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New sensors benchmark report on WorldView-4

Geometric benchmarking over Maussane test site for CAP purposes

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Contents

Abstract

Imagery collected by recently launched WorldView-4 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 planimetric accuracy of produced ortho imagery does not exceed certain values regulated by JRC. Therefore, benchmarking tests were carried out on three WorldView-4 imagery collected in March and April 2017. This report (together with [xix]) describes in details how the tests were performed i.e. auxiliary data used, methodology and workflow as well as outcome from the Internal Quality Control. However, to make the tests objective, the ortho imagery have been handed to JRC for External Quality Control which is a base for certification of the sensor

1 Introduction

This report describes in details steps that have been taken in order to qualify WorldView-4 sensor to The Common Agricultural Policy (CAP) image acquisition Campaign. The main requirement according to VHR image acquisition specifications for the CAP checks [ii] is planimetric accuracy of ortho imagery, i.e.

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

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

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

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

- number and distribution of GCPs
- incidence angle
- sensor model implemented in the software (PCI and ERDAS)

2 WorldView-4 satellite

WorldView-4 sensor was launched in November 2016 from the Vandenberg Air Force Base located in California, US. The resolution of 0.31m makes WorldView-4 the highest resolution commercial satellite in the world. Satellite sensor characteristics (design and specifications) are given in the table below.

Table 1. WorldView-4 specifications

Launch information	Date: November 11, 2016 Launch Site: Vandenberg Air Force Base, California
Orbit	Altitude: 617 km Type: SunSync, 10:30 am descending Node Period: 97 min
Mission Life	Estimated Service Life: 10 to 12 years
Spacecraft Size, Mass and Power	Size: 5.38 m (17.7 ft) tall x 2.65 m (8.7 ft) across 7.75 m (25.5 ft) across deployed solar arrays Aperature:1.1m
Revisit Frequency (at 40°N Latitude)	1 m GSD: <1.0 day 4.5 days at 20° off-nadir or less
Sensor bands: spectral range	• Panchromatic: 454-796 nm • 4 Multispectral: Blue: 446 - 508 nm Green: 507 - 580 nm Red: 655 - 690 nm Near-IR1: 778 - 902 nm
Sensor Resolution (GSD at nadir)	0.31 m - Panchromatic at nadir 1.24 m - Multispectral at nadir
Dynamic Range	11-bits per pixel Pan and MS
Swath Widths	13.1 kilometers at nadir
Geolocation Accuracy (CE90)	Predicted <5 m CE90 without ground control/in flat terrain
Capacity	680,000 km² per day

3 WorldView-4 image products

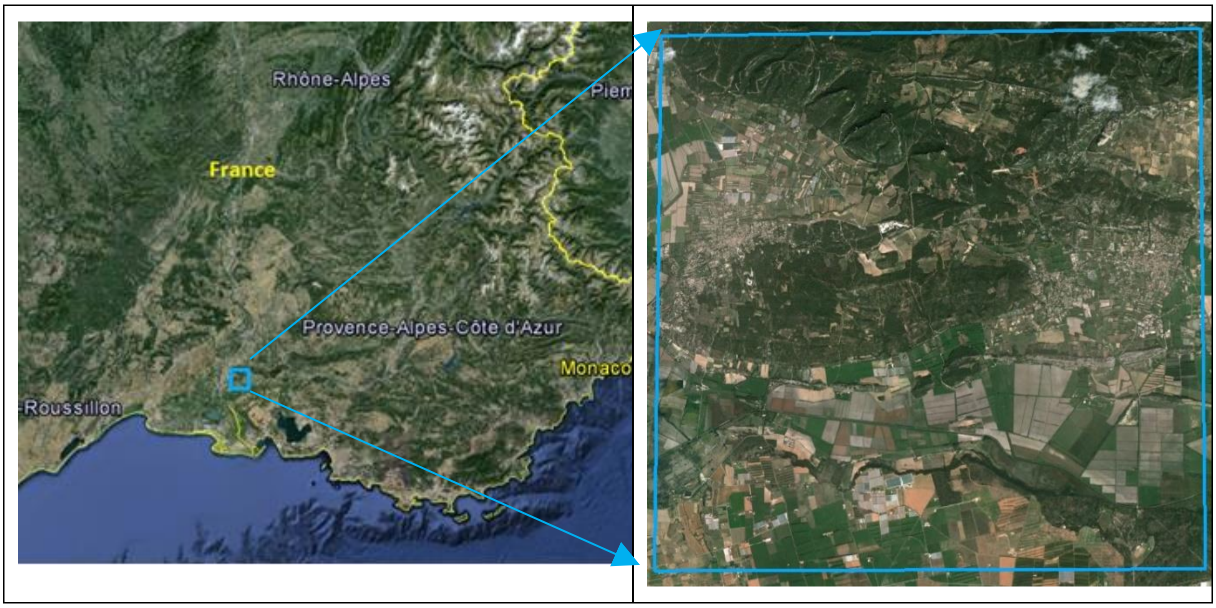
WorldView-4 imagery can be processed and delivered as **Basic Imagery 1B (System-Ready)** or **Standard Imagery 2A (View-Ready 2A)** or **OR2A (View-Ready OR2A)**. A brief description of mentioned image products is given below.

1. **Basic Imagery Products 1B (System-Ready)** are designed for customer with advanced image processing capabilities. Each unique image in a Basic Product is processed individually and delivered as scene. This product is radiometrically and sensor corrected. However, not projected to a plane using a map projection or datum (therefore, it’s a geometrically raw product with no implied accuracy).
2. **Standard Imagery** are designed for users requiring modest absolute accuracy and/or large area coverage. Standard imagery are radiometrically corrected, sensor corrected, and projected to a plane using the map projection and datum of the customer's choice and comes in two varieties:
   (a) Standard Imagery 2A (View-Ready 2A) has a course DEM applied to it, which is used to normalize for topographic relief with respect to the reference ellipsoid. The degree of normalization is relatively small therefore cannot be considered as orthorectified.
   (b) Ortho Ready Standard Imagery OR2A (View-Ready OR2A) has no topographic relief applies with respect to the reference ellipsoid (making it suitable for orthorectification), is projected to a constant base elevation calculated on the average terrain elevation per order polygon.

4 Study Area

The test AOI is located in 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 (high difference between highest and lowest point is around 300m). The area used in the tests is 100km2 and spans 4◦41′ to 4◦48′E and 43◦40′ to 43◦45′N (**Figure 1**)

Figure 1. Location of the test site



5 Auxiliary data

5.1 Ground Control Points

Ground Control Points play an important role in orthorectification process of satellite imagery because help to improve planimetric accuracy of created ortho image. However, these points cannot be random points, general principles for selection 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 [i] specifies the accuracy requirements for GCPs 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 for the CAP checks (CwRS and LPISQA) - VHR profile-based, target ortho image accuracy for VHR prime is 2m/1.5m/1.25m and 5m for VHR Backup [ii].

Considering all the above, set of 12GCPs (**Table 3**, **Figure 2**) to be used in the modeling phase in the orthorectification process of three WorldView-4 imagery has been selected from GCP dataset received from JRC (**Table 2**).

Table 2. Ground Control Points available for the Maussane test site

Dataset	Point ID	RMSEx [m]	RMSEy [m]
ADS40_GCP_dataset_Maussane_ prepared_for_ADS40_in_2003	11XXXX	0,05	0,10
VEXCEL_GCP_dataset_Maussane_ prepared_for_VEXEL_in_2005	44XXXX	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_ for_Cartosat_in_2006	33XXX	0,55	0,37
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

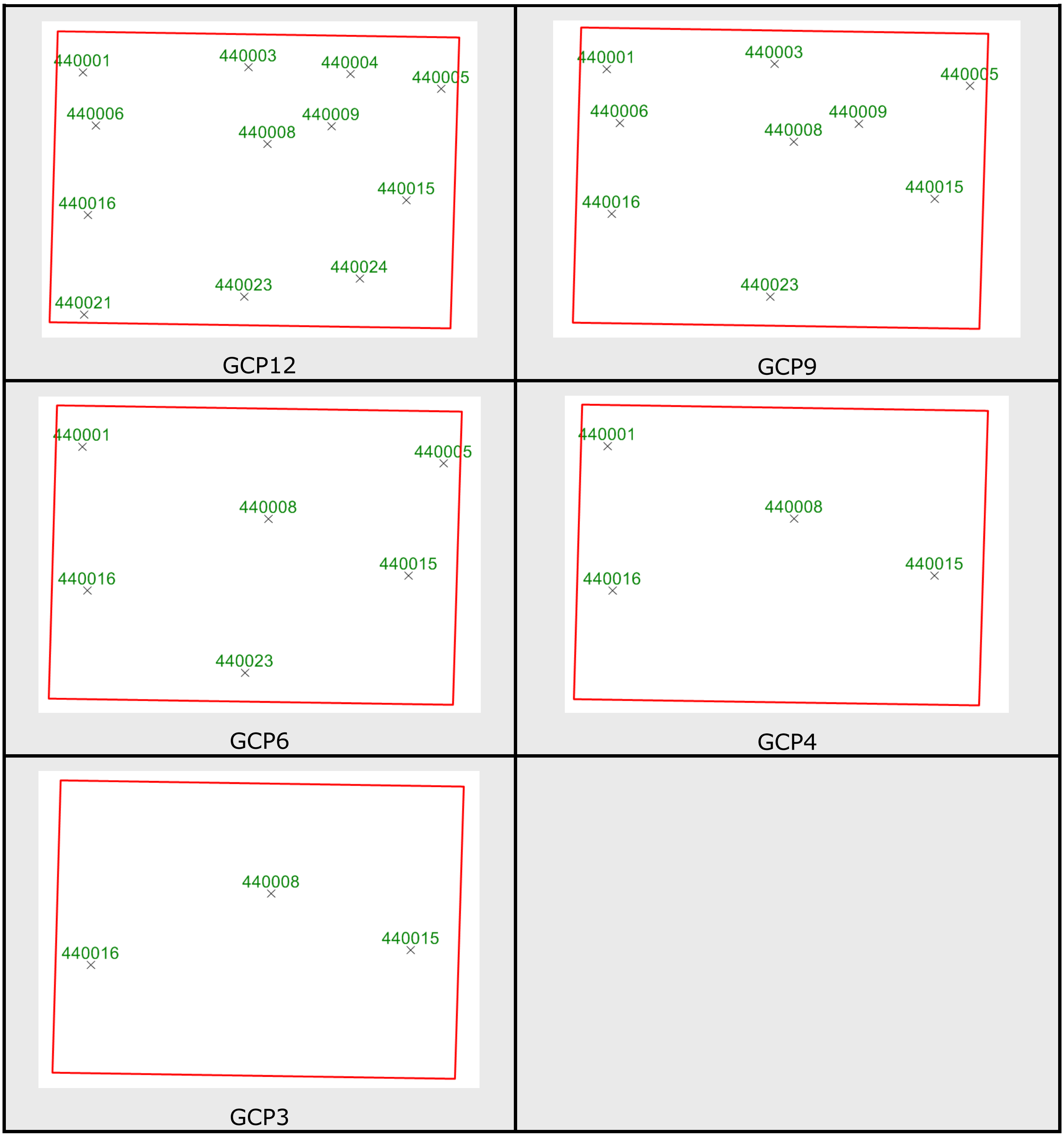
Table 3. Ground Control Points selected for WorldVIew-4 benchmarking and scenarios used

#	ID	GCP3	GCP4	GCP6	GCP9	GCP12
1	440001		x	x	x	x
2	440003				x	x
3	440004					x
4	440005			x	x	x
5	440006				x	x
6	440008	x	x	x	x	x
7	440009				x	x
8	440015	x	x	x	x	x
9	440016	x	x	x	x	x
10	440021					x
11	440023			x	x	x
12	440024					x

Table 4. Coordinates of Ground Control Points selected for WorldView-4 benchmarking

ID	Easting	Northing	Ellips_H
440001	636881.715	4845450.019	56.21
440003	640999.134	4845715.569	153.48
440004	643544.233	4845535.279	197.24
440005	645815.166	4845076.105	176.54
440006	637241.307	4843631.124	56.87
440008	641527.505	4843087.455	121.11
440009	643112.409	4843729.238	120.04
440015	645030.500	4841227.208	60.33
440016	637104.554	4840553.202	54.18
440021	637082.024	4837127.366	66.11
440023	641060.734	4837826.921	87.87
440024	643930.013	4838510.152	51.24

Figure 2. Ground Control Points distribution

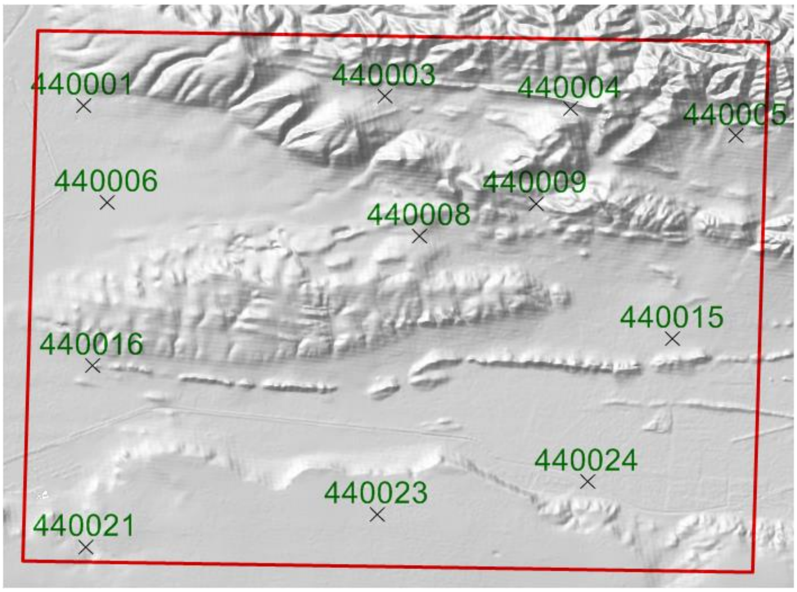


5.2 DEM

A DEM is used to remove image displacement caused by topographic relief, therefore should be as accurate as possible. However, recommendation Guidelines for Best Practice and Quality Checking of Ortho Imagery [i] is to use DEM:

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

Figure 3. Intermap5mDTM



From two available DEM it was decided to use INTERMAP5mDTM in the tests. As explained in New sensors benchmark report on Kompsat-3. Geometric benchmarking over Maussanne test site for CAP purposes [xvii] 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 smearing effect in ortho image. For the open areas there are only minor differences between these DEMs.

Table 5. DEM Specifications

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

5.3 Aerial Orthomosaics

Table 6. Aerial Orthomosaics 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 WorldView-4 satellite imagery

WorldView-4 satellite imagery that have been used to perform benchmarking tests have been collected in March and April 2017 at off nadir angle 8.8º, 24.4º and 35,9º. The data have been processed as Ortho Ready Standard Pansharened with GSD 50cm. Pansharpened imagery consist of Blue, Green, Red and NIR1 bands which are delivered in one image file. Each Ortho Ready Standard product has associated RPC information - simpler empirical mathematical models relating image space (line and column position) to latitude, longitude, and surface elevation.

Table 7. Collection and production parameters of WorldView-4 imagery

CAT_ID	1070050001DD0B00	1070050001DCD600	1070050001DCD900
Image Quicklook			
Collection Parameters			
Collection date	05.04.2017	30.03.2017	30.03.2017
Off nadir angle	8.8º	24.4º	35.9º
Elevation Angle	80.5º	63.2º	49.7º
Cloud cover [%]	0	0	0
Production Parameters			
Product Name	Ortho Ready Standard (OR2A)		
Product Option	4 Band Pansharpened (BGRN)		
GSD	50cm		
Resampling Kernel	4x4cubic convolution		
File Format	Geotiff		
Bit Depth	16bit		
Projection/Datum	UTM/WGS84		

5.5 Software

- PCI Geomatica Orthoengine 2016
- ERDAS Imagine 2016

6 WorldView-4 Benchmarking Tests

6.1 Benchmarking Methodology

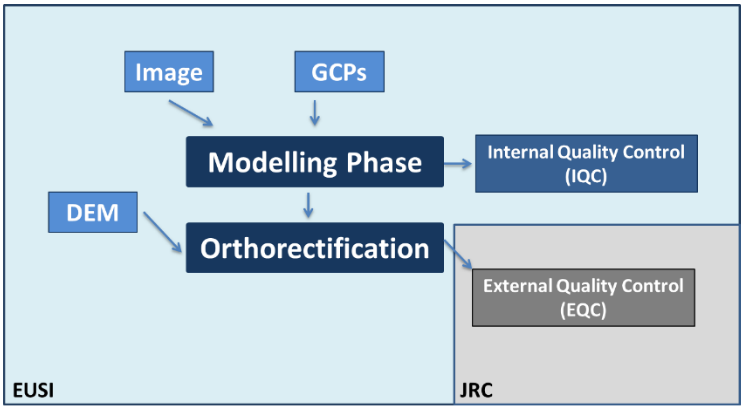
Orthorectification is the geometric transformation of an image (which is fraught with displacements due to sensor orientation and terrain) to the projection of a map coordinate system. Therefore, orthorectification is the process of reducing geometric errors inherent within imagery and consists of 3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

Phase 1: Modeling - 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 Ground Control Points 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 [i] minimum 20 check points should be checked in order to assess ortho image planimetric accuracy. The points used during the geometric correction phase should be excluded.

Figure 4. Standard benchmarking procedure



Tests were performed using two softwares: PCI Geomatica Orthoengine 2016 and ERDAS Imagine 2016. In both softwares, RPC model has been tested with the same combination of GCPs given beforehand by JRC. Rigorous model has been tested in PCI Geomatica Orthoengine 2016 only (Rigorous Model for OR2A is not supported in ERDAS Imagine 2016). However, the selection of appropriate GCPs was done by EUSI/GAF (**Table 3**) from the set of GCPs available for Mausane test site (**Table 2**). Tested scenarios are described in chapter 6.2 (**Table 8**), residuals obtained from geometric correction model phase are listed in chapter 6.3 (**Table 9**, **Table 10**).

In total 45 ortho imagery were prepared and handed for External Quality Control to JRC.

6.2 Test Scenarios

The following scenarios have been considered in our benchmarking tests:

Table 8. Tested Scenarios

COTS Software	Sensor Model – Phase 1	No. of GCPs	DEM	No. of source imagery	No. of ortho images created
		0		3 (36 °/ 24° / 9 °)	6
		3		3 (36 °/ 24° / 9 °)	6
		4		3 (36 °/ 24° / 9 °)	6
		6		3 (36 °/ 24° / 9 °)	6
		9		3 (36 °/ 24° / 9 °)	6
		12		3 (36 °/ 24° / 9 °)	6
		6		3 (36 °/ 24° / 9 °)	3
		9		3 (36 °/ 24° / 9 °)	3
		12		3 (36 °/ 24° / 9 °)	3
					45 ortho images

6.3 Internal Quality Control

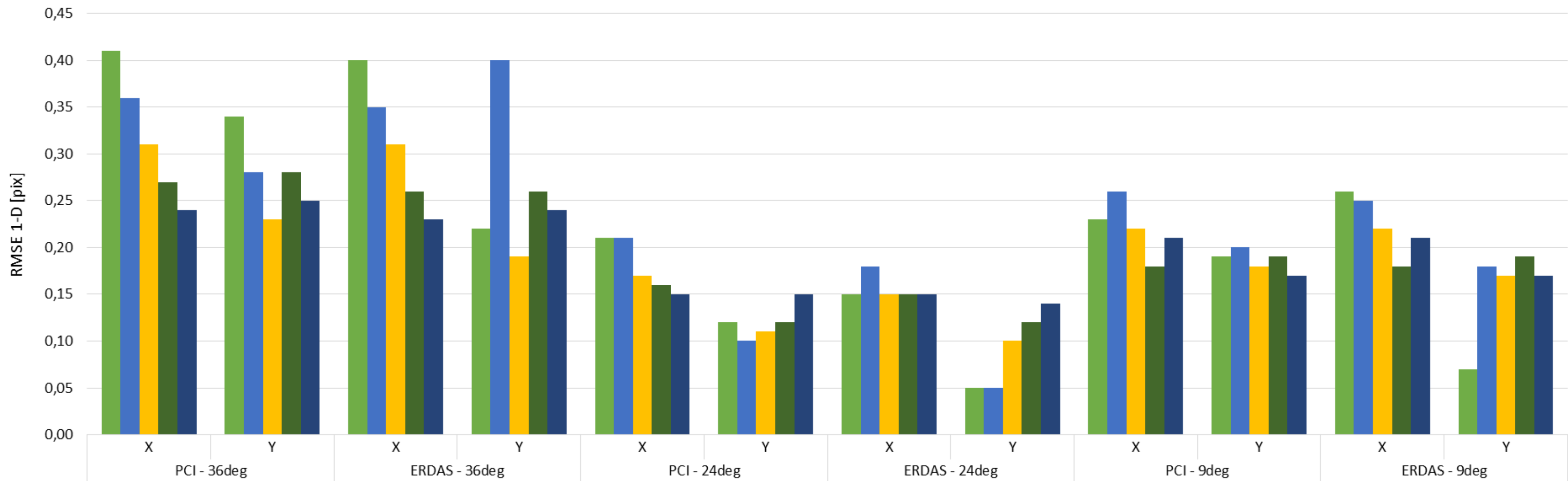
Table 9. Residuals obtained in modeling Phase 1 – RPC0

Off-nadir angle	Number of GCPs	Direction	RPC		DEM
			PCI Geomatica Orthoengine 2016	ERDAS Imagine 2016	
			RMSE[pix]	RMSE [pix]	
		X	–	–	
		Y	–	–	
		X	0.41	0.40	
		Y	0.34	0.22	
		X	0.36	0.35	
		Y	0.28	0.40	
		X	0.31	0.31	
		Y	0.23	0.19	
		X	0.27	0.26	
		Y	0.28	0.26	

[1] Rigorous Model for OR2A is not supported in ERDAS Imagine 2016

	12	X	0.24	0.23	
		Y	0.25	0.24	
		X	–	–	
		Y	–	–	
		X	0.21	0.15	
		Y	0.12	0.05	
		X	0.21	0.18	
		Y	0.10	0.05	
		X	0.17	0.15	
		Y	0.11	0.10	
		X	0.16	0.15	
		Y	0.12	0.12	
		X	0.15	0.15	
		Y	0.15	0.14	
		X	–	–	
		Y	–	–	
		X	0.23	0.26	
		Y	0.19	0.07	
		X	0.26	0.25	
		Y	0.20	0.18	
		X	0.22	0.22	
		Y	0.18	0.17	
		X	0.18	0.18	
		Y	0.19	0.19	
		X	0.21	0.21	
		Y	0.17	0.17	

Figure 5. Residuals obtained in modeling phase 1 – RPC0 modelling

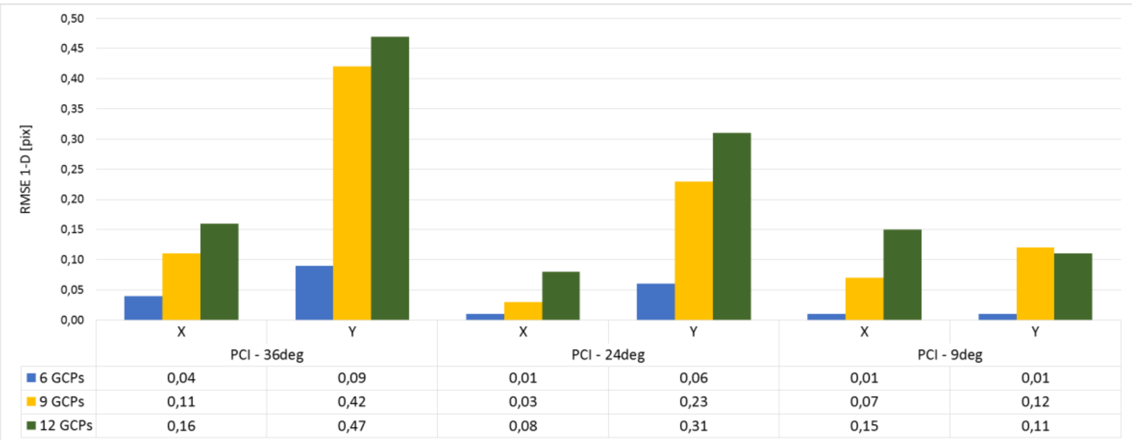


	PCI - 36deg X	PCI - 36deg Y	ERDAS - 36deg X	ERDAS - 36deg Y	PCI - 24deg X	PCI - 24deg Y	ERDAS - 24deg X	ERDAS - 24deg Y	PCI - 9deg X	PCI - 9deg Y	ERDAS - 9deg X	ERDAS - 9deg Y
3 GCPs	0,41	0,34	0,4	0,22	0,21	0,12	0,15	0,05	0,23	0,19	0,26	0,07
4 GCPs	0,36	0,28	0,35	0,4	0,21	0,1	0,18	0,05	0,26	0,2	0,25	0,18
6 GCPs	0,31	0,23	0,31	0,19	0,17	0,11	0,15	0,1	0,22	0,18	0,22	0,17
9 GCPs	0,27	0,28	0,26	0,26	0,16	0,12	0,15	0,12	0,18	0,19	0,18	0,19
12 GCPs	0,24	0,25	0,23	0,24	0,15	0,15	0,15	0,14	0,21	0,17	0,21	0,17

Table 10. Residuals obtained in modeling Phase 1 – Rigorous

Off-nadir angle	Number of GCPs	Direction	Rigorous PCI Geomatica Orthoengine 2016 RMSE[pix]	DEM
		X	0.04	
		Y	0.09	
		X	0.11	
		Y	0.42	
		X	0.16	
		Y	0.47	
		X	0.01	
		Y	0.06	
		X	0.03	
		Y	0.23	
		X	0.08	
		Y	0.31	
		X	0.01	
		Y	0.01	
		X	0.07	
		Y	0.12	
		X	0.15	
		Y	0.11	

Figure 6. Residuals obtained in modeling phase 1 – Rigorous model



7 External Quality Control

JRC as an independent entity performs a validation phase of the benchmarking workflow methodology used for verifying of a satelite's ortho-product compliance with the geometric quality criteria set up for the Control with Remote Sensing program (CwRS), in Common Agriculture Policy (CAP). The workflow follows the Guidelines for Best Practice and Quality Checking of Ortho Imagery [i] and is in detail described in the chapter 6.1.

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 Worldview-4 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 three 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 [i]. 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 correction) GCPs taken into account in the geometric correction have been excluded from the datasets considered for EQC.

Regarding the positional accuracy of ICPs, according to the Guidelines [i] 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 slightly above the mentioned threshold (**Table 11**, **Table 12**).

Table 11. Identical check points specifications

Dataset	RMSEx [m]	RMSEy [m]	N.of points
VEXEL_GCP_dataset_Maussane 2005	0,49	0,50	2
Multi-use_GCP_dataset_Maussane 2009	0,30	0,30	15
Maussane GNSS field campaign 2012	< 0,15	< 0,15	4

Figure 7. ICPs dataset used by JRC in the EQC of Worlview-4 ortho imagery.

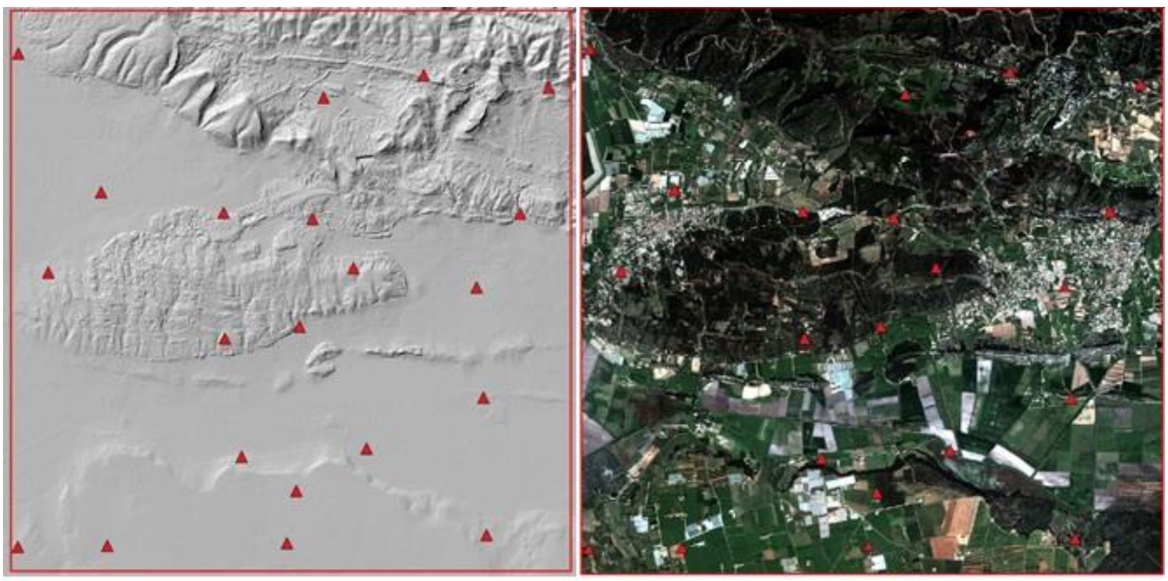


Table 12. ICPs overview

ID	E[m]	N[m]
66004	636363,62	4846077,52
66007	641804,02	4845298,88
66010	643598,10	4845690,29
66015	645830,46	4845477,35
66016	636347,01	4837279,93
66022	637947,95	4837300,70
66024	641320,70	4838276,56
66025	641380,52	4841215,07
66026	640049,05	4840996,07
66031	644655,96	4839947,67
66035	644717,26	4837489,03
66038	644535,09	4841910,06
66045	642336,27	4842251,71
66046	641148,67	4837348,79
66063	636896,93	4842180,72
440007	640019,09	4843239,85
440019	642578,11	4839029,46
C2R4	637829,72	4843609,87
C3R4	641608,72	4843129,15
C3R5NEW	640341,36	4838887,55
C4R4	645317,64	4843233,64

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 Independent Check Points.

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

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

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 ortho image 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).

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

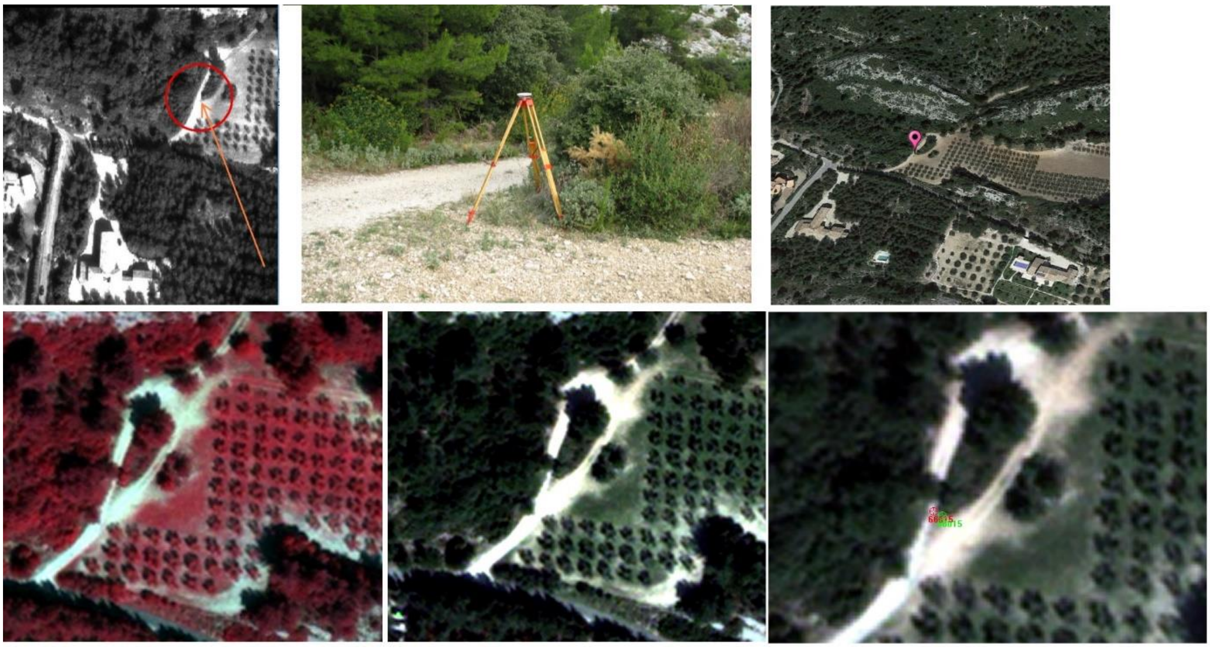
If the error is normally distributed in each the x- and y-component, the error for the x-component is equal to and independent of error for the y-component, and sufficient check points are available to accurately estimate the variances, CE90 can be expressed as 2,146 times the one dimensional root mean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

Figure 8. Example of the ICP localization on the ortho image



Since the JRC datasets of DGPS points are of a high variety as for the date of origin is concern (2003-20012) 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 ortho images the other complementary sources to the aerial image were used, like for instance previously orthorectified VHR images or Google Earth 2D sequences, which helps to follow the change of the situation during the years, 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 13. Obtained quality control results ($RMSE_{1D}$) on ortho image produced by applying Rational Function Modelling, using JRC ICPs dataset.

	RPC	PCI		ERDAS	
ONA	GCPs	RMSEx [m]	RMSEy [m]	RMSEx [m]	RMSEy [m]
	0	1,52	0,73	1,46	0,82
	3	1,15	0,74	1,15	0,71
	4	1,12	0,63	1,23	0,59
	6	1,15	0,60	1,24	0,59
	9	1,20	0,59	1,24	0,59
	12	1,15	0,63	1,18	0,62
	0	0,67	0,79	0,67	0,87
	3	0,95	0,71	0,91	0,70
	4	0,91	0,72	0,96	0,70
	6	0,87	0,66	0,94	0,72
	9	0,94	0,67	0,97	0,70
	12	0,99	0,70	0,93	0,72
	0	0,70	1,29	0,66	1,24
	3	0,69	0,96	0,56	0,75
	4	0,50	0,73	0,66	0,74
	6	0,58	0,84	0,67	0,79
	9	0,58	0,72	0,64	0,75
	12	0,57	0,80	0,60	0,73

8.1.2 Rigorous model

Table 14. Obtained quality control results ($RMSE_{1D}$) on ortho image produced by applying Rigorous Modelling, using JRC ICPs dataset.

	RIGOROUS	PCI	
ONA	GCPs	RMSEx [m]	RMSEy [m]
	6	1,27	0,61
	9	1,33	0,63
	12	1,27	0,65
	6	1,02	0,82
	9	0,98	0,85
	12	0,97	0,78
	6	1,77	0,81
	9	0,67	0,91
	12	0,70	0,91

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

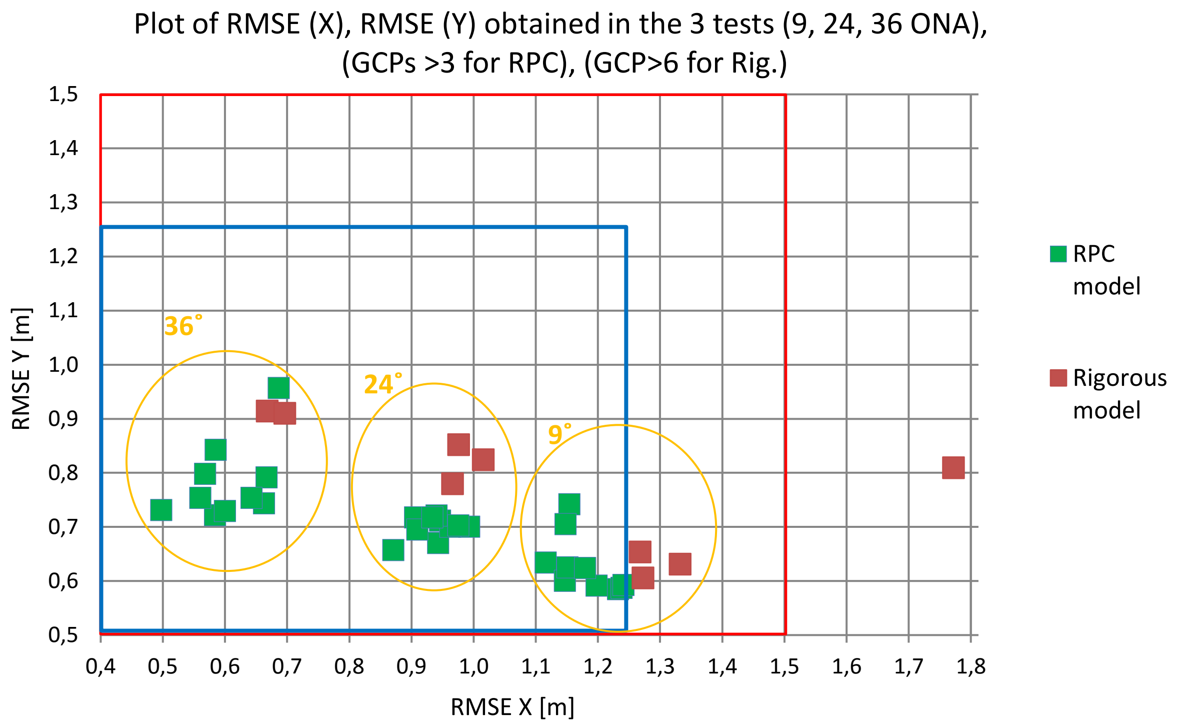
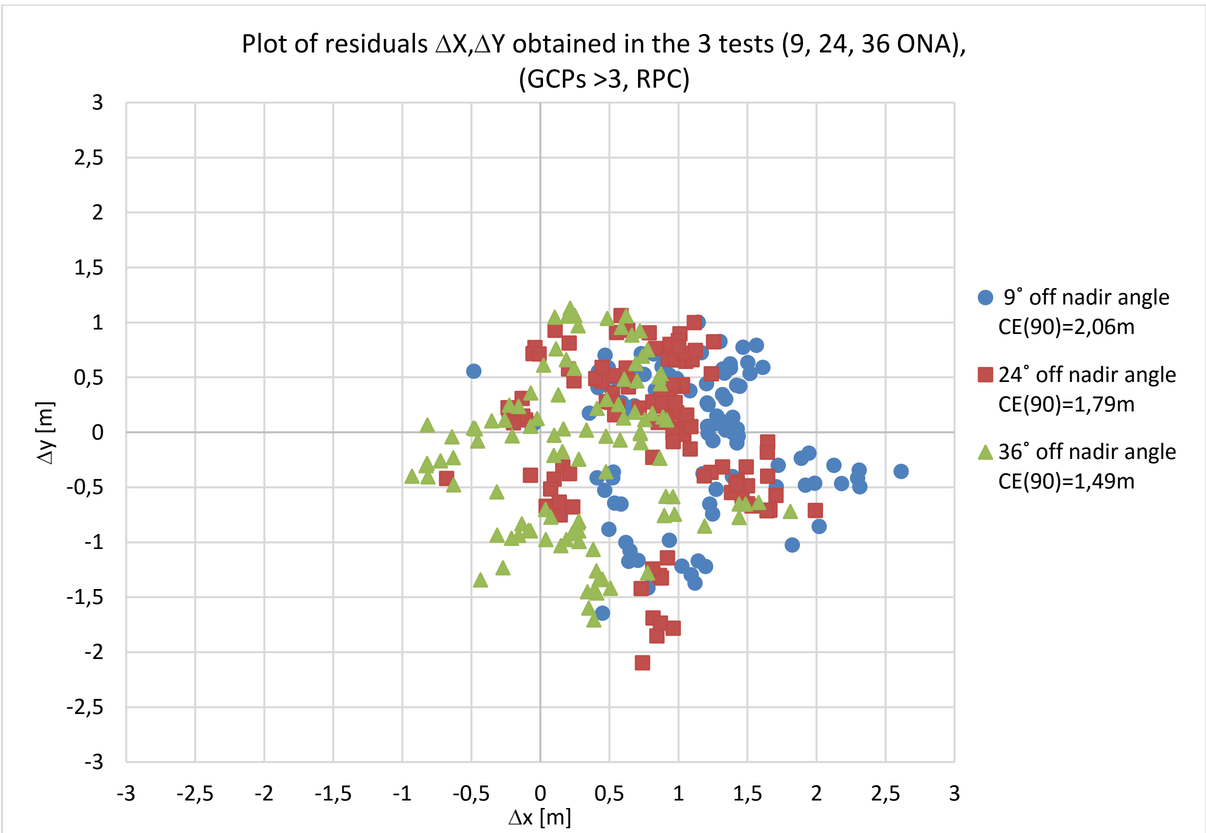


Figure 10. Point representation of planimetric residuals measured on ortho images based on RPC modelling using JRC ICPs dataset



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 9°off nadir angle, RPC modelling

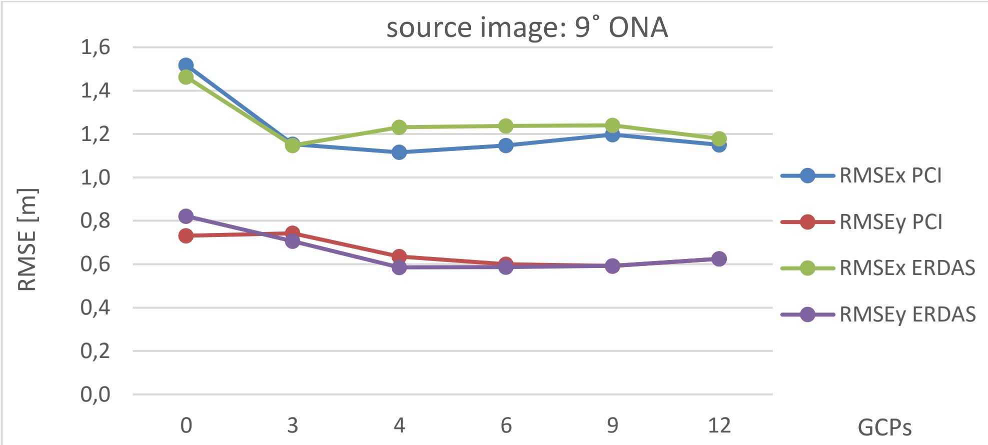


Figure 12. Behaviour of RMSEs across the various number of GCPs for PCI and ERDAS software, source image 24°off nadir angle, RPC modelling

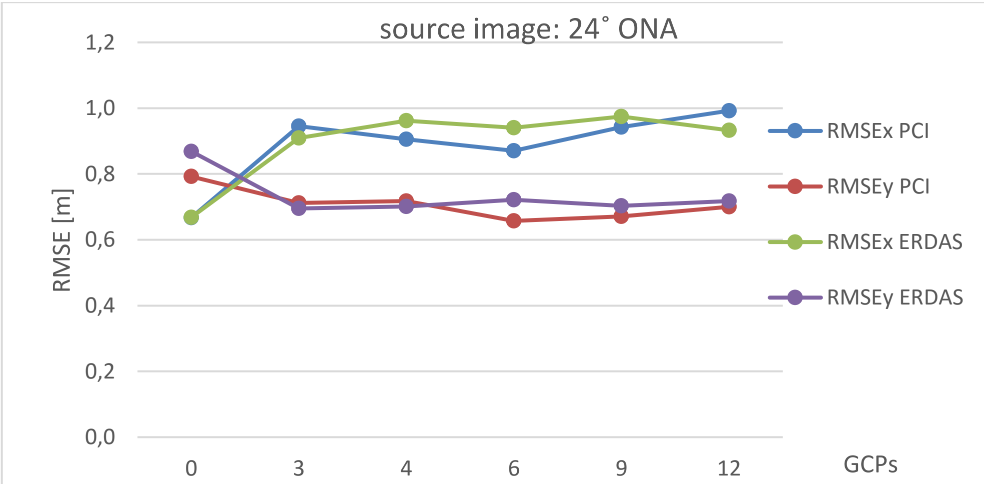


Figure 13. Behaviour of RMSEs across the various number of GCPs for PCI and ERDAS software, source image 36°off nadir angle, RPC modelling

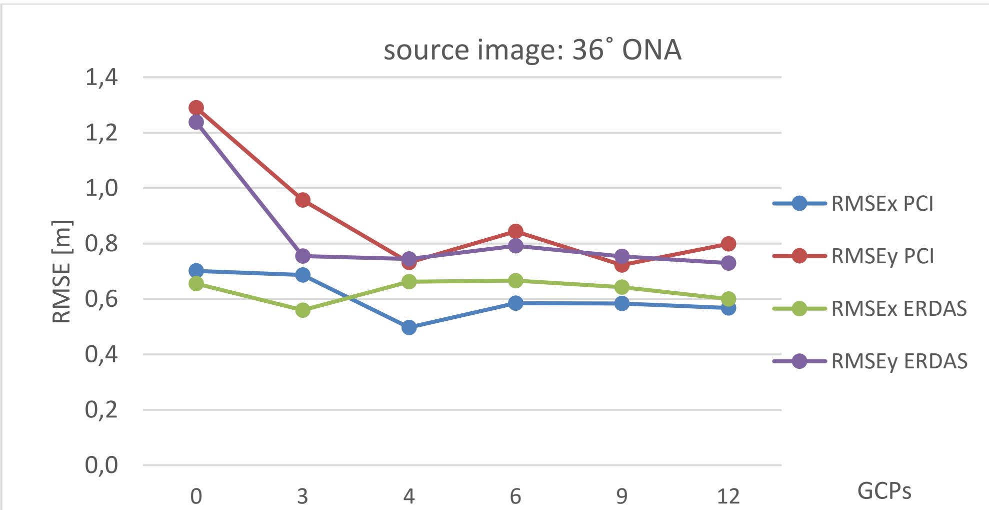


Figure 14. Behaviour of RMSEs across the various number of GCPs for PCI software, source image 9˚off nadir angle, Rigorous modelling

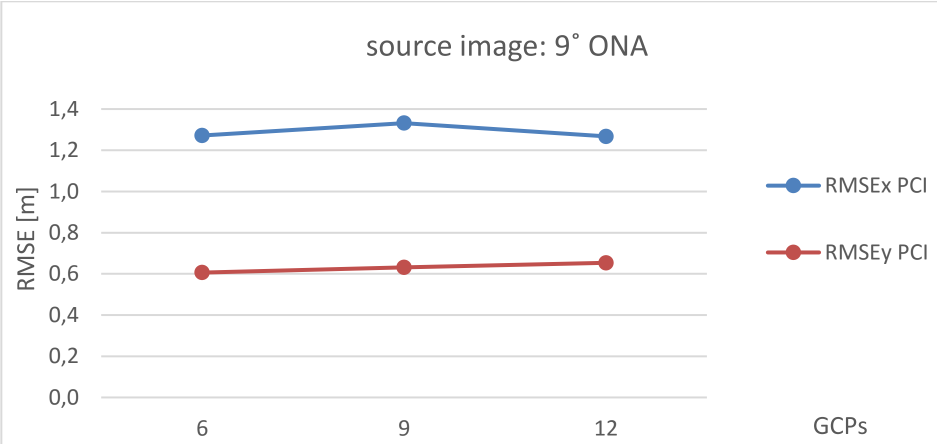


Figure 15. Behaviour of RMSEs across the various number of GCPs for PCI software, source image 24˚off nadir angle, Rigorous modelling

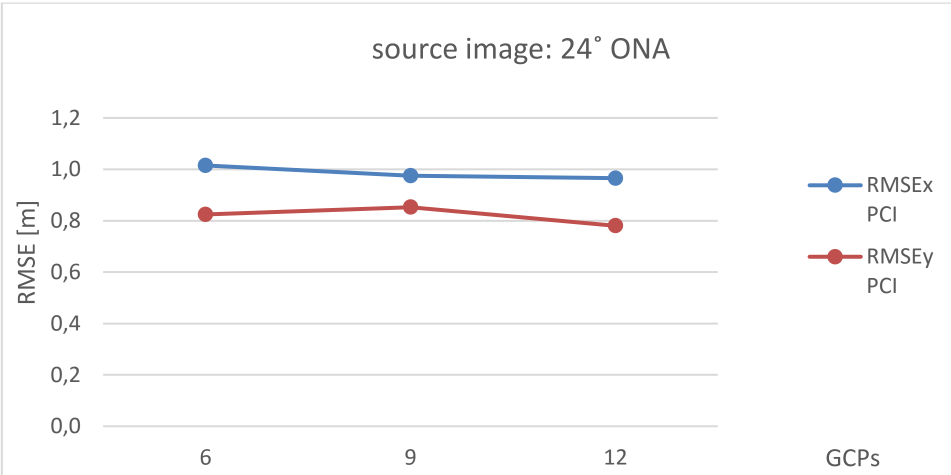
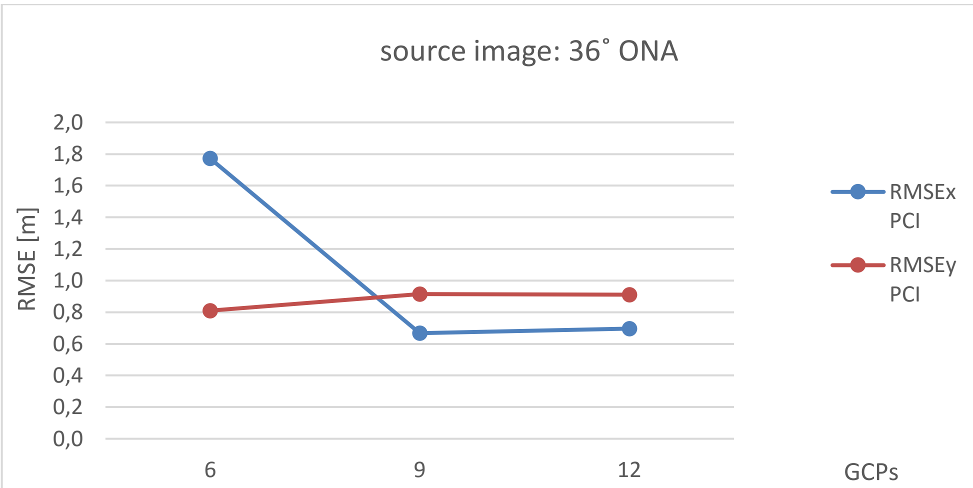


Figure 16. Behaviour of RMSEs across the various number of GCPs for PCI software, source image 36˚off nadir angle, Rigorous modelling



Looking at the **Figure 11** - **Figure 16** we can summarise the following findings:

- Using RPC modelling to create an orthophoto, when ≥3GCPs are used further increasing of a number of GCPs does not have any substantial influence on RMSE value.
- Applying the rigorous model, there is also no clear correlation between the obtained RMSEs and the number of GCPs used for the modelling. An exception is RMSEx, for the 36° off nadir angle scene, where a significant decrease (1.0m) is observed while going from 6 GCPs to 9 GCPs.

8.3 Discussion on software usage factor

To compare the performance of different algorithms implemented in various COTS, PCI Geomatica Ortho-engine 2016 and ERDAS Imagine 2016 were selected to derive the corresponding ortho products from the source images.

Looking at **Figure 11 - Figure 13** 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 17. Graph of RMSEs as a function of the number of GCPs and off nadir angle, PCI software, RPC modelling

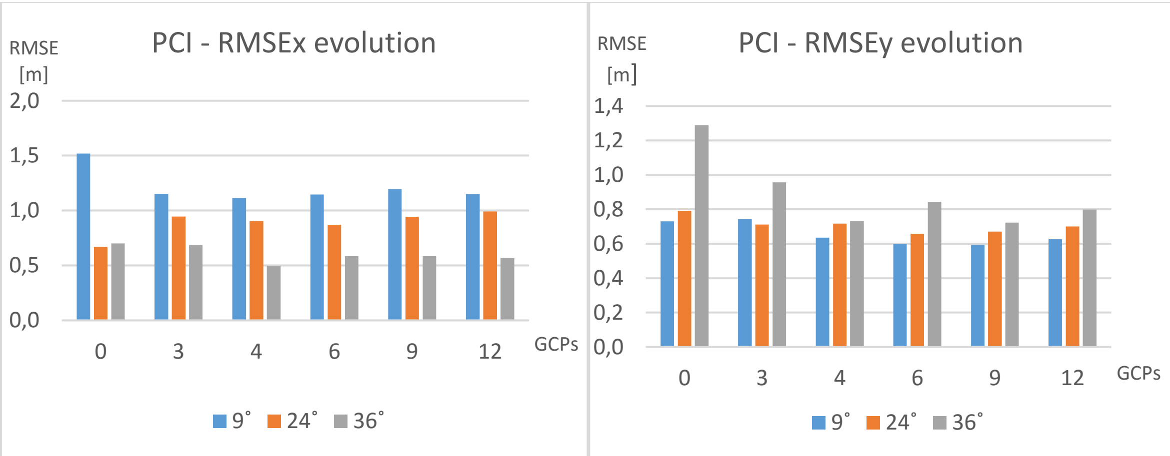


Figure 18. Graph of RMSEs as a function of the number of GCPs and off nadir angle, Erdas software, RPC modelling

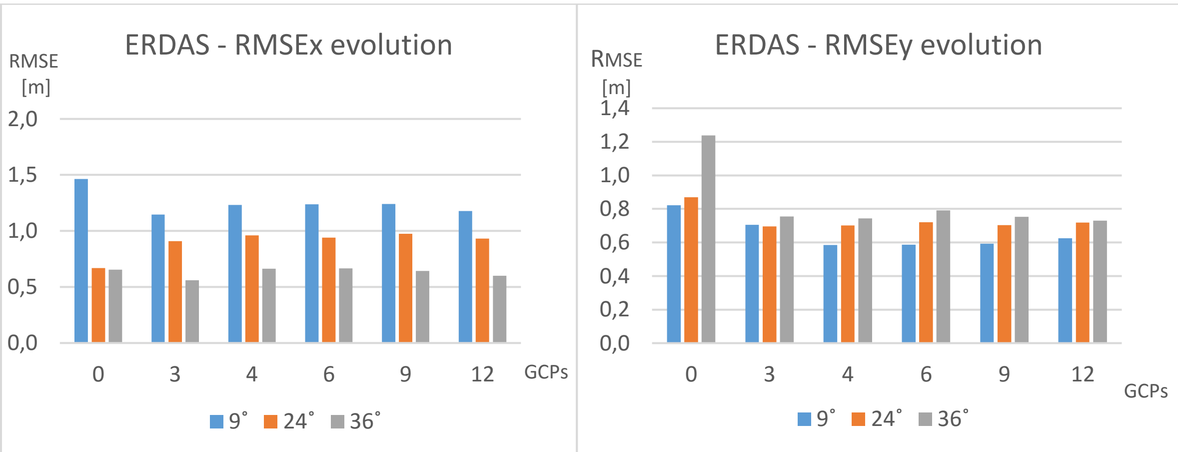
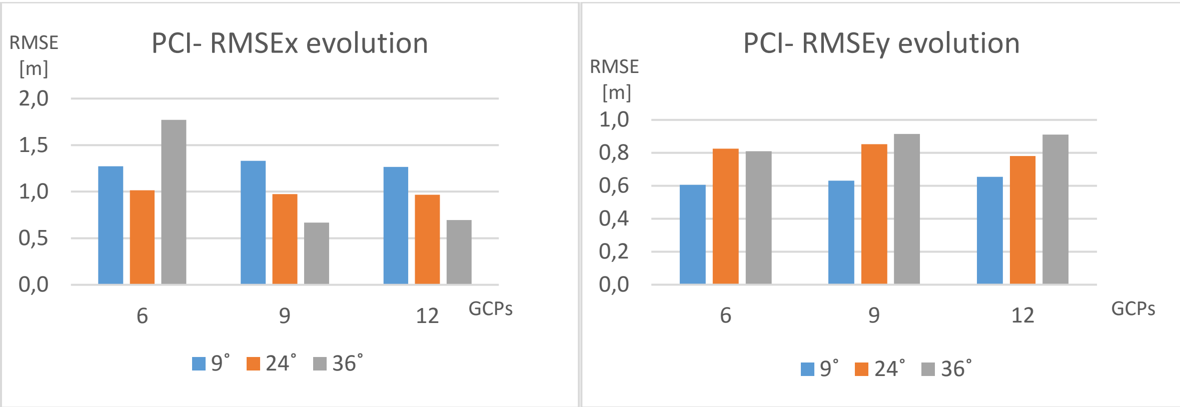


Figure 19. Graph of RMSEs as a function of the number of GCPs and off nadir angle, PCI software, Rigorous modelling



Comparing the results displayed in the **Figure 17 - Figure 19** we can summarise the following findings:

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

- As far as RMSEs in the Northing direction (RMSEy) are concerned the increase with the increasing off nadir angle of the source image is observed.
- Values of RMSEs in the Easting direction (RMSEx) for tested ortho imagery decrease with the increasing off nadir angle of the acquired image.

8.5 Discussion on Rigorous and Rational Function Modelling

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

- There is only a small difference between RMSE values measured on RPC based ortho images and rigorous ones. However, we can conclude that RPC modelling gives equal or slightly better results than rigorous model. An overall behaviour of RMSEs is the same for both models.

8.6 Summary

As regards the factors influencing the final ortho image accuracy, on basis of the test results following conclusions can be drawn:

- For near nadir imagery (9° ONA) higher RMSEx errors were observed compared to the 2 image sets at 24° and 36° ONA. RMSEx errors are slightly decreasing with higher ONA angle of source image. This unusual behavior is suggested to be further investigated with another set of data.
- The RMSEx obtained in the rigorous tests (36° ONA) for 6 GCPs needs further investigation since it appears exceptionally high in comparison to other values. However it has to be taken into account that the rigorous model requires preferably a minimum of 8 GCPs per scene and possibly more
- RMSEy – 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 and ≥9 GCPs per scene for rigorous modelling, depending on the accuracy of the GCPs and the accuracy requirements of the project.
- A maximal circular error at 90% CE(90) significant level resulted in 2.06m

9 Conclusions

A far as the validation of the Worldview-4 ortho products is concerned, on the basis of the presented results, it is asserted that:

- The WorldView-4 PSH ortho imagery geometric accuracy meets the requirements of 2m and 1.5 m 1D RMSE corresponding to the VHR prime profiles defined in the VHR profile based technical specifications [ii].
- The RMSEx, and RMSEy threshold of 1:5.000 scale imagery of 1.25m is fulfilled for all angles 24°, 36°, 9° ONA orthos when GCPs (≥3) are applied in addition to RPC function. For the ortho image produced from the 9° ONA image without use of GCPs, the RMSEx result is at the limit of this value.
- The WorldView-4 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 [ii].

The initial findigs on Worldview-4 ortho image geometric accuracy have given satisfactory results and meet all requirements of the CAP-CwRS Image Acquisition project.

The number of tested images is too small to draw a general conclusions about the anomalies that were observed and further investigations with another/additional datasets are suggested.

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xix. Quality Control Record L- WorldView-4

List of abbreviations and definitions

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
EQC	External Quality Control
EUSI	European Space Imaging
G	Green
GCP	Ground Control Point
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
NIR	Near-infrared
ONA	Off Nadir Angle
PAN	Panchromatic
R	Red
RMSE	Root Mean Square Error
RPC	Rational Polynomial Coefficients
US	The United States
UTM	Universal Transverse Mercator
VHR	Very High Resolution
VNIR	The visible and near-infrared
WGS84	World Geodetic System '84
WV4	WorldView-4
1-D	One-dimensional

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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:

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