Validation Studies on ASTER GDEM over several CEOS-WGCV-TMSG test sites

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Abstract
ASTER 30m GDEM DEMs were provided by NASA/USGS over 3 CEOS-WGCV-TMSG test sites: Aix-en-Provence, Barcelona and Three Gorges as well as 2 cells over the UK over central England and over London. We report here on validation results for these five tiles using the best practices described by Dowman & Muller (1998)[1]. The best available DTMs were employed as reference with kinematic GPS potentially available in 4 of the 5 tiles. Unfortunately, only two tiles had reliable kGPS data available. Apart from the Three Gorges area where the pedigree of the reference DTM is unknown, the other 4 regions all showed consistent DTMs with mean differences which vary from 0 to10m and standard deviation of height differences around 10-15m. For the Three Gorges area, differences are significantly higher. Most DTMs show ASTER DEMs higher than the reference DTMs which is expected due to landscape objects, particularly for artificial surfaces. There is a great deal of DTM noise and strong scene-based for the 2 UK scenes, presumably as only few data takes were acquired. However, these had negligible impact on the overall statistics. Median filters were applied to try to minimise DTM noise and results of this are shown. All height differences show a strong and consistent relationship between error and the number of ASTER frames. Differences were also computed between all the other data-sets and ASTER-SRTM show consistently lower mountain peaks cf ASTER which is likely to be the case.

Context

The creation of a global 30m DEM is one of the stated goals of the GEO task (DA-07-01)[2] and its implementation is currently the subject of DA-09-03d. Ideally, this 30m DEM would be created using the format specification of the US DoD/NGA called DTED® level 2 (1 arc-second grid-spacing, 16m 90% LE= 12m Zrms). In 2000, SRTM

[1] Dowman, I.J., Muller, J.-P. (1998) Evaluation of spaceborne DEMs: a guide to methodology. Unpublished report, 15pp
[2] Muller, J-P. (2008) GEOSS Interoperability Guidance on DEM data. Version 1, 21 March 2008, 27pp

acquired such a dataset for some 80% of the Earth's land-mass. A variety of analyses (e.g. Weydahl, D. J., Sagstuen, J., Dick, O. B., and Ronning, H., 2007) show that the SRTM DEM in many areas meet or exceed the SRTM-2® specification. However, aside from the conterminous US (lower 48 states) where such DEM data is available, the SRTM DTED-2® has not been released due to constraints caused by the data policies of US allies (NGA, private communications, 2005-7). Also, some authors (Guth, P. L., 2006: Kelindorfer, J., 2007) have questioned whether these datasets are truly 1 arc-second when several studies have indicated that as a result of SAR speckle filtering, the resolution is more likely to be around 2 arc-seconds. However, even if SRTM-DTED-2® were publicly available, there would still be around 2-3% gaps within the region from 60ºN to 56ºS. These gaps or voids result from radar topographic shadows, layover or due to penetration in dry desert sands. They can be brute-force filled using existing DEM data sources and increasingly sophisticated feathering/merging techniques or 3rd party DEM souyrces can be employed to fill the gaps (Grohman, G., Kroenung, G., and Strebeck, J., 2006: Reuter, H. I., Nelson, A., and Jarvis, A., 2007). An alternative source, which up until recently was difficult to access due to the very high cost that the sensor owners have placed on the derived products are DEMs derived from ASTER. The SilCAST software (Fujisada, H., Bailey, G. B., Kelly, G. G., Hara, S., and Abrams, M. J., 2005) allows DEMs to be routinely and rapidly produced from input ASTER along-track stereo-pairs. This software has been installed at the US Geological Survey's EROS Data Center (EDC) since June 2006. Through an online ordering system, it is possible to acquire tens of ASTER DEMs with only a few hours turnaround time period. One of the reasons why this is possible is that the DEM extraction process is fully automated and one of the reasons why this is the case is that the accuracy of the exterior and interior orientation is sufficiently high that "dead reckoning" can be employed to transform the stereo-matched disparities into 3D positions on the surface of the Earth (see details Austin et al., 2009).

The ASTER GDEM was created by a small company in Japan under contract to METI and NASA. It uses a modified version of the SilCAST software to generate 1.5 million DEMs and an unknown algorithm to clear the stacked individual ASTER DEMs of clouds prior to processing an averaged ASTER GDEM. Muller[3] assessed the impact of using stacking on the propagation of cloud-related effects as well as the inclusion of noise related to individual scene noise artefacts for two of the CEOS-WGCV-TMSG test sites used in this analysis.

Aims and Objectives

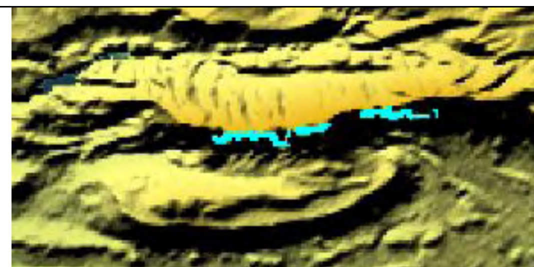
To assess the quality of the ATER GDEM using reference data sources available or the CEOS-WGCV test sites. Three different sources were available:

1. Digitised contours gridpoint interpolate to regular gridded DEMs
2. manually generated aerial stereo photogrammetric DEMs
3. automatically generated aerial stereo photogrammetric DEMs
4. airborne scanning lidar
5. kinematic GPS

[3] Trade Studies on best source and best fusion method for global DTED2 over the CEOS-WGCV-TMSG test sites. J-P Muller (31 March 2008), 27pp

CEOS-WGCV-TMSG Test sites

The Committee on Earth Observing Satellites (CEOS) was set up in 1987 as a result a G7 summit in Paris. CEOS has 3 Working Groups of which the WGCV (Working Group on Cal/Val) is the most long established. As well as national space agency representations, there are 6 Sub-groups of which the "Terrain Mapping from satellites SG" (TMSG) is one of the most active. The first author has chaired the TMSG since 2001 and prior to this he was an active member since 1996. In addition to the development of a manual of best practise and keeping abreast of current developments in the creation and validation of spaceborne DEMs, TMSG maintains an active list of cal/val sites. Table 1 lists the current TMSG sites which have been established over the last 12 years. They also show what the DEM looks like and summarise what ancillary datasets are available for validation and what issues there are for each site. All except for US/Wales site were used.

Short-name	Extent (lon)	Extent (lat)	Validation datasets	ICEDS WMS image
Aix-en-Provence Europe (F)	5.528-5.685ºE	43.502-43.560ºN	Aerial top-of-canopy Pitkin DEM (UCL), DTM (IGN)	
Barcelona Europe (ES)	1.5-2.75ºE	41.25-41.82ºN	Aerial top-of-canopy DEM (ICC)	
North Wales Europe (UK)	-3 to -5ºW	52-53.5ºN	OS® 50m DTM kGPS	
Puget Sound WA (USA)	-121.397 to -123.897ºW	46.364-48.864ºN	NED 30m DTM Lidar 2m top and bottom of canopy DEM	

Three Gorges (China)	108.252-111.302ºE	30.638-31.229ºN	CASM 50m DTM, kGPS	

Table 1. Current portfolio of CEOS-WGCV TSMG test-sites including colourised hill-shaded DEMs derived from the SRTM (V2, edited) layer of ICEDS (http://iceds.ge.ucl.ac.uk)

Reference DEM descriptions

Badong, P.R. China (N31E110)

No information is available on the reference DTM other than it is derived from 1/50,000 scale contour maps. Assuming that this is typical contour range, it is likely that this will be around 7m Zrmse. This is also supported in a kinematic GPS study described in Austin et al. (2009).

Barcelona, Spain (N41E002)

Catalonia is a test site which was set up in the scope of the Spot HRS (W. Kornus, ICC). ICC supplied a reference DTM derived manually from aerial photography at a scale of 1/5,000 in urban areas and 1/32,000 in all other areas. The DEM was interpolated from TINs and gridded on a 15m raster. Its accuracy is round 1m. It was projected in UTM Zone31N on the ED50 datum for Spain. This became a CEOS-WGCV test site in 2004.

Montagne Sainte Victoire, France (N43E005)

Two different reference DEMs, were available for this test site in the southeast of France, maintained by UCL. For a specific region covering the Montagne Sainte Victoire a high precision DEM was derived manually by M. Pitkin from 1/30,000 aerial photography[4] at the observable surface (DSM), rather than on the "bare earth" terrain (DTM). This makes it an excellent source to assess spaceborne DEMs. However, it has a small extent of 12.4*6.9 km. It has an accuracy of 1.3m.

The second DEM, which is from IGN (Institut Geographique Nationale), covers a wider area of 61*63km but is less accurate (5m in north and 2.5m elsewhere although dependent on relief).

Both reference DEMs are projected in Lambert Conic Projection, French Zone 3. The datum definition is specific to France. This was the first CEOS-WGCV test site and was originally established in 1987.

See Appendix 1 for further details

London, UK (N51W001)

Two different reference DEMs are available for the 1 x 1º tile which includes most of Greater London. In the first case, the DTM was generated by a commercial company called BlueSky Limited on a grid of 5m with a vertical height accuracy of 1.5m (nominal). In the second case, the first observable surface DTM was created from airborne lidar on a 1m grid with an

[4] Theodossiou, E.I. and Dowman, I.J., 1990 Heighting accuracy of SPOT. Photogrammetric Engineering and Remote Sensing. 56(12): 1634-1649.

accuracy of 15cm (0.15m) by another commercial company, the Geoinformation Group Limited.

The reference DTMs were made available as a result of an UK nationally funded HEFCE-JISC (Higher Education Funding Council of England – Joint Information Systems Committee) grant to the JISC-support LANDMAP service at the University of Manchester.

Kinematic GPS data was collected by the LANDMAP project[5]. See http://landmap.org for more details. There were two different types (one using base stations with cm accuracy and the other after selective acquisition was removed by US Presidential Executive Order in 2000.

See Appendix 2 for BlueSky details and Appendix 3 for Geoinformation Group characteristics.

Central England, UK (N52W002)
Only BlueSky DTM was available for this region and LANDMAP kinematic GPS. See details for London

Co-registration

The ASTER GDEM DEMs are available in WGS84 ellipsoid and EGM96 geoid co-ordinates on a 1 arc-second grid. The Announcement of Collaborative Opportunity requested that all validation scientists co-register reference DEMs to the ASTER GDEM in order to obtain an uniform set of results. This had a number of implications. Firstly, there are no published datum conversions for many non-US datums. Secondly, it meant that a large class of validation activities could not be performed as no GIS software available could perform computations in equal angles involving arc distances. This meant that not only slopes and aspects could not be computed but no higher order statistics such as those derived by J. Wood[6] and employed within the ENVI software under Topographic modelling.

[5] Cross, P. A., R. Keenan, J. Barnes, N. Anthis, K. K. Chugani, A. H. Walker, J.-P. Muller, and K. Kitmitto, 2000: GPS Validation of IfSAR Digital Elevation Models from LANDMAP. 26th Annual Conference of the Remote Sensing Society, University of Leicester, 12-14 September 2000, Remote Sensing Society.

Muller, J.-P., J. G. Morley, A. H. Walker, K. Kitmitto, K. L. Mitchell, K. Chugani, A. Smith, J. Barnes, R. Keenan, P. A. Cross, I. J. Dowman, and N. Quarmby, 2000: The LANDMAP project for the automated creation and validation of multi-resolution orthorectified satellite image products and a 1" DEM of the British Isles from ERS tandem SAR interferometry. 26th Annual Conference of the Remote Sensing Society, University of Leicester, 12-14 September 2000, Remote Sensing Society.

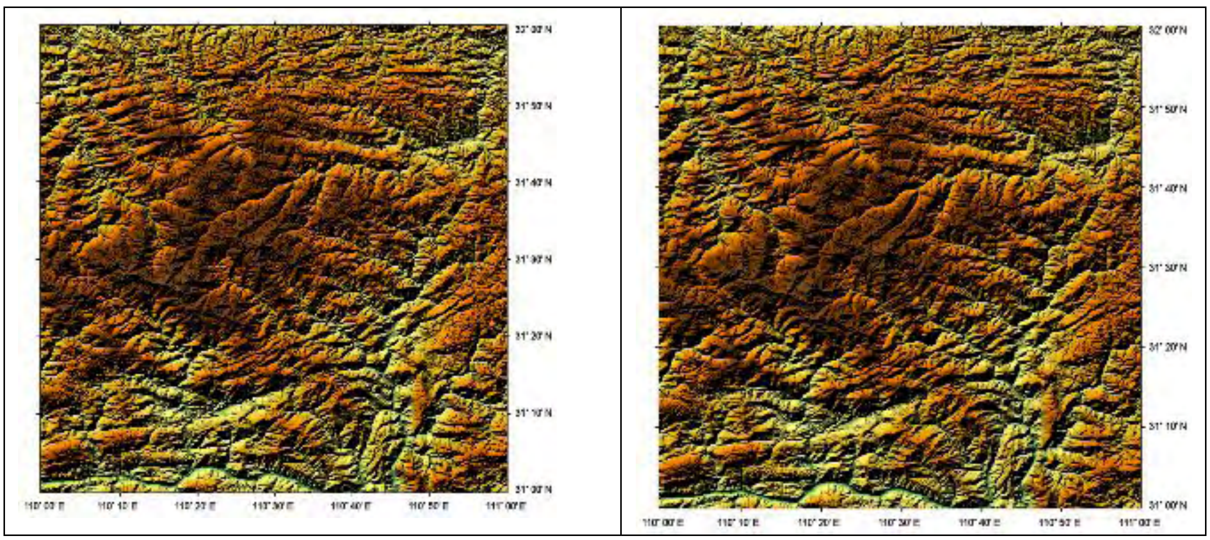
[6] Wood, Joseph The Geomorphological Characterization of Digital Elevation Models, Ph. D. Thesis, University of Leicester, Department of Geography, Leicester, UK, 1996

Co-registration was performed employed using a new and novel technique called surface matching[7]. Previous use of GCPs to try to identify river confluences to employ in a rubber sheet low order polynomial produces unsatisfactory results, especially where datums are not known. The reader is referred to the references for further detail. Suffice it to say, that each set of reference DEMs were co-registered to the ASTER GDEM in most cases to sub-pixel precision. Exceptions were for MSV where there was still a residual 1 pixel shift visible when flickering between the IGN and ASTER and UCL and ASTER DEMs. Unlike previous studies, we believe that misregistration plays no role here.

Presentation of Input Datasets

In this section, the DEM collection is presented for each of the study sites.

<u>DEMs and Land cover : Badong, P.R. China</u> (N31E110)



[7] Lin, S.-Y., J.-P. Muller, J. Mills, and P. Miller, 2009: An assessment of surface matching for the automated co-registration of MOLA, HRSC and HiRISE DTMs. Earth and Planetary Science Letters, in review.

Miller, P.E., Mills, J.P., Edwards, S.J., Bryan, P., Marsh, S., Mitchell, H.L. and Hobbs, P., 2008. A robust surface matching technique for coastal geohazard assessment and management. ISPRS Journal of Photogrammetry and Remote Sensing, 63(5): 529-542.

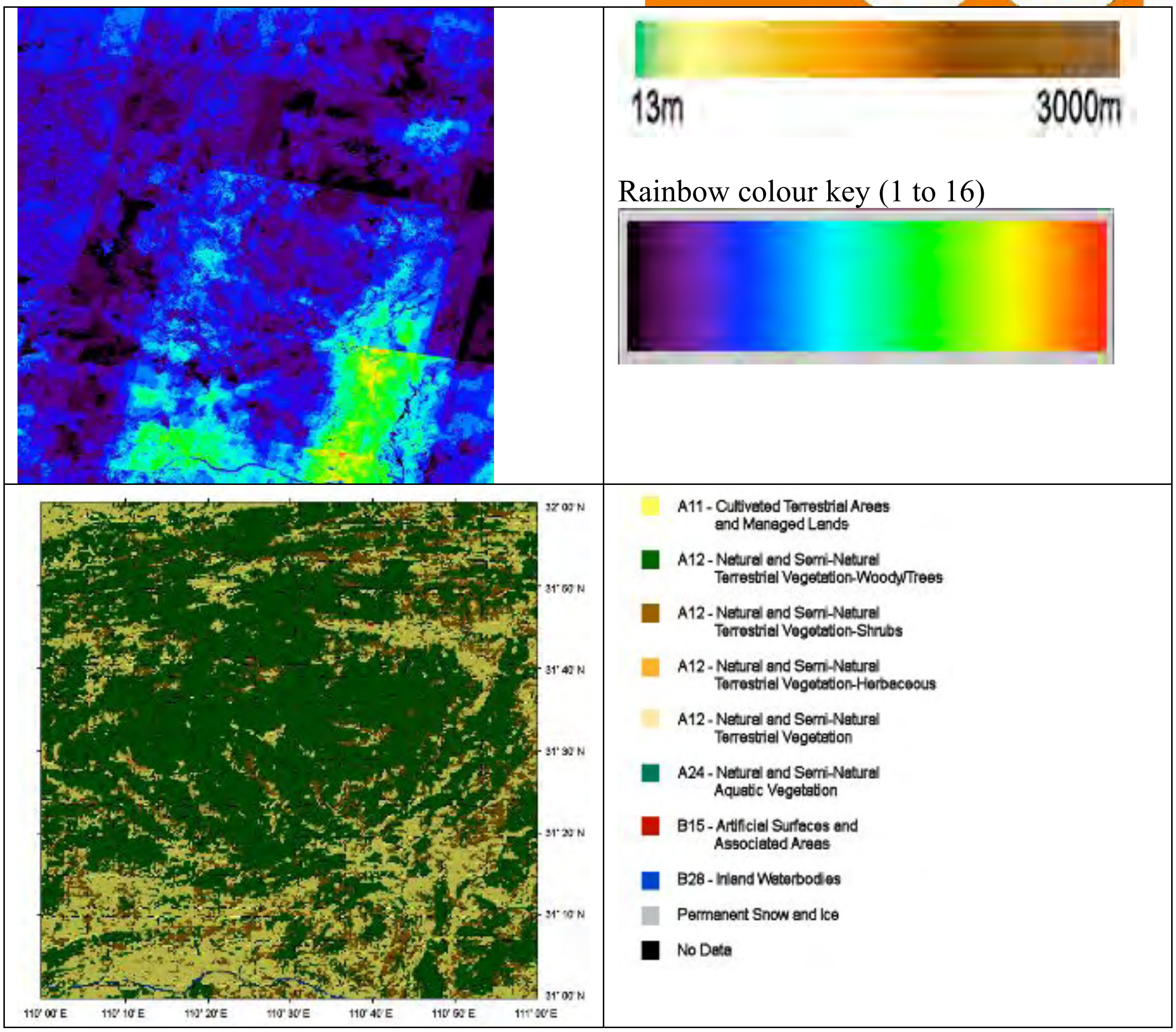
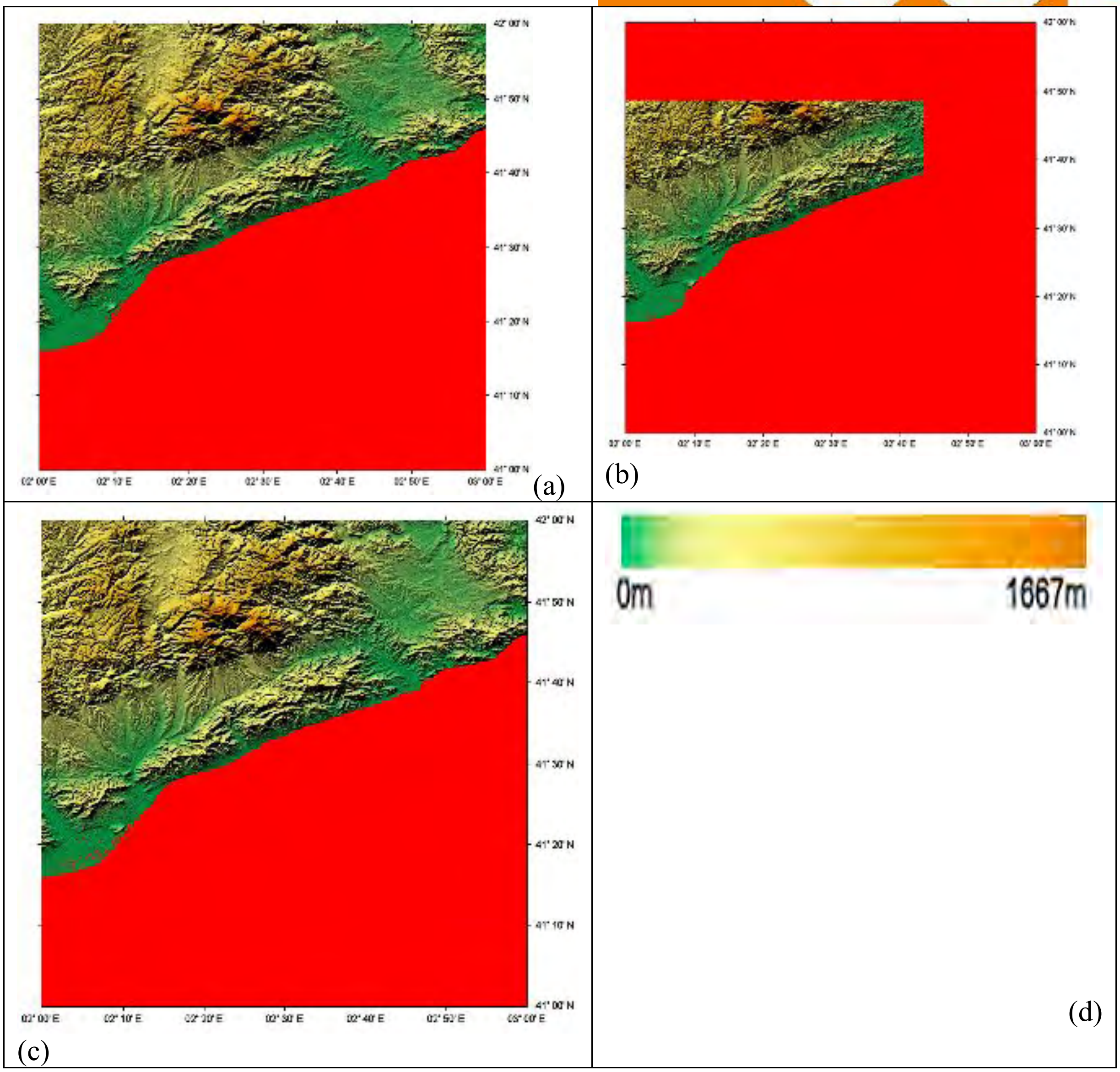


Figure 1. Badong (P.R. China). UL: ASTER GDEM; UR: SRTM DEM; ML: ASTER NUM; MR: colour keys for ASTER GDEM and NUM; LL: GlobalCover2000: Global land cover

A very rugged area with 3000 metres of relief including very steep slopes. This region is frequently covered in mist, haze and clouds so the low number of input scenes is not surprising.

DEMs and Land cover : Barcelona, Spain (N41E002)


(a)
(b)
(c)
0m
1667m
(d)

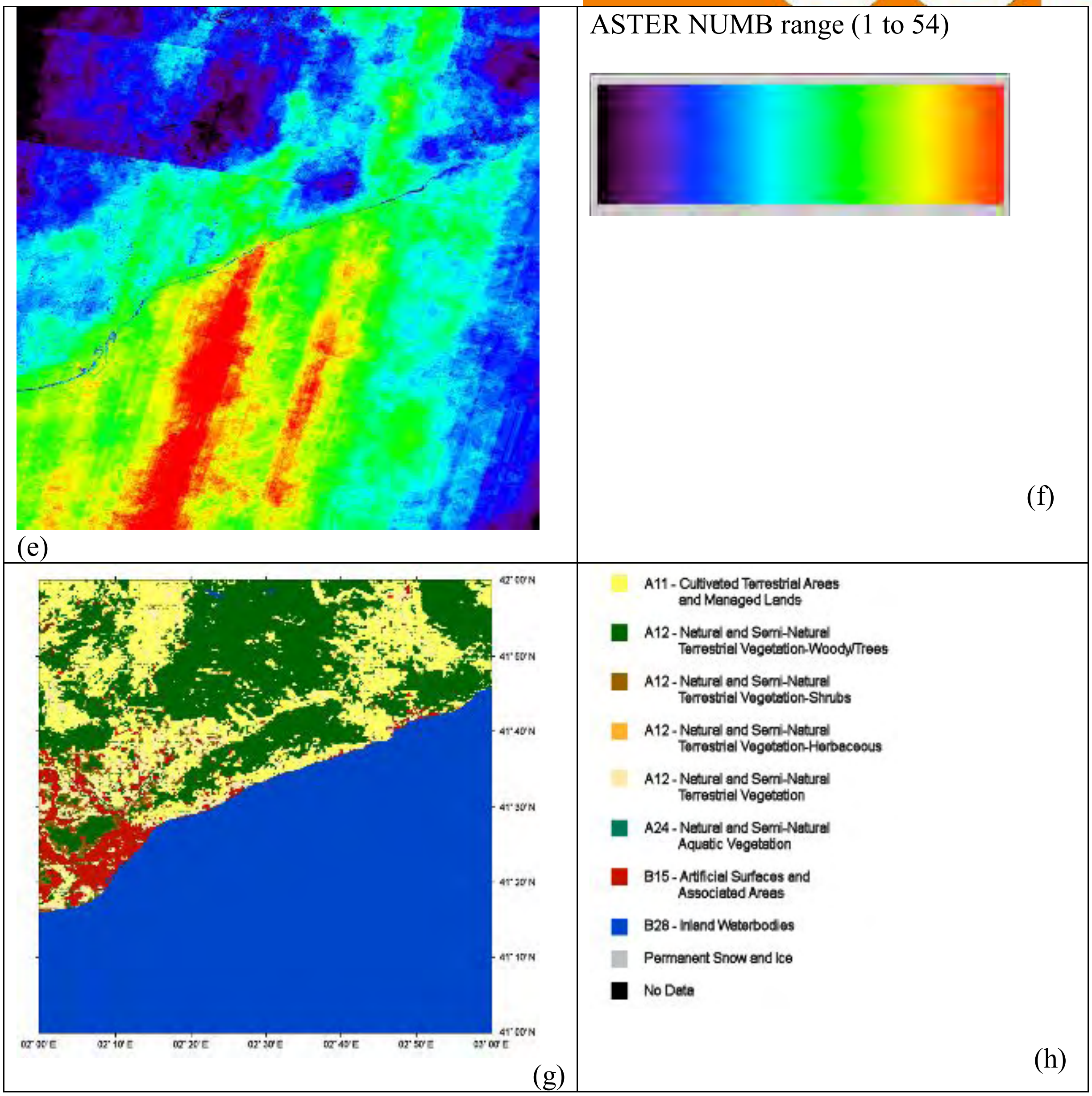
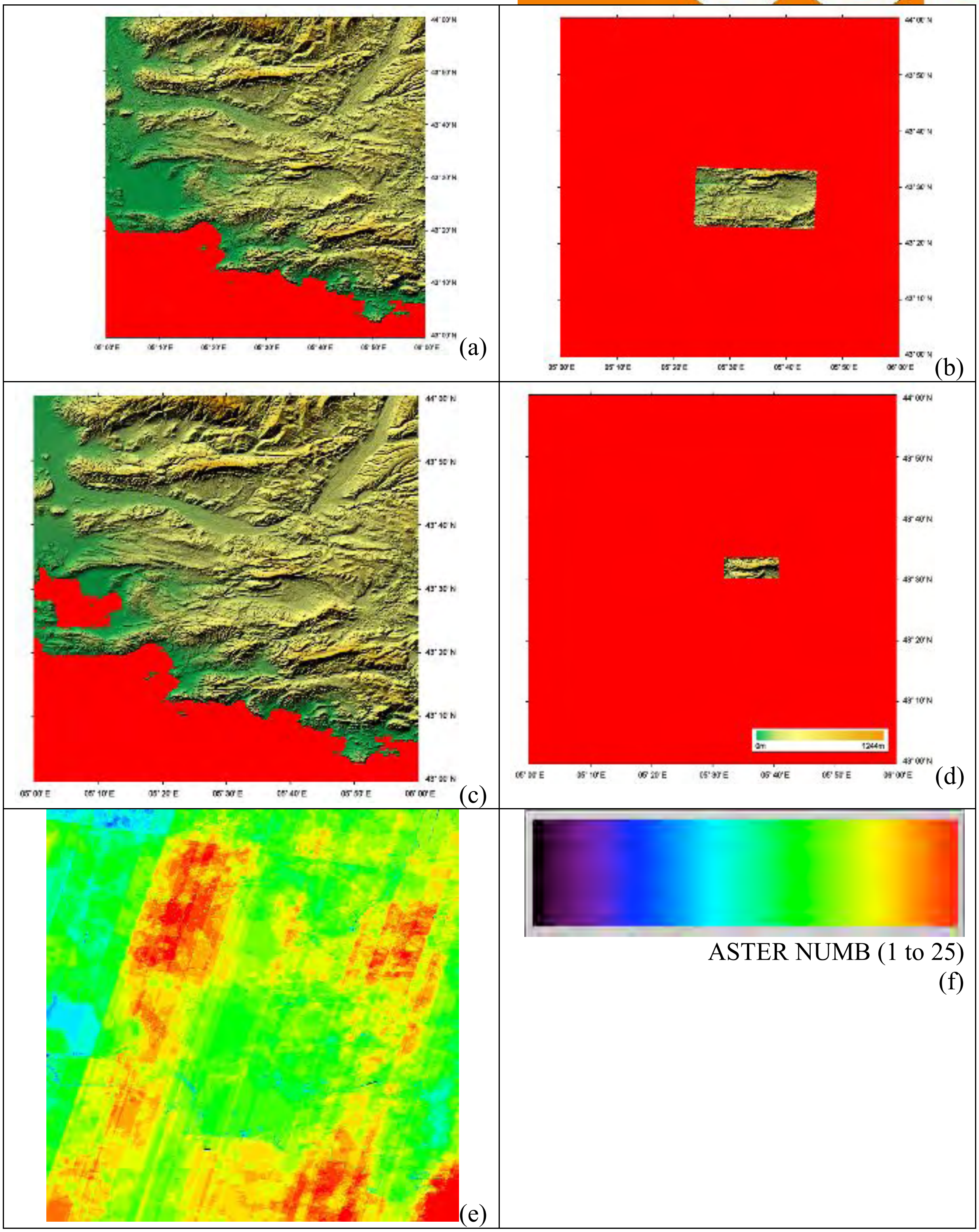


Figure 2. Barcelona datasets. (a) ASTER GDEM; (b) ICC DEM; (c) SRTM DEM; (d) DEM colour key; (e) ASTER NUM; (f) ASTER NUM colour key;(g) GlobalCover land cover; (h) land cover key

Another rugged area with a large range of relief. Large Urban cover (mainly Barcelona)

<u>DEMs and Land cover : Montagne Sainte Victoire, France</u> (N43E005)


(a)
(b)
(c)
(d)
(e)
ASTER NUMB (1 to 25)
(f)

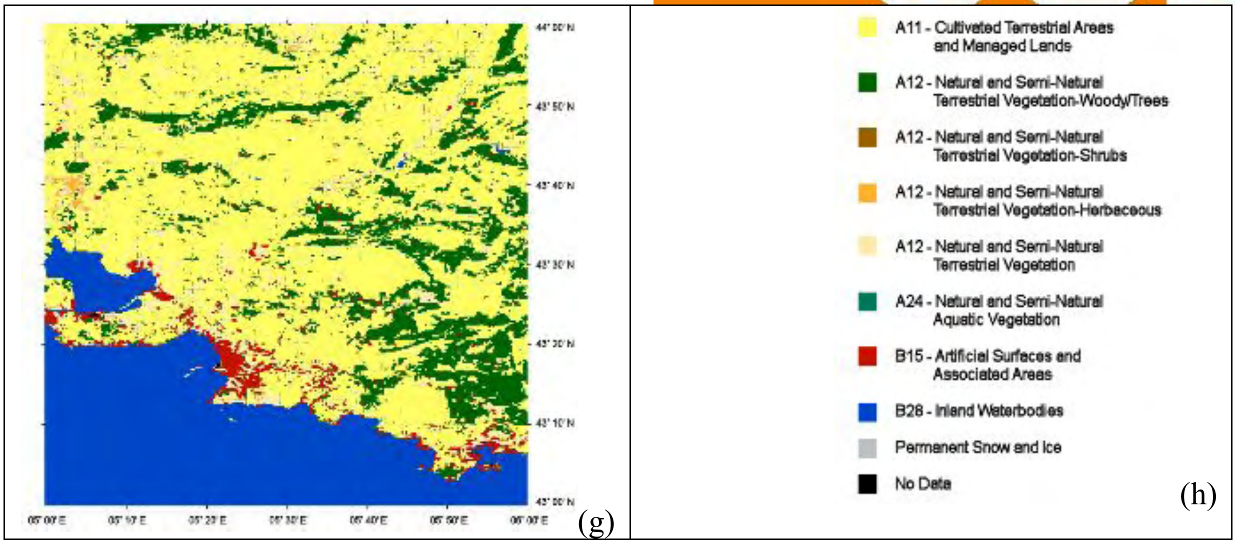
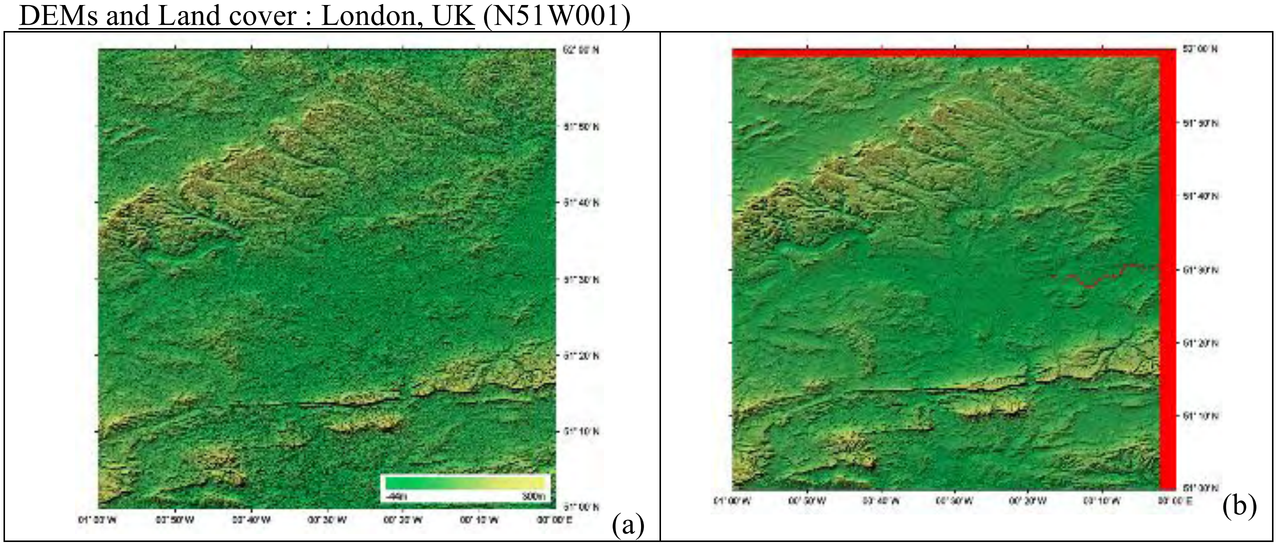
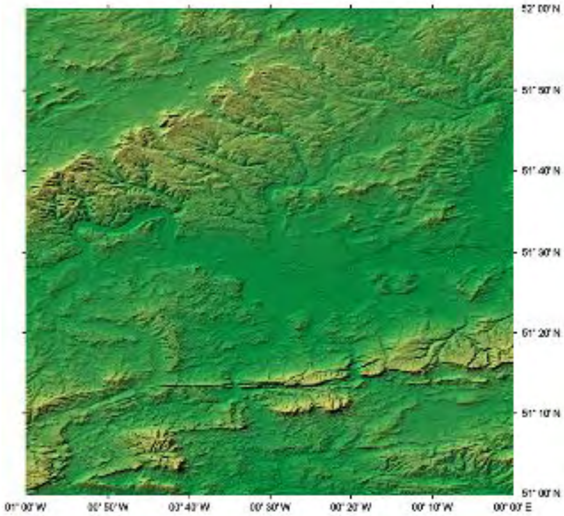
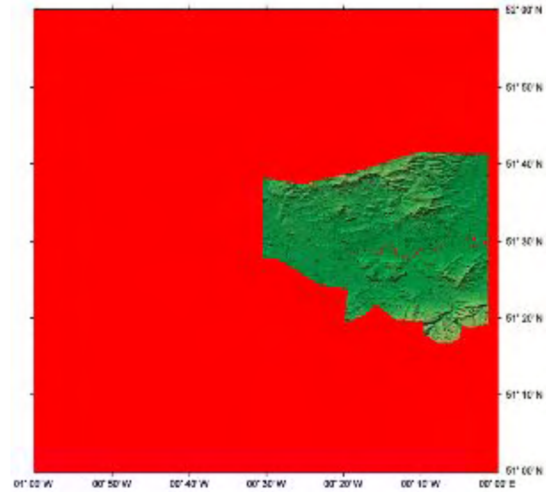


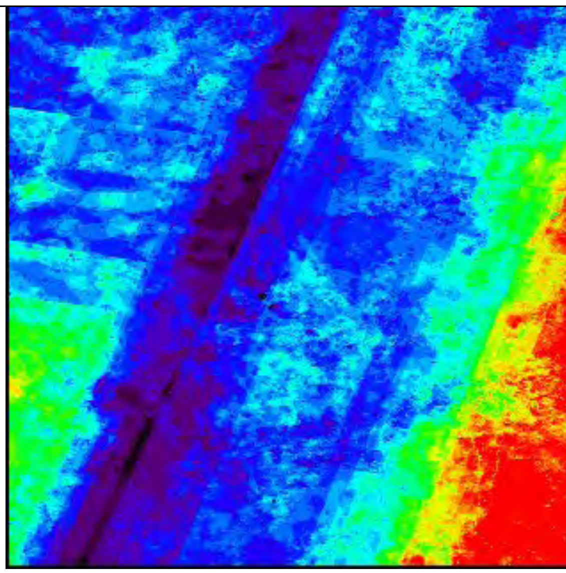
Figure 3. Montagne Sainte Victoire DEMs. (a) ASTER GDEM; (b) IGN; (c) RTM; (d) UCL + colour key; (e) ASTER NUMB; (f) ASTER NUMB key (1- 25) (g) Land cover; (h) land cover key

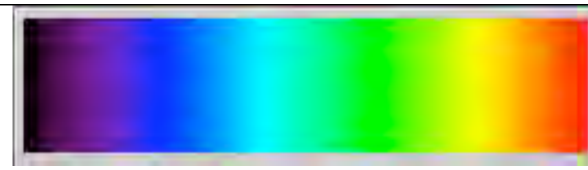
<u>DEMs and Land cover : London, UK</u> (N51W001)

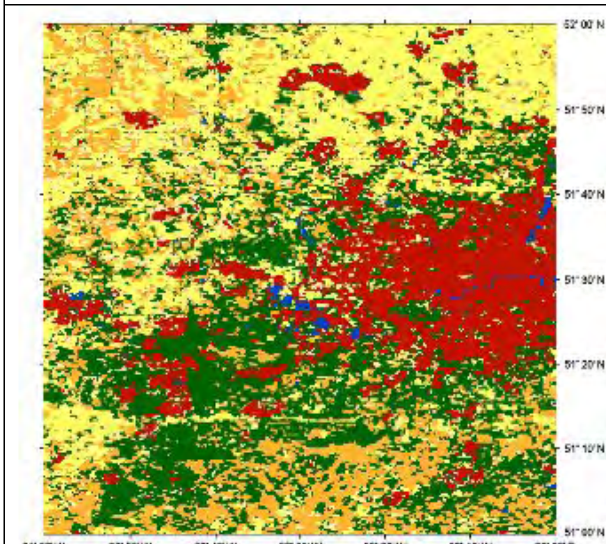


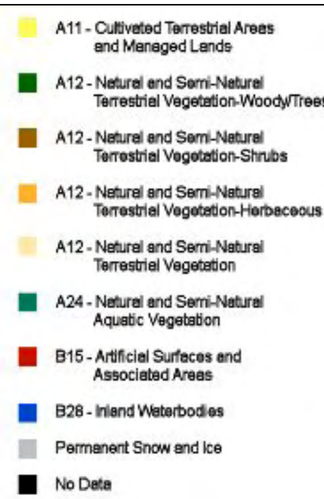

(c)


(d)


(e)


ASTER NUMB (range 1-27)
(f)


(g)

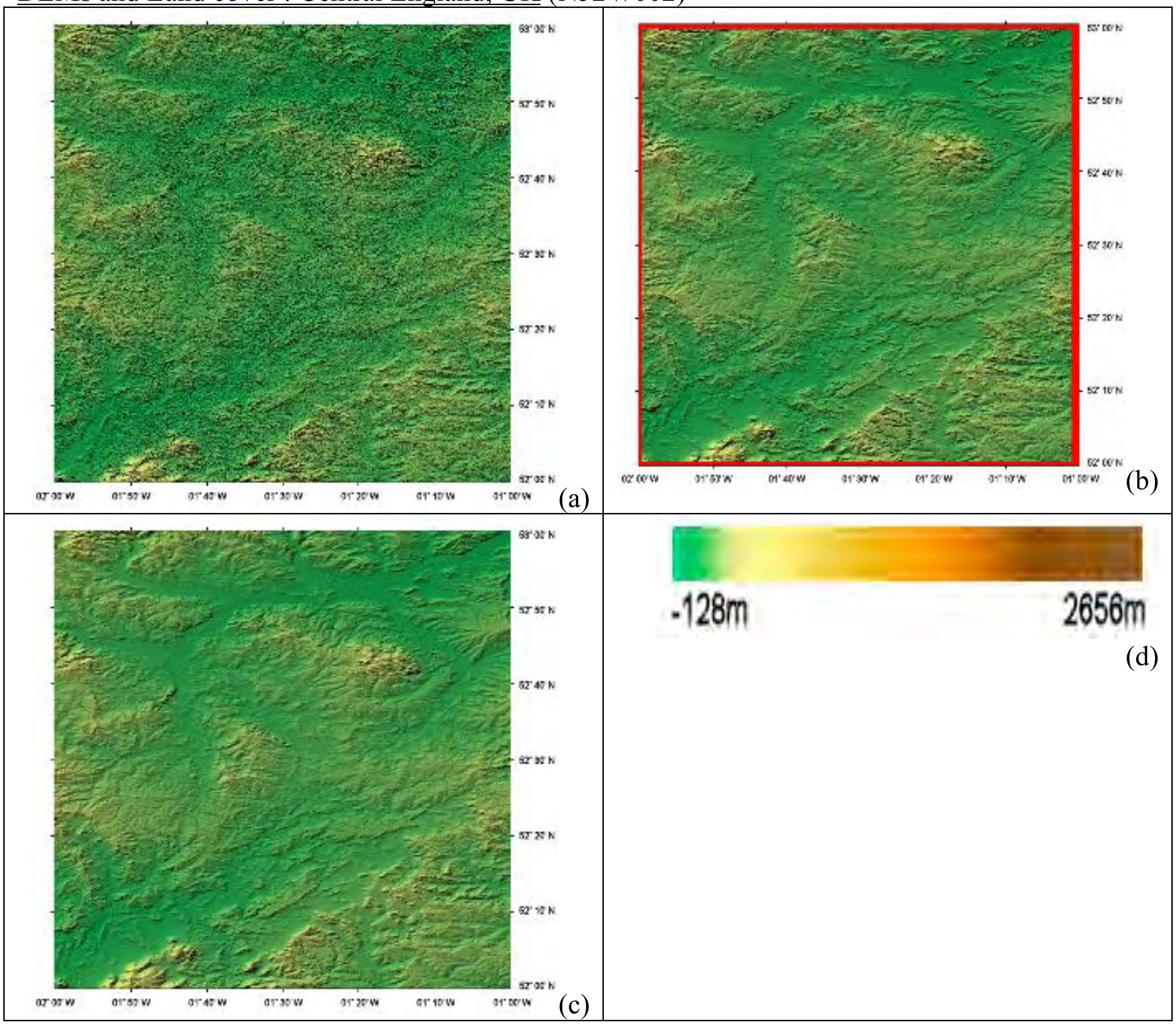


(h)

Figure 4. London, UK. (a) ASTER GDEM with key; (b) BlueSky; (c) SRTM; (d) Lidar; (e) ASTER NUMB; (f) key (1-27); (g) GlobCover land cover; (h) land cover key

An area of gentle relief with large amounts of cloud cover. A significant fraction is urban

<u>DEMs and Land cover : Central England, UK</u> (N52W002)



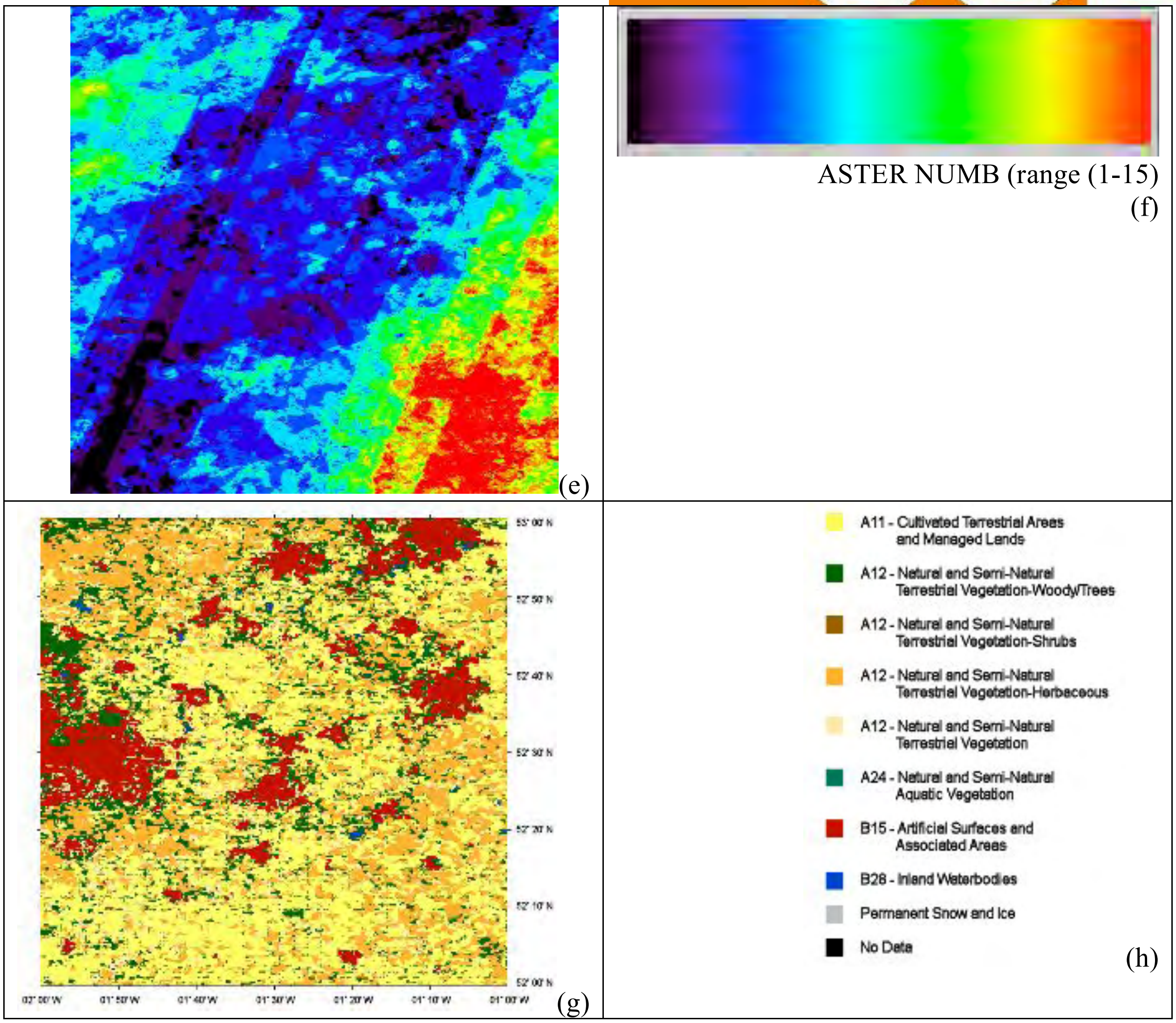


Figure 5. Central England, UK. (a) ASTER GDEM; (b) BlueSky; (c) SRTM; (d) ASTER key; (e) ASTER NUMB; (f) NUMB key (1-15); (g) GlobCover land cover; (h) land cover key

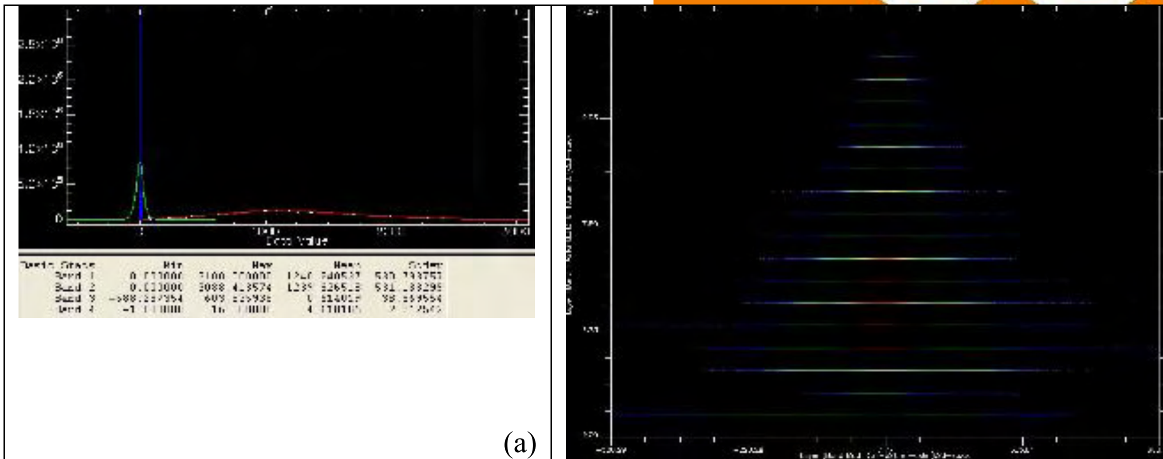
The wrong tile was chosen by accident – the one ordered is in central England and is NOT the correct CEOS test site for North Wales. This was discovered too late to re-order the data. Also, as expected for this region, the area has a very large cloud cover.

Presentation of Elevation Statistics and Elevation Differences by sample site

A similar rainbow colour LUT is employed with values below the minimum in black and those above the above threshold in white.

Height statistics and Height differences : Badong, P.R. China (N31E110)

Owing to the source of the China DEM, it is not possible to show the height differences. Instead, we present histograms of the ASTER GDEM and China DEM and a 2D scatterplot of height difference (ASTER-China) vs ASTER NUM(ber of frames)



(a) (b)

Figure 6. Badong, P.R. China. (a) Height histograms of (i) China DEM (white); (ii) ASTER-GDEM (red); (iii) ASTER-China (green); (iv) ASTER NUM (blue). (b) ASTER NUM vs ASTER-China DEM difference

Note the apparent correlation of error with ASTER NUM. The ASTER-China DEM difference shows a significant standard deviation especially when compared against other areas. However, this is the most rugged relief and densest tree cover of all areas examined and may represent the true situation. Further work, beyond the scope of this report, will be conducted to try to isolate the source of this larger standard deviation.

Analysis of the tables of height differences via land cover class in Appendix 4 indicate that the height differences may reflect true differences as the urban height differences have a large bias as well as the waterbodies which is reflected in other areas as well.

<u>Height statistics and Height differences : Barcelona, Spain</u> (N41E002)
Height statistics and height difference statistics as well as visualisations of these were created between ASTER-ICC, ASTER-SRTM and SRTM-ICC which are shown below.

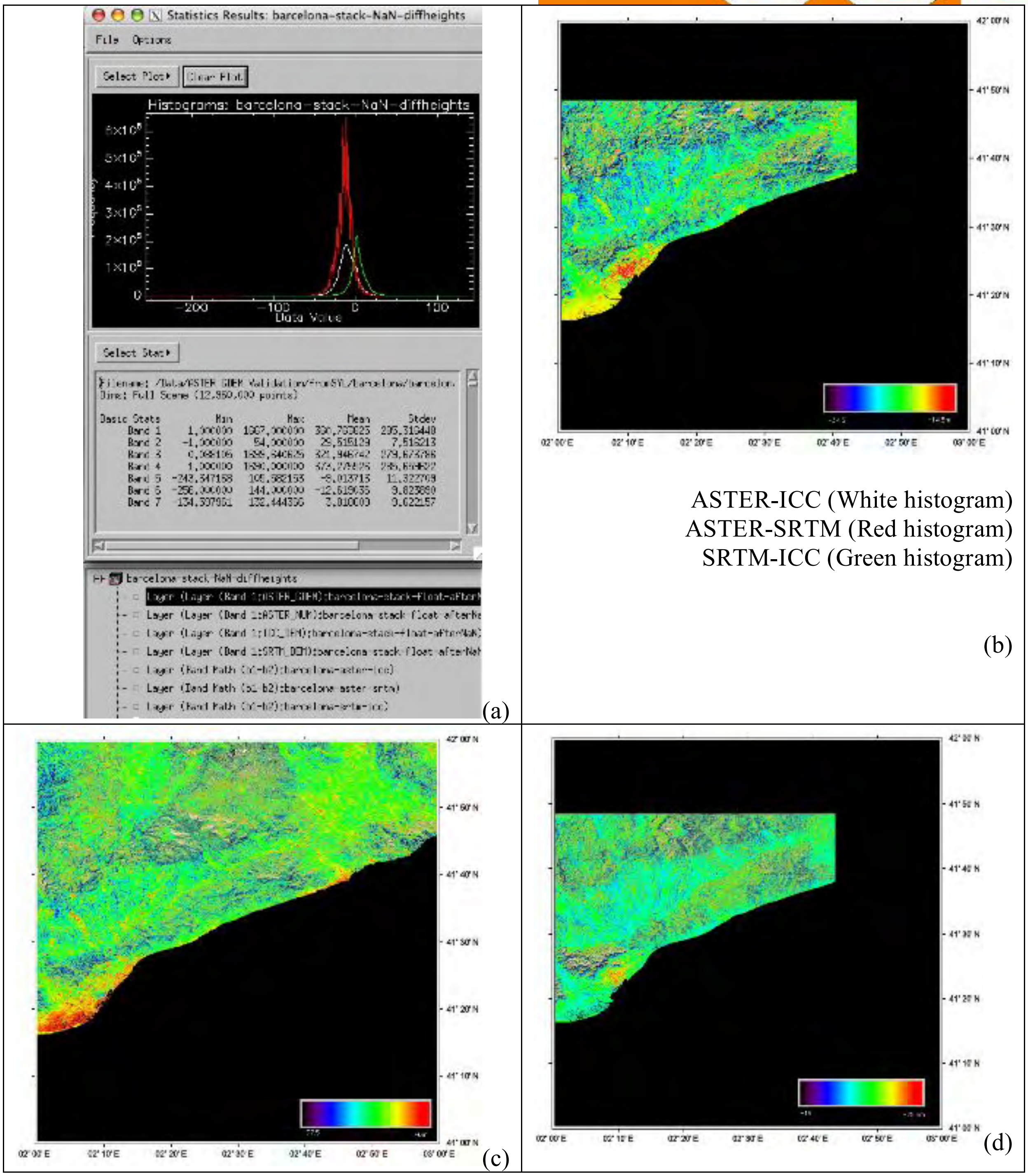
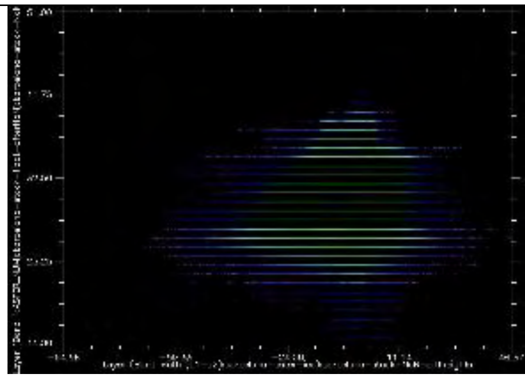
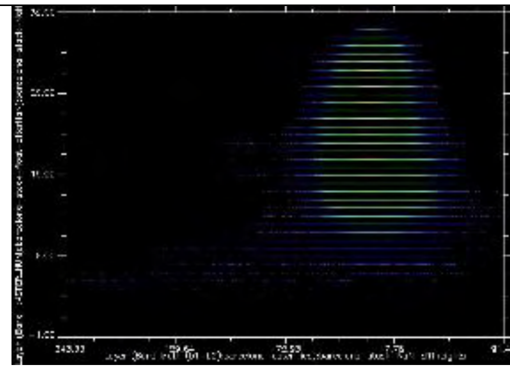


Figure 7. Barcelona, Spain height differences. (a) histograms and statistics. (b) ASTER-ICC; (c) ASTER-SRTM; (d) SRTM-ICC

The height differences show large bias wrt ICC photogrammetric DEM. The height difference plots indicate that most of the large height differences are due to relief and the urban areas, especially to the west of Barcelona. For some inexplicable reason, the bias is negative with ASTER BELOW the reference DEM. This may be caused by some unaccounted for datum shift. The standard deviations are all around 10m. To investigate whether there was any correlation, 2D scatterplots were produced of the height differences vs the ASTER NUM which are shown in the next Figure. As ENVI only plots 2D scatterplots over the current window, two plots were produced, one over the SW corner and the other the NE. The SW corner includes Barcelona.



(a)



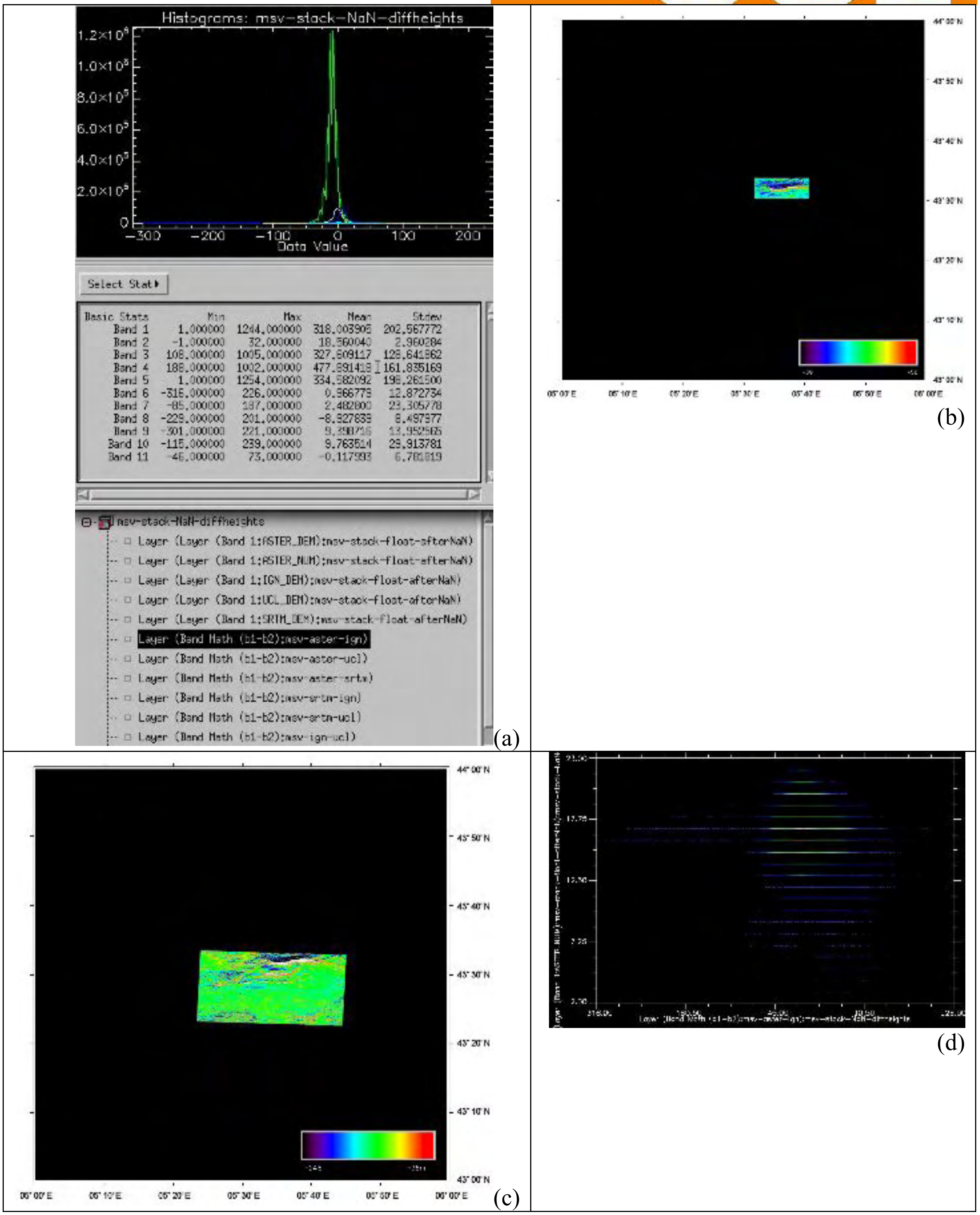
(b)

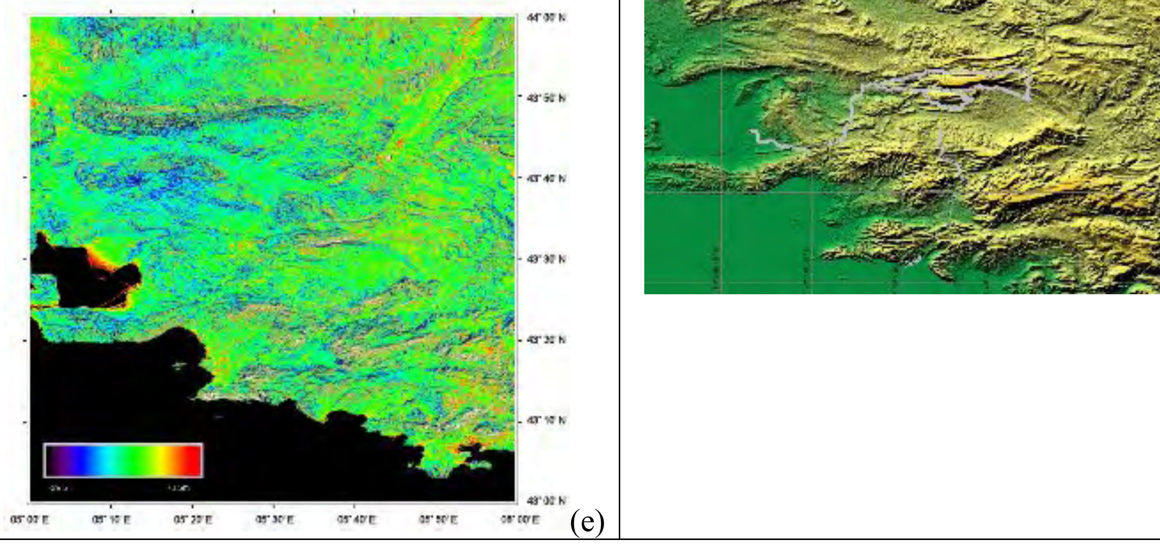
Figure 8. 2D scatterplots of ASTER NUM vs ASTER-ICC for (a) SW; (b) NE areas.

For the area showing the largest height difference shown in Figure 8(a), there appears to be a strong correlation with ASTER NUM. The correlation is much weaker for the other area.

<u>Height statistics and Height differences : Montagne Sainte Victoire, France</u> (N43E005)

Figure 9 shows a series of height difference maps and statistics for the CEOS-WGCV-TMSG test site located over the region centred on the Montagne Sainte Victoire in Provence, France close to Aix en Provence.


Histograms: msv-stack-NaN-diffheights
Data Value
Select Stat
Basic Stats Min Max Mean Stdev
Band 1 1.000000 1244.000000 318.003906 202.567772
Band 2 -1.000000 32.000000 18.560040 2.960284
Band 3 108.000000 1005.000000 327.609117 128.641862
Band 4 188.000000 1002.000000 477.891418 161.835169
Band 5 1.000000 1254.000000 334.582092 198.261500
Band 6 -316.000000 226.000000 0.966779 12.872734
Band 7 -85.000000 187.000000 2.482800 23.305778
Band 8 -229.000000 201.000000 -8.927839 8.497977
Band 9 -301.000000 221.000000 9.398716 13.952565
Band 10 -115.000000 239.000000 9.763514 29.913781
Band 11 -46.000000 73.000000 -0.117993 6.781819
msv-stack-NaN-diffheights
Layer (Layer (Band 1:ASTER_DEM):msv-stack-float-afterNaN)
Layer (Layer (Band 1:ASTER_NUM):msv-stack-float-afterNaN)
Layer (Layer (Band 1:IGN_DEM):msv-stack-float-afterNaN)
Layer (Layer (Band 1:UCL_DEM):msv-stack-float-afterNaN)
Layer (Layer (Band 1:SRTM_DEM):msv-stack-float-afterNaN)
Layer (Band Math (b1-b2):msv-aster-ign)
Layer (Band Math (b1-b2):msv-aster-ucl)
Layer (Band Math (b1-b2):msv-aster-srtm)
Layer (Band Math (b1-b2):msv-srtm-ign)
Layer (Band Math (b1-b2):msv-srtm-ucl)
Layer (Band Math (b1-b2):msv-ign-ucl)
44° 00' N
43° 50' N
43° 40' N
43° 30' N
43° 20' N
43° 10' N
43° 00' N
05° 10' E
05° 20' E
05° 30' E
05° 40' E
05° 50' E
06° 00' E
(a) (b) (c) (d)



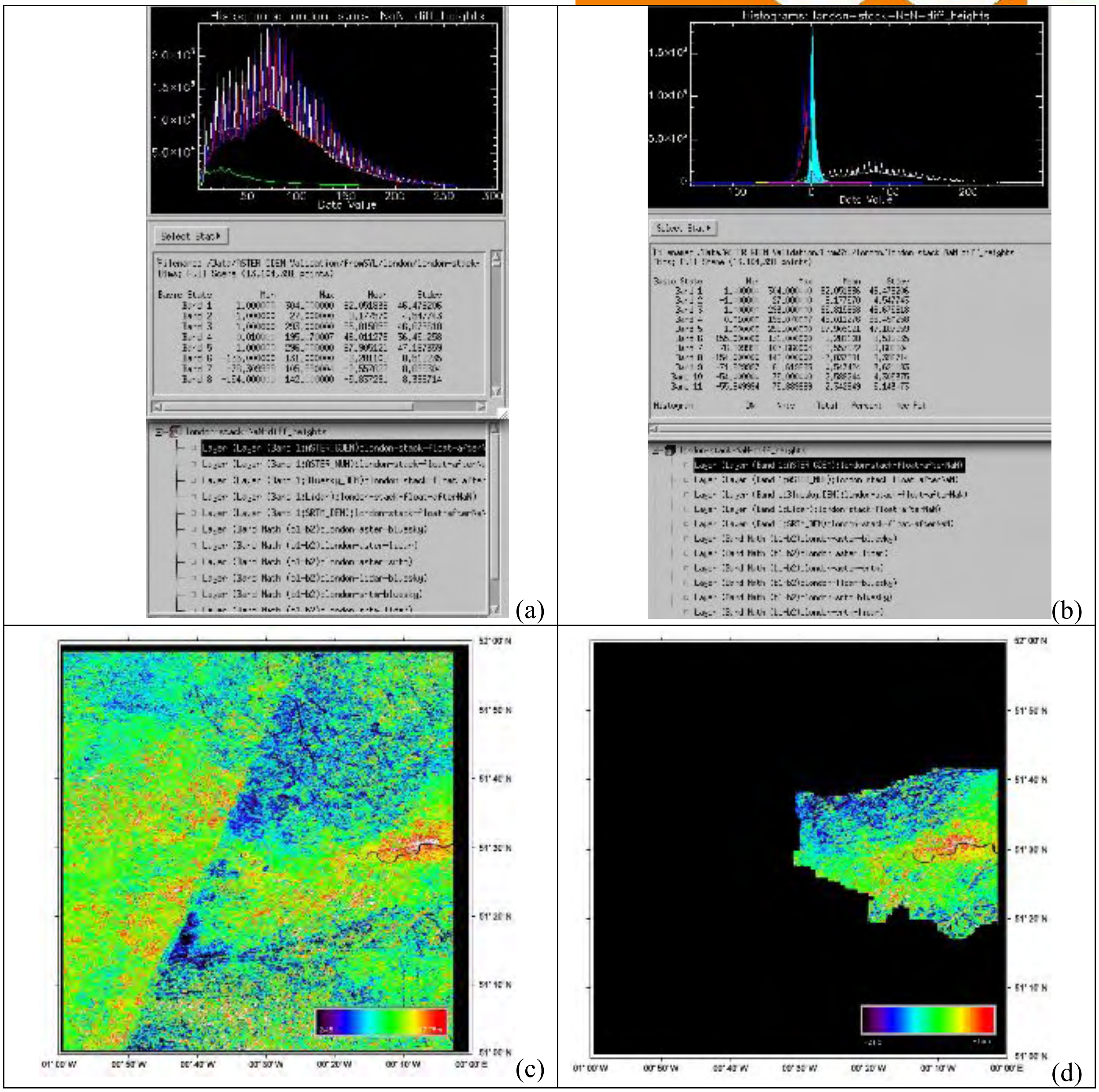
(e) (f)

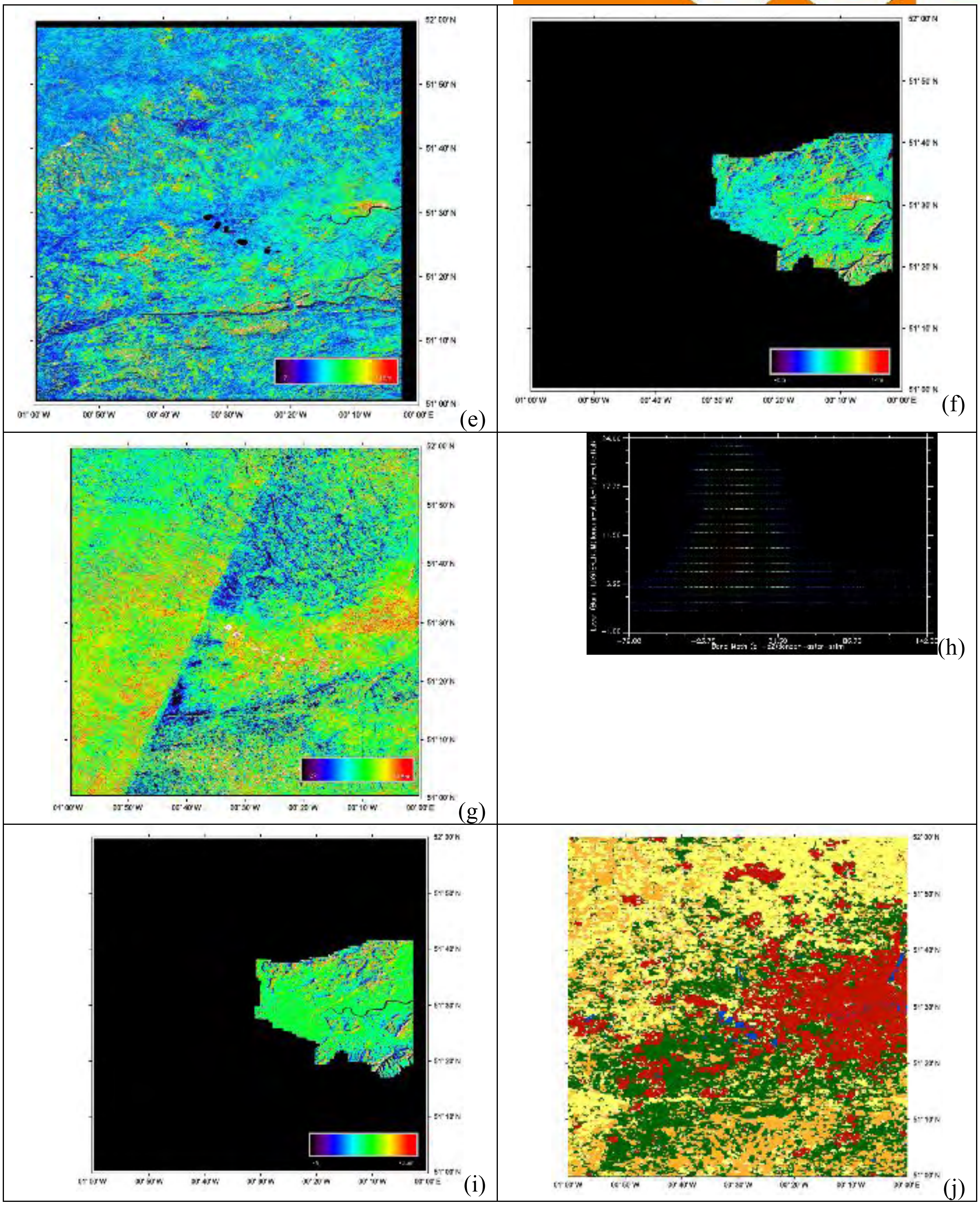
Figure 9. Montagne Sainte Victoire, F. (a) ASTER heights and ASTER and other height <u>difference</u> statistics showing ASTER-IGN (white), ASTER-SRTM (green), ASTER-UCL (blue); (b) ASTER-UCL height difference map; (c) ASTER-IGN height difference map; (d) ASTER-IGN vs ASTER NUM 2D scatterplot; (e) ASTER-SRTM height difference map; (f) ASTER DEM showing location of kinematic GPS measurements made in 2007.

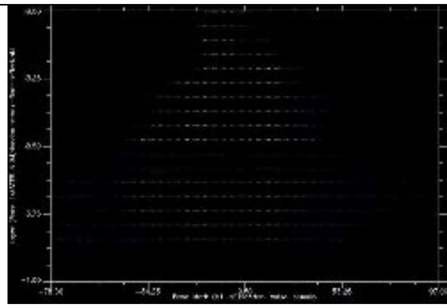
The ASTER height difference statistics indicate that for both reference DEMs, there is very little bias but the standard deviation for the ASTER-UCL is almost double that of ASTER-IGN due to the much higher variation of relief in the UCL area. For ASTER-SRTM, SRTM indicates higher altitudes than ASTER which Figure 9(e) shows is mainly associated with coastal regions and high relief areas. Although kinematic GPS data was collected , the heights were all in error and so no meaningful height difference analysis could be calculated.

<u>Height statistics and Height differences : London, UK</u> (N51W001)

Figure 10 shows a set of height difference maps and statistics for the 1º x 1º cell centred just west of London.


(a)
(b)
(c)
(d)


(e)
(f)
(g)
(h)
(i)
(j)


(k)

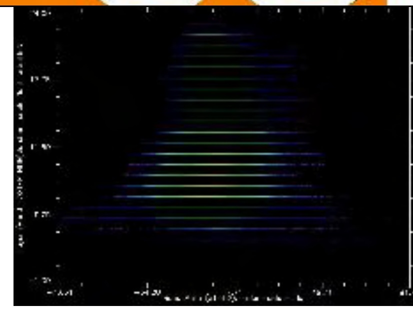
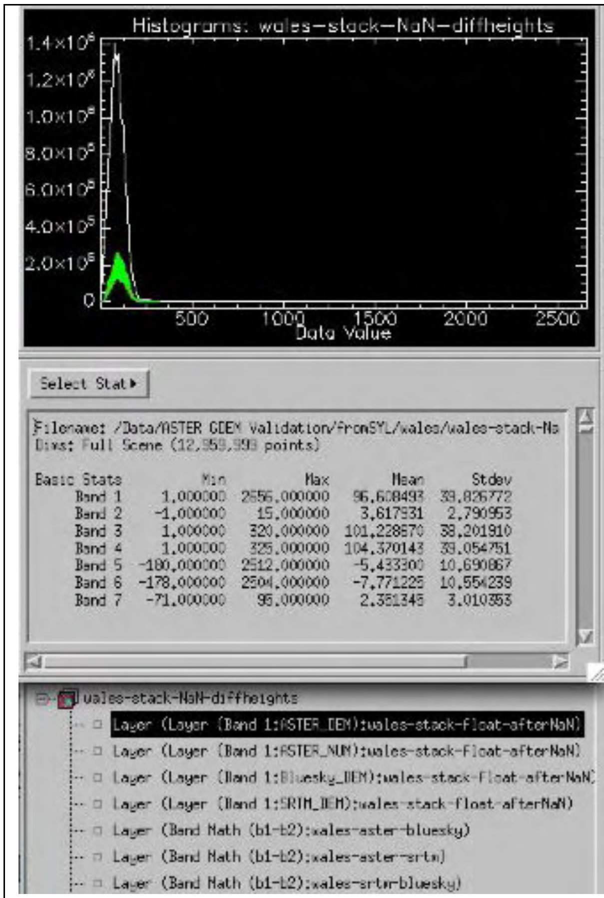

(l)

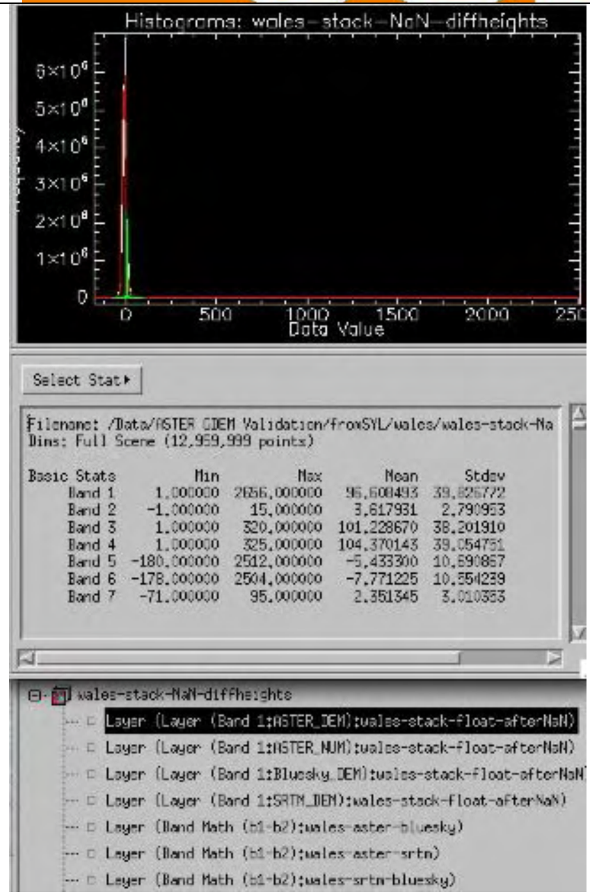
Figure 10. London height histograms and difference statistics. (a) Height histograms: ASTER (white), BlueSky (green), Lidar (red), SRTM (blue); (b) Height difference histograms: ASTER-BlueSky (white), ASTER-lidar (green), aster-srtm (red), lidar-Bluesky (blue); (c) ASTER-BlueSky; (d) ASTER-lidar; (e) SRTM-Bluesky; (f) SRTM-lidar; (g) ASTER-SRTM; (h) 2D scatterplot of ASTER-SRTM vs NUM; (i) lidar-BlueSky; (j) Landcover; (k) 2D scatterplot of ASTER-BlueSky vs NUM; (l) 2D scatterplot of ASTER-lidar vs NUM

The ASTER DEM over the cell near London appears to have noise effects due to low numbers of ASTER frames and imperfect exclusion of clouds. However the impact of these on the height difference statistics is limited as all the biases are close to zero and the standard deviations around 8.5m. However, across the large diagonal feature there are height differences of almost 35 metres. The SRTM heights appear closer to the reference DEMs. The 2D scatterplots indicate once again increasing height difference wrt ASTER NUM.

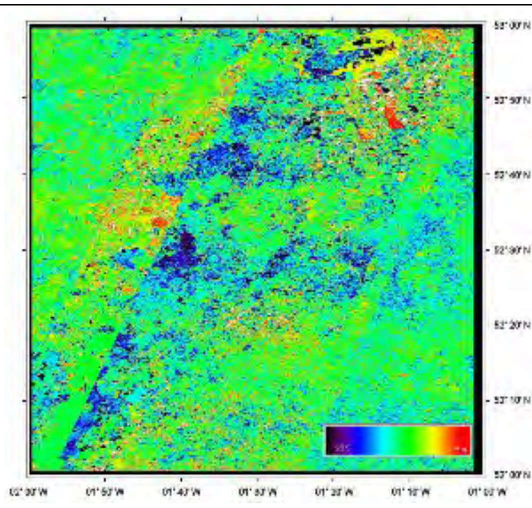
<u>Height statistics and Height differences : Central England, UK</u> (N52W002)


Histograms: wales-stack-NaN-diffheights
Data Value
Select Stat
Filename: /Data/ASTER GDEM Validation/fromSYL/wales/wales-stack-Na
Dims: Full Scene (12,959,999 points)
Basic Stats Min Max Mean Stdev
Band 1 1.000000 2656.000000 96.608493 39.826772
Band 2 -1.000000 15.000000 3.617931 2.790953
Band 3 1.000000 320.000000 101.228670 38.201910
Band 4 1.000000 325.000000 104.370143 39.054751
Band 5 -180.000000 2512.000000 -5.433300 10.690867
Band 6 -178.000000 2504.000000 -7.771225 10.554239
Band 7 -71.000000 95.000000 2.351345 3.010353
wales-stack-NaN-diffheights
Layer (Layer (Band 1:ASTER_DEM):wales-stack-float-afterNaN)
Layer (Layer (Band 1:ASTER_NUM):wales-stack-float-afterNaN)
Layer (Layer (Band 1:Bluesky_DEM):wales-stack-float-afterNaN)
Layer (Layer (Band 1:SRTM_DEM):wales-stack-float-afterNaN)
Layer (Band Math (b1-b2):wales-aster-bluesky)
Layer (Band Math (b1-b2):wales-aster-srtm)
Layer (Band Math (b1-b2):wales-srtm-bluesky)

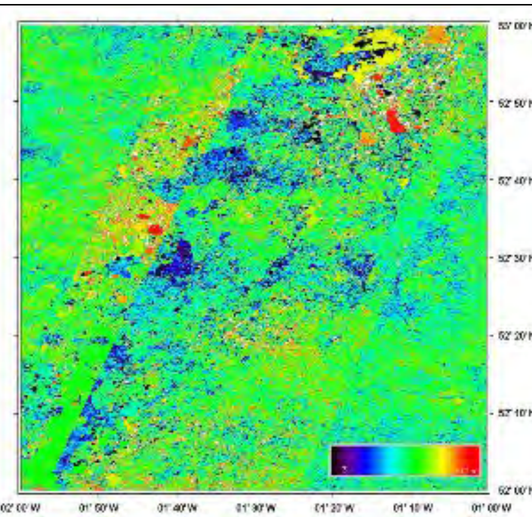
(a)


Histograms: wales-stack-NaN-diffheights
Data Value
Select Stat
Filename: /Data/ASTER GDEM Validation/fromSYL/wales/wales-stack-Na
Dims: Full Scene (12,959,999 points)
Basic Stats Min Max Mean Stdev
Band 1 1.000000 2656.000000 96.608493 39.826772
Band 2 -1.000000 15.000000 3.617931 2.790953
Band 3 1.000000 320.000000 101.228670 38.201910
Band 4 1.000000 325.000000 104.370143 39.054751
Band 5 -180.000000 2512.000000 -5.433300 10.690867
Band 6 -178.000000 2504.000000 -7.771225 10.554239
Band 7 -71.000000 95.000000 2.351345 3.010353
wales-stack-NaN-diffheights
Layer (Layer (Band 1:ASTER_DEM):wales-stack-float-afterNaN)
Layer (Layer (Band 1:ASTER_NUM):wales-stack-float-afterNaN)
Layer (Layer (Band 1:Bluesky_DEM):wales-stack-float-afterNaN)
Layer (Layer (Band 1:SRTM_DEM):wales-stack-float-afterNaN)
Layer (Band Math (b1-b2):wales-aster-bluesky)
Layer (Band Math (b1-b2):wales-aster-srtm)
Layer (Band Math (b1-b2):wales-srtm-bluesky)

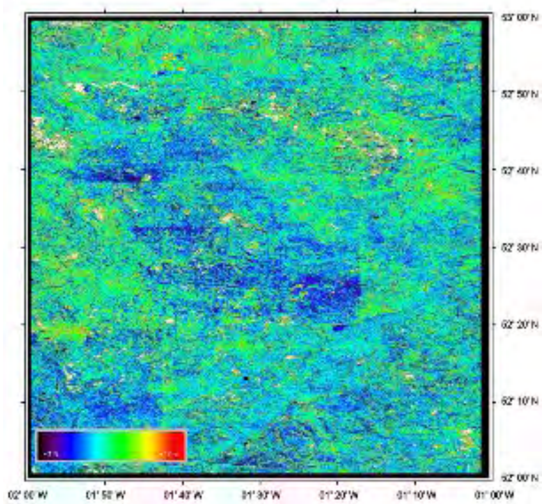
(b)



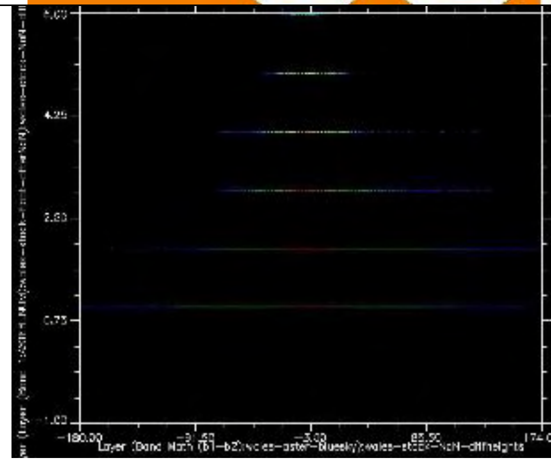
(c)



(d)



(e)



(f)

Figure 11. Height and height difference plots and statistics over central England. Histograms of (a) heights: ASTER (white), BlueSky (green); (b) height differences: ASTER-BlueSky (red), ASTER-SRTM (white), SRTM-BlueSky (green). Height difference map of (c) ASTER-BlueSky; (d) ASTER-SRTM; (e) SRTM-BlueSky. 2D scatterplot of height difference ASTER-BlueSky vs ASTER NUM.

A few erroneous values in the ASTER DEM cause an overall huge negative height difference of ASTER-BlueSky and ASTER-SRTM up to 2500m. However, the overall height difference statistics show height difference bias slightly negative with a standard deviation around 10.5m. The SRTM-BlueSky show good agreement between SRTM and BlueSky DEMs.

Impact of median filtering on height differences

It was noted that the ASTER DEMs were very noisy for the UK scenes. Previous experiments with SRTM showed that a median filter was a highly effective way of reducing height noise with an overall small improvement in the DEM height difference statistics with reference DEMs.

In Figure 12, heights are shown from before and after median filtering for the whole area and for a zoom-in over an area with large amounts of noise. It is not clear if median filtering preserves all the DEM height details, especially the true resolution. Further experiments are required in the future which are outside the scope of this study.

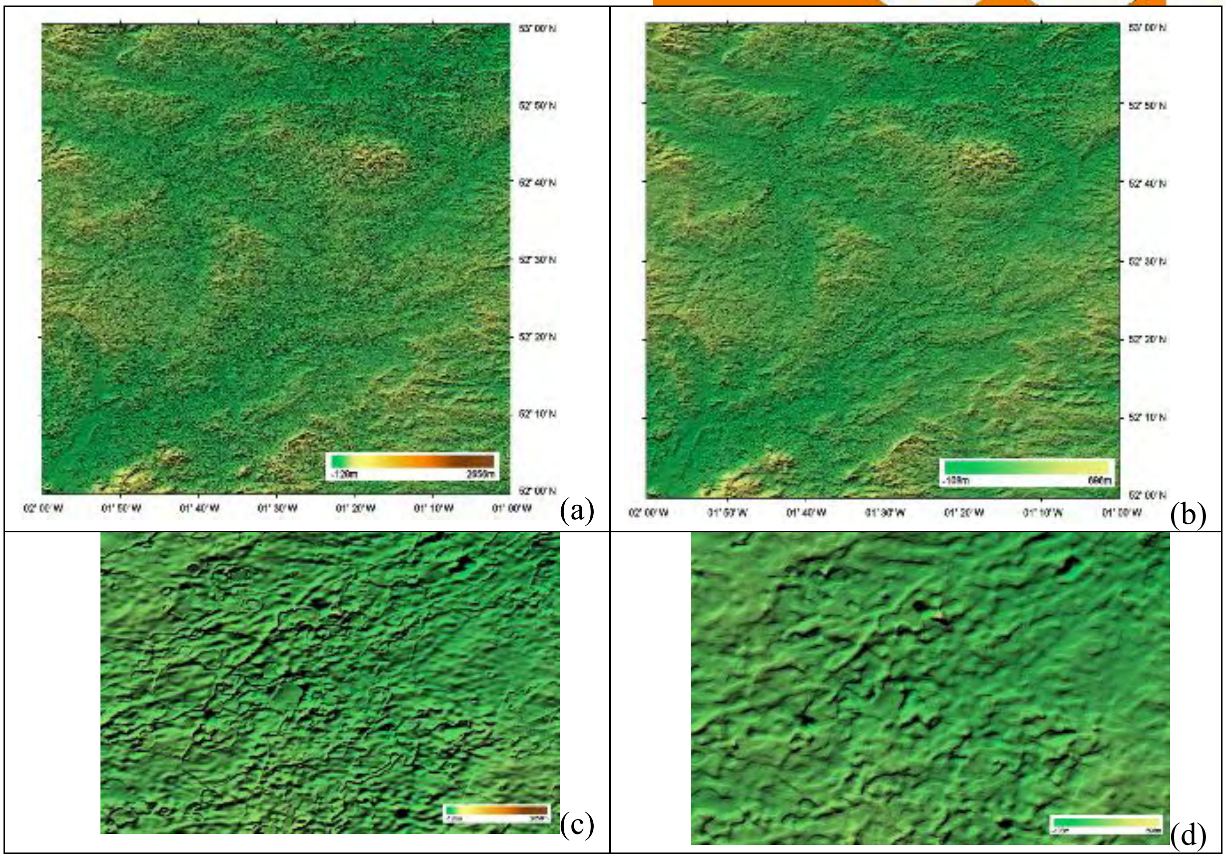


Figure 12. ASTER DEM before (a) & detail (c) and after median filtering (b) & detail (d).

Table 1 shows the impact of median filtering in London and central England on the height difference statistics which indicates that median filtering not only removes gross errors (blunders, outliers) but also improves the overall height difference statistics, especially a reduction in the standard deviation.

Dataset	ASTER-BlueSky Min	ASTER-BlueSky Max	ASTER-BlueSky Mean	ASTER-BlueSky Stdev
London (Original)	-155	131	-3.267	8.496
London (after filtering)	-103	120	-3.344	7.644
Central England (Original)	-180	2512	-5.382	10.653
Central England (after filtering)	-164	553	-5.572	8.931

Conclusions

Five 1º x 1º cells of ASTER GDEM have been compared with ground reference DEMs for three CEOS-WGCV-TMSG areas (Three Gorges, P.R. China; Barcelona, Spain; Montagne Sainte Victoire, France) and two areas in the UK for which complete high resolution DEMs were available. All reference DEMs were proprietary or restricted. It should be noted that this is normally the case for almost all areas of the planet outside North America. Nevertheless significant assessments have been performed.

For all the areas except China, the DEM height difference statistics indicate that the ASTER DEM is within specification. For the area in China, due to very rugged terrain it is not clear how accurate how the reference DEM is and it is likely that the ASTER DEM reflects this also.

A correlation was found between increasing height differences of ASTER with respect to reference DEMs and a decreasing number of ASTER frames employed. The fact that this relationship also appears to hold with ASTER-SRTM suggests that it may be possible if ASETR-SRTM height differences are produced worldwide to establish an underlying prediction of expected height error for for each individual pixel.

Attempts to reduce DEM height noise using median filtering appears successful for the two areas which suffered most due to insufficient number of ASTER frames (London and central England).

Unfortunately the wrong cell was ordered for the CEOS-WGCV-TMSG test sites in North Wales as shown in the last figure.

Figure 13. ICEDS display of central UK showing the 2 cells ordered (red borders) and the correct cell (purple border) for North Wales with much more rugged relief over North Wales (N52W004).

It is hoped that this mistake can be rectified and an additional analysis performed in the future.

Acknowledgements

The author would like to thank Mark Churchyard for all his help in securing funding support from BNSC to enable this study to be undertaken. The authors would like to thank Xiaofan Li (Peking University and University College London) and Lixia Gong (China Earthquake Bureau) for all their help with the China DEM analysis. In addition, thanks to Wolfgang Kornus (ICC) for the kind loan of the Barcelona DEM, Mike Pitkin for the production of the AeP DEM which has played such an important role over the last 20 years of research. The author would also like to thank Brian Bailey (USGS-EDC) for helpful discussions.

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CONDITIONS FOR THE USE OF A DIGITAL LISTING OF GEOGRAPHICAL DATA

The **digital terrain models (DTMs)** defined below :

Lat. & Long. :	E 5°03′ - 5°45′ / N 43°12′- 43°44′
Area (km2) :	3480 km2
Cell size :	50 m
Projection system :	Lambert 3 - Clarke 1880 IGN - NTF
Lat. & Long :	E 5°24′ - 5°45′ / N 43°23′-43°34′
Area (km2) :	580 km2
Cell size :	10 m
Projection system :	Lambert 3 - Clarke 1880 IGN - NTF

are extracts from the Altimetric Data Base ® and the Topographic Data Base ® of the Institut Géographique National (I.G.N. France).

These files are made available, by the IGN-F to the user :

Name, Company name ....
Postal address ....
(Capital letters) ....

on a **non-exclusive basis**, are strictly limited to the user's internal use and must not be transmitted to third-parties.

By this present agreement, the user undertakes to :

- limit the use of the files to the specific use defined below, to the exclusion of all other uses :

  .... Scientific use for the Terrain Mapping sub group ....
  .... of the CEOS / CAL VAL Working Group (WGCV) ....

- not to distribute, or make available to third parties, at any time and in any form whatsoever, the said files without having obtained beforehand the express and written consent of the IGN-F and in accordance with the conditions fixed by the latter;
- Waive any claims concerning the accuracy, integrity or up-to-dateness of the file;
- Waive any claims against the IGN-F concerning any compatibility defects between the file and other systems or any defect concerning the suitability of the file for the requirements corresponding to the use defined above.

Done in .... , date ....

Read and approved
(written by hand)

Signature
(Occupation of the person
signing for a legal entity)

5. Reporting pro forma

RESULTS FROM WORK WITH CEOS DEM TEST SITE DATA

Summary sheet

Name of Test site

Name

Organisation

Date

Fill in one form for each area which is used

Images used for DEM computation

Method of DEM computation

Method of resampling

Area tested (km x km)

DEM used for checking

No of control points used in checking

rmse in ht against control points

Max, min

rmse in ht against check points

Max, min

rmse against DEM

Max, min

Comments

4.3. IGN DEM from the Topographic Data Base

Name	dem_ign_846.6_146_10
Grid interval	10 meters
Area	test site of AIX, covered by the IGN 1:50 000 map sheet 3244
Source	the original altimetric data are obtained by stereoplotting, from aerial photographs at scale 1:30 000, and field measurements. The DEM is then obtained by interpolation with a 10 m grid
Accuracy	accuracy is generally around 1 meter

4.4. ISTAR DEM from SPOT panchromatic stereo

This DEM was derived from SPOT stereo using automatic correlation on ISTAR production line.

Name	dem_istar_819_162_20
Grid interval	20 meters
Area	SPOT stereoscopic overlap of two images centered N 43°11′ E5°25′
Source	SPOT 1 panchromatic stereo pair b/h ratio: 0.6 KJ 51 262.5 25.5 W 30/08/86 KJ 50 262.5 7.6 E 3/09/86
Accuracy	accuracy is 9 meters rms

4.5. ISTAR urban DEM from aerial photographs

This DEM was derived from aerial photographs of a scale 1:8 000 using automatic correlation and manual correction of building edges. Ground level is interpolated from manually selected axis

Name	dem_istar_846.100_115.900_0.4
Grid interval	0.40 meters
Area	around Marseille old harbor 1.0 km x 1.1 km
Source	1/8 000 specific aerial survey with 90% overlap
Accuracy	Z - buildings 2m, ground 40 cm XY - 40 cm

4. Detailed technical Description of the Data

4.1. UCL DEM from aerial photographs

This DEM was derived from aerial photographs of a scale 1:30 000 using manual measurement on a Kern DSR1 analytical stereo plotter. A full description of the data set and tests carried out with can be found in Theodossiou and Dowman [1].

Name	dem_ucl_858_145.5_30
Grid interval	30 meters
Area	around Montagne Sainte Victoire 12.4 km x 6.9 km
Source	1:30 000 aerial photographs
Accuracy	+/- 1.3 m

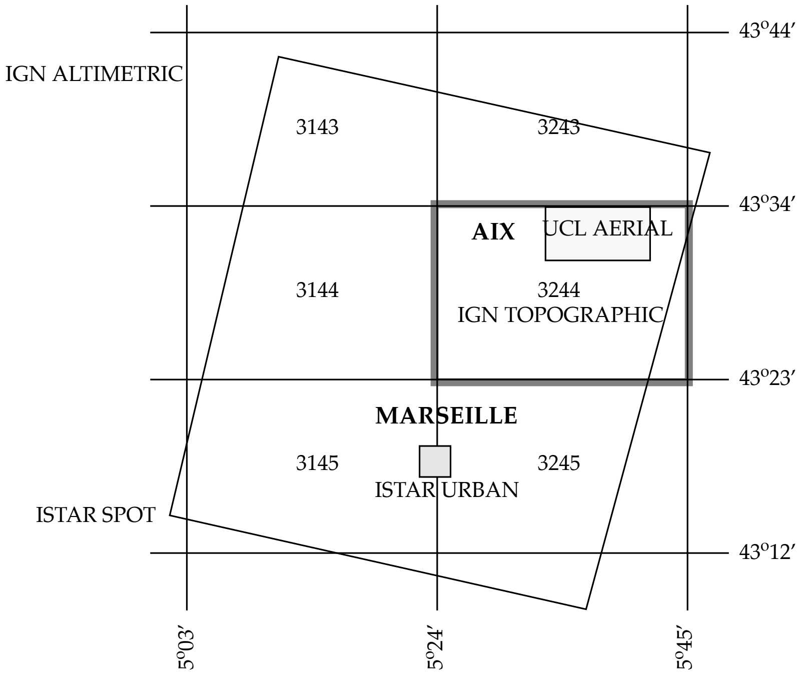
4.2. IGN DEM from Altimetric Data Base

Name	dem_ign_817_166_50
Grid interval	50 meters
Area	test site of AIX-MARSEILLE, covered by the IGN 1:50 000 map sheets 3143, 3144, 3145, 3243, 3244 and 3245
Source	the original altimetric data are obtained by stereoplotting from aerial photographs at scale 1:60 000 (for map sheets 3144, 3145, 3244 and 3245 i.e. the southernmost sheets) with a 20 meters contour interval, or at scale 1:30 000 (for the 2 northern sheets), with a 10 meters contour interval for the sheet 3243 and a 5 meters contour interval for the sheet 3143. The DEM is then obtained by interpolation
Accuracy	accuracy of stereoplotting is generally better than 5 meters in the southern part of the work area and better than 2.5 meters in the northern part. The final accuracy of the delivered DEM depends on local relief characteristics

1. THEODOSSIOU, E.I. and DOWMAN, I.J., 1990 Heighting accuracy of SPOT. Photogrammetric Engineering and Remote Sensing. 56(12): 1634-1649.

3. Technical Description of the Data

3.1. Area



3.2. Coordinates

Geodetic system	NTF (Nouvelle Triangulation de la France)
Ellipsoid	Clarke 1880 IGN
Prime meridian	Paris
Projection	Lambert III
Altimetric system	IGN 1969

3.3. Format

Structure	unix tar file
Raster images	raw with 2 bytes per pixel

3.4. Delivery media

Exabyte 8500

2.3. Quick description of the data set

Approximate longitude and latitude: 43°28’ / N 5°24’ E

Size: 60 x 60 km

Z range: 0 - 1000 m

Table 1 : DEMs provided in the AIX - MARSEILLE test site data set

	UCL	IGN	IGN	ISTAR	ISTAR
NW X origin (km)	858.0	817.0	846.6	819.0	846.1
NW Y origin (km)	145.5	166.0	146.0	162.0	115.9
Grid	30 m	50 m	10 m	20 m	0.4 m
Rms	+- 1.3 m	5m - 2.5 m	1 m	10 m	ground 0.4 m building 2 m
Source	Aerial	Aerial	Aerial	Spot	Aerial
Extent (km x km)	12.4 x 6.9	61 x 63	30.6 x 21.7	60 x 62	1.0 x 1.1
Dimx	415	1221	3060	3000	2600
Dimy	231	1261	2170	3100	2880
Bytes	2				
Unknown value	0				
Offset	10000				
Scale factor	0.1				

2.4. Other sources available over the area

Maps	1:25 000, 1: 50 000, 1: 100 000 IGN + 1: 10 000 scanned in Marseille urban area
GCPs	available from maps + IGN catalogue
Targets	none
Images Orthoimages	SPOT, ERS-1, JERS-1 OPS and SAR, CNES push broom and SPOT 5 simulated stereo, aerial 1:5 000 scanned, aerial 1:30 000 scanned, metric camera

2.2. How to read the tape and the DEMs

You need 50 Mb of free disk space to extract the data.

The data on the tape can be extracted using the unix *tar* command:

tar xvbf 64 /dev/nrst0

The files extracted from the tape are :

- aix_marseille_test_site.ascii   an *ascii* version of this documentation without figures
- aix_marseille_test_site.frame   the *frame maker* version of this documentation
- dem_ucl_858_145.5_30
- dem_ign_817_166_50
- dem_ign_846.6_146_10
- dem_istar_819_162_20
- dem_istar_846.100_115.900_0.4

The dems files are 5 DEMs whose characteristics are described in section 2.3.

DEMs are binary encoded, in **raw format**.

Each pixel is encoded with 2 bytes in a *big endian unsigned int* format.

The first pixel is located at the NW corner of the DEM, the last pixel is located at the SE corner of the DEM.

Coordinates refer to the centre of the pixel.

The **z_value** in meters is extracted from the integer **pixel_value** of the pixel using :

```
if (pixel_value != 0)
   {
   z_value = 0.1*(pixel_value - 10000)
   }
   else
   {
   /* this is an unknown value */
   }
```

2. Description

2.1. Origin of data and further information

This data set has been prepared by ISTAR, IGN and UCL from data originating from them. The following sections gives a description of the data. Further information may be obtained from:

Dr. Laurent Renouard
ISTAR
Sophia Antipolis
Espace Beethoven - Route des Lucioles
06560 Valbonne
France

Tel: 33 93 95 72 30
Fax: 33 93 95 93 29
e-mail renouard@istar.fr

Mrs. Sylvia Sylvander
IGN Espace
Parc Technologique du Canal
24 rue Hermes
31527 Ramonville Cedex
France

Tel: 33 62 19 18 18
Fax: 33 61 75 03 17

Professor Ian Dowman
Department of Photogrammetry and Surveying
University College London
Gower Street
London WC1E 6BT
UK

Tel: 44 71 380 7226
Fax: 44 71 380 0453
e-mail idowman@ps.ucl.ac.uk

1.4. Contacts

Any information about the Terrain Mapping sub group and about data sets available may be obtained from the chairman of the group:

Professor Ian Dowman
Department of Photogrammetry and Surveying
University College London
Gower Street
London WC1E 6BT
UK

Tel: 44 71 380 7226 - Fax: 44 71 380 0453 - e-mail idowman@ps.ucl.ac.uk

Further information about the data set included in this package should be made to the relevant person listed below.

UCL **IGN** **ISTAR**

AIX - MARSEILLE TEST SITE

Documentation - Version 1.0

1. Introduction

1.1. Background

This data set has been prepared for the Terrain Mapping sub group of the CEOS Calibration/ Validation Working Group (WGCV). It is one data set within a dossier of data sets which are available to groups with an interest in deriving digital elevation data from satellite sensors who wish to test their algorithms or systems against a recognised standard which is used by other groups. In this way comparative performance of sensors and processing systems can be assessed.

1.2. Data provided

The basic data set which is distributed consists of Digital Elevation Models of the specified test area. The details of these are described below. Additional data in the form of maps, images and products may also be available. This data is described below and may be obtained from the sources listed.

1.3. Conditions of use

The digital elevation data may be freely used by the recipient, as soon as the form «Conditions for the use of a digital listing of geographical data» is signed by the recipient and returned to the organisation IGN Espace listed in section 2.1.

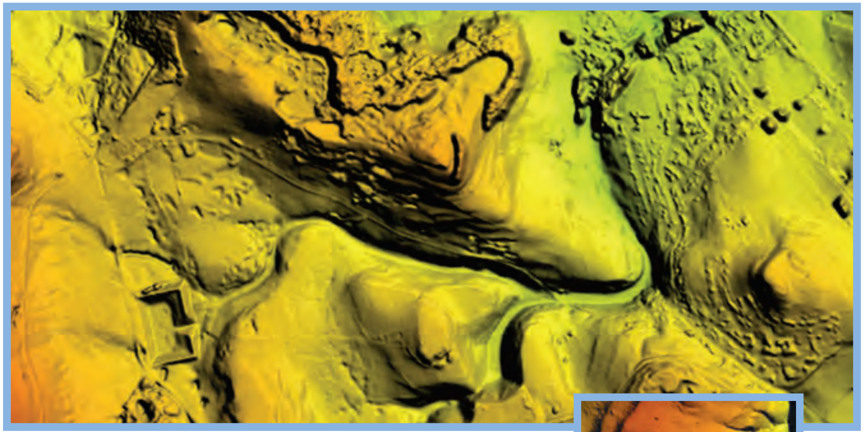
Recipients of the data are required to provide progress reports to the Terrain Mapping sub group when requested to do so, this will normally be on the occasion of meetings of the group which are held about every twelve months. Anyone who has worked with data provided by the group is welcome to attend the meetings of the group. These conditions apply to anyone who has received the data, whether directly from the group or as a third party.

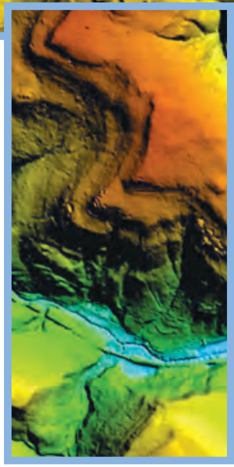
A pro forma for reporting is included with this data set.

Any reports or published papers resulting from this work must acknowledge the CEOS WGCV Terrain Mapping sub group and the organisations listed in Section 2.1.

digital terrain model (DTM)

The Digital Terrain Model (DTM) is derived photogrammetrically and provides ground heights in grid format. Urban areas, greater than 100,000 population, are enhanced with LiDAR data to deliver higher accuracy.





Applications:

- Civil Engineering; Cut & Fill
- Flood Risk Assessment
- Quarrying & Volumetrics
- Mobile Network Planning
- Line of Sight, Visual Impact Studies
- Noise Modelling

Benefits:

- National Coverage
- Off-the-Shelf Data
- GIS Ready
- Crown Copyright Free
- Flexible Licencing
- Photogrammetrically Derived

DTM Feature	Digital Terrain Model	
	National Perspectives	**Urban Perspectives**
Resolution	5m	1m
Coverage Status	Full England and Wales coverage	Areas with population >100,000
Accuracy XY rmse	1m	50cm
Accuracy Z rmse	1.5m	25cm
Optimum Viewing Scale	1:10,000	1:10,000
Update Programme	Every 5 years	Every 5 years
Formats	ASCII XYZ, ARC Grid, GeoTiff, 3DS/MAX, Erdas Imagine	ASCII XYZ, ARC Grid, GeoTiff, 3DS/MAX, Erdas Imagine

GeoPerspectives™

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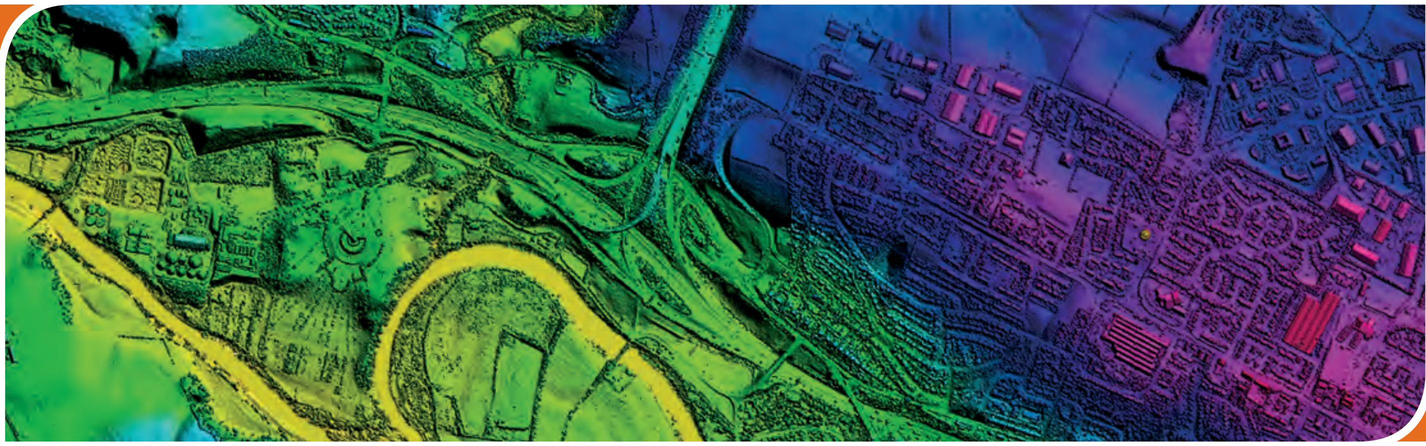
Cities Revealed™



LiDAR

LiDAR

Elevating your world

As a leading supplier of geographic information and aerial imagery The GeoInformation Group continues to provide the latest geographic information products to its clients. **LiDAR** (Light Detection and Ranging) is an airborne mapping technique that uses a laser to measure the distance between the aircraft and the ground providing a very accurate 3D model of the world.

LiDAR data, once reserved for specialist users and niche applications, is now readily available from Cities Revealed. With an already comprehensive and current archive of many metropolitan areas, including London, Manchester, Birmingham, Liverpool, Newcastle, Edinburgh and Glasgow, Cities Revealed will further expand the archive to meet industry demand.

Cities Revealed **LiDAR** is a very dense network of elevation points with vertical and horizontal accuracies of +/- 15 cm. Each point is collected at intervals of between 1m and 2m, which produces detailed 3D ground and surface models.

LiDAR has revolutionised the acquisition of digital elevation data and has quickly become a de facto method of collecting height and surface information for a myriad of applications and analysis. There is no other method that can collect ground and surface height information as quickly, accurately and as cost-effectively. These factors make **LiDAR** a highly viable option for all applications that require height, volume or 3D visualisation information.

Case Study

Luton Airport

Site Assessment for Runway Development

As part of the ongoing expansion of London Luton Airport, detailed topographic information was required to assess development options in and around the existing airport site. An area of approximately 80 sq km was inaccessible for ground survey. With an undulating terrain, accurate level data formed a crucial part of the optioneering process. Due to its quick and reliable collection method **LiDAR** data was the ideal choice for the analysis.

*"We chose The GeoInformation Group to provide **LiDAR** data as they are a regular and trusted supplier of aerial photography data. We have been a client for a number of years and the Airport has developed an excellent working relationship with them."* Neil Thompson, Airspace and Airfield Environment Manager, London Luton Airport Operations Ltd.

LiDAR

Features

- A geographic database with height and surface measurement information
- Collected by a laser at intervals of between 1m and 2m on the ground
- Height point vertical accuracy of +/- 15 cm
- Referenced to the National Grid system
- Integrates with other geographic databases and Ordnance Survey mapping
- Produces both Digital Terrain Models (ground surface only) and Digital Elevation Models (the ground and all features on it)
- Supplied in a number of formats and easily integrates with all major GIS and CAD systems
- Extensive coverage of UK urban areas available

Benefits

A very accurate collection method of ground and surface height information.

LiDAR data can be integrated directly within an existing mapping system therefore reducing initial setup costs.

Fastest collection method for data of this type and highly cost effective.

LiDAR provides a true 3D view on the world; a realistic representation of the world provides better understanding and improves project communication.

LiDAR enhances the decision-making process and reduces overall project timeframes.

LiDAR data and models can be used in a wide variety of applications, providing a high degree of flexibility to the end user.

LiDAR data collection is not dependent on lighting conditions, therefore capture can take place at any time, including at night. This drastically improves the chance of collecting the data in a single flight, resulting in rapid delivery times.

Applications

LiDAR surveys can be utilised in many applications, a few of which are listed below.

- Flood modelling
- Planning control
- Property management
- Wind farm visualisation
- Urban regeneration projects
- CCTV location planning
- Microwave antenna modelling
- Cut and fill analysis
- Airport planning
- Tree height measurement
- Water supply modelling
- Emergency planning
- Buildings insurance risk assessment
- Telecommunications planning
- Gas pressure modelling
- Road network planning

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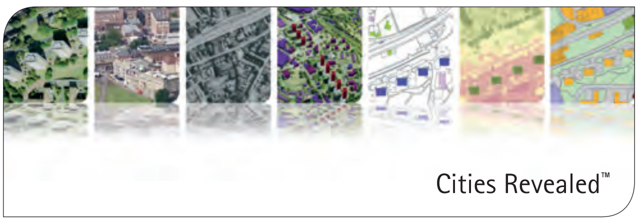

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