

ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP)

TECHNICAL REPORT – TEST AREA MAUSANNE AND WARSAW

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ABSTRACT:

In the frame of the ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) the orientation of 3 stereo scenes has been computed by bias corrected RPC-solution. The generation of digital elevation models (DEMs) followed by least squares matching. An analysis of the DEMs against reference DEMs showed sub-pixel accuracy of the height values as x-parallax.

1. USED SOFTWARE

The Cartosat-1 data of the test fields Mausanne, with stereo scenes from January and February 2006, and Warsaw from February 2006 have been handled with the software of the University of Hannover. After control point measurement in the images with program DPLX the orientation has been made based on the RPCs and the control points with program RAPORIO. The image matching followed with program DPCOR, imbedded in DPLX, by least square matching leading to corresponding scene coordinates. With program RPCDEM the height models have been generated and analysed with program DEMANAL. A filtering for elements not belonging to the bare ground followed with program RASCOR. The horizontal fit of the generated DEMs with the reference DEMs has been checked with program DEMSHIFT. Partially the reference data had to be improved by geoid undulation with program UNDUL.

2. IMAGE ORIENTATION

The control point measurement in the images of the test field Mausanne (January and February scenes) was difficult. The control point specification fits to the resolution of the ADS40-flight but not to the 2.5m ground sampling distance (GSD) of Cartosat-1. So most control points could not be identified precisely, but the higher number still guarantees a sufficient image orientation. This problem does not exist with the Warsaw data set.

The orientation with the Hannover program RAPORIO computes at first the object coordinates with the given height values based on the rational polynomial coefficients. After this step a horizontal transformation to the control points is required. For this horizontal fitting an affine transformation was required and sufficient. The used unknowns are checked for correlation and significance by Student-test. The not required unknowns can be eliminated from the adjustment. Only the Y-scale of the horizontal affine transformation in some cases was not significant. The program shows the shift of the direct sensor orientation via the RPCs against the control point frame. In

January shift values up to 5937m occurred, the later scenes do have shift values below 360m. Of course the large shift of up to 5937m may be caused also by the satellite attitude and this may cause a not negligible influence to object points located in a different altitude than the dominating number of control points. By this reason in addition to the horizontal affine transformation an improvement of the view-direction can be introduced as unknowns, but in no case this was significant. So finally only a horizontal affine transformation followed the RPC-solution.

		SX [m]	SY [m]	SZ [m]
Mausanne January	after	3.39	2.89	
	forward	3.70	2.95	
	3D solution	3.96	2.86	3.77
Mausanne February	after	2.87	4.28	
	forward	3.00	3.68	
	3D solution	2.98	4.10	4.35
Warsaw	after	1.41	1.50	
	forward	1.35	1.27	
	3D solution	1.33	1.14	1.76

table 1: root mean square discrepancies at control points of the Cartosat-1 orientation
Mausanne January: 32 control points
Mausanne February: 29 control points
Warsaw: 33 control points

The difference in the orientation accuracy between Mausanne and Warsaw (table 1) is obvious. The accuracy of the control points in Mausanne is dominated by the control point definition in the images as mentioned before, but based on the sufficient number and good distribution of the control points this is not causing a negative influence to the scene orientation. The orientation accuracy of the Warsaw scenes is in the range of 0.5 up to 0.6 GSD, for the vertical component in the case of the 3D-solution the height to base relation of 1.6 has to be respected, that means, the standard deviation of the x-parallax is in the range of 0.45 GSD. This is a satisfying result for such control points and it demonstrates that there is no problem with the scene geometry.

2. DEM GENERATION

The automatic image matching of the 3 Cartosat-1 scenes was made with the program DPCOR based on least squares matching using region growing by the Otto Chau algorithm. It was tried to match every third pixel centre in the x- and y-direction. The matching of all pixel centres only leads to highly correlated neighbored Z-values. As tolerance limit for the correlation coefficient the value 0.6 was used, causing some gaps in the data set.

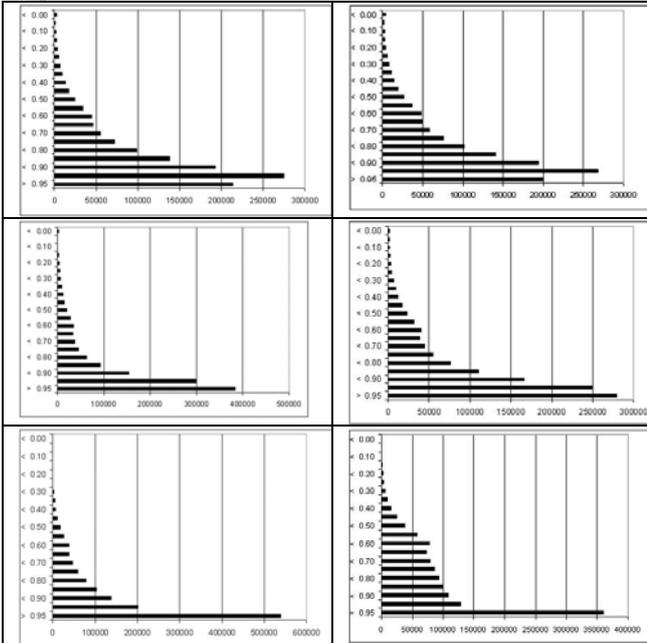


Fig. 1: frequency distribution of correlation coefficients
 first row: 2 sub-sets of Mausanne, January 84% accepted
 second row: 2 sub-sets of Mausanne, February 93% accepted
 third row: 2 sub-sets of Warsaw 94% accepted
 horizontal: number of points in the correlation group
 vertical: correlation groups (step width 0.05), above 0., below 1.0
 8 lower lines $> r=0.6 =$ accepted

The matching of the Mausanne January scene was not so good like the others. The highest number of matched points is in the correlation coefficient group from 0.90 up to 0.95 while for both other models the highest number of matched points are in the group 0.95 – 1.0. In the Warsaw scene this group is dominating (figure 1). In addition in the Mausanne January scene only 84% of the possible points have been accepted while it was 93% for the February scene and even 94% for the Warsaw scene. This can be seen also very well at the overlay of the matched points to the after scenes (figure 2). In the Mausanne January model the contrast in the fields is very low, not allowing a matching. The field boundaries always have been matched. The forest in the northern centre part even did not cause any problem. In the Mausanne February scene (figure 2, centre) the situation was better, but also some fields disturbed. In the left centre side some small clouds did not allow the matching. In the north-east corner dark shadows of the mountain caused some problems. The matching in the Warsaw scene was better than expected – the snow coverage on the fields still included some contrast, nevertheless also some fields covered by snow could not be matched. The failure in the fields did not cause large problems in the DEM generation

because the fields are dominating flat, allowing interpolation between the surrounding points.

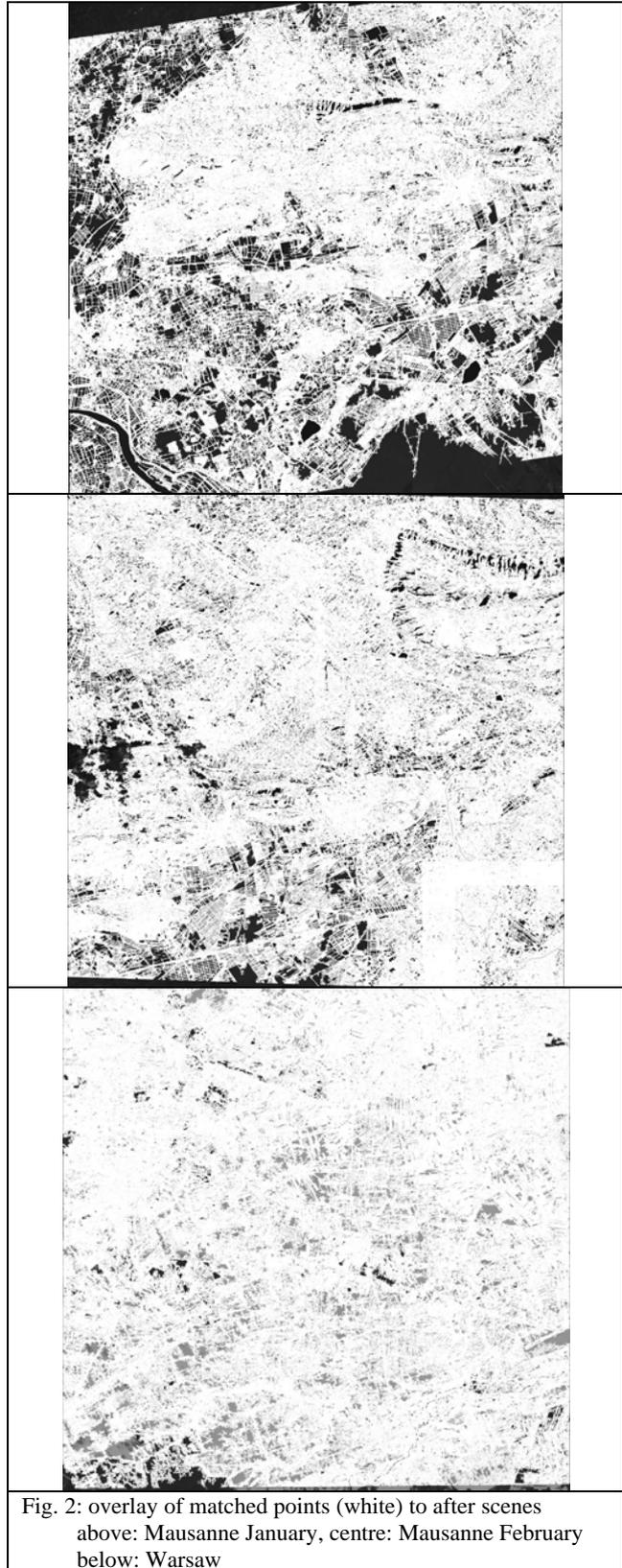


Fig. 2: overlay of matched points (white) to after scenes
 above: Mausanne January, centre: Mausanne February
 below: Warsaw

The quality images (figure 3) do show the distribution of the correlation coefficients, presented as grey values. The correlation coefficient 1.0 corresponds to the grey value 255,

while the correlation coefficient 0.6 is shown with grey value 51. The not accepted points ($r < 0.6$) are not presented.

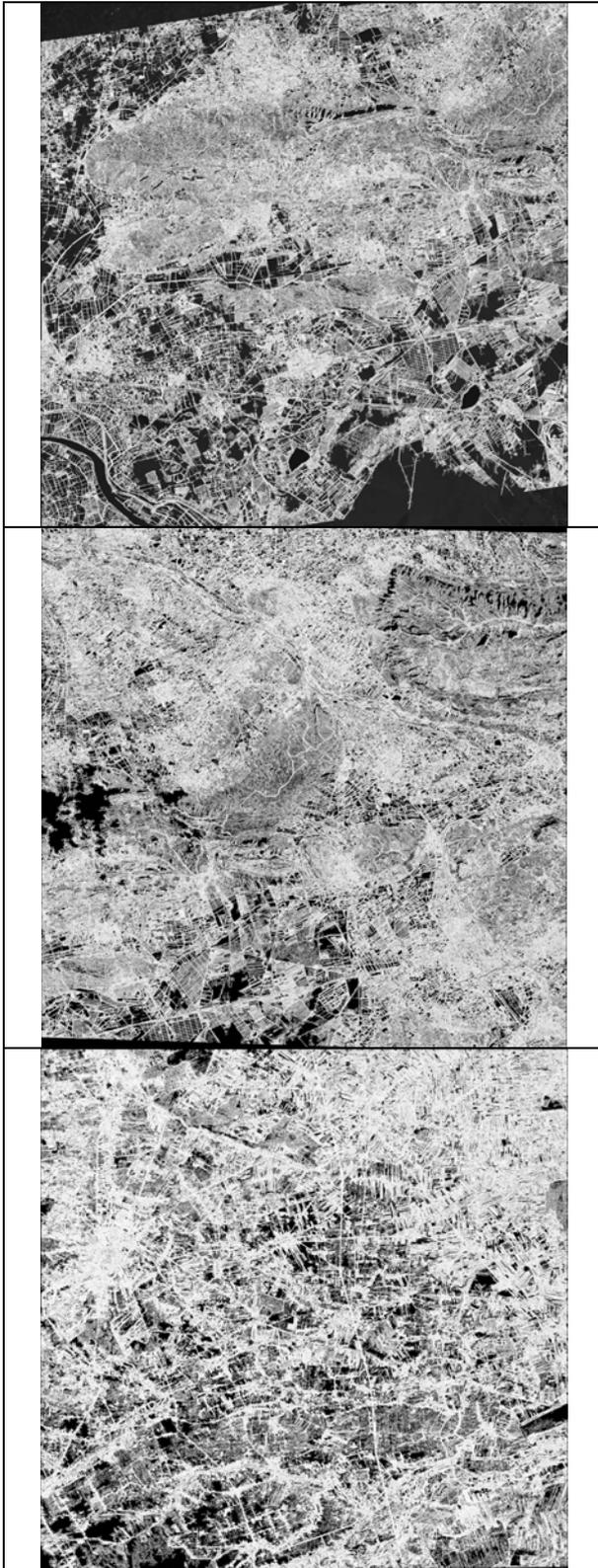


Fig. 3: quality of matching - correlation coefficient shown as grey value $r=1.0 = \text{grey value } 255$ $r=0.6 = \text{grey value } 51$
 above: Mausanne January, centre: Mausanne February
 below: Warsaw

In the Mausanne January scene the matched forest in the above centre location shows lower correlation coefficients (figure 3 above), while the urban areas, roads and field boundaries do have larger values. Also the Mausanne February model shows lower correlation values in the forest areas as well as in some fields with low contrast. In the build up areas the good contrast caused large correlation values. The same can be seen in the Warsaw model, here in addition some snow covered fields caused problems.

The reference DEM in the Mausanne test field is presenting ellipsoidal heights while the control points and corresponding to this also the generated height models are in orthometric heights. This required a correction of the Mausanne reference DEM by geoid undulations with a vertical shift by approximately 50.0m. The precise EGG97 with spacing of 0.025° respectively 0.017° was used. A check against the free of charge available EGM96 having 0.25° spacing showed only 10cm difference to this.

Often the generated height models, based with the horizontal location on the control points, are shifted against the reference height models. By adjustment of the shift with the Hannover program DEMSHIFT only negligible differences in the horizontal location have been determined for all 3 data sets. The negligible shifts did not influence the root mean square height differences.

The heights from automatic image matching are presenting the height of the visible surface; that means they are digital surface models (DSM) and not DEMs which should have the height values of the bare ground. If between the height values on top of vegetation – especially trees and also buildings, points of the bare ground are available; such a DSM can be filtered to a DEM. This filtering was made with the Hannover program RASCOR (Passini et al 2002). The filtering is limited in dense forest areas where no point may be located on the bare ground. The influence of the filtering can be seen at the frequency distribution of the discrepancies against the reference DEM. Without filtering the frequency distribution is quite more asymmetric (figure 4, left) than after filtering (figure 4, right) – the number of points not belonging to the bare ground, has been reduced. The negative values shown in figure 4 are located above the reference DEM.

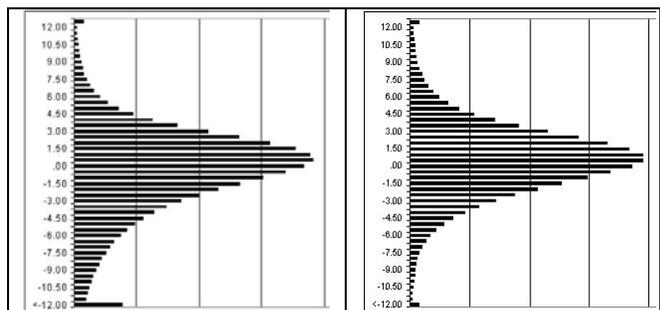


Fig. 4: frequency distribution of Z-differences against reference DEM – left: original matched DSM, right: filtered DSM
 negative: matched DSM is located above reference DEM

The accuracy of a DEM cannot be expressed just with one figure; at least a dependency of the accuracy upon the terrain inclination has to be investigated. Figure 4 shows the root mean square discrepancies of the generated and filtered height model of the Mausanne, January model as a function of the terrain inclination. A clear linear dependency to the tangent of the terrain inclination exists, by this reason the DEM accuracy has

to be expressed by the function: $SZ = A + B * \tan \alpha$ with α as terrain inclination.

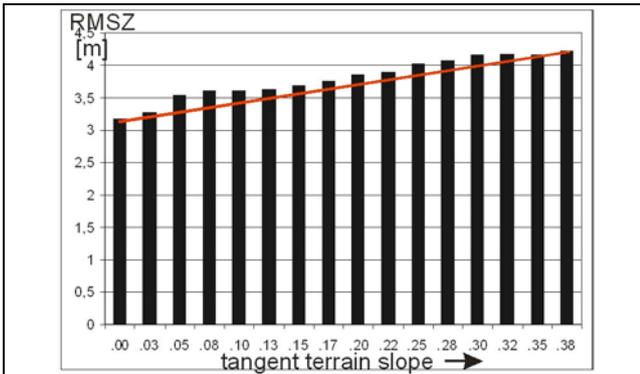


Fig. 5: root mean square discrepancies of generated DSM against reference DEM, as function of the terrain inclination; Mausanne, January after filtering $SZ = 3.15m + 1.9 * \tan \alpha$

In addition to the dependency upon the terrain inclination we have to expect different results depending upon the type of terrain. Usually forest areas are showing different results like the other parts, by this reason the forest areas have been analysed separately. Forest layer have been generated which can be used by program RASCOR for the separation of the forest and not forest areas, here named open areas.

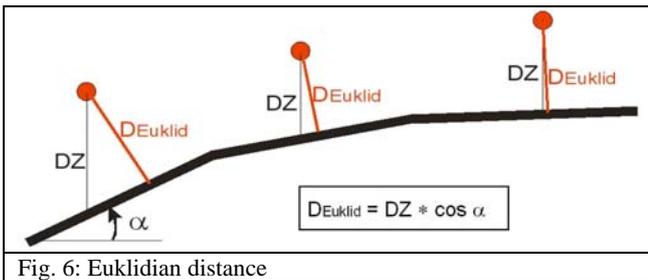


Fig. 6: Euklidian distance

The differences in the Z-coordinates do not describe the shortest distance between both compared height models – the shortest distance is the Euklidian distance, shown in one dimension in figure 6. The accuracy of the height models can be described also with the root mean square Euklidian distance. In the above mentioned formula as function of the terrain inclination, the Euklidian distance is not changing the constant value; it is only slightly reducing the dependency upon the terrain inclination. The difference is growing with more steep terrain. For example in the Mausanne January model the root mean square Z-difference in open areas, not filtered, is as function of ΔZ : $SZ = 3.17m + 3.14m * \tan \alpha$, as Euklidian distance it is: $SZ = 3.17m + 3.03m * \tan \alpha$. In general the difference between both is not important, by this reason only the root mean square ΔZ -values are listed.

	SZ	bias	SZ as F(inclination)
open areas	4.02	-0.51	$3.91 + 1.64 * \tan \alpha$
forest	3.55	0.92	$3.33 + 0.33 * \tan \alpha$
open areas filtered	3.30	0.48	$3.17 + 3.14 * \tan \alpha$
forest filtered	3.47	1,49	$2.93 + 1.81 * \tan \alpha$

table 2: analysis of the Mausanne January DSM [m]

	SZ	bias	SZ as F(inclination)
open areas	4.13	-1.16	$3.96 + 3.06 * \tan \alpha$
forest	3.59	0.58	$2.82 + 1.70 * \tan \alpha$
open areas filtered	3.39	-0.58	$3.22 + 1.97 * \tan \alpha$
forest filtered	3.42	1.43	$2.69 + 1.97 * \tan \alpha$

table 3: analysis of the Mausanne February DSM [m]

	SZ	bias	SZ as F(inclination)
open areas	3.23	-0.54	$3.16 + 1.19 * \tan \alpha$
forest	4.37	0.64	$4.11 + 0.34 * \tan \alpha$
open areas filtered	2.43	0.44	$2.39 + 8.80 * \tan \alpha$
forest filtered	3.13	0.81	$3.11 + 6.50 * \tan \alpha$

table 4: analysis of the Warsaw DSM [m]

The filtering for elements not belonging to the bare ground has improved in any case the results. Like shown in figure 4, the original frequency distribution in any case is a little asymmetric caused by elements located above the bare ground. After filtering, all frequency distributions are nearly symmetric. The constant part of the inclination depending analysis has been improved in the open areas 21% and in the forest areas 14%. In most cases the improvement in the forest is larger than the improvement in the open areas and usually the results in the forest areas are not as good as in all 3 test areas. This may be caused by the imaging in January and February. At this time of the year the trees in these areas do not have leaves, allowing seeing at least partially the bare ground. This also may be the reason why the results in the forest areas of both Mausanne test areas are partially better like in the open areas.

The systematic difference between the height models, named bias, is influenced by the objects located above the terrain. It is strongly influenced by the filtering because mainly points identified by the filter process as not belonging to the bare ground are dominating located above the DEM. By filtering the bias is getting a positive correction.

The vertical accuracy can be expressed like following:

$$SZ = h/b * Spx \quad \text{formula 1: } SZ = \text{standard deviation of } Z$$

h=height b=base
Spx = standard deviation of x-parallax [GSD]

For Cartosat 1 the height to base relation is 1.6. With this relation and formula 1, the achieved results can be transformed into the standard deviation of the x-parallax, allowing a comparison with other sensors (table 5).

	matched DSM		filtered	
	open	forest	open	forest
Mausanne, January	0.98	0.83	0.79	0.73
Mausanne, February	0.99	0.70	0.80	0.67
Warsaw	0.79	1.02	0.60	0.78

table 5: accuracy of x-parallax (computed from constant value of function depending upon inclination) in [GSD]

The results achieved in the open areas of the Warsaw test area are better than in the Mausanne test areas. This is mainly caused

by the better contrast in the Warsaw images. In general the imaging conditions in the northern latitude of 44° (Mausanne) and 51° (Warsaw) in January and February are not optimal – the sun elevation in the Mausanne area was just 28.8° respectively 31.1° and in the Warsaw area 30.3°. With higher sun elevation and also with vegetation on the fields the object contrast will be better. Nevertheless under operational conditions no better results can be expected.

CONCLUSION

The geometric conditions of Cartosat-1 checked by bias corrected RPC-solution are not causing any problems. As usual, often the orientation checks more the control point accuracy and identification than the scene geometry. With the good conditions of the Warsaw test area discrepancies in the range of 0.6 GSD have been reached – totally sufficient for the planned applications.

The stereo models of Cartosat-1 do have optimal conditions for the generation of digital height models by automatic image matching. The short time interval between both images avoids a change of the object between imaging. The height to base relation of 1.6 is a good compromise for open and build up areas. A larger angle of convergence often causes problems in matching especially in mountainous and also in build up areas, so the percentage of matched points may be smaller than the reached 84% up to 94%. On the other side a smaller angle of convergence has a negative influence to the accuracy.

With a standard deviation of the x-parallax between 0.60 and 0.80 GSD similar x-parallax accuracies like with the comparable SPOT HRS have been reached (Jacobsen 2004). Of course with the different GSD and different height to base relation the absolute vertical accuracy based on SPOT HRS cannot be as good like for Cartosat-1.

Of course the matching results depend upon the used area. In general open areas with sufficient contrast are optimal, but also under the not so optimal conditions of forest the achieved results are satisfying.

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