

ERROR ESTIMATION OF ASTER GDEM FOR REGIONAL APPLICATIONS - COMPARISON TO ASTER DEM AND ALS ELEVATION MODELS

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Abstract

The last 20 years show an enormous resolution improvement of worldwide available Digital Elevation Models. At present, the ASTER Global Digital Elevation Model (GDEM) with a resolution of 30 m shows an evolution from the GTOPO 30 model (1000 m) of the year 1996 and the SRTM model (90 m) of the year 2000. However, little is known about the accuracy of the ASTER GDEM itself and for the official test regions the error varies very strong from -0.6 to -13.3 m (ASTER GDEM Validation Team 2009). This paper presents the comparison of ASTER GDEM data with ASTER DEM and ALS Elevation Data of the Rur catchment in Western Germany. The second part of the paper reflects the possibility of regional scale investigations with ASTER GDEM data in the hyper arid regions of the Eastern Desert of Egypt.

Keywords

ASTER, DEM, GDEM, CRC/TR 32, CRC 806

1. INTRODUCTION

In the last 20 years the resolution and availability of free worldwide Digital Elevation Models (DEM) increased dramatically. In the beginning of the 90th of the last century the ETOPO and GTOPO models are derived by different free and military elevation sources compiled to a new raster dataset. Due to the different primary data sources the quality and accuracy of the models are spatially different. Consequently, regional studies are difficult to perform (Bubenzer & Wagner 2002). At the beginning of the 21th century two different systems present two new models increasing the resolution of worldwide elevation models more than 100 times. The first one is the SRTM-model (Rabus et al. 2003), recorded in 2000 and presented area-wide for the region of 60°N to 54°S in 2004. In the presented paper, we analyse the newest worldwide elevation model, derived from stereoscopic ASTER satellite images. Table 1 gives a compilation of the available worldwide elevation models with some additional information.

Table 1. Compilation of free available worldwide Digital Elevation Models.

Name	Year	Cellsize/Resolution	Coverage	Add. Information
ETOPO-5 / ETOPO-2	1993 / 2001	~10 km / ~4 km	Worldwide	Incl. Bathymetry
GTOPO 30	1996	~1 km	Worldwide	Compiled by different elevation model sources
SRTM-3	2000 recorded / in 2004 available complete	90 m	60°N-54°S	SRTM-1 coverage for USA available for free
ASTER GDEM	2009	30 m	99 %	Compiled by 1.2 million individual ASTER-scenes

2. DATA

In the following we use three data models as a representation for the earth's topography. At first, an official model of the CRC/TR 32 investigation region (cf. 3.1), the DGM 10 model distributed by the district government of Cologne. Second, a subset of the ASTER Global Digital Elevation Model (GDEM), and third, a self derived ASTER elevation model from its stereoscopic data. We use these three models to assess on the one hand the quality of the datasets, in

particular the difference between the ASTER models and the DEM 10 and on the other hand possible applications for regional studies using the ASTER models.

2.1 DEM 10

For the quality assessment of the ASTER GDEM and the 'self made' ASTER DEM a regional elevation dataset with 10 m spatial resolution (further referred to as DEM 10), which was already available for the CRC/TR32 was chosen as reference. This data is derived from the 'Digitales Geländemodell 5L' (DGM5L), which is an official high resolution DEM for North Rhine-Westphalia, provided by the district government of Cologne. The DGM5L provides irregular point cloud elevation data derived from Airborne Laser Scanning (ALS) with an average point spacing of 1 to 5 m and an elevation accuracy of +/- 5 dm. In the acquired data product (last pulse data) elevation values, which do not belong to earth's surface (e.g. vegetation or buildings) were manually removed by the provider (LVERMA 2009). To meet the demands on an elevation dataset, e.g., for hydrological modelling at catchment scale, further processing and a resampling to 10 m was applied to the data. These calculations included void filling, noise reduction via a modified variable Lee-Filter (Lee 1980) and the removal of anthropogenic surface features using the GIS software package SAGA. All processing steps for the DEM 10 were done by Scilands GmbH, Germany (Scilands 2010).

As a result, in contrast to the ASTER elevation data, which stems from optical stereoscopic images, the z-values of the DEM 10 represent (more or less) the earth surface and not the height of tree canopies or buildings, for instance. Consequently, there is an elevation difference between pixels representing the earth's surface in the DEM 10 and e.g. forest situations in the ASTER models. However, since the ASTER scenes used for the DEM generation stem from late march of 2009 for other regions which represent, for example, arable land and pasture the influence of green vegetation on the elevation values should be negligible at this stage in the vegetation period. To identify regions suitable or unsuitable for the comparison a land use classification of 2009 (Waldhoff 2010) with 15 m spatial resolution (Fig. 1A+B) was incorporated. The classification is derived from multi temporal remote sensing data sets of 2009 (ASTER, RapidEye), in conjunction with additional data sets like the 'Authoritative Topographic-Cartographic Information System' (ATKIS Basic-DLM) (AdV 2009) which also contain useful land use information. By using the Multi Data Approach (MDA), knowledge based production rules are applied to select the most valuable spatial information of each data set (for further information on the applied methodology see Waldhoff & Bareth 2008).

2.2 ASTER DEM

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is a high spatial resolution, multispectral imager on the NASA spacecraft TERRA launched in 1999. Its spectral and geometric capabilities include 14 bands in different wavelengths, three bands in VNIR (visible and near infrared) with 15 m resolution, six bands in the SWIR (short-wave infrared) with 30 m and five bands in the TIR (thermal infrared) with 90 m, and a 15 m along-track stereo-band looking backwards with the same wavelength as band 3 (nadir) (Yamaguchi 1998). For generating elevation models, we use L1A raw data including the two stereo bands (3b and 3n) (Abrams 2000) to calculate a relative elevation model using PCI Geomatica remote sensing software. As a result, we get a 30 m elevation model. For the presented study, no post processing of the raw data were done. The error of an ASTER elevation model varies depending on the quality of the source image and the relief energy of the study regions (Bolten & Bubenzer 2006).

2.3 ASTER GDEM

The ASTER Global Digital Elevation Model (GDEM) covers 99 % of the land surface from 83° N and 83° S with an estimated accuracy of 20 meters (ASTER GDEM Validation Team 2009). The methodology to produce the ASTER GDEM involved automatic processing of the 1.5-million-scene archive. Hence, more than 1.2-million individual ASTER scene elevation models are used to mosaic the land surface with the aid of removing residuals and averaging techniques (ASTER GDEM Validation Team 2009).

The official validation process for the ASTER GDEM presents different values for the accuracy of the model dependent on different regional studies and different reference data. Table 2 gives an overview about the validation data and the different error values for the ASTER GDEM.

Table 2. Overview about the ASTER GDEM validation data (composed after ASTER GDEM Validation Team 2009).

Reference data	RMSE [m]	Region
National Elevation Data USA (NED)	10.87	USA
Japan's Geographical Survey Institute (GSI)	4.14-8.75	Japan
Japan's Geographical Survey Institute (GSI)	13.29-20.10	Japan (steep mountainous terrain)

Various (investigations of 20 int. study groups); mostly SRTM	4.18-57.61	Various
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In addition, there are several artefacts and residual anomalies in the GDEM, which decrease the value of quality and usefulness for scientific questions. These anomalies are irregular distributed, so an inspection for any investigation region is necessary.

3. INVESTIGATION AREAS

In the presented paper we use two different regions representing two of the investigation areas of the working group. First of all, two different areas within the river Rur catchment in the far western part of Germany and secondly a part of the Eastern Desert region in Egypt.

3.1 Rur catchment in Germany

The two study areas are located in the western part of Germany and are subsets of the Rur catchment, the study region of the Transregional Collaborative Research Center 32: 'Patterns in Soil-Vegetation-Atmosphere Systems: monitoring, modelling, and data assimilation' (CRC/TR32, <http://www.tr32.de>). The CRC/TR32, started in 2007, is an interdisciplinary research project which focuses on Soil-Vegetation-Atmosphere modelling at various scales in a regional context, funded by the German Research Foundation (DFG). Consequently, high quality elevation data in different spatial resolutions is of central importance for the project to model land surface processes. Figure 1 gives an overview of the investigation region with two subsets representing two different topographic settings.

As illustrated in figure 1 (II) the Rur catchment can be divided into two major parts. The regions with low elevations belong to lowland of the Lower Rhine Plain, while the elevated areas form the Eifel as the western part of the Rhenish Slate Mountains. The Eifel is a low mountain range with heights of 400 to 600 m in most parts, but it can rise up to 747 m a.s.l. like the mountain 'Hohe Acht' (Liedtke & Marcinek 2002).

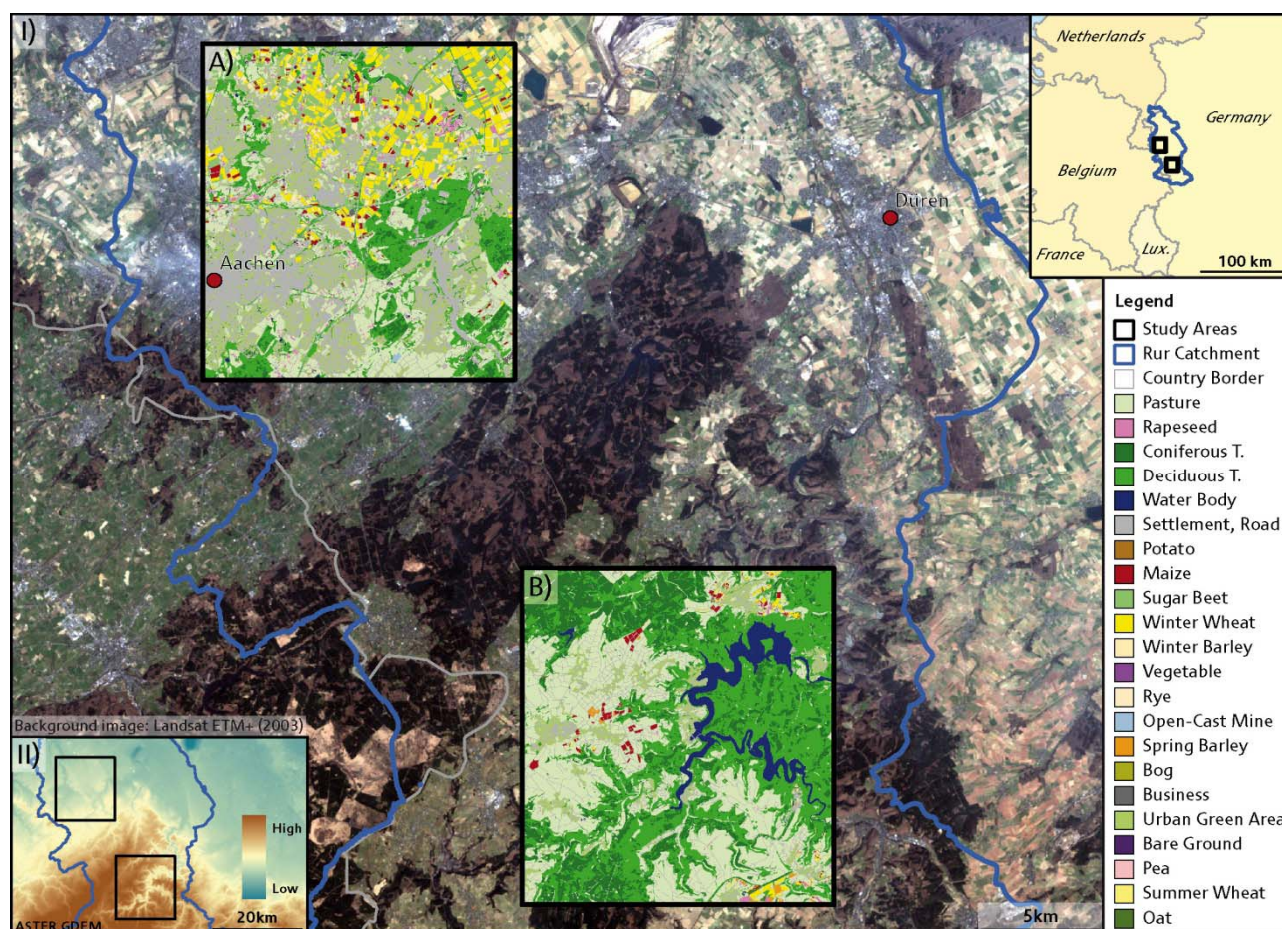


Figure 1. Overview of the investigation regions in the Rur catchment in the western part of Germany. The insets A and B show the elevation test regions with a land use classification. The inset II gives an elevation overview of the displayed area (more information see text).

Area A is more or less flat in the north, but ascends towards the south to the Eifel. The region comprises urban areas like the city of Aachen in the west, while the hilly southern part of the Aachener Hügelland is occupied by pasture and forests. The lowland in the northern half is dominated by the arable land of the Jülicher Börde.

The southern area B is located completely in the low mountain ranges of the Eifel (Rur Eifel). The landcover is dominated by forest and grassland, but also patches of arable land are present. The terrain of this region is a typical peneplain landscape with sometimes pronounced relief, steep valleys, and elevation differences between 210 to 560 m a.s.l. (Liedtke & Marcinek 2002). A prominent landscape feature is the artificial Rur dam embedded into the Rur valley system.

3.2 Eastern Desert of Egypt

The Eastern Desert of Egypt occupies more than 25 % of the total area of Egypt (around 220,000 square kilometres) and is characterized by mountains, plateaus, and large wadi systems. The mountains rise up to 2,000 m a.s.l., whereas the plateaus are in between 100 to 1,000 m a.s.l. (Embabi 2004, Sidebotham 2008, cf. fig. 4A). Similar to the Western Desert of Egypt the region passed through a drastic climatic change in the last 25,000 years, consequently the land-use of the prehistoric people changed and water source became more important (Sidebotham et al. 2008).

In the 2009 initiated interdisciplinary CRC 806 'Culture-Environment Interaction and Human Mobility in the Late Quaternary' (<http://www.sfb806.de>) this region represents one connecting region between the centre of origin of modern humans in northeast Africa and a potential route to Europe through Egypt and the Levant. The use of high resolution digital elevation models can support the geoarchaeological investigation of this region. No official elevation information are available for the most of the areas especially for Egypt. In several field studies in the Western Desert of Egypt within the 2007 finished CRC 389 'Arid Climate, Adaptation and Cultural Innovation in Africa' (ACACIA), the connection between the geomorphological and archaeological setting of a locality could be indicated (e.g. Bolten & Bubenzer 2006, Bolten et al. 2006, Bubenzer & Bolten 2008). Up to now, in the CRC 806, no detailed investigations could be performed in the presented area, but there are several evidences for archaeological findings like the existence of the famous Sodmein cave (Sidebotham et al. 2008).

4. METHODS

For the comparison of the models at first a horizontal shift of the datasets will be examined by the inspection of derivated data (in case of elevation datasets, edges from slope-analysis and calculated drainage lines) and the models are transformed to the same resolution and projection using GIS-software. The statistical investigation is done by using spread sheet software. The data values of the models itself and the derivated data is transferred to the software to calculate the root mean square errors and other statistical values in comparison to the DEM 10 model. In addition histogram-techniques are used to visualize the spreading of the elevation and error values.

For the hydrological investigations the software Watershed Modelling System (with TOPAZ algorithm) (Garbrecht & Martz 1999) is used to derive the drainage lines, catchment areas, and additional information.

5. RESULTS

The results of the investigation of the different elevation models are divided into two parts. At first, the results of the error calculation between the ASTER models and the DEM 10 and secondly the use of the ASTER models in geoarchaeological questions in the Eastern Desert of Egypt. The inspection of a potential shift of the models shows no significant error. The collecting of ground control points identifiable in all models could fortify this.

5.1 Comparison of ASTER models with standardized elevation model

To compare the ASTER and ASTER GDEM elevation data we use the 30 m-resampled DEM 10 and assume for the statistical compare no error. First of all both models the ASTER DEM and the ASTER GDEM show a good correlation to the DEM 10 model. The correlation factor of all elevation values of regions A and B in figure 1 for both ASTER models to the DEM 10 are higher than 0.99. A direct relation to the DEM 10 model gives us more information about the differences of the ASTER models.

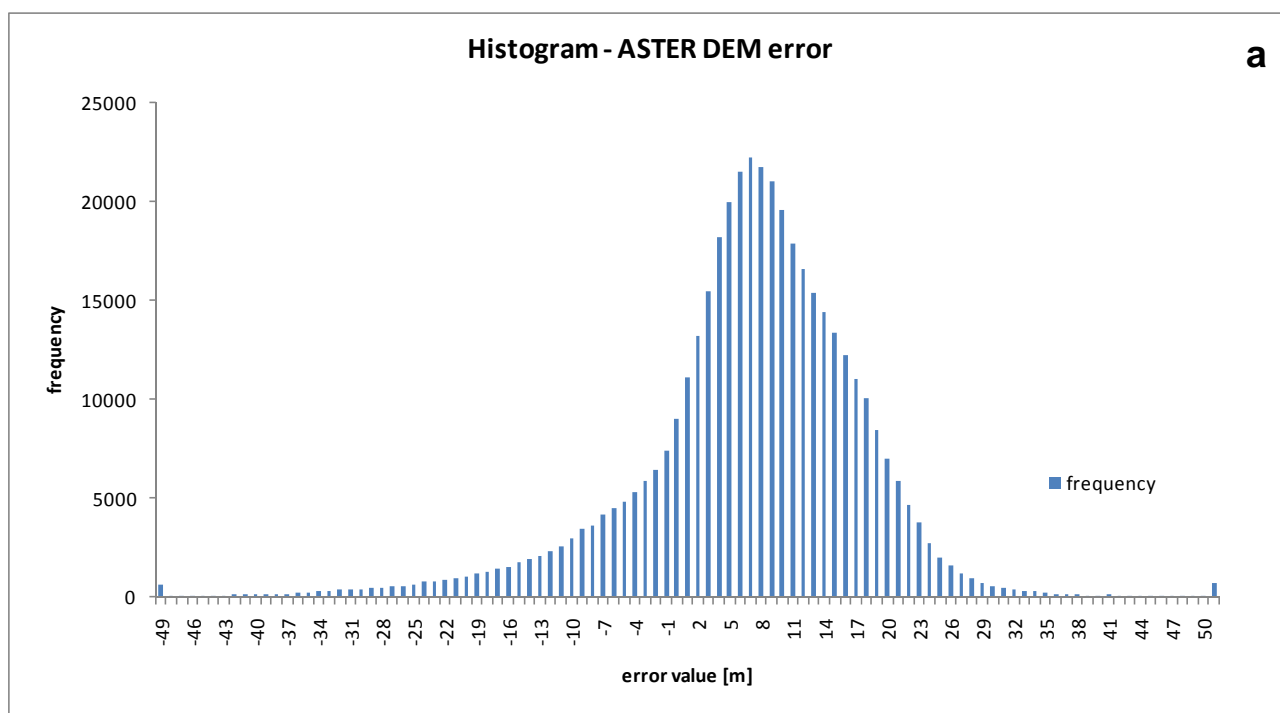
Table 3 shows the statistical values calculated by spread sheet technique. Clearly it is visible that the GDEM-model has a lower RMSE value against the DEM 10 model than the ASTER DEM. Both RMSE values for the entire region, 8.02 m and 12.90 m, match the error values of the ASTER GDEM Validation Team (2009). The inhomogeneous values for the southern and northern region depend on the different topographic energy of the regions. This correlation between the relief energy and the error is shown in several contributions (ASTER GDEM Validation Team 2009, e.g. Käab 2002). The skewness and kurtosis of the models gives us two more information. First of all the negative skewness of both models (e.g. Cramer & Howitt 2004) shows us that both models have a significant number of higher values than

the DEM 10 model. This effect is often apparent using elevation models generated by stereoscopically data. Both ASTER models give us elevation values including vegetation and anthropogenic modifications (e.g. buildings). Hence, in comparison to elevation ground models a positive or negative skewness is predictable. The skewness is also visible in the histograms in figure 2.

Second the kurtosis, which reflects the characteristic of the tails of a distribution (Cramer & Howitt 2004). Values greater than zero represent a platykurtic distribution with steeper tails than a normal distributed curve. The calculated values give us a more platykurtic curve for the ASTER against the ASTER GDEM model. Both information indicate that the ASTER GDEM model was reworked by cleanup positive and negative peaks and using smooth filters.

Table 3. Statistical summary of the ASTER DEM and GDEM for the entire region and subsets A and B (cf. fig. 1). More information see text.

Dataset	RMSE [m]	Comment (e.g. fig. 1)	
DEM10 - ASTER DEM	12.90	Entire region	
DEM10 - ASTER GDEM	8.02	Entire region	
DEM10 - ASTER DEM	8.75	Region A	
DEM10 - ASTER GDEM	6.86	Region A	
DEM10 - ASTER DEM	16.02	Region B	
DEM10 - ASTER GDEM	9.03	Region B	
DEM10 - ASTER GDEM (corrected by land use classification)	6.80	Entire region	
	Skewness	Kurtosis	
DEM10 - ASTER DEM	-0.86	5.42	Entire region
DEM10 - ASTER GDEM	-1.02	2.21	Entire region



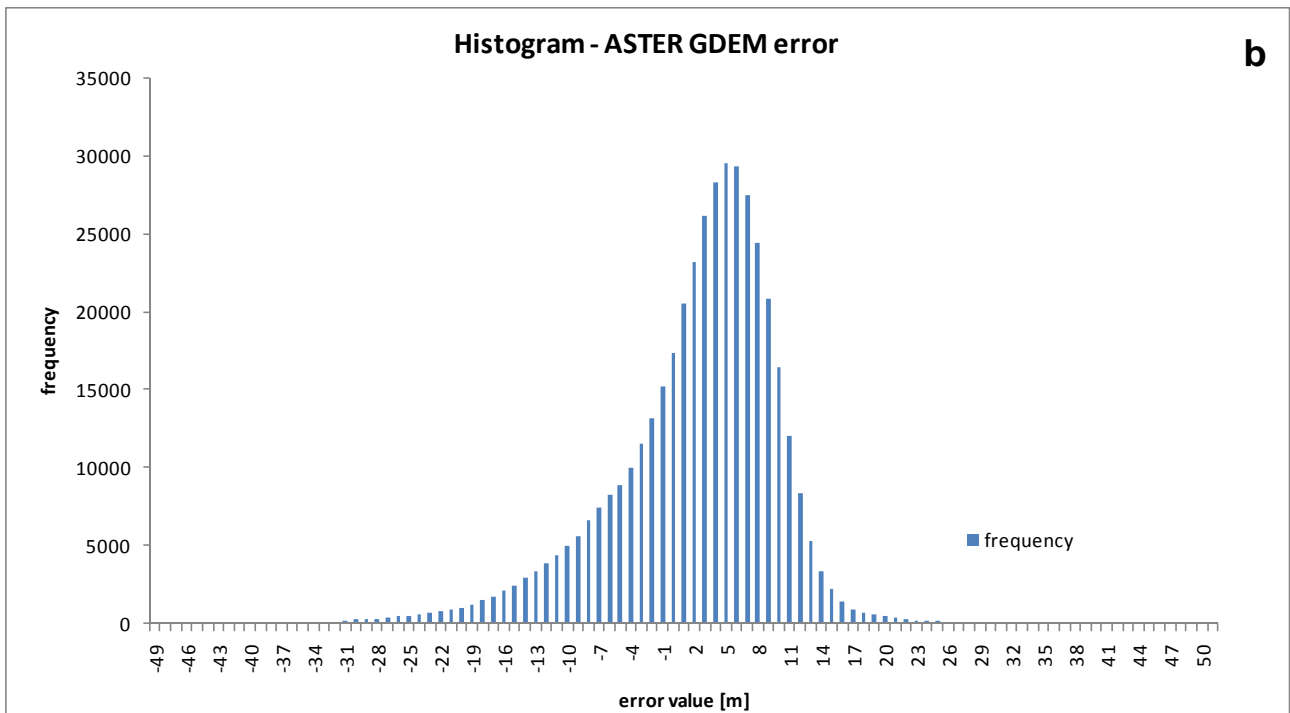


Figure 2 a. Histogram of the ASTER DEM error against the DEM 10 model. b. Histogram of the ASTER GDEM error against the DEM 10 model. Clearly the more-balanced distribution of the GDEM error is visible. In both models the negative skewness (cf. tab. 3) gives the notice to the origin of the models, stereoscopic visible datasets, which give not an elevation but a surface model including e.g. vegetation, buildings etc.

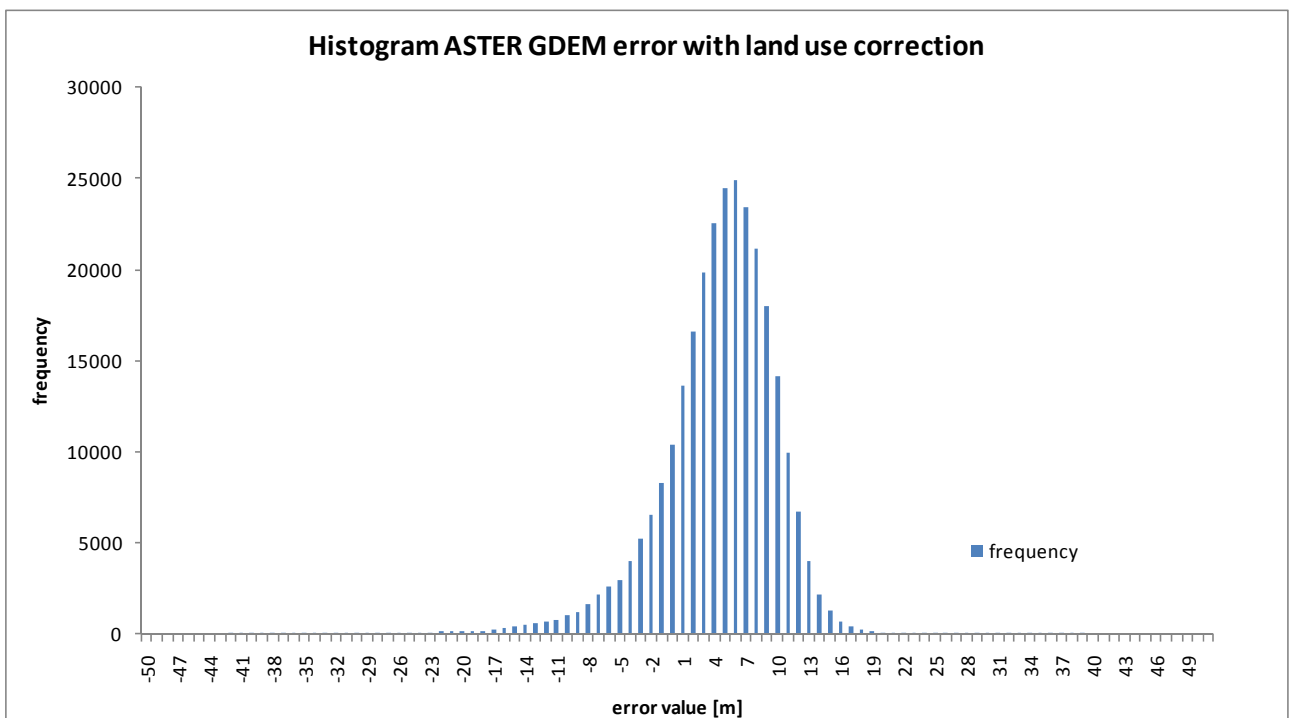


Figure 3. Histogram of the ASTER GDEM error against the DEM 10 with land use correction. The elevation pixels with land use classification "Coniferous T." and "Deciduous T." are corrected by a height of 10 m. The modification to figure 2b is clearly visible.

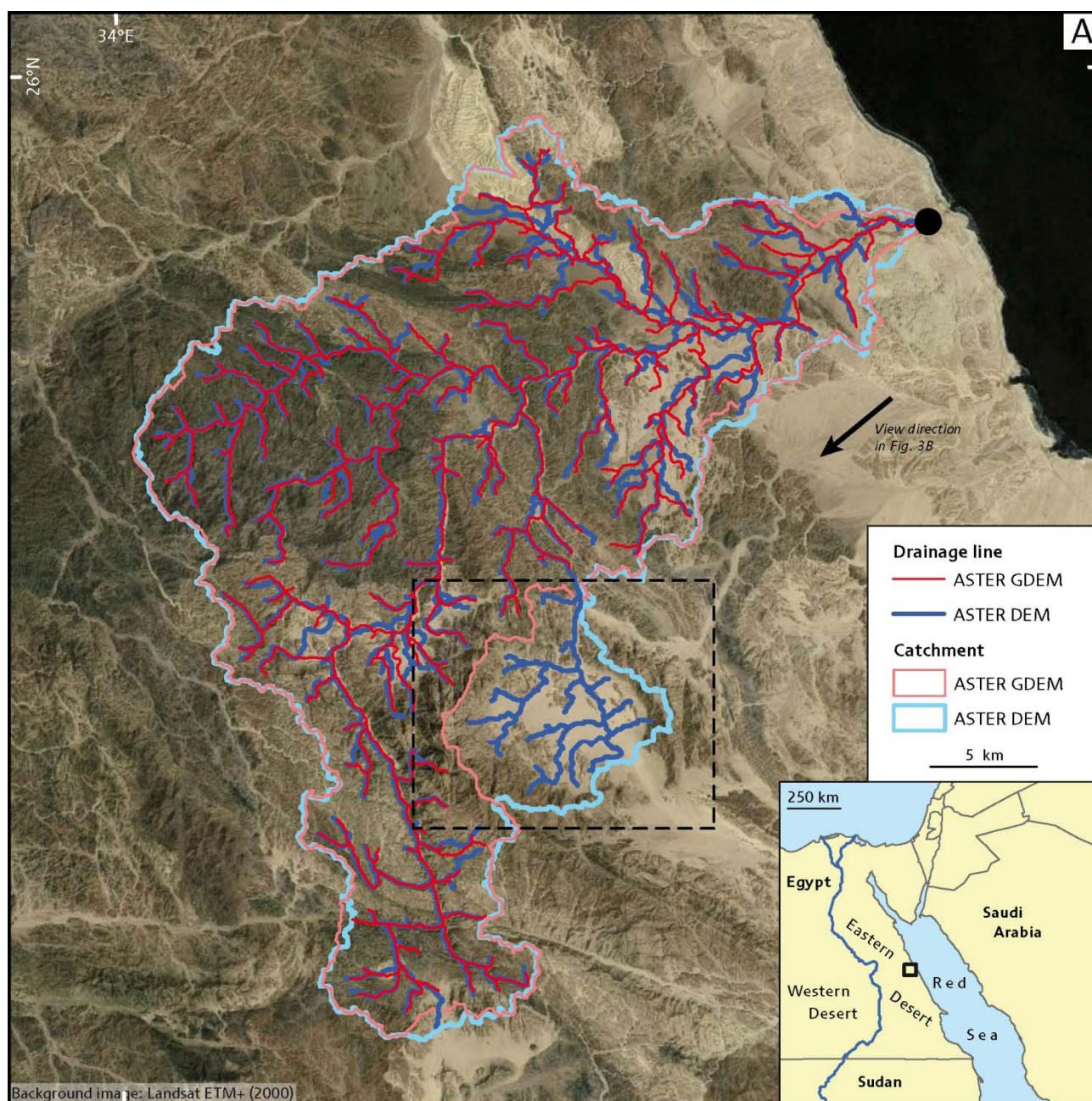
A land use dataset derived by multispectral remote sensing data gives us regions with higher (upper) vegetation to recalculate the ASTER models to modify this elevation values. This is one possibility to enhance the quality of the models. For the investigation region a land use classification (cf. 2.1) is available. From this starting point, regions with forest (in Figure 1 A and B marked as "Coniferous T." and "Deciduous T.") can be identified and subtract from the original model. With known of buildings and other higher constructions, this modification could be processed by the

same way (in the used classification settlements and roads are contained in the same class; cf. figure 1). In the presented case study the skewness of the model increase and the model histogram becomes more bell-shaped (cf. figure 3). The RMSE against the DEM 10 decreases for the ASTER GDEM from 8.02 to 6.80 m (cf. table 3).

5.2 Use in Geoarchaeological questions

In geoarchaeological investigations elevation models and the possibility to calculate the hydrological position of archaeological findings or areas are very important, even more in arid regions where water and their availability is existential.

Figure 4A shows an eastern part of the Eastern Desert where archaeological findings are assumed. For the two ASTER models the overall course of the drainage lines are very similar, in critical positions (marked in figure 4A) small differences in the models reaches to generate a different picture. However, both models based on the same source, the volcanic plateau (clearly visible in figure 4B) is located to different catchments according which model is used. This easy example shows, that field work in extreme positions is necessary to get a complete reconstruction of the actual situation and as a base for a reconstruction of former situations.



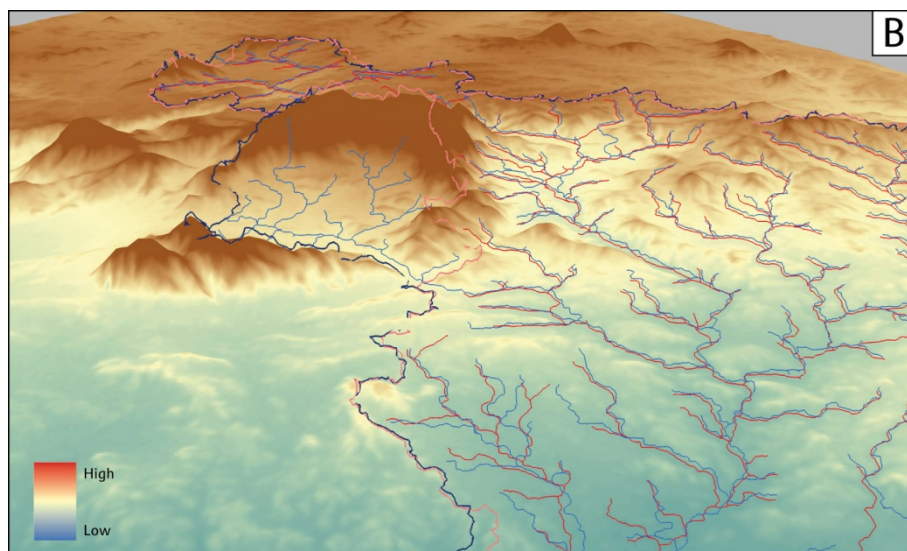


Figure 4 A. Subset of the Eastern Desert of Egypt. Clearly visible is the overlap between the drainage lines and catchment borders of both ASTER models. The marked area shows a problematic region based on small elevation differences in the ASTER models. B. The 3D-view (the viewing direction is marked in 3A) with exaggerated relief shows the situation even more clearly (colours see figure 4A).

5. SUMMARY

The presented paper investigates the quality and usability of ASTER elevation models in regional scale studies. The estimated error of the ASTER GDEM Validation Team (2009) of the ASTER GDEM model with 8.02 m RMSE could be confirmed in comparison to the DEM 10. The ASTER GDEM matches better than the raw ASTER elevation model. However, the ASTER DEM gives the chance to apply own post processing and having more control over the model. Due to the source of the ASTER models in stereoscopic satellite images a quality control and post processing is necessary. The use of a land use classification and consequently the possibility to identify higher vegetation can enhance the quality and usefulness of ASTER models. In the introduced method the RMSE could be improved by around 25 %.

The short example in the Eastern Desert demonstrates the effect of modification of elevation values resulting in different catchment borders and advises the importance of field work studies. In arid regions with no higher (upper) vegetation, the ASTER models give good results without corrections. In addition, due to the most often cloudless and dry atmosphere, the satellite images are mostly excellent and also archived time series are available.

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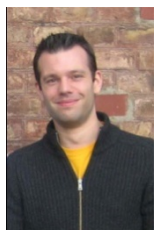
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