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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

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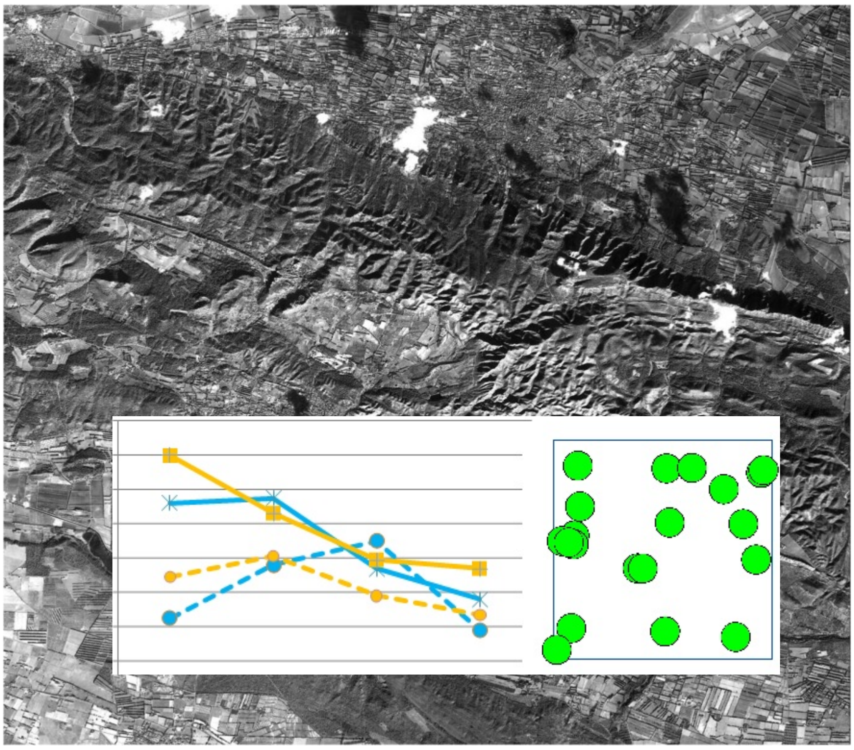

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1. Objective

Imagery acquired by the WorldView-2 (WV2) satellite is of potential interest to the Control with Remote Sensing (CwRS) Programme of the European Commission and therefore needs to be assessed.

The present report summarizes the outcome of the initial findings of geometric quality testing of the WorldView-2 images acquired over the JRC Maussane Test Site.

The objective of this study is fourfold:

- to study the sensitivity of WV2 satellite orthoimage horizontal accuracy with respect to mathematical model used for sensor orientation, i.e. RPC (Rational Functions) or Rigorous model;
- to study the sensitivity of WV2 orthoimage horizontal accuracy with respect to the satellite incidence angles;
- to study the sensitivity of the WV2 orthoimage horizontal accuracy with respect to number and distribution of the ground control points (GCPs) used during sensor orientation phase;
- to evaluate the planimetric accuracy in a routine basis production of orthorectified WV2 imagery applying PCI Geomatica, Keystone Spacemetric or Erdas Imagine implemented WV2 sensor models.

2. Introduction

In the frame of the Control with Remote Sensing (CwRS) Programme, the GeoCAP action establishes guidelines for Member States on the use of RS imagery for checking farmers' claims for CAP subsidies. In particular, the area of claimed parcels is checked using Very High Resolution (VHR) images which impose that these images should meet a certain quality. Since Worldview-2 has been recently launched and offers a 0.5m ground sampling distance fitting the CwRS needs, this imagery should be assessed from a geometric perspective through an external quality control (EQC).

This EQC is based on the root-mean-square (RMS) error between the true position and the position on the image of independent Control Points (i.e. points not included in the sensor model parameter estimation process and derived from an independent source preferably of higher accuracy). This RMS error is calculated in each dimension (Easting and Northing) in order to describe the horizontal accuracy of the orthoimage

In order to qualify as a VHR prime sensor (i.e. a sensor suitable for measuring parcel areas to the accuracy requested by the CAP regulation), the CwRS guidelines requires that the one-dimensional RMS error (i.e. in the X and Y directions) measured for any image of this sensor should not exceed 2.5meter.

3. Data description

3.1. WorldView-2 satellite and image data

WorldView-2 (WV2), launched October 8, 2009, is the first high-resolution 8-band multispectral commercial satellite. Its characteristics are given in the table below:

Orbital elements	
Orbit type	Near polar, Sun synchronous
Altitude	770 km
Inclination	97.9° (Sun synchronous)
Orbital per day	15
Revisit rate	1.1 days at 1 meter GSD or less 3.7 days at 20° off-nadir or less (0.52 meter GSD)
Instruments	
Spectral band	Panchromatic: 450 - 800 nm 8 Multispectral: Coastal: 400 - 450 nm Red: 630 - 690 nm Blue: 450 - 510 nm Red Edge: 705 - 745 nm Green: 510 - 580 nm Near-IR1: 770 - 895 nm Yellow: 585 - 625 nm Near-IR2: 860 - 1040 nm
Spatial resolution	PAN: 46 cm panchromatic at nadir 52 cm at 20° off-nadir resampled to 50 cm MS: 1.84 m resolution at nadir resampled to 2 m
Radiometric resolution	11 bits/pixel
Swath width	16.4 km at nadir
Viewing angle	nominally +/-45° off-nadir = 1355 km wide swath
Flight path	Descending

Table 1: WorldView-2 specifications (source: http://www.digitalglobe.com/)

3.2. Core WorldView-2 image Products

The WorldVew2 image provider, DigitalGlobe, supplies the following image products:

- Basic Satellite Imagery (http://www.digitalglobe.com/index.php/48/Products?product_id=1)
- Standard Satellite Imagery (http://www.digitalglobe.com/index.php/48/Products?product_id=2)

• Orthorectified Satellite Img (http://www.digitalglobe.com/index.php/48/Products?product_id=7)

Basic Satellite Imagery (also referred to as 1A) is characterized by following processing:

Radiometric Corrections	Sensor Corrections	Resampling Options
• Relative radiometric response • between detectors • Non-responsive detector fill • Conversion to absolute • radiometry	• Internal detector geometry • Optical distortion • Scan distortion • Any line-rate variations • Registration of the multispectral bands	• 4x4 cubic convolution • 2x2 bilinear • Nearest neighbor • 8 point sinc • MTF kernel

The metadata for this product contains ephemeris/attitude data and allows for the use of a rigorous orbital model.

Standard Satellite Imagery (also referred to as 2A) is a product with applied following corrections: radiometric, sensor, and geometric corrections. Standard product is mapped (resampled) to a cartographic projection and the metadata for this product contains data for a Rational Functions model.

DigitalGlobe provides with all data deliveries a set of Image Support Data File Entities (ISD files) that are described in the DigitalGlobe Imagery Products Format Specifications.

3.3. Nominal Geolocation Accuracy of WorldView-2 products

The WorldView-2 Product Specifications says that WV2 geolocation accuracy is of 6.5m CE90, with predicted performance in the range of 4.6 to 10.7 meters CE90, excluding terrain and off-nadir effects. In case of Orthorectified Product (with registration to GCPs in image), the WV2 geolocation accuracy reach 2.0 meters CE90.

The accuracy specification has been tightened to 6.5m CE90 directly right off the satellite, meaning no processing, no elevation model and no ground control, and measured accuracy is expected to be approximately 4m CE90 (Cheng and Chaapel, 2010).

Horizontal accuracy, represented as CE90, is a horizontal measurement on the ground defining the radius of a circle within which an object of known coordinates should be found on an image. The probability of a point in the image meeting the recorded accuracy is 90% for CE90. This parameter is expressed in meters.

In GeoCAP action the most common accuracy parameter is RMS error. The RMS value of a set of values is the square root of the arithmetic mean (average) of the squares of the values that, in our case, represent the residua between the original (reference) coordinates and the coordinates measured on the image (expressed in the same coordinate system).

$$\text{rms} = \sqrt{\left(\frac{1}{N}\sum_{i=1}^{N} {x_i}^2\right)}$$

Horizontal accuracy CE90 of 6.5m corresponds to the horizontal (2-D) RMS error of 3.3m.

3.4. Remark on WV2 image data provision

Some satellite sensors (e.g. WorldView, QuickBird) provide their level 2A image products as Mosaic Tiled product. The tiles do not overlap because they are not individual images but parts of the same image (scene or strip). All tiles constituting one WV2 strip are accompanied by one single set of support (metadata) files, including one single RPC file (called RPB in case of WV2).

These tiles need to be stitched (reassembled) into a single image file in order to proceed with the sensor orientation and subsequent orthorectification processes because the provided RPC parameters (RPB file) are valid only for the full reassembled image.

Not all available remote-sensing software are able to perform such stitching action: eg. PCI Geomatics, ENVI and lately also ERDAS Imagine/LPS (version 10.1) can cope with such data without problems but to use these image tiles by means of SocetSet already requires some experience or external help .

The stitched (reassembled) single image file can be as big as 25GB. Processing (e.g. orthorectifying) such large file may lead to the following issues:

(a) stitched images are too big to be processed by off-the-shelf remote sensing software;

(b) one single metadata (RPC) file for big or long scene (or strip) may result in low accuracy during modelling and orthorectification.

On special request, the WV2 image provider can provide the data in extraordinary tiles characterised by overlap and their own RPC parameters. This solution, extraordinary WV2 data provision mode is, however, not a standard production chain.

3.5. Study area and WorldView-2 data for testing

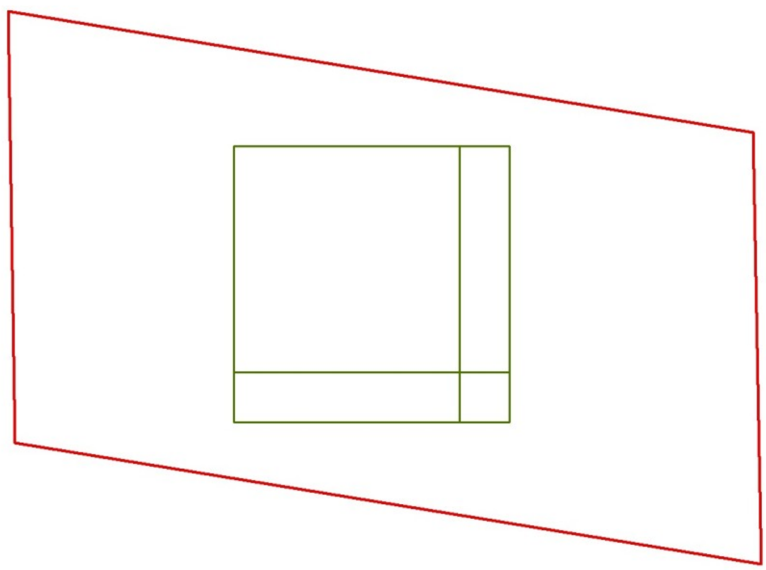

Figure 1: The extents of the sample of WorldView2 images: product level 1A in red and product level 2A in green. Note that WV2 product level 2A is provided as a Mosaic Tiled product, i.e. not overlapping tiles (here: four tiles).

For the described study the following WV2 sample images are available:

- five co-registered WV2 PAN and MS scenes (short strip), acquired between 15 and 31 January 2010, covering the same 10kmx10km area but differing with regards to their incidence angles (i.e. 10.5, 21.7, 26.7, 31.6, 36.0deg), available in processing levels 1A and 2A. Note: the imagery in the processing level 1A covers a bigger area (compare fig.1.)

The basic characteristics of the available sample of WorldView-2 images are as follows (tab.2):

WV2 ID	Acquisition date	Processing level	INTRACK VIEW ANGLE	CROSSTRACK VIEW ANGLE	OFF NADIR VIEW ANGLE
052299009030_01	2010-01-15 T10:18	1A, 2A	-10.4	34.7	**36.0**
052299009040_01	2010-01-22 T11:02	1A, 2A	1.8	-21.7	**21.7**
052299009050_01	2010-01-28 T10:43	1A, 2A	9.5	4.6	**10.5**
052299009060_01	2010-01-28 T10:42	1A, 2A	31.1	5.8	**31.6**
052299009070_01	2010-01-31 T10:33	1A, 2A	20.0	18.2	**26.7**

Table 2: Chosen metadata of the tested WorldView-2 images (according to the metadata files)

The JRC Maussane Test site is located near to Mausanne-les-Alpilles in France. It has been used as test site by the European Commission Joint Research Centre since 1997. It comprises a time series of reference data (i.e. DEMs, imagery, and ground control) and presents a variety of agricultural conditions typical for the EU. The site contains a low mountain massif (elevation up to around 650m above sea level), mostly covered by forest, surrounded by low lying agricultural plains and a lot of olive groves. A number of low density small urban settlements and a few limited water bodies are present over the site.

3.6. Auxiliary Data

The identifiability conditions check of the all GCPs within the range of the tested WV2 tiles resulted in establishing the sets of available GCPs for WV2 PAN and WV2 MS imagery.

These two sets are further divided into two sub-sets: one for sensor orientation phase and the other for orthoimage validation phase (Independent Check Points – ICP).

The ground control points for sensor orientation and orthorectification of the WV2 PAN images (2A processing level) are chosen from the following GCPs auxiliary data sets:

- Set of points prepared for the ADS40 project: RMSEx<0.05m; RMSEy=0.10m (11XXXX);
- Set of points prepared for the VEXEL project: RMSEx=0.49m; RMSEy=0.50m (44YYYY);
- Set of points prepared for the MULTI-use project: RMSEx = RMSEy = 0.50m (66ZZZZ);

The projection and datum details of the above listed data are UTM zone 31N ellipsoid WGS84.

In case the GCPs configuration consists of six equally-distributed ground control points (v6), the following GCPs auxiliary data is used during sensor orientation and orthorectification of the WV2 PAN tiles:

GCPs calibration set for WV2 PAN (v6):

- From MULTI-use GCPs set (3): 66003, 66009, 66045;
- From VEXEL GCPs set (3): 440011, 440017, 440019;

In case of version/arrangement with nine GCPs (v9) the set will include as follows:

GCPs calibration set for WV2 PAN (v9):

- From MULTI-use GCPs set (4) 66003, 66009, 66010, 66045,
- From VEXEL GCPs set (5): 440006, 440011, 440016, 440017, 440019,

In case of the base GCPs configuration (six equally-distributed ground control points, v6), the following GCPs auxiliary data is used during sensor orientation and orthorectification of the WV2 multispectral tiles:

GCPs calibration set for WV2 MS (v6):

- From MULTI-use GCPs set (3) 66003, 66005, 66039,
- From VEXEL GCPs set (2): 440016, 440019,
- From ADS40 GCPs set (1): 110014,

The following height auxiliary data is available for this project

- DEM_ADS40: grid size 2mx2m, ellipsoidal heights; data source: ADS40 (Leica Geosystems) digital airborne image of GSD of 50cm; RMSEz<=0.6m;
- DEM_25m_FR: grid size 25m x 25m, orthometric/topographic heights; data source: stereo-measurements of analogue photos from 1997; metadata concerning accuracy is lost, usually we set the DEM accuracy to 3m both CE90 and LE90;

The projection and datum details of the above listed data are UTM zone 31N ellipsoid WGS84 (EPSG 32631).

3.7. Validation Data

The points with known position that were not used during the used during the geometric correction model phase served as the validation sets in order to evaluate horizontal error of the test orthoimage data.

The check points for external quality control (validation phase) of the orthorectified WV2 PAN are chosen from the following GCPs auxiliary data sets:

- Set of points prepared for the ADS40 project: RMSEx<0.05m; RMSEy=0.10m (11XXXX);
- Set of points prepared for the VEXEL project: RMSEx=0.49m; RMSEy=0.50m (44YYYY);
- Set of points prepared for the MULTI-use project: RMSEx = RMSEy = 0.50m (66ZZZZ);

The projection and datum details of the above listed data are UTM zone 31N ellipsoid WGS84.

For a given GCPs calibration set, different GCPs configurations will be chosen and studied, while the set of the independent check points (ICPs) will remain unchanged.

In case the GCPs configuration consists of six equally-distributed ground control points (v6), the following auxiliary data is used during EQC of the orthorectified WV2 PAN tiles:

ICPs validation set for WV2 PAN (v6):

- MULTI-use (17) 66004, 66005, 66007, 66008, 66010, 66025, 66026, 66027, 66028, 66039, 66043, 66050, 66062, 66063;
- VEXEL (9): 440003, 440006, 440007, 440008, 440009, 440016;

- ADS40 (4): 110005, 110020, 110001, 110014,

In case of version/arrangement with nine GCPs (v9) the ICPs validation set for WV2 PAN (v9) includes as follows:

- MULTI-use (13) 66004, 66005, 66007, 66008, 66025, 66026, 66027, 66028, 66039, 66043, 66050, 66062, 66063;
- VEXEL (4): 440003, 440007, 440008, 440009;
- ADS40 (4): 110001, 110005, 110014, 110020;

In case of the base GCPs configuration (six equally-distributed ground control points, v6), the following auxiliary data is used during EQC of the orthorectified WV2 MS tiles:

ICPs validation set for WV2 MS (v6):

- MULTI-use (8) 66004, 66010, 66025, 66026, 66027, 66028, 66050, 66063;
- VEXEL (1): 440009;

The projection and datum details of the above listed data are UTM zone 31N ellipsoid WGS84.

4. Methodology

4.1. Methodology overview

The EU standard for the orthoimagery to be used for the purpose of the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS) requires the quality assessment of the final orthoimage ('Guidelines …,' 2008).

The RMS error calculated for Independent Control Points (i.e. points not included in the sensor model parameter estimation process, derived from an independent source of higher accuracy) in each dimension (either Easting or Northing) is used to describe the geometric characteristics of the orthoimage (product accuracy). This procedure is often referred as to external quality control (EQC).

Our quality assessment workflow consists of the following phases:

(a) geometric correction model phase, also referred as to image correction phase, sensor orientation phase, space resection or bundle adjustment phase;

(b) orthocorrection - elimination of the terrain and relief related distortions through the use of sensor and terrain (elevation) information, then reprojection and resampling;

(c) external quality control (EQC) of the final product, also referred as to absolute accuracy check or validation phase.

The planimetric accuracy of orthoimage is quite sensitive to the number and distribution of the several ground control points (GCPs) used during image correction phase and orthorectification. Therefore, we studied several ground control points (GCPs) configurations, while the set of the independent check points (ICPs) remained unchanged for all tested variants. Each time, the 1-D RMS errors, for both X and Y directions were calculated for GCPs during the geometric correction model phase, and for ICPs – during the validation phase (EQC).

For this exercise we used:

- five WV2 PAN and five WV2 MS images (co-registered), covering the same area but differing with regards to their incidence angles;
- two auxiliary height data (DEM), covering the same area but differing with regards to their accuracy and resolution;
- two mathematical models for sensor orientation, i.e. Rational Functions model (RPC) and Toutin's Rigorous model;
- five configurations of GCPs with regards to the number of ground control points (equally distributed).

Each testing partner used the same image and auxiliary data but different software systems:

- Tragsatec, Spain - PCI Geomatics,
- Spacemetric, Sweden – Keystone,
- JRC (author) – ERDAS LPS.

For each of 5 WV2 PAN images the following arrangements/variants were foreseen to be tested using each of the available software (tab.3.)

# variant	IMG ID	DEM data	sensor model	GCPs configuration
1	1	more accurate DTM	Rigorous	configuration of 6 GCPs
2			Rational Functions	
3		less accurate DTM	Rigorous	
4			Rational Functions	
5		more accurate DTM	Rigorous	configuration of 9 GCPs
6			Rational Functions	
7		less accurate DTM	Rigorous	
8			Rational Functions	

Table 3: Arrangements (variants) of different GCPs configurations and modelling method to be analysed in detail for a given WorldView2 image (here image ID=1)

In case that a software misses one of the foreseen mathematical models for sensor orientation, only the existing one will be tested.

4.2. WV2 Sensor Support

At the time of the described WorldView2 samples testing, the available ERDAS Imagine and LPS version was 10.0. According to the ERDAS Support Team WV2 model was going to be officially implemented in ERDAS Imagine and LPS v10.1. The 10.0 ERDAS Imagine and LPS version supports WorldView-2 sensor by providing WorldView-1 and QuickBird both RPC-based and rigorous models that can be used instead of missing WV2 models. And these models (WV1/QB) were used in this study.
The PCI Geomatics version 10.3.0 supports both the rigorous (Toutin's) and RPC-based WorldView-2 sensor model.
Similarly, the current version of the Swedish digital photogrammetry software, Keystone Spacemetric, supports WorldView-2 sensor by providing both the RPC-based and rigorous model.

5. Results

5.1. Outcome of the external quality control for RPC model based orthoimages

The external quality control results of the orthoimages produced using WV2 2A single scene correction by RPC-based sensor modeling (1st polynomial order) are summarised in the tab.4 and 5. The number and distribution of the ICPs is constant (12-point data set).

OFF NADIR view angle	RMSE_E	RMSE_N	RMSE_E	RMSE_N	RMSE_E	RMSE_N	RMSE_E	RMSE_N
10.5°	0,61	1,00	0,63	0,72	0,75	0,89	0,65	1,05
21.7°	0,55	0,97	0,83	0,72	0,66	0,60	1,45	1,42
26.7°	0,80	1,10	0,77	0,99	0,83	0,93	1,09	1,38
31.6°	0,87	1,56	1,22	1,24	1,20	1,28	2,43	3,15
36°	1,62	1,75	1,21	1,14	1,26	1,40	1,24	1,32
	ERDAS LPS 6 GCP DTM_ADS40		Keystone 6 GCP DTM_ADS40		Keystone 6 GCP DTM_25		PCI 10.3.1 9 GCP DTM_ADS40	

Table 4: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modelling (1st polynomial order) using ERDAS LPS, PCI Geomatics or Keystone software and based on 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40) or a DTM with 3m vertical accuracy (DEM_25). The number and distribution of the ICPs is constant (12 points).

Number of GCPs	RMSE_E	RMSE_N	RMSE_E	RMSE_N	RMSE_E	RMSE_N
9	1,72	1,48	0,70	1,30	0,74	1,06
6	1,62	1,75	0,87	1,56	0,55	0,97
4	1,61	1,65	0,76	1,41	0,78	0,98
3	2,66	2,25	0,76	1,48	0,62	1,09
2	3,41	2,02	0,70	1,40	0,96	1,05
1	3,27	2,11	1,10	2,01	1,33	0,74
	36° off nadir view angle		31.6° off nadir view angle		21.7° off nadir view angle	

Table 5: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by first order Rational Polynomial using ERDAS LPS and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

5.2. Outcome of the external quality control for rigorous model based orthoimages

We performed the external quality control on each of the orthoimage produced using Toutin's rigorous model implemented in the PCI Geomatica 10.3.1 OrthoEngine or Keystone Spacemetric software (tab.6). The number and distribution of the ICPs is constant (12-point data set).

OFF NADIR view angle	RMSE_E	RMSE_N	RMSE_E	RMSE_N	RMSE_E	RMSE_N	RMSE_E	RMSE_N
10.5°	0,99	0,41	1,42	0,97	0,53	0,71	0,66	0,65
21.7°	1,95	0,69	2,15	0,89	0,79	0,84	0,89	0,71
26.7°	1,42	0,57	1,51	0,79	0,70	0,91	0,75	0,94
31.6°	0,83	0,81	0,80	0,87	0,72	1,18	0,81	0,90
36°	0,85	0,50	1,49	0,60	1,01	1,28	1,40	1,56
	PCI (Toutin's) 9 GCP DTM_ADS40		PCI (Toutin's) 9 GCP DTM_25		Keystone 6 GCP DTM_ADS40		Keystone 6 GCP DTM_25	

Table 6: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 1A single scene correction by rigorous sensor modeling using PCI Geomatics or Keystone software and based on 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40) or a DTM with 3m vertical accuracy (DEM_25). The number and distribution of the ICPs is constant (12 points).

6. <u>Discussion</u>

6.1. WV2 RPC-based model summary

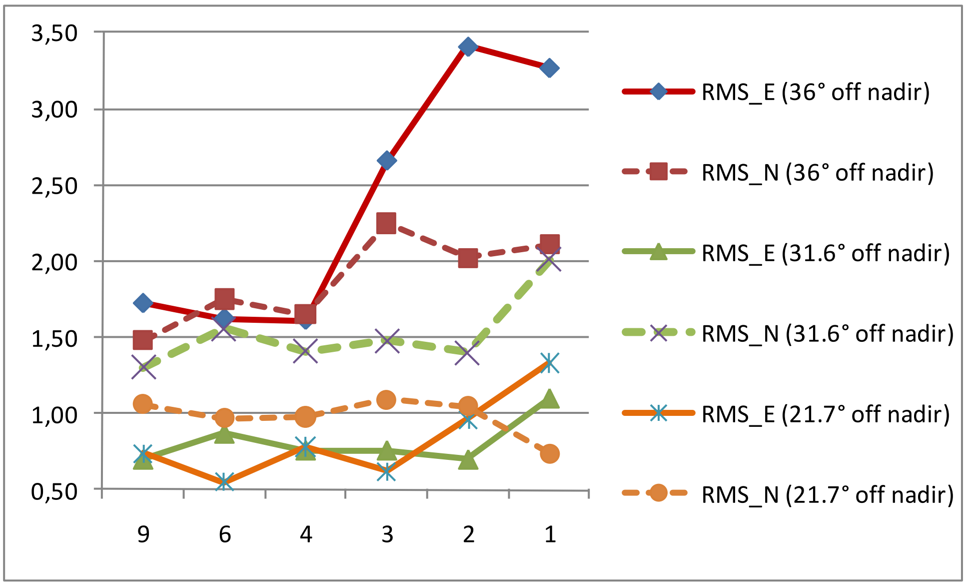

Figure 2: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by first order Rational Polynomial using ERDAS LPS and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

The 1-D RMSE_ICP measured on the final WV2 orthoimage after the single 2A scene correction applying first order Rational Polynomial based on 9, 6, 4, 3, 2 or 1 GCP, are presented in fig.2. The 1-D RMSE_ICP results in the Easting direction are presented as solid lines, while the results in the Northing direction are presented as dotted lines.

The one-dimensional RMS error based on the manual measurement of 12 well-distributed Independent Check Points (ICPs):

- is sensitive to the number of GCPs;
- decreases with increasing number of GCPs (negligible for more than 4);
- falls within the CwRS prime sensor accuracy criteria, i.e. an absolute 1-D RMSE of < 2.5m, based on 4 (or more) well-distributed GCPs with mean RMSEx,y < 0.6m, provided a DTM with 0.6m vertical accuracy used.

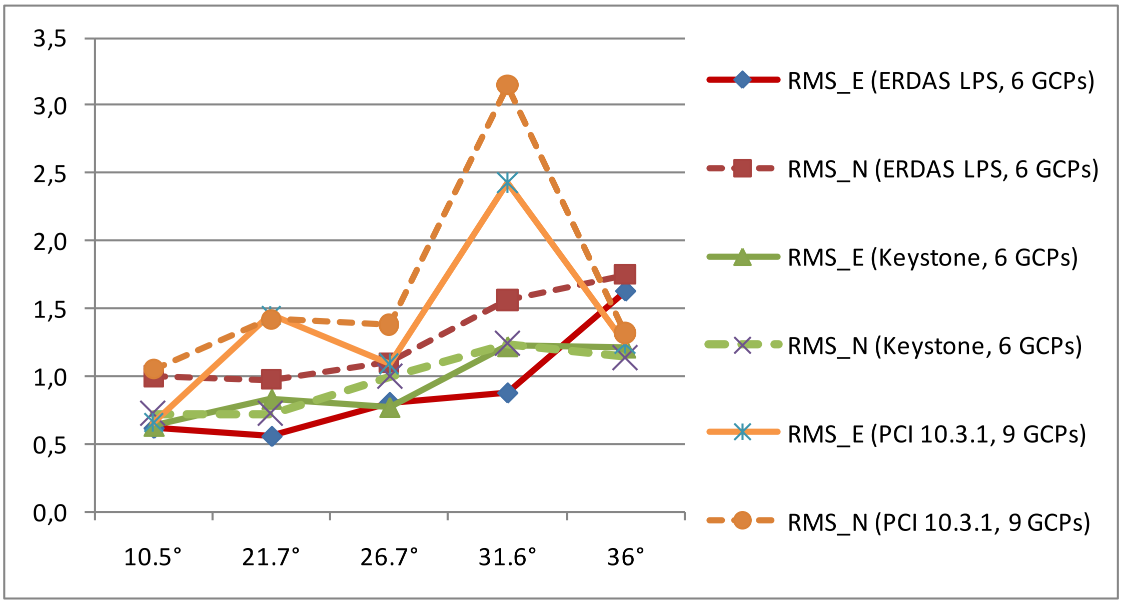

Figure 3: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by RPC-based sensor modelling (1st polynomial order) using ERDAS LPS, PCI Geomatics or Keystone software and based on 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

The 1-D RMSE_ICP measured on the final WV2 orthoimage as a function of the overall off-nadir after the single 2A scene correction applying first order Rational Polynomial based on 6 or 9 GCPs, are presented in fig.3. The 1-D RMSE_ICP results in the Easting direction are presented as solid lines, while the results in the Northing direction are presented as dotted lines.

The one-dimensional RMS error based on the manual measurement of 12 well-distributed Independent Check Points (ICPs):

- is sensitive to the off-nadir angle;
- increases with increasing off-nadir angle;
- reaches the value of two WV-2 pixels for 25°(or lower) off-nadir angle (ERDAS and Keystone cases);
- reaches the value of three WV-2 pixels for 25°(or lower) off-nadir angle (PCI Geomatics case).

Note the lack of harmonisation between the results obtained using PCI Geomatics and the results using the other softwares, i.e. ERDAS LPS or Keystone.

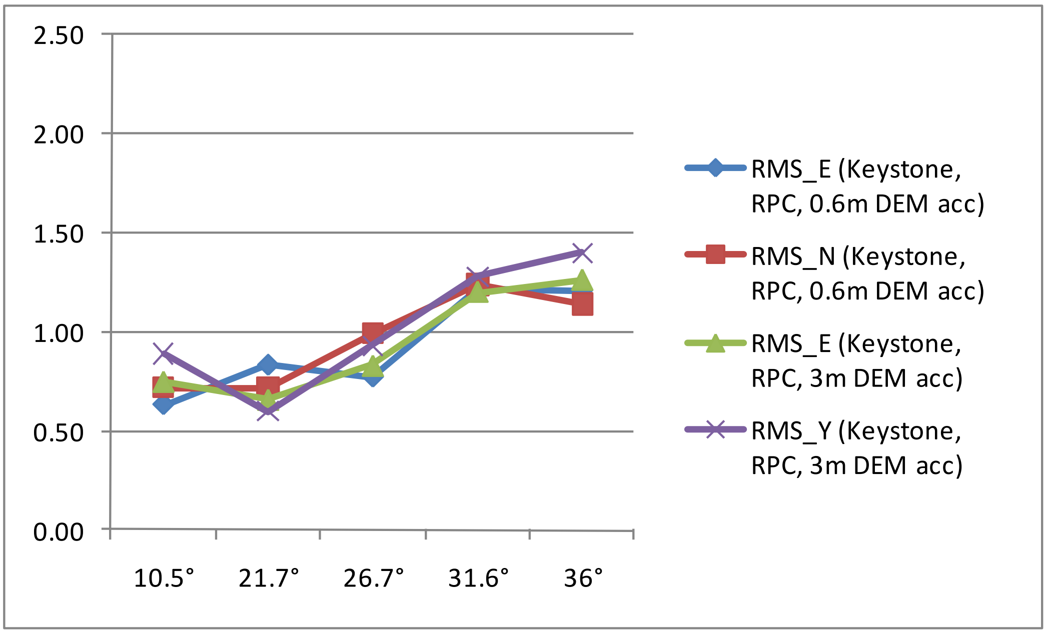

Figure 4: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by RPC-based sensor modelling (1st polynomial order) using Keystone software and based on 6 well-distributed GCPs and a DTM with 0.6m or 3m vertical accuracy. The number and distribution of the ICPs is constant (12 points).

The 1-D RMSE_ICP measured on the final WV2 orthoimage as a function of the overall off-nadir after the single 2A scene correction applying Keystone Rational Polynomial based on 6 GCPs and two DTMs of different accuracy (0.6m vs. 3m) are presented in fig.4.

The one-dimensional RMS error based on the manual measurement of 12 well-distributed Independent Check Points (ICPs) is negligible sensitive to the DTM accuracy, provided the DTM accuracy decrease from 0.6 to 3m;
This observation needs to be re-checked for less accurate DTM data.

6.2. WV2 rigorous model summary

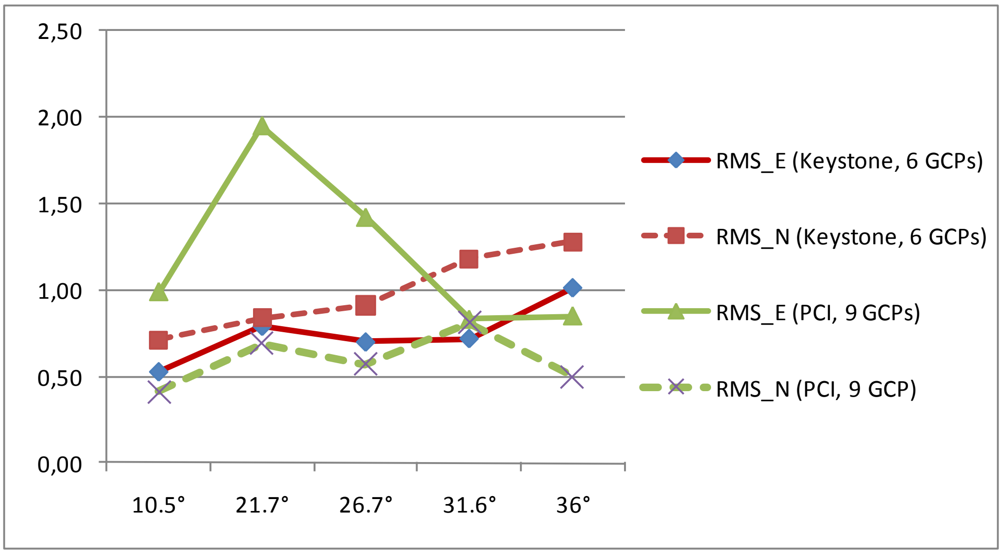

Figure 5: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by rigorous sensor modelling using PCI Geomatics or Keystone software and based on 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

The 1-D RMSE_ICP measured on the final WV2 orthoimage as a function of the overall off-nadir after the single 2A scene correction applying rigorous WV2 sensor model based on 6 or 9 GCPs, are presented in fig.5. The 1-D RMSE_ICP results in the Easting direction are presented as solid lines, while the results in the Northing direction are presented as dotted lines.

The one-dimensional RMS error based on the manual measurement of 12 well-distributed Independent Check Points (ICPs):

- is sensitive to the off-nadir angle;
- increases with increasing off-nadir angle; e.g. in case of using Keystone the values' increase is 100%, provided the satellite off-nadir angle increase from 10 to 36 degrees.

Note the lack of convergence with decreasing off-nadir angle for the RMS errors in the easting direction, particularly when using PCI Geomatics.

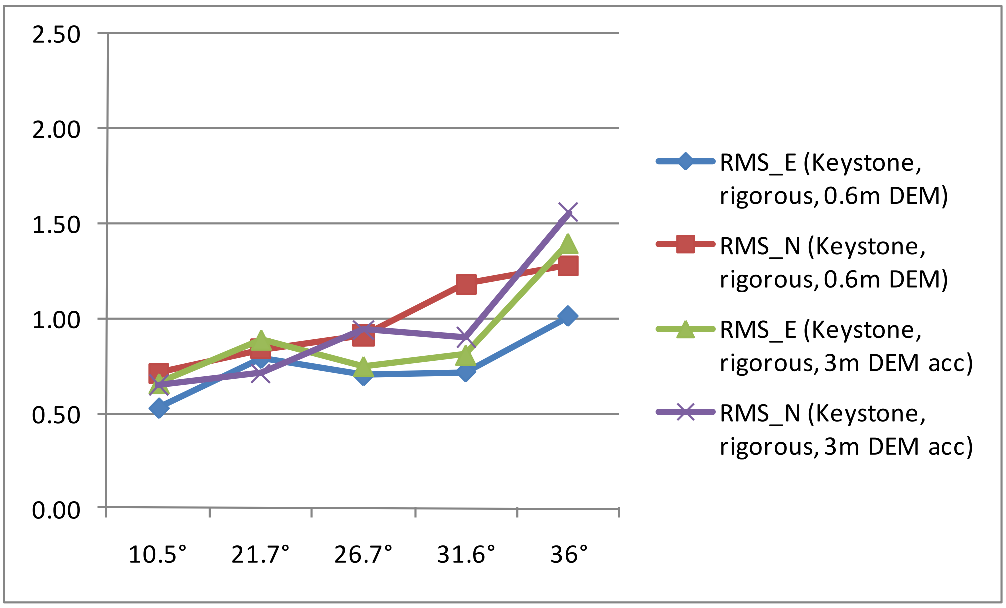

Figure 6: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by rigorous sensor modelling using PCI Geomatics or Keystone software and based on 6 well-distributed GCPs and a DTM with 0.6m or 3m vertical accuracy. The number and distribution of the ICPs is constant (12 points).

The 1-D RMSE_ICP measured on the final WV2 orthoimage as a function of the overall off-nadir after the single 2A scene correction applying Keystone rigorous sensor model based on 6 GCPs and two DTMs of different accuracy (0.6m vs. 3m) are presented in fig.6.

The one-dimensional RMS error based on the manual measurement of 12 well-distributed Independent Check Points (ICPs):

- is sensitive to the DTM accuracy;
- in easting direction declines of 15%, provided the DTM accuracy decrease from 0.6 to 3m;
- in northing direction the behaviour is incomprehensible;

Further testing is required, especially for less accurate auxiliary data, i.e. GCPs and DTM.

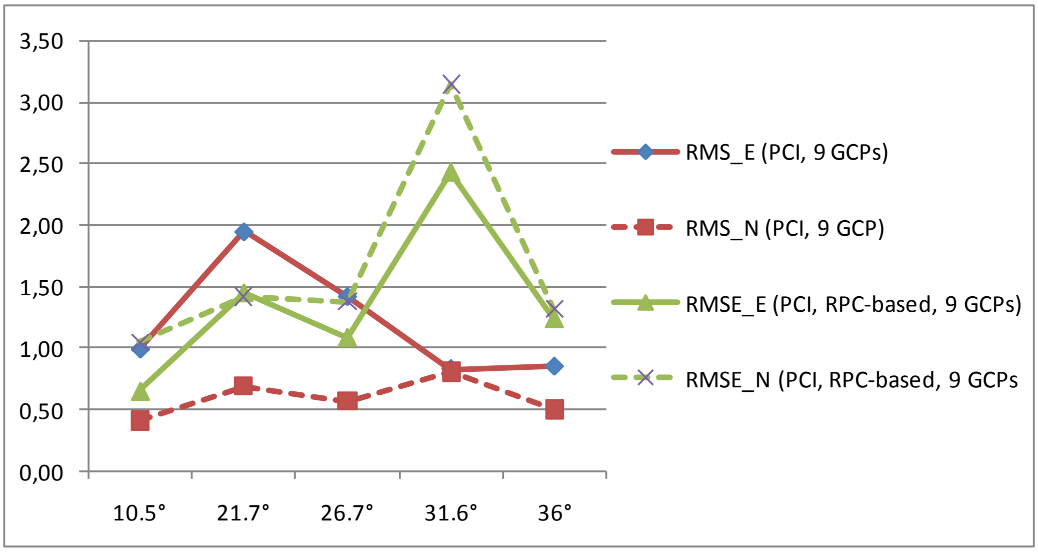

Figure 7: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by rigorous sensor modelling (in red) and by RPC-based modelling (in green) using PCI Geomatics or Keystone software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

The 1-D RMSE_ICP measured on the final WV2 orthoimage as a function of the overall off-nadir after the single 2A scene correction applying rigorous WV2 sensor or Rational Polynomials based on 9 GCPs, are presented in fig.7. The 1-D RMSE_ICP results in the Easting direction are presented as solid lines, while the results in the Northing direction are presented as dotted lines.

Note the non harmonised RMSE values during the external quality control of the WV2 orthoimages that are products of PCI Geomatics v.10.3.1 using the same image and auxiliary input data (including nine accurate well-distributed GCPs and DTM with 0.6m vertical accuracy).

7. Summary of Key Issues

This report presents the geometric quality results recorded for the five samples of the WorldView-2 Basic and Standard (processing level 1A and 2A) imagery acquired over the JRC Maussane Test Site.

The key issues identified during the geometric quality testing based on a limited sample of WorldView-2 images that were made available to us for of the Control with Remote Sensing Programme are summarised below:

1) WV2 sensor support

There is a concern that similar results are not achieved irrespective of remote-sensing software or modelling method used. Provided the same image and auxiliary data is introduced, the difference factor can be as much as 1:4. The WorldView-2 image provider was asked if all off-the-shelf remote-sensing packages fully support WV2 imagery. This was confirmed during the tele-conference held on April 22nd, 2010.

The role of the JRC is to evaluate the images acquired by spaceborne platforms for the Common Agriculture Policy (CAP) Control with Remote Sensing (CwRS) Programme and not to evaluate off-the-shelf photogrammetric packages. The EU Member States National Agencies, are equipped with the PCI Geomatics, ERDAS Imagine and LPS, Keystone Spacemetric and Socet Set digital photogrammetry software suites, therefore we use these software packages to perform the geometric image quality testing. In no way is this an endorsement by the JRC of any photogrammetric software package.

2) WV2 geolocation accuracy with respect to off-nadir angle

The EU standard for the orthoimagery to be used for the purpose of the CAP CwRS requires the assessment of the final orthoimage, also referred to as External Quality Control - EQC. Following EU guidelines, the 1-D RMS error is calculated for Independent Check Points (ICPs), measured on the final orthoimage.

WorldView2 nominal geolocation accuracy specification is 6.5m CE90 excluding terrain and off-nadir effects. This means that for WV2 imagery characterised by an overall off-nadir angle close to zero degrees acquired over a flat terrain their 1-D RMSE can be as big as 3.3m. It already exceeds the EU technical requirements (1-D RMSE < 2.5m), not mentioning the errors in case of an inclined WV2 imagery and/or acquired over hilly or mountainous terrain.

Different mathematical models of the WV2 sensor were tested, i.e. RPC-based and rigorous models implemented into PCI Geomatics, Keystone Spacemetric, and ERDAS IMAGINE& LPS software based on the following auxiliary data:

- several configurations (eg. 9, 6, 4) of equally distributed GCPs of 0.1m<RMSEx,y,z<0.6m;
- DEM of 2m grid and RMSEz=0.6m;
- 12 well-distributed independent check points (ICPs) of RMSEx,y,z<0.6m.

The preliminary results of the analysis show that the 1-D RMSE of the WV2 image characterised by large off-nadir angle, i.e. greater than 30 degrees (or elevation angle less than 56 deg) is close to or below the 2.5m EU acceptable threshold.
Further testing is required, especially for less accurate auxiliary data, i.e. GCPs and DTM.

2) WV2 geolocation accuracy with respect to digital terrain model (DTM) accuracy

Two digital terrain models, differing with respect to their accuracy, were tested. The first one, DTM ADS40, is very accurate, i.e. RMSEz=0.6m. The second one (DTM_25) accuracy is assumed to be between 1 and 3 meters.
The preliminary results show that the one-dimensional RMS error based on the manual measurement of a group of equally distributed Independent Check Points (ICPs) is sensitive to the DTM accuracy. Further testing is required, especially for less accurate DTM data, diverse terrains and images characterised by high satellite inclination angle.

Consequently, this report recommends that at least 6 (or 9 in areas with terrain slope diversity or high off-nadir angle) well-distributed ground control points during the WV2 sensor modelling phase using the Rational Functions mathematical model should be used. The rigorous model requires a minimum 9 or more ground control points. Accuracy requirements for auxiliary date, i.e. ground control points and DEM, given in 'Guidelines for Best Practice and Quality Checking of Ortho Imagery' should be strictly followed.

8. ANNEX: re-check of the tests performed using PCI Geomatics

8.1. How the issue has been evolving

1. Since the WV2 satellite launch (Oct. 2009) the JRC MARS has been asking the VW2 image provider (i.e. European Space Imaging - EUSI) for WV2 samples for testing. We were finally provided with the imagery in February, March and April.
2. Tragsatec (Spanish contractor) and Spacemetric (Keystone software developer) were involved in the WV2 image data geometry testing. And the WV2 image provider gave the permission to share the WV2 samples with our co-operators for testing purposes.
3. All co-operators received the same set of image and auxiliary data (including the image coordinates) and the 11-page Technical Specifications prepared specifically for the testing (Geometric Quality Analysis of the WorldView2 Image Data for the use in the CAP Control with Remote Sensing Programme - FMP 11620).
4. As soon as the testing results were available (April 2010), they were announced to the WV2 image provider and to the PCI Geomatics software representatives, together with a request for a support. In particular, there was a concern that similar results were not achieved irrespective of remote-sensing software or modelling method used.
5. The WorldView-2 image provider was asked if all off-the-shelf remote-sensing packages fully support WV2 imagery. This was confirmed during the tele-conference held on April 22nd, 2010 (Participants: Pascal Schichor and Edith Simon from EUSI, Bob Kudola (DG Production Engineer) and Melanie Rowe (DG Account Manager) from DigitalGlobe US; Beata Hejmanowska, Pavel Milenov and Joanna Nowak Da Costa from the JRC).
6. Post tele-conf list of actions included the action of DG&EUSI to provide some recommendations with regards to modelling method, number&accuracy of GCPs for WV2 orthorectification. Follow-up: EUSI&DG informed us that PCI suspects the elevation values of some GCPs as not accurate enough. Based on the example they shown (using heights read from Google Earth), I explained that both these elevations values can be good, i.e. they just refer to different Earth representations (geoid, ellipsoid).
7. The MARS JRC is confident about the adequacy of our auxiliary data with regards to their accuracy, distribution and reference; however we are concerned how PCI could doubt our elevation data since we never provided PCI with any WV2 image and auxiliary data. We shared these worries with EUSI who did not explain in what way PCI could possess that data.
8. There was no new input from EUSI or PCI for next several months until the day before the conference in Bergamo when the JRC MARS Personnel received several e-mails from both institutions. The WV2 image provider seems not to be satisfied neither by large WV2 image purchase in this campaign, nor by fact that the testing results and tech specs to use their data within the CwRS context are favourable.

With regards to our presentations, our publications and all related comments from all interested parties, the EC Services undertook a re-check of the tests performed on the WV2 datasets over the Maussane test site. This re-check was done in-house, i.e. no external contractors performing any part of the analysis. The test is mainly focused on the suspicious results from the PCI Geomatics obtained for the WV2 images with high and very high off-nadir angles.

8.2. Re-check methodology

We undertook a re-check of the tests performed on the WV2 datasets over the Maussane test site, and in particular WV2 images with high and very high off-nadir angles. The testing methodology was as described in chapter 4.1, however, this time all phases of testing were done in-house, i.e. no external contractors performing any part of the analysis. We focused on the suspicious results from the PCI Geomatics software. For the aim of comparison we also performed the same testing using ERDAS LPS. To provide identical testing conditions, the ground control points were measured only once, and then these measurements were directly imported into each project (as required by used software).

We undertook two tests. For TEST_A exercise we used:

- Three WV2 PAN images, covering the same area but differing with regards to their incidence angles (i.e. 36.0 deg, 31.6deg and 26.7 deg);
- Very accurate height data (DEM),
- Two mathematical models for sensor orientation, i.e. Rational Functions model (RPC) order 0 and 1; and Toutin's Rigorous model;
- Three configurations of GCPs with regards to the number of ground control points, i.e. nine, six and four equally distributed points;
- The constant 12-point set of the independent check points for external quality control;
- (suspicious) PCI Geomatics software version 10.3.1 and ERDAS LPS 2010 ver.10.1.

For TEST_B exercise we used:

- Four WV2 PAN images, covering the same area but differing with regards to their incidence angles (i.e. 36.0 deg acquired in January and April, 31.6deg and 26.7 deg);
- Very accurate height data (DEM),
- Two mathematical models for sensor orientation, i.e. Rational Functions model (RPC) order 0 and 1; and Toutin's Rigorous model;
- Three configurations of GCPs with regards to the number of ground control points, i.e. nine, six and four equally distributed points;
- Set of nine well accurate GCPs;
- The constant 19-point set of the independent check points for external quality control of the WV2 othoimages.
- (suspicious) PCI Geomatics software version 10.3.1 and ERDAS LPS 2010 ver.10.1.

8.3. Auxiliary data used for re-check

TEST A: The set of the ground control points consists of the nine GCPs characterised by RMSEx = RMSEy = 0.50m positional accuracy and 0.60m vertical accuracy (RMSEz). Their projection and datum are UTM zone 31N ellipsoid WGS84 (EPSG 32631).

The sensor orientation phase and the subsequent orthoimages were based on three different GCPs configurations, namely: nine (v9), six (v6) and four (v4) equally-distributed ground control points (fig.8).

990010	v9	v6	v4
66014	v9	v6	v4
66035	v9	v6	v4
66020	v9	v6	v4
66038	v9	v6	
440011	v9	v6	
990015	v9		
66027	v9		
66029	v9		

The following height auxiliary data was used for this project: DEM_ADS40: grid size 2mx2m, ellipsoidal heights; data source: ADS40 (Leica Geosystems) digital airborne image of GSD of 50cm; vertical accuracy of RMSEz<=0.6m.

TEST B: The set of the ground control points consists of the nine GCPs characterised by RMSEx = RMSEy = 0.50m positional accuracy and 0.60m vertical accuracy RMSEz (66003, 66009, 66010, 66045, 440006, 440011, 440016, 440017, 440019). Their projection and datum are UTM zone 31N ellipsoid WGS84, i.e. EPSG 32631.

8.4. Validation data used for re-check

TEST A

The constant 20-point set of the independent check points (fig.8) for external quality control of the TEST A orthorectified WV2 PAN are characterised by RMSEx = RMSEy = 0.50m accuracy (990002, 990003, 990005, 990006, 990008, 990009, 990011, 990014, 440008, 66026, 66028, 66036, 66049, 66050, 66062, 66063, 990013, 990016, 66015, 66016).

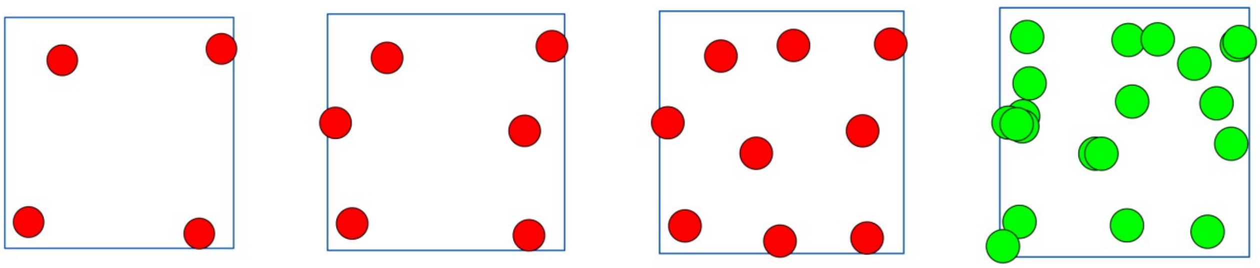

Figure 8: All tested variants (GCPs configurations) during TEST_A exercise: in red - the variants with 4, 6 and 9 GCPs; in green - the unchanged set of the 19 independent check points.

TEST B

The constant 12-point set of the independent check points for external quality control of the TEST B orthorectified WV2 PAN are characterised by RMSEx = RMSEy = 0.50m accuracy (66004, 66007, 66008, 66025, 66026, 66027, 66039, 66050, 66062, 66063, 440008, 440009).

8.5. TEST_A Results

The following tables and figures summarise the results obtained using TEST A data.

Off-nadir angle	Image ID	Method, order	No.of GCP	RMSE_E	RMSE_N	No.of ICP	software
36	052299009030_01	RPC, 0	4	0,808	0,725	20	PCI Geomat.
			6	0,831	0,696	20	
			9	0,834	0,671	20	
31.6	052299009060_01	RPC, 0	4	0,943	0,695	20	PCI Geomat.
			6	0,898	0,719	20	
			9	0,781	0,794	20	
26.7	052299009070_01	RPC, 0	4	0,590	0,524	20	PCI Geomat.
			6	0,682	0,469	20	
			9	0,578	0,456	20	

Table 7: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modeling (zero order polynomial) using PCI Geomatics software and based on 4 or 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	RMSE_E	RMSE_N	No.of ICP	software
36	052299009030_01	RPC, 1	4	1,249	0,989	20	PCI Geomat.
			6	1,181	0,851	20	
			9	0,576	0,563	20	
31.6	052299009060_01	RPC, 1	4	1,044	0,834	20	PCI Geomat.
			6	0,933	0,811	20	
			9	0,748	0,854	20	
26.7	052299009070_01	RPC, 1	4	0,655	0,566	20	PCI Geomat.
			6	0,632	0,567	20	
			9	0,594	0,529	20	

Table 8: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modeling (1st order polynomial) using PCI Geomatics software and based on 4 or 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	software
36	052299009030_01	Rigorous	9	20	1,221	0,947	PCI Geomat.
31.6	052299009060_01	Rigorous	9	20	0,810	1,118	PCI Geomat.
26.7	052299009070_01	Rigorous	9	20	0,813	0,543	PCI Geomat.

Table 9: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 single scene correction by rigorous sensor modelling using PCI Geomatics software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	software
36	052299009030_01	RPC, 0	4	20	0.98	0.74	ERDAS LPS.
36	052299009030_01	RPC, 0	6	20	1.04	0.73	ERDAS LPS
36	052299009030_01	RPC, 0	9	20	0.87	0.67	ERDAS LPS
36	052299009030_01	RPC, 1	4	20	1.06	0.75	ERDAS LPS.
36	052299009030_01	RPC, 1	6	20	1.08	0.70	ERDAS LPS
36	052299009030_01	RPC, 1	9	20	0.86	0.67	ERDAS LPS

Table 10: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 single scene correction by rigorous sensor modelling using ERDAS LPS software and based on 4 or 6 or 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 image is characterised by 36.0° off nadir angle.

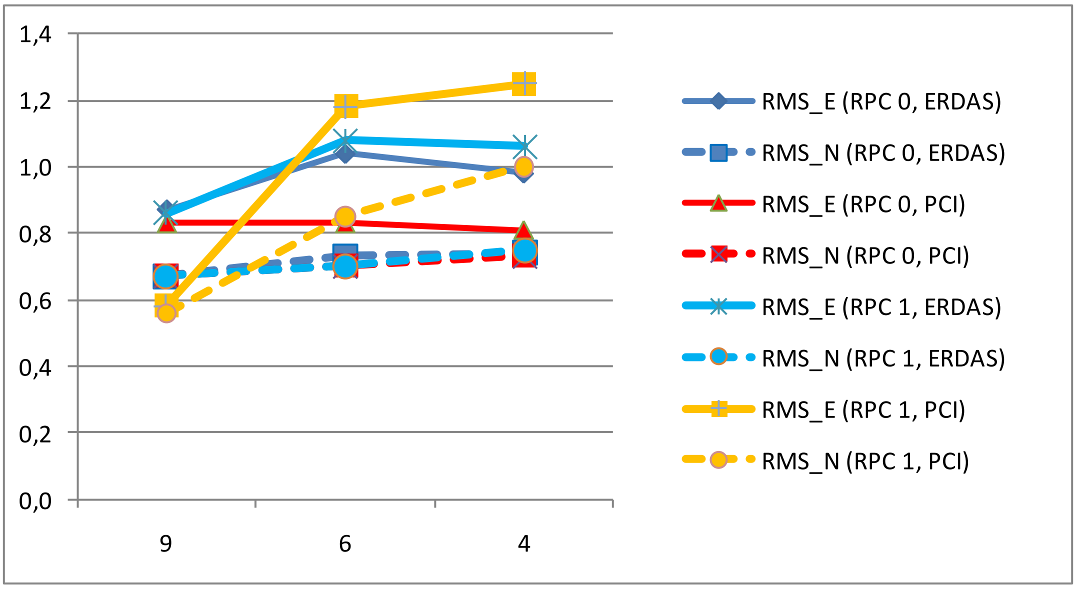

Figure 9: 1-D RMSE_ICP [m] measured on the final WV2 orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by first or zero order Rational Polynomial using PCI Geomatics or ERDAS LPS software and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 image is characterised by 36.0° off nadir angle.

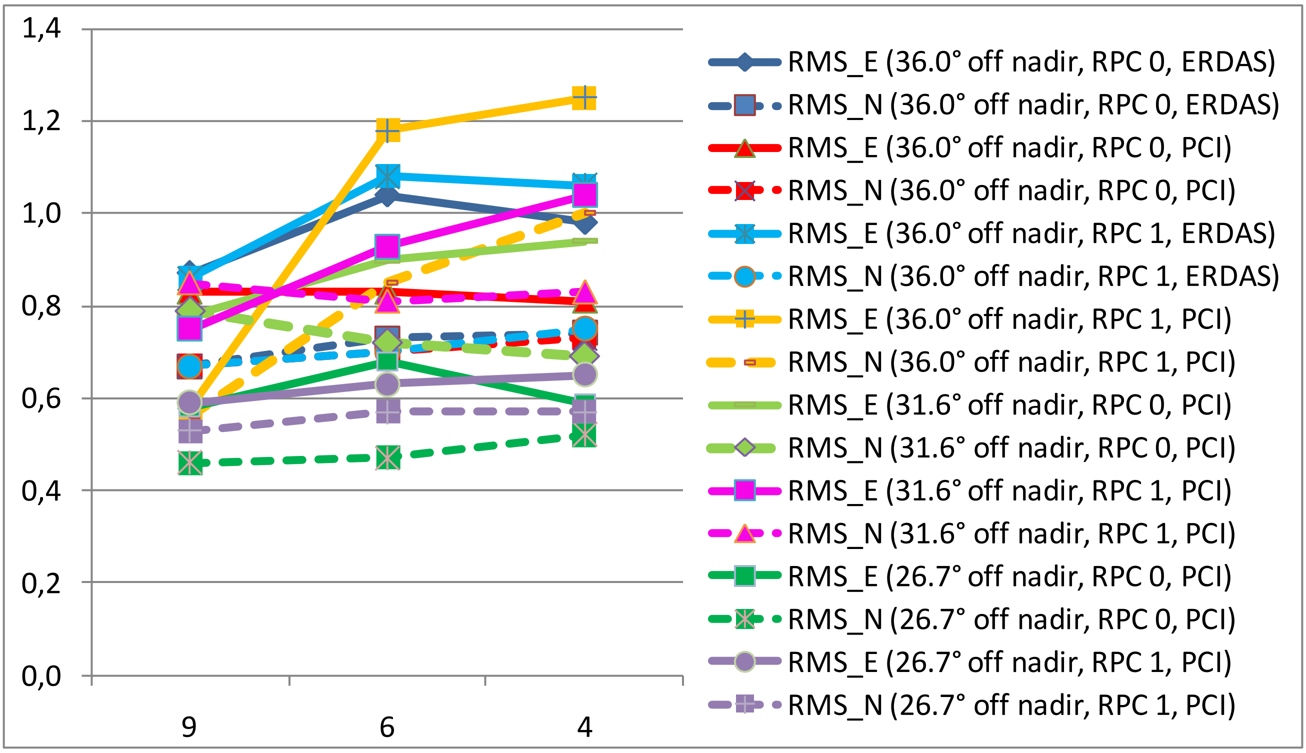

Figure 10: 1-D RMSE_ICP [m] measured on the final WV2 orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by first or zero order Rational Polynomial using PCI Geomatics or ERDAS LPS software and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 images are characterised by 36.0°, 31.6° or 26.7° off nadir angle.

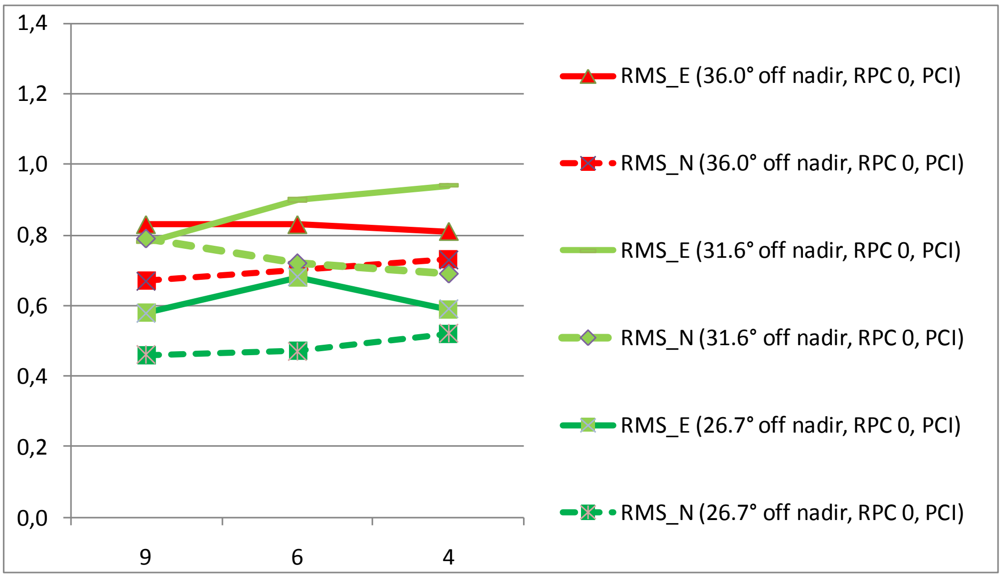

Figure 11: 1-D RMSE_ICP [m] measured on the final WV2 orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by zero order Rational Polynomial using PCI Geomatics software and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 images are characterised by 36.0°, 31.6° or 26.7° off nadir angle.

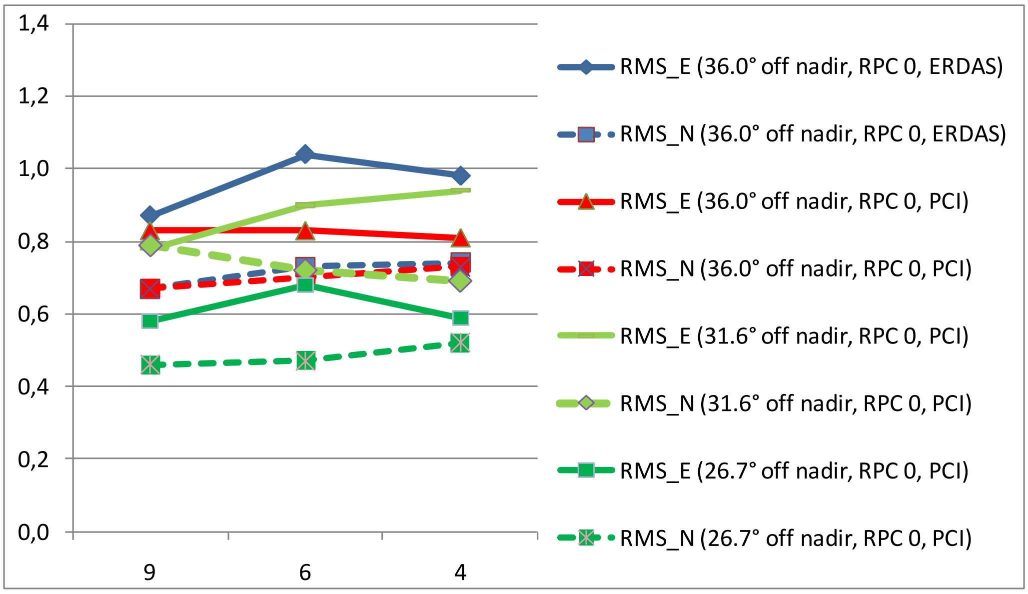

Figure 12: 1-D RMSE_ICP [m] measured on the final WV2 orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by zero order Rational Polynomial using PCI Geomatics or ERDAS LPS software and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 images are characterised by 36.0°, 31.6° or 26.7° off nadir angle.

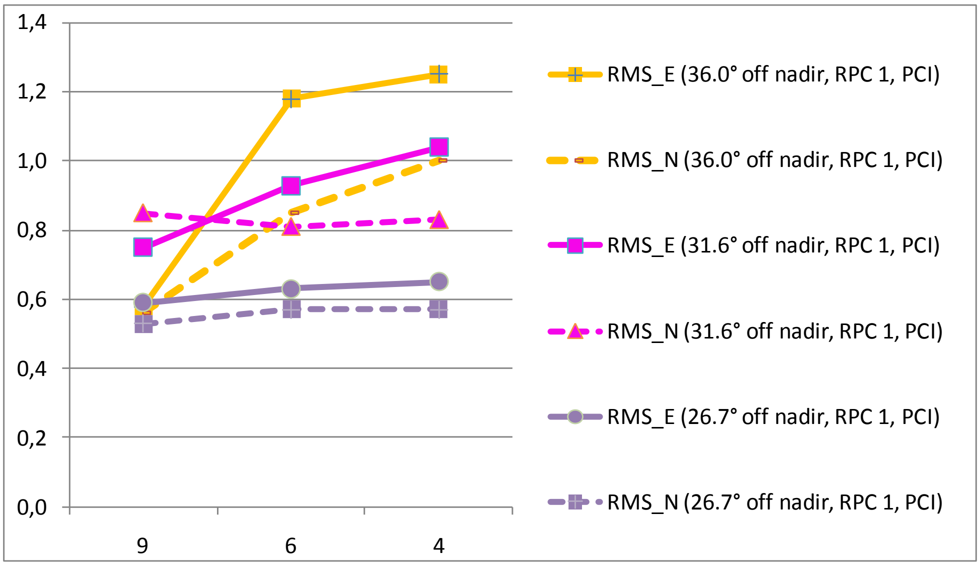

Figure 13: 1-D RMSE_ICP [m] measured on the final WV2 orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by first order Rational Polynomial using PCI Geomatics software and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 images are characterised by 36.0°, 31.6° or 26.7° off nadir angle.

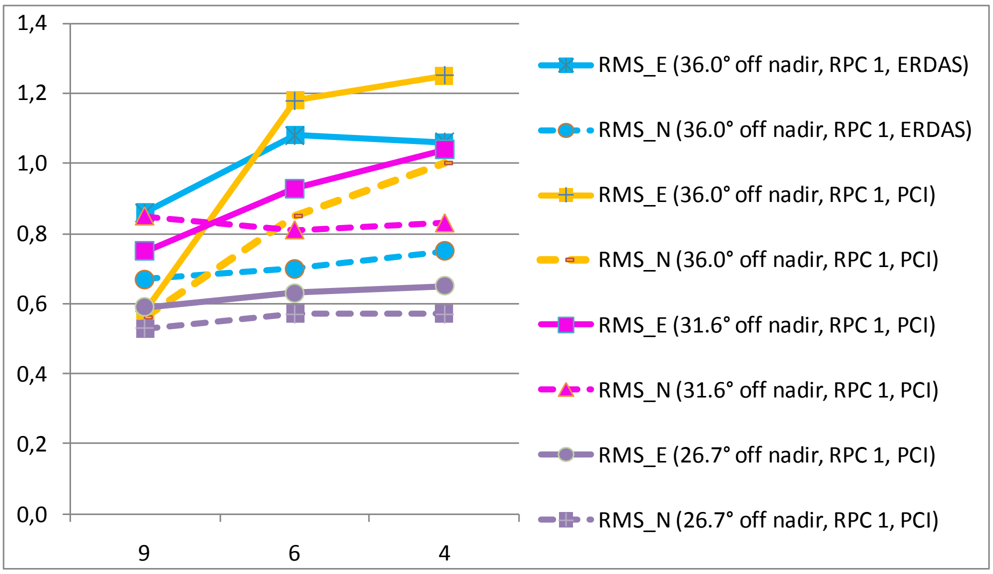

Figure 14: 1-D RMSE_ICP [m] measured on the final WV2 orthoimage as a function of the number of GCPs used during the WV2 2A single scene correction by first order Rational Polynomial using PCI Geomatics or ERDAS LPS software and based on a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points). The tested WV2 images are characterised by 36.0°, 31.6° or 26.7° off nadir angle.

8.6. TEST_B Results

The following tables and figures summarise the results obtained using TEST B data.

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	software
36	052299009030_01	RPC, 0	9	12	1,176	0,548	PCI Geomat.
31.6	052299009060_01	RPC, 0	9	12	0,553	0,493	PCI Geomat.
26.7	052299009070_01	RPC, 0	9	12	0,647	0,603	PCI Geomat.
36	10APR18102949	RPC, 0	9	12	1,168	0,698	PCI Geomat.

Table 11: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modeling (zero order polynomial) using PCI Geomatics software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	software
36	052299009030_01	RPC, 1	9	12	1,062	0,809	PCI Geomat.
31.6	052299009060_01	RPC, 1	9	12	0,792	0,582	PCI Geomat.
26.7	052299009070_01	RPC, 1	9	12	0,738	0,474	PCI Geomat.
36	10APR18102949	RPC, 1	9	12	1,400	0,693	PCI Geomat.

Table 12: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modeling (1st order polynomial) using PCI Geomatics software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	software
36	052299009030_01	Rigorous	9	12	1,272	0,839	PCI Geomat.
31.6	052299009060_01	Rigorous	9	12	1,223	0,588	PCI Geomat.
26.7	052299009070_01	Rigorous	9	12	0,988	0,789	PCI Geomat.
36	10APR18102949	Rigorous	9	12	1,415	0,858	PCI Geomat.

Table 13: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 single scene correction by rigorous sensor modelling using PCI Geomatics software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	software
36	052299009030_01	RPC, 0	9	12	1,133	0,845	ERDAS LPS
31.6	052299009060_01	RPC, 0	9	12	0,624	0,502	ERDAS LPS
26.7	052299009070_01	RPC, 0	9	12	0,338	0,621	ERDAS LPS
36	10APR18102949	RPC, 0	9	12	0,945	0,462	ERDAS LPS

Table 14: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modeling (zero order polynomial) using ERDAS LPS software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

Off-nadir angle	Image ID	Method, order	No.of GCP	No.of ICP	RMSE_E	RMSE_N	Software
36	052299009030_01	RPC, 1	9	12	1,146	0,764	ERDAS LPS
31.6	052299009060_01	RPC, 1	9	12	0,741	0,900	ERDAS LPS
26.7	052299009070_01	RPC, 1	9	12	0,556	0,380	ERDAS LPS
36	10APR18102949	RPC, 1	9	12	1,124	0,454	ERDAS LPS

Table 15: 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 2A single scene correction by RPC-based sensor modeling (1st order polynomial) using ERDAS LPS software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

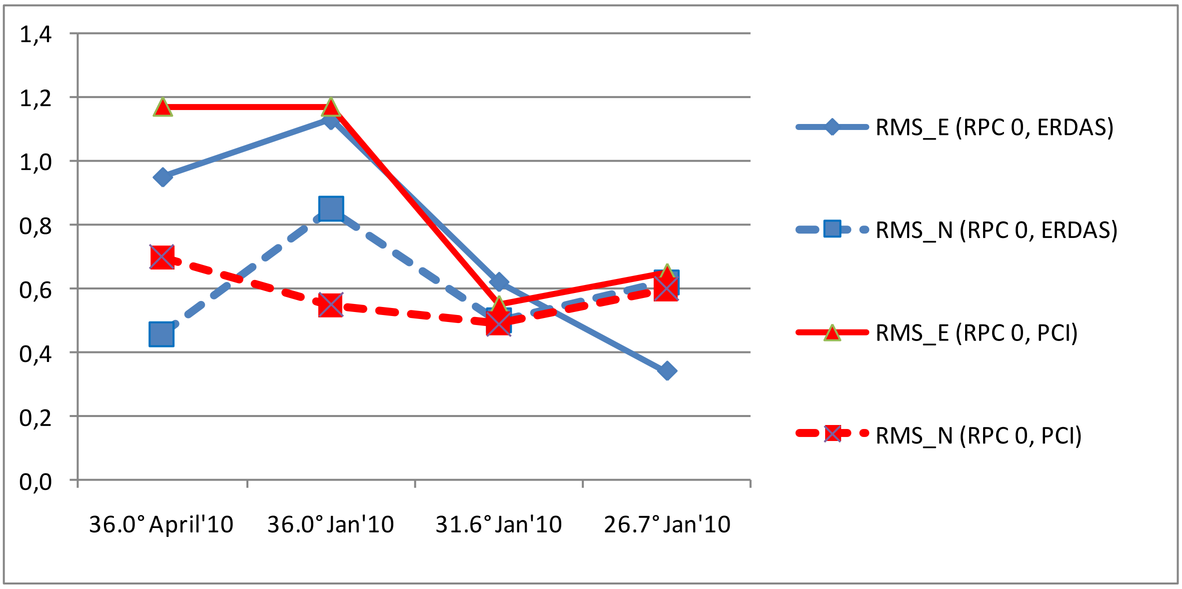

Figure 15: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by RPC-based sensor modelling (<u>zero polynomial order</u>) using <u>ERDAS LPS or PCI Geomatics</u> software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

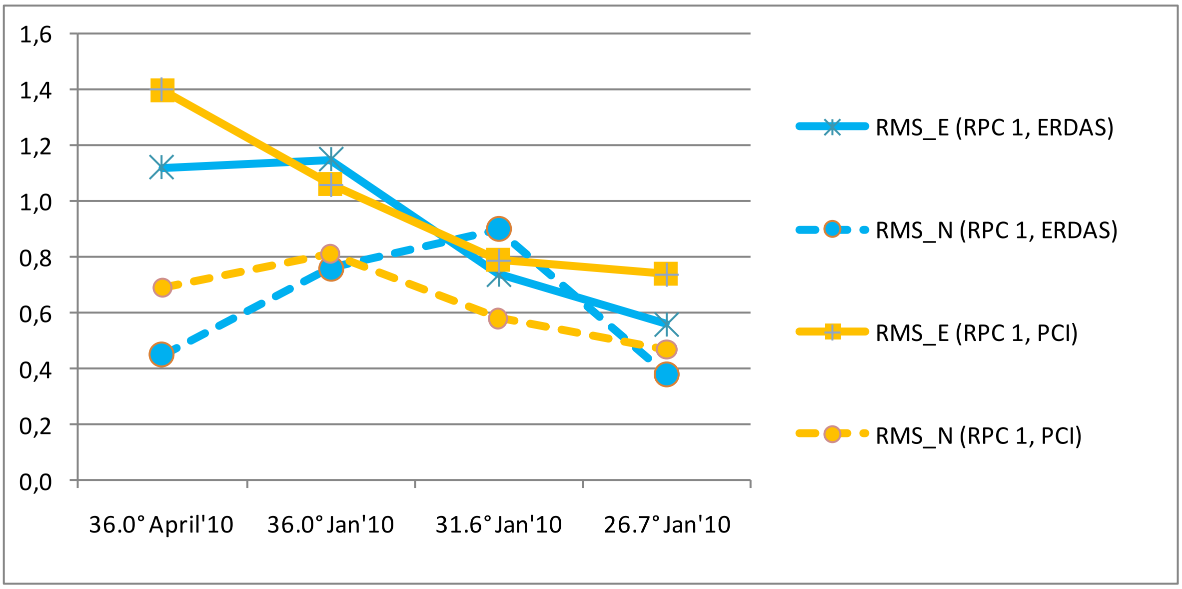

Figure 16: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by RPC-based sensor modelling (<u>1st polynomial order</u>) using <u>ERDAS LPS or PCI Geomatics</u> software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

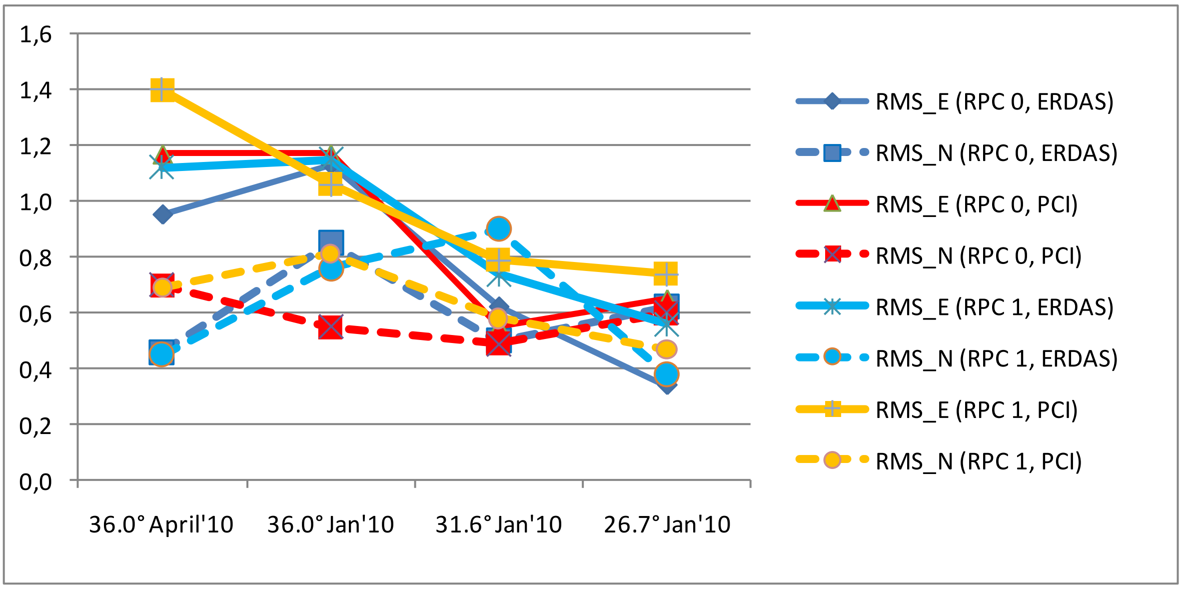

Figure 17: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by RPC-based sensor modelling (<u>zero or 1st polynomial order</u>) using <u>ERDAS LPS or PCI Geomatics</u> software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

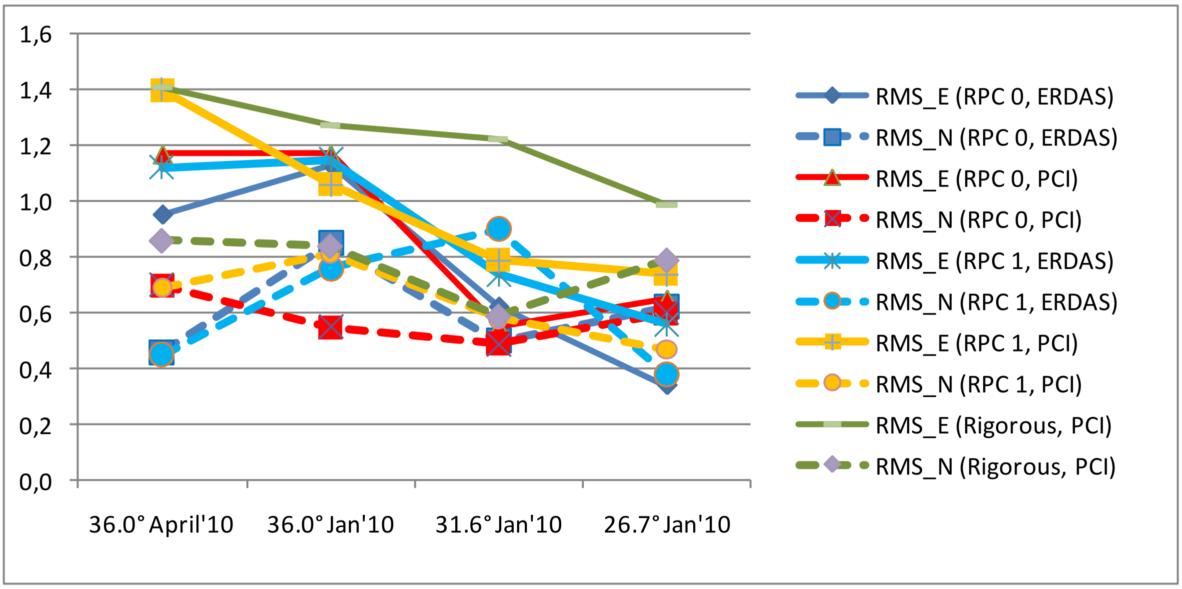

Figure 18: 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the overall off-nadir angle after the WV2 2A single scene correction by <u>rigorous or RPC-based sensor modelling</u> (zero or 1st polynomial order) using ERDAS LPS or PCI Geomatics software and based on 9 well-distributed GCPs and a DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (12 points).

9. <u>Final Conclusions</u>

This report presents the geometric quality results recorded for the five samples of the WorldView-2 Basic and Standard (processing level 1A and 2A) imagery acquired over the JRC Maussane Test Site.

In order to quantify the influence of ground control points and the incidence angle on orthoimage geolocation accuracy, several configurations of well-distributed GCPs (of 0.1m<RMSEx,y,z<0.6m) were set up, and the WV2 images characterised by various off-nadir angles were tested. Accuracy investigations were performed using different mathematical models of the WV2 sensor were tested, i.e. RPC-based and rigorous models implemented into PCI Geomatics, Keystone Spacemetric, and ERDAS IMAGINE& LPS software based on the accurate DEM of 2m grid and RMSEz=0.6m.

The horizontal accuracy assessment included computing the Root Mean Square Error (RMSE) of the residuals between the positions measured on the final product (orthoimage) and the reference positions of the 12 well-distributed independent Check Points (of RMSEx,y,z<0.6m) for each horizontal component (East, North).

The results lead to the following conclusions:

The one-dimensional RMS error based on the manual measurement of a set of well-distributed Independent Check Points (ICPs) on the WV2 orthoimage:

- is sensitive to the number of GCPs and decreases with increasing number of GCPs (fig. 9,10);
- increases with increasing off-nadir angle and can reach the value of 2.5 WV-2 pixels for 30°(or higher) off-nadir angle provided 4-9 well-distributed GCPs with mean RMSEx,y < 0.6m and a DTM with 0.6m vertical accuracy is used (fig. 15, 16, 17, 18);
- falls within the CwRS prime sensor accuracy criteria, i.e. an absolute 1-D RMSE of < 2.5m, based on 4 (or more) well-distributed GCPs with mean RMSEx,y < 0.6m, provided a DTM with 0.6m vertical accuracy used.

Hence, this report recommends that at least 6 (or 9 in areas with terrain slope diversity and/or high off-nadir angle) well-distributed ground control points during the WV2 sensor modelling phase using the Rational Functions mathematical model should be used. The rigorous model requires a minimum 9 or more ground control points. Accuracy requirements for auxiliary date, i.e. ground control points and DEM, given in 'Guidelines for Best Practice and Quality Checking of Ortho Imagery' should be strictly followed.

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Abstract
This report presents the geometric quality results recorded for the five samples of the WorldView-2 Basic and Standard (processing level 1A and 2A) imagery acquired over the JRC Maussane Test Site.
In order to quantify the influence of ground control points and the incidence angle on orthoimage geolocation accuracy, several configurations of well-distributed GCPs (of 0.1m<RMSEx,y,z<0.6m) were set up, and the WV2 images characterised by various off-nadir angles were tested. Accuracy investigations were performed using different mathematical models of the WV2 sensor were tested, i.e. RPC-based and rigorous models implemented into PCI Geomatics, Keystone Spacemetric, and ERDAS IMAGINE& LPS software based on the accurate DEM of 2m grid and RMSEz=0.6m.
The horizontal accuracy assessment included computing the Root Mean Square Error (RMSE) of the residuals between the positions measured on the final product (orthoimage) and the reference positions of the 12 well-distributed independent Check Points (of RMSEx,y,z<0.6m) for each horizontal component (East, North).
The results lead to the following main conclusions:
The one-dimensional RMS error based on the manual measurement of a set of well-distributed Independent Check Points (ICPs) on the WV2 orthoimage:

- is sensitive to the number of GCPs and decreases with increasing number of GCPs (fig. 9,10);
- increases with increasing off-nadir angle and can reach the value of 2.5 WV-2 pixels for 30°(or higher) off-nadir angle provided 4-9 well-distributed GCPs with mean RMSEx,y < 0.6m and a DTM with 0.6m vertical accuracy is used (fig. 15, 16, 17, 18);
- falls within the CwRS prime sensor accuracy criteria, i.e. an absolute 1-D RMSE of < 2.5m, based on 4 (or more) well-distributed GCPs with mean RMSEx,y < 0.6m, provided a DTM with 0.6m vertical accuracy used.

The report recommends that at least 6 (or 9 in areas with terrain slope diversity and/or high off-nadir angle) well-distributed ground control points during the WV2 sensor modelling phase using the Rational Functions mathematical model should be used. The rigorous model requires a minimum 9 or more ground control points. Accuracy requirements for auxiliary date, i.e. ground control points and DEM, given in 'Guidelines for Best Practice and Quality Checking of Ortho Imagery' should be strictly followed.

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