CEOS-WGCV Terrain Mapping Sub-group: Current Status and GEO IN-02-C2.1 report

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Chair, UK Space Agency Planetary Exploration (AurAC)

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HRSC Science Team Member (ESA Mars Express 2003)
Stereo Panoramic Camera Science Team Member (ESA EXOMARS)
MODIS & MISR Science Team Member (NASA EOS Project)
TerraSAR-X and TANDEM-X science team member (DLR-Astrium)
**partially supported by UK Space Agency*

CEOS WGCV Terrain Mapping

- **What is the mission of the Terrain Mapping Sub-Group (TMSG)?**
  - **To ensure that characteristics of digital terrain models produced from Earth Observation sensors at global and regional scale are well understood and that products are validated and used for appropriate applications.**
- **What are the specific objectives of this group?**
  - **To develop specifications for the generation of '*standardised terrain surface products with known accuracy*' from similar sensing systems in the context of data continuity,**
  - **to specify evaluation methods and statistics which give transparent information about the *quality and heritage of terrain models*.**
  - **To update the current dossier of test sites and identify new sites, particularly to satisfy the cal/val requirements of future missions and generally improve access to validation data sets.**
  - **To keep an up to date record of the current status of sensors which produce data for terrain mapping and of the DEMs available.**
  - **To produce a DEM requirements document with a science rationale, taking into account the output from SRTM.**

TMSG Modus Operandi

- Terrain mapping SG linked to ISPRS IV/? on "Global DEM interoperability" and GEO task IN-02-C2.1 on "Global DEM"
- Annual technical workshops as part of an international conference
  - IGARSS09, Cape Town , South Africa, July 2009
  - ISPRS Commission IV Symposium, Orlando, FL, 16-18 November 2010
  - 2011 symposium had to be abandoned due to Japanese tsunami
  - Special session at ISPRS Congress, Melbourne, 26 August – 2 September 2012
- News announcements as and when there is relevant news (e.g. release of the ASTER GDEM v2)
- Emails to collect inputs for WGCV #35 (54 on email list, 17 responses in total including 14 from the ISPRS WG IV/6 sessions)
- Everything done on a "best efforts" basis with minimal funding so limited ambitions at present to meet specific objectives
- JPM stepping down in 6/2013 after more than 12 years in the post. Hannes Reuter (International Soil Survey) agreed to become Vice-Chair and has received affirmation/support by Dutch Space Agency
- UK Space Agency able to provide partial support for travel. UKSA will be launching new Applications programme in 2013 with possibility of small amounts of funding QA4EO showcase

QA4EO Showcase

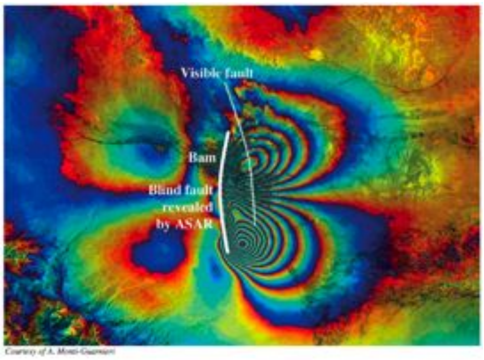
- Most DEMs (except for SRTM & TanDEM-X) do NOT include a Quality Indicator (QIs). The one for ASTER GDEM is not "fit for purpose" (see later)
- For spaceborne-derived bathymetry TMSG want to demonstrate how including QIs can affect tsunami landfall predictions
- Request sent to DLR and CSIRO/Curtin in July 2012 for TerraSAR-X and Worldview-derived bathymetry respectively for area close to Perth, WA with QIs to investigate this
- No response was received from either party so will try again soon
- Other test sites possible but unclear who could provide bathymetry estimates

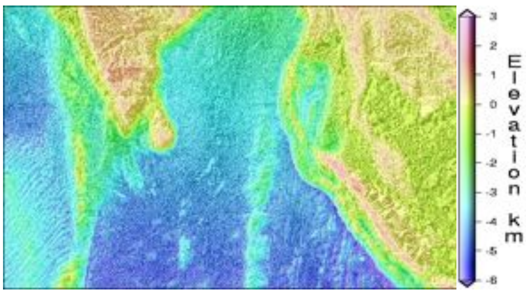
Overview

- Why does GEO need global topography/bathymmetry?
- Highlights from the ISPRS WG IV/6 Melbourne Congress relevant to WGCV/GEO
  - ASTER, NASADEM, GMTED2010, SPOT-DEM
  - CSIRO "bare earth" & data fusion efforts
  - EU-DEM: data fusion of DEMs for Europe
- NASA ICESat, ICESat-2 and Airborne multi-beam lidar activities (Supplied by David Harding, NASA-GSFC)
- National Aerospace Institute of Spain (INTA) report on preparation for TanDEM-X validation activities in Spain (supplied by Enrique Nicolás Gesé & Pablo Sánchez Gámez, INTA
- Current status of ALOS PRISM (Supplied by T. Tadono, JAXA)
- Definition of IN-02-C2.1 Global DEM priorities including Plans for GEO Task in the 2012-2015 work plan
- Next steps and recommendations for CEOS Plenary for global bathymetry

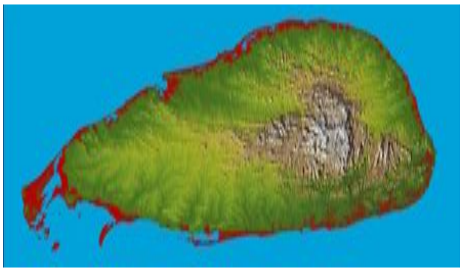
Why does GEO need global topography/bathymmetry?

- *Global DEM required for 6 of the 9 societal benefit areas identified by the 10 year Implementation Plan of GEOSS*
- *Natural disasters all require detailed knowledge of topography*
  - *either directly for volcanic dome monitoring, flood inundation areal predictions, landslides*
  - *or for downstream EO processing, e.g. InSAR for earthquake monitoring and possible prediction*
- *Poor bathymetric and topography knowledge hinders tsunami forecasts*
- *Tsunami a main spur for GEO implementation*





2' (≈4km) Smith, Walter H.F., and David T. Sandwell, 1997 "Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings", Science, 277, 1956-1962, 1997



30m height "flood-fill" based on SRTM-DTED1® 3" (≈90m)

Climate and Land Use Change

Earth Resources Observation and Science (EROS) Center

Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010): Final Products and Accuracy Assessment

Work performed with support from the National Geospatial-Intelligence Agency (NGA)

Authors: Jeffrey J. Danielson and Dean B. Gesch

Date: 8-29-2012

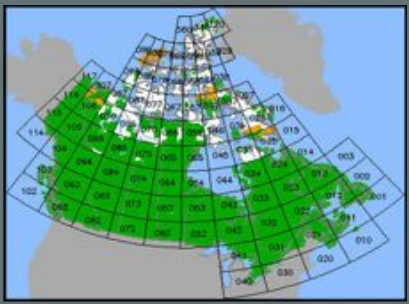
USGS

Global Multi-resolution Terrain Elevation Data 2010

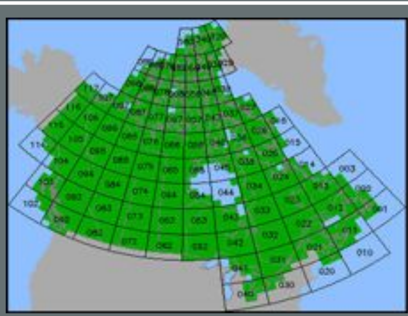
- Primary Goal
  - Develop a global medium scale elevation model to replace GTOPO30. Generate seven products at three separate resolutions (horizontal post spacings) of 30 arc-seconds (1 km), 15 arc-seconds (500 m), and 7.5 arc-seconds (250 m) from the best available higher resolution data sources.
- Elevation Data Sources
  - New Source Data:
    - Shuttle Radar Topography Mission (SRTM) DTED 2 ® (Void-Filled), 1 arc-second
    - U.S. National Elevation Dataset (NED), 1 and 2 arc-seconds
    - Canadian Digital Elevation Data (CDED), 0.75 and 3 arc-seconds
    - Digital Terrain Elevation Data (DTED 1 ®), 3 arc-second
    - SPOT5 Reference3D®, 15 arc-second
    - Australia GEODATA 9 arc-second DEM
    - University of Bristol, Greenland Satellite Radar Altimeter DEM, 30 arc-seconds
    - University of Bristol, Antarctica Satellite ERS-1 Radar and ICESat Laser Altimeter DEM, 30 arc-seconds
- Spatially referenced metadata has been produced for all the datasets.

USGS

Input Data Sources: Canadian Digital Elevation Data (CDED)



CDED1: 0.75 Arc Second Coverage Map

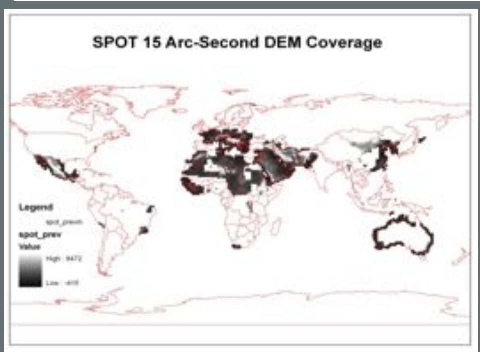


CDED3: 3 Arc Second Coverage Map

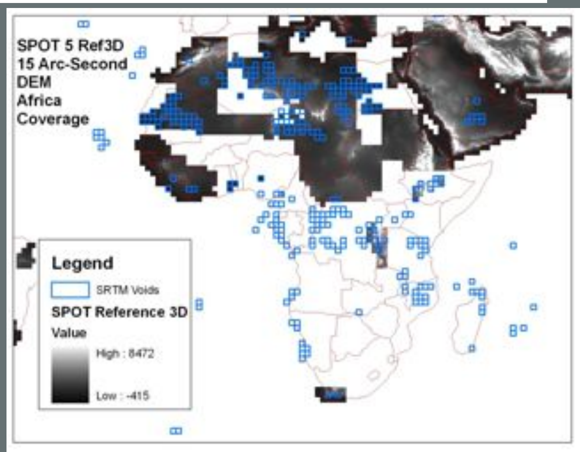
- **Dataset Information:**
  - Organizational Source: Natural Resources Canada (GeoBase)
  - Surface Type: Land Surface – Reflective and Bare Earth
  - Horizontal Resolution: 0.75 and 3 arc-second
  - Vertical Unit: Integer Meter
  - Projection System: Geographic Lat / Long
  - Elevation Source: CDED is extracted from the hypsographic and hydrographic elements of the Canadian National Topographic Data Base (NTDB)
  - Source Production Date: Depends on Input Data Sources

USGS

Input Data Sources: SPOT5 Reference3D, 15 Arc-Second



SPOT5 Reference3D 15" Global Coverage



SPOT5 Reference3D 15" Africa Coverage

- **Dataset Information:**
  - Organizational Source: SPOT Image / IGN
  - Surface Type: Land Surface – Reflective
  - Horizontal Resolution: 15 arc-second
  - Vertical Unit: Integer Meter
  - Projection System: Geographic Lat / Long
  - Elevation Source: SPOT5 Reference3D
  - Source Production Date: Depends on Input Data Sources

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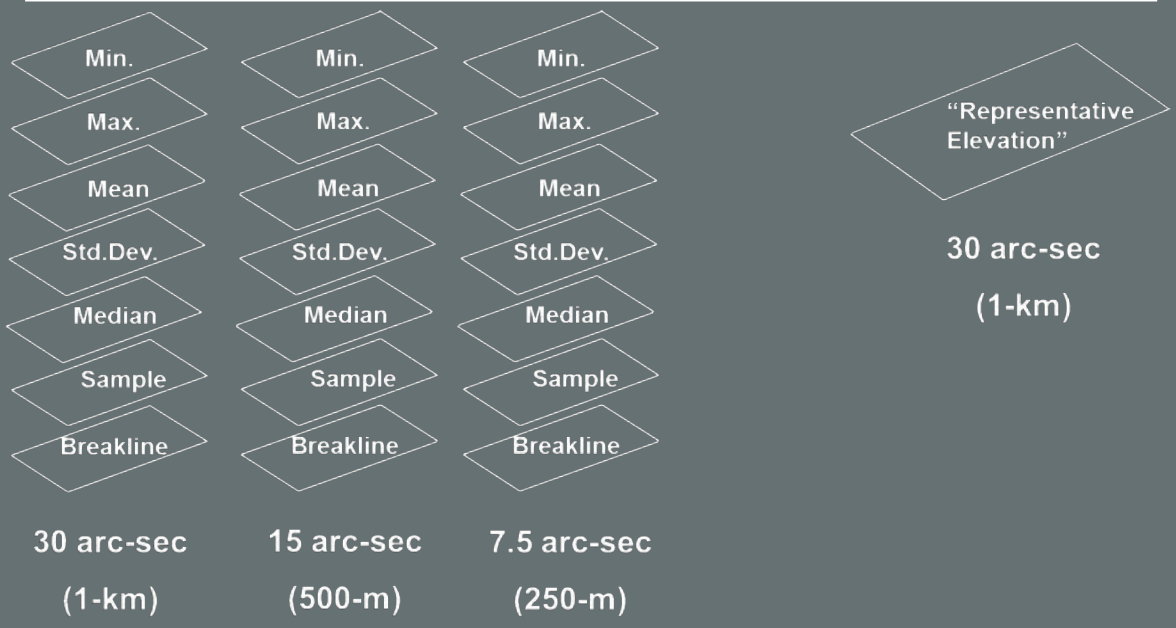
GMTED2010 GTOPO30



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GMTED2010: Products

- Products / Algorithms
  - Seven products generated at each resolution (7.5, 15, and 30 arc-seconds)
    - Breakline Emphasis (Hydrologic Applications)
      - Breakline emphasis maintains the critical topographic features within the landscape by retaining any stream (minimum elevation) or ridge (maximum elevation) value that passes within the specified analysis window.
    - Minimum Elevation Statistic (Stream Channel Identification)
    - Maximum Elevation Statistic (Air Traffic Navigation Application)
    - Mean Elevation Statistic (All-Purpose Visualization and Morphological Processing)
    - Median Elevation Statistic
    - Standard Deviation Statistic (Surface Texture / Roughness)
    - Systematic Subsample (Actual Source Elevation Values)

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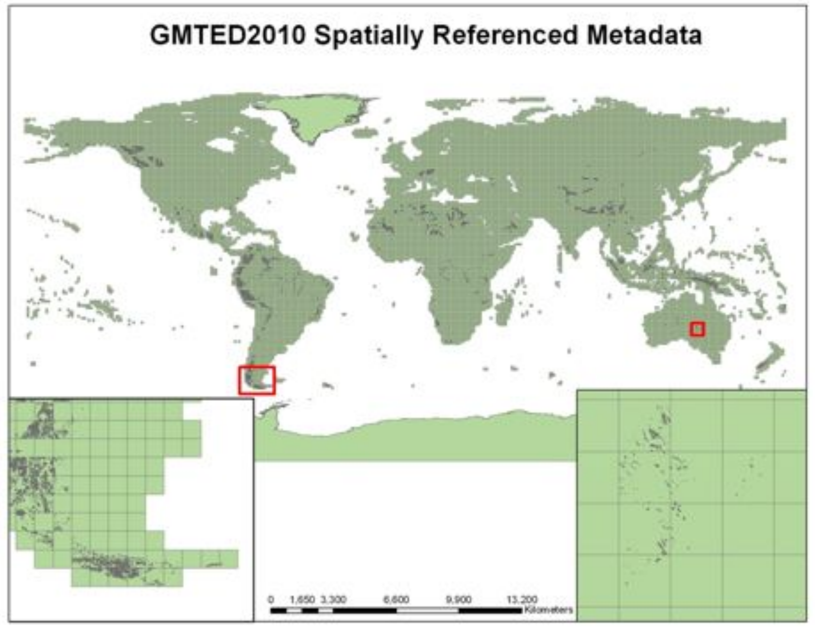
GMTED2010 Spatially Referenced Metadata

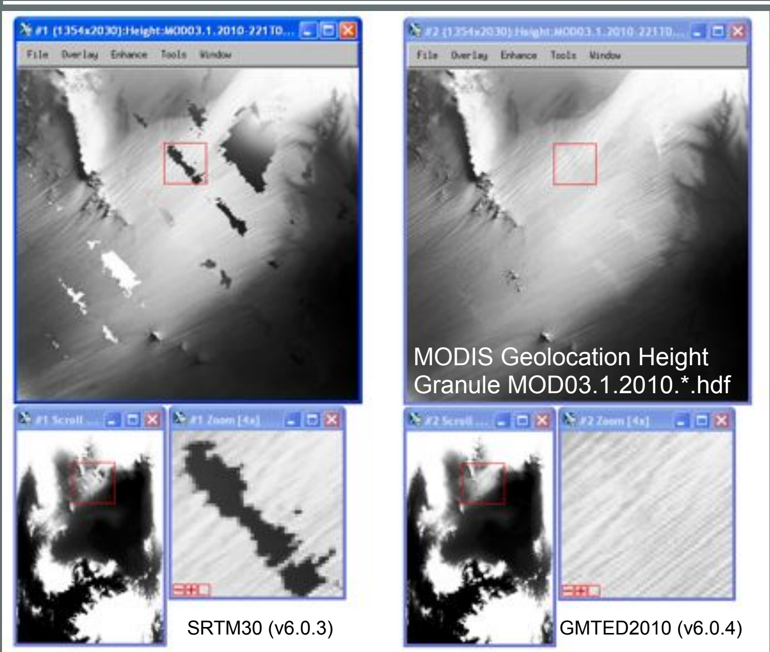


Field	Value
FID	792
Shape	Polygon
ID	793
SOURCE_ORG	NGA
SOURCE	SRTM DTED2 Void Filled
EL_SURFACE	Reflective
NORTH	-27
SOUTH	-28
WEST	121
EAST	122
X_SRCE_RES	1
Y_SRCE_RES	1
HORZ_UNIT	Second
COORD_SYS	Geographic
HORZ_DATUM	WGS 84
VERT_DATUM	EGM96
VERT_UNIT	Meter
MIN_ELEV	307
MAX_ELEV	629
MEAN_ELEV	497.64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

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

USGS

GMTED2010 Mean 15 Arc-Second and JPL Hybrid SRTM 30 Arc-Second Product Comparisons (Void-Fill Area Improvements)



MODIS Geolocation Height Granule MOD03.1.2010.*.hdf

SRTM30 (v6.0.3)

GMTED2010 (v6.0.4)

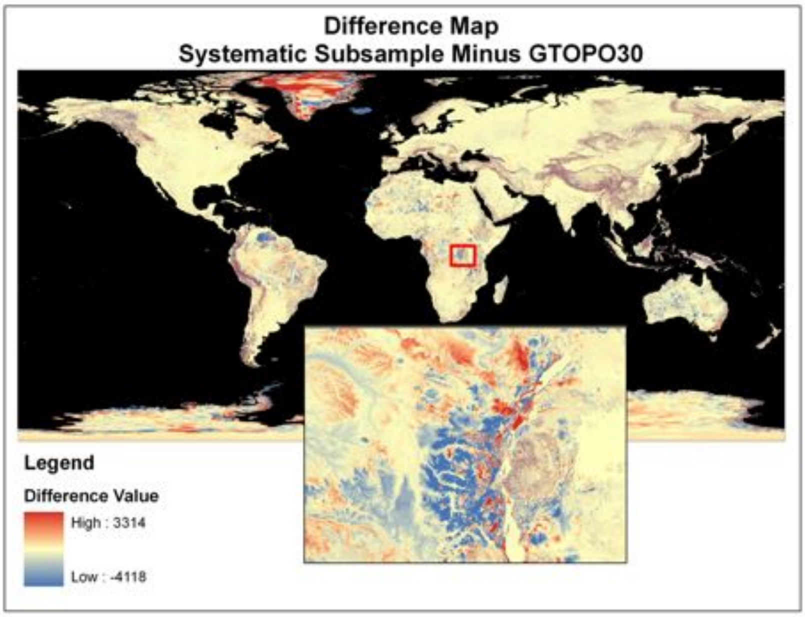
Center Point (in Niger)
Longitude: 14.027759°,
Latitude: 18.651239°

Credit: Robert Wolfe and James Kuyper, NASA GSFC

USGS

GMTED2010: Raster-Based Assessment

- Difference Map: Systematic Subsample Minus GTOPO30 (30 Arc-Seconds)



Difference Statistics:

Minimum = -4118
Maximum = 3314
Mean Difference = 4.394
Standard Deviation = 91.440

USGS

GMTED2010 Comparison with other Global DEMs

DEM	GMTED2010	GTOPO30	SRTM	ASTER GDEM
Resolution	30 arc-sec 15 arc-sec 7.5 arc-sec	30 arc-sec	3 arc-sec 1 arc-sec	1 arc-sec
Coverage	Global	Global	60° N to 56° S	83° N to 83° S

- **New Global Elevation Model:**
  - Global / Continental / Regional Applications (not requiring 1 or 3 arc-sec data)
  - SRTM Voids Filled
  - Areas north of 60 degrees, the 0.75 and 3 arc-second Canadian Digital Elevation Data (CDED) and the 3 arc-second Digital Terrain Elevation Data (DTED) have been incorporated.
  - Updated Antarctica and Greenland Data

USGS

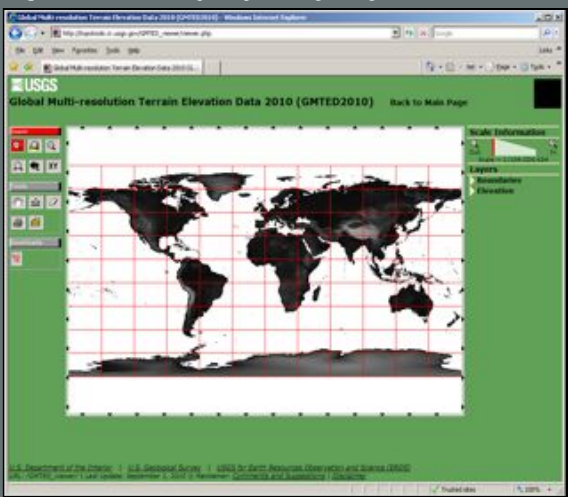
GMTED2010 – Technical Documentation (Online)

- Available online at http://pubs.usgs.gov/of/2011/1073

USGS

Global Multi-resolution Terrain Elevation Data 2010 (GMTED2010) - Publicly Released in August 2011

GMTED2010 Viewer



Earth Explorer

http://eros.usgs.gov/#Find_Data/Products_and_Data_Available/GMTED2010

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

http://earthexplorer.usgs.gov/

USGS

ASTER Global DEM: the Kaizen Approach

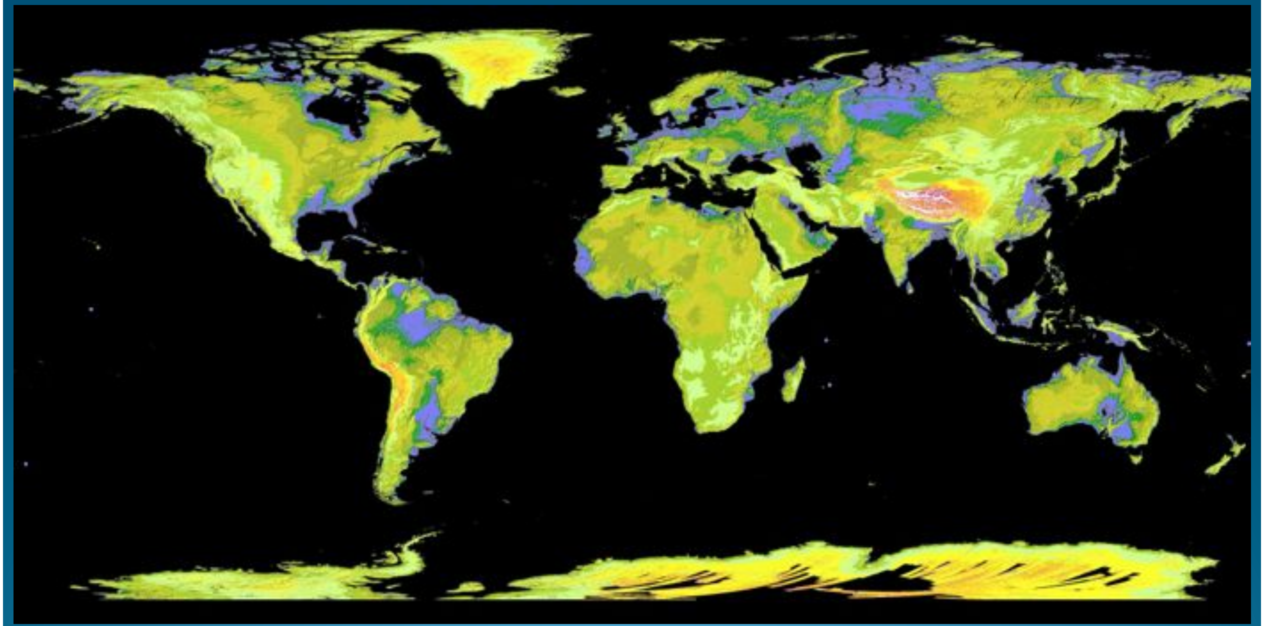
Michael Abrams, Jet Propulsion Lab/California Institute of Technology
Hiroji Tsu, Earth Remote Sensing Data Analysis Center
David Meyer, U.S. Geological Survey

The XXII Congress
of the International Society for
Photogrammetry and Remote Sensing
25 August - 1 September 2012
Melbourne Convention and Exhibition Centre | Melbourne, Australia

Available Global DEM Data Sets

DEM	Posting	Coverage	X-Y, Z accuracy	Cost
GMTED2010	215 m	Global	30m	Free
SRTM	100 m	60N to 59S	10 m, 7 m	Free
ASTER GDEM	30 m	Global	18 m, 17 m	Free
SPOT 5 DEM	20 m	Global, 201?	15 m, 15 m	$2-5/km^2$?
TanDEM-X	12 m	Global	10 m, 10 m	$2-5/km^2$?

ASTER GDEM



ASTER GDEM V2 Improvements vs V1

- ~250,000 new scenes added => fewer holes at latitudes >60 degrees
- Correlation kernel changed to 5x5 from 9x9 => improved high frequency topographic information
- Lakes flattened and given uniform value => removal of artifacts (steps, wrong elevations)
- Improved cloud screening and anomaly detection => almost complete elimination of artifacts (pits, bumps, mole runs)

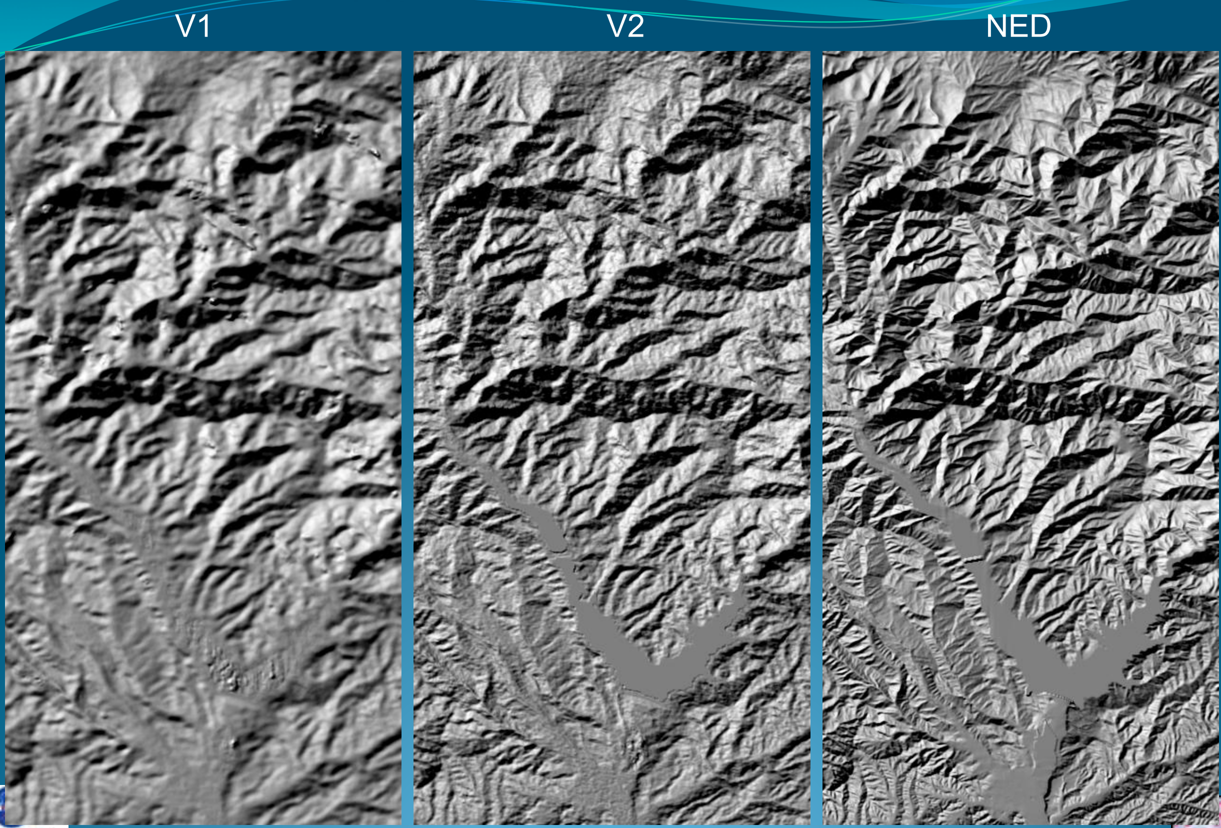
GDEM V2 Validation

- Performed by several organizations: US Geological Survey; US National Geospatial Agency, US Jet Propulsion Lab, and Japan Earth Remote Sensing and Data Analysis Center
- Report is available on the web:
  - GDS:

    http://www.jspacesystems.or.jp/ersdac/GDEM/ver2Validation/Summary_GDEM2_validation_report_final.pdf
  - LP DAAC:

    https://lpdaac.usgs.gov/products/aster_products_table/aster_gdem_version_2_validation

Los Angeles GDEM Tile



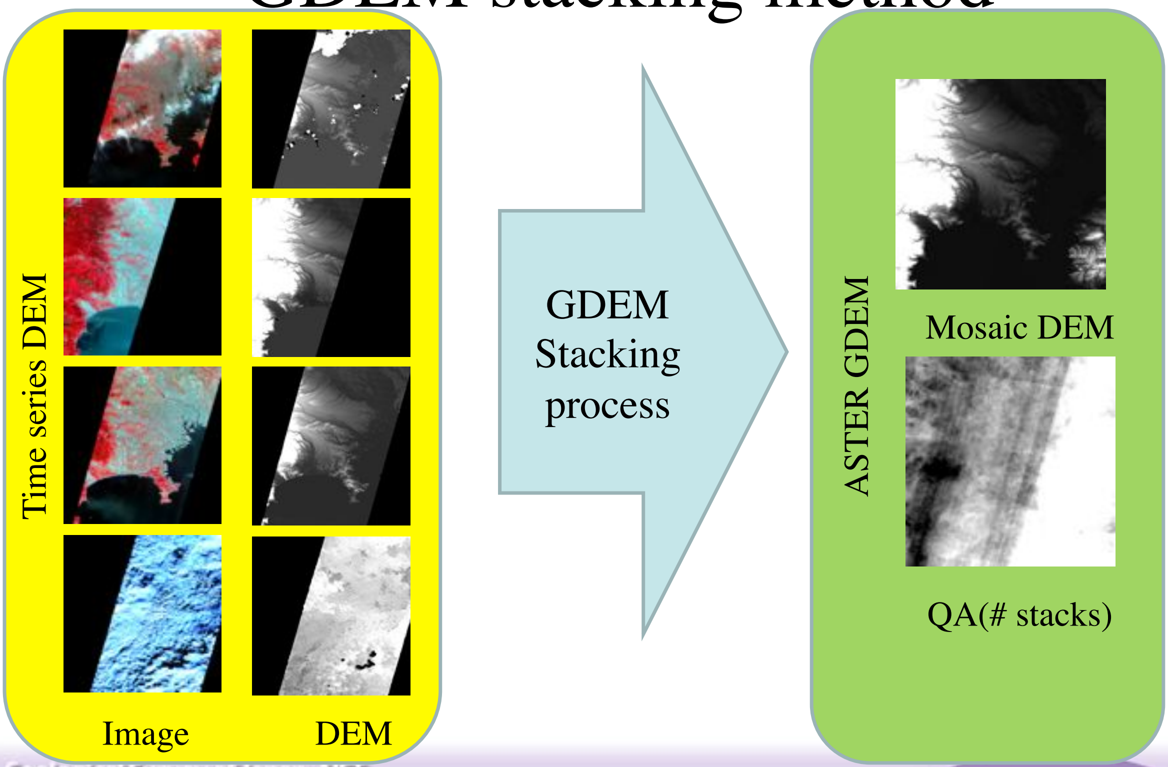
GDEM V3

- Release 1-2 years from now
- Additional 250,000-400,000 scenes to further eliminate holes in coverage and improve quality of data
- Studying including global land-water mask at high resolution
- Studying precision co-registration of stereo pairs before DEM calculation; can improve resolution by 2-3X

Data Acquisition Strategies for ASTER Global DEM Generation

M.Urai, T. Tachikawa and H.Fujisada

GDEM stacking method



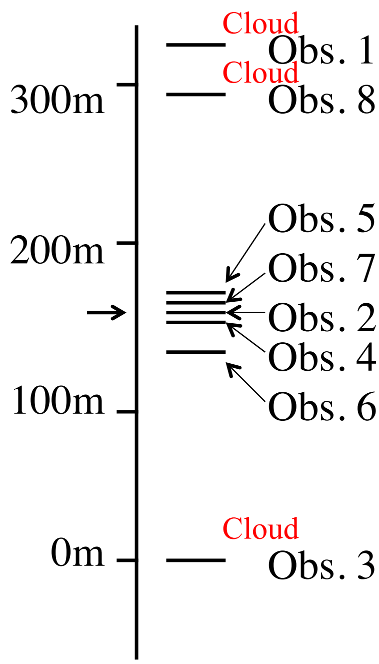
GDEM stacking method

- Elevations at a point are calculated every ASTER observations.

- Maximum or minimum value is removed from elevations derived from individual ASTER observation at a point until the range of the elevation is less than a constant level (for example 50 m).

- The average of remaining elevations is regarded as the elevation of the point.

- If |each elevation – average elevation| > 50m, the point is marked "cloud".



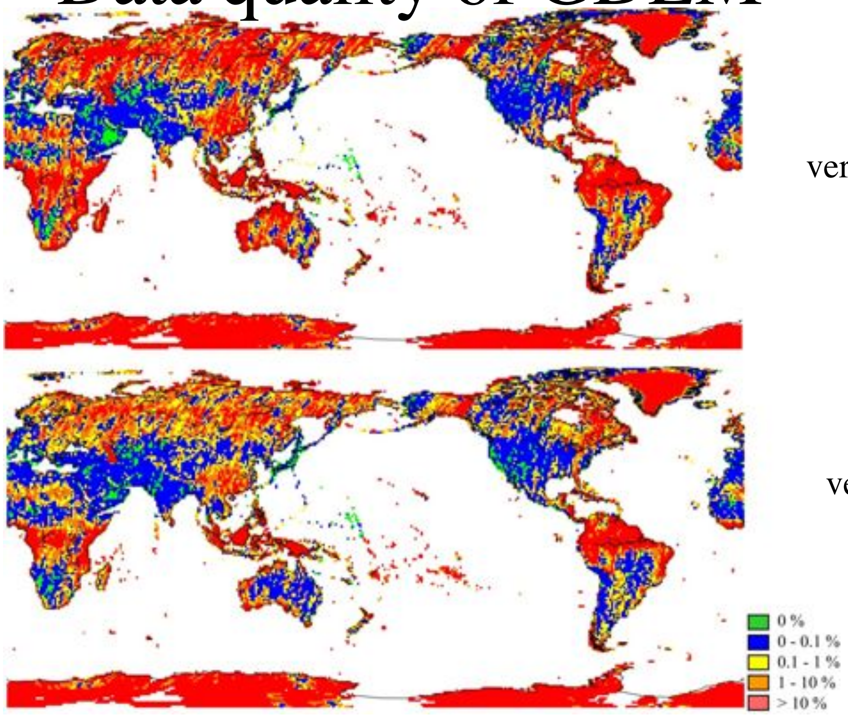
Data quality of GDEM-1

•The GDEM consists of tiles that are one degree latitude and one degree longitude.

•Each GDEM tile consists of two files, DEM file and quality assessment (QA) file.The QA file is used to describe number of stack (number of valid elevation) by positive values.

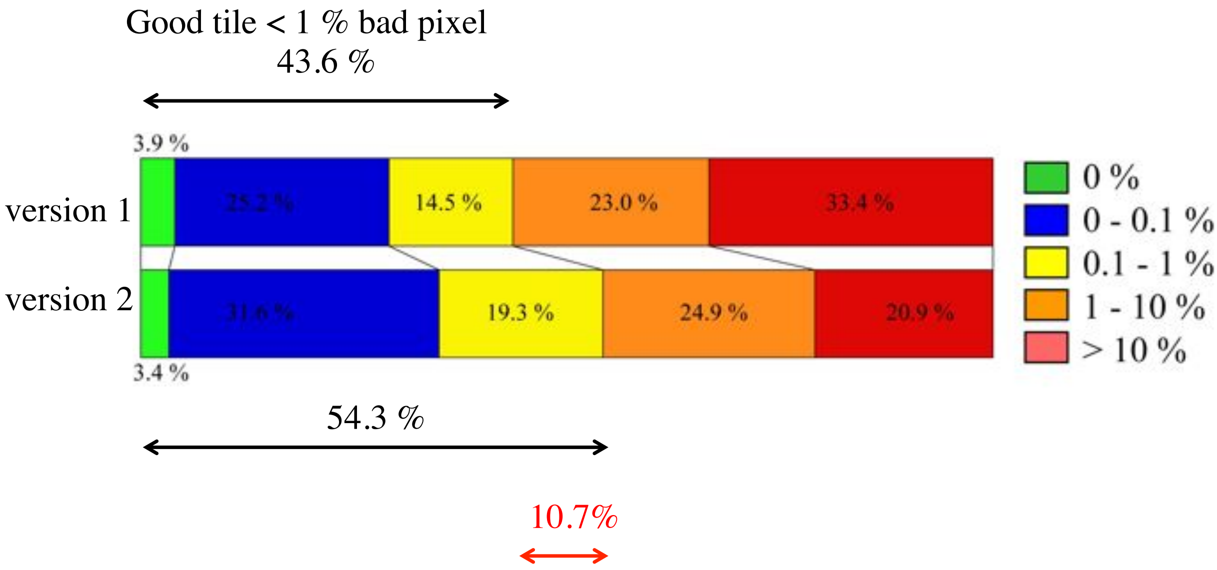
•In our strategy a pixel with two or less stacks was defined as a “bad” pixel.

Data quality of GDEM



Tile based bad pixel rate distribution and statistics of ASTER GDEM version 1 and 2

Data quality of GDEM



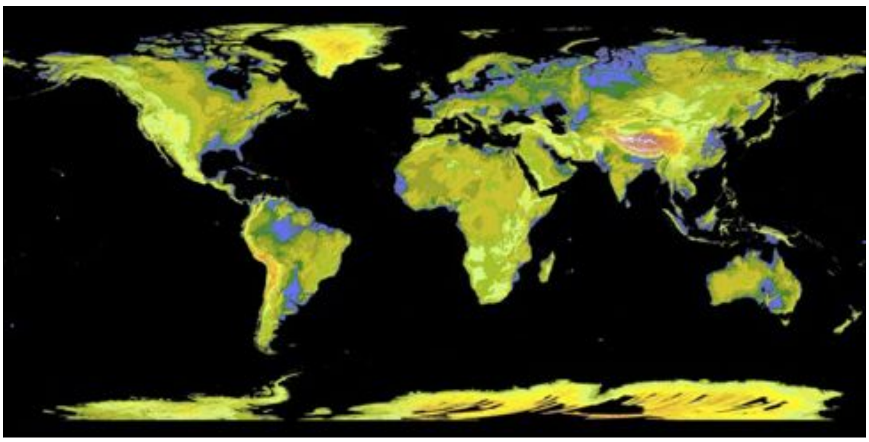
Tile based bad pixel rate distribution and statistics of ASTER GDEM version 1 and 2

USGS ASTER JAPAN/USA NASA

Validation of the Second Version of the ASTER GDEM

XXII Congress of the ISPRS - 28 August, 2012 - Melbourne, Australia

Dave Meyer[1]
Tetsushi Tachikawa[2]
Dean Gesch[1]
Robert Crippen[3]
Claudia Carabajal[4]
Tabatha Krieger[5]
Michael Abrams[3]



1 US Geological Survey, Earth Resource Observation and Science Center
2 Earth Remote Sensing Data Analysis Center (ERSDAC)
3 Jet Propulsion Laboratory, California Institute of Technology
4 Sigma Space Corp. under contract to NASA Goddard Space Flight Center
5 US National Geospatial Intelligence Agency/SNAT

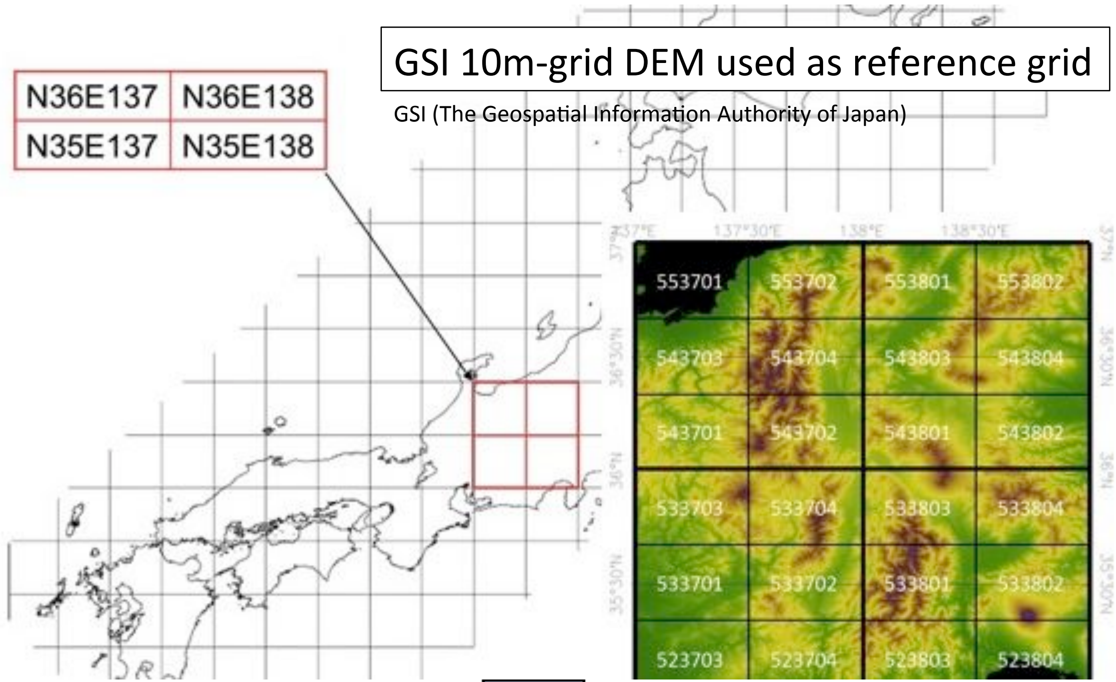
Components of the Validation Study

- Vertical assessment using geodetic references
  - CONUS benchmarks (USGS)
- Horizontal and vertical error assessment using reference elevation grids
  - Japan GSI 10-m grid (ERSDAC) – vertical and location accuracy
  - CONUS NED, SRTM 1 arc-second (USGS) – vertical accuracy
  - Global SRTM 1 arc-second (NGA) – vertical and location accuracy
  - Horizontal Resolution (JPL, ERSDAC)
- Vertical error assessment using ICESat altimetry
- GDEM quality and artifacts

Japan Study (Tachikawa et al.)

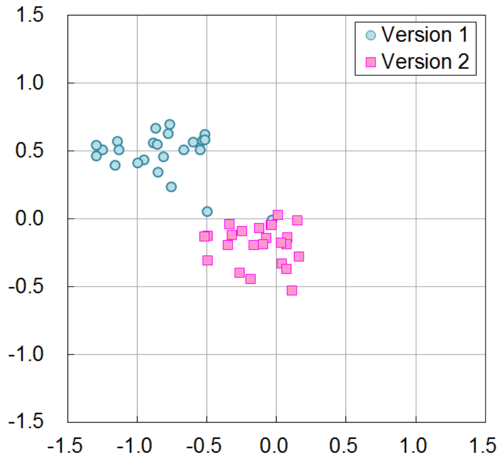
GSI 10m-grid DEM used as reference grid

GSI (The Geospatial Information Authority of Japan)



Japan study: locational accuracy

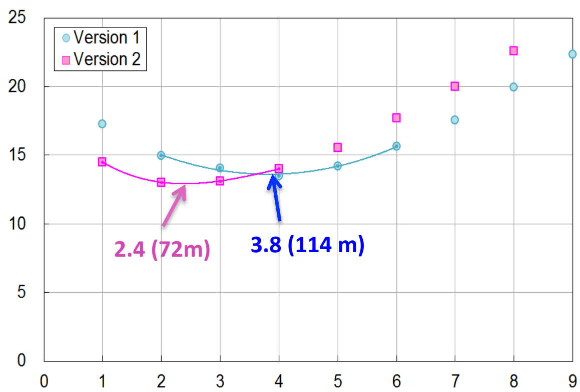
- ERSDAC estimated horizontal resolution and accuracy against 10-meter national elevation grid (Tachikawa et al.).

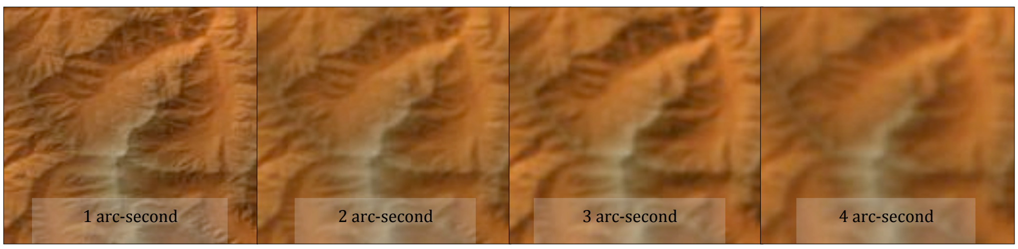


- Using 4 GDEM tiles in central Honshu (elevation range 0-3000 meters)
- Circular locational accuracy is 0.23 for GDEM2 (0.94 for GDEM1)

Japan study: horizontal resolution estimation

- 10 m GSI DEM sampled to 1 through 9 arc-seconds in 1 arc-sec intervals.
- “best fit” decimated grid taken as integer portion of the error (interpolated for sub-pixel location).





Results: Japan study

			Version 1	Version 2
Horizontal Error			0.82 arc-sec. to west 0.47 arc-sec. to south	0.13 arc-sec. to west 0.19 arc-sec. to north
Elevation Error	Flat and open area (rice farm)	offset	-4.8 m	-0.7 m
		SD	6.2 m	5.9 m
		RMSE	-	6.1 m
	Mountainous area largely covered by forest	offset	+2.2 m	+7.4 m
		SD	15.4 m	12.7 m
		RMSE	-	15.1 m
Horizontal Resolution			3.8 arc-sec. (114m*)	2.4 arc-sec. (72m*)

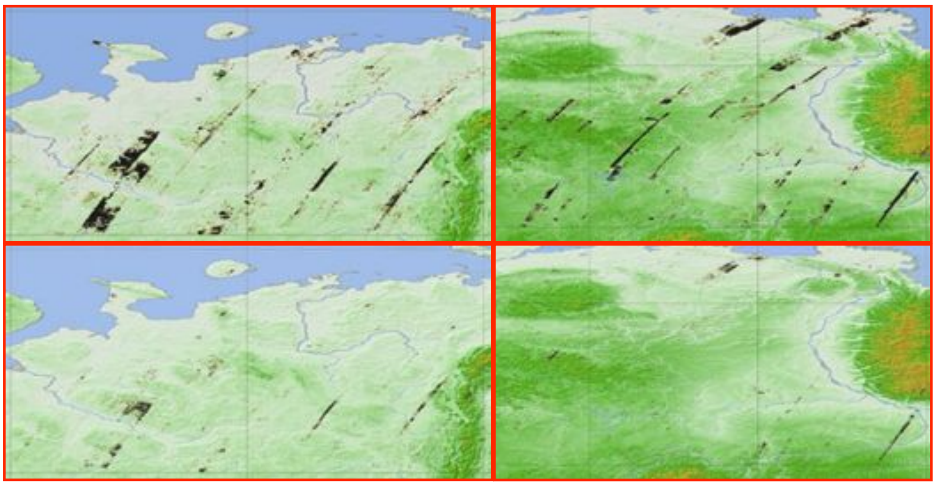
GDEM v2.0 validation: horizontal resolution

- From Tachikawa, Crippen:
  - JPL used both LIDAR & non-LIDAR high resolution reference for resolution estimation.
  - GDEM2 comparable to SRTM 1 arc-second resolution
  - units in meters

DEM	Japan Non-LIDAR	West Virginia Non-LIDAR	Utah LIDAR	California LIDAR	Average Non-LIDAR	Average LIDAR
GDEM-1	114	118	119	124	116	121
GDEM-2	72	70	81	83	71	82
SRTM 1-arc-sec	--	72	76	79	72	77
SRTM 3-arc-sec	--	97	101	103	97	102

Void reduction due to increased acquisitions

- Siberian example



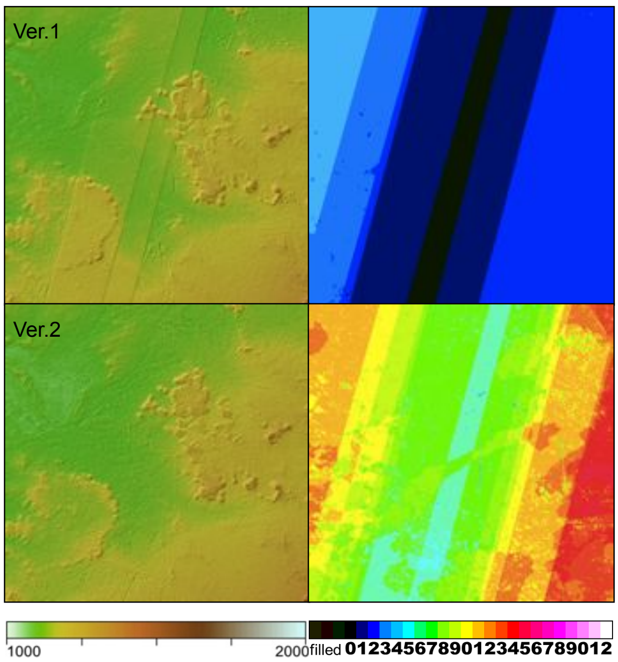
GDEM1

GDEM2

Increased # of acquisitions reduces artifacts

Left column is elevation value

Right column is "num" value (number of scenes used in elevation estimation).



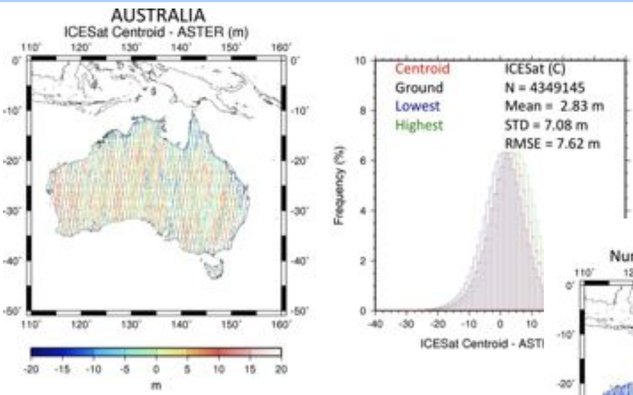
ICESat Evaluation (Carabajal et al.)

- ICESat Global Laser Altimetry Sensor “footprint”:
  - Resolves ~50 m on the ground
  - Space 170 m along satellite track
- ASTER comparison
  - GDEM compared to ICESat at ground, lowest, centroid and highest returns
  - Global by continent + Greenland & New Zealand
  - Mean errors between GDEM v2 & ICESat lowest (or ground) returns is +/- 3 m (For Greenland, results are good for bare, ice-free areas)

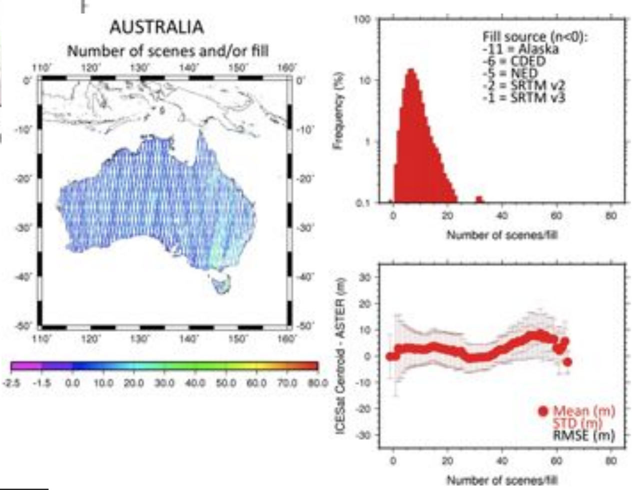
Region	N	Mean (m)	Median (m)	STD (m)	RMSE (m)	Min (m)	Max (m)
Africa	3601586	2.11	0.97	10.66	10.86	-198.99	361.90
Australia	243066	-1.64	-1.78	6.64	6.84	- 66.72	63.34
Eurasia	4049072	0.58	0.10	10.36	10.38	-389.23	590.38
N. America	7172	-1.96	-2.60	5.86	6.18	-31.93	89.41
S. America	157484	0.86	0.53	7.92	7.97	-155.08	141.41
N. Zealand	111	4.25	1.18	10.59	11.41	-21.03	35.77
W. Europe	107217	-1.56	-1.57	6.34	6.53	-83.00	573.56
Greenland	6	-0.93	-0.48	6.80	6.86	-9.91	7.41

ICESat results over areas identified as "bare" (Globcover class 200) (GDEMv2 – ICESat)

ICESat – Differences, “num” error dependencies

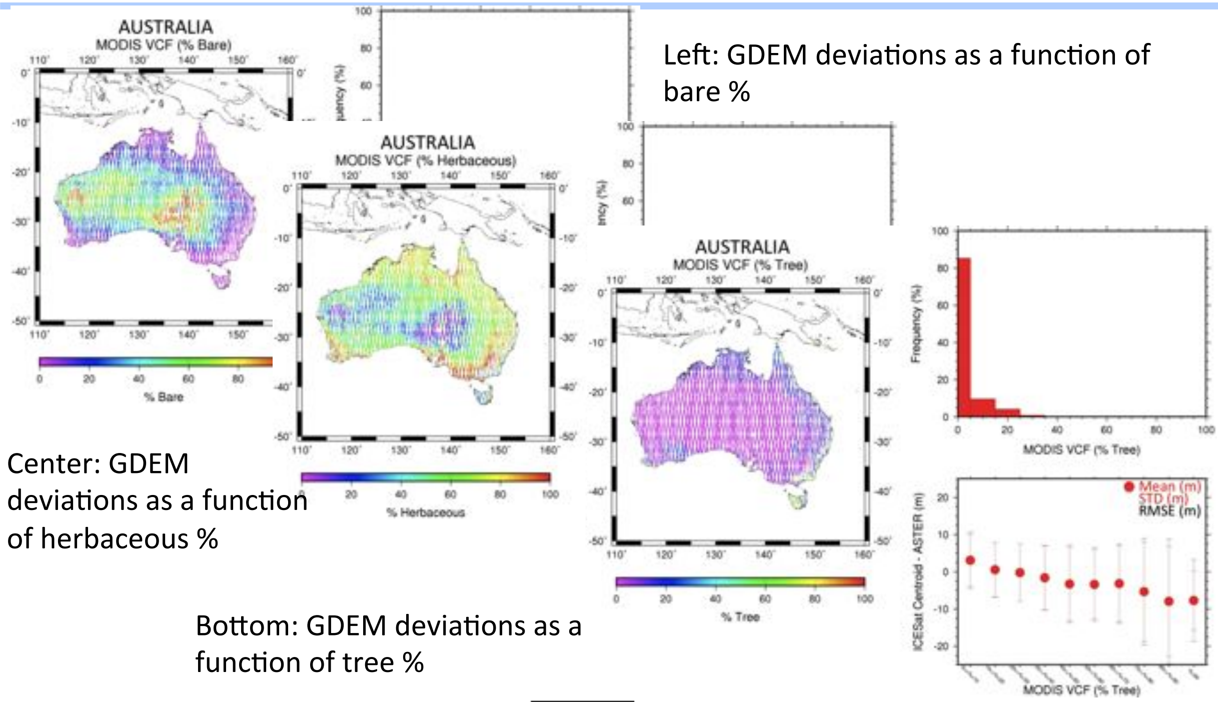


Left: map, histogram of GDEM deviations from ICE over Australia



Right: map, histogram & graph of GDEM deviations from ICE over Australia as a function of # of scenes used in elevation determination.

ICESat – Land cover effects using MODIS VCF

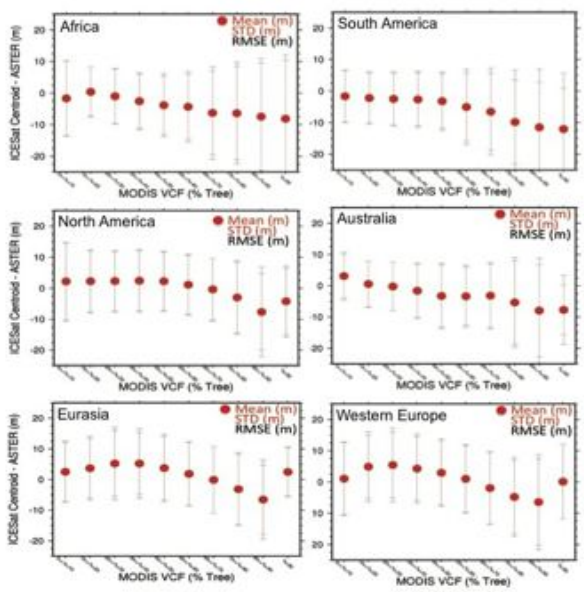


Left: GDEM deviations as a function of bare %

Center: GDEM deviations as a function of herbaceous %

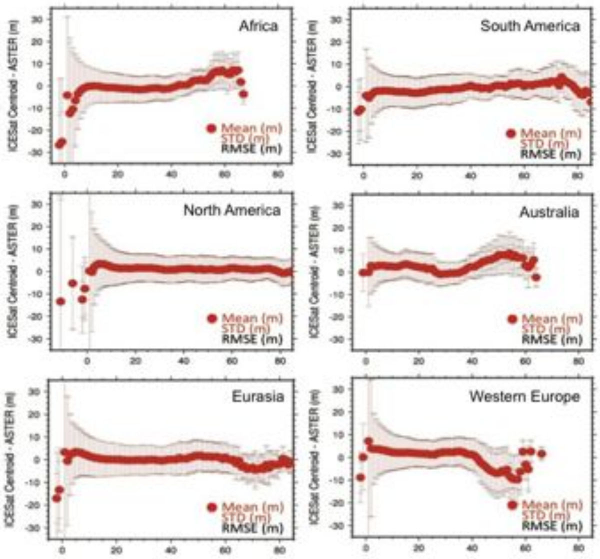
Bottom: GDEM deviations as a function of tree %

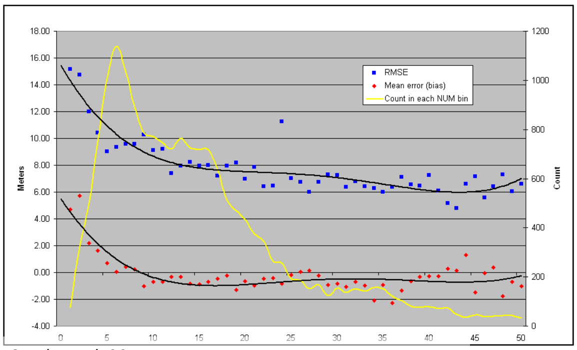
ICESat errors as a function of tree cover



Dependency of errors on tree canopy % cover for 6 continents (tree covered determined from MODIS Vegetation Continuous Fields product – MOD44B)

ICESat: errors as a function of # of scenes

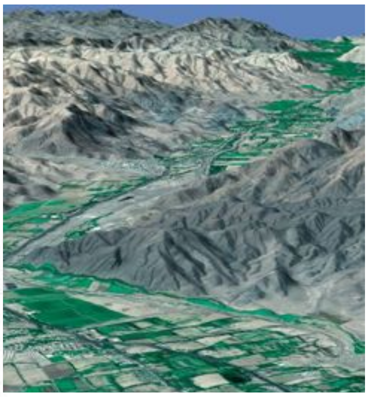


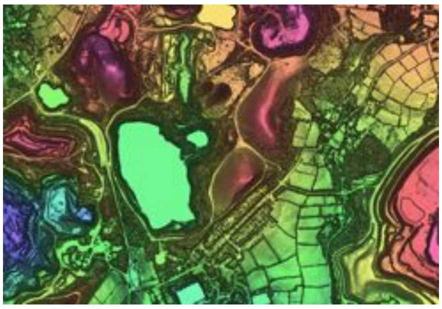


Gesch, et al. 2011

ICESat (left) and CONUS results (above) - Improvements to mean error and RMSE are minimal beyond 10-15 scenes.

45





Extracting precise DEMs despite of clouds AJAX: joining radar and optical strengths

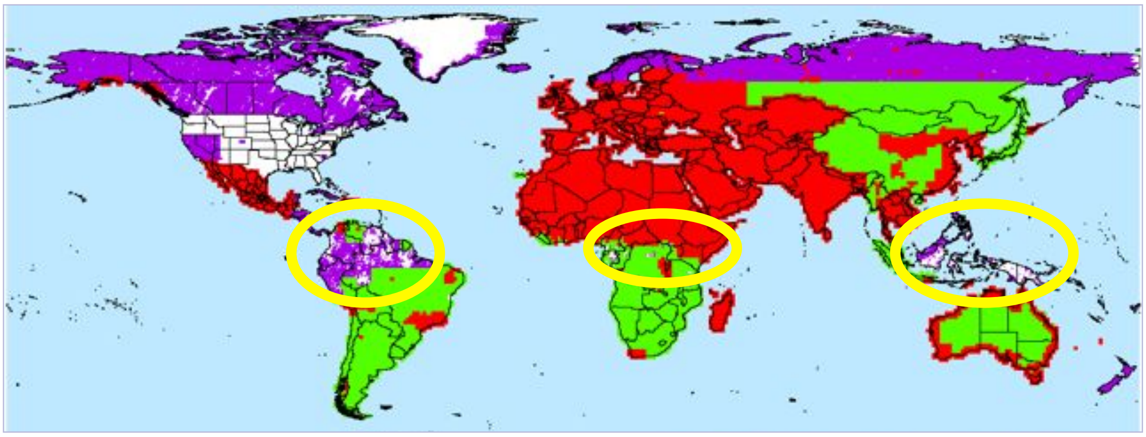
Laurent Cunin (IGN, France),
Juergen Janoth (ASTRIUM Services, Germany),
Philippe Nonin, Marc Bernard (ASTRIUM Services, France)

Melbourne ISPRS 2012

All the space you need

Context

- **SPOT 5 HRS stereo archive,** collected from 2002, covers most of landmasses, with important voids over equatorial areas
- **Reference3D product,** continuously extracted from SPOT 5 HRS stereo data since 2002, currently covers 62 M km² (08.2012), growing 8-10 M km²/yr

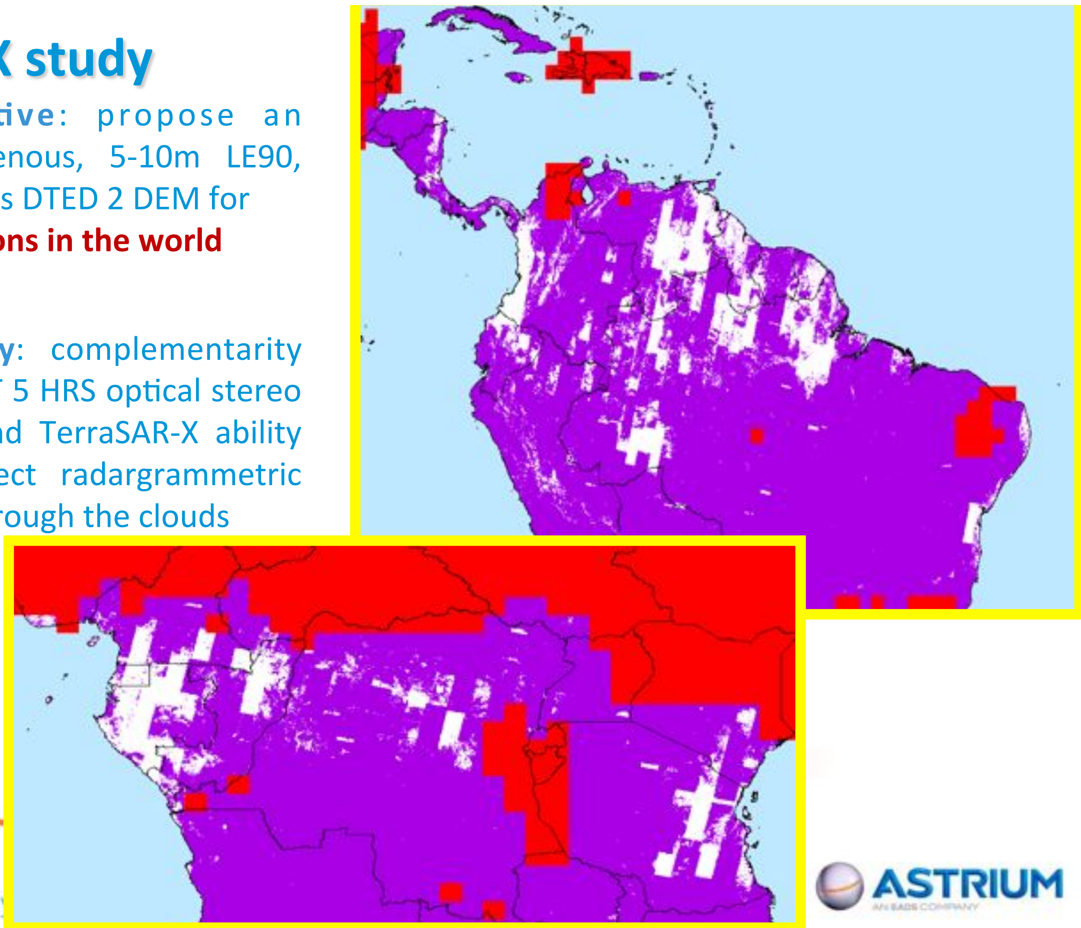


- 62 M km² Reference3D products available off-the-shelf (6040 geocells)
- 46 M km² HRS stereo data ready for Reference3D production (some coverage concerns)
- 122 M km² of validated HRS stereo data waiting for completion or block adjustment

AJAX study

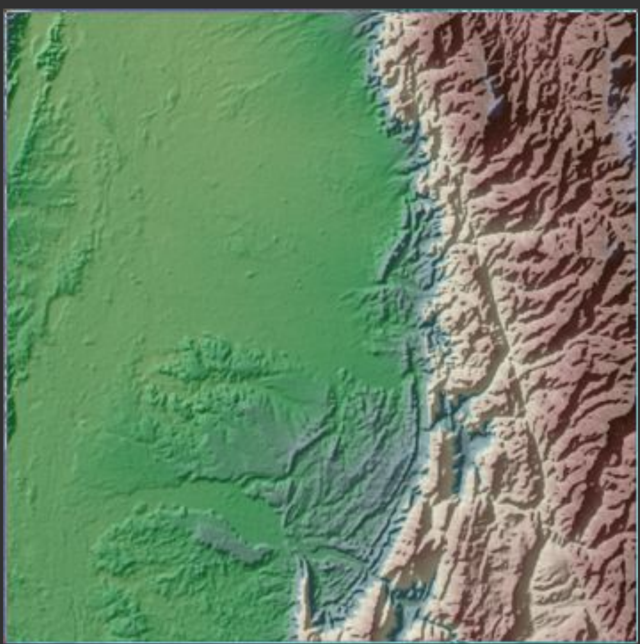
- **Objective**: propose an homogenous, 5-10m LE90, void-less DTED 2 DEM for **all regions in the world**

- **Strategy**: complementarity of SPOT 5 HRS optical stereo data and TerraSAR-X ability to collect radargrammetric data through the clouds



Ref3D product specifications to be met

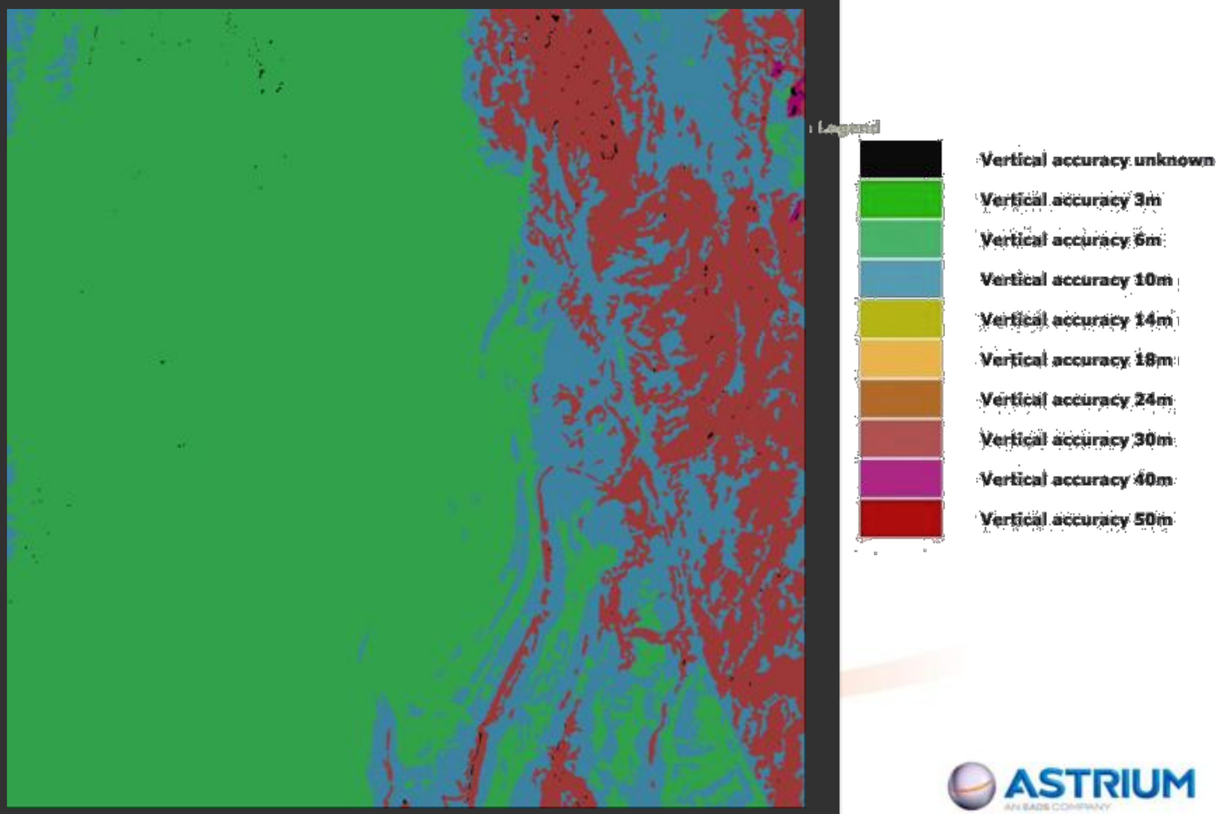
Grid Spacing	1 arc.second (ca. 30 m on the equator)
Absolute vertical accuracy	5-10m (90% linear error) depending on terrain
Absolute horizontal accuracy	5-10m (90% circular error) depending on terrain
Vertical Unit, Framing	Metre, 1°x1° geocell
Datum, Projection	WGS84, EGM96, GeoTiff 16 bits
Other specs	Homogenous rendition of the relief, homogenous overall quality at geocell level & throughout the world
Complementary info	Geo layers for reliability and accuracy of the DEM & orthoimage Geo layer for Water edition, seamless across geocells Metadata in XML-Format



Merged TSX+HRS DEM

TSX/HRS source layer

Vertical accuracy commitment (LE90)

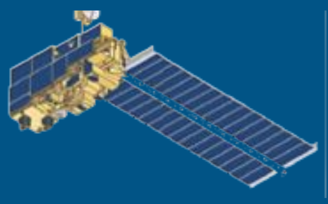


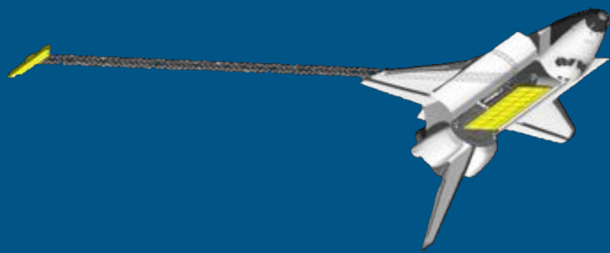
Elevation30 product range

Unique worldwide 3D geographic reference database for all global coverage needs, especially suited for large area coverage for mapping, GIS and military needs.

- Available for more than 50 million sq km worldwide
- Up to 6m horizontal and vertical accuracy
- 1 arc.second grid spacing
- DTED level 2 standards
- 3 layers: DTED2 DEM, Orthoimage, Quality masks
- Derived from both optical (SPOT) and radar (TerraSAR-X) spaceborne technologies

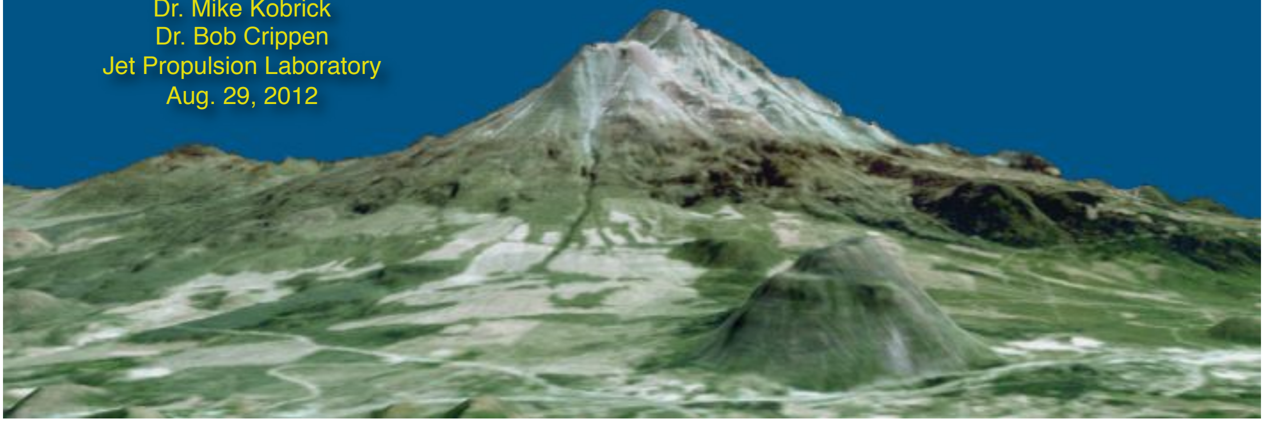
Jet Propulsion Laboratory





NASADEM - A New NASA Digital Topographic Data Set

Dr. Mike Kobrick
Dr. Bob Crippen
Jet Propulsion Laboratory
Aug. 29, 2012



NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

SRTM Limitations

- Distribution of full-res data limited by NASA/NGA agreement
- Geographic distribution limited to ±60° latitude
- Voids (small regions of no data)
- Processed with sparse ground control

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

SRTM Data Restrictions

- Re original NASA/NGA Memorandum of Understanding, DEMs better than 3 arcsec outside U.S territory may not be distributed outside NASA
- 3 arcsec DEMs and any derived, ancillary or associated products may be distributed at any resolution, as long as they cannot be reverse-engineered to better than 3 arcsec DEMs
- The MOU has now expired

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

MEaSUREs Program

Making Earth Science Data Records for Use in Research Environments

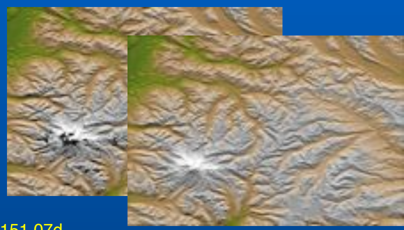
- Administered by Martha Maiden at NASA Hq
- Initiated in 2007 produce Earth Science Data Records, defined as "a unified and coherent set of observations of a given parameter of the Earth system, optimized to meet specific requirements"
- Included program to enhance and improve SRTM data products, completion due end of Sept, 2012

NASADEM - A New NASA Digital Topographic Data Set

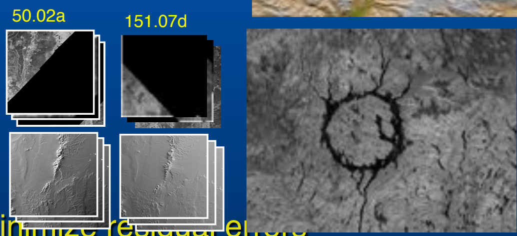
Jet Propulsion Laboratory

MEaSUREs Tasks

1. 'Void filling'
- Enhance SRTM DEMs w/best available auxiliary data



2. Image data
- Construct global seamless mosaics at various scales and formats



3. IceSAT utilization
- Incorporate additional ground control to minimize residual errors

4. Raw data set
- Package example radar echo and ancillary data for distribution

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

SRTM Void Filling Task

- Better is the enemy of good enough
- Originally proposed to void-fill few tens of percent of cells
- New good quality data sets have appeared, allowing void-filling all cells

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

Available (near) Global DEM Products

Freely available
No restrictions

- NED, CDED
  Available at 30m resolution, covers U.S., Canada, Mexico
- GMTED2010
  Available at 1km, 500m and 250m resolution
- SRTM
  Distribution limited to 90m worldwide, contains voids

Freely available
Some restrictions

- SRTM X-SAR
  Distributed at 30m, coverage limited to 40% landmass
- GDEM2 (From ASTER stereo pairs)
  Distributed at 30m, global coverage, numerous artifacts

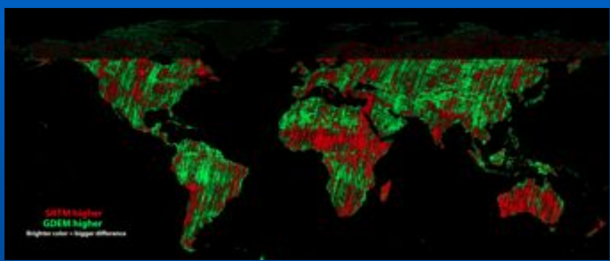
Commercial products

- SPOT (Optical stereo pairs)
  Near-global coverage, 20m resolution
- TanDEM-X (Multi-satellite interferometry)
  Global access, 12.5m resolution
- Intermap Nextmap World30
  Near-global coverage, 30m resolution

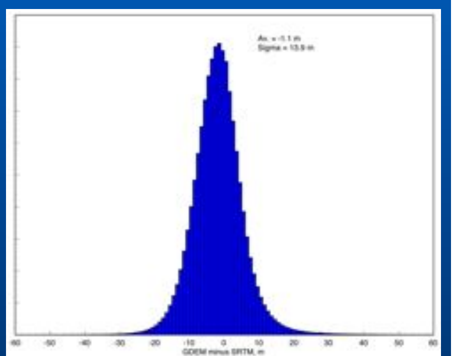
Underlined items were not available at start of MEASUREs project

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory



GDEM2 - SRTM



Global Land Cover

EGM96

NASADEM - A New NASA Digital Topographic Data Set

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NASADEM - A New NASA Digital Topographic Data Set

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- MEaSUREs DEM product will be entire SRTM set completely void-filled with combination of NED, CDED, GDEM2, GMTED2010, re-controlled by ICESat
- Metadata will include source, # scenes or swaths for each sample
- Delivery to LPDAAC around be end of Sept.

Reunion Island

SRTM

SRTM filled with GDEM2, GMTED2010

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

MEaSUREs DEM product (Ver. 3) will represent substantial improvement over current product

Processed at 1 arcsec but non-U.S. data distributed at 3 arcsec (unless NGA has change of heart)

BUT, we can do significantly better: NASADEM

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

NASADEM

• Original MOU between NASA and NGA for SRTM has expired
- However DEM has been designated 'LIMDIS' and still cannot be distributed

• NASA is entertaining proposal to

- Reprocess raw SRTM radar echoes to generate new DEM
    - Utilize improved algorithms (esp. 'phase unwrapping'), faster computers, etc.

- Control swaths with ICESat before mosaicing

- Merge (not just void-fill) with NED, CDED, GDEMn, GMTED2010, et al

- Generate new data types
    - Error data sets
    - Slope, aspect
    - Correlation data set (useful for classification, biomass)

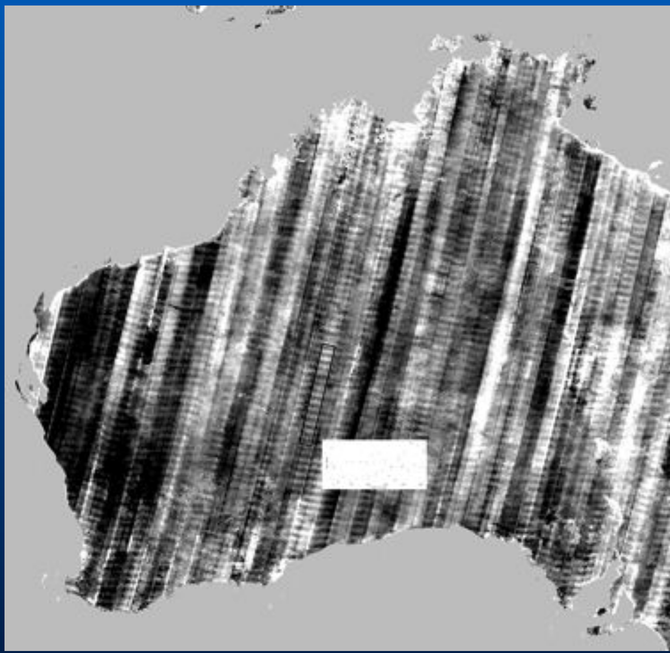
- Distribute all data sets at 1 arcsec sampling

NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

SRTM minus GDEM2

'Ripple' wavelength ~ 32.5 km

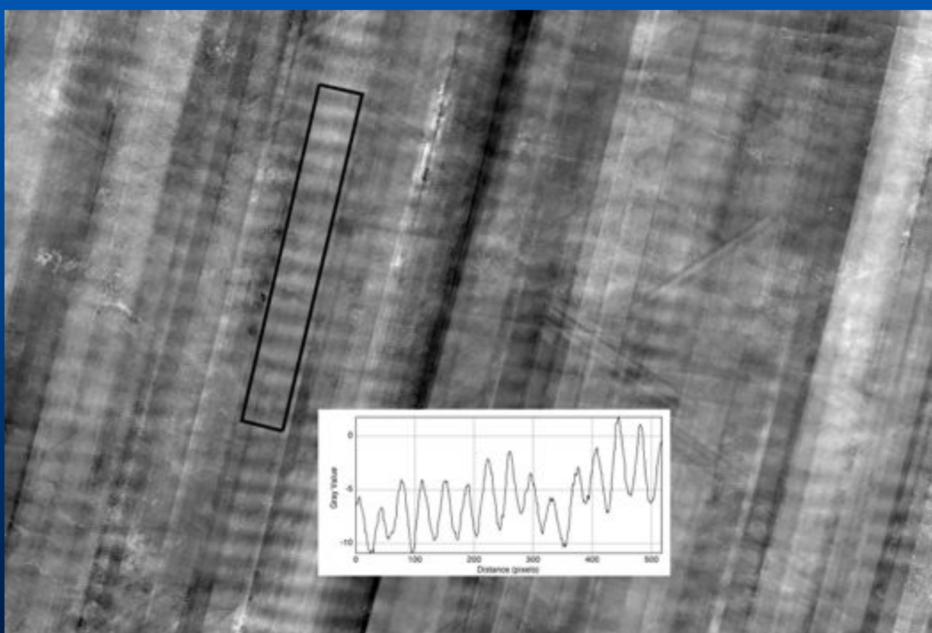


NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

SRTM minus GDEM2

'Ripple' wavelength ~ 32.5 km



NASADEM - A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

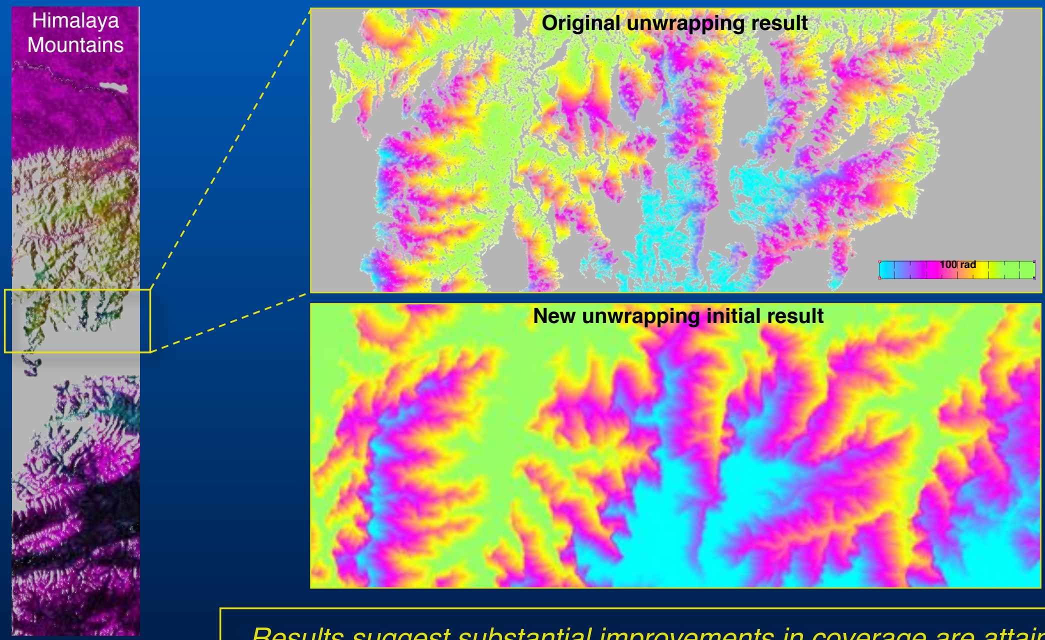
SRTM minus GDEM2

'Ripple' wavelength ~ 4.5 km

A New NASA Digital Topographic Data Set

Jet Propulsion Laboratory

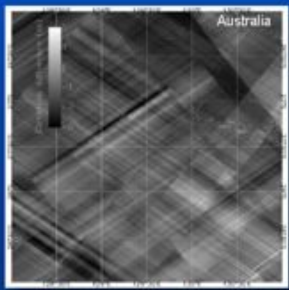
Reducing SRTM Voids with Improved Unwrapping



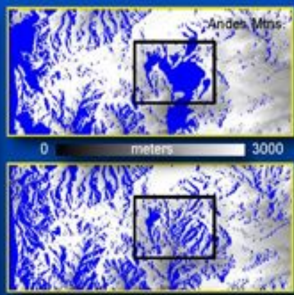
Results suggest substantial improvements in coverage are attainable

NASADEM: Creating New NASA Elevation Products

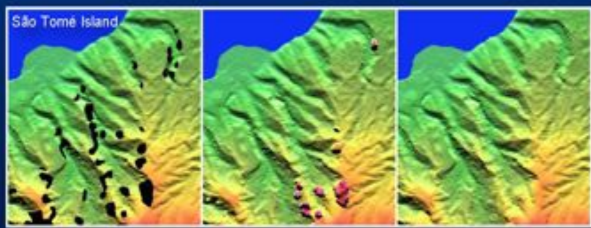
- Significant modernization of publicly and freely available DEM data
  - Global one arcsecond (~30m) products
- Reprocess all SRTM data
  - From raw sensor measurements
  - With algorithm enhancements from recent NASA investment
  - Integrated ICESat control
- Fill voids and merge DEMs
  - Incorporate strategies from MEaSUREs 2006 enhanced SRTM DEM project
  - Include significant other global data sources (e.g., GDEM2, GMTED2010)
- Create new SRTM and DEM products
  - Pixel-based elevation error propagated from SRTM system parameters
  - Estimated vegetation bias maps
  - Interferometric coherence
  - Radar backscatter imagery
  - DEM slope, aspect & curvature



SRTM elevation ripple removal. Criss-cross pattern comes from merging SRTM data containing ripples from unmeasured Shuttle boom motion. Artifacts are mitigated with use of ICESat data.



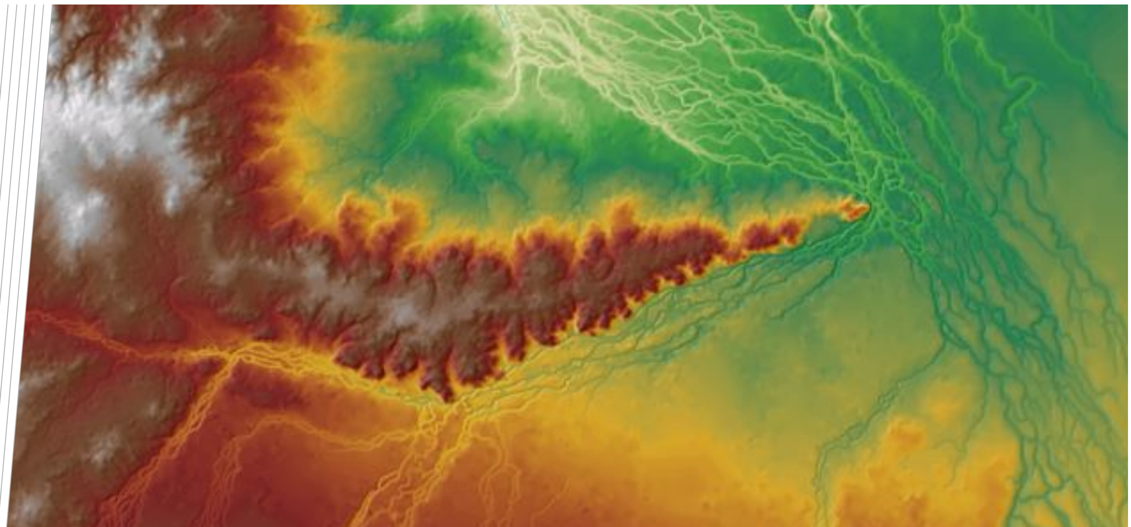
SRTM void reduction through improved phase unwrapping. Standard unwrapper (top) and new unwrapper (bottom) results will be merged to reduce voids in high relief areas.



DEM fusion with cloud-avoidance algorithm. Left: SRTM with voids. Center: After fusion with GDEM2. Most of fill is good but some has anomalously high elevations from clouds (magenta). Right: After GDEM2 cloud avoidance (Crippen, 2011) and filled with GMTED2010.

Jet Propulsion Laboratory
California Institute of Technology

Contact: Sean Buckley (buckley@jpl.nasa.gov), 9/2012



www.csiro.au

Removal of Tree Offsets from SRTM and Other Digital Surface Models

Dr John Gallant, Mr Arthur Read, Mr Trevor Dowling

CSIRO Land and Water
Canberra, Australia

National Research FLAGSHIPS
Water for a Healthy Country
CSIRO

1 second national DEM products

2000
2005 — 1 second SRTM

Destripe, void fill

2008 — 1 second DSM v1.0 → 3 second DSM v1.0, 9 second DSM v1.0

Remove tree offsets

2009 — 1 second DEM v1.0 → 3 second DEM v1.0, 9 second DEM v1.0

Adaptive smoothing

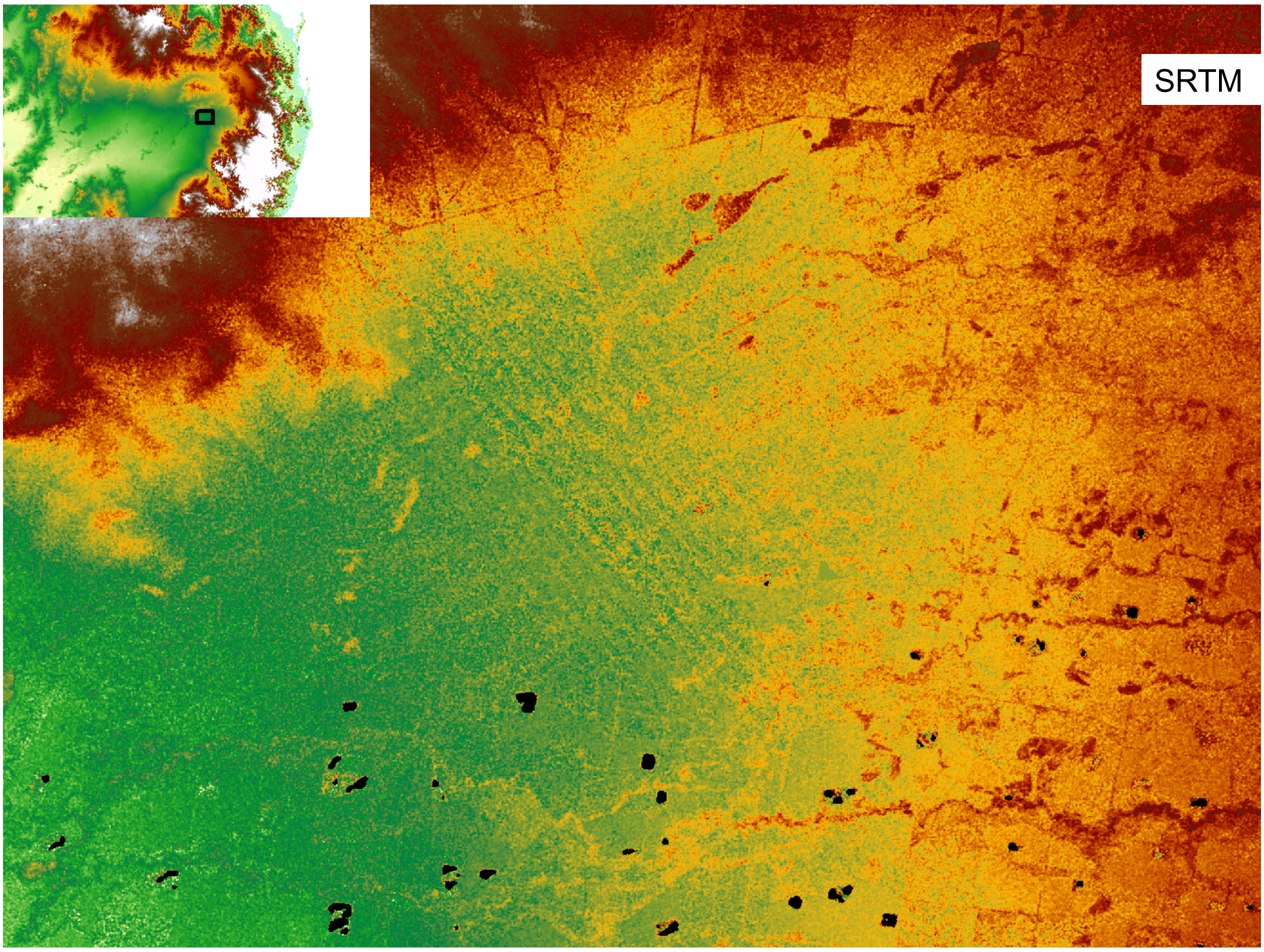
2010 — 1 second DEM-S v1.0 → 3 second DEM-S v1.0, 9 second DEM-S v1.0

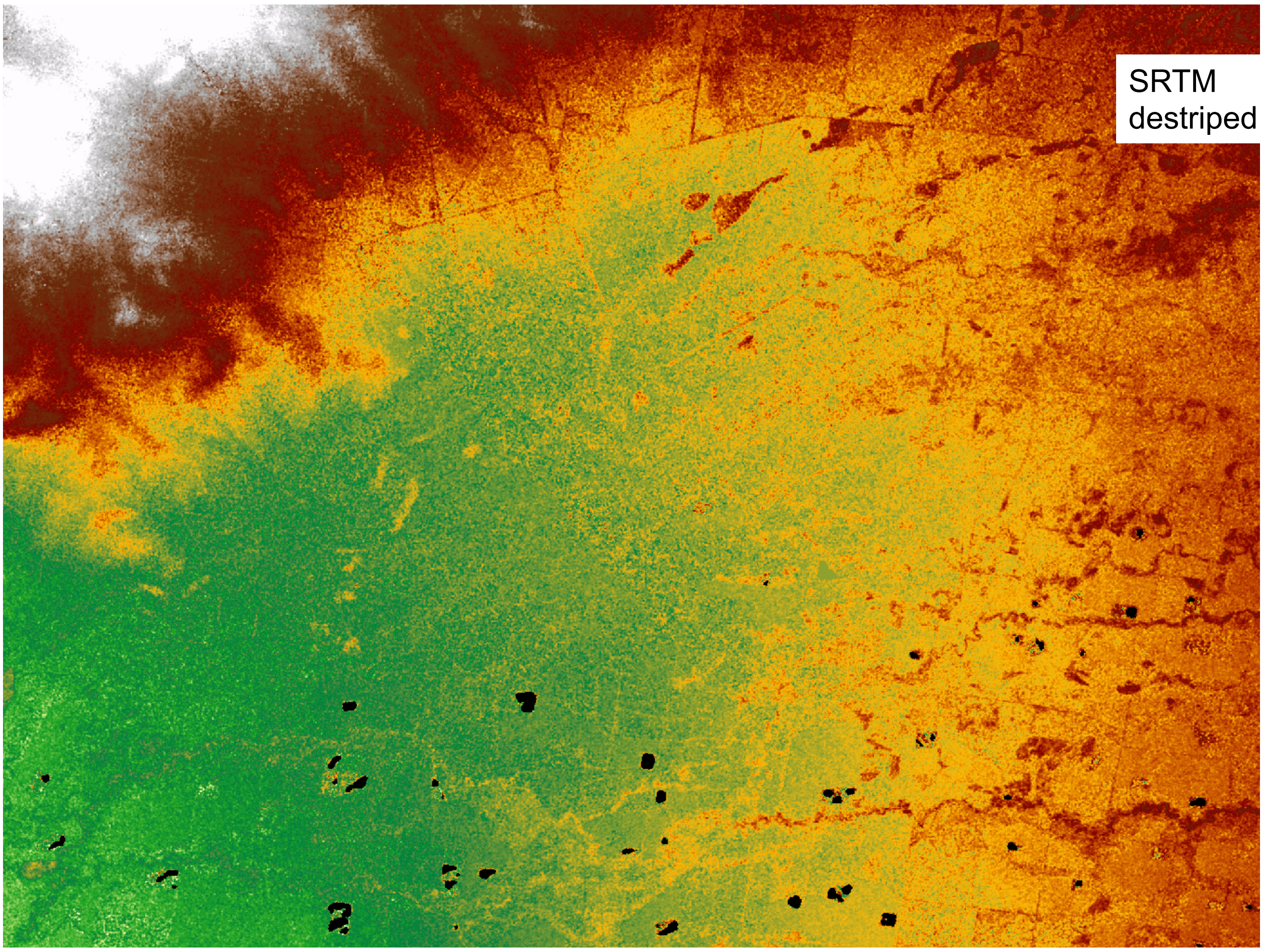
Drainage enforcement

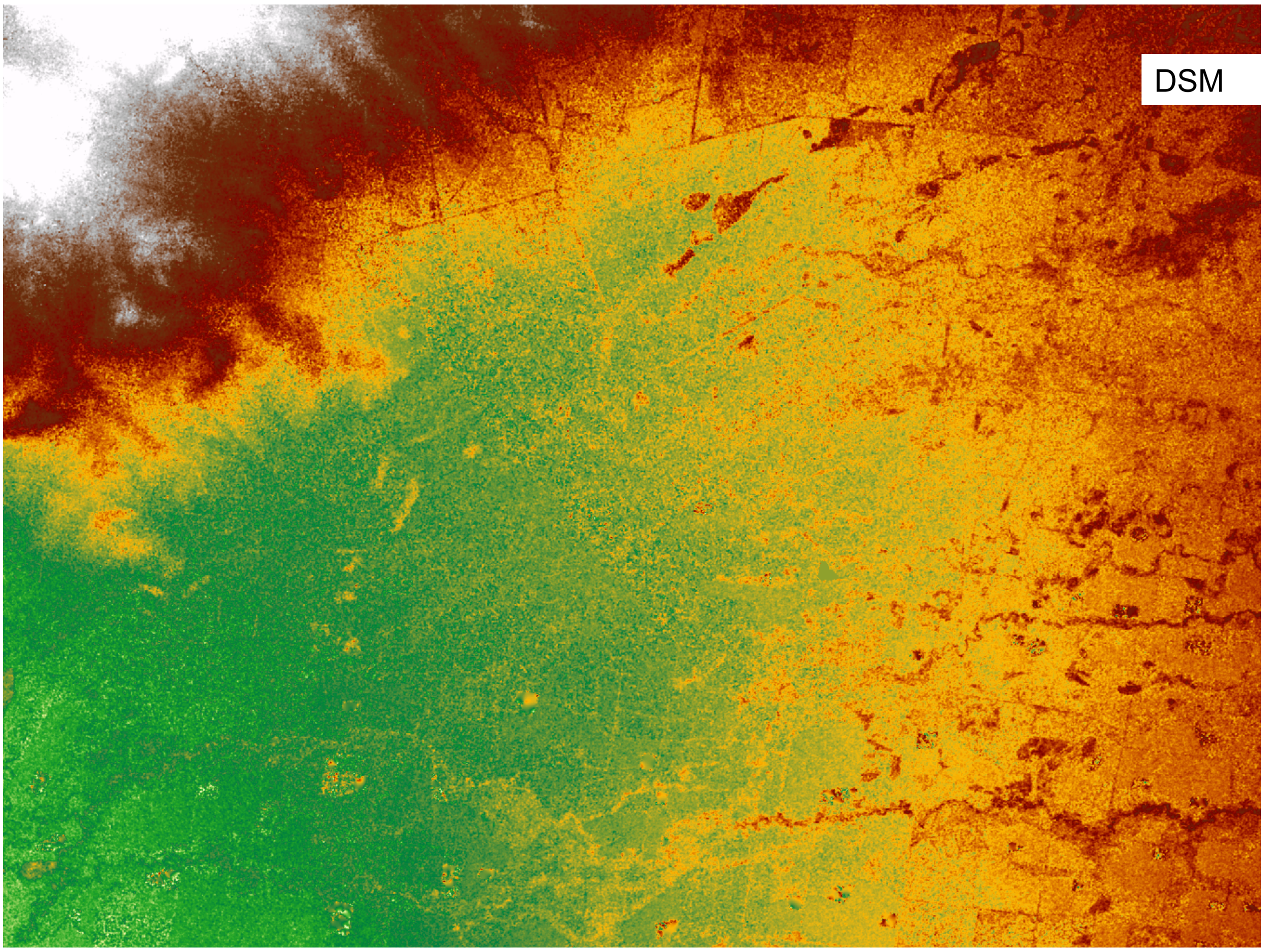
2011 — 1 second DEM-H v1.0

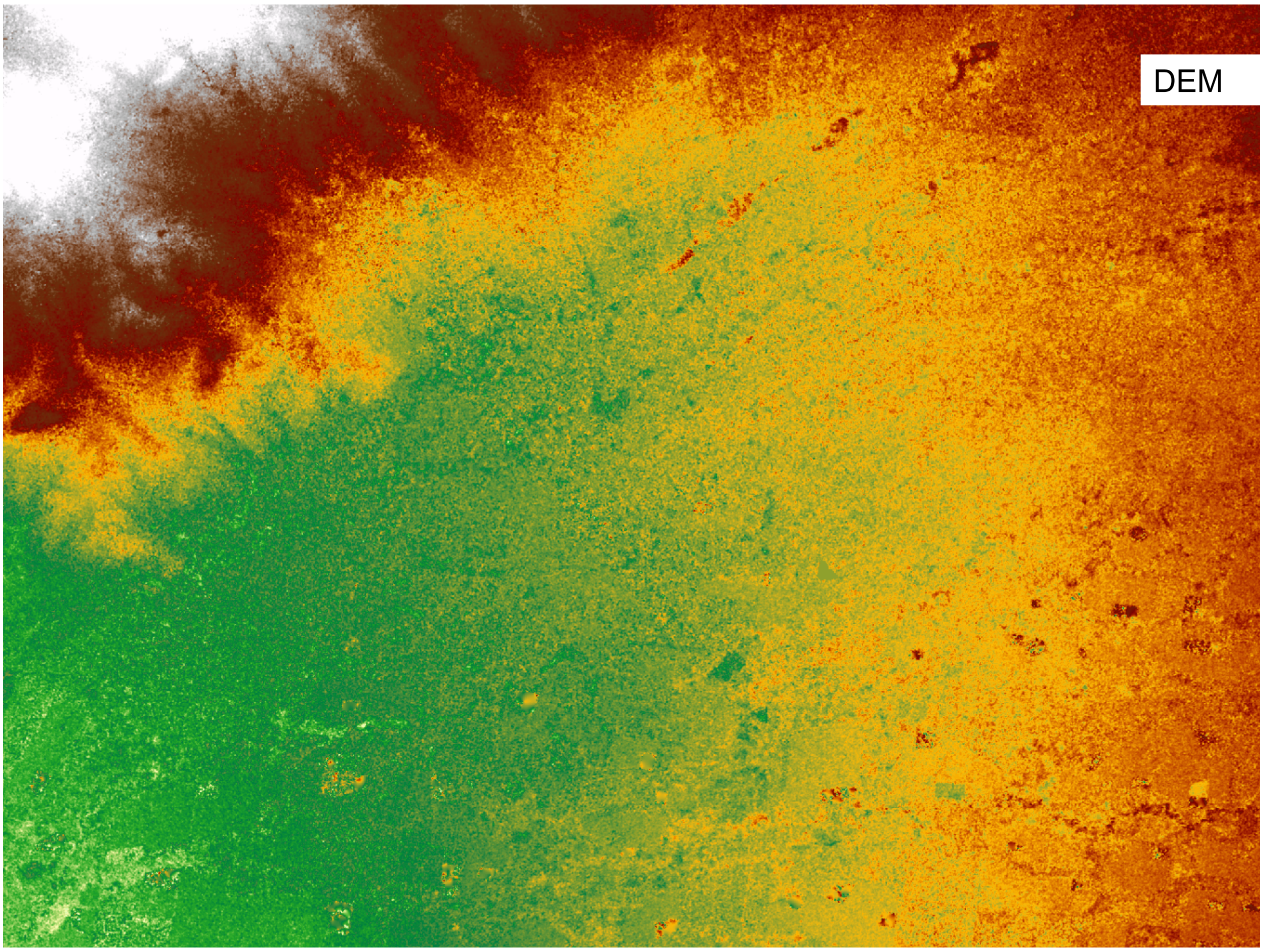
Drainage enforcement (from 3 second DEM-S v1.0 / 9 second DEM-S v1.0) → 3 second DEM-H v1.0, 9 second DEM-H v1.0

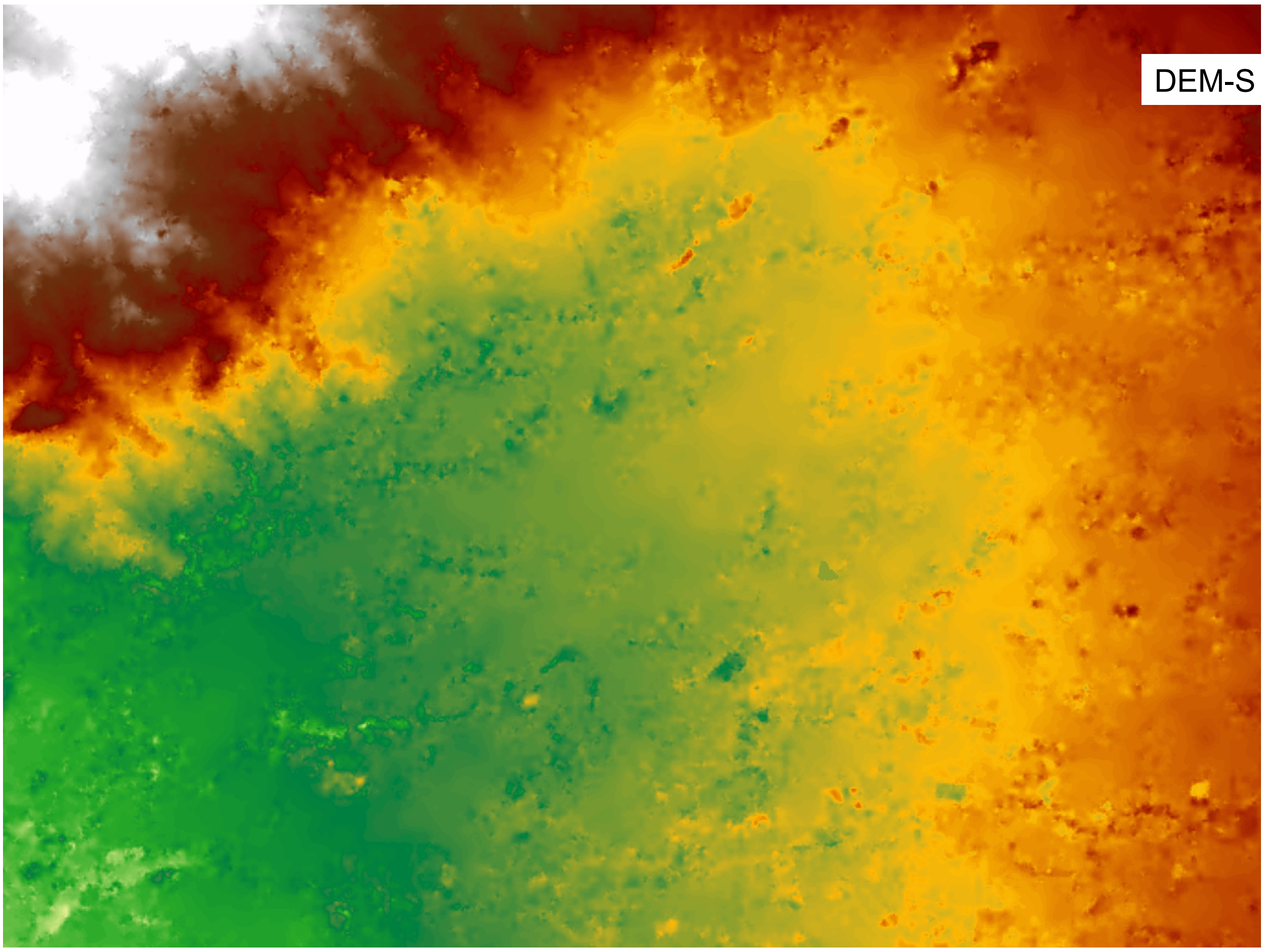
- Collaboration between CSIRO, BoM, GA and ANU

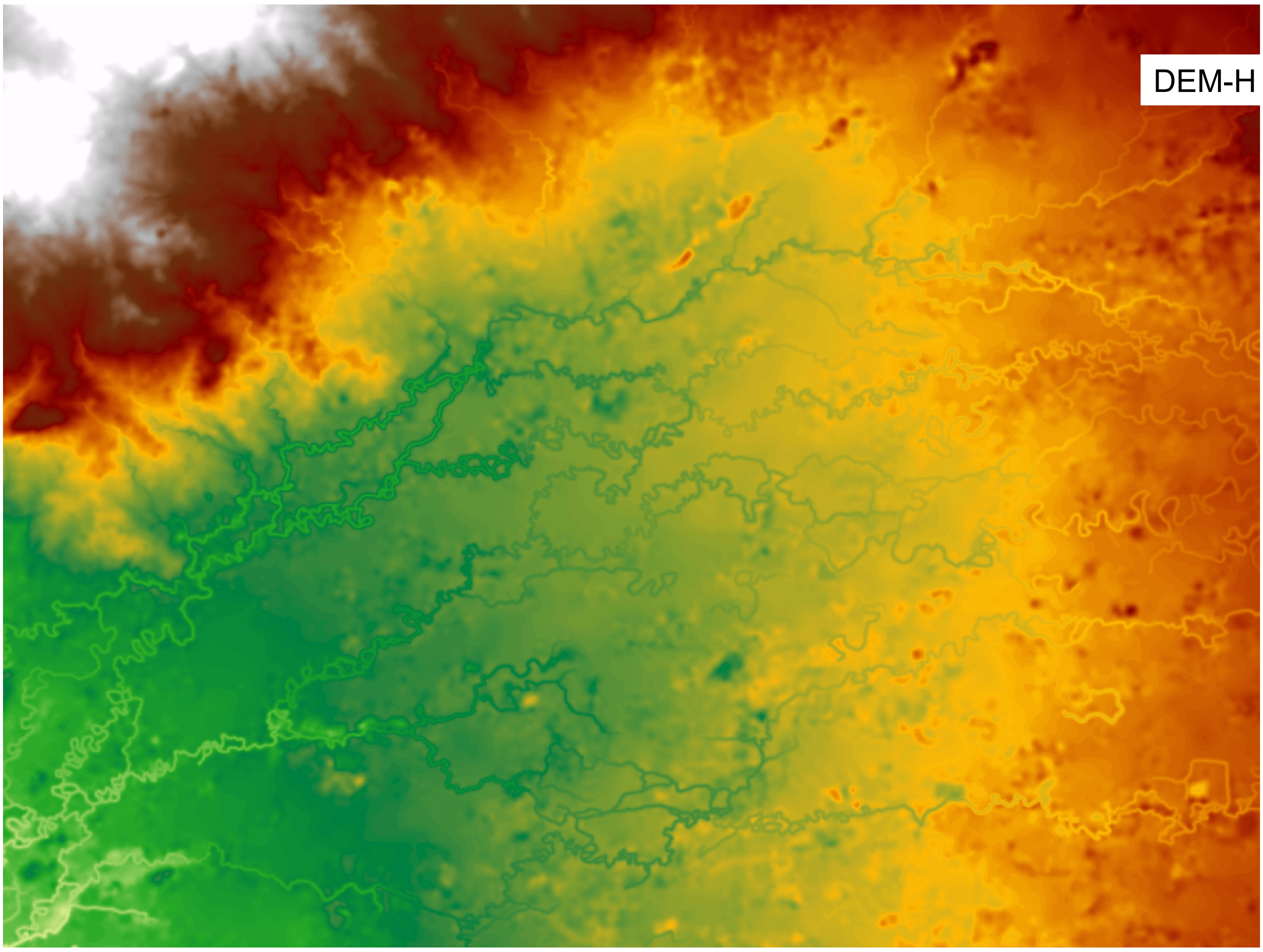



SRTM
destriped


DSM

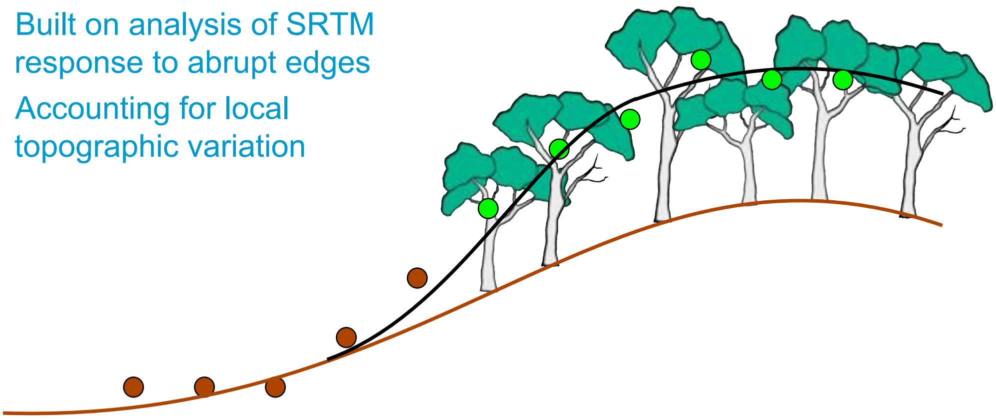

DEM


DEM-S



DSM to DEM: Vegetation offset estimation

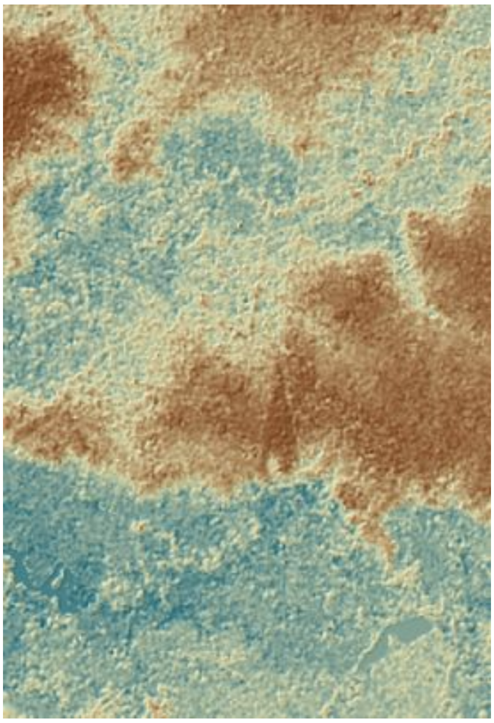
- Local least-squares estimation of vegetation offsets at patch edges
- Built on analysis of SRTM response to abrupt edges
- Accounting for local topographic variation



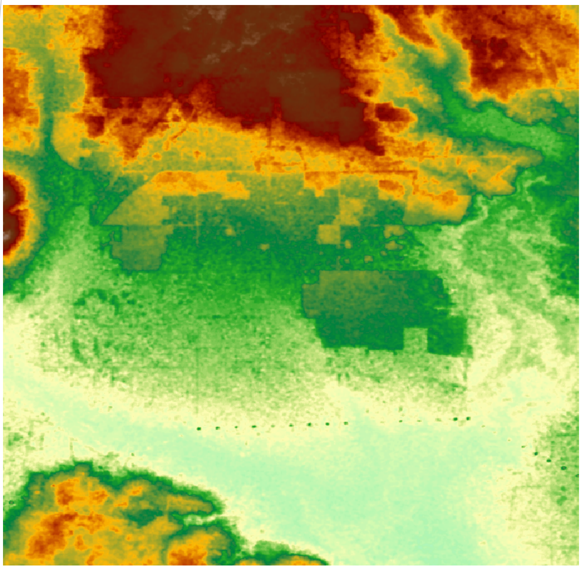
$$SRTM = ground + veght * vegmask + slope\ terms + noise$$

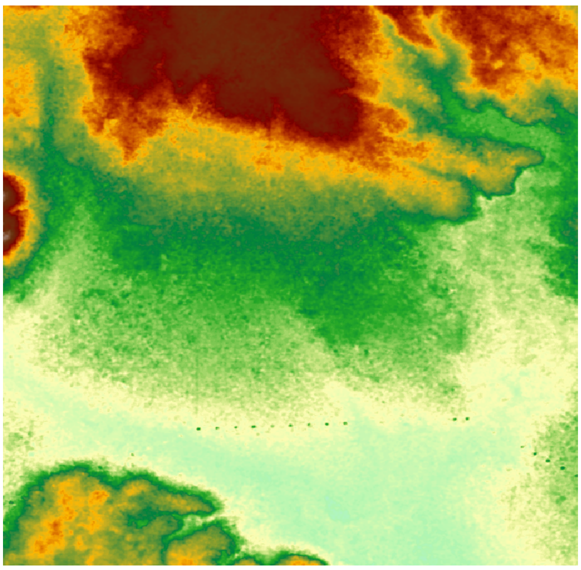
Fitted over a 5-cell radius circle

Estimate vegetation offset at edges

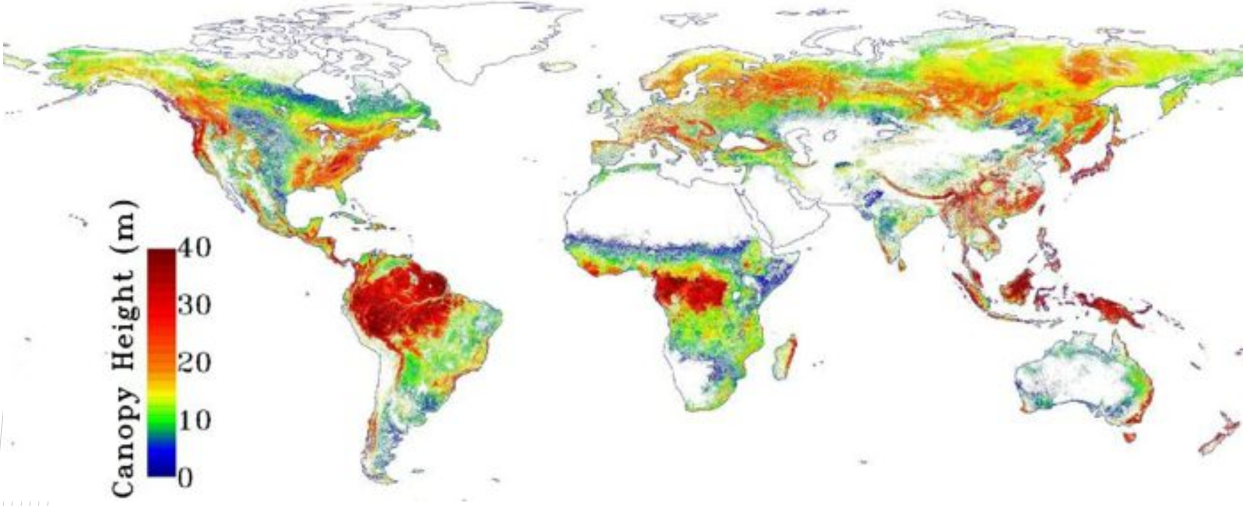


DSM to DEM: end result





NASA global tree height map @ 1km



Marc Simard, JPL
http://www.nasa.gov/topics/earth/features/forest20120217.html

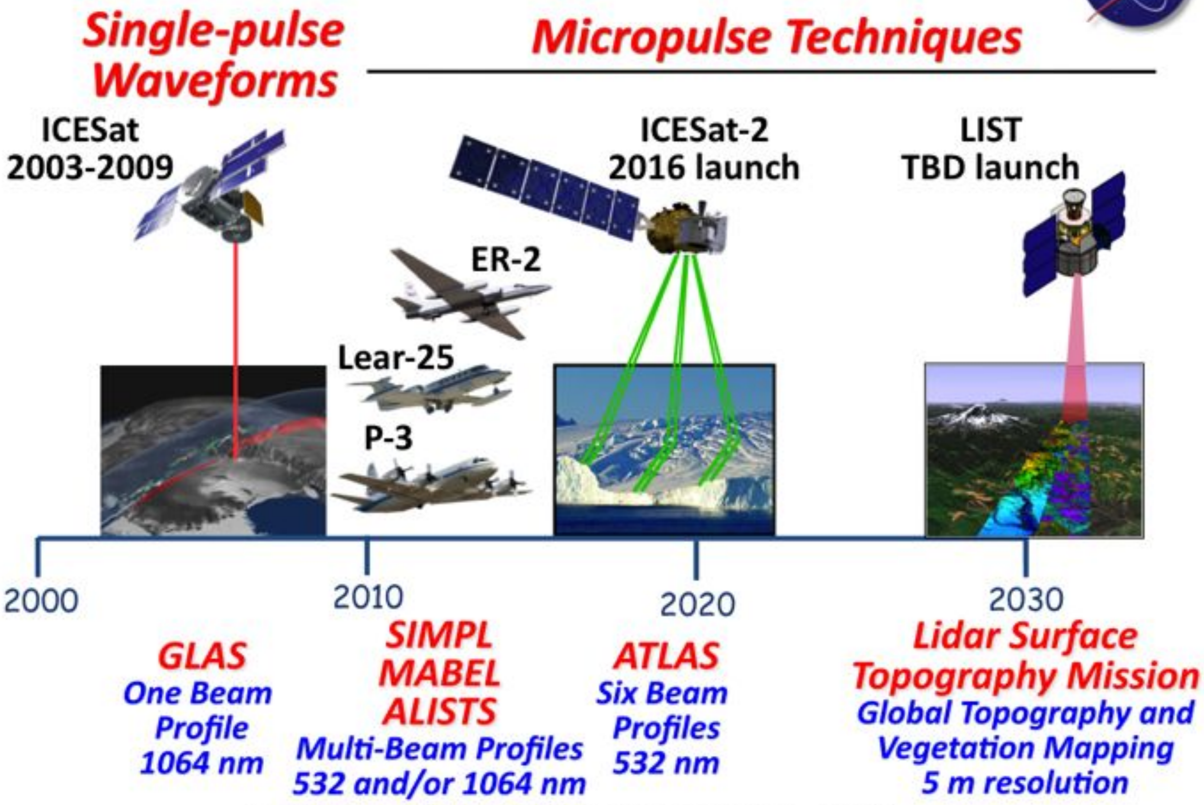
From MODIS imagery calibrated by ICESat data

National Research FLAGSHIPS CSIRO

NASA ICESat, ICESat-2 and Airborne Multi-beam Lidar Activities

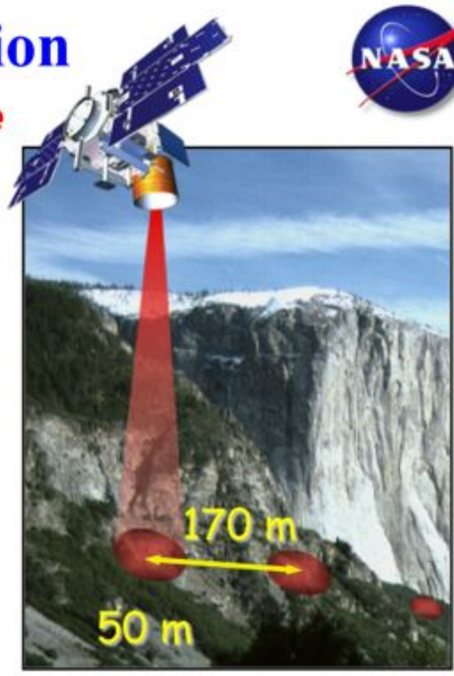
David Harding
Goddard Space Flight Center
September 19, 2012

Earth Science Multi-beam Lidar Timeline



David Harding, NASA Goddard Space Flight Center, Sept. 22, 2012

ICESat Mission



Ice Cloud and land Elevation Satellite

GLAS instrument operated from 2003 to 2009

Primary Science Objectives

- Ice sheet elevation and its change
- Cloud and aerosol profiling
- Land topography profiles
- Forest canopy height sampling

Traditional Laser Altimeter

- Full waveform recording @ 1064 nm
- Single beam at 40 Hz rate
  - 50 m footprints with 170 m spacing

Recent Activities

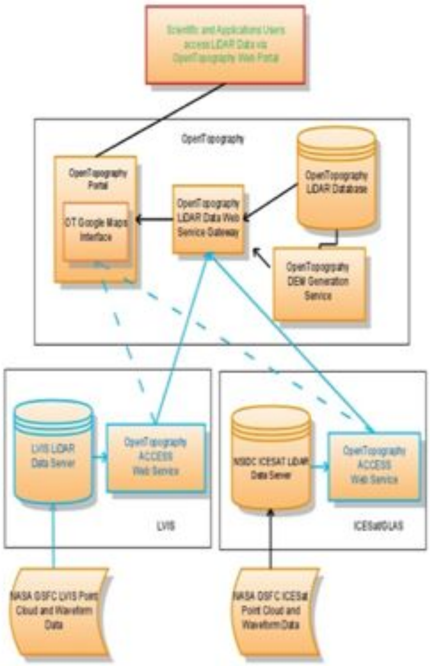
- Derivation and use of geodetic ground control points for evaluation and improvement of global DEMs
- Final data product V. 33 released at nsidc.org/data/icesat/
- Conversion to HDF5 for interoperability with planned ICESat-2 data
- Development of NASA Lidar Access System (NLAS)

David Harding, NASA Goddard Space Flight Center, Sept. 22, 2012

NASA Lidar Access System (NLAS)

Integrated Access to NASA Waveform Lidar Data Archives

ICESat satellite data at NSIDC
LVIS airborne data at GSFC
Improves their accessibility and utility
Funded by NASA's ACCESS program
Charles Meerten, PI, UNAVCO



Utilizes Open Standard Web Services

RAMADDA to service search, sub-setting, format conversion and data transfer requests
SDSC OpenTopography portal acts as services client and provides interoperable data access

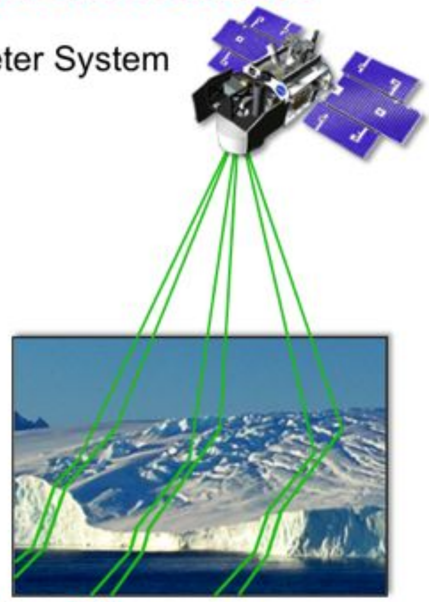
Enhanced ICESat product

Consolidated parameters from 8 GLAS products
25 derived parameters for improved ease of use
QA/QC parameters added to guide selection and use of appropriate data

ICESat-2 Mission

Follow on to the Ice Cloud and land Elevation Satellite

Scheduled for 2016 launch
Instrument: Advanced Topographic Laser Altimeter System



Primary Science Objectives

Ice sheet elevation and its change
Sea ice thickness and its change
Forest canopy height sampling

New Laser Altimeter Technology

Micropulse laser transmitter
Narrow divergence at 10 kHz rate
- 10 m footprints with 0.7 m spacing

Single photon ranging at 532 nm
Six beams
- Close pairs 90 m apart for local slope
- Three pairs 2 km apart for coverage

Benefit for global DEM ground control points

Significantly improved sampling and resolution as compared to ICESat
Profiles will be uniformly distributed across land areas through the mission

Airborne Multi-beam Systems

SIMPL: Slope Imaging Multi-polarization Photon-counting Lidar

- Low-altitude with four beams at 532 nm and 1064 nm
- 10 kHz micropulse, single photon ranging, polarimetric measurement
- Technology, measurement approach and science pathfinder for ICESat-2
- Initial flights in February, 2009
- Recent flights: Eco3D eastern U.S. ecosystem campaign (August, 2011)
- David Harding, PI, Goddard Space Flight Center

MABEL: Multiple Altimeter Beam Experimental Lidar

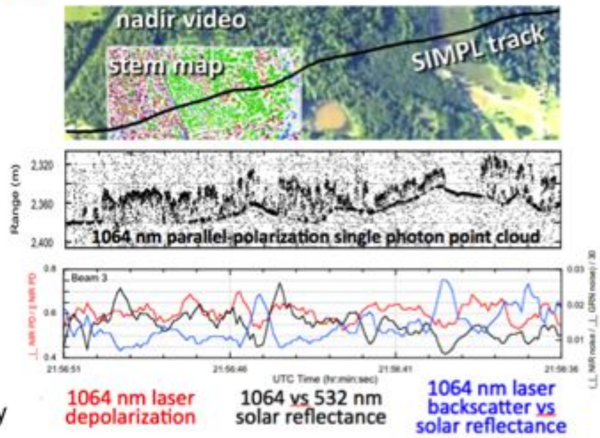
- High-altitude with sixteen 532 nm beams and eight 1064 nm beams
- 5 to 25 kHz micropulse, single photon ranging measurement
- Technology, measurement approach and science emulation for ICESat-2
- Initial flights in December, 2010
- Recent flights: polar ice sheet & sea ice (April, 2012); U.S. forest cover (Sept., 2012)
- Developed by Matthew McGill, Goddard Space Flight Center, for ICESat-2 Project

ALISTS: Airborne LIST Simulator

- Medium-altitude with sixteen adjacent 1064 nm beams forming narrow swath
- Highly-efficient 10 kHz micropulse, photon-sensitive, waveform recording measurement
- Technology, measurement approach and science pathfinder for LIST mission
- Initial flights in September, 2011
- Recent flights: eastern U.S. forest cover (August, 2012)
- Anthony Yu, PI, Goddard Space Flight Center

Slope Imaging Multi-polarization Photon-Counting Lidar

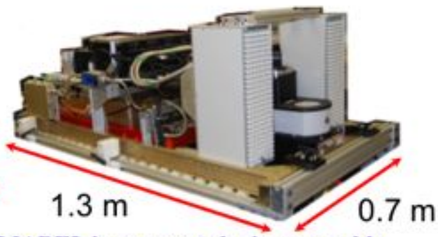
- **SIMPL is a technology and remote sensing pathfinder for next-generation, micropulse, multi-beam, spaceflight laser altimeters including ICESat-2**
- **Funded by NASA's Earth Science Technology Office Instrument Incubator Program**
  - David Harding, PI, Goddard Space Flight Center
- **Densely sampled single photon point clouds**
  - 15 cm range precision per photon
  - highly resolved surface vertical structure
- **Eight channels on each of four beams**
  - laser backscatter and solar reflectance at 532 nm (green) and 1064 nm (near IR) with parallel and perpendicular polarization
- **Amplitude ratios sensitive to surface structure and composition**
  - perpendicular / parallel: multiple scattering
  - 1064 nm / 532 nm: composition
  - backscatter / reflectance: self-shadowing geometry



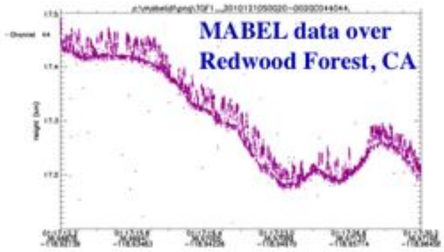
Multiple Altimeter Beam Experimental Lidar

- **MABEL developed by the ICESat-2 Project as demonstrator and validation tool for its micropulse, photon-counting altimetry implementation.**
- **MABEL is designed to explore science and engineering trade spaces:**
  - variable beam spacing/pattern;
  - variable laser rep rate (5-25 kHz);
  - two wavelength operation (532 and 1064);
  - variable energy level per footprint;
  - oversamples expected spaceborne resolution;
  - time tags every photon;
  - Matthew McGill, PI,GSFC
- **Designed for high-altitude ER-2 aircraft to provide optimal satellite simulation and validation.**
- **Instrument parameters:**
  - operational altitude: 20 km
  - wavelength: 532 and 1064 nm
  - telescope diameter: 6 inches
  - laser footprint diameter: 100 µrad (2 m)
  - detector field of view: 210 µrad (4.2 m)
  - sampling width: +/- 1.05 km (max)
  - 16 simultaneous footprints at 532 nm
  - 8 simultaneous footprints at 1064 nm

NASA ER-2 aircraft

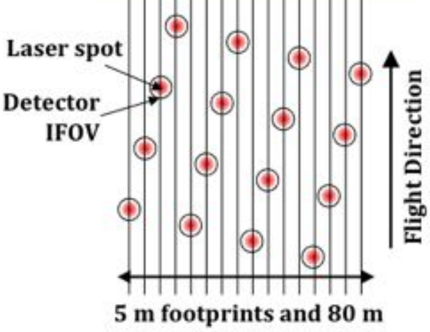


MABEL instrument during assembly

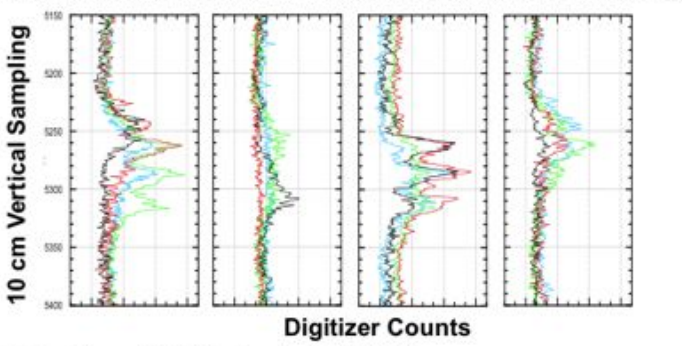


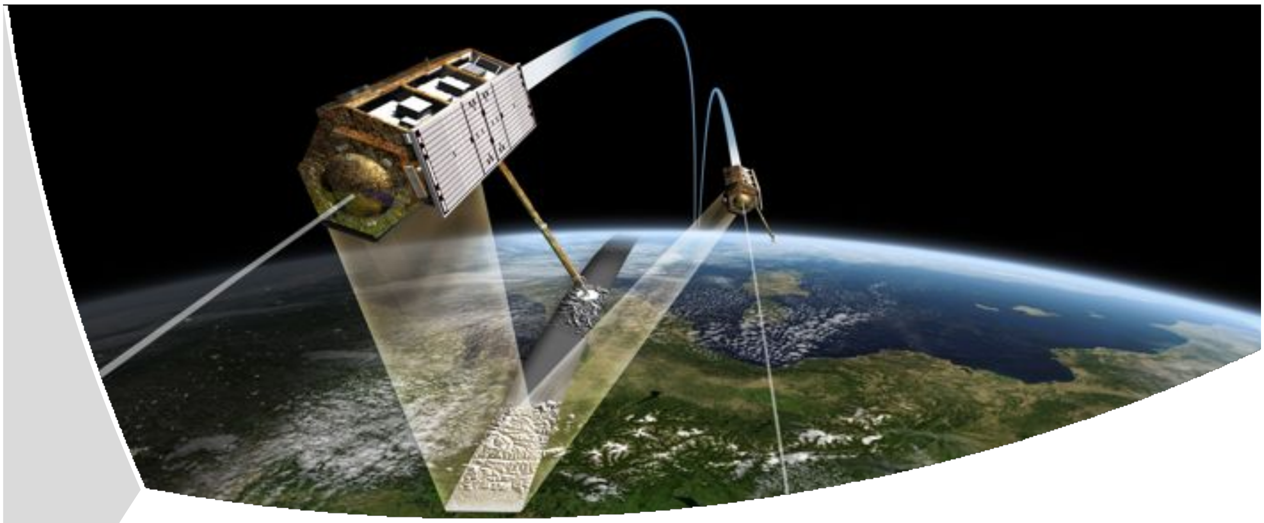
Airborne Lidar Surface Topography Simulator (ALISTS)

- **Highly Efficient Swath Mapping for Spaceflight**
  - 16 beam system with scalable architecture
  - Optically split,10 kHz, 1064 nm micropulse laser
  - 4 x 4, linear-mode, photon-sensitive analog detector
  - Demonstrating highly-efficient waveform measurement approach meeting LIST mission requirements
  - Engineering flights conducted Sept. 2011
  - Science flights conducted Aug. 2012
  - Anthony Yu, PI, Goddard Space Flight Center
  - Funded by NASA Earth Science Technology Office



Forest-cover waveforms: 16 channels, 200 shot averaging





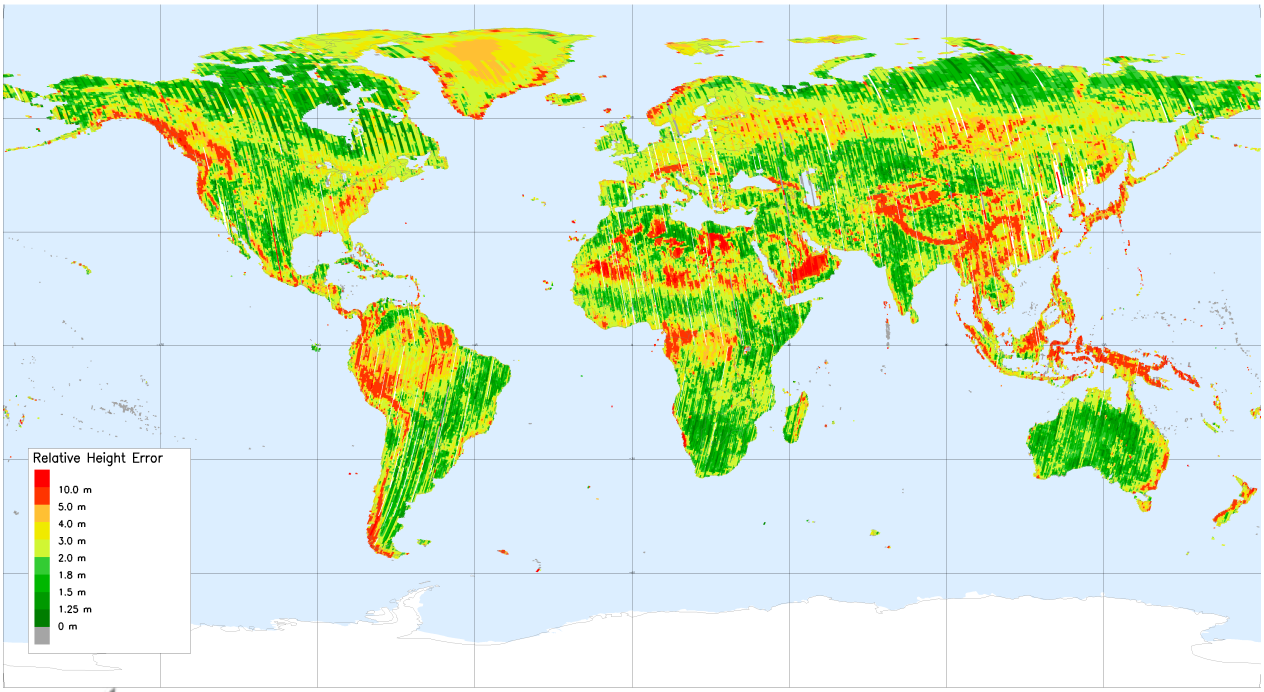
TanDEM-X Status

M. Zink

DLR Deutsches Zentrum für Luft- und Raumfahrt e.V. in der Helmholtz-Gemeinschaft

TANDEM

Relative height error of first global acquisition

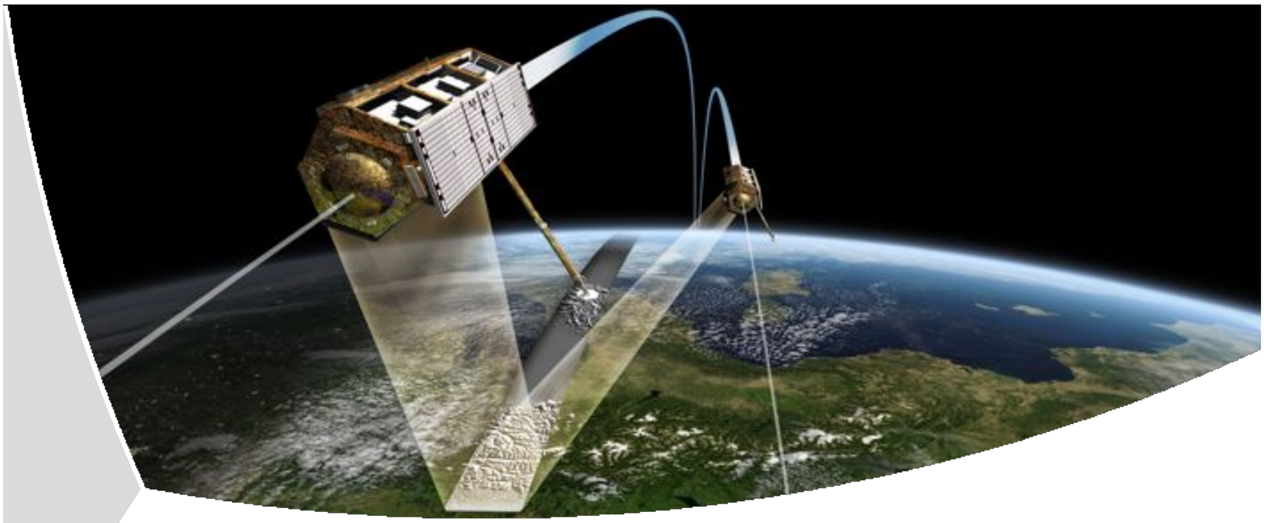


Outline of the Data Acquisition Plan

t →

2010 6 months	2011	2012	6 months	≥ 6 months
Commissioning Phase	1st global DEM acquisition with small baselines + acquisition of scientific radar data products	2nd global DEM acquisition with scaled (larger) baselines + acquisition of scientific radar data products	DEM data takes for difficult terrain with different viewing geometry + radar data products	radar data products and high res. DEMs with large interferometric baselines

Mid 2014: DEM processing finished (90%) - 1500 TByte to handle



TanDEM-X: Science Activity Status

Irena Hajnsek & Thomas Busche
Science Coordination

Experiences since July 2010…

- Announcement of Opportunity for user specific experimental acquisition requests (open from July until October 2010)
- 166 Proposals were received from more than 400 PIs and Co-Is
- More science data take requests as expected…
  - during the AO already ~ 16.000 dt
  - only 10 sec/per orbit for science available
  - solution: 64 super test sites included
    - 20 Geology, 33 Glaciology, 11 Vegetation/Hydrology
- Start of science data take acquisition in April 2011
  - Total success rate ~43% (calculated since June 2011)
  - Science data takes acquisition are not the main goal of the TanDEM-X mission. The priority for data acquisition is low.
- Science data distribution starting from February 2012

Time Line DEM Products for Scientific Use

- **TanDEM-X DEM:** From 2 global coverages + additional acquisitions for difficult terrain; availability starting end 2014++
- **Intermediate DEM (IDEM):** From first global coverage, difficult terrain excluded, for selected regions only; availability starting ~end 2012++
- **DEMs on special user-request**:
  - **FDEM:** Product variant of the TanDEM-X DEM, finer pixel spacing, higher random height error; selected regions only; availability end 2014++
  - **HDEM:** High resolution DEM with additional DEM acquisitions; better vertical accuracy; selected regions only; availability end 2014++
- All data can be ordered via Announcement of Opportunity
- **Change**: Fully compatible to SRTM Specs!

VALIDATION STUDIES OF TANDEM-X DATA

Ground truth preparation
6 months evolution

Enrique Nicolás Gesé
National Aerospace Institute of Spain (INTA).
Earth Observation, Remote Sensing and Atmosphere Department.
Observation Systems Area / Image Processing Laboratory.
nicolasge@inta.es

Main objectives: 6 months evolution

-Consolidation of TSAs – Ground truth increasing:
- -More than 5000km of Z-tracks acquired (419.000 filtered points).
- -GCPs acquired with accuracy below 0.15m (375 acquired, in progress).
- -Z-tracks in high relief. More than 100km in ridges between 1500-2500m ASL.

-DEMs analysis (evolution with new ground truth):
- -DEM benchmarking
  - -Free sources: SRTM / SRTMX / GDEMv1 / GDEMv2 / IGN25 / **PNOA5**.
  - -Comercial sources: Intermap NextMap / Reference 3D.
  - -Restricted sources: DTED2 / CEGET.
- - Slope analysis.
- - Continuous DEM source selection for TanDEM-X DEMs validation.

Best DEM

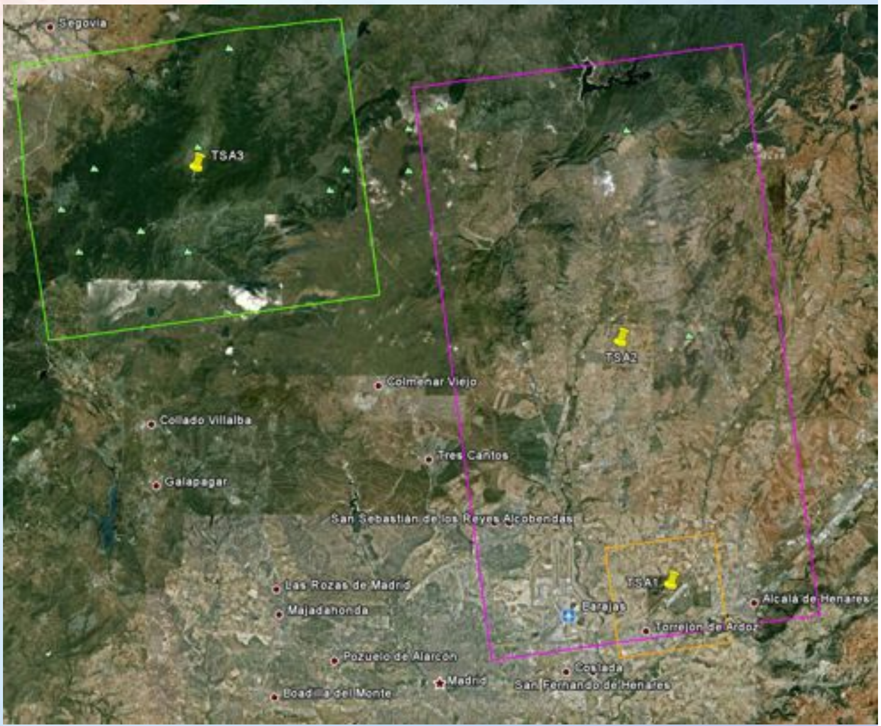
-TanDEM-X images acquisition (different geometric/polarimetric configuration):
- - 44 TanDEM-X SM pairs acquired (4 more in progress).
- - Two ascendant orbits 71 and 162.
- - Different incidence angles between 20º and 40º.
- - Single polarization change VV or HH.

Test site areas

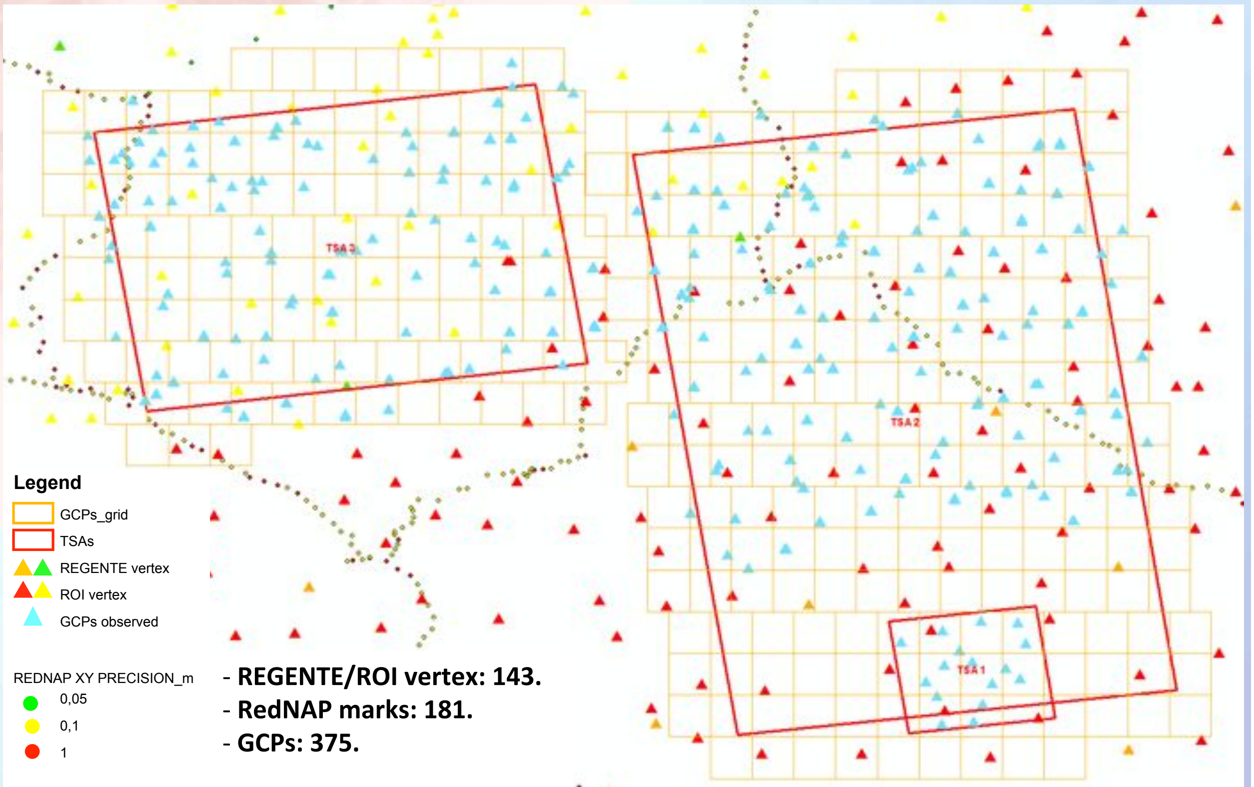
TSA1 Overview:
-Centred at INTA, 20km NE from Madrid
-Size 10x10km.
-Relative flat terrain. 620m-750m ASL.
-Torrejón Airport. Controlled site for CR deployment.
-Urban/rural interface

TSA2 Overview:
-Size 52x30km
-Hilly terrain: 630m-1700m ASL (increasing S to N)
-Mixed area: between Torrejón/ Madrid and the escarpment of Madrid's northern Sierras
-Agricultural fields, forests, suburban and urban areas.

TSA3 Overview:
-Size 25x30km
-High mountain terrain: 950m-2450m ASL (Cambric, smooth ridges)
-Centred over Valdesqui Ski resort (74km from Madrid-city)
-Mainly pine forests and bare rock/ snow.

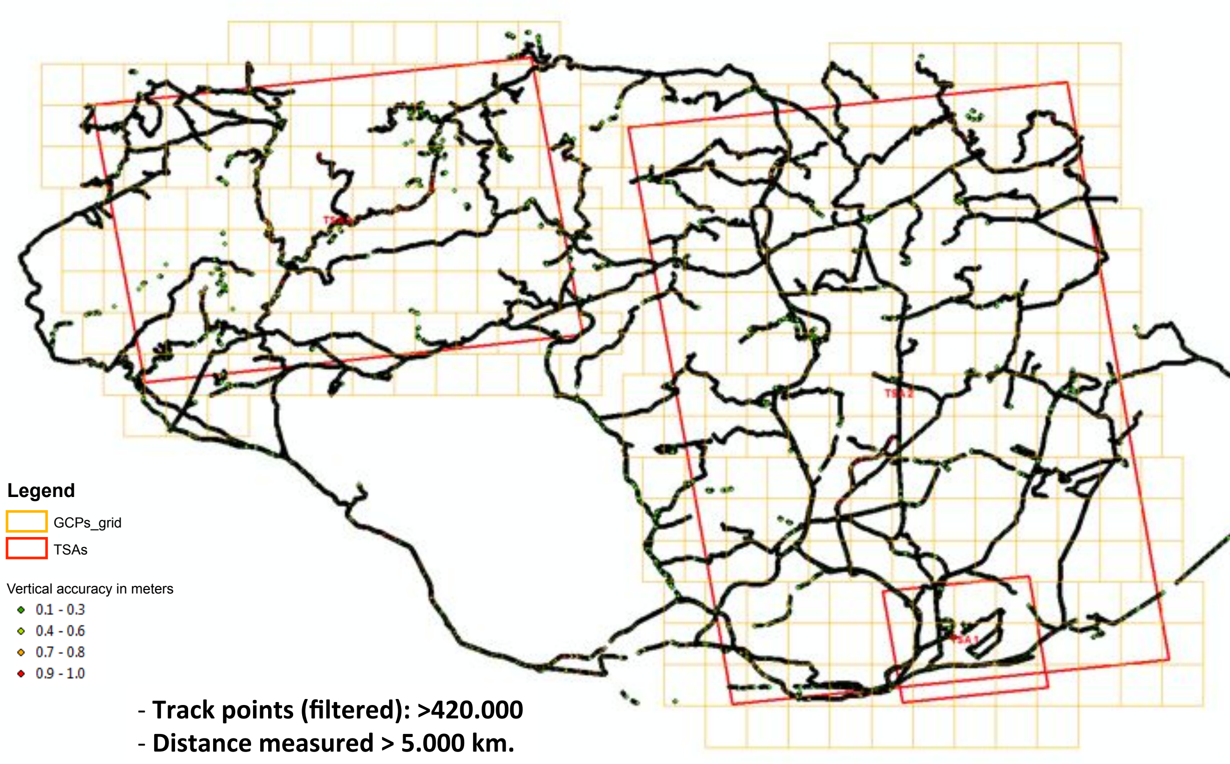


Ground truth data – Vertex, marks and GCPs
(status at sep 2012)



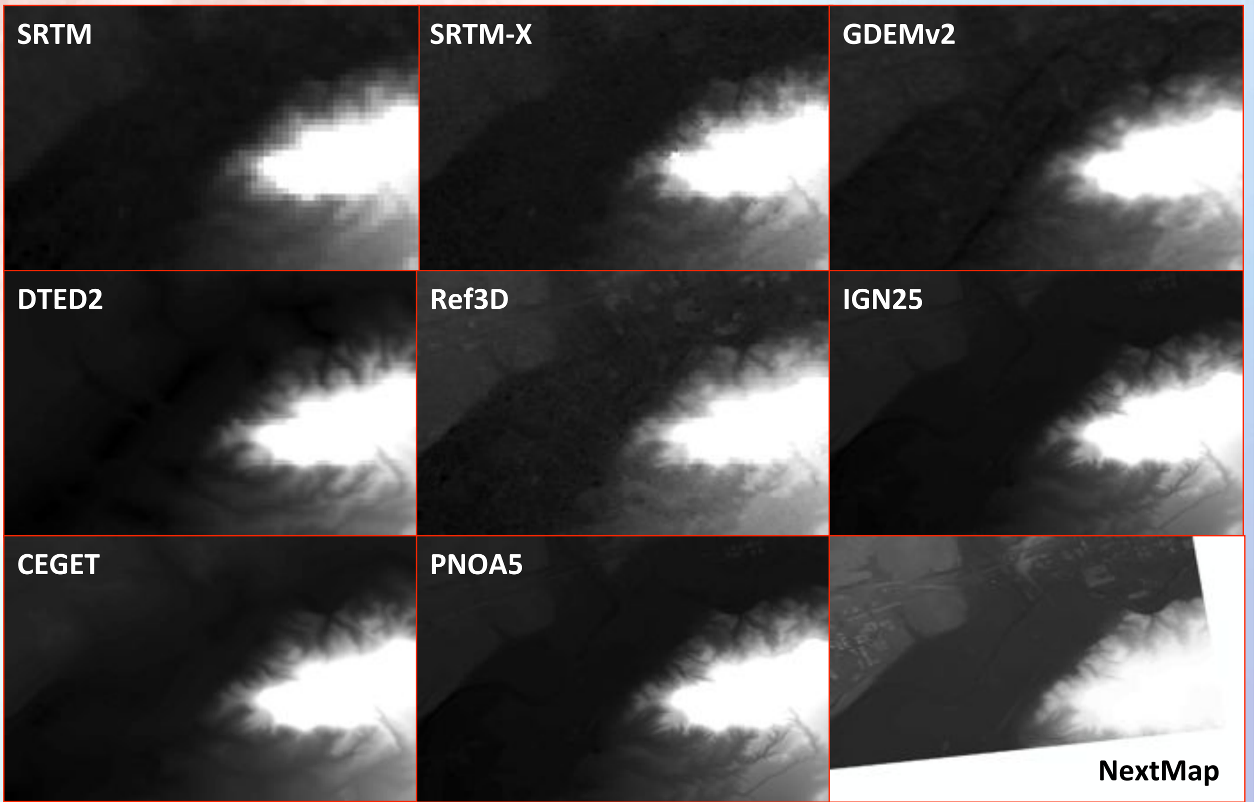
- **REGENTE/ROI vertex: 143.**
- **RedNAP marks: 181.**
- **GCPs: 375.**

Ground truth data – Z-Tracks
(status at sep 2012)



- Track points (filtered): >420.000
- Distance measured > 5.000 km.

QA of the continuous sources with discrete data. Benchmarking process
(finished)



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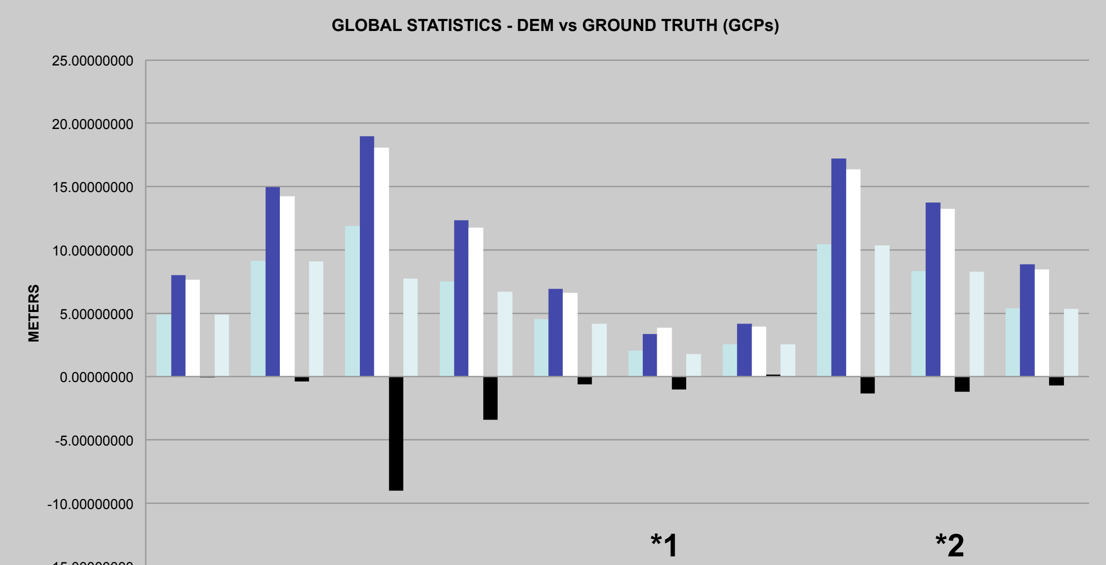
QA : GCPs analysis (in progress)

(status at sep 2012)



	CEGET	DTED2	GDEM1	GDEM2	IGN25	NEXTMAP	PNOA5	SRTMV4	SRTMX	REF3D
RMSZ	4.88071927	9.116484105	11.87731403	7.506952275	4.524338846	2.060280118	2.530798062	10.43377194	8.341721991	5.37601695
LMAS	8.02	14.98	18.98203039	12.3501987	6.936636781	3.3749546	4.163968601	17.19972833	13.7476842	8.87
LMAS ADJ	7.633627799	14.25493899	18.06234585	11.75182822	6.60032904	3.843638799	3.962087643	16.36583693	13.22600856	8.438648207
DIF AVG	-0.062300269	-0.406596474	-9.005686406	-3.42866536	-0.619253443	-1.010275823	0.160125753	-1.344541466	-1.195487151	-0.691032873
STAND DEV	4.876746452	9.107399192	7.758231915	6.676930398	4.167668042	1.787198253	2.525719926	10.36204319	8.264800629	5.343246155

MAX_DIF	14.40533781	37.49525809	17.294613	13.294613	25.0903354	6.2430198	6.22249859	57.4053378	75.371341	17.4053378
MIN_DIF	-50.77529023	-60.77529023	-72.7510176	-58.7533176	-51.2302463	-5.69228867	-53.84035371	-113.751018	-88.28105	-55.7752902

686 Samples (*1) 35 Samples (*2) 490 Samples (*1 & *2 due to reduced coverage)

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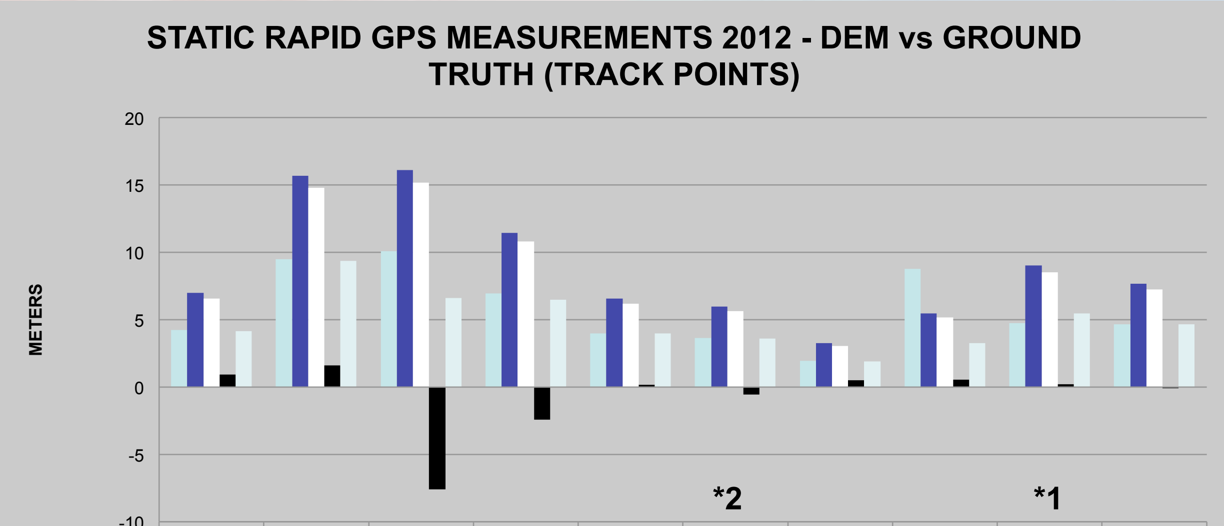
QA : Z-Track analysis (in progress)

(status at sep 2012)



	CEGET	DTED2	GDEM1	GDEM2	IGN25	NEXTMAP	PNOA5	SRTMV4	SRTMX	REF3D
RMSZ	4.234791576	9.51872937	10.07290176	6.938819662	3.988627974	3.626449117	1.97002240	8.796552843	4.763088571	4.662066583
LMAS	6.98	15.67	16.10	11.43	6.55	5.97	3.25	5.48	9.03	7.67
LMAS ADJ	6.58428326	14.79462057	15.19353487	10.79131336	6.185986876	5.63568136	3.063734045	5.17264887	8.519471801	7.236730096
DIF AVG	0.9175	1.604109028	-7.609410585	-2.409443849	0.189488245	-0.548009701	0.516076512	0.56953053	0.219280716	-0.105959967
STAND DEV	4.134202486	9.382592227	6.600006245	6.50705654	3.9841244	3.584803278	1.901223986	3.278873586	5.487020287	4.66086229

MAX_DIF	34.90407	56.19897	32.41602000	38.12603	36.65958	28.42645	27.3708	29.48075	109.75776	34.28815
MIN_DIF	-55.53802	-57.57167	-56.95468	-55.15002	-66.01647	-34.10599	-65.97771	-18.54298	-62.67898	-55.26398

> 419.000 Samples (*1) 290.716 Samples, (*2) 74.623 Samples (*1, *2 due to reduced coverage)

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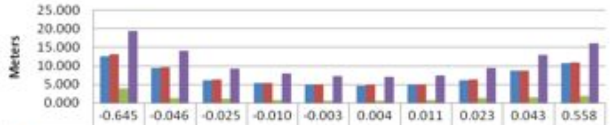
QA : Slope analysis
(status at sep 2012)

SRTMV4

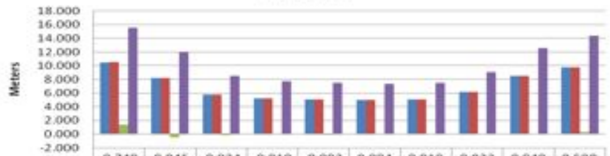


	-0.645	-0.046	-0.025	-0.010	-0.003	0.004	0.011	0.023	0.043	0.558
Est. Dev.	12.57	9.478	6.103	5.380	4.897	4.697	5.017	6.191	8.648	10.78
RMSZ	13.17	9.562	6.212	5.429	4.927	4.738	5.059	6.323	8.769	10.94
Diff. Aver.	3.959	1.265	1.161	0.734	0.542	0.629	0.659	1.288	1.450	1.849
LMAS	19.50	14.13	9.190	8.029	7.285	7.007	7.481	9.355	12.96	16.18

GDEM1

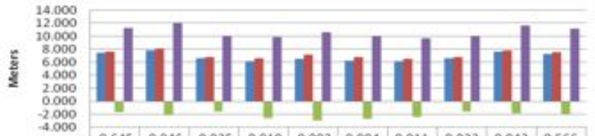
	-0.645	-0.046	-0.025	-0.010	-0.003	0.004	0.011	0.023	0.043	0.558
Est. Dev.	8.251	7.734	5.650	5.228	5.544	5.320	5.238	5.872	7.272	8.150
RMSZ	10.58	10.52	8.502	8.800	9.331	8.898	8.774	8.766	9.818	10.50
Diff. Aver.	-6.63	-7.14	-6.35	-7.07	-7.50	-7.13	-7.03	-6.50	-6.59	-6.62
LMAS	15.52	15.34	12.23	12.38	13.13	12.54	12.36	12.62	14.32	15.39

SRTMX



	-0.749	-0.045	-0.024	-0.010	-0.002	0.004	0.010	0.022	0.040	0.598
Est. Dev.	10.43	8.161	5.774	5.214	5.064	4.970	5.070	6.135	8.542	9.749
RMSZ	10.52	8.178	5.776	5.214	5.064	4.970	5.070	6.135	8.542	9.753
Diff. Aver.	1.381	-0.54	-0.15	-0.02	-0.09	-0.02	-0.03	-0.05	0.034	0.273
LMAS	15.53	12.06	8.522	7.692	7.472	7.333	7.481	9.052	12.60	14.39

GDEM2



	-0.645	-0.046	-0.025	-0.010	-0.003	0.004	0.011	0.023	0.043	0.566
Est. Dev.	7.478	7.837	6.635	6.136	6.546	6.218	6.129	6.595	7.666	7.317
RMSZ	7.662	8.132	6.828	6.669	7.193	6.776	6.583	6.777	7.876	7.562
Diff. Aver.	-1.66	-2.17	-1.61	-2.61	-2.98	-2.69	-2.40	-1.56	-1.81	-1.91
LMAS	11.33	12.03	10.10	9.868	10.64	10.02	9.742	10.02	11.65	11.19

DTED2

	-0.645	-0.046	-0.025	-0.010	-0.003	0.004	0.011	0.023	0.043	0.558
Est. Dev.	12.83	9.995	8.030	7.805	7.663	7.381	7.363	8.330	9.675	12.60
RMSZ	14.39	10.43	8.701	8.086	7.831	7.476	7.544	8.778	10.08	13.99
Diff. Aver.	6.515	3.013	3.352	2.115	1.616	1.186	1.643	2.768	2.835	6.082
LMAS	21.27	15.45	12.87	11.96	11.58	11.05	11.16	12.99	14.92	20.70

REF3D

	-0.648	-0.045	-0.024	-0.010	-0.003	0.004	0.011	0.023	0.043	0.576
Std. Dev.	5.226	5.429	3.741	3.660	3.836	3.660	3.506	3.791	5.870	5.137
RMSZ	5.259	5.429	3.744	3.678	3.876	3.684	3.519	3.795	5.869	5.154
Diff. Aver.	0.585	0.085	0.153	-0.369	-0.562	-0.421	-0.304	0.181	-0.008	0.416
LMAS/LE90 adj	7.776	8.022	5.534	5.438	5.733	5.447	5.202	5.609	8.673	7.619

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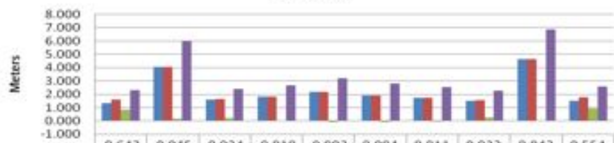
CEOS TMSG 2012

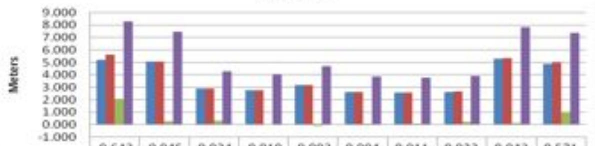
QA : Slope analysis
(status at sep 2012)

PNOA5



	-0.643	-0.045	-0.024	-0.010	-0.003	0.004	0.011	0.023	0.043	0.554
Est. Dev.	1.349	4.060	1.604	1.812	2.169	1.901	1.732	1.529	4.648	1.498
RMSZ	1.579	4.063	1.620	1.812	2.171	1.903	1.732	1.549	4.647	1.756
Diff. Aver.	0.820	0.178	0.229	0.037	-0.09	-0.08	-0.01	0.248	0.013	0.917
LMAS	2.330	6.005	2.396	2.679	3.209	2.813	2.560	2.291	6.867	2.592

IGN25



	-0.643	-0.045	-0.024	-0.010	-0.003	0.004	0.011	0.023	0.043	0.571
Est. Dev.	5.208	5.042	2.894	2.735	3.165	2.617	2.549	2.629	5.319	4.899
RMSZ	5.602	5.048	2.908	2.735	3.167	2.618	2.550	2.635	5.320	4.998
Diff. Aver.	2.067	0.259	0.279	0.028	-0.10	-0.07	-0.07	0.191	0.121	0.993
LMAS	8.291	7.461	4.299	4.042	4.680	3.870	3.769	3.896	7.862	7.397

CEGET

	-0.645	-0.046	-0.025	-0.010	-0.003	0.004	0.011	0.023	0.043	0.558
Est. Dev.	4.269	5.655	4.320	4.094	3.950	3.830	3.842	4.114	5.992	4.266
RMSZ	4.756	5.701	4.514	4.171	3.977	3.875	3.898	4.208	6.026	4.561
Diff. Aver.	2.098	0.726	1.308	0.802	0.465	0.593	0.661	0.885	0.641	1.614
LMAS	7.032	8.430	6.681	6.171	5.881	5.731	5.766	6.226	8.909	6.751

Netxmap1

	-1.475	-0.044	-0.022	-0.010	-0.002	0.003	0.011	0.023	0.042	0.928
Est. Dev.	3.090	3.086	2.409	1.988	1.942	1.796	2.392	2.110	3.059	3.149
EMC	3.118	3.086	2.414	2.104	2.067	1.954	2.442	2.253	3.056	3.147
Diff. Aver.	-0.44	-0.15	-0.17	-0.69	-0.70	-0.77	-0.49	-0.79	-0.05	-0.08
LMAS	4.428	4.356	3.485	3.059	3.015	2.843	3.522	3.269	4.322	4.488

Nextmap3

	-0.433	-0.051	-0.024	-0.011	-0.002	0.004	0.011	0.023	0.046	0.407
Est. Dev.	4.244	4.985	5.181	4.786	4.178	3.775	4.012	4.290	4.783	3.829
RMSZ	4.728	5.856	5.834	5.488	4.510	4.052	4.188	4.515	5.713	4.478
Diff. Aver.	2.088	3.084	2.716	2.714	1.732	1.504	1.239	1.432	3.137	2.327
LMAS	6.816	8.254	7.970	7.513	6.200	5.557	5.785	6.330	7.988	6.446

-Interferometric DEMs (SRTM/X, NextMap) show a correlation between an increasing of the slope and the height error.

-Stereocorrelated DEMs like PNOA5/IGN25/GDEM/ Reference3D present a more equilibrated distribution except in high slope areas .

- DEMs from digitalization sources (DTED2/CEGET) present variable behaviour depending of the source.

GOBIERNO DE ESPAÑA MINISTERIO DE DEFENSA
SECRETARIA DE ESTADO DE DEFENSA
Instituto Nacional de Técnica Aeroespacial

FUTURE

-Finish the acquisition of the discrete ground truth data.

-Process the TDX data and validate the DEMs extracted with different tools using our ground truth database (DSM).
- Height analysis.
- Slope analysis.
- Land cover analysis.

-Analize the quality improvement between DEM extraction techniques.
- Single pass interferometry.
- Repeat pass interferometry.
- Radargrammetry.
- Multiple stereocorrelation.
- Stereocorrelation.

-Analize the different DEM fusion techniques and explore new ones.

-Share our Ground truth database for Global DEM analysis purposes.

Advanced Land Observing Satellite (ALOS, 'DAICHI')

ALOS Advanced Land Observing Satellite

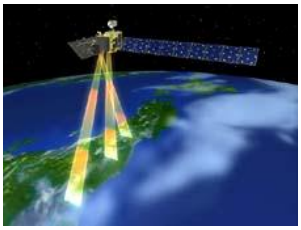
✓ **Operation**

24 Jan. 2006 by H-2A Rocket #8
12 May 2011 Mission ended
~22 Apr. 2011: Low Load Mode (LLM)
> 1,934 days=**5.3 years > 12 mil. scenes**

✓ **Objectives**

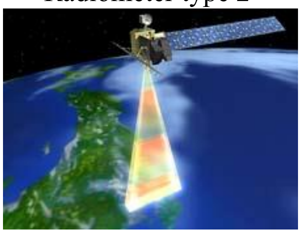
- Cartography (1/25,000 scale)
- Regional environmental monitoring
- Disaster monitoring, *etc.*

PRISM
Panchromatic Remote sensing Instrument for Stereo Mapping



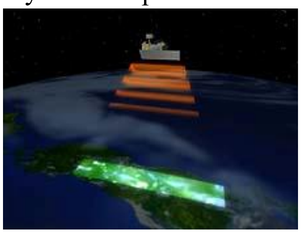
PRISM can acquire **triplet stereo** imageries by nadir-, forward-, and backward-radiometers with **2.5 m spatial resolution in 35 km swath**.

AVNIR-2
Advanced Visible and Near-Infrared Radiometer type 2



AVNIR-2 can observe with **10 m resolution in 70 km swath**, and it can be changed the observation area by pointing capability within +/-44 deg. in across track.

PALSAR
Phased Array type L-band Synthetic Aperture Radar

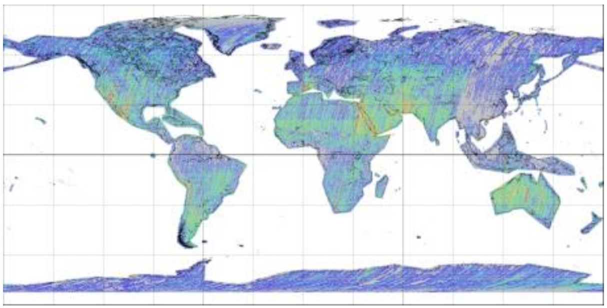


PALSAR can acquire the data in not only daytime but also nighttime as well as cloudy and rainy whether conditions.

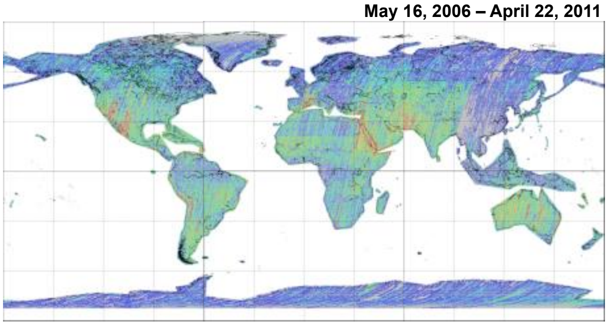
JAXA
EORC Earth Observation Research Center

Acquisition Result of PRISM

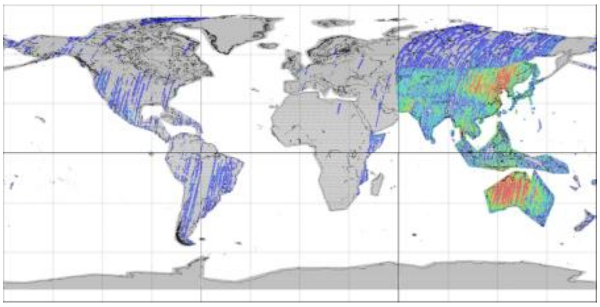
May 16, 2006 – April 22, 2011



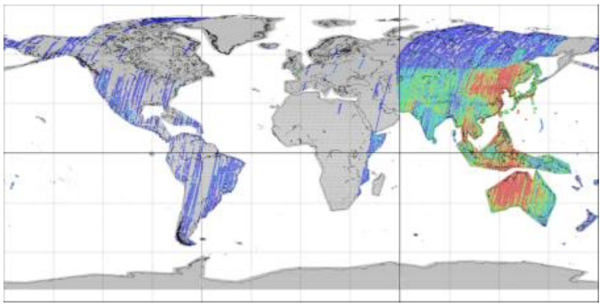
PRISM OB1 (35km) (Cloud cover: 0~2% / scene)



PRISM OB1 (35km) (Cloud cover: 0~20% / scene)



PRISM OB2 (70km) (Cloud cover: 0~2% / scene)



PRISM OB2 (70km) (Cloud cover: 0~20% / scene)

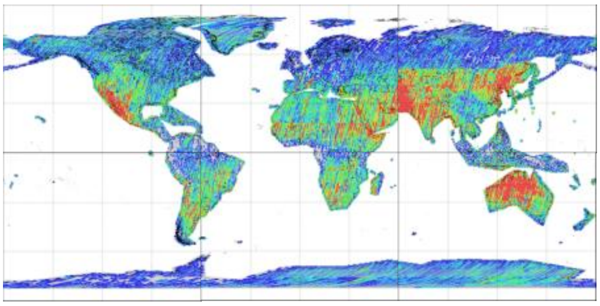
PRISM coverage based on the basic observation scenario

Total: 8,737,329 scenes for all directions
3,118,518 scenes for nadir radiometer

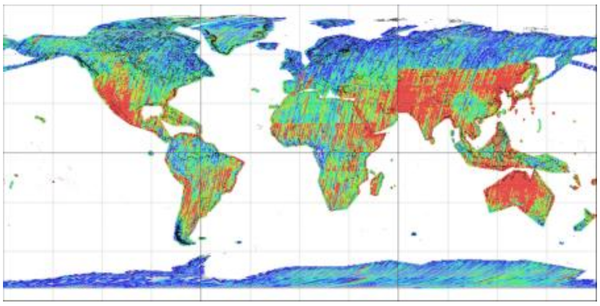
1 4 7 More than 10
2 5 8
3 6 9

Acquisition Result of AVNIR-2

May 16, 2006 – April 22, 2011



AVNIR-2 (Cloud cover: 0~2% / scene)



AVNIR-2 (Cloud cover: 0~20% / scene)

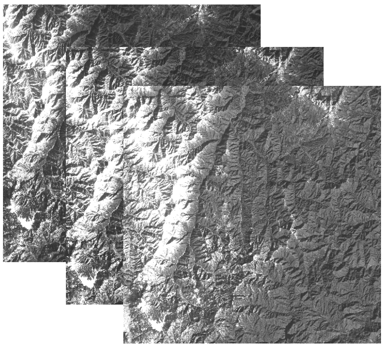
1 4 7 More than 10
2 5 8
3 6 9

AVNIR-2 coverage based on the basic observation scenario

Total: 1,325,411 scenes

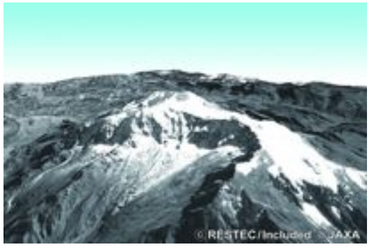
DSM and Ortho Image Generation Software for ALOS PRISM (DOGS-AP)

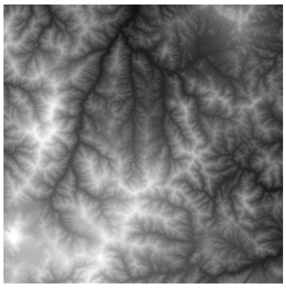
- **Digital Surface Model (DSM) generation from ALOS PRISM**
  - with DOGS-AP (DSM and Ortho-rectified image Generation Software for ALOS PRISM) – JAXA's exclusive triplet-image-matching software
  - Full support PRISM sensor model, orbit and attitude information
  - Grid spacing: 10 m (0.3 arcsec) > 2.5 m
  - Unit: 35 km x 35 km / scene



PRISM
Triplet stereo images

DOGS-AP





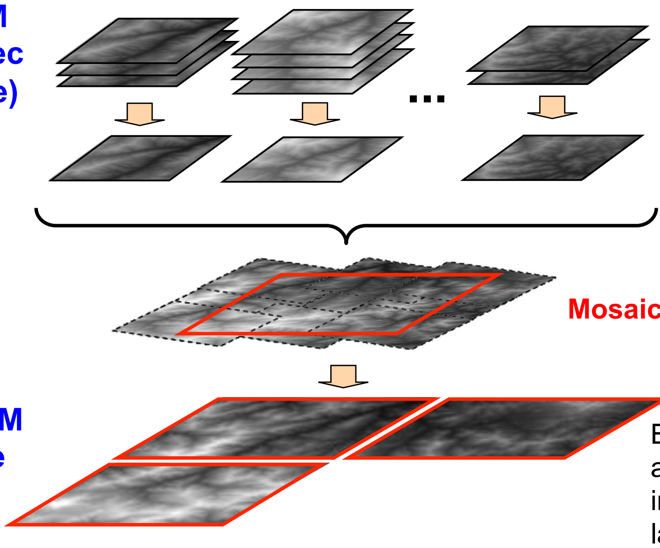
DSM
(and Ortho Rectified Image, ORI)

PRISM DSM Mosaic for Global Dataset

- **Mosaic Processing**

Scene-DSM in 0.3 arcsec (path-frame)

Stack-DSM



QC/QA and **stacking** on same path-frame

Mosaicking on 1°x1° tile

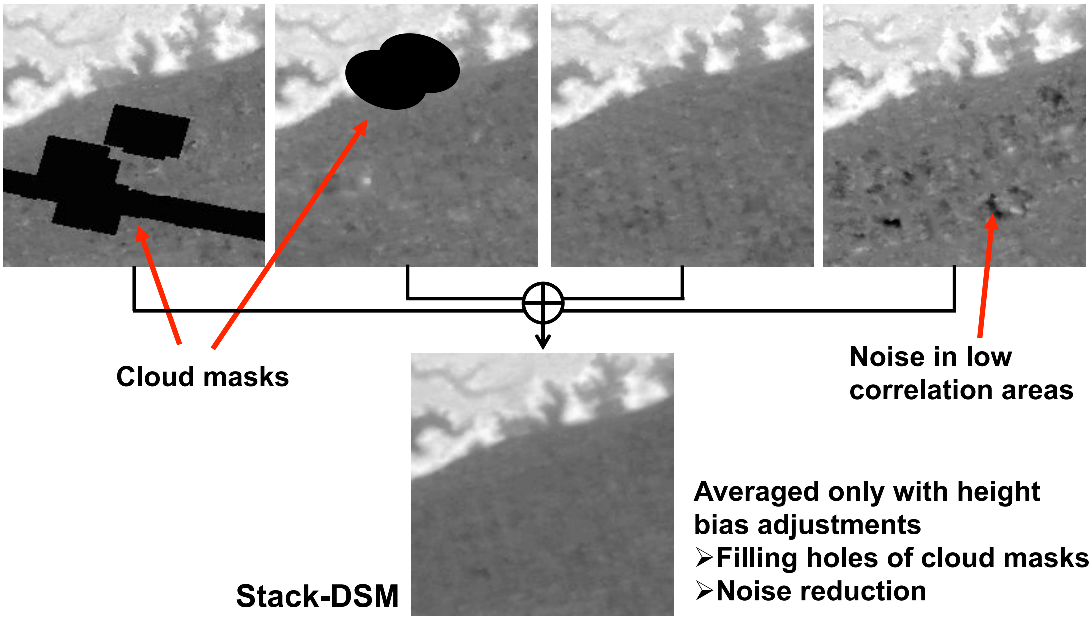
Mosaic-DSM on 1°x1° tile

Boundary smoothing among 1°x1° tiles and interpolating data on land-water/sea masks

PRISM DSM Mosaic for Global Dataset

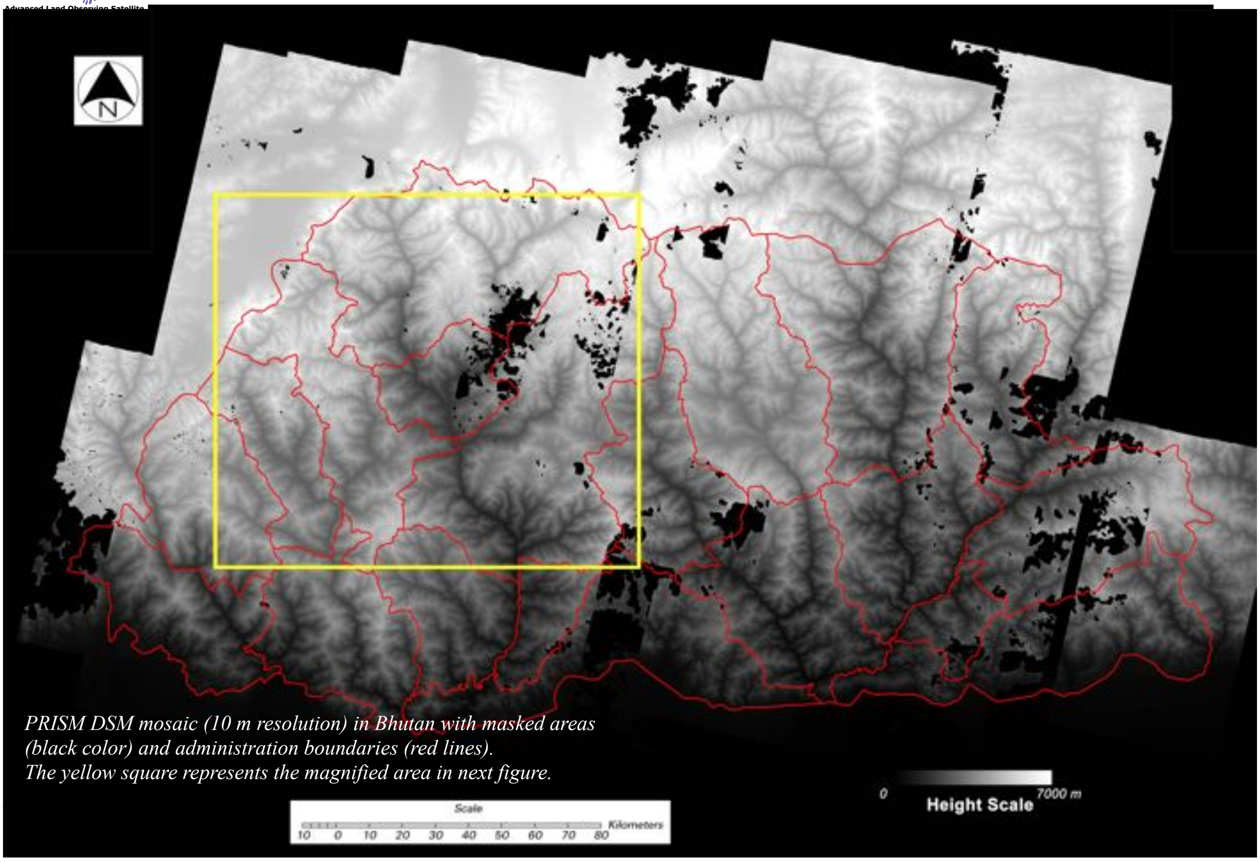
- DSM data stacking

Scene-DSMs of different dates



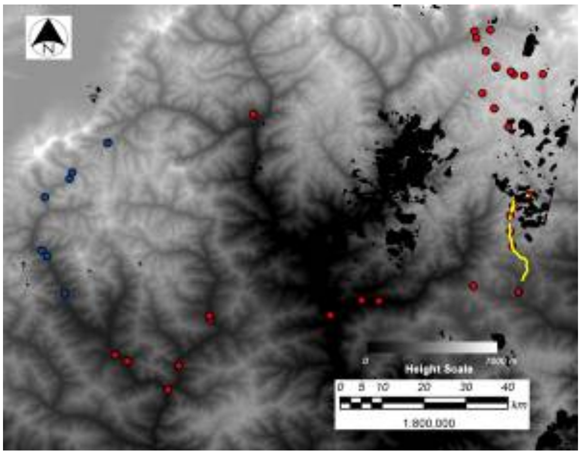
Averaged only with height bias adjustments
- Filling holes of cloud masks
- Noise reduction

PRISM DSM Mosaic in Bhutan



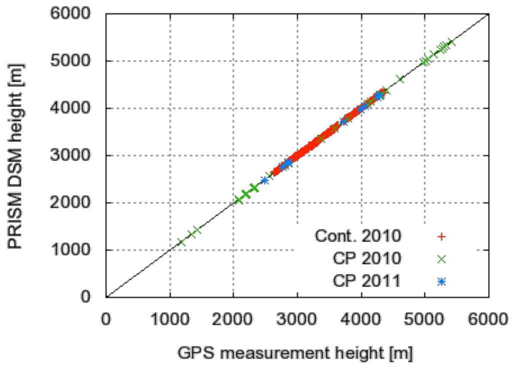
PRISM DSM mosaic (10 m resolution) in Bhutan with masked areas (black color) and administration boundaries (red lines).
The yellow square represents the magnified area in next figure.

Validation of PRISM DSM Mosaic (1)

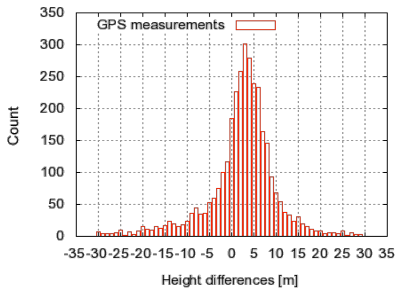


Magnified PRISM DSM mosaic and location of GPS measurements points (yellow: continuous measurement in 2010; red: CPs in 2010; and blue: CPs in 2011).

The points **within +/-30 m errors** compared with the PRISM DSM were selected due to condition and accuracy of GPS.

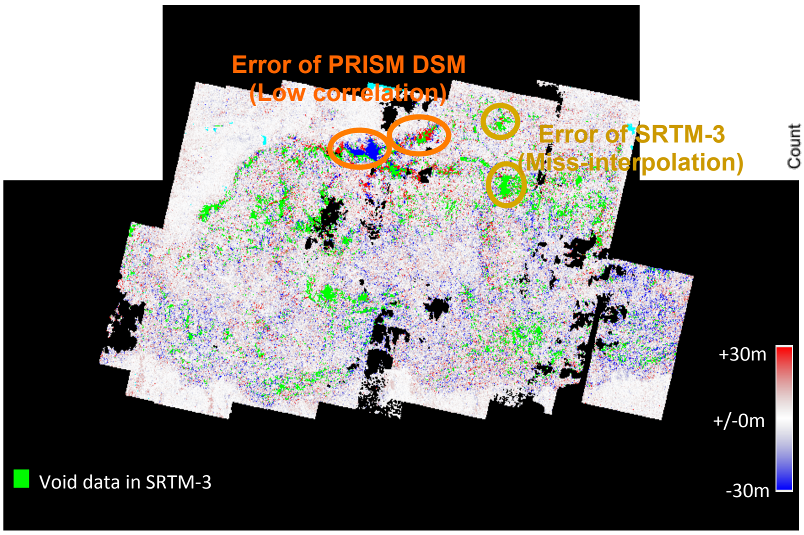


Comparison of height between the GPS measurements and PRISM DSM (red: continuous measurement in 2010; green: CPs in 2010; and blue: CPs in 2011).

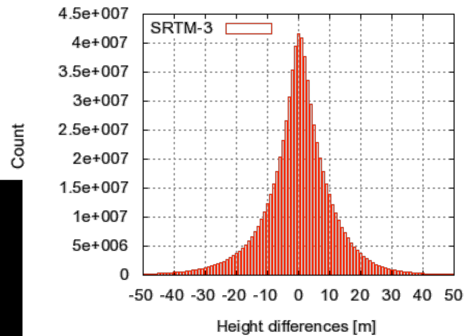


Total: 3,268 check points (CPs)
Bias=2.28 m, STDEV=7.79 m, RMSE=8.12 m

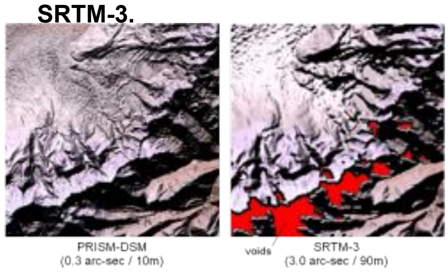
Validation of PRISM DSM Mosaic (2)



Height difference (*i.e.*, PRISM DSM minus SRTM-3) in the Bhutan Himalayas. The black colors indicate the masked areas in the PRISM DSM, while the green indicates the void data areas in SRTM-3.



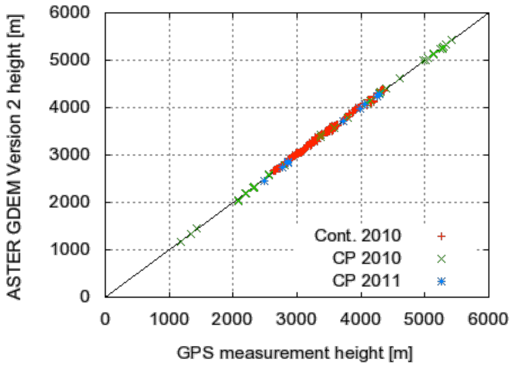
Histogram of height difference between PRISM DSM and SRTM-3.



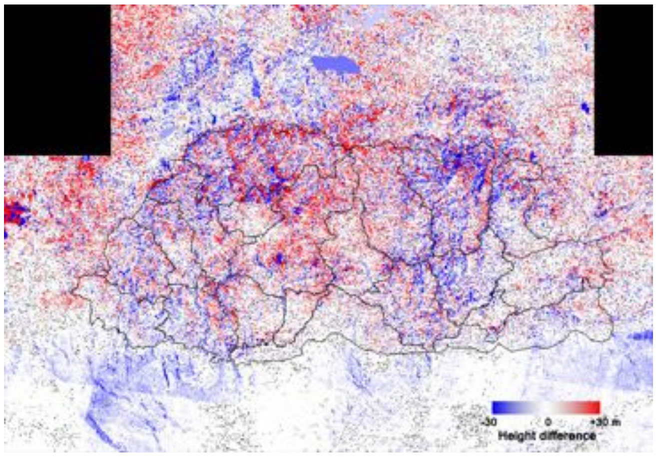
Visual comparison between PRISM DSM (left) and SRTM-3 (right).

Total: 738,107,875 points
Bias=-0.44 m, STDEV=20.71 m, RMSE=20.72 m

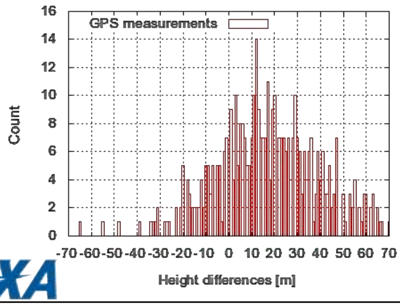
Validation of ASTER GDEM-2



Comparison of height between the GPS measurements and ASTER GDEM-2 (red: continuous measurement in 2010; green: CPs in 2010; and blue: CPs in 2011).



Height difference (ASTER GDEM-2 minus SRTM-3). The void data areas were not considered.



Total: 426 CPs
Bias=16.95 m, STDEV=24.08 m, RMSE=29.42 m

Visual Comparison among Digital Terrains

(a) PRISM DSM (0.3 arcsec) (b) ASTER GDEM-2 (1 arcsec) (3) SRTM-3 (3 arcsec)

Visual comparison of (a) PRISM DSM, (b) ASTER GDEM-2 and (c) SRTM-3 for the same area. The red lines show administration boundaries, and blue dots represent the locations of several CPs in 2011.

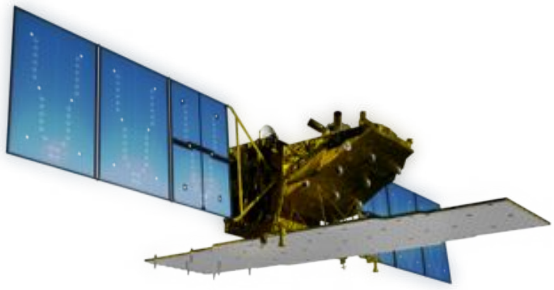
Concept of ALOS F/O Mission

ALOS F/O Mission: ALOS-2 (SAR) and ALOS-3 (Optical)

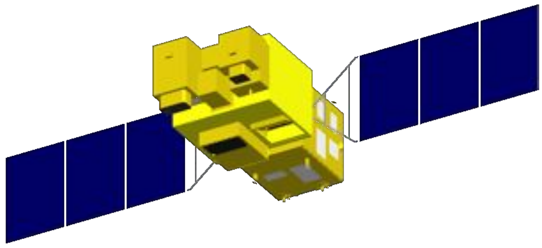
- National land monitoring and managements
- Resources managements
- Disaster monitoring
- ALOS-2 is planed to be launch in JFY2013, and ALOS-3 is hoped in 2017 (TBD)

Current System Concept (under investigation)

- Monitoring disaster area affected by earthquake, volcano, flood, etc.
- Observing the disaster affected area within 3 hr (6 hr in night)
- A satellite constellation of two optical sensor satellites and two SAR satellites
- ALOS-2: 3 m resolution (3x1 m in spotlight mode) with 50 km swath (SAR)
- ALOS-3: Panchromatic - 0.8 m resolution in 50 km swath; multi - 5 m in 90 km swath; and hyper-spectral - 30 m in 30 km swath (TBD)



ALOS-2: SAR Satellite



ALOS-3: Optical Sensor Satellite

ALOS-2 Specification

ALOS-2: SAR Satellite

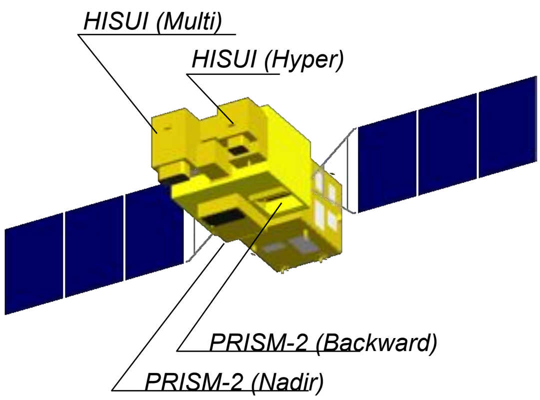
August, 2009: Project Team was established
~December 2009: Preliminary Design Phase
~October 2010: Critical Design Phase
Now: manufacturing PFM

- ✓ Both sides looking
- ✓ Band width: 14, 28, 84 MHz
- ✓ Full Pol and compact Pol in Fine Mode

ALOS 4th Research Announcement (RA4) is now issuing. The proposal submission deadline is on 31 October 2012. Refer to
http://www.eorc.jaxa.jp/ALOS/en/ra/ra4_guide.htm

Orbit		Sun-Synchronous Sub-Recurrent, 14 days
		Altitude: Approx. 630 km
		LST: 12:00 in descending orbit
Design Life		5 years
Launch	Target	JFY 2013
	Rocket	H-2A
Satellite	Mass	Approx. 2 ton
	Solar Paddle	Two-wings type panel
Mission Data Transmission		Direct / via. Data Relay Satellite
Mission Sensor		Synthetic Aperture Radar (SAR)
Frequency		L-band (1.2GHz)
Major Observation Mode	Spotlight	Resolution: 1-3 m, Width: 25 km
	Fine	Resolution: 3 / 6 / 10 m Width: 50 / 50 / 70 km
	ScanSAR	Resolution: 100 / 60 m Width: 350 / 490 km
Mission Objectives		Crustal change, volcano monitoring, surface deformation
		Sea ice, river, forest and agriculture monitoring etc.

ALOS-3 Specification (TBD)



ALOS-3: Optical Sensors Satellite

- ✓ 50 km swath / 0.8 m GSD = 62,500 pxls
- ✓ 11 bits quantization
- ✓ JPEG 2000 onboard compression
- ✓ Stereo function (two telescopes)
  - BWD: 1.7 m GSD and 50 km swath width (TBD)
- ✓ Body pointing function (+/-60 deg.)

Orbit		Sun-Synchronous Sub-Recurrent, 60 days
		Altitude: 618 km
		LST: 10:30 in descending orbit
Design Life		5 years
Launch	Target	JFY 2017
	Rocket	H-2A
Satellite	Mass	Approx. 2 ton
	Solar Paddle	Two-wings type panel
Mission Data Transmission		Direct / via. Data Relay Satellite
Mission Sensor		Optical instruments
	Panchromatic	Nadir: 0.8 m resolution, 50 km width Backward: <2.5 m, 50 km (TBD)
	Multi spectral	Resolution: 5 m, Width: 90 km
	Hyper spectral	Resolution: 30 m, Width: 30 km
	Thermal	Compact InfraRed Camera *experimental
Mission Objectives		**Land management:** cartography, agriculture, disasters monitoring, surface change detection **Environ. monitoring:** forest, glacier, glacial lake, costal region monitoring etc.

Summary and Conclusions

Summary of DSM/DEM validation study with CPs in Bhutan

Elevation data	# of CPs	Bias (m)	STDEV (m)	RMSE (m)
PRISM DSM Mosaic	3,268	2.28	7.79	8.11
SRTM-3	321	4.09	11.52	12.21
ASTER GDEM2	426	16.95	24.08	29.42

Conclusions

- ✓ Bhutan contains the eastern Himalayans: Hard conditions to generate DEMs for both optical stereo and InSAR,
- ✓ Point-scale validations: PRISM DSM mosaic, SRTM-3 and ASTER GDEM2,
- ✓ Large-scale validations: PRISM and GDEM-2 with SRTM-3,
  PRISM -0.4 m (bias), 20.7 m (RMSE); GDEM-2 17.0 m (bias) and 29.4 m (RMSE)
- ✓ GDEM-2 is remaining height gaps between neighboring scenes,
- ✓ Clouds are disappointing things for optical,
  ALOS-3 will be recovered them and be improve height accuracy
- ✓ Global PRISM DSM generation!?

EORC Earth Observation Research Center

GMES reference data acces: **EU-DEM**

GMES
Preparatory
Action 2009

Hugo.Zunker@ec.europa.eu
Michel.Massart@ec.europa.eu

September 2012

EU-DEM call for tender requirements

- *Requirements*
  - **30m pixel**
  - **+/- 7m height accuracy**
  - **Fulfilling GMES Land monitoring (LMCS) & Emergency Response (ERCS) services**
- *Solution*
  - **ASTER GDEM based**
  - **SRTM for accuracy improvement -> Manual Edition**
  - **Ownership of EU-DEM by EC**
- *Project Consortium: Indra, Intermap & AGI*

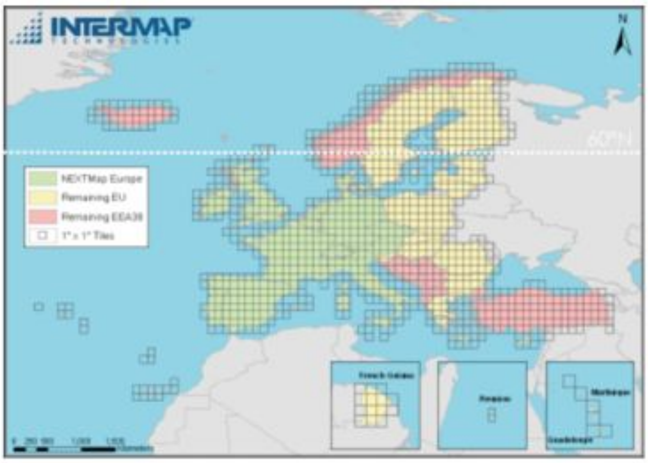
Contactpoint at Indra:
Antonio Garzón
T +34 91 627 32 96
agarzon@indra.es
www.indra.es

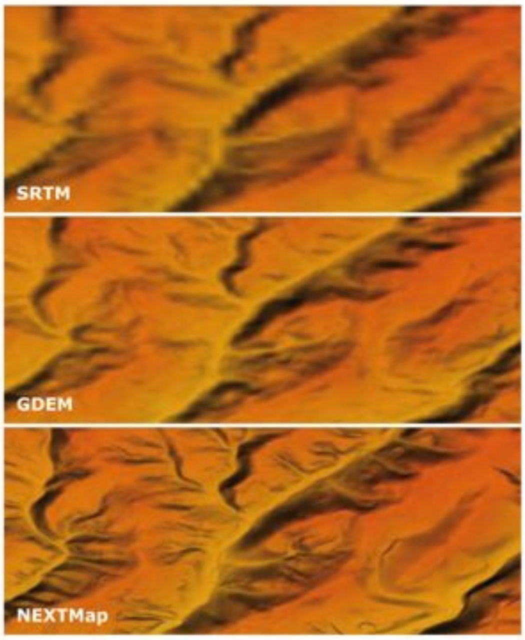
EU-DEM specifications

	GDEM	SRTM-3	EU-DEM
Producer	METI/NASA	NASA/USGS	Intermap/EC
DEM type	DSM	DSM	DSM
Data format	GeoTIFF, signed 16-bit	DTED1, signed 16-bit	GeoTIFF, 32-bit float
Coordinates	geographic	geographic	geographic
Datum (X,Y)	WGS84	WGS84	ETRS89
Datum (Z)	WGS84	WGS84	EVRS2000
Geoid	EGM96	EGM96	EGG08
Tile size	1°x1°	1°x1°	1°x1°
Grid	1″	3″	1″
Area coverage	83°N-83°S	60°N-56°S	EEA38
Accuracy (Z) [LE95]	~20 m	~14 m	~14 m
Accuracy (X,Y) [CE95]	~30 m	~10 m	~8 m

Data preparation

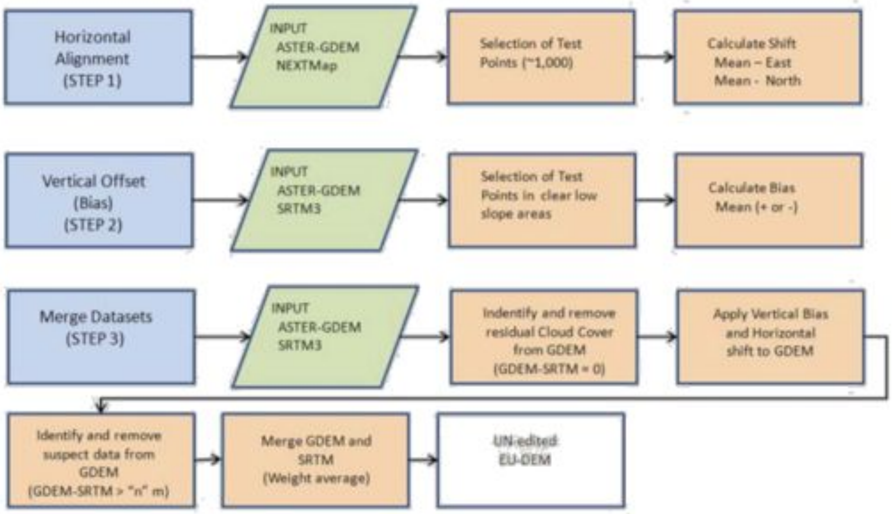
- *Aligning input data (NEXTMap(®), GDEM, ASTER, Landsat, …)*
- *Pilot area definition (2° x 2°)*





Process development

- *ASTER GDEM void masking*
- *Horizontal/ vertical shift correction*
- *FITS & Interpolator Algorithm port*
- *Fusion & water „burn-in“ tool*



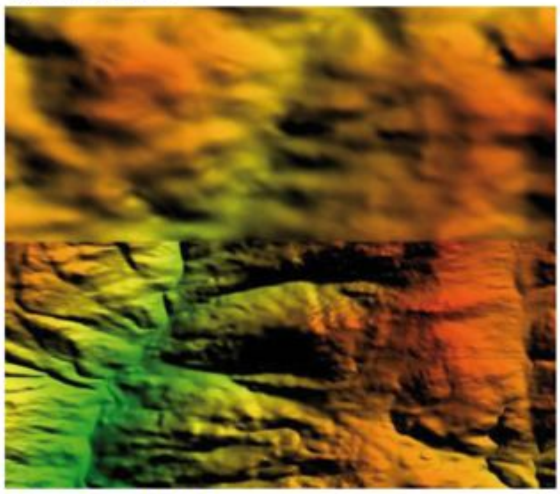
Data processing

Production of un-edited EU-DEM

Running developed tools for:

- **Horizontal & vertical shift correction in ASTER GDEM**
- **Void filling/ interpolation**
- **Weighted averaging**

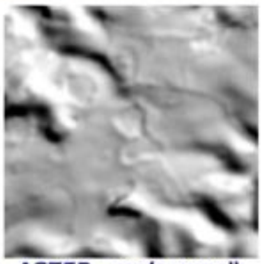
ASTER DEM



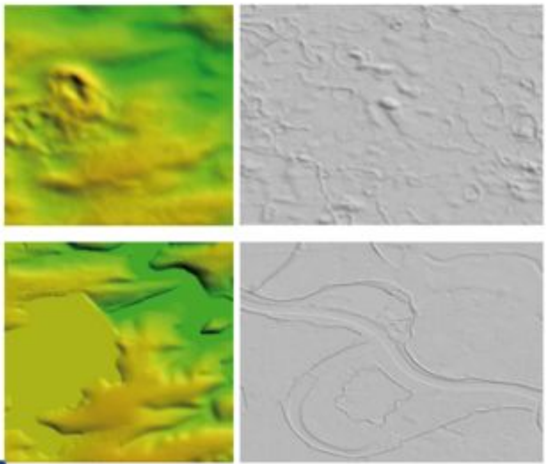
NEXTmap DTM

Data editing & harmonisation

- *Edge matching of EU-DEM & NEXTMap Enhanced EU-DEM*
- *Editing of blunders and water features in 3D stereo environment using QCed water layer provided by AGI*



ASTER „mole runs"

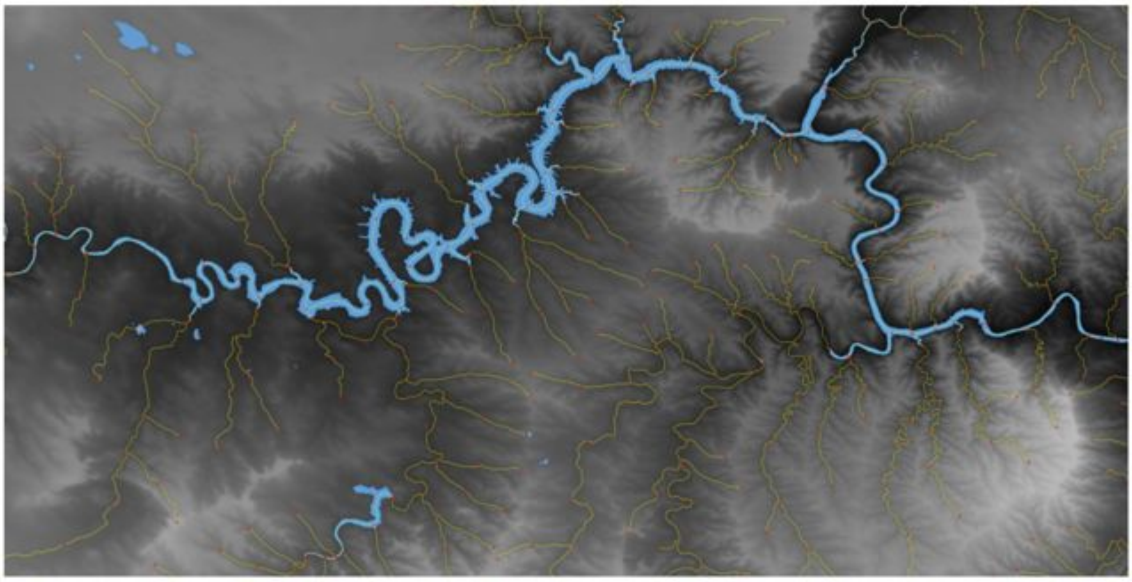


Final data QC & validation

- *Vertical accuracy checks using available reference data (LIDAR, GPS, survey, etc.)*
- *Tiles review for adherence to product specifications*
- *Validate adherence to edit rules*
- *Reports*

European Commission

Integration of EU-DEM and EU-hydro



European Commission

Final results

- Production finished
- External validation planned 2013
- Data available according to GMES data & information policy

GEO Task IN-02: Global Datasets Role for Global DEM

- **IN-02 Earth datasets consist of 2 sub-tasks:**
  - **C1: Advances in Life-cycle Data Management**
  - **C2: Development of Regional/Global Information and Cross-cutting Datasets**
- **IN-02 Point of Contact: Mike Abrams (JPL, ASTER PI)**
- **Proposed activities to continue DA-09-03d within IN-02-C2 received public debate in a special session lasting 1.5 hours at ISPRS 2012 Congress in Melbourne, Australia on 2-Sep-12 which had more than 30 participants**

GEO Task IN-02: Global Datasets Proposed activities for Global DEM

- **Global DEM fusion methods**
- **Temporal aspects of DEMs (as the DEMs become higher spatial resolution they become dynamic), e.g. time-tagging metadata**
  - **Vegetation**
  - **Mining**
  - **Ice-sheets**
  - **Urban**
  - **Landslides**
  - **Fracking**
- **Bare-earth DTM extraction methods? Link between land cover and bare earth DTMs**
- **Low contrast methods due to surface low surface roughness and desert (surface penetration)**

GEO Task IN-02: Global Datasets Proposed activities for Global DEM

- **Establishment of a global set of 3D GCPs and CCPs (Canopy Control Points)**
  - ICESat from NASA-GSFC (waveform processed for retrieval of ToC (Top of Canopy) and Bare Earth (DTM))
  - Global Elevation testing facility (runways)
  - SRTM control data from Marc Simard (JPL)
- **Creation of coastal zone 3D models including**
  - (a) bathymetry of continental shelves;
  - (b) coastline;
  - (c) uniform co-ordinate reference system for merging land topography (France & US have exemplary projects in this area)
- **Biomass retrieval from X, C & L as well as ICESat-II**
- **Polar areas have specific requirements**
- **Possibility of joining with Global land cover at 30m?**

Global DEM for continental shelves and coastal zones: a new GEO sub-task

- **EO visible/near-IR data can be employed to derive bathymetry for shallow water with low turbidity for depths up to 30m**
- **Turbidity is mapped from ocean colour sensors such as the ESA MERIS and could be used to decide when higher resolution systems such as LDCM or Sentinel-2 could be employed to map water depth**
- **EO SAR high resolution (1-3m) data can be employed to map how swell-wave patterns are transformed and these SAR amplitude images can then be inverted to provide bathymetry as demonstrated by Susanne Lehner and colleagues at DLR/OP**
- **Coastal zones, particularly those with wetlands are extremely difficult to map. Work needs to focus on use of higher resolution VIS/NIR and high-res SAR**

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Recommendation to CEOS Plenary

- **CEOS should encourage the relevant space agencies to set-up Global test sites for (a) clearwater; (b) turbid water offshore bathymetric DEMs from EO sensors**
- **CEOS should encourage a space agency to take leadership of an evaluation of different spaceborne methods for acquiring 30m gridded bathymetric measurements**
- **Bathymetry is part of the Global DEM and extremely important for tsunami prediction (i.e. Disasters SBA). It is not currently represented in oceanographic organisations such as GEBCO that are mainly concerned about deep water low resolution (>>1km)**
- **Request that CEOS agencies to supply data (e.g. high resolution multispectral visible/NIR, very high resolution SAR (TSX, Cosmo-SkyMEd, Radarsat-2, NASA-NOAA SHOALS) that could be employed to evaluate different approaches for mapping continental shelves**