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New sensors benchmark report on KOMPSAT-3A

Geometric benchmarking over Maussane test site for CAP purposes

EUROPEAN SPACE IMAGING

GAFAG

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Contents

Abstract

Imagery collected by KOMPSAT-3A satellite can be potentially used in The Common Agricultural Policy (CAP) image acquisition Campaign. The qualification and certificate is conducted by performing benchmarking tests, i.e. it has to be checked whether the planimetric accuracy of the produced orthoimages does not exceed certain values regulated by JRC. Therefore, a benchmarking test was carried out based on two KOMPSAT-3A imagery collected in February 2017 and March 2018. The first part of the report (chapter 2-6) describes in detail how the tests were performed, i.e. the auxiliary data, methodology and workflow used as well as outcome from the Internal Quality Control (IQC). The second part (chapter 7-9) deals with External Quality Control (EQC) and conclusions made on the basis of this assessment with regards to the VHR Image technical specifications criteria [iii]. While the first part, i.e. production of ortho imagery, was carried out by external an contractor (European Space Imaging - EUSI) the second part, i.e EQC, was performed by Joint Research Centre (JRC). In this way an independent and objective test was assured.

1 Introduction

This report describes in detail the steps taken in order to qualify the KOMPSAT-3A sensor to the CAP image acquisition Campaign. The main geometric requirement according to the VHR image acquisition specifications for the CAP checks [iii] is the planimetric accuracy of orthoimages, i.e.

- RMSEx ≤2m/1.5m and RMSEy ≤2m/1.5m for VHR Prime profiles
- RMSEx ≤5m and RMSEy ≤5m for VHR Backup profile

Due to new CAP requirements (valid for the CAP 2014+), all VHR imagery should have a spatial resolution compliant at least with a scale of 1:5000 or better. This translates into a required positional accuracy of maximum 1.25m RMSE1-D. Therefore this value is also assessed in this report.

- RMSEx ≤1.25m and RMSEy ≤1.25 for VHR Prime profiles

As several scenarios are tested, the influence of different factors on the accuracy of orthoimages can be checked, i.e.

- number and distribution of GCPs
- off nadir angle
- sensor model implemented in the software (PCI and ERDAS)
- different methods of modelling (RPC and rigorous)

2 KOMPSAT-3A satellite

Launched in March 2015, KOMPSAT-3A is a Korean Earth Observation satellite, operated by The Korea Aerospace Research Institute (KARI) in cooperation with SI Imaging Services (SIIS). KOMPSAT-3A aims to provide data continuation after KOMPSAT-3.

The KOMPSAT-3A spacecraft was launched on March 25th, 2015 (22:08:53 UTC) on a Dnepr-1 vehicle (RS-20) from the Jasny Dombarovsky launch site in Russia. The launch was executed by the Russian Strategic Rocket Forces of the Russian Ministry of Defense with the support of the Russian, Ukrainian and Kazakhstan organizations, which are part of the ISC (International Space Company) Kosmotras industrial team.

Satellite sensor characteristics (design and specifications) are given in the tables below.

Table 1 KOMPSAT-3A characteristics – design and specifications

Launch information	Date: 25.03.2015 (22:08:53 UTC) Launch Vehicle: Dnepr-1 vehicle (RS-20) Launch Location: Jasny Dombarovsky launch site in Russia
Satellite weight/size/power	approx. 1100 kg; 3.8 m height, 2.0 m diameter; 1.3 kW
Orbit	Altitude: 528 km Type: Sun-synchronous, near-circular, 13:30 pm ascending node Period: 95.2 min Inclination: 97.513 deg
Orbits per day	15.1 orbits per day Repeated ground track after 28days /423 revolutions
Revisit rate	3.7 days average revisit time at 30 degrees latitude within 30 degree tilt angle

Table 2 KOMPSAT-3A parameters

Sensor bands (spectral range)	Panchromatic: 450 – 900 nm MS1 (Blue): 450 – 520 nm MS 2 (Green): 520 – 600 nm MS3 (Red): 630 – 690 nm MS4 (NIR): 760 – 900 nm MWIR: 3.3 μm ~ 5.2 μm (not commercially available)
Sensor Resolution **(GSD at nadir)**	0.55 m PAN 2.20 m MS 5.50 m IR (not commercially available)
Dynamic Range	14 bits/pixel

Swath Width	>13 km at nadir
Geolocation Accuracy (CE90)	8.9m $RMSE_{2D}$, 13.5m CE90 with PAD/POD in strip mode (at the end of LEOP))
Capacity	Global: 10% per orbit (duty cycle) Up to 277,992 km^2 per day
(Operation) Tilt Angle	Roll (-30~30 deg.) Pitch (-30~30 deg.)
Imaging Modes:	Strip Multi Pointing Wide Area Along Single Pass Stereo
Expected End of Operational Life	Designed life time more than 7 years

2.1 Benefits of the KOMPSAT-3A

Benefits:

- Native dynamic range of 14 bits/pixel provides more details for any spectral analysis including NDVI, classification, etc. It also provides better data extraction from shadow areas and better colour balancing results during mosaic processing
- High collection capacity makes it suitable for large area mapping
- Afternoon imaging capability increases the chance of acquiring cloud-free images over specific targets/areas
- Satellite agility permits event monitoring as well as single-pass stereoscopic observations. Acquisition of multi-targets in one (1) pass is also available, which is beneficial for monitoring several targets during short time periods. Wide Area Along Imaging mode enables to acquire wider images (23~24 km swath) by acquisition of 2 strips in 1 overpass.

3 KOMPSAT-3A image products

KOMPSAT-3A imagery can be processed and delivered as Level 1R and Level 1G. A brief description of the mentioned image products is given below in Table 3.

Table 3 KOMPSAT-3A image products

Product level	**1R (Standard)**	**1G (Standard)**
Horizontal Accuracy* (m, CE90) **Specification (Expectation)** ***excluding terrain effect**	70.0 (9.9)	70.0 (9.9)
Maximum off-nadir angle (degree)	30	30
Product Resolution (m)	0.55	0.55
Products/band combination	bundle (pan + 4 multispectral) pan-sharpened (4 pan-sharpened bands)	bundle (pan + 4 multispectral) pan-sharpened (4 pan-sharpened bands)
Processing:	-without GCP -using POD/PAD -radiometric correction -sensor correction -MTF compensation -PAN-MS Registration -Geo-information included	-without GCP -using POD/PAD -radiometric correction -sensor correction -MTF compensation - geometrical correction -PAN-MS Registration

KOMPSAT-3A imagery is available with the following band combinations:

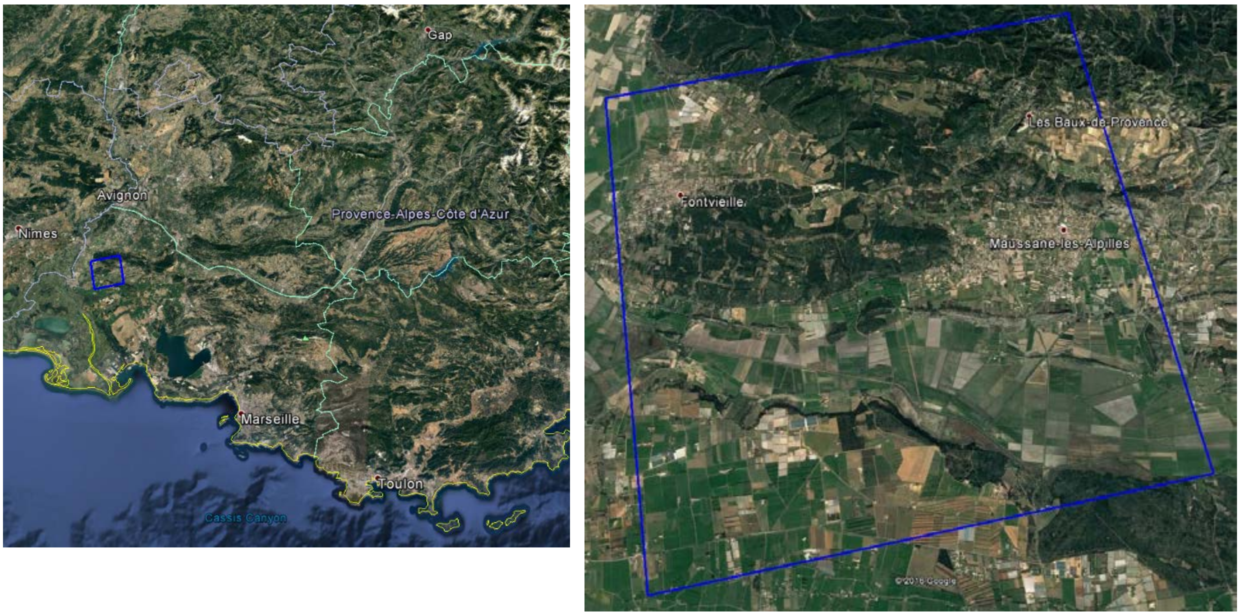
Bundle – the panchromatic and multispectral products are delivered together. Those bands are acquired simultaneously and registered together.

Pan-sharpened – is a process to combine the panchromatic and multispectral image to acquire higher resolution multispectral images thanks to the spatial characteristic of panchromatic data and the spectral information of multispectral data. As a result, four band data, i.e. red, green, blue and NIR, with GSD of panchromatic are provided.

4 Study area

The test AOI is located in the French commune Maussane-les-Alpilles in the Provence-Alpes-Cote d'Azur region in southern France and is being used as a 'test site' by the European Commission since 1997. The AOI is characterized by different land use types and the terrain variations (elevation difference between highest and lowest point is around 300m). The area used in the tests is 100km² and spans $4^\circ41'$ to $4^\circ48'$E and $43^\circ40'$ to $43^\circ45'$N (Figure 1).

Figure 1 Location of the test site



The tested area was shifted compare to usually used one to allow performing the orthorectification on a single image.

5 Auxiliary data

The auxiliary data received from JRC can be divided into three groups:

- Ground Control Points (Chapter 5.1)
- Digital Elevation Model (Chapter 5.2)
- Aerial Orthomosaics (Chapter 5.3)

5.1 Ground control points

Ground Control Points play an important role in the orthorectification process of satellite imagery as they help to improve the planimetric accuracy of the created orthoimage. However, these points cannot be random points, hence, general principles for selection of GCPs would be as follows:

- should represent a prominent feature
- should be well identified features
- should be well identified in the image
- should be well distributed
- objects that represent vertical displacements should not be used.

In addition, Guidelines for Best Practice and Quality Checking of Ortho Imagery specify the accuracy requirements for GCPs [ii] i.e.

''GCPs should be at least 3 times (5 times recommended) more precise than the target specification for the ortho, e.g. in the case of a target 2.5m RMSE, the GCPs should have a specification of 0.8m RMSE or better''

According to VHR Image Acquisition Specifications Campaign 2018 - VHR profile-based, target orthoimage accuracy for VHR prime is 2m/1.5m/1.25 and 5m for VHR Backup [iii].

Considering all the above, set of 6 GCPs (Table 5, Figure 2) to be used in the modelling phase in the orthorectification process of two KOMPSAT-3A imagery has been selected from GCP dataset received from JRC (Table 4).

Table 4 GCPs available for Maussane test site

Dataset	Point ID	RMSE x [m]	RMSE y [m]	Projection and datum	Source
ADS40_GCP_dataset_Maussane_ prepared_for_ADS40_in_2003	11XXXX	0,05	0,10	UTM 31N WGS84	GPS measurements
VEXCEL_GCP_dataset_Maussane_ prepared_for_VEXEL_in_2005	44XXX	0,49	0,50		
Multi-use_GCP_dataset_Maussane_ prepared_for_multi-use_in_Oct-2009	66XXX	0,30	0,30		
Cartosat-1_GCP_dataset_Maussane_prepared_	33XXX	0,55	0,37		

for_Cartosat_in_2006					
Formosat-2_GCP_dataset_Maussane_prepared_for_Formosat2_in_2007	7XXX	0,88	0,72		
Cartosat-2_GCP_dataset_Maussane_prepared_for_Cartosat-2_in_2009	55XXX	0,90	0,76		
SPOT_GCP_dataset_Maussane_prepared_for_SPOT_in_	22XXX	n/a	n/a		
Maussane GNSS field campaign 21-26 November 2012	CXRX	0,15	0,15		

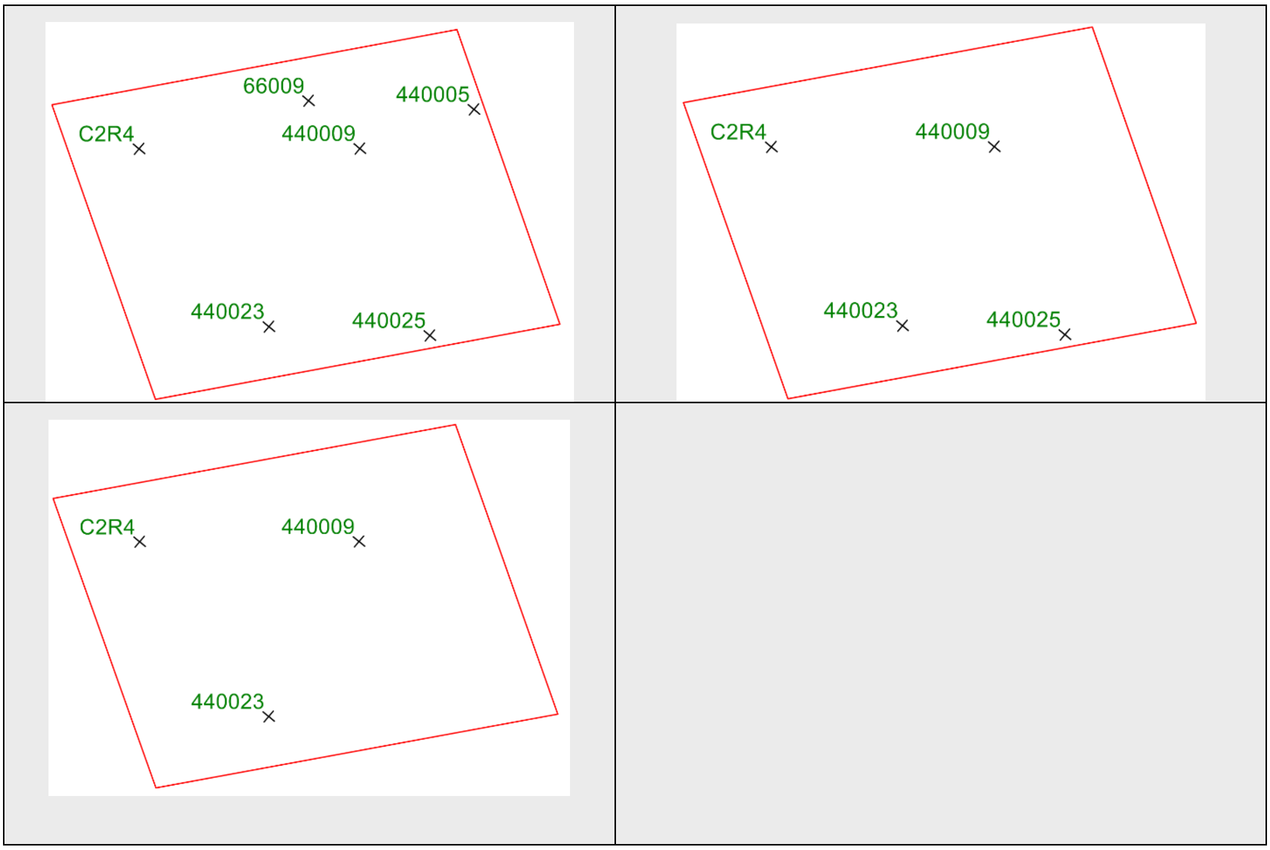
Table 5 GCPs selected for KOMPSAT-3A benchmarking scenario

#	ID	GCP3	GCP4	GCP6
1	440009	x	x	x
2	440005			x
3	66009			x
4	C2R4	x	x	x
5	440023	x	x	x
6	440025		x	x

Table 6 Coordinates of GCPs selected for KOMPSAT-3A benchmarking scenario

ID	Easting	Northing	Ellips_H
440005	645815.166	4845076.105	176.540
440009	643112.409	4843729.238	120.040
C2R4	637829.720	4843609.870	63.160
440025	644920.321	4837617.876	55.885
66009	641850.726	4845276.823	147.466
440023	641060.734	4837826.921	87.870

Figure 2 Distribution of GCPs

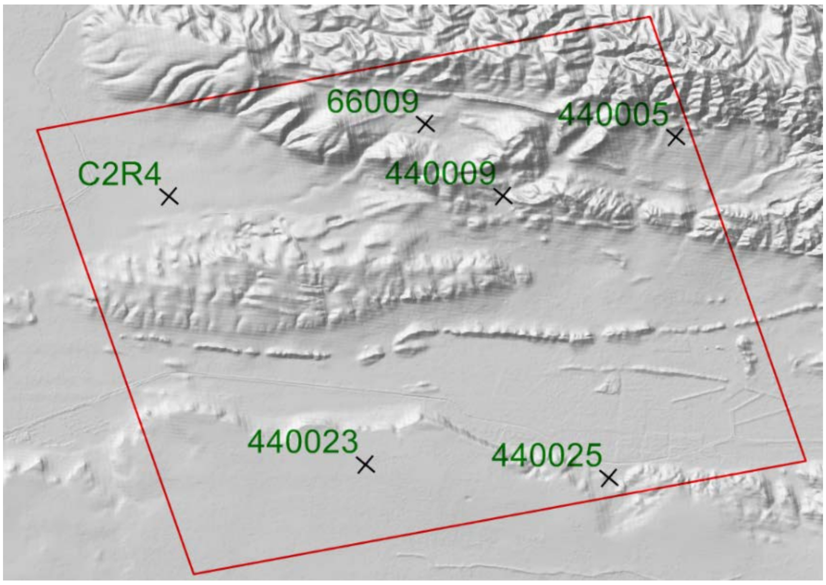


5.2 DTM

A DTM is used to remove image displacement caused by topographic relief, therefore it should be as accurate as possible. However, according to the Guidelines for Best Practice and Quality Checking of Ortho Imagery [ii] a DEM with the following specifications is recommended to be used:

- with a grid spacing 5 to 20 times better than the orthophoto pixel size (depending on the terrain flatness) and
- with a height accuracy of 2 x planimetric 1-D RMSE

Figure 3 Intermap5mDTM



From two available DEMs it was decided to use INTERMAP5mDTM in the tests. The specifications of the INTERMAP5mDTM is given in the **Table 7**.

As explained in the New sensors benchmark report on Kompsat-3 [ix] the DEM_ADS40 has been edited/filtered for agriculture areas. However, delineation of these areas seems to be very rough and therefore some areas may suffer from a smearing effect in the orthoimages. For the open areas there are only minor differences between these DTMs.

Table 7 DEM specifications

Data set	Grid size	Accuracy	Projection and datum	Source
DEM_ADS40	2m x 2m	RMSEz ≤0,60m	UTM 31N WGS84 (EPSG 32631)	ADS40 (Leica Geosystems) digital airborne image of GSD 50cm
INTERMAP5m DTM	5m x 5m	1m RMSE for unobstructed flat ground		aerial SAR

5.3 Aerial orthomosaic

Table 8 Aerial orthomosaic's specifications

Aerial Orthomosaics	Grid size	Accuracy	Projection and datum	Source
ADS40	0,5m	n/a	UTM 31N WGS84	ADS40 aerial flight by ISTAR, 2003. Bands: R, G, B, IR, PAN
Vexel UltraCam	0,5m	n/a		Vexel Ultracam aerial flight by Aerodata, 2005. Bands: R, G, B, IR, PAN

5.4 KOMPSAT-3A satellite imagery

KOMPSAT-3A satellite images that have been used to perform benchmarking tests have been collected in February 2017 and March 2018 at an off nadir angle of ~7.2□ and of ~28.01□, respectively. The data have been processed as Level1R Pansharpened product. Pansharpened imagery consist of Blue, Green, Red and NIR1 bands and are delivered in separate files. Each Level1R product has associated RPC information.

Table 9 Collection and production parameters of KOMPSAT-3A imagery

CAT_ID	K3A_20170224122954_10602_00038205_L1R_PS	K3A_20180313123330_16375_00049277_L1R_PS
Collection Parameters		
Collection date	24-02-2017	13-03-2018
Off nadir angle	28.01□	7.2□
Elevation Angle	59.4□	82.2□
Cloud cover [%]	0	3
Production Parameters		
Product Option	Level1R - Pansharpened	
Resampling Kernel	4x4cubic convolution	
File Format	Geotiff	
Bit Depth	14bit	
Projection/Datum	UTM/WGS84	

5.5 Software

- ERDAS 2016 v16.1
- PCI Geomatics 2017 SP1

6 KOMPSAT-3A benchmarking tests

6.1 Benchmarking methodology

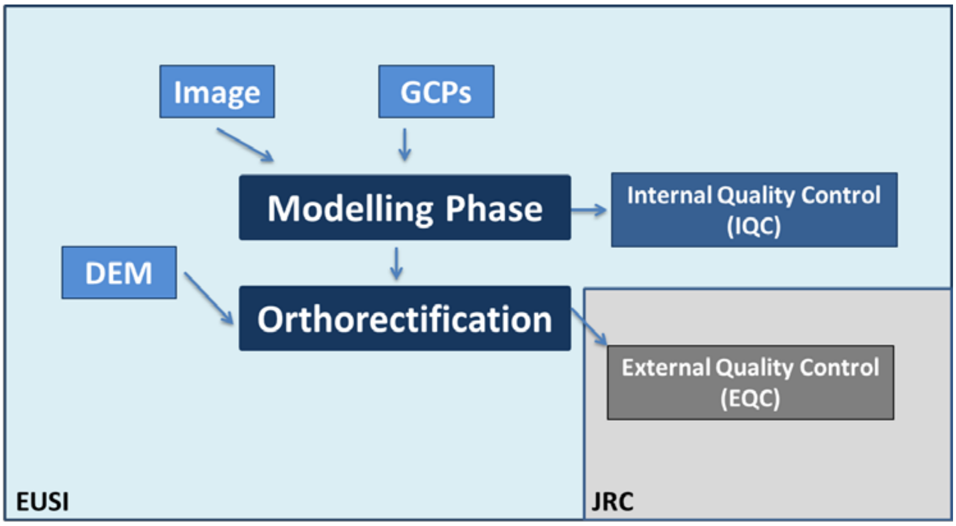
Orthorectification is the geometric transformation of an image (which is fraught with displacements due to sensor orientation and terrain) to the projection of a map coordinate system. Therefore, orthorectification is the process of reducing geometric errors inherent within imagery. It consists of 3 phases:

Phase 1: Modelling - geometric correction model phase, also referred as to image correction phase, sensor orientation phase, space resection or bundle adjustment phase. Sensor models are mathematical models that define the physical relationship between image coordinates and ground coordinates, and they are different for each sensor. In this phase GCPs are used for improving absolute accuracy. However, the tests were also performed without using GCPs.

Phase 2: Orthorectification - the phase where distortions in image geometry caused by the combined effect of terrain elevation variations and non-vertical angles from the satellite to each point in the image at the time of acquisition are corrected.

Phase 3: External Quality Control (EQC) of the final product - described by 1-D RMSEx and 1-D RMSEy – performed by JRC. According to Guidelines for Best Practice and Quality Checking of Ortho Imagery [ii] minimum 20 check points should be checked in order to assess orthoimage planimetric accuracy. The points used during the geometric correction phase should be excluded.

Figure 4 Standard benchmarking procedure



Tests were performed using two softwares: ERDAS 2016 v16.1 and PCI Geomatics 2017 SP1. In both softwares, the RPC model has been tested with the same combination of GCPs given beforehand by JRC. The Rigorous model has been tested in PCI Geomatics 2017 SP1 only (Rigorous Model for OR2A is not supported in ERDAS 2016 v16.1). However, the selection of appropriate GCPs was done by EUSI/GAF (Table 5, Figure 2) from the set of GCPs available for the Maussane test site (Table 4). Tested scenarios are described in chapter 6.2 (Table 10), residuals obtained from geometric correction model phase are listed in chapter 6.3 (Table 11, Table 12).

In total, 18 orthoimages were prepared and handed to JRC for External Quality Control.

6.2 Test scenario

The following scenarios have been considered in our benchmarking tests:

Table 10 Tested scenarios

IMAGES	DEM	GCP #	MODEL	ERDAS	PCI
Image ~ 7.2° ONA	Intermap5mDTM	0	RPC (0)	1	1
		3		1	1
		4		1	1
		6		1	1
		6	Rigorous	0	1
Image ~ 28° ONA	Intermap5mDTM	0	RPC (0)	1	1
		3		1	1
		4		1	1
		6		1	1
		6	Rigorous	0	1
In total: 18 orthoimages					

6.3 Internal quality control

The residuals obtained in modelling Phase 1 are as follows:

Table 11 Residuals obtained in phase 1 – image (~7.2° ONA)

Image (~7.2° ONA)		ERDAS		PCI	
No of GCPs	**Model**	**X [pix]**	**Y [pix]**	**X [pix]**	**Y [pix]**
0	RPC (0)	n.a	n.a	n.a	n.a
3		0,84	0,65	0,85	0,65
4		0,74	0,60	0,74	0,60
6		0,80	0,50	0,83	0,50
6	Rigorous	n.a	n.a	0,06	0,14

Table 12 Residuals obtained in phase 1 – image (~28° ONA)

Image (~28° ONA)		ERDAS		PCI	
No of GCPs	**Model**	**X [pix]**	**Y [pix]**	**X [pix]**	**Y [pix]**
0	RPC (0)	n.a	n.a	n.a	n.a
3		0,44	1,22	0,45	1,22
4		0,57	1,09	0,57	1,09
6		0,75	0,95	0,77	0,96
6	Rigorous	n.a	n.a	0,14	0,71

Figure 5 Residuals obtained in phase 1 – image (~7.2° ONA)

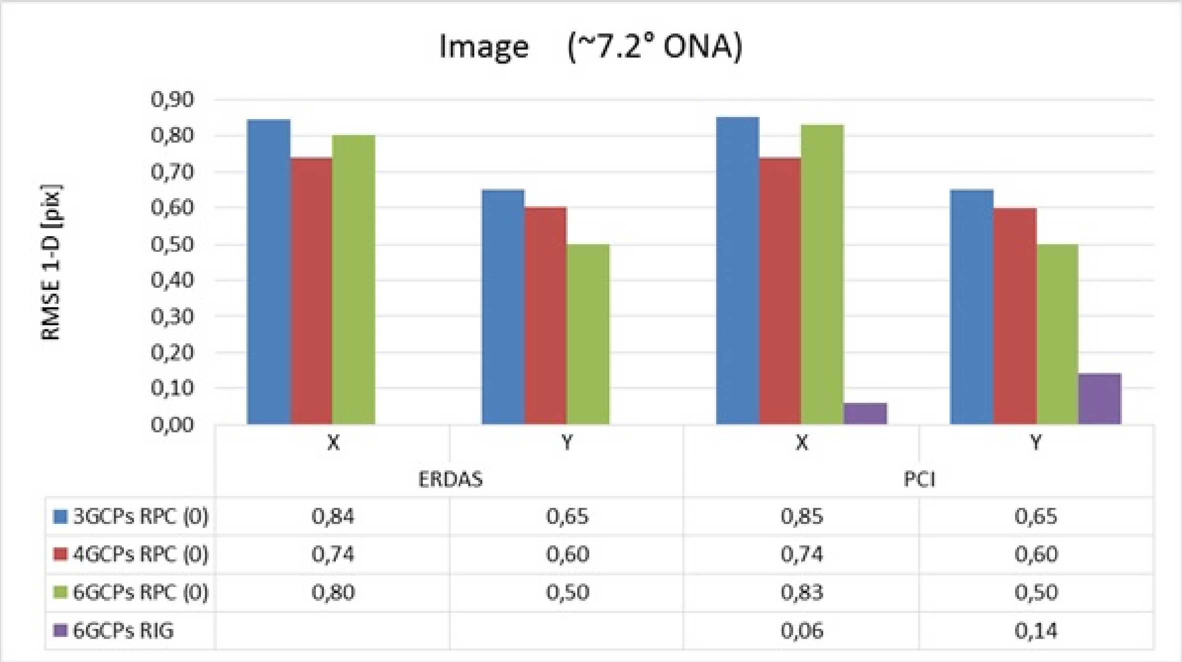
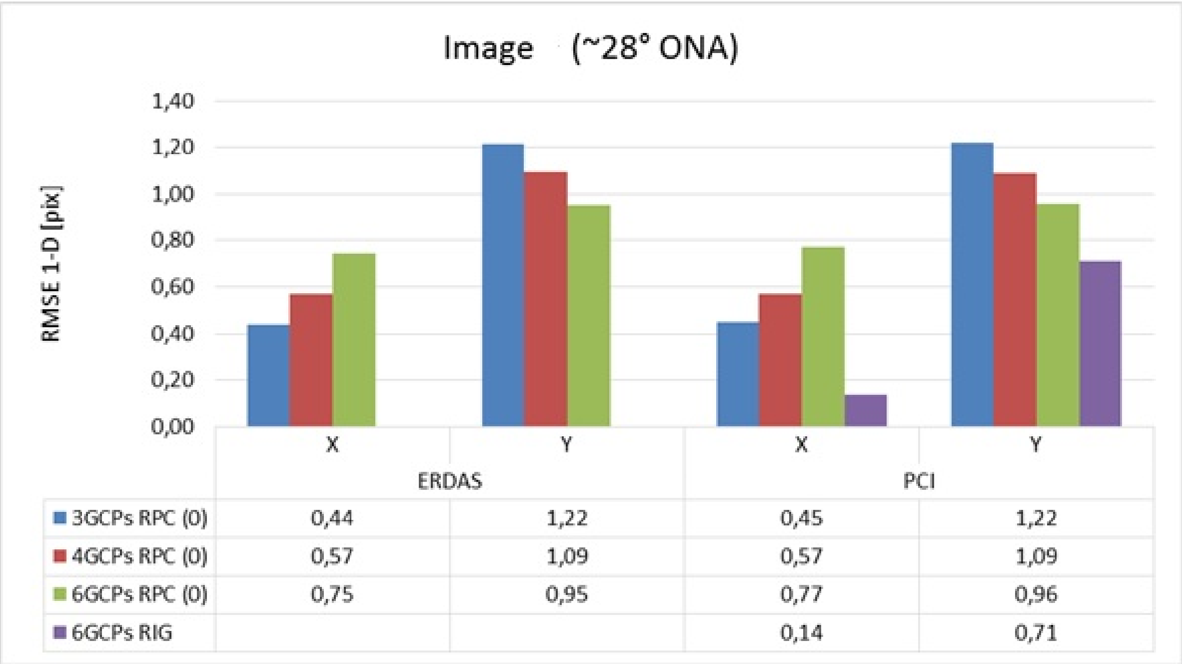


Figure 6 Residuals obtained in phase 1 – image (~28° ONA)



6.4 Summary

Based on the residuals received from the modelling phase, the following conclusions from the performed tests can be drawn:

- the residuals are well below 1 pix for the image collected at 1^0 Off Nadir Angle and are almost identical for ERDAS and PCI

- the residuals are well below or slightly above 1 pix for the image collected at 28^0 Off Nadir Angle and are almost identical for ERDAS and PCI
- the residuals obtained for the image collected at 1^0 Off Nadir Angle are slightly better than residuals obtained for the image collected at 28^0 Off Nadir Angle
- the residuals obtained for the x-direction are slightly better than the residuals obtained for y-direction.

7 External Quality Control

JRC as an independent entity performs a validation phase of the benchmarking workflow methodology used for verifying of a satellite's ortho-product compliance with the geometric quality criteria set up for the Control with Remote Sensing program (CwRS), in the Common Agriculture Policy (CAP). The workflow follows the Guidelines for Best Practice and Quality Checking of Ortho Imagery [ii] and is in detail described in the chapter 6.

7.1 Method for external quality check of ortho imagery

7.1.1 Independent check points (ICPs)-selection and distribution

For the evaluation of the geometric accuracy of the KOMPSAT-3A ortho imagery, 21 independent ICPs were selected by a JRC operator. Both GCPs and ICPs were retrieved from already existing datasets of differential global positioning system (DGPS) measurements over Maussane test site. These datasets are updated and maintained by JRC. Considering the accuracy, distribution and recognisability on the given images, points from the five datasets were decided to be used for the EQC. The intention was to spread the points evenly across the whole image while keeping at least the minimum recommended number of 20 points [ii]. JRC for the location of the ICPs took into account the distribution of the GCPs determined by the FW Contractor and provided to JRC together with the products. Since the measurements on ICPs have to be completely independent (i.e. ICP must not correspond to GCP used for the correction), the GCPs taken into account in the geometric correction have been excluded from the datasets considered for EQC.

Regarding the positional accuracy of the ICPs, according to the Guidelines [ii] the ICPs should be at least 3 times (5 times recommended) more precise than the target specification for the ortho, i.e. in our case of a target 1.25m RMS error (the most strict value was taken into account here) the ICPs should have a specification of 0.42m (0.25m recommended). 19 ICPs that have been selected fulfil the defined criteria and 2 ICPs are above the mentioned threshold (**Table 13**, **Table 14**).

Table 13 Identical check points specifications

Dataset	RMSEx [m]	RMSEy [m]	N.of points
VEXEL_GCP_dataset_Maussane 2005	0,49	0,50	3
Multi-use_GCP_dataset_Maussane 2009	0,30	0,30	14
Maussane GNSS field campaign 2012	< 0,15	< 0,15	1
ADS40_in_2003	0,05	0,10	2
Formosat2_in_2007	0,90	0,76	1

Figure 7 ICPs dataset used by JRC in the EQC of KOMPSAT-3A ortho imagery.

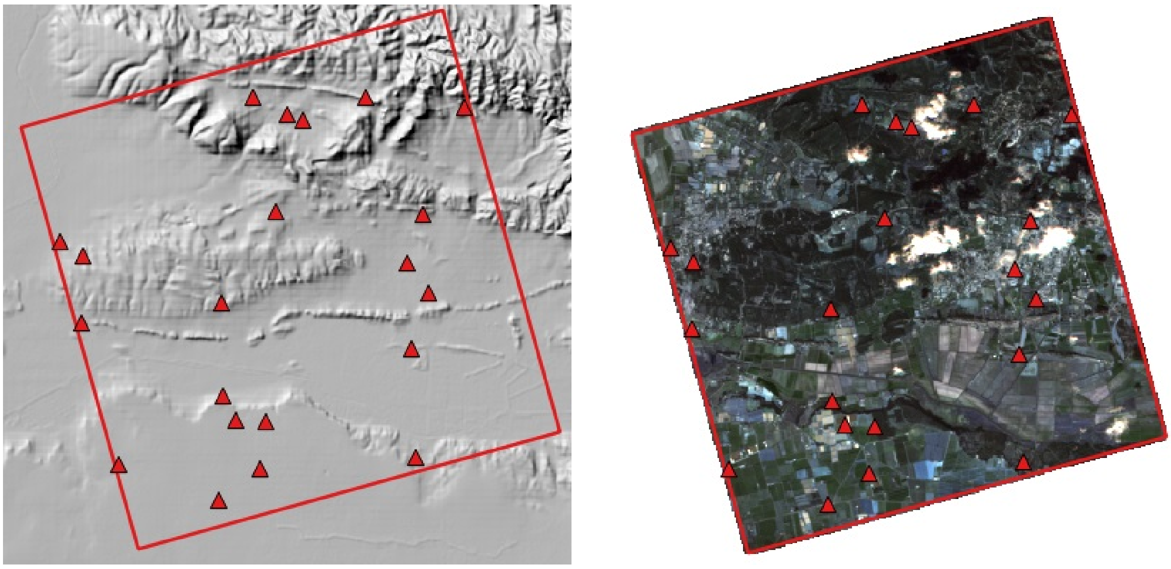


Table 14 ICPs overview

ID	E[m]	N[m]
440003	640999,13	4845715,57
440008	641527,51	4843087,46
440016	637104,55	4840553,20
66030	641183,52	4837211,10
66039	636607,21	4842393,70
66038	644535,09	4841910,06
66035	644717,26	4837489,03
66007	641804,02	4845298,88
66010	643598,10	4845690,29
66050	637124,68	4842091,98
66049	644906,91	4843017,78
66015	645830,46	4845477,35
66064	644632,99	4839952,34
66024	641320,70	4838276,56
66023	640624,49	4838320,52
66022	637947,95	4837300,70
66028	640296,27	4840992,69
550011	642162,00	4845190,25
110022	645030,76	4841227,48
110015	640241,83	4836497,77
C3R5	640341,36	4838887,55

The projection and datum details of the above mentioned data are UTM 31N zone, WGS 84 ellipsoid.

7.2 Geometric quality assessment-measurements and calculations

Geometric characteristics of orthorectified images are described by Root-Mean-Square Error (RMSE) $RMSE_x$ (easting direction), $RMSE_y$ (northing direction) and CE(90), calculated for a set of ICPs.

$$RMSE_x = \mathrm{RMSE}_{1D}(East) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(X_{REG(i)} - X_{(i)}\right)^2}$$

$$RMSE_y = \mathrm{RMSE}_{1D}(North) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_{REG(i)} - Y_{(i)}\right)^2}$$

where $X,Y_{REG(i)}$ are ortho imagery derived coordinates, $X,Y_{(i)}$ are the ground true coordinates, n express the overall number of ICPs used for the validation.

This geometric accuracy representation is called the positional accuracy, also referred to as planimetric/horizontal accuracy and it is based on measuring the residuals between coordinates detected on the orthoimage and the ones measured in the field or on a map of an appropriate accuracy.

According to ISO 19157, the circular error at 90% CE(90) significant level (or confidence interval) is defined as a radius describing a circle, in which the true point location lies with the probability of 90 %. It is also known as CMAS (circular map accuracy standard).

$$\mathrm{CE}(90) = 2{,}146\,\frac{\sqrt{RMSE(East)^2 + RMSE(North)^2}}{\sqrt{2}}$$

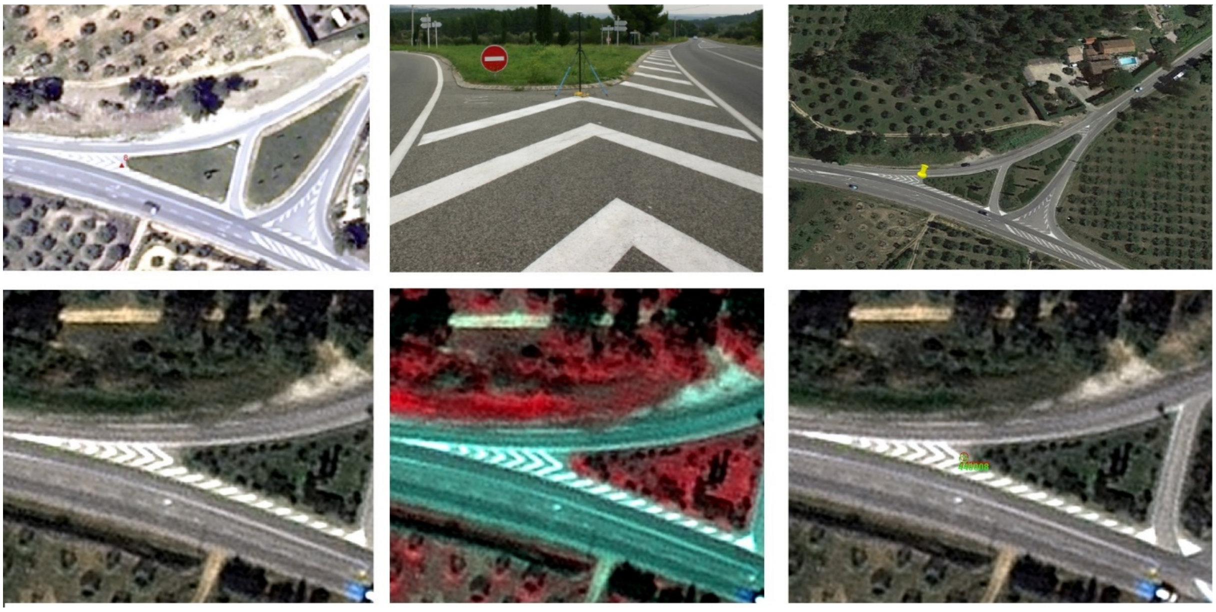
If the error is normally distributed in each the x- and y-component, the error for the x-component is equal to and independent of the error for the y-component, and sufficient check points are available to accurately estimate the variances, CE90 can be expressed as 2,146 times the one dimensional root mean square error:

$$\mathrm{CE}(90) = 2{,}146 * RMSE_{(East)} \quad \text{or} \qquad \mathrm{CE}(90) = 2{,}146 * RMSE_{(North)}$$

Unlike the values obtained from the field measurements (in our case with GPS device) which are of the defined accuracy the coordinates registered from the involved orthoimages are biased by various influencing factors (errors of the source image, quality of auxiliary reference data, visual quality of the image, experience of an operator etc.). It should be taken into account that all these factors are then subsequently reflected in the overall RMSE which in practice aggregates the residuals into a single measure.

All measurements presented were carried out in ERDAS Imagine 2016 software, using Metric Accuracy Assessment. Protocols from the measurements contain other additional indexes like mean errors or error standard deviation that can also eventually help to better describe the spatial variation of errors or to identify potential systematic discrepancies [ii].

Figure 8 Example of the ICP localization on the orthoimage



Since the JRC datasets of DGPS points are of a high variety as for the date of origin is concerned (2003-2012) many points were difficult to detect due to the meanwhile change of the overall landscape. Also the ADS40 aerial orthomosaic is 11 years old and therefore does not always correspond to the actual state of the region. Thus, for the selection of some ICPs on the orthoimages other complementary sources to the aerial image were used, like for instance previously orthorectified VHR images or Google Earth 2D sequences, which help to follow the change of the situation during the years, and in addition for some cases (where available) also 3D view.

Due to the fact that JRC datasets are obsolete (i.e some GCPs/ICPs are difficult to identify) the results may be encumbered with additional errors.

8 Outcome and discussion

8.1 Overall results

8.1.1 Rational Function Modelling

Table 15 Obtained quality control results ($RMSE_{1D}$) on orthoimage produced by applying Rational Function Modelling, using JRC ICPs dataset.

ONA	RPC	PCI			ERDAS		
	GCPs	RMSEx [m]	RMSEy [m]	CE(90) [m]	RMSEx [m]	RMSEy [m]	CE(90) [m]
7,2°	0	0,32	3,32	5,06	0,32	3,43	5,22
	3	0,35	0,71	1,20	0,31	0,90	1,44
	4	0,32	0,71	1,18	0,22	0,86	1,34
	6	0,30	0,70	1,16	0,40	0,90	1,50
28°	0	10,99	2,47	17,10	11,57	2,14	17,86
	3	0,69	1,16	2,05	0,74	1,17	2,11
	4	0,68	1,02	1,86	0,67	1,23	2,12
	6	0,80	1,07	2,03	0,70	1,21	2,12

8.1.2 Rigorous model

Table 16 Obtained quality control results ($RMSE_{1D}$) on orthoimage produced by applying Rigorous Modelling, using JRC ICPs dataset.

ONA	RIGOROUS	PCI		
	GCPs	RMSEx [m]	RMSEy [m]	CE(90) [m]
7,2°	6	0,71	0,78	1,60
28°	6	1,86	1,22	3,37

Figure 9 Point representation of planimetric RMSE 1D errors calculated on orthoimages using JRC ICPs dataset

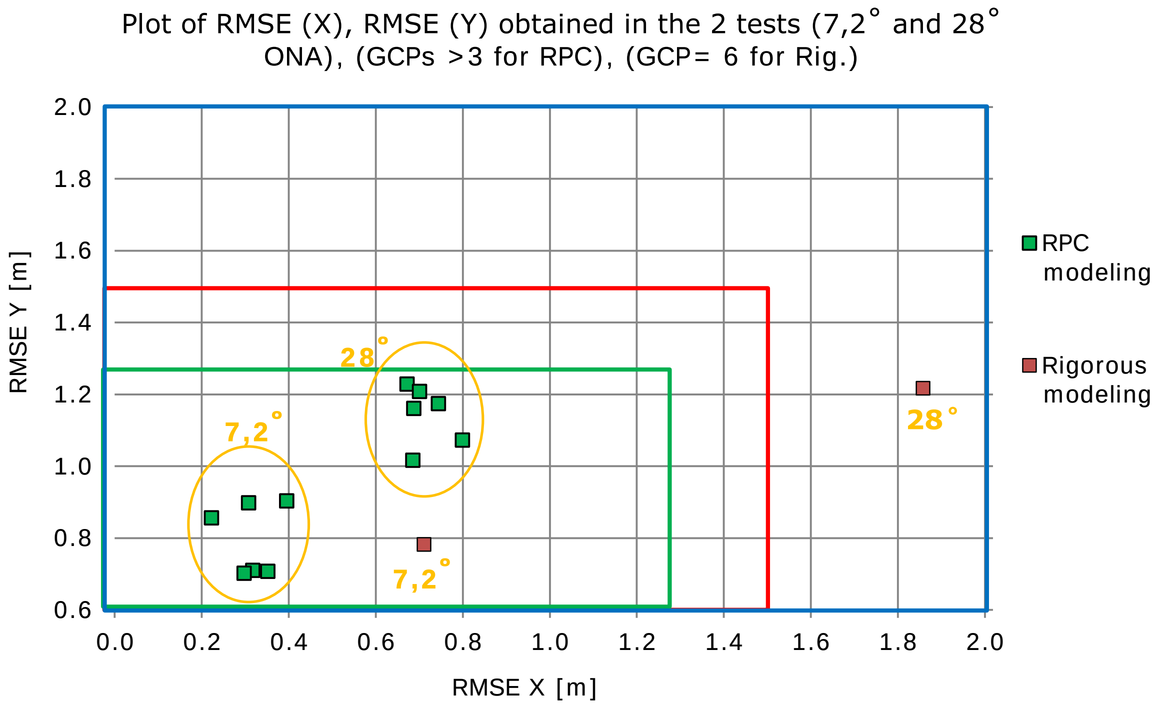
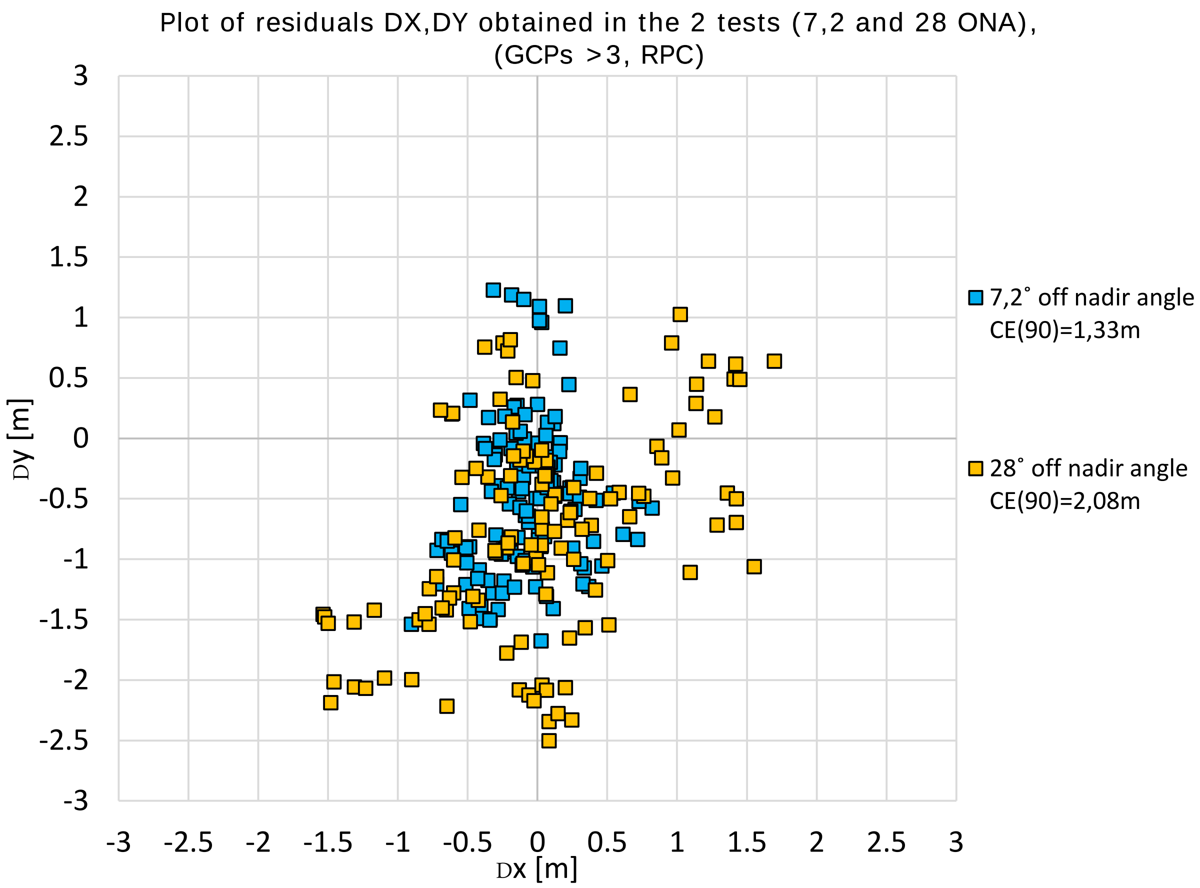


Figure 10 Point representation of planimetric residuals measured on orthoimages based on RPC modelling using JRC ICPs dataset



Plot of residuals DX,DY obtained in the 2 tests (7,2 and 28 ONA), (GCPs >3, RPC)
3
2.5
2
1.5
1
0.5
0
-0.5
-1
-1.5
-2
-2.5
-3
DY [m]
-3
-2.5
-2
-1.5
-1
-0.5
0
0.5
1
1.5
2
2.5
3
DX [m]
7,2˚ off nadir angle CE(90)=1,33m
28˚ off nadir angle CE(90)=2,08m

8.2 Discussion on the number of GCPs used for the modelling

Figure 11 Behaviour of RMSEs across the various number of GCPs for PCI and ERDAS software, source image 7,2°off nadir angle, RPC modelling

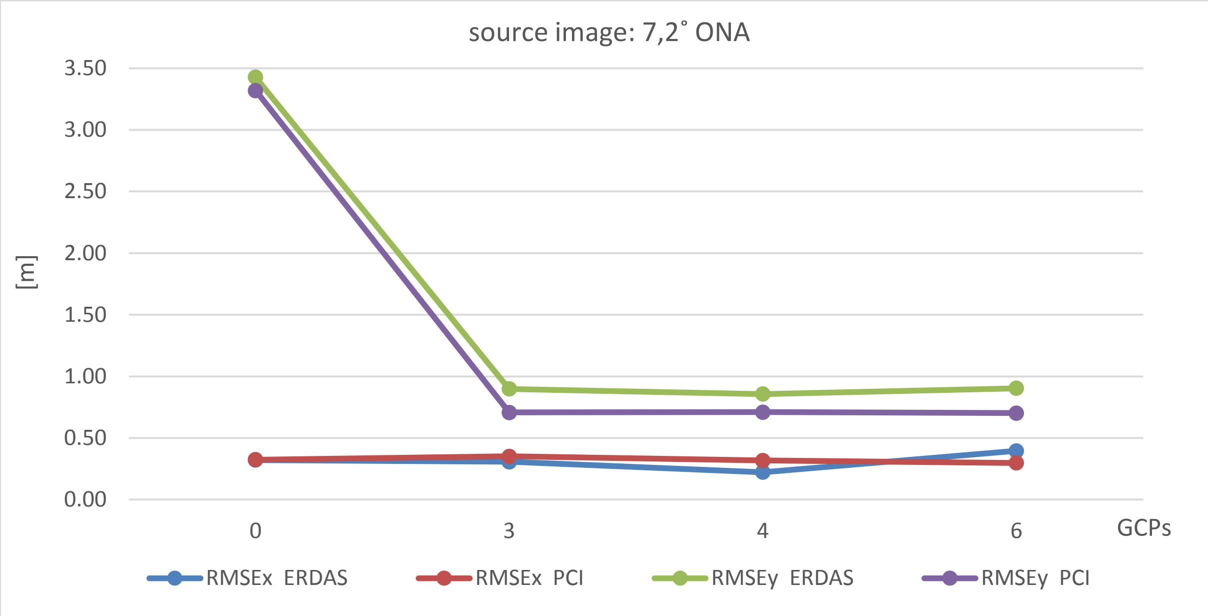
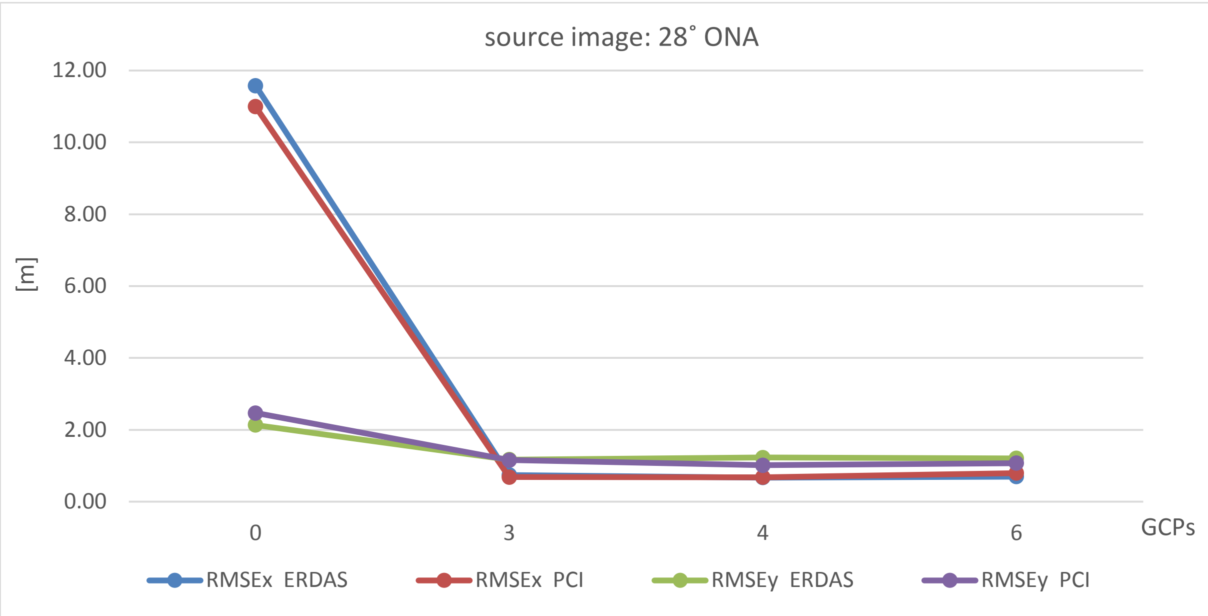


Figure 12 Behaviour of RMSEs across the various number of GCPs for PCI and ERDAS software, source image 28°off nadir angle, RPC modelling



Looking at the **Figure 11** and **Figure 12** we can summarise the following findings:

- There is an expected difference between RMSEs of orthoimages derived with 0 GCPs and 3 (and more) GCPs, using RPC modelling. The behaviour of RMSEs of orthoimages depends on the off nadir angle of the source image. Using far off nadir angle and 0 GCP, the RMSEy is relatively low, the RMSEx results in 11.5m however decreases to cca 0.7m when 3GCPs are applied.
- Using RPC modelling to create an orthoimage with ≥3GCPs does not have any substantial influence on RMSE value.
- As far as rigorous modelling is concerned, the influence of the number of GCPs on the RMSE couldn't be assessed as only the 6 GCPs scenario was tested.

8.3 Discussion on software usage factor

To compare the performance of different algorithms implemented in various COTS, PCI Geomatics 2017 SP1 and ERDAS 2016 v16.1 were selected to derive the corresponding ortho products from the source images.

Looking at **Figure 11 - Figure 12** we can summarise that both software products produce ortho imagery of a very similar geometric accuracy.

8.4 Discussion on influence of off nadir angle of a source image

Figure 13 Graph of RMSEs as a function of the number of GCPs and off nadir angle, PCI software, RPC modelling

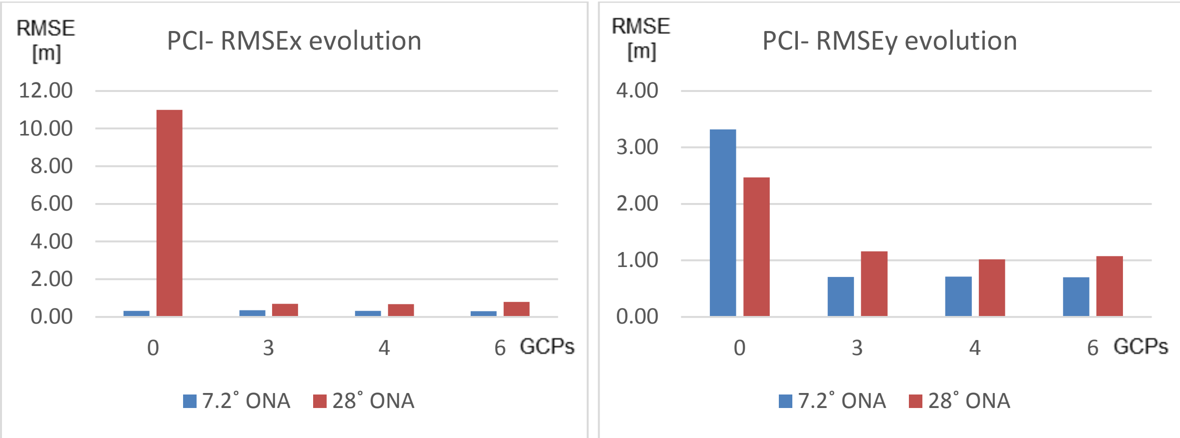


Figure 14 Graph of RMSEs as a function of the number of GCPs and off nadir angle, ERDAS software, RPC modelling

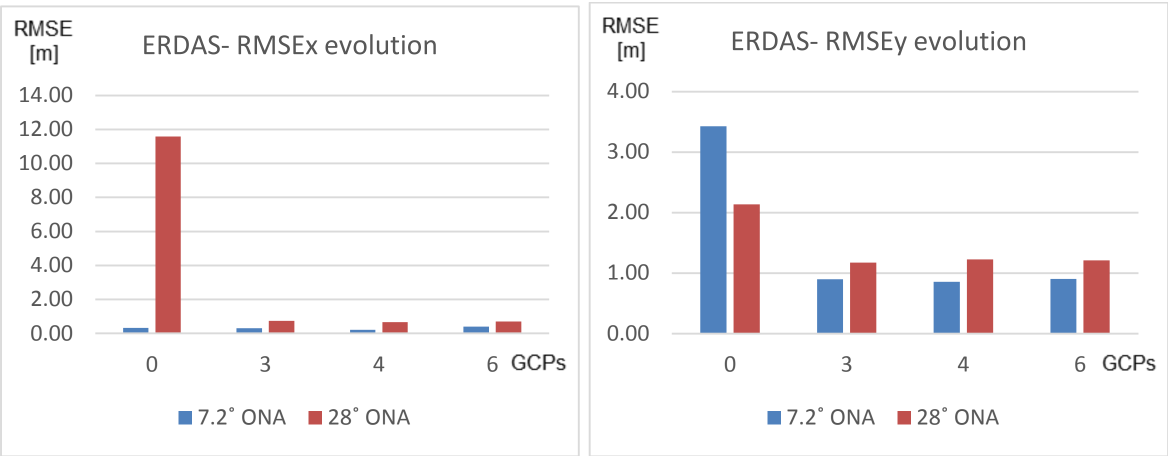
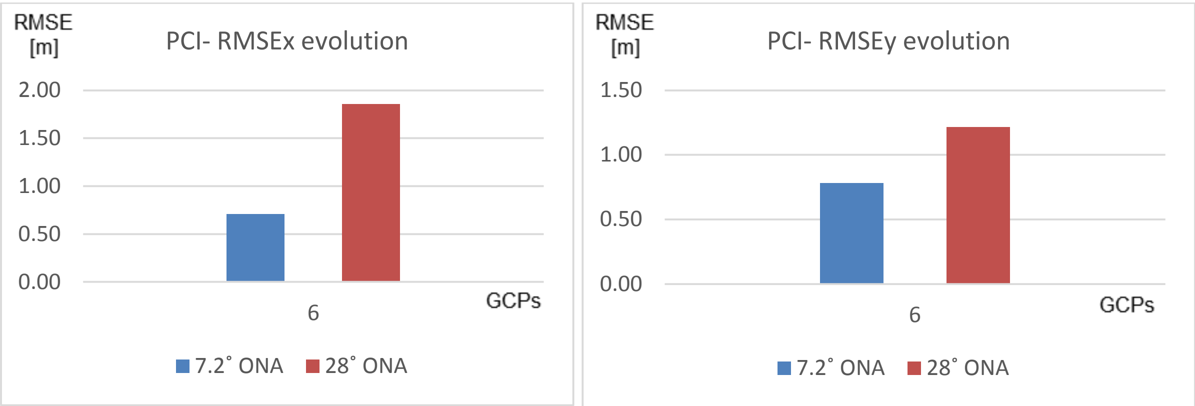


Figure 15 Graph of RMSEs as a function of the number of GCPs and off nadir angle, PCI software, Rigorous modelling



Comparing the results displayed in the **Figure 13** - **Figure 15** we can summarise the following findings:

It can be concluded that 1-D RMSE errors are sensitive to the overall off nadir angle of the acquired scene.

- As far as RMSEs in the Northing direction (RMSEy) are concerned an increase with the increasing off nadir angle of the source image is observed. The exception is 0 GCP scenario where RMSEy of orthoimages derived from 28° off nadir angle source image are lower than RMSEy calculated from orthoimages derived from 7,2° off nadir angle source image.
- Values of RMSEs in the Easting direction (RMSEx) for tested ortho imagery always increase with the increasing off nadir angle of the acquired image.
- 0 GCP scenario: while RMSEy is relatively stable with a changing ONA (even if surprisingly going slightly down with higher ONA), RMSEx increased by 10m with the change of ONA from 7.2° to 28° ONA

8.5 Discussion on Rigorous and Rational Function Modelling

From **Figure 9** we can summarize that:

- RPC based orthoimages and rigorous ones give comparable results as regards to RMSEy values.
- Using only 6 GCPs the rigorous method have a difficulty to model North-South direction and gives higher RMSEx errors than RPC modelling.

8.6 Summary

With regard to the factors influencing the final orthoimage accuracy, on basis of the test results the following conclusions for the tested scenarios can be drawn:

- In general, RMSEx values are lower than RMSEy, thus modelling of East-West direction is better than North-South direction.
- RMSEy – is increasing with higher ONA angle of source image, with exception of 0 GCP scenario.
- RMSEx – is increasing with higher ONA angle of source image.
- Both software packages Erdas and PCI perform equally.
- From the results obtained, it is suggested to always use ≥ 3 GCPs for RPC modelling, depending on the accuracy of the GCPs and the accuracy requirements of the project. Regarding the rigorous modelling the number of GCPs that would give satisfactory results need further investigation. We could assume ≥ 9 GCPs per scene.
- When ≥ 3 GCPs for RPC modelling are used the number of GCPs doesn't influence the final geometric accuracy of the orthoimage.

9 Conclusions

A far as the validation of the KOMPSAT-3A ortho products is concerned, on the basis of the presented results, it is asserted that:

- The KOMPSAT-3A PSH ortho imagery geometric accuracy meets the requirements of 2 m and 1.5 m 1D RMSE corresponding to the VHR prime profiles defined in the VHR profile based technical specifications [iii].
- The RMSEx, and RMSEy threshold of 1:5.000 scale imagery of 1.25m is fulfilled for all angles 7,2°, 28° ONA orthos when GCPs (≥3) are applied in addition to RPC function.
- The KOMPSAT-3A PSH ortho imagery geometric accuracy meets the requirement of 5 m 1D RMSE corresponding to the VHR backup profile defined in the VHR profile based technical specifications [iii].

The findings on the KOMPSAT-3A orthoimage geometric accuracy have given satisfactory results and meet the requirements of the CAP-CwRS Image Acquisition project.

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List of abbreviations and definitions

1-D	One-dimensional
ADS40	The Airborne Digital Sensor
B	Blue
CAP	The Common Agricultural Policy
CE90	Circular Error 90%
CwRS	Control with Remote Sensing
DEM	Digital Elevation Model
DTM	Digital Terrain Model
EQC	External Quality Control
EUSI	European Space Imaging
G	Green
GCP	Global Positioning System
GNSS	Global Navigation Satellite System
GPS	Global Positioning System
GSD	Ground Sample Distance
ICP	Independent Check Point
IQC	Internal Quality Control
IR	Infrared
JRC	Joint Research Centre
KARI	Korea Aerospace Research Institute
KOMPSAT	Korean Multi-Purpose Satellite
LPISQA	Land Parcel Information System quality assessment
LEOP	Launch and Early Orbit Phase
MS	Multispectral
ONA	Off Nadir Angle
PAD	Precision Attitude Determination
PAN	Panchromatic
POD	Precision Orbit Determination
R	Red
RMSE	Root Mean Square Error
RPC	Rational Polynomial Coefficient
SIIS	SI Imaging Services
UTC	Universal Time Coordinated
UTM	Universal Transverse Mercator
VHR	Very High Resolution
WGS84	World Geodetic System '84

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Annexes

Annex 1. Internal Quality Control Reports
Annex 2. External Quality Control Reports

Both Annex I and Annex II are archived in:
//ies-ud01.jrc.it/D5_capland/ Data/Imagery/Maussane/KOMPSAT-3A

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