Geometric Accuracy Evaluation, DEM Generation and Validation for SPOT-5 Level 1B Stereo Scene

Buyuksalih, G.*, Oruc, M.*, Topan, H.*, .*, Jacobsen, K.**
** Karaelmas University Zonguldak, Turkey*
***University of Hannover, Germany*

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ABSTRACT: Against the preceding SPOT satellites SPOT 5 is generating images with a physical pixel size of 5m on the ground. This has improved the geometric and semantic possibilities by the factor 2. A SPOT stereo scene over the test area of Zonguldak, Turkey, has been used with automatic image matching for the creation of a digital elevation model (DEM). Of course at first a digital surface model (DSM) with the height of the visible surface will be computed which can be filtered to a DEM containing only the points on the bare ground. With the SPOT images more accurate height values have been reached like with other space information which is available for the same test area.
The SPOT level 1B is a rectification of the original image to a plane with constant height. In most cases for a 3D-solution, original images - the level 1A product - have been used. The mathematical model for the handling of the level 1B is quite different like for the handling of the level 1A scenes. A solution corresponding to the handling of the IKONOS Geo scenes has been used which is reconstructing the view direction for every pixel after perspective transformation to the reference. By this method with the level 1B-stereo model no loss of accuracy against the level 1A-scenes occurred. At well defined ground points by automatic image matching with a height to base relation of 1.9 a vertical accuracy of 3.2m corresponding to an x-parallax of 0.33 pixels has been reached with the level 1B-scenes.

1 INTRODUCTION

Digital Elevation Models (DEM) are fundamental contents of any modern GeoInformation System. For the largest part of the world DEMs generated by the Shuttle Radar Topography Mission (SRTM) with a spacing of 3” (approximately 90m) are available free of charge. Especially in mountainous areas for several applications not enough details are included in the SRTM DEMs. On the other hand DEMs also can be generated with the very high resolution space images like QuickBird and IKONOS, but these images do cover only 16km ∗ 16km or 11km ∗ 11km and are very expensive. In addition only few stereo pairs are available in the archive and for very high resolution images it is important to have both images of a stereo model from the same orbit. SPOT 5 is covering an area of 60km ∗ 60km with the moderate resolution of 5m. The HRG instruments are looking like usual for SPOT to the side of the orbit, so it is important to have the second image of the stereo pair with a shorter time interval to avoid larger radiometric differences between the images of a model. SPOT 5 also includes the HRS imager with a view 20° fore and 20° after, enabling a stereo model from one orbit, but these images are usually not distributed. The use of the SPOT 5 HRG-images is for some applications an optimal solution.
In the test area Zonguldak, Turkey, the same SPOT stereo pair has been available as level 1A and as level 1B product, enabling a direct comparison of the image orientation. There was only one day between imaging the left and the right image – this is the best condition for SPOT images, so no mayor radiometric differences can be seen.

2 IMAGE ORIENTATION

SPOT is generating satellite line scanner images with perspective geometry only in the across orbit direction. In the orbit direction every CCD-line has a different exterior orientation, but the orientations of the neighboured lines are strongly correlated. With the exception of high frequent jitter, which will be corrected by SPOT Image in advance, during imaging the traditional SPOT images do have the same angular relation to the orbit.

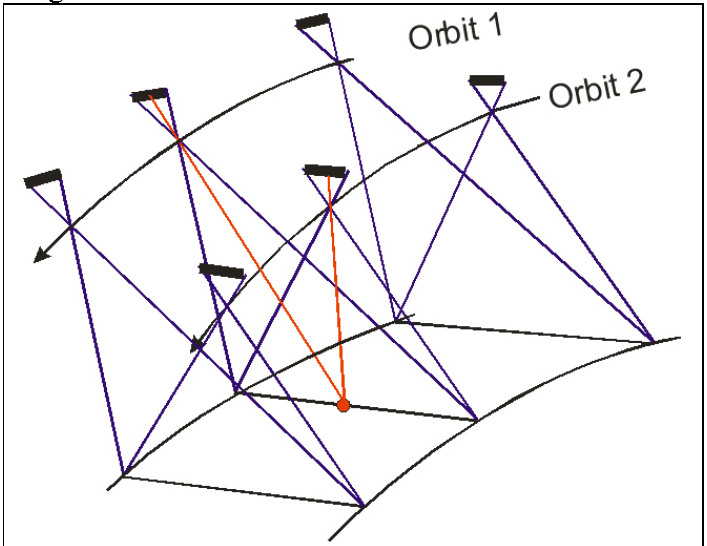

Figure 1: geometry of CCD-line images

The standard CCD-line imaging is influenced by the earth rotation causing a not perpendicular shape of the scenes. SPOT 5 is compensating this by the yaw control – a permanent change of the view direction across the orbit for the compensation of the effect of the earth rotation to the shape of the scene (figure 2).

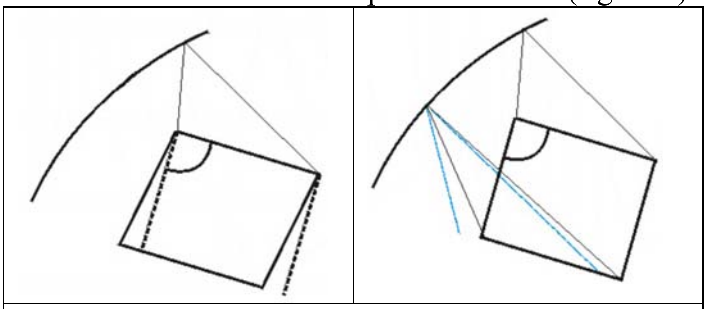

Figure 2: yaw control of SPOT 5
left: scene size influenced by earth rotation
right: SPOT 5 scene size with yaw control

The SPOT images are delivered with the scene orientation information based on the direct sensor orientation. This has to be improved with control points. The described image geometry is delivered only improved by the internal calibration as level 1A product. The orientation of the level 1A SPOT images has been made with the Hannover program BLASPO, a general program for the orientation of satellite line scanner images. BLASPO is using only the information about the view direction and the general orbit information (inclination and ellipse parameters). Based on 3 control points the orientation parameters can be adjusted. For the determination of the yaw control one more control point is required. SPOT images are also available as level 1B product, a rectification of the image to a plane with constant height. This is a quite different geometry which has to be handled with a different program. Of course it is possible to reconstruct the level 1A-geometry from a level 1B-image and to handle it also with a program like BLASPO, but this is not necessary.

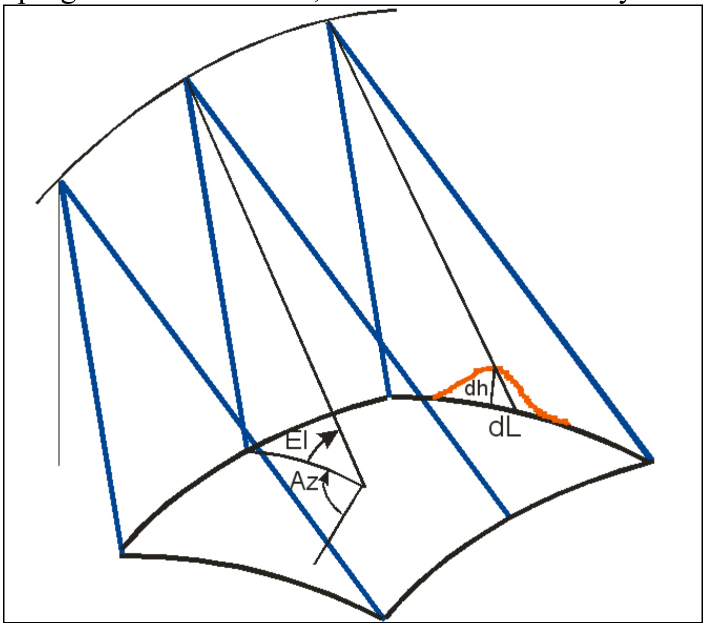

Figure 3: Geometry of level 1B images

The level 1B images have been oriented with the Hannover program CORIKON, a program for handling rectified images. Rectified images are not orthoimages, height differences dh are causing horizontal displacements dL like shown in figure 3. For the handling of single images the height must be available. For the correct determination of the horizontal location, the view direction has to be reconstructed for every scene point. This is possible with the information about the azimuth and elevation of the scene centre together with the general orbit information. Control points are required for the exact location of the scene.

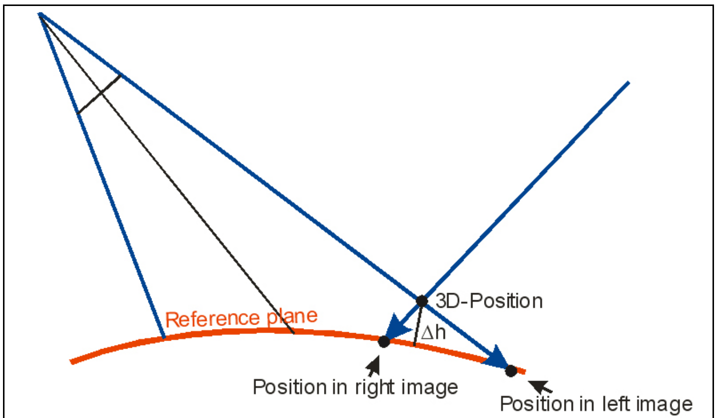

Figure 4: 3D-location based on level 1B images

The three dimensional determination of points based on level 1B images can be made directly like shown in figure 4. Based on the position in the left and the right image together with the view direction from CORIKON, the 3D-location can be computed. The over-determination is causing a y-parallax indicating the accuracy of the ground point.

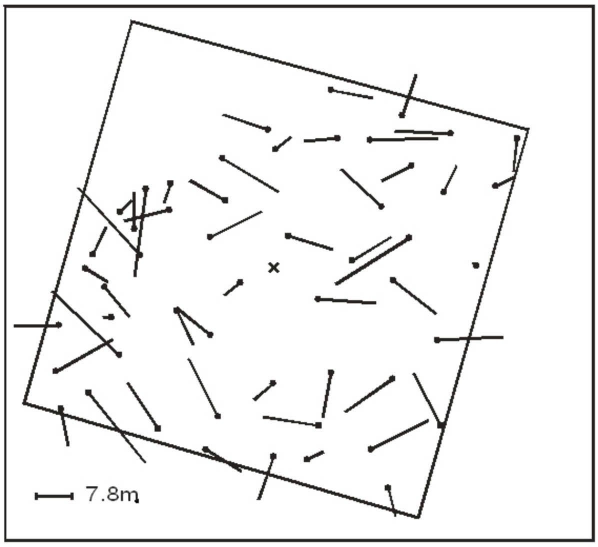

Figure 5: SPOT 5, level 1A, orientation

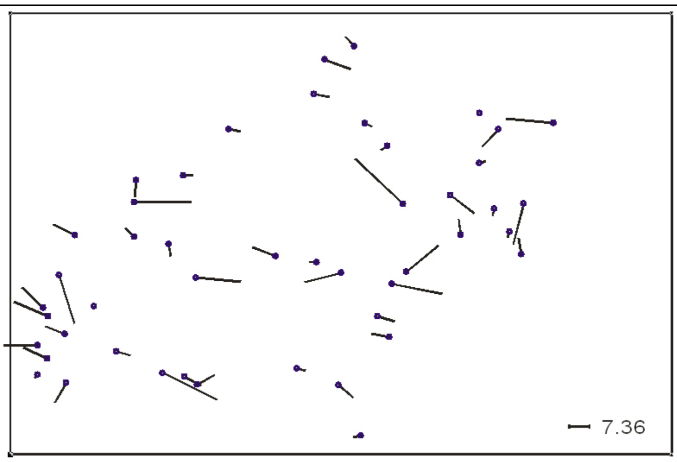

Figure 6: SPOT 5, level 1B, orientation

The orientation of the SPOT scenes in the test area has been based on 44 / 47 control points digitized from topographic maps 1 : 25 000 – see figure 5 and 6 with the point distribution and the residuals at the control points. Of course the image measurements had to be done separately for the level 1A and level 1B scenes, so not exactly the same results can be reached. But the results are very similar for both image products with root mean square discrepancies at the control points for level 1A with +/-7.80m and for level 1B with +/-7.36m. Of course this is not an optimal result – but it corresponds to the accuracy of the topographic map. With a standard deviation of 1.5 pixels the orientation can be used for operational purposes. The high number of 44 and 47 control points guarantees a better orientation quality.

3 DIGITAL ELEVATION MODELS

The SPOT HRG images have been taken with incidence angles of 13.52° and -16.65° corresponding to a height to base relation of 1.85. This is close to the optimal height to base relation.

$$SZ = \frac{height}{base} \bullet pixel\_size\_on\_ground \bullet factor$$

Formula 1: standard deviation of height

Corresponding to formula 1, better height accuracy can be reached with a height to base relation of 1.0, but formula 1 respects only the geometric relation. A DEM will be generated by automatic matching. The quality of the image matching in the dimension of pixels is identical to the factor in formula 1. The quality of matching is better if the images in the sub-matrix used for matching are not too different, but in rough terrain and in build up areas the local height variations are causing discrepancies, reducing the matching quality. The matching in the image space is more accurate for larger height to base relations, so the final optimum between the geometric and the matching aspect for the very rough area around Zonguldak may be not far away from the available height to base relation of 1.85 (see also Börner et al 1997).

The both images of the stereo model have been taken at August 13th and 14th, 2003. Just one day of time interval is optimal. Only below 1% of the area is covered by clouds and cloud shadows and the atmospheric conditions are the same.

Figure 6: histogram of SPOT 5 image Zonguldak
left: whole image right: forest

The panchromatic SPOT images do have some problems with the grey value variation in forest areas. Figure 6 shows on the left hand side the histogram of the SPOT scene from August 14th with a mean value of 119 and a standard deviation of +/-24.3 grey values. In a typical forest area the standard deviation of the grey values is just +/-6.3. The second scene is very similar. In some homogenous forest areas, especially in shadow parts, the grey value variation even was smaller leading to problems with the image matching. As tolerance level for the image matching a correlation threshold of 0.6 has been used.

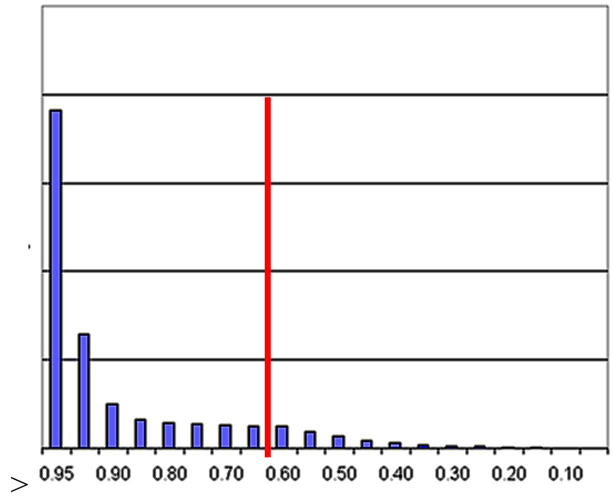

Figure 7: distribution of correlation coefficients of image matching by least squares

Figure 7 shows the frequency distribution of the correlation coefficients in a typical sub-area with approximately 50% forest. In this sub-area 11% of the points have not been accepted because of correlation coefficients below 0.6. In this case the automatic image matching has been made with the Hannover program DPCOR for least squares matching.

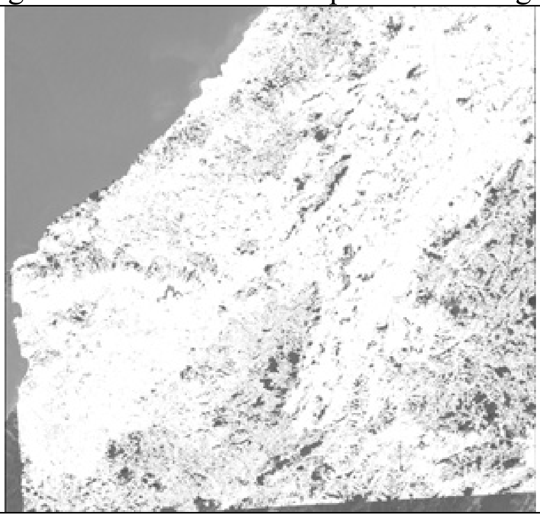
Figure 8: matched points of SPOT 5-model Zonguldak Matched points = white Upper left: Black Sea

The accepted points are shown in figure 8 in white. The not accepted points are located in the sea and in forest areas. Figure 9 shows the details of the distribution of the correlation coefficients depending upon the location. In the open areas the correlation coefficient is quite higher like in the forests. The darker areas – identical to lower correlation coefficients – do fit very well with the forest areas. Corresponding to this also a lower accuracy of the generated DSM in the forest areas can be expected.

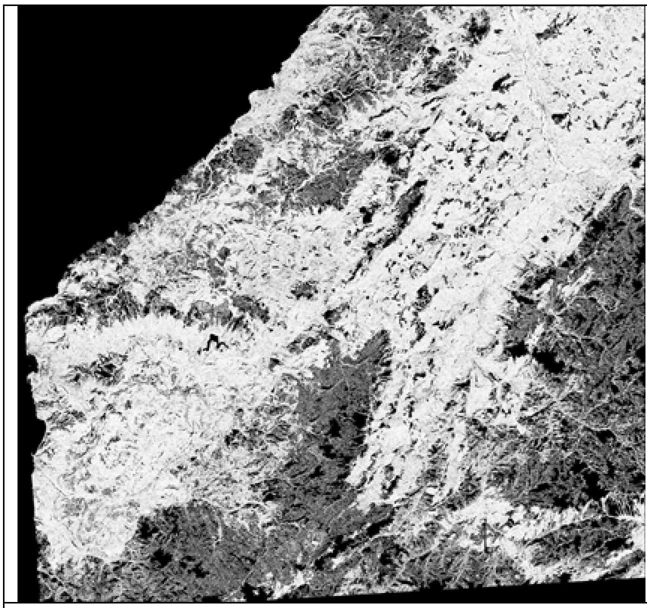
Figure 9: quality map of image matching
grey value 51 = correlation coefficient 0.6
grey value 255 = correlation coefficient 1.0

The generated height models have been checked against a reference DEM generated from topographic maps 1 : 25 000. It is estimated with an accuracy of 6m and has a spacing of 40m. The reference DEM is available in the Turkish national coordinate system, the control points in UTM, WGS84, so also the generated DEMs are in UTM, WGS84. The transformation from the Turkish national coordinate system to UTM is a standard procedure, but the datum of the Turkish coordinate system was not known. By this reason the reference DEM has been shifted by adjustment with the program DEMSHIFT to the SPOT DEMs. The shift of the DEM was absolutely necessary; it reduced the root mean square differences in Z by the factor 2.0.

SPOT 5 level 1A	DZ > 50m	RMSZ [m]	Bias [m]	RMSZ – bias F(slope)
All points	0.82%	13.5	7.1	9.3 + 5.7*tan α
Open areas	0.87%	11.9	5.4	8.4 + 6.3*tan α
Forest	0.76%	15.0	9.2	9.8 + 5.3*tan α

Table 1: RMSZ of level 1A model against reference DEM from the map 1 : 25 000

SPOT 5 level 1B	DZ > 50m	RMSZ [m]	Bias [m]	RMSZ – bias F(slope)
All points	0.84%	13.2	7.2	9.5 + 3.9*tan α
Open areas	0.89%	11.6	5.4	8.6 + 4.3*tan α
Forest	0.79%	14.9	9.4	10.0 +3.3*tan α

Table 2: RMSZ of level 1B model against reference DEM from the map 1 : 25 000

The results achieved with level 1A and level 1B data are nearly the same. So it does not matter which SPOT product will be used for DEM generation and mapping. The results shown in table 1 and 2 are presenting the determined height values. The gaps shown in figure 8 are not respected. A final DEM must be complete, so the missing part has to be interpolated. The test area Zonguldak is very rough with an average inclination of 23% and an average change of the inclination from one 40m grid spacing to the next by 32%. This includes the information about problems of the interpolation which has been checked by the reference DEM over the double distance of 80m. Such an interpolation over 80m has caused root mean Z-discrepancies of 12.0m.
The generated height model is describing the visible surface, a Digital Surface Model (DSM) and not the bare ground required for a DEM. If the noise of the DEM generation is below the height of buildings and trees and if there is a sufficient number of points on the bare ground, the DSM can be filtered to a DEM. This has been done by program RASCOR (Jacobsen 2001). RASCOR has removed 27% of the points as not belonging to the bare ground. So after filtering and DEM-interpolation a final DEM was generated. Because of the negligible differences between the results based on level 1A and level 1B, in the following only the results achieved with the level 1B-product is shown.

SPOT 5 level 1A	DZ > 50m	RMSZ [m]	Bias [m]	RMSZ F(slope)
All points	1.82%	13.9	-0.1	11.2 + 9.2*tan α
Open areas	1.92%	13.7	0.0	10.9 + 8.9*tan α
Forest	1.26%	15.7	-0.6	12.7+10.3*tan α
check points	0	3.8	0.1	3.5 + 0.9*tan α

Table 3: RMSZ of filtered and interpolated level 1B DEM against reference DEM from the map 1 : 25 000 and against check points

The results shown in table 3 are the final results of the achieved DEM. This DEM has no gaps and the elements not belonging to the bare ground have been removed like possible. There are still larger values in the forest caused by points still located on top of the vegetation and in the interpolated gaps. The final results are slightly below the direct generated points. This is caused by the interpolation of the gaps in the rough terrain. The DEM accuracy in open and flat terrain of 10.9m corresponds to a standard deviation of the x-parallax of 1.2 pixels. This is a satisfying result in this rough terrain.

The results achieved at check points determined by GPS are quite below the DEM accuracy. Check points are located at positions with good contrast and are free of disturbing elements around, so the accuracy is always quite better like for the DEM it self which includes also areas with poor contrast. The check points do show more the accuracy of the model orientation. With +/- 3.8m it corresponds to a standard deviation of the x-parallax of 0.4 pixels – this is a satisfying result.
The frequency distribution of the discrepancies between the SPOT DEM and the reference DEM (figure 10) for the open area is nearly a symmetric normal distribution; there is only a very small tendency to the negative values (SPOT DEM is above the reference DEM) which can be explained by some features not belonging to the bare ground, but remaining in the DEM also after filtering. In the forest area the frequency distribution is less symmetric caused by points not belonging to the bare ground.

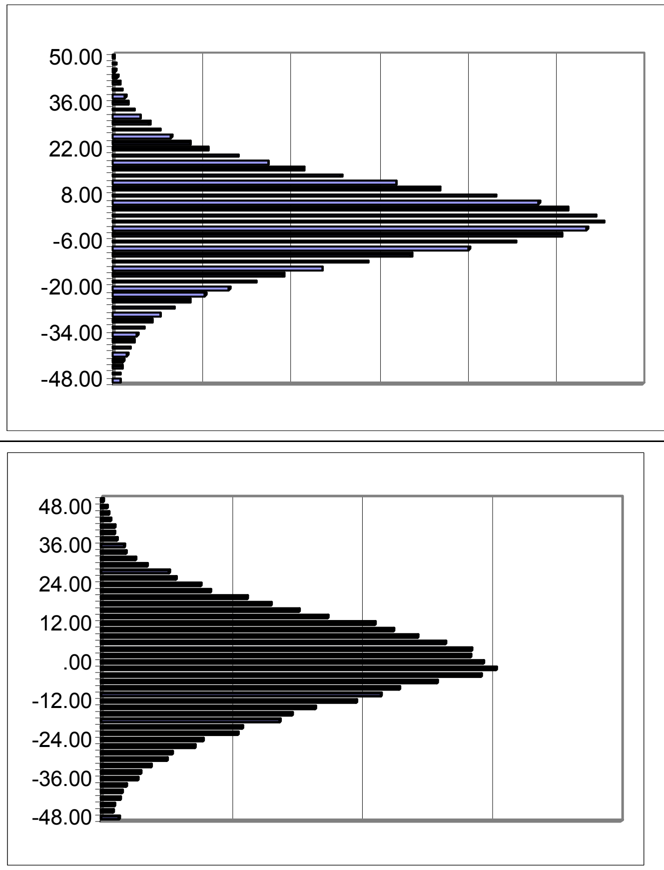

Figure 10: frequency distribution of Z-differences final DEM – reference DEM
above: open area below: forest

The DEM accuracy achieved with SPOT images should be compared with the DEM of the Shuttle Radar Topography Mission (SRTM) which is free of charge available with a spacing of 3” in the Internet (http://edcsgs9.cr.usgs.gov/pub/data/srtm/) – see Buyuksalih et al 2004. The SRTM DEM has in the area of Zonguldak a similar accuracy like the SPOT DEM, but the spacing of 3" (approximately 90m) is not optimal for the rough terrain. With 90m spacing the morphologic details visible in the SPOT DEM (figure 11 above) cannot be seen in the SRTM C-band DEM (figure 11 below). The SPOT DEM has been generated with a spacing of 3 pixels corresponding to 15m. A denser matching like 3 pixels is not leading to better information about the surface. With the used 10 pixel ∗ 10 pixel sub-matrix for matching, a shorter matching interval will cause a strong correlation of neighboured points.

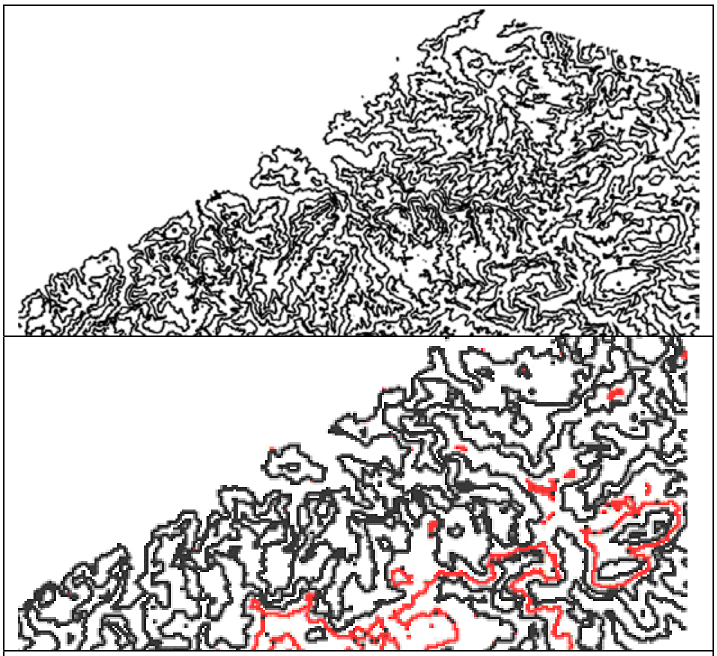

Figure 11: contour lines with contour interval 100m
above: SPOT-DEM below: SRTM C-band DEM

4 CONCLUSION

Nearly the same quality of image orientation and automatic image matching has been reached with SPOT 5 level 1A and level 1B images. In the mountainous area of Zonguldak, partially covered by forest, the image matching is quite more difficult like in smooth areas without forest. The generated DSM includes some gaps especially in darker forest areas. The largest part of the points not belonging to the bare ground could be removed by filtering. By the following filling of gaps by interpolation, not the same accuracy like for the original matched points can be reached in the rough terrain. The accuracy of the final DEM with approximately 10m for open and flat terrain is sufficient for the mountainous area. The quite better potential of matching can be seen at check points with a standard deviation of 3.8m, but this is not representative for the DEM itself.

The SPOT DEM has to be compared with the SRTM DEM which is available free of charge. The DEM points do have approximately the same accuracy, but the SRTM DEM has a spacing of 3" (approximately 90m) and this is leading to a loss of details in this area.

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