DEM GENERATION BY ASTER AND TK350

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KEY WORDS: DEM, space images, ASTER, TK350

ABSTRACT:

Digital elevation models (DEM) have been generated by means of ASTER- and TK350-images in the mountainous area of Zonguldak, Turkey. The automatic image matching of the ASTER-data did not cause any problems; even in the forest areas the near infrared images do show a good contrast. This is different for the TK350-photos. At first several scratches had to be removed by a scratch-filter, but also this was not sufficient. The visible influence of the film grain did not allow an image matching, it was successful only after low pass filtering, removing also some image details. In the forest areas the panchromatic TK350-images had no sufficient contrast, so also the lower percentage of matched points has not been useful.

In the open areas the DEMs determined by ASTER and by TK350 do show approximately the same accuracy in relation to the reference DEM from the survey administration. In both cases a clear linear dependency upon the terrain inclination can be seen. If the DEMs generated by means of space images are compared with a reference DEM, not the same accuracy like at well defined check points will be reached. Check points are located at areas of good contrast and here the automatic image matching is quite better like in other areas and an accuracy corresponding to the bundle orientation can be reached.

1. INTRODUCTION

Digital elevation models are a basic requirement for any mapping and GIS. Up to now in several areas no sufficient DEM is existing or accessible. An economic possibility is the generation based on space images. Not in any case the claimed and published accuracy of the DEM generation is realistic. Sometimes the DEMs have been checked only at well defined points not taking care about areas with not optimal contrast, not taking care about the influence of the vegetation and also the terrain inclination. An overview about the possibilities of the generation of DEMs is given in Jacobsen 2003. In the area of Zonguldak, Turkey, DEMs have been generated by means of TK350- and ASTER-images. The major elevations in the test area are in the range up to 500m above sea level with an average altitude of 299m and a maximal height of 847m. The size of the coastal zone is limited. The mountainous area has an average slope of 25%.

2. TK350

2.1 Image Orientation

With the Russian TK350-photos large parts of the world have been covered. They are available from Sojuzkarta and several distributors. The used TK350 stereo model is covering an area of 183 km x 165 km with a height to base relation of 2.0. It was taken in October 1986, but the elevations in the area have not changed so much. The photos available with a scale of 1 : 610 000 have been scanned with 16 µm pixel size corresponding to approximately 10m on the ground.

The photo size of 45cm x 30cm does not fit into usual photogrammetric scanners, by this reason it has been scanned with the drum scanner EskoScan 3648 of the survey administration in Lower Saxony, in Hannover. The TK350 includes reseau crosses with a spacing of 10mm; they have been used for a check of the scanner accuracy but also for a check of the inner accuracy of the TK350-photos by measuring 1073 reseau crosses in the photos with a Planicomp P1 and also in the digital images.

	rmse [µm]	local systematic part [µm]	random part [µm]
P1, image 324	8.2	5.1	6.4
P1, image 326	7.7	4.1	6.4
digital, im. 324	10.2	6.8	7.5
digital, im. 326	7.0	3.4	6.1

Table 1: root mean square discrepancies at TK350-reseau crosses (mean for x' and y')

The Planicomp P1 has been calibrated with a dense reseau platen, resulting in an accuracy of 1µm – this is negligible for the investigation. In the average of both images the error component of the scanning process has just a part of 4µm what is not important for the whole error budget. On the other hand the internal image accuracy is limited to approximately 8 microns.

control / check points	σo [µm]	rmse control points [m]			rmse check points [m]		
		X	Y	Z	X	Y	Z
128/0	13.5	10.9	10.0	17.0	-	-	-
12 / 116	12.4	12.1	14.1	13.2	12.4	13.3	19.8

Table 2: results of the TK350 bundle orientation

The control points for the image orientation have been digitised from a topographic map 1:50 000. The resulting accuracy of the bundle block adjustment with the Hannover program BLUH is typical for this map scale – the control point quality is dominating the result. Because of the high number of control points, the model orientation is quite better than the individual control or checkpoints.

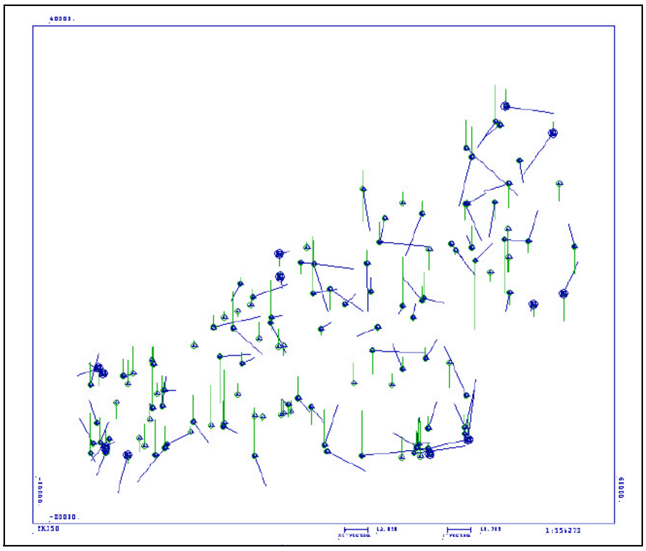
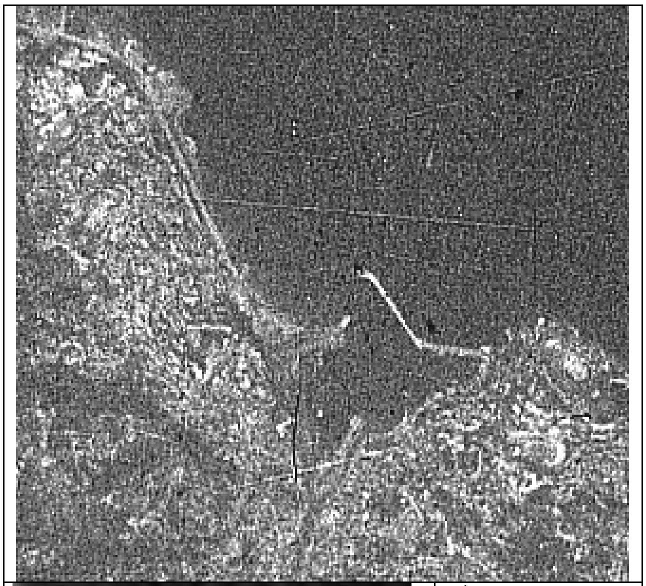


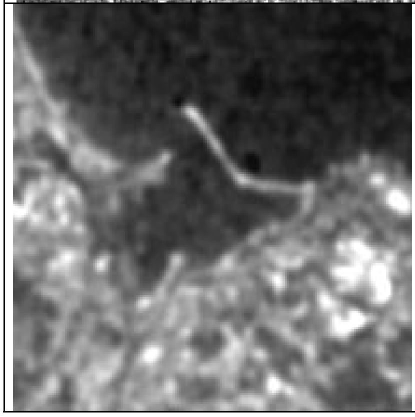
Figure 1: bundle orientation of the TK350-model, thick points = control points, green (vertical) vectors = DZ

2.2 DEM Generation with TK350

The photo quality of the TK350-images is limited. Several scratches can be seen (see figure 2). In addition the film corn is visible instead of the 16µm pixel size corresponding to a photographic resolution of 31 lp/mm. With the original digital data the automatic image matching failed, a scratch removal filter and a low pass filter were required. But also with the filtered images an automatic matching was difficult. Especially in the forest area the image contrast is limited. The final matching was done with the PCI-software. In the inclined forest areas a matching was partially not possible.

A check of the generated DEM at the positions of the control points was leading to mean square height differences of just +/-6.6m against the adjusted ground coordinates, but this is not a realistic accuracy for the DEM itself. At the control points the contrast is optimal, the terrain inclination is usually limited and there is no influence of buildings and vegetation.





↑ **Figure 2:** original TK350 image

← **Figure 3:** TK350 image after scratch removal and low pass filtering

The generated DEM has been analysed by comparing it with a DEM of the Turkish mapping organisation based on digitised contour lines of the topographic maps 1:25000. This reference DEM has been checked with 36 points determined by GPS ground survey. As a function of the terrain inclination it can be expressed as SZ = 4.7m + 22m * tan α with α as terrain inclination.

For a separation of the influence of the forest to the DEM-generation, the results of an object classification with a Landsat-scene has been used for the analysis. The forest layer can be respected in the Hannover analysis program DEMANAL. It compares the DEM with the reference DEM. The analysis can be separated for areas belonging to a special object class based on a classification layer. The frequency distribution of the discrepancies leads to information about special problems which can be caused by the height of the vegetation. The reference DEM corresponds to the surface while the matched DEM corresponds to the visible surface of the vegetation and to the roofs of buildings. Obvious mismatching can be excluded by a chosen tolerance limit.

Figure 4: Zonguldak test area: black = Black Sea, dark grey = open areas, bright grey = forest, white spots = not accepted points of the TK350-DEM exceeding DZ=150m

Even after filtering, the automatic image matching showed gaps especially in the forest area, but also the accepted points in larger parts of the forest showed discrepancies against the reference DEM exceeding the used tolerance limit of 150m (see figure 4).

area	RMSZ [m]	shift [m]	RMSZ without shift
open area	23.1	2.2	27.0
forest	51.3	7.3	50.7

Table 3: root mean square discrepancies of the TK350-DEM against the reference DEM

The problems of the automatic image matching with the TK350-images in the forest areas are also obvious at the results, even if the points exceeding a height difference of 150m are excluded; the root mean square differences in the forest areas are reaching approximately twice the values like in the open areas. The bias of 7.3m, which can be explained by the matching on top of the trees, has only a limited influence to the result. The analysis shows very clear a linear influence of the terrain inclination to the achieved accuracy.

open areas	SZ = 20.0m + 23.9 * tan α
inside forest	SZ = 49.0m + 11.4 * tan α

Table 4: standard deviation of the TK350-heights depending upon terrain inclination

The accuracy of the generated DEM in the flat parts of the open areas corresponds to a standard deviation of 16µm for the x-parallax. This is not a very good result, but under the condition of the high number of scratches and the influence of the film grain it can be accepted. In the forest area the contrast of the TK350-images is too poor, so the DEM based on the TK350-images is not useful for the forest area.

3. ASTER

3.1 Image Orientation

ASTER (Advanced Spaceborne Thermal Emission and Reflection Radiometer) is a Japanese sensor mounted on NASAs TERRA-platform. It has fourteen spectral bands – the visual and near infrared with green, red, near infrared with a pixel size of 15m, 6 bands in the Short Wave Infra-Red range with 30m and 5 bands in Thermal Infra-Red with 90m. The VNIR subsystem consists of two independent telescopes, a backward and a nadir looking one. The focal plane of the nadir telescope contains three CCD linear arrays (bands 1,2,3N) while the focal plane of the backward telescope has only one (3B). The two near-infrared spectral bands (0.76-0.86µm wavelength), 3N and 3B, generate an along-track stereo-pair from the 705km orbit altitude with an intersection angle of 30°. In this configuration it takes 9 seconds to acquire a single scene and approximately 64 seconds for a stereo-pair.

ASTER has typical satellite line scanner geometry with perspective relation only in the sensor line. In the direction of the orbit it is close to a parallel projection. So the photo coordinates as input for the collinearity equation are simplified to **x’** = (x’, 0, -f) - the image coordinate y’ is identical to 0.0. The pixel positions in the orbit-direction are a function of the satellite position, or reverse, the exterior orientation of the sensor can be determined depending upon the image position in the orbit-direction. The used Hannover program BLASPO is fitting the exterior orientation to an orbital ellipse fixed in the sidereal system - the earth rotation will be respected. This has been shown as sufficient for all satellite line scanner images also over larger orbital parts. It is not necessary to use the satellite ephemeris, just with the standard orbit information and the view direction a bundle orientation is possible without loss of accuracy against the use of the actual ephemeris. Remaining systematic effects can be compensated with additional parameters.

As typical for the use of control points defined in maps, 4 of 22 control points had to be eliminated. The control points digitised from maps 1 : 25 000 are not free of error. This is explaining the results listed in table 5. Four control points are sufficient, but of course the individual control points are influencing the results at the independent check points, so the mean square discrepancies at the check points are becoming larger with a reduced number of control points. By a combination of 3 statistic tests, the used number of additional parameters is reduced automatically to the required set of individual additional parameters

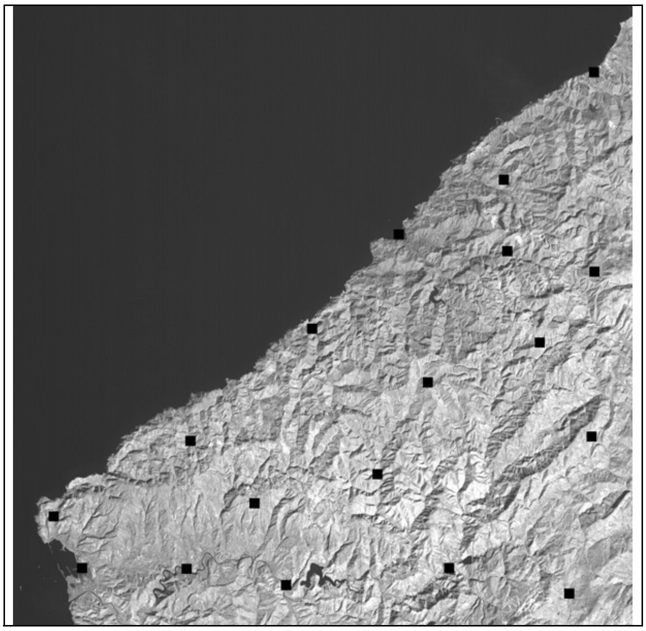


Figure 5: ASTER scene of the Zonguldak area with used control points

control points	σ_0 [µm]	RMSE X	RMSE Y	RMSE Z
18	7.2	13.7	11.7	12.6
9	6.3	10.1	9.8	10.6
7	5.6	5.3	10.6	10.6
5	5.5	5.4	11.1	10.6
4	4.7	3.1	3.8	9.2

Table 5: bundle orientation of the ASTER stereo model Zonguldak - σ_0 and root mean square discrepancies at control points

control points	check points	RMSE X	RMSE Y	RMSE Z
18	-	-	-	-
9	9	11.5	15.4	15.5
7	11	15.8	15.7	16.7
5	13	15.2	15.3	18.6
4	14	15.4	16.4	19.0

Table 5: bundle orientation of the ASTER stereo model Zonguldak - root mean square discrepancies at independent check points

The results of the bundle orientation are satisfying. The sigma0 in the range of 6 µm corresponding to 0.5 pixels is dominated by the identification of the control points. The discrepancies at the control and independent check points are dominated by the control point accuracy itself. But even with only 4 control points, the vertical accuracy of the check points of 19m corresponds to just a standard deviation of the x-parallax of 0.7µm.

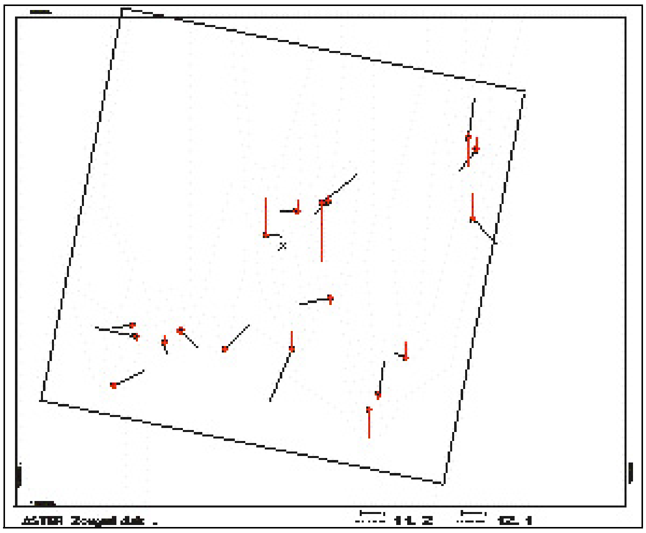


Figure 6: discrepancies of the ASTER-bundle orientation with 18 control points, vertical vectors (red) =DZ

3.2 DEM Generation with ASTER

The automatic image matching of the ASTER-stereo model has been done with the Hannover program DPCOR. DPCOR is using a least squares matching which is leading to the most accurate results. It is based on a region growing method, starting usually at the manually measured control points. This includes the advantage of a matching in the image space which is independent upon the image geometry. So DPCOR can be used for any imaging geometry without modification of the program.

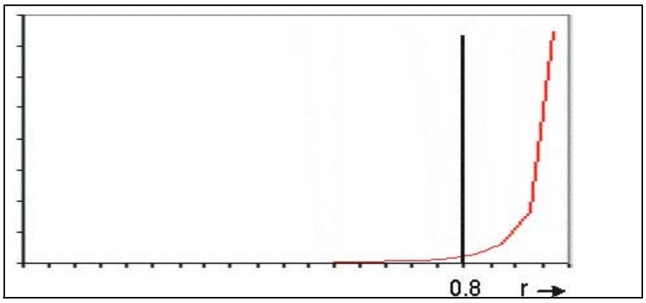


Figure 7: frequency distribution of the correlation coefficients of the ASTER image matching

The automatic image matching of the ASTER data was without any problems. 97.2% of the points not located in the water do have a correlation coefficient exceeding 0.8, 72% even are exceeding 0.95 (see figure 7). The distribution of the matched points can be seen in figure 8. The not accepted points are located in the Black Sea, lakes, at some small clouds and partially in very steep areas. The quite opposite results in relation to the TK350-images is mainly caused by the spectral range – in the near infrared also in the forest areas there is a good contrast available. In addition, the digital images are not affected by scratches and film grain.

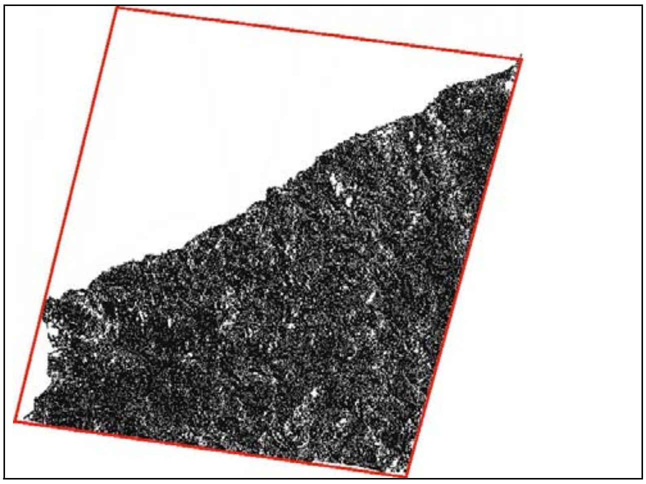


Figure 8: matched points of the ASTER model Zonguldak, upper left = Black Sea

An accuracy check of the DEM was at first carried out against the control points used for the sensor orientation. Against all control points a mean square difference of 12.7m has been reached, which is a realistic result for the stereo-images with a pixel size of 15m and a height to base relation of 1.7 – it corresponds to a parallax accuracy of 0.5 pixels. In a second test, GPS check points distributed over the main city center area with an accuracy of about ±10cm were used – this resulted in SZ=13.9m. As next, points were digitised from 1:2000 scale road maps produced by the Highway Department of Turkey. This resulted in an rmse value for Z of 14.0m; however these values are influenced by steep slopes, just besides the roads in the mountainous region.

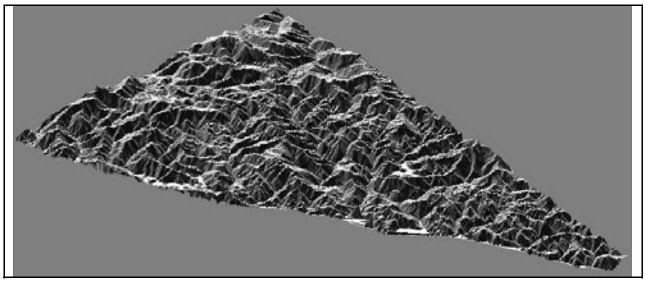


Figure 9: DEM of the Zonguldak area viewed from sea side

The ASTER-DEM was also checked against the same DEM based on the Turkish maps 1 : 25 000 like the TK350-data.The analysis of the DEM was also made with program DEMANAL separately for the open areas and the forest.

The distribution of the discrepancies of the ASTER-DEM to the reference DEM for the open areas is very close to a normal distribution (figure 10). In the forest area there is a bias of –4.5m caused by matching on top of the trees. Also the frequency distribution (figure 11) does show the maximum at this location and a not symmetric distribution with more negative values. The discrepancies are handled with the sign of the correction, so negative values do present discrepancies on top of the trees.

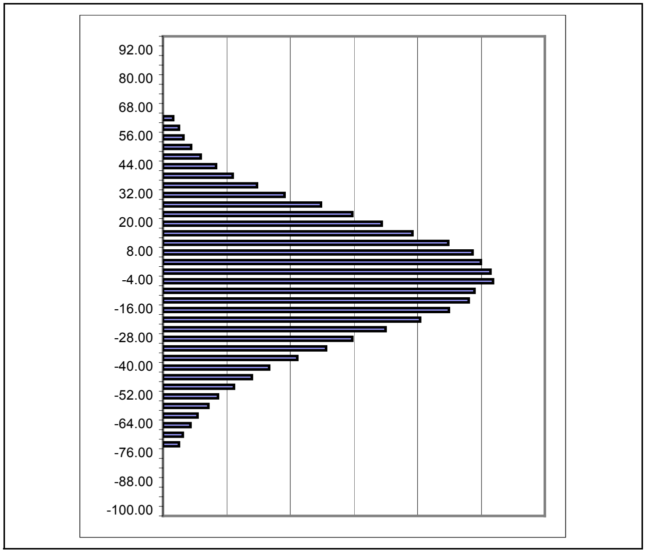


Figure 10: ASTER-DEM: frequency distribution of the Z-discrepancies in the open areas

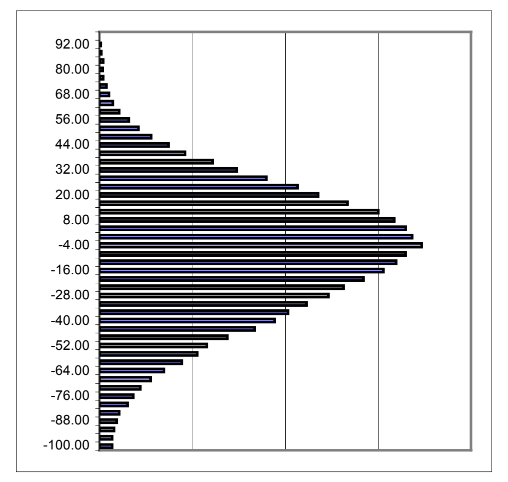


Figure 11: ASTER-DEM: frequency distribution of the Z-discrepancies in the forest areas

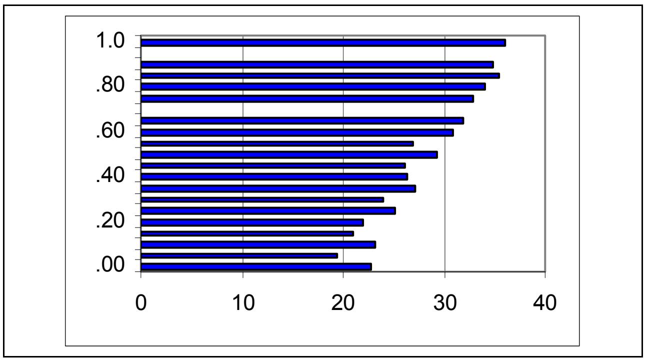


Figure 12: standard deviation of Z as a function of terrain inclination – vertical: tangent of slope, horizontal: standard deviation of Z

The analysis of the ASTER-DEM also shows a very clear dependency upon the slope (see figure 12), requiring an expression as a function of the slope. The lower accuracy in the forest area is within the expectation – if the ground cannot be seen, also the image matching with the following filtering of the points not belonging to the bare surface cannot reach the same accuracy like in open areas. For a flat terrain, the vertical accuracy for the open areas corresponds to a standard deviation of the x-parallax of 0.8 pixels and in the forest area to 1.1 pixels. This is a satisfying result for the not in any case optimal area. Of course for the whole DEM not the same accuracy like at control points, roads and in the city, like mentioned before, can be reached because such points do show a very good contrast which is not always available in the whole area. In addition the well defined check points are not influenced by vegetation and buildings.

	area	RMSZ [m]	shift [m]	RMSZ without shift
ASTER DEM	open area	25.0	0.6	25.0
	forest	31.2	-4.5	30.9

Table 6: root mean square discrepancies of the ASTER-DEM against the reference DEM

open areas	SZ = 21.7m + 14.5 * tan α
forest	SZ = 27.9m + 18.5 * tan α

Table 7: standard deviation of height depending upon terrain inclination

CONCLUSION

The orientation of the TK350- and the ASTER-model did not cause any problem. The orientation was possible with a small number of control points without loss of accuracy. Of course, if control points are digitised from topographic maps, a larger number should be used for the identification of blunders which cannot be avoided and for reaching a higher orientation accuracy based on the average of several control points.

The TK350-photos do have the advantage of covering a large area with just one model, but the automatic image matching was strongly influenced by scratches and the film grain. In addition the image contrast of the panchromatic film in the forest area was very poor causing large problems of the matching. The generated DEM is not useful in the forest area.

The good contrast of the near infrared band also in the forest area, which is used by ASTER for the stereo model, is leading to satisfying results in the whole area. At positions with good contrast, an accuracy of 13m up to 14m could be reached corresponding to an accuracy of the x-parallax of 0.5 pixels. Over the whole area for the flat parts this is reduced to 0.8 pixels in the open areas and to 1.1 pixels in the forest areas caused by the sometimes not optimal image contrast and the influence of the vegetation. The dependency upon the terrain inclination is in the range of the horizontal orientation accuracy.

In general there was no problem with the generation of the DEM based on the ASTER-images. The image quality of the TK350-photos was limited, but nevertheless the results in the open areas can be accepted, this is not the case in the forest areas.

ACKNOWLEDGEMENT

This research project was supported by TUBITAK, Turkey and the Jülich Research Centre, Germany.

REFERENCE

Jacobsen, K. (2003): DEM Generation from Satellite Data, EARSeL conference Ghent 2003