The Accuracy of ASTER Digital Elevation Models, a Comparison to NEXTMap Britain

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Abstract
In many overseas geological surveying projects an accurate elevation model is often required for analysis, image orthorectification, navigation and the generation of contours. Acquiring an accurate elevation model can be a difficult and expensive task. One possible solution is to generate a DEM from ASTER satellite imagery. However, to fully understand the potential of ASTER DEMs the accuracy of these models needs to be established. The DEM was created using the Sulsoft ASTER DTM add-on ENVI module.

NEXTMap provides an ideal reference dataset for comparison. In this study the accuracy of an ASTER generated DEM was assessed for a 50km by 50km area in central Wales. A total of 2.4 million points were compared.

Visual and statistical assessments were made including profile and contour comparisons allowing the spatial variation in accuracy to be explored. A mean vertical difference of –0.98m and a standard deviation of approximately 9m were calculated. This suggests that 95 % of the ASTER DEM points are within ±20m of the NEXTMap DEM. Considering these accuracy levels, contours from ASTER can be generated at 40m intervals.

(End of Abstract)

Words: 2600

The Accuracy of ASTER DEMs

Digital Elevation Models (DEMs) have been successfully generated from stereo satellite imagery for some time with the use of cross track stereo SPOT 1-4 from 1986 onwards. The launch of along track stereo sensors allowed the images forming the stereopairs to be collected within a short time separation overcoming temporal changes within the scene common in cross track systems such as variations in lighting, atmospheric conditions, cloud cover and vegetation. This high temporal correlation, allows the automatic stereomatching process to run more effectively and for the resultant DEM to be generated more accurately. The Advanced Spacebourne Thermal Emission and Reflection Radiometer (ASTER) is only one of a series of platforms offering along track stereo capability, including IKONOS and SPOT 5, but the low cost of ASTER data coupled with its multispectral capability gives it a significant advantage over other sensors for Geological applications.

Previous Studies

In this study ASTER will be compared to NEXTMap DEMs for an area in Wales. There have been a number of accuracy studies assessing ASTER data (Kaab 2002; Hirano *et al.* 2003; Cuartero *et al*. 2004; Poli *et al*. 2004); San and Suzen, 2005), but few have had access to such a high quality DEM with as many comparison points. Accuracies are usually reported to be around one pixel (15m) in Root Mean Square Error (RMSE) and standard deviation (SD). Figure 1 shows a review of previous studies.

Commonly the RMSE and SD are the statistics used to measure DEM accuracy. In order for these figures to be interpreted by users of the DEM giving confidence levels (68/95/99%) is useful. However is should be noted that assigning a confidence level to RMSE and SD based on reference to a dems true position is not possible unless the mean offset is accounted for or is zero or very close to it in relation to the size of the SD.

ASTER

ASTER is one of a number of sensors carried by the National Aeronautics and Space Administration’s (NASA’s) Terra spacecraft. It was launched in 1999 and offers wide spectral coverage with a total of 14 bands in the visible, near infrared, shortwave infrared and thermal infrared sections of the electromagnetic spectrum, as shown in Table 2. Stereo images are acquired in band three using both the nadir (3N) and backward (3B) pointing telescopes at 15m resolution with the scene covering approximately 60km by 60km.

NEXTMap Britain

NEXTMap Britain is a national high-resolution elevation dataset with a 5m-post spacing, generated from airborne infererometric synthetic aperture radar (INSAR) having a quoted accuracy of 1.0m RMSE (Type 2 data). Two main elevation models make up the dataset, these are the digital surface model (DSM) and the digital terrain model (DTM). The DTM has undergone editing to remove cultural features and smaller areas of trees, where as the DSM represents the unedited model. It is assumed in this study that the NEXTMap DEM is of a higher level of accuracy than the ASTER DEM and will be used as a reference dataset against which comparisons will be made.

DEM Generation

ENVI was used to generate the DEM using the ASTER DEM extraction module. The scene chosen covers an area in Central Wales and is a level 1B processed image (Figure 2). The topography on the area could be classed as low mountains. Nine control points were located across the scene (Figure 1), extracted from OS 1:50000 scale mapping. Although higher accuracy maps are available for the test site 1:50000 scale maps were chosen to simulate the scale of maps that are typically available in overseas projects. Furthermore it has been stated that '1:100,000 or 1:50,000 scale sources will probably provide sufficient accuracy' (Lang and Welch, 1999). GCPs were typically located on spot heights at road intersections with an even distribution across the imagery (Figure 1), returning a maximum reported error of 3.3 pixels (Table 3). These values should be treated with caution as the manual states that they are not strictly accurate, so the emphasis was placed on locating the points correctly rather than trying to achieve a low RMSE value. The ENVI ASTER DEM extraction module expects co-ordinates to be given in UTM, WGS84 datum so the GCP co-ordinates were transformed from OSGB using IMAGINE co-ordinate calculator before being entered.

The correlation score map produced within the ASTER DEM Extraction module is shown in Figure 4. Darker colours indicate areas that have low correlation between the two 3N and 3B images. These low correlation areas were found to correspond to forest, open water and moorland areas The 30m generated DEM (Figure 3) was exported to Imagine and then reprojected with z values recalculated to OSGB.

The 5m-post spacing NEXTMap DEM was resampled to 30m using the Degrade function within IMAGINE and then subtracted from the ASTER DEM to create a difference dataset. Statistics were calculated using SPLUS and visual comparisons made within ArcMap.

Accuracy assessment

The main statistical comparison was carried out over a subset centred on the scene, as shown in Figure 5. Visually there appears to be no apparent holes within the ASTER DEM. However when the ASTER DEM is viewed as a shaded relief image and compared to the NEXTMap DEM, a terracing artefact effect can be seen on the steeper slopes (Figure 6).

The results of the statistical comparison are shown in Table 4. The comparison between the NEXTMAP DSM and the ASTER DEM show that there is a mean difference of –0.98m and a standard deviation of approximately 9m. Taking into account this mean offset the results suggests that 68 % of the ASTER DEM points are within 10m of the NEXTMap DEM, 95% within 20m and 99% within 30m. Based on the 2.4 million comparison points a RMSEz of ± 9m was calculated, which compares more favourably than other accuracy assessment studies. The high minimum and maximum difference (-110m, 102m) relate to outliers that exist within the dataset, the significance of these points is low as shown by the histograms illustrating the spread of data in Figures 7 and 8. A negative shift in the mean can be observed but the magnitude of the differences follow the typical normal distribution.

The ASTER DEM has a slightly higher accuracy when compared to the NEXTMap DTM this is likely to be related to the smoothing of surface features during the ASTER DEM generation process.

The spatial variation in the magnitude of elevation difference is shown in Figure 9. This has been calculated by taking the NEXTMap DSM elevation values from the ASTER and then colour coded according to magnitude of elevation difference. Colder colours indicate areas where the ASTER DEM is lower than the NEXTMap DEM and warmer colours areas that are higher on the ASTER DEM. The most striking feature of the difference model is a cyclic banding pattern with alternating zones of positive and negative elevation differences. This spatial variation in accuracy does not correspond to variations in topography but is aligned parallel to the scan direction of the ASTER Image. It is difficult to be certain, what is causing these areas of local offset but possible sources include initial pre-processing of the ASTER data, calibration problems or artefacts caused by the DEM extraction process.

To further investigate the DEM points within the areas of banding two subsets were taken (shown in Figure 9) one in the area where the ASTER DEM is higher than the NEXTMap DSM (subset area 1) and one where the ASTER DEM is lower (subset area 2). Table 4 shows the statistics for the two subset areas. In subset area 1 the mean difference is 10.2m and in area 2 the mean difference is –6.4m, this shift is also illustrated by the histogram of pixel differences (Figures 10 & 11). Area 1 has a RMSEz of ±11.7m and area 2 ± 10.6m. Although these areas represent the lowest accuracy zones in comparison to NEXTMap the statistical accuracy is comparable to other studies, namely Poli *et al.* (2004).

Looking more closely at the difference image (Figure 12), we can start to find the causes of local variations between the ASTER and NEXTMap datasets. Valley bases are higher on the ASTER DEM and areas of trees generally lower, suggesting a general smoothing of features. However there are differences that cannot be easily explained by topographic variations in terrain characteristics and may be simply a result of the ASTER DEM extraction process.

There is also a tendency for the ASTER DEM to be higher than the NEXTMap DSM on northwest and north facing valley sides, which may be due to a shadowing effect, influencing the ASTER DEM extraction routine.

A profile comparison across a 2km transect (Figure 3), generally shows a good correspondence between the ASTER DEM and NEXTMap DSM (Figure 13). The terracing effect discussed earlier can be seen on one of the slopes together with a smoothing of valley bottoms. For the first 1km of the profile the ASTER DEM can be seen to follow closely to the NEXTMap DEM but with a negative offset.

Contour Comparison

Contours, automatically generated for the ASTER DEM and NEXTMap DSM are shown in Figure 14. Although not superimposing perfectly they show a reasonable correspondence in location. Valleys tend to be less well defined on the ASTER DEM and a degree of smoothing was noted on spurs. It was found that viewing 20m ASTER contours at 1:100,000 or even 1:50,000 scale is possible, without showing significant disparity with the NEXTMap contours. Assuming a four times standard deviation rule to define contour intervals, a 40m contour interval can be deemed appropriate.

Conclusions

It has been demonstrated that ASTER DEMs can be generated with a level of accuracy suitable for fulfilling many geological and mapping application in international projects, provided adequate ground control is available. In comparison to the NEXTMap DSM the calculated accuracy was found to be comparable or better than previous assessments of ASTER DEMs.

The marked spatial variation in accuracy, shown by areas of positive and negative offset aligned parallel to the scan direction, represents the lowest accuracy zones in comparison to NEXTMap. However, the statistical accuracy of these areas is still comparable to other studies, namely Poli *et al*. (2004) and clearly warrants further investigation.

Cuartero, A. Felicisimo, A.M. & Ariza, F.J. 2004. Accuracy of DEM generation from Terra-Aster stereo data. IAPRS&SIS, vol **35**, Part B6, pp. 225-260.

Hirano, A. Welch, R. & Lang, B. 2003. Mapping from ASTER stereo image data: DEM validation and accuracy assessment. *ISPRS Journal of Photogrammetry and Remote Sensing* **57**: 356-370

Kääb, A. 2002. Monitoring high-mountain terrain deformation from repeated air- and spaceborne optical data: examples using digital aerial imagery and ASTER data. *ISPRS Journal of Photogrammetry and Remote Sensing*, **57**(1-2), 39-52.

Lang, H. & Welch, R., 1999. Algorithm Theoretical Basis Document for ASTER Digital Elevation Models, Version 3.0 Jet Propulsion Laboratory, Pasadena, CA. 69 pp.

Poli, D. Remondino, F. & Dolci, C. 2004. Use of satellite imagery for DEM extraction, landscape modelling and GIS applications. World Wide Web Address: http://www.photogrammetry.ethz.ch/general/persons/fabio/thai_DTM.pdf

San, B.T. & Suzen, M.L. 2005. Digital elevation (DEM) generation and accuracy assessment from ASTER stereo data. *International Journal of Remote Sensing*, **26**, 5013-5027

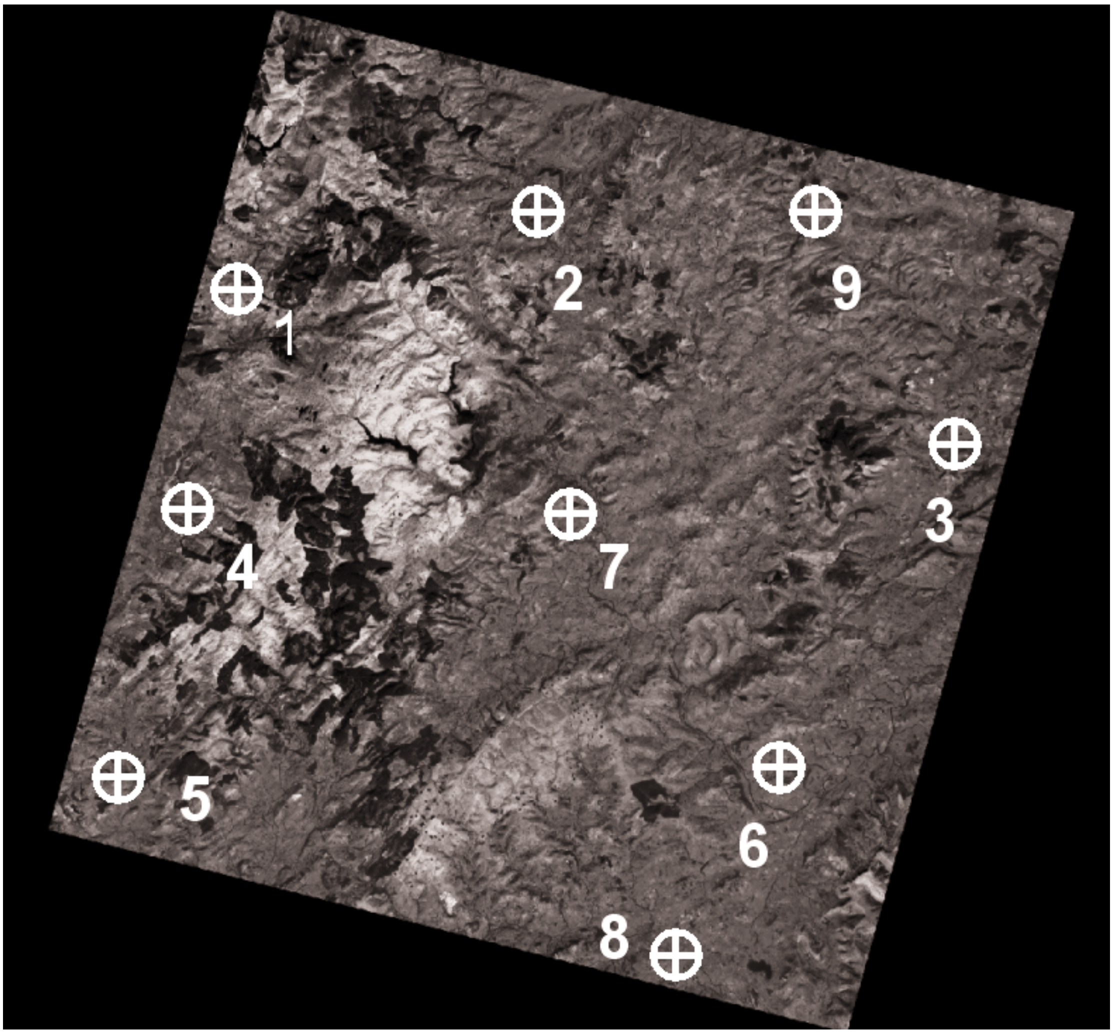

Fig. 1. Location of control points within the scene.

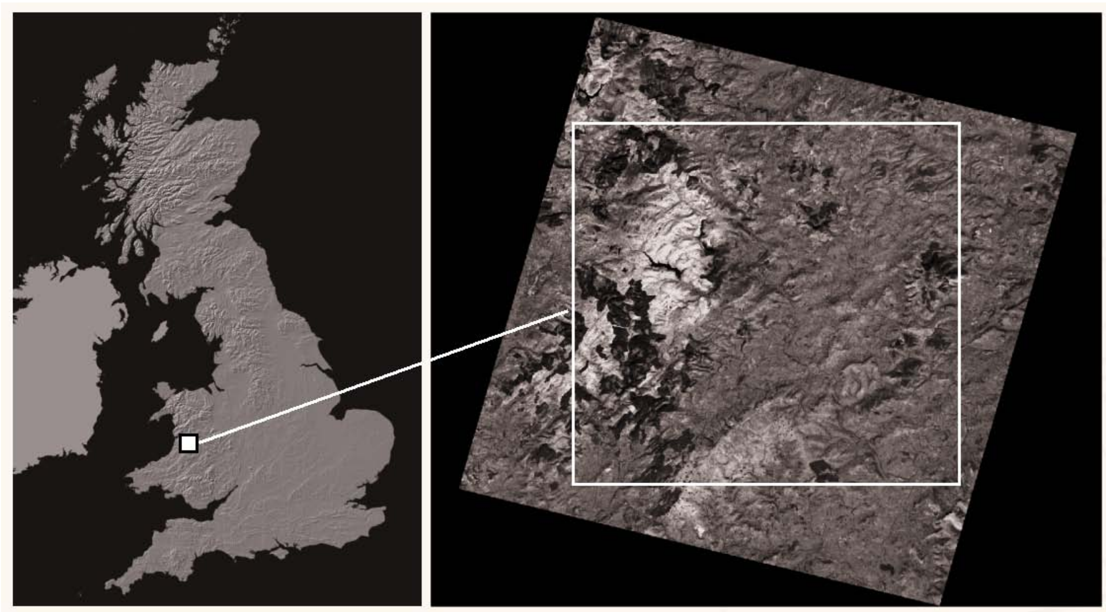
Fig. 2. ASTER Image location**.**

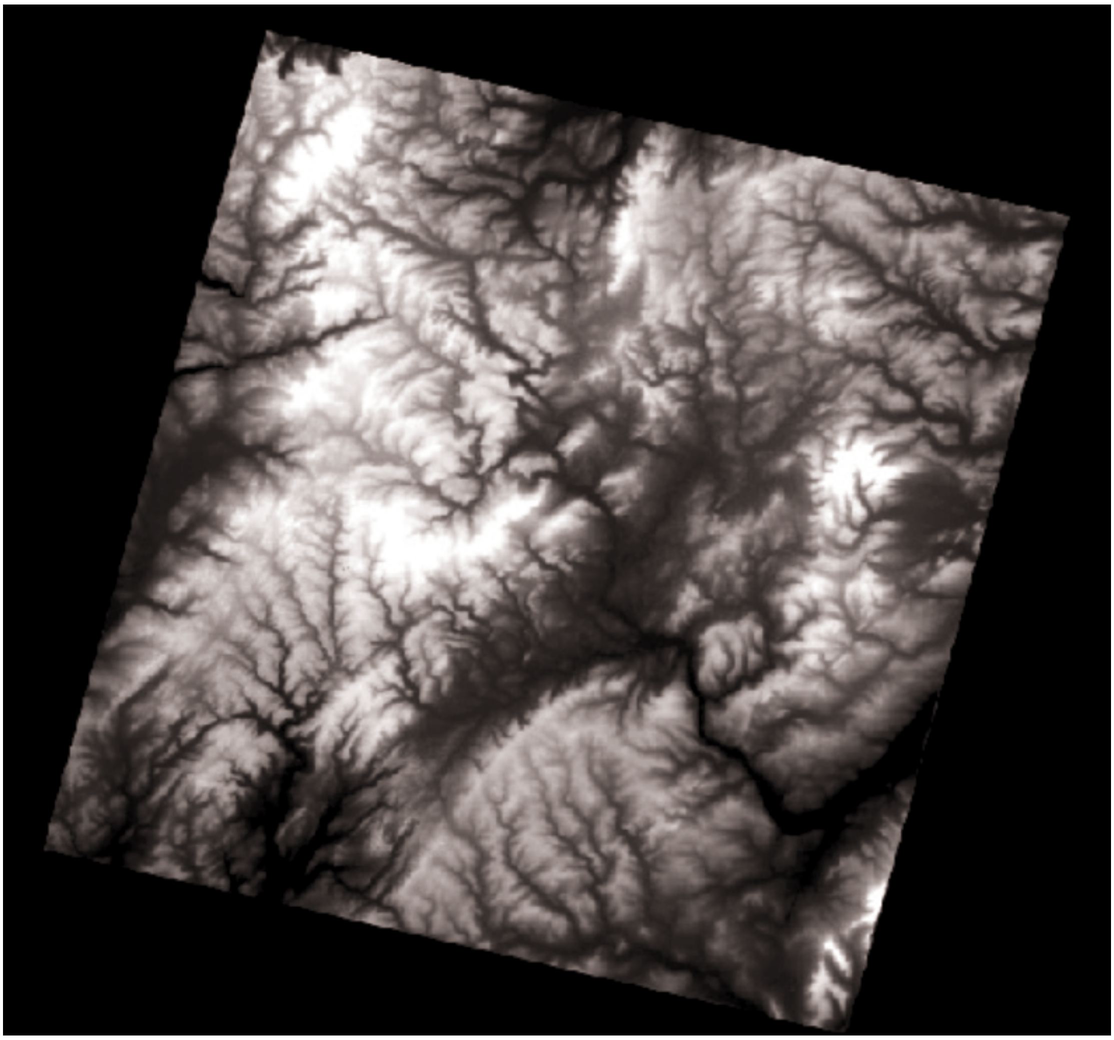

Fig. 3. Generated 30m DEM

Fig. 4. Correlation score map, darker areas indicate lower correlation between the 3N and 3B image.

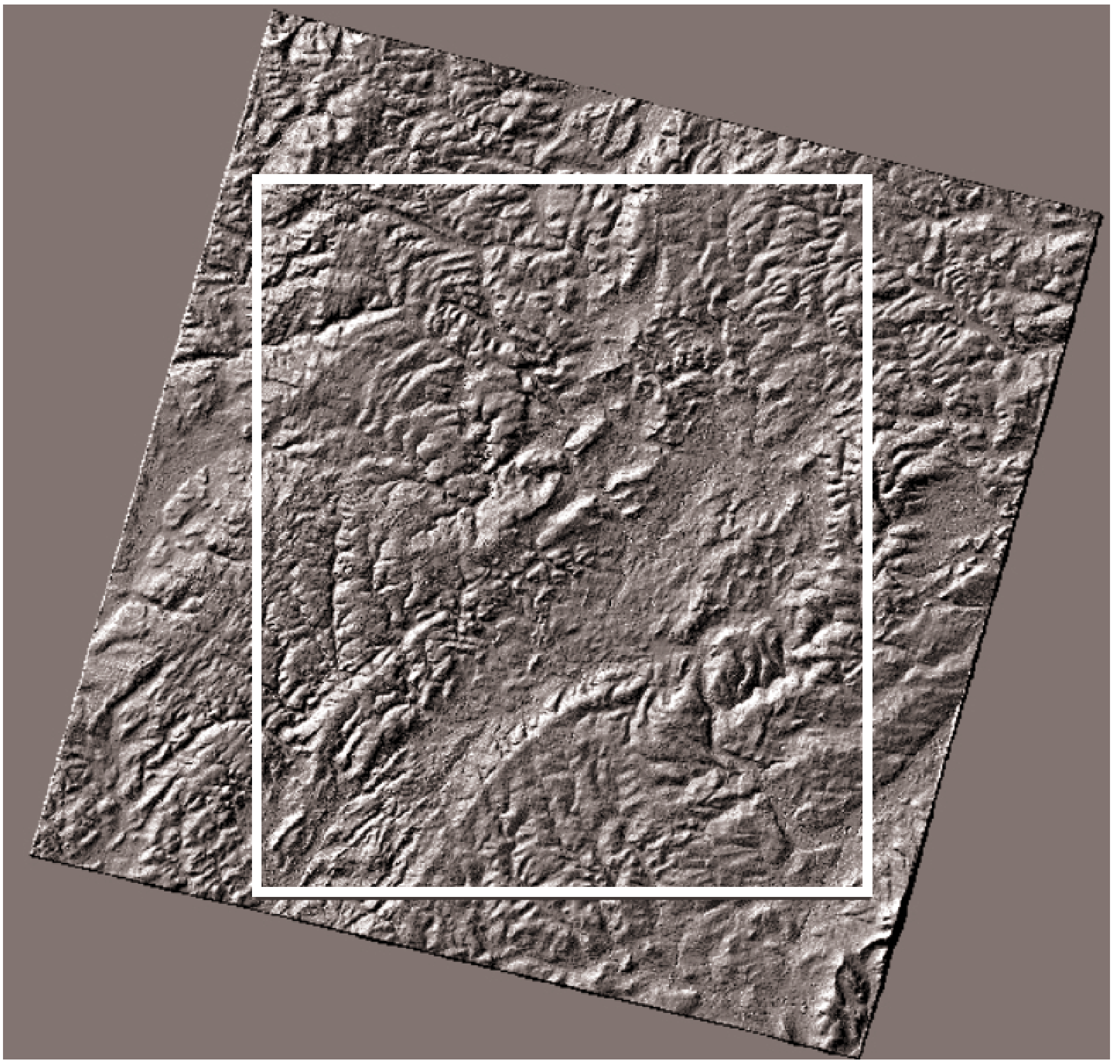

Fig. 5. ASTER generated 30m DEM – shaded relief image, main study area is shown by box. Profile location shown by line.

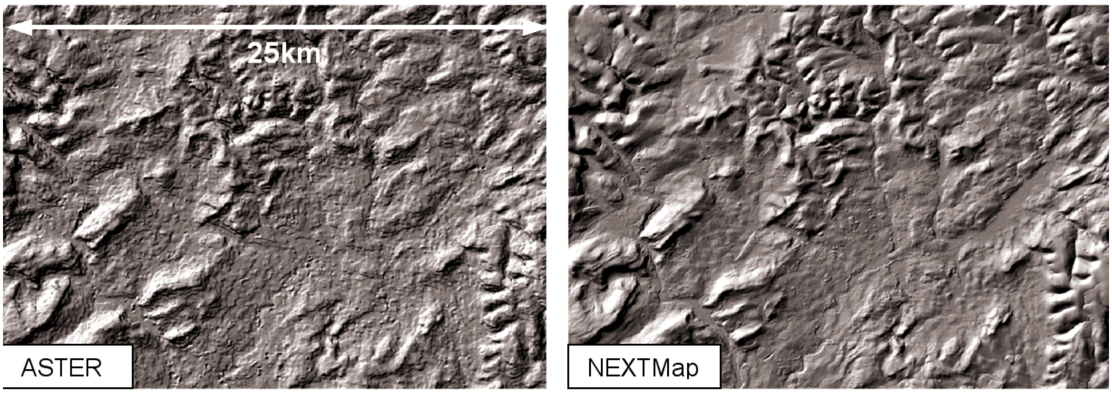

Fig. 6. Visual comparison between ASTER and NEXTMap DEM. ASTER DEM appears to show a terracing effect when viewed as a shaded relief image.

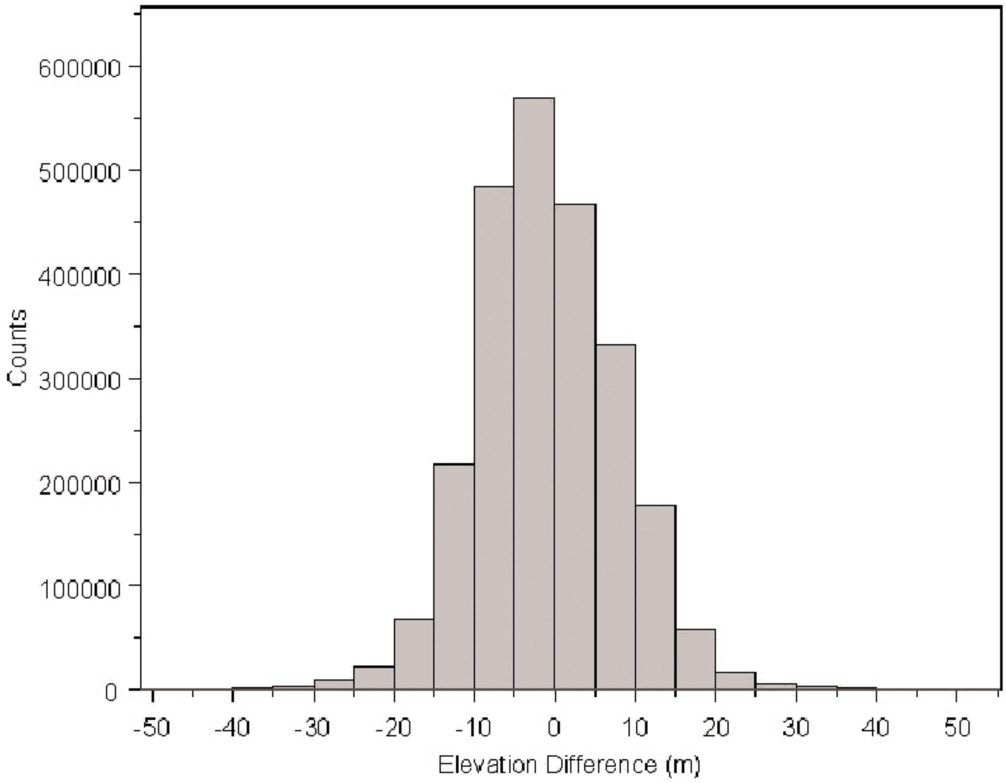

Fig. 7. Histogram showing the elevation differences between the ASTER and NEXTMap DSM, as pixel counts. Date grouped into 5m classes. Approximately 2.4 million points.

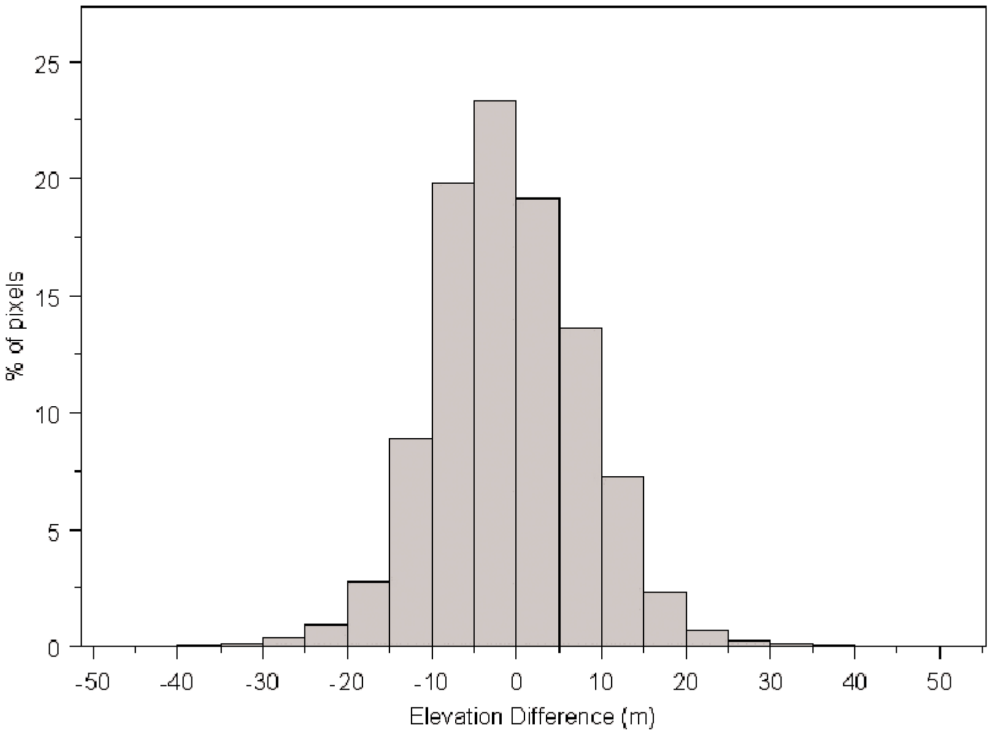

Fig. 8. Histogram showing the elevation differences between the ASTER and NEXTMap DSM, as percentages. Data grouped into 5m classes. Approximately 2.4 million points.

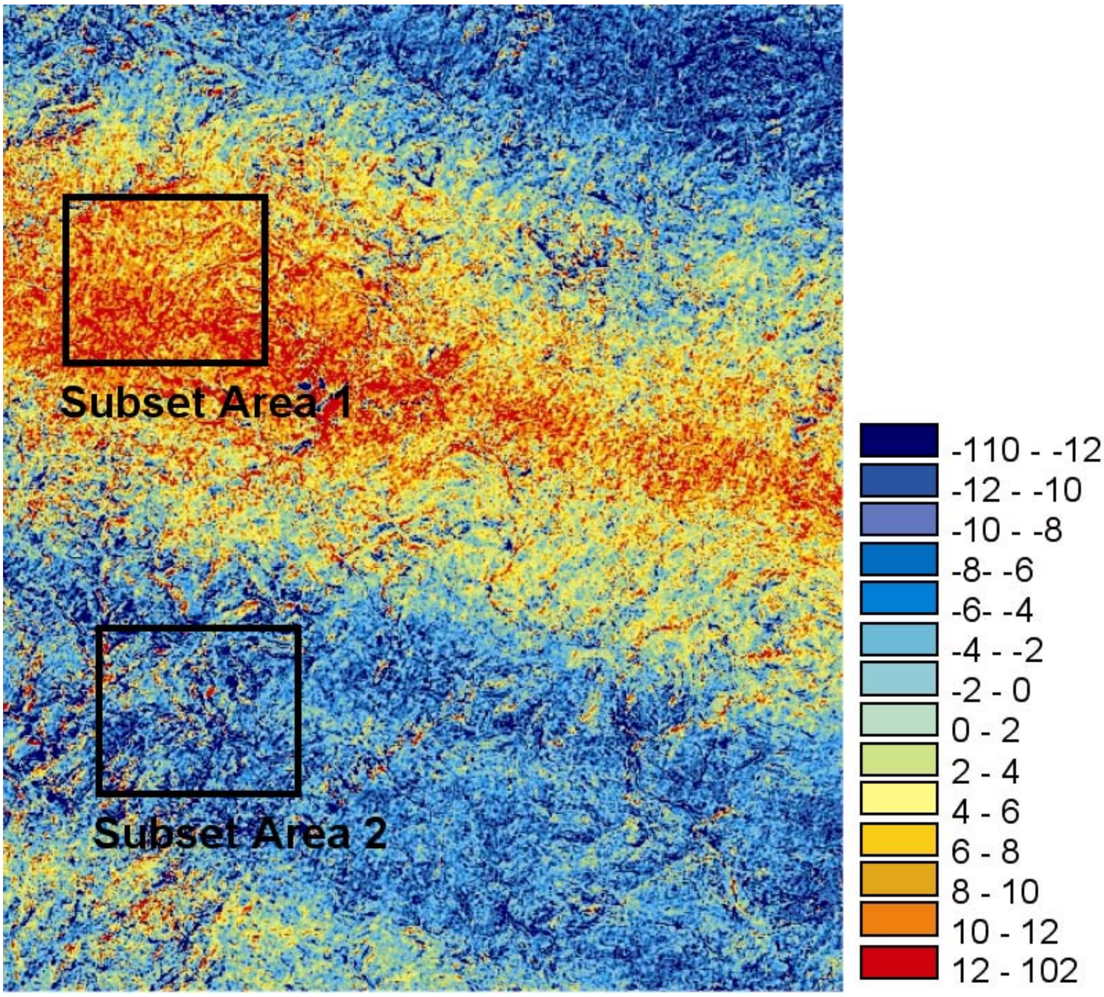

Fig. 9. Difference between ASTER and NEXTMap DSM, colder colours indicate area areas lower on the ASTER DEM.

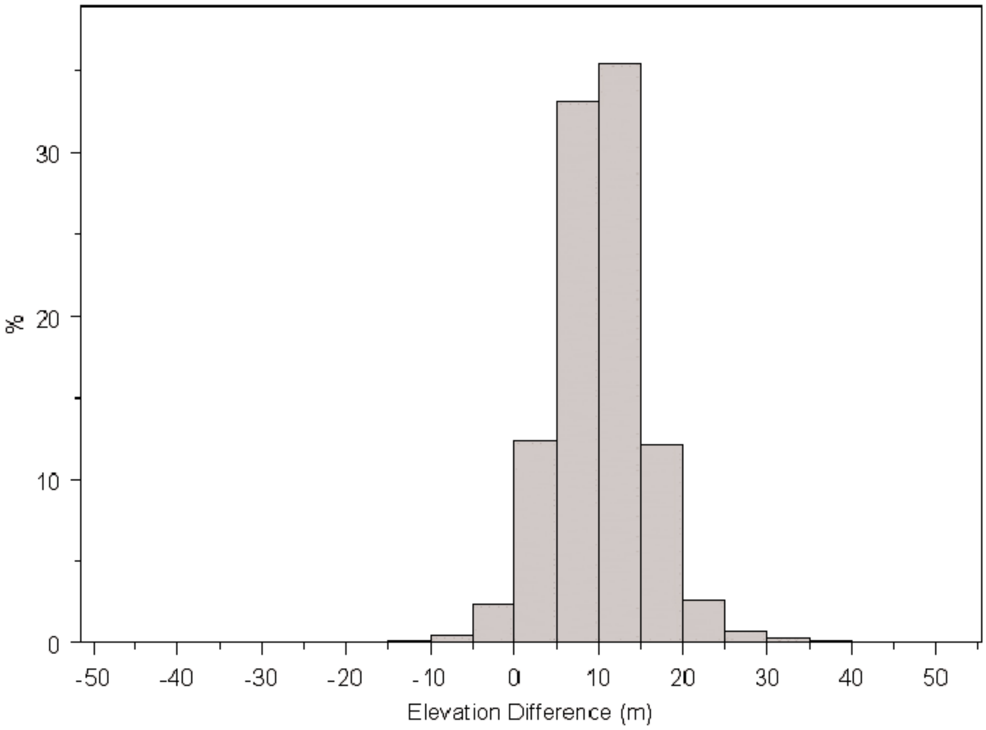

Fig. 10 Histogram showing the elevation differences between the ASTER and NEXTMap DSM as percentage of pixels for subset area 1, data grouped into 5m classes.

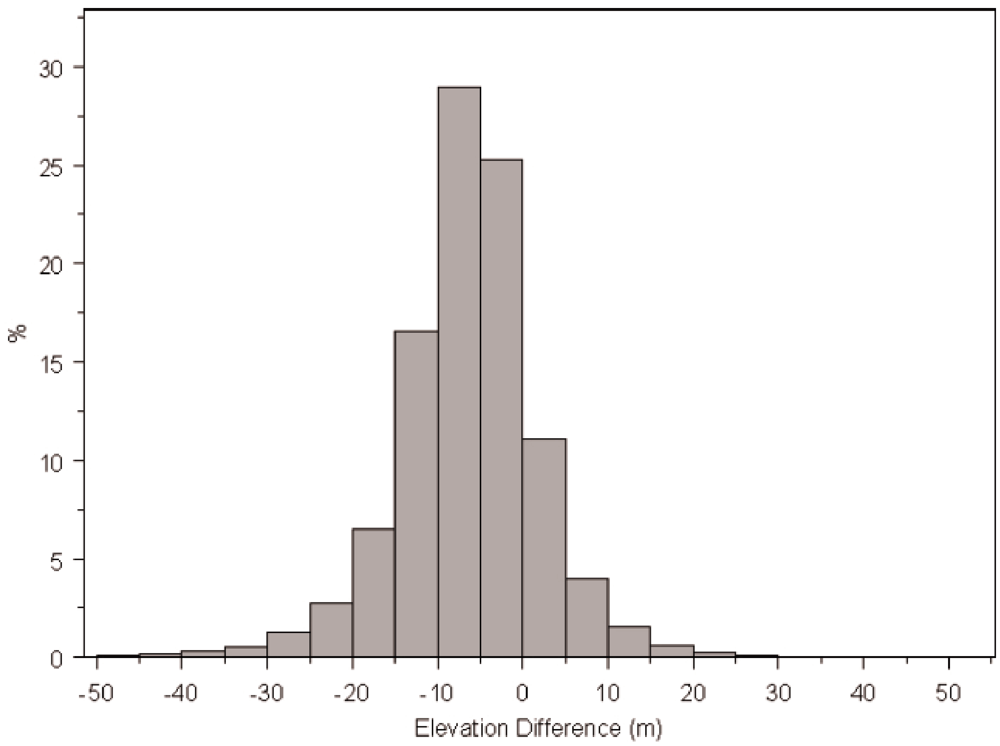

Fig. 11. Histogram showing the elevation differences between the ASTER and NEXTMap DSM as percentage of pixels for subset area 2, data grouped into 5m classes.

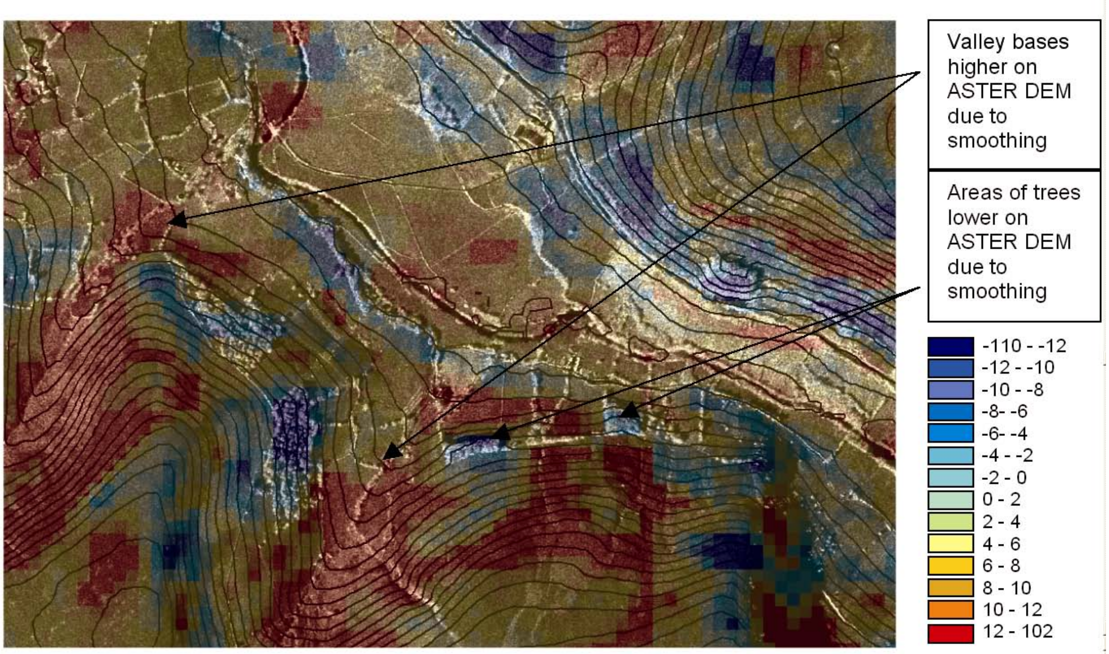

Fig. 12 Difference image illustrating the spatial pattern of differences between ASTER and NEXTMap DSM, NEXTMap contours overlaid to illustrate relief variations.

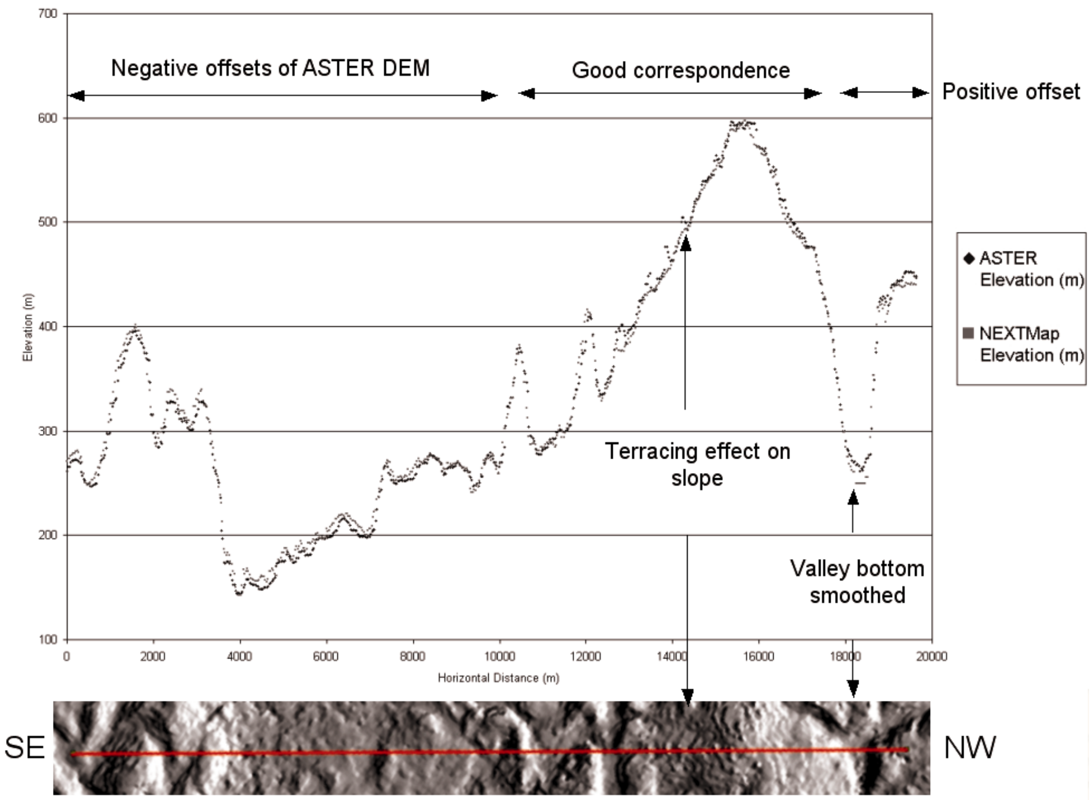

Fig. 13 Profile across ASTER and NEXTMap DSM, shaded relief and ASTER VNIR images shown for terrain characteristics.

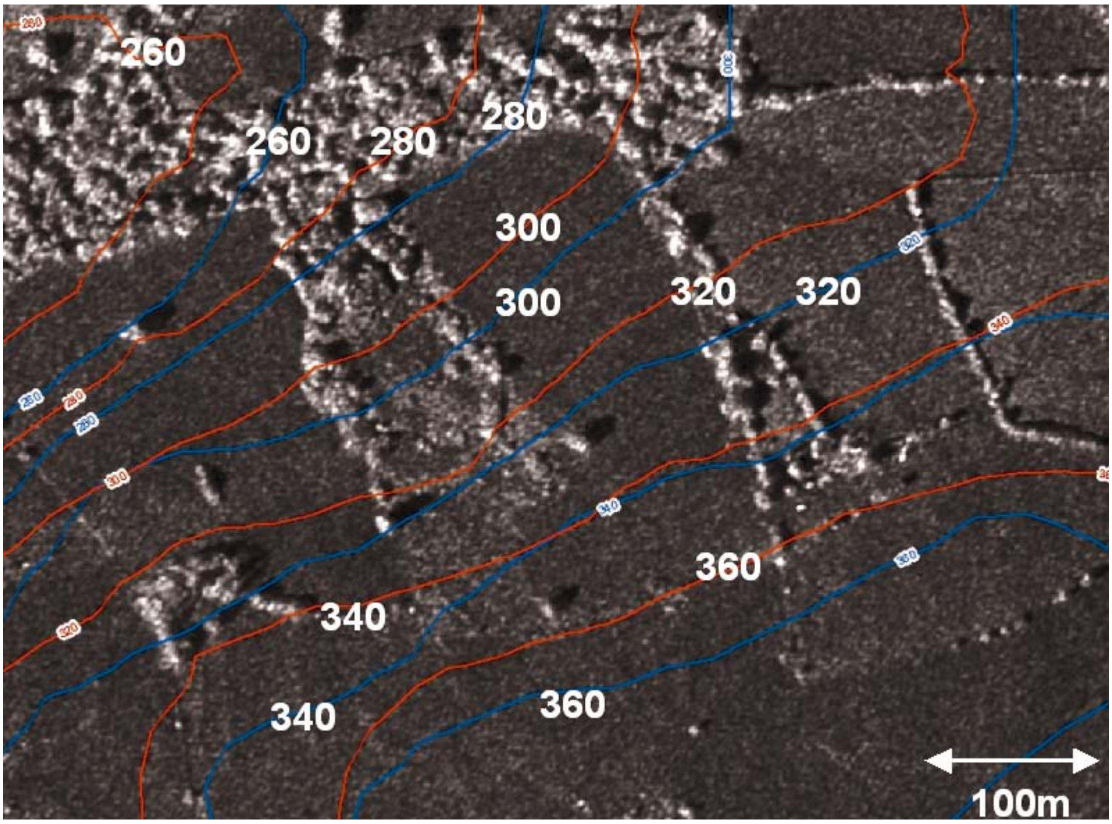

Fig. 14 A comparison of generated 20m contours from ASTER DEM and NEXTMap DSM for a regular sloping hillside, overlaid onto NEXTMap orthorectified radar image. NEXTMap contours in blue, ASTER contours in red.

Table 1. *Summary table of ASTER DEM accuracy studies (after Hirano et al. 2003)*

Study	Area and size	DEM post spacing	Number of GCPs	Number of comparison points	RMSEz (m)	SD (m)	Min (m)	Max (m)	Mean (m)
A Hirano *et al.* (2003)	Mt.Fuji (24x21 km)	75m	5 map points 1:25000	51 map points 1:25000	±26.3	-	-	-	-
“	Andes Mountains (55.5x57 km)	150m	5 map points 1:50000	53 map points 1:50000	±15.8	-	-	-	
“	San Bernardino (22.5x22.5km)	75m	12 DGPS points	16 map points 1:24000	±10.1	-	-	-	-
“	Huntsville (22.5x18km)	30m	8 DGPS points	239776 posts (USGS DEM)	±14.7	-	-	-	
Poli *et al*. (2004)	Switzerland	-	46 map points 1:25000	112326 posts (25m DEM)	±18.32	16.68	-84.49	67.89	-7.58
Cuartero *et al.* (2004)	Granada, southern Spain	30m	15 map point	315 DGPS points	±12.6	12.5	-	-	-1.5
San and Suzen (2005)	Asarsuya River Basin, Turkey (20x10km)	15m	60 map points 1:25000	DEM generated from 1:125000 contours	-	17.69	-110.15	128.39	15.77

*Results from ASTER DEM generation using automatic tie points

Summary table of ASTER DEM accuracy studies (after Hirano *et al.* 2003)

Table 2. *ASTER specifications*

Subsystem	Band No.	Spectral Range (μm)	Spatial Resolution (m)
VNIR	1	0.52-0.60	15
	2	0.63-0.69	
	3N	0.78-0.86	
	3B	0.78-0.86	
SWIR	4	1.600-1.700	30
	5	2.145-2.185	
	6	2.185-2.225	
	7	2.235-2.285	
	8	2.295-2.365	
	9	2.360-2.430	
TIR	10	8.125-8.475	90
	11	8.475-8.825	
	12	8.925-9.275	
	13	10.25-10.95	
	14	10.95-1.65	

Review of ASTER specifications

Table 3. *Summary report of GCP point accuracy*

GCP	Error X (pixels)	Error Y (pixels)	RMS (pixels)
1	-1.7100	0.1574	1.7172
2	1.9592	1.4835	2.4575
3	-2.1303	-1.9018	2.8557
4	3.2322	-0.3926	3.2560
5	-2.5019	-0.1770	2.5082
6	-1.3601	0.5820	1.4794
7	1.3620	0.3014	1.3949
8	1.7940	0.3254	1.8233
9	-0.6451	-0.3783	0.7478

Summary report of GCP point accuracy

Table 4. *Accuracy assessment summary statistics*

	ASTER-DSM*	ASTER-DTM*	ASTER-DSM Subset1†	ASTER-DSM Subset2§
Mean (m)	-0.98	-0.96	10.20	-6.38
Minimum (m)	-110.50	-111.64	-50.97	-71.42
Maximum (m)	102.17	94.63	73.01	51.74
Standard Deviation (m)	9.012	8.73	5.77	8.41
RMSEz (m)	9.07		11.72	10.55

*2441463 points
† 101136 points
§ 96990 points

Table illustrating accuracy assessment summary statistics