TOPOGRAPHIC ESTIMATION BY TERRASAR-X

U. G. Sefercik [a,] *, U. Soergel [b]

[a] Zonguldak Karaelmas University, Engineering Faculty, Department of Geodesy and Photogrammetry Engineering, 67100 Zonguldak, Turkey - ugsefercik@hotmail.com

[b] Leibniz University Hannover, Institute of Photogrammetry and Geoinformation, 30167, Hannover, Germany - soergel@ipi.uni-hannover.de

Commission VII, WG VII/2

KEY WORDS: SAR, Estimation, DEM, Generation, Comparison, Accuracy, Visualization, Analysis

ABSTRACT:

SAR Interferometry (InSAR) is a technique to derive Digital Elevation Model (DEM) from at least two complex SAR images. The data are either taken simultaneously (single-pass mode) or sequentially (repeat-pass mode) by airborne or space-born sensors (carriers: plane, satellite, shuttle etc.). To date, one of the most important single-pass interferometry measurement campaigns is the Shuttle Radar Topography Mission (SRTM) completing its mission successfully after 11 days of operation between 11th and 22nd of February 2000. On the other hand, repeat-pass InSAR has been used by several satellite systems: ENVISAT, ERS 1-2, RADARSAT 1-2, ALOS, JERS-1 etc. One of the most advanced systems is the German TerraSAR-X (TSX) satellite launched on June 15th, 2007. TSX offers high resolution (~1m by Spotlight mode) imagery which could not been achieved from radar technologies up to this time similar to high resolution optical imagery. In contrast to optical sensors, TSX can be operated under all weather conditions without being influenced by clouds. The data sets provided by TSX newly obtained by scientific community and evaluations are currently being performed. As mentioned above, utilizing the advantages of SAR technology, indeed the planimetric locations of target ground objects, elevations of them can be determined using interferometry. Through the interferometric data, interferograms (fringe maps) can be generated and applying interferometric processing steps height models can be created for large coverage interest areas. The main targets of this investigation can be summarized as; generation of height models derived from TSX InSAR image-pairs and evaluation by comparison with more accurate reference height models as well as height models based on high resolution optical satellite images. Absolute and relative accuracy, stability, homogeneity and dependency upon various parameters are determined. The approach will be demonstrated using TSX data covering Istanbul area, Turkey.

1. INTRODUCTION

As it is known, Radar remote sensing has a significant role in remote sensing technologies and develops rapidly. Once in a few years new SAR (synthetic aperture radar) satellites are launched to space including various types of operation modes which offer different resolutions and advantages to each other. The most actual SAR satellite is German TerraSAR-X was launched to its orbit on 15th June 2007. This satellite is a revolution for the SAR technologies at the resolution side and offers 1m high resolution in Spotlight mode. To assess the quality of DSM which is derived from this high resolution data of this current satellite a comparison has been made between the DSM of one of the most advanced optical systems IKONOS. For this aim, the DSMs have been generated using both satellites' data in Istanbul, Turkey and compared with a more accurate DEM of same area, produced by photogrammetry.

2. TEST FIELD AND DATA SETS

2.1 Test Field

Istanbul is located in north-west area of Turkey. The Greater Municipality Area has a coast line to the Black Sea and the Marmara Sea connected by the Bosporus. Istanbul is one of the biggest cities in the world. About 14 million people leave in the city and most of settlements are at the surrounding of Bosporus and coast line of Marmara Sea. The city is a suitable test area for the accuracy analysis because its topography contains various characteristics and this enables to understand the quality of evaluated DEMs in different types of terrain formations. In patches, terrain is open-flat, hilly-steep and woody. The test area is a part of Istanbul and covers 10km×8km. It includes the historical peninsula and near surroundings. Historical Peninsula (Old City) is one of the most important regions in Istanbul, located on the European side, neighbored to the Bosporus and Marmara Sea. This part named as Historical Peninsula because of its historic heritage. Figure 1 shows the high resolution satellite image of the test field with the frequency distribution of terrain inclination. This area has smoother topography in relation to the rest of Istanbul. The elevation reaches from sea level up to 130m.

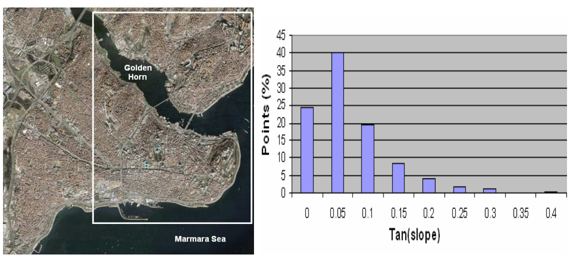

Figure 1. Test area and slope distribution of terrain inclination

* Umut Günes Sefercik, ugsefercik@hotmail.com

2.2 Data Sets

In these days, TSX is one of the most modern SAR satellites and its data will be evaluated in this study. The satellite has been launched on June 15th 2007 from oldest Russia's space launch facility, Baikonur Cosmodrome in Kazakhstan. It is built in German; the lifetime will be at least 5 years on the space. The mission is a joint project in a public private partnership (PPP) between the German Ministry of Education and Science (BMBF), the German Aerospace Center (DLR) and the Astrium GmbH. Under DLR contract Astrium constructed and built the satellite while DLR is responsible for the development of the ground segment, instrument calibration and scientific use of satellite at its lifetime (URL 1).

TSX is one of the most advanced SAR satellites using interferometry until this day and offers the highest quality spatial data that were not available from space before using high frequency X-band SAR sensor which can be operated in different imaging and polarization modes. Figure 2 and Table 1 present the system components of the satellite.

As it can be seen from Table 1, TSX uses 3 different operation modes as Stripmap, Spotlight, and ScanSAR. These modes provide high resolution images for detailed analysis as well as width swath data whenever a larger coverage is required and imaging can be possible in single, dual and quad-polarization. Besides, TSX data can be used for interferometry by this way the DSM generation is possible.

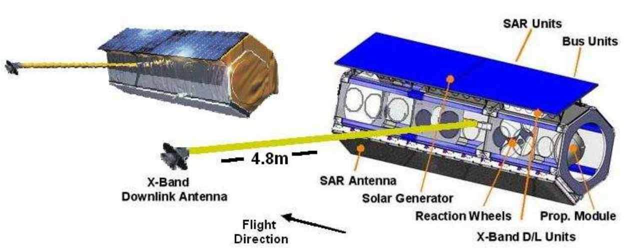

Figure 2. System components of TSX

Launch date, Life	15 June 2007, at least 5 years
Launch site	Baikonur, Kazakhstan (Russia)
Carrier	Dnepr-1
Satellite mass	1230 kilogram
Satellite size	5 m height x 2,4 m diameter
Orbit characteristics	514 km altitute, 11 days repetition, 97.44° inclination
Antenna	4.8 m active array, multi-pol, steerable in elevation and azimuth
Radar frequency	9.65 GHz
Power consumption	800 W in average
Data reception, Mission operation	DLR, Neustrelitz, Oberpfaffenhofen, Weilheim
Bandwidth	150 MHz (300 MHz experimental)
Memory	256 Gbit (end of life)
Downlink	300 Mbit/s
Imaging modes	Stripmap (3m), Spotlight (1-2m), and ScanSAR (16m)

Table 1. System components of TSX (URL 1)

TSX is capable to operate two types of Spotlight modes. The first type purely named as Spotlight mode the scenes of interest area can be obtained for an area of 10kmx10km (length and width) and recorded with 2m resolution. At the second type, the lengths of the scenes are shorter by 5kmx10km but offer higher resolution. This type is named as high resolution Spotlight mode and the scenes have 1m azimuth resolution. Between these two types of Spotlight mode just the geometric azimuth resolution is different in order to increase the azimuth scene coverage of Spotlight mode. During the observation of a particular ground scene the radar beam is steered like a spotlight so that the area of interest is illuminated longer and hence the synthetic aperture becomes larger. The Maximum azimuth steering angle range is ±0.75° (Roth, 2003).

At the investigation, for the generation of a DSM, two HRS mode TSX SAR images were used which have 1m resolution and five months time interval. Figure 2 shows these images and the following Table 2 presents the characteristics of them.

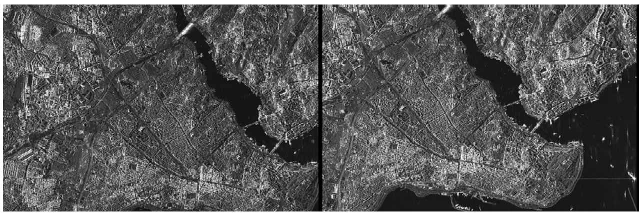

Figure 3. HRS TSX SAR images

Characteristics	HRS TSX Image 1	HRS TSX Image 2
Sensor Id	SAR	SAR
Sensor mode	High resolution Spotlight	High resolution Spotlight
Start date	2008-05-05T15:57:33,98	2008-10-06T15:57:42,52
End date	2008-05-05T15:57:34,73	2008-10-06T15:57:43,26
Polarization mode	Single polarization	Single polarization
Polarization channel	HH	HH
Looking direction	Right looking	Right looking
Pass direction	Ascending pass	Ascending pass
Centre incidence angle	40.9752891207	41.0898290780
Length and width of scene	5km×10km	5km×10km

Table 2. Characteristics of high resolution TSX SL images

For the generation of TSX DSM, interferometric processing steps of SARScape module of program ENVI Version 4.6 have been used. Interferometric processing steps of DSM generation are not as simple as DSM generation with optical imagery. The operator has to apply several complex steps and assign threshold application values depending up on quality and characteristics of the SAR images which are used for DSM generation (e.g. co-registration settings, best choice of azimuth and range looks etc.). At the interferometric processing, after the registration of images, baseline estimation, interferogram generation along with co-registered single look complex (SLC) generation, flattening, filtering and coherence generation, phase unwrapping, orbital refinement, phase to height conversion and geocoding steps have been performed step by step and DSM of TSX HRS mode SAR image-pairs has been obtained (Figure 4).

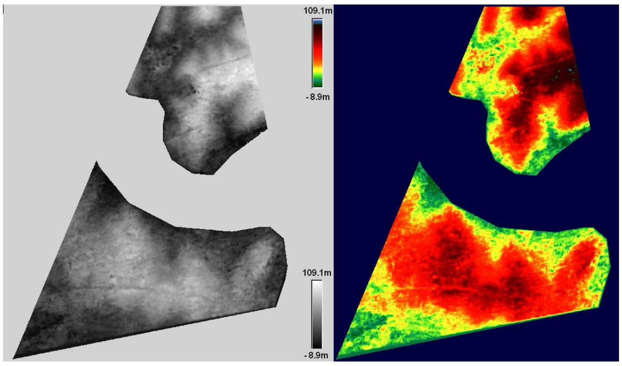

Figure 4. TSX SL DSM, grey and color coded presentation

The world's first commercial very high resolution optical satellite IKONOS (means image in Greek) was launched to space in 1999 by Geoeye, USA. It has panchromatic and multispectral sensors and is able to take images with a ground resolution of 0.82m (PAN) and 4m (MS) with 11.3km swath width from 681km orbital altitude. By the combination of both sensor products 1m pan-sharpened color images can be created. The more than 300 million square kilometers of imagery that IKONOS has been collected over every continent; they are used for national security, military mapping, air and marine transportation, by regional and local governments and others (URL 2).

In this study, in Istanbul test field, PAN IKONOS GEO stereo model with a ground sampling distance (GSD) of 1m was available. The height-to-base (h/b) ratio value was 1.6 (angle of convergence 35°) and the sun elevation angle is 65.5° (Alobeid et. al., 2009). Using this stereo model DSM have been generated in 3m grid spacing overlapping with test field and with the refinement processes (shifting, blunder filtering etc.) regulated for the evaluation analysis. Figure 5 shows the IKONOS stereo-images and figure 6 illustrates the generated DSM along with its color coded version after the refinement process.

Figure 5. High resolution IKONOS PAN images

Against optical images, SAR images have some speckle effects which can be reduced by filtering but this causes also a loss of information. On the other hand some special objects like railroads with the metallic rails can be seen clearer like in optical images. The information contents of SAR images can be improved by multi polarization like shown in Figure 7. By the combination of HH and VV polarization the image interpretation is improved (Jacobsen, 2008).

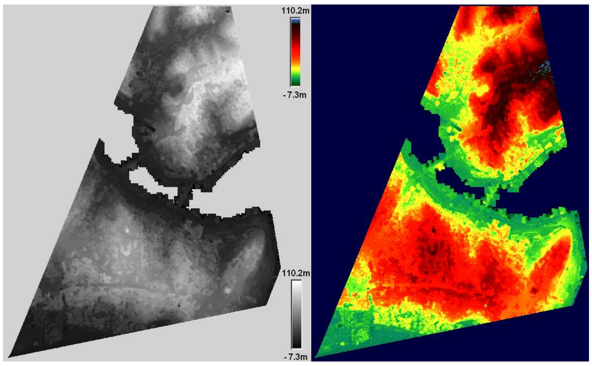

Figure 6. IKONOS DSM, grey value and color coded

Figure 7. Multi-polarization (HH/VV) TSX SL image from the city of Dresden

The reference DEM was derived from 1:1000 scale digital aerial photogrammetric maps, a project of Greater Istanbul Municipality and involves the large part of Historical Peninsula and near surroundings. This DEM was generated between 2007 and 2009. The original grid spacing of the DEM is 5m but it has been resampled into 1m according to the needs of the project. Figure 8 illustrates this reference DEM along with colored version to visualize the elevation levels easier.

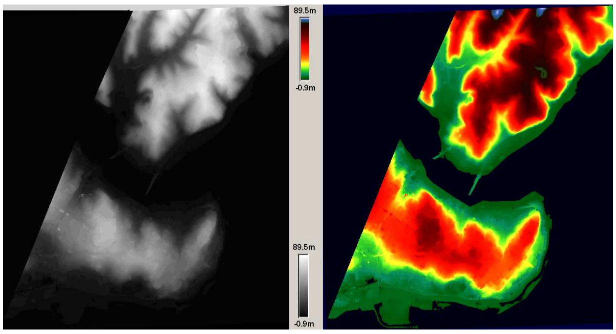

Figure 8. High resolution IKONOS PAN images

This DEM overlaps with the test field, approximately 5km×5km and covers more than 95% built-up areas that’s why accuracy analysis were not performed for open and forest areas separately. It has 10cm up to 1m accuracy and the elevations are in between sea level and 90m. This reference DEM is named as ‘REFDEM’ in the study.

3. DEM EVALUATION STRATEGY

In the project, initially, the common coordinate system was defined as UTM (universal transverse Mercator) for the whole of data sets and references. That's why before the evaluation processes, the transformation of the coordinate systems of all of data sets into UTM suitable zone have been performed using program BLTRA. This program is a member of system BLUH (Bundle Block Adjustment Leibniz University Hannover), developed by Dr. Karsten Jacobsen, Institute of Photogrammetry and Geoinformation (IPI), Leibniz University of Hannover, Germany.

After the transformation of all models into UTM suitable zone, for the evaluation analysis, a number of investigations have been performed using several modules of the software package BLUH. Table 3 shows these evaluation programs and their functions.

Program	Function
RASCOR	Filtering, analysis, correction and plot of a DEM
DEMSHIFT	Shifting of a DEM to another in X, Y, Z and scaling in Z
DEMANAL	Accuracy Analysis of DEM against a reference DEM
MANI	Manipulation of object coordinates, image orientations, IMU-data and pixel addresses, numbering the points
BLCON	Conversion of ground coordinates window function, reduction to equal distributed points, change of spacing
DEMINT	Computation of Z-value for points with given X and Y by interpolation of a raster-digital elevation model
ZANAL	Analysis of a DEM
ZPROF	Plot profiles
UNDUL	Calculation of Geoid Undulation
HPSHOW	Creation of aspects

Table 3. Evaluation programs and their functions

Besides, for the visualization, interpolation (by triangulation, moving surfaces etc.) and regular gridding of DSMs and DEMs, program LISA has been used. This program has been generated at the Institute of Photogrammetry and Geoinformation, Leibniz University of Hannover, Germany by Dr. Wilfred Linder. In program LISA, a height model and its height levels can be seen in a color scale accompanied minimum up to maximum heights at the same screen and different color palettes can be created and used for visualization. Using the optimum palette in every process, the details can be established clearly. All color coded versions of the height models have been created by this program.

4. RESULTS AND DISCUSSION

4.1 Shift of DSMs and Preparations

In order to perform the correct accuracy analysis, the DSM which will be evaluated must have the same location as the reference DEM. For this the determination of shifts to the reference height model has to be determined. Initially, using program DEMSHIFT shifts against the reference DEMs are determined. In this operation, maximum accepted ΔZ is selected as 50m and based on the handling the number of iterations are preferred as 11.

As the result of this first determination, the large shift values which cause large incorrect RMSZ values up to 14m have been seen and the radius of convergence for the shift adjustment was exceeded. Accordingly, for the elimination of large shifts the DEMs were pre-corrected by manual shift via point matching using program MANI. The points of corresponding location and their planimetric coordinates (X and Y) were selected from evaluated DSMs and reference DEMs. The coordinate differences were calculated and used for the rough shifts. Figures 9 shows the selected points at the corresponding locations for the pre-correction of the evaluated DSMs and reference DEMs in the test field.

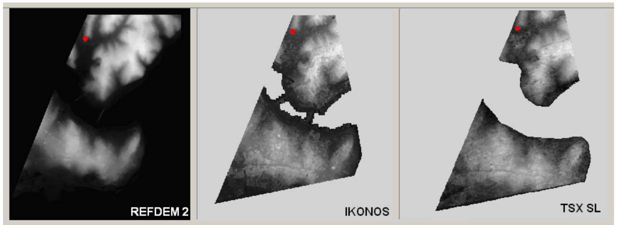

Figure 9. High resolution IKONOS PAN images

The Table 4 shows the RMSZ values before and after the pre-correction of the shifts, adjusted shift values by DEMSHIFT and the final RMSZ values.

DEM	Original RMSZ (m)	RMSZ After Manual Shift(m)	Shift by DEMSHIFT (m)		Final RMSZ (m)
			ΔX	ΔY	
IKONOS	13.67	7.44	-11.38	+8.03	7.32
TSX SL	13.78	8.44	-7.93	+21.4	8.25

Table 4. Adjusted shifts after pre-correction by MANI

4.2 Accuracy Analysis of DSMs

After shifting of DEMs, the accuracies of them have been analyzed in relation to the reference DEMs using program DEMANAL. For the analysis by DEMANAL, the maximal accepted DZ was limited as 50m and the maximal accepted tangent of terrain inclination was selected as 1.00. In the second iteration, shift and vertical scale were respected. These settings were made depending upon the characteristic of the test fields.

Following Tables and Figures show the results of accuracy analysis for IKONOS and TSX SL DSMs against REFDEM. Nearly full area of test field is built-up area and the forest coverage is so less that's why the accuracy analysis were performed just for the general area not separate for open and forest layers.

DSM	General	
	SZ [m]	NAP[%]
IKONOS (3m)	7.04+1.03×tan(α)	0.00
TSX SL (3m)	7.09+11.22×tan(α)	0.00

Table 5. Adjusted shifts after pre-correction by MANI

The frequency distribution of DZ values between evaluated models and reference models is shown in Figure 5.23. The components of this graphic are achieved from the list file of program DEMANAL after the analysis and generated by Microsoft Excel. The height differences and the corresponding number of points can be seen in this graphic presentation. The main point which should be analyzed in this graphic is the symmetric distribution. If the frequency distribution is symmetric, no influence of the buildings and vegetation exist. In this project, these graphic visualizations have been prepared between all evaluated models and reference models to form an opinion about the frequency distribution of DZ values. Figure 10 shows the frequency distribution of DZ values between IKONOS and TSX SL DSMs and REFDEM.

As mentioned before, at the accuracy analysis of heights, for the elimination of blunders, the maximal accepted DZ value is selected to 50m in program DEMANAL and the points which exceed this threshold value are automatically excluded by the program. If the image of this exception process is generated, the parts which are constituted by eliminated points can be seen clearly. By this way, these parts which have problems can be excluded when the models will be used for the precise applications. Using program DEMANAL, images have been created containing the excluded points. Figure 11 illustrates the image which contains the excluded points for IKONOS and TSX SL DSMs against REFDEM. The excluded points are represented by the dark spots.

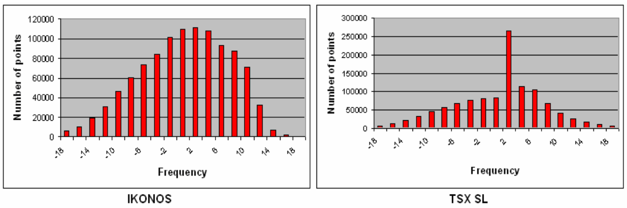

Figure 10. Height differences distribution of DZ between IKONOS and TSX SL DSMs and REFDEM

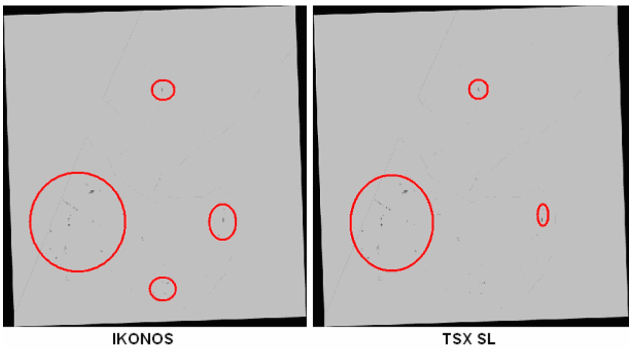

Figure 11. Excluded points of IKONOS and TSX SL

Besides these information's, RMSE of evaluated models against reference models as a function of the terrain inclination direction (aspects) can be visualized using program HPSHOW. Especially, in SAR imagery the accuracy shows dependency upon the aspects. As mentioned above aspects are the functions of the terrain inclination direction and present information about the mean value, the situation for zero inclination, factor for multiplication 'tan(slope)' and for average inclination. Considering aspects, the most effective contents on the accuracy results can be appeared easily. Figure 12 shows the aspects of the accuracy analysis between IKONOS and TSX SL models and REFDEM.

As expected, the IKONOS DSM shows no dependency upon the aspects but TSX SL DSM has a clear dependency up on the red arrow's direction and differences from mean value are obvious.

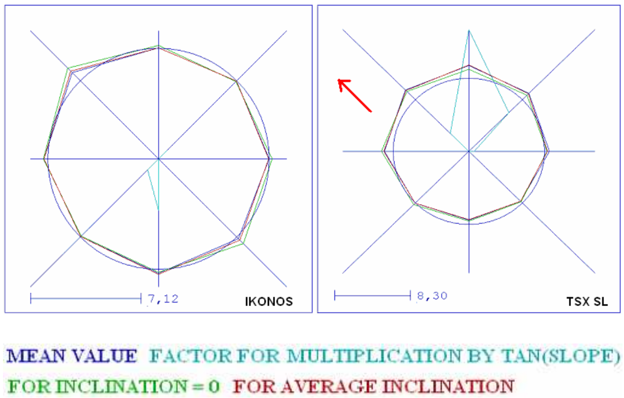

Figure 12. Excluded points of IKONOS and TSX SL

Besides the absolute accuracy assessments the relative accuracies (relative standard deviations) of evaluated DEMs have been identified in the study. As distinct from absolute accuracies, relative accuracies indicate the interior accuracy of a model that means a point in relation to the neighbored points.

$$\mathbf{RSX} = \sqrt{\Sigma(Dxi - Dxj)^2 \ / \ (2\bullet nx)}$$

RSX = relative standard deviation, d = distance between points
dl < d < du dl = lower distance limit du = upper distance limit of the distance

The relative accuracy is important especially for the morphologic details. The morphologic details for example, are not influenced by an error of phase unwrapping, leading to a local absolute error of the DSM, but not to a relative error of closely neighbored points. In this study, for the evaluation of relative accuracy, the accuracy from each point to the neighbored points was calculated for each evaluated DSM. For example, for a DSM has 3m grid spacing the relative accuracies were calculated between 3m and 30m at the 3m distance interval. The relative accuracies of the evaluated DSMs can be seen on the Table 6. Depending upon the reference model's grid spacing, the relative accuracies have been calculated from 1m to 10m.

Distance [m]	IKONOS	TSX SL
1	.98	.69
2	1.63	.98
3	2.14	1.31
4	2.57	1.57
5	2.92	1.82
6	3.23	2.04
7	3.48	2.21
8	3.70	2.37
9	3.89	2.52
10	4.05	2.65

Table 6. Relative accuracies of IKONOS and TSX SL DSMs

It can be seen in Table 6 TSX SL DSM has a better relative accuracy than IKONOS DSM. That means the interior integrity of TSX model is powerful, limitations may be caused by phase unwrapping.

4.3 Differential DEMs

Here differences between height models (DIFFDEMs) have been created for visualization. During the generation of three dimensional DIFFDEMs with program LISA, a view direction of 160º (0= North, 90= East) and an inclination angle of 35º was chosen for all DIFFDEMs. An exaggeration factor of 5 was used to provide an optimal visibility of the differences. Figure 13 shows the DIFFDEMs between IKONOS and TSX SL DSMs.

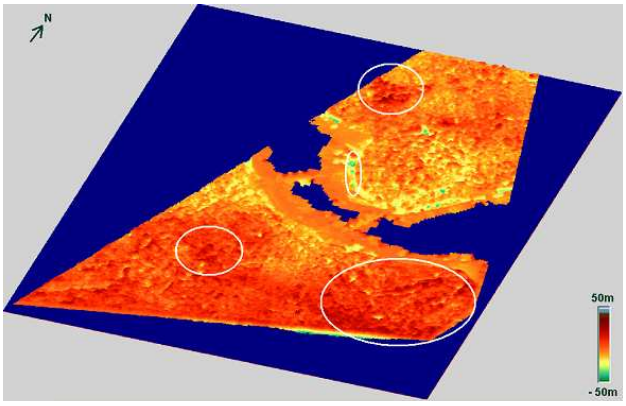

Figure 13. DIFFDEM between IKONOS and TSX SL

Height differences are obvious in patches especially in woody areas (black parts). Except woody regions TSX SL and IKONOS DSMs are coherent and the height differences are in between 0-5m

4.4 Shading

The shading is one of the best possibilities of visualizing a DSM. All buildings, vegetation and forest coverage in a DSM can be seen clearly. By this method, the shadings of IKONOS and TSX SL DSMs which have the same grid spacing (3m) have been generated and compared. Figure 14 and 15 illustrate the results of shadings.

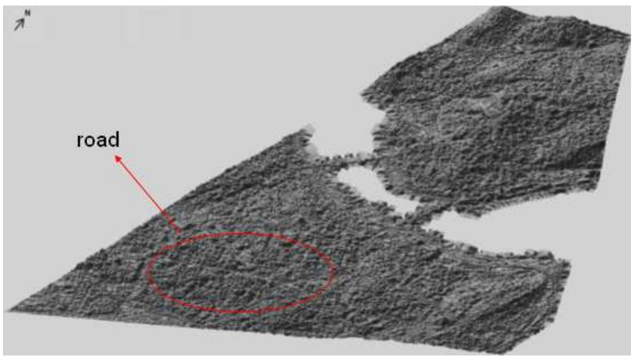

Figure 14. Shading (IKONOS)

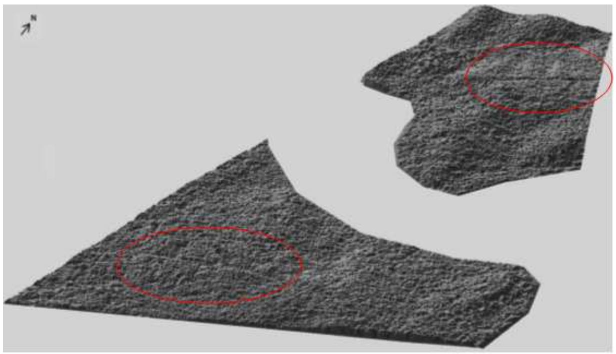

Figure 15. Shading (TSX SL)

Looking at the results, it can be mentioned that the visualizations of both DSMs are pretty good. They illustrate the ground objects like roads (in red circles), buildings, vegetation and forest.

5. CONCLUSION AND FUTURE TARGETS

In this study, DSMs which have 3m grid spacing have been generated from TSX SL and IKONOS Pan image-pairs. And these models have been compared in Istanbul test field, Turkey using a reference digital elevation model, derived from 1:1000 scale aerial photos and has 10cm up to 1m accuracy.

In the densely build up area of Istanbul DSMs are strongly influenced by buildings, partly also by trees and forest. The influence of the buildings and the vegetation can not be filtered totally because of missing satisfying number of points on the ground.

InSAR height models have a clear dependency upon the aspects. TSX SL DSM have a better relative accuracy as absolute accuracy, which may be explained by the influence of phase unwrapping, but also the case that DSMs are compared with reference elevation model containing the height of the bare ground.

It can be mentioned that TSX SL image-pair which has suitable baseline length (135m) presents an absolute accuracy competitive to the height model based on the very high resolution optical images. A dominating effect of the accuracy is still the vegetation and buildings.

Future investigations and development will be DSM fusion with optical DEMs based on space and/or aerial images and support high resolution optical images for generation of maps 1/5000 scale and below.

ACKNOWLEDGEMENTS

Thanks are going to TUBITAK, Turkey and DLR, Germany for their supports to this research. And to Dipl. -Ing. Abdalla Alobeid for supporting the generation of IKONOS DSM.

REFERENCES

Alobeid, A., Jacobsen, K., Heipke, C., 2009. *Building Height Estimation in Urban Areas from Very High Resolution Satellite Stereo Images*, ISPRS Hannover Workshop, 2-5 June, Hannover, Germany

Jacobsen, K., 2008. 3D-Remote Sensing, *Status Report 2008*, 28th EARSeL Symposium: Remote Sensing for a Changing Europe, 2-5 June, Istanbul, Turkey

Roth, A., 2003. *TerraSAR-X: A new perspective for scientific use of high resolution spaceborne SAR data*, 2nd GRSS/ISPRS Joint Workshop on "Data Fusion and Remote Sensing over Urban Areas, 22-23 May, Berlin, Germany

URL 1, 2008: http://www.dlr.de/, German Aerospace Center (DLR), November

URL 2, 2009: http://www.geoeye.com/CorpSite/, GeoEye, United States, 15th September