*International achievements in generating and validating global DEMs**

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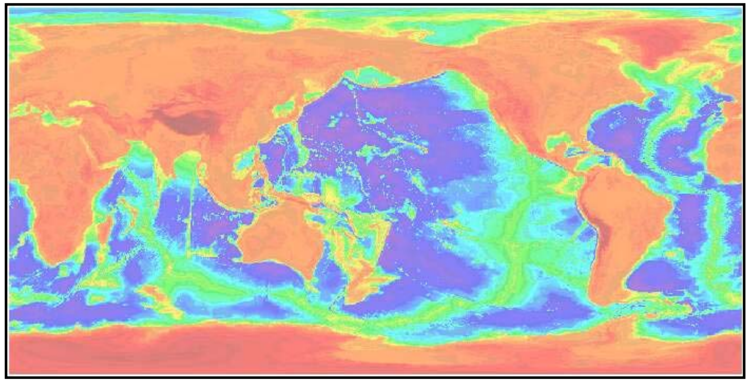
** Partially supported by BNSC-Qinetiq under the ICP2 programme*

Overview

- What <u>global</u> DEMs are available now and how well validated are they?
- What is GEO Task DA-07-01?
- Why does GEO need global topography/bathymmetry?
- What global DEM is available now to meet the GEO needs?
- Where are the voids and how large are they?
- What might partially fulfill the global DEM goal & be fit for purpose?
  - e.g. SPOT5 Global DEM
- An example of data fusion of ASTER single scene and SRTM for the Terrain modelling of the 3 Gorges area of China (support from ESA under ESA-NRSCC DRAGON Programme)
- Global ASTER Project (METI-NASA)
- Global ASTER stereo DEM production method initial assessment
  - Assessment of the potential of multiple ASTER DEMs to fill gaps using one of the CEOS-WGCV-TMSG test sites (Montagne Sainte Victoire, France)
- Conclusions
- Outstanding issues: Gap-filling, Validation and Dissemination
- A truly global effort is needed for this global project
  - Cartosat DEM of India
  - JAXA ALOS-PRISM DEM for 100 scenes worldwide

What is available now? ETOPO5

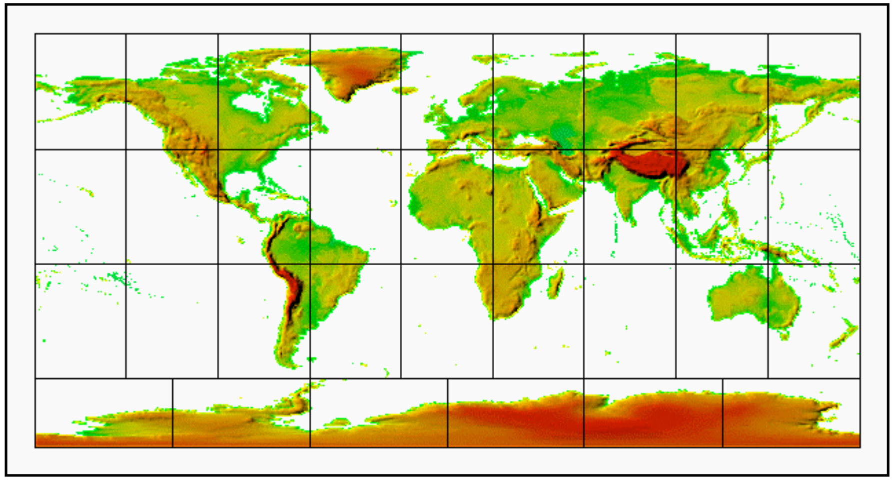
- **Stakeholder: NOAA, National Geophysical Data Center (NGDC)**
- **Surface Type: Land Surface and Sea Floor**
- **Horizontal Resolution: 5 arc-minutes (about 10 km)**
- **Vertical Unit: Integer Metre**
- **Projection System: Geographic Lat / Long**
- **Elevation Source: Digital Database of Land and Sea Floor Elevations**
- **Production Date: May 1988**
- **Information: courtesy of J. Danielson, USGS-EDC**



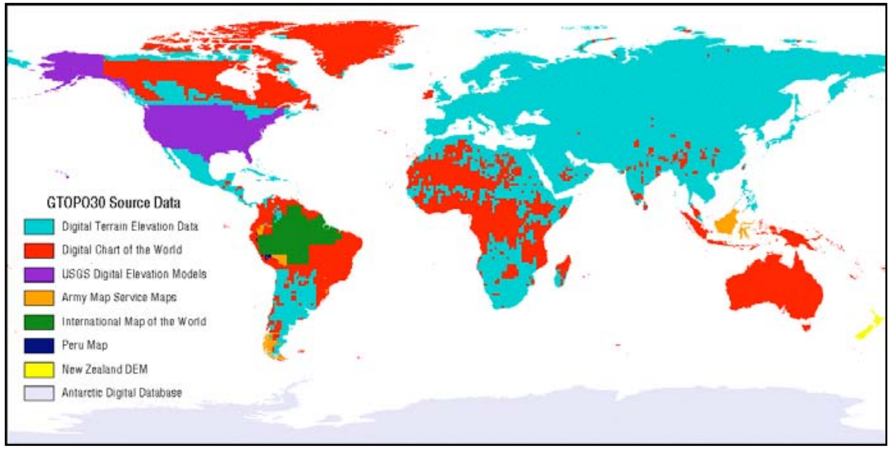
http://www.ngdc.noaa.gov/mgg/global/relief/ETOPO5/

What is available now? GTOPO30 and variants (GLOBE, ACE-DEM)

- **Stakeholder: U.S Geological Survey**
- **Surface Type: Land Surface – Bare Earth - Map sources**
- **Horizontal Resolution: 30 arc-seconds (about <u>1 kilometre</u>)**
- **Vertical Unit: Integer Metre**
- **Projection System: Geographic Lat / Long**
- **Elevation Sources: 5 Vector and 3 Raster**
- **Production Date: November 1996, Initial Release 1997**
- **Information: courtesy of J. Danielson, USGS-EDC**

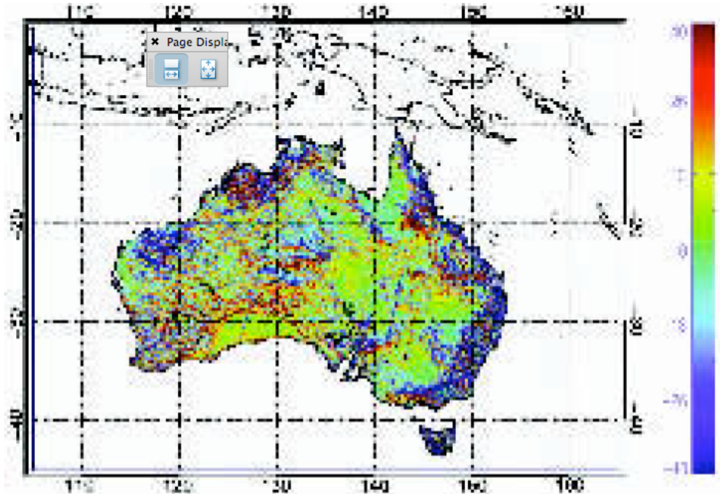


http://edc.usgs.gov/products/elevation/gtopo30/gtopo30.html

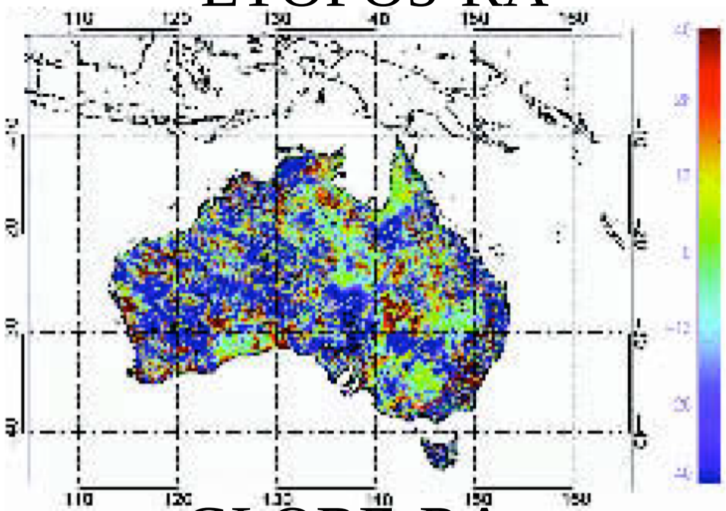


How well validated are these global DEM datasets : ETOPO5 vs GLOBE vs ERS-RA?

- **..although the spatial resolution of both ETOPO5 and TerrainBase is only 5-arcminutes, these global DEMs give better representation of the Australian topography than the 30-arc-second resolution GTOPO30 or GLOBE_v1**
- QUOTED from
  Hilton, R. D., W. E. Featherstone, P. A. M. Berry, C. P. D. Johnson, and J. F. Kirby, 2003: Comparison of digital elevation models over Australia and external validation using ERS-1 satellite radar altimetry. *Australian Journal of Earth Sciences*, **50,** 157-168



ETOPO5-RA



GLOBE-RA

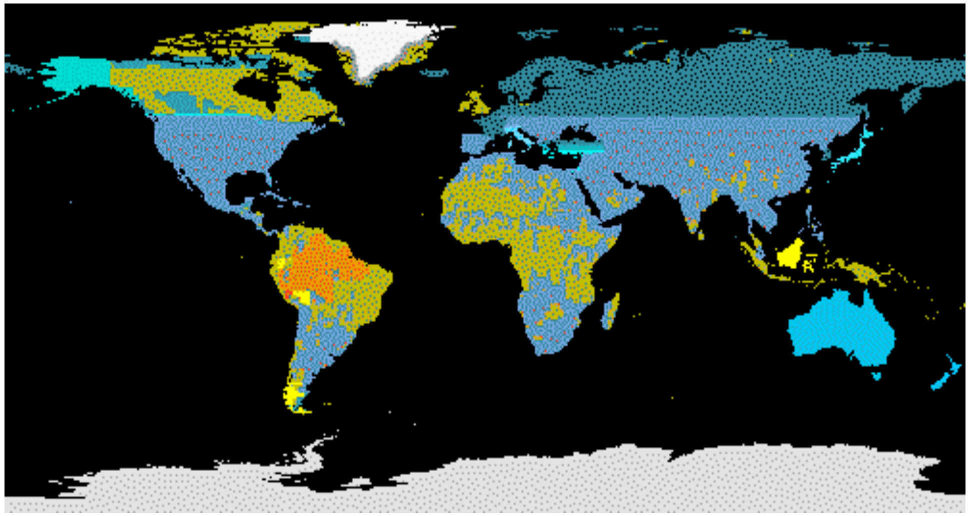
How well validated are these global DEM datasets: GTOPO30 vs ERS RA?

Source Description	EDC source	a priori Ranking	JEPSEN_ AIRPORTS ranking	GTOPO30-RA N	GTOPO30-RA RMS
DCW2 (DCW+DTED)	3	4	3	87622	48.31
South America 1:1M	8	7	5	42947	56.09
USGS	6	2	1	96398	62.34
DTED	1	3	2	659744	65.82
DCW3 no contours	4	8	7	21686	69.63
Indonesia Army	5	6	4	4181	90.54
DCW1	2	5	6	392697	98.03
Army Map Service	9	6	8	4255	103.74
SCAR Antarctica	11	12		99173	106.99
Peru	10	11		9	155.24
New Zealand	7	1	9	62	161.73

- **Muller (ISPRS 2000 Congress) showed how global ERS Radar Altimetry and a global set of airport runway locations could be employed to estimate accuracy of global DEMs. However, poor accuracy of GTOPO30 DEM. GTOPO30-RA stats of 10.98±77.67m for N=11,408,774**
- **ERS-RA data compared with nearest planimetric neighbour from the Jepsen Airport runway ends' point data-sets (see Bamber & Muller: JGR, 103(D4):32,159-32,168)**
  - **elevation difference (ERS-Jepsen) stats of -0.49±79.01m for N=2,339**

Intercomparison of NOAA-GLOBE with NASA-SLA1+2 Laser Altimeter

Source Description	N	Mean	Stddev
DTED-based 30" median DEM from USGS/GTOPO30	59,082	9.46	27.04
DTED Level 0 discrete (spot) 30" DEM, sampled from the southwestern corner of the 30" GLOBE grid cell.	157,923	8.57	27.79
DTED-based nearest-neighbor (to center of 30" GLOBE grid cell) DEM from USGS/GTOPO30. (More	7,266	16.18	33.18
DTED resampled to 30" by NIMA, provided to NGDC for public distribution in the 1980s. Spot (nearest-neighbor)	1,101	19.98	36.84
DTED-based DEM. Linear blending between classes 2 and 6 at their suture.	1,605	4.57	39.75
DTED-based 30" ?breakline? DEM from USGS/GTOPO30.	1,169	4.46	40.35
Digital Chart of the World. Developed by DMA from 1:1,000,000-scale maps, converted to 30" grid by USGS	76,544	0.37	40.73
Maps for part of Brazil. Produced at 1:1,000,000 scale by the Fundacao Instituto Brasiliero de Geografia e Estatistica	6,917	11.00	41.34
Maps for parts of southeast Asia and South America at 1:1,000,000 scale by AMS, digitized by GSI, gridded at 30" by USGS	2,035	-2.88	47.90



NOAA–NGDC GLOBE Source map

Taken from Muller, Kim, Morley (RSS99)

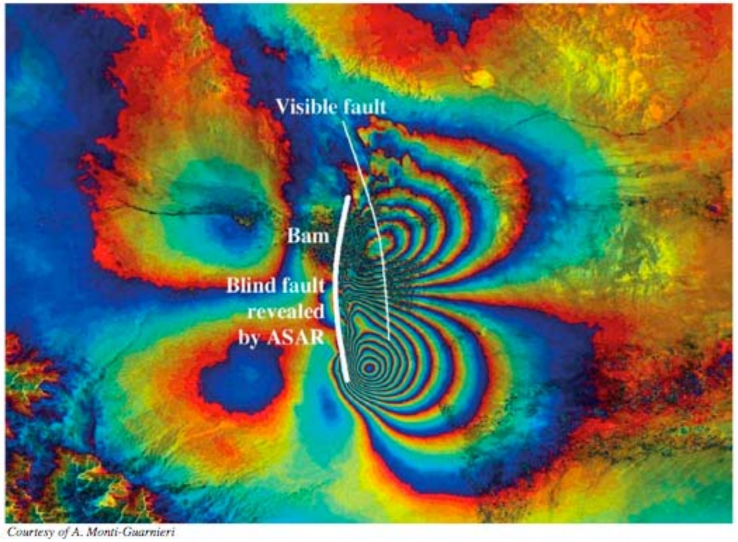
Code	Source/Lineage
1	DTED Level 0 discrete 30" DEM.
2	DTED-based 30" median DEM from USGS/GTOPO30.
3	DTED-based nearest-neighbor (to center of 30" GLOBE grid cell) DEM from USGS/GTOPO30.
4	DTED resampled to 30" by NIMA, provided to NGDC for public distribution in the 1980s.
5	DTED provided to USGS in the 1970s, regridded to 30" by nearest-neighbor techniques by USGS.
6	DTED-based 30" "breakline" DEM from USGS/GTOPO30.
7	DTED-based DEM. Linear blending between classes 2 and 6 at their suture.
8	DEM for Australia; copyright 1998 by AUSLIG, licensed to NGDC for distribution with GLOBE.
9	DEM of Japan, from GSI.
10	DEM for Italy at high resolution from SGN, converted to 30" gridding by NGDC (for SGN).
11	DEM of New Zealand at 500m gridding by LCR, reprojected to 30" by USGS.
12	DEM of Greenland at 90" by Zwally (and others)/NSIDC, converted to 30" by JPL.
13	Zwally (and others)/NSIDC/JPL and DCW DEM. Linear blending between classes 12 & 14 at their suture.
14	Digital Chart of the World developed by DMA, converted to 30" grid by USGS.
15	Maps for parts of southeast Asia and South America by AMS, digitized by GSI, gridded by USGS.
16	Maps for part of Brazil by the FBGE, adapted by GSI, gridded by USGS.
17	Map for part of Peru by the Ministerio de Guerra of Peru, adapted by GSI, gridded by USGS.
18	SCAR Antarctic Digital Database, converted by USGS, repaired by NGDC.

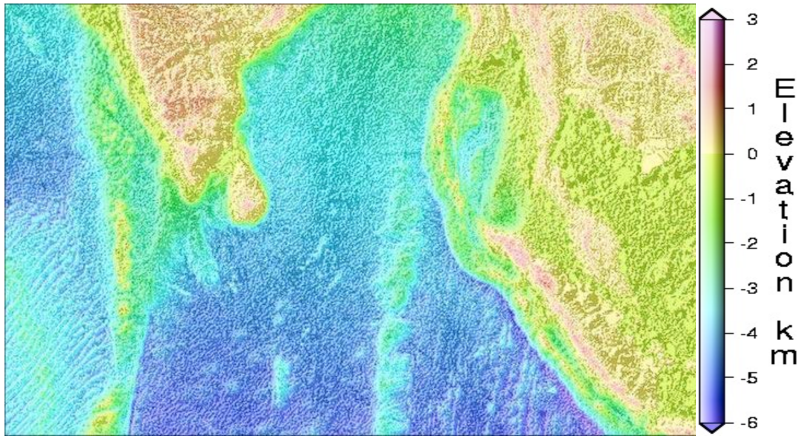
GEO Task DA-07-01 : Global DEM Inter-operability

- ***Objectives are to***
  - *facilitate interoperability among Digital Elevation Model (DEM) data sets*
  - *the end goal is to produce a global, coordinated and integrated DEM*
  - *This global DEM should be embedded into a consistent, high accuracy, and long term stable geodetic reference frame for Earth observation.*
  - *This activity shall also include*
    - *coastal zone bathymetric maps in shallow waters (~30-40 m),*
    - *DEMs of DTED1-class (3”, ≈90m),* ***now updated to DTED2 (1”, ≈30m)***
  - *for the generation of topographic maps and land use/land cover maps at scale 1/50,000 or 1/100,000.*
- ***Specific tasks include:***
  - *Request input from system operators and data users (GEO members or participating organizations) regarding their experience on interoperability*
  - *Compile list of current DEM data and its specifications.*
  - *Based on the above results, develop the first "GEOSS Interoperability Guidance on DEM data”. First draft completed in May 08. Second draft completed by August 2008*
  - *Submit this document for review to the GEO plenary (Beijing, November 2008)*
- 40 members of Task Team (UK (lead supported by BNSC), US, AU, DE, FR, IT, ES, JP, CN, KR, WMO, OGC)

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 inunadtion areal predictions, landslides*
  - *or for downstream EO processing, e.g. InSAR for earthquake monitoring and possible prediction*
- ***Poor bathymmetric and topography knowledge hinders tsunami forecasts***
- ***Tsunami a main spur for GEO implementation***





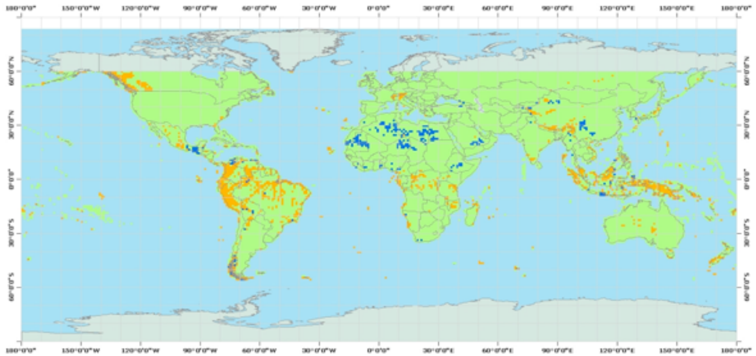
2’ (≈4km) Smith, Walter H.F., and David T. Sandwell, 1997 "Global Sea Floor Topography from Satellite Altimetry and Ship Depth Soundings", Science, 277, 1956-1962, 1997

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

What is available now? SRTM and variants with filled gaps

- **Stakeholder: National Geospatial-Intelligence Agency (NGA)**
- **Surface Type: Land Surface - Reflective**
- **Horizontal Resolution: 1 arc-second**
- **Vertical Unit: Integer Metre**
- **Projection System: Geographic Lat / Long**
- **Elevation Source: Shuttle Radar Topography Mission (SRTM) DTED 2 ® (void-filled), US Limited Distribution**
- **Source Production Date: February 2000/September 2003**
- **Publicly released: 3 arc-second except for US: 1 arc-second**

http://www2.jpl.nasa.gov/srtm/



CONTINENT	SRTM-ENVISAT RA MEAN	SRTM-ENVISAT RA STD.DEV.	kGPS-SRTM MEAN	kGPS-SRTM STD.DEV.	DTED2-SRTM MEAN	DTED2-SRTM STD.DEV.	GCP-SRTM MEAN	GCP-SRTM STD.DEV.
Africa	1.86	15.62	1.30	3.80	4.13	4.26	0.40	4.80
Australia	1.09	11.49	1.80	3.50	2.10	3.44	0.10	4.40
Eurasia	2.54	16.09	-0.70	3.70	-1.79	5.99	0.20	5.00
North America	3.15	15.18	0.10	4.00	-0.61	4.86	-0.20	4.60
South America	12.22	18.51	1.70	5.90			0.00	5.10
Global	3.60	16.16						

N.B. ENVISAT RA stats taken from Berry et al. (RSE, 2007), rest from Rodriguez et al. (PERS, 2005)

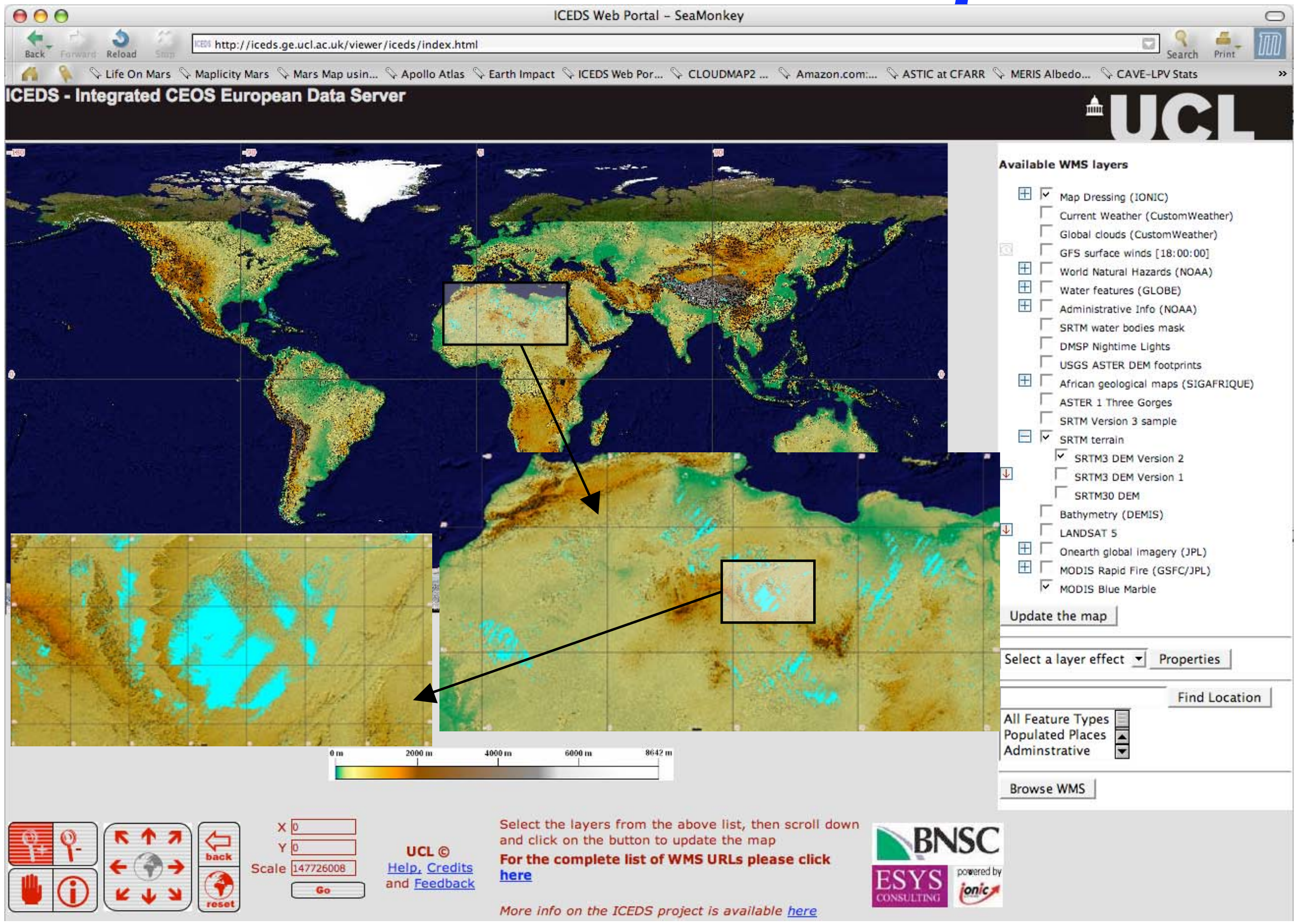
What DEM(s) are available NOW to fulfill the Global DEM objective

- **SRTM C-band DEM produced at DTED-2 (1 arc-second≈30m) but only publicly available (apart from the conterminous US) at DTED-1 (3 arc-second≈90m)**
- **BUT, there are significant gaps/voids in the coverage even after (“edited” or “finished”) V2 of the product was produced and SRTM is only available for the region from 60ºS-56ºN**

	North and South America		Eurasia		Australia		Africa		Total	
Percent Full	No. of Cells	Cumul. % of Total	No. of Cells	Cumul. % of Total	No. of Cells	Cumul. % of Total	No. of Cells	Cumul. % of Total	No. of Cells	Cumul. % of Total
100	1,174	28.7	1,846	32.2	380	35.8	527	16.2	3,927	27.8
99	2,666	93.7	3,531	93.8	677	99.7	2,288	86.6	9,162	92.6
98	84	95.8	102	95.6	2	99.9	117	90.2	305	94.8
95–97	108	98.4	117	97.7	1	100.0	123	94.0	349	97.2
90–94	44	99.5	67	98.8	0		81	96.5	192	98.6
85–89	7	99.7	27	99.3	0		29	97.4	63	99.0
80–84	2	99.7	16	99.6	0		22	98.1	40	99.3
70–79	5	99.8	19	99.1	0		33	99.1	57	99.7
50–69	4	99.9	5	100.0	0		20	99.7	29	99.9
<50	3	100.0	0		0		9	100.0	12	100.0
Total	4,097		5,730		1,060		3,249		14,136	

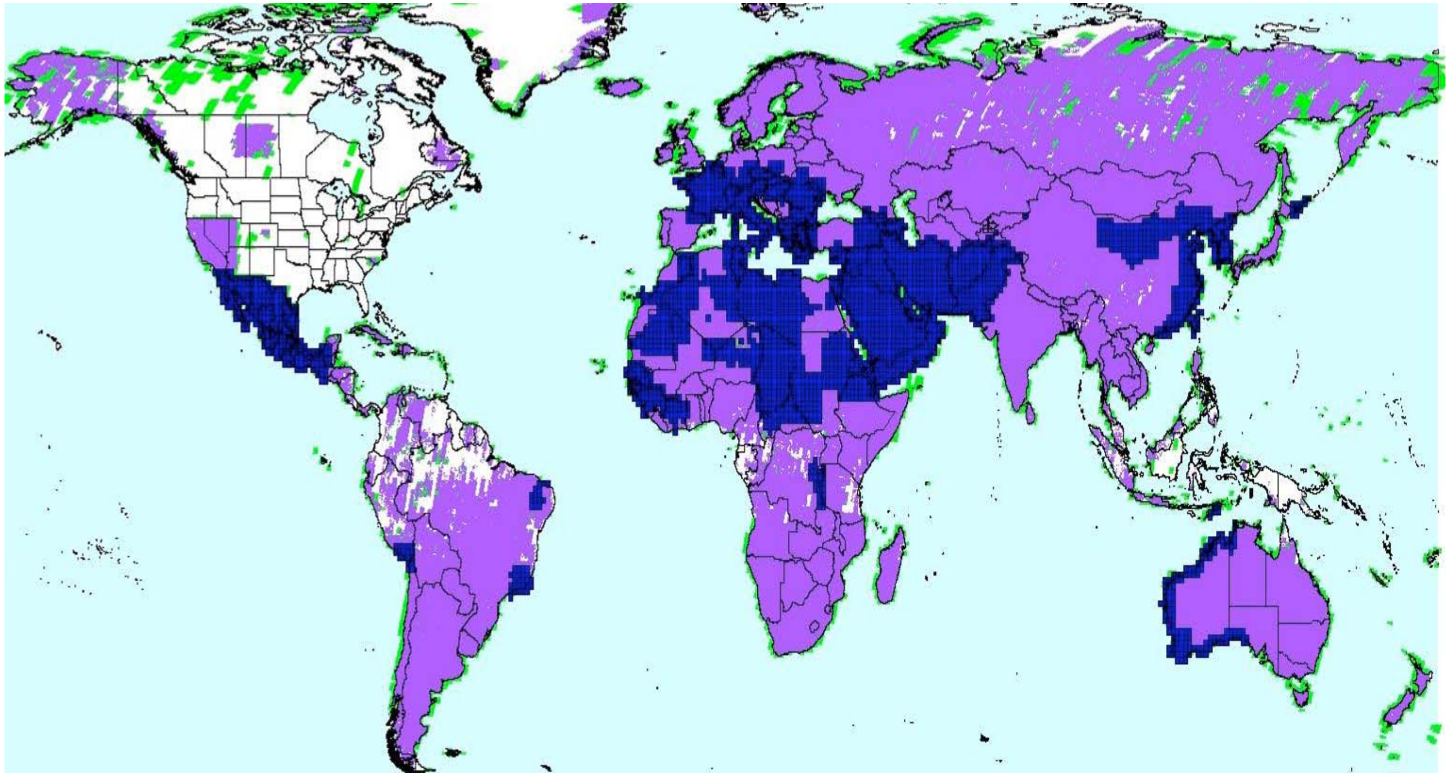
Table 1: Void statistics for SRTM-C 1 x 1º DTED2 cells (taken from Slater et al., PERS March 2005)

What areas contain gaps at present in the SRTM DTED-1 product?



- **Areas highlighted in V1 and V2 (shown here) can be visualised in ICEDS http://iceds.ge.ucl.ac.uk including giving context from LANDSAT-5 or LANDSAT-7 False-colour-Composites, SRTM water, etc..**

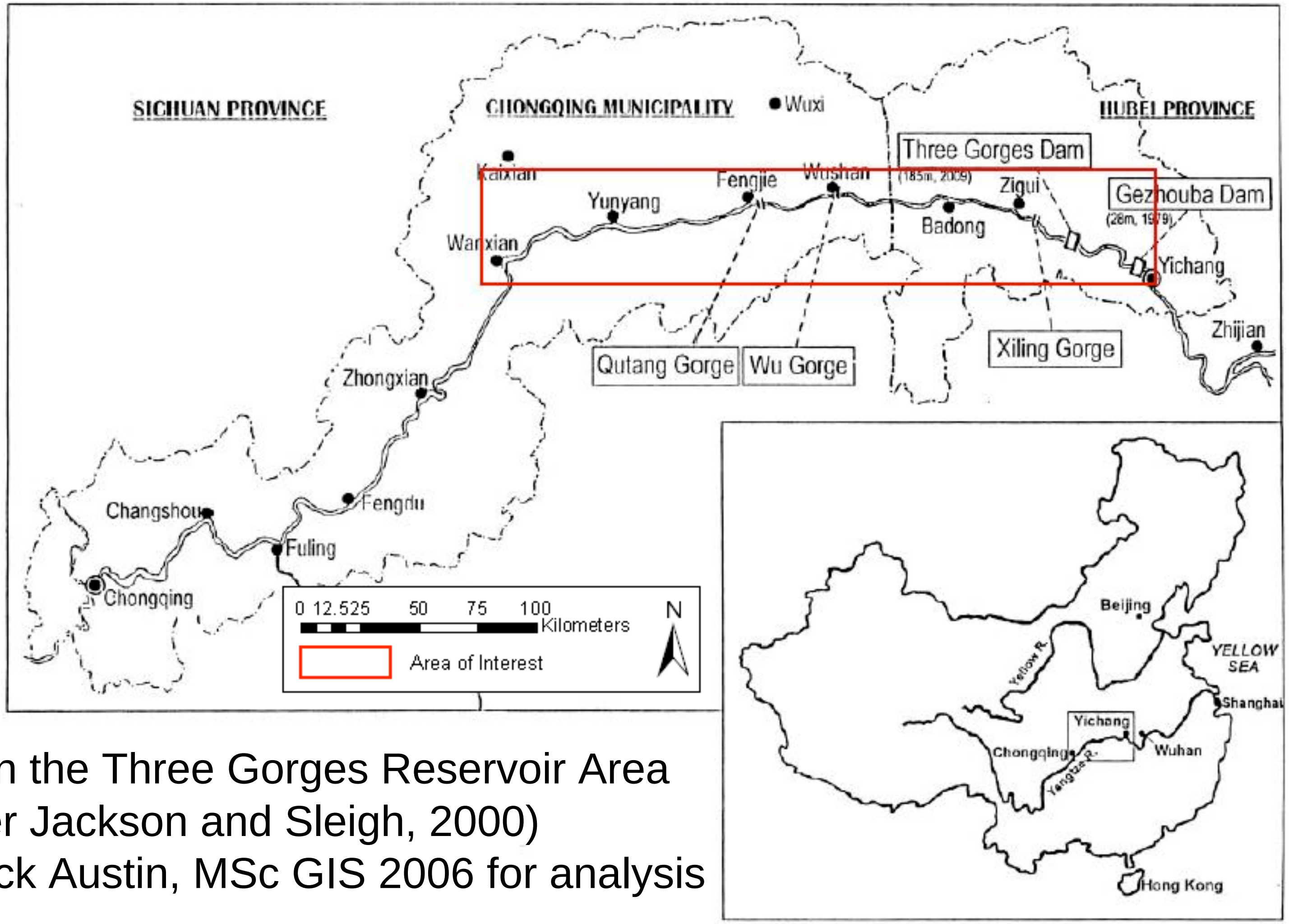
What datasets could be employed to fill these voids if they were available?



SPOT5 coverage (courtesy of M Bernard, ©SPOT Image 10 June 2008)

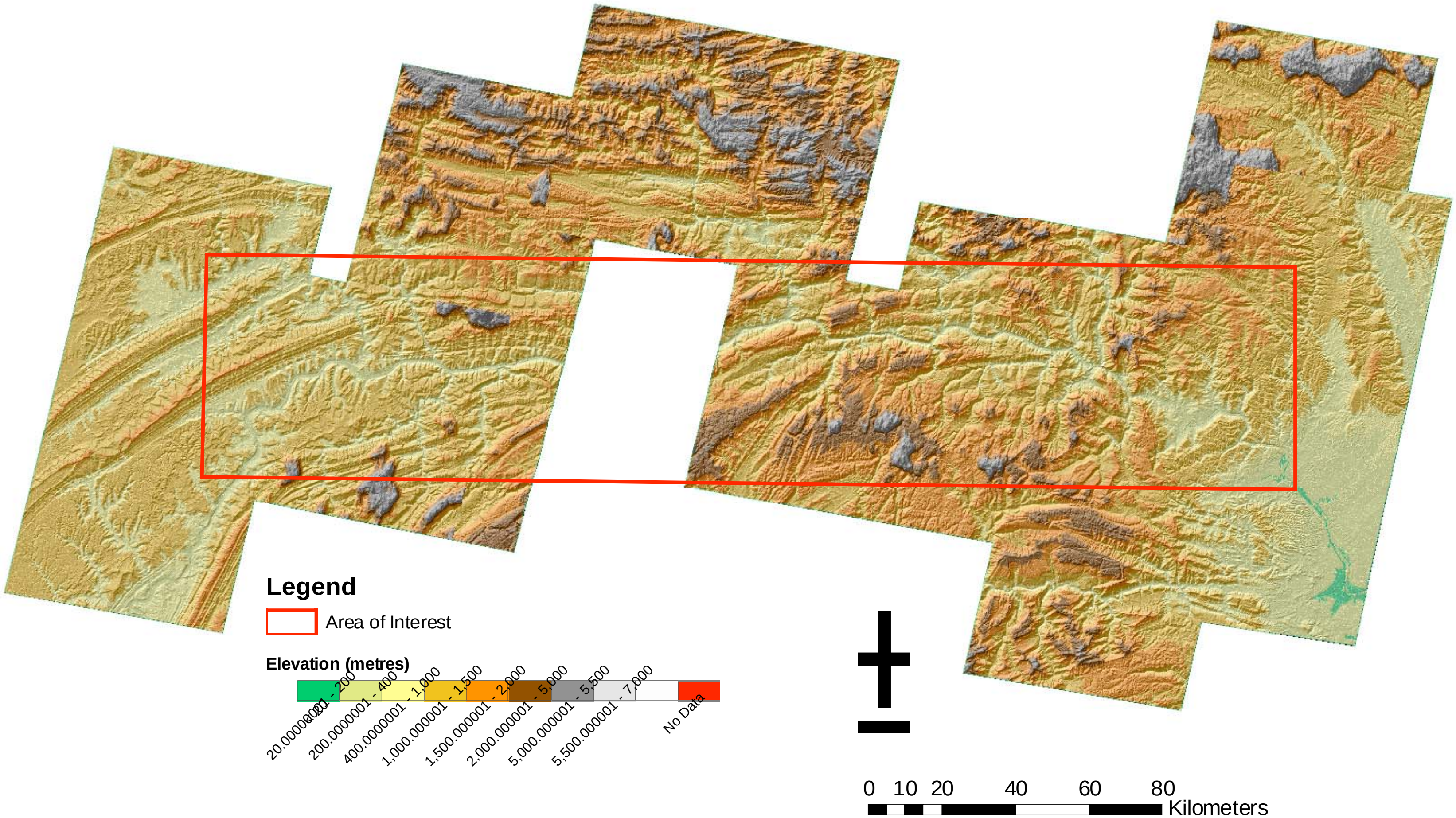
- **SPOT-5 : complete coverage for 1 arc-second Reference3D® DEMs shown in blue and potential scenes for global coverage in purple**
- **30 M sq.km. at NATO DTED2 specification inc coastal DEMs for Antarctica**
- **Objective is to have completed 100 M sq.km. by 2013**

Example of data fusion for ESA DRAGON project Study Site using ASTER and SRTM



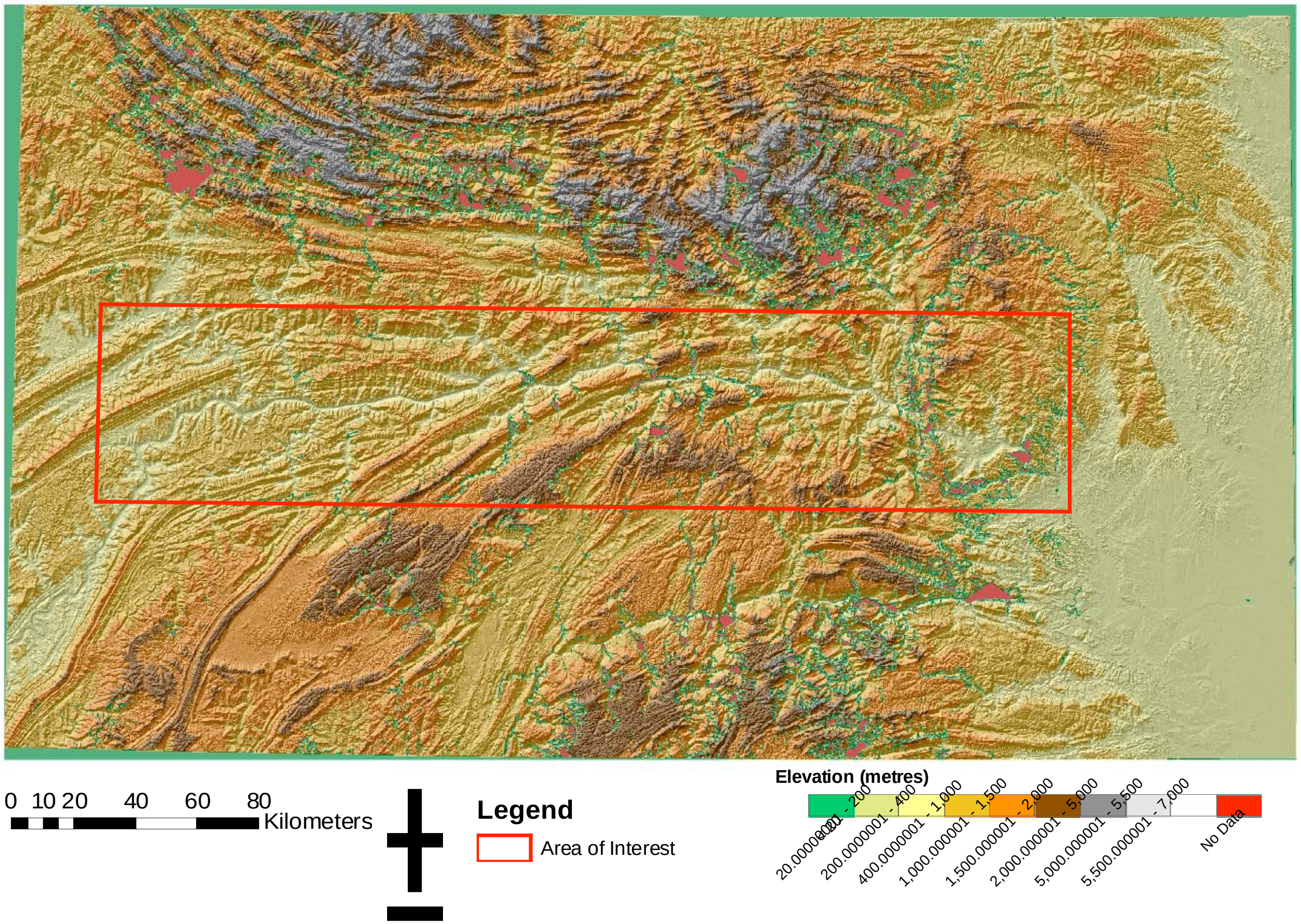
Study Site in the Three Gorges Reservoir Area
(after Jackson and Sleigh, 2000)
Thanks to Nick Austin, MSc GIS 2006 for analysis

ASTER DEM for area of interest (generated at USGS EDC using SILCAST)



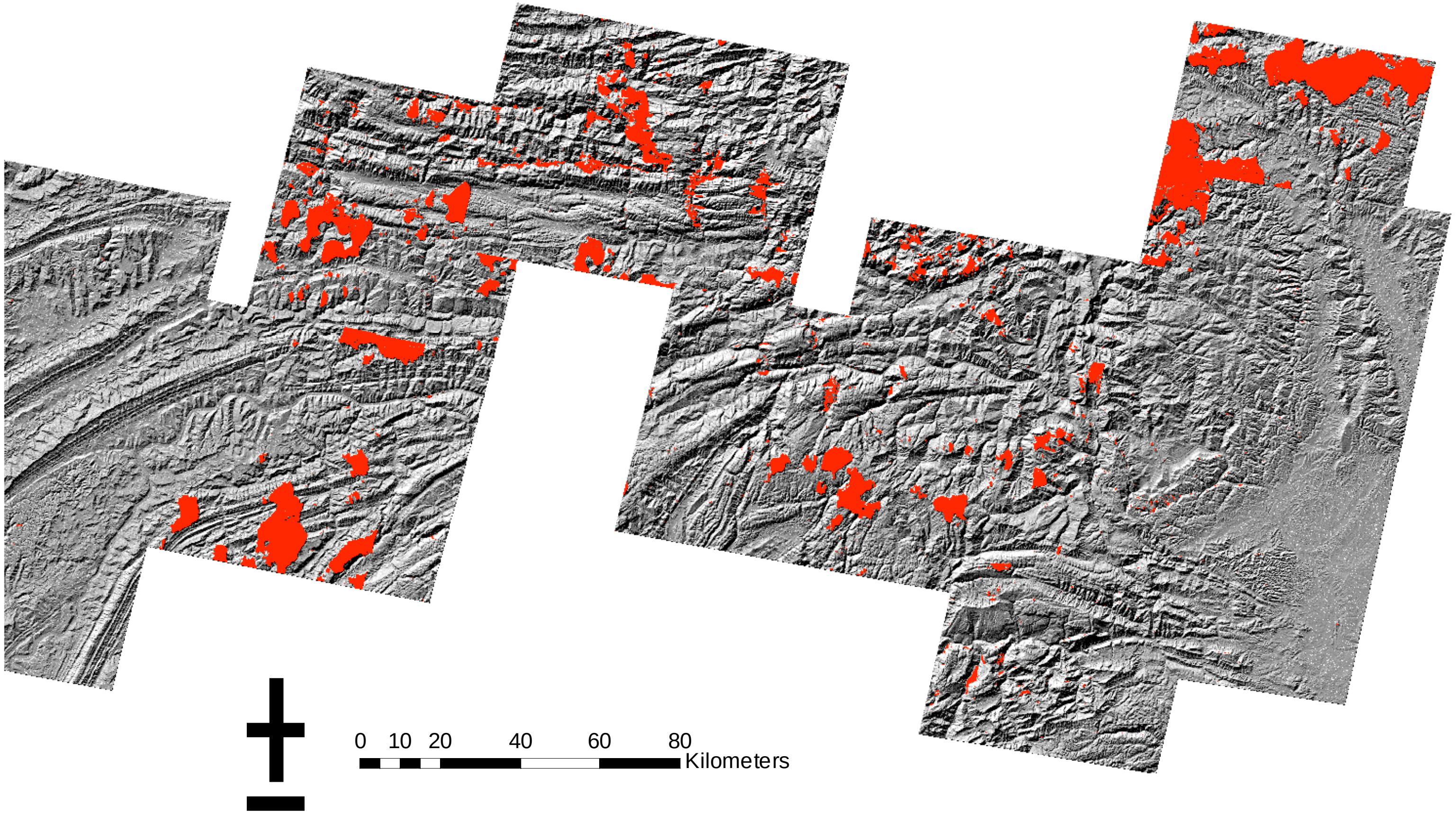
ASTER DEM mosaic hill-shaded in ArcMap with 30° altitude and 330° azimuth for the light direction and using the ICEDS custom hill-shading colour scheme. Note the grey areas which appear to be clouds.

SRTM v2 (edited) DEM for area of interest



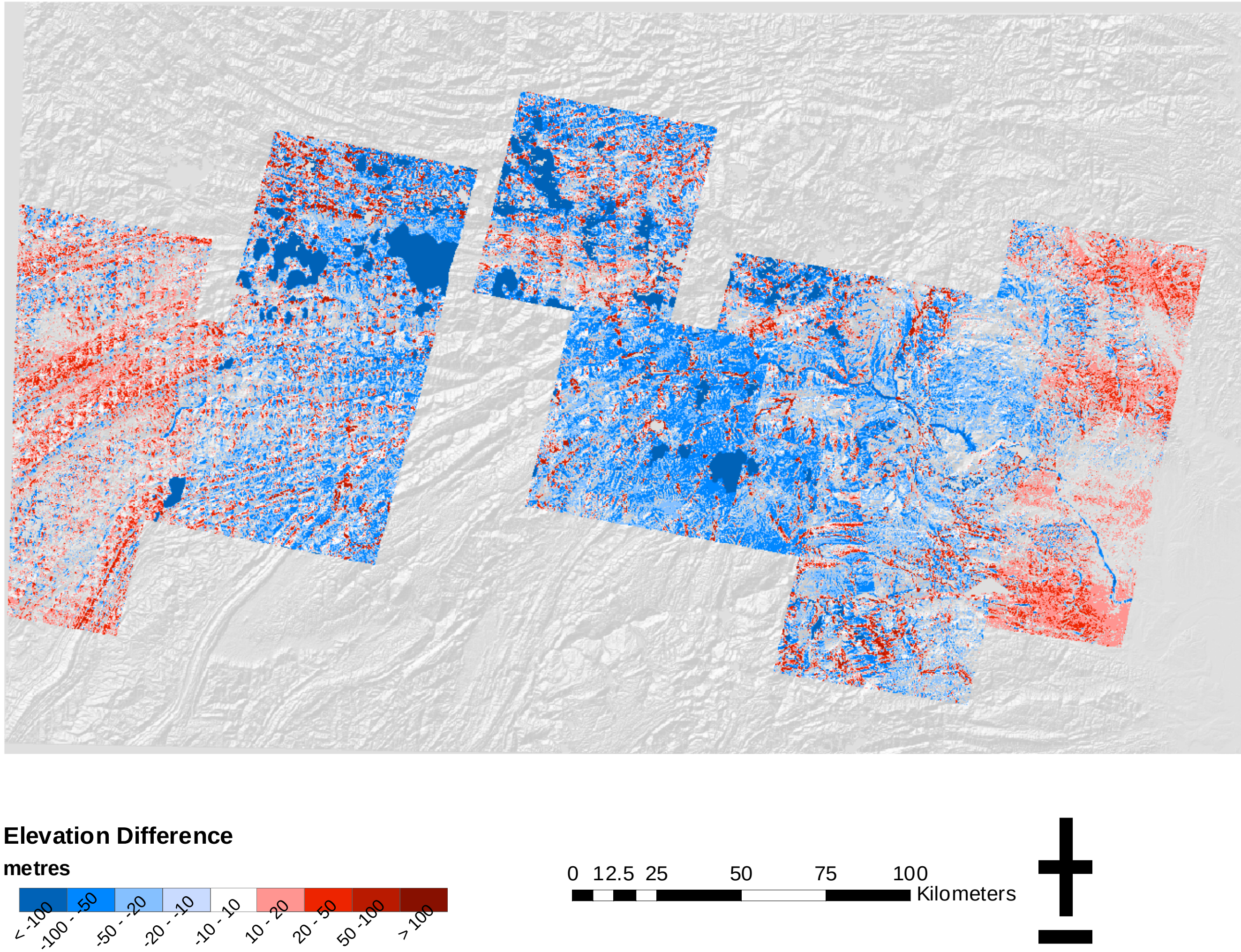
SRTM DEM mosaic hill-shaded in ArcMap with 30° altitude and 330° azimuth for the light direction and using ICEDS custom hill-shading colour scheme. Notice the red areas of missing data.

ASTER DEM Mosaic contains a number of artefacts (clouds in the original data)



Elevation difference map created in ArcMap showing cloud cover artefacts in the ASTER DEMs. The map was obtained by subtracting the SRTM DEM mosaic from the ASTER DEM mosaic, removing subtle differences between the DEMs and applying a mask. The red areas represent height differences caused by clouds in the original ASTER L1a stereo images

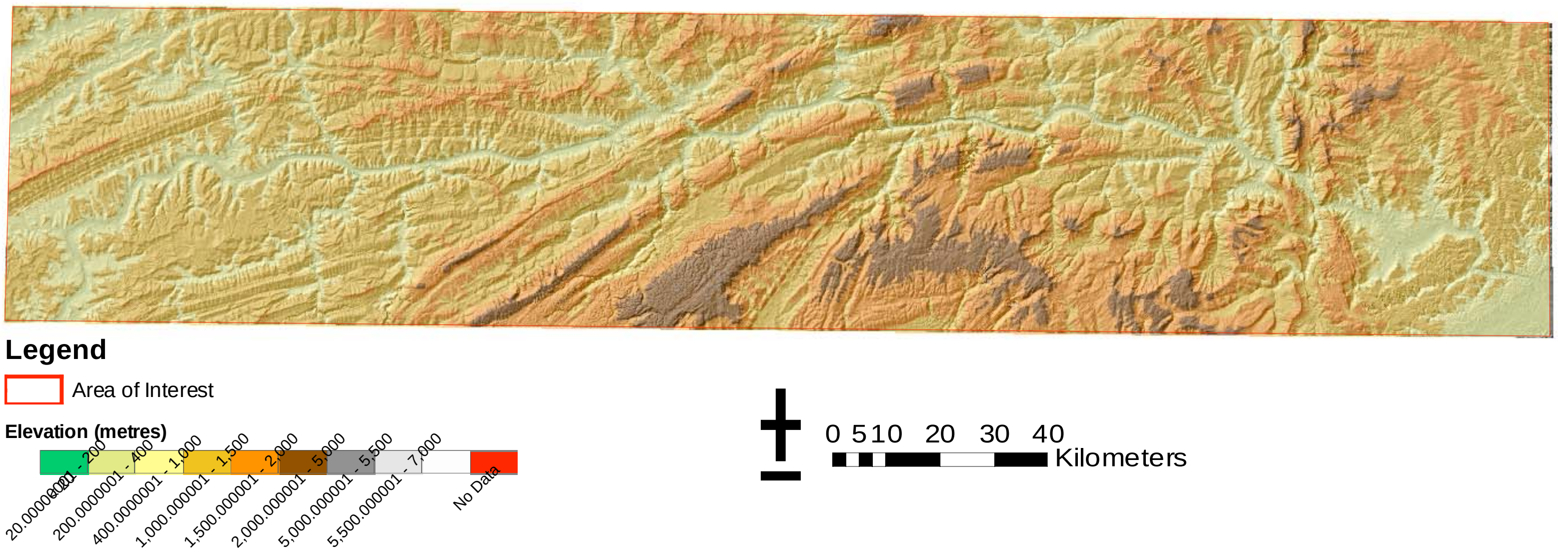
Elevation difference image: SRTM DEM – ASTER DEM Mosaic



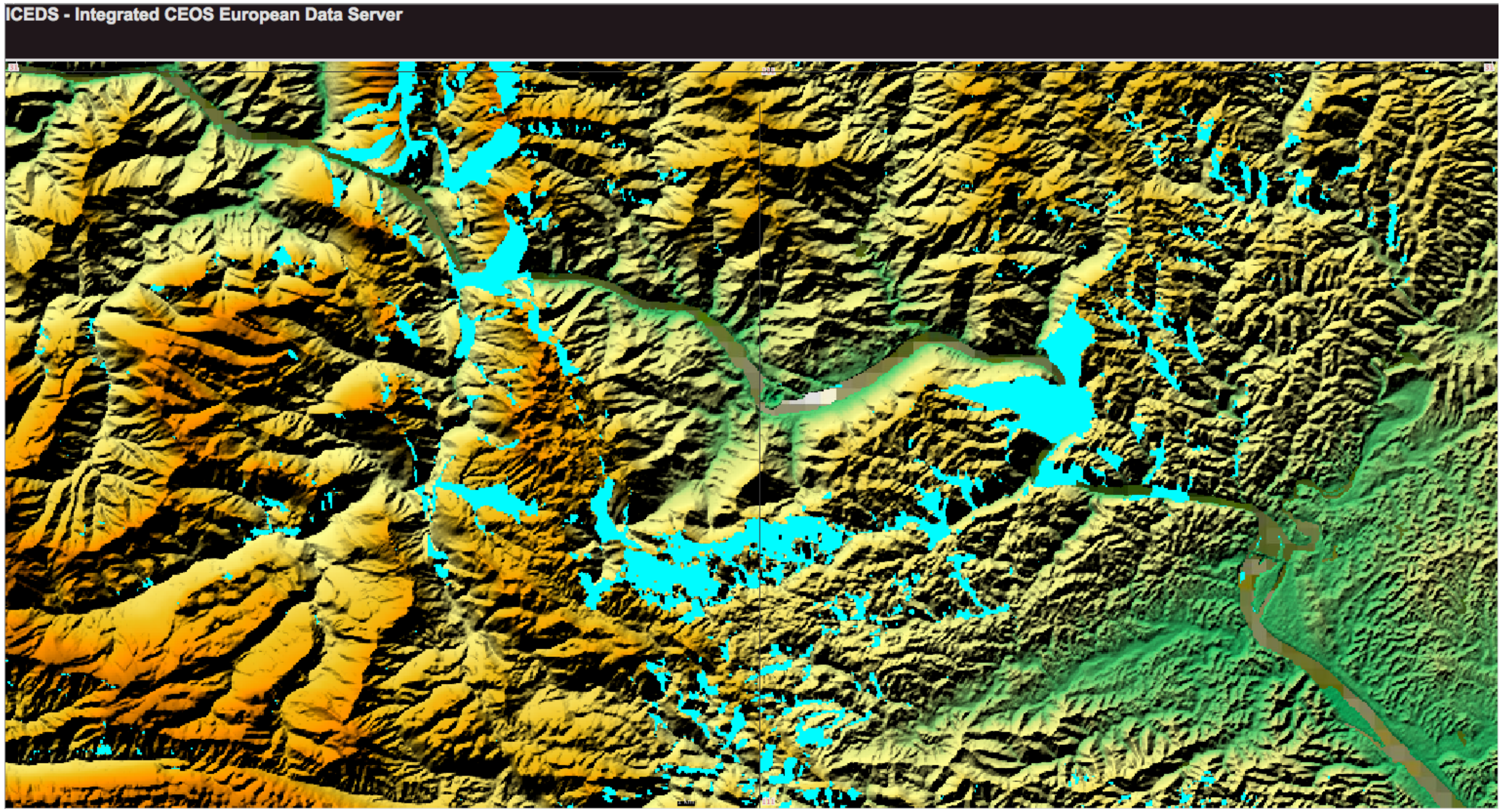
Elevation Difference Map created in ArcMap displayed on top of the hill shaded SRTM DEM. SRTM DEM used as the ‘correct’ DEM and the ASTER DEM mosaic subtracted from it. Notice clouds shown as areas of dark blue. **Notice the variable offset for each ASTER-DEM (mean = -29.79m, min = -3178m, max = 545m, std. deviation = 176.45m) as well as the low frequency variation (banding)**

Fusion of DEMs

- **Step 1: ‘fill in’ voids in SRTM DEM using ASTER**
- **Step 2: Use improved SRTM DEM to remove artefacts (e.g. clouds) in ASTER DEM**
- **Step 3: ‘fill in’ remaining voids using interpolated SRTM DEM layer**

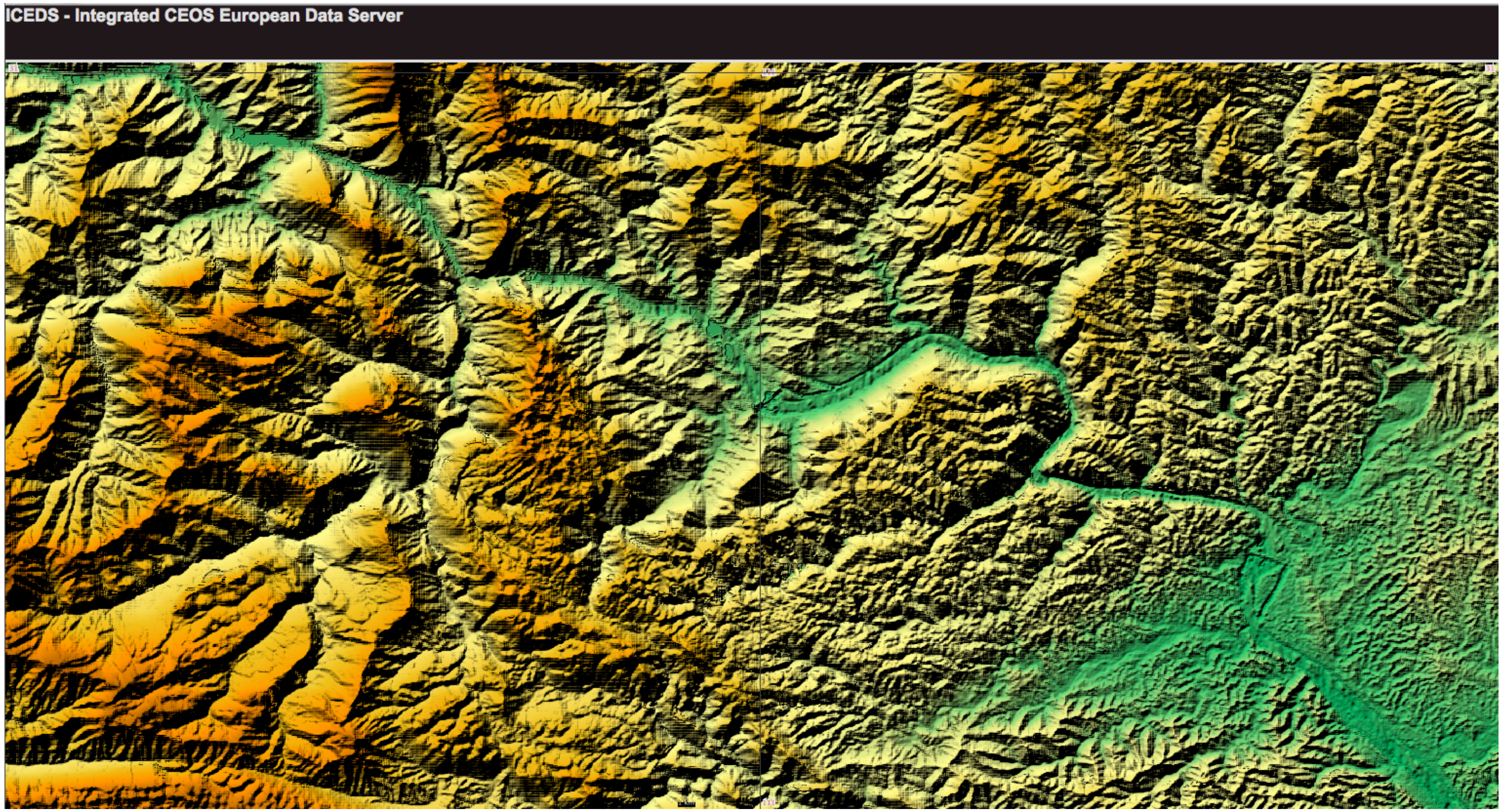


Inter-comparison of fused ASTER-SRTM with SRTM original



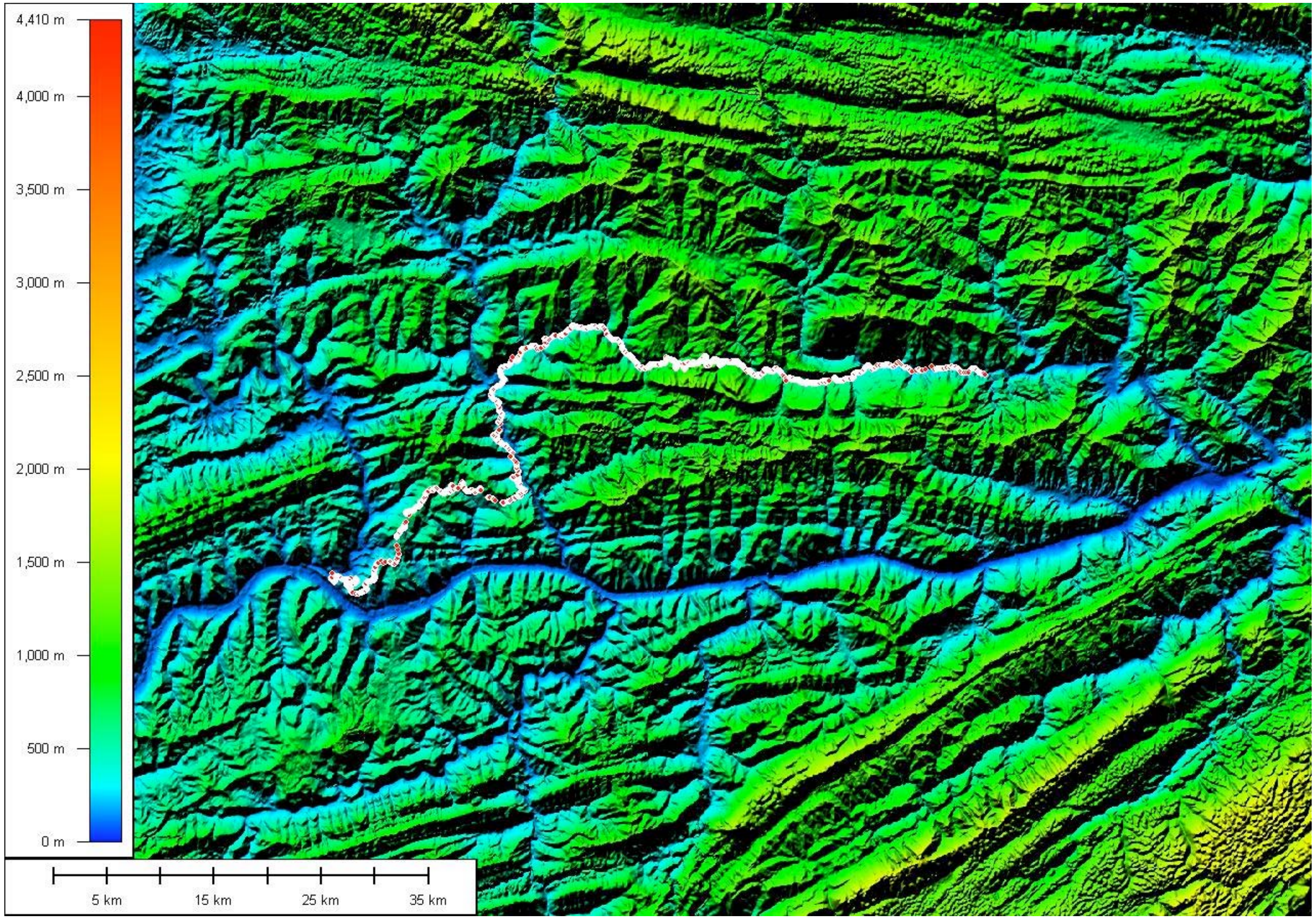
SRTM version 2 (so-called “finished”) DTED1 at 3” (≈90m)

Inter-comparison of fused ASTER-SRTM with SRTM original



ASTER-SRTM version 2 fusion at 30m (≈1”)

Height assessment campaign: ASTER+SRTM fused 30m DEMs



True DEM - 30m fused DEM

Mean 1.74

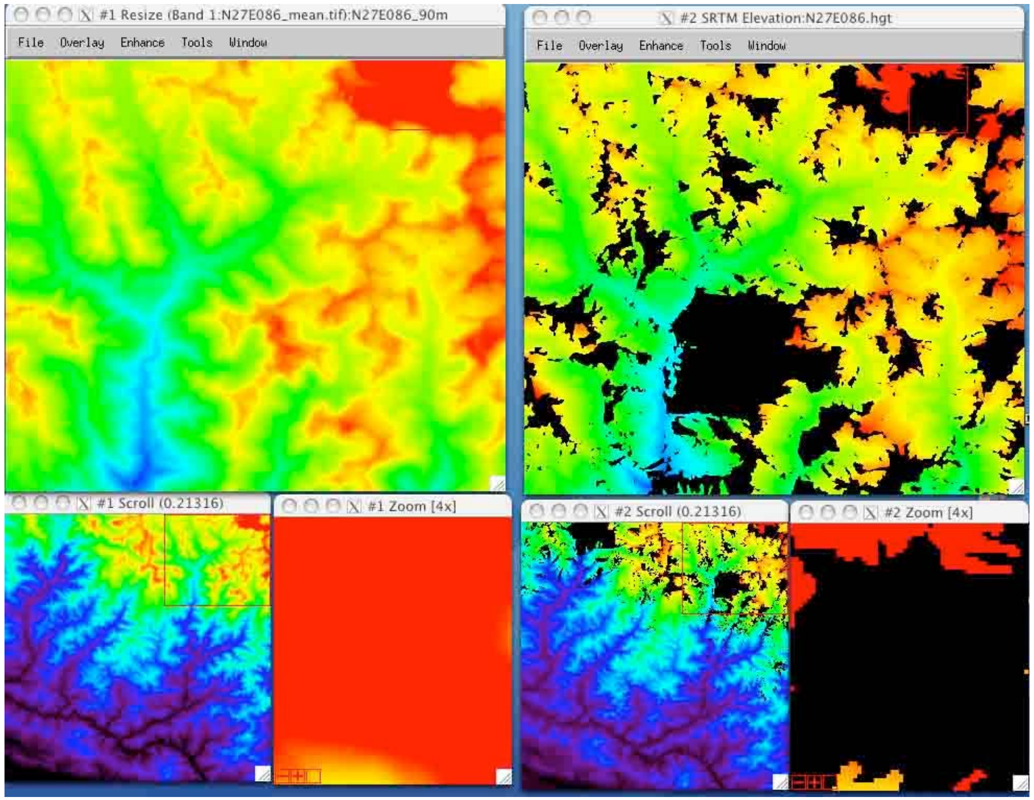
St Dev 19.72

Joint US-Japan project to create a global 30m ASTER-DEM

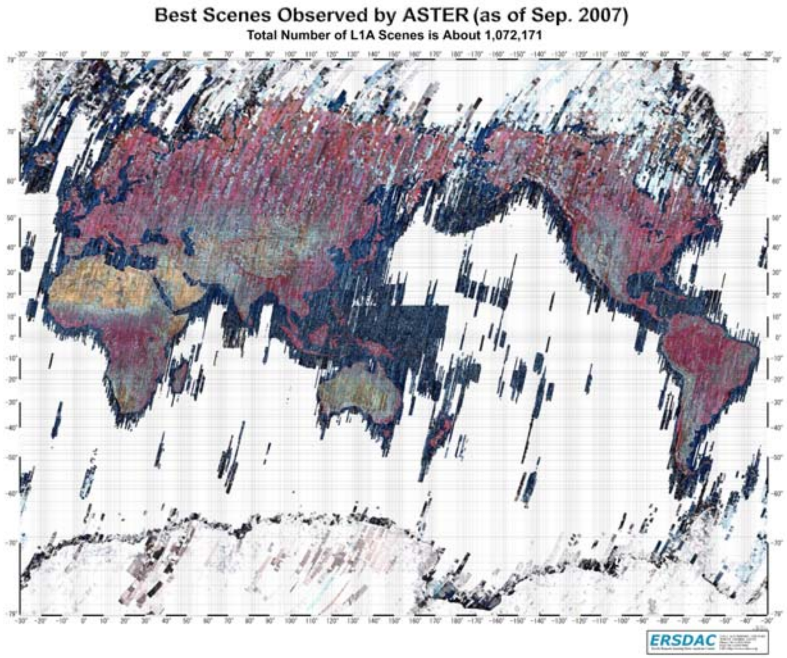
- **On 4 October 2007, updated on 21 February 2008, Bryan Bailey (Principal Remote Sensing Scientist, USGS, EDC) reported and I quote**
  - **"The National Aeronautics and Space Administration (NASA) and Japan's Ministry of Economy, Trade and Industry (METI), in cooperation with the U.S. Geological Survey (USGS) and METI's Earth Resources Data Analysis Center (ERSDAC), have announced plans to produce a global digital elevation model (DEM) from stereo data acquired during the past 8 years by Japan's Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) that flies on the U.S. Terra spacecraft.**
  - **The ASTER Global DEM (GDEM) will have 30m postings, and it will cover land surfaces between 83N and 83S with estimated accuracies of 20 m at 95 % confidence for vertical data (elevation) and 30 m at 95 % confidence for horizontal data (geolocation).**
  - **METI and NASA have accepted an invitation from the Group on Earth Observations (GEO) to contribute the ASTER GDEM to the Global Earth Observing System of Systems (GEOSS), and it will be available at no cost to users from around the world.**
  - **At the GEO Summit in Cape Town, South Africa, last November, US Secretary Kempthorne and Japanese Minister Tokai announced the two countries' plans to produce the ASTER GDEM and contribute it to GEOSS. .**
- **It is very likely that some (unknown number of) gaps will still exist due to persistent cloud cover or lack of contrast in the stereo images**

ASTER Global DEM Project Thanks to Bryan Bailey, EDC

Stacked ASTER SRTM



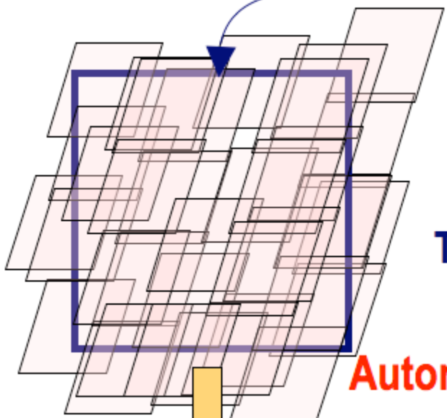
- **203 scenes used**
- **No holes for ASTER DEM**
- **Many large holes for SRTM**



- 22,895 1° x 1° tiles
- 83° N to 83° S
- 10 m Zrms
- May 2009 release

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 ---

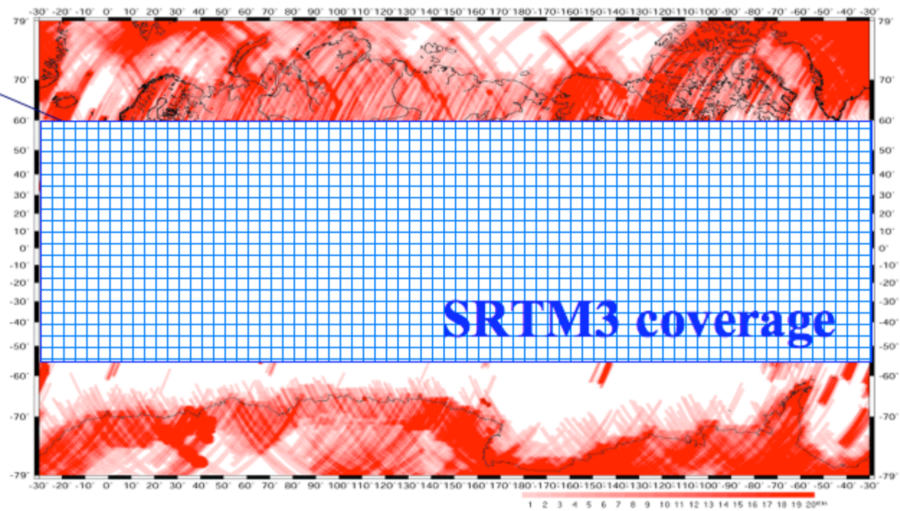


ASTER scene
(60km x 60km)

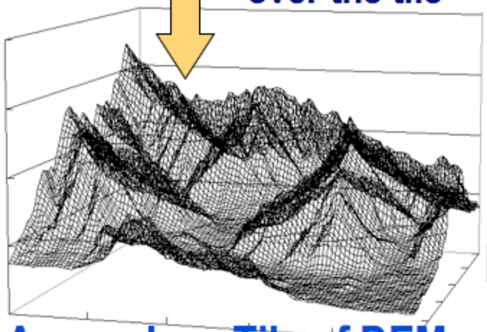
Tile (1 arc degree square)

Automated processing

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



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



A seamless Tile of DEM

Global coverage

ASTER GDEM

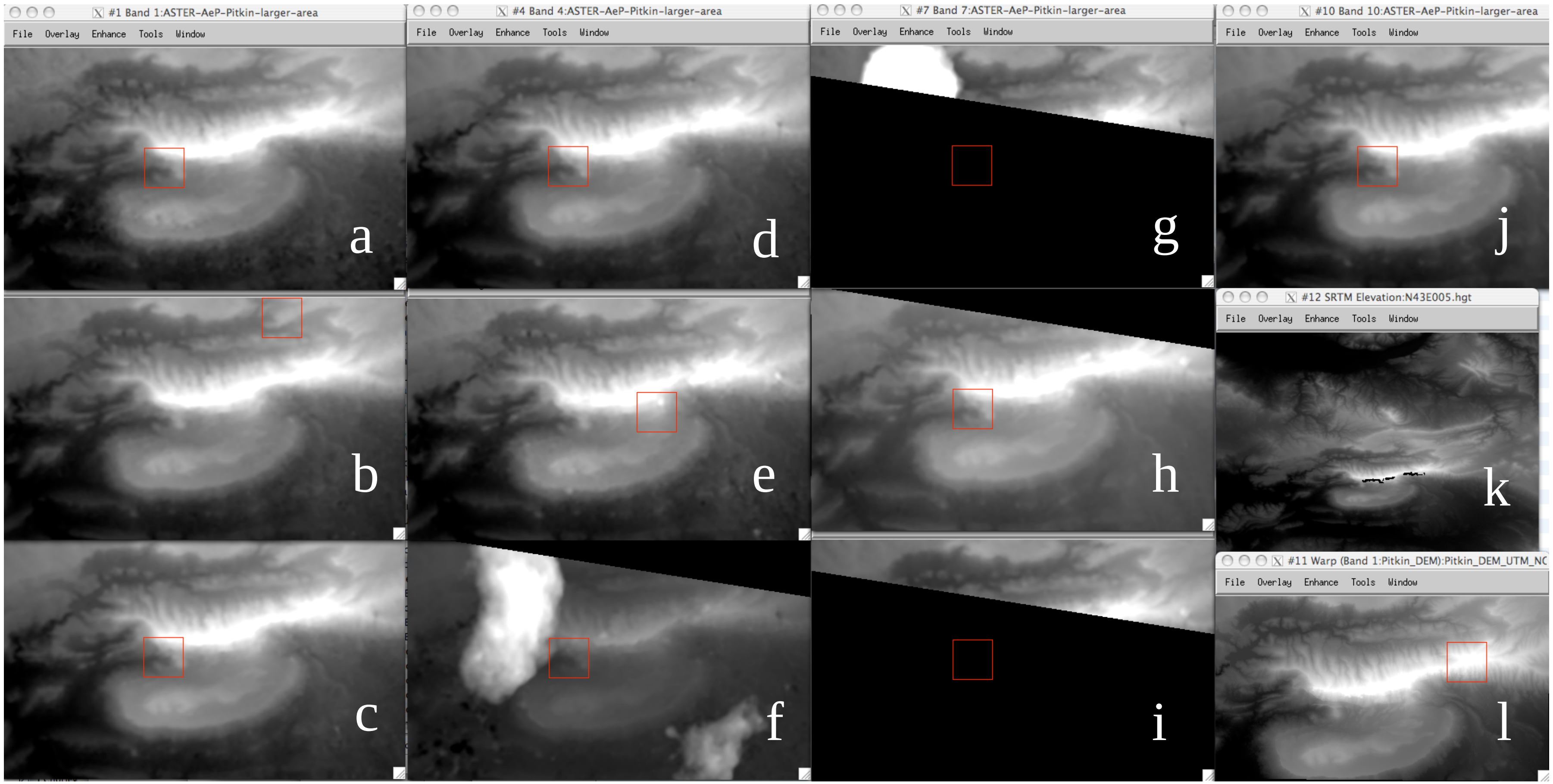
Contribution to GEOSS

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

Stacking ASTER DEMs to achieve better coverage and accuracy

- **Global ASTER DEM (see later slides) employ a method of stacking and averaging of cloud-screened ASTER L1B data**
- **Assessed the impact of stacking using multiple ASTER DEMs over some of the CEOS-WGCV-TSMG test-sites (see later)**
- **As USGS-supplied ASTER DEMs contained heights above clouds irrespective of cloud cover, applied a fixed threshold (ASTER Z>1060m) as a threshold to eliminate clouds, rather than the cloud clearing methods being employed by ASTER-DEM project**

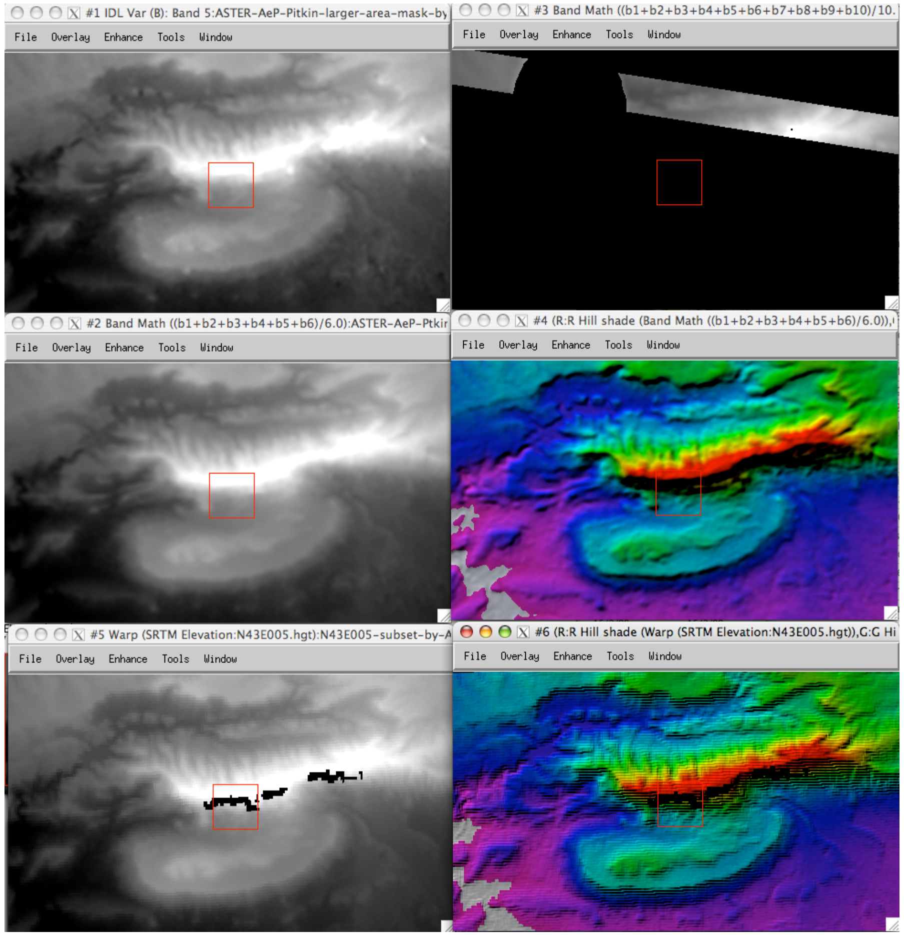
10 Input ASTER DEMs, SRTM DEM 1º x 1º tile and “ground truth”



Note the clouds in (f) & (g), the missing areas in ASTER in (f-i). (k) shows SRTM (≈90m) and (l) ground truth DEM (Zrms=1.3m)

ASTER DEM Stacking examples

- **ASTER single DEM shows clusters of bad data**
- **Mean of 6 cloud-free ASTER DEMs. Low Noise but residual 1 pixel smear**
- **SRTM DEM showing gaps on southern facing slopes**



- **Mean of 10 ASTER DEMs. NaN issues with ENVI v4.4**
- **Colour hill-shaded 6-mean ASTER DEM**
- **Colour hill-shaded SRTM showing more detail cf mean ASTER given that SRTM is 90m original**

Conclusions

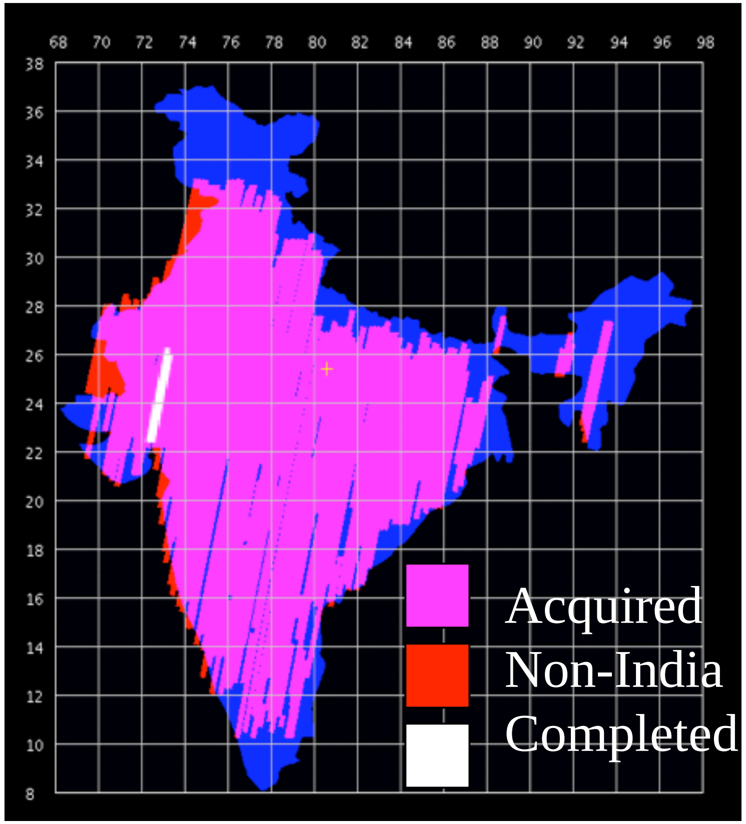
- **Global Land Surface topography is now a realistic goal at resolutions from 1km down to 30m**
- **At 3 arc-seconds (90m), the fusion of SRTM with ASTER GDEM may provide the necessary accuracy**
- **At 1 arc-second (30m), the ASTER Global DEM (GDEM) will provide a very significant step forward towards meeting the land surface topography goal**
- **However, it is unclear how much of the Earth's land mass will contain gaps or bad data from the GDEM**
- **It is also unknown how we will obtain comparable resolution and accuracy for the world's continental shelves to help protect coastal communities from the impacts of tsunamis**

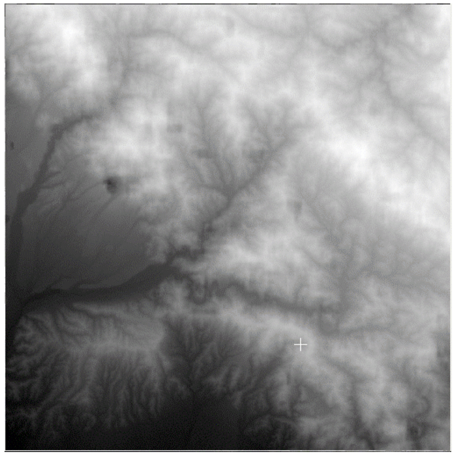
Outstanding Issues to resolve

- **How will the voids in the ASTER GDEM be filled? How many of the CEOS-GEOSS space agency partners are willing and able to contribute height pixels to a free and unrestricted global dataset at 30m?**
- **How will the global ASTER GDEM be validated in 4 months prior to release and where will the resources come from ? (see CEOS example)**
- **How can we ensure that the ASTER GDEM receives the same intensive worldwide effort for validation that SRTM received?**
- **What role could ISPRS play in co-ordinating such a global effort? For example through the establishment of a WG to address technical issues**
- **How do we ensure that there is a similar level of effort for producing global bathymmetric data over continental shelves?**
  - **NOAA-NGDC are engaged in mapping extensive areas around the US coastline. USGS have demonstrated the fusion of such bathymetric and land DEMs**
  - **However, most other such bathymmetric data sources are extremely expensive (e.g. UKHO) and subject to © restrictions.**
  - **How does GEO persuade the oceanographic community that it is in their best interests to donate such proprietary data for the 9 societal benefit areas agreed by the GEOSS ministers, especially that of natural disasters and hazards?**

Higher resolution DEMs for gap-filling or validation? India's CartoSAT

- **1/3 arc-second (10m) resolution**
- **7.5 x 7.5 arc-minute tiles**
- **Completion due by end 2008**
- **Formal invitation from GEO for participation in GDEM void-filling and validation**
- **Information courtesy of Dr Pradeep K Srivastava, ISRO**



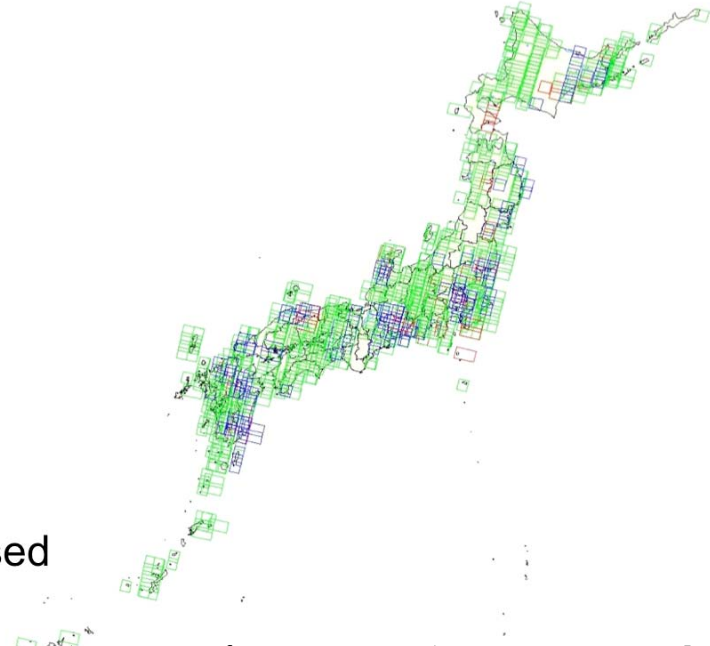


Status of PRISM DSM Generation

- **PRISM DEM**
  - ✓ 1/3 arc-second resolution (≈10m)
  - ✓ Height accuracies are approx. 5m (1-sigma) for flat & urban and 6~7m (1-sigma) for various terrain and approx. 6~8m (1-sigma) for mountainous with/without GCP
  - ✓ Large errors are focused on high building urban areas and dense tree areas, and

- **Generation Priority in JAXA**
  - ✓ Validation and accuracy assessment
  - ✓ Japan area including internal/PI's requests
  - ✓ High latitude region (*e.g.*, Alaska)
  - ✓ Asian region (*e.g.*, SW Asia)
  - ✓ **For GEOS/CEOS-WGCV TMSG:**
  - ✓**JAXA will allocate resources to generate 100 PRISM scenes in JFY2008**

- **Generation Status：1,266 scenes processing**
  - ✓ Total 1,266 scenes (stereo pairs) have been processed
  - ✓ Not only Japan, but also foreign area



Processing status of PRISM DSM in Japan as example.

- **Issue**
  - ✓ Sensor alignment variation model is currently working very well, and it will be continuously evaluated as operational calibration due to time trend.

N.B. Information courtesy of T. Tadono, JAXA

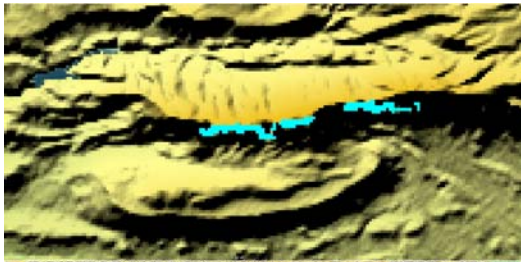
CEOS-WGCV-TMSG test site characteristics

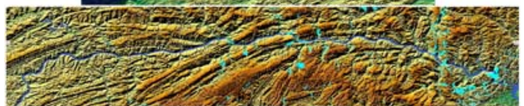
- **Montagne Sainte-Victoire, France referred to as Aix-en-Provence 5.528-5.685ºE, 43.502-43.560ºN mixed arable, forest, limestone**

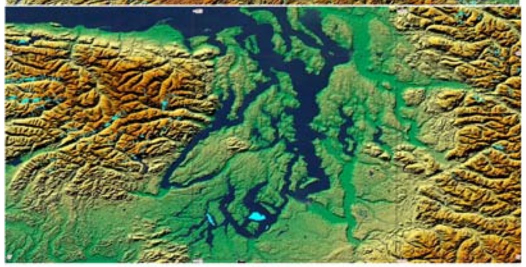
- **Barcelona, Spain 1.5-2.75ºE, 41.25-41.82ºN urban, mixed arable, forest**

- **North Wales, UK 3-5ºW, 52-53.5ºN urban, pasture, forest**

- **Three Gorges, China 108.252-111.302ºE, 30.638-31.229ºN forest, arable, limstone shales**
- **Puget Sound, WA, USA -121.397 to -123.897ºW, 46.364-48.864ºN forest, urban, wetlands**



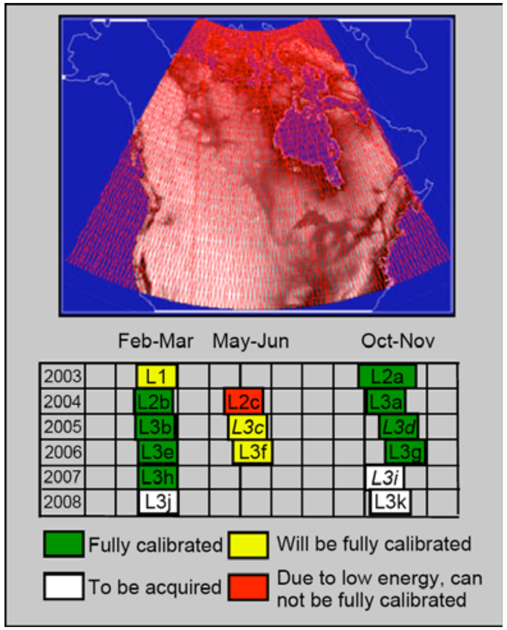


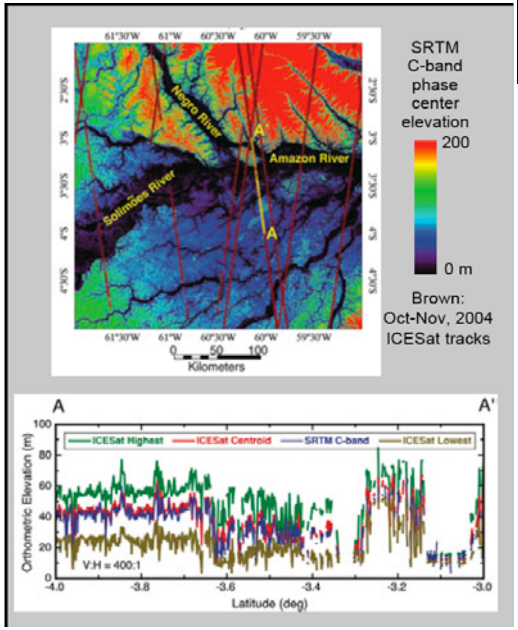


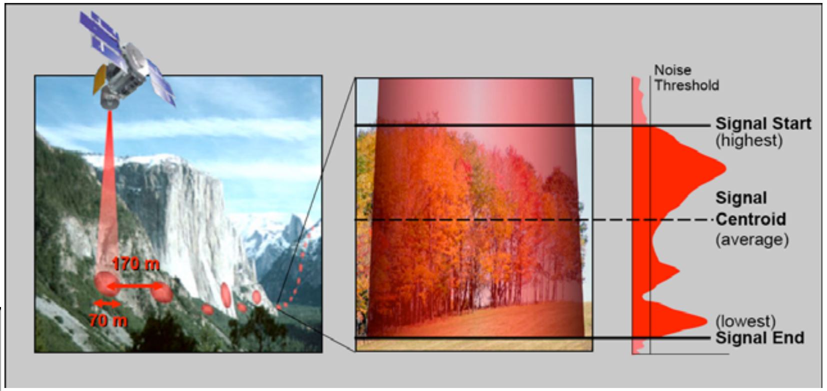
N.B. screenshots from ICEDS extracts

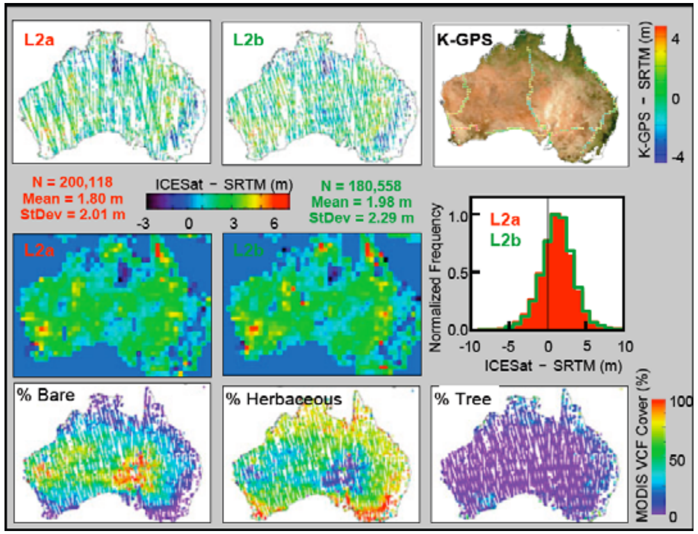
Opportunity for Global Validation of ASTER GDEM using ICESAT-GLAS

- **NASA's ICESat-GLAS lidar with a 70m footprint every 170m would be an ideal (OGC) source of global validation points**
- **It would also enable the penetration depth from InSAR and stereo to be quantified**



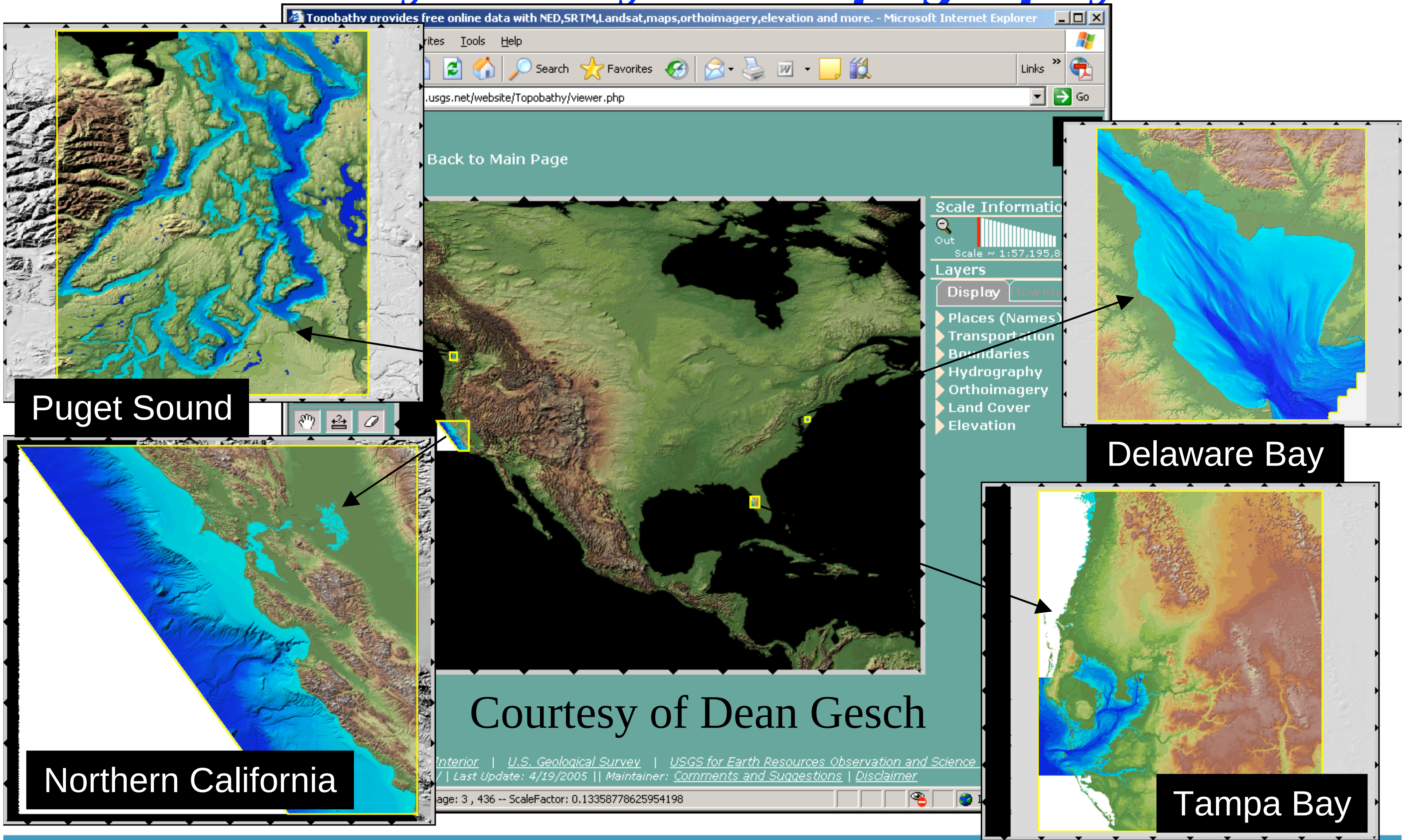






Contact: David Harding, NASA Goddard Space Flight Center, Code 698, David.J.Harding@nasa.gov

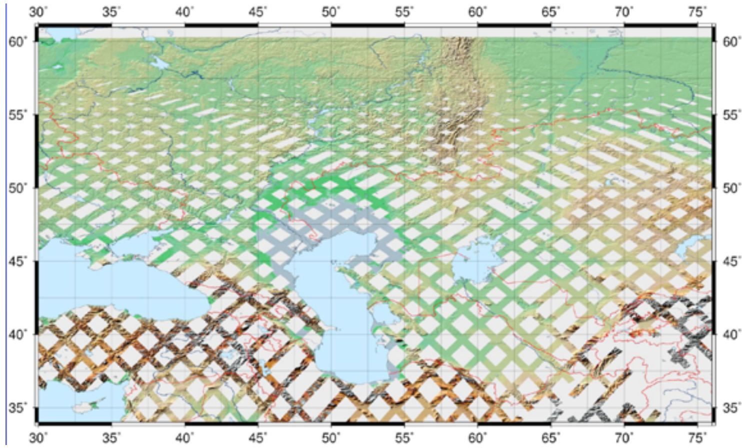
Example of USGS (EDC) merger of bathymmetry and topography



Courtesy of Dean Gesch

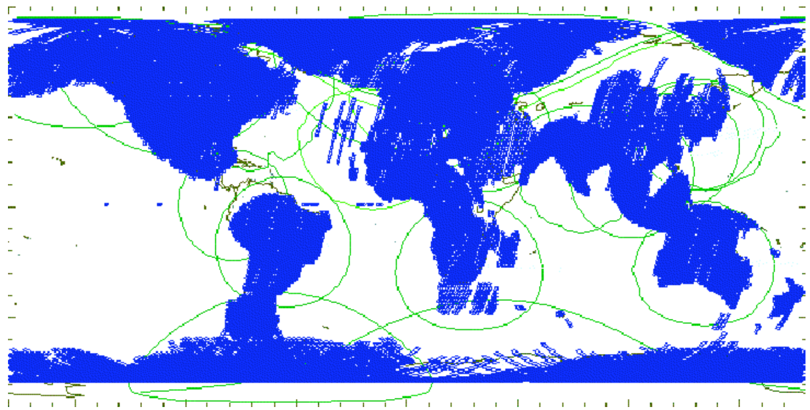
What datasets NOW could be exploited to fill these voids if they were available? InSAR

- **SRTM-X (available at 1”, ≈30m) but only for subset strip areas (Europe example shown) after height adjustments made for the differences between the SRTM-X and C-band datums**



SRTM-X DEM coverage over Europe © DLR

- **ERS-1/2 tandem available at ≈30m (most of Europe available from DLR, SARMAP/Telespazio, UCL) but problems with WV effects remain in all cases. Also, would require very extensive processing effort to generate the DEMs**



ESA ERS-1/ERS-2 SAR tandem acquisition pairs with optimum baseline values for DEM generation (status of 1 June 1996)