Comparison of Accuracy of DEM's Available For The Republic of Macedonia

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Abstract

In this paper, accuracy assessment of several DEM's available for the Republic of Macedonia is made. These include from coarse scale 30"SRTM (near 1 km), to the semi-fine scale 3"SRTM (around 90 m), and fine scale 1"ASTER GDEM (30 m), 1"X-SAR SRTM (30 m) and 20 m DEM of the Agency of Real Estate and Cadastre of the Republic of Macedonia (ARECRM). Today most used worldwide is 3"SRTM DEM because vertical and horizontal errors of this model are tolerable for different purposes. Since of international coverage, there are possibilities for comparison of results with other areas and countries. After the initial release of the model in 2004, its quality was gradually improved by software algorithm corrections. Thus, for our research version 4 is used (JARVIS et al. 2008). According to our tests, 3"SRTM model has average horizontal and vertical accuracy of ±5 m, with maximum errors up to ±15 m. Such height inaccuracies are generally due to the resolution of the model, and the location of DEM points around the prominent peaks. To minimize the effect of these shifts, in some geomorphometric procedures as for slope gradient, empirical correction coefficient can be used. A higher quality DEM from the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) instrument of the Terra satellite is also freely available for Macedonia, and represents elevation at a 30 meter resolution. But there are some quality issues with both (ASTER GDEM V1 and V2) versions of this fine scale model. 1"X-SAR SRTM DEM is also with 1" (about 25x25 m) horizontal resolution, but with narrow bands coverage, large voids and with significant elevation shifts. Finally, currently the most accurate model is 20m DEM of the State Agency of Cadastre, which is confirmed with detailed topographic and morphometric analyses. Aside that is commercial product, it show best results in terrain accuracy. Further step is expected with data acquisitions from radar satellites TerraSAR-X and TanDEM-X which will be available in 2014 as uniform global coverage with a resolution of 12 x 12 meters.
Keywords: DEM, comparison accuracy assessment, Republic of Macedonia.

Introduction

In latest years several high quality DEM's with global or almost global coverage and coarse to fine scale resolution were realized for free public usage. That is very significant because of increased needs for applications based on digital terrain modeling versus insufficient free or inexpensive high quality national DEM's. Most of them cover up the area of the Republic of Macedonia. In this paper accuracy comparison of digital elevation models freely available for the Republic of Macedonia is presented.

First of these was worldwide SRTM (Shuttle Radar Topography Mission) DEM which is join project of National Aeronautics and Space Administration – NASA, National Imagery and Mapping Agency – NIMA, German Space Agency (DLR) and Italian Space Agency (ASI). SRTM is publicly realized in the end of 2003 and cover latitudes from 60N to 54S or about 80% of Earth landmass area. The data for SRTM mission are recorded in the February 2000 in the period of 11 days using the method of radar interferometry (Bamler, 1999). Original resolution of

SRTM DEM is 1” or 30m but because of “security reasons” the datasets are interpolated to 3” or 90m. Thus, SRTM DEM is freely available in 30 m resolution for the area of USA and 90m resolution for the rest of the World. Until now, there are several enhanced and updated versions of this model which are more accurate than original (Jarvis et al., 2008; Keeratikasikorn & Trisirisatayawong 2008). For the area of the Republic of Macedonia, original 3”SRTM DEM is available in tiles of 1 x 1 degree (1201 columns x 1201 rows) with total of about 4 million grid cells (Markoski & Milevski, 2005).

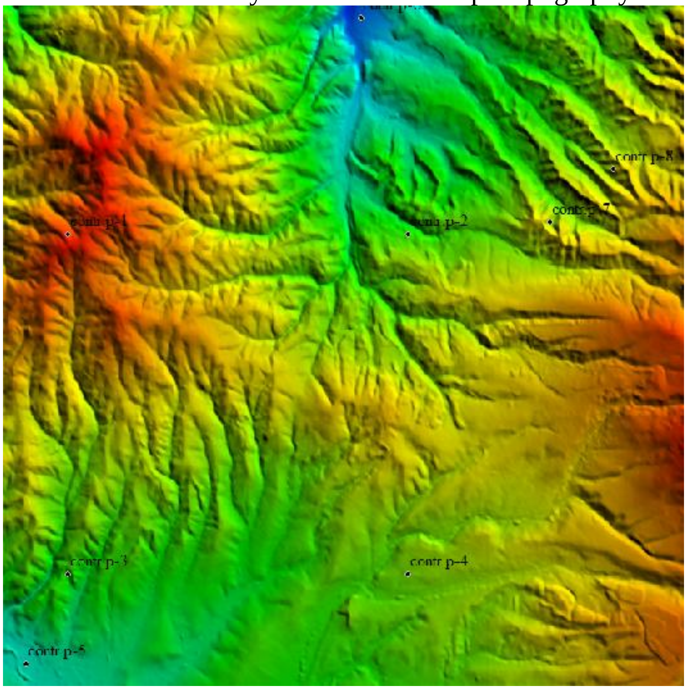
Another product related with SRTM mission is X-SAR SRTM DEM which is available at no cost since December 2010. The elevation models were generated from X-band synthetic aperture radar (SAR) data acquired during the Shuttle Radar Topography Mission (SRTM) in February of 2000. The American system operating in C-band, was complemented by a higher resolution German-Italian X-band system. Similar to the SRTM C-band data, the DLR/ASI X-band DEMs cover the entire globe between 60N to 54S latitude. However, the coverage of the X-band DEMs is not continuous. The gaps between the individual crossing image strips are a result of the higher precision and therefore the narrow swath width of the X-band system. One pixel of the DEM files corresponds to approximately 22 m x 30 m resolution for the area of Macedonia. The elevation values are provided at a resolution of 1 m. The horizontal accuracy of the SRTM X-band DEMs is ±20 m (abs.) / ±15 m (rel.) and the vertical accuracy is ±16 m (abs.) / ±6 m (rel.).

SRTM30 is the third product of SRTM mission as very coarse global digital elevation data set that has a horizontal grid spacing of 30 arc-seconds (approximately 1 km). While SRTM30 has the same resolution as GTOPO30, it can be considered a more accurate global digital data set compared to GTOPO30 because of its seamless and uniform representation, due to the fact that it was created over a short period of time from a single source rather than from the numerous sources spanning many decades that went into creating the GTOPO30 data set.

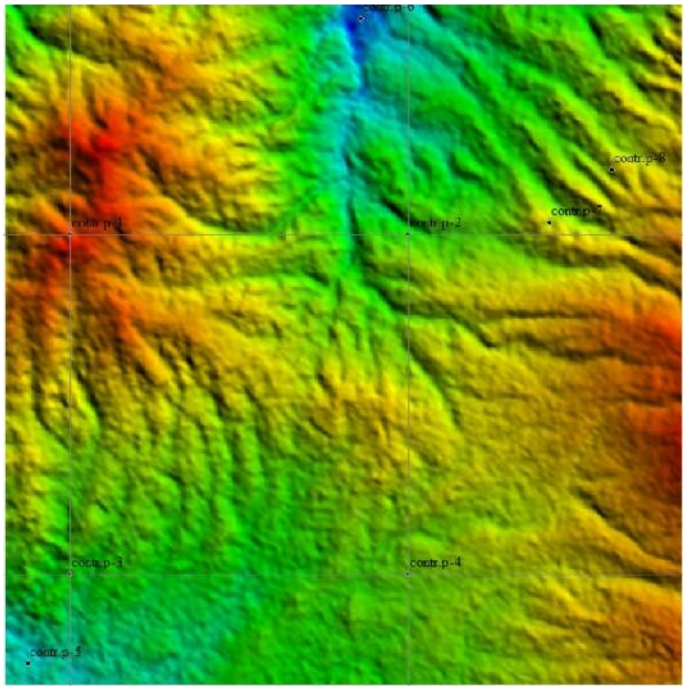
Among the newest digital elevation model with global coverage, good quality and high resolution is realized in 2009 from ASTER (Advanced Space borne Thermal Emission and Reflection Radiometer) Satellite imagery. The model is called ASTER GDEM and it is product of NASA and Japan Ministry of Economy, Trade and Industry (METI). ASTER GDEM has 30m resolution and until now there are two versions of this model. The first version of the ASTER GDEM (v.1), realized in June 2009 was generated using stereo-pair images collected by the ASTER instrument on board Terra. ASTER GDEM coverage spans from 83N to 83S latitude encompassing 99 percent of Earth’s landmass. The improved GDEM V2 realized on October 17 2011, adds 260000 additional stereo-pairs, improving coverage and reducing the occurrence of artifacts. The refined production algorithm provides improved spatial resolution, increased horizontal and vertical accuracy, and superior water body coverage and detection (Hengl & Reuter, 2011). The data are provided “as is”, and neither NASA nor METI/Japan Space Systems (J-space systems) will be responsible for any damages resulting from use of the data. Because of resolution, the country area is covered by 12 ASTER GDEM tiles of 1 x 1 degree and total of 28.2 million grid cells.

Study Area

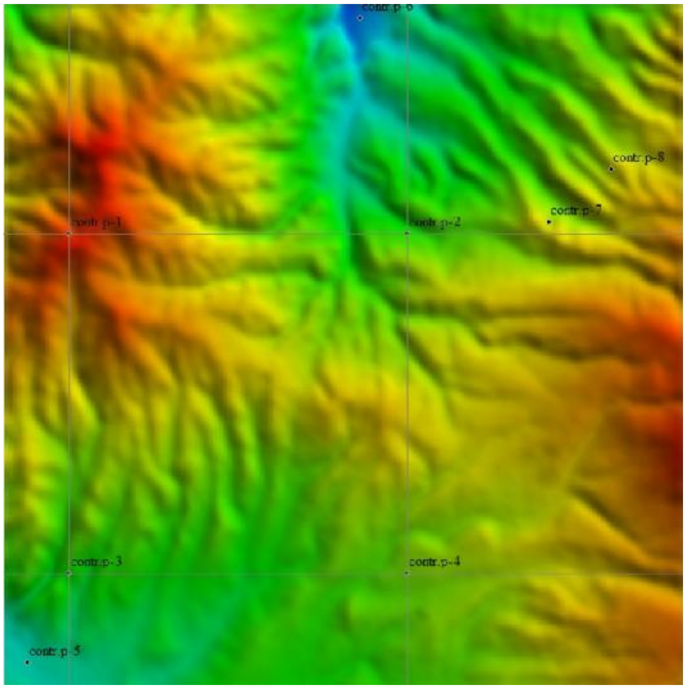
As a test area of DEM analysis and comparisons is selected one site in the easternmost part of Macedonia near to the border with Bulgaria. More precisely it’s in Berovo-Delchevo Basin and cover up most of the Pehchevo municipality. The reason for its selection is because very diverse terrain landscape in regard to elevation and slope. Also we already have several available DEMs which cover this area, including very precise 20m DEM of the ARECRM (Agency of Real Estate and Cadastre of the Republic of Macedonia) and 5m DEM from MAFWERM (Ministry of Agriculture, Forestry and Water Economy) as a reference models. Because of consistency in analysis and comparisons, a square area with side’s length of 10x10 km and total of 100 km2 is selected and used. In the frame of the square test area there are many deep and shallow valleys, flat areas, steep mountain sides and hills. The highest point of the area is Bejaz Tepe peak with 1348 m, and the lowest point is valley bottom of Zelevica River on north with 742 m. Thus entire area is very diverse in landscape topography.



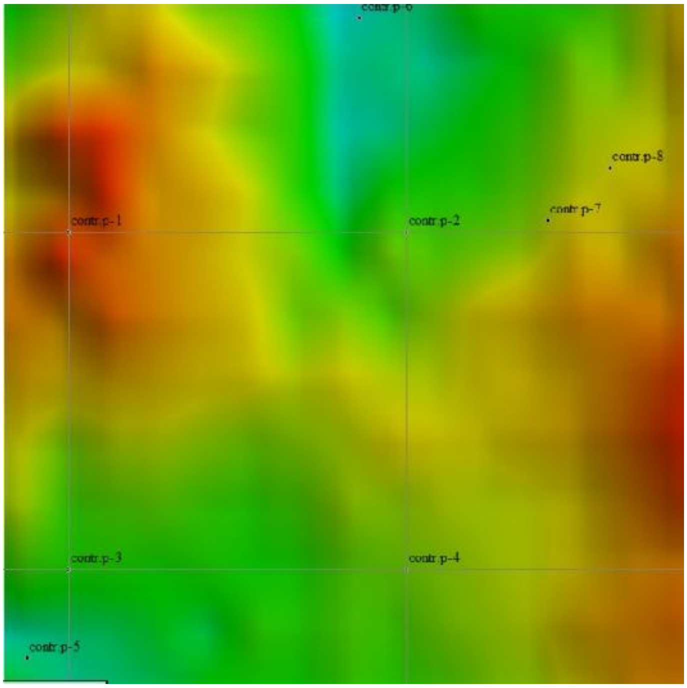
20m ARECRM DEM



1”ASTER GDEM



3"SRTM DEM



30"SRTM DEM

Fig. 1, Some of analyzed DEMs of test area with control point position.

Methodology and Data

In our methodological approach, several DEMs of interest was analyzed and compared: 3"SRTM DEM, 1"X-SAR SRTM DEM, 1"ASTER GDEM and 30"SRTM DEM. As a reference, 20m DEM created by Agency of Real Estate and Cadastre of the Republic of Macedonia (ARECRM) and 5m DEM of the Ministry of Agriculture, Forestry and Water Economy (MAFWRM) are used. That is because these models by various evaluations are considered as the most accurate digital elevation models available in the country up to day. In our analysis several parameters are checked in relation to the referent 20m and 5m DEMs. Those are minimum, maximum, and mean elevation of the test area, minimum, maximum, and mean values for the slopes and all of those parameters for selected and digitized 8 control points. The control points were selected on different elevations and slopes which result with greater objectivity of evaluations. Another 7 control points which represent trigonometric points from topographic map in scale 1:25,000 are selected for absolute elevation comparison of DEMs.

First of all digital elevation models which are included in our analysis are downloaded, adjusted and cropped with previously defined square polygon test area. After that 8 control points and 7 trigonometric points was selected and digitized. Finally, calculations and evaluation of the values was made. In the procedure SAGA GIS v.2.1 is used with suitable modules for grid analysis as well as the module for the grid property of points.

Results

Our analyses show some degree of deviation in elevation between the different DEMs. The highest deviation is recorded on the SRTM X-SAR model showing vertical shift of around for 40 m. This is probably systematic error and for that reason a correction is made with Z-value subtraction for 40 m. After that procedure the elevation differences was substantially lower and close to the value of referent 20m DEM (Table 1). Another high shift and large value differences are on the coarse resolution SRTM30 DEM, which is logical keeping mind low resolution of that model. 1”ASTER GDEM have satisfactory good vertical accuracy with only small shifts with maximum of 13 m (cont. p-7). Surprisingly 3”SRTM DEM also show tolerable vertical shifts in range of several to maximum 15 m (contr.p-7).

Table 1, Elevation differences and deviations from referent 20m DEM.

Type of DEM	Min. elev.	Dev.	Max. elev.	Dev.	Mean elev.	Dev.
20m ARECRM	742	1.000	1343	1.000	993	1.000
1”ASTER GDEM	734	0.989	1345	1.001	988	0.995
1”SRTM X-SAR	741	1.001	1343	1.000	992.9	1.000
3”SRTM DEM	749	1.009	1330	0.990	993	1.000
30”SRTM DEM	771	1.039	1291	0.961	994	1.001

Better evaluation of DEMs accuracy is when compared to the absolute values of trigonometric control points. Thus, 1”GDEM and corrected 1”X-SAR SRTM shows vertical shifts of about ±8m, while 3”SRTM show higher shifts of ±6 m in average and even ±18 m in extreme case (contr.p-1). Normally, 30”SRTM have relative shifts of ±35 m and absolute of ±75 m.

Slope Comparisons

Aside of elevation differences and accuracy evaluation, slope deviation and shifts are also analyzed and calculated. The compared slope depends on the quality of the DEM, and the data spacing. As data spacing increases, the DEM captures less of the fine scale changes of slope, including the extreme values and the slope distribution becomes less steep (Guth, 2010). The results show that the differences of slopes are more extreme than for elevation. These shifts highly influenced geomorphometrical procedures and applications.

In correlation with spatial resolution, the highest slope differences of analyzed DEMs show SRTM30, where mean slope value for the entire test area is only a half compared to other DEMs. Results for control points shows that on flats and gentle slopes, deviation is much smaller than on steep slope areas arising to more than 70% in regard to the reference DEM.

Table 2, Elevation values and deviations of the control points for different DEM's.

Name	5m MAFW		20m ARECRM		1"GDEM		1"X-SAR		3"SRTM		30"SRTM	
contr. p-1	1269.7	0.999	1268.7	1.0	1263.2	0.996	1266.6	1.002	1265.1	0.997	1226.4	0.967
contr. p-2	891.8	0.997	889.3	1.0	886.1	0.996	888.4	1.001	882.0	0.992	913.3	1.027
contr. p-3	859.2	1.005	863.3	1.0	859.9	0.996	863.9	0.999	867.8	1.005	873.4	1.012
contr. p-4	938.3	1.002	940.6	1.0	931.7	0.991	940.1	1.001	941.1	1.001	944.6	1.004
contr. p-5	786.8	1.004	789.6	1.0	786.3	0.996	785.7	1.005	787.5	0.997	809.3	1.025
contr. p-6	757.0	0.995	753.4	1.0	751.4	0.997	755.9	0.997	757.2	1.005	787.8	1.046
contr. p-7	980.8	0.996	976.8	1.0	989.8	1.013	978.7	0.998	992.3	1.016	993.4	1.017
contr. p-8	1010.8	0.999	1009.6	1.0	1008.9	0.999	1008.1	1.001	1008.0	0.998	1018.0	1.008

Table 3, Elevation values in relation to trigonometric control points (m).

NAME	Value	5m MAFW	20m ARECRM	1"GDEM	1"X-SAR	3"SRTM	30"SRTM
contr.p-1	1348	1346	1343	1342	1342	1330	1273
contr.p-2	1084	1088	1086	1083	1085	1079	1019
contr.p-3	941	940	941	936	939	934	917
contr.p-4	886	886	889	890	889	893	911
contr.p-5	1100	1101	1100	1099	1101	1098	1089
contr.p-6	1240	1241	1241	1232	1238	1231	1194
contr.p-7	964	961	960	956	956	953	910
average	1080	1080	1080	1078	1078	1074	1045

SRTM X-SAR from the other side tend to show huge extremes of the values, thus the maximum slope for the entire test area is 68.7º in relation to the referent 20m DEM (42.7º). Usually, it is quite normal for better, more precise and higher resolution DEMs to show better slope accuracy. When it is impossible to use fine resolution DEM, the slope values must be corrected with some factor. Our empiric estimation show that for SRTM DEM that factor is in form of: a=a*1+(a/150) (Milevski, 2005).

From the Table 4 and Table 5 it is obvious that for SRTM30 slope values are highly undervalue for about 1/3 than the referent DEM, except for very flat slopes. Actually the stepper the slope, the higher is shift. As previously mentioned X-SAR usually show higher values on higher slopes than the referent DEM. 3" SRTM show some errors, but in average mean values for some are or region are about 10-15 % underestimated.

Table 4, Slope values for the test area compared to the 20m DEM.

Type of DEM	Min. slope	Dev.	Max. slope	Dev.	Mean slope	Dev.
20m ARECRM	0	1.000	42.7	1.000	11.7	1.000
1”ASTER GDEM	0	1.000	41.0	0.960	10.7	0.915
1”SRTM X-SAR	0	1.000	68.7	1.609	11.9	1.017
3”SRTM DEM	0	1.000	27.6	0.646	8.3	0.709
30”SRTM DEM	0	1.000	17.5	0.410	4.95	0.423

Table 5, Slope values and deviations of the control points for different DEM’s.

Name	20m ARECRM		1”GDEM		1”X-SAR		3”SRTM		30”SRTM	
contr.p-1	21.9	1.0	21.0	1.0	27.3	1.2	17.3	0.8	7.0	0.3
contr.p-2	13.2	1.0	16.7	1.3	8.5	0.6	12.7	1.0	4.3	0.3
contr.p-3	15.1	1.0	13.6	0.9	16.9	1.1	7.3	0.5	2.9	0.2
contr.p-4	2.7	1.0	4.7	1.7	4.9	1.8	3.3	1.2	2.7	1.0
contr.p-5	4.1	1.0	0.9	0.2	3.5	0.9	0.8	0.2	2.1	0.5
contr.p-6	2.7	1.0	2.0	0.7	3.0	1.1	1.9	0.7	2.0	0.7
contr.p-7	17.7	1.0	18.4	1.0	18.5	1.0	13.6	0.8	7.7	0.4
contr.p-8	19.9	1.0	26.2	1.3	36.4	1.8	12.6	0.6	3.3	0.2

Conclusion

In this paper 4 types of freely available global (or nearly global) DEMs which cover also the area of the Republic of Macedonia are compared and evaluated. Those are: 1”ASTER GDEM, 1” X-SAR SRTM, 3” SRTM and 30”SRTM. As a referent 20m ARECRM is used, in some cases in combination with 5m DEM of MAFWERM. Our analyses show that because of resolution and some systematic errors, all of freely available DEMs have some degree of inaccuracy in elevation or slope values. Highest inaccuracy shows 30” SRTM DEM which is normal because of very course resolution. However, in our tests not only to the study area but also to all country coverage mean elevation shift is not so large and it is possible to use this model for obtaining the mean elevation of entire country. For example, 30”SRTM show average elevation of Macedonia of 835 m, while 3” SRTM show 832 m or only 4 m of difference.

1”ASTER GDEM according to the results is relatively better than 3”SRTM, but there are some problems with quality of the DEM, especially in regard to the noise. The problem with too noise of the GDEM can be partially resolved with denoise modules in some software tools like in SAGA GIS. Then the quality and usability of ASTER GDEM will be higher.

1”X-SAR is another DEM with fine resolution (about 22*30m for Macedonia), but it have also some issues with quality and many noise regions which is difficult to resolve. In future maybe those quality problems can be resolved with special software procedures. This model has systematic vertical shift error of about 40m and that must be corrected before any application of the model.

3” SRTM DEM is a good compromise between the quality and spatial resolution. In the extent of Macedonia the resolution of this model is 72*90m, which is enough for most of applications on country level. There are larger shifts of slope, but with use of correction equations slope values can be acceptable. Some procedures of bicubic polynomial interpolation may significantly improve the quality and resolution of 3”SRTM to be closely to the original 1”SRTM (Keeratikasikorn & Trisirisatayawong 2008). Because of that this model is widely used by many institutions in Macedonia.

In 2014, TanDEM-X, very precise DEM with horizontal resolution of 12 m and global coverage is expected to introduce new standards of fine scale global DEMs. First validation results show that its vertical accuracy is fantastic ±2m (Huber et al., 2012). This model if freely available will be of enormous

References

Guth P.L. (2010): Geomorphometric comparison of ASTER GDEM and SRTM. A special joint symposium of ISPRS Technical Commision IV&AutoCarto in conjuction with ASPRS/CaGIS 2010 Fall Specialty Conference, Orlando, Florida, 1-9

Keeratikasikorn C. Trisirisatayawong I. 2008 Reconstruction of 30m DEM from 90m SRTM DEM with bicubic polynomial interpolation method. The International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences. Vol. XXXVII. Part B1. Beijing 2008

Jarvis, A., H.I. Reuter, A. Nelson, E. Guevara, 2008, Hole-filled SRTM for the globe Version 4, available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org).

Markoski B., Milevski I. (2005): Digital elevation model of the Republic of Macedonia, Proceedings of the scientific conference: "Global energy optimization and automation of technological processes," Research Institution "Independent researcher Dr. Boris Nikodinovski" Skopje p. 89-104 (in Macedonian)

Milevski, I. (2005). Using 3"SRTM DEM for geomorphometrical analysis. In Stamenkovic, S., ed. Proceedings: Serbia and modern processes in Europe and World (Tara, Serbia, 26–27 May 2005). Faculty of Geography, University of Belgrade, Serbia, 825 – 832. (in Serbian).

Hengl, T., Reuter, H. (2011). How accurate and usable is GDEM? A statistical assessment of GDEM using LiDAR data. In Hengl, T., Evans, S. I., Wilson, P. J., Gould, M., eds. Geomorphometry 2011 - Proceedings (Redlands, CA, USA, 7–11 September 2011). Redlands, 45 – 48.

Bamler R. (1999). The SRTM Mission: A World-Wide 30m Resolution DEM from SAR Interferometry in 11 Days. Photogrammetric Week 1999, Wichmann Verlag, Heidelberg, 145-154.

Huber M., Gruber A., Wendleder A., Wessel B., A. Roth and Schmitt A. (2012). The Global TANDEM-X DEM: Production status and first validation results. International Archives of the Photogrammetry, Remote Sensing and Spatial Information Sciences, Volume XXXIX-B7, 2012 XXII ISPRS Congress, 25 August – 01 September 2012, Melbourne, Australia

Bashfield A., Keim A. (2011). Continent-wide DEM Creation for the European Union. 34th International Symposium on Remote Sensing of Environment. The GEOSS Era: Towards Operational Environmental Monitoring. Sydney, Australia 10-15 April 2011,

ASTER GDEM Validation Team (2009). ASTER global DEM validation summary report. METI & NASA, 28pp.