DSM GENERATION WITH HIGH RESOLUTION SPACE IMAGERY OVER MOUNTAINOUS FOREST AREA

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ABSTRACT:

For an extension of the water catchments areas for the Greater Istanbul Municipality investigations in a mountainous forest area in Turkey, at the Bulgarian border, named Istiranca, have been made. In the project area a height model from SPOT-5 HRS, the SRTM C-band height model and a digital elevation model (DEM) for the topographic map 1:25 000 are available like also a Cartosat-1 stereo pair. For comparison a SPOT-5 HRS height model has been checked in Istanbul vicinity against a reference DEM from more accurate maps 1:5000 and also the SRTM C-band height model.Based on the Cartosat-1 stereo pair a digital surface model (DSM) has been generated by automatic image matching. For the orientation of the Cartosat-1 images control points from the topographic map 1:25 000 have been used, leading in the average to RMSX=6.78m, RMSY=7.11m and RMSZ=6.08m. This accuracy is dominated by the limited control point quality, but with the 14 well distributed control points a satisfying orientation can be guaranteed. The automatic matching by least squares resulted in an astonishing complete coverage of the area by matched points. The matching failed only in small sub-areas covered by clouds. In the forest, not influenced by clouds, more than 98% of the possible object points have been matched successfully with correlation coefficients above 0.5 and with a maximum of the correlation coefficients in the range of 0.85. For mountainous forest areas this is an unusual good result. The matching was made for every third pixel, leading to a point spacing of approximately 7.5m. SRTM C-band and the results from image matching with optical images lead to DSMs, including the height of the visible surface, while the reference height model from the topographic map 1:25 000 refers to the bare ground. The SRTM height model is available with a spacing of 3 arcsec, including only limited morphologic details. All the height models have been compared to each other. A strange correspondence of the SPOT-5 HRS height model to the SRTM C-band height model can be seen, which only can be explained by filling the gaps in the SPOT-5 HRS height model in the forest area by SRTM C-band data.

1. INTRODUCTION

A planning of water catchments areas without digital elevation model is not possible. The existing DEM from the topographic map could be used, but has to be checked for changes and also correctness which is not guaranteed in any case in mountainous forest areas.

Free of charge the height model from the Shuttle Radar Topography Mission (SRTM), generated using the interferometric C-band radar, is available in the internet. This data set has the disadvantage of a point spacing of just 3 arcsec, corresponding to 93m in north-south and 70m in east-west direction. The C-band radar cannot penetrate the vegetation, so the height values are representing the visible surface – in the project area mainly the top of trees. In flat and open areas this DSM may have a vertical standard deviation of 3m to 5m (Passini, Jacobsen 2007), while it is less accurate in mountainous areas, showing also a dependency of the standard deviation upon the tangent of the terrain inclination (table 1). There is a strong influence of the vegetation to the accuracy, shown also by the bias, which is always negative. That means the SRTM C-band height points are located above the ground, which was presented by the reference height models.

Based on the height model from the topographic map 1 : 25000 (DEM25000), having a point spacing of 20m, the character of the project area has been analyzed. For an interpolation the change of the terrain inclination from one spacing to the next is important. This is identical to the roughness of the terrain. The root mean square change of the tilt is between 0.04 = 2.3° close to the shore line up to 0.10 = 5.7° in the mountainous part. That means it is a rough area, visible also at the frequency distribution of the terrain inclination (figure 1).

	RMSZ	bias	RMSZ [m] F(terrain slope)
Bavaria, steep mountain	8.0m	-2.4m	$4.4 + 33.4 * \tan\alpha$
Zonguldak, rough mountain	7.0m	-4.4m	$5.9 + 5.6 * \tan\alpha$
West-Virginia, mountain, forest	11.6m	-7.7m	$7.3 + 7.2 * \tan\alpha$
Pennsylvania, mountain, forest	7.9m	-4.3m	$7.0 + 6.4 * \tan\alpha$

Table 1: root mean square Z-discrepancies of SRTM C-band height models in mountainous areas α = terrain inclination

Important for the influence of the point spacing is the loss of accuracy by interpolation over larger distance. Corresponding to the 80m point spacing of the SRTM C-band height model, the DEM25000 has been interpolated over a distance of 80m and the interpolated points have been checked against the original values. In the project area the root mean square loss of accuracy by interpolation over 80m distance is between a root mean square value (RMS) of 1.3m close to the shore and 3.9m in the mountainous part. As RMS over the whole area a loss of accuracy by interpolation over 80m of 2.9m occurs. An interpolation over 40m causes an RMS loss of accuracy of 1.2m. That means, if the SRTM DSM is compared with another height model, an RMS error component of 2.9m is just caused by the interpolation.

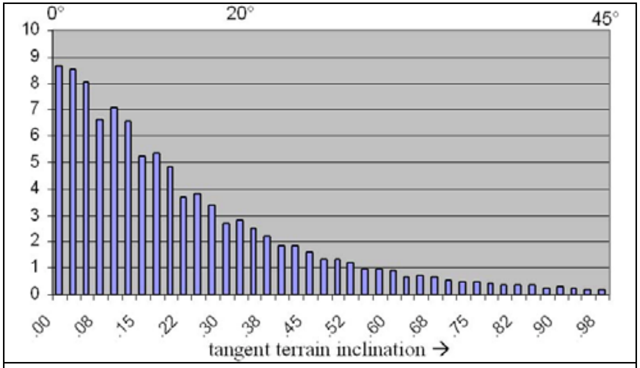


Fig. 1: frequency distribution of terrain inclination, Istiranca

In any case the horizontal fit of the height models has to be checked – in this investigation the location of the height models to each other was checked and respected by adjustment with the Hannover program DEMSHIFT.

Nearly world wide height models are also available from the high resolution stereo (HRS) sensor of SPOT-5. The images of this additional stereo sensor are not sold, only the generated height models. The HRS of SPOT-5 includes two optics viewing forward and after in the orbit direction with incidence angles of 23°, generating a stereo model with a height to base relation of 1.2. With 12000 pixels a swath width of 120km is generated. In the orbit direction, the pixel size on the ground is just 5m, so a standard scene with 12 000 x 12 000 pixels is covering an area of 120km x 60km. The smaller pixel size in orbit direction has an advantage for the vertical accuracy. Like the SRTM-height model, the height models from automatic image matching are DSMs. In not too much undulated area, where also points of the bare ground are included, the DSM can be filtered to a DEM. In a closed forest area such a filtering is not successful. SPOT HRS-height models have been analyzed in (Jacobsen 2003).

	RMSE	bias [m]	RMSE F(slope)
open areas	6.7m	-3.0	$6.4 + 4.9 * \tan \alpha$
forest	17.0m	-14.3	$16.4 + 3.4 * \tan \alpha$
open areas filtered	4.4m	-1.3	$4.2 + 1.6 * \tan \alpha$
Forest filtered	12.3m	-8.5	$10.0 + 6.9 * \tan \alpha$

Table 2: SPOT-5 HRS height model in mountainous region - root mean square difference against reference DEM determined by laser scanner Test area Inzell

The SPOT-5 HRS height models are only slightly better than the SRTM-height model, but they have a point spacing of 20m, showing more morphologic details. If such a height model is not sufficient, height models may be generated by means of other sources like by automatic matching of Cartosat-1 stereo models.

Fig. 2: mountainous project area Istiranca, dominated by forest, right hand side = Black Sea

2. CARTOSAT-1 HEIGHT MODEL

The Istiranca area is covered by a Cartosat-1 stereo pair. Cartosat-1 (figure 3), also named IRS-P5, provides along track stereo imagery based on 2 cameras, having a view direction of 26° forward and 5° backward, leading to stereo models with just approximately 53sec time difference in imaging. The camera configuration corresponds to a height to base relation of 1.6 if the curvature of the orbit is respected. The 12000 pixels, each with 7x7 microns, in the image plane are covering with the focal length of 1.98m a swath of 30km with the forward view and 26.6km with the backward view. The GSD for a scene not rotated around the orbit direction is 2.5m x 2.78m respectively 2.22m x 2.23m. The satellite can be rolled around the orbit direction to cover the project areas (figure 3).

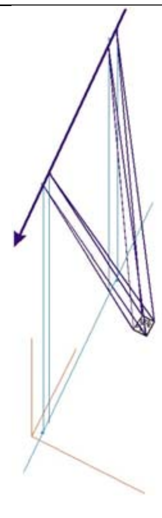


Figure 3: imaging configuration, Cartosat-1 stereo pair Istiranca, 8.8° roll around orbit

For the orientation of the Cartosat-1 images, control points from the topographic map 1:25 000 have been used, leading in the average to RMSX=6.78m, RMSY=7.11m and RMSZ=6.08m. This accuracy is dominated by the limited control point quality, but with the 14 well distributed control points a satisfying orientation can be guaranteed. Based on accurate and well defined control points a sub-pixel accuracy of independent check points has been reached in other areas as well as a vertical accuracy of well defined points up to 1.8m (Jacobsen 2006). The automatic matching by least squares resulted in a nearly complete coverage of the area by matched points. The matching failed only in small sub-areas, covered by clouds (figure 4). In the forest, not influenced by clouds, more than 98% of the possible object points have been matched successfully with correlation coefficients above 0.5 and with a maximum of the correlation coefficients in the range of 0.85 (figure 6). For mountainous forest areas this is an unusual good result and it is caused by the spectral range of Cartosat-1 from 0.50 up to 0.85µm, including the near infrared having good contrast in forest regions.

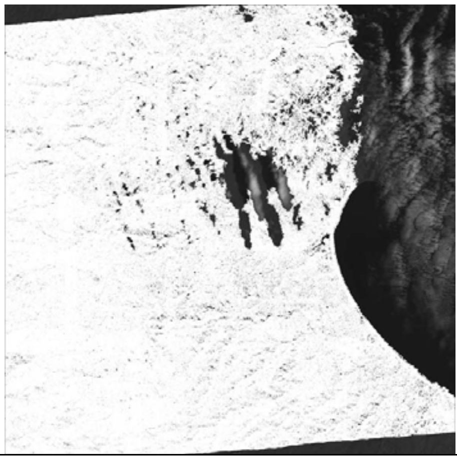


Figure 4: matched points overlaid to image – matched points = white, right hand side = Black Sea

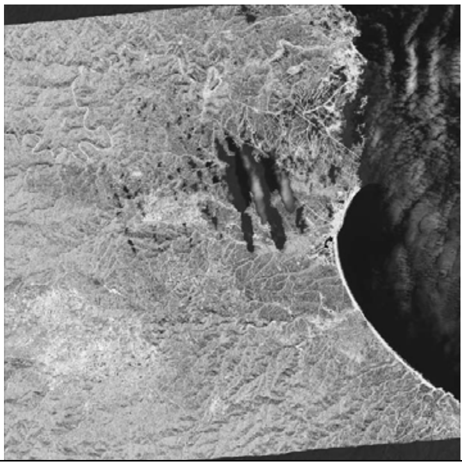


Figure 5: quality image - overlay to image with grey value depending upon correlation coefficient
correlation coefficient r=1.0 = grey value 255 (white)
r=0.5 = grey value 123 (grey)

Close to the centre of the images cloud bands disturbed the image matching (figures 4 and 5). The clouds have different location in both scenes, enlarging the area where a three-dimensional point determination is not possible. The successfully matched points, having a correlation coefficient exceeding the used threshold of 0.5 are laid over a Cartosat-1 scene in figure 4. In the quality image (figure 5), the matched points are laid over a Cartosat-1 scene with a grey value corresponding to the value of the correlation coefficient – points with r=1.0 (optimal) are shown in white, while points with a correlation coefficient r=0.5 are shown with the grey value 123. This quality image looks like an image because it is showing the valleys, roads and costal area, where the contrast is better, in white, while the forest areas are darker.

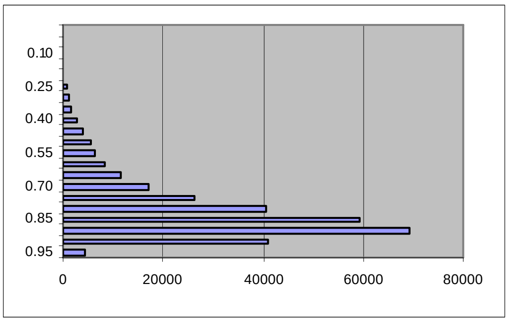


Figure 6: frequency distribution of least squares matching correlation coefficients – sub-area of Cartosat-1 Istiranca
vertical axis: correlation coefficient
horizontal axis: number of matched points

The matching was made for every third pixel, leading to a point spacing of approximately 7.5m. This results in more detailed morphologic information like based on the SPOT-5 HRS DSM having 20m spacing and the SRTM C-band DSM with 92m x 80m spacing.

The height model from the topographic map 1 : 25000 is not a sufficient reference for the Cartosat-1 height model. In a corresponding area the standard deviation of the DEM25000 is in the range of approximately 6m, while in the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) (Jacobsen 2006) in flat and open areas the standard deviation of the Cartosat-1 height model was between 2.5m and 3.5m.

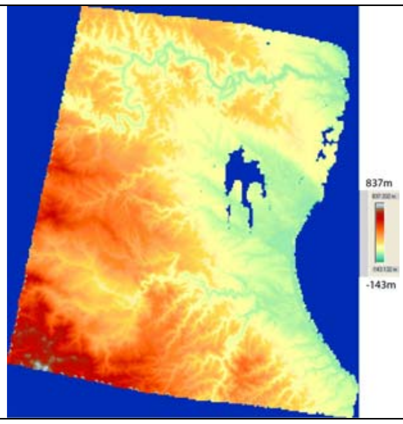


Figure 7: height model based on Cartosat-1 stereo model with height-scale

3. COMPARISON OF HEIGHT MODELS

As mentioned before, for the project area the DEM25000 with a spacing of 20m, a SPOT-5 HRS height model also with a spacing of 20m and the SRTM C-band height model with a spacing of 93m / 70m are available in addition to the DSM generated by means of the Cartosat-1 stereo model. The Cartosat-1 DSM is able to show with 7.5m spacing quite more details like the other.

Several SRTM C-band height models have been investigated (Passini, Jacobsen 2007), the results of comparable areas are listed in table 1. The height model of the Turkish topographic map 1 : 25 000 was also investigated in the area around Zonguldak, which has a similar characteristics like Istiranca.

Like usual, the SPOT-5 HRS height model has been bought as “Reference 3D” from SPOT Image, because the HRS images are not distributed. Only in the frame of the “HRS Scientific Assessment Program” images have been made available. The accuracy of the height model generated by automatic matching of a SPOT-5 HRS stereo model can be seen in table 2. The area Inzell can be compared with Istiranca, it is also covered by forest and is mountainous.

The accuracy numbers are only one indicator for the quality of a height model. The SPOT-5 HRS sensors have a spectral range from 0.48 up to 0.70µm wavelength, that means only the very first part of infrared is included, while Carosat-1 has a spectral range from 0,50 up to 0.85µm, including the near infrared. In the near infrared the vegetation has a strong reflectance. By this reason the automatic image matching with Cartosat-1 images over forest areas is very successful, as shown above. In SPOT-5 HRS images the forest is always dark, causing severe matching problems.

The reason for the matching problems of SPOT-5 HRS images in forest areas is obvious at the small variation of the grey values shown in figure 8, centre, while the conditions for Cartosat-1 are quite better (figure 8 below).

Parts of the Istiranca area are covered or influenced by clouds. So the comparison of the height models was limited to a sub-area of 10km x 10km in the southern part of the scene.

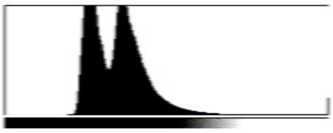
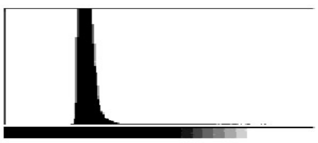
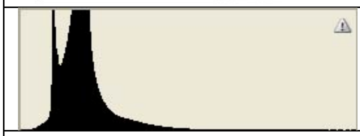
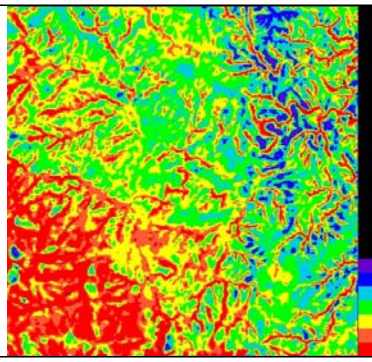
	SPOT-5 HRS forest + open area
	SPOT-5 HRS Only forest area
	Cartosat-1 only forest area

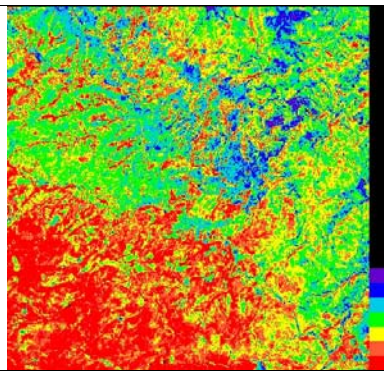
Fig. 8: grey value histogram of SPOT-5 HRS and Cartosat-1 images over forest areas

Compared height models	RMSZ [m]	Bias [m]	RMSZ as F (slope)
Cartosat – SRTM	7.97	0.75	7.28 + 1.1∗tan α
Cartosat - HRS	6.68	1.91	6.34 + 1.0∗tan α
Cartosat – DEM25000	10.41	-4.29	9.29 + 4.7∗tan α
Filtered Cartosat – DEM25000	9.86	-4.12	7.86 + 8.2∗tan α
HRS - SRTM	3.13	-1.23	1.73 + 6.8∗tan α
HRS – DEM25000	8.68	-4.14	6.80 + 7.3∗tan α
SRTM – DEM25000	10.23	-5.36	7.98 + 8.6∗tan α
Filtered Cartosat - SRTM	7.94	-1.15	6.41 + 4.8∗tan α

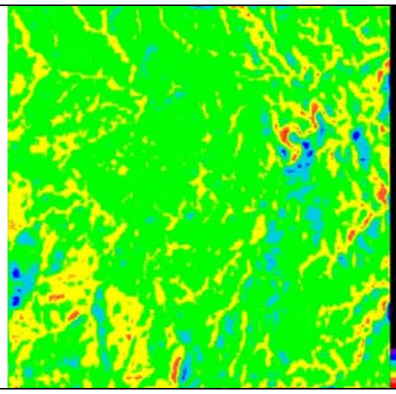
Table 3: root mean square differences between height models, Istiranca, sub-area 10km x 10km



DEM 25000 - SRTM

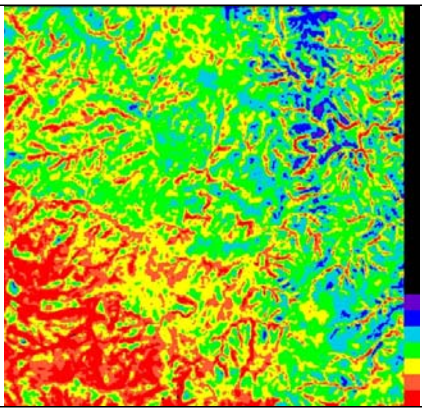


DEM 25000 - Cartosat

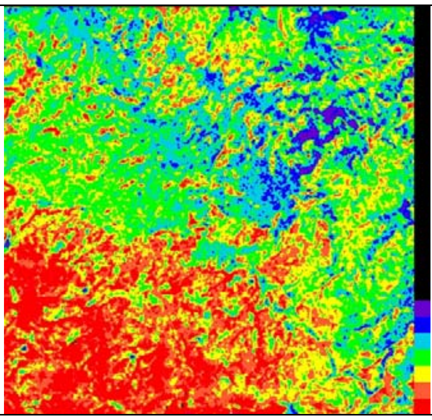


SPOT-5 HRS – SRTM

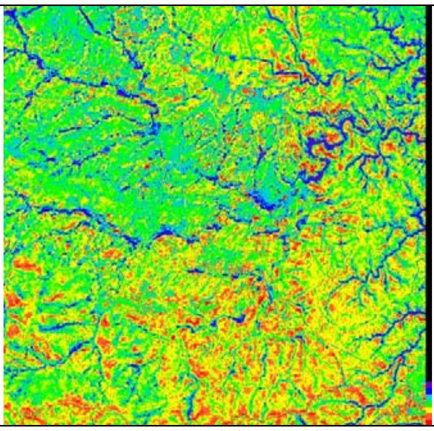
Figure 9a: colour coded differences of height models



DEM 25000 - SPOT-5 HRS



DEM 25000 – Cartosat filtered



SPOT-5 HRS - Cartosat

Figure 9b: colour coded differences of height models

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GROUPING OF COLOUR-CODING:
     DZ-RANGE
     3.00  9.00 GREEN-BLUE
     9.00 15.00 BLUE
    15.00 21.00 VIOLETT
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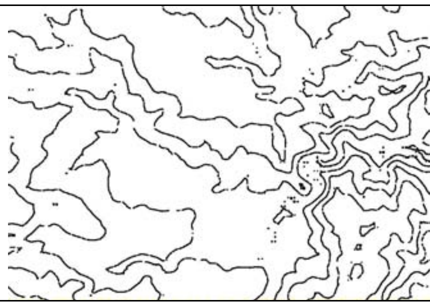
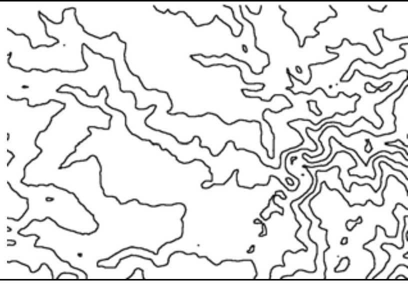
Corresponding to the above mentioned results of other investigations, the accuracy of the Cartosat-1 height model against the SRTM-DSM and the SPOT-5 HRS DSM is within the expectation. The discrepancies against the DEM from the topographic map 1:25 000 is dominated by the influence of the vegetation, shown by the larger bias. Of course the DSMs can be filtered for objects not belonging to the bare ground, but in a closed forest area the filtering is limited because no points are located on the ground, nevertheless the filtered Cartosat DSM fits better to DEM25000. The discrepancies of the SPOT-5 height model against the SRTM height model are a little strange – they are quite below the accuracies from the references (tables 1 and 2) shown above and cannot be explained by similarities of the height determination. The differences of both height models are even smaller in areas with more dense forest, where under usual conditions the SPOT-5 HRS height models fails.

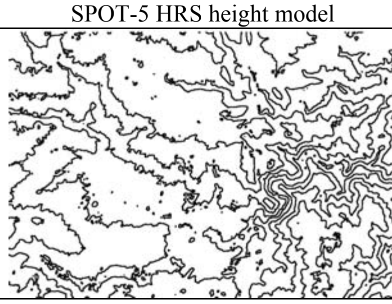
The influence of the forest to the Cartosat DSM can be seen also in the frequency distribution of the height differences shown in figure 11. The asymmetric frequency distribution is caused by the trees, shown by the more negative values of the height differences.



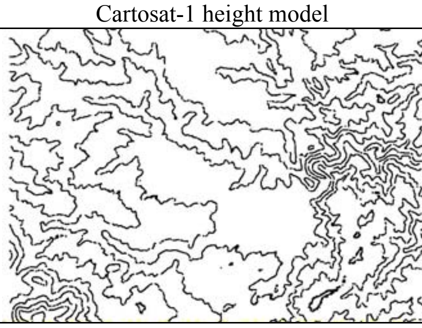
SRTM C-band height model



SPOT-5 HRS height model



Cartosat-1 height model



DEM 1:25 000

Figure 10: contour lines from a 10km x 10km sub-area of Istiranca 50m contour interval

The differential height models (figure 9) indicate the characteristics of the height models in the chosen 10km x 10km window. The characteristics of the DSMs against the reference DEM from the map 1:25 000 can be seen in the height differences shown by red colour – this indicates forest with high trees. The strange similarity between SRTM and HRS is obvious. In the corresponding differential height model only in the open parts remarkable differences exist. The Cartosat DSM shows quite more details like the other.

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In addition to the accuracy the morphologic details have to be respected. The morphologic details are important for the identification of the terrain characteristics shown by the contour lines (figure 10). The more precise morphologic information of the Cartosat-1 height model is obvious; it is based on the point spacing of just 7.5m, while SPOT-5 HRS has 20m and SRTM 92m/80m spacing. The correspondence between the SPOT-5 HRS and the SRTM C-band contour lines can be seen, underlining the question about the original source of the HRS DSM. The Cartosat-1 height model fits better than the other to the DEM 1:25 000, but it has to be respected, that only the DEM 1:25 000 presents the bare ground, while the other represent the visible surface, that means the top level of the trees in the forest. In the nearly closed forest area a filtering for points not belonging to the bare ground has only limited effect.

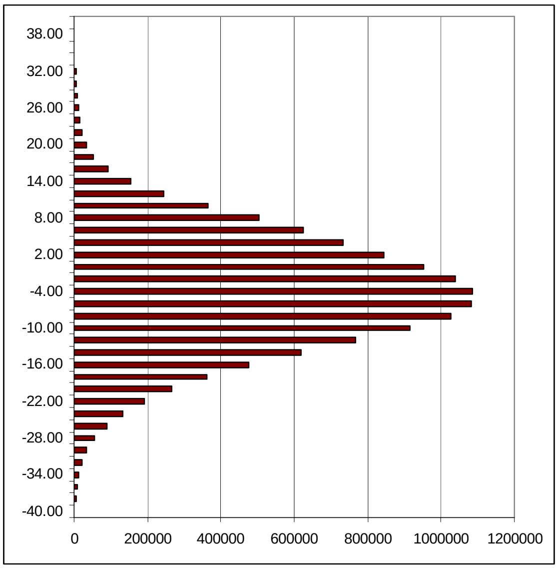

Figure 11: frequency distribution of height differences Cartosat-1 DSM against DEM25000

In suburbs of Istanbul the SPOT-5 HRS height model and the SRTM C-band DSM have been analysed against a more precise reference DEM from the maps 1:5000 (table 4). Only 42% of this area is covered by forest. In this area no similarity between the SPOT-5 HRS DSM and the SRTM DSM can be seen. The accuracy estimation for SPOT-5 HRS and SRTM in the forest area of this location may be used as reference for the analysis of the height models in the region shown at first.

Compared height models	RMSZ [m]	Bias [m]	RMSZ as F(slope)
HRS – DEM 1:5000	6.02	0.84	5.14+10.6∗tan α
HRS – SRTM C-band	4.62	-1.33	3.72+ 3.3∗tan α
SRTM – DEM 1:5000	5.70	-2.29	4.51+ 5.8∗tan α

Table 4: root mean square differences between height models, Istanbul, sub-area 20km x 20km

The differential height model between the SPOT-5 HRS DSM and the DEM 1:5000 in the Istanbul area shows larger buildings and forest areas. Also small valleys can be identified caused by the smoothening effect of the SPOT-5 HRS data set with 20m spacing, while the valleys are shown clearer in the DEM 1:5000.

4. CONCLUSION

Digital height models based on Cartosat-1 images, SPOT-5 HRS and SRTM C-band have been investigated in a mountainous forest area in Turkey. The root mean square height differences of the different height models are in most cases within the expectation for the mountainous area, nearly completely covered by forest. The bias of the DSMs against the reference DEM from the map 1:25000 indicates the average tree height. Elements not belonging to the bare ground can be filtered from a DSM if enough points belonging to the bare ground are included, but in the forest area the influence of filtering is limited, so the filtered Cartosat data are fitting only 10% better to the reference DEM like the original matched data. A filtering of the SPOT-5 HRS DSM has nearly no effect. The influence of the vegetation to the DSMs can be seen also at the asymmetric frequency distribution of the height differences of the DSMs against the reference DEM.

The automatic image matching of Cartosat-1 images was very successful and includes quite more details like the free of charge available SRTM C-band height models. Astonishing is the SPOT-5 HRS DSM in relation to the SRTM height model. The matching in forest areas with HRS images is usually difficult because of the limited spectral range of the HRS sensor between 0.48 and 0.70µm wavelength, not including the near infrared, which leads to sufficient contrast in the forest; so gaps have to be expected in the HRS DSM, but they are not available. It seems, the SPOT-5 HRS height model has been completed by the SRTM C-band data without mentioning this fact. For detailed analysis the HRS DSM has been reduced to 80m spacing and compared with the original HRS heights having 20m spacing. The resulting effect of the interpolation is with the size and distribution nearly identical to the discrepancies between the SPOT-5 DSM and the SRTM DSM, supporting the mentioned hypothesis.

All height models based on space information are digital surface models, showing the visible surface of the vegetation and artificial objects. A filtering of the DSMs in the closed forest area has limited effect because only few object points are really located on the bare earth. Nevertheless the morphologic details in the Cartosat-1 height model are at least on the level of the existing DEM of the topographic map 1 : 25 000. The SRTM C-band height model of course cannot show the same level of detail, but it can be used for several applications. The bought SPOT-5 HRS height model is disappointing in this area because it seems to be mainly a copy of the SRTM height model.

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