*Status Report on Global DEM inter-operability : GEOSS Task DA-07-01**

Jan-Peter Muller

jpm@mssl.ucl.ac.uk

Point-of-Contact, GEOSS Task DA-07-01

Chairperson, CEOS-WGCV Sub-group on Terrain mapping from satellites

Vice-Chair, UK JISC Geospatial Working Group (2002-2008)

Head, Imaging Group

Professor of Image Understanding and Remote Sensing

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 BNSC-Qinetiq under the ICP2 programme*

CEOS-WGCV Programmatic issues

- **Joint ISPRS-CEOS-GEOSS Special Session 18 (SS-18) on "Global DEM Interoperability" will be held on 10 July at ISPRS08 Congress in Beijing Convention Centre**
- **Joint ISPRS-CEOS-GEOSS one-day workshop (venue tbd) on "Practical Aspects of Global DEM Interoperability" to be held on 2 July 2008 in Beijing**
- **TMSG Vice-Chair, Veljko Jovanovic (JPL) has resigned from the post. JPM is actively seeking replacement, preferably from Asia, Australasia or Europe.**

SUGGESTIONS MOST WELCOME!

Overview

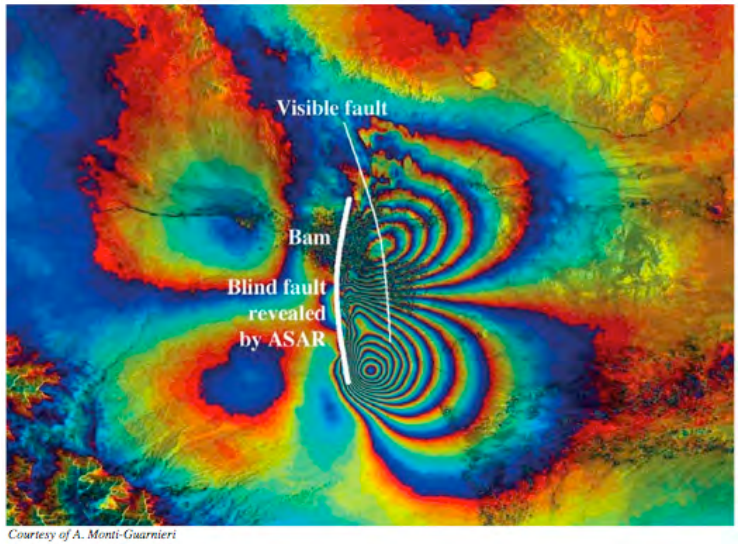
- What is GEO Task DA-07-01?
- Why do we need global topography/bathymmetry?
- What might partially fulfill and/or address the global DEM goal?
- Where are the voids and how large are they?
- What could be used to fill these voids?
- How could these voids be best filled:
  - An example of data fusion of ASTER and SRTM for the Terrain modelling of the 3 Gorges area of China (support from ESA under ESA-NRSCC DRAGON Programme)
  - Assessment of the potential of multiple ASTER DEMs to fill gaps using one of the CEOS-WGCV-TMSG test sites (Montagne Sainte Victoire, France)
- Joint US-Japan project to create a global 30m ASTER-DEM
- How CEOS-GEOSS members might contribute to filling gaps:
  - DEM sources
  - Web Processing Services
  - Web Validation Service
- How ICEDS Web-GIS can be employed for Global DEM Inter-operability
- Outstanding Issues to resolve
- Actionable ACTIONS: CEOS Plenary & CEOS-WGISS

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

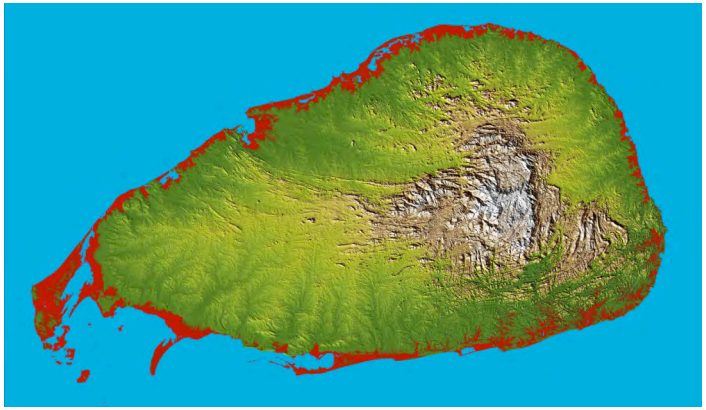
- ***Objectives are to***
  - *facilitate interoperability among Digital Elevation Model (DEM) data sets*
  - *the end goal is to produce a global, coordinated and integrated DEM*
  - *This global DEM should be embedded into a consistent, high accuracy, and long term stable geodetic reference frame for Earth observation.*
  - *This activity shall also include*
    - » *coastal zone bathymetric maps in shallow waters (~30-40 m),*
    - » *DEMs of DTED1-class (3 arc-seconds, ≈90m),* ***now updated to 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"*
  - *Submit this document for review to the GEO plenary*
- 40 members of Task (UK, US, AU, DE, FR, IT, ES, JP, CN,KR, ES, WMO, OGC)

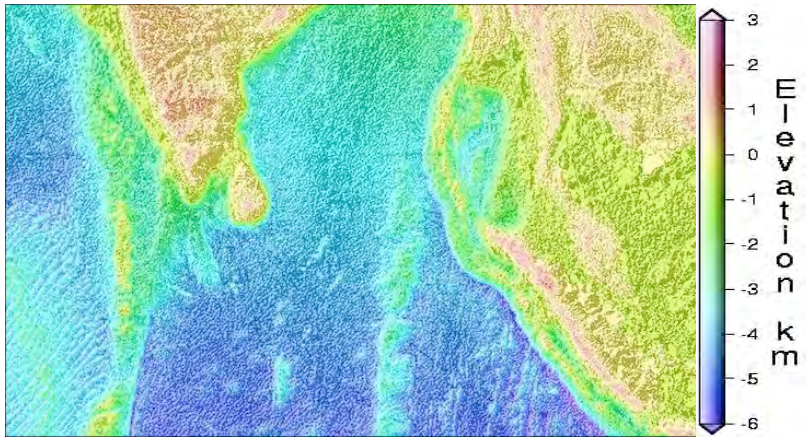
Why do we need global topography/bathymmetry?

- ***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 or for downstream EO processing, e.g. InSAR for earthquake monitoring and possible prediction***
- ***Poor bathymmetric and topography knowledge hinders tsunami forecasts***



Courtesy of A. Monti-Guarnieri


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



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

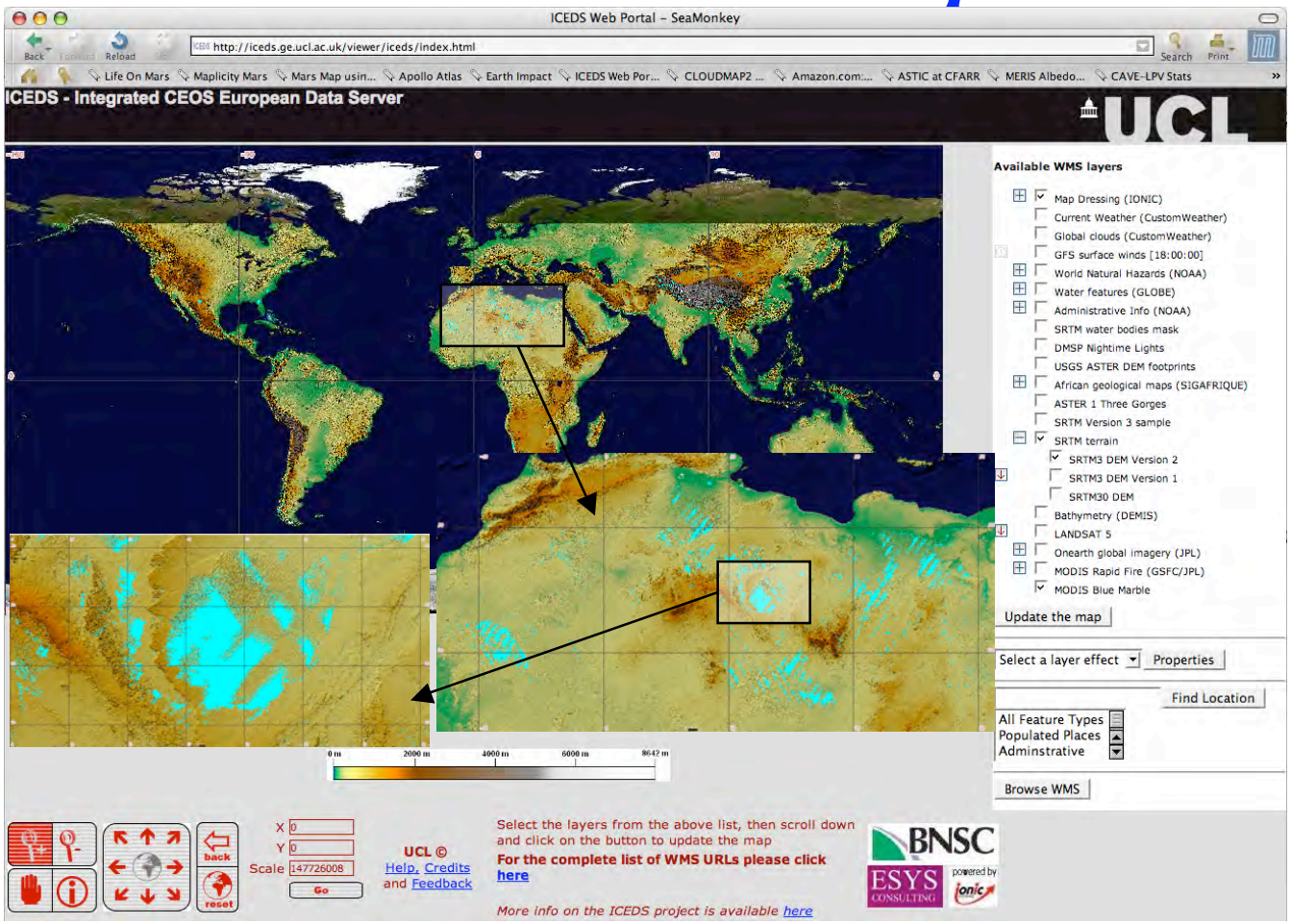
What DEM(s) are available NOW to fulfill the Global DEM objective

- **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)

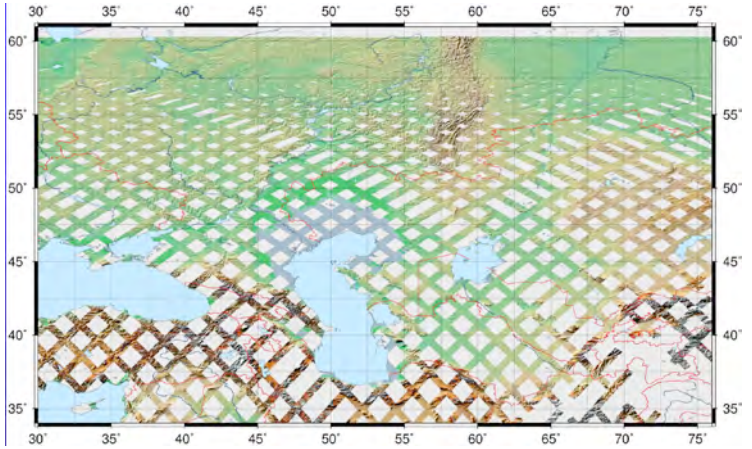
What areas contain gaps at present in the SRTM DTED-1 product?



- **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..**

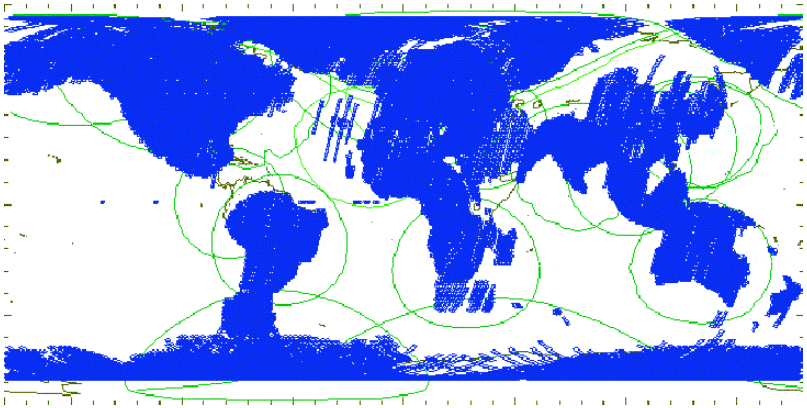
What datasets NOW could be exploited to fill these voids if they were available? InSAR

- **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**



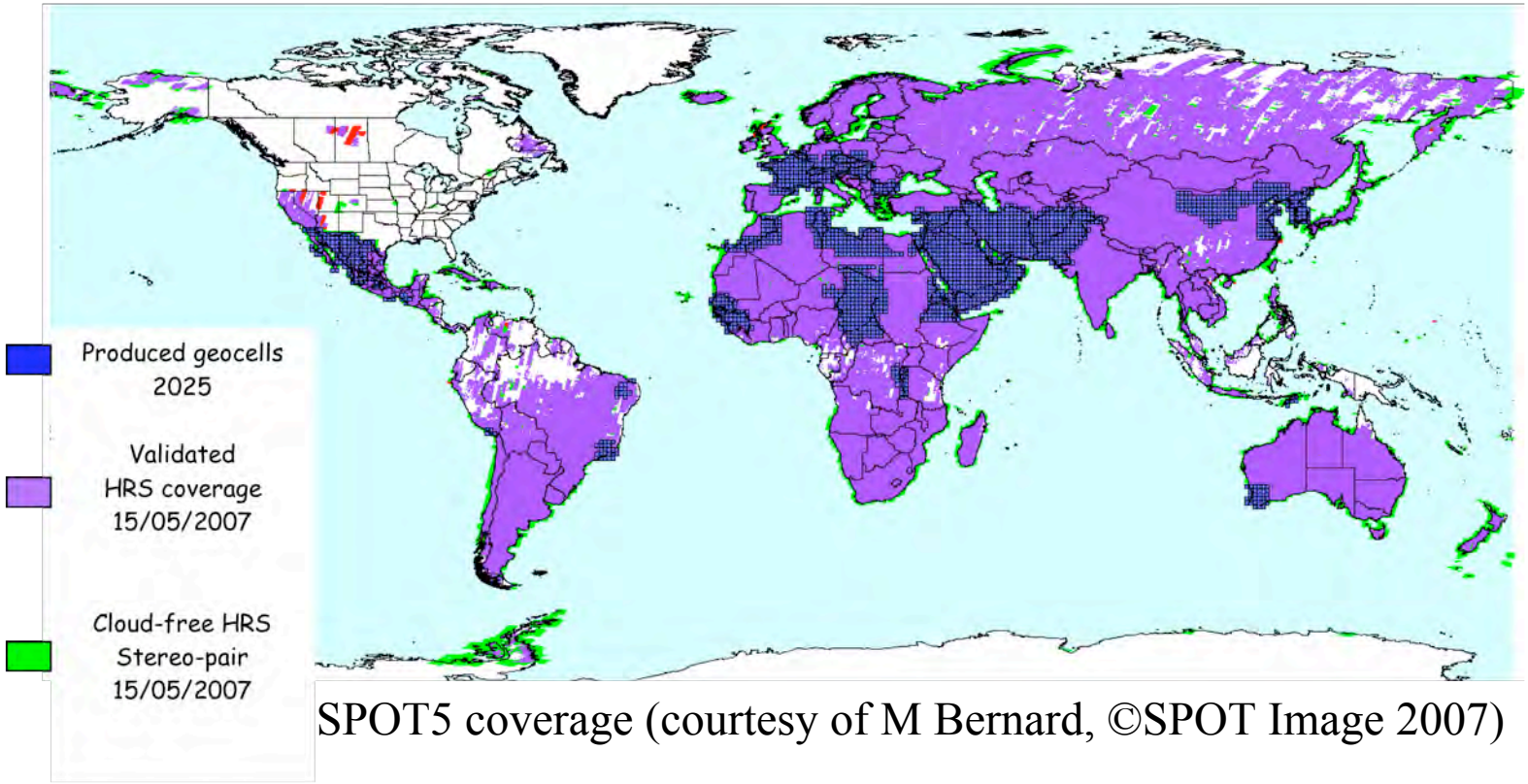
SRTM-X DEM coverage over Europe © DLR

- **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**



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

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



SPOT5 coverage (courtesy of M Bernard, ©SPOT Image 2007)

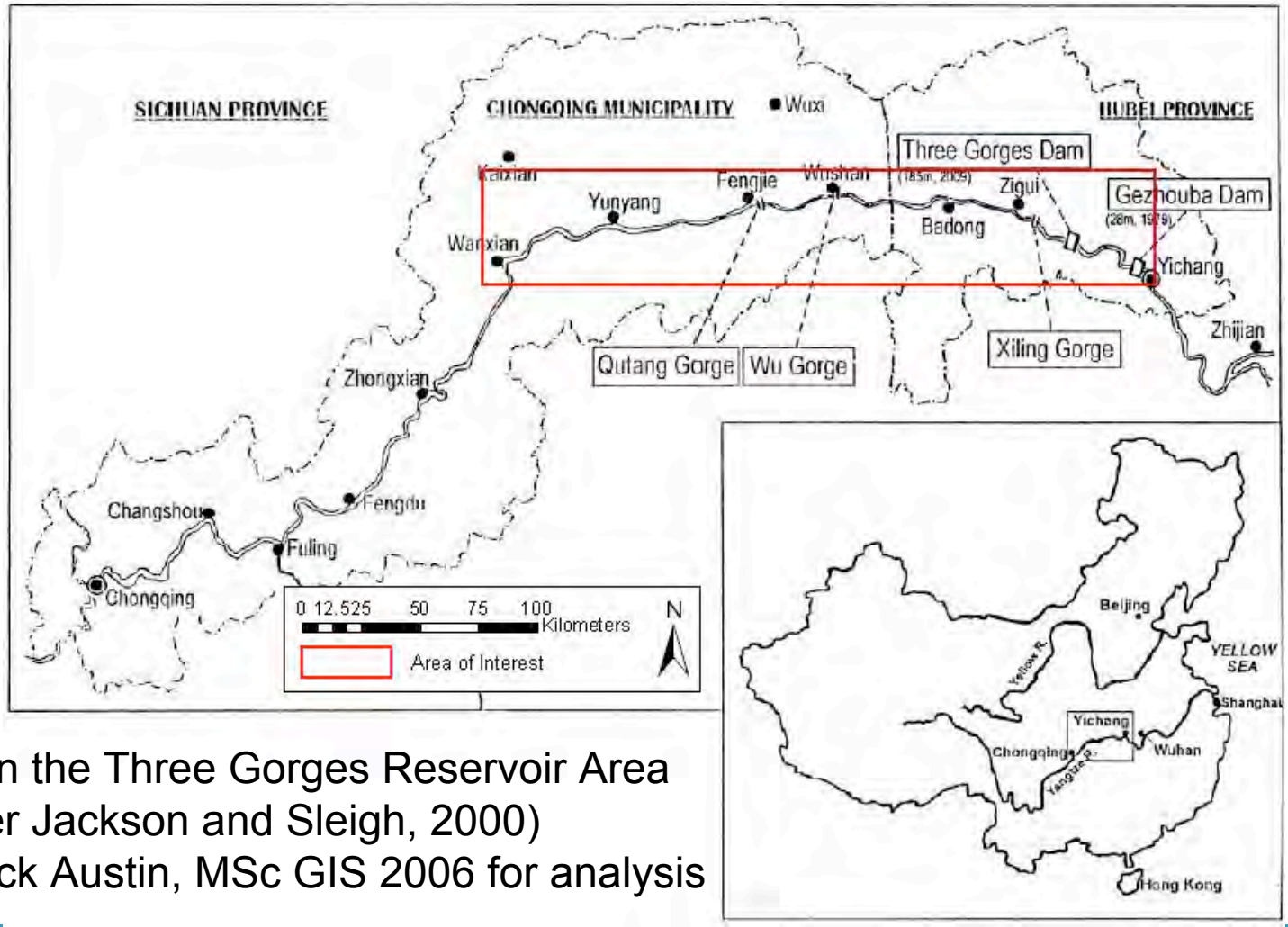
- **SPOT-5 : complete coverage for 20m DEMs shown in blue and potential scenes for global coverage in purple**
- **ONLY available at a very high cost at present**

Global DEM Interoperability: Some Definitions

- **the ability of two or more systems or components to exchange information and to use the information that has been exchanged***
- **is a property referring to the ability of diverse systems and organizations to work together (inter-operate). http://en.wikipedia.org/wiki/Interoperability**
- **Interoperability means the ability of information and communication technology (ICT) systems, as well as, of the business processes they support in order to exchange data and enable the sharing of information and knowledge. http://ec.europa.eu/idabc/en/chapter/5883**

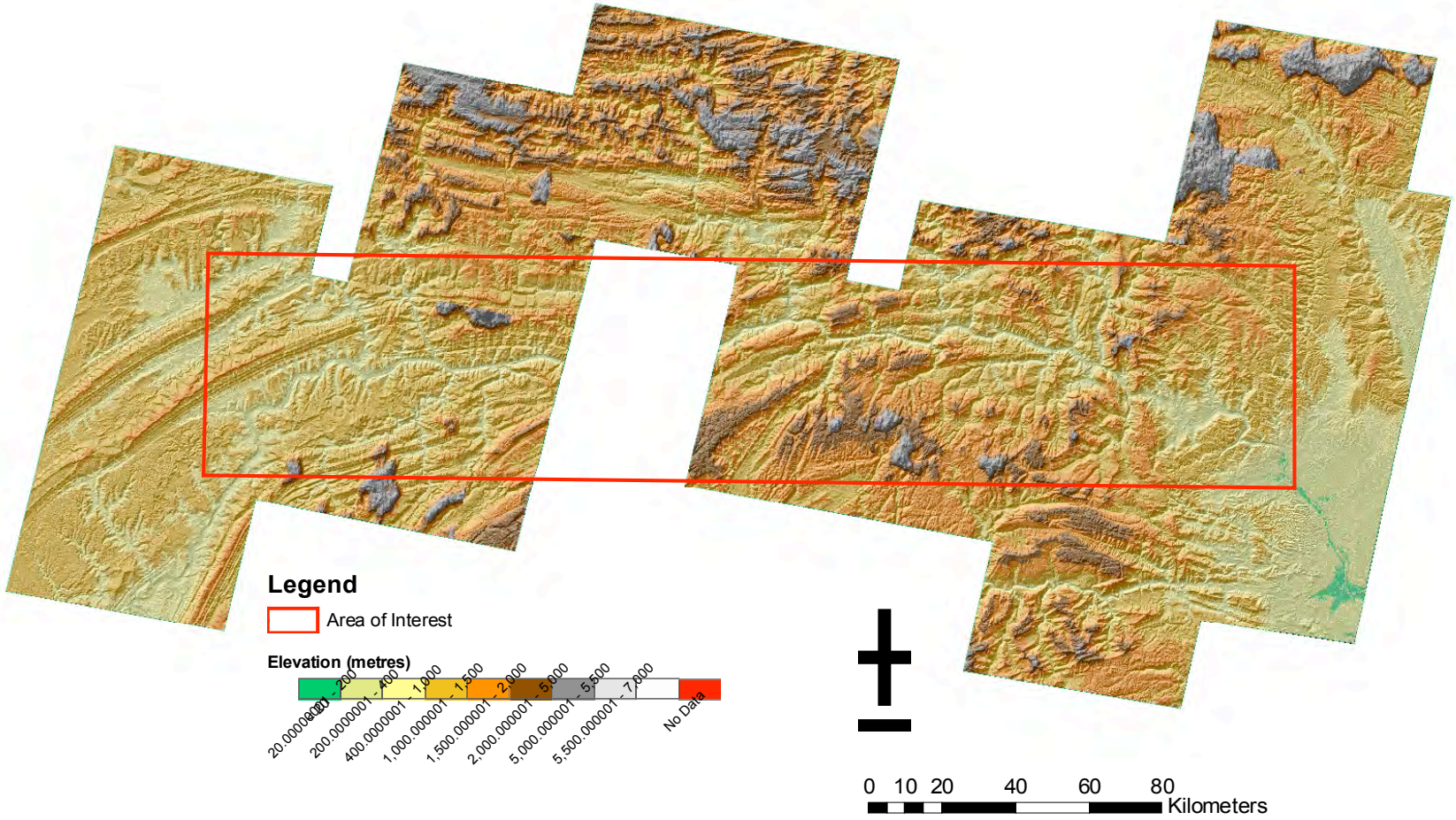
* Institute of Electrical and Electronics Engineers. IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. New York, NY: 1990.

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



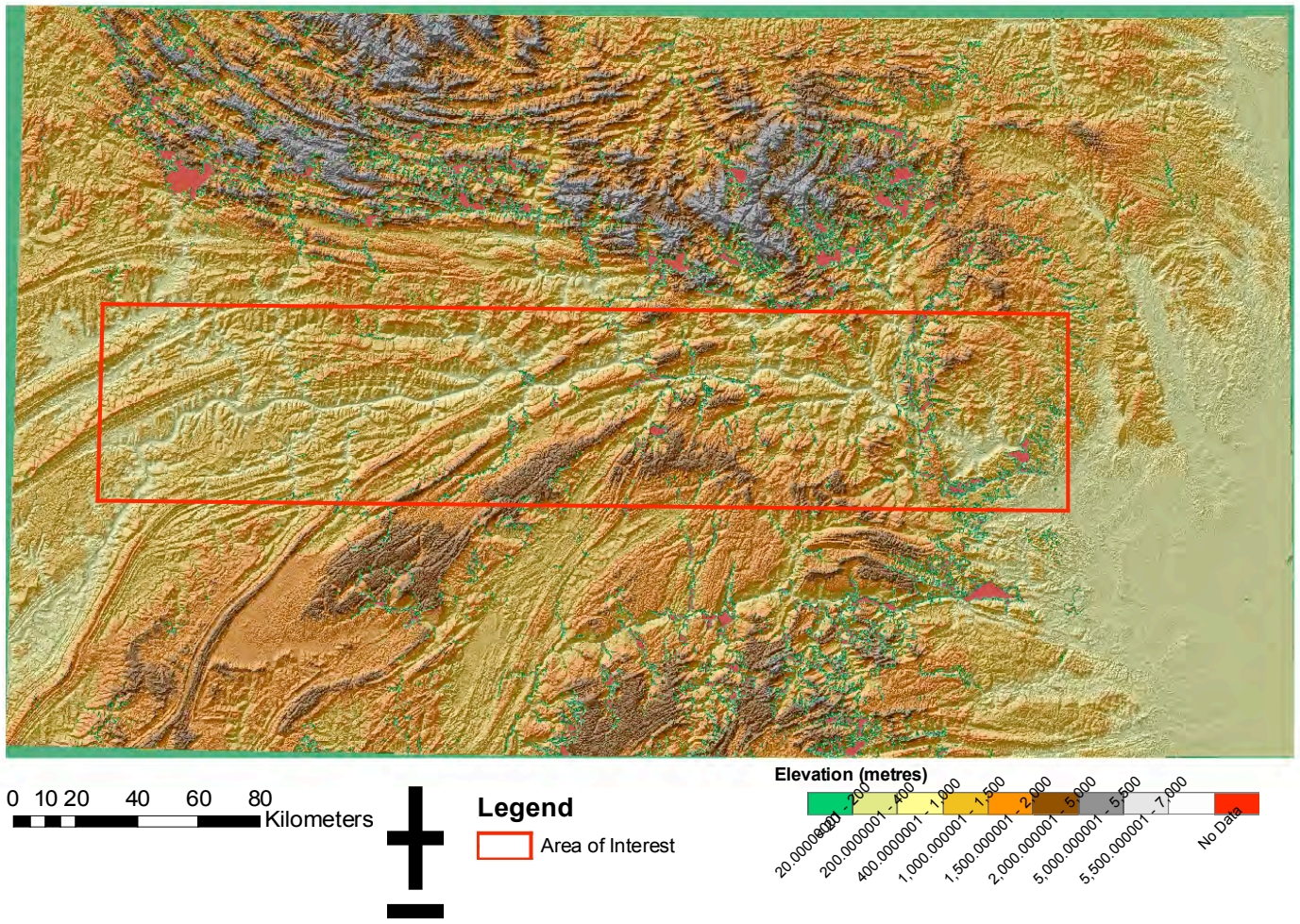
Study Site in the Three Gorges Reservoir Area
(after Jackson and Sleigh, 2000)
Thanks to Nick Austin, MSc GIS 2006 for analysis

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



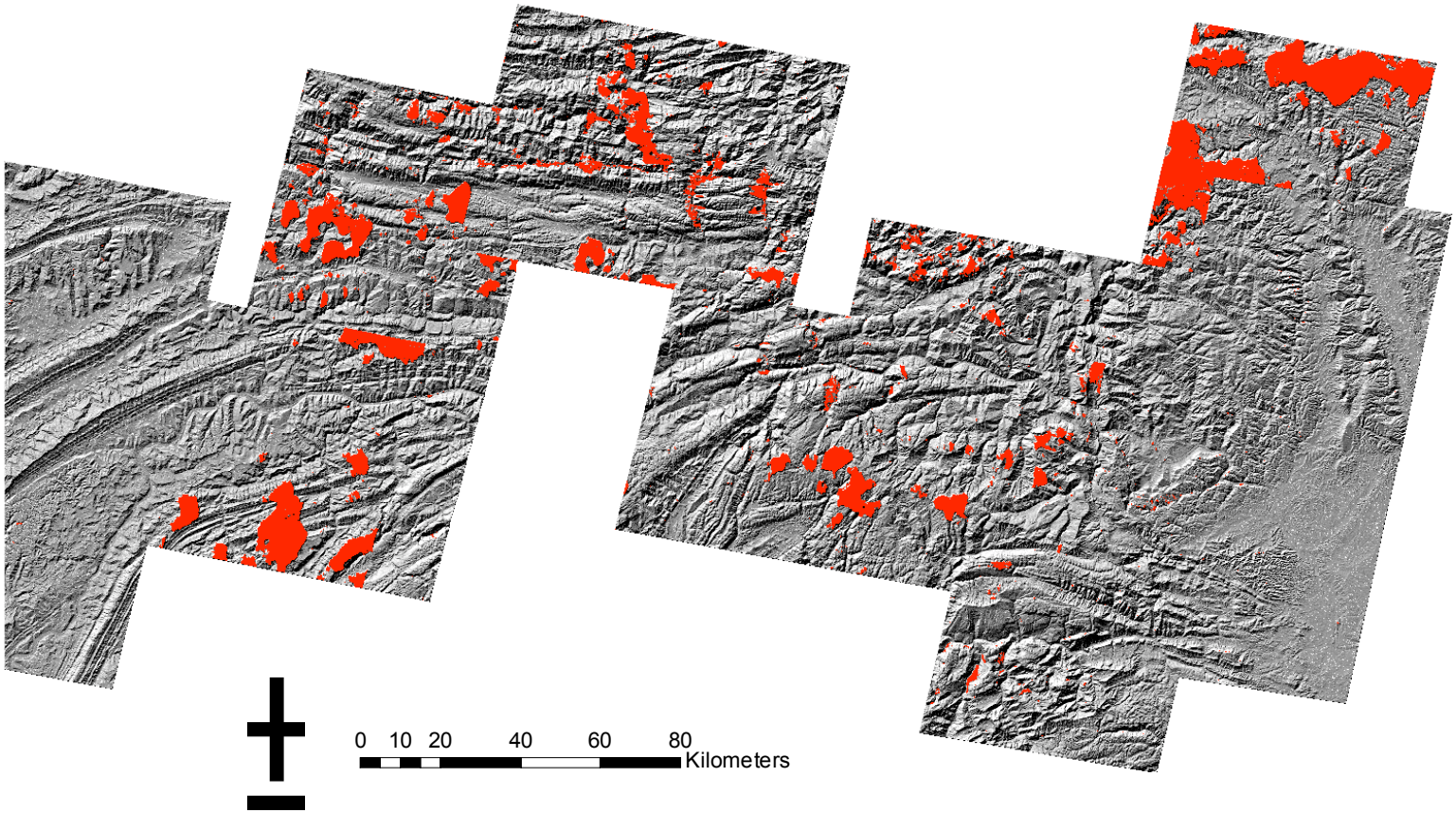
ASTER DEM mosaic hill-shaded in ArcMap with 30° altitude and 330° azimuth for the light direction and using the ICEDS custom hill-shading colour scheme. Note the grey areas which appear to be clouds.

SRTM v2 (edited) DEM for area of interest



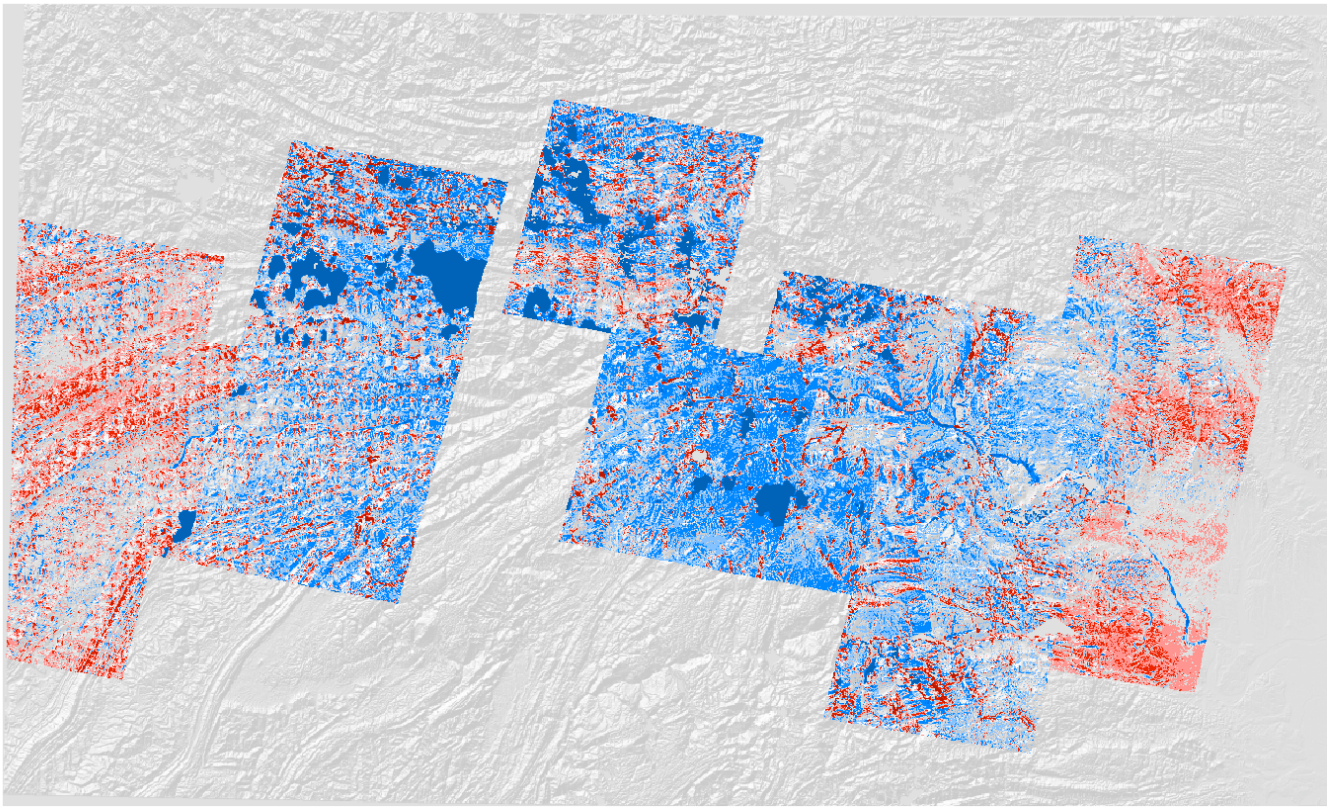
SRTM DEM mosaic hill-shaded in ArcMap with 30° altitude and 330° azimuth for the light direction and using ICEDS custom hill-shading colour scheme. Notice the red areas of missing data.

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

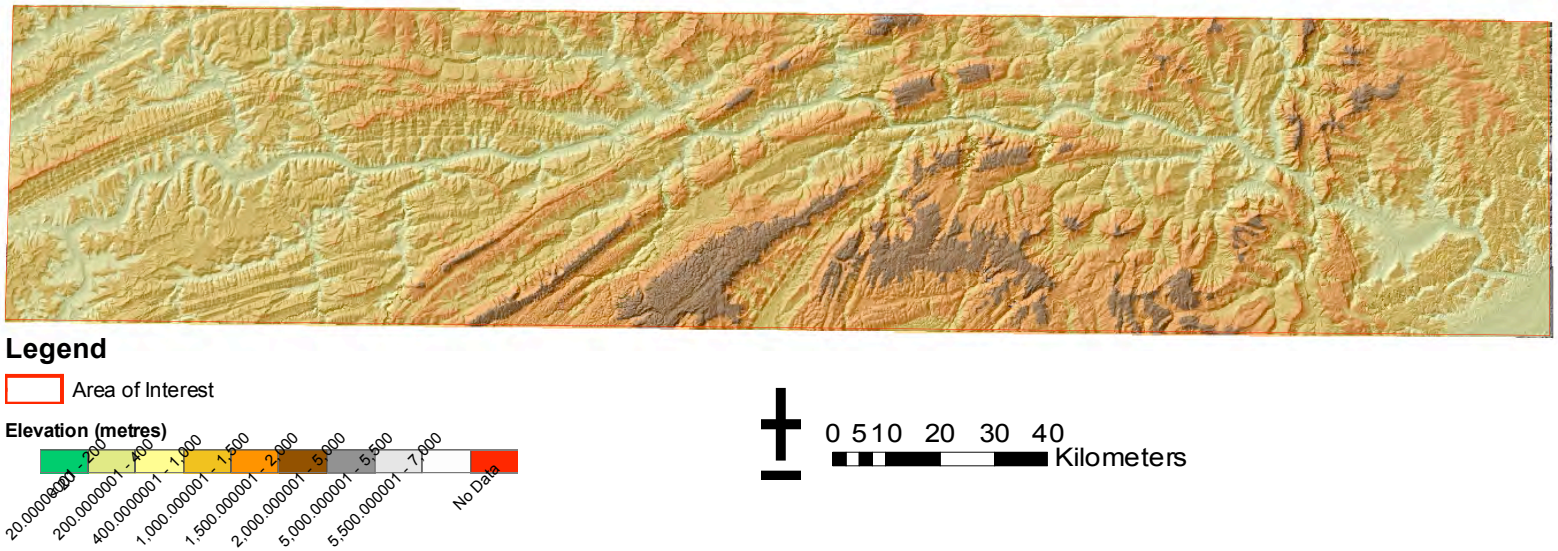
Elevation difference image: SRTM DEM – ASTER DEM Mosaic



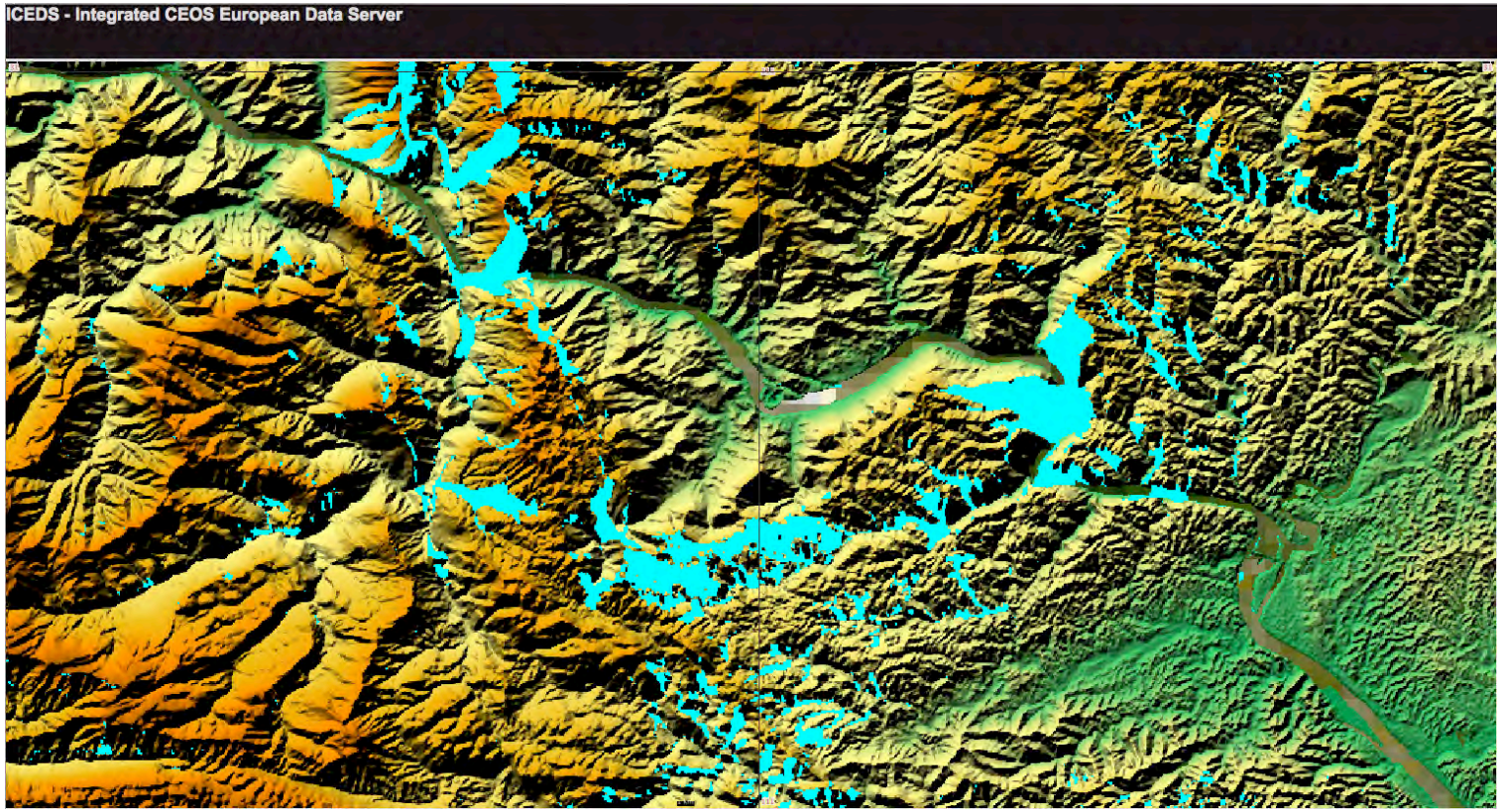
Elevation Difference Map created in ArcMap displayed on top of the hill shaded SRTM DEM. SRTM DEM used as the 'correct' DEM and the ASTER DEM mosaic subtracted from it. Notice clouds shown as areas of dark blue. **Notice the variable offset for each ASTER-DEM (mean = -29.79m, min = -3178m, max = 545m, 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**

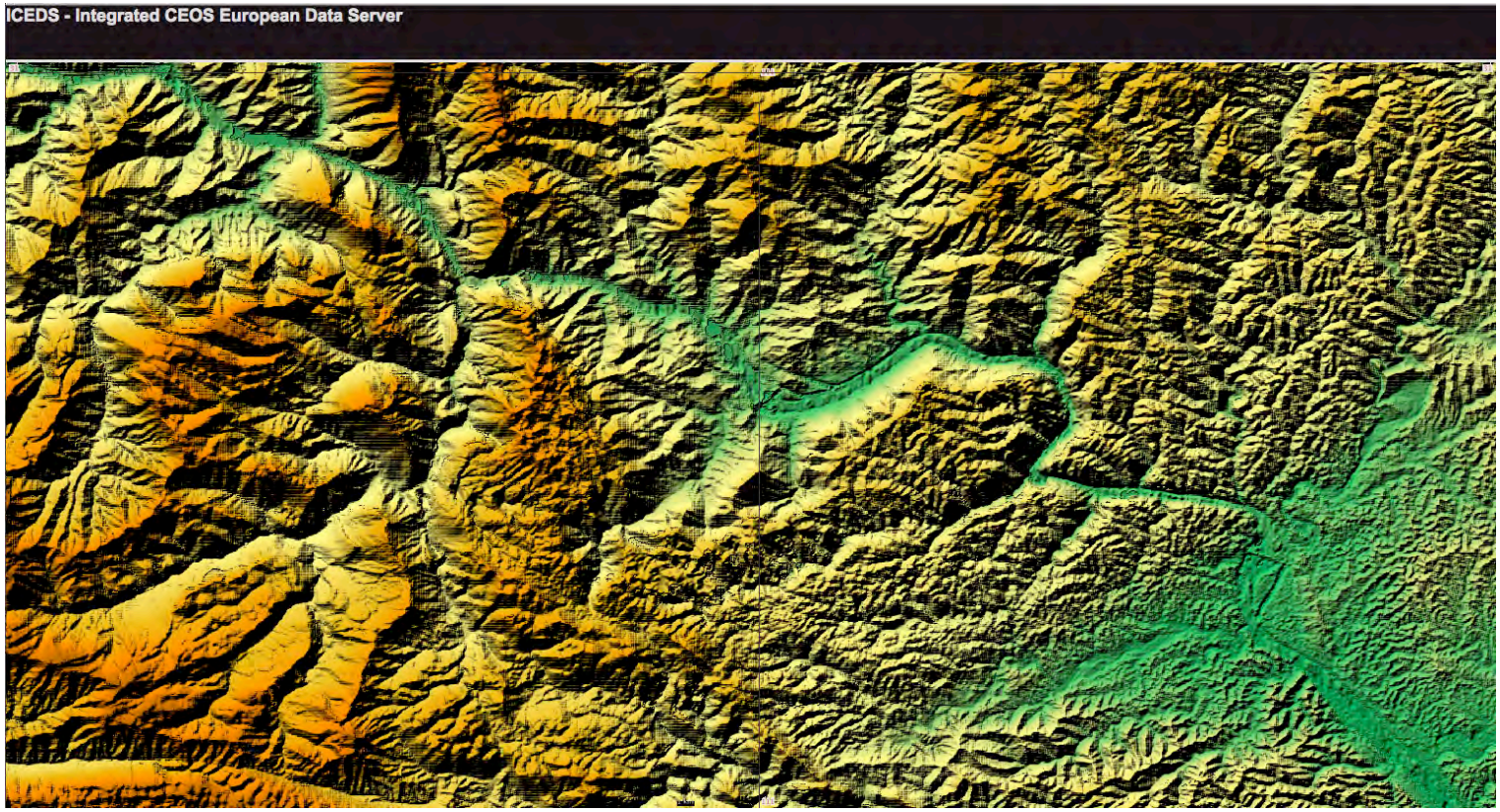


Inter-comparison of fused ASTER-SRTM with SRTM original



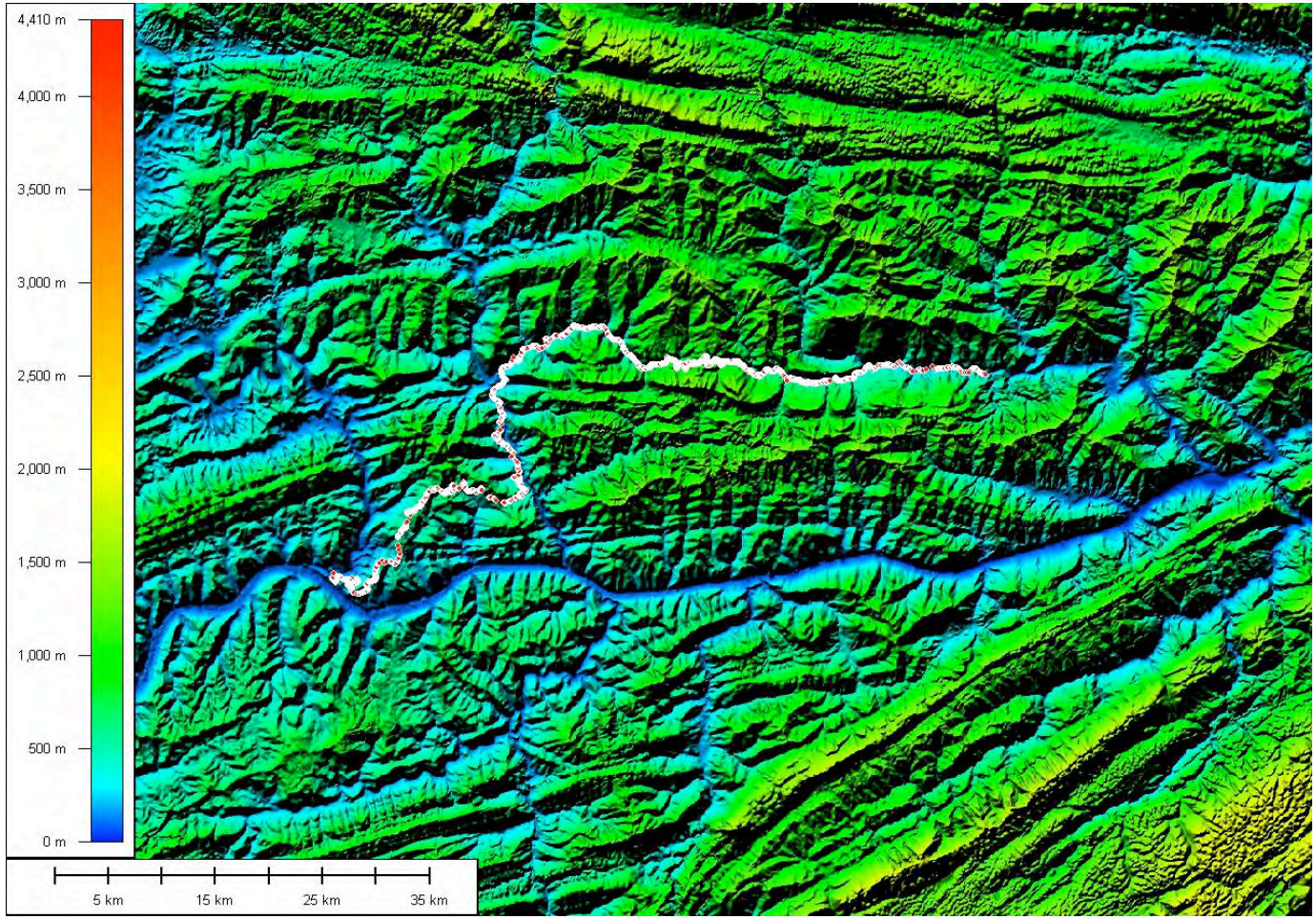
SRTM version 2 (so-called “finished”) DTED1 at 3” (≈90m)

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

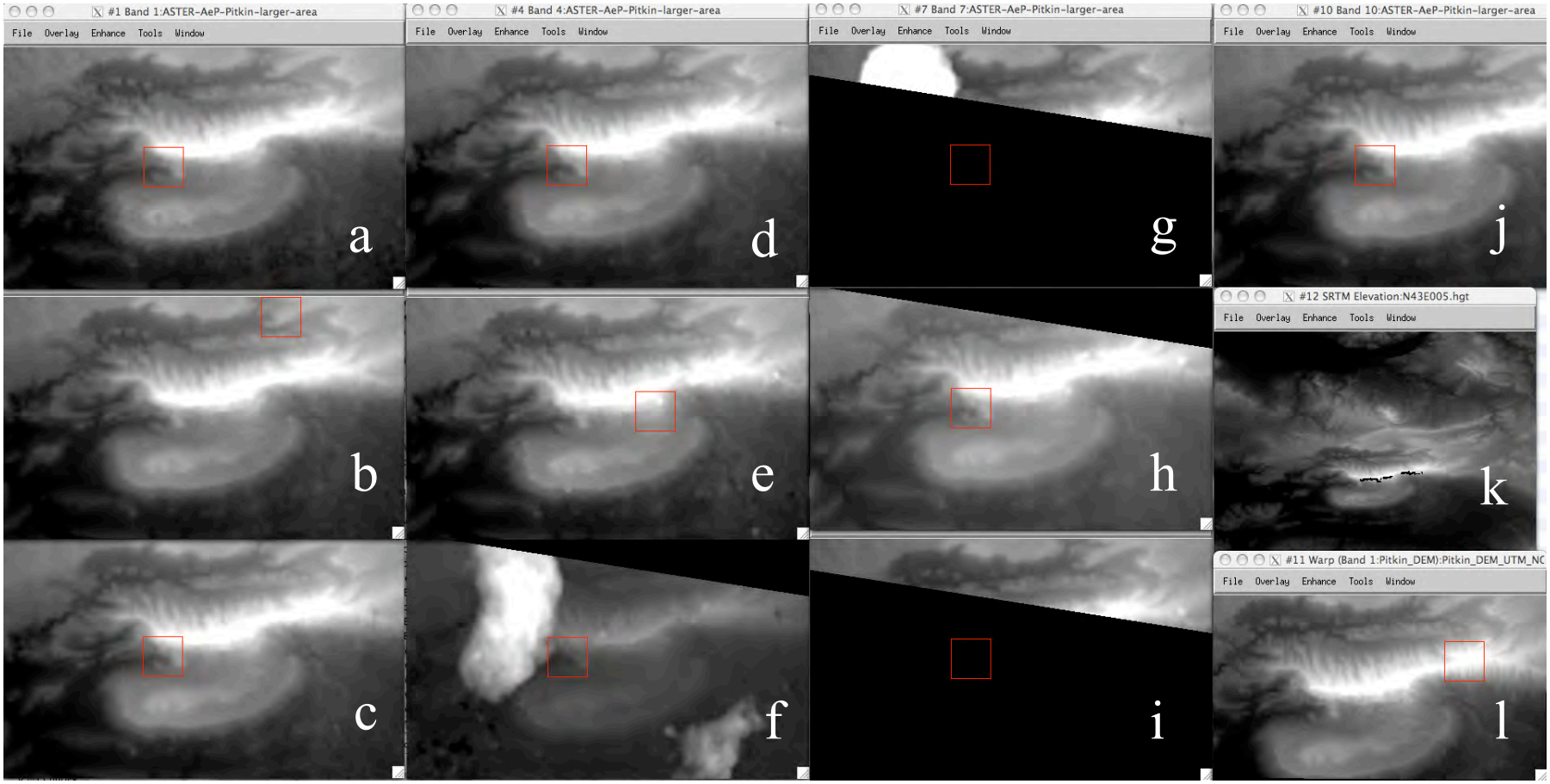
Mean 1.74

St Dev 19.72

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**

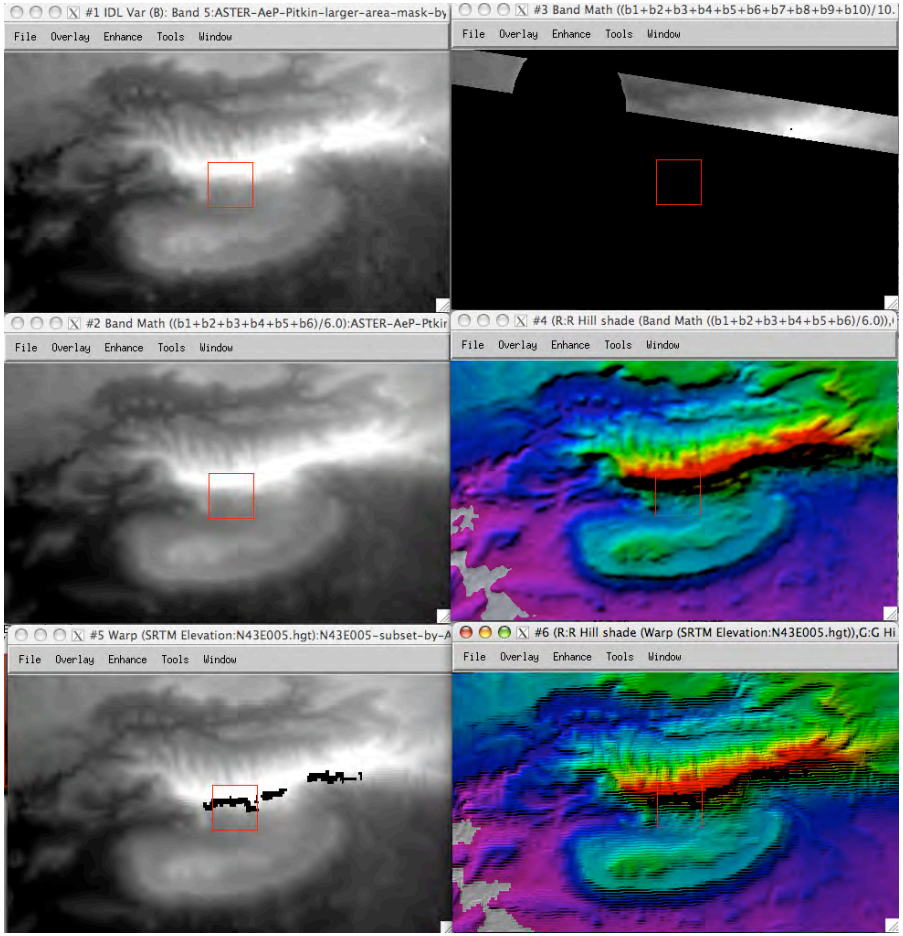
10 Input ASTER DEMs, SRTM DEM 1° x 1° tile and "ground truth"



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**

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. That announcement was very well received, as you might imagine.**
- **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 (GDEM): Description*

- Created from ASTER 15m NIR stereo pair images, covering 60 x 60 km each, B/H = 0.6
- Archive holds ~1,400,000 images of the land surface from 0 to 83 degrees latitude
- Stereo-correlation used to create DEMs with 1 arc-second (30m) postings
- Output 22,895 1 x 1 degree tiles
- Format is GeoTIFF, signed 16 bits, 1m/DN, referenced to WGS84 geoid
- Accuracies: 20m with 95% confidence for elevation; 30m with 95% confidence for horizontal data
- GDEM will be distributed at no cost by (at least) NASA and METI

* Thanks for inputs from Mike Abrams (NASA PI, ASTER)

ASTER Global DEM (GDEM): Schedule

- December 2007-December 2008: stereo-correlation of 1,400,000 ASTER scenes to produce individual DEMs#
- January-March 2009: creation of 1 x 1 degree tiles by creating seamless mosaic of all individual DEMs
- April-May 2009: Validation of GDEM tiles**
- May 2009: delivery of all GDEM tiles to NASA and METI
- May 2009: Staging GDEM on FTP sites for global, no-cost distribution

more than 350,000 already have been processed. At the current rate, scene-based DEM production should be completed by August, 2008 (B. Bailey, 21/2/08)
** We plan to include a contribution from CEOS-WGCV-TMSG for non-US sites

How might CEOS-GEOSS members contribute to validation?

- **CEOS-WGCV-TMSG has 4 test sites outside of the US, given that the largest site (Puget Sound) is likely to be covered by activities at USGS**
- **For each of these sites, 3rd party information is available which consists of one or more of the following:**
  - **DEM at higher resolution and of better accuracy (around 1m vertical and <1m in plan)**
  - **Kinematic GPS tracts (plan <10m, Zrms≈1-3m)**
  - **Land cover information at 30m**
- **Standardised methods have been developed for assessing the accuracy of input satellite-derived DEMs which will be applied to ASTER GDEM data**
- **TMSG very keen to obtain from CEOS members similar "ground truth" information for other areas, particularly in Africa, South America, Australasia, Antarctica so that a wider range of land cover types can be covered**
- **It is preferred if such information is in the public domain but willing to work with 3rd party agencies to either (a) keep © data restricted or (b) have 3rd party agencies perform QA and not release proprietary/restricted DEM information**

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

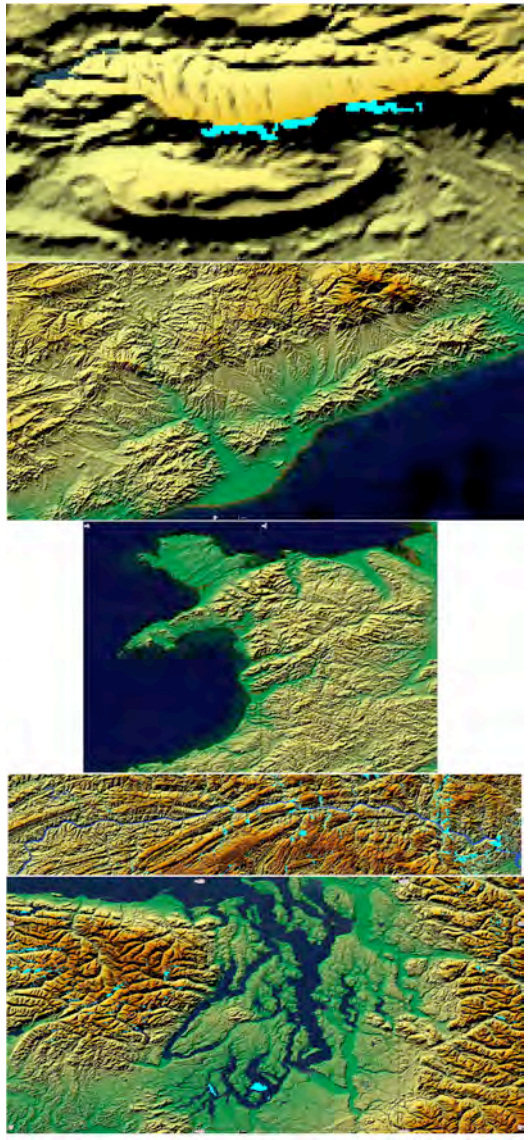
- **Barcelona, Spain**
  1.5-2.75ºE, 41.25-41.82ºN
  urban, mixed arable, forest

- **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



How might CEOS-GEOSS members contribute to filling gaps? DEM Sources

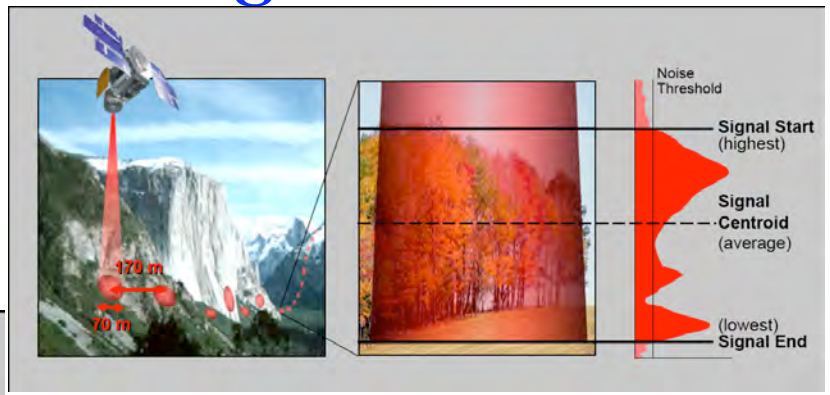
- **SPOT Image could provide height points averaged/downsampled to 30m to plug gaps**
- **DLR could provide SRTM-X and/or TANDEM-X height points at 30m to plug gaps**
- **ESA could provide ERS-tandem derived height points at 30m to plug gaps (especially for regions above ±83º latitude)**
- **JAXA could provide ALOS-PRISM derived height points averaged/downsampled to 30m to plug gaps**
- **Other Agencies (e.g. India Cartosat or ASI's Cosmo SkyMed) could provide height points averaged/downsampled to 30m to plug gaps**

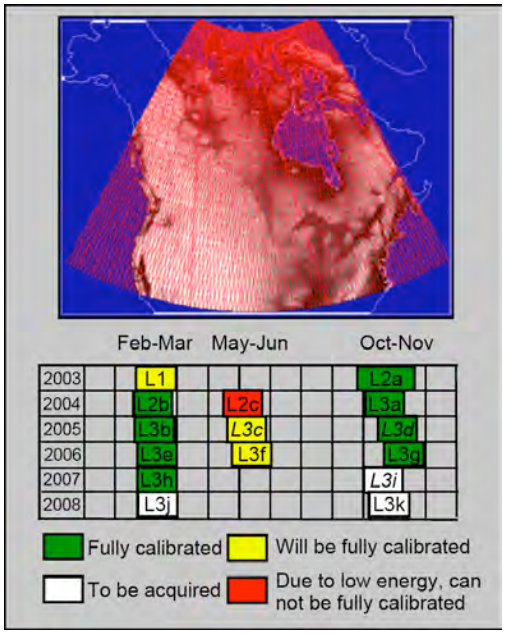
How might CEOS-GEOSS members contribute to filling gaps? Web Processing Services

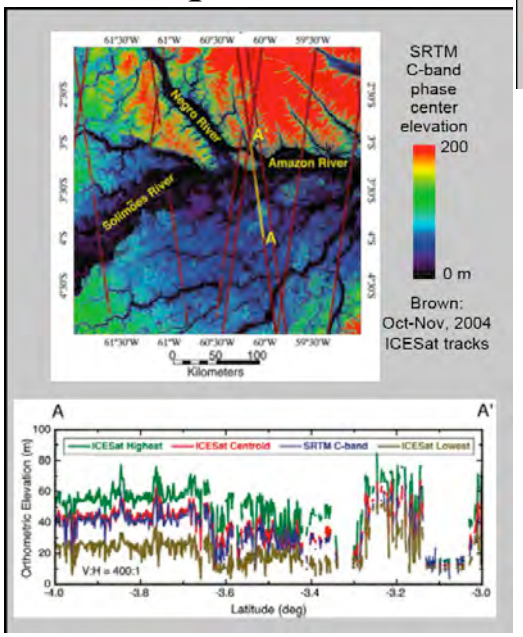
- **Initially Satellite DEM suppliers could provide**
  - **WMS of colourised hill-shaded DEMs already produced (e.g. DLR SRTM-X browse products from a WMS server at DLR)**
  - **WFS of footprints of areas covered by existing DEMs. This would permit a visual (and GIS) assessment of the potential of different sources to plug these gaps**
- **EITHER set-up a gap-filler server so that any gap areas identified in the Japan-US ASTER DEM product could be plugged from different sources on-the-fly using chained Web Processing Services**
- **OR encourage one (or more) data centre(s) (e.g. UCL) to merge DEM height points from different DEM suppliers under strict confidentiality conditions to produce a fused 30m DEM which would be freely available from numerous mirror sites around the world. A mask would be created showing the provenance and accuracy of each height point**

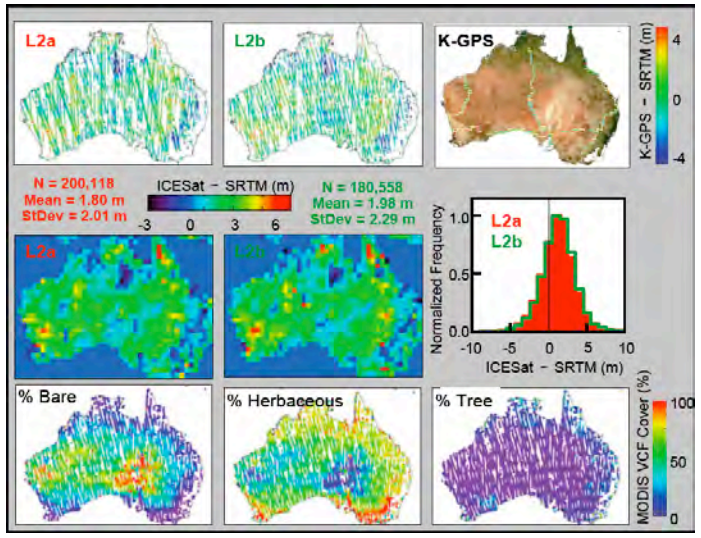
How might CEOS-GEOSS members contribute to the global DEM? Validation Web Processing Service

- **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

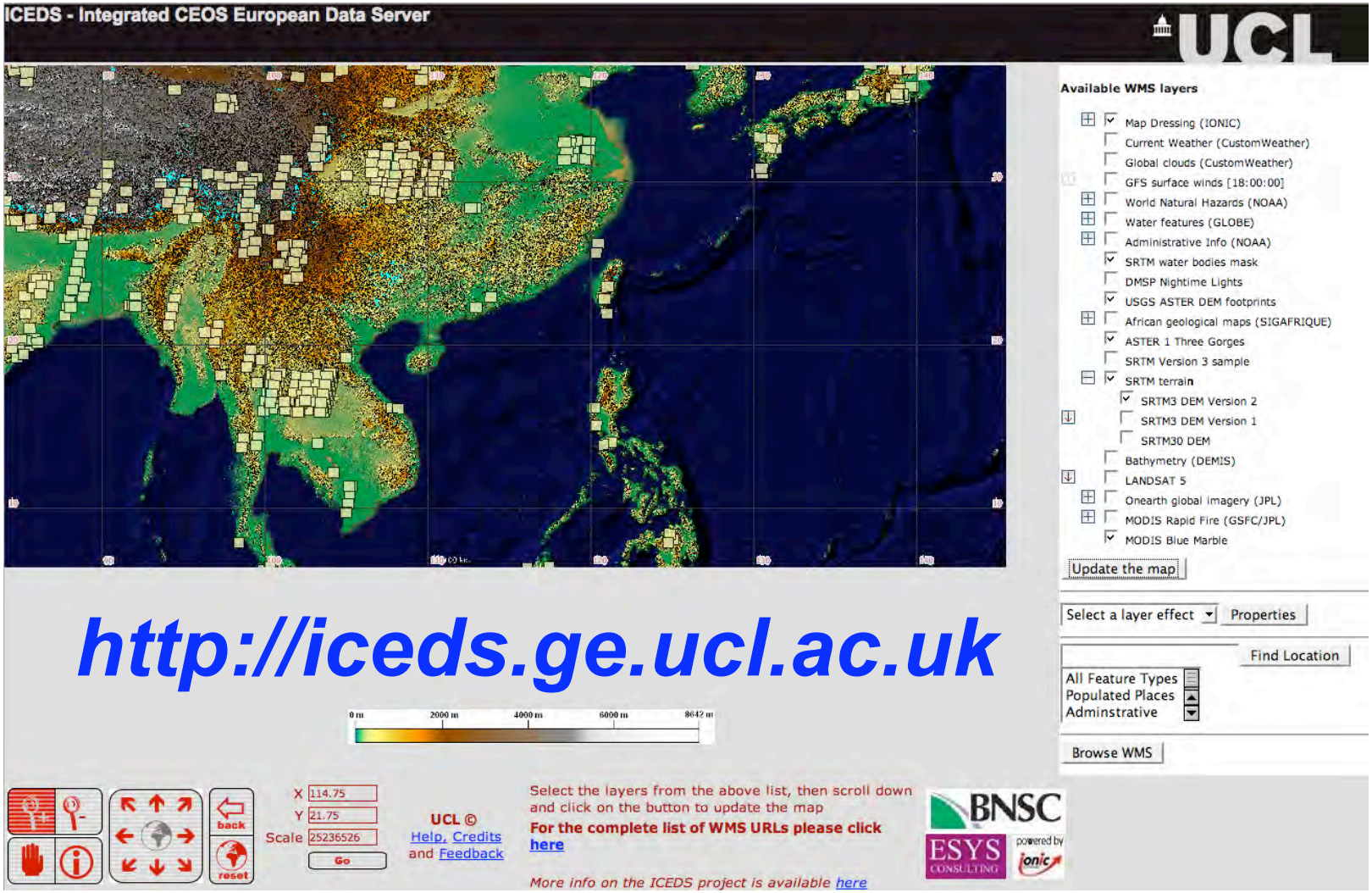
How can ICEDS contribute to Global DEM Inter-operability TODAY

http://iceds.ge.ucl.ac.uk

- **Provide a platform for viewing different sources of DEMs as WMS maps**
- **Display ASTER-GDEM using SRTM colourised hill-shaded WMS LUT including location of all data gaps (as system does currently for SRTMv1 & v2)**
- **View topography alone or merged with image maps from multiple sources with overlaid best available mapping information**
- **Compare blue-line (water) datasets derived from SRTM vs derived from traditional maps and in future from ASTER and other sources of DEMs**
- **View multiple datasets from different sources or different versions using transparency, swipe and flicker as well as on-the-fly height difference maps**
- **Assess any planimetric offsets using flicker between DEMs and derive amount**
- **Browse any WMS server images including internal datasets from within a firewall in context or for inter-comparison**
- **Provide links to WCS pixel filler datasets, identified by data gaps**
- **Explore online several GEOSS applications by adding RSS models at the regional, continental and global scale (e.g. tsunami impact on global population, dispersal of chemical or nuclear releases)**

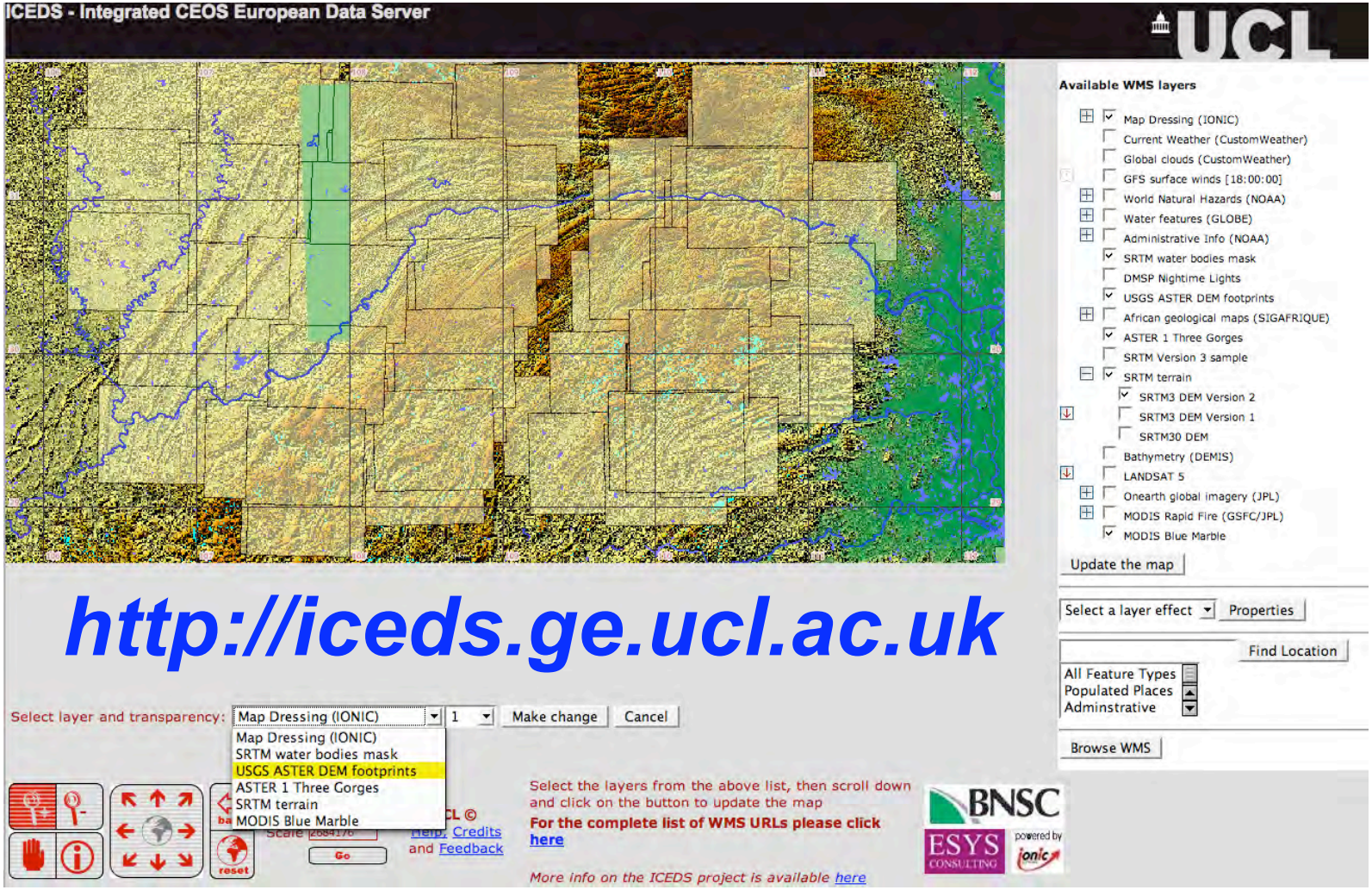
N.B. Thanks to Jeremy Morley (UCL-CEGE) and Ludwig Brinckmann (UCL-MSSL)

Example 1: SRTM V2 with (old) ASTER-DEM footprint locations superimposed

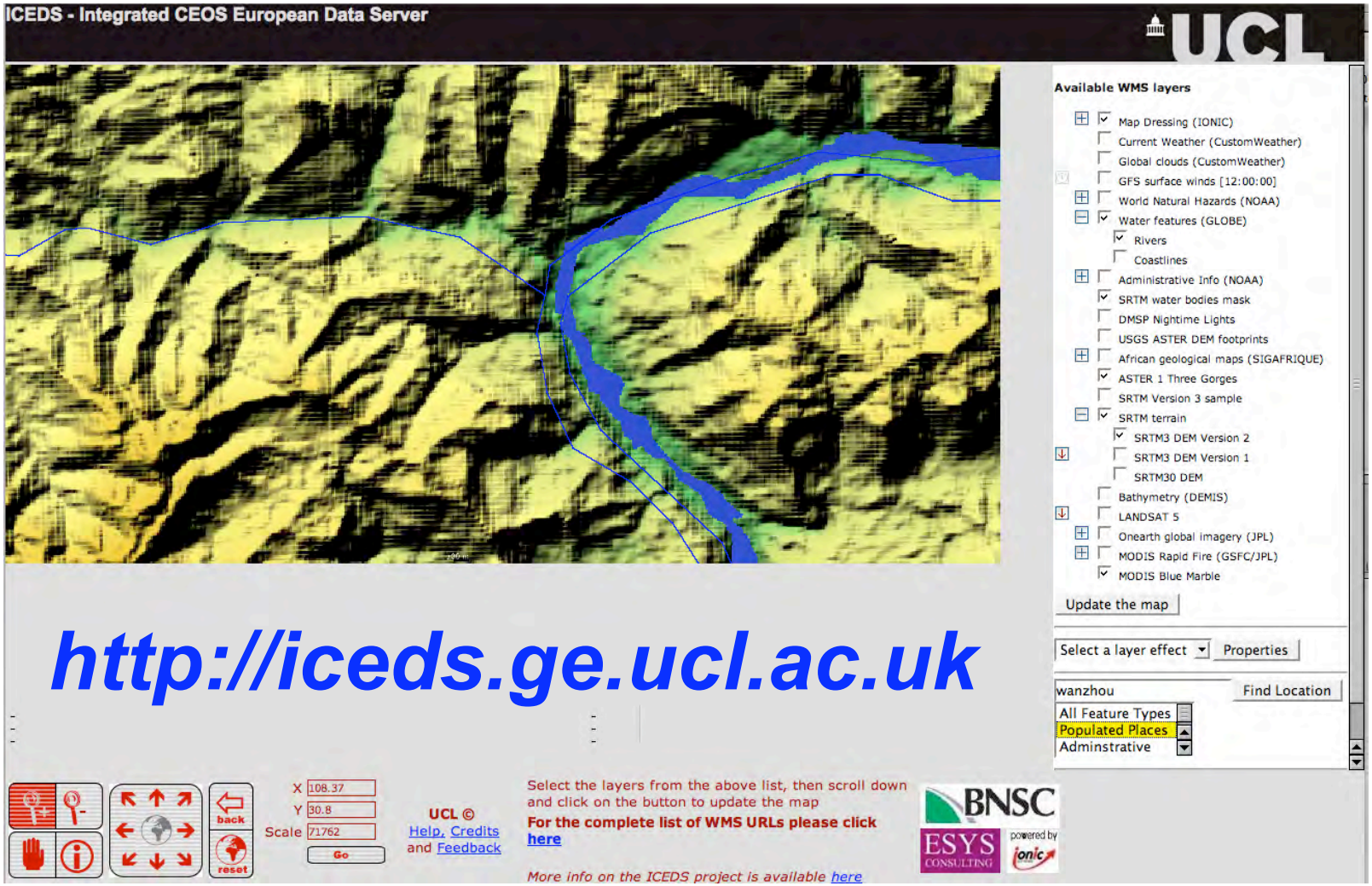


http://iceds.ge.ucl.ac.uk

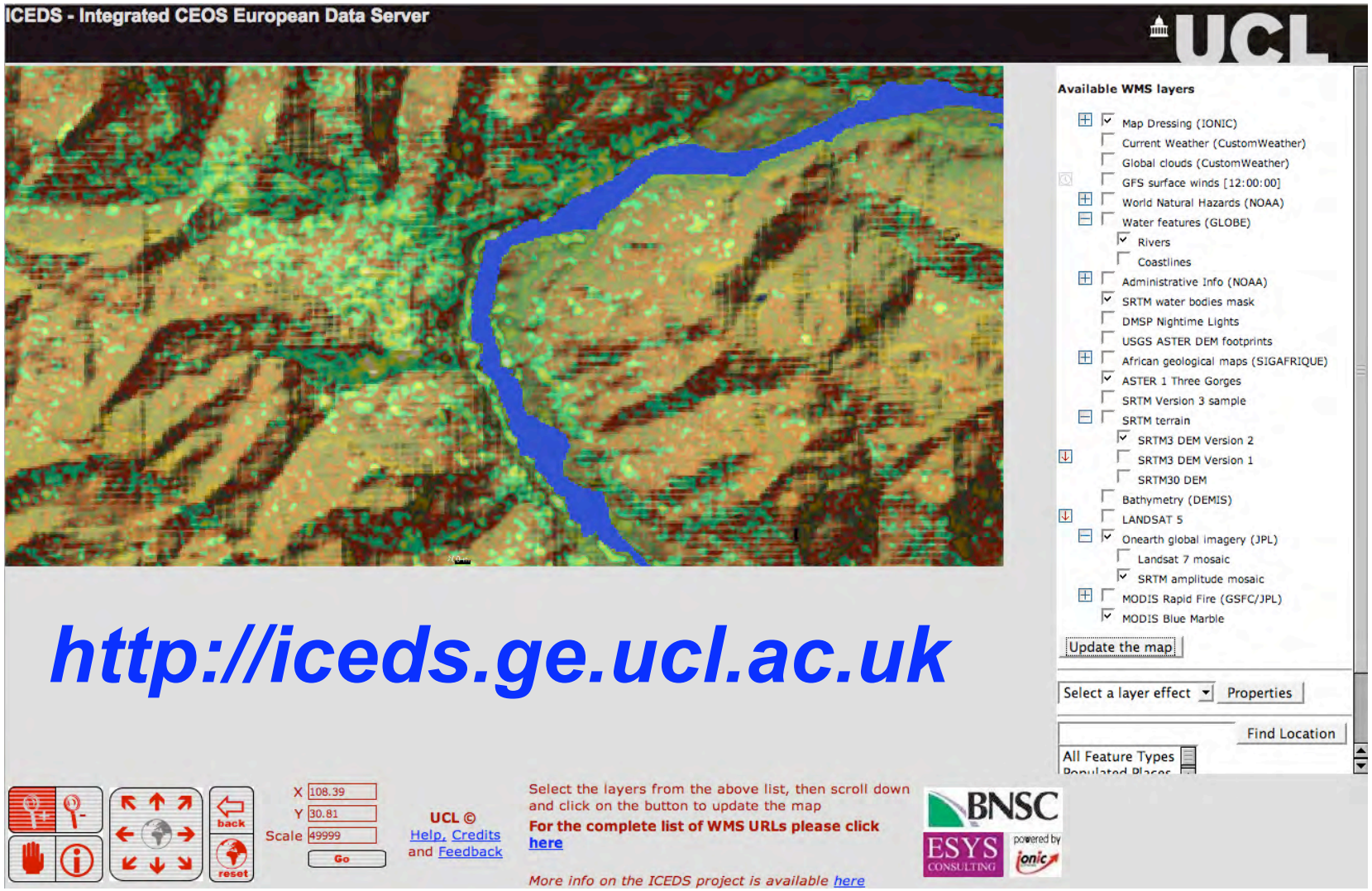
Example 2: SRTM V2 with (old) ASTER-DEM footprints, SRTM water and transparency



Example 3: ASTER-SRTM merged DEM with SRTM-derived and NOAA rivers (note errors!)



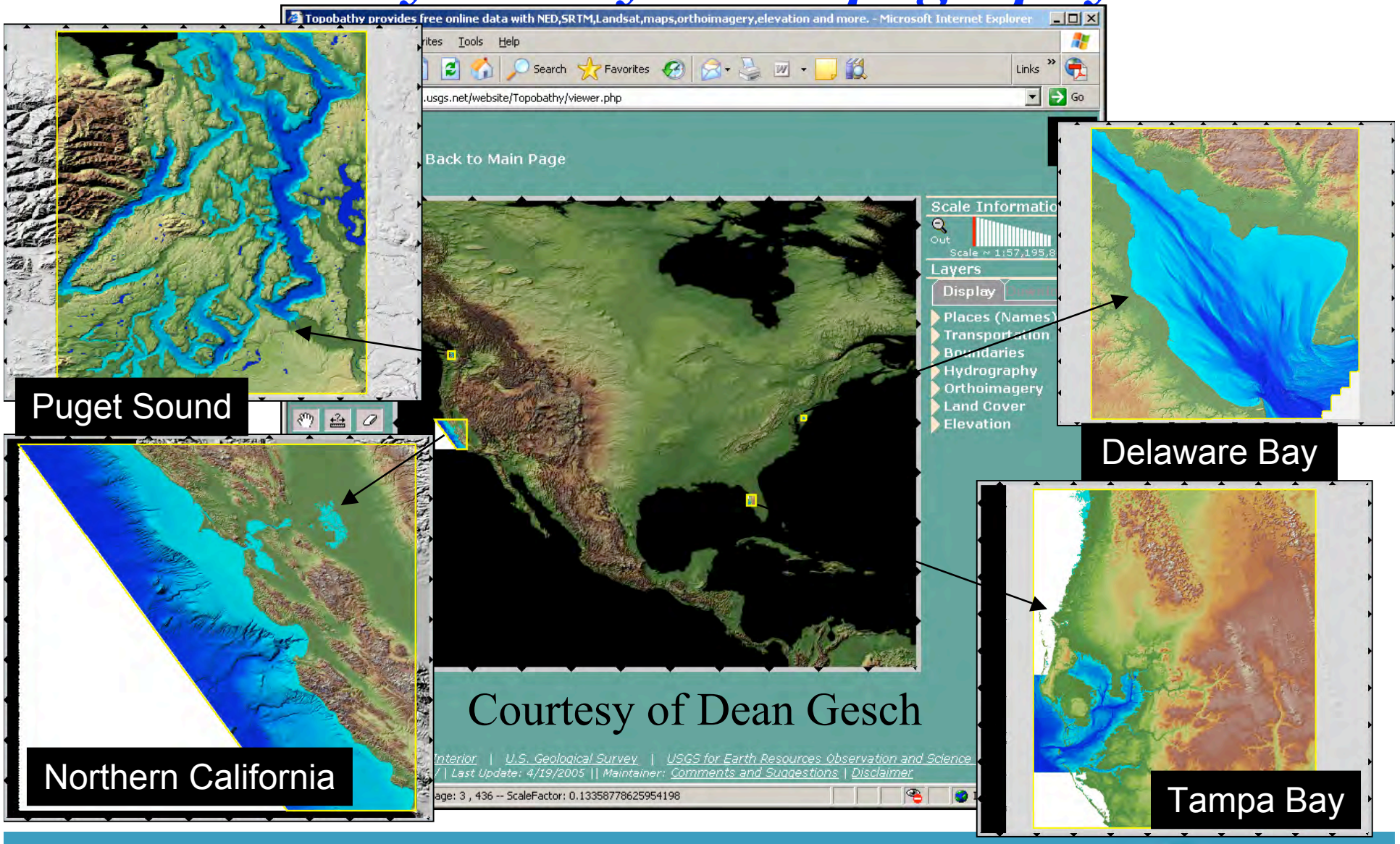
Example 4: ASTER-SRTM merged DEM with SRTM-water and SRTM backscatter image



Outstanding Issues to resolve

- **How many of the invited CEOS-GEOSS partners are willing and able to contribute height pixels to a free and unrestricted global dataset at 30m?**
- **What role will CEOS-WGISS play in promoting this GEOSS task in the context of the GDTT, Web Processing Services, provision of WMS, WCS, WFS data servers?**
- **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. USGS (see next slide) are also working in this area.**
  - **However, most other such bathymmetric data sources are extremely expensive (e.g. UKHO) and subject to © restrictions.**
  - **How does CEOS-GEOSS 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?**

Example of USGS (EDC) merger of bathymmetry and topography



Summary of Actionable ACTIONs: CEOS Plenary

- **CEOS Plenary is recommended by WGCV and WGISS to support GEOSS task DA-07-01 through the following actions**
  - **Encourage all CEOS member space agencies who are creating global EO-DEMs to consider making these DEMs or different DEM subsets (e.g. small groups of pixels identified in ASTER GDEM as missing) publicly available through OGC-compliant servers**
  - **Encourage all CEOS member space agencies to liaise with their national mapping agency to provide DEM test sites with publicly available "ground truth" data for assessment of global EO-derived DEMs**
  - **Encourage each EO-DEM data supplier to provide web-GIS facilities for the reporting of "Known Issues" including the delineation of areas of "bad data" which can later be flagged as such and compared against and substituted by other datasets**
  - **Ensure that resources are made available so that all published DEM datasets can be re-processed if "Known Issues" identify bad data and these cannot be replaced from another source**
  - **Encourage all member agencies to develop continental-shelf bathymmetry programmes and request CEOS member agencies to encourage their relevant international and national body to make publicly available their bathymmetry heights using the mechanisms proposed for land DEM or something consistent with these principles**

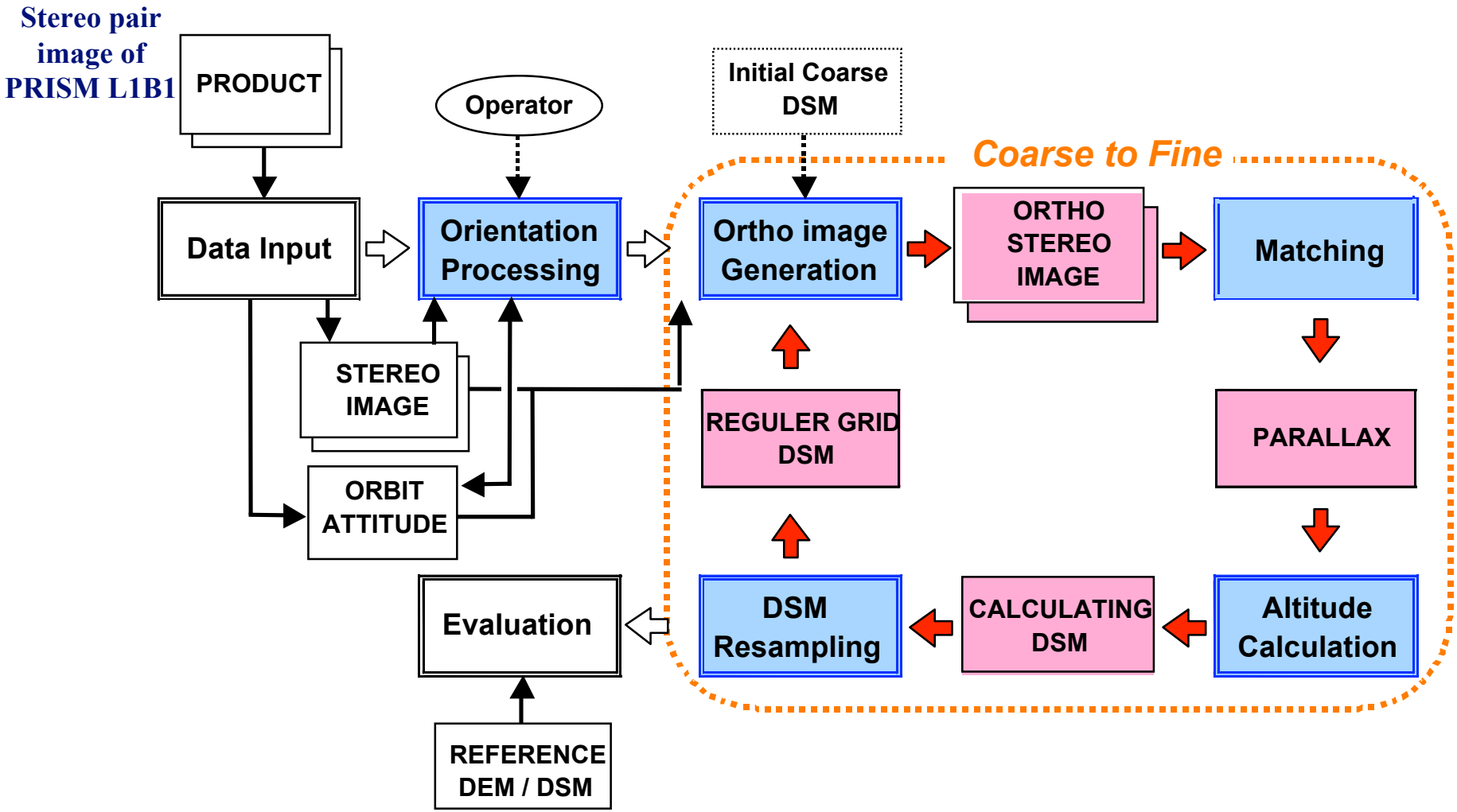
Summary of Actionable ACTIONs: CEOS-WGISS

- **CEOS-WGISS is invited to contribute technology to facilitate interoperability between different global DEM datasets**
  - **To ensure that all Global DEMs are made available in OGC-compliant (WMS and WCS) formats and their URLs are easily discoverable**
  - **To agree on a common standard for the representation of WMS (e.g. ICEDS colour LUT and 30º (elevation), 330º (azimuth))**
  - **To agree on a common standard for WCS format (e.g. geotiff)**
  - **To facilitate the filling in of gaps (or artifact identified regions) in ASTER GDEM from another dataset including how QC information is to be incorporated into the data fusion process. This procedure should be best incorporated within a Web Processing Service**
  - **To allow easy inter-comparison of different satellite-derived DEM datasets stored as WCS datasets including both publicly released versions and those stored in-house**
  - **To allow standard QA procedures to be fully automated so that when new "ground truth" datasets become available, existing EO-derived DEMs can be assessed**
  - **To develop "Known Issues" web facilities to allow users of global DEMs to report issues with the data including geospatial reporting (e.g. the following DEM pixels via this shapefile have been shown to be in error)**

Backup slides

ALOS-PRISM DEM data for WGCV-TMSG assessment (courtesy of T. Tadono, JAXA)

PRISM DSM and Ortho Image Generation Software (DOGS)



Processing flowchart of PRISM DSM generating software (DOGS) in EORC, JAXA.

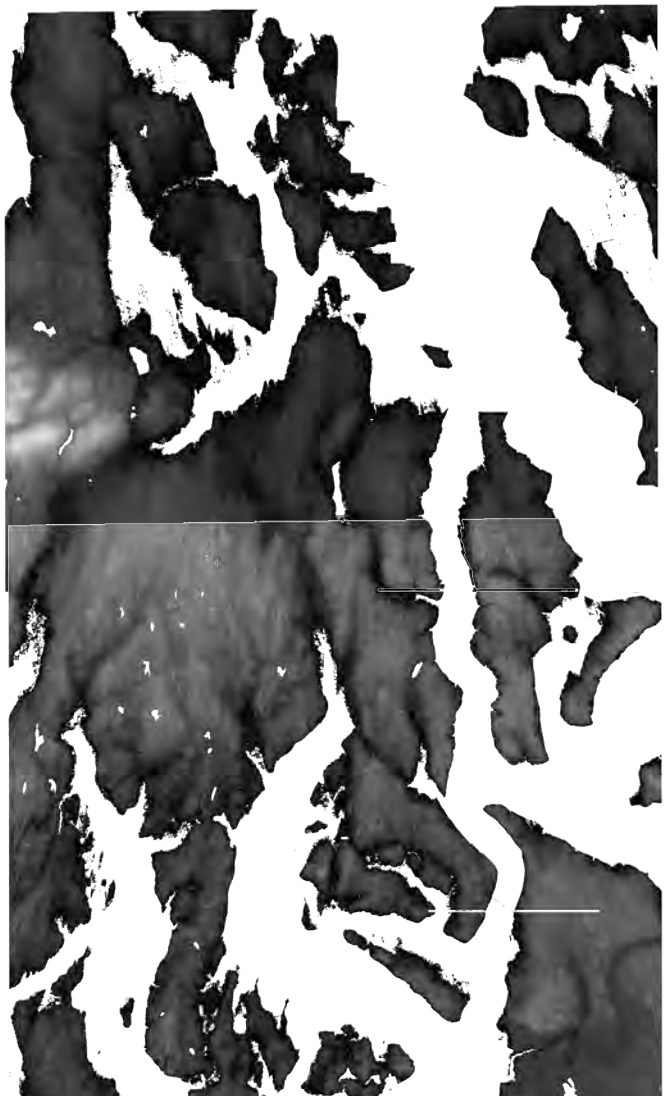
PRISM/DSM – CEOS-WGCV-TMSG Test Site

Puget Sound, US (12 Sep. 06).

PRISM DSM and Ortho-rectified product by JAXA

Contents of DSM is as follows (in default case);

- ✓ Generated DSM using PRISM triplet imageries.
  - Data type: Signed 16bit Binary data (LSB)
  - The height contains over ellipsoid (GRS80) with ITRF 97 coordinate.
  - Spatial resolution is 0.3 arc-sec (about 10m) and pixels spacing is 2.5m.
- ✓ There are masked out areas, which covered by cloud, water, and ocean.

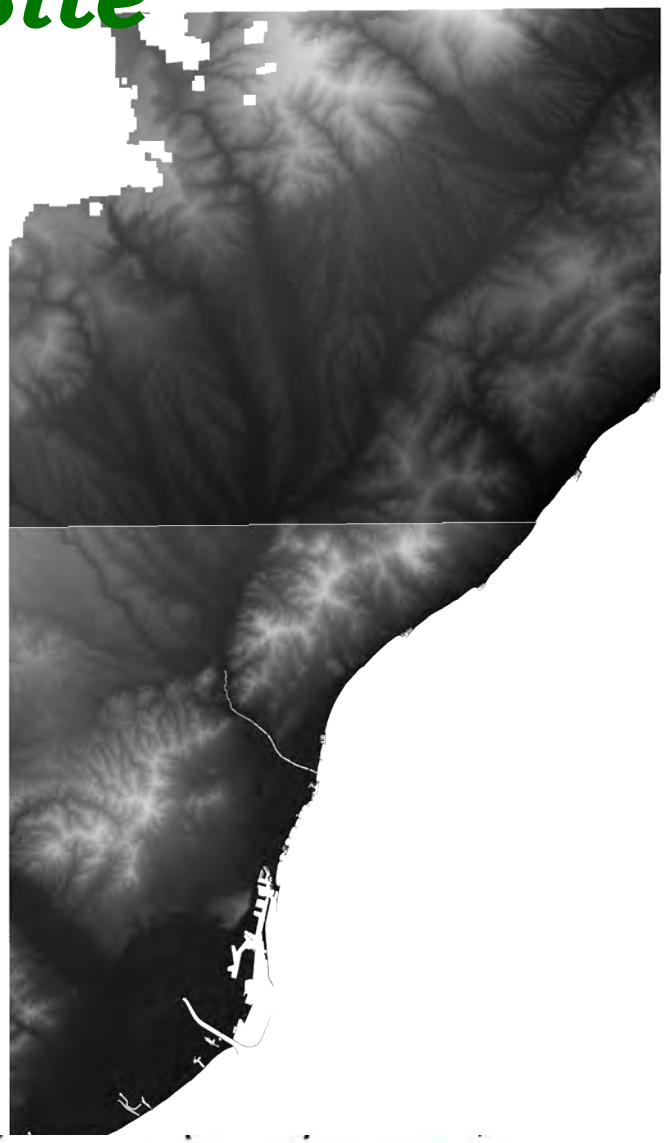


Generated DSM by PRISM onboard ALOS.

Gray scale correspond to height after enhanced color individual scene.
White color shows masked out area due to cloud, ocean, river, and lakes.

PRISM/DSM – CEOS-WGCV-TMSG Test Site

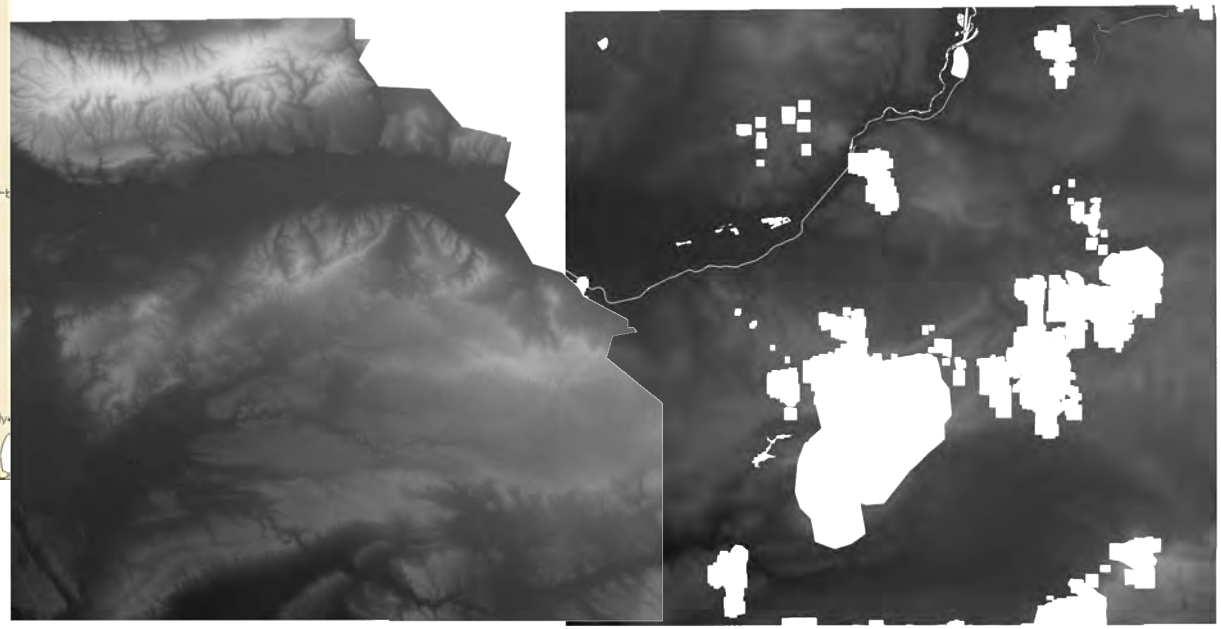
Barcelona, Spain (3 Dec. 06).



Generated DSM by PRISM onboard ALOS.
Gray scale correspond to height after enhanced color individual scene.
White color shows masked out area due to cloud, ocean, river and lakes.

PRISM/DSM – CEOS-WGCV-TMSG Test Site

Aix-en-Provence, France.
left: 12 Mar. 07; right: 25 Jul. 06.

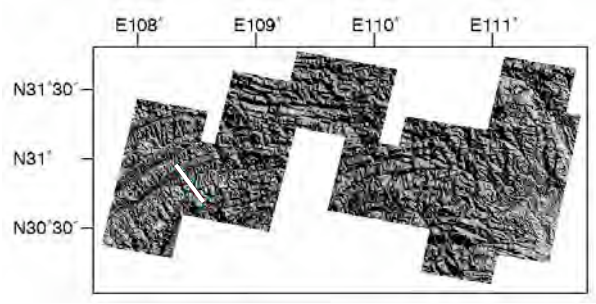


Generated DSM by PRISM onboard ALOS.
Gray scale correspond to height after enhanced color individual scene.
White color shows masked out area due to cloud, ocean, river and lakes.

JAXA has a plan to generate PRISM /DSM for validation
- ✓ **North Wales, UK**
- ✓ **Three Gorges, China**

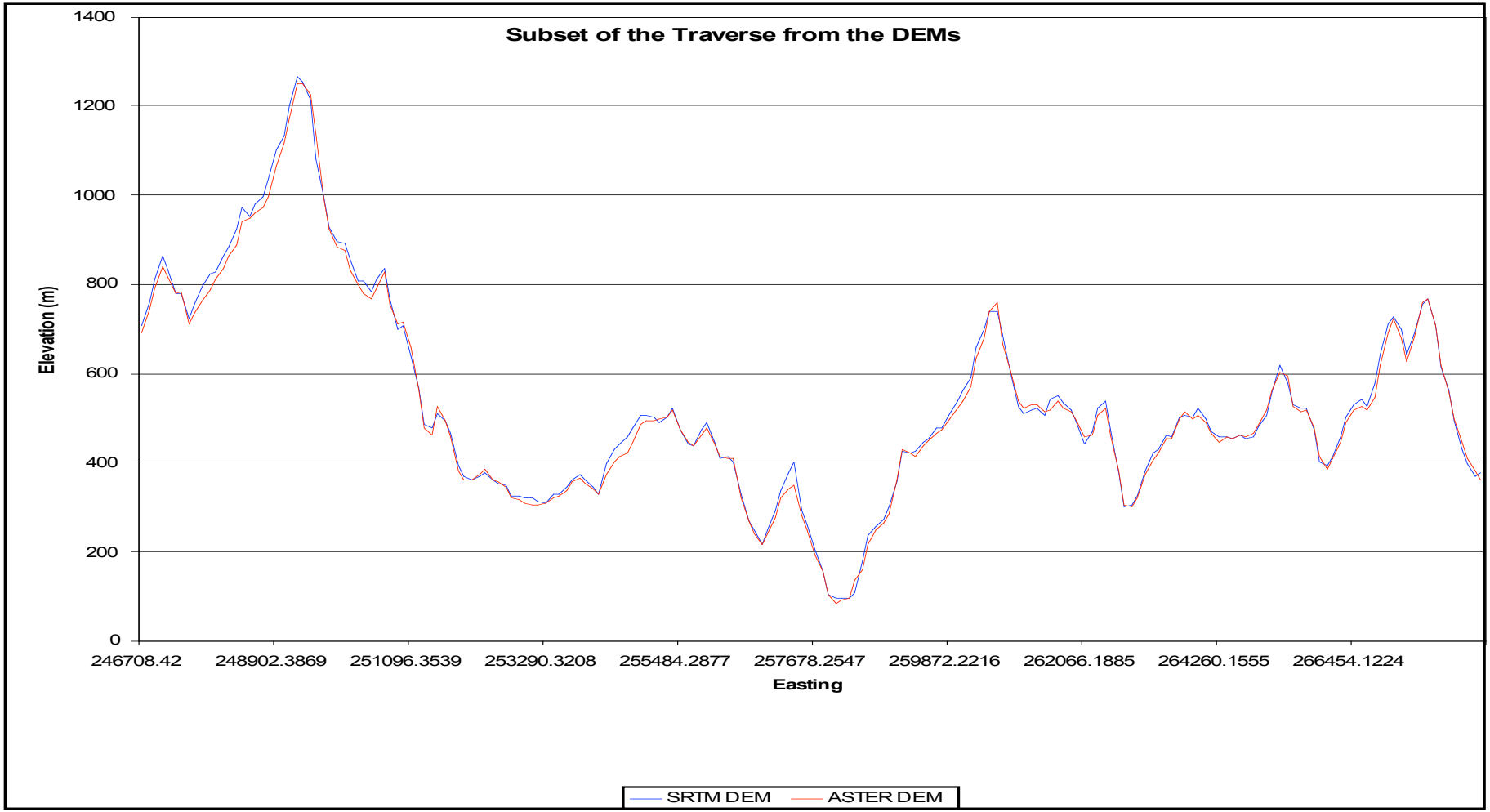
Backup slides

Details of ASTER-SRTM DEM fusion



Good comparison between two DEMs

Mean difference = 7.59m
Standard deviation = 13.42m



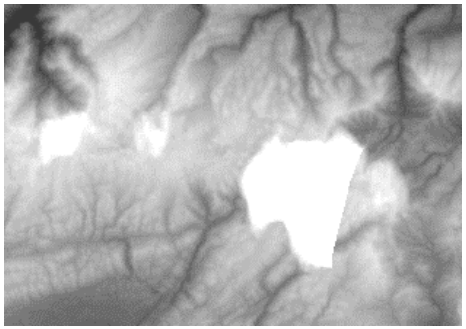
Formula applied in ER Mapper® to fuse DEMs together, remove cloud and improve vertical accuracy of ASTER DEM mosaic

The formula used is as follows:

If i1 = 0 then i2 else if abs(i1 – i2) > 100 then i2 else (i1+i2)/2

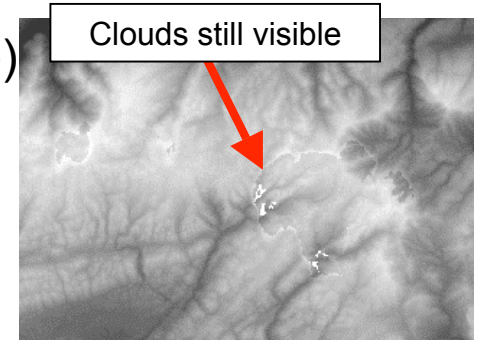
Where i1 = ASTER DEM
Where i2 = Improved SRTM DEM
Where 0 is the no data value in the ASTER DEM mosaic

a)



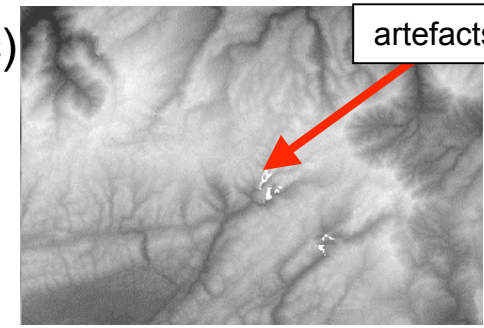
ASTER DEM Prior to cloud removal

b)



DEM with 500m threshold applied filled with SRTM data

c)



DEM with 100m threshold applied filled with SRTM data

The artefacts in the final DEM, shown in (c) were the result of limited data availability. They are areas of the DEM where cloud existed in the original ASTER DEM mosaic and data missing from the original SRTM DEM

Fusion of DEMs

- **Step 1: 'fill in' voids in SRTM DEM using ASTER**

ER Mapper® 7.1 formula applied

If (i1 = -32768) then i2 else i1

Where i1 = ASTER DEM
Where i2 = SRTM DEM
Where -32768 is the SRTM 'No Data' value.

- **Step 2: Use improved SRTM DEM to remove artefacts in ASTER DEM**

ER Mapper® 7.1 formula applied

If i1 = 0 then i2 else if abs(i1 – i2) > 100 then i2 else (i1+i2)/2

Where i1 = ASTER DEM
Where i2 = Improved SRTM DEM
Where 0 is the no data value in the ASTER DEM mosaic

Fusion of DEMs (2)

- **Step 3: 'fill in' remaining voids using interpolated SRTM DEM layer**

ArcMap 9.1 formula applied

con(isnull(original_grid), interpolated_grid, original_grid)
Where 'original_grid' is the DEM with null data holes
Where 'interpolated_grid' is the interpolated SRTM DEM made using SRTMFill