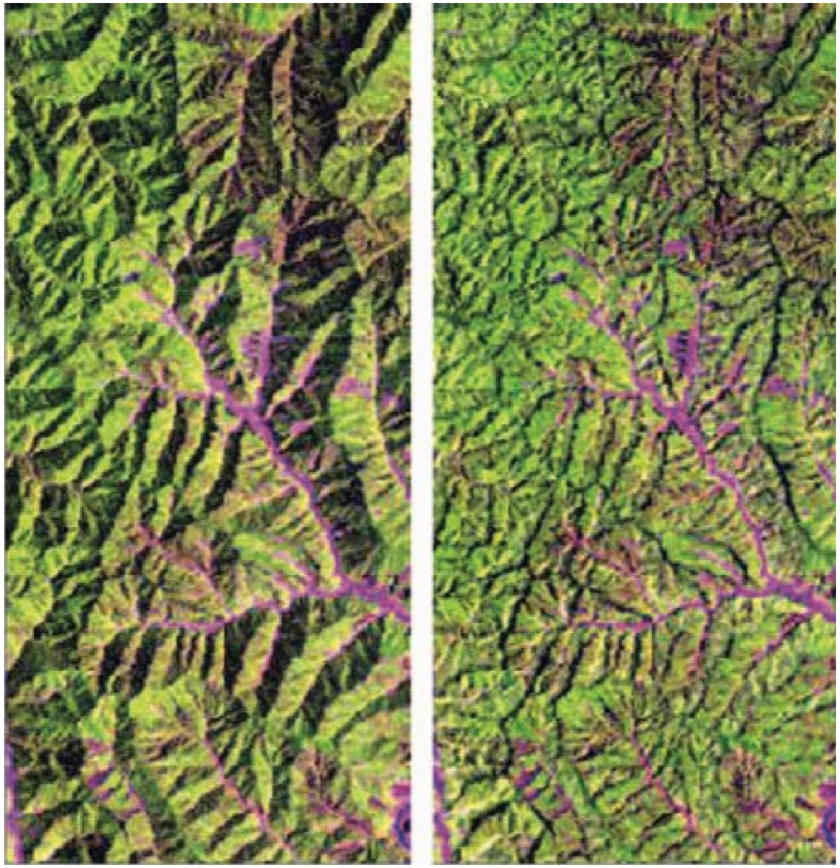
Global DEM :
why do we need it, what do we need and how can we achieve these requirements

Jan-Peter Muller
j.muller@ucl.ac.uk
Point-of-Contact, GEOSS Task IN-02
Chairperson, CEOS-WGCV Sub-group on Terrain mapping from satellites*
Chairperson, ISPRS Commission IV WG on "Global DEM Interoperability"
Head, Imaging Group
Professor of Image Understanding and Remote Sensing
Curiosity Science Team Member (NASA MSL 2012)
HRSC Science Team Member (ESA Mars Express 2003)
Stereo Panoramic Camera Science Team Member (ESA EXOMARS)
MODIS & MISR Science Team Member (NASA EOS Project)
TerraSAR-X and TANDEM-X science team member (DLR-Astrium)

**partially supported by UK Space Agency*

Why do Space Agencies need global topography: VIS/NIR?

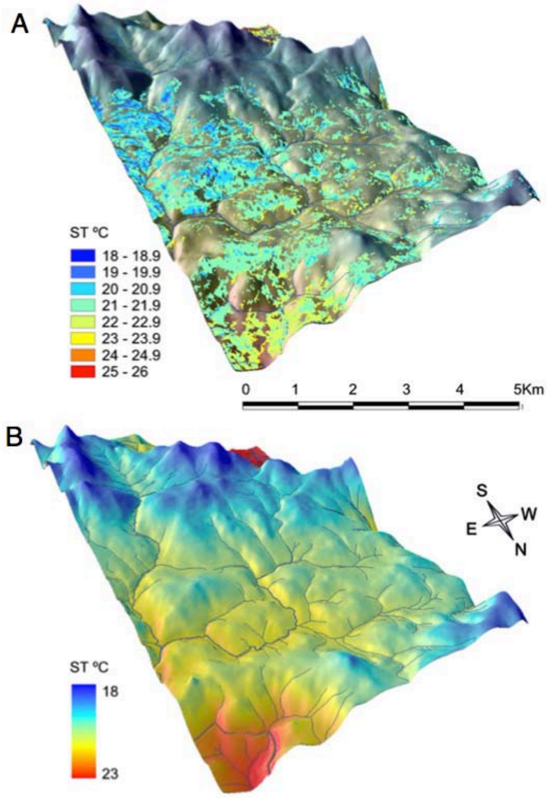
- ***Optical sensors with IFoV≤1km and any off-nadir directional viewing ≥30º require terrain relief correction to co-align pixels***
- ***Atmospheric correction requires calculation of path radiance which depends on altitude***
- ***Land cover classification of VIS/SWIR multispectral/hyperspectral imagery require hill-shading correction to minimise misclassification errors***
- ***All land (ToA & BoA) VIS/SWIR products require geo-radiometric correction (e.g. Sentinel-2 requires 30m DEM)***



Gao and Zhang (2009). A simple empirical topographic correction method for ETM+ imagery. IJRS, 30(9): 2259-2275

Why do Space Agencies need global topography : TIR?

- ***Thermal sensors with IFoV≤1km and any off-nadir directional viewing ≥30º require terrain relief correction to co-align pixels***
- ***Thermal retrievals require corrections for altitude, slope and aspect as well as vegetation cover fraction within a pixel***
- ***All land surface temperature products require geo-radiometric correction (e.g. Sentinel-3 requires 1,500m DEM)***

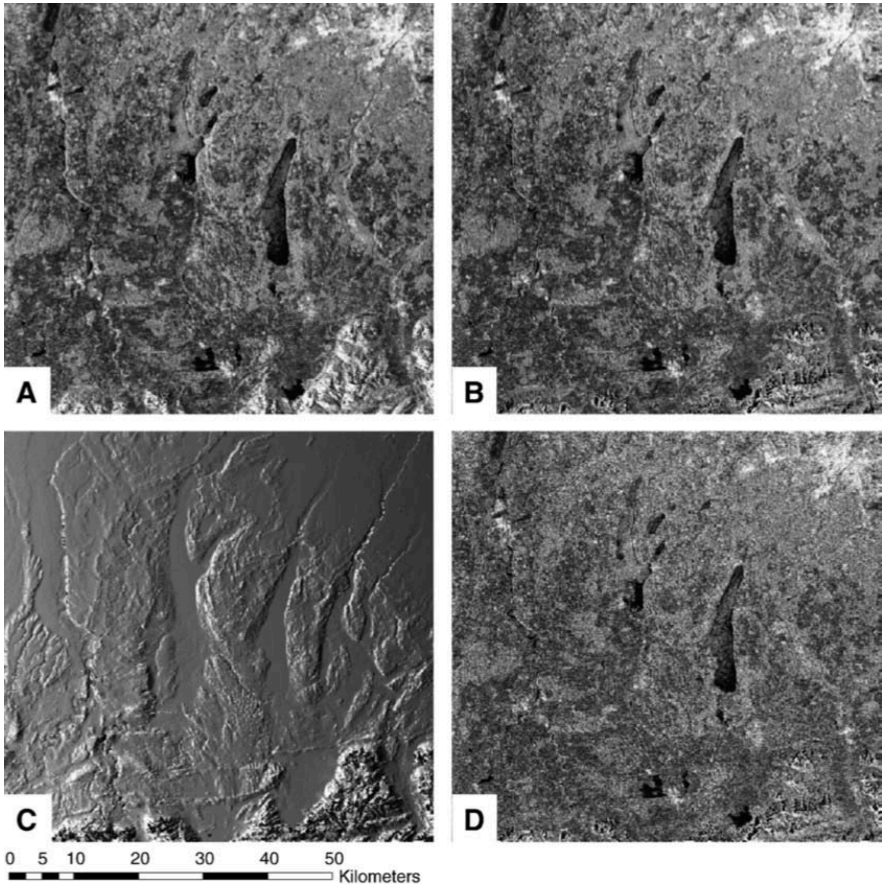


(A) Surface temperature (ST) of spruce forest stands from Landsat 7 ETM+ (28 July 2002). Higher temperatures of the small forest areas and also of areas with lower elevation can clearly be seen. (B) Estimated surface temperature according to Eq. (9) (above). The ST was extrapolated for the whole area.

Hais and Kučera (2009) The influence of topography on the forest surface temperature retrieved from Landsat TM, ETM+ and ASTER thermal channels. ISPRS J.Photogram & Rem. Sens., 64: 585-591

Why do Space Agencies need global topography : SAR?

- *SAR imaging is always off-nadir and therefore requires accurate DEM for terrain distortion removal (shadow, occlusions, layover)*
- *SAR imaging also contains slope/aspect related radiometric distortions that require correction*
- *All land products require geo-radiometric correction (e.g. Sentinel-1 requires 10m DEM)*



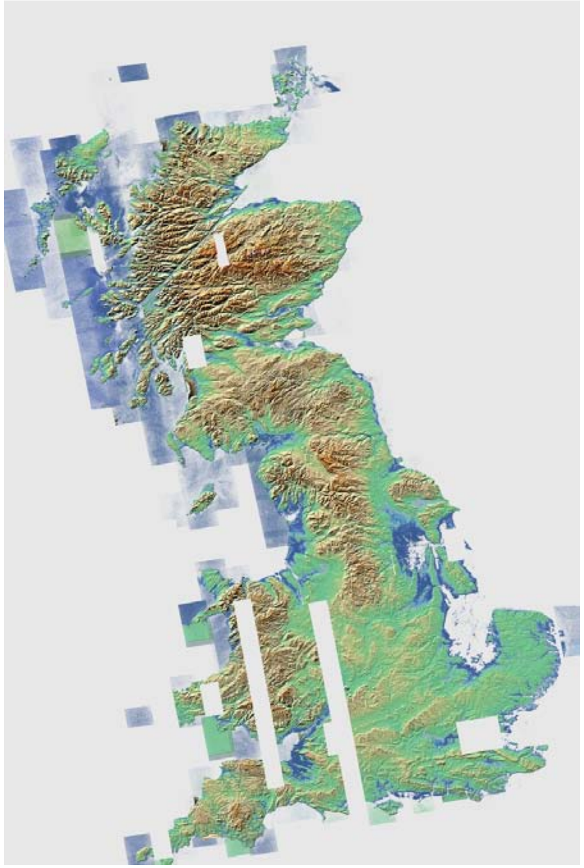
Loew and Mauser (2007) Generation of geometrically and radiometrically terrain corrected SAR image products. Remote sensing of environment,106: 337-349

What do Space Agencies need for different spectral regions?

- For geometric and radiometric (commonly called “georadiometric”), a ratio of 3:1 has been established by common practice for <u>terrain relief correction</u>, so for ESA
  - Sentinel-1 (10m-100m) needs DEMs from 30-300m, Zrmse unknown
  - Sentinel-2 (5m-60m) needs DEMs from 15-180m, Zrmse unknown
  - Sentinel-3 (300m-1km) needs DEMs from 1-3km, Zrmse unknown
- For radiometric correction, slope angle precision or accuracy - unknown unknown
- For atmospheric correction (path radiance) need DEMs with sampling up to 100m
- For impacts on atmospheric composition, known unknowns (e.g. spectral refelcatnec at 1.65µm for xCO2 & xCH4 need better than 0.01 in reflectance (H. Bosch, U of Leicester)

So what is available to meet these requirements: 15m

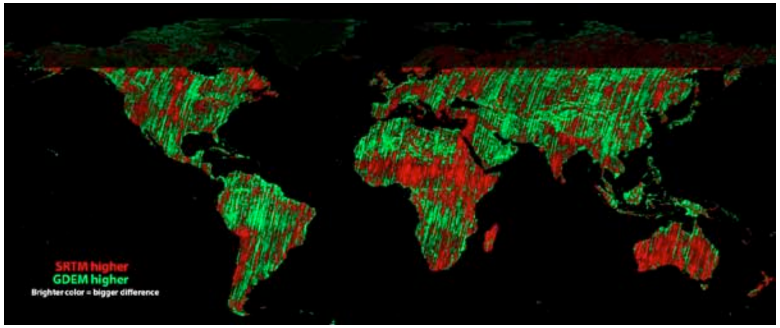
- **Astrium GmbH WorldDEM®**
- **12m grid, 10m absolute, 2m relative**
- **Unknown if the absolute accuracy is sufficient**
- **Need for simulation studies to be performed**
- **Cost per sq.km. unknown but for global land surface likely to be astronomical**



http://www.astrium-geo.com/worlddem/

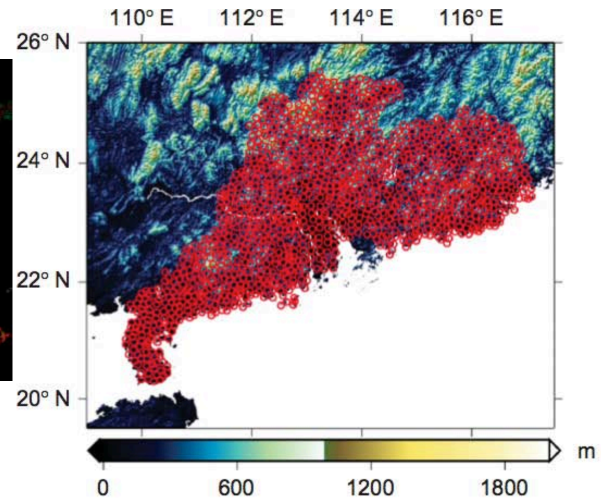
So what is available to meet these requirements: 30m

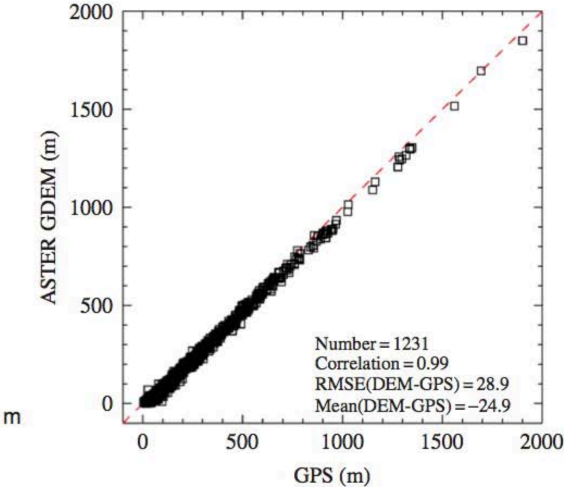
- **ASTER GDEM v2.0; Astrium GmbH: WorldDEM®**
- **≈30m (1”) grid: Zrms=23-26m; 10m absolute, 2m relative**
- **ASTER DEM freely available under GEO restrictions**
- **NASADEM (SRTM+ASTER) due for release in 2017**



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Courtesy M. Kobrick, JPL

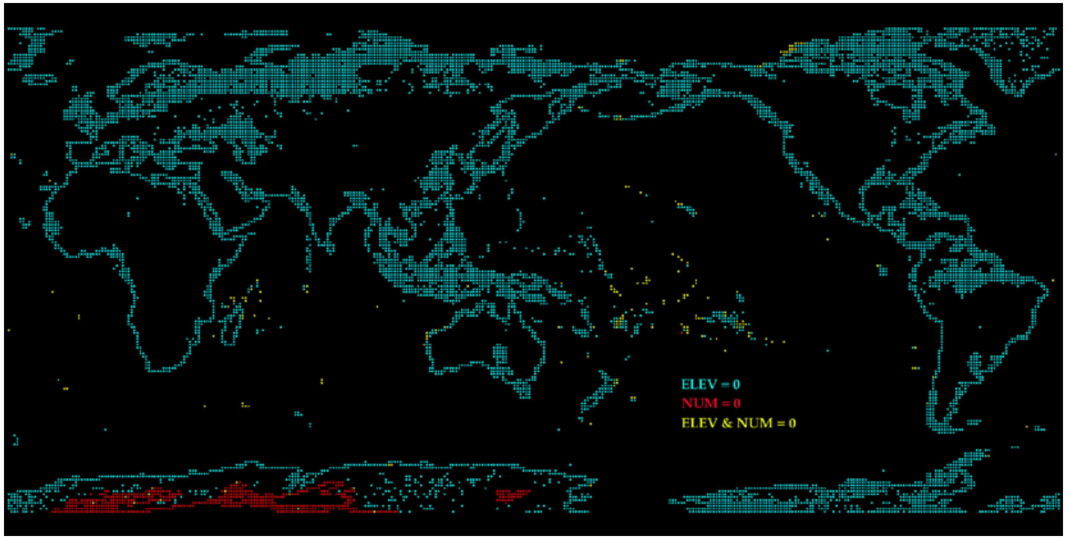




Li, Muller et al. (2013) Evaluation of ASTER GDEM using GPS Benchmarks and SRTM in China. Int. J. of Rem. Sens. 34(5): 1744-1771

So what is available to meet these requirements: 90m

- SRTM v3.0 – mashup of ASTER GDEM v2 with SRTM v2.0
- ≈90m (3”) grid, 10-15m absolute, 2m relative based on experience with ASTER GDEM v2 and SRTM v2
- Need for validation
- Unknown if the relative accuracy is sufficient for slope correction
- Need for simulation studies to be performed
- Freely available



National Aeronautics and Space Administration
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, California

Courtesy R. Crippen, JPL

What next?

- **Need for validation of SRTM v3.0 to ensure that quality can be maintained across boundaries between ASTER GDEM & SRTM**
- **Need to look into low cost solutions to the DEM "requirements gap" for ASTER GDEM v2.0.**
- **Are there other solutions?**
- **Need for simulation studies to evaluate the impact of the use of the 30m for use at 15m and whether errors in the 30m DEM datasets will make the resultant products "fit for purpose" for the different EO sensors**
- **Where could these simulation studies be performed? CEOS-WGCV TMSG test sites, of course!**
- **How could we assess whether the Global DEM sources are "fit-for-purpose"?
  DEMqis**

CEOS-WGCV-TMSG test sites – ground “truth”

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

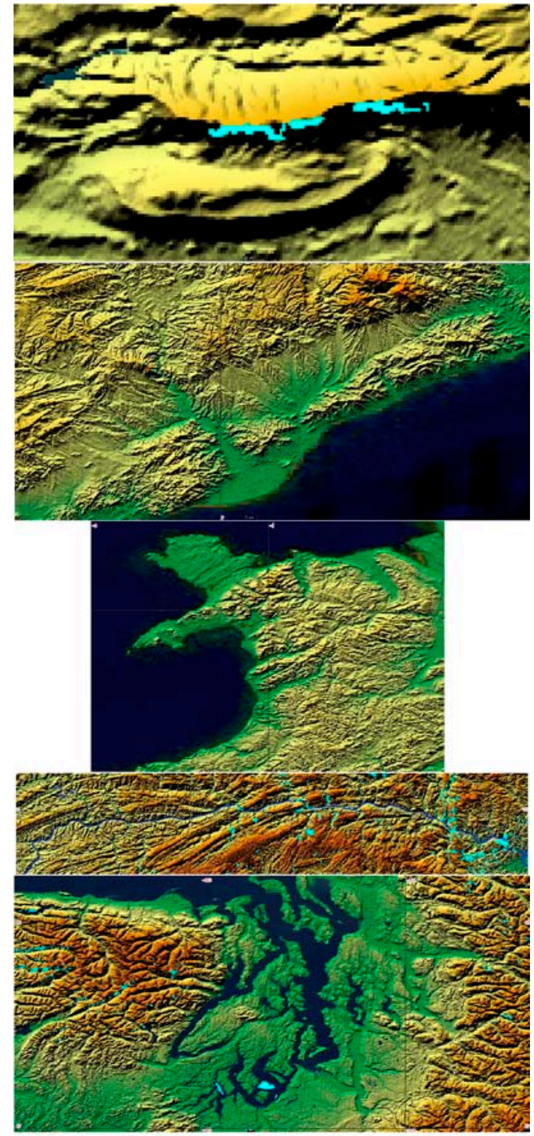
- **Barcelona, Spain**
  1.5-2.75ºE, 41.25-41.82ºN
  urban, mixed arable, forest

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

- **Three Gorges, China**
  108.252-111.302ºE, 30.638-31.229ºN
  forest, arable, limestone shales

- **Puget Sound, WA, USA**
  -121.397 to -123.897ºW, 46.364-48.864ºN
  forest, urban, wetlands

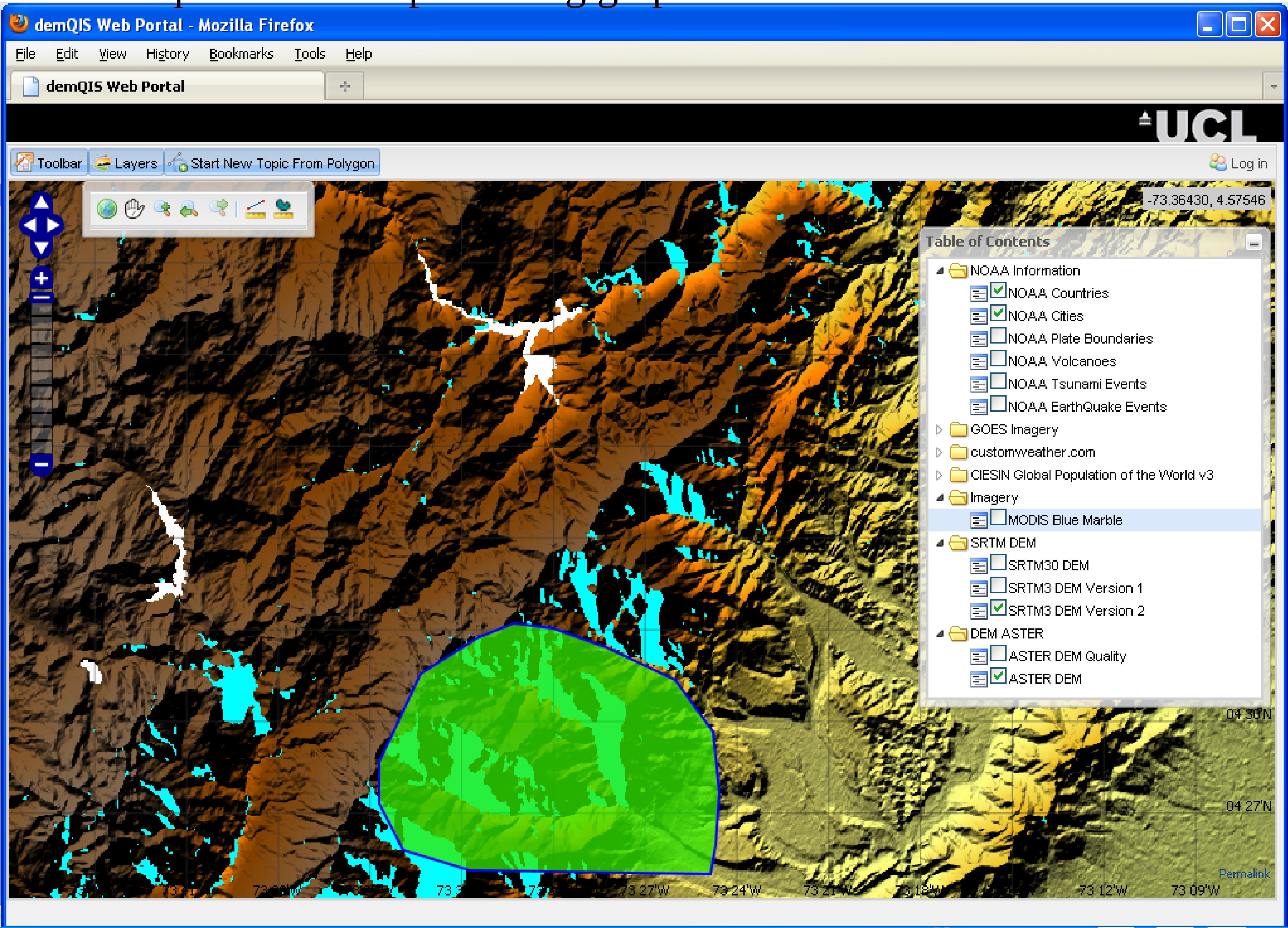
- **Simmons Creek (courtesy of J. Gallant)**
  146.833ºE, -35.615ºS (+3 others not shown)



DEMqis functions

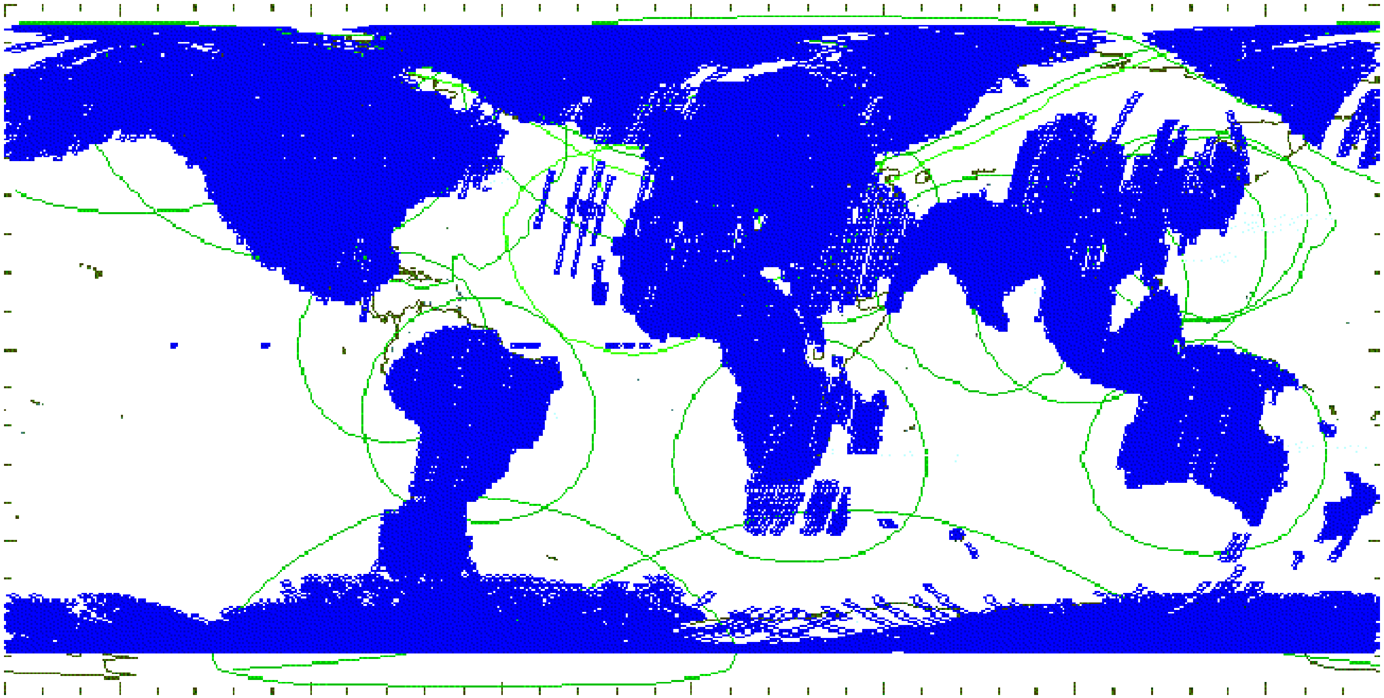
- Display in-house hosted SRTM and ASTER GDEM as WMS
- Cascade to WMS such as George Mason University DEMexplorer WMS
- Includes transparency to mix and match different datasets
- Includes flicker to allow two datasets to be compared (e.g. ASTER and SRTM)
- Includes change of overlay priority from one dataset to another
- Includes graphical outlining of areas where artifacts have been identified
- Allows descriptive information to be added to each artifact located and inserted into the PostGreSQL database
- Current system only available inside the MSSL firewall

DEMqis screendump showing graphical outline of area with artifact



What datasets NOW could be exploited to meet the requirements for the 30m DEM

- **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. These problems could be addressed using the SRTM v3.0, ASTER GDEM v2 and 90m TanDEM-X**



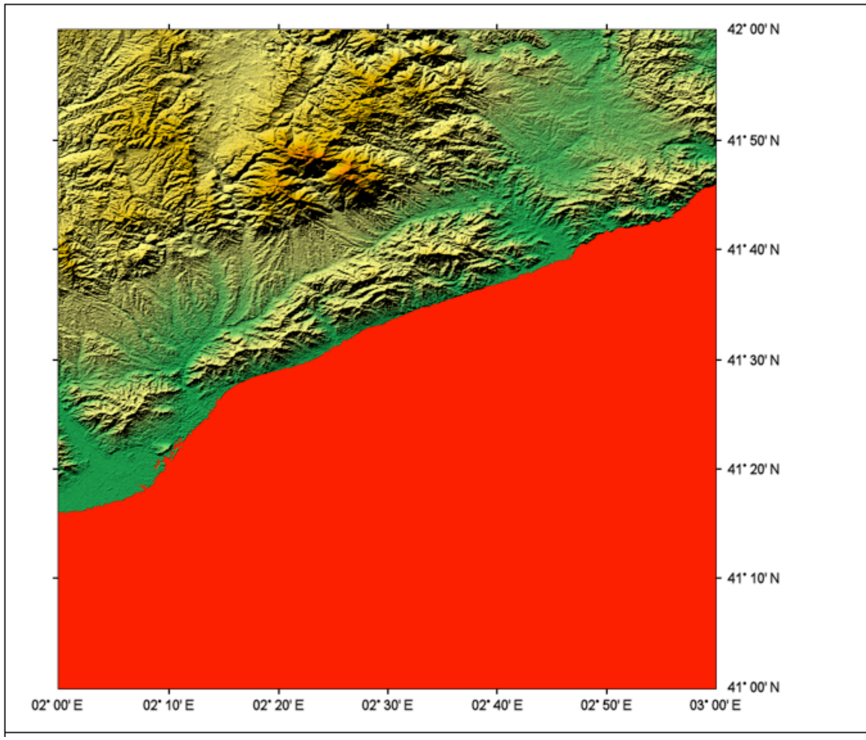
ESA ERS-1/ERS-2 SAR tandem acquisition pairs with optimum baseline values for DEM generation
(status of 1 June 1996)

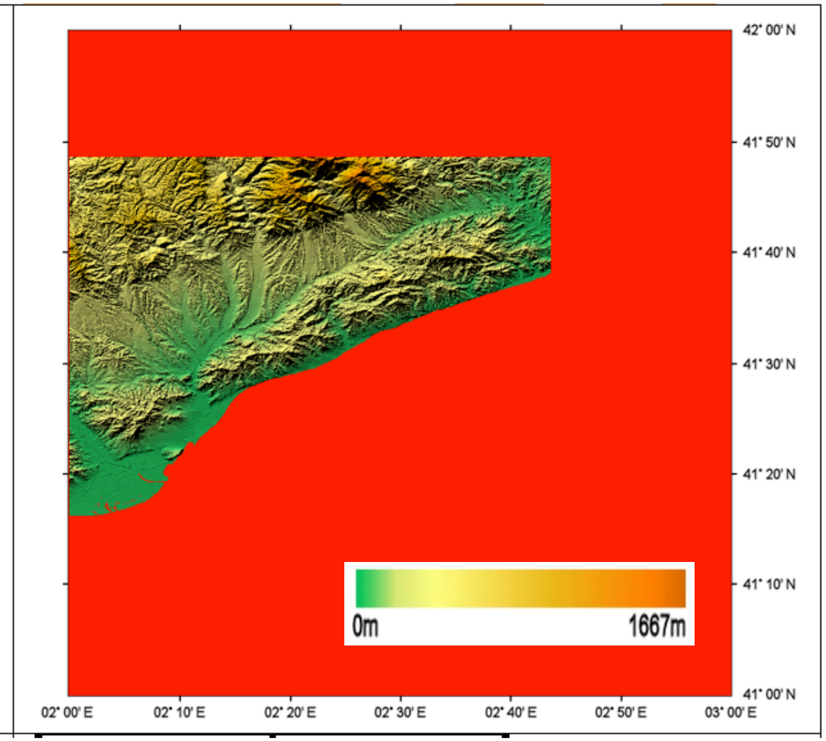
P.S.

- **A number of space agencies around the world require a 3D GCP dataset for optical (& SAR) georeferencing of global EO imaging data**
- **Creating a global DEM at 30m would allow you to generate a global set of GCPs**
  - **if multispectral images such as Landsat-8 were available and**
  - **could be used together with automated feature extraction (e.g. SIFT) and**
  - **the image chips were made publicly available**

Backup Slides

ASTER intercomparison with ICC DTM : Barcelona (1)

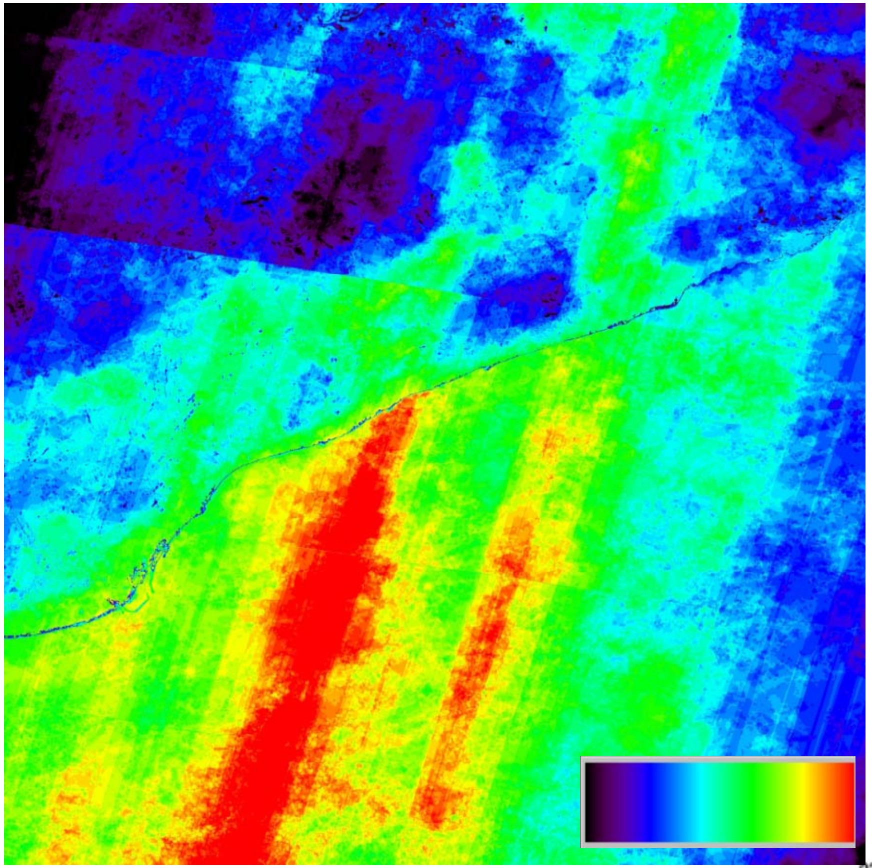




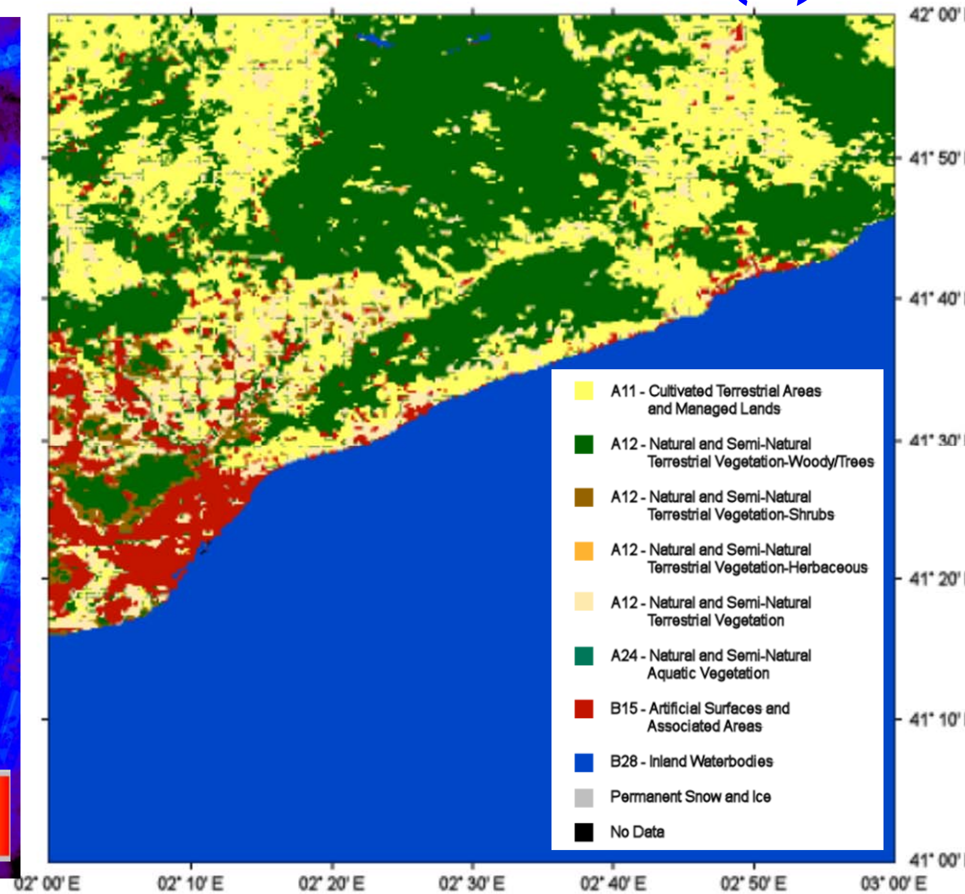
ASTER at 1 arc-seconds

ICC resampled to 1”

ASTER intercomparison with ICC DTM and GLC2000 Land Cover: Barcelona(2)

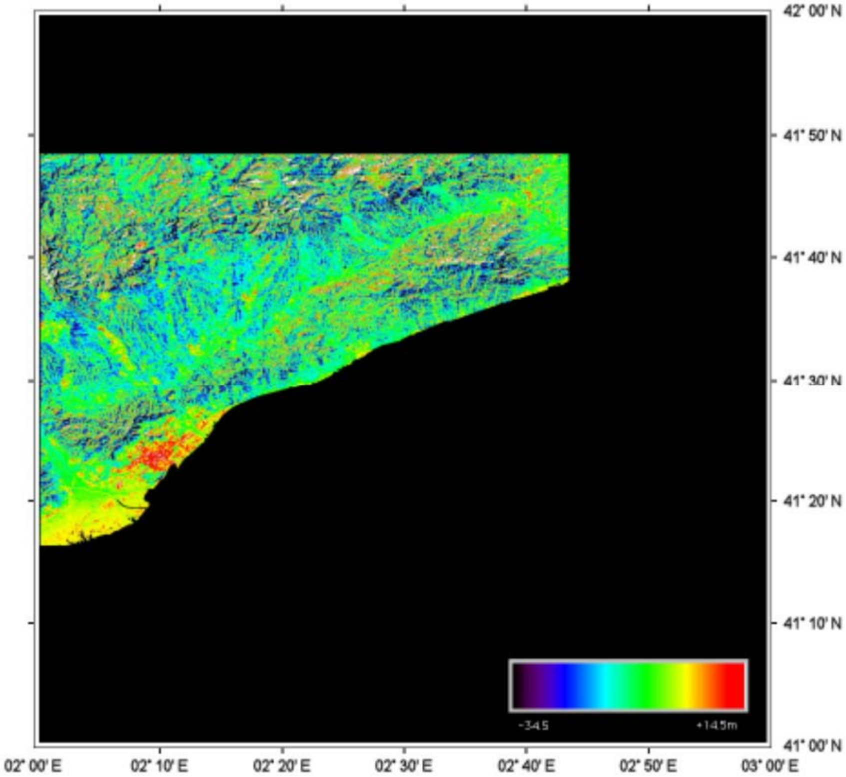


Stacking Number (1-54)



GLC2000 resampled to 1”

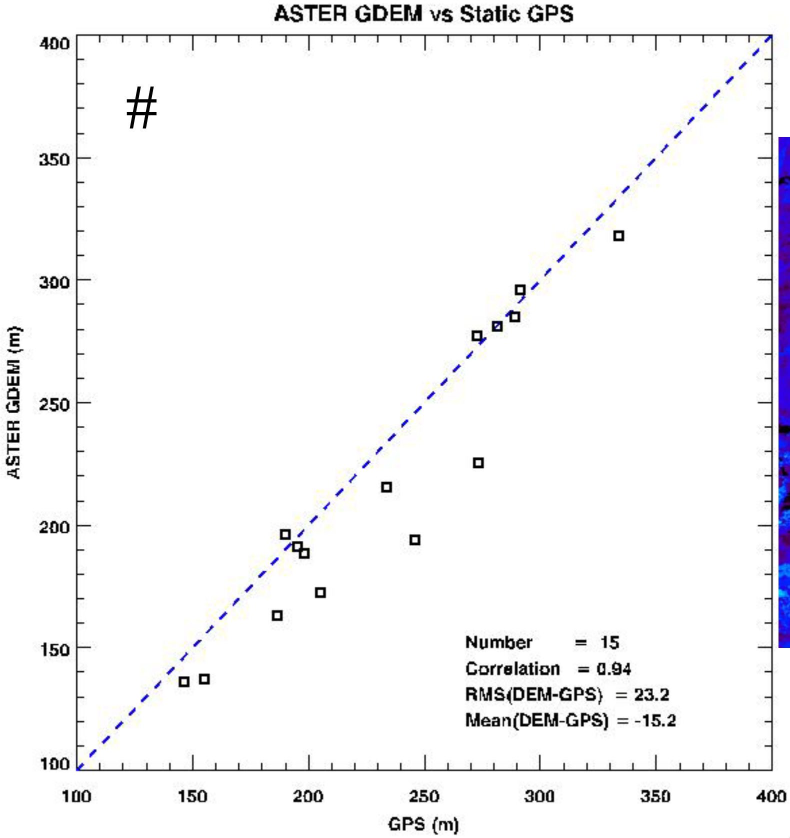
ASTER-ICC DEM height difference

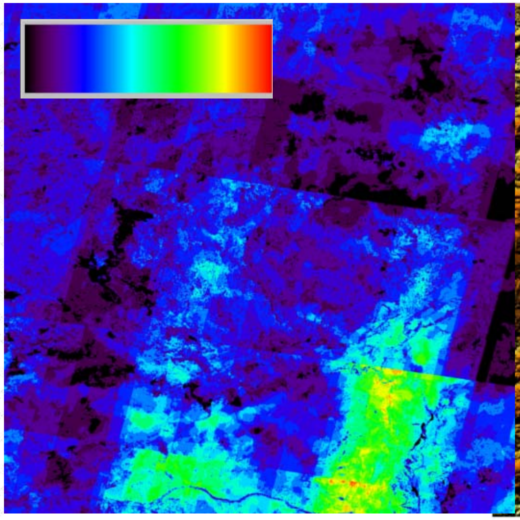


Largest negative height difference in downtown urban area. Still indication of topographic shifts

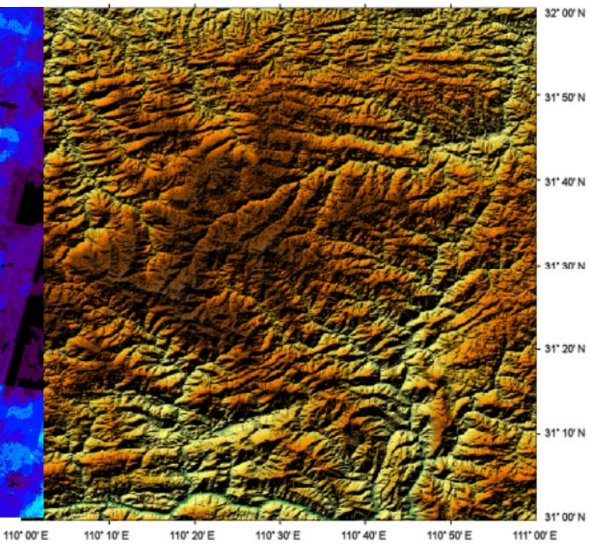
Minimum	Maximum	Mean	Standard Deviation	RMSE	Land cover class	% of Land cover Class
-243.347	105.582	-8.688	11.243	14.209	All	25.3%
-130.577	88.030	-11.090	8.893	14.215	A11-Cultivated Terrestrial Areas and Managed Lands	6.5%
-243.347	105.582	-8.194	13.586	15.866	A12-Natural and Semi-Natural Terrestrial Vegetation-Woody/Trees	10.5%
-67.203	36.786	-11.539	9.704	15.077	A12-Natural and Semi-Natural Terrestrial Vegetation-Shrubs	1.0%
-41.012	16.213	-18.662	10.011	21.175	A12-Natural and Semi-Natural Terrestrial Vegetation-Herbaceous	0.0%
-114.895	77.297	-9.712	8.636	12.996	A12-Natural and Semi-Natural Terrestrial Vegetation	3.3%
N/A	N/A	N/A	N/A	N/A	A24-Natural and Semi-Natural Aquatic Vegetation	0.0%
-127.141	64.932	-5.521	9.062	10.611	B15-Artificial Surfaces and Associated Areas	3.4%
-40.970	11.530	-0.106	1.258	1.263	B28-Inland Waterbodies	0.7%

ASTER inter-comparison for China (1)





NUMB (0-16 range)



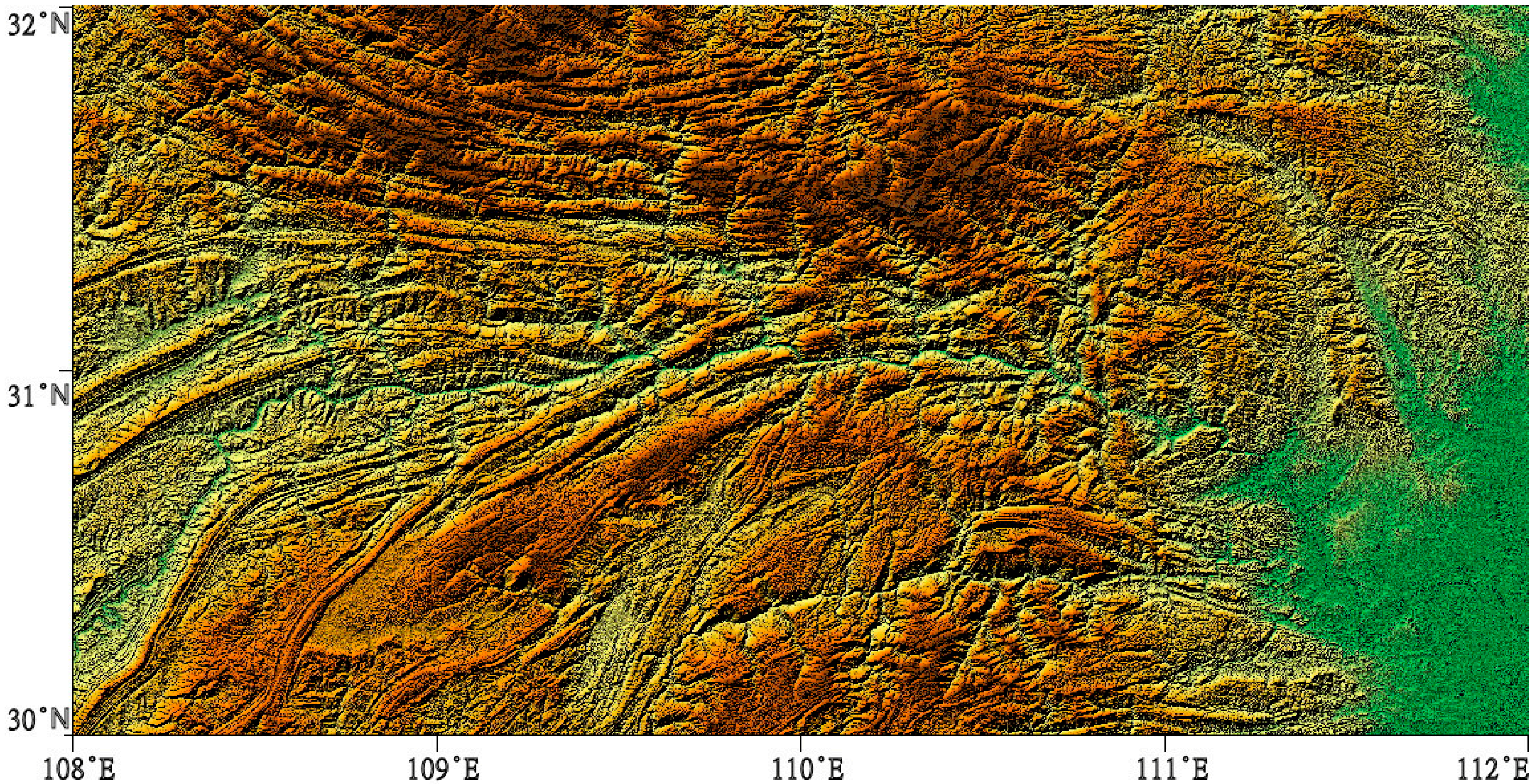
N31E110 cell

Minimum	Maximum	Mean	Standard Deviation	RMSE	Land cover class	% of Land cover Class
-598.4117	588.2874	-0.8835	38.7811	38.2586	All	100%
-449.6283	388.3965	-1.9291	30.7005	30.6784	A11-Cultivated Terrestrial Areas and Managed Lands	30.00%
-598.4117	588.2874	-0.1675	42.7544	42.5062	A12-Natural and Semi-Natural Terrestrial Vegetation-Woody/Trees	57.40%
-492.6981	444.2789	-1.8396	37.1318	37.1413	A12-Natural and Semi-Natural Terrestrial Vegetation-Shrubs	12.20%
-215.4204	87.0000	-2.3945	20.7468	20.8688	A12-Natural and Semi-Natural Terrestrial Vegetation-Herbaceous	0.20%
-46.0093	80.4022	18.0907	21.2755	27.9181	B15-Artificial Surfaces and Associated Areas	0.01%
-211.3181	142.8655	9.1473	28.7320	30.0996	Inland Waterbodies	0.19%

N.B. Much larger standard deviation but smaller bias but topography much rougher than UK

Zhenhong Li (Glasgow University), Yingbing Li, Peng Li (Wuhan University)

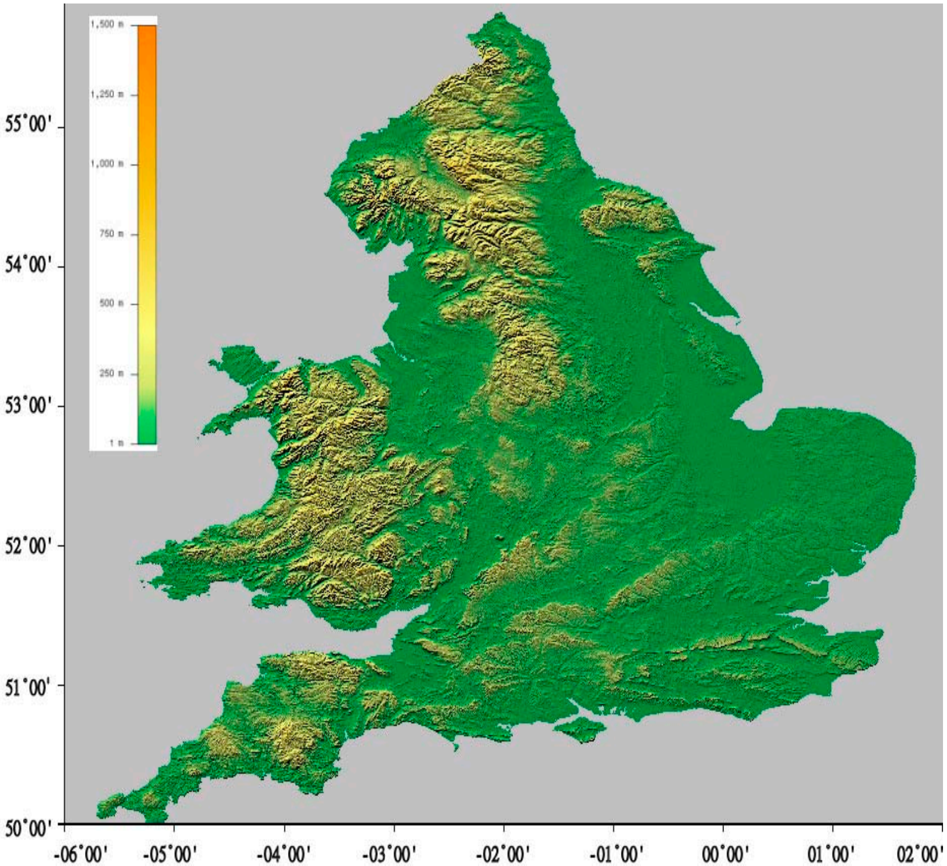
ASTER inter-comparison for China (2): 3G



ASTER-CNED** ALL points 3G area
-4.12 ± 35.94 for 101, 052, 840 points

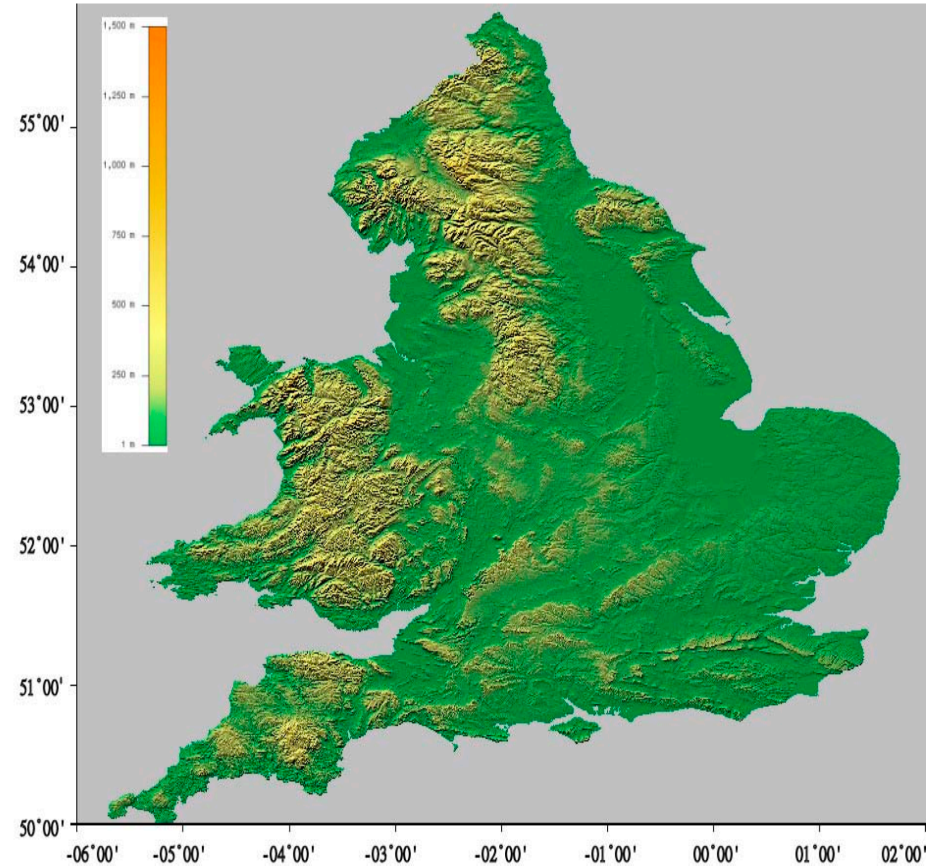
** analysis performed by G. Lixia (CSB)

UK Intercomparison of ASTER, with BlueSky DTM



ASTER DEM at 1 arc-seconds

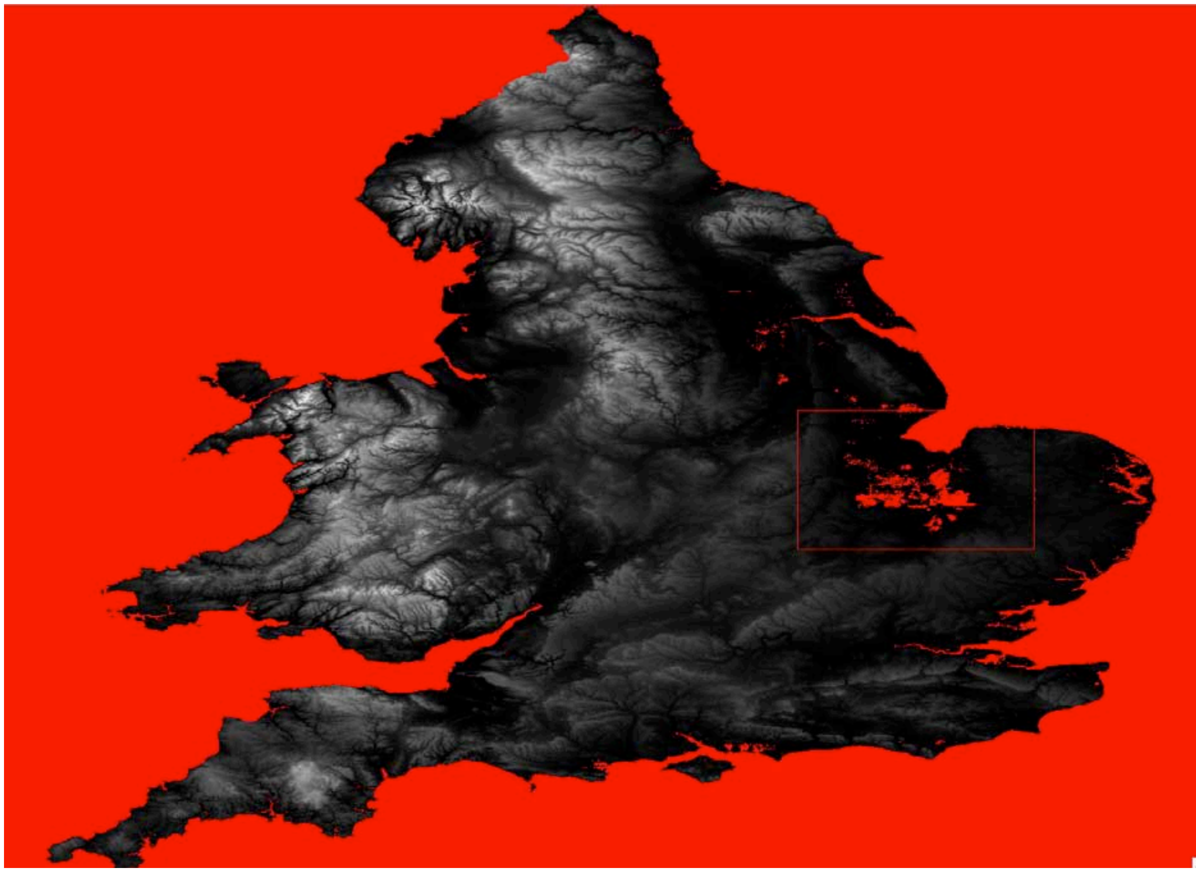
Zrms=10m

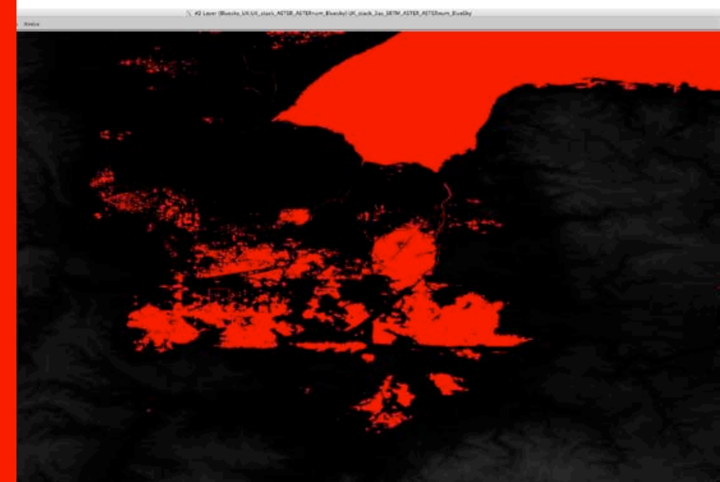


BlueSky DTM resampled to 1"

Zrms= 1.5m

UK Intercomparison of ASTER, SRTM with BlueSky (1)

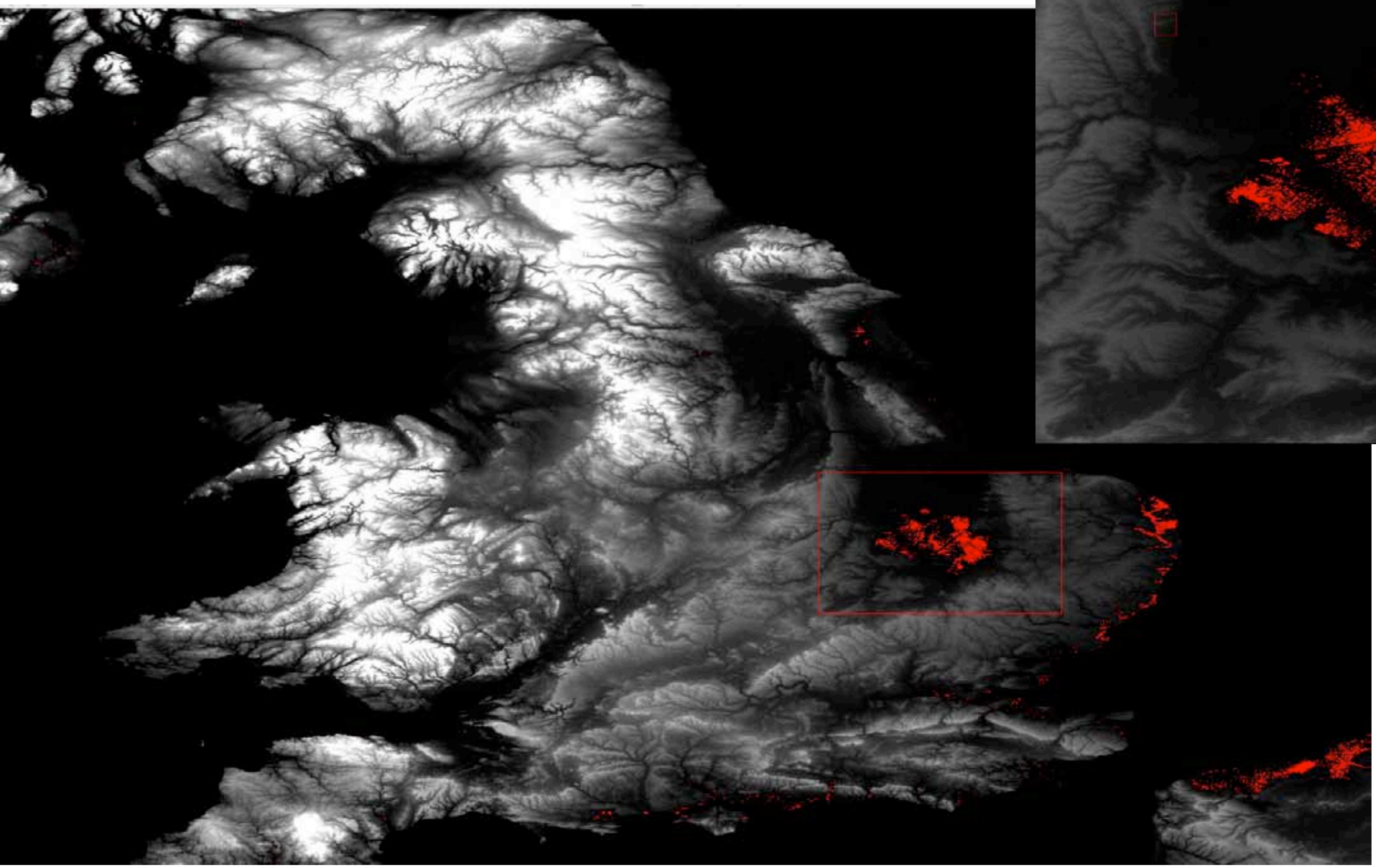


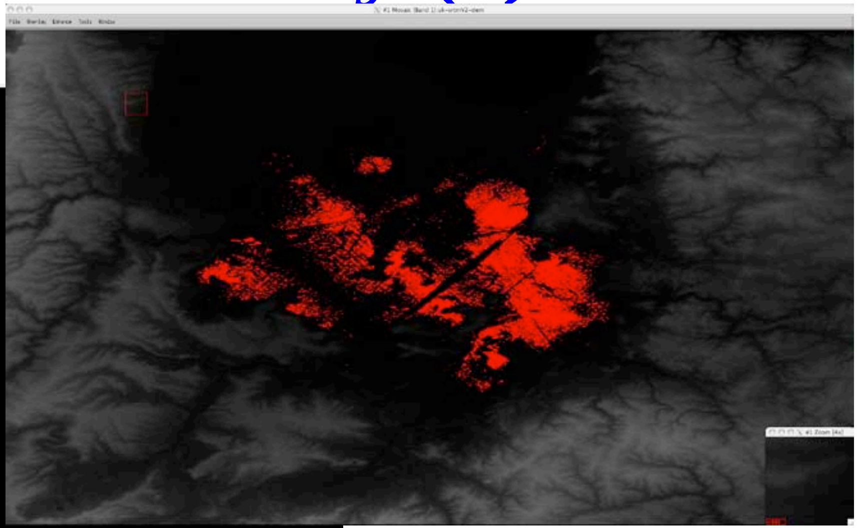


Heights at zero metres Above Mean Sea Level

BlueSky resampled to 3 arc-seconds

UK Intercomparison of ASTER, SRTM with BlueSky (2)

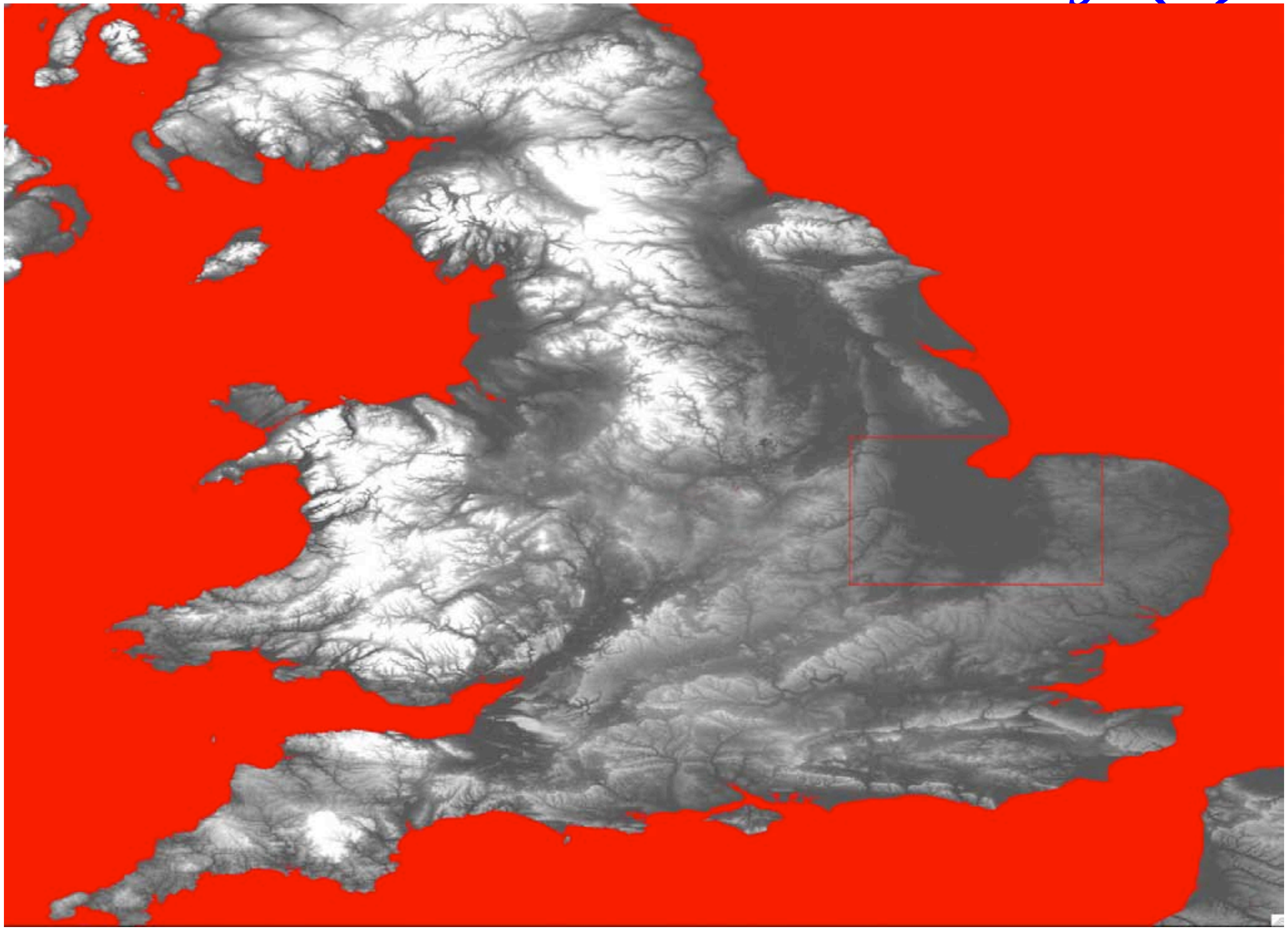




Heights at zero metres Above Mean Sea Level

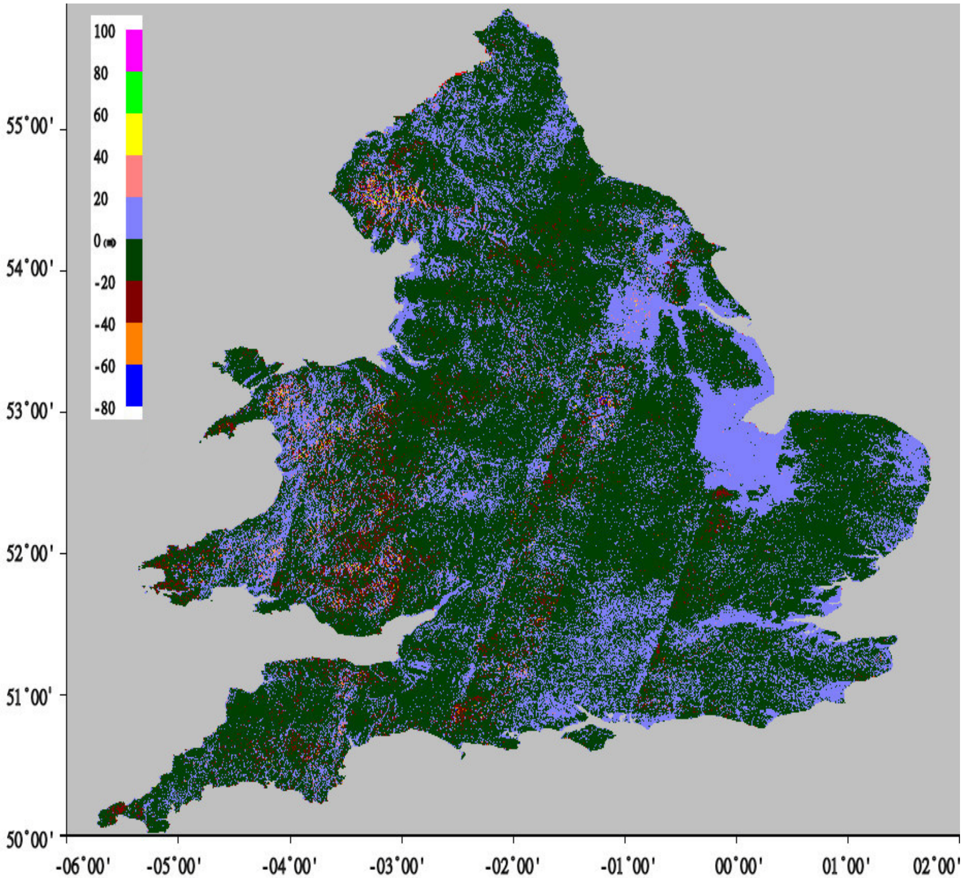
SRTM at 3 arc-seconds

UK Intercomparison of ASTER, SRTM with BlueSky (3)

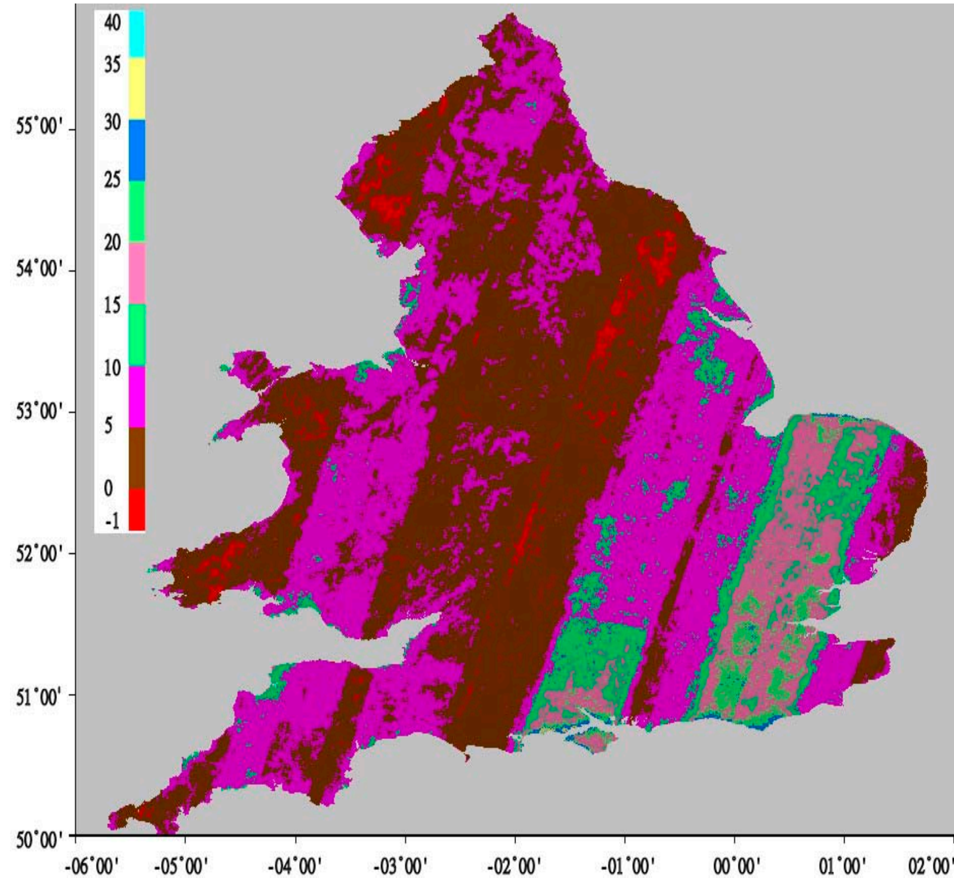


ASTER resampled to 3”. NO Heights at ≤0 metres above MSL

UK Intercomparison of ASTER, SRTM with BlueSky (5)



ASTER-BlueSky DEM at 1"



ASTER Stacking Number

ASTER-BlueSky at 3 arc-second (≈75m) for England and Wales

ASTER-BLUESKY	-4.651 m ± 11.232
SRTM-BLUESKY	1.081 m ± 8.612
ASTER-SRTM	-5.681 m ± 9.271

N.B. Overall ASTER heights lower than BlueSky (is this a datum issue?)
Height difference statistics do not (quite) meet global specification (10m RMS)