Global DEM inter-operability : GEOSS Task DA-07-01

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Overview

- What is GEO Task DA-07-01?
- What might partially fulfill/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 the UK LANDMAP project for *ab initio* 30m DEM construction from ERS-tandem
  - An example of data fusion of ASTER and SRTM for the Terrain modelling of the 3 Gorges area of China
- 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
- Web-GIS for Global DEM Inter-operability
- Outstanding Issues to resolve

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 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.*

*3 arc-second (≈90m) grids

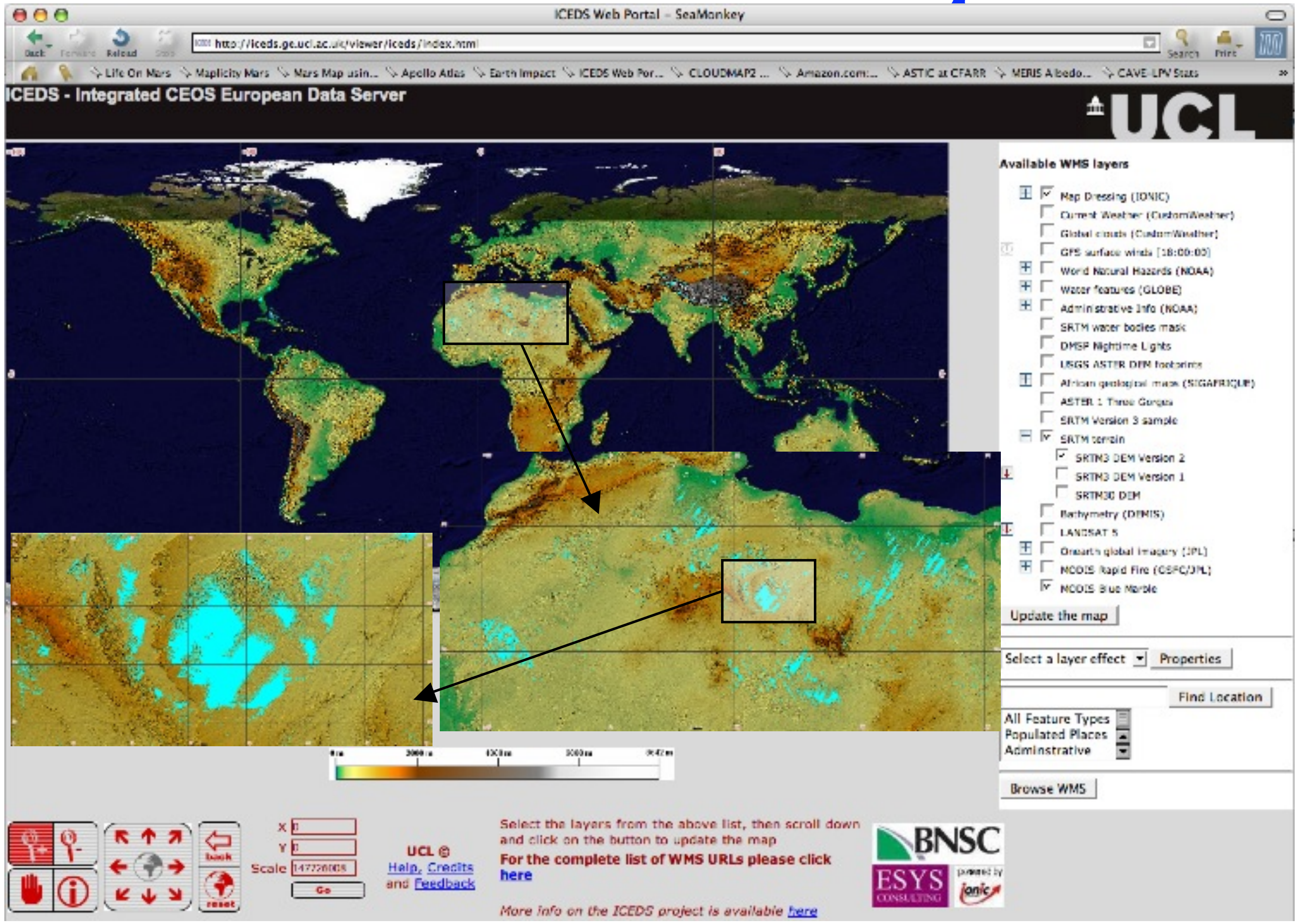
What DEM(s) are available NOW to fulfill the Global DEM objective

- **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 (taken from Slater et al., PERS March 2005) even after V2 of the product was produced ("edited" or "finished") 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

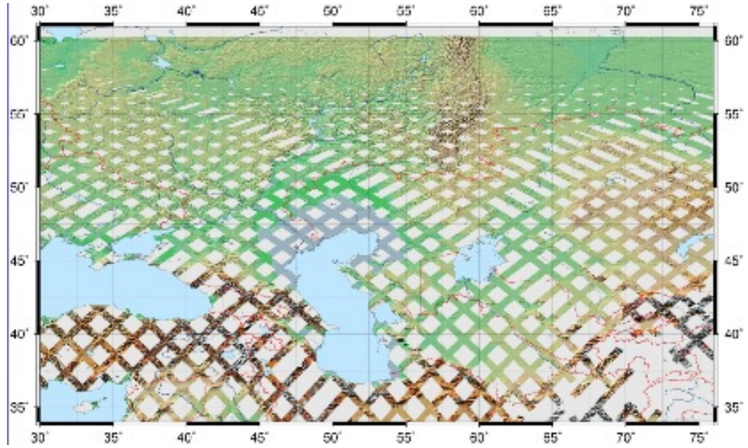
What areas contain gaps at present in the SRTM DTED-1 product?



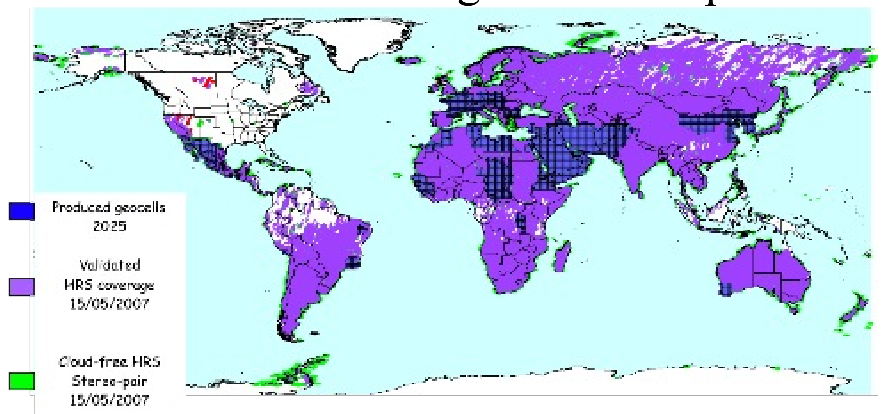
- Areas highlighted in V1 and V2 (shown here) can be viusalised in ICEDS http://iceds.ge.ucl.ac.uk including in context from LANDSAT-5 or LANDSAT-7 False-colour-Composites, SRTM water, etc..

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

- **SRTM-X (available at ≈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**
- **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**
- **SPOT-5 : complete coverage shown in blue and potential scenes for global coverage in purple**
- **ONLY available at a very high cost at present**



SRTM-X DEM coverage over Europe © DLR



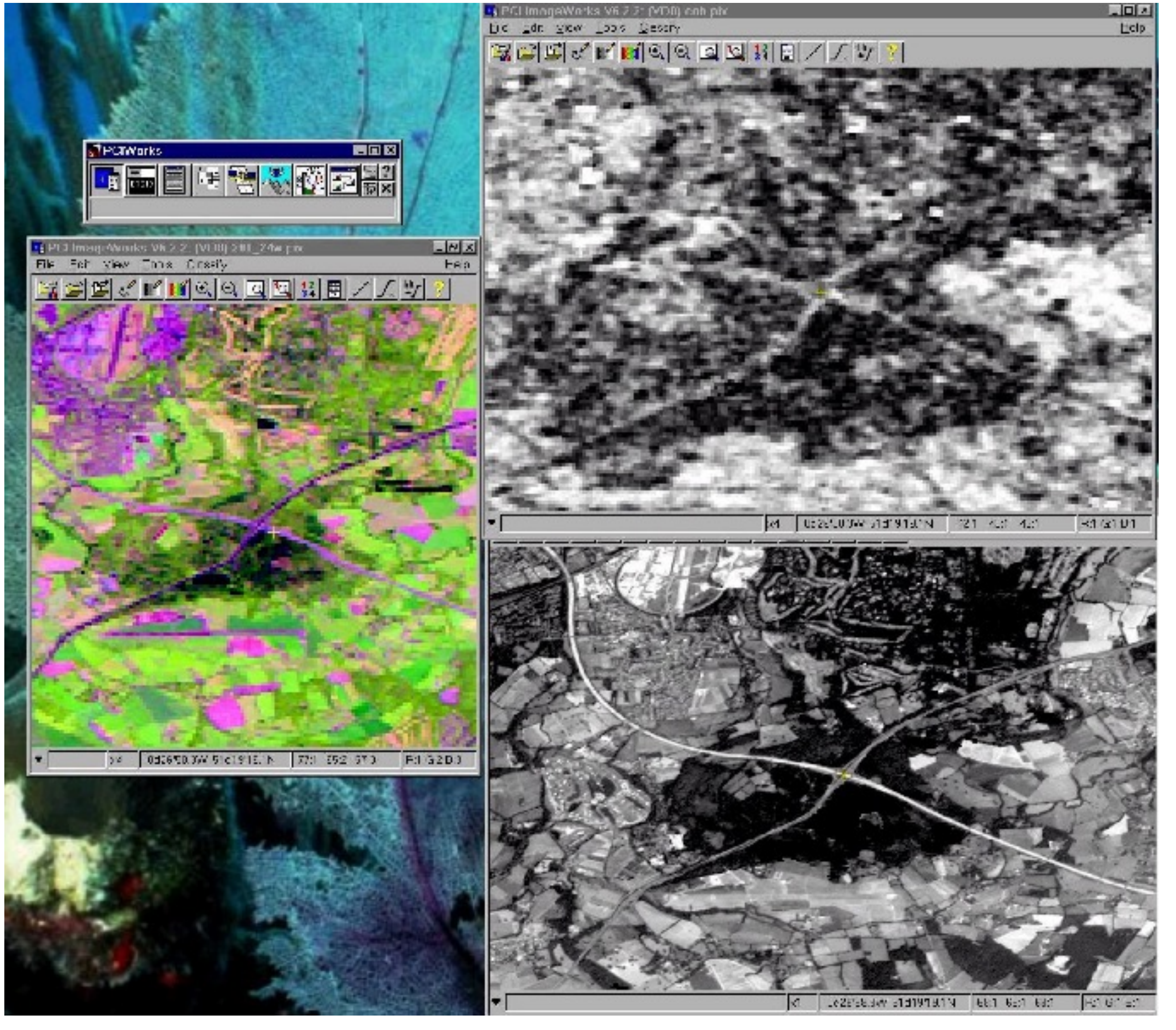
SPOT5 coverage (courtesy of M Bernard, ©SPOT Image)

LANDMAP Objectives

- **Creation of a set of <u>Digital Elevation Models</u> (DEMs) and production of a set of <u>base image maps</u> of the British Isles through orthorectification of the national Higher Education satellite archive, current and future**
- **ERS Tandem multi-pass SAR interferometry to create DEMs**
  - **3rd party royalty free 1” (≈30m) DEM to be used for orthorectification**
  - **Orthorectified SAR products to be used as a base map for LANDSAT & SPOT geocoding**
- **All processing was to be <u>automated and independent of ANY external copyrighted data-sets</u> so that it can be applied anywhere in future using any satellite data**
  - **“dead reckoning” : no need for Ground Control**
  - **Use of DTED0 (UK) & GLOBE (Ireland) to provide phase flattening**

Example LANDMAP multi-sensor tiepointing

LANDSAT



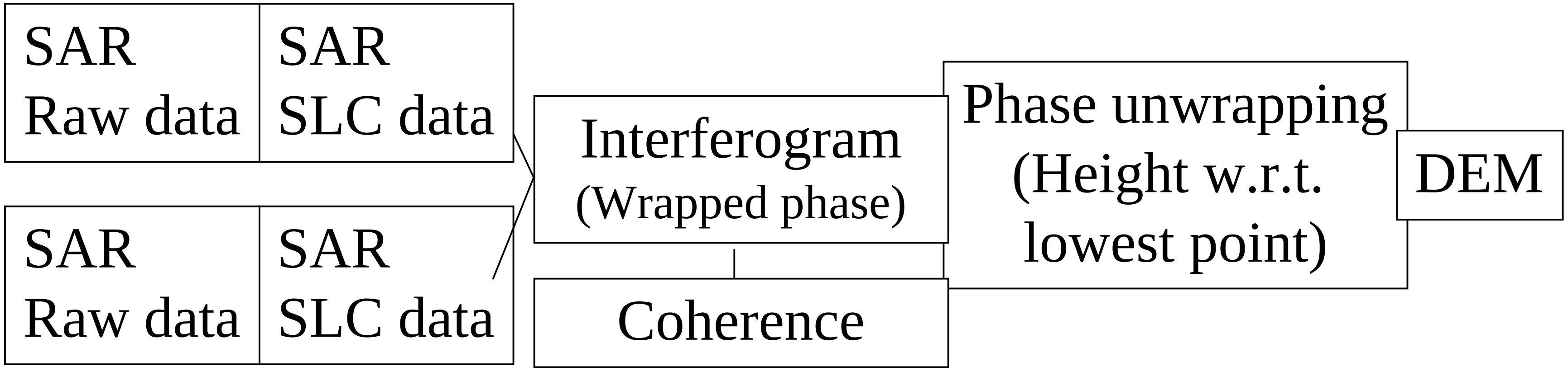
ERS

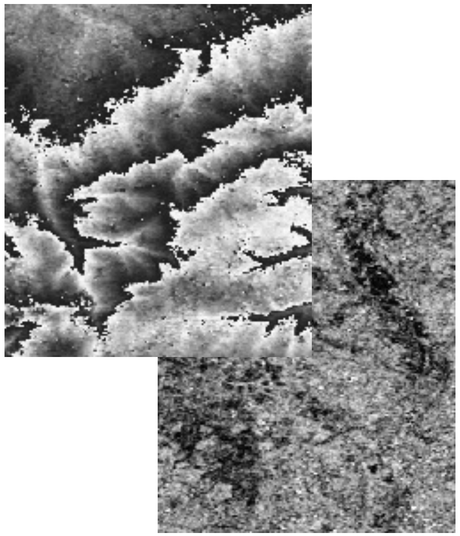
SPOT

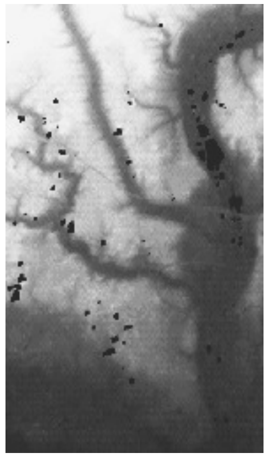
LANDMAP IfSAR-DEM production system

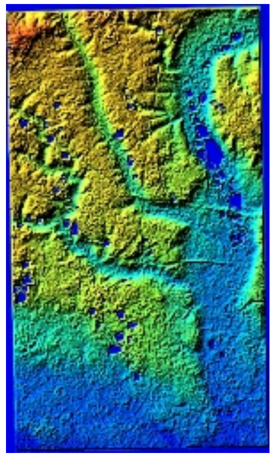
- **LANDMAP IfSAR-DEM processing used Phoenix Systems PulSAR™ for SAR focussing and InSAR Toolkit™ for interferogram/phase coherence for ERS SAR <u>strips</u>**
- **Strip processing developed to minimise number of individual scenes to be processed (e.g. 82 to 13 for 1st pass)**
- **Precision orbital elements (PRCs) used from D-PAF**
- **Coarse 30" (1km) DEM from CEOS-GLOBE (Ireland) and DTED0 (Britain) used to correct for inaccuracies in PRCs & to enable <u>"dead reckoning" without control points</u>**
- **Low phase coherence mask used to eliminate water features which cause problems for phase unwrapping**
- **All output products in geoTIFF format for subsequent use in GIS, standard image display and processing software**

IfSAR DEM Generation



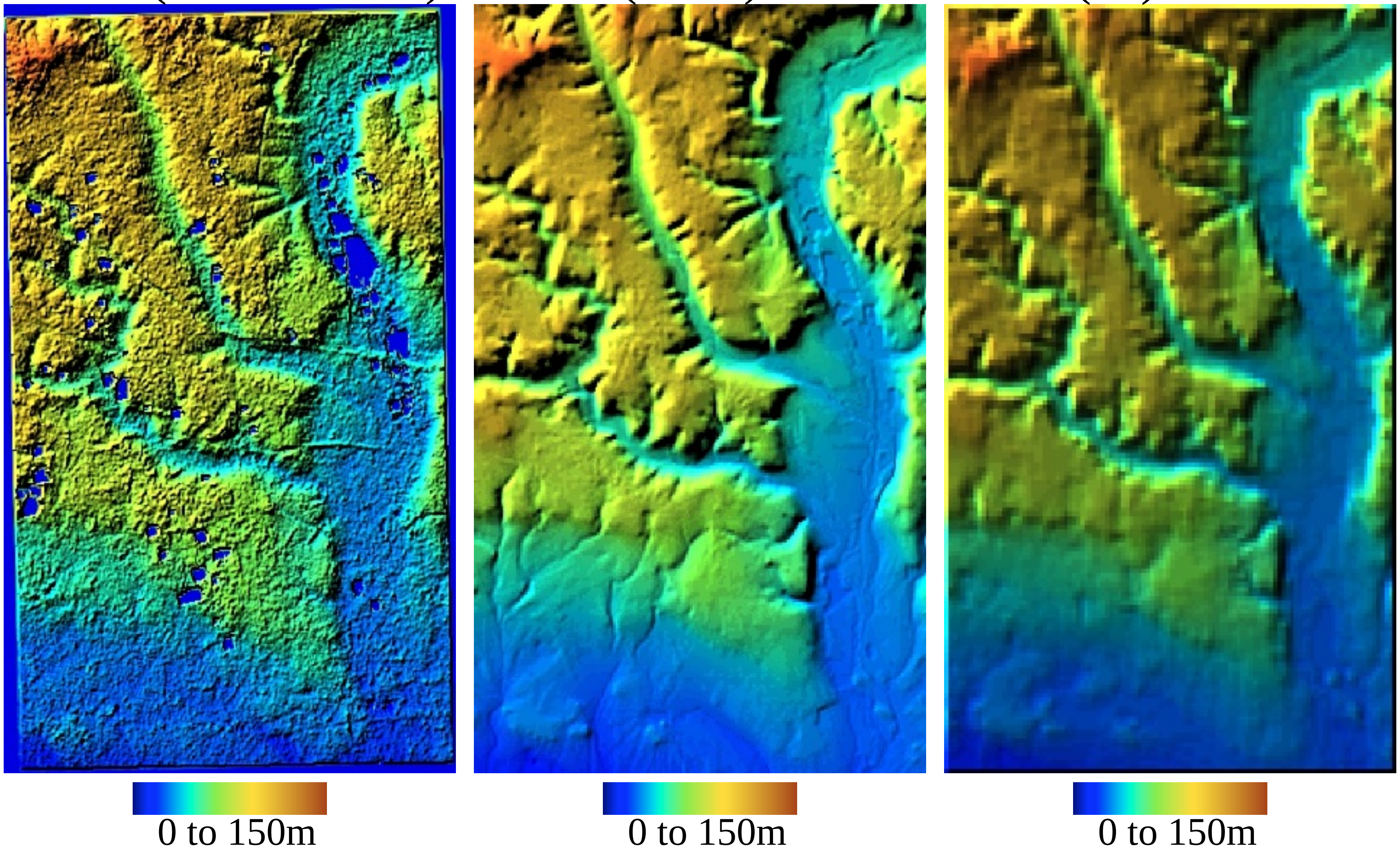






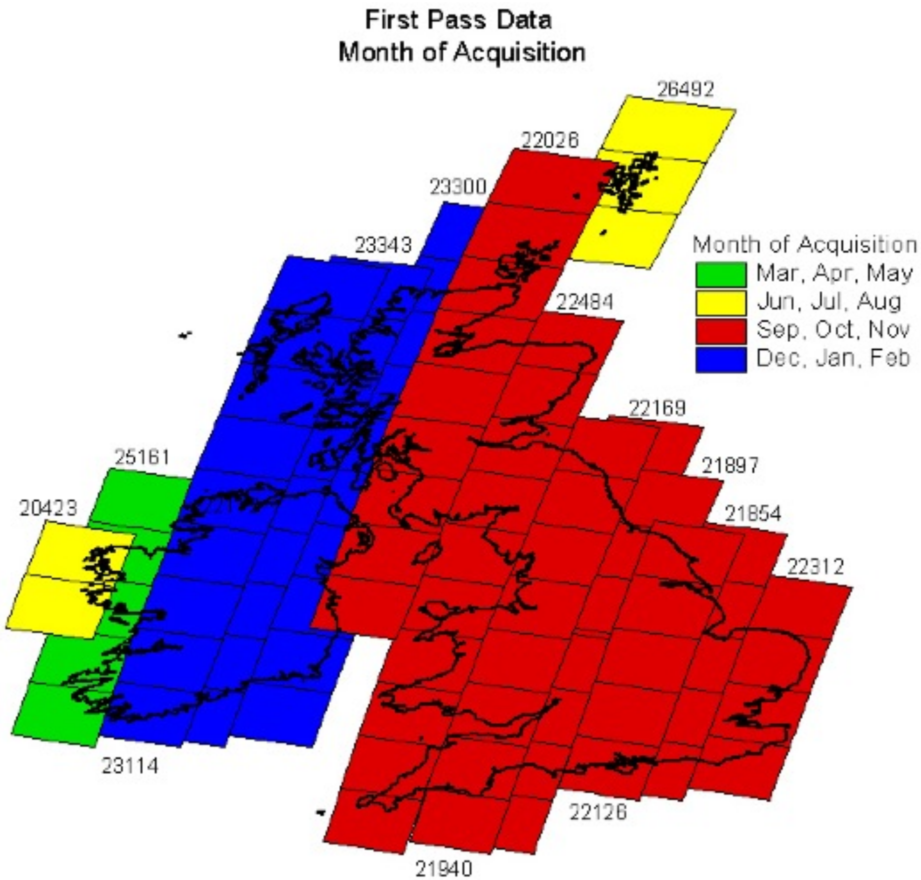
IfSAR vs. OS vs. DTED-1

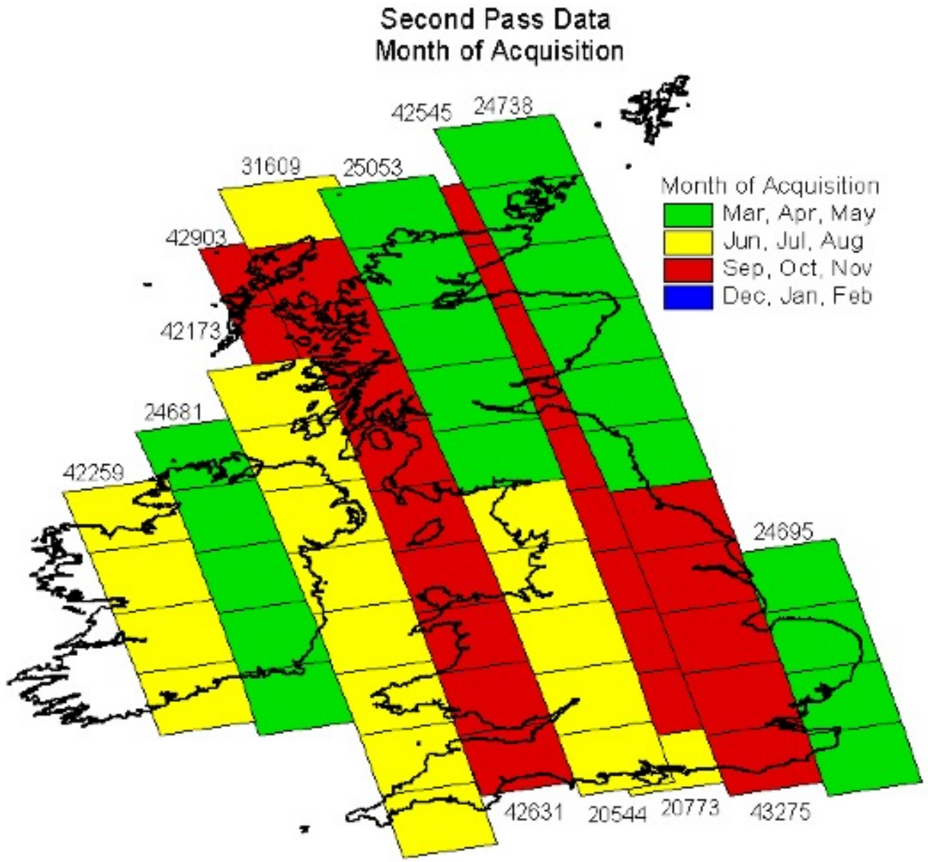
30m (LANDMAP) 50m (OS®) ~93m (3”) DTED-1



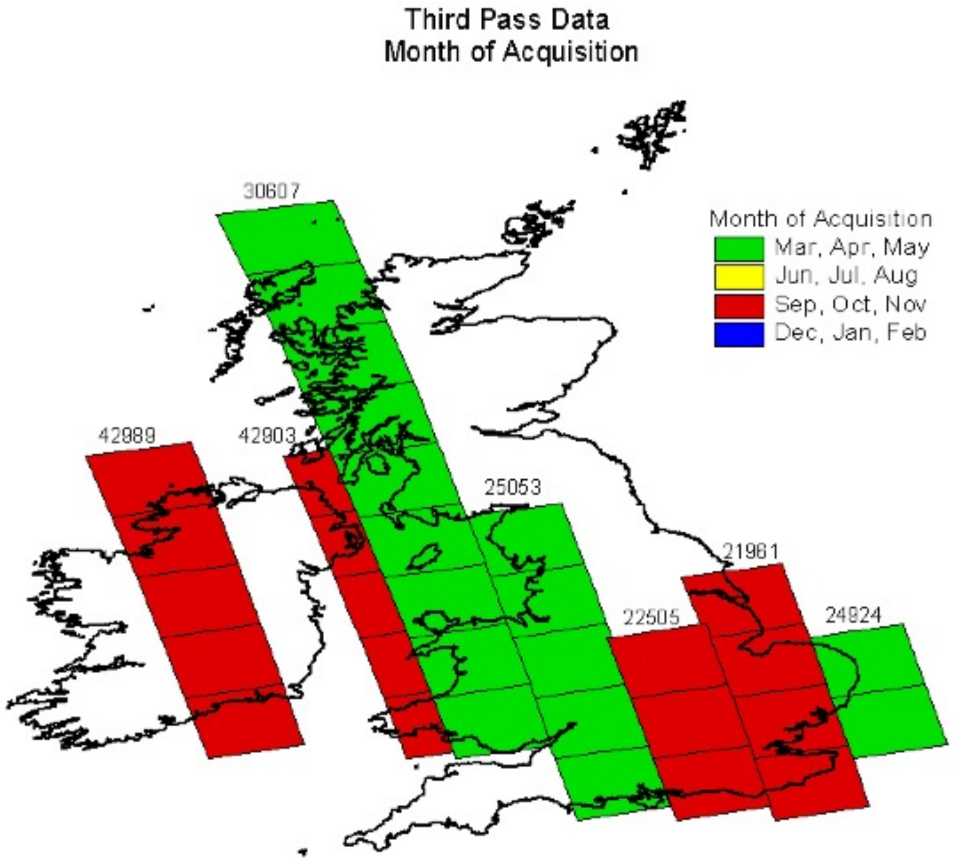
N.B. when fusing different DEM sources, note the very different noise characteristics of InSAR vs stereo and acrtographically-derived DEMs

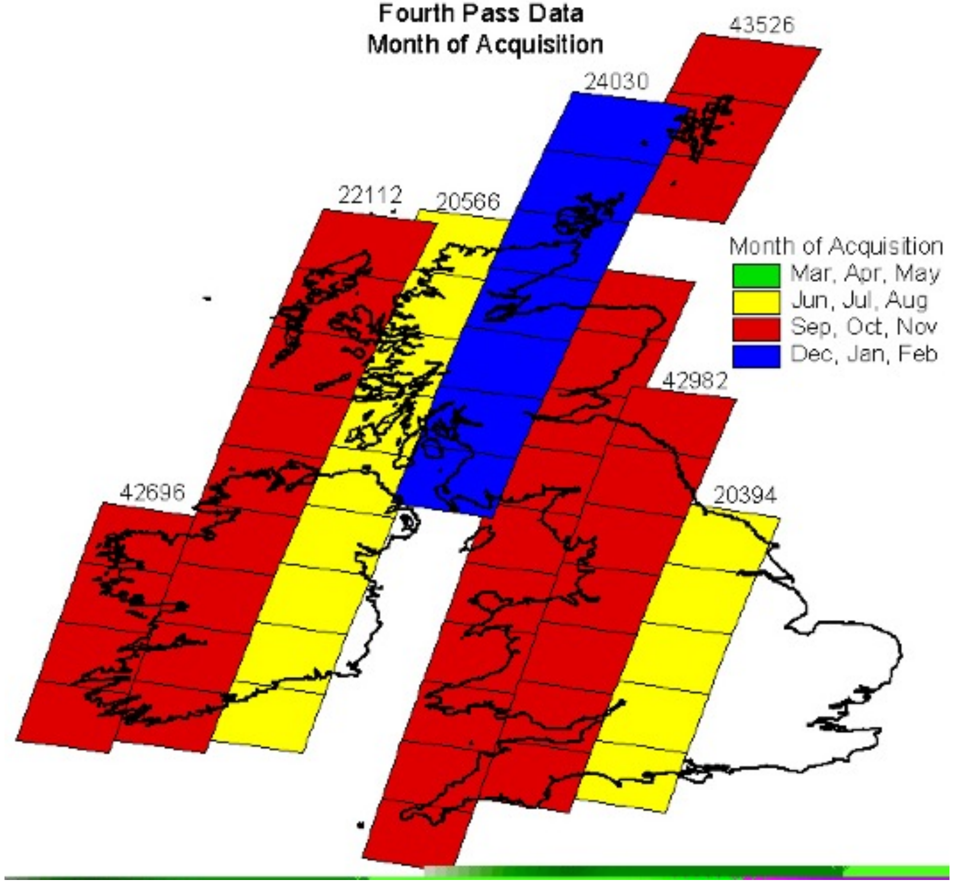
ERS Tandem data selection for 4 Passes (daytime (descending) and night-time (ascending) to maximise coverage & imaging geometry



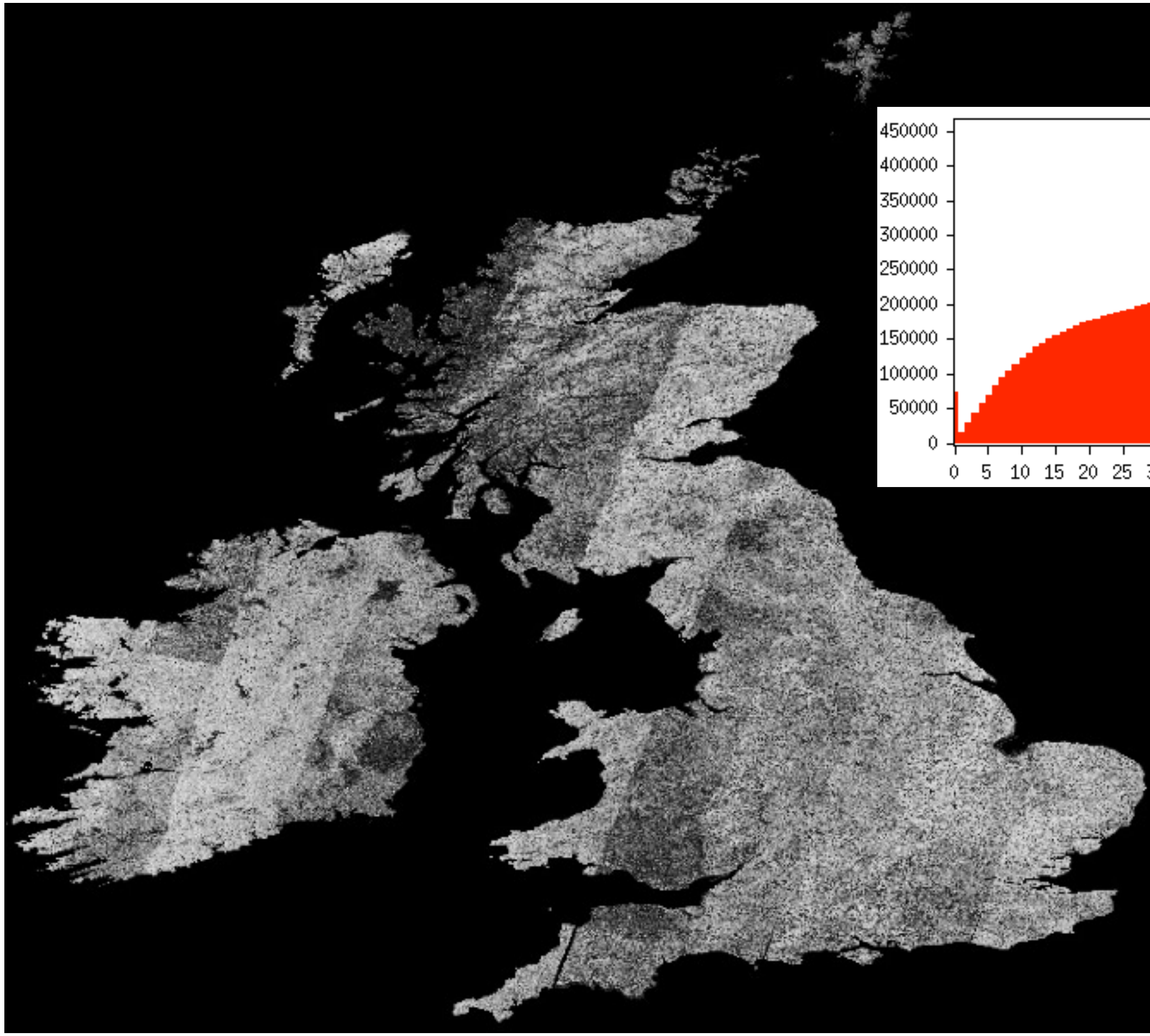


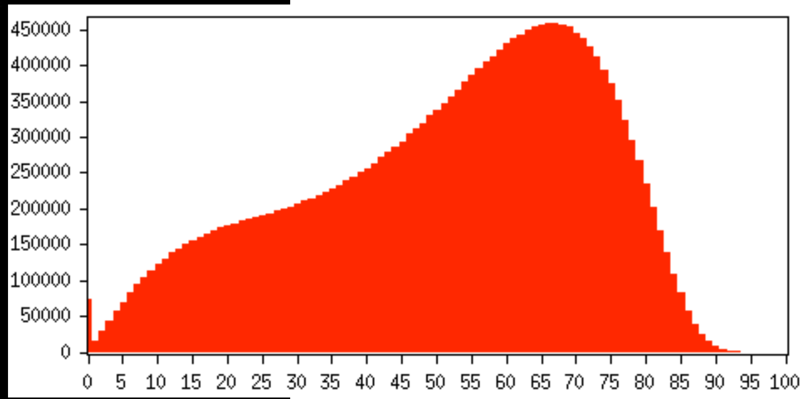
ERS Tandem data selection for 4 Passes (night-time and daytime "gap-fillers") to maximise coverage & imaging geometry





First-pass Phase Coherence





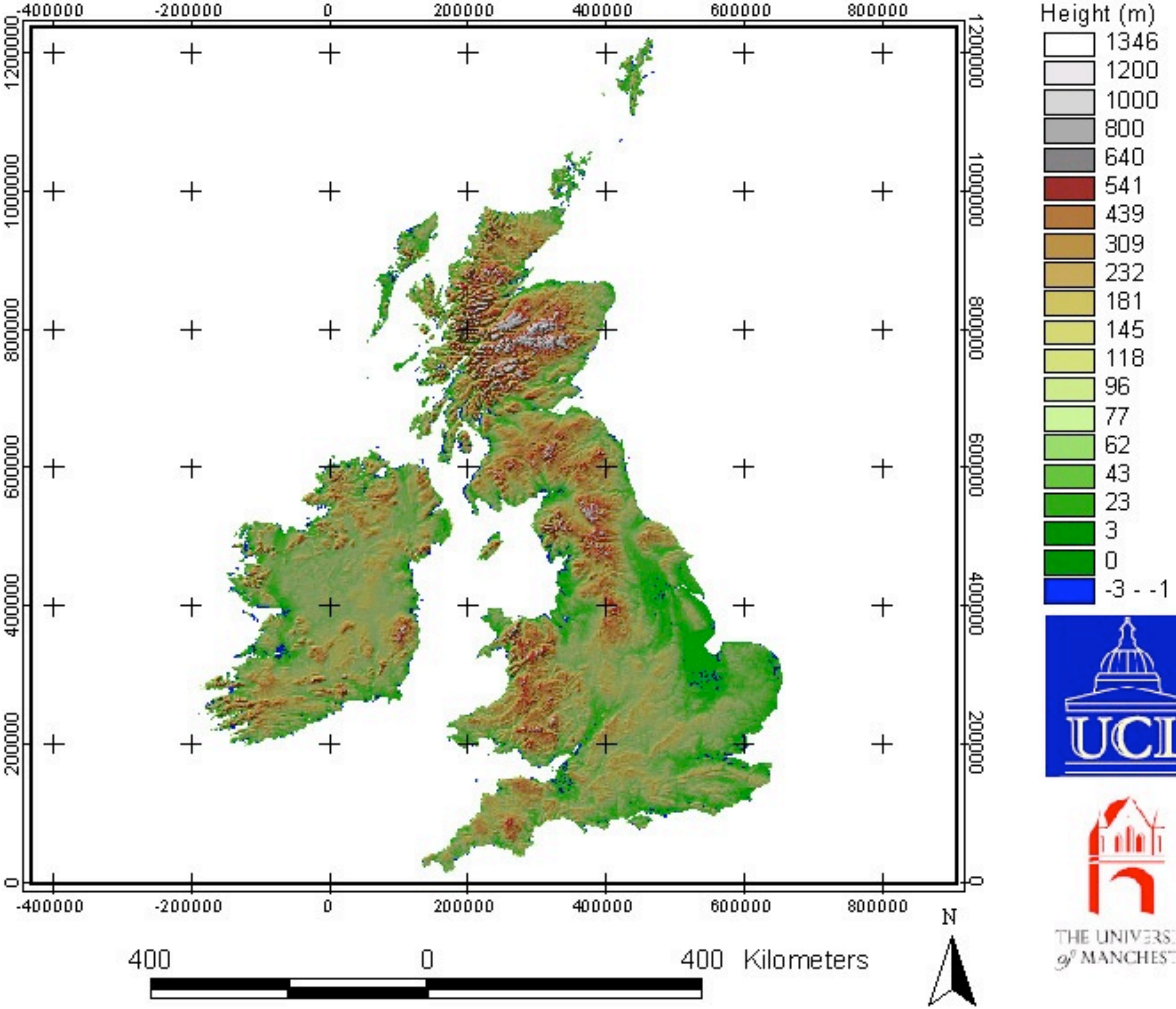
N.B. Large areas
With PC>50%
Lower phase
Coherence over
Scotland & Wales.
No apparent relationship
to height difference with
OS® PANORAMA®

ERS-1 Amplitude OrthoMosaic

N.B. No range correction applied

Coloured and Hillshaded LANDMAP DEM - British Isles

1" DEM Projected to Ordnance Survey National Grid at 1km pixel spacing

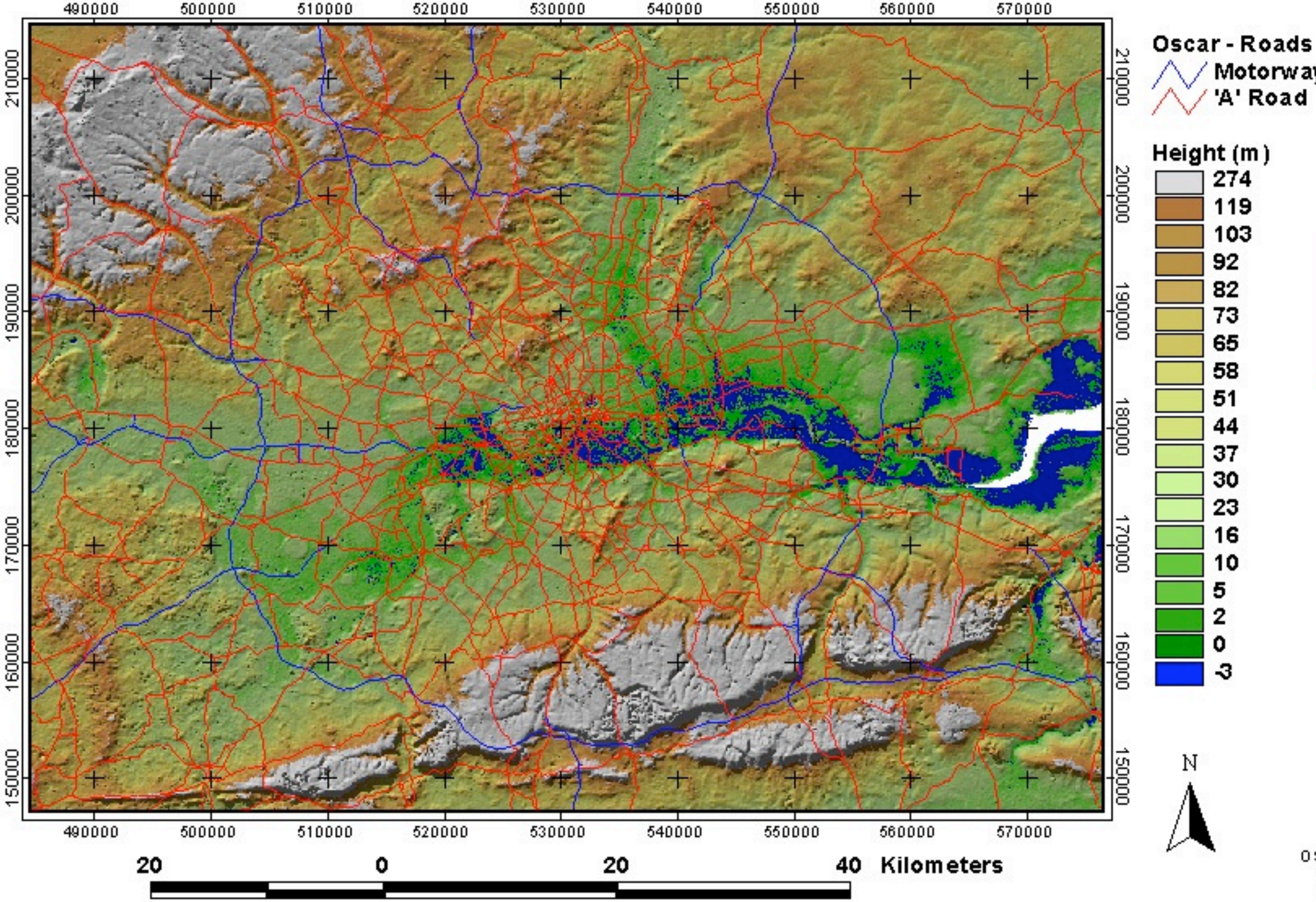


UCL

THE UNIVERSITY of MANCHESTER

Coloured and Hillshaded LANDMAP DEM - London, UK

1" DEM projected to Ordnance Survey National Grid at 100m pixel interval

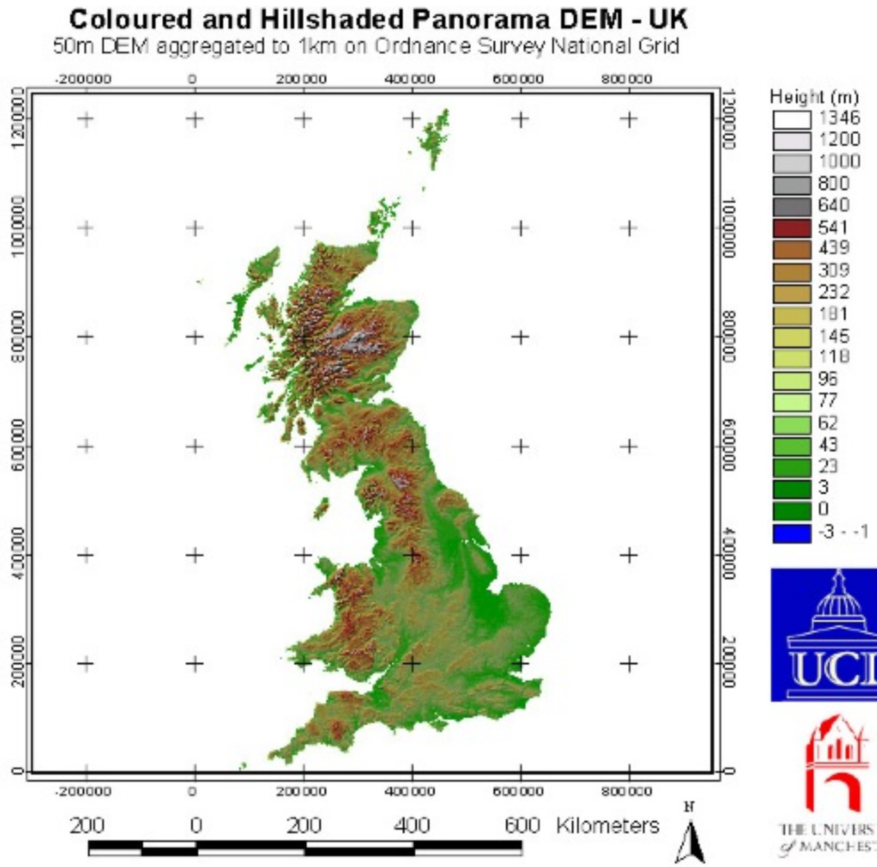


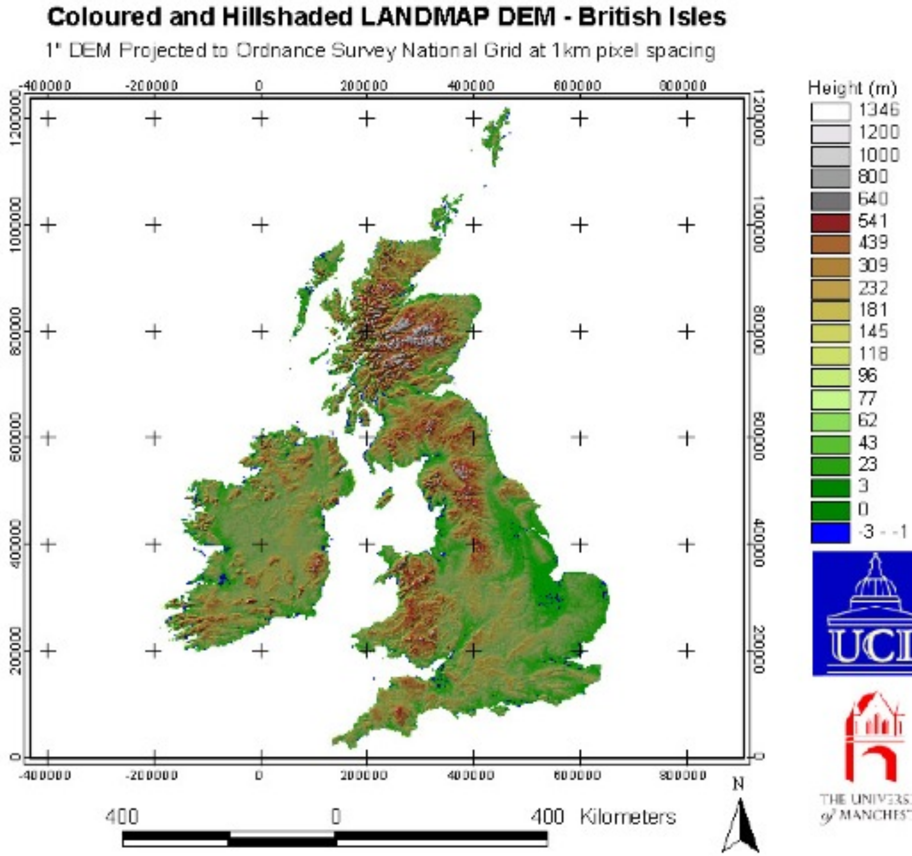
OSCAR Road dataset
Crown Copyright
Ordnance Survey

Accuracy assessment of IfSAR-DEM

- **Independent Assessment of IfSAR-DEM accuracy**
  - **3rd party DEMs such as the OS® PANORAMA 50m DTM**
- **Assessment of hydrological network cf. OS® blue-line data which was edited for hydrological consistency by the NERC Centre for Hydrology and Ecology**
- **Assessment of planimetric and elevation accuracy through 2 special dedicated 2 week campaigns to collect kinematic GPS around British Isles and intercomparison with OS® digital map positions**
- **EA laser altimetric DEMs was employed to try to understand what level the heights represent in canopy**
- **<u>Best</u> accuracy appears to be around 1.5m Zrmse vs. IH-OS 50m DEM (further details in Walker, Muller, Naden, IGARSS99) but more typically 3-10m Zrmse vs. kGPS**

Accuracy assessment of IfSAR-DEM: Intercomparison of OS® PANORAMA® and LANDMAP IfSAR DEM at 50m

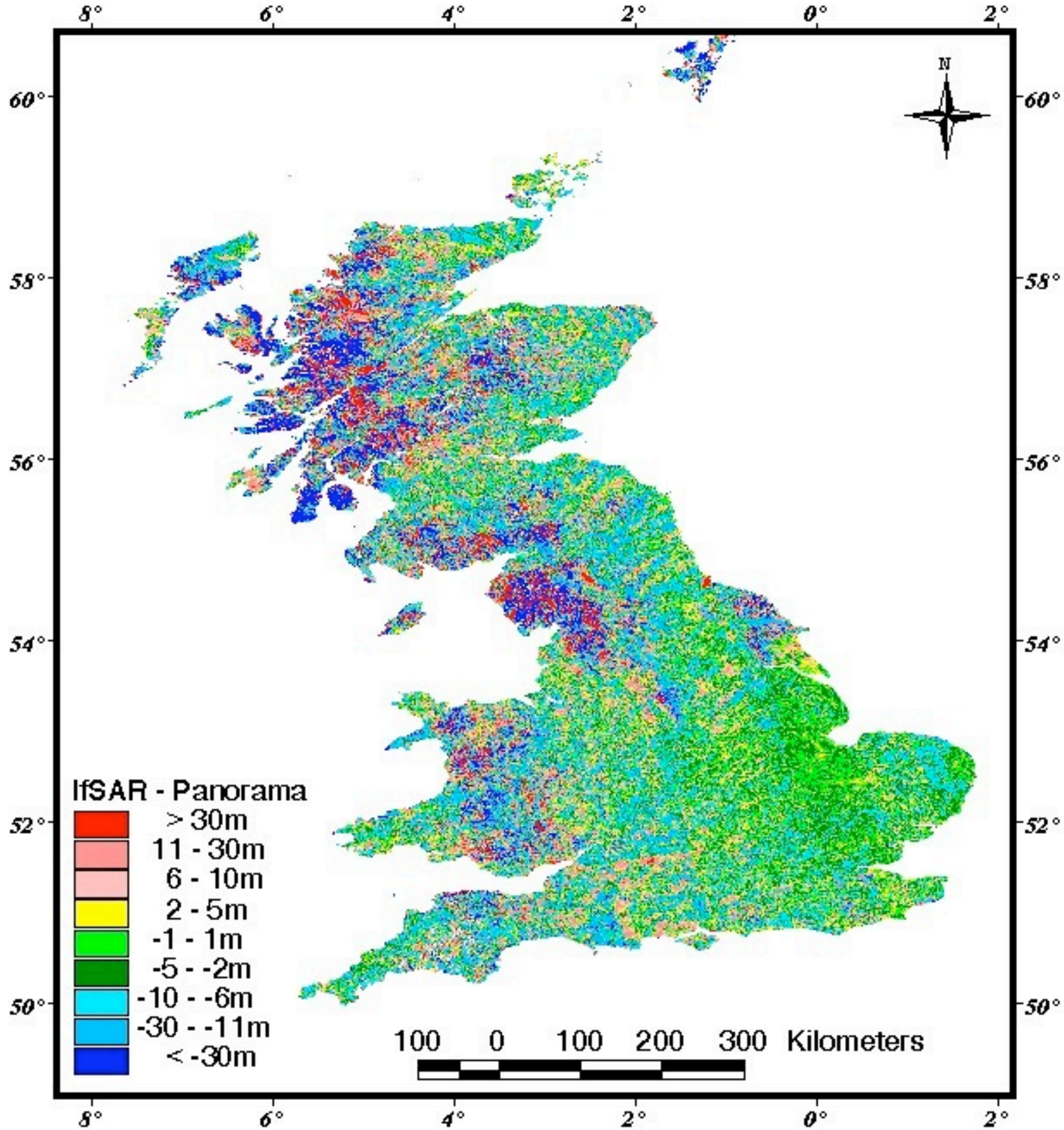




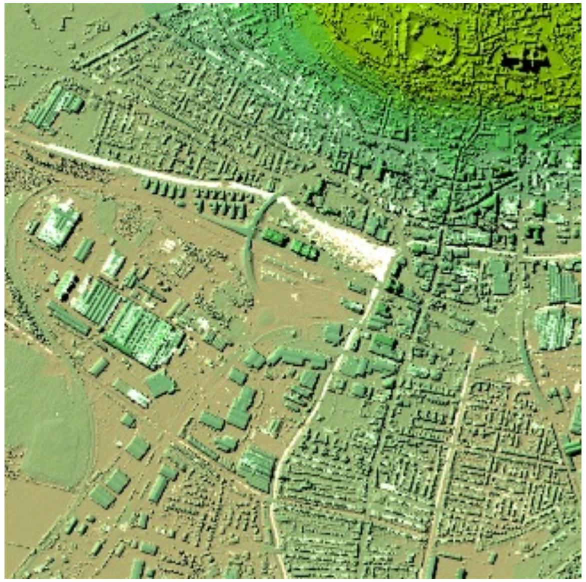
IfSAR DEM - Panorama DEM (1”)

N.B. Most areas <300m have height differences within the range -5 to +1m

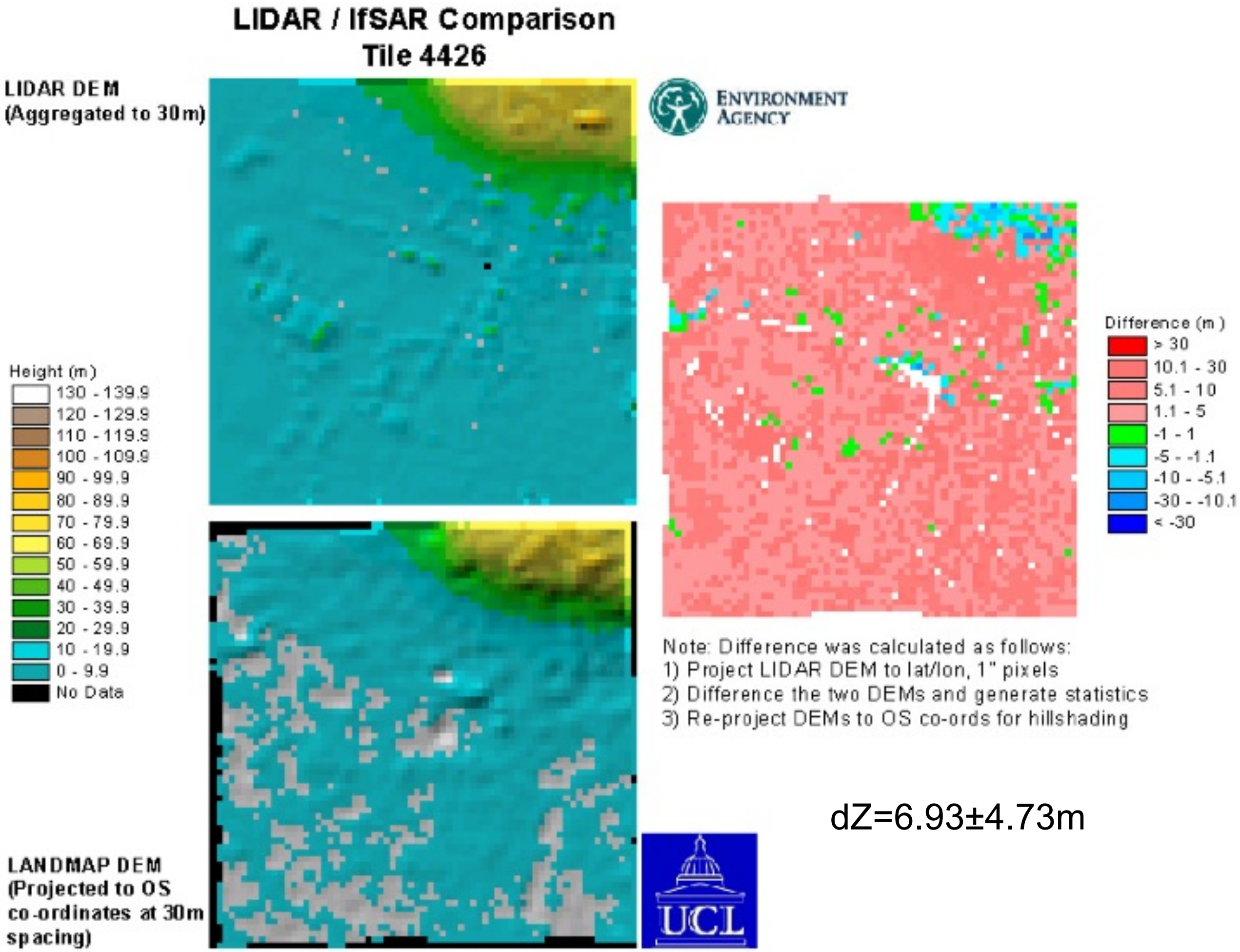
It is meaningless to calculate a single Bias and RMS for the total data-set as it is height and slope-dependent



Accuracy assessment of IfSAR-DEM : Example of comparison of EA lidar vs IfSAR

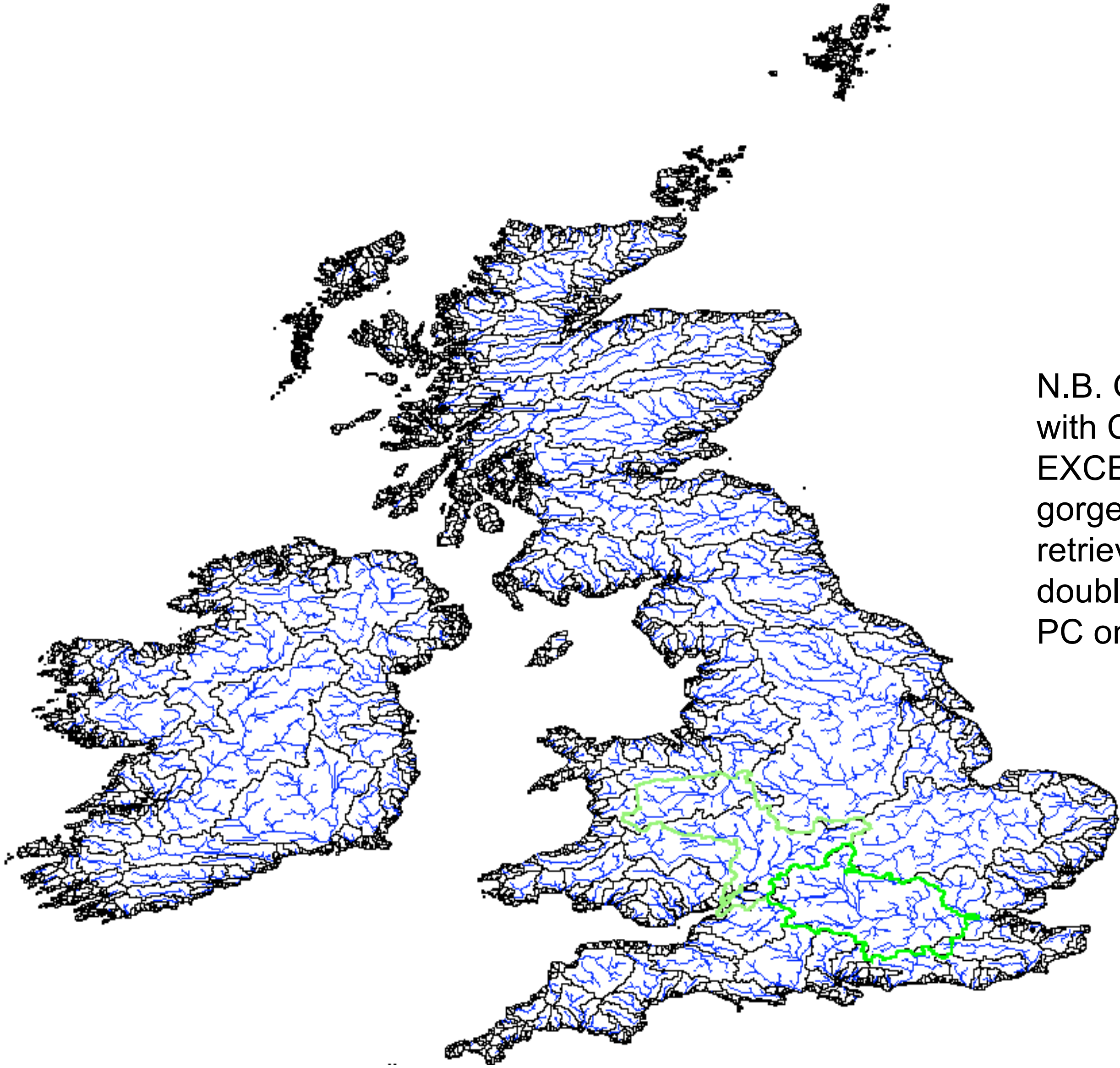


Original 2m lidar data kindly supplied by A. Duncan, NCEDS



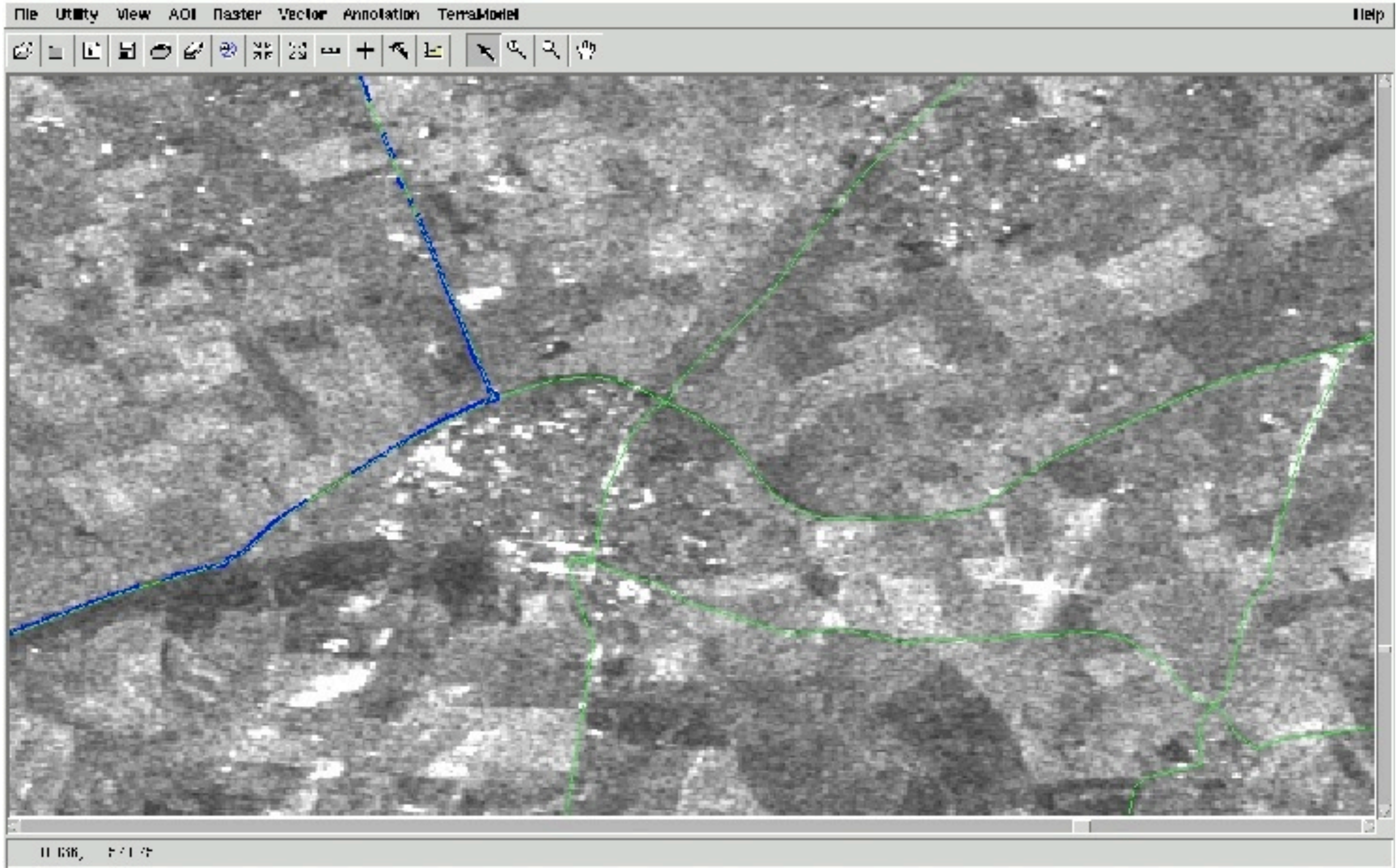
dZ=6.93±4.73m

IfSAR Derived networks/catchments - UK



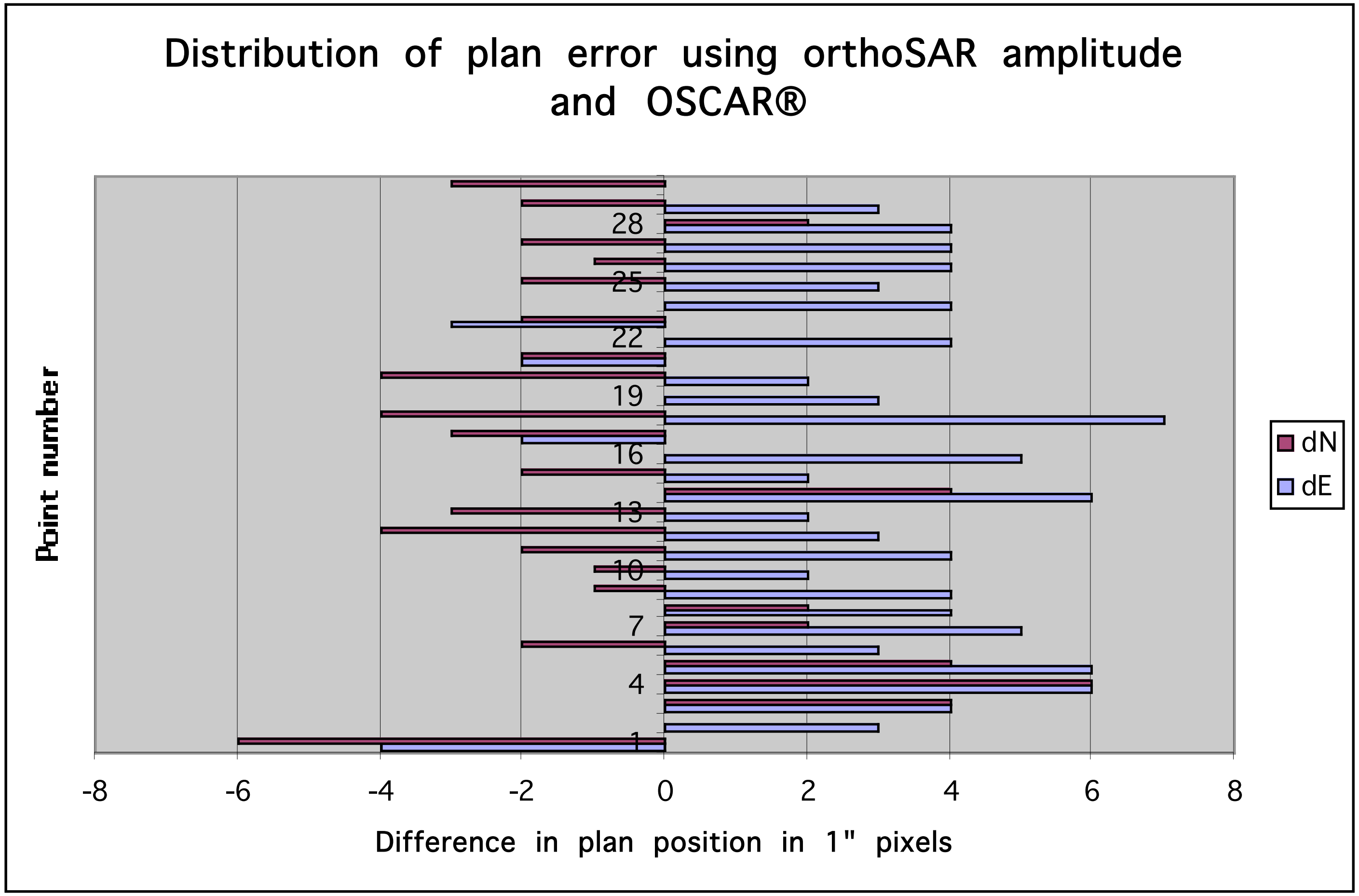
N.B. Good agreement with CEH blue-line 1:50k EXCEPT in 2 narrow gorges where no IfSAR retrieval possible due to double-bounce and low PC on steep valley walls

Planimetric accuracy



OSCAR road lines, 1:50,000 map derived (Crown Copyright 1999) in Green,
kGPS trails in Blue superimposed on SAR amplitude image

Planimetric accuracy of GCPs over UK from OSCAR comparison(2)

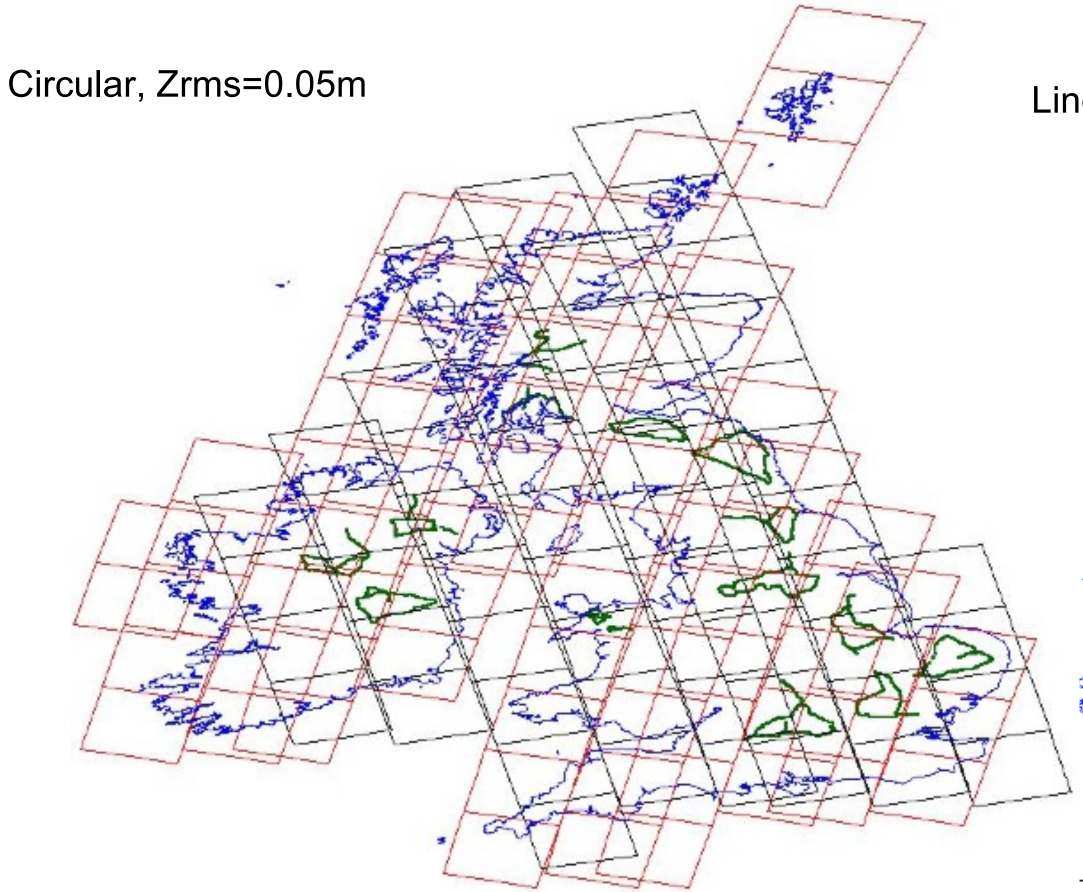


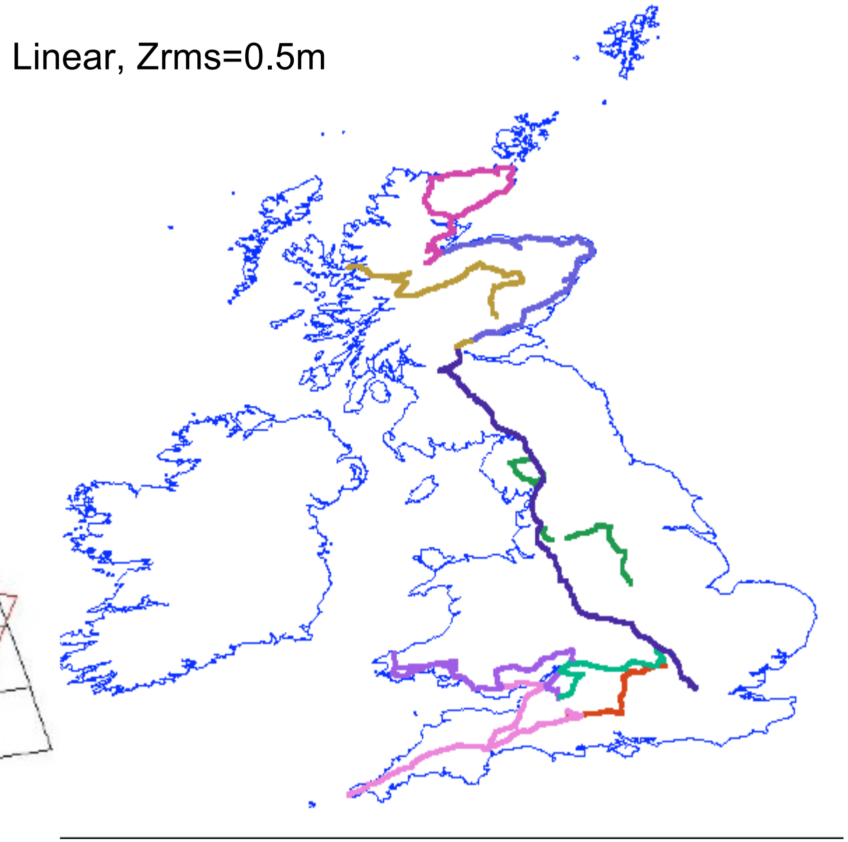
N.B. RMS lat=2” & lon=1” and NO GCPs used

Factors affecting Accuracy of IfSAR-DEM

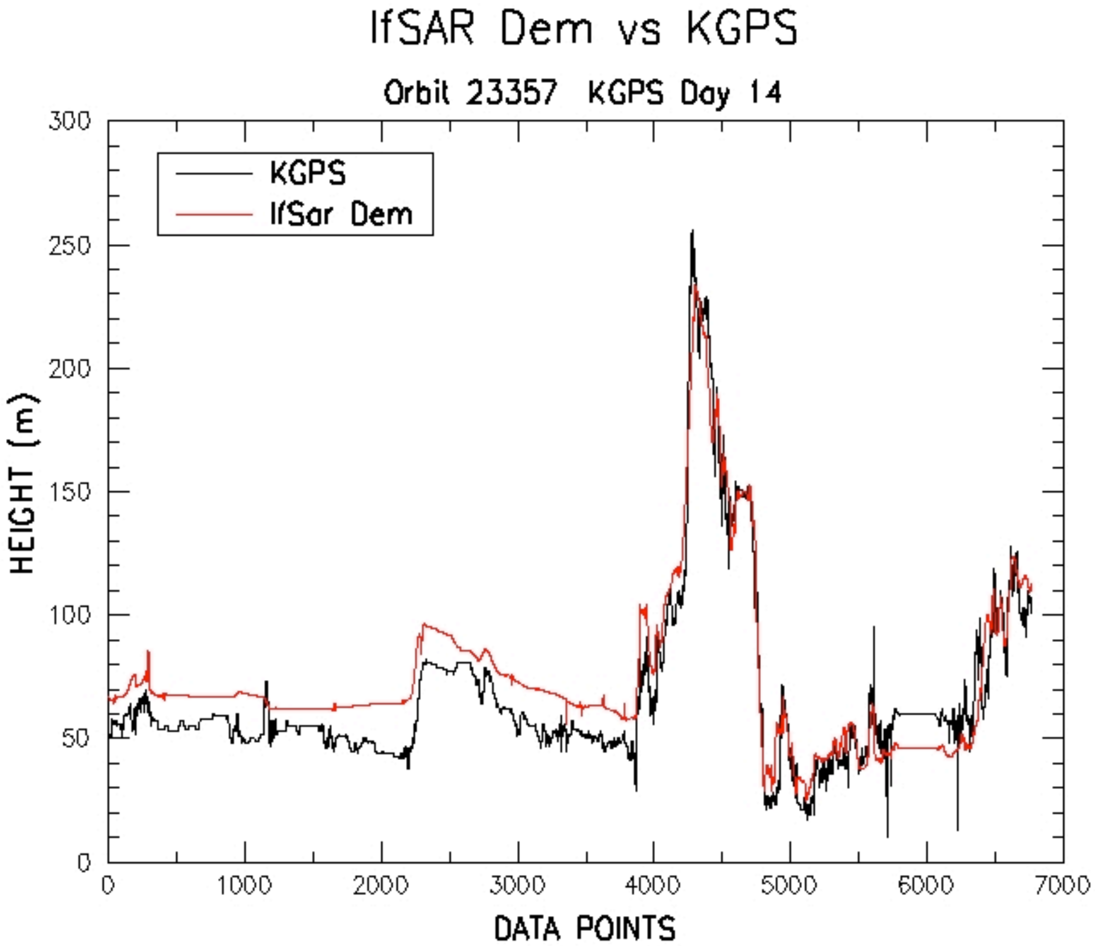
- **Surface level for scattering centres are frequently NOT the top of the observable canopy. This "surface" level is affected by tree cover, depth of penetration, tower obstacles**
- **Atmospheric effects due to time delay effects from water vapour variability**
- **Phase unwrapping artefacts**
- **Planimetric accuracy due to PRC and timing errors**
- **Artefacts in the GLOBE or DTED-0 DEM which cannot be corrected by ERS-1 RA as there are insufficient density of such points in the UK**
- **Phase coherence effects due to land cover and local surface wind/water conditions (little, if any evidence found for correlation with height differences)**

GIS was also employed to select optimal routes for Kinematic GPS (kGPS)profiling to assess the quality of Individual strips, their overlap, the final merged results from the 3 phases and orthorectification



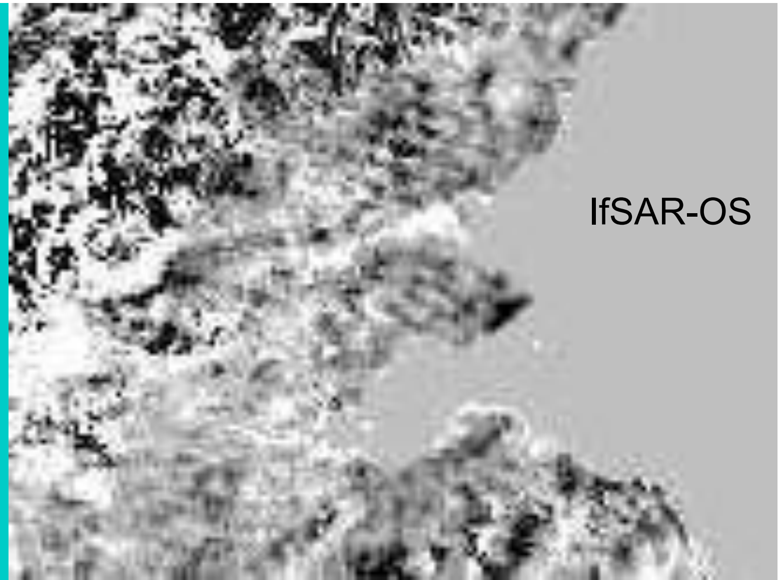


Accuracy assessment of IfSAR-DEM : Kinematic GPS showing the effects of canopy tops cf. kGPS road surface



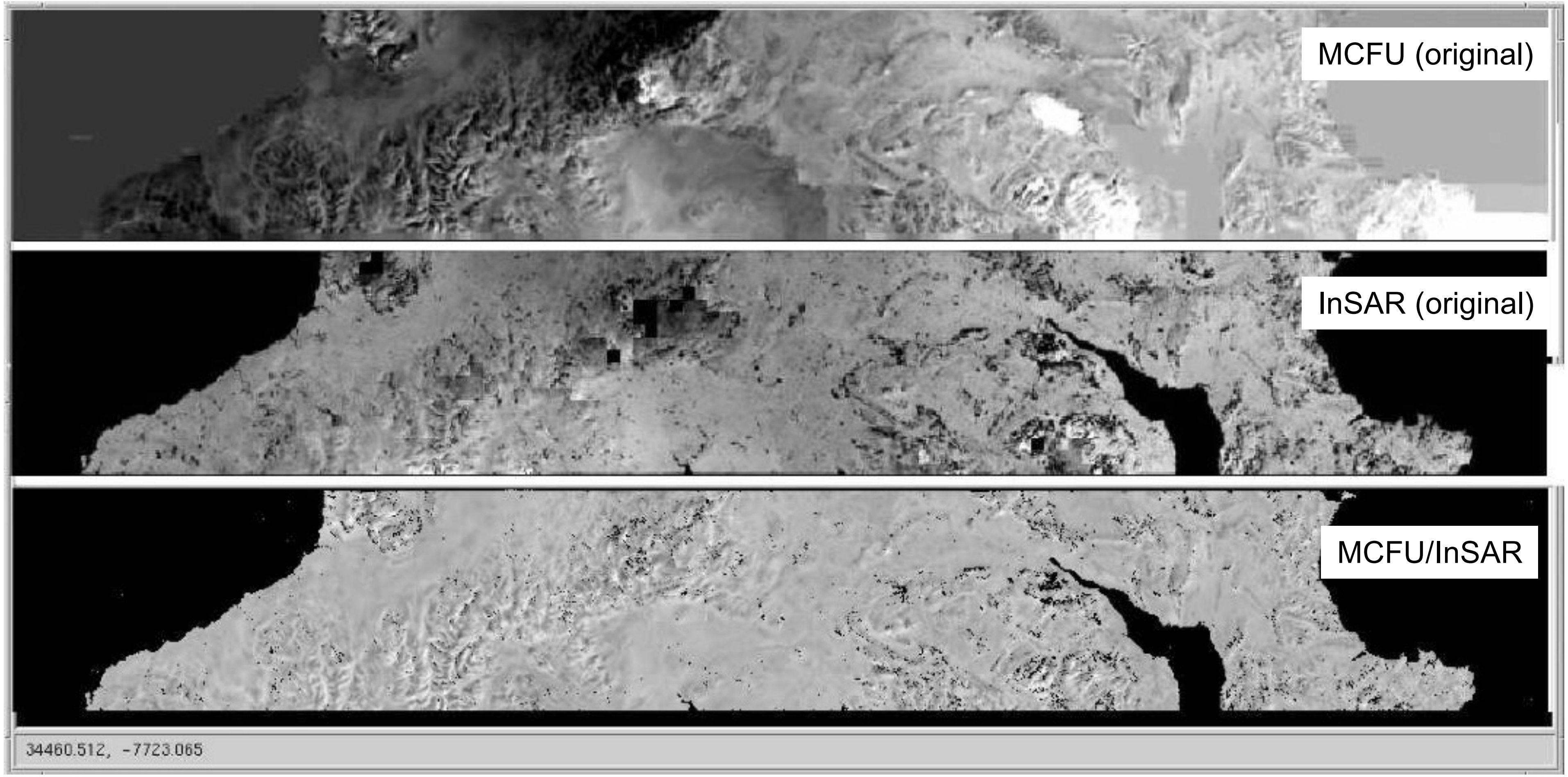
Accuracy assessment of IfSAR-DEM : Atmospheric artefacts detected by comparison with OS® PANORAMA

Red-PC
G/B- IfSAR-OS



N.B. Atmospheric artefacts present in most regions but their magnitude is <5m through averaging of multiple passes

Accuracy assessment of IfSAR-DEM : Phase unwrapping artefacts

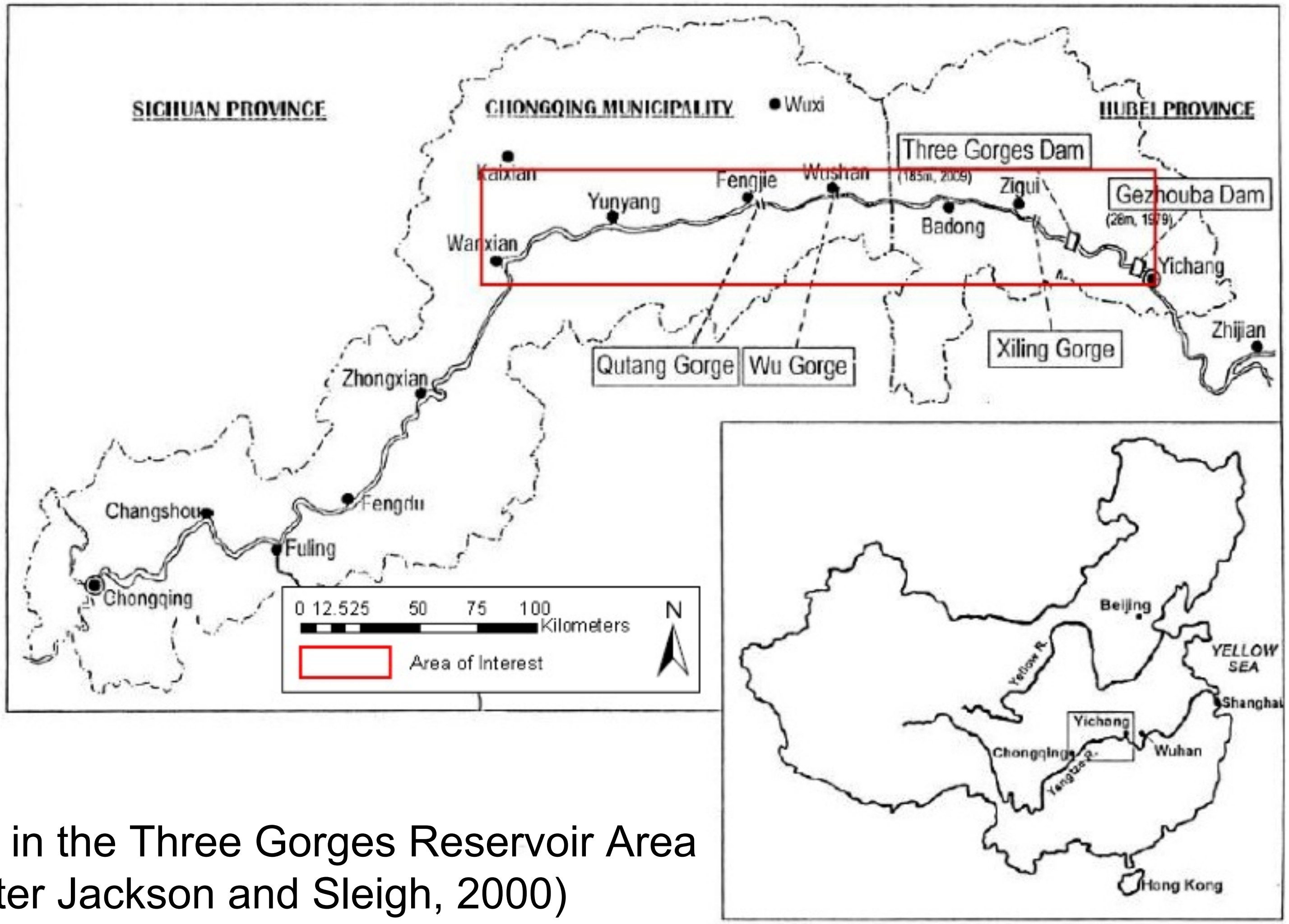


N.B. MCFU/InSAR produces tile artefacts due to the local adjustment wrt DTED-0 which is minimised using multi-pass combinations. MCFU developed at ESA by Constantini (1999)

Status and Future Prospects

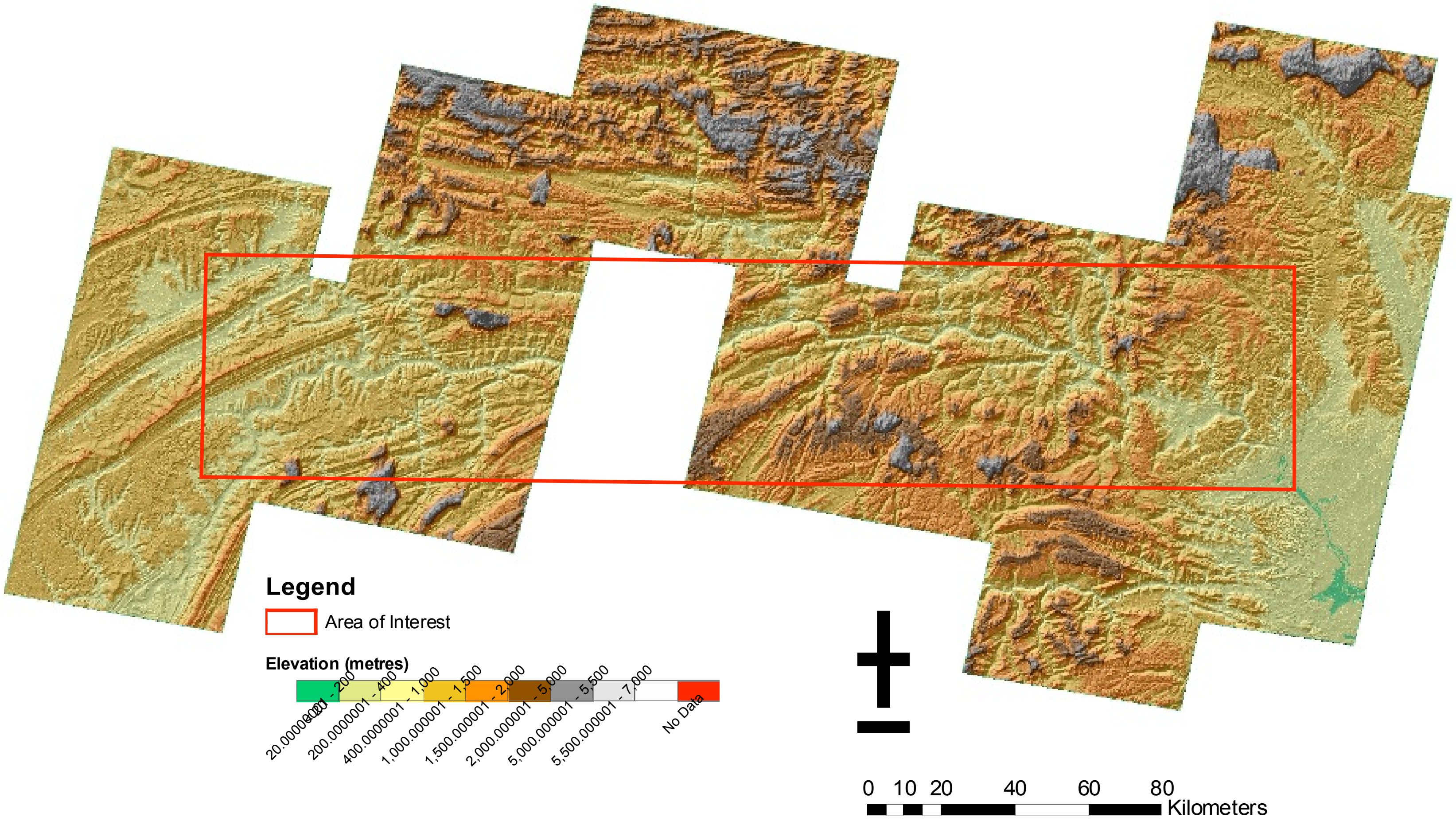
- **Final version completed in September 2001**
- **Orthoimages of ERS1,2 amplitude and Phase Coherence**
- **Orthoimage created for LANDSAT 7**
- **Orthoimage for LANDSAT 5 and SPOT completed**
- **Public Web pages to introduce techniques and to deliver DEMs & metadata using a "point-and-click" interface based on ArcIMS and OpenGIS Web Mapping testbed completed**
- **URL: http://www.landmap.ac.uk**
- **Thousands of users in the UK academic community**

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



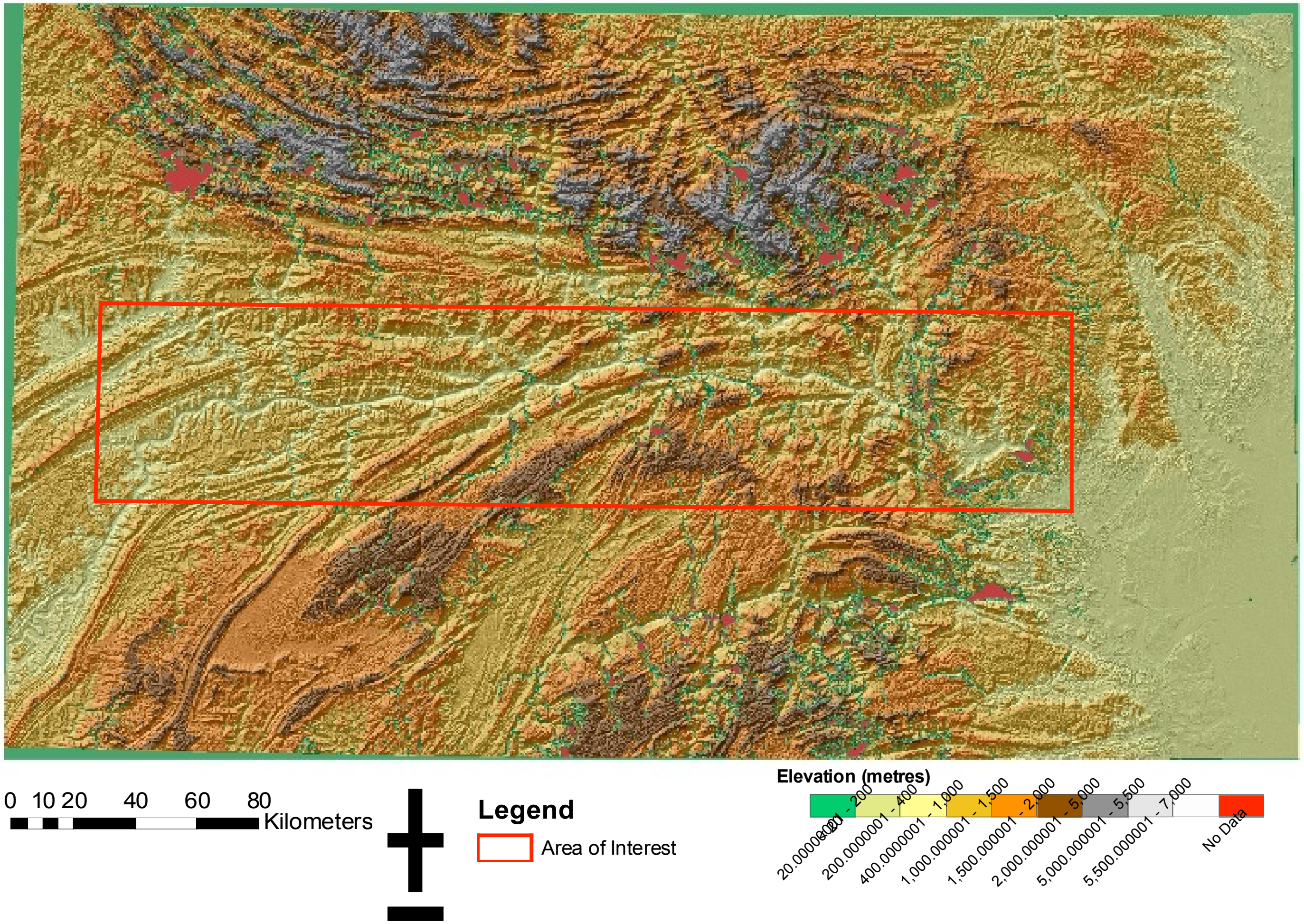
Study Site in the Three Gorges Reservoir Area
(after Jackson and Sleigh, 2000)

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



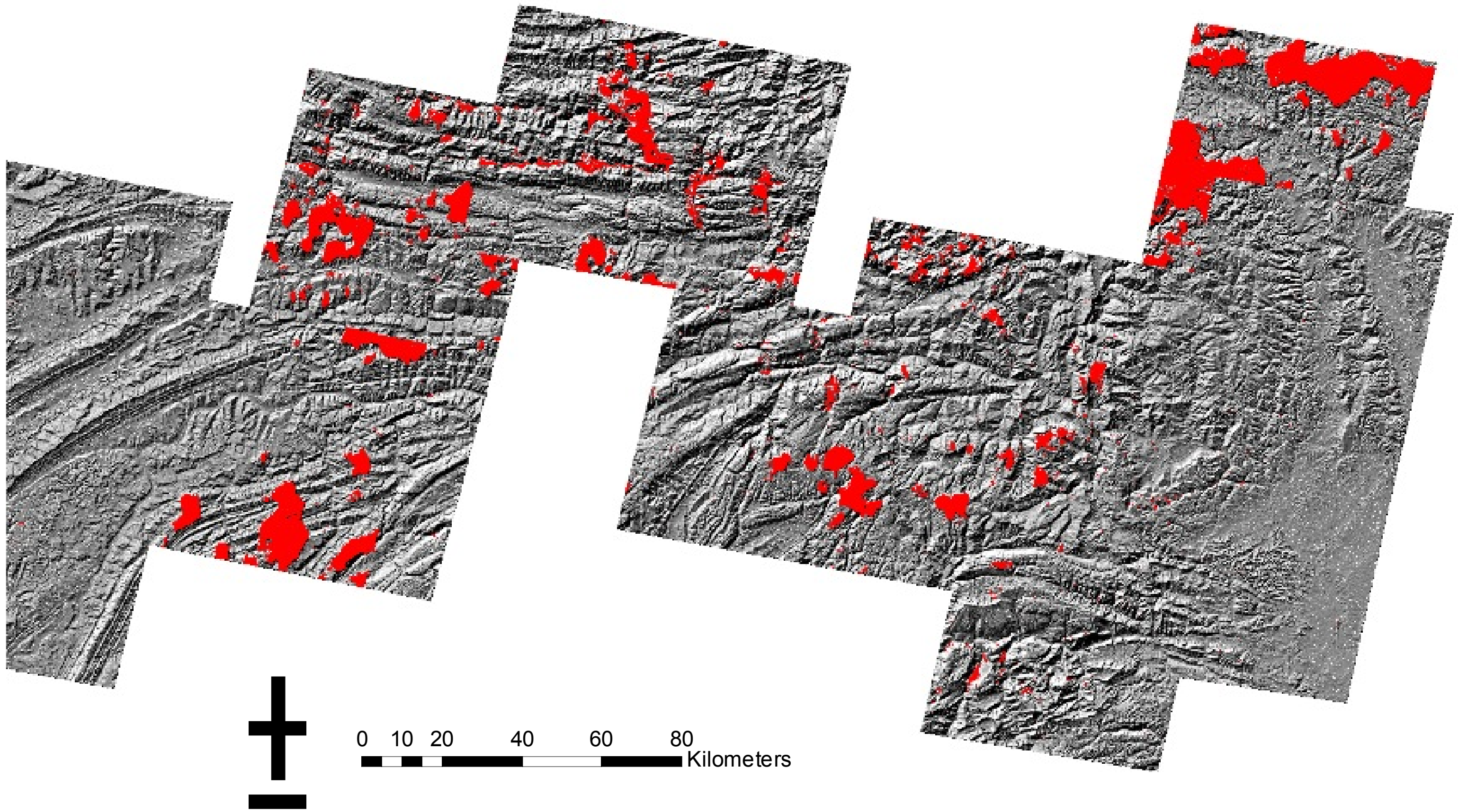
ASTER DEM mosaic hill-shaded in ArcMap with 30° altitude and 330° azimuth for the light direction and using the ICEDS custom hill-shading colour scheme. Note the grey areas which appear to be clouds.

SRTM v2 (edited) DEM for area of interest



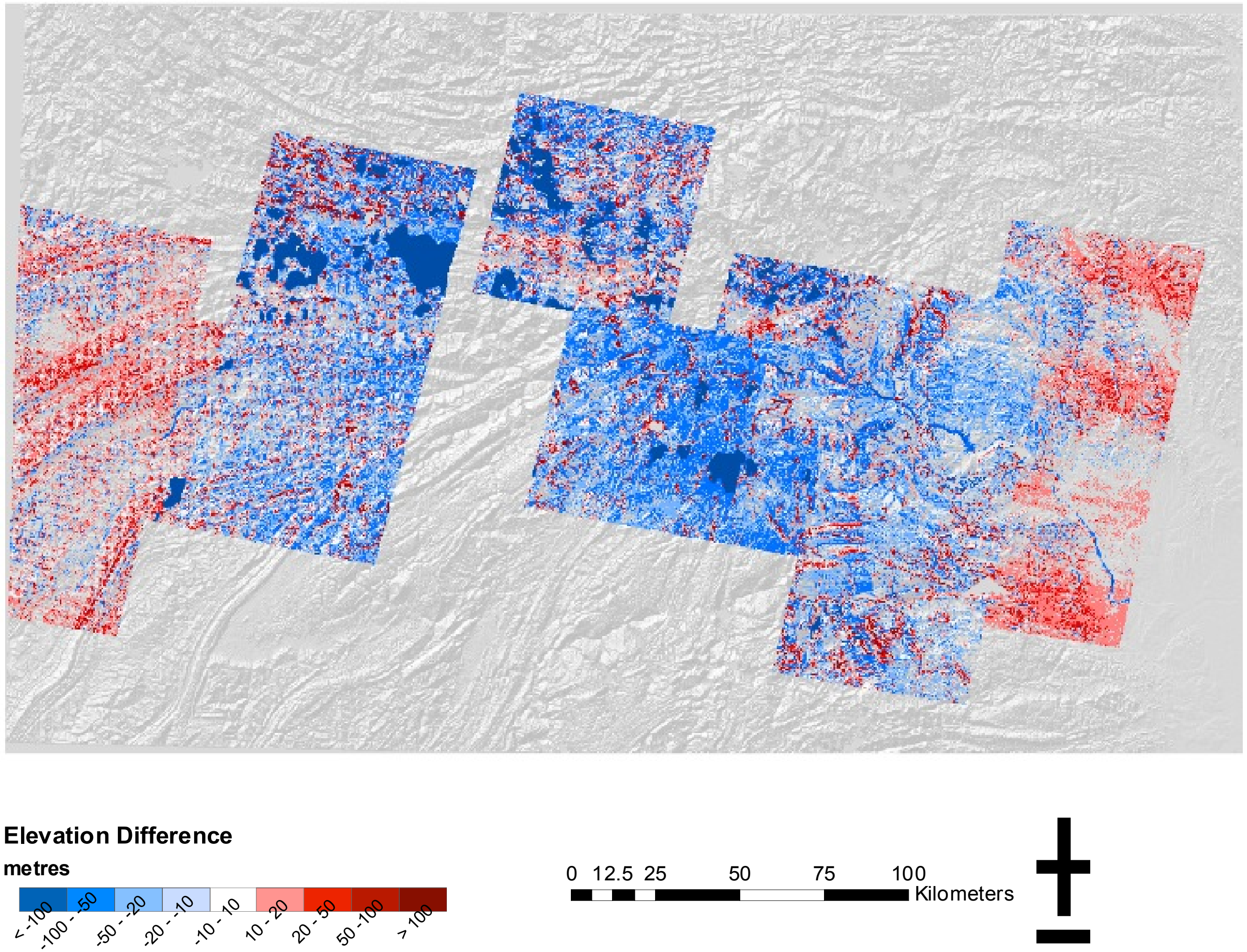
SRTM DEM mosaic hill-shaded in ArcMap with 30° altitude and 330° azimuth for the light direction and using ICEDS custom hill-shading colour scheme. Notice the red areas of missing data.

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

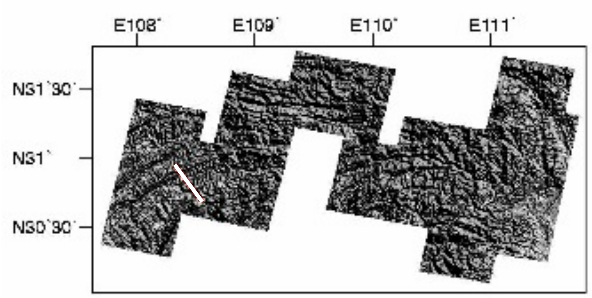


Elevation difference map created in ArcMap showing cloud cover artefacts in the ASTER DEMs. The map was obtained by subtracting the SRTM DEM mosaic from the ASTER DEM mosaic, removing subtle differences between the DEMs and applying a mask. The red areas represent height differences caused by clouds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

Elevation difference image: SRTM DEM – ASTER DEM Mosaic

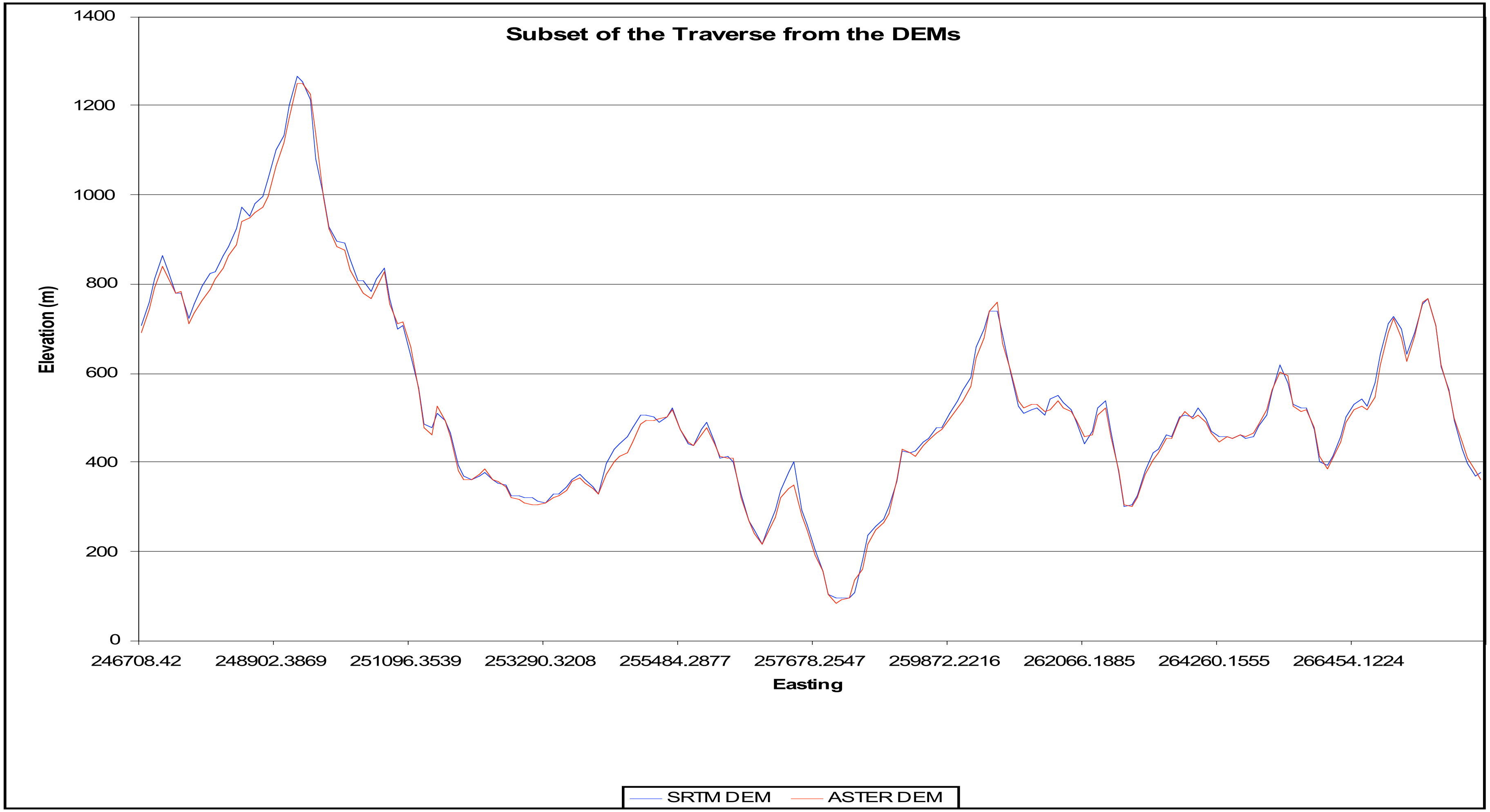


Elevation Difference Map created in ArcMap displayed on top of the hill shaded SRTM DEM. SRTM DEM used as the 'correct' DEM and the ASTER DEM mosaic subtracted from it. Notice clouds shown as areas of dark blue. Notice also the variable offset for each ASTER-DEM (mean = -29.79m, min = -3178m, max = 545m,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



Good comparison between two DEMs

Mean difference = 7.59m
Standard deviation = 13.42m



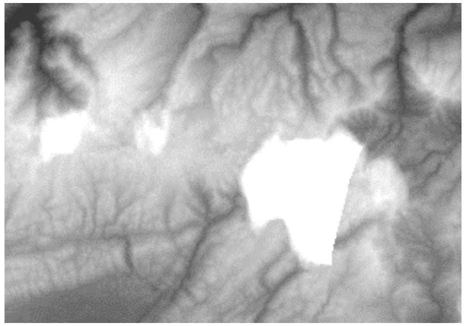
Formula applied in ER Mapper® to fuse DEMs together, remove cloud and improve vertical accuracy of ASTER DEM mosaic

The formula used is as follows:

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

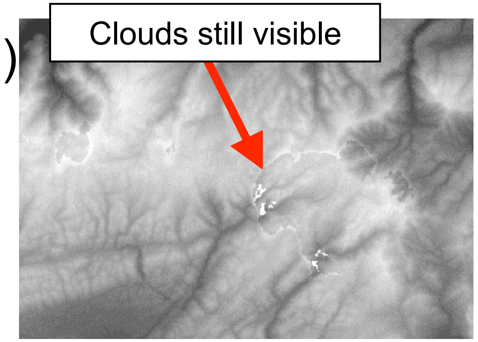
Where i1 = ASTER DEM
Where i2 = Improved SRTM DEM
Where 0 is the no data value in the ASTER DEM mosaic

a)



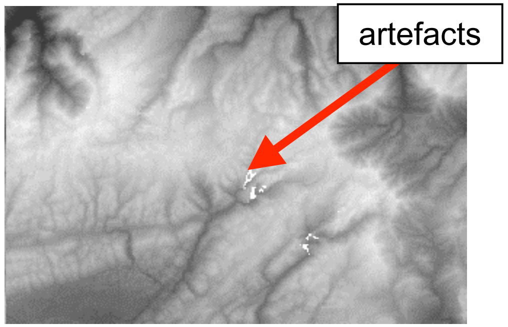
ASTER DEM Prior to cloud removal

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

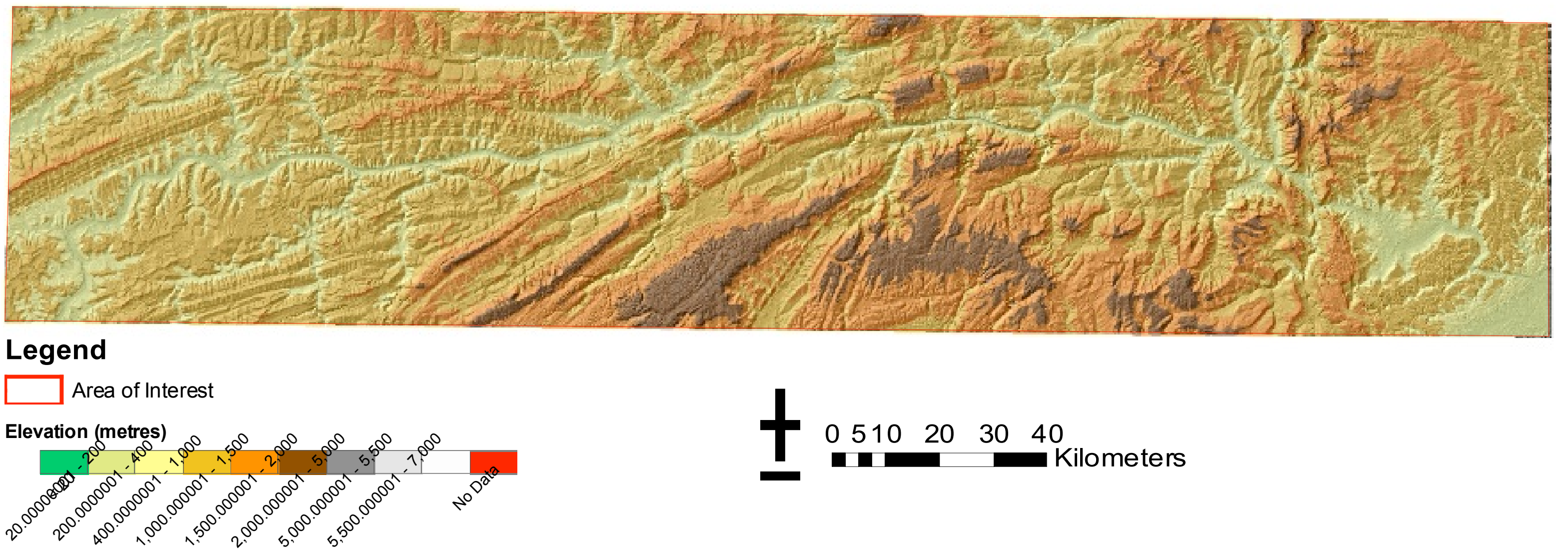
Where i1 = ASTER DEM
Where i2 = Improved SRTM DEM
Where 0 is the no data value in the ASTER DEM mosaic

Fusion of DEMs (2)

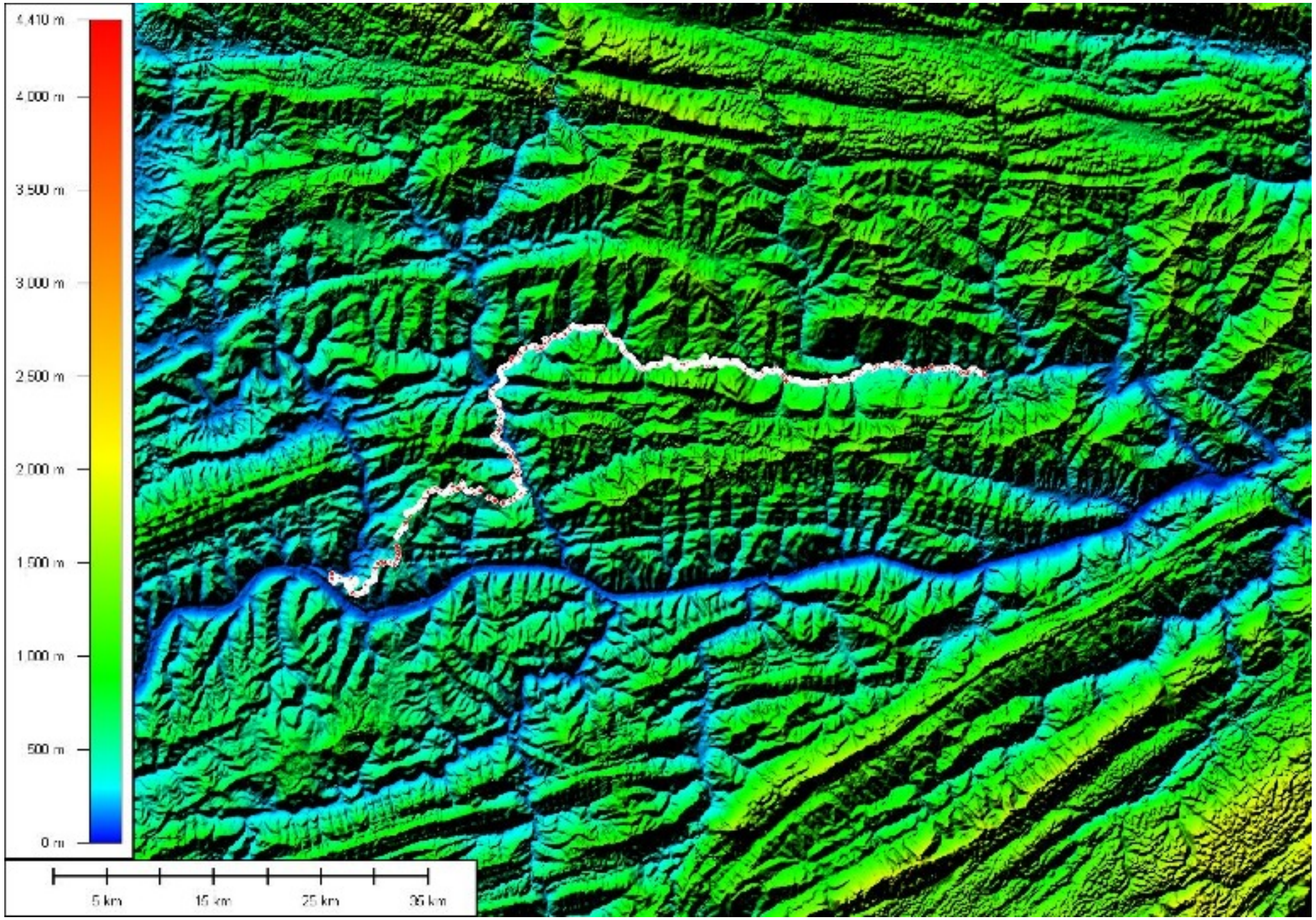
- **Step 3: ‘fill in’ remaining voids using interpolated SRTM DEM layer**

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



Height assessment campaign: SRTM + ASTER 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, Bryan Bailey (Principal Remote Sensing Scientist, USGS, EDC) reported and I quote**
  - **"The Ministry of Economy, Trade and Industry (METI) of Japan and the U.S. National Aeronautics and Space Administration (NASA) have announced plans to produce and validate, in conjunction with the Earth Remote Sensing Data Analysis Center (ERSDAC) and the U.S. Geological Survey (USGS), a 30m DEM of the global land surface from Advanced Spaceborne Thermal Emission and Reflectance Radiometer (ASTER) data.**
  - **The ASTER Global DEM (GDEM) will cover land surfaces between 83°N and 83°S with estimated accuracies of 20 m at 95 % confidence for vertical data (elevation) and 30 m at 95 % confidence for horizontal data (geolocation).**
  - **The ASTER GDEM should be available in the first half of calendar year 2009, and will be delivered in geotiff format and geographic lat/long coordinates.**
  - **METI and NASA currently are considering an invitation from GEO to contribute the ASTER GDEM to GEOSS."**
- **It is very likely that gaps will exist due to persistent cloud cover or lack of contrast in the stereo images**

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

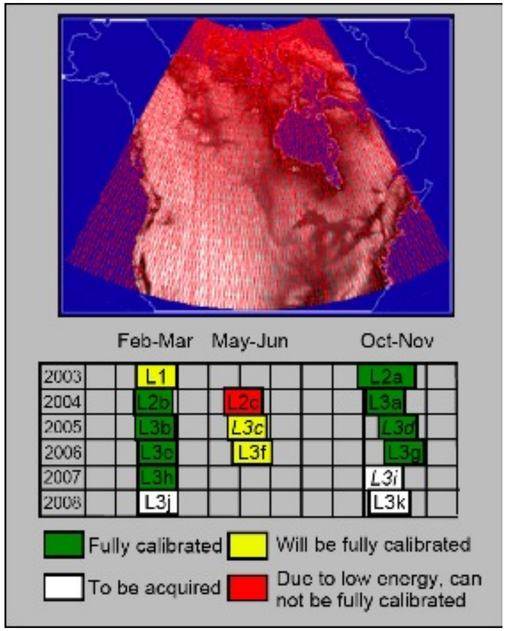
- **SPOT Image could provide height points at 30m to plug gaps**
- **DLR could provide SRTM-X and/or TANDEM-X height points at 30m to plug gaps**
- **ESA could provide ERS-tandem derived height points at 30m to plug gaps (especially for regions above ±83^o latitude)**
- **JAXA could provide ALOS-PRISM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

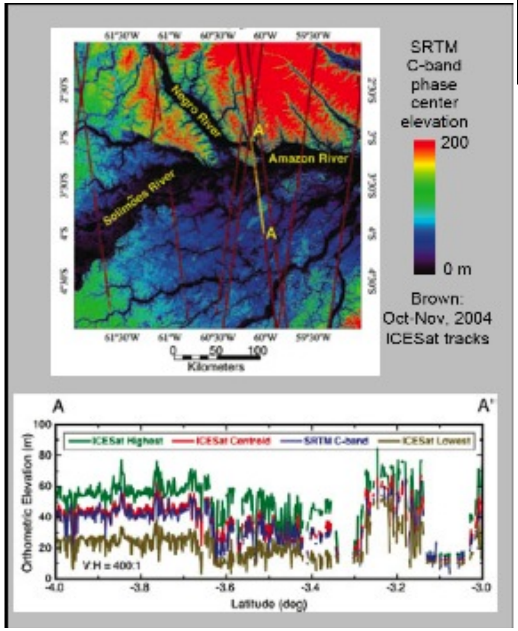
How might CEOS-GEOSS members contribute to filling gaps?
Web Processing Services

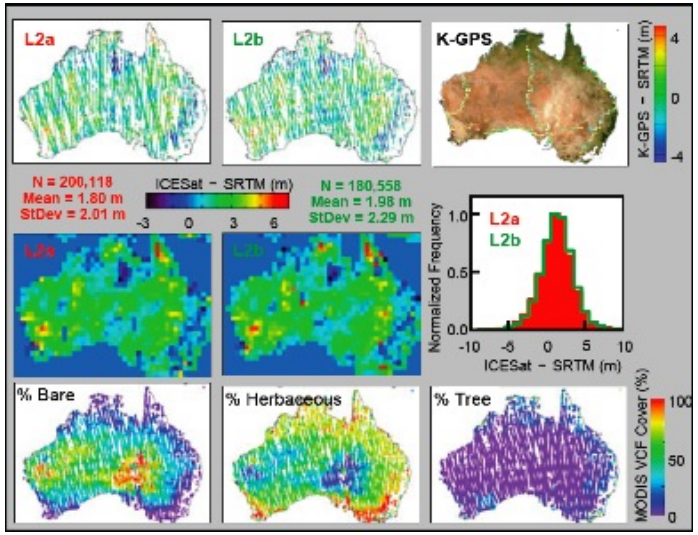
- **Initially Satellite DEM suppliers could provide**
  - **WMS of colourised hill-shaded DEMs already produced (e.g. DLR SRTM-X browse products from a WMS server at DLR)**
  - **WFS of footprints of areas covered by existing DEMs. This would permit a visual (and GIS) assessment of the potential of different 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 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**





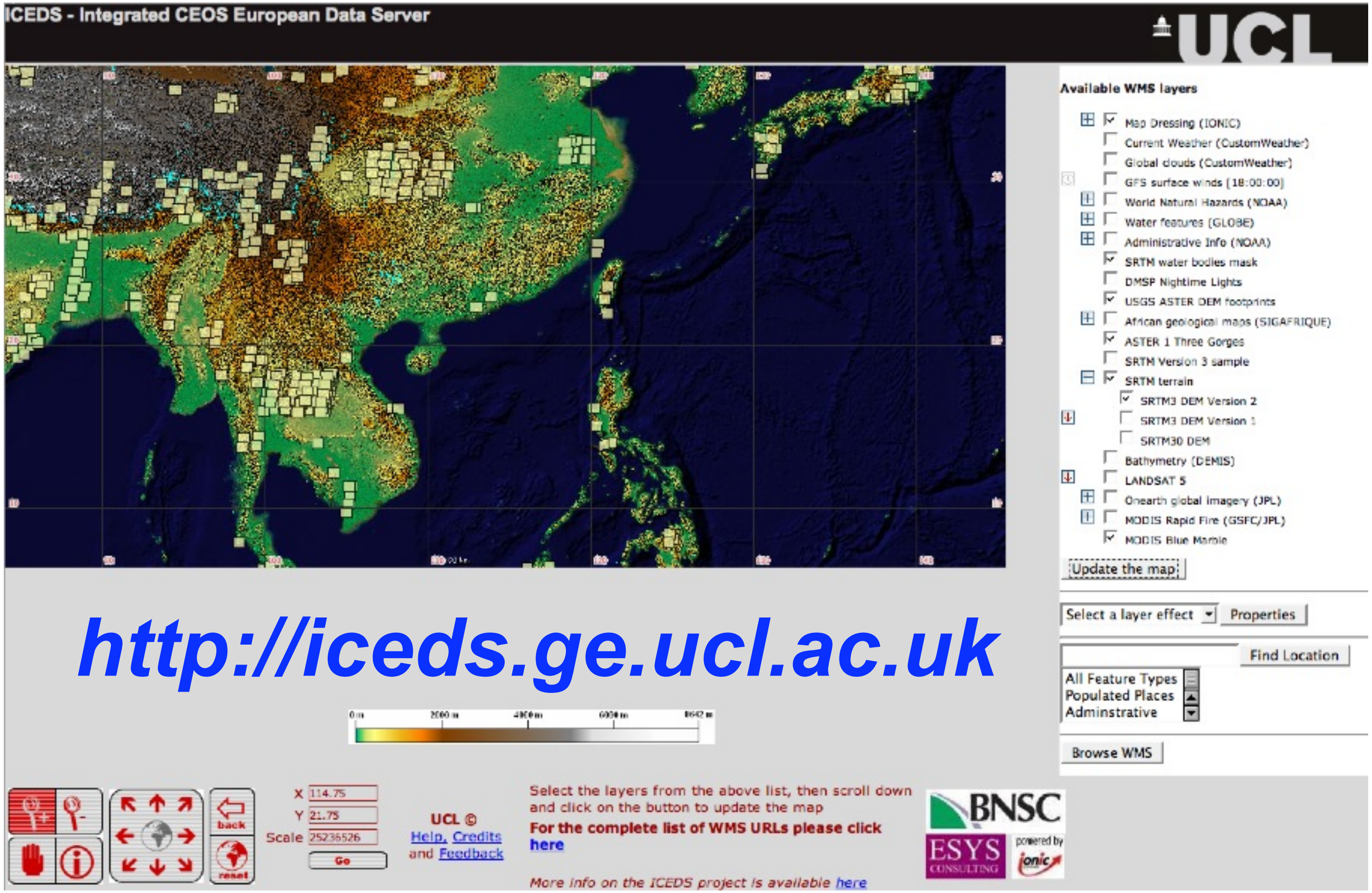


Contact: David Harding, NASA Goddard Space Flight Center, Code 698, David.J.Harding@nasa.gov

A web-GIS for Global DEM Inter-operability
http://iceds.ge.ucl.ac.uk

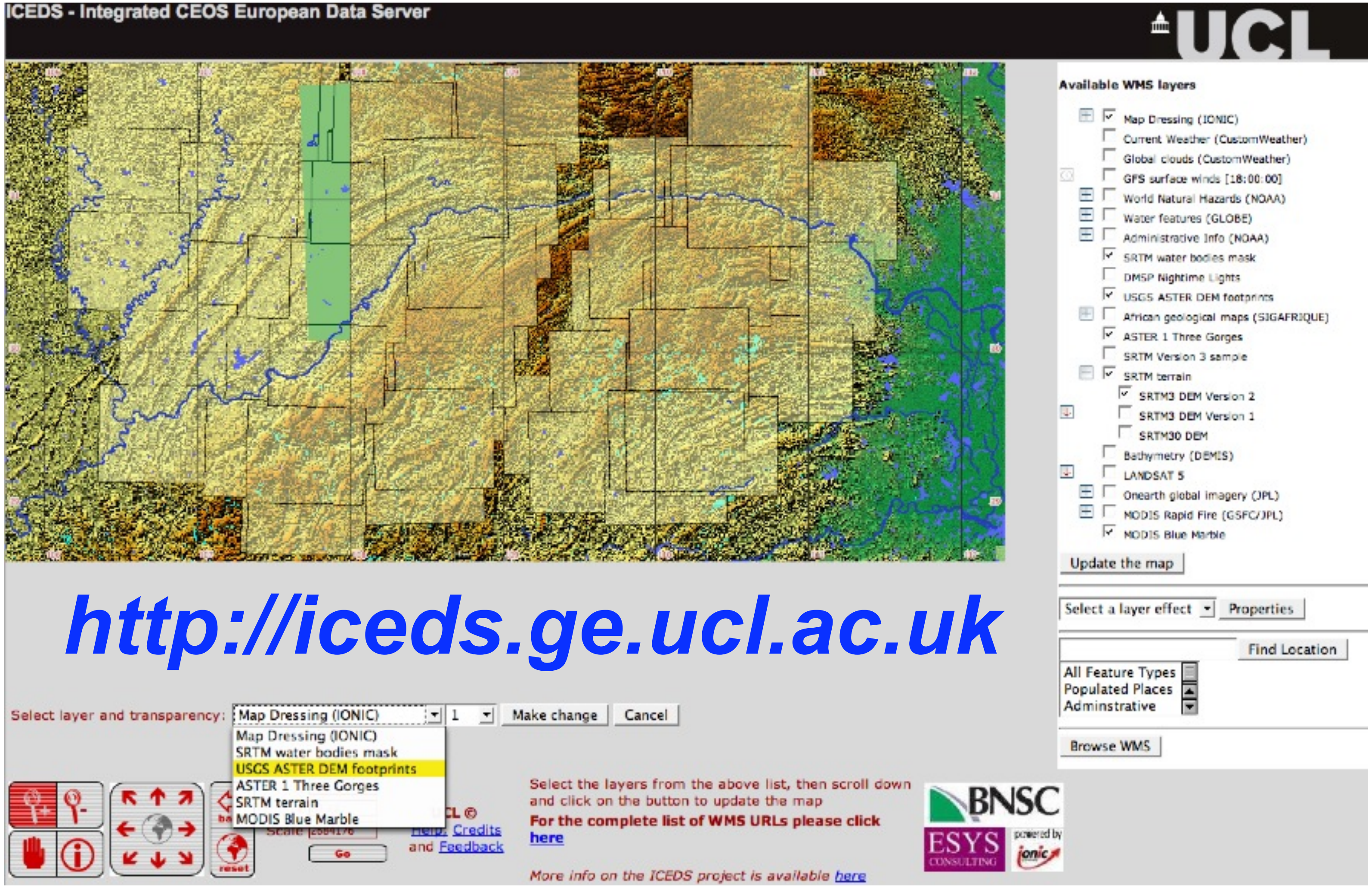
- **CEOS-WGISS project (EO Data Portal) sponsored by BNSC**
- **OGC-compliant web-site using any standard web browser (IE, Firefox, Safari, Netscape). NO need for plug-in (cf. Google Earth).**
- **OpenSource available as well as guidelines on how to setup ICEDS**
- **Delivering maps AND geospatial data-sets for any user-selectable area using OGC (Open Geospatial Consortium) protocols**
- **View topography alone or merged with image maps from multiple sources with overlaid best available mapping information**
- **Drill-down to anywhere on the planet to resolutions of 25m and map scales of 1:25 000 (at present)**
- **Explore change (e.g. Landsat 5 to 7) and context (e.g. rivers, transportation networks)**
- **View multiple datasets using transparency, swipe and flicker**
- **Explore geographical relationships by adding models at the regional, continental and global scale (e.g. tsunami impact on global population, dispersal of chemical or nuclear releases)**
- **Browse any WMS server images including internal datasets from within a firewall in context or for inter-comparison**
- **Ingest maps as new background images for Google Earth for 3D visualisation**

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

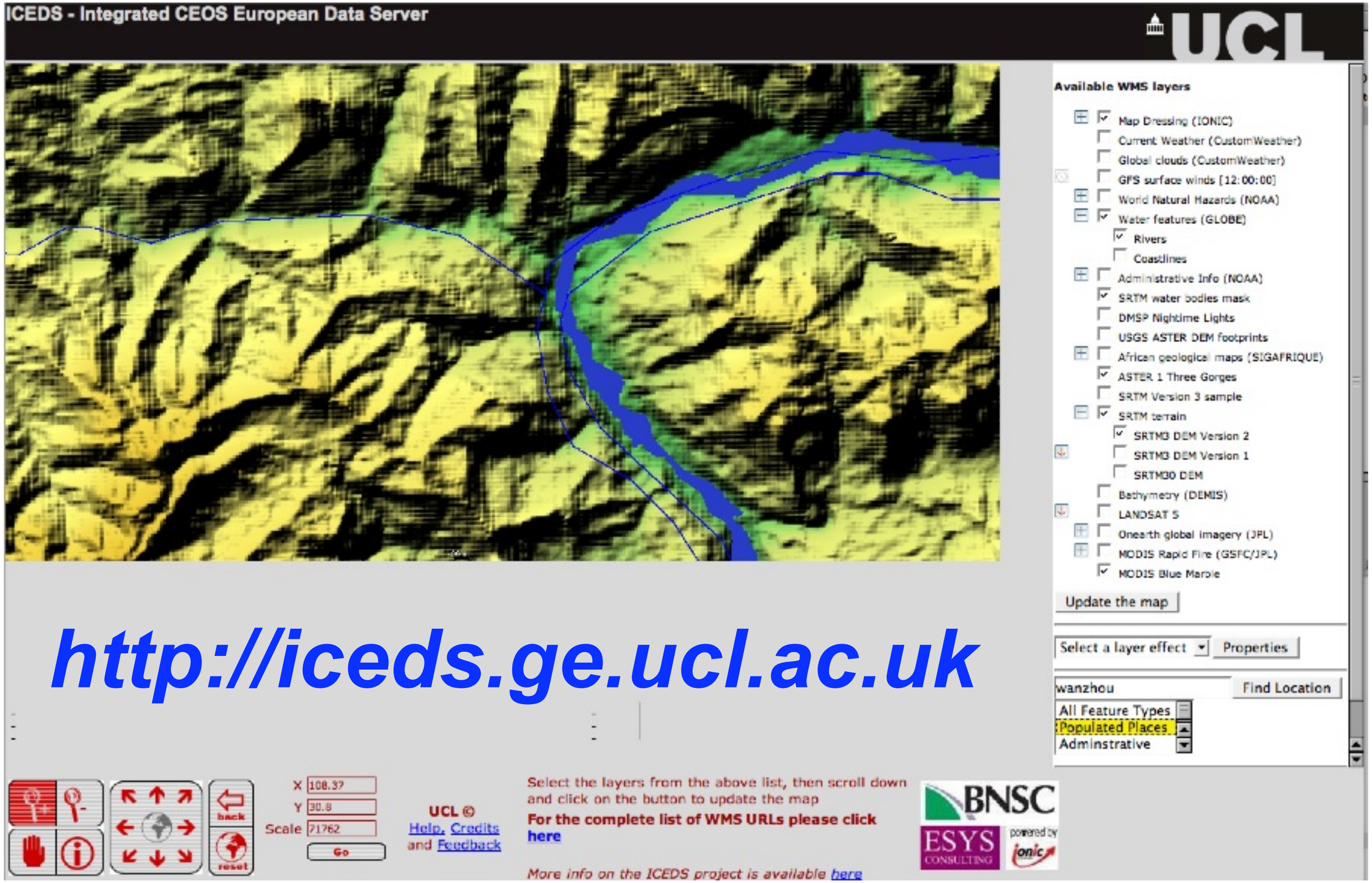


http://iceds.ge.ucl.ac.uk

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

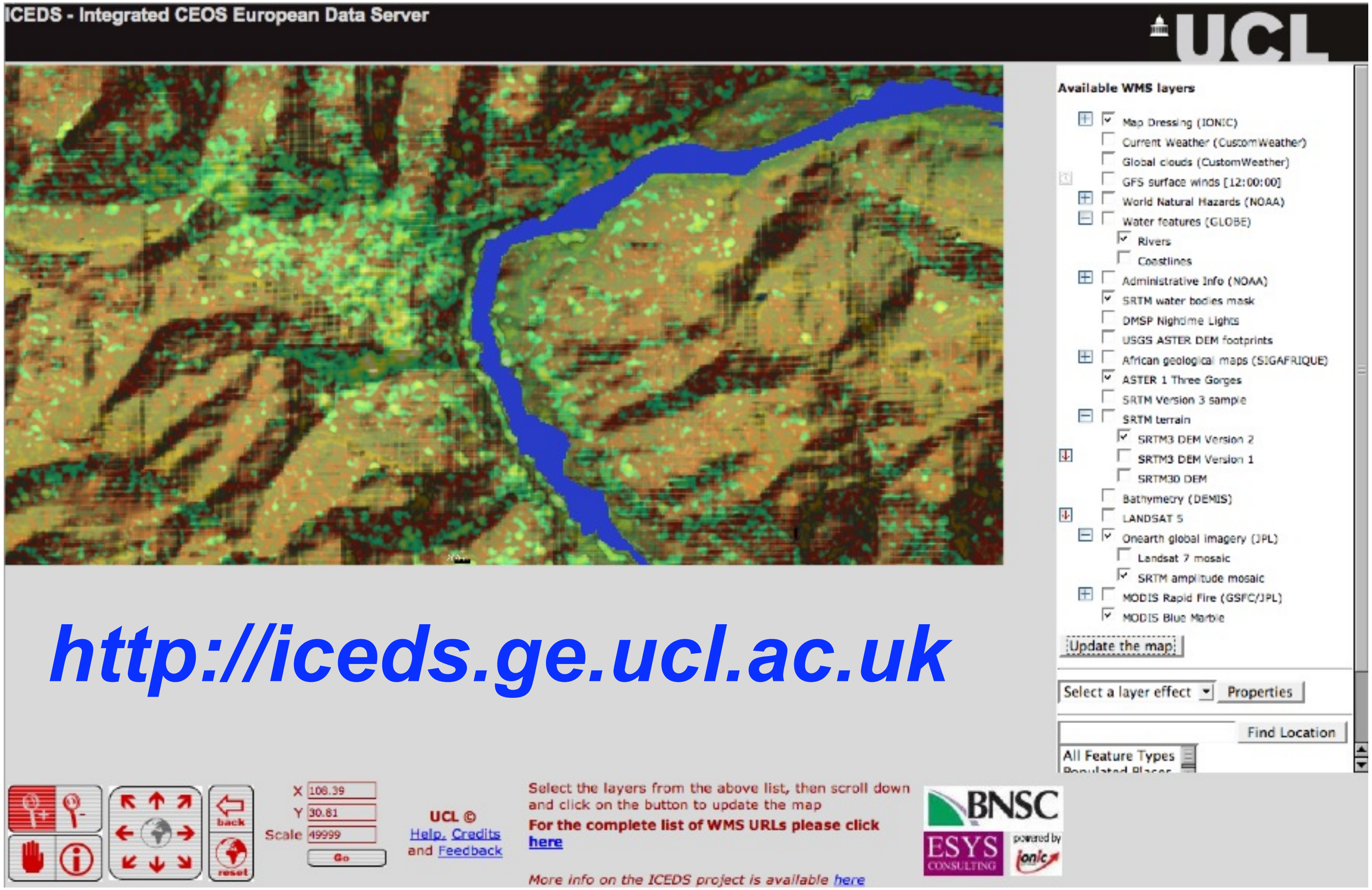


Example 3: ASTER-SRTM merged DEM with SRTM-derived and NOAA rivers (note errors!)



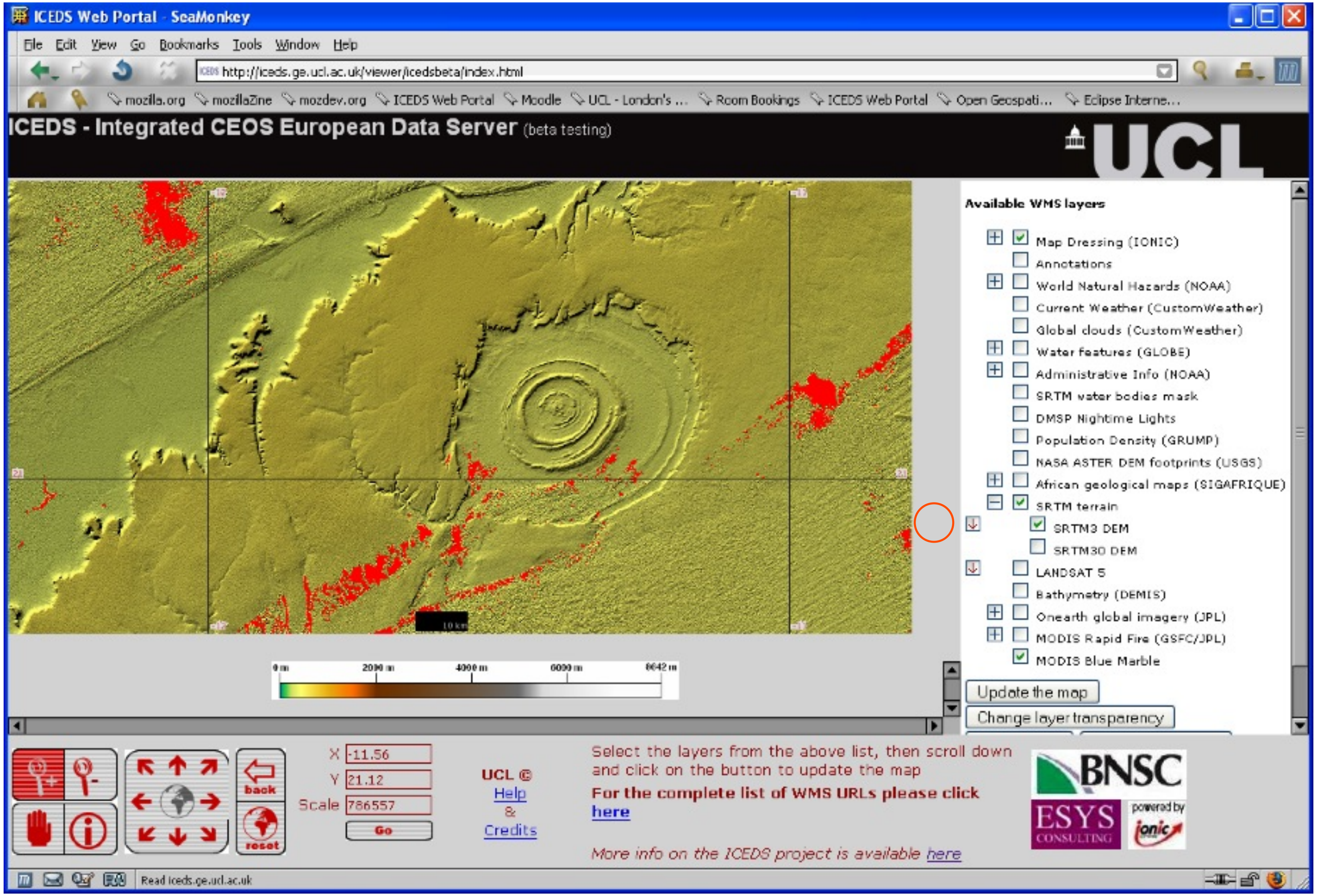
http://iceds.ge.ucl.ac.uk

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

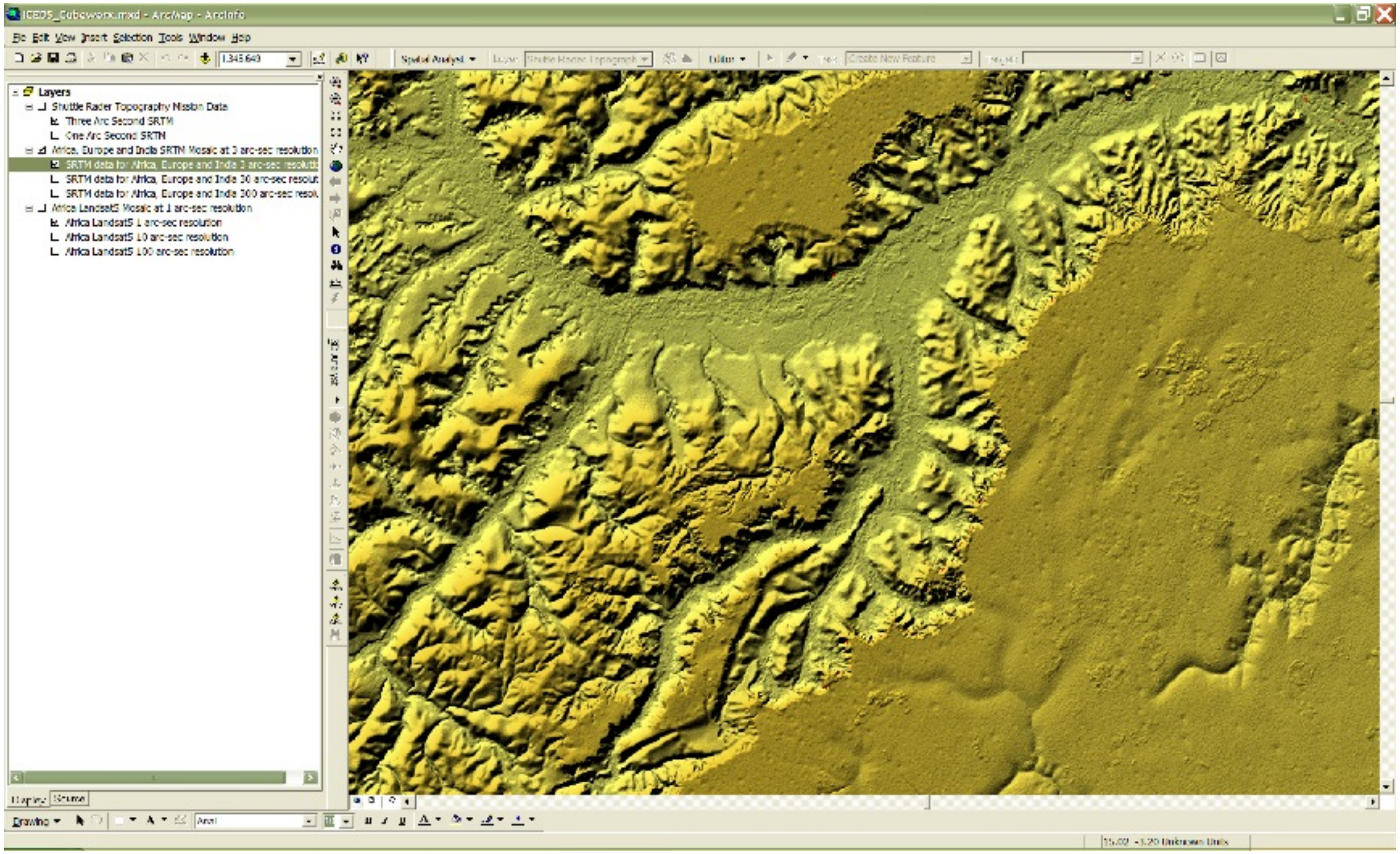


http://iceds.ge.ucl.ac.uk

And download data



Inter-operability : WMS Connection from ArcGIS



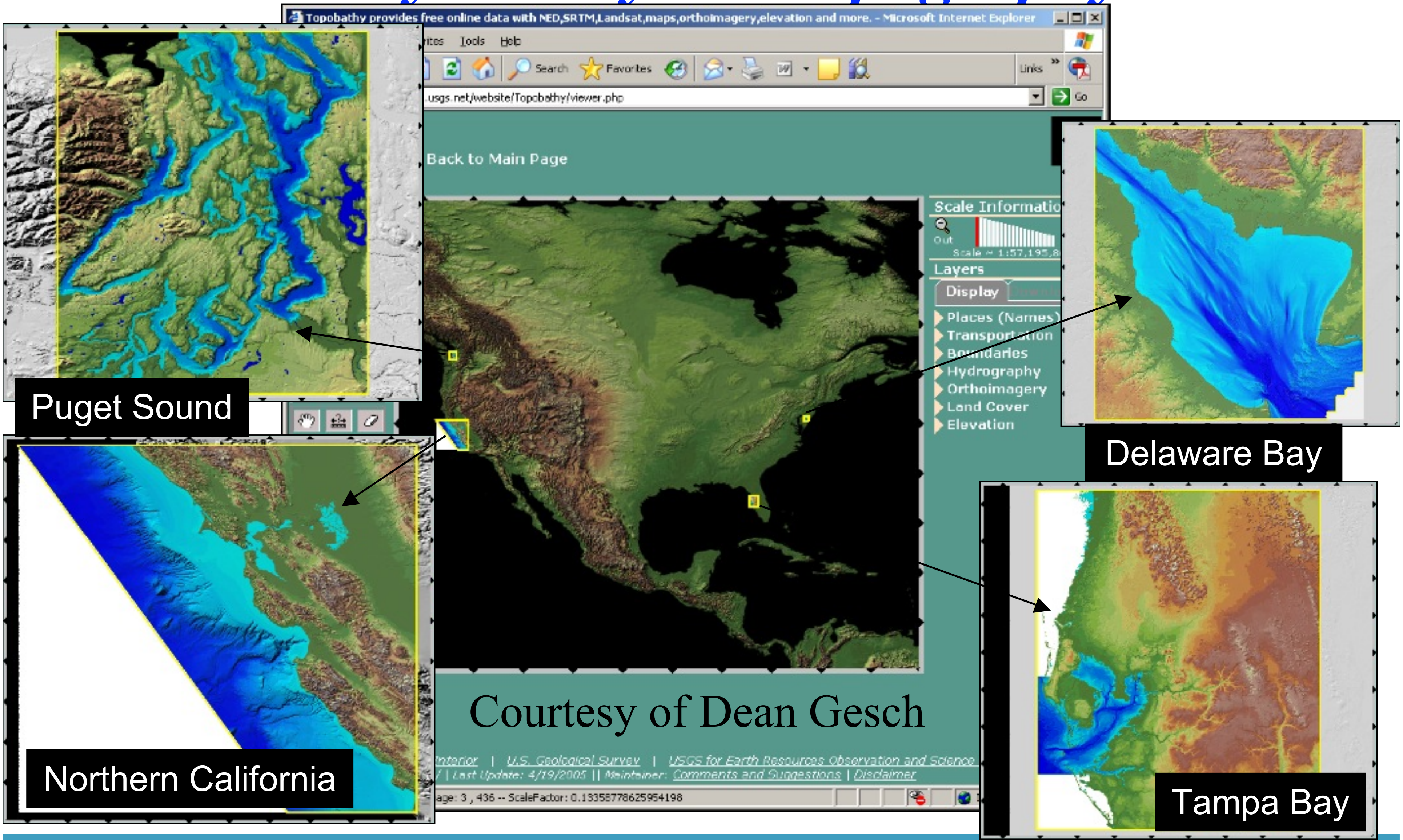
Inter-operability : Google Earth – live connection

Uses a PHP script at ESA to translate from WMS to KML for each refresh request

Outstanding Issues to resolve

- **Will any of the invited CEOS-GEOSS partners be willing and able to contribute height pixels to a free and unrestricted global dataset?**
- **What role WILL 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?**
  - **NOAA-NGDC are engaged in mapping extensive areas and USGS (see next slide) are also working in this area.**
  - **However, most other such bathymmetric data sources are extremely expensive 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



Courtesy of Dean Gesch