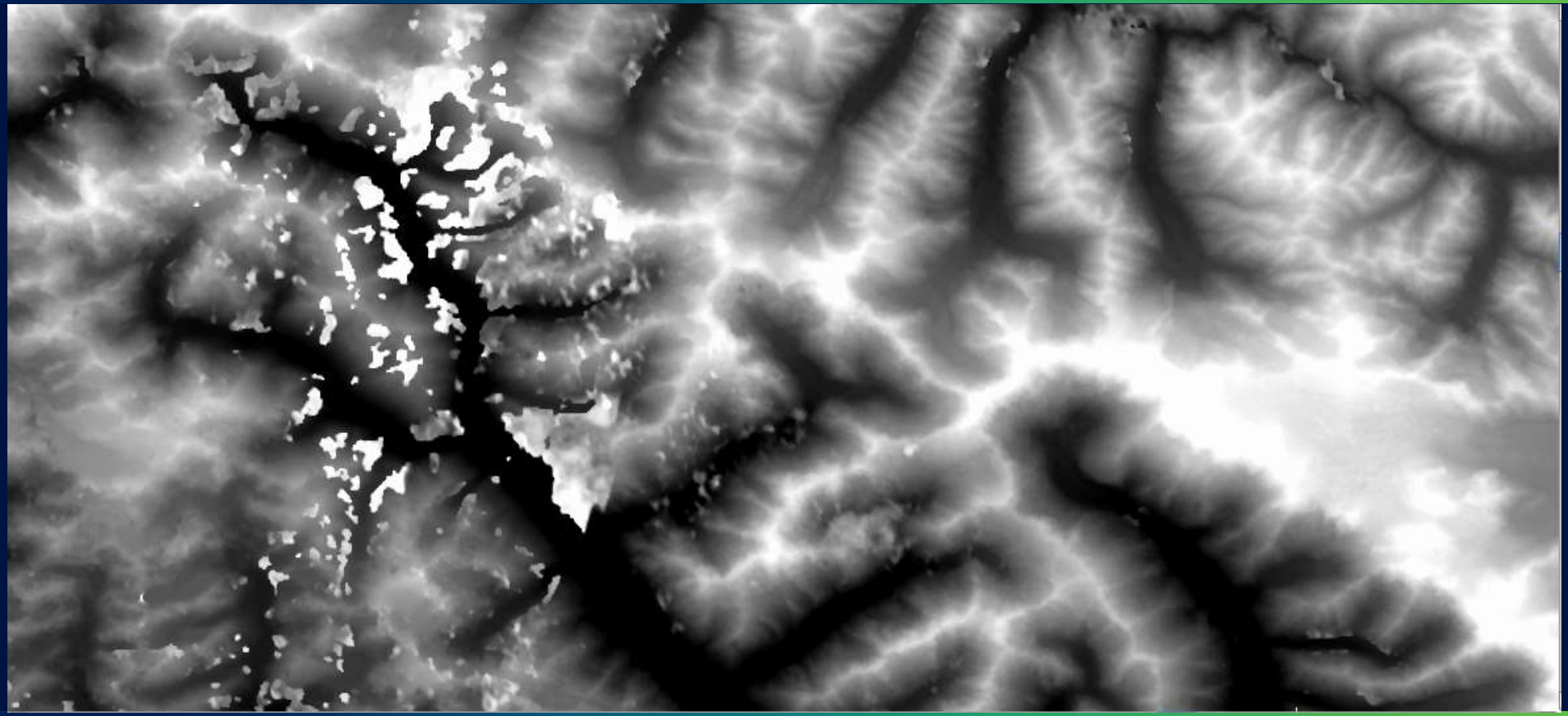


TFRM



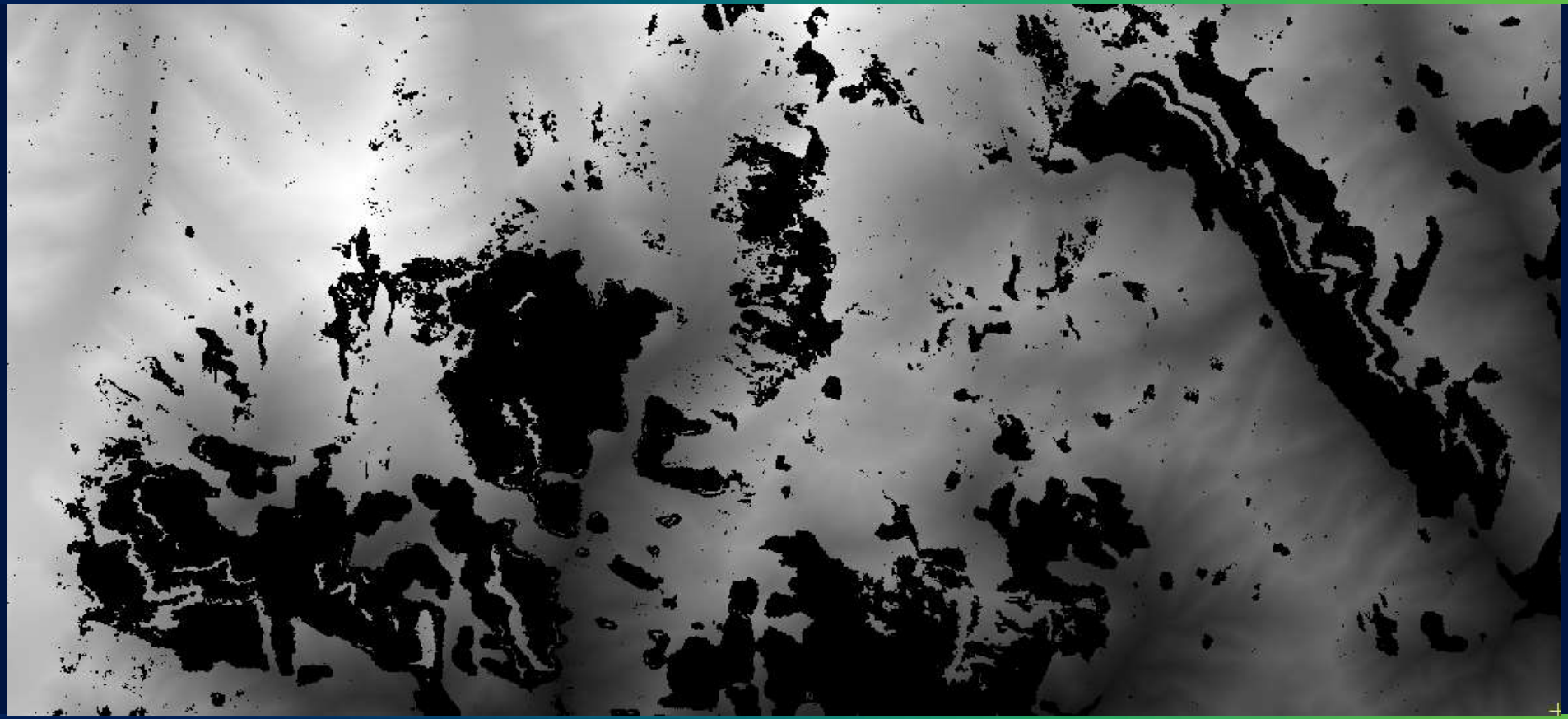
GDEM



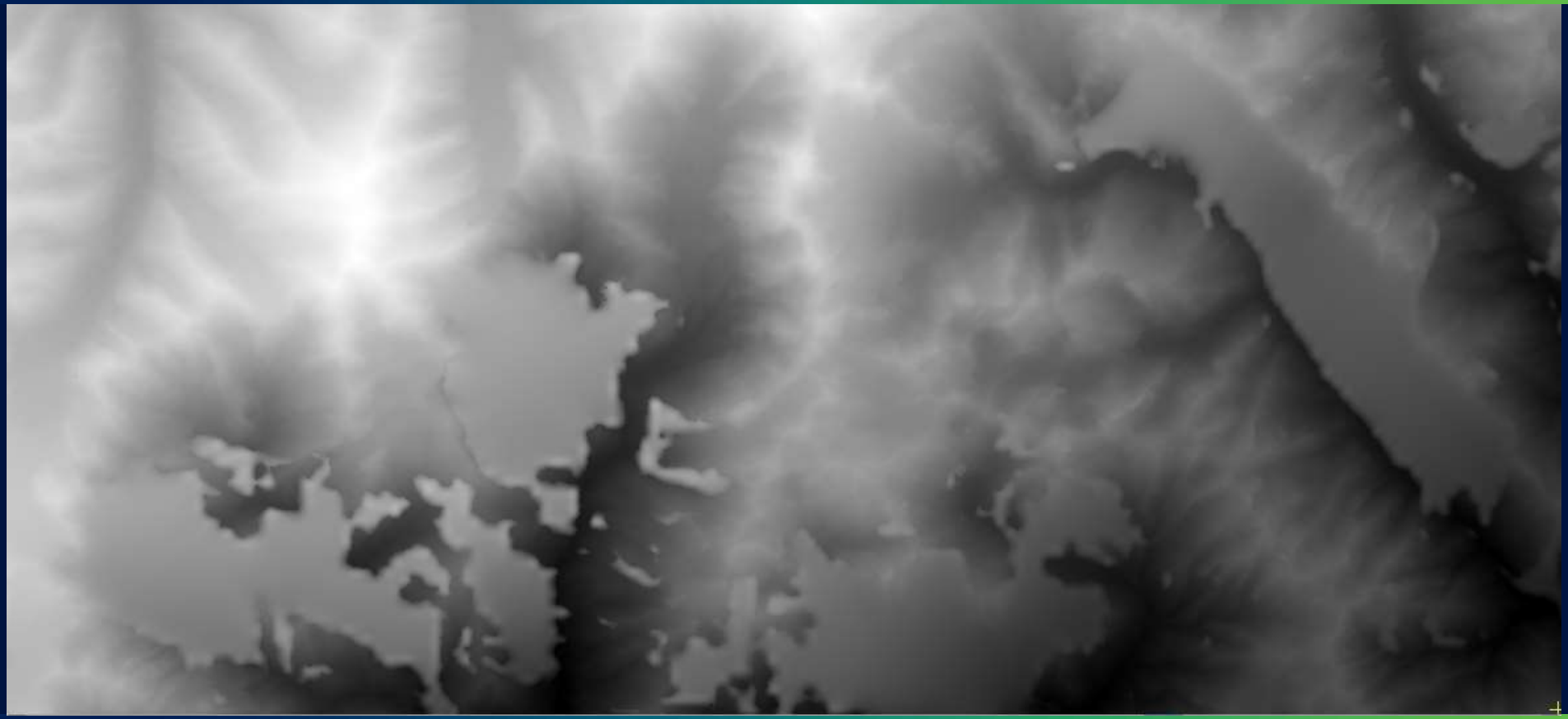
Mountainous Void Areas

N 27° 50’ E 92° 36’

NASADEM No Void Fill



SRTMGL1



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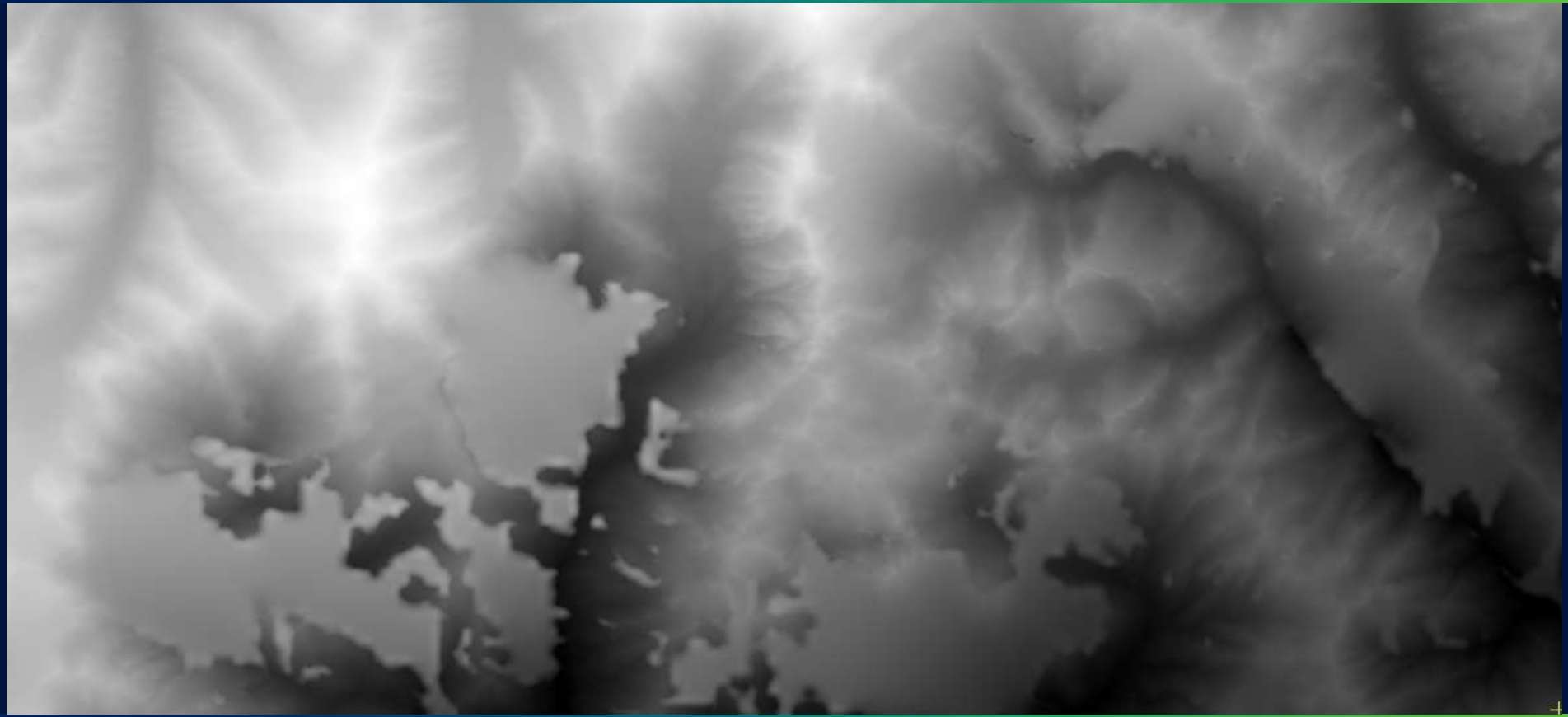

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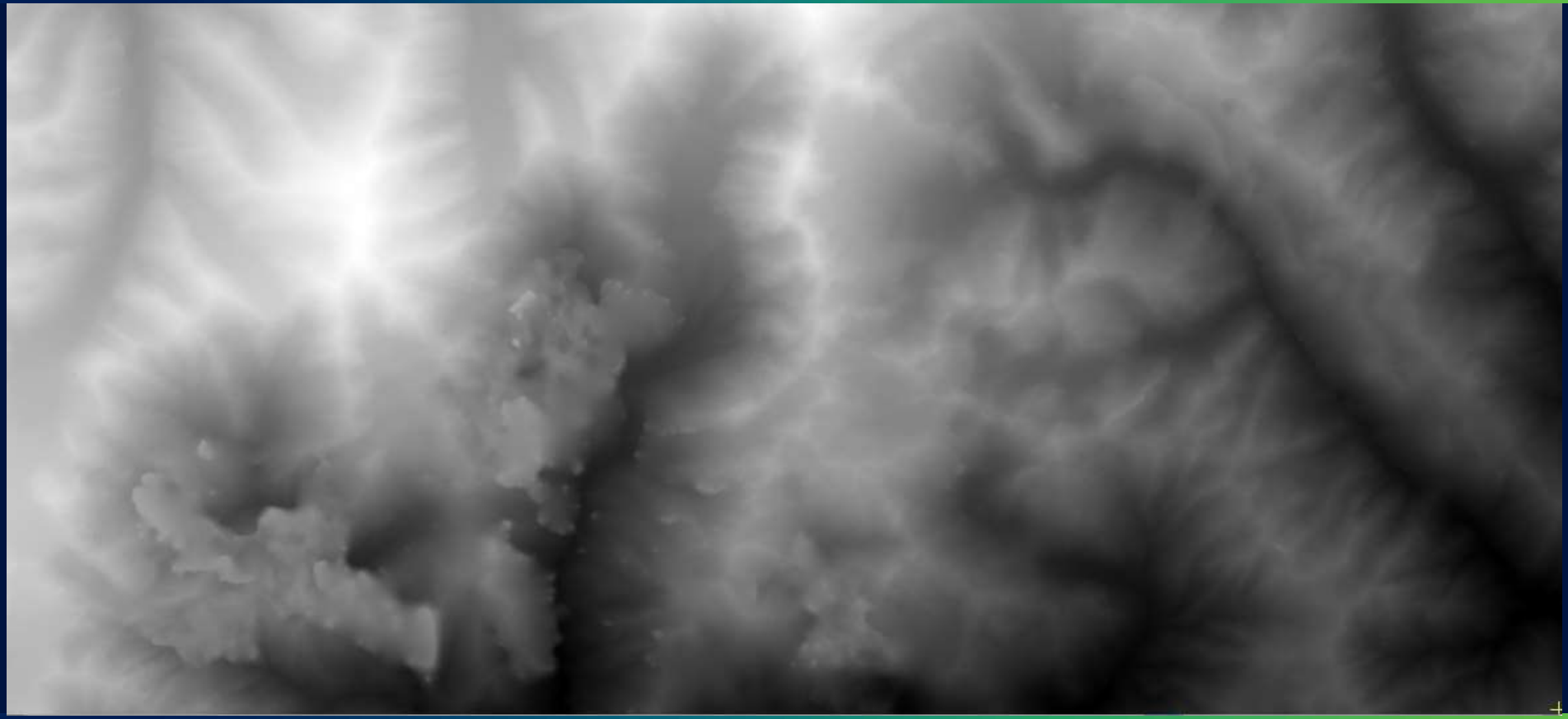
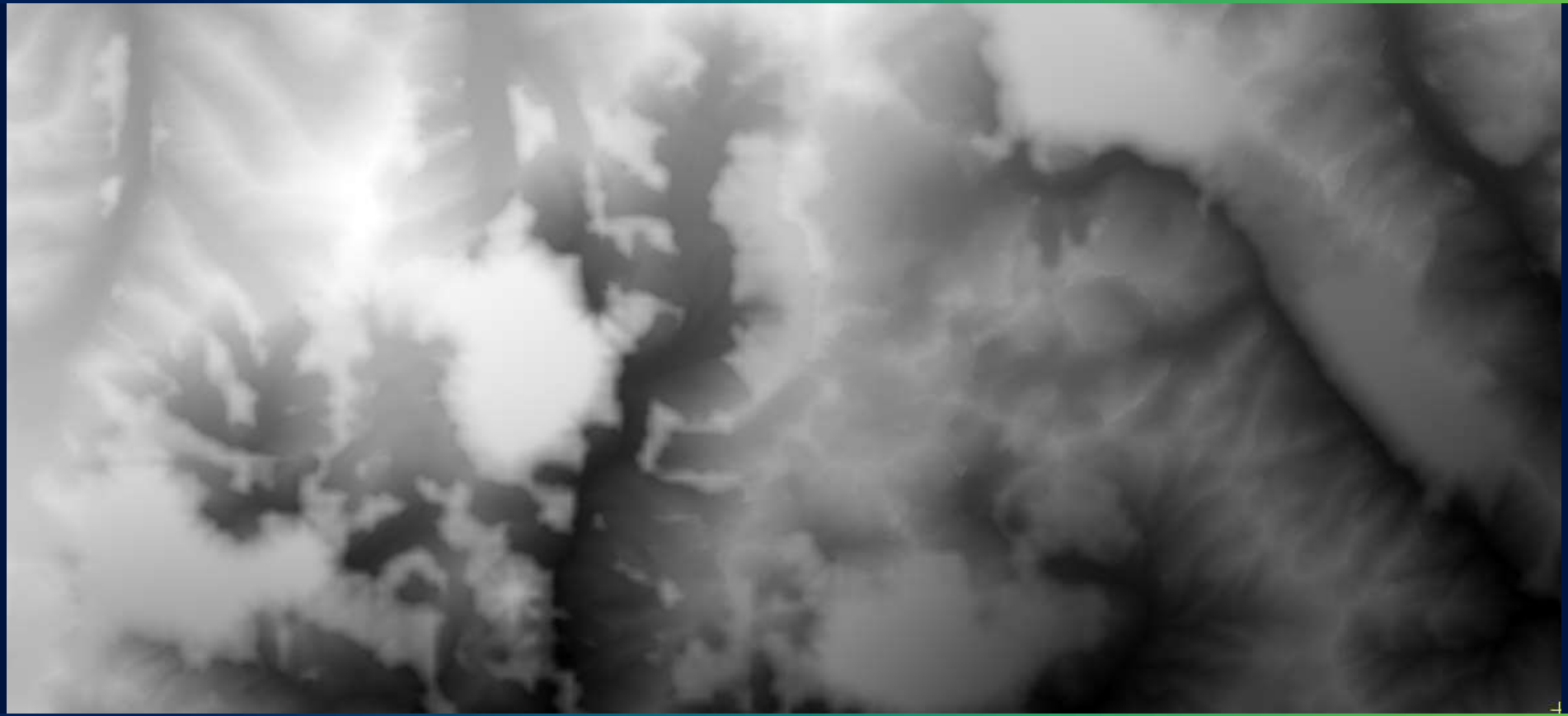
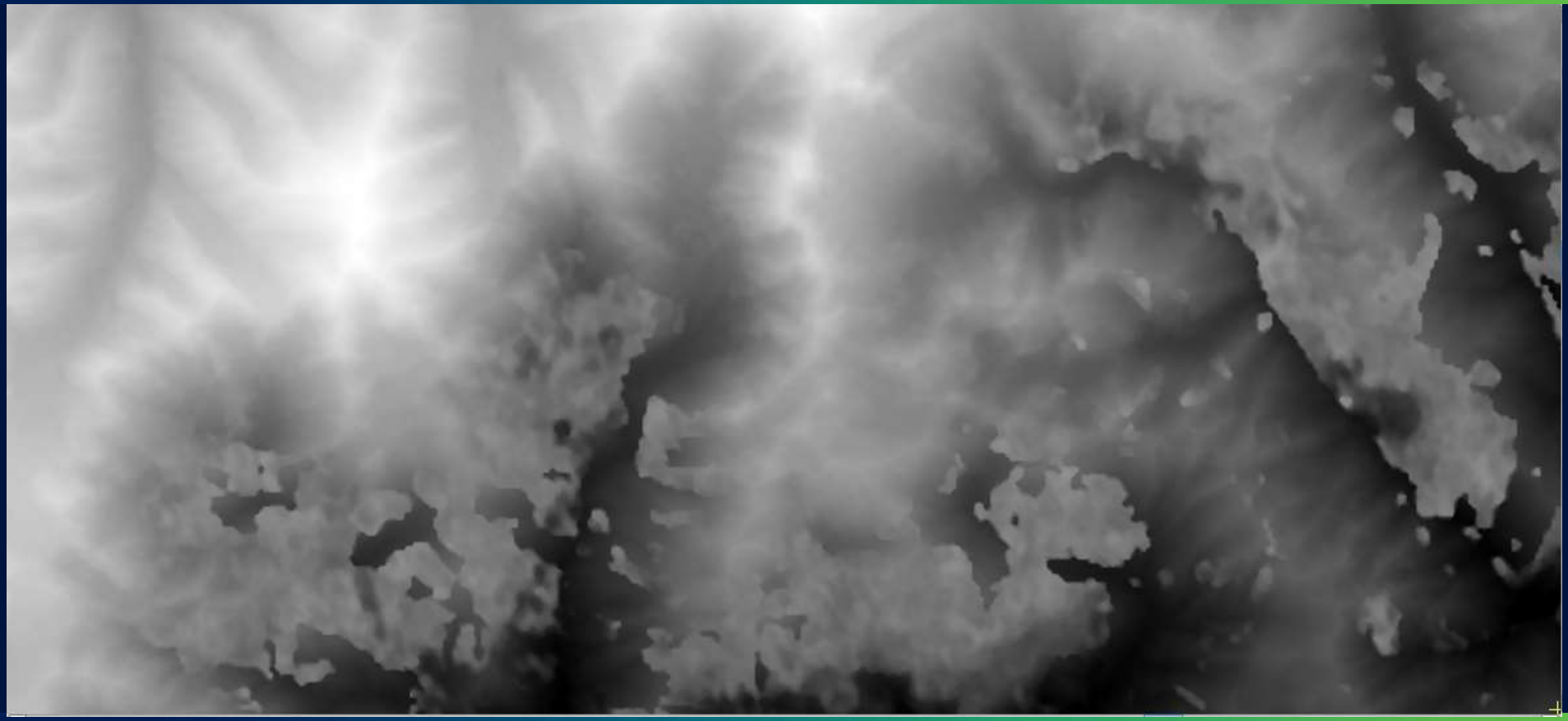


TFRM



GDEM



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

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- 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

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- 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?