European Commission

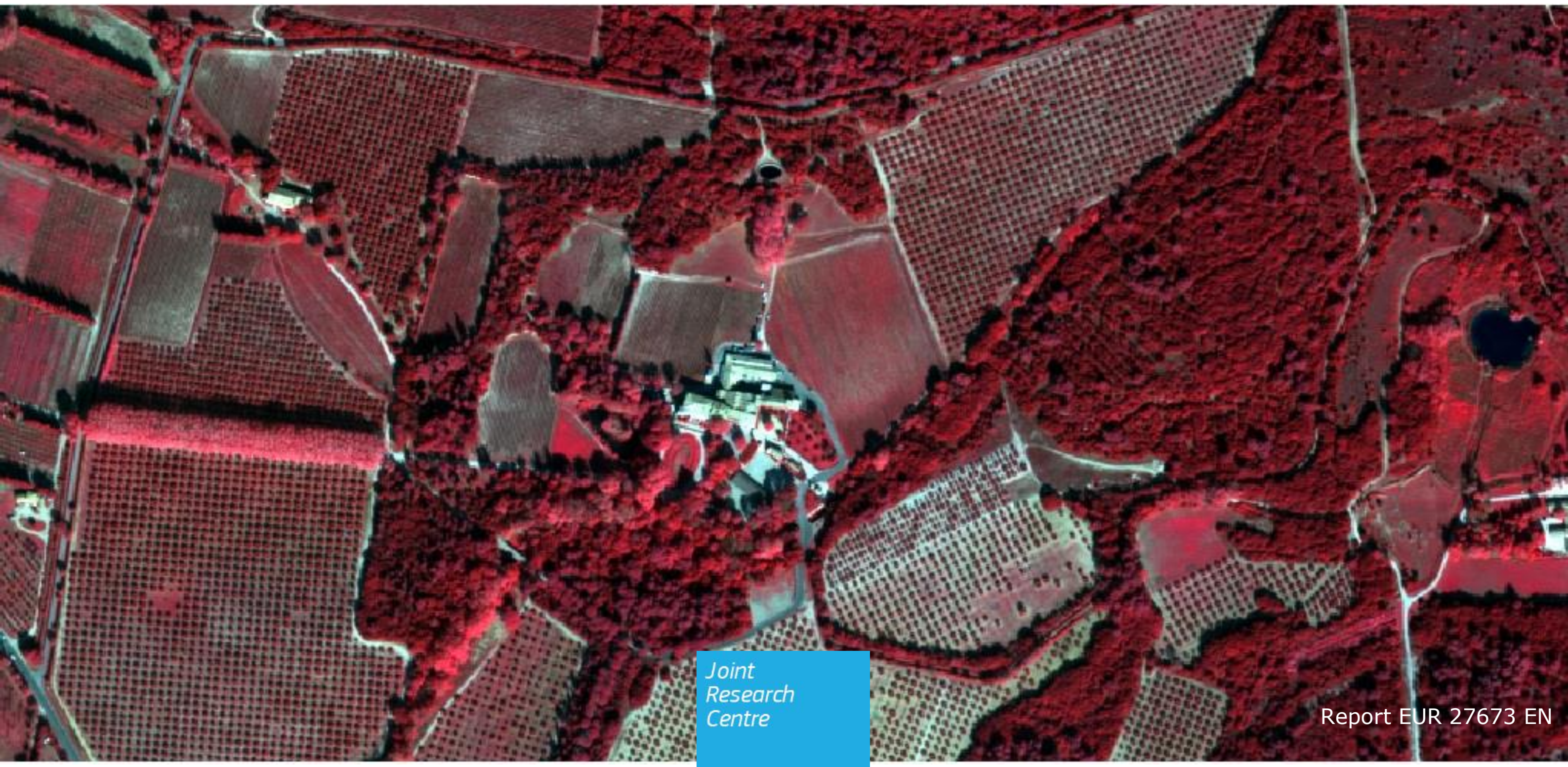
JRC TECHNICAL REPORTS

New sensors benchmark report on WorldView-3

Geometric benchmarking over Maussane test site for CAP purposes

Blanka Vajsova
Agnieszka Walczynska
Pär Johan Åstrand
Samuel Bärisch
Susanne Hain

2015



Joint Research Centre

Report EUR 27673 EN

New sensors benchmark report on WorldView-3

This publication is a Technical report by the Joint Research Centre, the European Commission’s in-house science service. It aims to provide evidence-based scientific support to the European policy-making process. The scientific output expressed does not imply a policy position of the European Commission. Neither the European Commission nor any person acting on behalf of the Commission is responsible for the use which might be made of this publication.

JRC Science Hub
https://ec.europa.eu/jrc

JRC99433

EUR 27673 EN

ISBN 978-92-79-54236-7

ISSN 1831-9424

doi:10.2788/237561

Luxemburg: Publications Office of the European Union

The geographic borders are purely a graphical representation and are only intended to be indicative. The boundaries do not necessarily reflect the official position of the European Commission.

How to cite: Vajsová B, Walczynska A, Aastrand P, Barisch S, Hain S. New sensors benchmark report on WorldView-3. EUR 27673 EN. Luxembourg: Publications Office of the European Union; 2015. doi:10.2788/237561

Table of contents

Abstract

Imagery collected by recently launched WorldView-3 satellite can be potentially used in The Common Agricultural Policy (CAP) image acquisition Campaign. The qualification and certificate is conducted by performing benchmarking tests namely, it has to be checked whether planimetric accuracy of produced orthoimagery does not exceed certain values regulated by JRC. Therefore, benchmarking tests were carried out on two WorldView-3 imagery acquired in October and November 2014. This report describes in detail 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 orthoimagery was handed to JRC for External Quality Control which is a base for certification of the sensor. Such external QC has been performed by the JRC and included in Chapter 7.

1. Introduction

This report describes in details steps that have been taken in order to qualify WorldView-3 sensor to The Common Agricultural Policy (CAP) image acquisition Campaign. The main requirement according to VHR image acquisition specifications for the CAP checks [iii] is planimetric accuracy of orthoimagery, i.e.

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

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

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

2. WorlView-3 satellite [ref. i]

WorldView-3 sensor has been launch in August 2014 from the Vandenberg Air Force Base located in California, US. The resolution of 0.31m makes WorldView-3 the highest resolution commercial satellite in the world. Satellite sensor characteristics (design and specifications) are given in the table below.

Orbit	Altitude	617km
	Type	SunSync, 10:30am descending Node
	Period	97min
	Inclination	98°
	Revisit Frequency (at 40° lat)	< 1 days (1-m GSD) 4.5 days (< 20° off-nadir)
Imaging System	Sensor Bands	
	Panchromatic	400-450nm
	8 Multispectral	
	Coastal: 400-450nm Blue: 450-510nm Green: 510-580nm Yellow: 585-625nm	Red: 630-690nm Red Edge: 705-745nm Near-IR1: 770-895nm Near-IR2: 860-1040nm
	8 SWIR Bands	
	SWIR-1: 1195-1225nm SWIR-2: 1550-1590nm SWIR-3: 1640-1680nm SWIR-4: 1710-1750nm	SWIR-5: 2145-2185nm SWIR-6: 2185-2225nm SWIR-7: 2235-2285nm SWIR-8: 2295-2365nm
	12 CAVIS Bands	
	Desert Clouds: 405-420nm Aerosol-1: 459-509nm Green: 525-585nm Aerosol-2: 635-685nm Water-1: 845-885nm Water-2: 897-927nm	Water-3: 930-965nm NDVI-SWIR: 1220-1252nm Cirrus: 1365-1405nm Snow: 1620-1680nm Aerosol-3: 2105-2245nm Aerosol-3: 2105-2245nm
	Dynamic Range	11-bits per pixel Pan and MS; 14-bits per pixel SWIR
	Sensor Resolution (GSD)	Panchromatic: nadir: 0.31m 20deg off nadir angle: 0.34m Multispectral: nadir: 1.24m 20deg off nadir angle:1.38m

		SWIR: nadir: 3.70m 20deg off nadir angle:4.10m
Collection Capabilities	Swath Width	At nadir: 13.1 km
	Capacity	680,000 km2 per day
	Geolocation Accuracy (CE90)	Predicted <3.5 m CE90 without ground control

Table 1: WorldView-3 – Specifications

3. WorldView-3 image products [ref. v]

Worldview-3 imagery can be processed and delivered as Basic Imagery (1B) or Standard Imagery (2A or OR2A). A brief description of mentioned image products is given below.
Basic Imagery Products (1B) 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).
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:

- Standard Imagery (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.
- Ortho Ready Standard Imagery (OR2A) has no topographic relief applied with respect to the reference ellipsoid (making it suitable for orthorectification). It 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. Since the site is used as a 'test site' by the European Commission since 1997 there are data (GCPs and DTMs) available and suitable to be used in benchmarking tests of WorldView-3 (please see the chapter 5)
The AOI is characterized by different land use types and the terrain variations. 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.

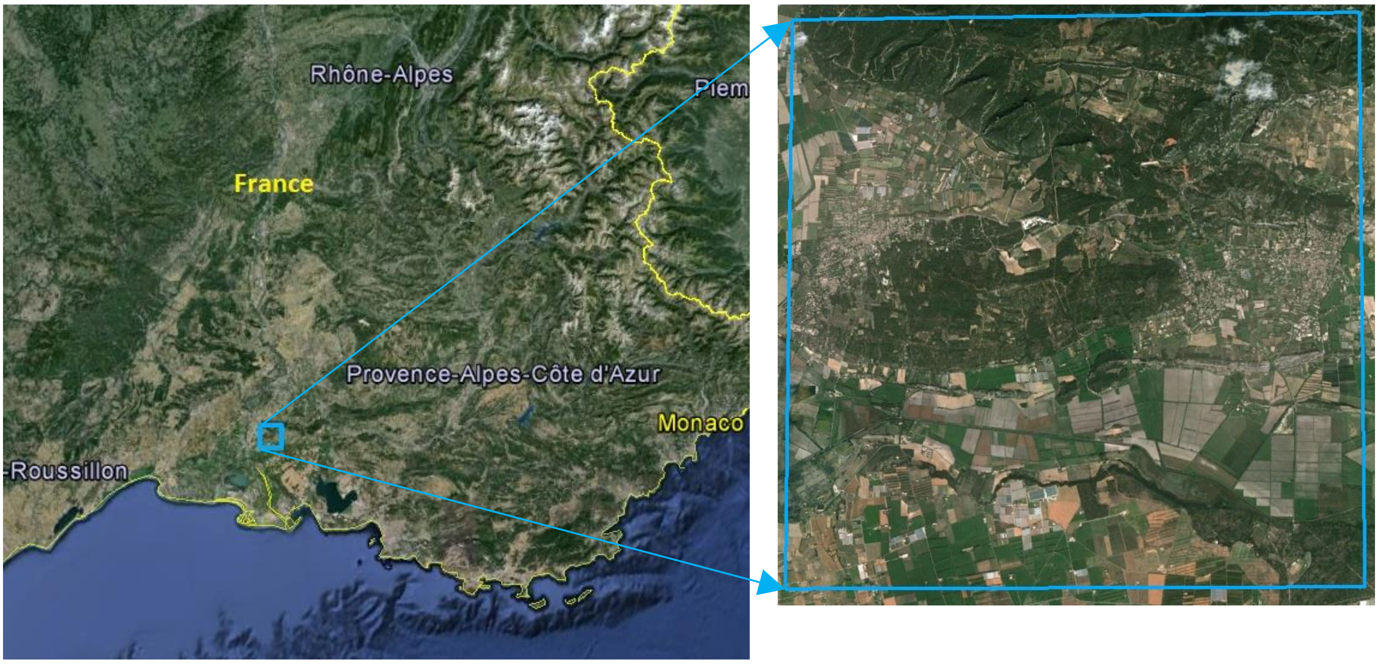


Figure 1: Location of the testing site

5. Auxiliary data [ref. vi, vii, viii, ix]

5.1. Ground Control Points

Ground Control Points play an important role in the orthorectification process of satellite imagery because they help to improve planimetric accuracy of created orthoimage. 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 [ref ii] 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 the VHR Image Acquisition Specifications for the CAP checks (CwRS and LPISQA) - VHR profile-based [ref.iii], target orthoimage accuracy for VHR prime is 2m and 5m for VHR Backup.
Considering all the above, a set of 12GCPs (Table 3, Table 4) to be used in the modeling phase in the orthorectification process of 2 WorldView-3 imagery have been selected from GCP dataset received from JRC (Table 2).

Dataset	Point ID	RMSEx [m]	RMSEy [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_ 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		

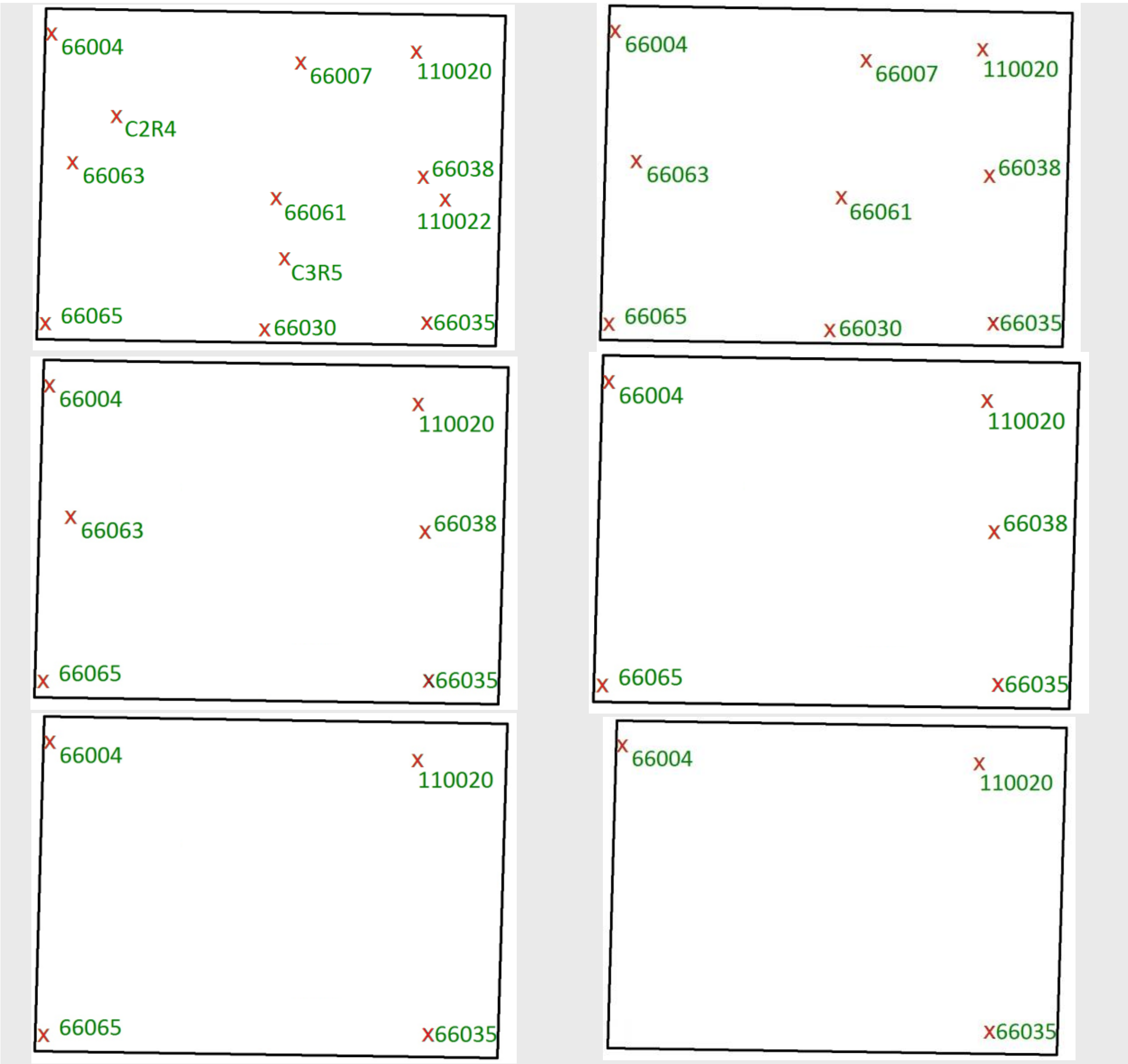
Table 2: Ground Control Points available for Maussane test site

#	ID	GCP1	GCP2	GCP3	GCP4	GCP6	GCP9	GCP12
1	60061						X	X
2	66004		X	X	X	X	X	X
3	66007						X	X
4	66030						X	X
5	66035	X	X	X	X	X	X	X
6	66038					X	X	X
7	66063					X	X	X
8	66065				X	X	X	X
9	110020			X	X	X	X	X
10	110022							X
11	C2R4							X
12	C3R5NEW							X

Table 3: Ground Control Points selected for WorldView-3 benchmarking and scenarios used

ID	Easting	Northing	Ellips_H
60061	641347,480	4841196,354	82,164
66004	636363,620	4846077,515	54,584
66007	641804,022	4845298,880	145,865
66030	641183,519	4837211,098	82,113
66035	644717,258	4837489,030	63,612
66038	644535,092	4841910,055	62,494
66063	636896,931	4842180,715	66,587
66065	636400,713	4837301,772	79,769
110020	644315,711	4845689,97	252,446
110022	645030,755	4841227,483	60,343
C2R4	637829,72	4843609,87	63,16
C3R5NEW	640341,36	4838887,55	58,11

Table 4: Coordinates of Ground Control Points selected for WorldView-3 benchmarking



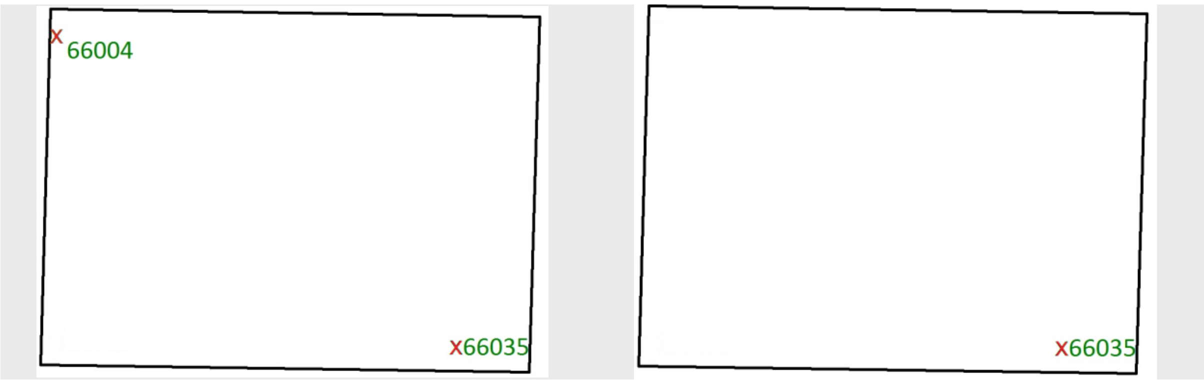


Figure 2: Ground Control Points distribution

5.2. DTM

A DTM 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 is to use DEM:

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

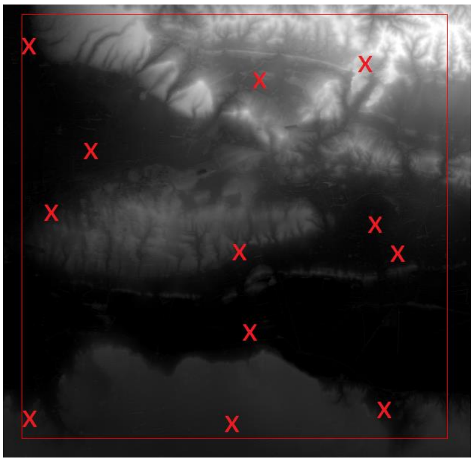


Figure 3: INTERMAP5mDTM

From two available DEM it was decided to use INTERMAP5mDTM in the tests. As explained in D.14.1 New sensors benchmark report on Kompsat-3 [ref xviii] the alternative 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 orthoimage. For the open areas there are only minor differences between these DTMs.

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

Table 5: DEM – Specifications

5.3. Aerial Orthomosaics

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

Table 6: Aerial Orthomosaics Specifications

5.4. WorldView-3 satellite imagery

WorldView-3 satellite imagery that have been used to perform these benchmarking tests have been collected in October and November 2014 at off nadir angle 14deg and 32,5deg. The data have been processed as Ortho Ready Standard Pansharened with GSD 40cm. 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.

CAT_ID	10400100041B0A00	10400100047BEF00
Image ID	IMG_1 	IMG_2 
Collection Parameters		
Collection date	2014-10-28	2014-11-16
Off nadir angle	14,1 deg	32,5 deg
Elevation Angle	74,5 deg	54 deg
Cloud cover [%]	0,003	0
Production Parameters		
Product Name	Ortho Ready Standard (OR2A)	
Product Option	4Band Pansharpened	
GSD	40cm	
Resampling Kernel	4x4cubic convolution	
File Format	Geotiff	
Bit Depth	16bit	
Projection/Datum	UTM/WGS84	

Table 7: Collection and production parameters of WorldView-3 imagery

5.5. Software

- PCI Geomatica Orthoengine 2014
- ERDAS Imagine 2014

6. WorldView-3 Benchmarking Tests

6.1. Benchmarking methodology [ref. x, xi, xii, xiii, xiv, xv, xvi, xvii, xviii]

Orthorectification is the geometric transformation of an image (containing 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 [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.

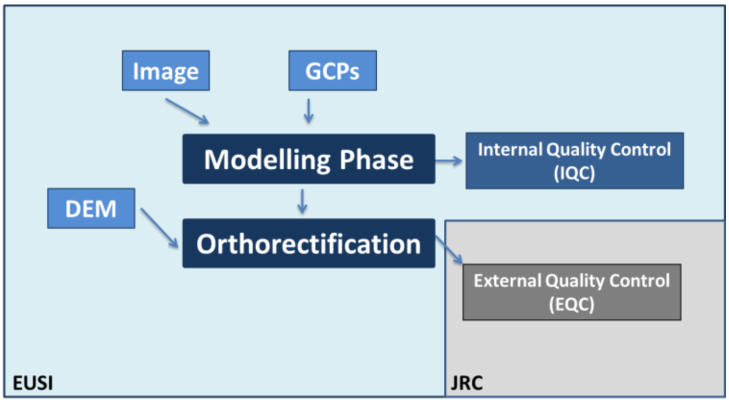


Figure 4: Standard benchmarking procedure

Tests were performed using two software products: PCI Geomatica Orthoengine 2014 and ERDAS Imagine 2014. In both software packages, the RPC model has been tested with the same combination of GCPs given beforehand by JRC. However, the selection of appropriate GCPs was done by EUSI/GAF (Table 3) from the set of GCPs available for Maussane 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).

In total 32 orthoimages were prepared and handed for External Quality Control to JRC.

6.2. **Test Scenarios**

The following scenarios have been considered in our benchmarking tests:

COTS Software	Sensor Model – Phase 1	No. of GCPs	DEM	No. of source imagery	No. of source orthoimagery created
ERDAS Imagine 2014	RPC 0	0	Intermap5mDTM	2 (14°/ 32,5°)	2
		1		2 (14°/ 32,5°)	2
		2		2 (14°/ 32,5°)	2
		3		2 (14°/ 32,5°)	2
		4		2 (14°/ 32,5°)	2
		6		2 (14°/ 32,5°)	2
		9		2 (14°/ 32,5°)	2
		12		2 (14°/ 32,5°)	2
PCI Geomatica Orthoengine 2014	RPC 0	0	Intermap5mDTM	2 (14°/ 32,5°)	2
		1		2 (14°/ 32,5°)	2
		2		2 (14°/ 32,5°)	2
		3		2 (14°/ 32,5°)	2
		4		2 (14°/ 32,5°)	2
		6		2 (14°/ 32,5°)	2
		9		2 (14°/ 32,5°)	2
		12		2 (14°/ 32,5°)	2
					32orthoimages

Table 8: Tested scenarios

In initially planned tests [xvii] Rigorous model has been considered to be tested. However, due to the software restriction i.e. Rigorous Model for OR2A is not supported in PCI Geomatica Orthoengine 2014 and ERDAS Imagine 2014, it was decided and approved (by JRC) to perform the tests using RPC model only. In ERDAS, Rigorous model is not implemented at all. In PCI, implemented Rigorous model is designed for use with Level 1B products (and not recommended for OR2A). However for such small AOI like Maussane, it could be used for OR2A (It can be mentioned that in the meantime PCI managed to improve the support for rigorous modeling of WV3 ORS data), but still it was decided to use only the RPC approach.

6.3. Internal Quality Control

Off-nadir angle	Number of GCPs	Direction	RPC PCI RMSE[pix]	RPC Erdas RMSE [pix]	DEM
14°	0	East	–	–	Intermap5mDTM
		North	–	–	
	1	East	0.24	0.00	
		North	0.22	0.00	
	2	East	0.15	0.08	
		North	0.12	0.02	
	3	East	0.15	0.13	
		North	0.14	0.11	
	4	East	0.16	0.15	
		North	0.17	0.15	
	6	East	0.22	0.22	
		North	0.17	0.16	
	9	East	0.22	0.22	
		North	0.19	0.18	
	12	East	0.22	0.22	
		North	0.18	0.17	
32,5°	0	East	–	–	Intermap5mDTM
		North	–	–	
	1	East	0.50	0.00	
		North	0.24	0.00	
	2	East	0.33	0.15	
		North	0.19	0.11	
	3	East	0.26	0.15	
		North	0.15	0.09	
	4	East	0.21	0.13	
		North	0.13	0.10	
	6	East	0.21	0.18	
		North	0.12	0.99	
	9	East	0.21	0.20	
		North	0.14	0.12	
	12	East	0.20	0.19	
		North	0.19	0.18	

Table 9: Residuals obtained in modeling Phase 1

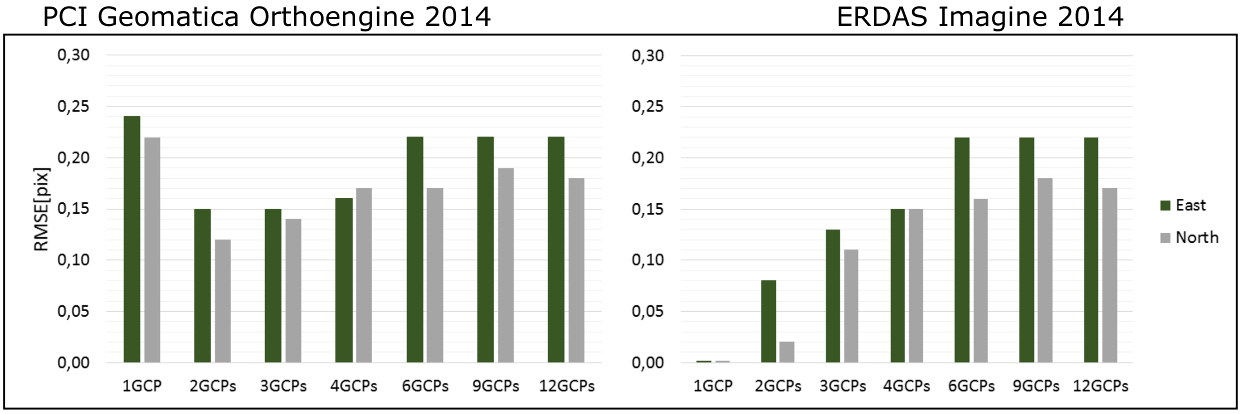


Figure 5: IQC - RMSE (pix) in northern and eastern direction for image collected at ONA 14deg

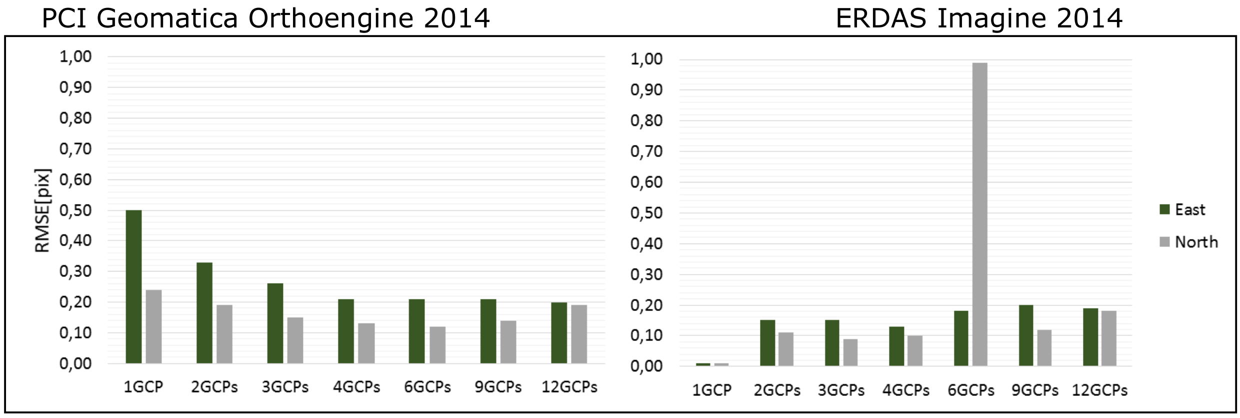


Figure 6: IQC - RMSE (pix) in northern and eastern direction for image collected at ONA 32,5deg

Conclusions that can be drawn after performing Internal Quality Control:

- there is no observed significant difference between RPC models implemented into PCI Geomatica Orthoengine 2014 and ERDAS Imagine 2014, when using ≥ 3 GCPs (except the outlier N-S, 6 GCPs)
- the accuracy does not seem to be correlated to the ONA (there is no observed significant difference in RMSEs between imagery collected at ONA 14deg as well as 32,5deg), when using ≥ 3 GCPs, (except the outlier N-S, 6 GCPs)
- the accuracy does not seem to be correlated to the number of the GCPs ($RMSE_{1\text{-}D\ North}$ seem to be slightly better than $RMSE_{1\text{-}D\ East}$ for almost all cases)
- RMSE errors in most of the cases do not exceed 0,26pix, when ≥ 2 GCPs.

7. External quality conrol of WV3 orthoimagery

7.1. Method for external quality checks of ortho images

The method for the external quality checks (EQCs) strictly follows the Guidelines for Best Practice and Quality Checking of Ortho Imagery (Kapnias et al., 2008) [ref. ii].
For the evaluation of the geometric accuracy of the WorlView-3 ortho imagery, 20 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 (Kapnias et al., 2008). JRC for the location of the ICPs took into account the distribution of the GCPs determined by the FW Contractor which were 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 [xvii].

Regarding the positional accuracy of ICPs, according to the Guidelines (Kapnias et al., 2008)[ii] the ICPs should be at least 3 times more precise than the target specification for the ortho, i.e. in our case of a target 2.0m RMS error the ICPs should have a specification of 0.65m. All ICPs that have been selected fulfil therefore the defined criteria , see Table 10.

Dataset	RMSEx	RMSEy	Number of points
ADS40 GCP_dataset_Maussane	0,05	0,10	1
VEXEL_GCP_dataset_Maussane	0,49	0,50	10
Multi-use_GCP_dataset_Maussane	0,30	0,30	9

Table 10: Identical check points specifications

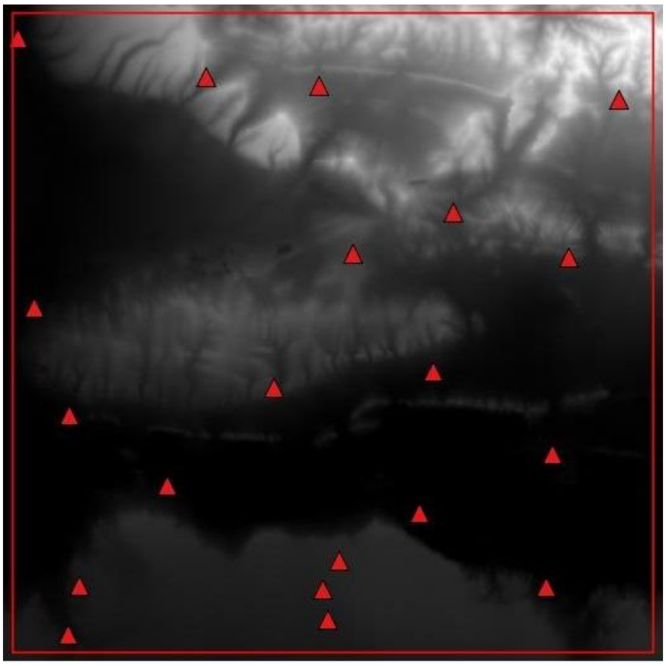


Figure 7: ICPs dataset used by JRC in the EQC of Worldview-3 ortho imagery.
ICPs displayed over the INTERMAP5m DTM

ID	E [m]	N [m]	All GCPs' combinations	
			Off nadir angle	
			14°	32°
66003	636305,21	4846448,28	x	x
66014	645687.64	4845487.95	x	x
66021	637266.47	4837886.15	x	x
66024	641320.7	4838276.56	x	x
66028	640296.27	4840992.69	x	x
66029	641151.79	4837361.12	x	x
66031	644655.96	4839947.67	x	x
66036	644548.6	4837864.28	x	x
66049	644906.91	4843017.78	x	x
440002	639252.6	4845847.94	x	x
440003	640999.13	4845715.57	x	x
440008	641527.51	4843087.46	x	x
440009	643112.41	4843729.24	x	x
440011	636560.47	4842244.52	x	x
440014	642791.88	4841240.22	x	x
440016	637104.55	4840553.2	x	x
440019	642578.11	4839029.46	x	x
440021	637082.02	4837127.37	x	x
440023	641060.73	4837826.92	x	x
110016	638647.34	4839449.61	x	x

Table 11: ICPs overview

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

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

$$RMSE_{1D}(East) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(X_{REG(i)} - X_{(i)}\right)^2} \qquad RMSE_{1D}(North) = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(Y_{REG(i)} - Y_{(i)}\right)^2}$$

where $X,Y_{REG(i)}$ are ortho images 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 therefore 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 [xvii].

All measurements presented in this annex were carried out in Intergraph ERDAS Imagine 2010 software, using Metric Accuracy Assessment tool for quantitatively measuring the accuracy of an image which is associated with a 3D geometric model. 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. (Kapnias et al., 2008)[ref.ii].

7.2. Overall results

			RPC	
Off-nadir angle	Number of GCPs	Direction	PCI	Erdas
			RMSE [m]	
14°	0	East	0.72	0.76
		North	0.89	0.88
	1	East	0.56	0.55
		North	0.56	0.53
	2	East	0.54	0.54
		North	0.52	0.52
	3	East	0.59	0.58
		North	0.54	0.52
	4	East	0.60	0.56
		North	0.52	0.51
	6	East	0.58	0.57
		North	0.51	0.50
	9	East	0.57	0.58
		North	0.51	0.54
	12	East	0.54	0.55
		North	0.52	0.52
32°	0	East	0.89	0.91
		North	0.85	0.86
	1	East	0.40	0.50
		North	0.86	0.86
	2	East	0.42	0.51
		North	0.86	0.86
	3	East	0.57	0.55
		North	0.89	0.86
	4	East	0.51	0.54
		North	0.90	0.88
	6	East	0.51	0.53
		North	0.85	0.85
	9	East	0.49	0.54
		North	0.86	0.87
	12	East	0.53	0.52
		North	0.90	0.87

Table 12: Results of $RMSE_{1D}$ measurements in JRC ICPs dataset

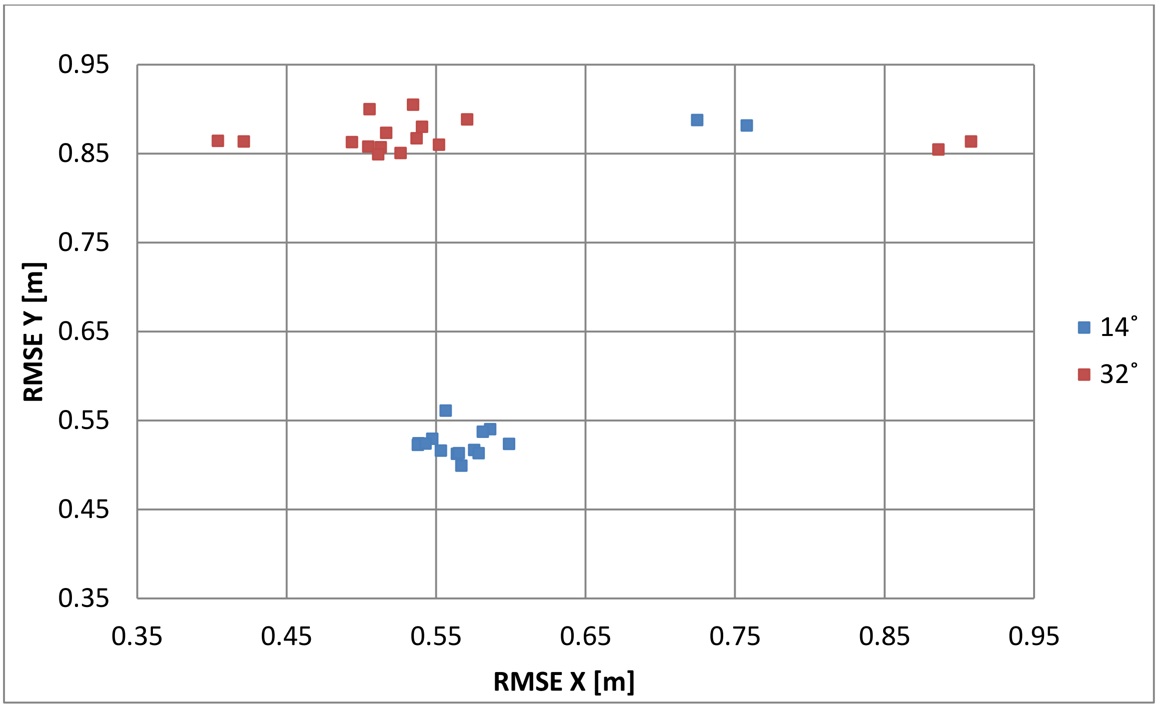


Figure 8: Point representation of all planimetric $RMSE_{1D}$ errors measured in JRC ICPs dataset

7.3. Discussion on off-nadir angle factor

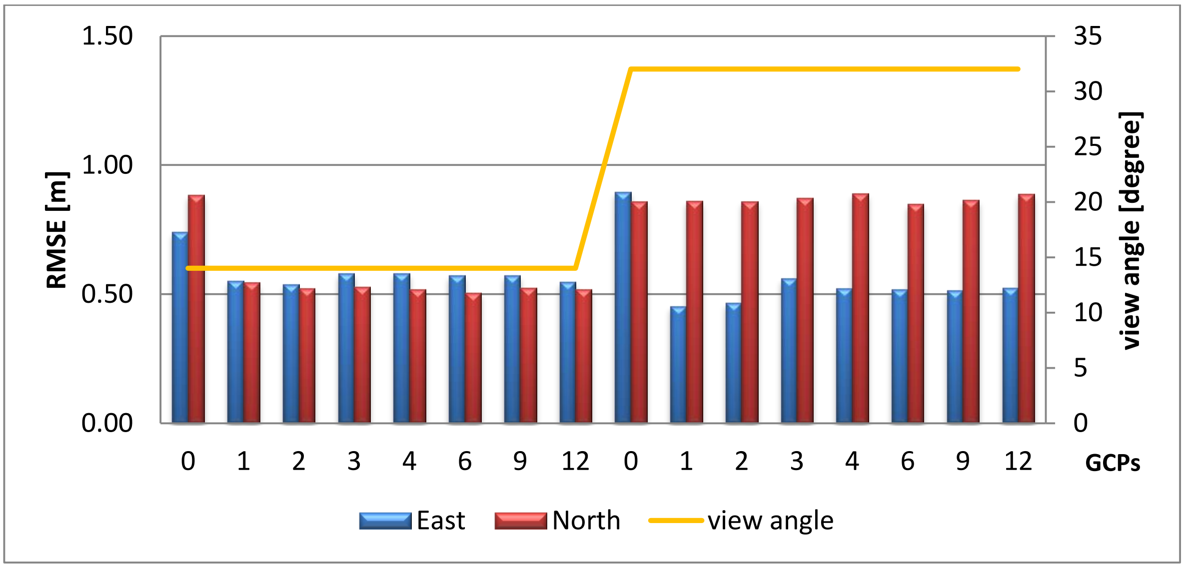


Figure 9: Graph of average RMSEs as a function of the number of GCPs and off nadir angle

Comparing the results displayed in the Figure 8 and the Figure 9, we can summarise the following findings:

- The change of the off nadir angle does not seem to effect the RMSEs in the Easting direction. Although the RMSE values measured on 32 ˚ off nadir angle image resulted slightly better than those measured on 14 ˚ off nadir angle scene. However, the differences are so small (in centimeters) that we can consider it as stable.

- The RMSEs in the Northing direction are sensitive to the overall off nadir angle of the acquired scene. The increase with the increasing off nadir angle is observed (~35cm).

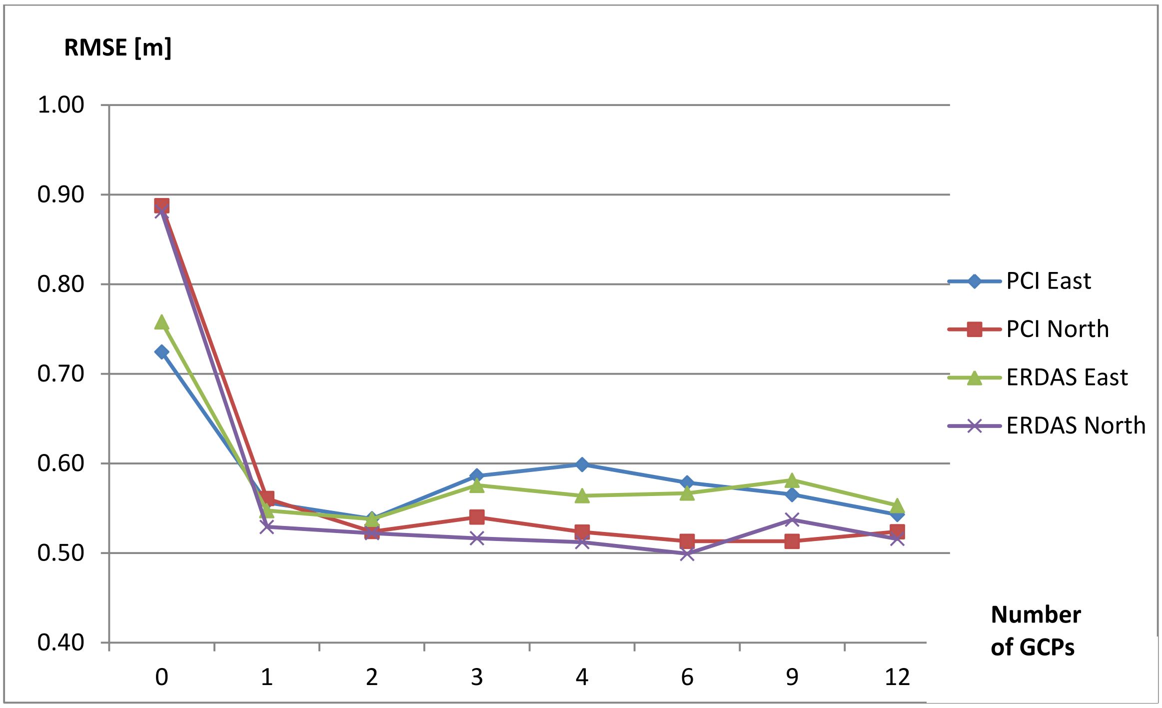


Figure 10: Behaviour of RMSEs across the various number of GCPs for PCI and ERDAS software, measured on 14° off nadir angle image

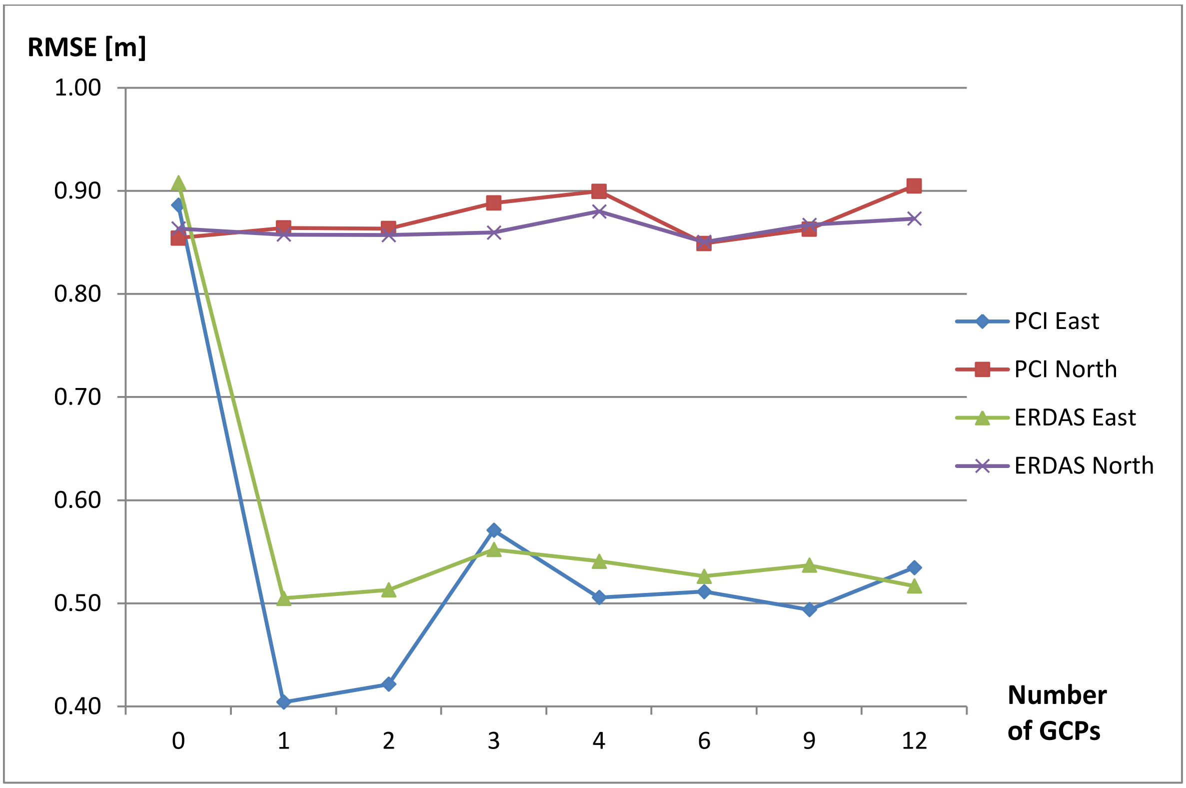


Figure 11: Behaviour of RMSEs across the various number of GCPs for PCI and ERDAS software, measured on 32° off nadir angle image

7.4. Discussion on the number of GCPs used for the modelling

From the Figure 10 and the Figure 11 could be concluded the following:

- There is a substantial improvment of RMSEs when at least 1GCP is used. The exception are RMSEs in the Northing direction registred on 32° off nadir angle scene which have a steady trend regardless if any GCP is used for modeling
- Using more than 1GCP does not have a significant influence on RMSEs values.

7.5. Discussion on software usage factor

To compare the performance of different algorithms implemented in various COTS, PCI Geomatica Orthoengine 2014 and ERDAS Imagine 2014 were selected to derive the corresponding ortho products from the acquired images.
Looking at Figure 10 and Figure 11 we can summarise that both software products produce ortho imagery of a very similar geometric accuracy.

8. Conclusions

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

- The WorldView-3 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.

- The WorldView-3 PSH ortho imagery geometric accuracy meets the requirement of 2 m 1D RMSE corresponding to the VHR prime profile defined in the VHR profile based technical specifications.

As regards the factors influencing the final orthoimage accuracy, following general conclusions can be drawn:

- The RMSE values measured on the WorldView-3 PSH ortho images did never exceed 90cm.

- While the geometric accuracy in the Easting direction is independent on the off nadir angle change, the RMSEs in the Northing direction are getting worse with its increasing value.

- The increasing number of GCPs (when ≥ 1) does not have any substantial effect on the positional accuracy of ortho products. However it is anyway recommended to use 3-4 GCPs for the WorldView-3 scene orthorectification.

- Both software products tested (PCI Geomatics and ERDAS Imagine) suit the orthoimage generation with the accuracy required for CAP checks purposes, and produce similar results.

References

i. http://www.digitalglobe.com/sites/default/files/DG_WorldView3_DS_forWeb.pdf (available on 11.11.2014)

ii. Kapnias, D., Milenov, P., Kay, S. (2008) Guidelines for Best Practice and Quality Checking of Ortho Imagery. Issue 3.0. Ispra

iii. JRC IES, VHR image acquisition specifications for the CAP checks (CwRS and LPIS QA), VHR profile-based specifications including VHR+ profiles (2015, 2016), available at
https://g4cap.jrc.ec.europa.eu/g4cap/Portals/0/Documents/17359.pdf
https://g4cap.jrc.ec.europa.eu/g4cap/Portals/0/Documents/21449_21112015_final.pdf

iv. Annex I to the Framework Contract for the supply of satellite remote sensing imagery and associated services in support to checks within the Common Agricultural Policy. Technical Specifications for the Very High Resolution profile Framework Contract (2013) Contract Notice No. 2013/S 161-280227

v. http://www.euspaceimaging.com/images/products/downloads/WVGA%20Core%20Product%20Imagery%20Guide.pdf (available on 11.11.2014)

vi. Nowak Da Costa, J., Tokarczyk P., 2010. Maussane Test Site Auxiliary Data: Existing Datasets of the Ground Control Points. The pdf file received on 06.02.2014 via FTP.

vii. Lucau, C., Nowak Da Costa J.K. (2009) Maussane GPS field campaign: Methodology and Results. Available at
http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/14588/1/pubsy_jrc56280_fmp11259_sci-tech_report_cl_jn_mauss-10-2009.pdf

viii. Lucau, C. (2012) Maussane GNSS field campaign 21-26 November 2012

ix. Maussane test site (& geometry benchmarks). KO-Meeting-Presentation January 30, 2014.

x. Åstrand, J.P., Bongiorni, M., Crespi, M., Fratarcangeli, F., Nowak Da Costa, J.K., Pieralice, F., Walczynska, A. (2012). The potential of WorldView-2 for ortho-image production within the "Control with Remote Sensing Programme of the European Commission. International Journal of Applied Earth Observation and Geoinformation 19 (2012) 335–347.

xi. Nowak Da Costa, J.K., Walczynska, A. (2011). Geometric Quality Testing of the WorldView-2 Image Data Acquired over the JRC Maussane Test Site using ERDAS LPS, PCI Geomatics and Keystone digital photogrammetry software packages – Initial Findings with ANNEX. Available at
http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/22790/1/jrc60424_lb-nb-24525_en-c_print_ver.pdf

xii. Nowak Da Costa, J.K., Walczynska, A. (2010). Geometric Quality Testing of the Kompsat-2 Image Data Acquired over the JRC Maussane Test Site using ERDAS LPS and PCI GEOMATICS remote sensing software. Available at http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/15039/1/lbna24542enn.pdf

xiii. Nowak Da Costa, J.K., Walczynska, A., 2010. Evaluating the WorlView-2, GeoEye-1, DMCII, THEOS and KOMPSAT-2 imagery for use in the Common Agricultural Policy Control with Remote Sensing Programme. Scientific presentation at the 16th Conference on ''Geomatics in support of the CAP" in Bergamo, Italy, 24-26 November 2010. JRC Publication Management System. Available at http://mars.jrc.ec.europa.eu/mars/content/download/1998/10589/file/P4-2-Joanna_Nowak.pdf

xiv. Grazzini, J., Astrand, P., (2013). External quality control of Pléiades orthoimagery. Part II: Geometric testing and validation of a Pléiades-1B orthoproduct covering Maussane test site. Available at http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/29229/1/lb-na-26-100-en-n.pdf

xv. Grazzini, J., Lemajic, S., Astrand, P., (2013). External quality control of Pléiades orthoimagery. Part I: Geometric benchmarking and validation of Pléiades-1A orthorectified data acquired over Maussane test site. Available at http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/29541/1/lb-na-26-101-en-n.pdf

xvi. Grazzini, J., Astrand, P., (2013). External quality control of SPOT6. Geometric benchmarking over Maussane test site for positional accuracy assessment orthoimagery. Available at http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/29232/1/lb-na-26-103-en-n.pdf

xvii. Kay, S., Spruyt, P., Alexandrou, K., (2003).Geometric Quality Assessment of Or thorectified VHR Space Image Data. Photogrammetric Engineering and Remote Sensing.

xviii. Vajsova, B , Walczynska, A , Bärisch, S , Åstrand, P, Hain, S, (2014), New sensors benchmark report on Kompsat-3. Availabl at: http://publications.jrc.ec.europa.eu/repository/bitstream/JRC93093/lb-na-27064-en-n.pdf

xix. Bärisch, S., Walczynska, A., (2014). Quality Control Record L- WorldView-3.

xx. Bärisch, S., Walczynska, A., (2015). D.14.1 New sensors benchmark report on WV3

List of abbreviations and definitions

AD	Attitude Determination
ADS	Airborne Digital Sensor
AOI	Area of Interest
CAP	The Common Agricultural Policy
CE90	Circular Error of 90%
COTS	Commercial off-the-shelf
CPU	A central processing unit
DEM	Digital Elevation Model
DSM	Digital Surface Model
EO	Earth Observation
EPSG	European Petroleum Survey Group
EQC	External Quality Control
EUSI	European Space Imaging
FFT	Fast Fourier Transform
FFTP	Fast Fourier Transform Phase
GCP	Ground Control Point
GPS	The Global Positioning System
GSD	Ground Sample Distance
IPC	Independent Check Point
IQC	Internal Quality Control
JRC	Joint Research Centre
KARI	The Korea Aerospace Research Institute
LE90	Linear Error of 90%
LPIS	Land Parcel Information System
LVLH	Local Vertical/Local Horizontal
MS	Multispectral
MSL	Mean Sea Level
MTF	Modulation Transfer Function
NCC	Normalized Cross Correlation
NDVI	The Normalized Difference Vegetation Index
OD	Orbit Determination
ONA	Off Nadir Angle
PAD	Precision Attitude Determination
PAN	Panchromatic
POD	Precision Orbit Determination
RMSE	Root Mean Square Error
RPC	Rational Polynomial Coefficient
SAR	Synthetic-Aperture Radar
TP	Tie Point
UTM	Universal Transverse Mercator
VHR	Very High Resolution
WGS 84	World Geodetic System 1984
1-D	One-dimensional

List of figures

List of tables

List of Annexes

Both Annex I and Annex II are archived in:
SimsEC archive drive S: drive:
S:\Data\CID\MAUSSANE\WorldView-3

LB-NA-27673-EN-N

JRC Mission

As the Commission's in-house science service, the Joint Research Centre's mission is to provide EU policies with independent, evidence-based scientific and technical support throughout the whole policy cycle.

Working in close cooperation with policy Directorates-General, the JRC addresses key societal challenges while stimulating innovation through developing new methods, tools and standards, and sharing its know-how with the Member States, the scientific community and international partners.

Serving society
Stimulating innovation
Supporting legislation

doi:10.2788/237561

ISBN 978-92-79-54236-7

Publications Office