CARTOSAT-1 STEREO ORTHOKIT DATA EVALUATION

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Cartosat-1 (IRS P5), C-SAP, ISPRS, ISRO, Orthoimagery, DEM, Evaluation

ABSTRACT:

The results of Cartosat-1 imagery investigation as part of ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP) are presented. Different images orientation methods are tested; the recommended one is bias-and-drift refined RPC model. Four well-distributed reliable ground control points are enough for sub-pixel orientation accuracy (evaluated using numerous check points). The derived DEM accuracy is 3 meters RMSE. The orthoimagery meets the geometric accuracy requirements to 1 : 10 000 scale maps.

1. INTRODUCTION

The investigation presented was held as part of ISPRS-ISRO Cartosat-1 Scientific Assessment Programme (C-SAP). Racurs company participates in the programme as Co-Investigator, so the appropriate Primary Investigator (Geosystems Polska) supplied us with the Test Data Set (Test Site #9).

The investigation was aimed at the evaluation of achievable geometric accuracy of photogrammetric products (digital elevation model and orthoimagery) derived from Cartosat-1 imagery.

2. CARTOSAT-1 SATELLITE AND STEREO ORTHOKIT IMAGERY PRODUCT

Cartosat-1 satellite was built by the Indian Space Research Organization (ISRO) mainly for mapping. The satellite was launched into circular (altitude is 618 km) near-polar sun-synchronous orbit on May 5, 2005 from the Satish Dhawan Space Centre, Sriharikota, India. Cartosat-1 is equipped with two panchromatic cameras capable of simultaneous acquiring images of 2.5 meters spatial resolution. One camera is looking at +26 degrees forward while another looks at –5 degrees backward to acquire stereoscopic imagery with base to height ratio of 0.62. The time difference between acquiring of the stereopair images is approximately 52 seconds. The cameras are across-track-steerable to enhance the system productivity. On-board solid-state recorders capacity is 120 Gigabits. The radiometric resolution is 10 bits, stereoscopic swath width is about 26 km while wide-field (using both cameras) mono swath is 55 km. (*Lutes, 2006; Navalgund, 2005; NRSA brochure*)

Orthokit products (Mono/Stereo) are geometrically raw but radiometrically corrected. The imagery is supplied with Rational Polynomial Coefficients (RPC) and intended for photogrammetric processing (*NRSA brochure*). The investigation presented is focused on the Stereo Orthokit product that consists of the along-track stereopair, RPCs for each image and product metadata.

3. DATASET USED

The dataset used for the investigation is C-SAP programme Test Site #9 (Warsaw, Poland).

Imagery data provided by ISRO are Stereo Orthokit Product; it includes images themselves along with RPC and metadata files for each image. The images were acquired on February 25, 2006; the images sizes are 12000×12000 pixels while approximate geographic extents of their overlap are: latitude 51.6÷51.8 degrees, longitude 20.2÷20.5 degrees.

Reference data provided by the Test Site #9 Primary Investigator (Geosystems Polska) consists of Digital Elevation Models (DEM) and Ground Control Points (GCP).

DEM data includes two datasets. In accordance with comments given by the Primary Investigator, the first dataset called “NM DTEDT” was derived from off-the-shelf topographic maps of scale 1 : 50 000; accuracy of about 5 meters was expected. The second dataset called “DTM Warsaw” has accuracy of 1-2 meters and was derived from 1 : 25 000 topographic maps and TK 350 satellite images. Moreover the dataset extents are much wider than first DEM ones (see Figure 1 for available DEMs and imagery overlap). Furthermore the cell size of “DTM Warsaw” DEM is smaller. So the second DEM is obviously preferable and should be used for the investigations.

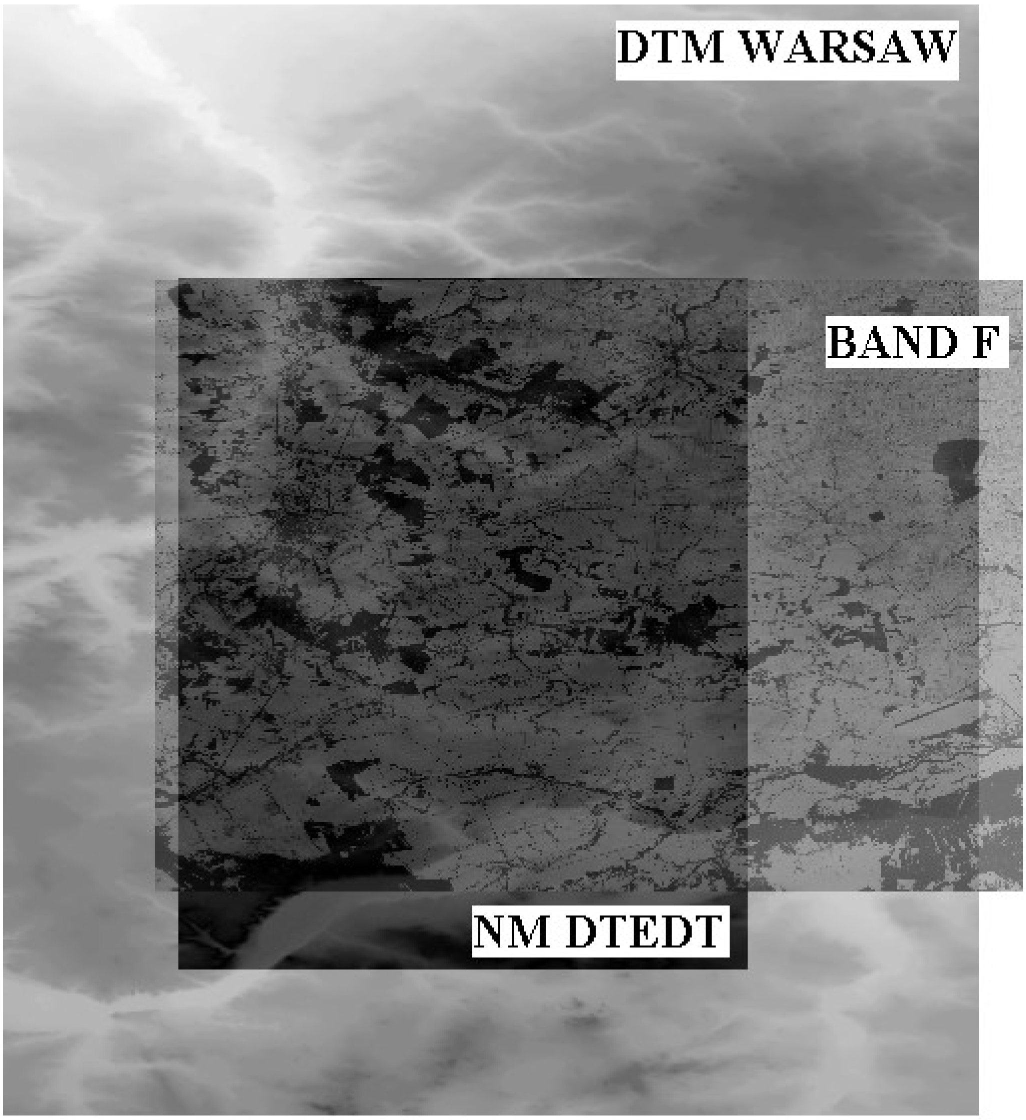

Figure 1: Overlap of DEM and image data.

The ground control points set includes 36 points. Their ground coordinates are given with respect to WGS 84 (latitude/longitude and UTM) as well as in Polish local reference systems. It should be noted that heights are available both above ellipsoid and EGM 96 geoid. The sketches are provided to facilitate point's measurement on the images. The points location is marked by circle which shows that the GCP is somewhere inside; no pixel coordinates or unambiguous mark is available, so sometimes it is rather problematically to measure point as accurately as one pixel. Nevertheless it should be noted that the points are distributed very well.

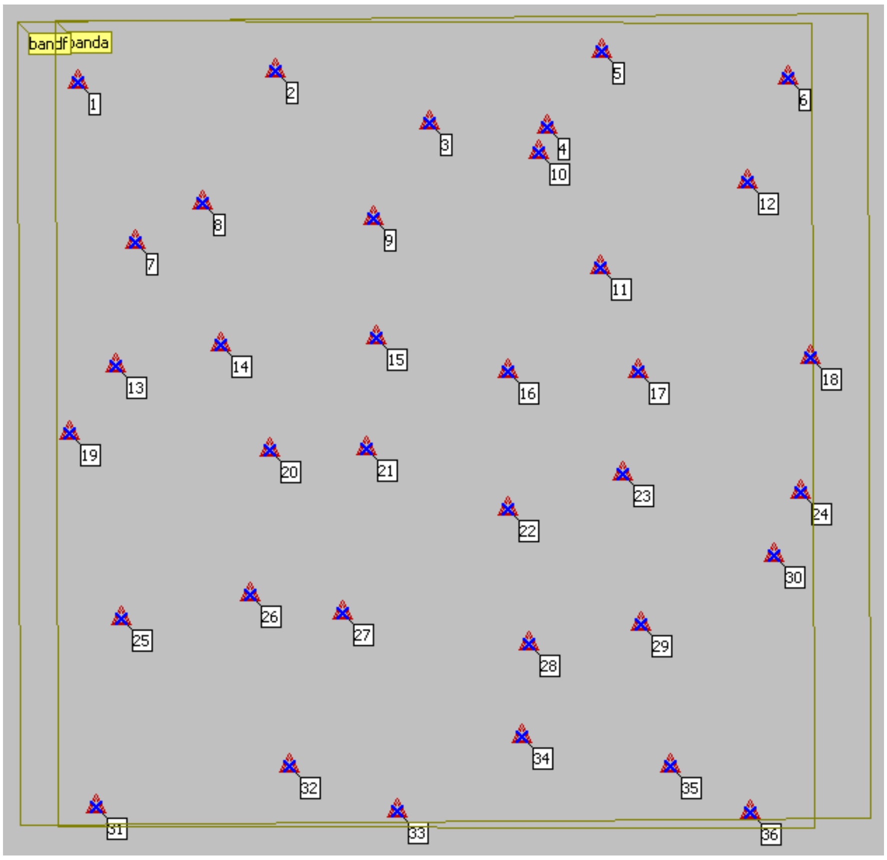

Figure 2: Ground points location scheme.

4. THE ELEMENTS OF PUSHBROOM PHOTOGRAMMETRY

4.1. 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 during orthoimagery generation. The objective of space resection is to calculate pixel coordinate of the point on image from its ground coordinates.

The method to solve the problems depends on the applied images geometric models that are briefly summarized below.

4.2. 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 modeling 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 RPCs, which are the approximation of rigorous model; these methods are applicable to Cartosat-1 Orthokit imagery products. 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 ground control points only. A classic example of the "parametric" model is Direct Linear Transformation (DLT). Others are parallel-perspective model, affine model, pure polynomial models and so on.

Obviously RPC is preferable approach for Cartosat-1 Orthokit imagery products, but it may be interesting to explore parametric ones too. To begin with it characterize 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 secret or unknown.

4.3. Photogrammetric processing based on RPC

RPC (the abbreviation is expanded as Rational Polynomial Coefficients but also as Rapid Positioning Capability) is so-called replacement model. Detailed description of this model as well as RPC-based bundle adjustment procedure is given in *Grodecki, 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):

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

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, Dial, 2003*. Two refinement forms will be tried in the investigation: bias-only refinement:

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

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

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

where l_D, s_D are denormalized values of l_N, s_N which are given by (1).

The space resection problem is solved straightforward following equations (2) or (3). The space intersection problem is mathematically equal to a set of four non-linear equations with three unknowns. The solution is iterative; the first approximation is calculated using DLT derived from the RPC by approximation.

4.4. Photogrammetric processing based on GCPs only

Two methods are 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 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 GCPs.

Parallel-perspective model is defined by 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 ground control points; using tie points (together with GCPs) 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 a system of four linear equations with three unknowns X, Y, Z, which are derived from a pair of equations (4) or (5).

5. DATA EVALUATION METHODOLOGY

The data assessment process includes two experiments:

- evaluation of the images orientation accuracy;
- DEM quality assessment.

5.1. 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 different ground points set. The orientation experiments are outlined in Table 1.

Table 1: Imagery orientation accuracy investigation experiments

Experiment #	Method	Ground points		
		Height above	Control points	Check points
1	RPC only	Ellipsoid	No	All available
2	RPC + bias	Ellipsoid	All available	No
3	RPC + bias + drift	Ellipsoid	All available	No
4	RPC + bias + drift	Ellipsoid	Optimal	All the rest
5	RPC + bias + drift	Geoid	Optimal	All the rest
6	DLT	Geoid	All available	No
7	DLT	Geoid	Optimal	All the rest
8	Parallel-perspective	Geoid	All available	No
9	Parallel-perspective	Geoid	Optimal	All the rest

The experiments 1-4 are performed using ground points heights above the ellipsoid to evaluate "pure" (not affected by the geoid model) accuracy of RPC-based adjustment since RPC are given with respect to ellipsoid.

The experiments 1-3 was planned to check the accuracy of RPC itself and to recognize the adequate error model. The experiment 4 is to evaluate optimal (minimal but redundant) number of reliable ground control points, which is enough for accurate image orientation.

The experiment 5 is the most practical one.

The experiments 6-9 are 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.

5.2. DEM quality assessment

The procedure used for DEM quality assessment is very simple but reliable because every node of the DEM is checked. 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 is compared with height calculated (by bilinear interpolation) from the reference DEM. The procedure output includes the height root-mean-square error (RMSE), mean error, mean absolute error (mean error modulus), errors range and the number of nodes in the DEMs intersection.

6. THE EVALUATION AND RESULTS

6.1. Software

The whole processing workflow (images radiometric enhancement, points measurement, images orientation, DEM and orthoimagery creation) is implemented using PHOTOMOD digital photogrammetric system (developed by "Racurs" company, Russia).

The DEMs comparison procedure is performed using the specific software developed by the author for the investigation.

6.2. Image orientation accuracy

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

Table 2: Imagery orientation accuracy investigation experiments.

Experiment #	Ground Points		RMSE, m			Max. error, m		
	Type	Number	*X*	*Y*	*Z*	*X*	*Y*	*Z*
1	Check	36	14.7	114.7	761.1	23.6	118.3	769.9
2	Control	36	16.2	2.1	5.6	27.0	4.7	9.7
3	Control	36	1.2	1.1	0.8	2.7	2.9	2.3
4	Control	4	0.2	0.4	0.2	0.2	0.4	0.2
	Check	32	1.5	1.1	0.9	2.8	3.0	2.2
5	Control	4	0.2	0.4	0.1	0.2	0.4	0.2
	Check	32	1.5	1.1	0.9	2.8	3.0	2.1
6	Control	36	1.2	1.3	2.7	3.0	3.1	7.0
7	Control	10	1,0	0,9	3,7	1,8	1,5	7,6
	Check	26	1,5	1,5	4,0	2,8	4,3	7,0
8	Control	36	1.1	1.4	6.1	2.3	3.0	11.5
9	Control	10	1,4	1,4	7,5	2,5	2,2	12,0
	Check	26	2,6	1,6	7,3	6,5	3,6	12,9

According to the experiment 1 results, the source (no refinement applied) RPC model gives large errors. The Figure 3 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 4 shows the errors, which are still systematic. The errors are large at the image sides and diminish while getting closer to the image center; the plane displacement is directed mainly along the image line. This kind of error may be caused by bias in focal length or satellite altitude involved into RPC model calculation or by systematic errors in detectors positions made during sensor geometric calibration.

The experiment 3 achieves sub-pixel RMSE; the errors seem to be random (Figure 5). It implies that the bias-and-drift refined RPC model adequately represents Cartosat-1 image geometry.

The orientation accuracy achieved in experiments 4 and 5 is the same. Four points in the images corners (1,6,31,36) are used as ground control points while all the rest ones are used as check points. The scheme is given in Figure 6. The experiments prove that the sub-pixel orientation accuracy can be achieved with four reliable and well-distributed ground control points.

The experiments 6-9 show that the alternative models (DLT and parallel-perspective) provide plane accuracy close to that achieved by RPC, but the height errors are several times larger. It also seems that DLT fits better for Cartosat-1 imagery than parallel-perspective model.

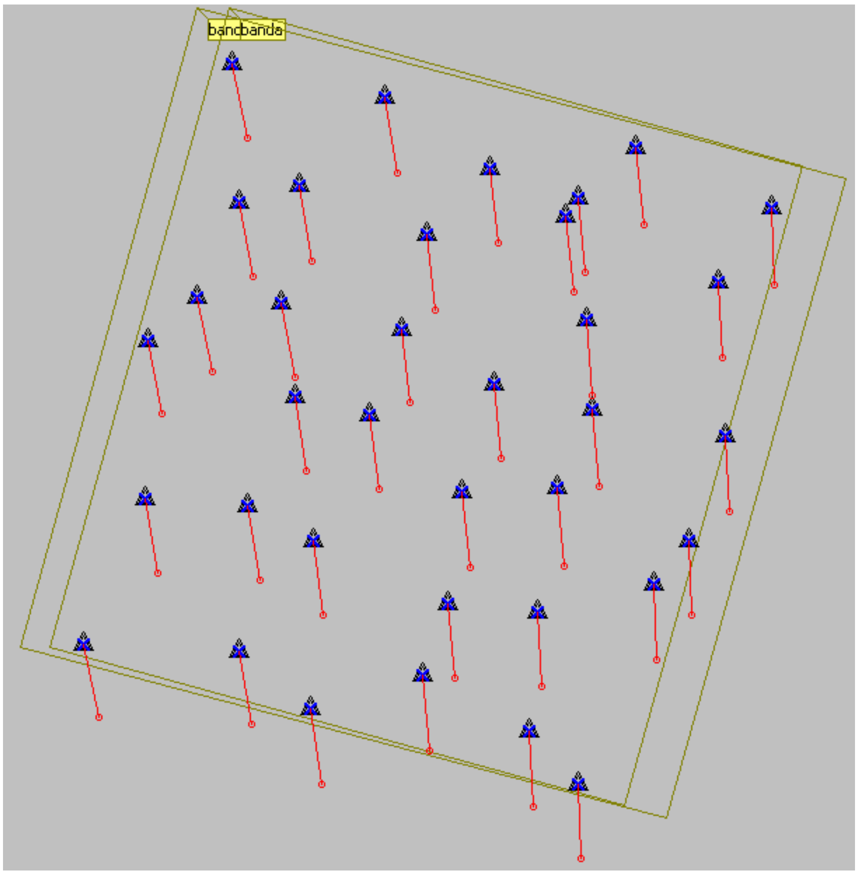

Figure 3: The plane errors given by RPC model with no refinements applied.

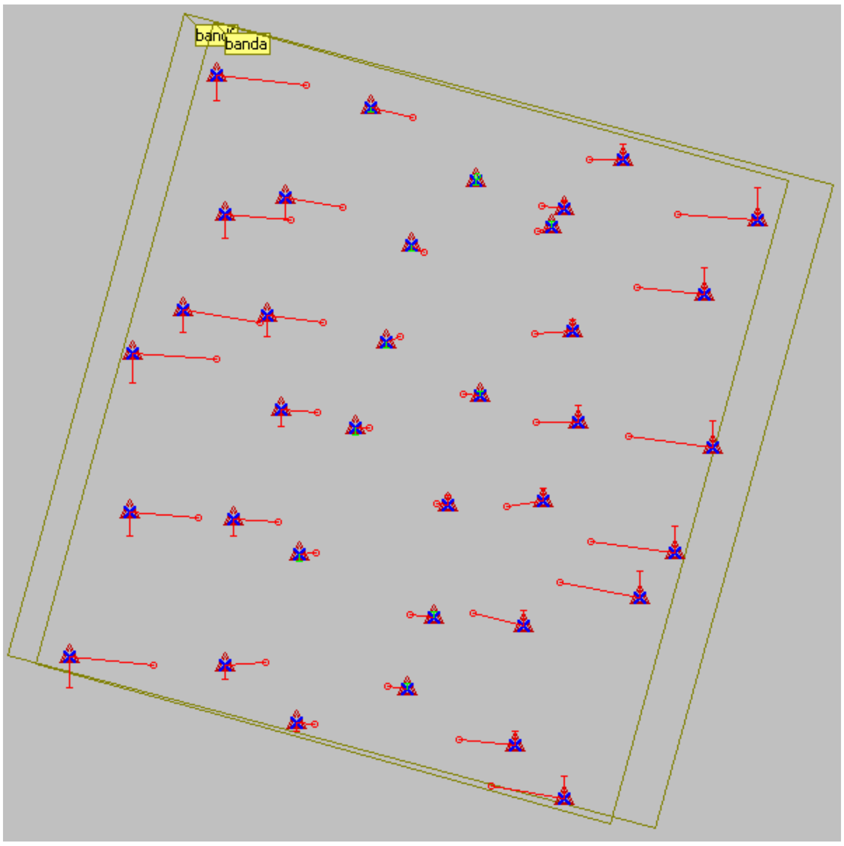

Figure 4: The errors of RPC model with bias-only refinement applied.

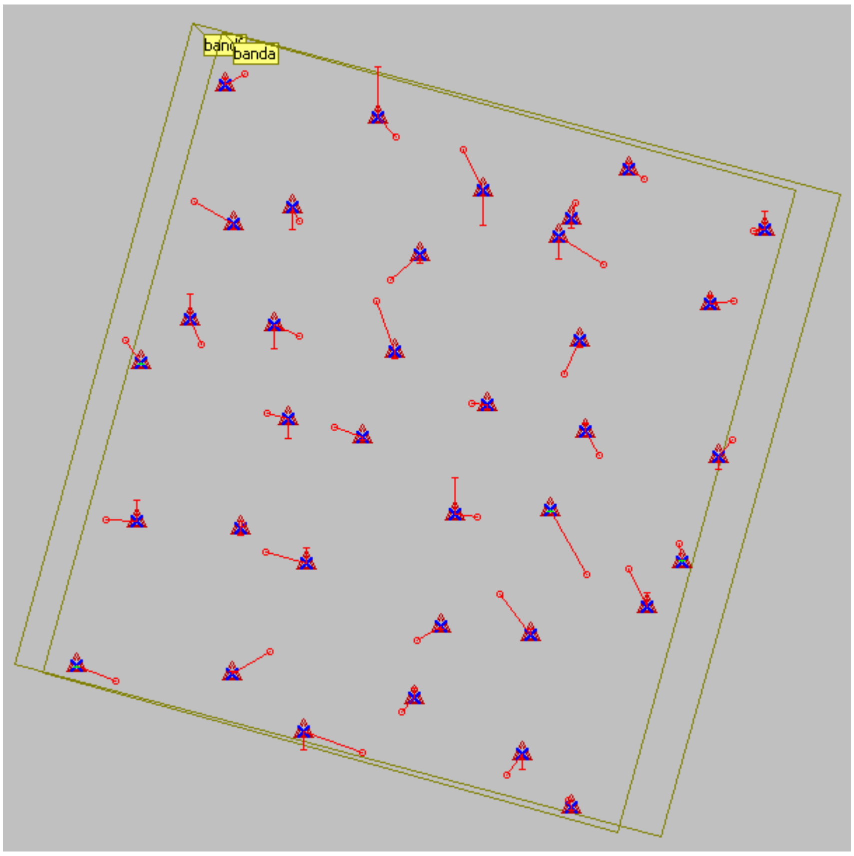

Figure 5: The errors of RPC model with bias-and-drift refinement applied (all the points are GCPs).

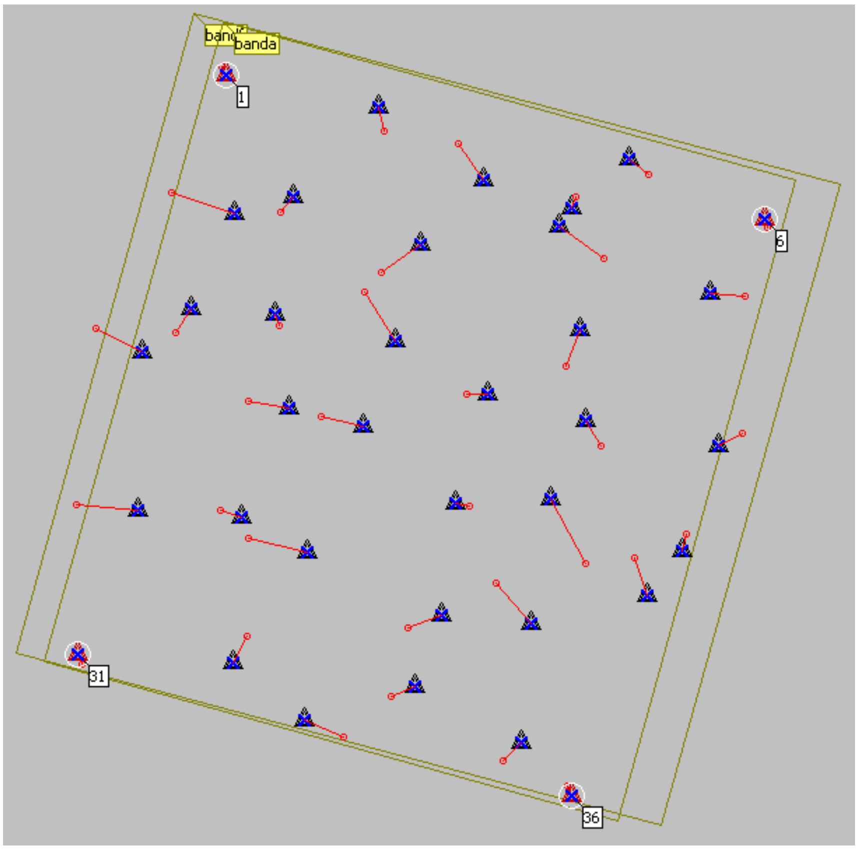

Figure 6: The errors of RPC model with bias-and-drift refinement applied (4 GCPs used).

6.3. DEM quality assessment

The stereopair for DEM creation is oriented in adjustment experiment #5 (refer to Tables 1,2 and Figure 6). Four ground control points in the stereopair corners are used for the orientation. The point's heights are specified above the EGM 96 geoid model. The orientation accuracy is sub-pixel RMSE on check points.

The DEM is created in PHOTOMOD standard workflow manner: first TIN is created using cross-correlation, then the TIN is automatically filtered and manually edited to eliminate peaks caused by correlation blunders, and finally the DEM is created. The derived DEM cell size is 20 m to be close to one of the reference DEM.

The derived and referenced DEMs are shown separately in Figure 7; their overlap is represented in Figure 8.

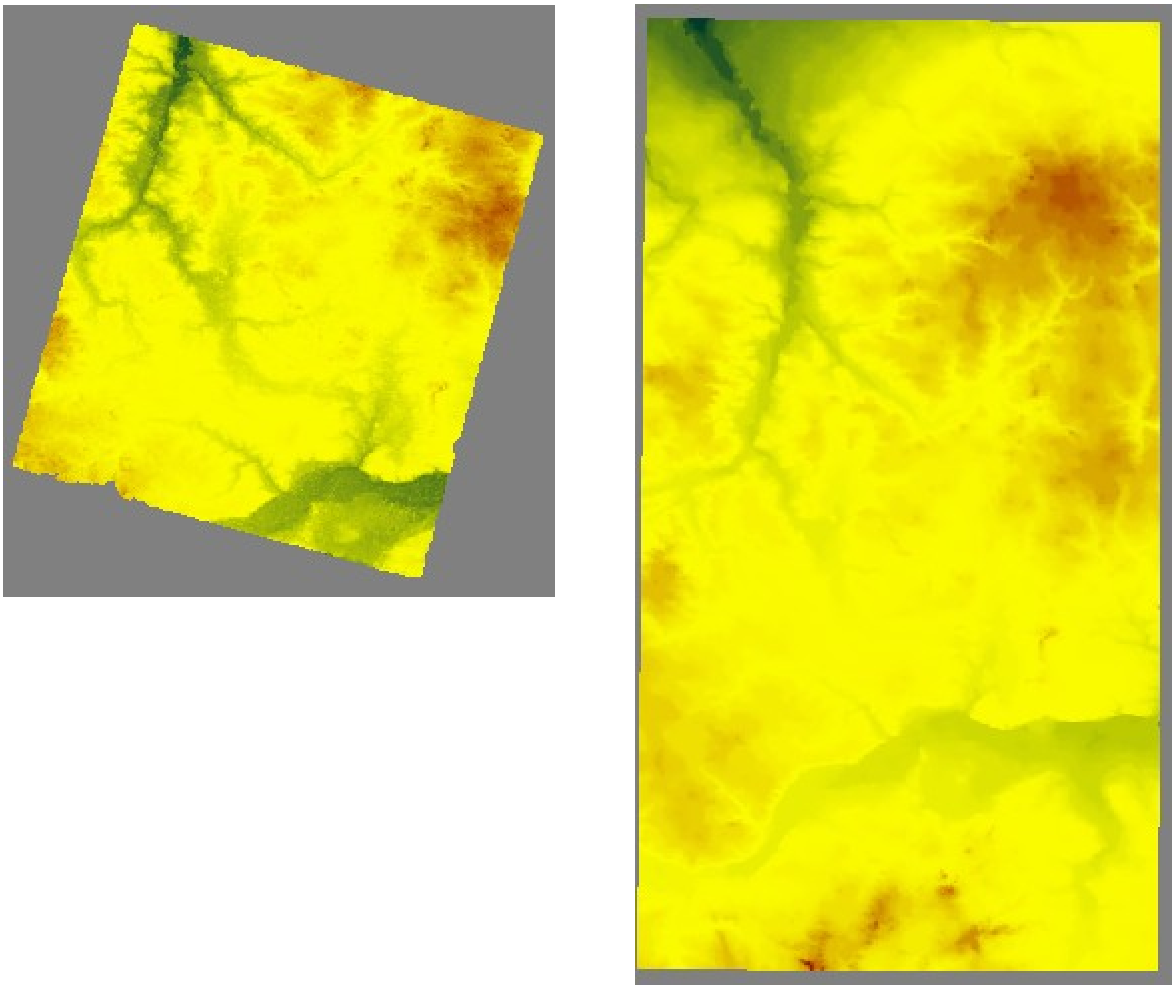

Figure 7: The derived (left) and reference (right) DEMs.

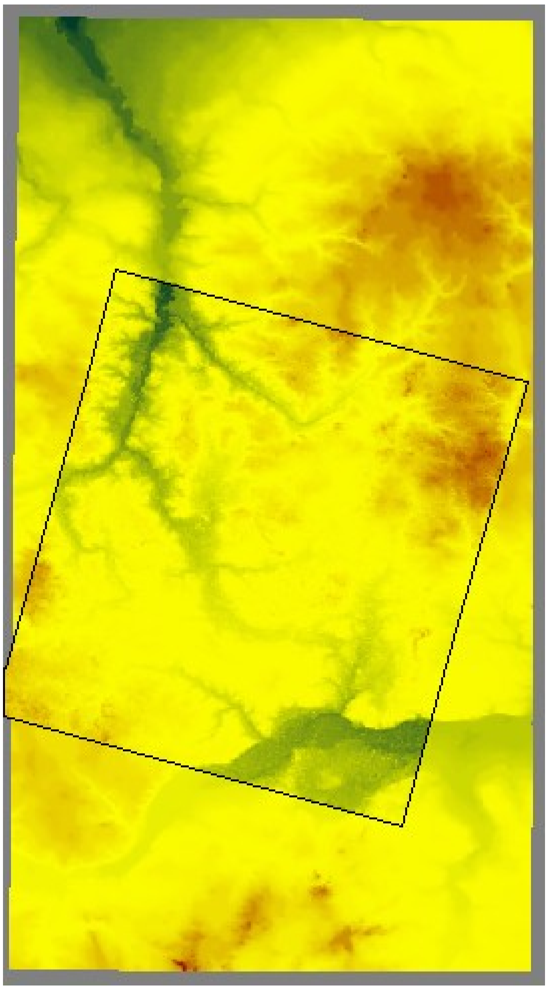

Figure 8: The derived and reference DEMs overlap.

The DEMs comparison shows that the derived DEM is extremely close to the reference one:

- RMSE 2.3 m;
- LE90 = 1.96×RMSE = 4.5 m;
- mean error +1.0 m;
- mean absolute error 1.7 m;
- errors range –20.0m ÷+37.2m;
- checked nodes number: 1 985 266.

The non-zero mean error discloses some systematic misalignment (about 1m) 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.

Keeping in mind that the declared accuracy of the reference DEM is 1-2 m RMSE, the absolute accuracy of the derived DEM is estimated to be about 3 meters RMSE.

6.4. Orthoimagery accuracy

Cartosat-1 satellite is capable of tilting up to 26 degrees cross-track to enhance its productivity. The images provided for the investigation were acquired with roll angle as small as 2 degrees. To estimate orthoimagery accuracy in the worst case, the prediction is made presuming off-nadir angle as large as 30 degrees. Assuming vertical DEM accuracy to be 3 meters RMSE, the DEM causes plane displacement $3\times tan30° \approx 1.7$ meters. The resultant plane displacement due to image orientation and DEM errors (presuming 1 pixel–level orientation accuracy) slightly exceeds 3 meters. The map accuracy requirements differ depending on the regional legislation, but in general the accuracy predicted 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.

7. CONCLUSIONS

The investigation shows that the optimal method of Cartosat-1 imagery orientation is bias-and-drift refined RPC. Four well-distributed reliable ground control points is enough to achieve sub-pixel orientation accuracy and to create DEM as accurate as 3 meters RMSE. The generated orthoimagery meets the geometric accuracy requirements to 1 : 10 000 scale maps.

8. REFERENCES

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