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Comparison of ASTER GDEMs with SRTM Height Models

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Abstract. With the free of charge available, close to worldwide covering SRTM C-band height models several problems of the remote sensing community have been solved or made simpler. With the ASTER GDEM now another free of charge available height model can be used, covering the earth from 83° southern up to 83° northern latitude filling the partially larger gaps of the original SRTM digital surface models (DSMs) and having an improved spacing of 1 arcsec (~ 31 m at the equator). An intensive validation of the ASTER GDEM is available at the WEB-page of ASTER GDEM, but it covers not all important topics of the height model analysis. For example no analysis of the important accuracy dependency from the terrain inclination is included, only limited morphologic aspects is respected and the improvement by filtering is missing.
With 12 test areas located in the USA, France, Germany, Poland, Turkey and Jordan, ASTER GDEM and SRTM DSMs were analyzed in relation to precise reference height models. It is obvious, that ASTER GDEM has not an even accuracy, it depends upon the number of stacks/object point (stacks = number of used ASTER images), which can exceed 50, but in one test area in the average just 2.5 stacks/point have been used. In addition the scene location error cannot be neglected and we have a clear dependency upon the terrain inclination. As SRTM DSMs, ASTER GDEM is describing the visible surface, which in urban areas and in forests is shifted against the bare ground. Both height models can be improved by filtering of objects not belonging to the bare ground.
In general ASTER GDEM has a lower vertical accuracy as SRTM height models. In spite of the improved point spacing, ASTER GDEM includes only slightly more morphologic details as the SRTM DSMs with three times larger point spacing. Nevertheless the ASTER GDEM is very helpful especially in mountainous areas, dry sand deserts and the area below 56° southern and above 60.25° northern latitude.

Keywords: height model, ASTER GDEM, SRTM DSM, analysis, filtering

Introduction

SRTM-height models are limited to the range from 56° southern up to 60.25° northern latitude and gaps exist especially in mountainous regions, dry sand deserts and water bodies. Of course such gaps are filled now with other data, but the accuracy of the SRTM gap filling is not uniform. In addition outside the USA only height models with 3 arcsec spacing (92m at the equator) are available, reducing the morphologic details. The height model determined by ASTER stereo pairs, the ASTER GDEM, is available for the area from 83° southern up to 83° northern latitude, with 1 arcsec spacing, corresponding to 31m at the equator. Of course with 15m GSD and a height to base relation of 2.1 based on a single ASTER stereo pair not a better accuracy as with SRTM interferometric SAR data can be expected, but the ASTER GDEM is not based just on one stereo pair, a higher number of stereo pairs have been used, allowing improved height models. The SRTM C-band DSM and the ASTER GDEM are including the height of the visible surface – the height of the vegetation and buildings, while reference height models in most cases are related to the bare ground.

The original SRTM height model has gaps in steep mountainous areas, caused by radar lay over and viewing shadows. Also in dry sand deserts gaps may occur. Such missing data cannot be reported from ASTER GDEM.

In the "ASTER Global DEM Validation, Summary Report" (see references) SRTM DSMs and ASTER GDEM have been investigated and compared, but the relation between the number of stacks used in ASTER GDEM (number of used images for the determination of a ground point) and the object point accuracy is not shown in a satisfying manner. Also the clear dependency of the standard deviation of the height from the terrain inclination is missing as well as the information about morphologic details and the possibility of DEM improvement by filtering. In addition the direct comparison between ASTER GDEM and SRTM DSMs has to be done more detailed.

1. Test Areas

ASTER GDEM and SRTM-DSMs have been compared with reference height models in Jordan, Istanbul - Turkey, Zonguldak – Turkey, Mausanne – France, Poland close to Warsaw, Gars – Germany, Inzell – Germany, West Virginia – USA, Pennsylvania – USA, Philadelphia – USA, Arizona – USA and Atlantic County – USA. They include flat, rolling and mountainous areas, partially covered by forest and also build up areas even with downtown districts. The dominating part of the test areas has been used before for the investigation of SRTM DSMs (Passini, Jacobsen 2007).

2. Preparation of test data

Height models not only have uncertainties in the vertical component, very often they are influenced by constant horizontal shifts also named datum errors. This may be caused by image orientation used for the ASTER GDEM, not directly based on ground control points, the SRTM scene orientation, but also datum problems of the reference height model. So as preparation ASTER GDEM and also SRTM DSMs have been shifted to the reference height models by adjustment with the Hannover program DEMSHIFT to allow a separation between horizontal and vertical error components. For the data sets without problems of the reference coordinate system datum the horizontal shifts for ASTER GDEM are in the range of 6m to 8m, while it is smaller with approximately 3m for SRTM DSMs. All reported results are related to the height models shifted in relation to the reference DEMs.

3. Dependency of ASTER GDEM from the number of used stacks

For the individual investigated ASTER GDEM tile the number of used images – also named stacks – for the determination of the individual ground points is varying from 2 up to 60 even within the tiles. There is also a strong variation for the 1° x 1° large tiles depending upon the usual cloud coverage and the priority in taking ASTER images (Figure 1).

The Hannover program for DEM analysis DEMANAL can read the available file with the number of stacks used for the individual object points and determine the root mean square height differences as function of the stacks including a linear adjustment of the dependency. As square mean over all test areas, root mean square Z-differences (RMSZ) between the ASTER GDEM and the reference height models of RMSZ = 12.43m – 0.35m∗stack/point have been adjusted, which has to be seen together with the average of 18.7 stacks/point, leading to an average RMSZ of 5.88 m.

Figure 2 gives an overview of the root mean square Z-discrepancies as linear adjusted function of the number of stacks per point for all test areas. Not in any case an improvement of the accuracy by a higher number of stacks/point can be seen, but there is a clear trend to an improvement, especially if the results are not so precise for a smaller number of stacks/point. Especially in the areas covered by forest the improvements by the number of stacks is not so clear. The adjusted lines in figure 2 shown in green are influenced by forest - ASTER GDEM includes the height of the visible forest surface while the reference height models are related to the bare ground.

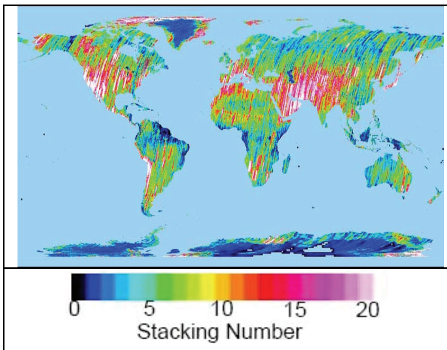	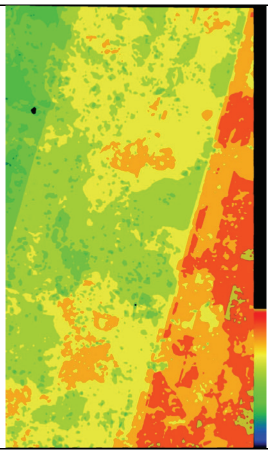	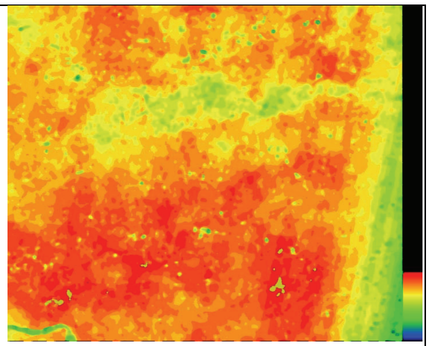
ASTER GDEM global stacking number map - source: ASTER GDEM validation summary report - number of stacks per object point	Poland, up to 16 stacks/point color scale = lower right	Pennsylvania, up to 56 stacks/point, colour scale = lower right

Figure 1. Number of stacks / object point

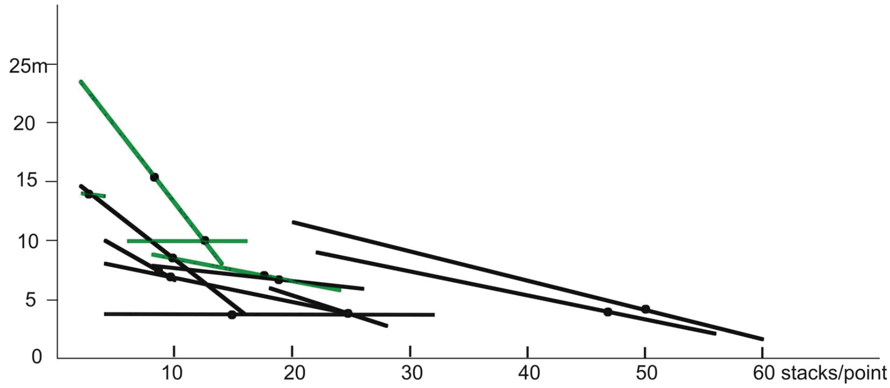

Figure 2. SZ as function of number of stacks/point for all test sites. Green: influence of forest, dot = average number of stacks/point, adjusted functions only shown for available range of stacks/point

4. Accuracy analysis

As mentioned, ASTER GDEM and SRTM DSMs are digital surface models with heights of the tree tops and buildings. Usually digital elevation models (DEMs) related to the bare ground are required corresponding to all used reference height models. A filtering of the elements not belonging to the bare ground is possible in open area, but in forest areas without any ground point the effect of filtering is limited. So forest areas should be handled separately from open areas.

As it can be seen in table 1, in the forest area the root mean square height differences against the reference height models and the bias (systematic error) are larger as in the open areas. By filtering of elements not belonging to the bare ground with Hannover program RASCOR, the height differences and the bias can be reduced in the open areas as well as in the forest. In the test area Atlantic County the forest is dominated by bushes and small trees, in addition several open parts exist within. Such a clear improvement by filtering could not be seen for example in the mountainous forest of Zonguldak and only a limited improvement was possible in the dense and higher forest area in West

Virginia. The standard deviation of the height is larger for ASTER GDEM as for SRTM DSM, but by filtering the ASTER GDEM was improved more as the SRTM DSM.

Not only forest areas are causing height discrepancies, this may be the case also for buildings. In the downtown area of Philadelphia the influence of buildings has been eliminated by filtering as it is the case in Philadelphia.

Table 1. Test area Atlantic County, influence of forest and filtering on DSMs

	SRTM DSM				**ASTER GDEM**		
	RMSZ	bias	SZ (without bias)		RMSZ	bias	SZ (without bias)
Whole area	5.38 m	-4.56 m	2.84 m		5.15 m	-3.36 m	3.90 m
Open area	4.37 m	-3.38 m	2.78 m		4.29 m	-2.28 m	3.64 m
forest	6.07 m	-5.46 m	2.65 m		5.89 m	-4.44 m	3.86 m
filtered					filtered		
Whole area	3.92 m	-3.10 m	2.40 m		2.96 m	-0.90 m	2.82 m
Open area	2.76 m	-1.94 m	1.96 m		2.13 m	-0.32 m	2.11 m
forest	4.77 m	-4.14 m	2.36 m		4.21 m	-2.37 m	3.48 m

Table 2. SRTM DSM and the ASTER GDEM analysis for all test areas (m)

	SRTM DSMs				ASTER GDEM			
	RMSZ	bias	SZ	SZ	RMSZ	bias	SZ	SZ
Jordan	5.10	0.28	5.09	4.05 + 1.8·tan α	13.62	11.92	6.59	5.03 + 2.4·tan α
W. Virginia	12.05	-8.30	8.73	8.53 + 0.02·tan α	14.04	-2.66	13.78	12.79+1.6·tan α
Atlantic C.	5.38	-4.56	2.84	2.84 + 0.0· tan α	5.15	-3.36	3.90	3.90 + 0.0·tan α
Pennsylvania	4.58	-1.89	4.18	3.48 + 22.5· tan α	9.32	8.30	4.25	3.63 + 23.2·tan α
Philadelphia	5.85	-3.60	4.61	4.61+ 0.0·tan α	7.07	-5.33	4.65	4.65 + 0.0·tan α
Arizona	3.70	1.32	3.46	2.34 + 11.1·tan α	5.82	3.32	4.78	2.92 + 17.4·tan α
Mausanne	3.86	-0.86	3.76	1.68 + 12.4·tan α	7.06	2.45	6.62	4.83 + 9.8·tan α
Poland	5.15	2.05	4.73	5.15 + 0.0·tan α	14.08	9.99	9.93	9.61 + 1.7·tan α
Zonguldak	9.33	-3.38	8.70	7.17 + 10.1·tan α	9.26	1.79	9.08	6.63 + 11.7·tan α
Istanbul	4.95	-1.30	4.77	3.37 + 6.2·tan α	7.20	1.44	7.06	6.04 + 3.6·tan α
Gars	5.44	-2.33	4.92	3.95 + 2.29·tan α	10.42	7.64	7.08	6.25 + 1.78·tan α
Inzell	8.02	-2.38	7.66	4.38 + 25.4·tan α	13.31	-3.52	12.84	7.88 + 17.6·tan α
RMS	**6.76**	**3.49**	**5.61**	**5.08 for α= 0.0**	**10.21**	**6.13**	**8.17**	**6.74 for α= 0.0**

Table 2 shows the accuracies achieved with original ASTER GDEM and SRTM DSMs just shifted in X and Y to the reference height models, where RMSZ is the root mean square difference and SZ the RMSZ improved by the bias. In general the SRTM DSMs are more accurate and have a smaller bias as ASTER GDEM. The results are partially influenced by vegetation and buildings, but this is similar for the height models based on the optical ASTER-images as well as for the InSAR-height models using the C-band. The results of the filtered height models are presented in table 3 and the accuracy of the original and filtered height models for flat terrain after improvement by the bias in figure 4. By filtering in most cases an improvement was possible with the exception of test area Zonguldak and for SRTM DSMs in Pennsylvania and Inzell. By filtering SZ of the ASTER GDEM is improved approximately 1m, while SRTM DSM is just getting better by 0.3m, but this is dominated by the outlying test areas West Virginia and Zonguldak. The test area West Virginia is covered by dense forest and has in the average only 2.5 stacks/scene and Zonguldak by steep mountains, partially covered by forest. If these test areas are not respected, SZ for flat terrain is reduced for SRTM DSM to 4.31 m and after filtering to 3.11m and for ASTER GDEM to 5.81m and after filtering to 5.12 m. In Figure 4 the results for West Virginia (#2) and Zonguldak (#8) are obviously not fitting to the other data. The largest improvement occurred in the test area Philadelphia where in the downtown area high buildings could be removed by filtering.

Table 3. SRTM DSM and ASTER GDEM analysis after filtering (m) in relation to reference DEMs

Filtered	SRTM DSMs				ASTER GDEM			
	RMS Z	bias	SZ	SZ	RMSZ	bias	SZ	SZ
Jordan	5.10	0.28	5.09	4.05 + 1.8·tan α	12.12	11.08	4.92	3.60 + 4.46·tan α
W. Virginia	11.93	-7.29	9.44	8.15 + 2.16·tan α	13.20	-2.01	13.05	11.17+3.65·tan α
Atlantic C.	4.77	-4.14	2.36	2.36	4.21	-2.37	3.48	3.48
Pennsylvania	4.58	-1.89	4.18	3.48 + 22.5·tan α	9.32	8.30	4.25	3.63 + 23.2·tan α
Philadelphia	3.16	-1.32	2.87	2.76+ 5.82·tan α	4.64	-3.56	2.98	2.96 + 1.63·tan α
Arizona	2.86	1.93	2.11	2.08 + 10.4·tan α	4.63	3.76	2.67	2.60 + 11.3·tan α
Mausanne	2.02	-0.98	1.77	1.48 + 7.89·tan α	5.94	2.07	5.57	4.66 + 2.89·tan α
Poland	4.99	4.18	2.72	2.72 + 0.0· tan α	13.73	10.78	8.50	8.48+ 2.39·tan α
Zonguldak	9.33	-3.38	8.70	7.17 + 10.1·tan α	9.26	1.79	9.08	6.63 + 11.7·tan α
Istanbul	4.20	-0.36	4.19	3.04 + 7.1·tan α	6.58	2.17	6.21	5.54 + 0.43·tan α
Gars	5.17	-2.17	4.38	3.64 + 2.64·tan α	10.77	9.13	5.72	5.13 + 1.84·tan α
Inzell	8.02	-2.38	7.66	4.38 + 25.4·tan α	11.00	-3.73	10.86	7.62 + 17.3·tan α
RMS	**6.16**	**3.16**	**5.51**	**4.23 for α= 0.0**	**9.39**	**6.14**	**7.16**	**5.99 for α= 0.0**

The filtering is changing the bias in a linear mean by +0.88 m for SRTM and +0.85 m for ASTER. The sign shows the reduced height level of the DSM corresponding to a reduced influence of the vegetation and buildings. The largest bias change occurred in the test area Philadelphia with 2.28m respectively 1.77 m caused by the high buildings in the downtown area.

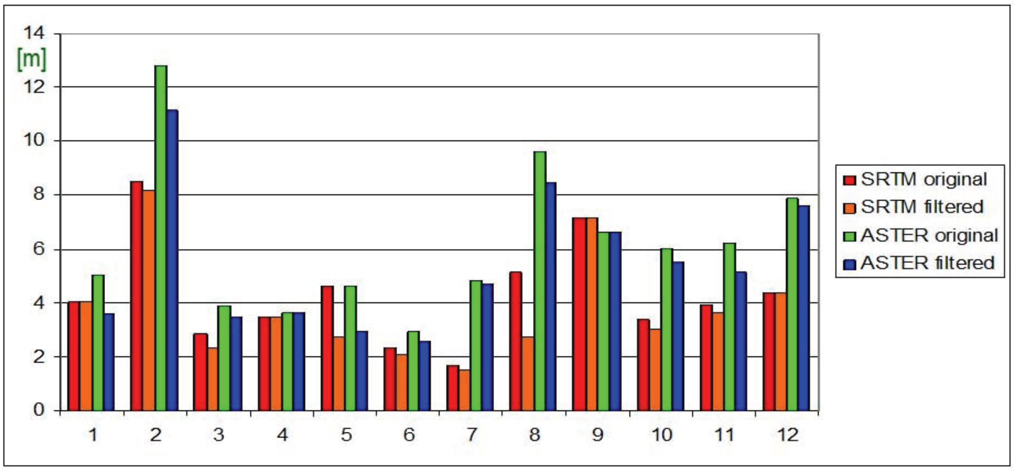

Figure 4. Standard deviation of Z for flat terrain

5. Morphologic details

Not only the absolute accuracy is important, for several application the morphologic details, expressed by the relative accuracy and the point spacing, has the same importance. The relative standard deviation (one point in relation to the neighboured point) for SRTM DSM is approximately 3.6m, while it is 3.2m for ASTER GDEM. The higher relative accuracy for ASTER may be explained by the point spacing of 1” in relation to 3” for SRTM. But the relative accuracy is only one indicator for the morphologic details. The best information is included in the shape of the contour lines and a 3D-view to a shaded model.

Confirmed by other results, Figure 5 demonstrates the available morphologic details. The details shown by the contour lines of ASTER GDEM are only slightly better as the details included in the SRTM C-band DSM with ~80m point spacing. Reverse the SRTM X-band DSM with the same point spacing as ASTER GDEM has quite more details and is not far away from the reference height model.

The same tendency exists for all test areas – the morphologic details of the ASTER GDEM are not corresponding to the point spacing of 1 arcsec, they are more corresponding to a height model with 2 arcsec point spacing. This may be caused by the averaging of several overlapping ASTER height models.

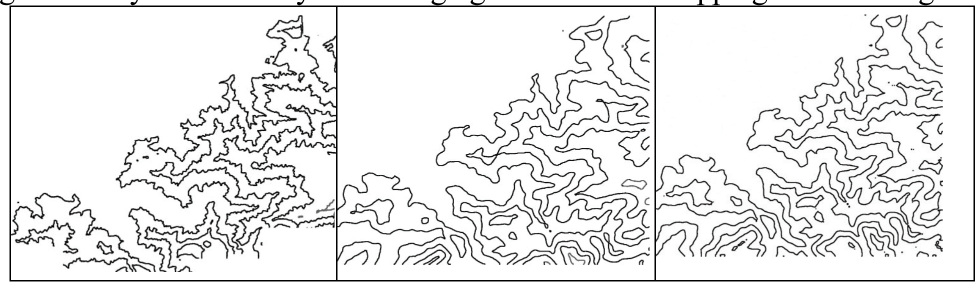

Figure 5. Test area Zonguldak: left: reference DEM, center: ASTER GDEM, right: SRTM DSM 3" spacing

In the ASTER Global DEM Validation, Summary Report 2009 (see references) the sharpness is mentioned as corresponding to 50 m. The expression sharpness is equivalent to morphologic details. In the investigated test areas the morphologic details correspond to approximately 60m which is in the same range.

6. Conclusion

ASTER GDEMS as well as SRTM DSMs have to be shifted in X, Y and Z to the local national coordinate systems. This is possible with a limited number of control points or in X and Y also by means of a map. Both height models are digital surface models including the height of building tops and visible vegetation. The influence of the elements on top of the bare ground can be reduced by filtering, which is limited in the case of closed forest areas, but with a high potential in open and build up areas.

ASTER GDEM is based on several stacks. In the used test areas up to 60 stacks per object points are included. The accuracy usually depends upon this. As average over all test areas the relation SZ = 12.43 m – 0.35 m·number of stacks/point) exist, which has to be seen together with an average of 18.7 stacks/point, leading to an average SZ of 5.88 m. As usual for all height models the vertical accuracy can be described by the formula SZ = a + b·tan(terrain slope). The dependency upon the terrain slope (factor b) is 7.5 m in the average; it depends upon elements on top of the ground – forests are located more in inclined as in flat areas. As root mean square height discrepancies in flat areas +/-6.7m for ASTER GDEM and 5.1m for SRTM DSMs have been achieved, which has been reduced by filtering to 5.99m respectively 4.23 m. Without the test area West Virginia, covered by dense forest and having only 2.5 stacks/point in the average, and the mountainous Zonguldak, in the flat areas a standard deviation of 5.12 m for ASTER GDEM and 3.11 m for SRTM DSMs exists.

The morphologic details of the ASTER GDEM are only slightly better as in the SRTM DSMs. In general ASTER has some advantages in mountainous areas in relation to SRTM, which original data show gaps caused by radar lay over and viewing shadows. In addition ASTER GDEM is covering a larger area as SRTM DSMs.

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