EVALUATION OF CARTOSAT 1 GEOMETRIC POTENTIAL

P.S. Titarov

Racurs Company, Moscow, Russia - titarov@racurs.ru

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ABSTRACT:

The results of Cartosat 1 (IRS P5) imagery investigation held in terms of participation in ISPRS and ISRO Cartosat 1 Scientific Assessment Programme (C-SAP) are presented. Different images orientation methods were tested; the recommended one is bias-and-drift adjusted RPC model. In the case of single stereopair or single scene, four well-distributed reliable ground control points is enough to achieve sub-pixel orientation accuracy (evaluated using numerous check points). In the case of block of stereopair, the number of ground control points required per stereopair can be diminished by replacing part of them by tie points measured in the stereopairs overlap (four-times overlapping area). The derived DEM accuracy is 2 m RMSE for flat area and 7 m RMSE for mountainous one (as compared to reference DEMs). The orthoimagery created meets the geometric accuracy requirements to 1 : 10 000 scale maps.

1. INTRODUCTION

The investigation presented was held in terms of participation in ISPRS (International Society for Photogrammetry and Remote Sensing) and ISRO (Indian Space Research Organization) Cartosat 1 Scientific Assessment Programme (C-SAP). Two C-SAP Test Sites were involved into the research. The results concerning one of these Test Sites (Warsaw, Poland) were reported on ISPRS Hanover Workshop 2007 "High Resolution Earth Imaging for Geospatial Information" (Titarov, 2007).

The research was aimed at the evaluation of achievable geometric accuracy of photogrammetric products (Digital Elevation Model (DEM) and orthoimagery) derived from Cartosat 1 imagery.

Cartosat 1 Stereo Orthokit data samples were provided for the evaluation by ISRO. Orthokit products (Mono/Stereo) are geometrically raw but radiometrically corrected panchromatic scenes of size 12000×12000 pixels with Ground Sample Distance (GSD) about 2.5 metres. The imagery is supplied with Rational Polynomial Coefficients (RPC) and intended for photogrammetric processing. Stereo Orthokit product consists of the along-track stereopair with base-to-height ratio 0.62, RPC for each image and product metadata (NRSA brochure).

Primary Investigators provided reference data for the C-SAP Test Sites. The reference datasets include DEM and Ground Control Points (GCP).

2. DATASETS INVOLVED

2.1. C-SAP Test Site #9 (Warsaw, Poland)

The imagery data consists of a single stereopair acquired on February 25, 2006; approximate geographic extents of the images overlap are: latitude 51.6÷51.8 degrees, longitude 20.2÷20.5 degrees. The reference DEM involved was derived from 1 : 25 000 topographic maps and TK 350 satellite images and has accuracy of 1-2 m, the grid cell size is 20 m. The DEM covers almost whole stereopair. The GCP set includes 36 points measured by GPS, which are very well distributed in the images overlap. The imagery and reference data layout for the test site is shown in Figures 1 and 6.

2.2. C-SAP Test Site #5 (Mausanne les Alpilles, France)

The imagery data for the Test Site consists of two partially overlapping stereopairs acquired on January 31 and February 06, 2006; approximate geographic extents are: latitude 43.6÷43.9 degrees, longitude 4.7÷5.2 degrees. The reference DEM provided covers only part of the imaged area; the DEM is derived from aerial images. Its accuracy is 0.6 m and grid cell size is 2 m. GCP set provided includes 32 points that are evenly distributed over the first mentioned stereopair; so the second one is supplied with GCPs only in the stereopairs overlap area. The GCPs coordinates accuracy is 5 cm. The imagery and reference data layout for the test site is shown in Figures 2, 7.

3. THE ELEMENTS OF PUSHBROOM PHOTOGRAMMETRY

3.1. Basic photogrammetric problems

Three main problems should be solved to implement photogrammetric procedures. The first one is images orientation problem, which is to improve accuracy of the images geometric models. The second is space intersection problem that must be solved to extract digital terrain model from stereopairs; the problem is to derive ground coordinates of a point from its pixel coordinates on the images of the stereopair. The third problem is space resection, which is solved to create orthoimagery. The objective of space resection is to calculate pixel coordinates of the point on image from its ground coordinates.

The method to solve the problems depends on the imagery geometry model applied. The methods commonly used are briefly summarized below.

3.2. Methods of pushbroom photogrammetry

Three main approaches are widely used for photogrammetric processing of pushbroom satellite imagery. The first one is rigorous approach, which implies physical modelling of satellite motion and attitude as well as internal sensor geometry. The approach cannot be applied to Cartosat 1 images because its metadata does not contain necessary data. The second approach is based on RPC, which are the approximation of rigorous model; these methods are applicable to Cartosat 1 Orthokit imagery. The third approach may be called "parametric". In this case no metadata is used; the model may be based on different formulae but anyway all the parameters involved are derived from GCP only. A classic example of the "parametric" model is Direct Linear Transformation (DLT). Others are parallel-perspective model, affine model and so on.

Obviously RPC is preferable approach for Cartosat 1 Orthokit imagery, but it may be interesting to try parametric one too. Firstly it characterizes possibilities of radiometrically corrected Cartosat 1 imagery without RPC (non-Orthokit standard products). Secondly it is sometimes problematic to apply RPC when the processing must be performed with respect to a local reference system, and all the reference data (DEM and GCP) as well as output photogrammetric products are related to it. Sometimes transformation parameters from the local system to WGS 84 are classified or unknown.

3.3. Photogrammetric processing based on RPC

RPC define so-called replacement model. Detailed description of this model as well as RPC-based bundle adjustment procedure is given in (Grodecki and Dial, 2003), so these aspects are summarized very briefly here.

RPC are supplied by the imagery product provider and define the relationship between normalized pixel coordinates l_N, s_N and normalized ground coordinates (usually given with respect to WGS 84) φ_N, λ_N, h_N (h_N is normalized height above the ellipsoid):

$$
\begin{aligned}
l_N &= \frac{Num_l(\varphi_N, \lambda_N, h_N)}{Den_l(\varphi_N, \lambda_N, h_N)} \\
s_N &= \frac{Num_s(\varphi_N, \lambda_N, h_N)}{Den_s(\varphi_N, \lambda_N, h_N)}
\end{aligned}
\tag{1}
$$

where Num_l, Den_l, Num_s, Den_s are third-order polynomials.

Bundle adjustment refines the model using ground control and tie points; the procedure is described in (Grodecki and Dial, 2003). Two types of the refinement were tried in the investigation: bias-only adjustment:

$$
\begin{aligned}
l &= l_D + a_0 \\
s &= s_D + b_0
\end{aligned}
\tag{2}
$$

and bias-and-drift adjustment involving both line and sample linear terms:

$$
\begin{aligned}
l &= l_D + a_0 + a_l \cdot l_D + a_s \cdot s_D \\
s &= s_D + b_0 + b_l \cdot l_D + b_s \cdot s_D
\end{aligned}
\tag{3}
$$

where l_D, s_D are denormalized values of l_N, s_N which are given by equation (1).
The space resection problem is solved straightforward following equations (2) or (3). The space intersection problem

is mathematically equal to the set of four non-linear equations with three unknowns. The solution is found iteratively; the initial values of unknowns are calculated using DLT derived from the RPC by approximation.

3.4. Photogrammetric processing based on GCP only

Two methods were used in the investigation and accordingly they are described here: well-known DLT method and parallel-perspective model. DLT is traditionally used for cameras with unknown or non-central projection geometry, while parallel-perspective model can be derived from rigorous pushbroom imaging model relying on some simplifying assumptions.
DLT is defined by the formulae

$$
\begin{aligned}
l &= \frac{A_1 X + A_2 Y + A_3 Z + A_4}{C_1 X + C_2 Y + C_3 Z + 1} \\
s &= \frac{B_1 X + B_2 Y + B_3 Z + B_4}{C_1 X + C_2 Y + C_3 Z + 1}
\end{aligned}
\tag{4}
$$

where X, Y, Z are Cartesian ground coordinates of the point and A_i, B_j, C_k are the model parameters derived from GCP.

Parallel-perspective model is defined by the formulae

$$
\begin{aligned}
l &= L_1 X + L_2 Y + L_3 Z + L_4 \\
s &= \frac{L_5 X + L_6 Y + L_7 Z + L_8}{L_9 X + L_{10} Y + L_{11} Z + 1}
\end{aligned}
\tag{5}
$$

where model parameters are L_i.

In both cases the model parameters are derived from GCP; using tie points (together with GCP) for parameters calculation is precarious because the model is not rigid enough. So image orientation ("adjustment") procedure is performed separately for each image and leads to a set of linear equations where parameters are unknowns.

The space resection problem is solved straightforward following equations (4) or (5) while space intersection problem is mathematically equal to the set of four linear equations with three unknowns X, Y, Z, which are derived from a pair of equations (4) or (5).

4. EVALUATION METHODOLOGY

The data assessment process concerns three aspects:
(a) evaluation of the images orientation accuracy;
(b) DEM accuracy assessment;
(c) orthoimagery accuracy assessment.

4.1. Evaluation of the images orientation accuracy

To evaluate the achievable image orientation accuracy, the adjustment procedure is performed several times using different methods (RPC, DLT, parallel-perspective) and various GCP sets. The orientation experiments are outlined in Table 1.

The experiments 1-3 were planned to check the accuracy of provided RPC itself and to recognize the adequate refinement model. The experiment 4 is to evaluate optimal (minimal but

redundant) number of reliable GCP, which is enough for accurate image or separate stereopair orientation. The experiment 5 is to evaluate the possibility of diminishing GCP count in the case of block of stereopairs orientation.

Test #	Orientation method	Ground points	
		Control points	Check points
1	RPC only	No	All available
2	RPC + bias	All available	No
3	RPC + bias + drift	All available	No
4	RPC + bias + drift	Optimal	All the rest
5	RPC + bias + drift	Partially replaced by ties	All the rest
6	DLT	All available	No
7	DLT	Optimal	All the rest
8	Parallel-perspective	All available	No
9	Parallel-perspective	Optimal	All the rest

Table 1. Imagery orientation accuracy investigation experiments.

The experiments 6-9 were devoted to alternative models. Ones number 6 and 8 are to test how close are the appropriate models to the Cartosat 1 image geometry while experiments 7 and 9 check their practical feasibility.

4.2. DEM accuracy assessment

The DEM accuracy assessment procedure is very simple but reliable because every node of the derived DEM is checked (if reference DEM is available). The procedure is bulky but it does not cause a problem because it is fully automated.

For each node of the DEM to be tested (one derived from Cartosat 1 imagery) the appropriate height was compared with height calculated (by bilinear interpolation) from the reference DEM. The procedure output included the height Root-Mean-Square Error (RMSE), mean error, mean absolute error (mean error modulus), and the number of nodes checked.

4.3. Orthoimagery accuracy assessment

The orthoimagery accuracy was evaluated by comparing the coordinates of the check points measured on it with their coordinates included into the reference datasets.

4.4. Software used for evaluation

The whole processing workflow (images radiometric enhancement, points measurement, images orientation, DEM and orthoimagery creation) was implemented using

PHOTOMOD 4.2 and 4.3 software (developed by Racurs Company).

The DEM comparison procedure was performed using the specific software developed by the author for the investigation.

5. THE EVALUATION RESULTS

5.1. Imagery orientation accuracy

The images orientation results are shown in Tables 2 and 3 (the experiments descriptions are given in the Table 1 above).

Test #	Control points			Check points		
	Count	RMSE, m		Count	RMSE, m	
		Horiz.	Vert.		Horiz.	Vert.
1	0	-	-	36	116	761
2	36	16.3	5.6	0	-	-
3	36	1.6	0.8	0	-	-
4	4	0.4	0.1	32	1.9	0.9
6	36	1.7	2.7	0	-	-
7	10	1.3	3.7	26	2.1	4.0
8	36	1.8	6.1	0	-	-
9	10	2.0	7.5	26	3.1	7.3

Table 2. Imagery orientation accuracy experiments results for Test Site #9 (Warsaw).

Test #	Control points			Check points		
	Count	RMSE, m		Count	RMSE, m	
		Horiz.	Vert.		Horiz.	Vert.
1	0	-	-	32	5138	451
2	32	8.9	4.6	0	-	-
3	30	2.2	1.5	0	-	-
4	7	1.6	1.7	23	2.5	1.5
5	4	1.1	4.0	26	2.5	2.6
6	30	21.7	10.2	0	-	-
7	10	53.1	17.2	20	97.7	20.3
8	30	3.0	5.5	0	-	-
9	10	2.2	7.0	20	8.8	8.5

Table 3. Imagery orientation accuracy experiments results for Test Site #5 (Mausanne les Alpilles).

According to the experiment 1 results, the source (no refinement applied) RPC model gives large errors. The Figure 1 shows the plane error vectors for the ground points. The errors are obviously systematic.
The experiment 2 shows that the bias refinement model is not adequate for Cartosat 1 imagery. The Figure 2 shows the errors, which are still systematic. The errors are large at the image sides and diminish while getting closer to the image centre; the plane displacement is directed mainly along the images lines.
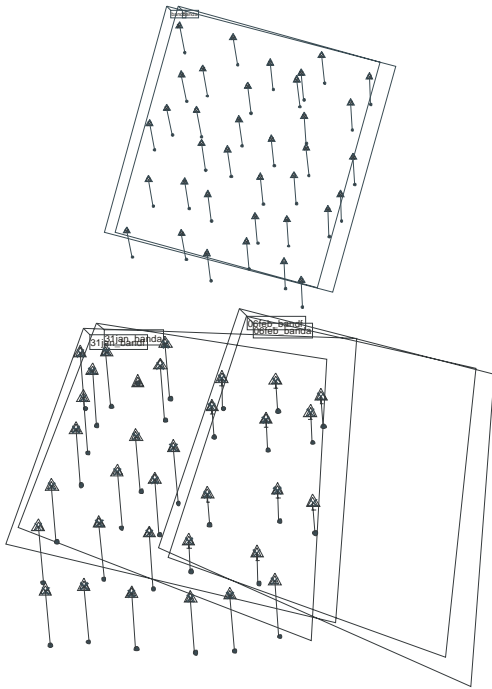
Figure 1. The errors obtained using RPC with no refinements applied (Test Site #9 is upper, Test Site #5 is lower).
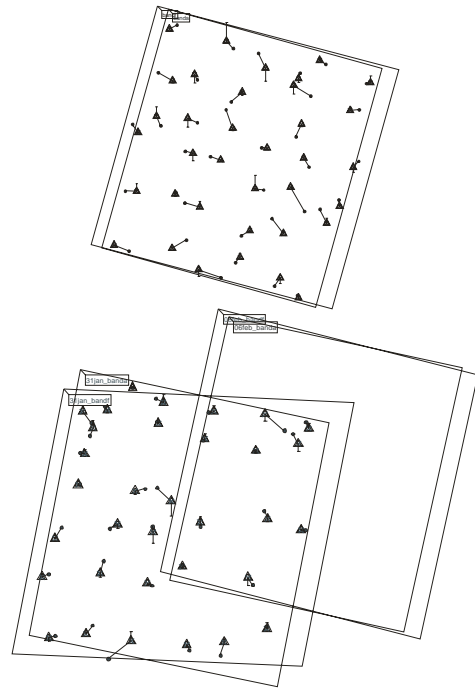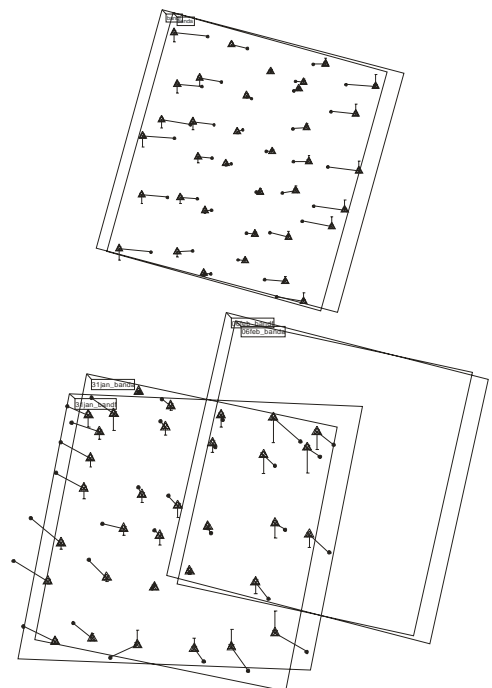

Figure 2. The errors obtained using RPC with bias-only refinements applied (Test Site #9 is upper, Test Site #5 is lower).

The experiment 3 achieves sub-pixel RMSE; the errors seem to be random (Figure 3). It implies that the bias-and-drift refined RPC model adequately represents Cartosat 1 image geometry. During the experiment two ground points were excluded out of Test Site #5 reference dataset since they gave errors significantly outstanding as compared to mean ones.

Figure 3. The errors obtained using RPC with bias-and-drift refinements applied (Test Site #9 is upper, Test Site #5 is lower), all the ground points are GCP.

Then the imagery orientation was performed using at least four GCP per stereopair. Since at least three GCP is required to calculate bias-and-drift refinement, four GCP provide minimal redundancy for a single image or stereopair. The GCP were measured at the corners of images inasmuch it is possible. The resulting scheme is given in Figure 4. The experiment proves that the sub-pixel orientation accuracy can be achieved with four reliable and well-distributed GCP.

The experiment 5 is to try replacing some of GCP in the stereopair overlap (four-times overlapping area) by tie points; obviously the experiment is relevant only to Test Site #5. Four GCPs were measured on the entire block: so one stereopair was supplied with a GCP at each corner, while the second stereopair contained only one GCP near its centre. The experiment shows that the RMSE is still close to the images GSD so tie points can be applied to diminish GCP count in the case of orientation of block of Cartosat 1 stereopairs. The GCP configuration as well as error vectors are shown in the Figure 5.

The experiments 6-9 show that in the case of flat terrain the alternative models (DLT and parallel-perspective) provide plane accuracy close to that achieved by RPC while the height errors are several times larger; but on mountainous areas the models are quite insufficient for Cartosat 1 stereopairs. For the Test Site #5 only the stereopair completely supplied with GCP was involved in the experiments 6-9.

Notice that the error vectors shown in the Figure 1-5 are scaled to be easily visible, so they depict the errors distribution but not absolute values.
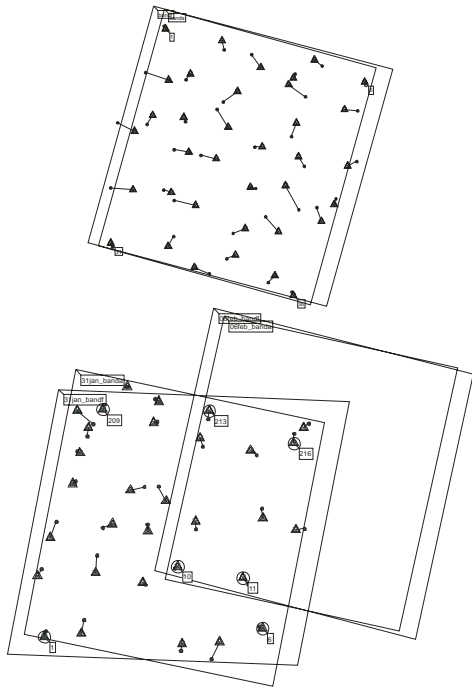
Figure 4. The errors obtained using RPC with bias-and-drift refinements applied (Test Site #9 is upper, Test Site #5 is lower). Al least four GCP per stereopair are involved (GCP are labelled).
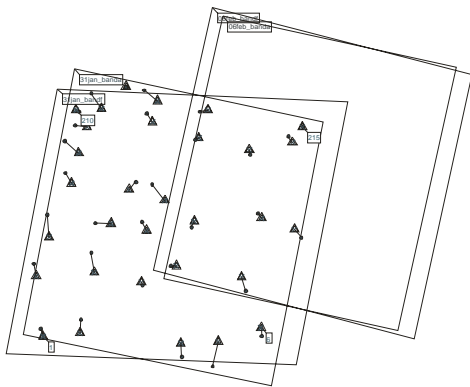

Figure 5. The errors obtained using RPC with bias-and-drift refinements applied (Test Site #5). Some GCP are replaced by tie points (GCP are labelled).

5.2. DEM accuracy

The stereopairs for DEM creation were oriented in adjustment experiment 4 (refer to Tables 1,2,3). The DEMs were created in PHOTOMOD standard workflow manner: first Triangulated Irregular Networks (TINs) were created using cross-correlation, then the TINs were automatically filtered and manually edited to eliminate peaks caused by correlation blunders, and finally the DEMs were created.

Grid cell size of Test Site #9 (Warsaw, Poland) derived DEM is 20 m to be close to one of the reference DEM. The DEMs comparison shows that the derived DEM is extremely close to the reference one: RMSE is 2.3 m (LE90 = 1.96×RMSE = 4.5 m); mean error +1.0 m; mean absolute error 1.7 m. Checked nodes count is 1 985 266. The non-zero mean error discloses

some systematic misalignment between the DEMs compared. It may be caused by the difference in vertical datum used for reference DEM and GCPs. So RMSE and LE90 given above are not calculated quite correctly; it is possible to diminish them twice by eliminating systematic error. It should be noticed, that after removing the systematic error, the RMS difference between created and reference DEMs does not exceed the reference DEM height RMSE. The derived and reference DEMs are shown separately and superimposed in Figure 6.
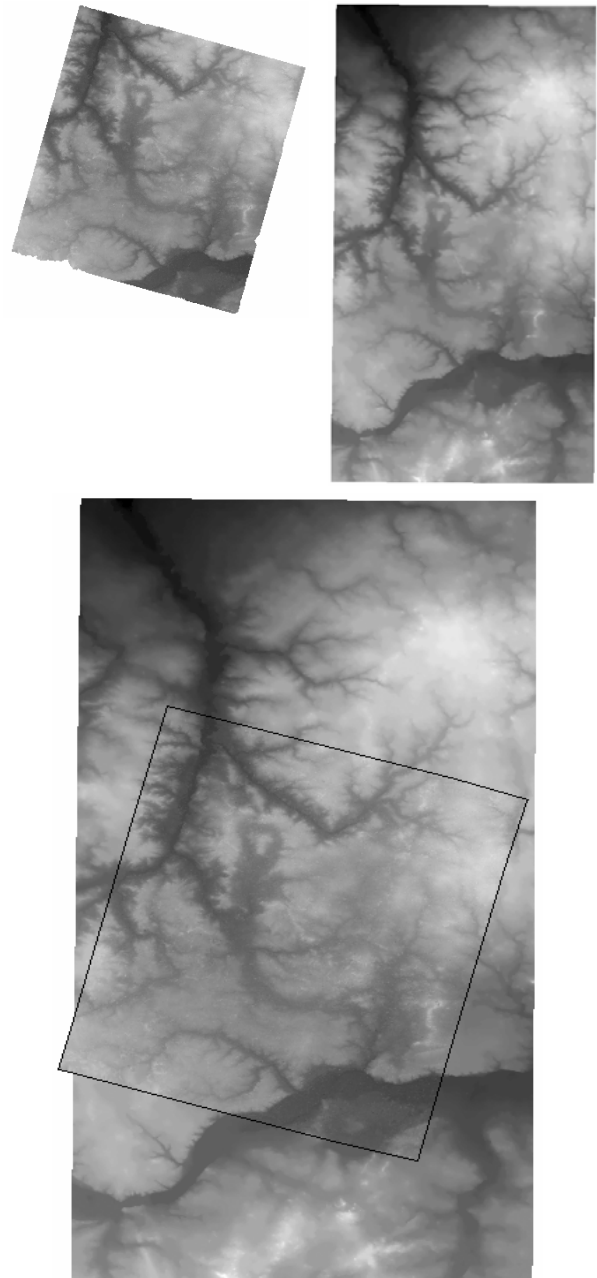

Figure 6. The derived (upper left) and reference (upper right) DEMs separately and superimposed (lower) for the Test Site #9 (Warsaw, Poland).

Grid cell size of Test Site #5 (Mausanne les Alpilles, France) derived DEM is 10 m. The test site contains mountainous area so derived and reference DEMs differ more significantly: RMSE is 7.2 m (LE90 = 14.1 m); mean error is +0.8 m; mean

absolute error is 4.4 m. Checked nodes count is 6 358 422. The derived and reference DEMs are shown in Figure 7.
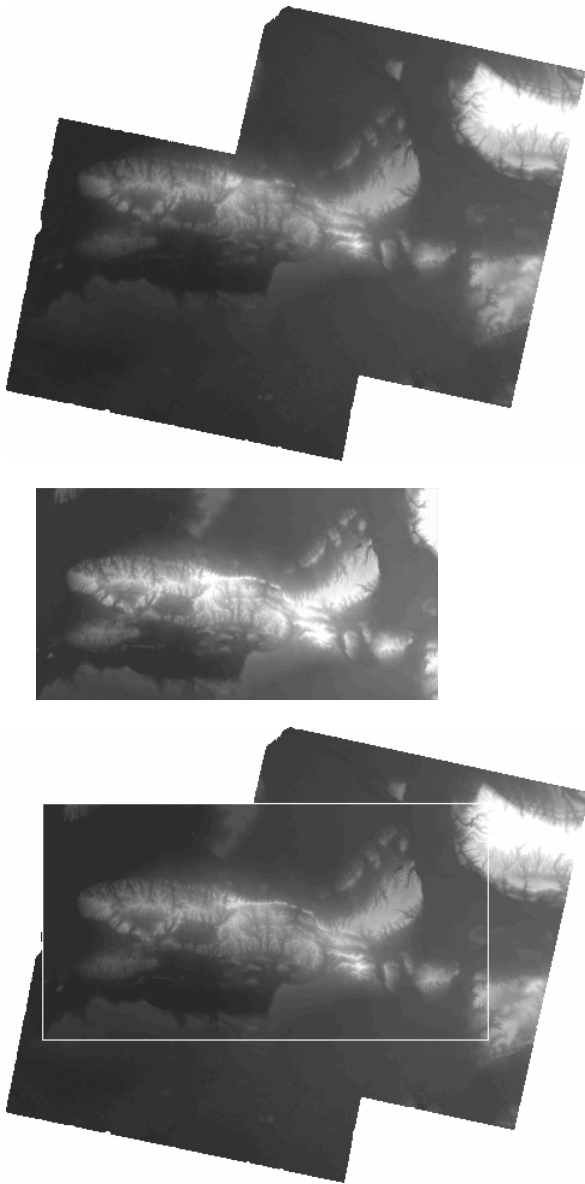

Figure 7. The derived (upper) and reference (in the middle) DEMs separately and superimposed (lower) for the Test Site #5 (Mausanne les Alpilles, France).

5.3. Orthoimagery accuracy

The orthoimagery accuracy was checked by measuring the coordinates of ground points that were used as check points in the imagery orientation procedure.

The test shows that in general the difference between coordinates measured on the orthoimagery and ones included in the reference dataset is approximately equal to GSD (2.5 m). The maximum difference achieved through the two test sites is 4.2 m.

The map accuracy requirements differ depending on the regional regulation, but in general the accuracy achieved corresponds to 1 : 10 000 map scale.

Nevertheless one should keep in mind that it may be difficult to recognize on the images all the objects that must be shown on the 1 : 10 000 map.

6. CONCLUSIONS

The investigation shows that the optimal method of Cartosat 1 imagery orientation is bias-and-drift adjusted RPC. Four well-distributed reliable ground control points per stereopair is enough to achieve sub-pixel orientation accuracy. It is possible to diminish the total GCP count in the block by replacing part of them by tie points in stereopairs overlap. The derived DEM accuracy is 2 m RMSE for flat areas and 7 m RMSE in the mountainous ones. The generated orthoimagery meets the geometric accuracy requirements to 1 : 10 000 scale maps.

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