DEM GENERATION WITH CARTOSAT-1 STEREO IMAGERY

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ABSTRACT

By the Shuttle Radar Topography Mission (SRTM) nearly worldwide digital height models have been generated. The SRTM height models can be used for several applications, but it has gaps in mountainous regions, caused by the radar layover, and is not so accurate in steep areas. In addition the grid width of 3 arcsec, corresponding to approximately 92m at the equator, is limiting the morphologic details. From the very high resolution optical space sensors only a limited number of stereo pairs, taken from the same orbit, are available. The automatic matching of images taken with significant time interval is very difficult and not leading to satisfying results. In addition stereo pairs from IKONOS, QuickBird and the former OrbView-3 are expensive. The stereo pairs from the SPOT HRS only have been available for test purposes, usually only the derived height models can be bought, but they may be critical in forest areas (Büyüksalih, Jacobsen 2008). As alternative solution the stereo sensors Cartosat-1 and ALOS/PRISM are now available; both systems with 2.5m ground sampling distance (GSD).

Cartosat-1 stereo pairs have been used for automatic image matching, leading even in forest areas to good results. Of course by matching as well as with the SRTM C-band and X-band digital surface models (DSMs) are generated, representing the visible surface. In most cases digital elevation models (DEMs) are requested, showing the height of the bare ground. DSMs can be filtered to DEMs if enough points of the bare ground are available. The height models based on Cartosat-1 stereo pairs have been analyzed, including filtering. Partially it was necessary to shift the reference to the corresponding location.

CARTOSAT-1

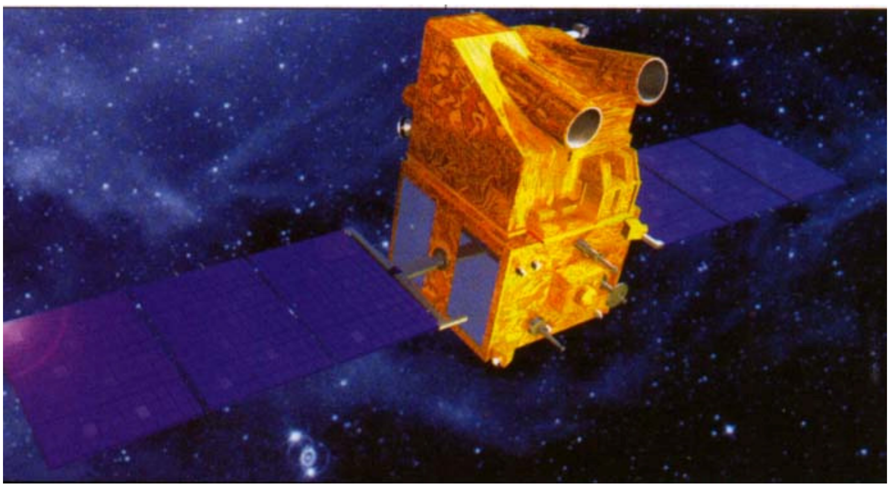
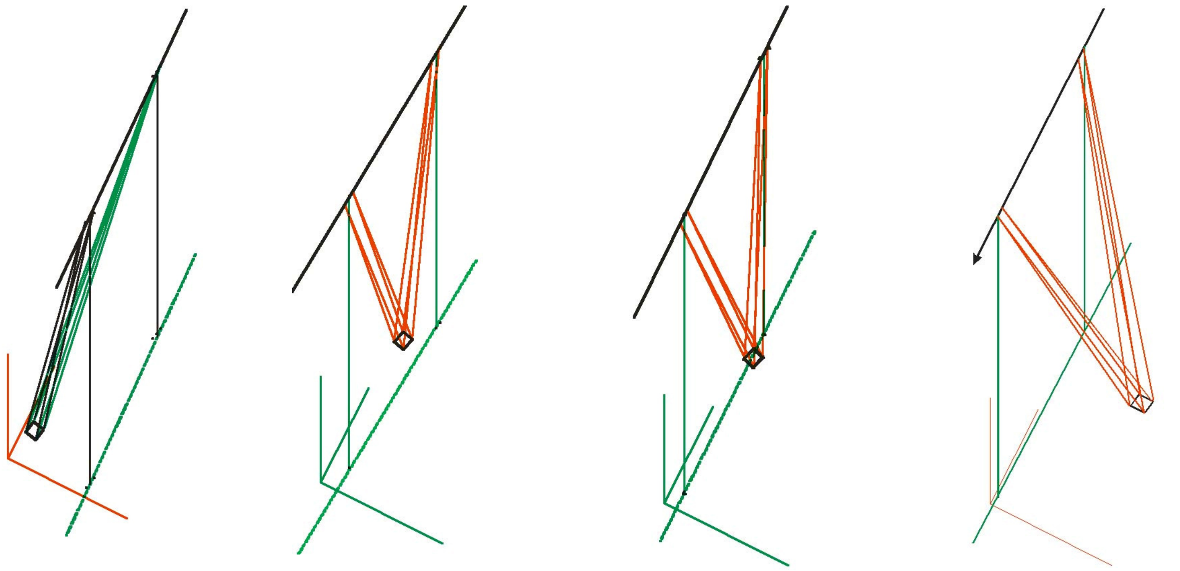


Figure 1: Cartosat-1 = IRS-P5; stereo imaging with two cameras; 26° forward; 5° after

Cartosat-1 (figure 1), 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 53sec time difference in imaging. The camera configuration corresponds to a height to base rela-

ISBN 978-3-925143-79-3

tion 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 rotated around the orbit direction to cover the project areas (figure 2). The incidence angle of 97.87° together with the flying height of 618km leads to a sun-synchronous orbit with 10:30 h equator crossing time in descending orbit. Cartosat-1 is equipped with a GPS receiver for the positioning and star sensors and gyros for the attitude determination. The absolute positioning without control points is specified with a standard deviation of 70m.



Mausanne, January roll = 13.6° | Mausanne, February roll = 4° | Warsaw, roll = 0.2° | Jordan, roll = 16.6°

Figure 2: imaging configuration in 4 used areas

The image quality is not the same for the forward and the after view. By edge analysis the effective image resolution has been checked. A sudden change of the brightness in the object from one location to the neighbourhood, e.g. from a bright roof to a dark shadow, is causing a continuous change of the grey value profile in the image. The grey value profile can be differentiated, leading to the point spread function. The width of the point spread function includes the information of the effective resolution.

Table 1: factor for effective GSD determined by edge analysis

	Mausanne J.	Mausanne F.	Warsaw	Istiranca	Jordan	average
after (5°)	1.21	1.08	1.19	1.06	1.04	1.12
forward (26°)	1.25	1.18	1.32	1.33	1.38	1.29

The factor for effective GSD has to be multiplied with the size of the GSD for getting the effective GSD. For example the factor 1.25 means, the GSD of 2.5m only corresponds to the information contents like with a GSD of 1.29 x 2.5m = 3.2m. In any case the stronger inclined forward view has a lower resolution – in the average an effective GSD of 3.2m instead of 2.5m. This is obvious in the images. A simple image inspection shows the forward view a little blurred in relation to the more nadir view of the after view (figure 3). This is also the case for the images when the satellite was rotated to the side (figure 2). The a little lower resolution does not mean, that the automatic image matching is negative influenced. The experience showed that sometimes a little blurred images lead to a good automatic image matching.

Figure 3: Cartosat-1 forward view *Cartosat-1 after view*

IMAGE ORIENTATION

Together with the images rational polynomial coefficients (RPCs) are delivered. They include the relation between the image and the ground coordinates, based on the direct sensor orientation – that means the GPS-positioning of the satellite and the attitude determination by gyros and star sensors. The direct sensor orientation is specified with a standard deviation of the ground coordinate components of approximately 70m. During the first scenes, which was the case in the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP), the positioning was not correct by some km. Later this was improved, so for the newer scenes it is within the expectation (table 2).

Table 2: absolute positioning of Cartosat-1 without control points A=after F=forward

	Istiranca A	Istiranca F	Jordan A	Jordan F	absolute average
DX	41.1 m	5.1 m	33.8 m	-90.6 m	43 m
DY	70.7 m	65.7 m	44.4 m	76.4 m	64 m

The absolute positioning without control points now seems to be within the specification, but for 2.5m GSD it is not accurate enough, requiring a correction by ground control points (GCPs) – the so called bias correction. For the Mausanne January images, Warsaw and Jordan precise and in the images well defined GCPs are available. In the case of the Mausanne February images the identification of the GCPs was limited and in the Istiranca scene the GCPs only had accuracy in the range of 6m.

Table 3: Root mean square errors at GCPs of bias corrected RPC orientation

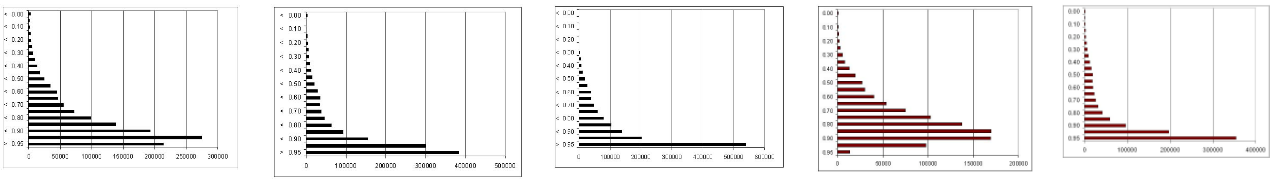
		RMSX	RMSY	stereo		
Mausanne January	after	2.4 m	2.1 m	RMSX	RMSY	RMSZ
	forward	2.0 m	2.1 m	2.1 m	2.7 m	3.4 m
Warsaw	after	1.4 m	1.5 m	1.3 m	1.1 m	1.8 m
	forward	1.4 m	1.3 m			
Jordan	after	1.9 m	1.8 m	2.3 m	1.7 m	1.5 m
	forward	2.5 m	1.7 m			

The accuracy of the bias corrected RPC-orientation is in the sub-pixel range. Also the height is very good – the height to base relation of 1.6 has to be respected, meaning, that the vertical component should be less accurate by this factor, so even 3.4m RMSZ for the Mausanne January stereo combination corresponds to a root mean square error of the x-parallax of 2.1m, that means to sub-pixel accuracy.

DIGITAL ELEVATION MODELS

Automatic image matching with the Hannover program DPCOR has been made. The program is using least squares matching combined with region growing, allowing a matching with the original images without any pre-condition. The least squares matching is not influenced by the rotation of the forward CCD-line against the backward CCD-line caused by the effect of earth rotation and the lateral rotation of the satellite. In the Jordan area for example the rotation between the CCD-lines is in the range of 10° and caused by local terrain inclination it goes up to 16°. Cartosat-1 is permanently generating stereo image configurations for long stripes; this is different to the very high resolution satellites like IKONOS, where the individual stereo combinations are generated by permanently rotating the satellite to the reference direction, usually specified in the ground coordinate system. By this reason Cartosat-1 has scenes aligned to the satellite orbit.

The automatic image matching of Cartosat-1 stereo pairs in all used scenes was very good. Caused by the spectral range including the near infrared, also in forest areas the matching was astonishing good (see also Buyuksalih, Jacobsen 2008) – a very high percentage of points could be matched and the correlation coefficients are very high in relation to other satellites. Of course if there is no contrast on the ground, no optical sensor is successful.

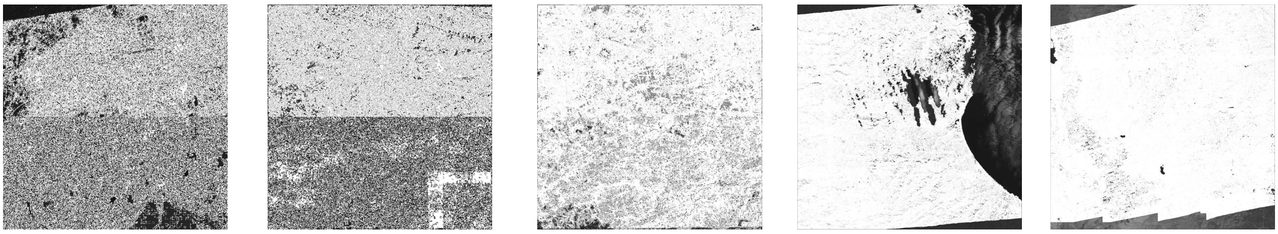


Mausanne Jan. Mausanne Feb. Warsaw Istiranca Jordan

Figure 4: frequency distribution of correlation coefficient

horizontal: frequency vertical: correlation coefficient - above r=0.0 below r=1.0

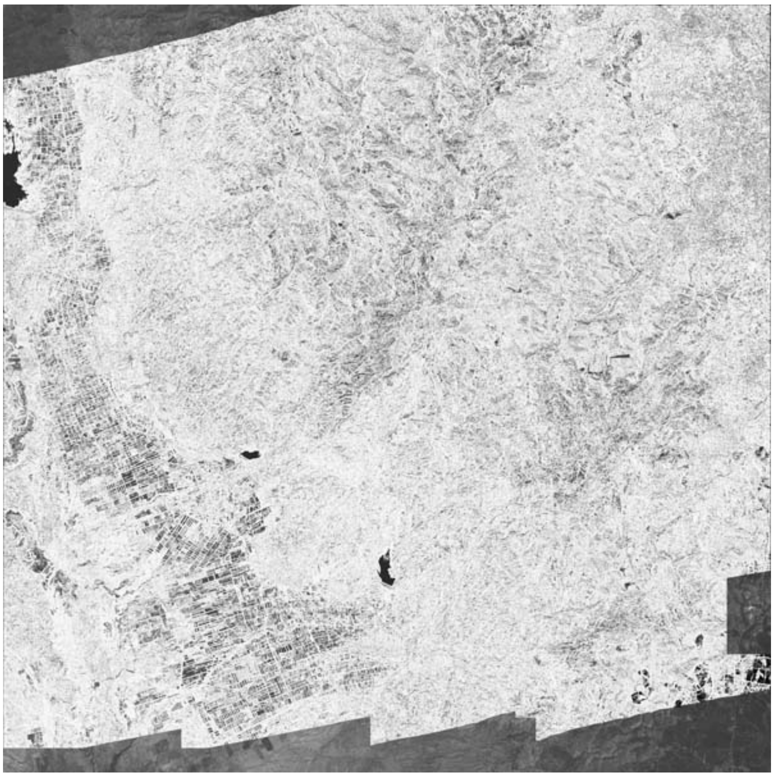
Figure 4 shows the frequency distribution of the correlation coefficients. In the Mausanne January model the object contrast was limited because of the winter, so that the highest number of correlation coefficients are in the group r=0.90 up to 0.95 and not like in Mausanne February, Warsaw and Jordan in the class r=0.95 up to 1.0. In Istiranca the correlation coefficients are lower caused by the mountainous area, nearly completely covered by forest (see also Buyuksalih, Jacobsen 2008). In relation to other satellites, the matching with Cartosat-1 models is extremely successful.



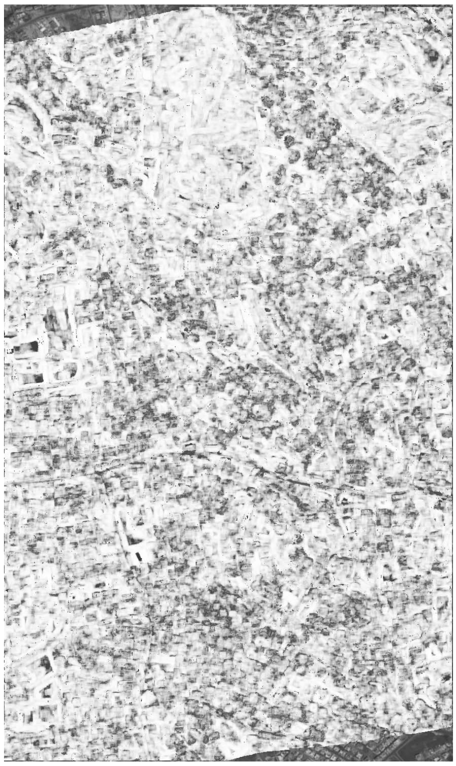
Mausanne Jan. Mausanne Feb. Warsaw Istiranca Jordan

Figure 5: overlay of matched points (white) to after scenes

The overlay of the matched and accepted points to one of the scenes in figure 5 demonstrates the successful solution. In the Mausanne January scene in some parts absolute no contrast was on the ground. This was not so much in the Mausanne February model which has a small overlap to the January scene. In Warsaw slight snow coverage caused some problems, while in Istiranca some problems with cloud coverage exist. Of course a matching on water surfaces is not possible like on the right hand side of Istiranca. The larger spots in the Jordan model are also water bodies.



Jordan, whole stereo model



Jordan, city area

Figure 6: quality image – overlay of scene by matched points with grey value corresponding to correlation coefficient grey value 255 (=white) = r=1.0 grey value 63 = r=0.50

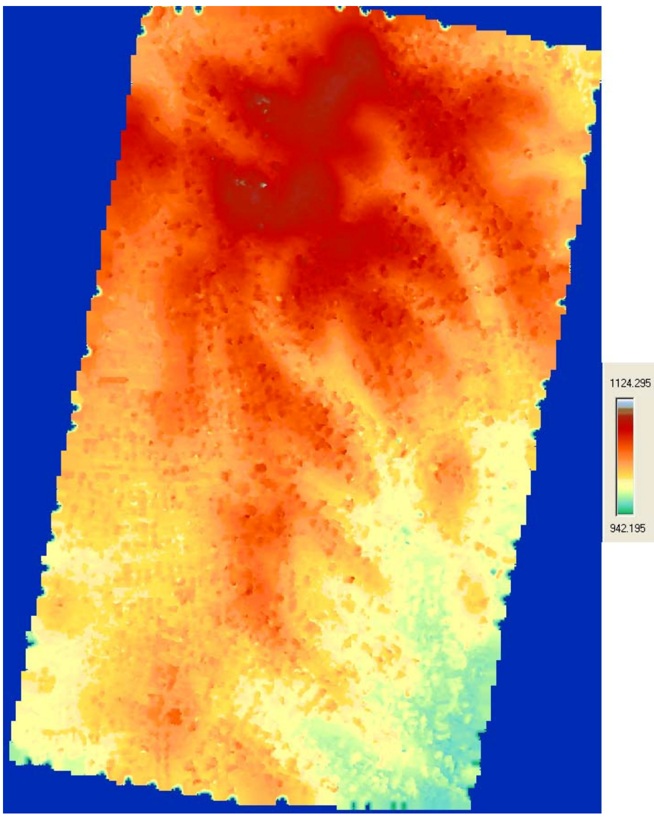
The quality images in figure 6 shows the relation of the correlation coefficients to the image location. The correlation coefficients are not so large on the fields on the left hand side of the Jordan model (figure 6, left) showing very limited variation of grey values on April 7th. In the city the lower correlation of parts is caused by building shadows and the different view direction to the buildings, showing different parts of the facades for the different view direction (figure 6, right).

Based on the bias corrected RPC-orientations the ground coordinates are computed by intersection. The y-parallaxes of the intersections are indicating the object point accuracy because there should be no general difference in image accuracy in the x- and the y-direction. For the intersection a tolerance limit of 6m (2.4 GSD) has been used. The points having a larger y-parallax than this limit are not accepted and respected for the generation of the height model. Only 2 to 3% of the points exceeded this threshold. If the accuracy of the y-parallax is identical to the x-parallax, the standard deviation of the height should be the root mean square (RMS) of the y-parallax multiplied with the height to base relation. In the case of the Jordan scene this should be 1.39m x 1.6 = 2.22m. For the Jordan scene not precise reference height values are available, but this was the case for both Mausanne and the Warsaw-scene which have been analysed within the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP). For the Mausanne January scene the RMS y-parallax of 14 million points was 2.87m and for the February scene 2.47m, corresponding to a standard deviation of the height of 4.59m respectively 3.95m.

Table 4: accuracy of Cartosat-1 height models checked by precise reference DEMs (Jacobsen 2006)

		SZ	bias	SZ as F(inclination)
Mausanne January	open areas	4.02	-0.51	3.91 + 1.64∗tan α
	open areas filtered	3.30	0.48	3.17 + 3.14∗tan α
Mausanne February	open areas	4.13	-1.16	3.96 + 3.06∗tan α
	open areas filtered	3.39	-0.58	3.22 + 1.97∗tan α
Warsaw	open areas	3.23	-0.54	3.16 + 1.19∗tan α
	open areas filtered	2.43	0.44	2.39 + 8.80∗tan α

In the open areas of Mausanne, the height model was even more precise than the accuracy estimated by means of the RMS y-parallax. Of course the generated DSM has to be filtered for objects not belonging to the bare ground because the reference DEM is related to this. The very good matching result of the Jordan model can be explained by the area. The Jordan-area is dominating open with only few elements not belonging to the bare ground and only parts of the model are covering the city of Amman. In the build up areas the RMS y-parallax is with 1.58m slightly larger like in the overall scene. The RMS y-parallax of 1.58m corresponds to a vertical accuracy of 2.53m and this seems to be realistic.



colour coded height model of build up area

corresponding Cartosat-1 image

Figure 7: Cartosat-1 Jordan, part of build up area

ISBN 978-3-925143-79-3

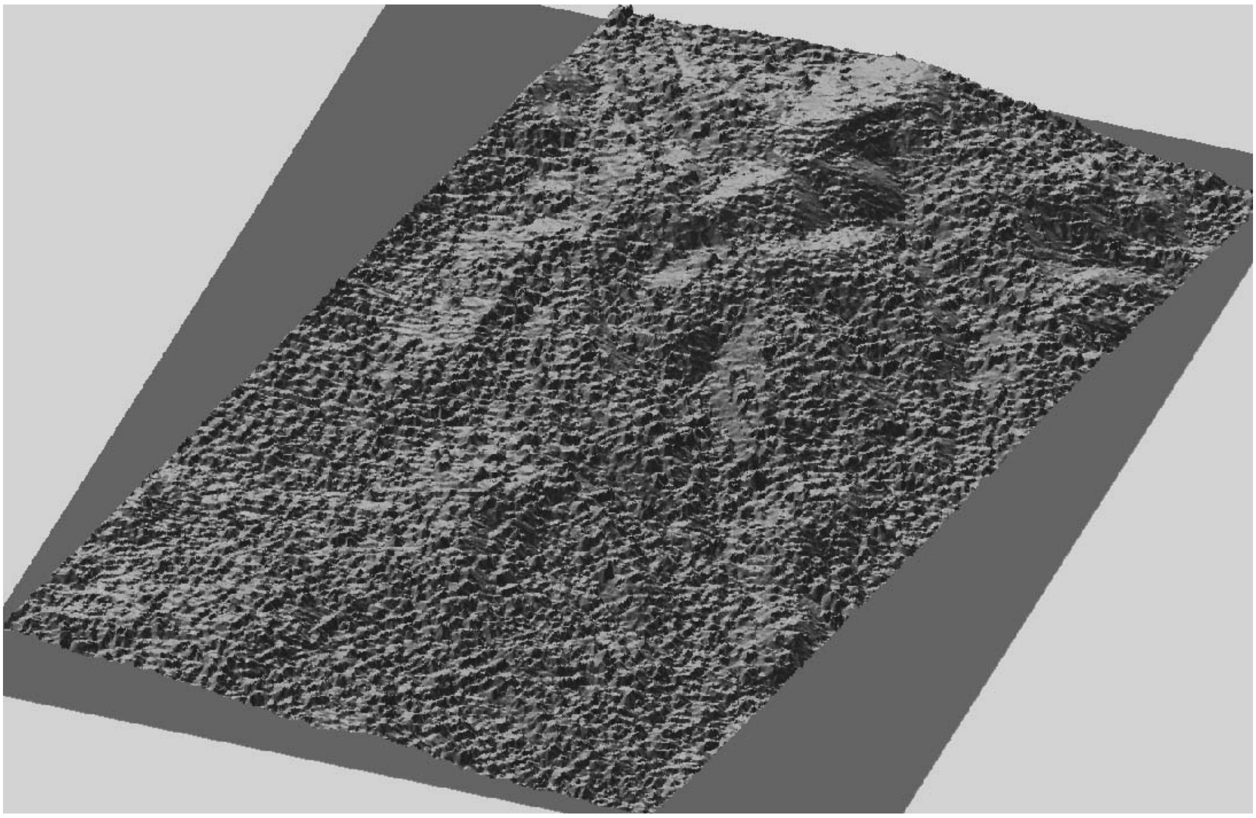
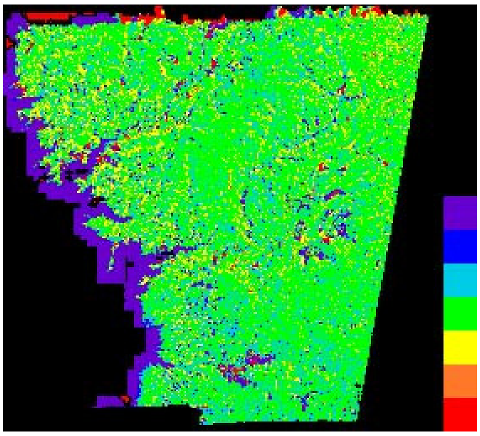


Figure 8: shaded model of build up area corresponding to figure 7

For the GSD of 2.5m the 3D-structure of the build up area (figures 7 and 8) comes out very well, confirming the high quality of the Cartosat-1 height model. Because of missing reference height values, the Cartosat-1 height model has been compared with the SRTM C-band height model, which is available free of charge in the internet. Of course the SRTM height model has only a spacing of 3arc sec, corresponding to 79m x 92m, and it is not so accurate (Serfercik et al 2007), but it gives at least some information. The root mean square difference between the Cartosat-1 and the SRTM C-band height models is 8.03m or as function of the terrain inclination 6.30m + 6.5m x tan (terrain inclination). This is not the best result for the SRTM height model, but it is not unusual.



colour scale for height differences [m]

18.00 30.00 blue
6.00 18.00 green-blue
-6.00 6.00 green
-18.00 -6.00 yellow
-30.00-18.00 brown

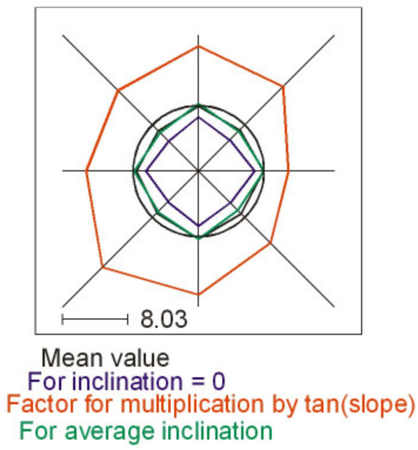


Figure 9: height differences Cartosat-1 against SRTM DSM

RMSZ as function of direction of terrain slope (aspects)

As typical result of the comparison of the Cartosat-1 and the SRTM C-band DSM, differences are mainly in narrow valleys, which cannot be modelled with the large spacing of the SRTM height model (figure 9). Also typical for SRTM-values is the dependency of the accuracy upon the aspects (direction of slope) (figure 9 right), especially the slope depending error component is a function of the radar view direction.

CONCLUSIONS

Digital height models have been generated by means of Cartosat-1 stereo pairs. The orientation of the models in any case was possible with sub-pixel accuracy by bias corrected RPC-solution. The image quality of the more inclined forward view usually is a little reduced, but this does not influence the automatic image matching. Supported by the spectral range of the cameras including the near infrared, even the matching of forest areas was not a problem, leading to a success of the matching in the range of 95% up to 98% if the area is not covered by water or clouds. In any case for flat terrain the height accuracy is better than 1 GSD for the x-parallax or 4m. After filtering for elements not belonging to the bare ground the vertical accuracy for flat terrain is not less than 3.2m corresponding to x-parallax accuracy of 0.8 GSD. In relation to other optical space sensors this is a very good result. The GSD of 2.5m also allows the generation of the main structures of build up areas

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