Accuracy evaluation of SRTM and ASTER DSMs

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Abstract. Over the last few years DSMs derived from satellite sensors, as SRTM (Space Shuttle Radar Topography Mission) and ASTER (Advance Space borne Thermal Emission and Reflection Radiometer) DSMs, have been issued and continuously updated. The SRTM DSM is delivered in three different versions (Finished, DTED, CGIAR), with different nominal accuracy covering a large part of the world at a resolution of 3'' x 3''. The goal of the work is to evaluate these products by a comparison carried out over Colli Albani area in Italy with two reference DSMs obtained by a LIDAR survey and by a CARTOSAT-1 stereopair, in order to assess both mean accuracy and its dependency on morphology and land cover types.

Keywords. SRTM, ASTER, DSM, accuracy assessment

Introduction

It is well known that Digital Surface Models (DSMs) are useful and required for several purposes attaining engineering, land management and geomatics. Overall, DSMs can be obtained by stereo photogrammetric techniques, by means of LIDAR (Laser Imaging Detection And Ranging) or using the Interferometric Synthetic Aperture Radar (InSAR).

At present there are available two DSMs with a near-global coverage, obtained respectively by the Shuttle Radar Topography Mission (SRTM) and by ASTER stereo images. They represent a fundamental standard for world surface representation at a very low (when not null) cost; so, it is an important topic to evaluate their actual accuracy and characteristics.

1. Tested DSMs

1.1. SRTM DSMs

The Shuttle Radar Topography Mission is an international project developed by the National Geospatial-Intelligence Agency (NGA) and the National Aeronautics and

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Space Administration (NASA) in order to obtain a near-global high-resolution database of the Earth's topography by single-pass Interferometric Synthetic Aperture Radar (InSAR) technique. In February 2000 the Space Shuttle was launched into space, outfitted with two radar antennas, both for C-band and X-band. One antenna was located in the shuttle's payload bay, the other on the end of a 60-meter (200-foot) mast. Data from the X-band radar are used by Germany and Italy to create slightly higher resolution DSMs but without the global coverage of the C-band radar. Moreover, X-band products are not available free of charge like the C-band height models [1].

For the area of the United States the Shuttle SRTM height models are available with 1 arcsec (~ 30m) spacing while, outside the country, it is reduced to 3 arcsec (~ 90m) spacing. The SRTM DSM is delivered in three different versions, based on different level of editing:

- Finished

The editing consisted of delineating and flattening water bodies, better defining coastlines, removing "spikes" and "wells", and filling small voids. The SRTM Finished data meet the absolute vertical accuracies of 16 m (Linear Error at 90% confidence - LE90)

- DTED

Spikes and wells in the data are detected and voided out if they exceed 100 meters compared to surrounding elevations. Small voids (16 contiguous posts or less) are filled by interpolation of surrounding elevations. Large voids are left in the data. The ocean elevation is set to 0 meters. The SRTM DTED absolute height accuracy is significantly better than the 16-meter (LE90) [2].

- CGIAR

The Consortium for Spatial Information (CGIAR-CSI) of the Consultative Group for International Agricultural Research (CGIAR) offers post-processed 3-arc second SRTM DEM containing regions of no-data, specifically over water bodies (lakes and rivers), and in areas where insufficient textural detail was available in the original radar images to produce three-dimensional elevation data [3]. This method produces a smooth surface of no-data regions. Whilst micro-scale topographic variation is not captured using this method, most macro-scale features are captured in small-intermediate sized holes. Previous studies (Jarvis et al., 2004) found an average vertical error of just 5m in interpolated regions when compared with a DEM derived from cartographic maps.

1.2. ASTER DSM

The ASTER Digital Elevation Model (DEM) product is generated using bands 3N (nadir-viewing) and 3B (backward-viewing) of an ASTER Level-1A image acquired by the Visible and Near Infrared (VNIR) sensor. The VNIR subsystem includes two independent telescope assemblies that facilitate the generation of stereoscopic data. The DSM generation (on request) is based on an automated stereo-correlation method that generates a relative DEM without any ground control points (GCPs)[4].

The ASTER DEM is a single-band product with 30-meters horizontal postings. Larger water bodies are detected and typically have a single value, but they no longer are manually edited. Any failed areas, while infrequent, remain as they occur. Cloudy areas typically appear as bright regions, rather than as manually edited dark areas. The declared accuracy is better than 25 meters RMSExyz.

1.3. Reference DSMs and test field

The accuracy evaluation of SRTM and ASTER height models was carried out by comparison over Colli Albani area (Rome District, Central Italy) with two reference data sets, available on different extensions, provided respectively by an airborne LIDAR survey and a DSM generated by a Cartosat-1 stereo pair.

LIDAR DSM is available over a small area (few Km^2) surrounding Albano and Nemi volcanic lakes, with an accuracy of 25 cm.

The reference DSM from Cartosat-1 satellite has been obtained using two stereo images acquired over the test area of Castel Gandolfo on 18th July 2006. Using these images a DSM has been obtained at 5 m spacing over an area of approximately 900 km^2 [5].

The accuracy of the DSM has been tested with respect to a reference coming by aerial photogrammetry. From DSM comparison an RMSEh of 3 meters is achieved over open areas, while over urban areas the RMSEh goes down to 4.7 meters.

The test site, located near the lakes of Albano and Nemi displays a hilly topography with terrain inclination lower than 45°. In order to investigate the effect of different terrain types over the accuracy, the analysis has been focused separately for three main land cover types: open (bare soil) areas, urban areas and forest areas, where SRTM DSMs do not display any gap.

Unfortunately, just a small percentage of the area covered by the Lidar DSM was suitable for the quality assessment because the two lakes represent a large part of the area, therefore just one area for each type of coverage has been selected (Figure 1).

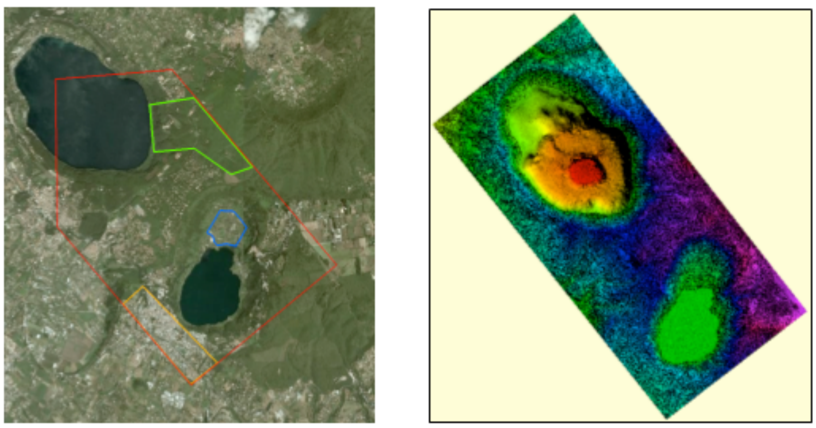

Figure 1. Representation of the test area of Castel Gandolfo with the different land covers (orange for the city, blue for open area, green for forest) on the left, LIDAR reference DSM on the right

2. Methodology

As mentioned, the main scope of the work is to assess the accuracy of the tested ASTER and SRTM products with respect to more accurate reference, in order to understand potentials and limits of such DSMs for the different applications.

The accuracy is computed as the Root Mean Square Error (RMSE) of the differences between the tested DSM and the reference, both in the height at a fixed horizontal position (2.5D comparison, RMSEh) and in the Euclidean distance between corresponding points over the two surfaces (3D comparison, RMSEd).

Starting from the original grid resolution the test products have been interpolated over the reference grid, after this step the surfaces have been compared. Two different software packages have been used: ERDAS Imagine 9.0, which is a commercial software distributed by Leica Geosystems, and DEMANAL, which is one of the several modules of the scientific software BLUH, developed at the Leibniz University Hannover.

The main advantages of the scientific approach adopted in BLUH for comparing two DSMs can be summarized as follows: DEMANAL has the possibility of taking into account the influence of the terrain inclination over the root mean square height difference (RMSEh); furthermore it computes the normal (3D) distance between two surfaces. Moreover the influence of a vertical scale difference between the DSMs can be analyzed and respected iteratively by the program. In addition the two datasets must not have the same resolution, in fact DEMANAL is operating by itself the interpolation of the reference product over the test, using the bilinear interpolation.

In reverse ERDAS is able to compare two DSMs only if they have the same spatial resolution; due to this reason, and in order to be consistent with DEMANAL approach, the test products used in ERDAS have been interpolated over the reference using the bilinear method.

2.1. ERDAS-DEMANAL 2.5D

The SRTM data are georeferenced in geographic (Lat/Lon) coordinates with respect to the WGS84 horizontal datum, whereas the heights are orthometric with respect to the EGM96 vertical datum.

A possible horizontal and vertical datum shift was checked by the Hannover program DEMSHIFT. No significant shifts were found for the SRTM products; on the other hand, ASTER DSM displayed a large shift in the height (about 20 m), which was subsequently removed.

The first analyses have been performed to investigate the response of the test products over the different land cover areas and, at the same time, to observe the behavior of the used software under the same conditions.

In Table 1, Table2 and Table 3 the results obtained interpolating the test products on the LIDAR DSM grid are shown, with respect to an open area (bare soil), an urban area and a forest area. Since we are comparing products with very different resolution quite a large bias is expected, especially in the forest area, where the reference DSM includes both elevation values of the bare ground and of the top of the trees, while both SRTM and ASTER refer to the top of the canopy. Discrepancies between the compared surfaces are reported with the sign of the correction to be applied to the test values (points located above the reference DSM have positive values).

Table 1. Analysis of test products versus reference LIDAR DSM, 2D comparison between ERDAS and DEMANAL results over the bare soil area (SQM = square mean after elimination of bias)

Bare soil area	**ERDAS**			
	ASTER	**SRTM Finished**	**SRTM DTED**	**SRTM CGIAR**
N° of data	372559	372367	372163	372632
BIAS (m)	27.73	-1.69	-0.31	1.52
SQM (m)	3.97	5.00	4.59	3.87
RMSEh (m)	28.01	5.27	4.60	4.16
	DEMANAL			
N° of data	327137	270840	270840	272934
BIAS (m)	27.59	-1.89	0.00	1.32
SQM (m)	3.56	3.65	2.49	2.35
RMSEh (m)	27.82	4.11	2.49	2.70

Table 2. Analysis of test products versus reference LIDAR DSM, 2D comparison between ERDAS and DEMANAL results over the urban area

Urban area	**ERDAS**			
	ASTER	SRTM Finished	SRTM DTED	SRTM CGIAR
N° of data	1355357	1351336	1350690	1356532
BIAS (m)	22.19	1.74	2.48	4.14
SQM (m)	7.22	8.76	8.45	8.79
RMSEh (m)	23.33	8.93	8.81	9.62
	DEMANAL			
N° of data	1282328	1174243	1174243	1172451
BIAS (m)	22.20	1.77	2.55	4.23
SQM (m)	7.08	7.61	7.41	7.70
RMSEh (m)	23.30	7.81	7.84	8.79

Table 3. Analysis of test products versus reference LIDAR DSM, 2D comparison between ERDAS and DEMANAL results over the forest area

Forest area	**ERDAS**			
	ASTER	SRTM Finished	SRTM DTED	SRTM CGIAR
N° of data	1737455	1739309	1350690	1739017
BIAS (m)	32.45	5.59	2.48	8.73
SQM (m)	8.48	11.89	8.45	11.47
RMSEh (m)	33.54	13.14	12.5	14.42
	DEMANAL			
N° of data	1587596	1486039	1500383	1502216
BIAS (m)	31.86	3.97	4.17	7.92
SQM (m)	7.97	8.89	8.11	8.71
RMSEh (m)	32.84	9.74	9.12	11.77

Figure 2 provides a global summary of the RMSEh of the test products. For the SRTM it is possible to see that the RMSEh increases passing from the open area to the forest area. This is both related to the trend of the bias and of the SQM: the bias is close to zero for the bare soil zone, while it increases in the urban and forest area which means that the test surfaces are globally located over the LIDAR surface. At the same time the difference between the tendency of the surfaces (which is expressed by the SQM values) grows together with the complexity of the surface which is investigated, the rougher the surface the higher the SQM, because the analyzed SRTM and ASTER models are too coarse (low-frequency surfaces) to describe a complex morphology (high-frequency surface).

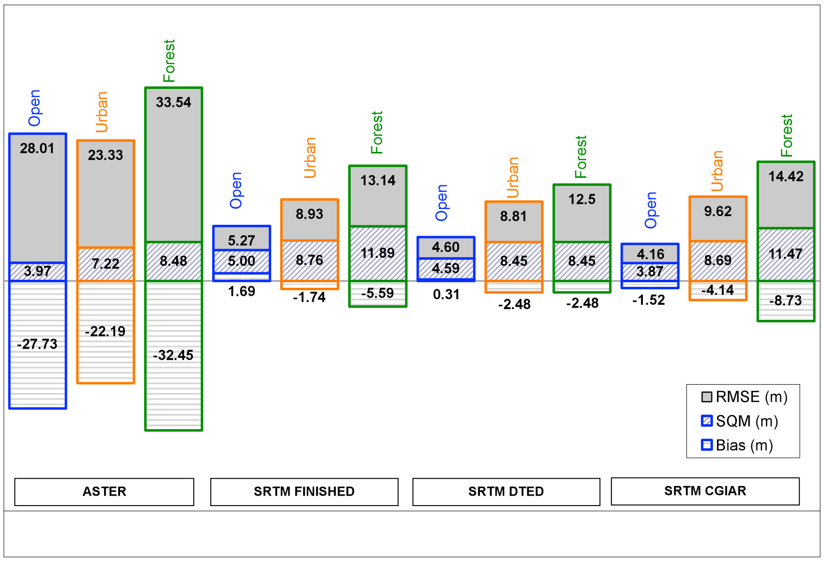

Figure 2. Overall 2D results of first analysis using ERDAS Imagine 9.0.

Considering ASTER DSM it is clear the presence of a large bias which affects all the investigated areas. Due to this bias effect RMSEh over the urban area is lower than RMSEh over the open area, which sounds strange. Nevertheless the SQM is fully comparable with the SRTM and reflects the different smoothness of the terrain, increasing from bare soil to forest areas.

DEMANAL approach addresses the bias problem since it allows to consider vertical shift and vertical scale difference between both DSMs, and to remove this effect in a second iteration. In Figure 3 the overall results obtained with DEMANAL are shown. It is interesting to point out how, after the removal of the vertical shift, the RMSEh follows the same trend as for SRTM.

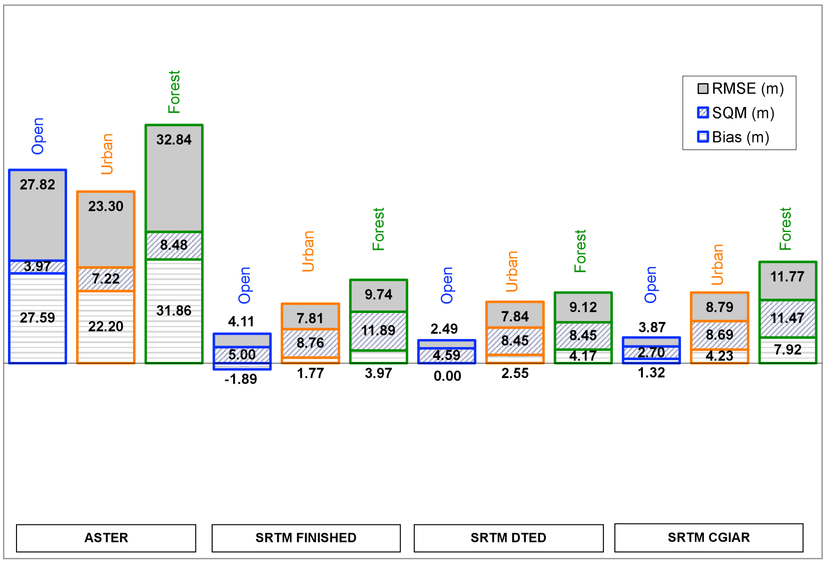

Figure 3. Overall 2D results of first analysis using DEMANAL.

This first analysis under the same operating conditions show that the two software packages behave almost in the same manner, even if some small differences in the number of points used for the comparison (which can be explained by the resampling operated in ERDAS Imagine 9.0) drive to slightly different RMSEh values. Moreover among the SRTM models the DTED seems to have the lowest RMSEh, while CGIAR is slightly less accurate than the other models. This result has not been fully investigated at present.

2.2. DEMANAL 3D

Starting from these results, the work has been focused on pointing out the additional information that DEMANAL scientific approach is able to offer.

The first big advantage of DEMANAL is the possibility of checking the DSM quality on the basis of the Euclidean distance (3D) between the compared surfaces. The results achieved with the 3D distance are shown in Table 4.

Table 4. Analysis of test products against reference LIDAR DSM, 3D comparison. Different land covers

Different land covers	**DEMANAL RMSEh (m)**				
	ASTER	ASTER (2° iter)	SRTM Finished	SRTM DTED	SRTM CGIAR
Bare soil area	27.82	3.14	4.11	2.49	2.70
Urban area	23.30	6.96	7.81	7.84	8.79
Forest area	32.84	7.63	9.74	9.12	11.77
	DEMANAL RMSEd 3D (m)				
Bare soil area	27.79	3.14	4.11	2.49	2.70
Urban area	23.27	6.95	7.81	7.84	8.78
Forest area	32.79	7.62	9.73	9.12	11.77

Looking at Table 4, the differences between 2.5D and 3D comparisons are negligible. Of course this is not a standard result but it can be partially explained thinking both at the low slopes and at the low spatial resolution of the products analysed, which does not allows, to encompass the finer morphology of the terrain.

A second tool supplied by DEMANAL is the possibility to estimate a linear dependency between terrain slope and RMSEh (Table 5); in our case this dependency is not significant over bare soil, again due to the low slopes.

Table 5. Analysis of RMSEz as function of the terrain inclination, with DEMANAL

Different land covers	**RMSEh as F(terrain inclination) (m)**				
	ASTER	ASTER (2° iter)	SRTM Finished	SRTM DTED	SRTM CGIAR
Bare soil area	26.56 + 1.47*tan (α)	2.58 + 0.69*tan (α)	4.11	1.67+ 0.94*tan(α)	2.25 + 0.06*tan(α)

2.3. Further analysis using Cartosat-1 as reference

Over the area of analysis a Cartosat-1 DSM with a grid spacing of 5 meters was available from previous investigations [8]. Using this DSM as reference, ASTER and SRTM DTED (the most accurate among the three available) have been compared over the different areas (Table 6).

Table 6. Analysis of test products against reference Cartosat DSM

	DEMANAL					
	ASTER (2°iter)	DTED	ASTER (2°iter)	DTED	ASTER (2°iter)	DTED
	Bare soil area		Urban area		Forest area	
BIAS (m)	0.48	-0.54	0.12	0.20	1.24	-0.83
SQM (m)	3.48	2.53	5.30	5.88	8.44	8.68
RMSEh (m)	3.52	2.59	5.30	5.88	8.53	8.72

In this case results are better, since also Cartosat-1 DSMs describe the visible surface and not the bare ground as the LIDAR data, what is clearly evidenced by low biases with all the different land covers. As expected, in bare soil area the results are very similar to those derived from LIDAR comparison, whereas now the accuracy of the reference DSM in urban and forest areas (at 6-7 m level) cannot be neglected and has to be taken into account according the standard square form.

3. Conclusions and future works

The accuracy evaluation of SRTM (Finished, DTED and CGIAR) and ASTER DSMs with respect to a (small) LIDAR DEM and a much larger Cartosat-1 derived DSM were performed using two software packages, ERDAS Imagine 9.0 and DEMANAL developed at Hannover University. The main results are as following:

- software performances under same condition (2.5D comparison) are similar, even if some small differences in the number of points used (which can be explained by the resampling operated in ERDAS Imagine 9.0) lead to slightly different RMSEh values

- a large bias in the height attains to ASTER DSM (around 20 m), which causes an accuracy similar or lower than declared (RMSExyz within 25 m), even in bare soil areas

- low biases, increasing from bare soil to urban and forest area, attains to SRTM products, whose accuracies are mainly driven by noise; the best product is DTED SRTM, but for all the products accuracies are much better than declared (LE90 within 16m, RMSEh within 9.7m) over bare soil areas (RMSEh at 2.5 level), whereas they are at the same level or worse than declared over urban and forest areas

- comparisons vs. the Cartosat-1 DSM display results quite similar to those derived using LIDAR DEM as reference for bare soil areas, and better results over urban and forest areas; this can be explained considering that a large part of the terrain high frequencies included into LIDAR DEM mainly in urban and forest areas are filtered out into Cartosat-1, so that this comparison attains to more similar height models, what is clearly evidenced by low biases with all the different land cover types

- no significant different results are obtained if 3D (instead of 2.5D) comparisons are performed by DEMANAL, mainly due to the limited slopes of the considered areas

Further investigations are necessary for comparing SRTM and ASTER DSMs to larger LIDAR DEMs. Moreover, it has to be better investigated the accuracy of CGIAR product, which should be the most refined.

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