Global DEM Update / Discussion

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U.S. Geological Survey, Earth Resources Observation and Science Center (EROS), Sioux Falls, South Dakota, USA

CEOS WGCV Plenary
May 16 to 19, 2017

→ **WGCV / Terrain Mapping Subgroup**
→ **GEO Global DEM Task**
→ **ISPRS WG IV/3 – Global DEM Interoperability**

Activities:

- SRTM workshop / PE&RS special issue
- ASTER GDEM evaluation / IGARSS session
- ISPRS sessions (2008, 2010, 2012, 2014, 2016)

Key Participants:

- J-P. Muller (UCL), R. Crippen & M. Kobrick (NASA/JPL), T. Tadono (JAXA), D. Gesch (USGS), C. Carabajal (NASA/GSFC), M. Bernard (SPOT/Airbus), J. Slater (NGA)

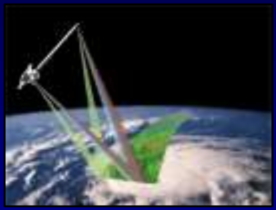
GMTED2010
250 m, 500 m, 1 km

1985

2020

Which global DEM is the best?

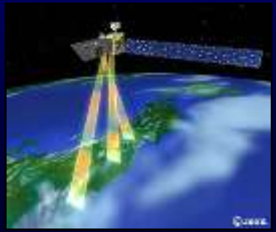
- Shuttle Radar Topography Mission (SRTM)



- ASTER Global Digital Elevation Model (GDEM)

- TanDEM-X / WorldDEM

- PRISM / ALOS World 3D




SRTM
Shuttle Radar Topography Mission
SHUTTLE RADAR TOPOGRAPHY MISSION
SRTM
NIMA NASA JPL DLR ASI
NASA
JPL
NATIONAL IMAGERY AND MAPPING AGENCY
USGS
-Archive
-Distribution
-Applications

SRTM – Mission Overview

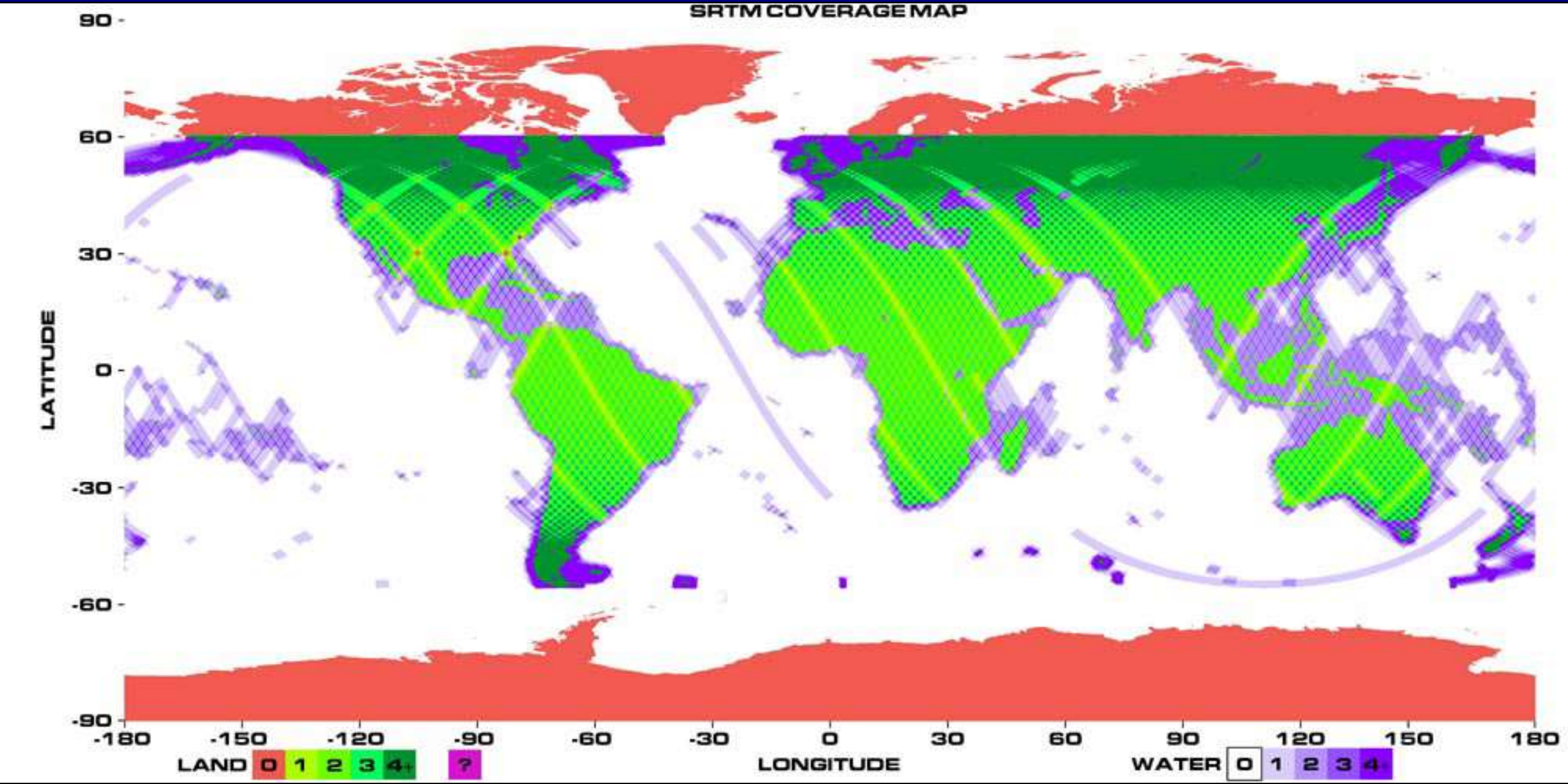
- 11-day Space Shuttle Endeavour mission in February 2000
- Based on SIR-C/X-SAR imaging radar flown in April and October 1994
- Joint NASA – NGA project to produce digital topographic data
  - Data points spaced every 1-arc-second (30-meters) for 80% of Earth's land surface
  - Absolute vertical accuracy specification: 16 meters (at 90% confidence)

(http://www2.jpl.nasa.gov/srtm/index.html)


ROCKETS AND MISSILES

SRTM – Mission Overview

- SRTM collected nearly 80% of the Earth's land surface (60ºN to 56ºS latitude)



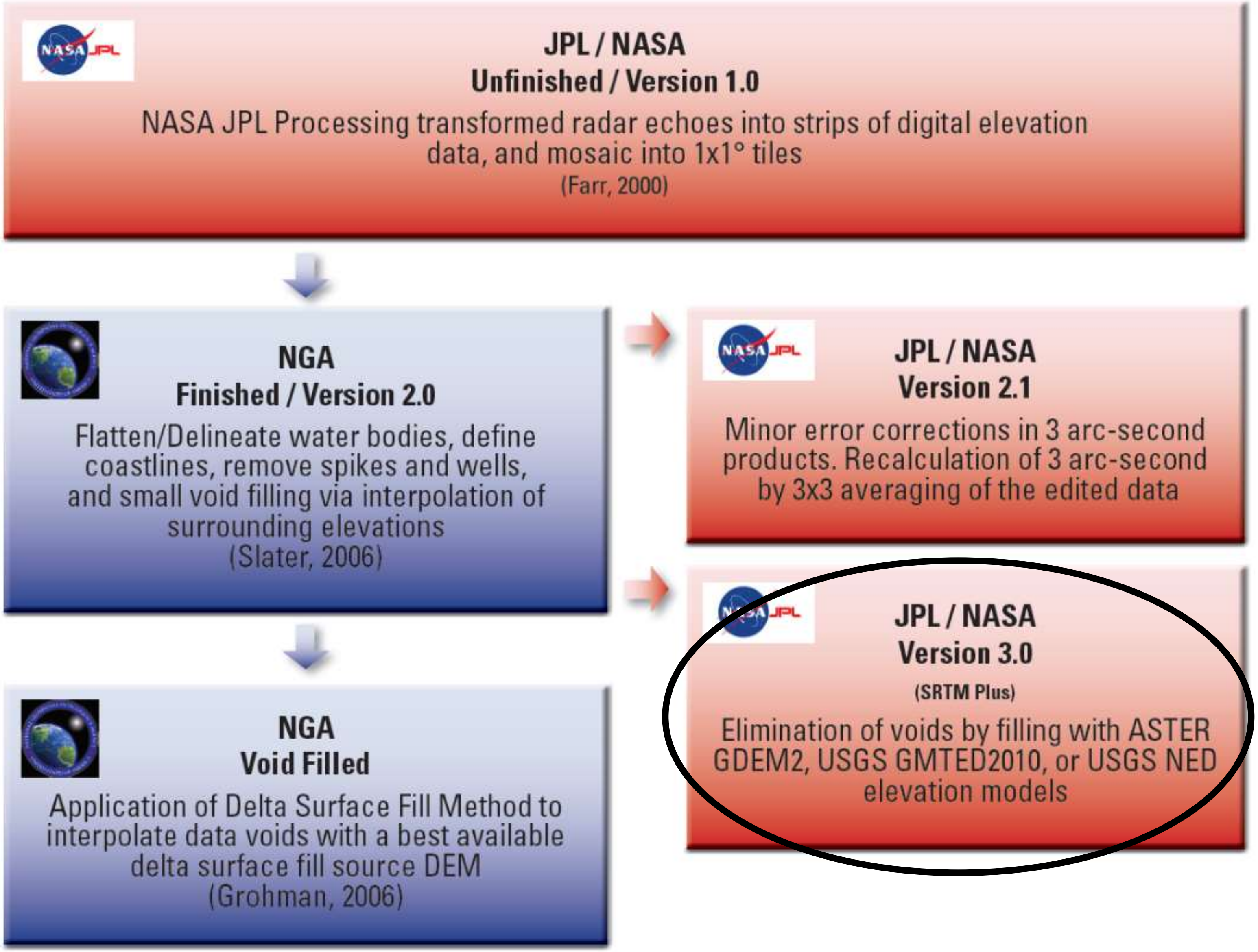
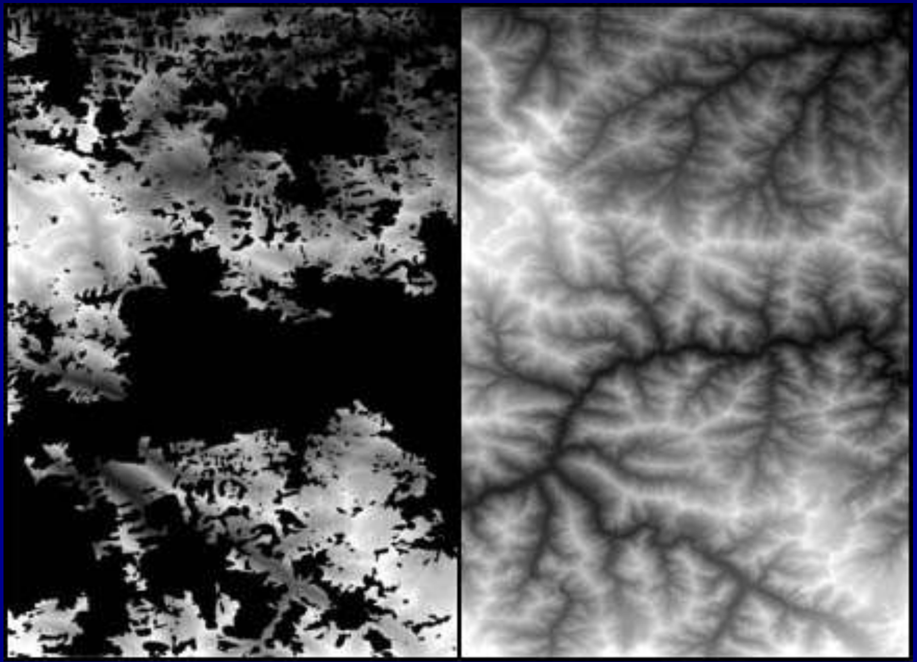


Figure 2: Genealogy of the SRTM versions

https://lpdaac.usgs.gov/sites/default/files/public/measures/docs/NASA_SRTM_V3.pdf

"SRTM Plus" Digital Elevation Model

(SRTM NASA Version 3)
LPDAAC Release November 20, 2013



SRTM Version 2
with voids

"SRTM Plus"
(Voids filled)

N36 E78: Southwest China
Elevation shown as brightness

Shuttle Radar Topography Mission DEM was void-filled primarily with the ASTER GDEM.

A novel error-detector was used to avoid cloud glitches in GDEM.

The USGS GMTED2010 or National Elevation Dataset (NED) was then used as the secondary fill.

A modified "Delta Surface Fill" algorithm produced the seamless DEM merger at one-arc-second postings.
(Released at 3-arc-seconds)

Crippen / Kobrick, JPL

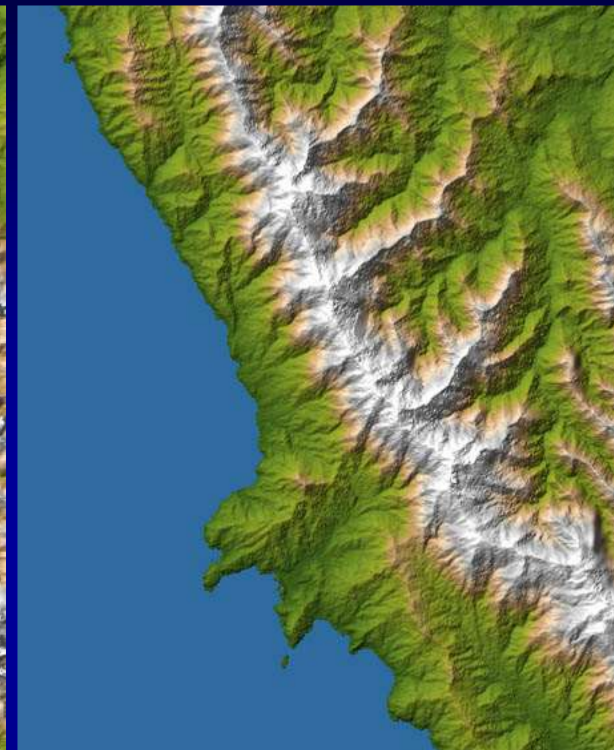
"SRTM Plus": Synergism of inputs for a superior DEM

SRTM Version 2

Voids &
Water-Mask Errors

GDEM

Clouds &
Shoreline Errors



"SRTM Plus"

<u>Clean Shoreline</u>,
<u>No Clouds</u>

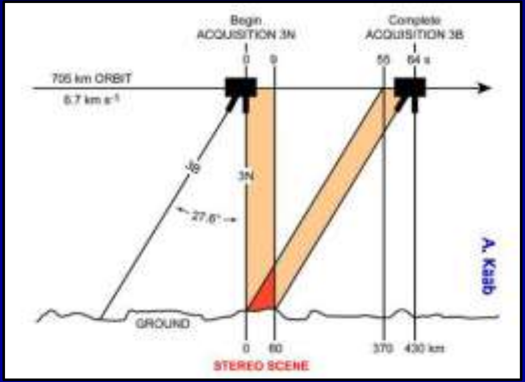
"SRTM Plus" also includes a 'NUM' (number) file that identifies the data source and number of data takes (ASTER scenes or SRTM swaths) for each pixel.

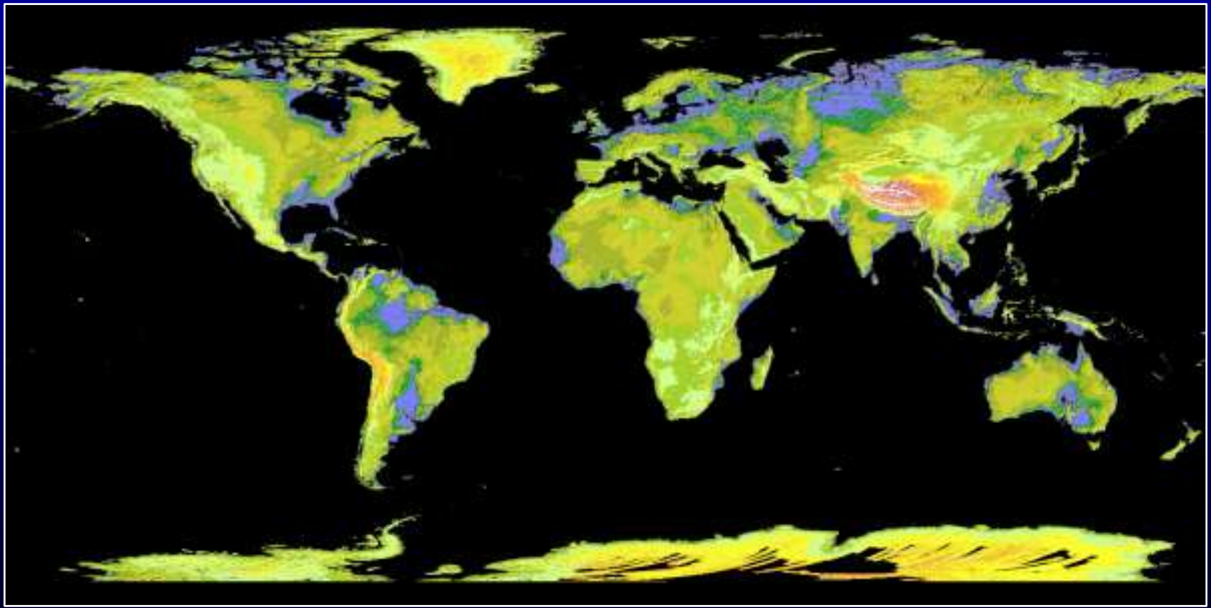
Southeast Panama

Crippen / Kobrick, JPL

ASTER Global Digital Elevation Model (GDEM)

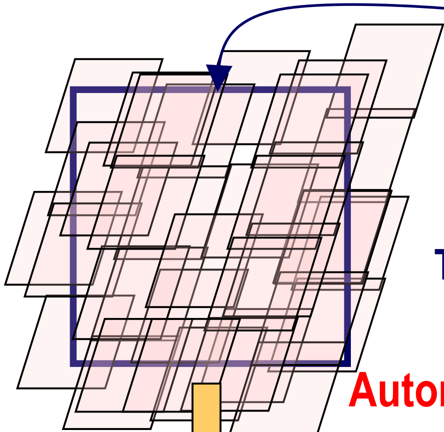
- 1-arc-sec (30-m) data for land areas ±83°
  - Release dates:
    - Version 1 – 2009
    - Version 2 – 2011
    - Version 3 – 2017?





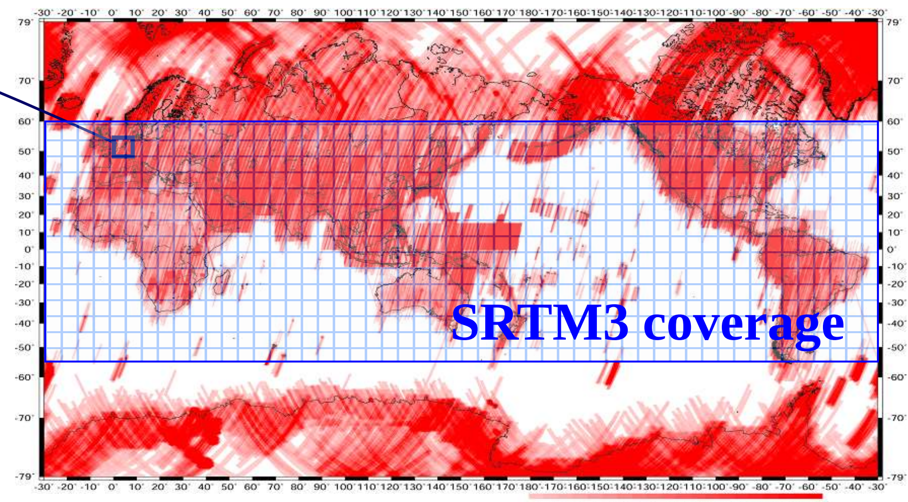
Methodology

1. Stereo-correlate entire ~ 1.5 million scene ASTER Archive; 2. Cloud mask to remove cloudy pixels; 3. Stack all DEMS & remove residual bad values and outliers; 4. Partition data into 1° x 1° tiles ---



ASTER scene (60km x 60km)

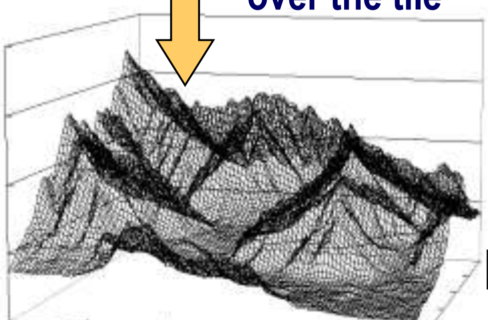
Tile (1 arc degree square)



ASTER coverage (~1.5 million scenes in summer 2008)
Deeper red indicates more data accumulated.

Automated processing

Generation of a seamless tile of DEM using all ASTER data ever acquired over the tile



A seamless Tile of DEM

Global coverage

ASTER GDEM

Contribution to GEOSS

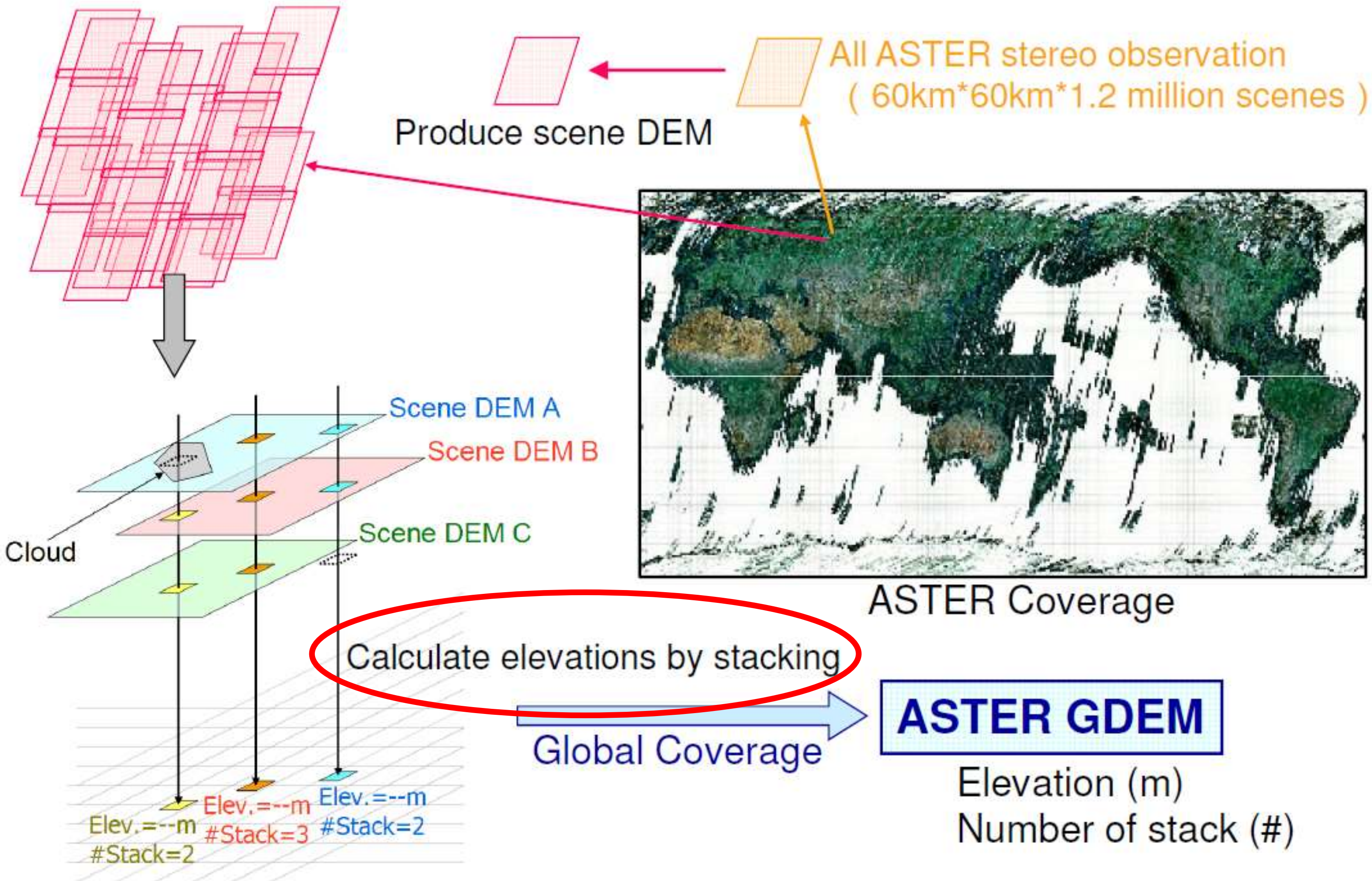
Both US and Japan committed to contribute to GEOSS at Capetown Summit 2007.

経済産業省 METI Ministry of Economy, Trade and Industry

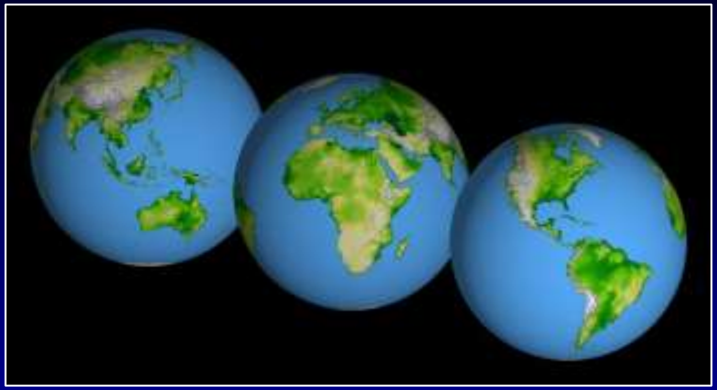
(Courtesy of B. Bailey)

SILC Sensor Information Laboratory Corp.

ASTER GDEM Production



(Courtesy of T. Tachikawa)



Question: What is a deep, dark secret about global DEMs?

Answer: Grid spacing ≠ true spatial resolution!

GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 9, 1467, doi:10.1029/2002GL016643, 2003

Accuracy and resolution of shuttle radar topography mission data

Bridget Smith and David Sandwell
IGPP, Scripps Institution of Oceanography, USA

Smith and Sandwell, 2003

Geomorphometry from SRTM: Comparison to NED

Peter L. Guth

Abstract

The Shuttle Radar Topography Mission (SRTM) produced

Terrain Parameters from DEMs

Geomorphometric DEM parameters include point a

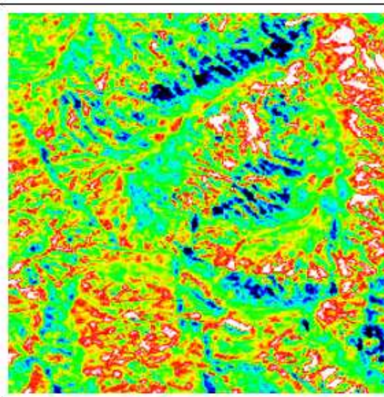
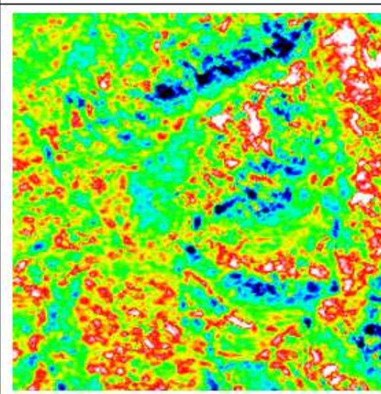
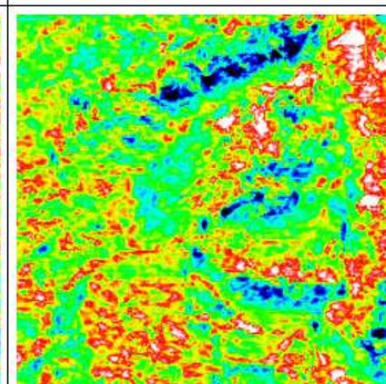
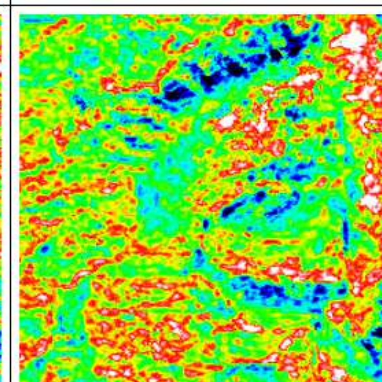
Guth, 2006

Evaluation of the Horizontal Resolution of SRTM Elevation Data

Leland Pierce, Josef Kellndorfer, Wayne Walker, and Oton Barros

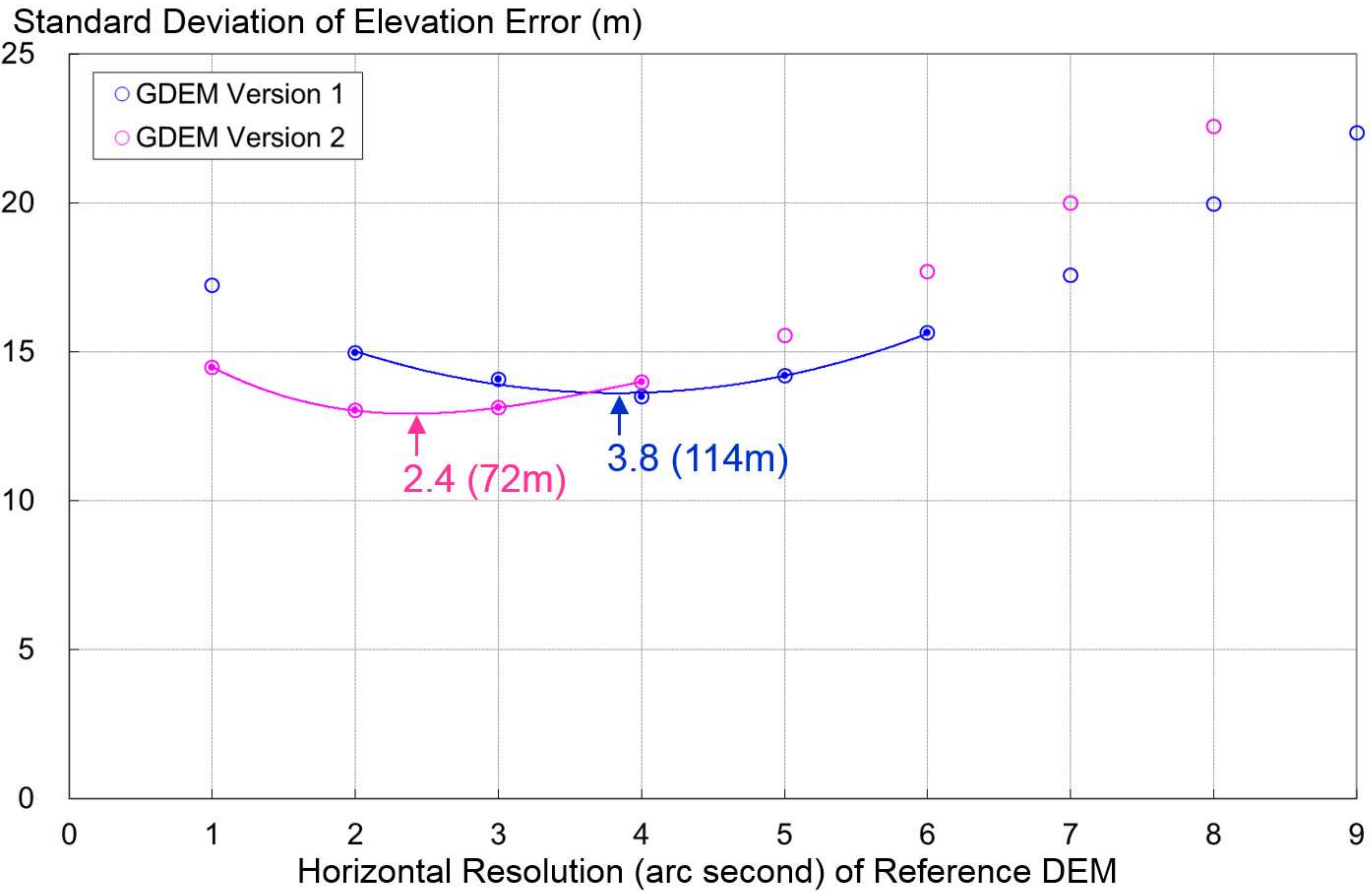
Pierce et al., 2006

Method to Estimate Resolution

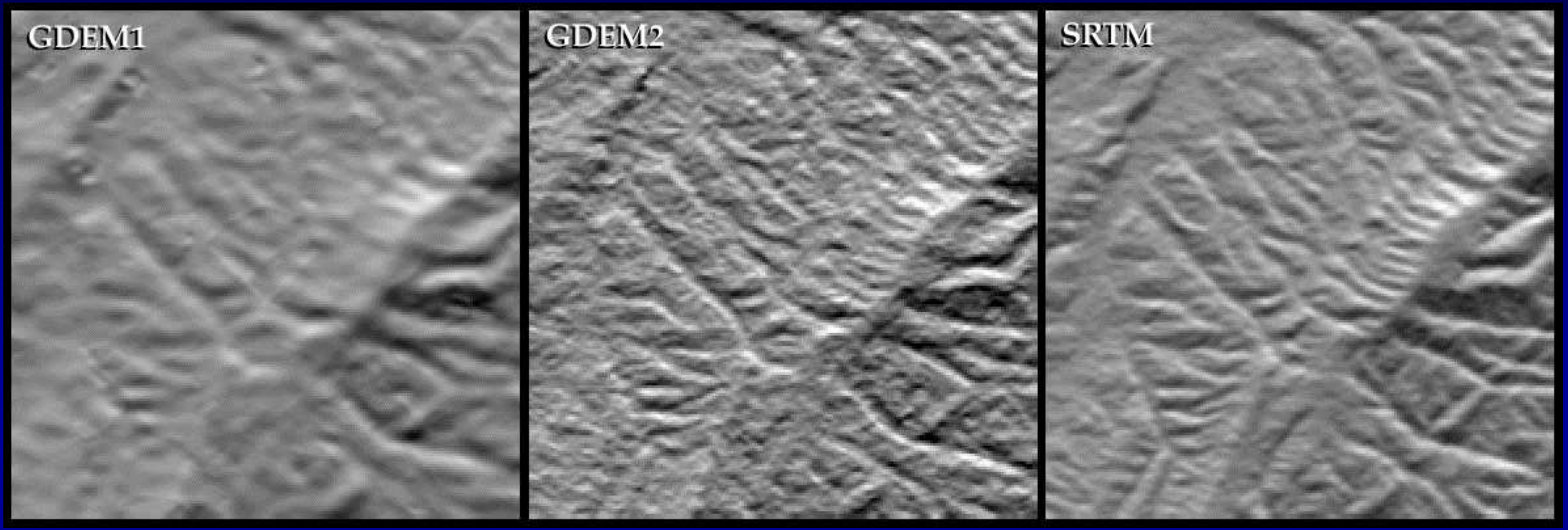
GDEM  0 4000 m	**Version 2**			**Version 1**
Reference DEM (Degraded 10m DEM)  0 4000 m	Resolution: **1** arc-sec 	Resolution: **2** arc-sec 	Resolution: **3** arc-sec 	Resolution: **4** arc-sec 
Elevation Error  -50 m 0 +50 m				
Standard Dev.	14.489	13.022	13.122	13.993

(Courtesy of T. Tachikawa)

Estimated Resolution



Resolution



	GDEM1	GDEM2	SRTM
	9x9 kernel	5x5 kernel	
Res =	121 m	82 m	77 m

West Virginia: Keyser-Romney area

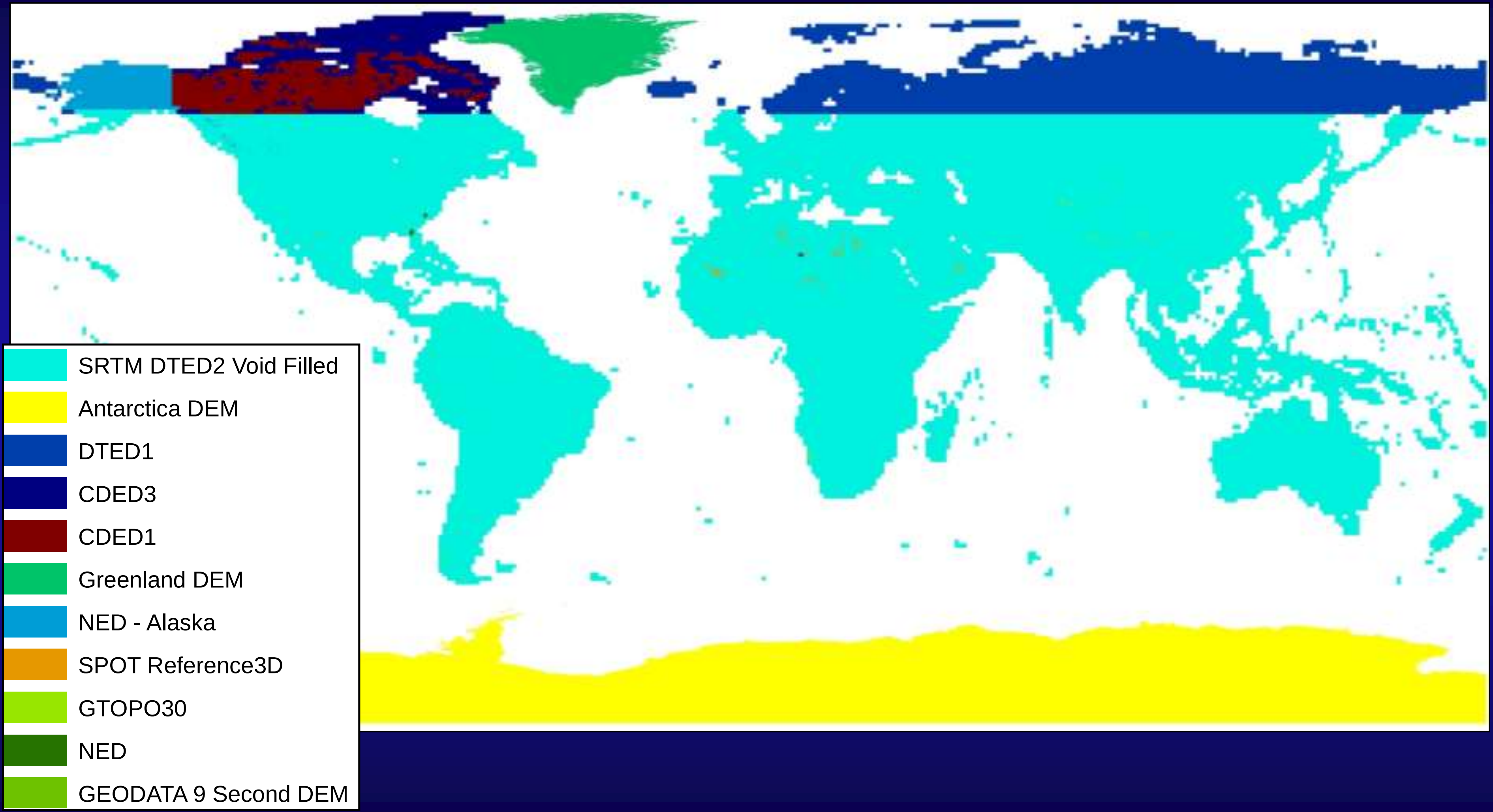
But at its best, GDEM2 nearly matches SRTM 1-arc-second data.

(Courtesy of R. Crippen)

Global Multi-resolution Terrain Elevation Data (GMTED2010)

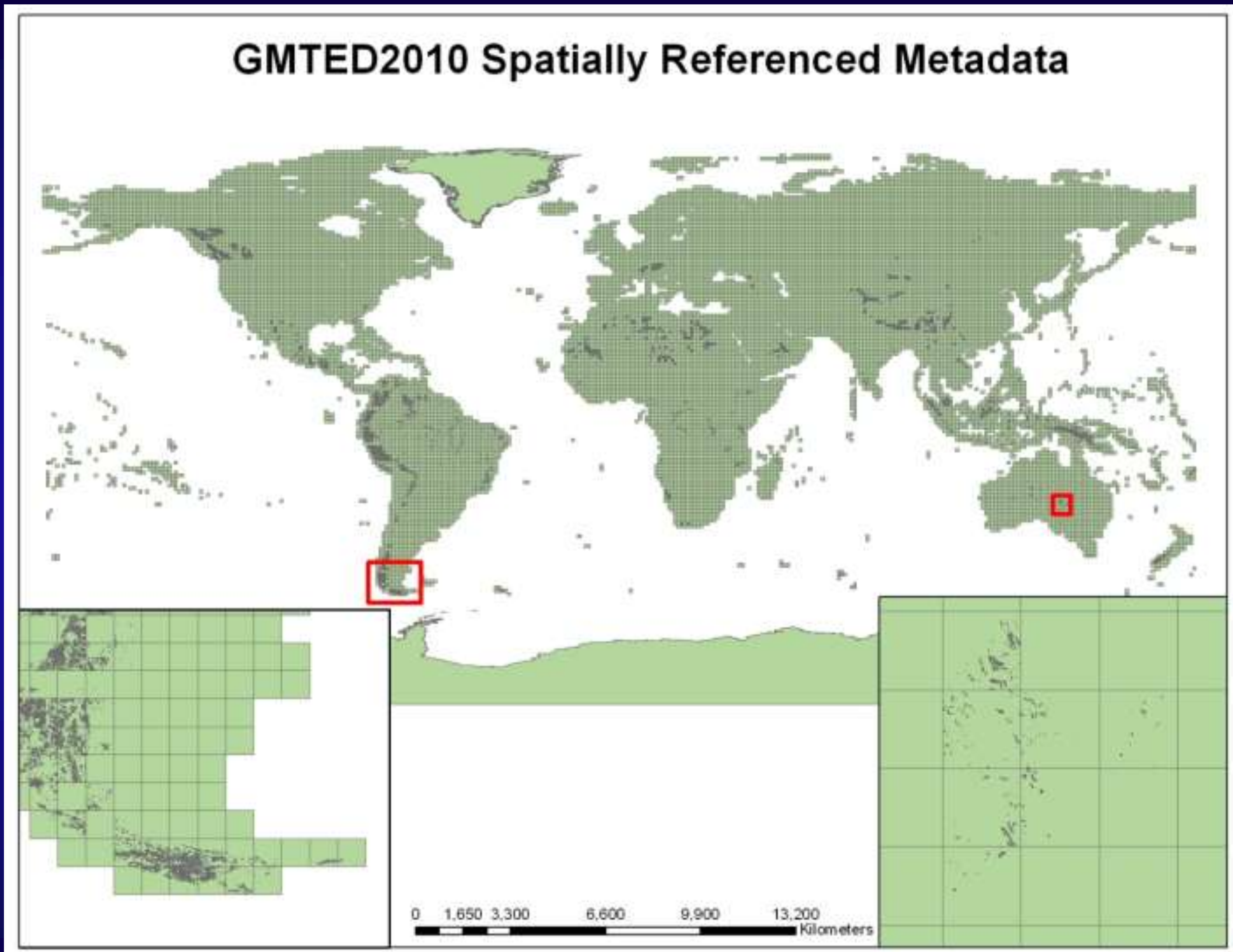
- A global DEM to replace GTOPO30:
  - Multiple elevation layers at three grid spacings:
    30-arc-sec (1 km), 15-arc-sec (500 m) 7.5 arc-sec (250 m)
  - Derived from "best available" higher resolution data:
    - SRTM (void-filled), 1-arc-second
    - Canadian Digital Elevation Data (CDED), 0.75 and 3-arc-second
    - U.S. National Elevation Dataset (NED), 1 and 2-arc-second
    - Digital Terrain Elevation Data (DTED®), 3-arc-second
    - SPOT Reference3D®, 15-arc-second
    - Australia GEODATA, 9-arc-second
    - University of Bristol Greenland radar altimeter DEM, 30-arc-sec
    - University of Bristol Antarctica ERS-1 radar altimeter and ICEsat laser altimeter DEM, 30-arc-second

GMTED2010 Source Data



(Courtesy of J. Danielson)

GMTED2010 Spatially Referenced Metadata

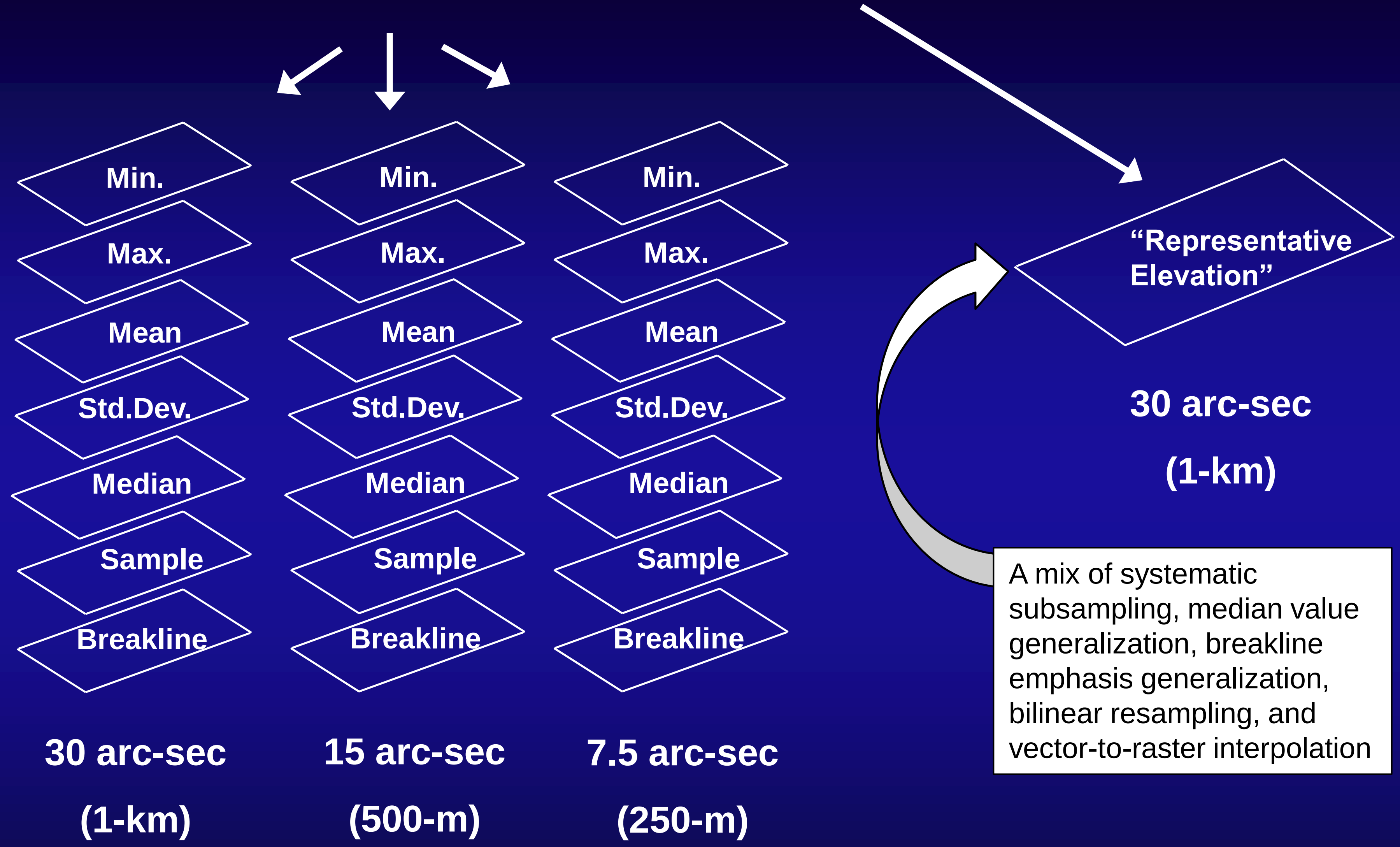


Field	Value
FID	792
Shape	Polygon
ID	793
SOURCE_ORG	NGA
SOURCE	SRTM DTED2 Void Filled
EL_SURFACE	Reflective
NORTH	-27
SOUTH	-28
WEST	121
EAST	122
X_SRCE_RES	1
Y_SRCE_RES	1
HORZ_UNIT	Second
COORD_SYS	Geographic
HORZ_DATUM	WGS 84
VERT_DATUM	EGM96
VERT_UNIT	Meter
MIN_ELEV	307
MAX_ELEV	629
MEAN_ELEV	497.64
SDEV_ELEV	45.231
PROD_DATE	31May2008

Metadata fields and values captured at full resolution from the input source data

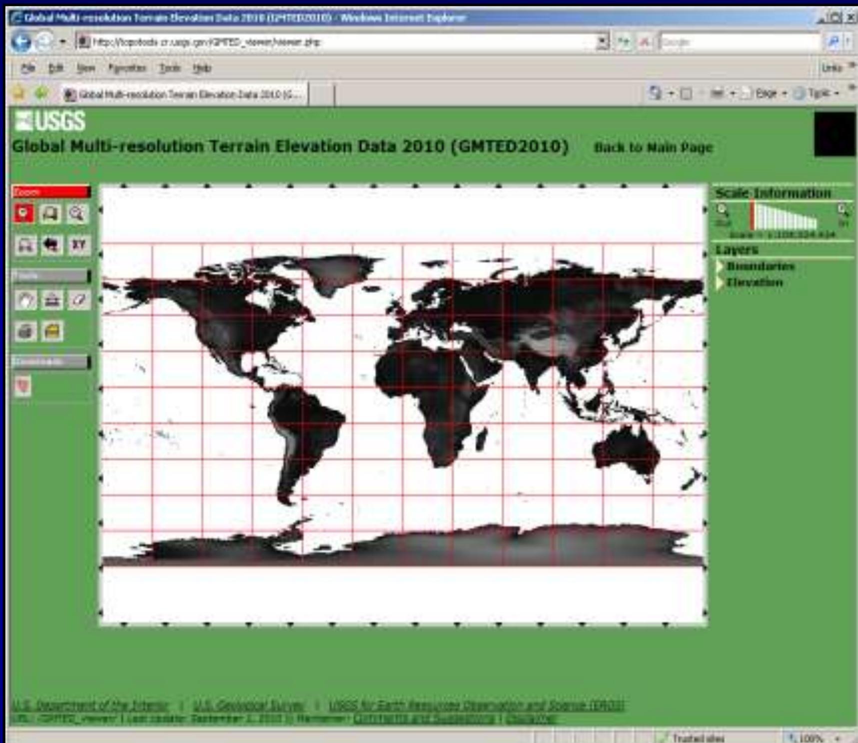
(Courtesy of J. Danielson)

GMTED2010 vs. GTOPO30

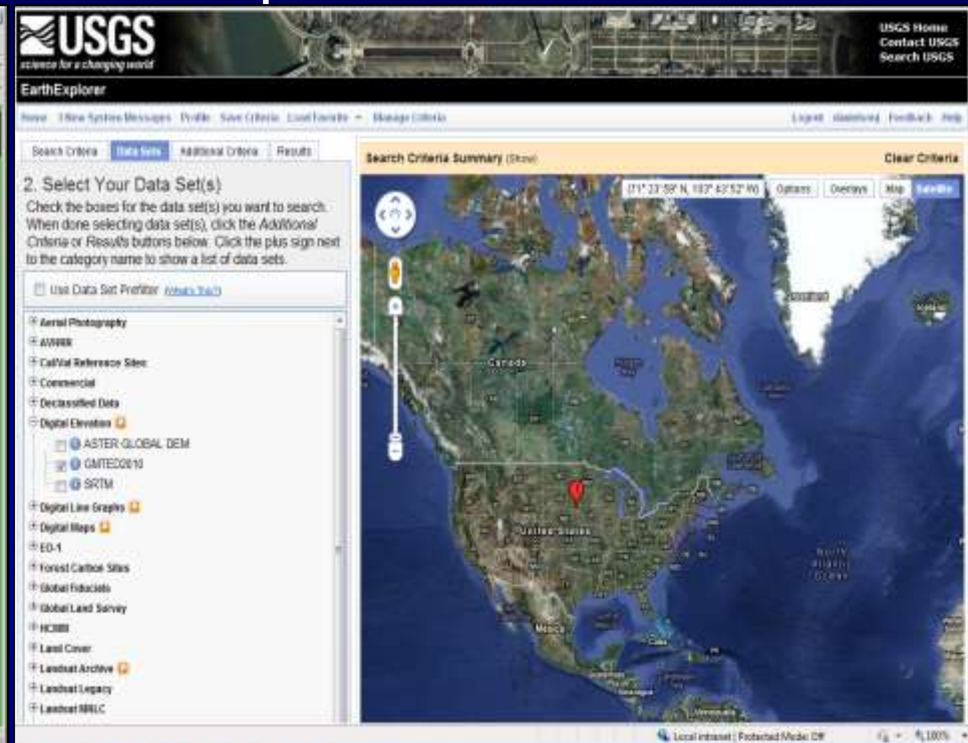


GMTED2010 - Public Release in August 2011

GMTED2010 Viewer



Earth Explorer



https://lta.cr.usgs.gov/GMTED2010

http://topotools.cr.usgs.gov/GMTED_viewer/

http://earthexplorer.usgs.gov/

(Courtesy of J. Danielson)

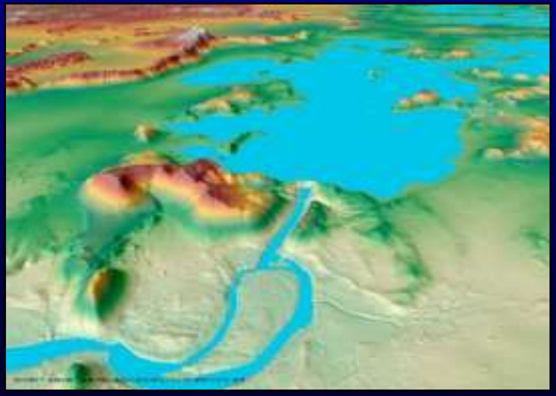
TanDEM-X

(TerraSAR-X add-on for Digital Elevation Measurement)

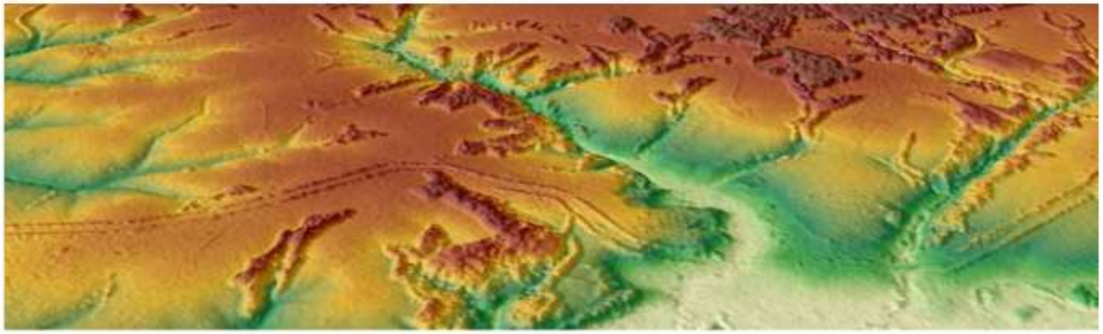
- TanDEM-X is an extension of the TerraSAR-X mission with a second satellite flying in close formation
  - X-band SAR interferometry system
  - Flying in formation since 2010, collected data for global DEM for four years
  - Completion of global DEM in 2016

TanDEM-X

- Mission objective:
  - Global DEM at 0.4-arc-second (12-m) grid spacing
    - *90-m free version to be available*
  - Accuracy specifications:
    - Absolute vertical: 10 m (linear error at 90% confidence)
    - Relative vertical (point-to-point within 1°x1° tile):
      - 2 m (slopes < 20%)
      - 4 m (slopes > 20%)



WorldDEM™: The New Standard of Global Elevation Models



Accuracy of a New Dimension

Pole-to-pole coverage coupled with unrivalled accuracy and quality - these are the defining characteristics of the WorldDEM. The accuracy surpasses that of any global satellite-based elevation model available today and defines a new industry standard.

WorldDEM™ in Brief:

- Superior elevation information anywhere on Earth
- Homogenous standardised pole-to-pole coverage
- Unrivalled accuracy: 2m (relative) / 4m (absolute) vertical accuracy in a 12m x 12m raster
- Easy access

WorldDEM™ is the product of the TanDEM-X Mission (TerraSAR-X add-on for Digital Elevation Measurements), realised as a Public Private Partnership (PPP) between Airbus Defence and Space and the German Aerospace Centre (DLR). Airbus Defence and Space holds the exclusive commercial marketing rights for the data and refines the elevation models according to the needs of commercial users worldwide.

Elevation Model of Choice for all Global Applications

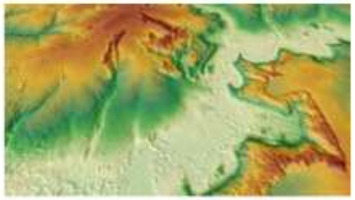
Integrating WorldDEM™ as a reliable and precise reference layer into operations and applications provides for a single confidence scale and enhances the performance of a wide range of systems and equipment.

- Enhanced responsiveness and efficiency for defence & security missions
- Improved flight safety and efficiency
- High-quality image orthorectification
- Reliable planning and operation of exploration projects
- Global availability enhances international cooperation and cross-border mission planning
- Timely intelligence for emergency response

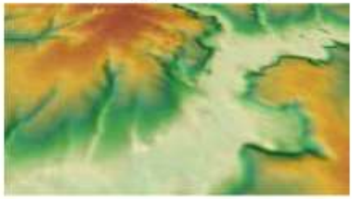
Unique Data Quality and Level of Detail

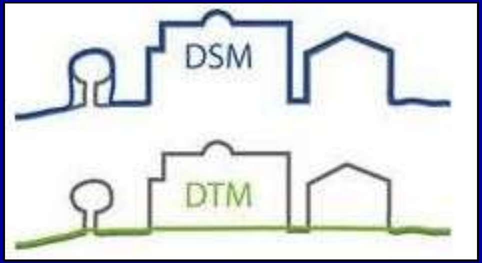
Airbus Defence and Space refines the DEM according to customer requirements and makes three WorldDEM products available:

- **WorldDEMcore**
  Unedited Digital Surface Model, usually contains radar artefacts and voids
- **WorldDEM™**
  Edited Digital Surface Model with assured hydrological consistency (editing of water bodies and shorelines, consistent flow of rivers)

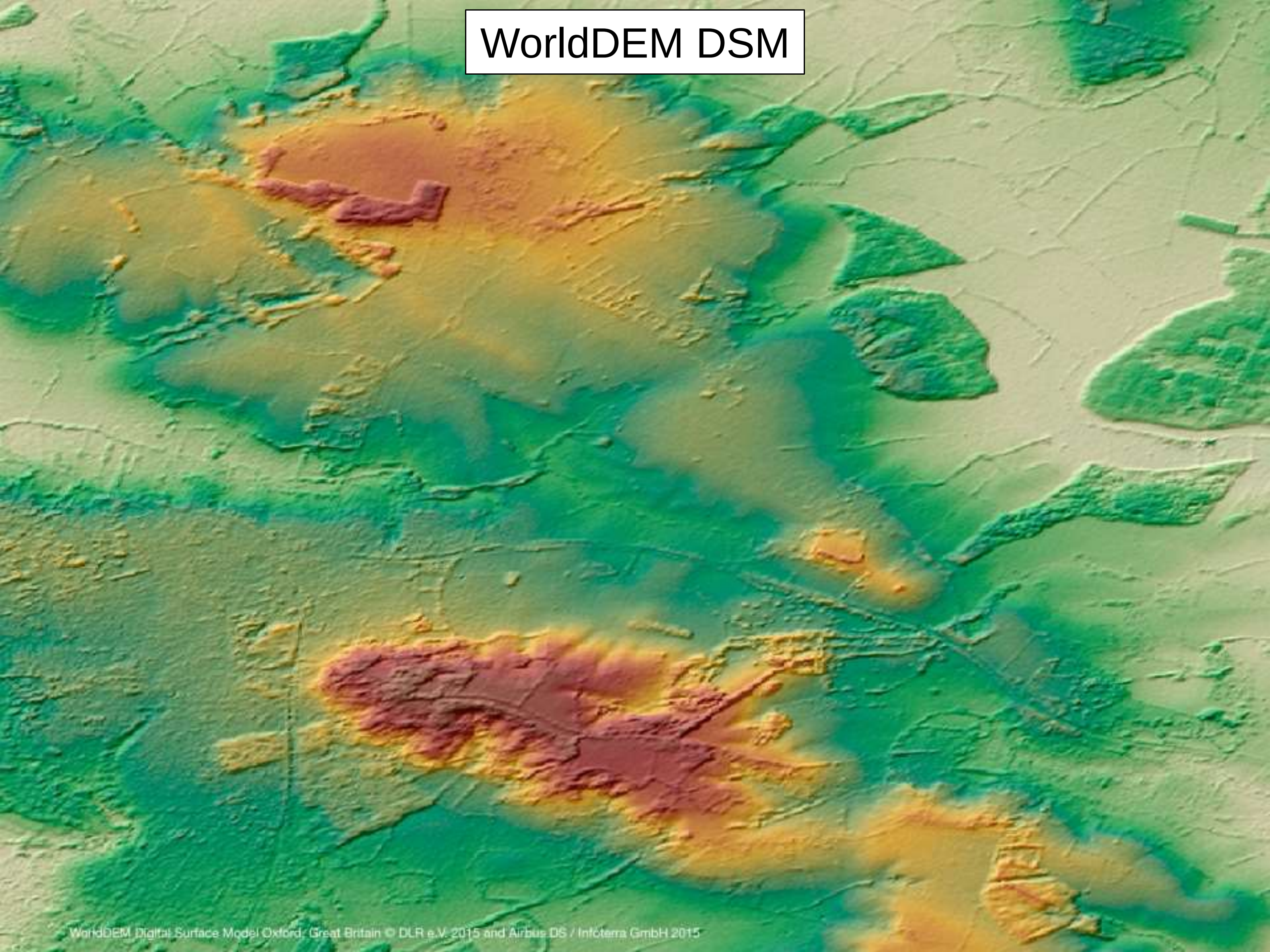


- **WorldDEM™ DTM**
  Digital Terrain Model representing the bare Earth terrain (vegetation and man-made objects removed)

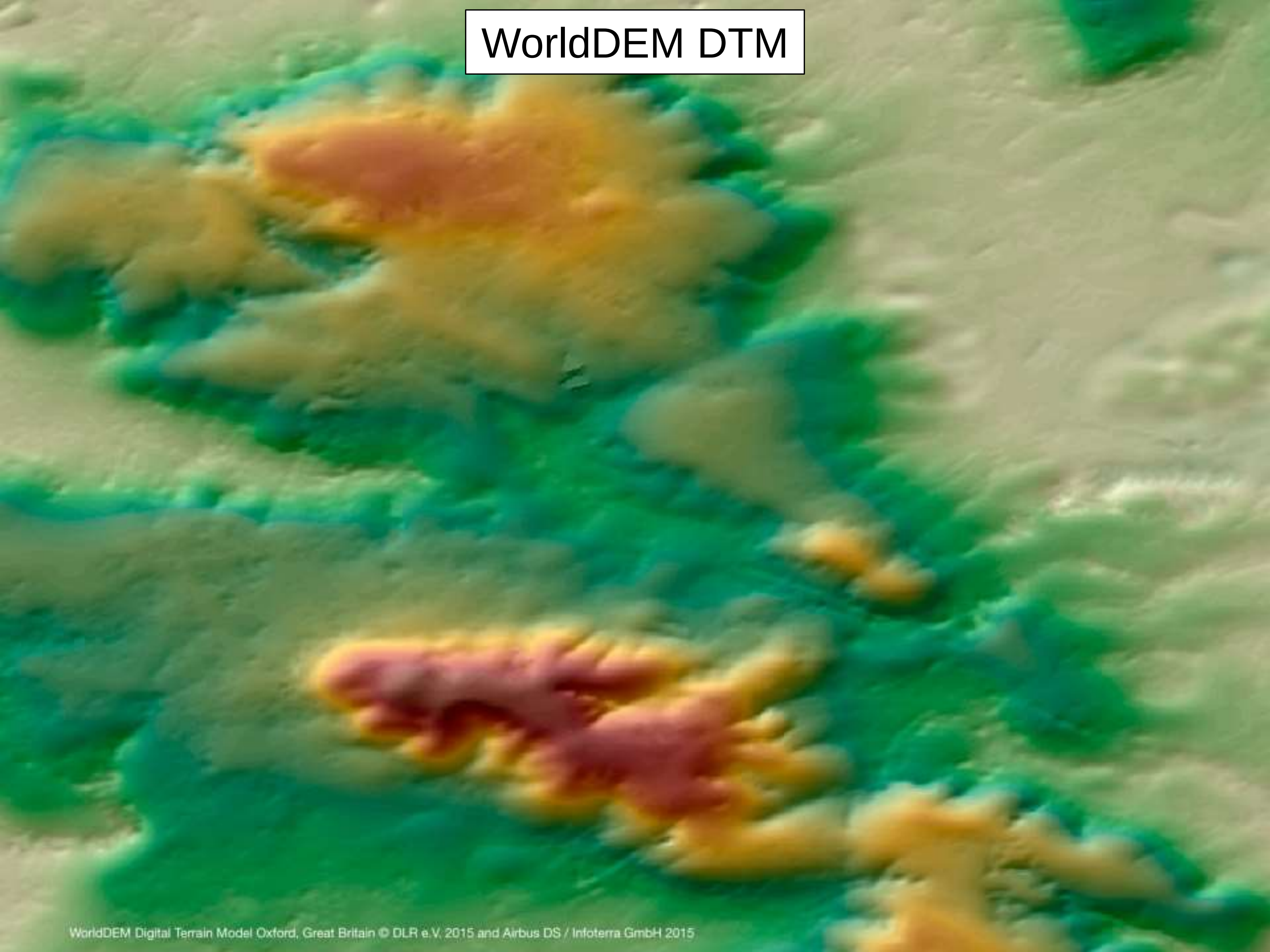




WorldDEM DSM

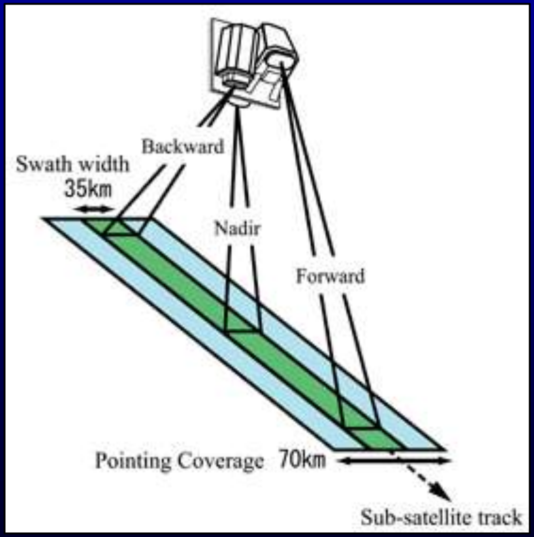


WorldDEM DTM



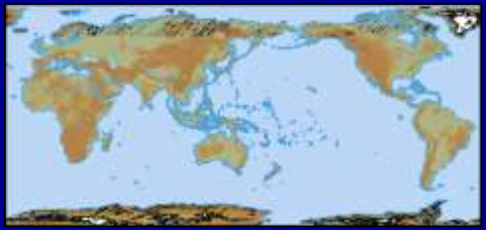
ALOS World 3D (AW3D)

- PRISM (Panchromatic Remote-sensing Instrument for Stereo Mapping)
  - On board ALOS (Advanced Land Observing Satellite)
  - Stereo-optical image data (2.5-m resolution)
    - Stereo triplets: nadir, +23.8°, -23.8°

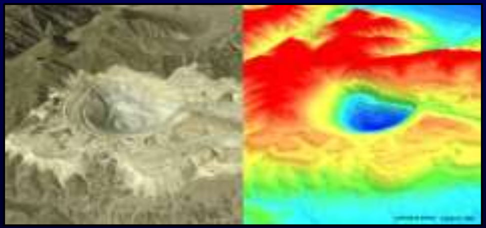


ALOS World 3D (AW3D)

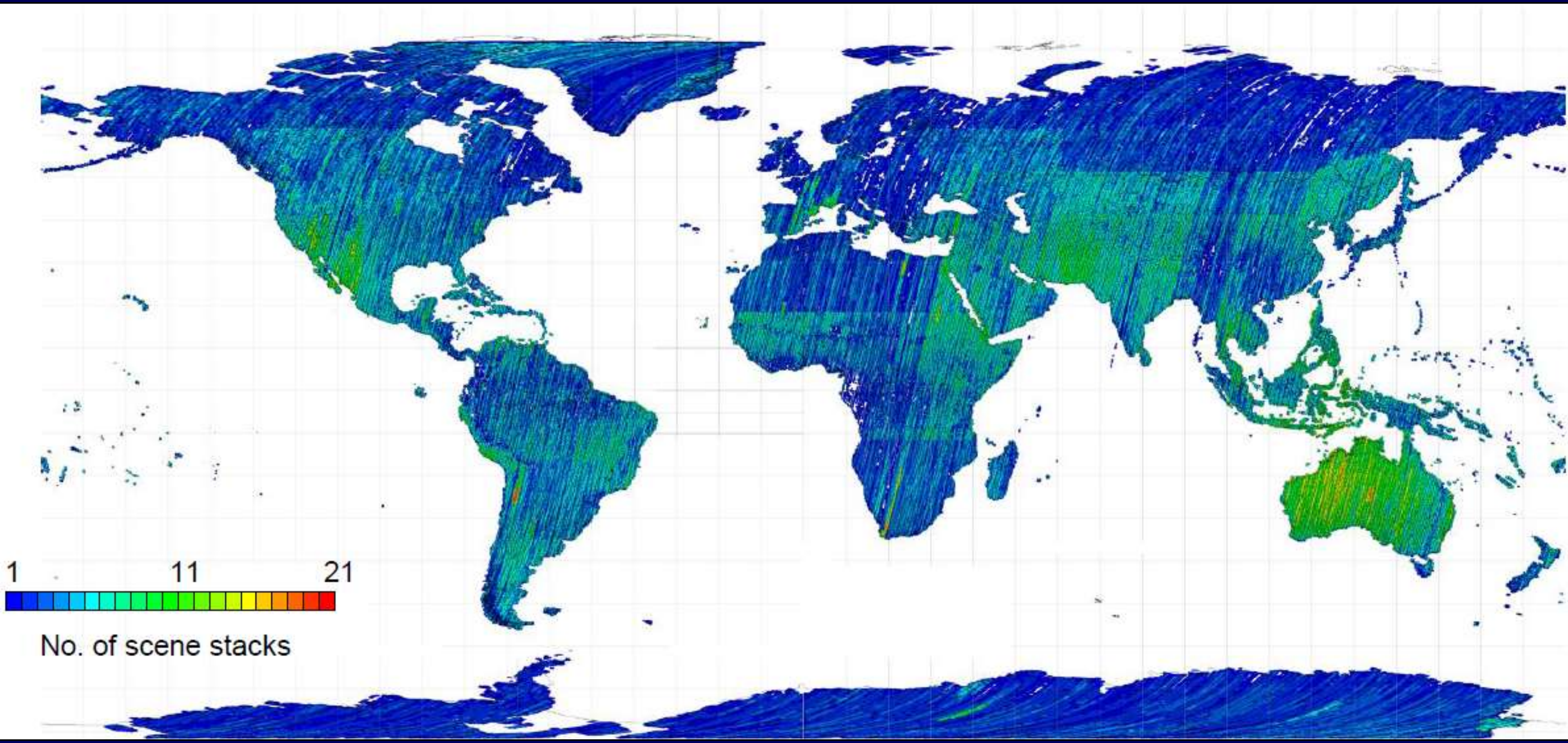
- PRISM collected 3 million scenes (<30% cloud cover) across the globe in 2006-2011
- Global DEM (DSM) specifications:
  - Grid spacing = 0.15-arc-sec (5-m)
    - *30-m free version is available*



  - Absolute vertical accuracy = 5 m (RMSE)
  - Absolute geolocation accuracy = 5 m (RMSE)
  - Production uses stacking (averaging) method
  - Completion of global DEM in 2016

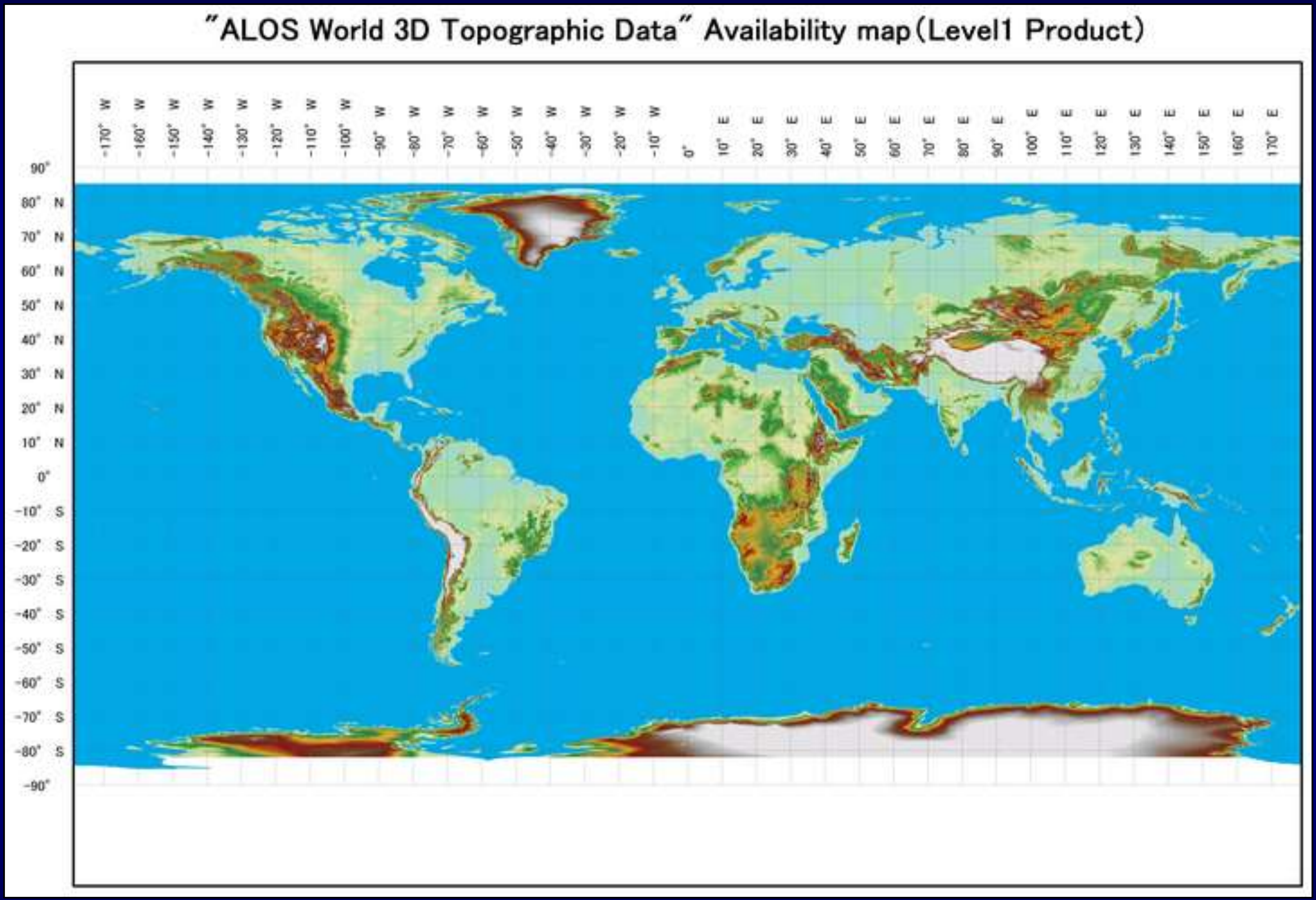


PRISM Stereo Scenes for AW3D



(Courtesy of T. Tadono)

ALOS World 3D – Current Coverage



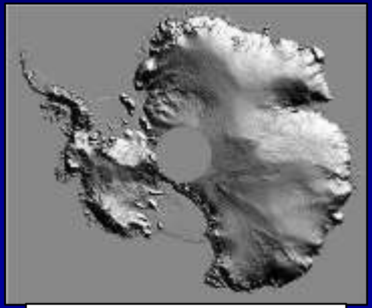
Data are distributed commercially by NTT DATA Corporation and RESTEC

ICESat (Ice, Cloud, and land Elevation Satellite) - GLAS (Geoscience Laser Altimeter System)

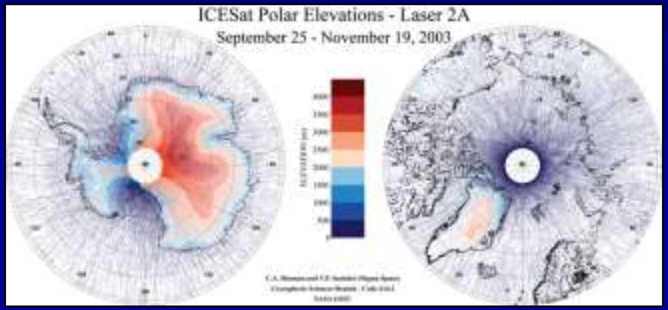
- Operated 2003 – 2009 (±86 degrees latitude)
- 70-m laser footprint spaced every 170 m along profile
  - Better than 10-cm vertical accuracy in best cases, usually around a meter or better in many cases
- Used extensively for <u>*validation*</u> of global DEMs
  - SRTM, ASTER GDEM, GMTED2010, PRISM (AW3D), TanDEM-X
- Used for production processing of global DEMs
  - PRISM (AW3D), TanDEM-X, NASADEM

ICESat / GLAS

- Convergence of ICESat's orbital paths near the poles resulted in close spacing of laser profiles allowing for generation of gridded continuous surface DEMs



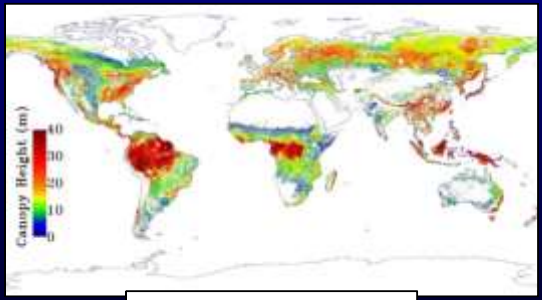
Antarctica 500-m DEM



Greenland 1-km DEM

- ICESat full waveform data can be processed to derive multiple surfaces within the laser footprint (ground level and vegetation canopy top), which has been exploited for global forest height mapping

(Lefsky, 2010)

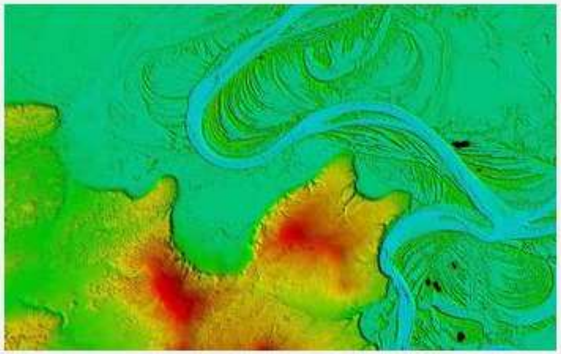


(Simard et al., 2011)

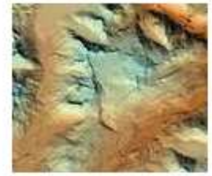
News Release 16-101

NSF, NGA release first unclassified digital elevation models of Alaska

High-resolution maps, issued in support of White House Arctic initiative, will aid researchers in studying range of issues, including effects of climate change



A digital elevation model of the 425-mile-long Koyukuk River, a tributary of Alaska's Yukon River.
Credit and Larger Version



Wolverine Glacier, a valley glacier in the mountains of south-central Alaska's Kenai Peninsula.
Credit and Larger Version

September 1, 2016

The National Science Foundation (NSF) and the National Geospatial-Intelligence Agency (NGA) have publicly released new three-dimensional topographic maps of Alaska in support of a White House Arctic initiative to inform better decision-making in the Arctic.

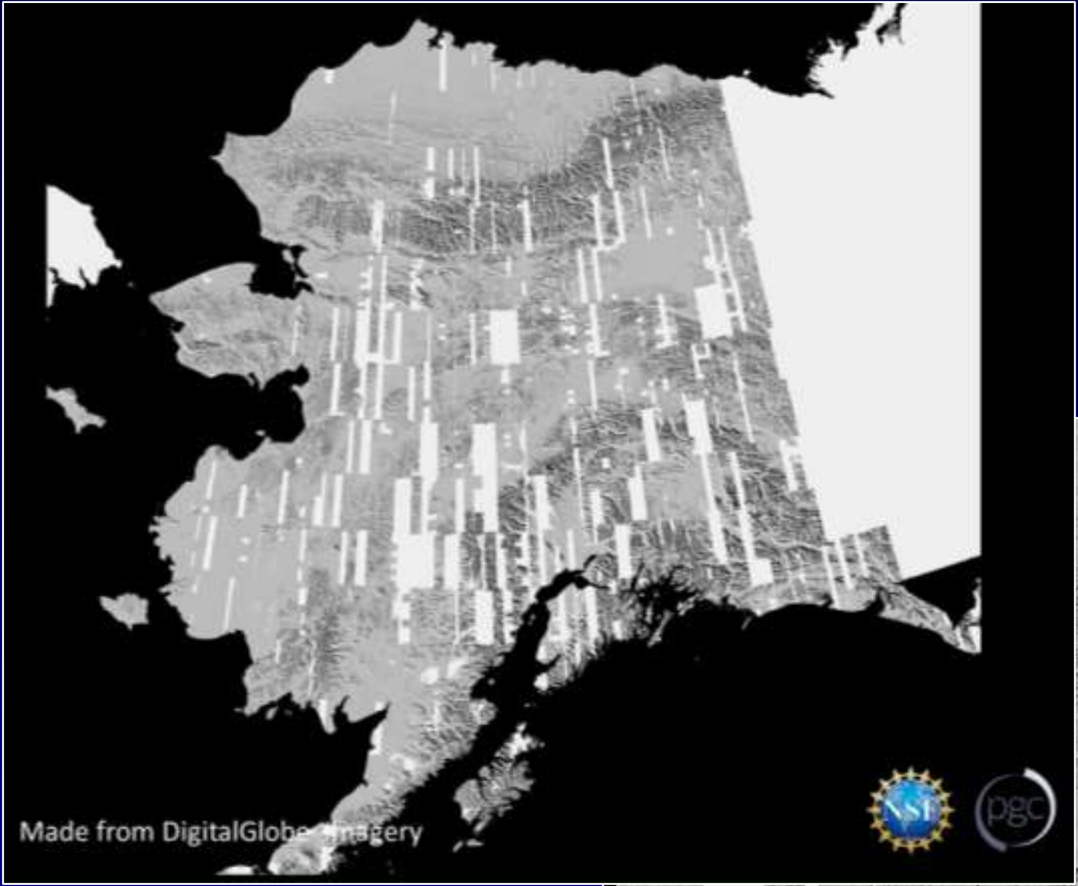
The digital elevation models, or DEMs, are the first maps to be released by the ArcticDEM project, which was created after a January 2015 executive order calling for enhanced coordination of national efforts in the Arctic.

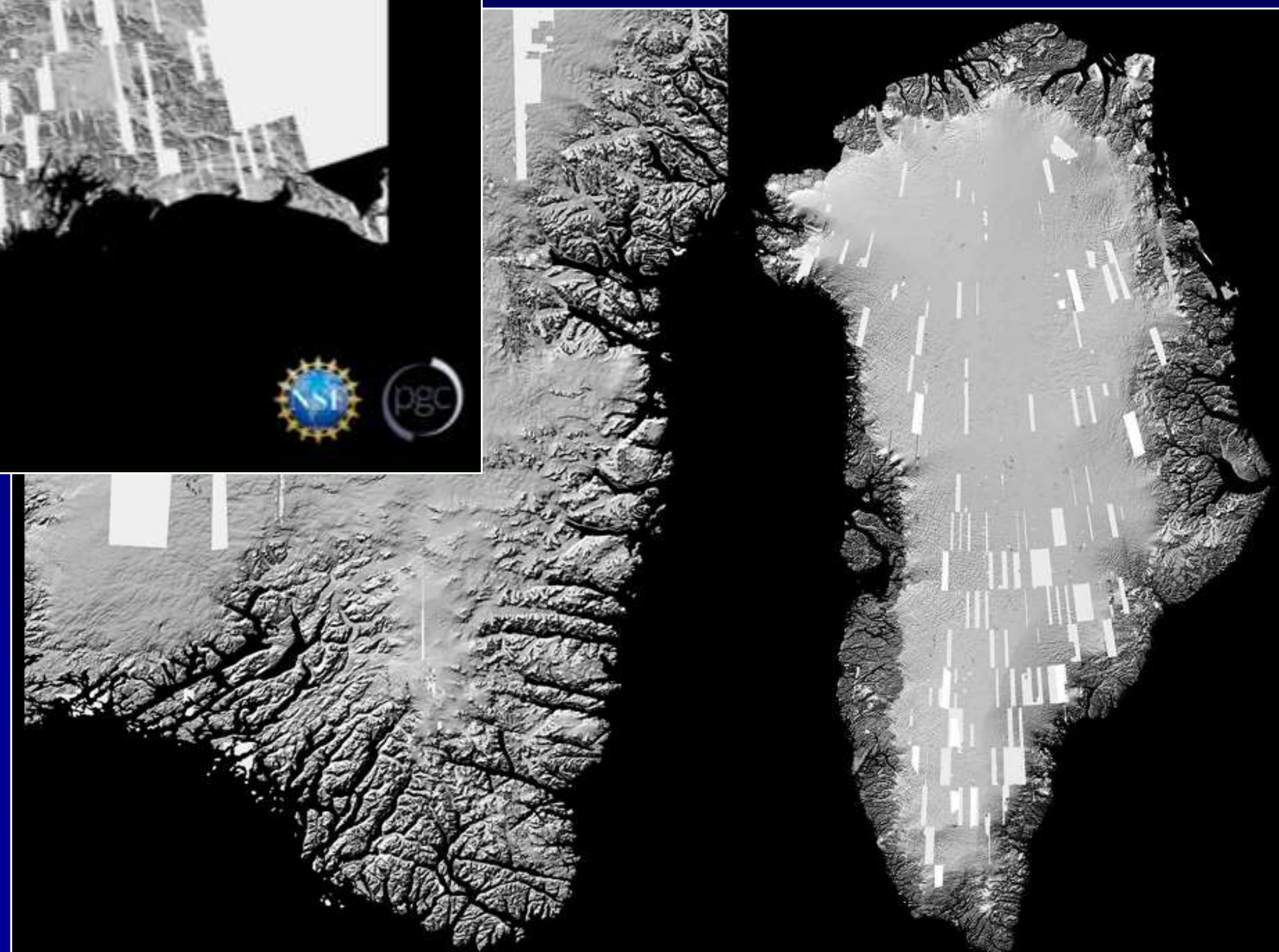
"To help Alaskans better plan for sustainable development, the National Geospatial-Intelligence Agency and the National Science Foundation are leading a public-private collaboration to create the first-ever publicly available, high-resolution, satellite-based elevation map of Alaska by next year and the entire Arctic by the year after that," said President Obama in remarks at Alaska's Kotzebue High School on Sept. 3, 2015.

Models of the entire Arctic are scheduled for release in 2017.

ArcticDEM Goal

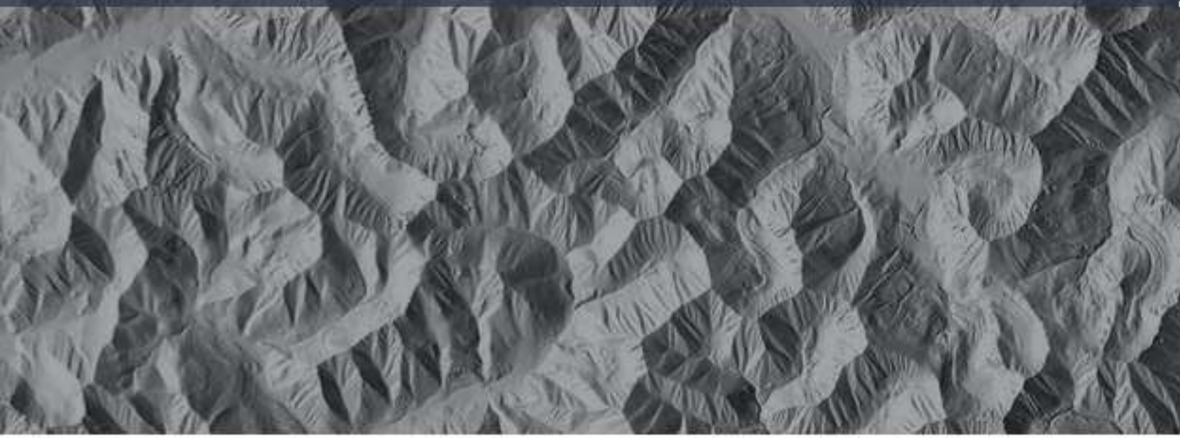
Produce a 2-8m posting digital surface model of the Arctic during the US Chairmanship of the Arctic Council using DigitalGlobe stereo imagery licensed by the National Geospatial-Intelligence Agency

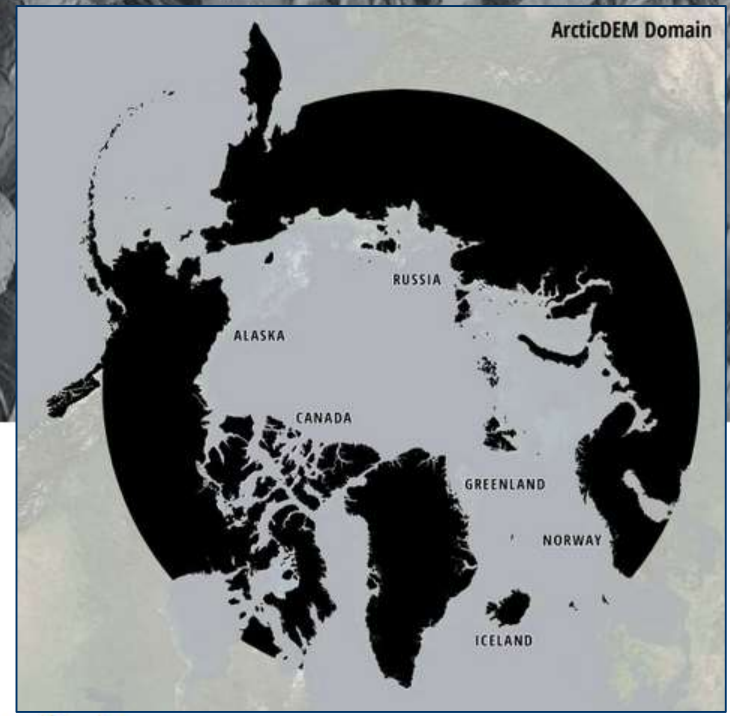




- 4-m vertical accuracy
- Based on 2012 – 2016 imagery
- Digital surface model (DSM)
- Alaska release in 2016
- Arctic release in 2017
- Unrestricted data

(Courtesy of P. Morin)





ArcticDEM

ArcticDEM is an NGA-NSF public-private initiative to automatically produce a high-resolution, high quality, digital surface model (DSM) of the Arctic using optical stereo imagery, high-performance computing, and open source photogrammetry software.

Comparison of Global DEMs

DEM	Grid spacing (m)	Absolute vertical accuracy specification (m)		
		RMSE	LE90	LE95
SRTM	30	9.7	***16***	19.07
ASTER GDEM	30	10.2	16.78	***20***
TanDEM-X (WorldDEM)	12	6.08	***10***	11.92
PRISM (AW3D)	5	***5***	8.22	9.8

RMSE = Root Mean Square Error

(RMSE is equivalent to the standard deviation [1σ] when errors are normally distributed and the mean error = 0)

LE90 = Linear Error at 90% confidence = RMSE * 1.6449

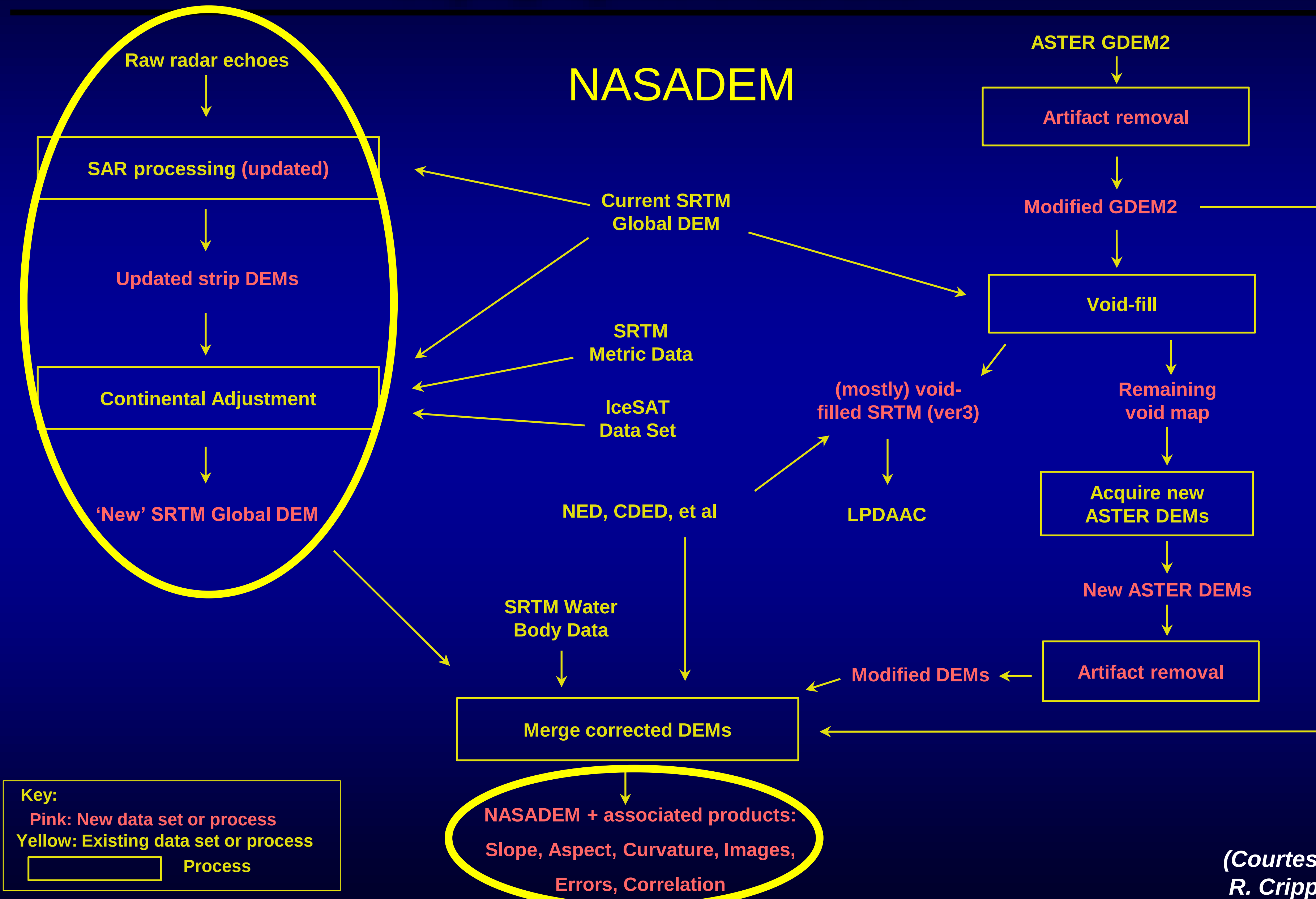
LE95 = Linear Error at 95% confidence = RMSE * 1.96

USGS

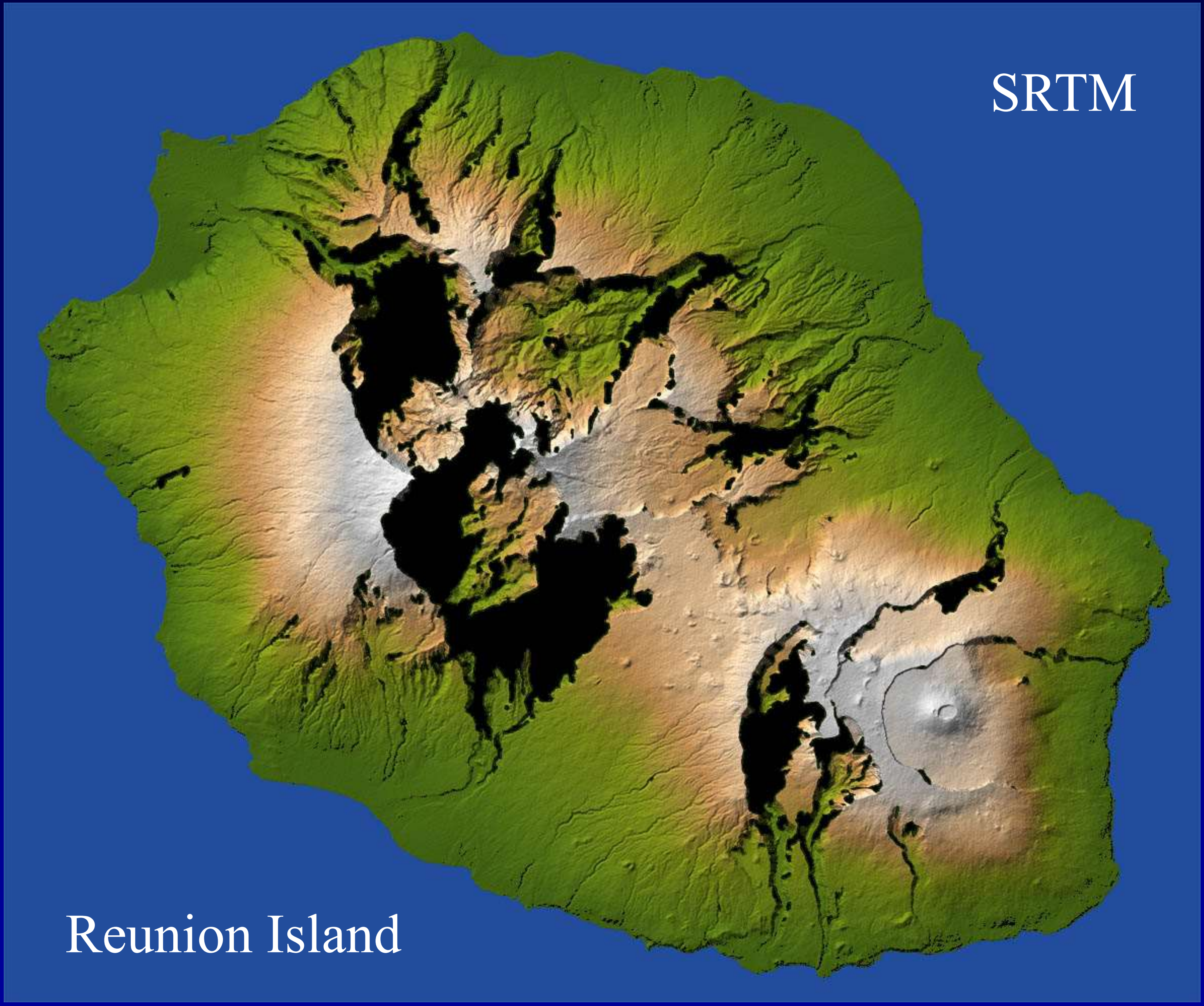
References:
Greenwalt and Shultz, 1962
Maune et al., 2007

NASADEM - A New NASA Digital Topographic Data Set

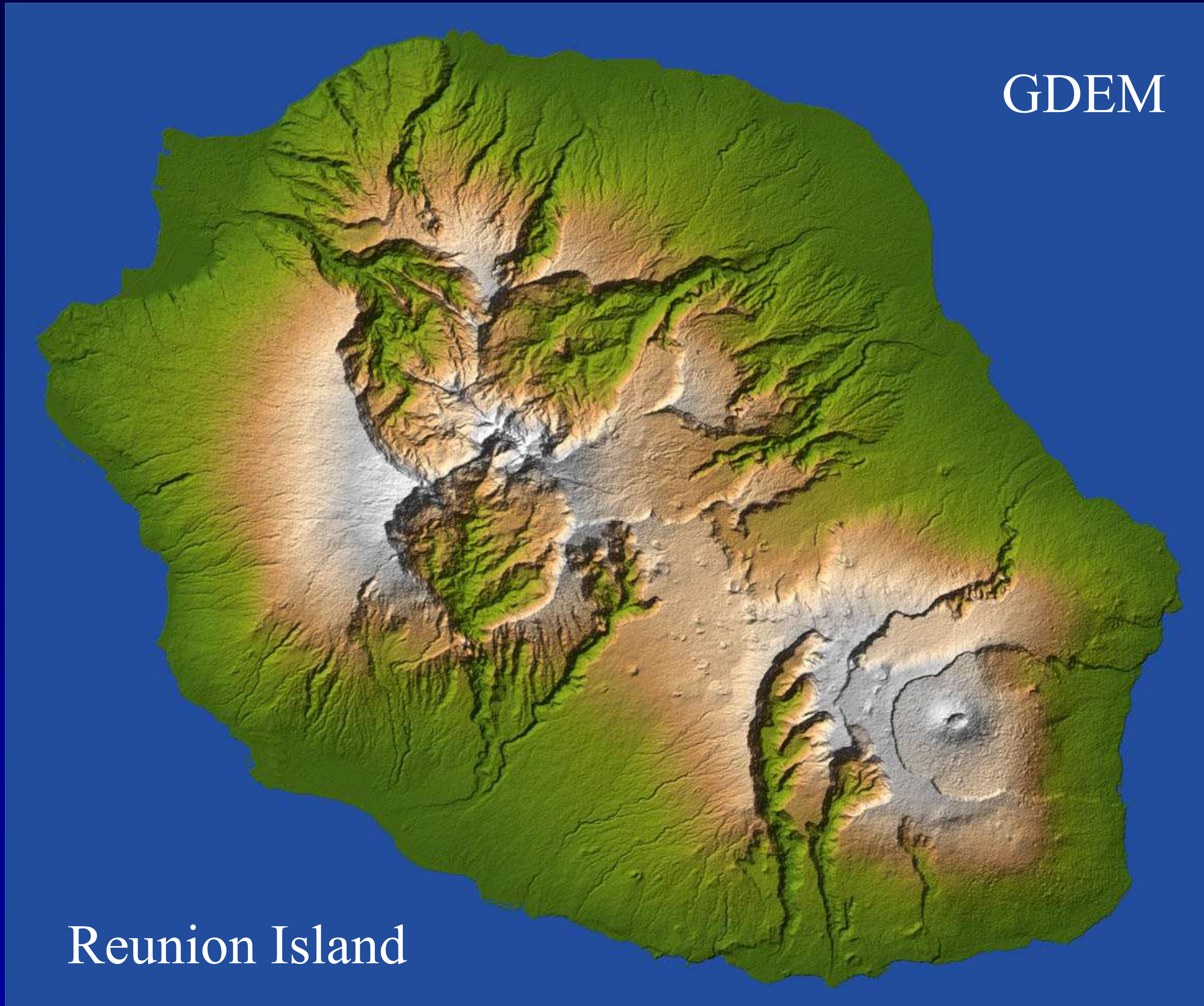
Jet Propulsion Laboratory



(Courtesy of R. Crippen)



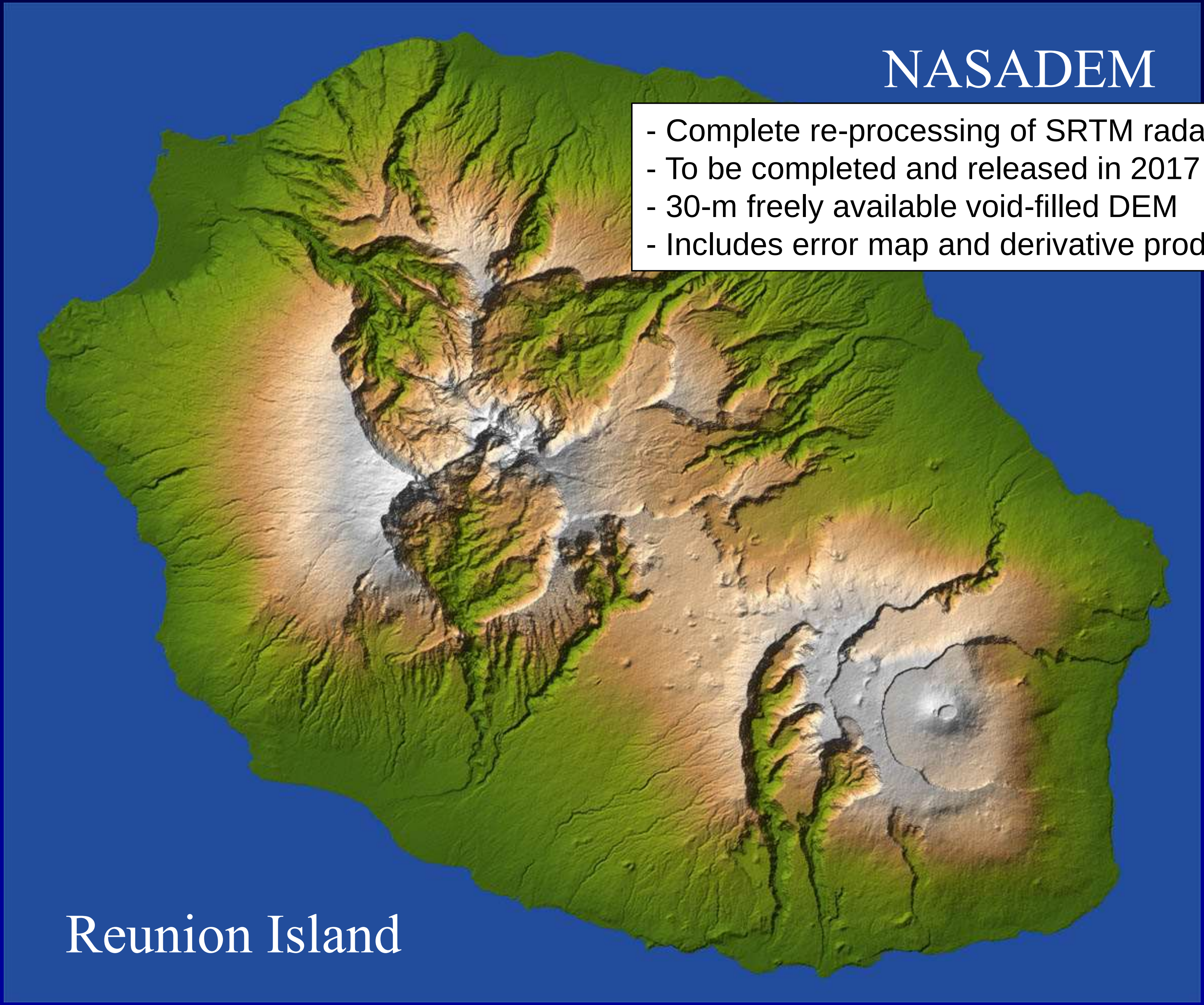
(Courtesy of R. Crippen)



(Courtesy of R. Crippen)

NASADEM

- Complete re-processing of SRTM radar data
- To be completed and released in 2017
- 30-m freely available void-filled DEM
- Includes error map and derivative products

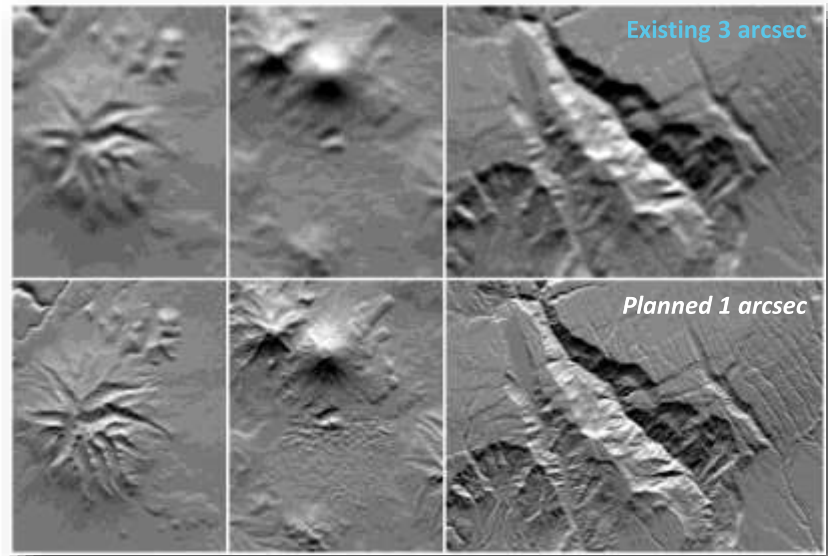


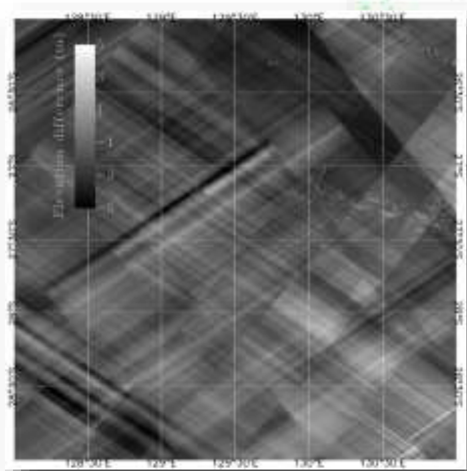
(Courtesy of R. Crippen)

NASADEM Project Overview

- Create an improved global NASA DEM and associated products
  - Reprocess SRTM raw sensor data
  - Merge with recent elevation data
  - Release at one arcsecond
- SRTM processing changes
  - Improve phase unwrapping
  - Reduce height ripples
  - Use ICESat as control
- New / additional data layers
  - Height error layer (precision est.)
  - Correlation
  - DEM slope/aspect and curvature
  - Veg bias estimates (experimental)
- Deliver provisional products to LPDAAC by continent with potential update at project end

Andes Mountains in Chile and Bolivia





DEM height ripples over Australia from unmeasured boom motion. Criss-cross pattern comes from merging SRTM strips. Difference of original SRTM & ripple removal demo.

(Courtesy of S. Buckley)

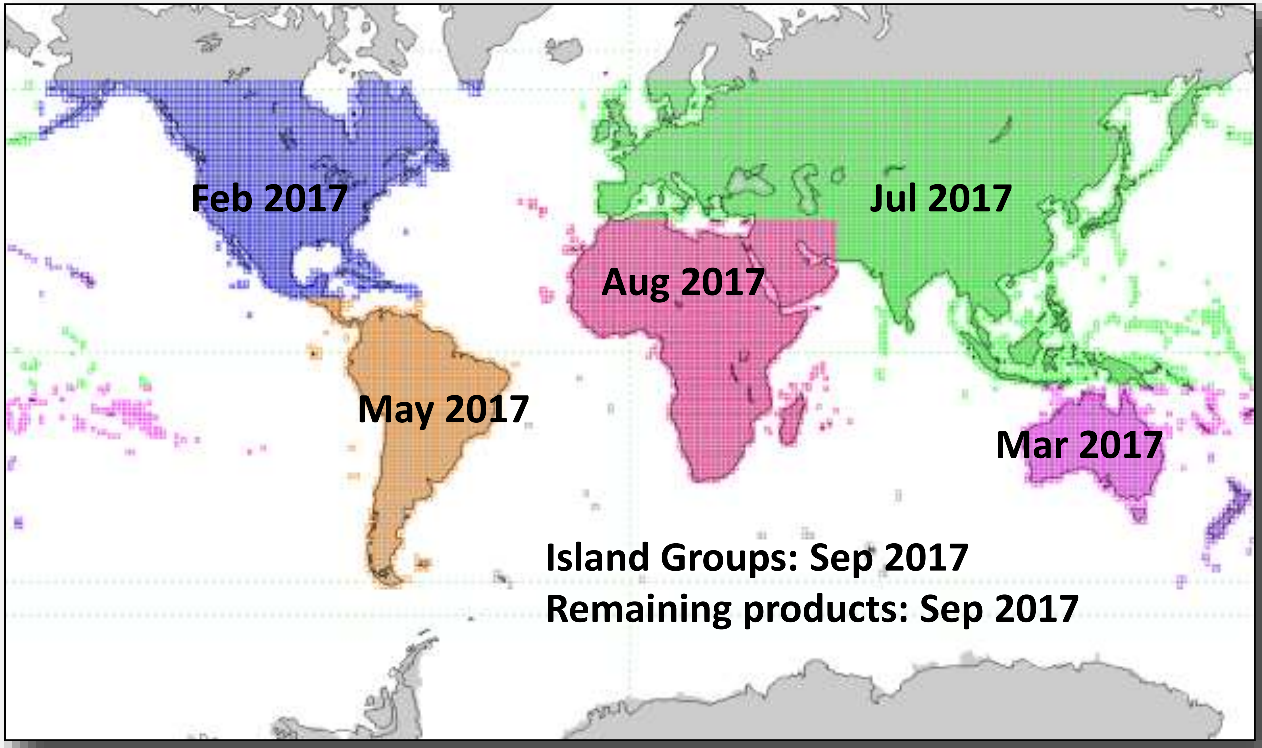
NASADEM Products

Product*	Brief Description	Delivery Format	Approx. # Files	Uncompressed & Compressed Size	
Void-Filled DEM	Elevations in 1x1-degree tile	16-bit signed int, meters	15,000	370 GB	105 GB
NUM Files	Identifying data source, # inputs	8-bit	15,000	185 GB	3 GB
Topographic Slope	Derived from void-filled DEM	16-bit unsigned int, hundredth degree	15,000	370 GB	–
Slope Aspect	Derived from void-filled DEM	16-bit unsigned int, hundredth degree	15,000	370 GB	–
Profile Curvature	Derived from void-filled DEM	16-bit unsigned int, hundredth 1/meter	15,000	370 GB	–
Plan Curvature	Derived from void-filled DEM	16-bit unsigned int, hundredth 1/meter	15,000	370 GB	–
Radar Images	Per image, subswath & tile	8-bit	175,000	–	195 GB
Radar Incidence Angle	Per image, subswath & tile	16-bit unsigned int, hundredth degree	175,000	–	391 GB
Merged Radar Images	Per tile	8-bit	15,000	–	55 GB
Radar Image Times	For each image tile	ASCII text file	1	Several MB	
Merged Radar Image NUMs	Number of images merged per pixel	8-bit	15,000	–	55 GB
Height Error	Height precision estimate	16-bit unsigned int, millimeters	15,000	370 GB	–
Radar Correlation	Per image, subswath & tile	16-bit unsigned int	175,000	Several hundred GB	
ICESat Single Shot Data	Control, assessment	ASCII text file	2	Several GB	
Vegetation Bias Maps	One for each DEM tile	16-bit signed int, meters	15,000	370 GB	–
SRTM-Only DEM	Wrt ellipsoid, unaltered water hgts	32-bit floating point, meters	15,000	740 GB	–

**** Bold refers to products also produced as part of MEaSUREs 2006 project***

(Courtesy of S. Buckley)

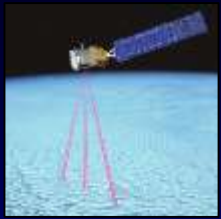
Expected Delivery Dates to LPDAAC (as of Jan 2017)



Recent info (R. Crippen, JPL):
- On target for 2017 completion
- AW3D 30-m is primary fill source, GDEMv3 is secondary
- North of SRTM footprint (> 60°N) may be filled if time allows (AW3D, GDEM, possibly CDED)

(Courtesy of S. Buckley)

Future Missions



- ICESat-2 (scheduled for late-2018 launch)
  - ATLAS: Advanced Topographic Laser Altimeter System
    - 14-m laser footprints spaced very closely (0.7 m) along profile
    - Centimeter-level vertical accuracy; ground and canopy products

- GEDI (scheduled for 2019 launch)
  - Global Ecosystem Dynamics Investigation
  - Lidar on board the International Space Station
  - Targeting forests between 50°N and 50°S latitude

- NISAR (scheduled for 2020 launch)
  - NASA-ISRO Synthetic Aperture Radar
  - Dual L-band and S-band polarimetric SAR with 12-day repeat pass interferometry capability

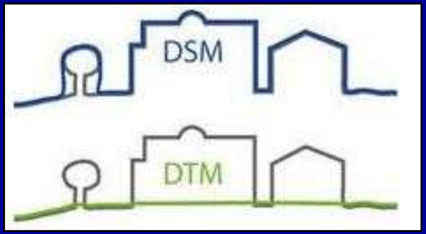
Characteristics Common to Global DEMs

- Voids
  - Stereo-optical sources:
    - Clouds
    - Areas of low image contrast (low illumination, shadows, smooth / homogenous surfaces)

  - IFSAR:
    - Steep terrain causing shadowing, foreshortening, layover
    - No radar return from smooth surfaces
  - Fix voids by:
    - Interpolation
    - Fill with other data sources
    - Additional data collection (stacking / averaging)

Characteristics Common to Global DEMs

- "First return" – DSM
  - Processing required to get to bare earth DTM
- Vertical accuracy varies spatially
  - By land cover conditions
  - By slope and relief conditions



- Effective spatial resolution
  - Often true resolution is much less than grid spacing
  - Influenced by data processing algorithms (e.g., kernel size in image matching, window size for smoothing functions)

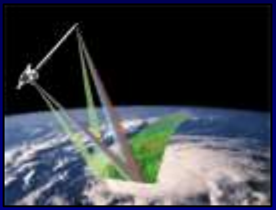
Interdependence of Global DEMs

- Incremental improvement as newer global DEMs make use of existing DEMs in production processes for:
  - – Systematic offset adjustment
  - – Calibration
  - – Anomaly detection
  - – Reference data for QA/QC
  - – Accuracy assessment
- Links:
  - – SRTM used DTED®
  - – ASTER GDEM used SRTM
  - – TanDEM-X uses ICESat and SRTM
  - – AW3D uses ICESat, SRTM, and ASTER GDEM

Which global DEM is the best?

The DEM should be “fit for use”:
-Vertical accuracy (absolute & relative)
- DSM vs. DTM
- True resolution
- Date (stack / avg.)

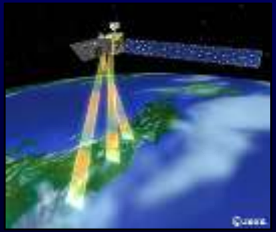
- Shuttle Radar Topography Mission (SRTM)
  - 30 m
  - 90 m



- ASTER Global Digital Elevation Model (GDEM)
  - 30 m

- TanDEM-X / WorldDEM
  - 12 m
  - 30 m
  - 90 m

- PRISM / ALOS World 3D
  - 5 m
  - 30 m



Thank You

Questions?
&
Discussion

USGS

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