European Commission

JRC SCIENTIFIC AND POLICY REPORTS

Sensitivity of the WorldView-2 satellite orthoimage horizontal accuracy

with respect to sensor orientation method, number and distribution of ground control points, satellite off-nadir angles and strip length

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2012

Report EUR 24973 EN

Joint Research Centre

European Commission
Joint Research Centre
Institute for Environment and Sustainability

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http://cidportal.jrc.ec.europa.eu
ftp://mars.jrc.ec.europa.eu

This publication is a Reference Report by the Joint Research Centre of the European Commission.

JRC66797

EUR 24973 EN

ISBN 978-92-79-21600-8 (pdf)

ISSN 1831-9424 (online)

DOI: 10.2788/83426

Luxembourg: Publications Office of the European Union, 2012

Printed in Italy

Final Report from Service contract 256379

Sensitivity of the WorldView-2 satellite orthoimage horizontal accuracy with respect to sensor orientation method, number and distribution of ground control points, satellite off-nadir angles, and strip length

Final Report – D3

Author:	University of La Sapienza, RM: M. Crespi F. Fratarcangeli F. Pieralice	***Status:***	**Deliverable D3 with addition of external QC**
Co-author:	Agnieszka Walczynska, Joanna Nowak Da Costa		
Approved:	Pär ÅSTRAND	***Circulation***	Internal/Commission, La Sapienza University, RM, external
Date:	19/07/2011, edited 13/12/2011	***Int. ref:***	file://S:\FMPArchive\C\13754.doc

Università degli Studi di Roma "La Sapienza"
Facoltà di Ingegneria Civile e Industriale

Dipartimento di Ingegneria Civile, Edile e Ambientale
Area di Geodesia e Geomatica

Study on

Sensitivity of the WorldView-2 satellite orthoimage horizontal accuracy with respect to sensor orientation method, number and distribution of ground control points, satellite off-nadir angles, and strip length

Final Report – D3

M. Crespi F. Fratarcangeli F. Pieralice

Contents

Figures and Tables 6
Acronyms and Abbreviations 8
Abstract 9
1. Introduction 10
2. Accuracy assessment of high resolution satellite imagery orientation by Hold-Out and Leave-One-Out Cross-Validation methods 11
3. The SISAR software 12
4. Data, tests and preliminary remarks 14
5. Maussane - Orientation tests with the Rigorous models 23
6. Maussane - Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata 27
7. Maussane - Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients generated with SISAR 29
8. Conclusions about Maussane orientation tests 32
9. Cosenza COSE_MODE_1- Orientation tests with the Rigorous models 32
10. Cosenza COSE_MODE_1- Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata 34
11. Cosenza COSE_MODE_1- Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients generated with SISAR 36
12. Conclusions about Cosenza COSE_MODE_1 orientation tests 37
13. Cosenza COSE_MODE_3 - Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata 37
14. Conclusions about Cosenza COSE_MODE_3 orientation tests 41
15. Conclusion towards orthoimages production 41
16. Maussane test site- Outcome of the external quality control 42
    16.1. Discussion about Maussane external quality control 43
    16.2. Summary of Key Issues 45
17. COSE test site - Outcome of the external quality control 45
    17.1. Discussion about COSE external quality control 46
    17.2. Summary of Key Issues 48
18. Conclusions 48
19. Possible future prospects 48
References 49

Figures and Tables

Figure 3.1. Grid for RPC generation in the terrain-independent approach 13
Figure 4.1. Maussane Test Site (Provence, South France) 16
Figure 4.2. Cosenza Test Site (COSE_MODE_1) (Southern Italy) 17
Figure 4.3 Cosenza Test Site (COSE_MODE_3) (Southern Italy) 18
Figure 4.4.GP 990011 on the images acquired on 15 January (top) and on 22 January (bottom) 19
Figure 4.5. GP 66029 surveyed by GPS receiver (top) and collected on the images (bottom) 20
Figure 4.6. GCPs distribution for Cosenza Test Site COSE_MODE_1 21
Figure 4.7. GCPs distribution for Cosenza Test Site COSE_MODE_3 22
Figure 5.1. Sets with 6 (top) and 9 (bottom) GCPs for Maussane Test Site 24
Figure 5.2. Results (RMSE-CPs) for the Rigorous models with 6 GCPs using SISAR (the most significant test in practice) and with 9 GCPs using Geomatica (the best test) 26
Figure 5.3. Screenshot of the Geomatica (PCI Geomatics) Help Guide 26
Figure 6.1. Set with 4 GCPs for Maussane Test Site 27
Figure 6.2. Results (RMSE-CPs) for the RPFs models with metadata RPCs using SISAR software with 4 GCPs - shift transformation (the most significant test in practice) and using SISAR software with 9 GCPs - affine transformation (the best test) 28
Figure 7.1. Results (RMSE-CPs) for the RPFs models with SISAR RPCs using SISAR and Geomatica software – no refinement (the most significant test in practice) and with 9 GCPs - affine transformation (the best test) 30
Figure 9.1. Sets with 6 (top) and 9 (bottom) GCPs for Cosenza Test Site 33
Figure 10.1. Set with 4 GCPs Cosenza Test Site 35
Figure 13.1. Set with 4 GCPs Cosenza Test Site – COSE_MODE_3 38
Figure 16.1 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the off nadir angle after WV2 2A single scene correction based on RPC parameters delivered by provider and DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (18 points). 43
Figure 16.2 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the off nadir angle after WV2 2A single scene correction based on RPC parameters calculated based on SISAR software and DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (18 points). 44
Figure 16.3 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the off nadir angle after WV2 2A single scene correction based on RPC parameters provider and calculated in SISAR software, DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (18 points). 45
Figure 17.1. The extend of the sample of WorldView-2 images: product level 2A. On the left side two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file. 46
Figure 17.2. On the left side 1-D RMSE_ICP [m] measured on the final orthoimage produced by ERDAS LPS. On the right side 1-D RMSE_ICP [m] measured on the final orthoimage produced by PCI Geomatics. 46
Figure 17.3. On the left side 1-D RMSE_ICP [m] measured on the final orthoimage produced by ERDAS LPS. On the right side 1-D RMSE_ICP [m] measured on the final orthoimage produced by PCI Geomatics. 47
Figure 17.4 Comparison of the distribution 1-D RMSE (ERDAS LPS, shift transformation, 4 GCPs). On the left the case with two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file. On the right- each strip provided as a set of overlapping subscenes, accompanied by metadata files, each with separate RPC file. 47

Table 1.1. WorldView-2 specifications (source: http://www.digitalglobe.com/) 10
Table 4.1. Characteristics of Maussane WorldView-2 images 15
Table 4.2. Characteristics of Cosenza (COSE_MODE_1) WorldView-2 images 15
Table 4.3. Characteristics of Cosenza (COSE_MODE_3) WorldView-2 images 15
Table 5.1. Results (RMSE-CPs) for the Rigorous models 25
Table 6.1. Results (RMSE-CPs) for the RPFs models with metadata RPCs 28
Table 6.2. Geomatica (PCI Geomatics) behaviour - averages of the GCPs residuals with metadata RPCs 29
Table 6.3. Estimation of shift parameters in Geomatica (PCI Geomatics) software.........................29
Table 7.1. Results (RMSE-CPs) for the RPFs models with SISAR RPCs.......................................31
Table 7.2. Geomatica (PCI Geomatics) behaviour - averages of the GCPs residuals with SISAR RPCs 32
Table 9.1. Results (RMSE-CPs) for the Rigorous models 34
Table 10.1. Results (RMSE-CPs) for the RPFs models with metadata RPCs 35
Table 11.1. Results (RMSE-CPs) for the RPFs models with SISAR RPCs.....................................36
Table 13.1. GCPs sets (upper: orientations with 4 GCPs only) used for Cosenza COSE_MODE_3...37
Table 13.2. Results (RMSE-CPs) for the RPFs models with metadata RPCs 39
Table 13.3. Results (RMSE-CPs) for the RPFs models with metadata RPCs using the same CPs 40
Table 16.1 The 1-D RMS errors obtained for img 052299009030_01 during the external quality control of the orthoimages. 42
Table 16.2 The 1-D RMS errors obtained for img 052299009040_01 during the external quality control of the orthoimages. 42
Table 16.3 The 1-D RMS errors obtained for img 052299009050_01 during the external quality control of the orthoimages. 42
Table 16.4 The 1-D RMS errors obtained for img 052299009060_01 during the external quality control of the orthoimages. 43
Table 16.5 The 1-D RMS errors obtained for img 052299009070_01 during the external quality control of the orthoimages. 43
Table 17.1 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 (two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file) correction by 0 order Rational Polynomial using ERSAS LPS and PCI Geomatics based on 4 GCPs..45
Table 17.2 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 (each strip provided as a set of overlapping subscenes, accompanied by metadata files, including one RPC file) correction by 0 order Rational Polynomial using ERSAS LPS and PCI Geomatics based on 4 GCPs. 46

Acronyms and Abbreviations

AGG-URS - Area di Geodesia e Geomatica-Università di Roma “La Sapienza”
BGRN – Blue, Green, Red, Near-infrared
CAP - Common Agriculture Policy
CPs – Check Points
CwRS - Control with Remote Sensing
GCPs – Ground Control Points
GPs - Ground Points (including GCPs and CPs)
HOV – Hold-Out-Validation accuracy assessment method
JRC –Joint Research Centre of the European Commission
LOOCV - Leave-One-Out-Cross-Validation accuracy assessment method
mAD – median Absolute Deviation
RMSE - Root Mean Square Error
RMSE-CP - Root Mean Square Error of the residuals on the Check Points
RPCs - Rational Polynomial Coefficients
RPFs - Rational Polynomial Functions
VHR - Very High Resolution
WV2 PAN - WorldView-2 Panchromatic
WV2 PANSHP - WorldView-2 Pan-sharpened

Abstract

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

In details, the horizontal accuracy of the orthoimages which can be derived from WV2 imagery have to be concerned, recalling that in order to qualify WV2 as a Very High Resolution (VHR) prime sensor (i.e. a sensor suitable for measuring parcel areas to the accuracy requested by the Common Agriculture Policy - CAP regulation), the CwRS guidelines requires that the one-dimensional RMSE error (i.e. in the East and North components) measured on the external Check Points - CPs for any orthoimage should not exceed 2.5 m.

This report summarizes the results regarding the orientation tests of the five WorldView-2 Panchromatic (WV2 PAN) images acquired over the JRC Maussane Test Site (Provence, Southern France), two Pan-sharpened (WV2 PANSHP) images (COSE_MODE_1) acquired over Cosenza Test Site (Southern Italy) and 9 Pan-sharpned (WV2 PANSHP) scenes (COSE_MODE_3) acquired over Cosenza Test Site (Southern Italy), carried out with Geomatica v.10.2 (PCI Geomatics), ERDAS Imagine 2011 and SISAR software, using both Rigorous model and Rational Polynomial Functions (RPFs) model with Rational Polynomial Coefficients (RPCs).

The Hold-Out-Validation accuracy assessment method (HOV) was considered, computing the Root Mean Square Error (RMSE) of the residuals between the estimated and the reference positions of the Check Points (CPs) for each horizontal component (East, North) varying the number of the GCPs. In addition the Leave-One-Out Cross Validation (LOOCV) method was been used to identify possible outliers.

Considering the results of the tests performed and of the accuracy assessment, the following remarks can be summarized.

First of all, as regards the orientation, on the basis of the presented results, some general conclusions can be drawn:

- the orientation accuracy displays a significant dependence on the off-nadir angle (higher accuracy for lower off-nadir angle)
- the best orientation accuracy is reached with the Rational Polynomial Functions model using the Rational Polynomial Coefficients supplied with the imagery metadata and applying a shift refinement even with 4 GCPs
- overall the accuracy is practically software independent and appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component
- concerning Cosenza Test Site appears more convenient to process the two long strips (up to 28 km) (COSE_MODE_1) instead of the separate 9 scenes (COSE_MODE_3), since the accuracy is practically the same whereas the number of the required GCPs is much lower

Secondly, as regards the orthoimages validation some general conclusions can be drawn:

- the goal stated by the EC Services - “Guidelines for Best Practice and Quality”, that is one-dimensional RMS error below 2.5 meter, can be reached, provided a good quality DSM is used
- all the orthoimages satisfy the previous requirement for Maussane Test Site
- for Cosenza Test Site, both for COSE_MODE_1 and COSE_MODE_3, there are quite similar bad results in the North component. This fact can be explained considering the satellite azimuths of the both acquisitions, that are nearly along the North-South direction; in fact the largest residuals regard only the mountainous area (where the used DSM probably displays the largest error) and they are aligned along the mean line of sight

1. Introduction

Imagery acquired by the WorldView-2 (WV2) sensor is of potential interest to the Control with Remote Sensing (CwRS) Programme of the European Commission and therefore needs to be assessed.
In details, the horizontal accuracy of the orthoimages which can be derived from WV2 imagery have to be concerned, recalling that in order to qualify WV2 as a Very High Resolution (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 RMSE error (i.e. in the East and North components) measured on the external Check Points - CPs for any orthoimage should not exceed 2.5 m.
This report summarizes the results regarding the orientation tests of the five WorldView-2 Panchromatic (WV2 PAN) images acquired over the JRC Maussane Test Site (Provence, Southern France), two Pan-sharpned (WV2 PANSHP) images (COSE_MODE_1) acquired over Cosenza Test Site (Southern Italy) and 9 Pan-sharpned (WV2 PANSHP) scenes (COSE_MODE_3) acquired over Cosenza Test Site (Southern Italy), carried out with Geomatica v.10.2 (PCI Geomatics), ERDAS Imagine 2011 and SISAR software, using both Rigorous model and Rational Polynomial Functions (RPFs) model with Rational Polynomial Coefficients (RPCs).
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Table 1.1. WorldView-2 specifications (source: http://www.digitalglobe.com/)

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

2. Accuracy assessment of high resolution satellite imagery orientation by Hold-Out and Leave-One-Out Cross-Validation methods

Currently, the most used method to assess spatial accuracy of oriented high resolution satellite image is the Hold-Out Validation (HOV), also known as test sample estimation. According to it, the data set (known ground points) is partitioned in two subsets: the first one used to determine the orientation-orthorectification model (GCPs) and the second to validate the model itself (check points or CPs). The only restriction on such selection is to have both sets sufficiently well-distributed on the whole image; apart from this consideration, the selection should be random. Once the model is trained, accuracy is usually evaluated as Root Mean Squared Error (RMSE) of residuals between imagery derived coordinates with respect to CPs coordinates, independently determined and used as reference.

This method has the advantage of being simple and easy to compute, but it also has some drawbacks, as it is generally not reliable and it is not applicable when a low number of ground points is available. First of all, once the two sets are selected, accuracy estimate is not reliable since it is strictly dependent on the points used as CPs; if outliers or poor quality points are included in the CPs set, accuracy estimate is biased. In addition, when a low number of ground points is available, almost all of them are used as GCPs and very few CPs remain, so that RMSE may be computed on a poor (not significant) sample. In these cases, accuracy assessment with the usual procedure is essentially lost, i.e. HOV is not appropriate to use. In addition, this method displays a low efficiency, making a poor use of the available information, as a large part of it must be collected and used only for validation purpose.

In order to overcome the drawbacks of HOV a possible alternative procedure to perform accuracy assessments of orthorectified image is the Leave-One-Out cross-validation (LOOCV) method. It is a special case of the k-fold cross-validation method, which involves the partitioning of the original data set in k subsets of equal size (approximately). The model is trained k times, using each subset in turn as the test set, with the remaining subsets being the training set. The overall accuracy can be obtained averaging the accuracy values computed on each subset. The LOOCV is a k-fold cross-validation computed with k=n, where n is the size of the original data set. Each test set is therefore of size 1, which implies that the model is trained n times. Therefore, the alternative proposal consists in applying the LOOCV as an effective accuracy evaluation method for image orientation, being particularly useful when a low number of ground points is available.

This method applied involves the iterative application of the orientation model, using all the known ground points as GCPs except one, different in each iteration, used as a check point. In every iteration, the residuals between image derived coordinates and the CP coordinates (prediction error of the model on CP coordinates) are calculated. The overall spatial accuracy achievable from the oriented image may be estimated by calculating the usual RMSE or, better, a robust accuracy index like the median Absolute Deviation (mAD) of the prediction errors on all the iterations.

In this way we solve both mentioned drawbacks of the classical procedure: it is a reliable and robust method, not dependent on a particular set of CPs and on outliers, and it allows us to use each known ground point both as a GCP and as a CP, maximizing all the available ground information. Obviously, this is of particular relevancy when the ground point number is kept as low as possible due to budget and/or logistic constraints. LOOCV may obviously apply to both with a rigorous and with a RPC-based (with possible zero or first order correction) orientation model.

Some experiments were carried out to assess how well LOOCV derivable accuracy indices (mAD and RMSE) are able to represent the overall accuracy and which are their advantages with respect to the HOV RMSE. They led to the following main conclusions, pointing out that the LOOCV method with accuracy evaluated by mAD seems promising and useful for practical cases:

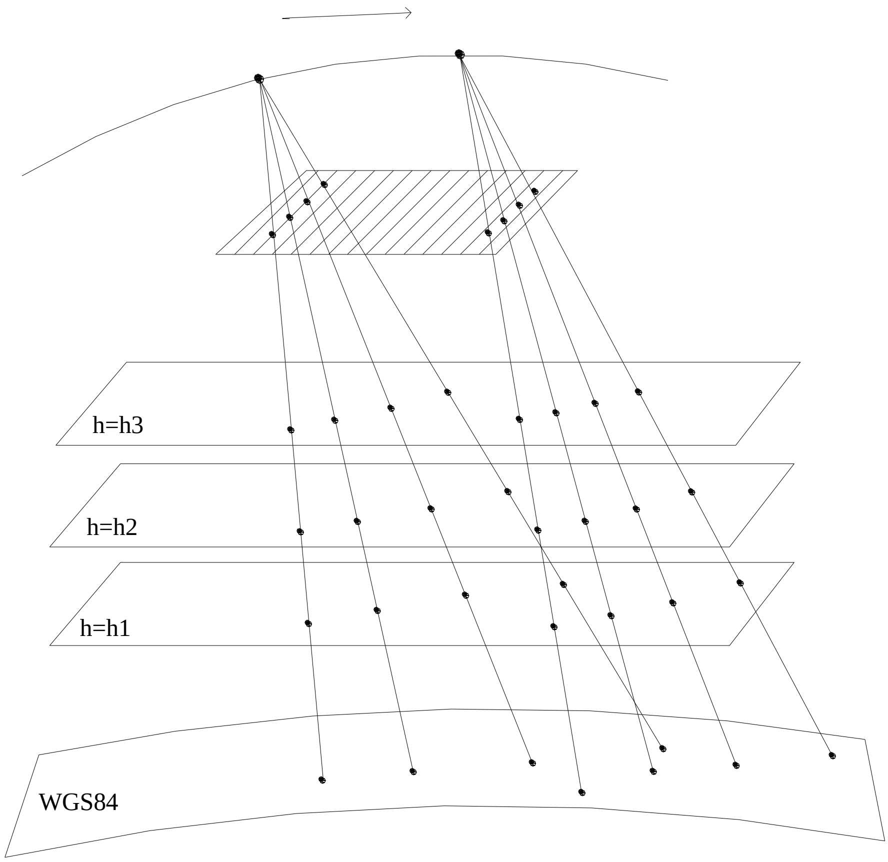
- the LOOCV RMSE and HOV RMSE are too sensitive to outliers and "critical" points (mainly located along the perimeter of the area covered by ground points), which may display high residuals when they act as CPs.
- HOV RMSE displays the risk to be too dependent on the geometric distribution of CPs, so that the HOV derived accuracy is likely not to be representative for the whole image when only a few CPs are available.
- the LOOCV mAD is a robust index able to filter out the effect of the high residuals; this is of particular relevancy for the "critical" points, which are not representative of the mean achievable accuracy.

3. The SISAR software

SISAR (Software per Immagini Satellitari ad Alta Risoluzione) is a scientific software that has been developed at the DICEA (Dipartimento di Ingegneria Civile Edile ed Ambientale), Area di Geodesia e Geomatica, University of Rome "La Sapienza".
Actually the software is able to orient single image and stereo model acquired by satellite high resolution optical and SAR sensors, and to generate Digital Surface Model. The software manages the imagery acquired by several optical sensors (EROS A, Ikonos, QuickBird, Cartosat-1, WorldView-1, GeoEye-1 & WorldView-2) and by COSMO-SkyMed and TerraSAR-X SAR sensors.
As regards the orientation model implemented, SISAR works both using the physical sensor models and the generalized sensor models, also called rigorous and Rational Polynomial Functions (RPFs) models respectively. In addition a specific tool for the Rational Polynomial Coefficients (RPCs) generation according to the terrain-independent scenario, based on the rigorous model, is implemented.
The rigorous model is based on a standard photogrammetric approach, i.e., the collinearity equations describing the physical-geometrical image acquisition. It must consider that an image from a push-broom sensor is formed by many (from thousands to tens of thousands) individual lines, each acquired with proper position (projection center) and attitude values. All the acquisition positions are related by the orbital dynamics. Therefore, the rigorous model is based on the reconstruction of the orbital segment during image acquisition through the knowledge of the acquisition mode, sensor parameters, satellite position and attitude parameters. The approximate values of these parameters can be computed by using the information contained in the image metadata file, delivered with each image. These approximate values are then corrected by a LS estimation process based on a suitable number of GCPs.
As it is widely known, actually some companies (for example DigitalGlobe for QuickBird and WorldView) usually supply the RPCs, as part of the image metadata to enable image orientation via RPF. Generalized sensor models, such as the RPFs, have smoothed the requirement to manage a physical sensor model. Furthermore, as the RPCs implicitly provide the interior and (approximate) exterior sensor orientation, the availability of several GCPs is no longer a mandatory requirement. Consequently, the use of the RPC for photogrammetric mapping is becoming a new standard in high-resolution satellite imagery.
For this reasons we considered to implement the RPCs generation tool in SISAR software.
For a terrain-independent scenario, a 2D image grid covering the full extent of the image is established and its corresponding 3D object grid with several layers (e.g., four or more layers for the third-order case) slicing the entire elevation range is generated. The horizontal coordinates (λ, φ) of a point of the 3D object grid are calculated from a point (I, J) of the image grid using the physical sensor model with an a priori selected elevation h. Then, the RPC are LS estimated with the object grid points and the image grid points. This terrain-independent

computational scenario can make the RPF model a good replacement to the physical sensor models, and has been widely used to determine the RPCs.

Figure 3.1. Grid for RPC generation in the terrain-independent approach



Note that the finest subdivision depends on the incompressible error of the rigorous model used to generate the RPCs, so that a very fine discretization is not useful and an upper discretization limit also exists. The RPCs least squares estimation is based on the linearization of the generic RPFs equations, which can be written as:

$$\begin{aligned} I_n + b_1\lambda_n I_n + b_2\varphi_n I_n + \ldots + b_{18}\varphi_n^3 I_n + b_{19}h_n^3 I_n - a_0 - a_1\lambda_n - a_2\varphi_n \ldots - a_{18}\varphi_n^3 - a_{19}h_n^3 = 0 \\ J_n + d_1\lambda_n J_n + d_2\varphi_n J_n + \ldots + d_{18}\varphi_n^3 J_n + d_{19}h_n^3 J_n - c_0 - c_1\lambda_n - c_2\varphi_n \ldots - c_{18}\varphi_n^3 - c_{19}h_n^3 = 0 \end{aligned} \quad (3.1)$$

where a_i, b_i, c_i, d_i are the RPCs (78 coefficients for third order polynomials), (I_n, J_n) and (φ_n, λ_n, h_n) are the normalized coordinates obtained throughout the equation (3.1), with scale and offset factors computed according to:

$$\begin{cases} w_{offset} = \min(w_k) \\ w_{scale} = \max(w_k) - \min(w_k) \end{cases} where \qquad w = \varphi, \lambda, h$$

$$\begin{cases} I_{offset} = J_{offset} = 1 \\ I_{scale} = n^\circ column - 1 \\ J_{scale} = n^\circ row - 1 \end{cases} \quad (3.2)$$

where k is the number of available GCPs and n° column/row are the overall columns/rows of the image; the normalization range is (0, 1).
Deeper investigations underlined that many RPCs are highly correlated. In order to avoid instability due to high correlations, a new alternative approach based on the Singular Value Decomposition (SVD) and QR decomposition is used to evaluate the actual rank of the design matrix and to select the actual estimable coefficients

4. Data, tests and preliminary remarks

The five co-registered WV2 PAN scenes over Maussane, acquired between 15 and 31 January 2010, covering the same 10 km x 10 km area but differing with regards to satellite off-nadir angles (i.e. 10.5, 21.7, 26.7, 31.6, 36.0 deg.), available at processing level 2A (Ortho Ready Standard Imagery), have been investigated.
As regard the Cosenza Test site two acquisition modes (COSE_MODE_1, COSE_MODE_3) have been analysed. In the first mode (MODE_1) two long strips (each about 28 km long and slightly overlapping) are provided as Mosaic Tiled product, which means that each strip is accompanied by a single metadata file. The swath extension is about 10 km and 15 km respectively, the satellite incidence (off-nadir) angles are 24.0 and 18.3 deg. In the second mode (MODE_3) 9 scenes (Image ID: 555, 556, 557, 593, 594, 595, 596, 597, 598) neighbour hooding overlapped, are supplied; each scene is approximately 10-15 x 10-15 km wide and it is accompanied by its own metadata files. The incidence angle is around 18.5 deg. for the eastern scenes and around 24.0 deg. for the western scenes.
Both strips (COSE_MODE_1) and the all scenes (COSE_MODE_3) are WV2 PANSHP products with 4 bands (BGRN), 2A processing level.
In details, all WV2 PAN images and WV2 PANSHP image in COSE_MODE_1 have been oriented with Rigorous and RPCs models using the commercial software Geomatica by PCI Geomatics and ERDAS Imagine, and the scientific software SISAR developed at the Area di Geodesia e Geomatica-Università di Roma “La Sapienza” (AGG-URS) by our research group. As far as the WV2 PANSHP in COSE_MODE_3 are concerned, considering the results already obtained with WV2 PAN images, only the RPCs model both with the commercial software Geomatica v.10.2 by PCI Geomatics and ERDAS Imagine 2011 and the scientific software SISAR have been used.
As regards the Maussane images, they were oriented using the same sets of GCPs considered for the orientation tests performed at JRC (pag. 23).
It is important to underline that some Ground Points (GPs) are not easily identifiable on the images; hence their positions on the images are not very accurate.
In details, the GP 990011 is easily identified on 4 images but not very well on the image acquired on January 15; moreover, it is not possible to replace it with the image acquired on April 15, like it is suggested, even if the GP 990011 is visible, because other GPs are hidden by clouds.
Further, the GP 66029 that it is used as GCP, has been surveyed by GPS receiver but quite far away from the electricity pole, which is the object collected on the image.

The GPs used in Cosenza Test Site COSE_MODE_1 were derived from the data set provided by JRC and from the cartography at 1:5000 scale freely available on the “Regione Calabria” website (http://pr5sit.regione.calabria.it/mapbuilderWeb/browserCTR.noSec). Among the JRC GPs only those well visible on the images were employed in the orientation tests; in particular they were the following 28 points: 93, 96, 97, 98, 99, 100, 101, 102, 103, 104, 105, 106, 107, 108, 109, 111, 1160, 1164, 1219, 1221, 1225, 1227, 1264, 1268, 74502, 731183, 731193, 731203. In addition 46 GPs were derived from collection on the cartography. Starting from the whole set of 74 GPs, a preliminary orientation test and an accuracy evaluation based on LOOCV were performed to identify possible outliers and to select the best and reliable set of points to be used in the final tests. In the LOOCV method a GP was considered affected by an outlier if its 2D residual exceeded the 3*mAD threshold. According to this criterion 69 GPs have been selected and employed in the orientation and accuracy evaluation procedure. Subsequently it was necessary to select 26 new GPs on the same cartography at 1:5000 scale to orient the images of Cosenza Test Site COSE_MODE_3 (201, 202, 203, 204, 205, 206, 207, 208, 209, 211, 212, 213, 214, 215, 216, 217, 218, 219, 220, 221, 222, 301, 302, 303, 304, 305), since the original GPs number were not enough to perform the image orientation and to assess its accuracy in some cases.

Table 4.1. Characteristics of Maussane WorldView-2 images

WV2 ID	Acquisition date	Processing level	InTrack View Angle [deg]	CrossTrack View Angle [deg]	Off Nadir View Angle [deg]	Satellite Elevation Angle [deg]
052299009030_01	2010-01-15 T10:18	2A	-10.4	34.7	36.0	48.6
052299009040_01	2010-01-22 T11:02	2A	1.8	-21.7	21.7	65.5
052299009050_01	2010-01-28 T10:43	2A	9.5	4.6	10.5	78.3
052299009060_01	2010-01-28 T10:42	2A	31.1	5.8	31.6	54.2
052299009070_01	2010-01-31 T10:33	2A	20.0	18.2	26.7	59.8

Table 4.2. Characteristics of Cosenza (COSE_MODE_1) WorldView-2 images

WV2 ID	Acquisition date	Processing level	InTrack View Angle [deg]	CrossTrack View Angle [deg]	Off Nadir View Angle [deg]	Satellite elevation angle [deg]
258	2010-04-30 T09:52	2A	-16.0	9.1	18.3	69.1
313	2010-04-30 T09:53	2A	-22.1	9.5	24.0	62.7

Table 4.3. Characteristics of Cosenza (COSE_MODE_3) WorldView-2 images

WV2 ID	Acquisition date	Processing level	InTrack View Angle [deg]	CrossTrack View Angle [deg]	Off Nadir View Angle [deg]	Satellite elevation angle [deg]
I001043_555	2010-04-30 T09:52	2A	-15.9	9.3	18.3	69.2
I001042_556	2010-04-30 T09:52	2A	-16.0	9.2	18.4	69.0
I001044_557	2010-04-30 T09:52	2A	-15.7	9.1	18.1	69.4
I001081_593	2010-04-30 T09:52	2A	-16.1	9.6	18.7	68.7
I001082_594	2010-04-30 T09:52	2A	-16.2	9.0	18.5	68.9
I001083_595	2010-04-30 T09:53	2A	-22.3	9.5	24.2	62.5

I001084_596	2010-04-30 T09:53	2A	-22.1	9.5	24.0	62.7
I001086_597	2010-04-30 T09:53	2A	-21.9	9.3	23.7	63.0
I001085_598	2010-04-30 T09:53	2A	-21.9	9.6	23.8	62.8

Figure 4.1. Maussane Test Site (Provence, South France)

Figure 4.2. Cosenza Test Site (COSE_MODE_1) (Southern Italy)

Figure 4.3. Cosenza Test Site (COSE_MODE_3) (Southern Italy)

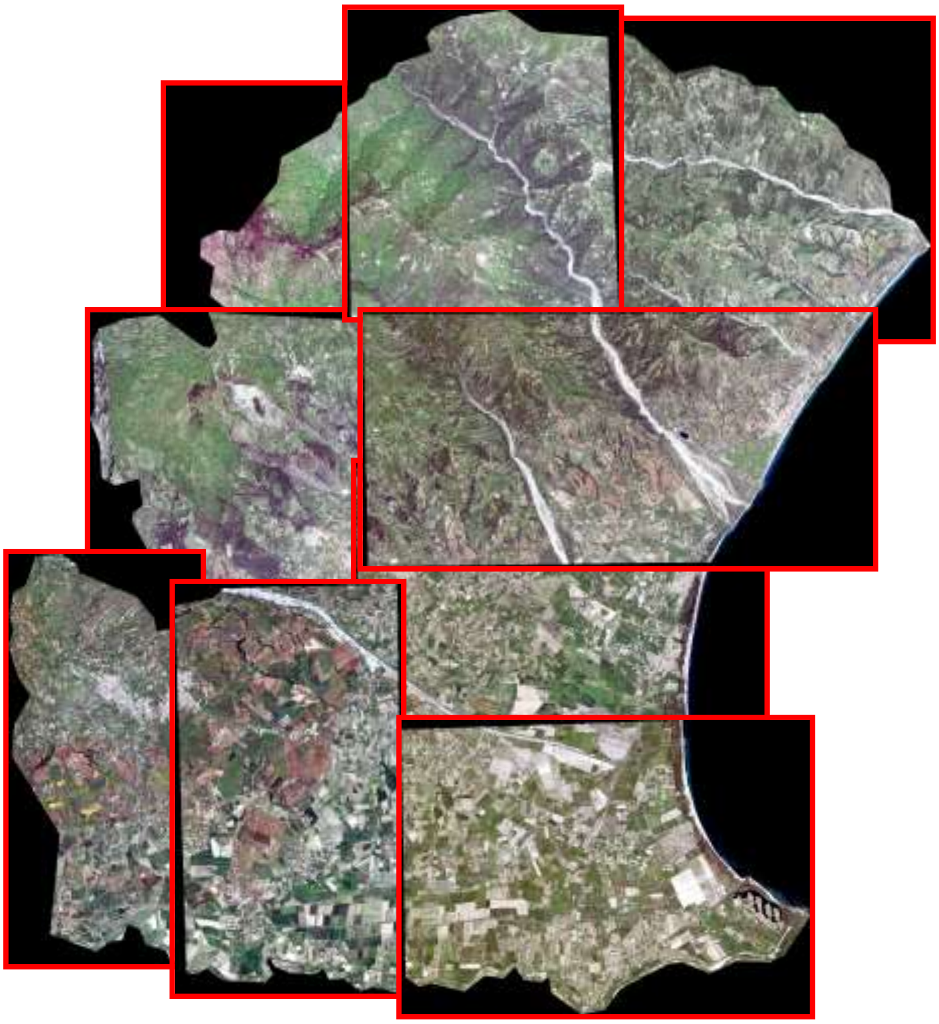


Figure 4.4. GP 990011 on the images acquired on 15 January (top) and on 22 January (bottom)

Figure 4.5. GP 66029 surveyed by GPS receiver (top) and collected on the images (bottom)

Figure 4.6. GCPs distribution for Cosenza Test Site COSE_MODE_1

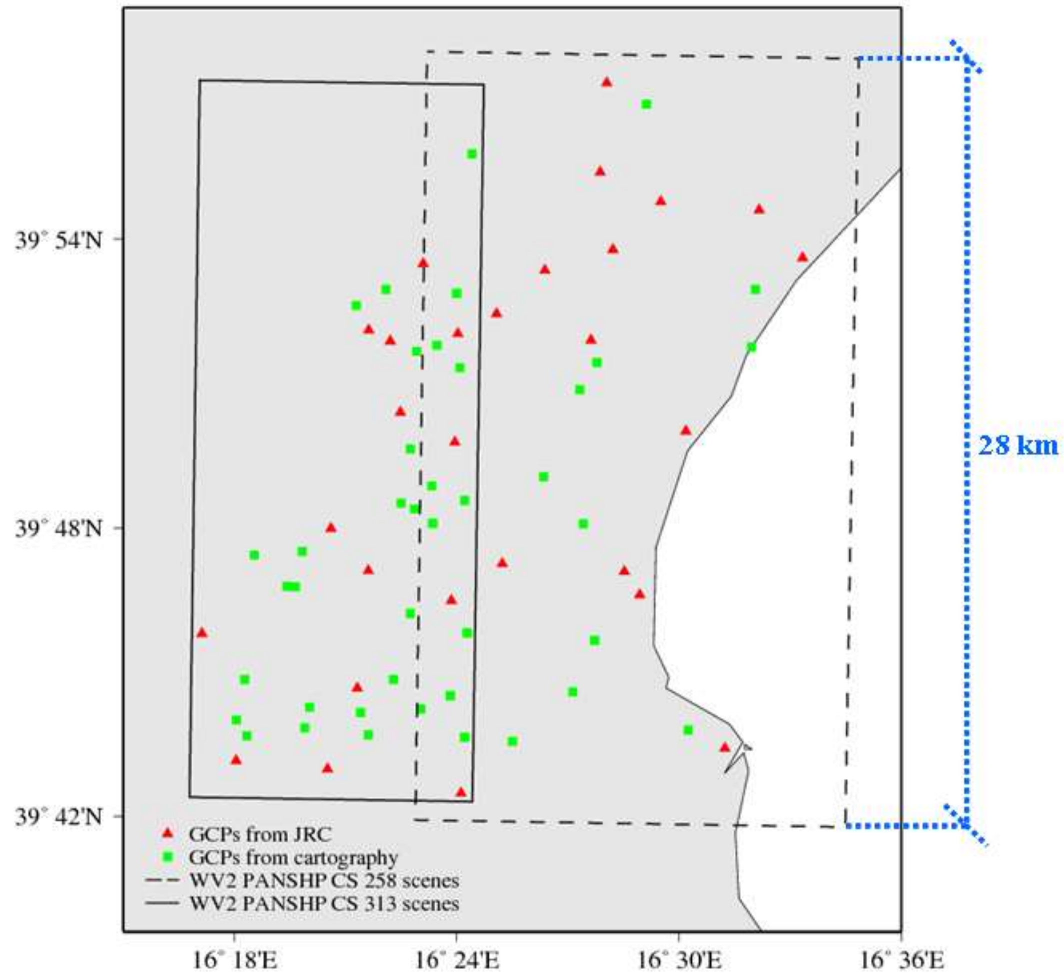
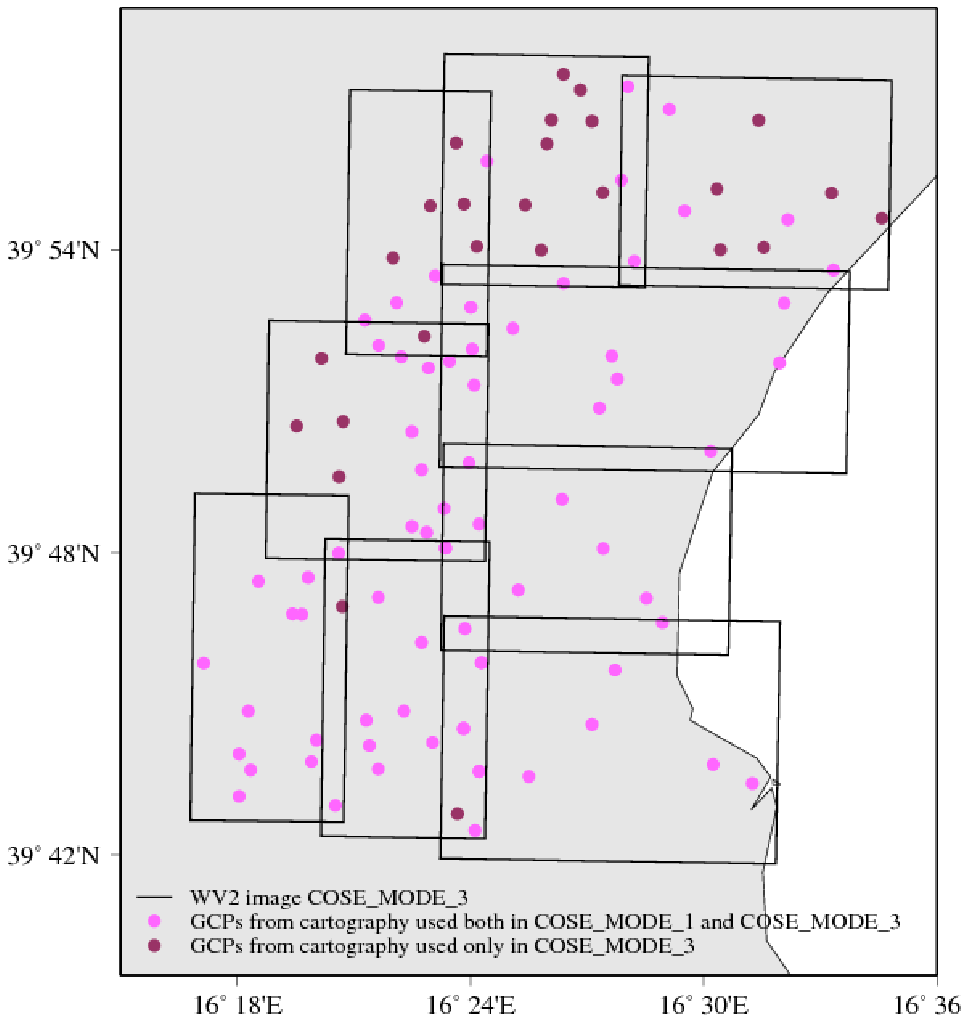


Figure 4.7. GCPs distribution for Cosenza Test Site COSE_MODE_3

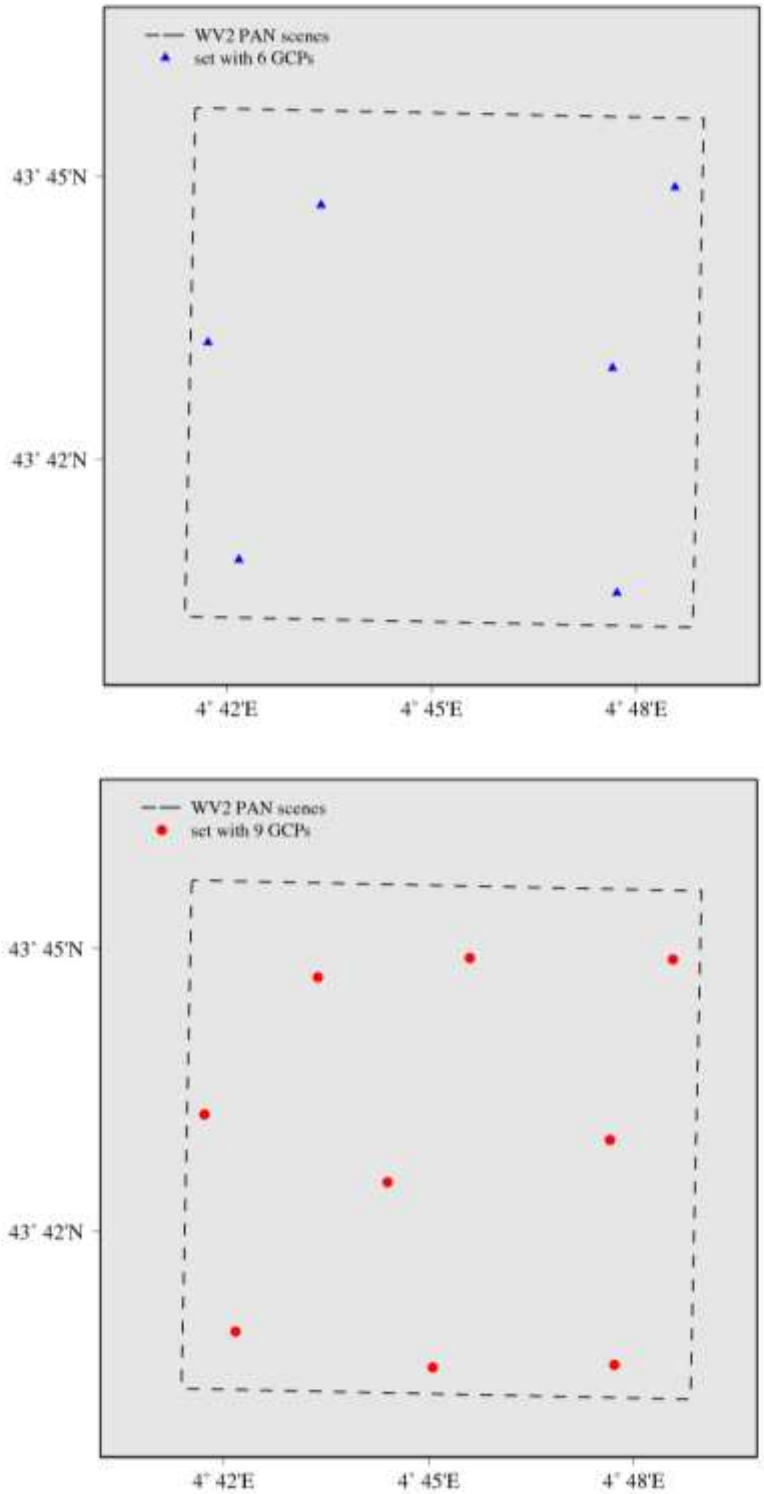


5. Maussane - Orientation tests with the Rigorous models

The orientation tests with the Rigorous model have been performed only with SISAR and Geomatica (PCI Geomatics) software because in the ERDAS Imagine this model is not implemented.

The orientation tests were carried out with the sets including 6 (66014, 66020, 66035, 66038, 440011, 990010) and 9 (66014, 66020, 66027, 66029, 66035, 66038, 440011, 990010, 990015) well distributed GCPs selected for the orientation tests performed at JRC.

Figure 5.1. Sets with 6 (top) and 9 (bottom) GCPs for Maussane Test Site



The results lead to the following main conclusions:

- for both software, mainly the orientation accuracy ranges from 0.4 to 1.1 m; even in the worst case, the orientation accuracy appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component

- for both software, the orientation accuracy displays a significant dependence on the off-nadir angle (higher accuracy for lower off-nadir angle)
- the orientation accuracy displays a practical independence from the number of GCPs according to SISAR, whereas it displays a strange behaviour with respect to the East component for Geomatica (PCI Geomatics) when the image is oriented with 6 GCPs for the images 31 Jan 26.7 deg. and 15 Jan 36.0 deg; this problem may be due to the too low number of GCPs, since the software manual suggests to use 8 points at minimum in order to orient a WorldView Standard OrthoReady image with the Rigorous Model (called Math Model). It is strange that the minimum GCPs number (8 GCPs) necessary to orient the WorldView Standard OrthoReady image, already geo-referenced on the reference ellipsoid at noted height, is lower than the GCPs number necessary to orient the WorldView Basic image (6 GCPs), which has not any kind of geometric correction.
-

It is highlighted that the best test (in yellow) is the test with the best accuracy level; on the contrary the most significant test (in green) is the test with accuracy level comparable with the best test but it is obtained with a lower number of GCPs.

Table 5.1. Results (RMSE-CPs) for the Rigorous models
(in green the most significant test in practice, in yellow the best one)

SISAR										
No. of GCPs	**28 Jan 10.5 deg**		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
6	0.41	0.42	0.85	0.50	0.64	0.60	0.58	0.88	1.07	1.10
9	0.40	0.41	0.68	0.47	0.68	0.59	0.53	0.85	1.06	1.05
Geomatica (PCI Geomatics)										
6	0.43	0.52	0.61	0.78	2.53	0.61	0.92	0.66	6.81	1.29
9	0.40	0.40	0.37	0.48	0.61	0.43	0.51	0.59	0.74	1.12
ERDAS Imagine 2011										
6 9	NO MODEL									

Figure 5.2. Results (RMSE-CPs) for the Rigorous models with 6 GCPs using SISAR (the most significant test in practice) and with 9 GCPs using Geomatica (the best test)

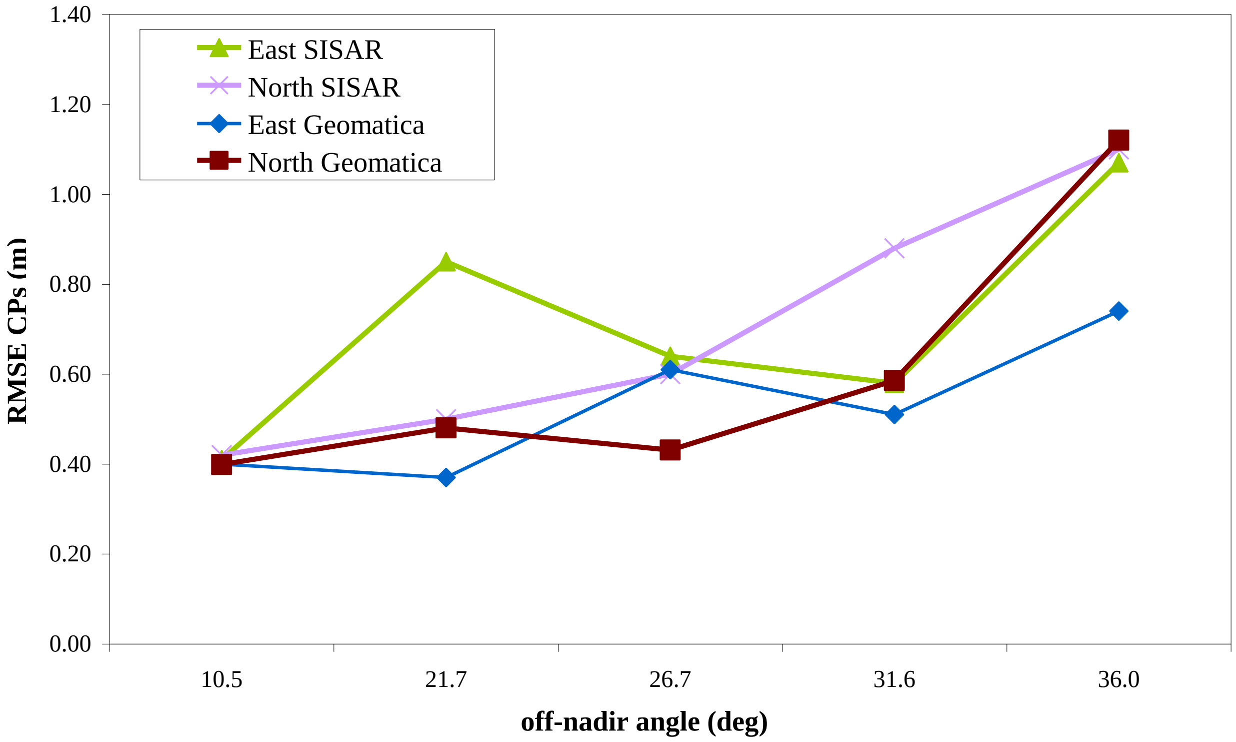
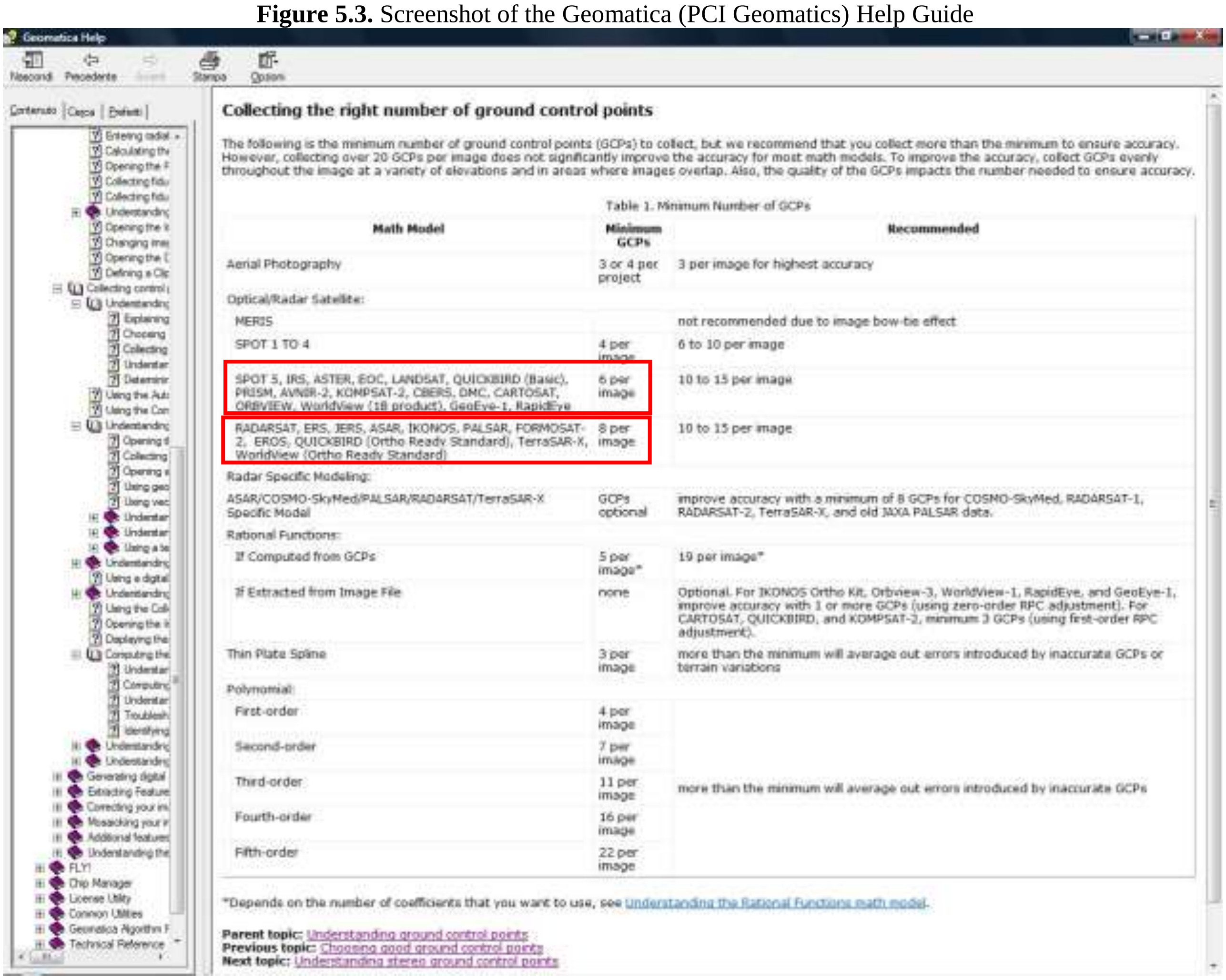


Figure 5.3. Screenshot of the Geomatica (PCI Geomatics) Help Guide



Collecting the right number of ground control points

The following is the minimum number of ground control points (GCPs) to collect, but we recommend that you collect more than the minimum to ensure accuracy. However, collecting over 20 GCPs per image does not significantly improve the accuracy for most math models. To improve the accuracy, collect GCPs evenly throughout the image at a variety of elevations and in areas where images overlap. Also, the quality of the GCPs impacts the number needed to ensure accuracy.

Table 1. Minimum Number of GCPs

Math Model	Minimum GCPs	Recommended
Aerial Photography	3 or 4 per project	3 per image for highest accuracy
Optical/Radar Satellite:		
MERIS		not recommended due to image bow-tie effect
SPOT 1 TO 4	4 per image	6 to 10 per image
SPOT 5, IRS, ASTER, EOC, LANDSAT, QUICKBIRD (Basic), PRISM, AVNIR-2, KOMPSAT-2, CBERS, DMC, CARTOSAT, ORBVIEW, WorldView (1B product), GeoEye-1, RapidEye	6 per image	10 to 15 per image
RADARSAT, ERS, JERS, ASAR, IKONOS, PALSAR, FORMOSAT-2, EROS, QUICKBIRD (Ortho Ready Standard), TerraSAR-X, WorldView (Ortho Ready Standard)	8 per image	10 to 15 per image
Radar Specific Modeling:		
ASAR/COSMO-SkyMed/PALSAR/RADARSAT/TerraSAR-X Specific Model	GCPs optional	improve accuracy with a minimum of 8 GCPs for COSMO-SkyMed, RADARSAT-1, RADARSAT-2, TerraSAR-X, and old JAXA PALSAR data.
Rational Functions:		
If Computed from GCPs	5 per image*	19 per image*
If Extracted from Image File	none	Optional. For IKONOS Ortho Kit, Orbview-3, WorldView-1, RapidEye, and GeoEye-1, improve accuracy with 1 or more GCPs (using zero-order RPC adjustment). For CARTOSAT, QUICKBIRD, and KOMPSAT-2, minimum 3 GCPs (using first-order RPC adjustment).
Thin Plate Spline	3 per image	more than the minimum will average out errors introduced by inaccurate GCPs or terrain variations
Polynomial:		
First-order	4 per image	
Second-order	7 per image	
Third-order	11 per image	more than the minimum will average out errors introduced by inaccurate GCPs
Fourth-order	16 per image	
Fifth-order	22 per image	

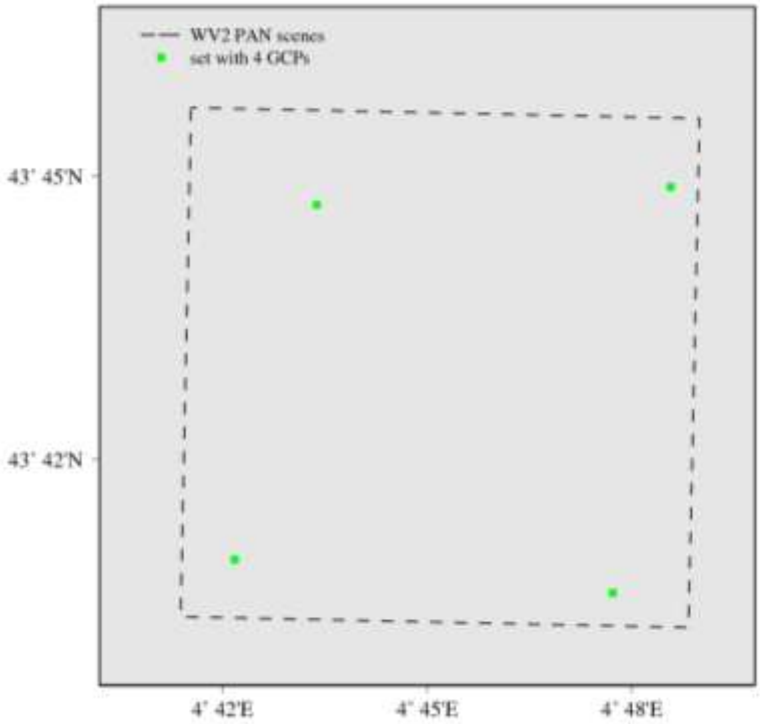
*Depends on the number of coefficients that you want to use, see Understanding the Rational Functions math model.

Parent topic: Understanding ground control points
Previous topic: Choosing good ground control points
Next topic: Understanding stereo ground control points

6. Maussane - Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata

The orientation tests based on the RPFs models implemented in SISAR, Geomatica (PCI Geomatics) and ERDAS Imagine, used with known RPCs (supplied with the image metadata), were carried out both without any GCP and with the sets including 4 (66014, 66020, 66035, 990010), 6 and 9 (same as before) well distributed GCPs selected for the orientation tests performed at JRC.

Figure 6.1. Set with 4 GCPs for Maussane Test Site



When GCPs were considered, two possible orientation refinements were performed, based on a shift (zero order) and an affine (first order) transformation.

The results lead to the following main conclusions:

- for all software, the orientation accuracy without any refinement ranges from 1 to more than 17 m, therefore is not always suited for the orthoimage generation, but still indicates what is the accuracy of the sensor system
- the orientation accuracy with the shift and the affine refinements displays a significant dependence on the off-nadir angle (higher accuracy for lower off-nadir angle)
- for all software, the orientation accuracy with the shift and the affine refinements ranges between 0.3 and 1.1 m, approximately the same level reached by the Rigorous model; even in the worst case, the orientation accuracy appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component; a sensible worse results is obtained with Geomatica only for the image 15 Jan 36.0 deg. and its accuracy is over 2.5 m when the affine refinement is applied
- the orientation accuracy with the shift and the affine refinements displays a practical independence from the number of GCPs and the type of refinement; overall, the orientation with 4 GCPs and shift refinement appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component

- for Geomatica when the shift and the affine transformations are estimated, the average of the GCPs residuals differ from zero. To this aim an example of orientation with the metadata RPCs, shift adjustment and 4 GCPs for the Maussane image (15 Jan 36.0 deg) is shown. The shift parameters estimated by Geomatica software are remarkably different from the SISAR ones and their differences should be equal to the GCPs residuals average, whereas a constant gap of 0.5 pixels is observed. This behaviour occurs in all tested images and cannot have any mathematical interpretation.

Figure 6.2. Results (RMSE-CPs) for the RPFs models with metadata RPCs using SISAR software with 4 GCPs - shift transformation (the most significant test in practice) and using SISAR software with 9 GCPs - affine transformation (the best test)

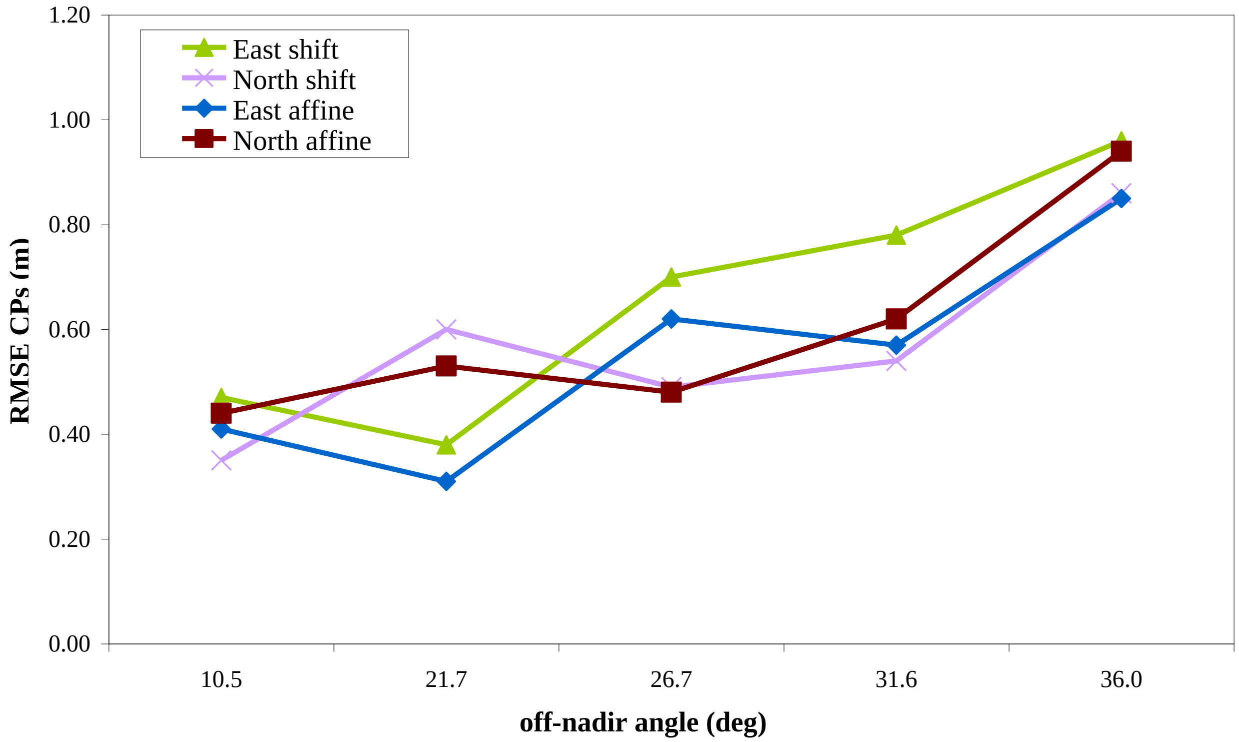


Table 6.1. Results (RMSE-CPs) for the RPFs models with metadata RPCs
(in green the most significant test in practice, in yellow the best one)

SISAR - no refinement										
No. of GCPs	**28 Jan 10.5 deg**		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
0	0.95	4.19	2.53	0.74	4.77	1.04	0.81	1.47	17.87	4.80
Geomatica (PCI Geomatics) - no refinement										
0	0.95	4.19	2.53	0.74	4.77	1.04	0.81	1.47	17.87	4.80
ERDAS Imagine 2011 - no refinement										
0	0.95	4.19	2.53	0.74	4.77	1.04	0.81	1.47	17.87	4.80

SISAR - shift transformation										
No. of GCPs	**28 Jan 10.5 deg**		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	0.47	0.35	0.38	0.60	0.70	0.49	0.78	0.54	0.96	0.86
6	0.44	0.34	0.35	0.53	0.69	0.48	0.60	0.54	0.98	0.92

9	0.42	0.36	0.33	0.49	0.67	0.51	0.58	0.57	0.93	0.77
Geomatica (PCI Geomatics) - shift transformation										
4	0.51	0.41	0.46	0.61	0.57	0.49	0.78	0.50	1.62	0.71
6	0.46	0.37	0.35	0.53	0.60	0.48	0.61	0.52	1.23	0.69
9	0.43	0.35	0.33	0.50	0.62	0.51	0.59	0.55	1.28	0.67
ERDAS Imagine 2011 - shift transformation										
4	0.47	0.35	0.38	0.60	0.70	0.49	0.78	0.54	0.96	0.86
6	0.44	0.34	0.35	0.53	0.69	0.48	0.60	0.54	0.98	0.92
9	0.42	0.36	0.33	0.49	0.67	0.51	0.58	0.57	0.93	0.77

SISAR - affine transformation										
No. of GCPs	**28 Jan 10.5 deg**		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	0.47	0.40	0.45	0.58	0.70	0.47	0.80	0.72	0.97	0.98
6	0.44	0.43	0.40	0.57	0.65	0.48	0.60	0.61	0.94	1.12
9	0.41	0.44	0.31	0.53	0.62	0.48	0.57	0.62	0.85	0.94
Geomatica (PCI Geomatics) - affine transformation										
4	0.50	0.64	0.63	0.61	0.73	0.44	0.79	0.52	3.09	1.14
6	0.46	0.55	0.50	0.58	0.70	0.46	0.61	0.52	2.28	1.13
9	0.41	0.55	0.36	0.54	0.65	0.46	0.58	0.55	2.22	1.14
ERDAS Imagine 2011 - affine transformation										
4	0.47	0.40	0.45	0.58	0.70	0.47	0.80	0.72	0.97	0.98
6	0.44	0.43	0.40	0.57	0.65	0.48	0.60	0.61	0.94	1.12
9	0.41	0.44	0.31	0.53	0.62	0.48	0.57	0.62	0.85	0.94

Table 6.2. Geomatica (PCI Geomatics) behaviour - averages of the GCPs residuals with metadata RPCs

shift transformation										
No. of GCPs	**28 Jan 10.5 deg**		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	0.05	0.24	-0.14	0.01	-0.32	0.00	0.00	-0.15	**-1.72**	**0.60**
6	0.04	0.16	-0.11	0.01	-0.22	0.00	0.01	-0.10	-1.19	0.42
9	0.03	0.11	-0.07	0.01	-0.14	0.00	0.01	-0.07	-0.79	0.28
affine transformation										
4	0.05	0.16	-0.10	0.02	-0.27	-0.03	0.04	0.00	-1.20	0.42
6	0.03	0.12	-0.08	0.01	-0.20	-0.02	0.01	-0.08	-0.92	0.32
9	0.03	0.08	-0.07	0.01	-0.14	-0.01	0.01	-0.05	-0.65	0.22

Table 6.3. Estimation of shift parameters in Geomatica (PCI Geomatics) software

	Shift parameters			GCPs Residuals average	
	Geomatica	SISAR	Residual		
I_0 [pix]	-32.40	-36.35	3.94	I [pix]	**3.45**
J_0 [pix]	-8.65	-10.35	1.70	J [pix]	**1.20**

7. Maussane - Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients generated with SISAR

The same orientation tests as before were carried out, now using the RPCs generated with SISAR. In fact, SISAR includes a tool devoted to RPCs generation based on its Rigorous model, following the so-called *independent terrain scenario* the generated RPCs are organized in a standard format file which can be used by whatever commercial software.

In this case, the RPCs were generated with the Rigorous model using the set with 6 GCPs.

The results lead to the following main conclusions:

- all software have the same behaviour in all the orientation tests
- the orientation accuracy without any refinement ranges from 0.5 to 1.3 m, due to the fact that the imagery were oriented with the Rigorous model before the RPCs generation; even in the worst case, the orientation accuracy appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component
- the orientation accuracy with the shift and the affine refinements ranges between 0.4 and 1.5 m, approximately the same level reached by the Rigorous model and without any refinement; overall, no refinement appears significant
- the orientation accuracy displays a significant dependence on the off-nadir angle (higher accuracy for lower off-nadir angle)
- the orientation accuracy with the shift and the affine refinements displays a practical independence from the number of GCPs
- the behaviour of Geomatica (PCI Geomatics) when the shift and the affine transformations are estimated is the same as previously mentioned, anyway the averages of the GCPs residuals do not differ significantly from zero because the SISAR RPCs do not have a bias and the shift and affine parameters are close to zero.

Figure 7.1. Results (RMSE-CPs) for the RPFs models with SISAR RPCs using SISAR and Geomatica software – no refinement (the most significant test in practice) and with 9 GCPs - affine transformation (the best test)

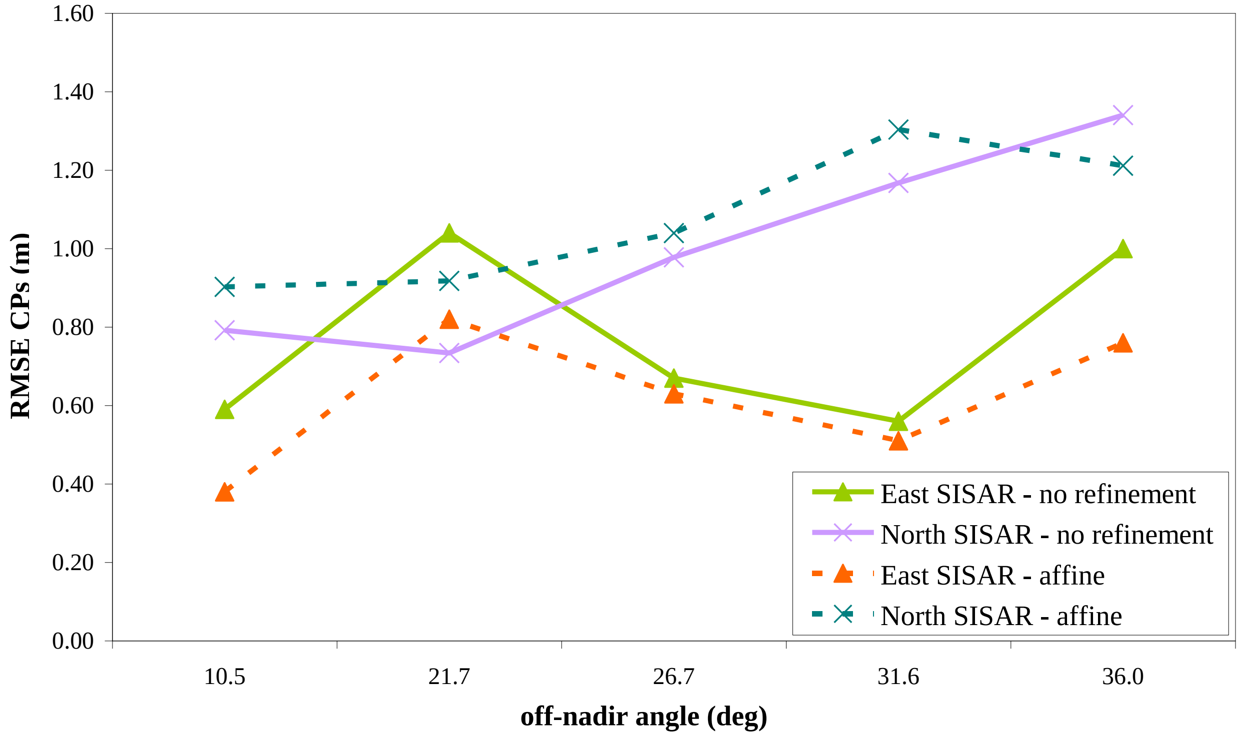


Table 7.1. Results (RMSE-CPs) for the RPFs models with SISAR RPCs
(in green the most significant test in practice, in yellow the best one)

SISAR - no refinement										
	28 Jan 10.5 deg		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
No. of GCPs	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
0	0.59	0.79	1.04	0.73	0.67	0.98	0.56	1.17	1.00	1.34
Geomatica (PCI Geomatics) - no refinement										
0	0.59	0.79	1.04	0.73	0.67	0.98	0.56	1.17	1.00	1.34
ERDAS Imagine 2011 - no refinement										
0	0.59	0.79	1.04	0.73	0.67	0.98	0.56	1.17	1.00	1.34

SISAR - shift transformation										
	28 Jan 10.5 deg		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
No. of GCPs	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	0.60	0.84	1.10	0.78	0.63	1.05	0.57	1.26	1.08	1.45
6	0.62	0.89	1.14	0.80	0.60	1.11	0.58	1.32	1.08	1.52
9	0.61	0.87	1.07	0.87	0.65	1.07	0.55	1.33	1.08	1.28
Geomatica (PCI Geomatics) - shift transformation										
4	0.60	0.84	1.10	0.78	0.64	1.05	0.57	1.26	1.08	1.44
6	0.62	0.89	1.14	0.80	0.61	1.11	0.58	1.32	1.08	1.52
9	0.61	0.87	1.07	0.87	0.65	1.07	0.55	1.33	1.08	1.28
ERDAS Imagine 2011 - shift transformation										
4	0.60	0.84	1.10	0.78	0.63	1.05	0.57	1.26	1.08	1.45
6	0.62	0.89	1.14	0.80	0.60	1.11	0.58	1.32	1.08	1.52
9	0.61	0.87	1.07	0.87	0.65	1.07	0.55	1.33	1.08	1.28

SISAR - affine transformation										
	28 Jan 10.5 deg		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
No. of GCPs	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	0.42	0.86	0.91	0.79	0.70	1.08	0.56	1.30	0.95	1.50
6	0.41	0.91	0.91	0.84	0.59	1.09	0.54	1.30	0.84	1.54
9	0.38	0.90	0.82	0.92	0.63	1.04	0.51	1.30	0.76	1.21
Geomatica (PCI Geomatics) - affine transformation										
4	0.42	0.86	0.92	0.79	0.70	1.08	0.52	1.29	0.96	1.49
6	0.41	0.91	0.93	0.84	0.60	1.09	0.53	1.30	0.84	1.52
9	0.39	0.90	0.83	0.91	0.64	1.04	0.50	1.30	0.77	1.21
ERDAS Imagine 2011 - affine transformation										
4	0.42	0.86	0.91	0.79	0.70	1.08	0.56	1.30	0.95	1.50
6	0.41	0.91	0.91	0.84	0.59	1.09	0.54	1.30	0.84	1.54
9	0.38	0.90	0.82	0.92	0.63	1.04	0.51	1.30	0.76	1.21

Table 7.2. Geomatica (PCI Geomatics) behaviour - averages of the GCPs residuals with SISAR RPCs

shift transformation										
No. of GCPs	**28 Jan 10.5 deg**		**22 Jan 21.7 deg**		**31 Jan 26.7 deg**		**28 Jan 31.6 deg**		**15 Jan 36.0 deg**	
	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	-0.01	0.00	-0.01	0.00	0.01	0.00	0.03	0.06	-0.01	0.01
6	0.00	0.00	0.00	0.00	0.01	0.01	0.00	0.01	-0.01	0.01
9	0.00	-0.01	0.00	-0.01	0.00	-0.01	0.00	-0.01	0.01	-0.01
affine transformation										
4	-0.04	-0.01	-0.06	0.00	0.00	-0.01	-0.03	-0.01	-0.03	0.02
6	-0.03	0.00	-0.04	0.00	0.02	0.01	-0.02	0.01	-0.04	0.02
9	-0.02	-0.01	-0.04	-0.01	0.01	0.00	-0.01	0.00	-0.01	-0.01

8. Conclusions about Maussane orientation tests

On the basis of the comparison of the presented results, some general conclusions can be drawn:

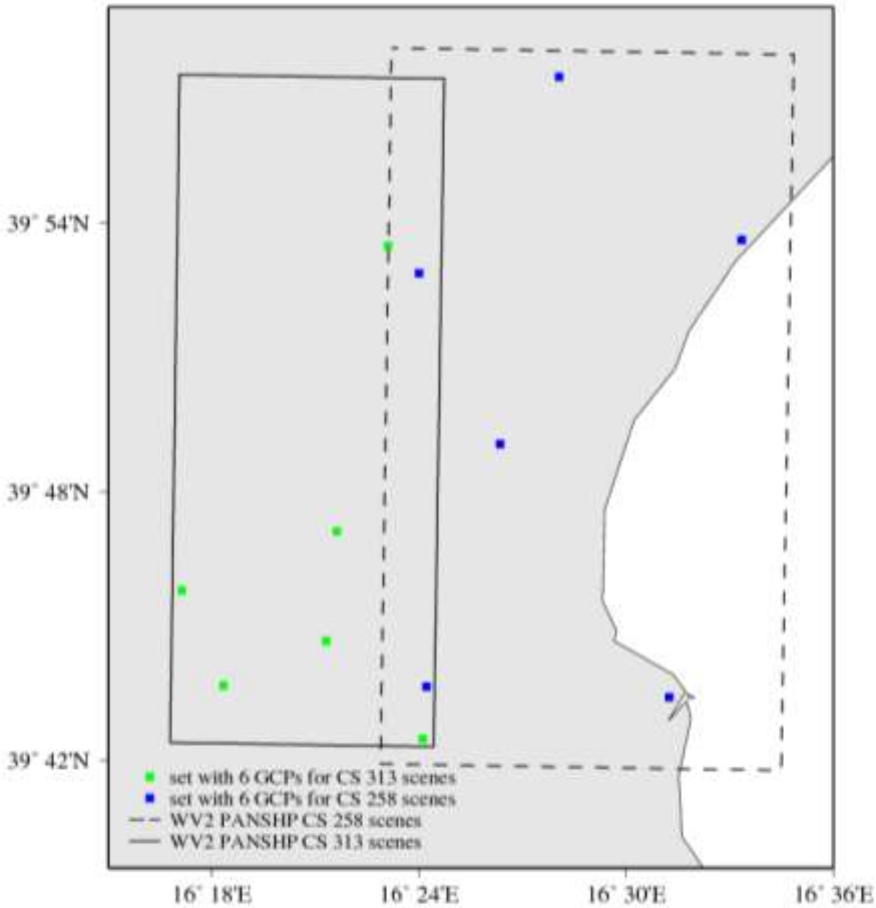
- the orientation accuracy displays a significant dependence on the off-nadir angle (higher accuracy for lower off-nadir angle)
- the best orientation accuracy is reached with the Rational Polynomial Functions model using the Rational Polynomial Coefficients supplied with the imagery metadata and applying a shift refinement with 4 GCPs
- the orientation accuracies reached with the Rigorous model and the Rational Polynomial Functions model using the Rational Polynomial Coefficients generated with SISAR is slightly worse than the mentioned best one
- the accuracy is the same for all software and ranges between 0.3 and 1.1 m and appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component.

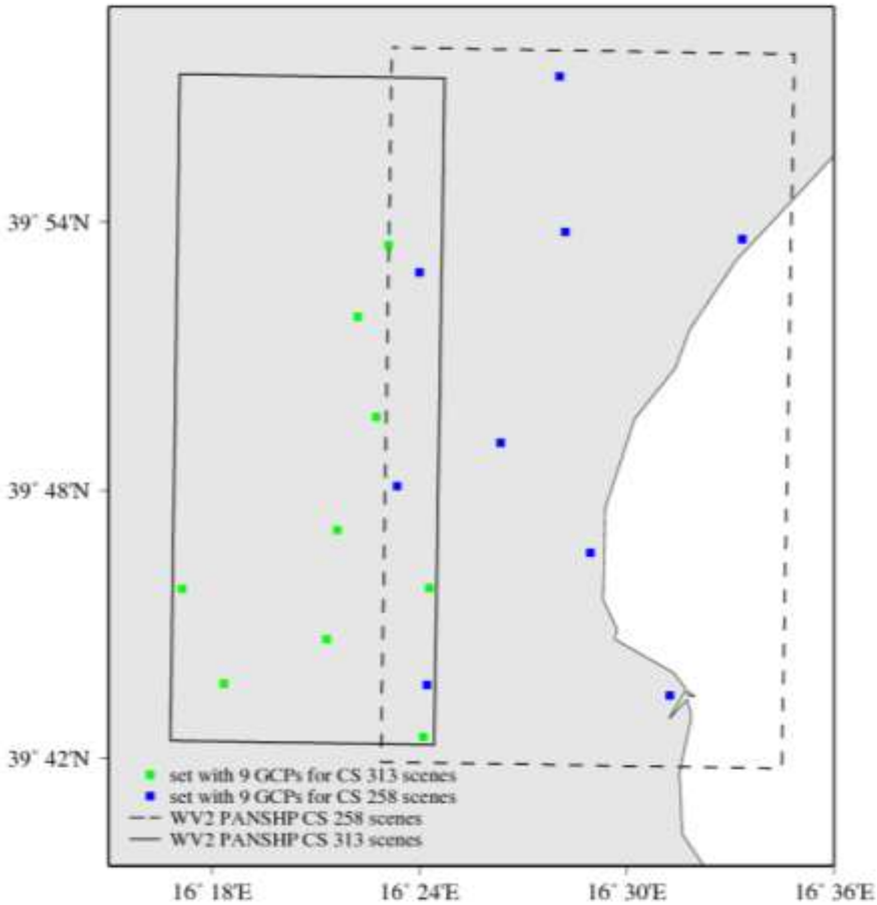
9. Cosenza COSE_MODE_1- Orientation tests with the Rigorous models

As previously mentioned the orientation tests with the Rigorous model have been performed only with SISAR and Geomatica (PCI Geomatics) software because in the ERDAS Imagine this model is not implemented.

The orientation tests were carried out with the sets including 6 (5, 32, 54, 96, 97, 109 for CS 258; 9, 105, 107, 1160, 74502, 731183 for CS 313) and 9 (5, 17, 32, 54, 96, 97, 99, 109, 111 for CS 258; 9, 21, 30, 105, 107, 1160, 1264, 74502, 731183 for CS 313) well distributed GCPs.

Figure 9.1. Sets with 6 (top) and 9 (bottom) GCPs for Cosenza Test Site





The results lead to the following main conclusions:

- for SISAR software, the orientation accuracy ranges from 1.2 to 1.9 m; even in the worst case, the orientation accuracy appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component
- for Geomatica (PCI Geomatics) software only the orientation of CS 313 images performed with 9 GCPs satisfies the accuracy required for the orthoimage generation, whereas results are remarkably worse in the other cases
- the orientation accuracy displays a practical independence from the number of GCPs according to SISAR

Table 9.1. Results (RMSE-CPs) for the Rigorous models

SISAR				
	CS 258		**CS 313**	
No. of GCPs	East [m]	North [m]	East [m]	North [m]
6	1.42	1.86	1.71	1.67
9	1.18	1.59	1.77	1.74
Geomatica (PCI Geomatics)				
6	8.25	3.70	7.30	13.55
9	12.43	1.96	2.13	1.68
ERDAS Imagine 2011				
6	NO MODEL			
9				

10. Cosenza COSE_MODE_1- Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata

The orientation tests based on the RPFs models implemented in SISAR, Geomatica (PCI Geomatics) and ERDAS Imagine, used with known RPCs (supplied with the imagery metadata), were carried out without any GCP and with the sets including 4 (5, 54, 97, 109 for CS 258; 9, 105, 1160, 731183 for CS 313), 6 and 9 (same as before) well distributed GCPs.

Figure 10.1. Set with 4 GCPs Cosenza Test Site

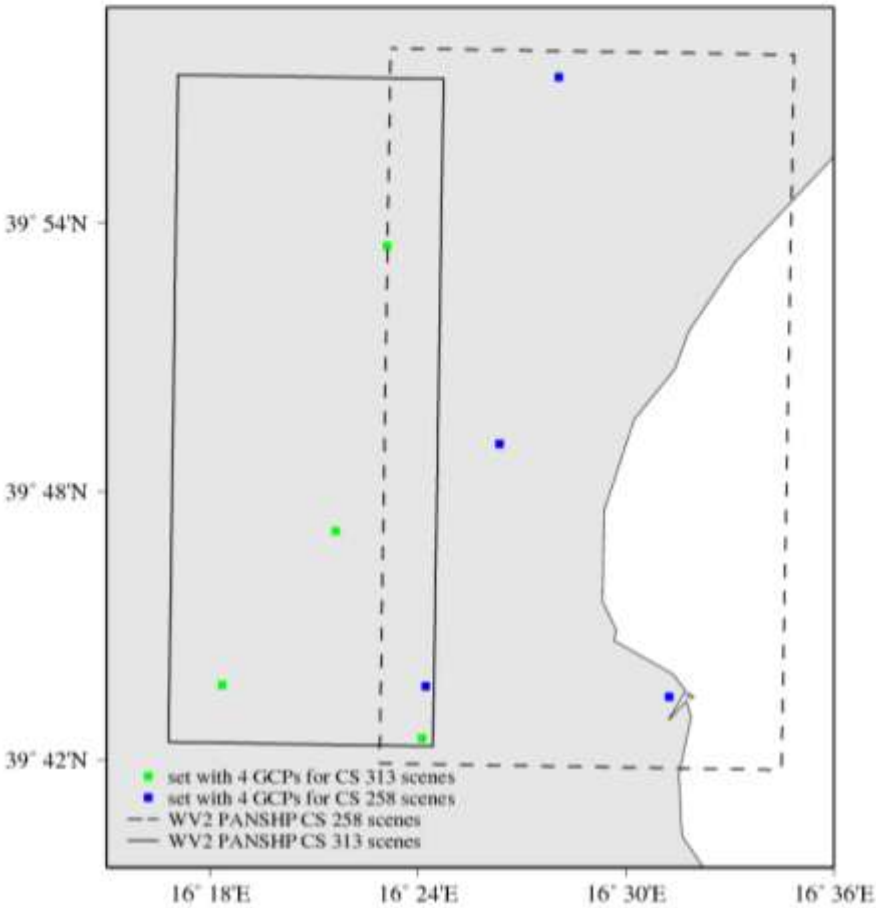


Table 10.1. Results (RMSE-CPs) for the RPFs models with metadata RPCs
(in green the most significant test in practice)

SISAR - no refinement				
	CS 258		CS 313	
No. of GCPs	East [m]	North [m]	East [m]	North [m]
0	6.30	2.81	6.27	2.32
Geomatica (PCI Geomatics) - no refinement				
0	6.30	2.81	6.27	2.32
ERDAS Imagine 2011 - no refinement				
0	6.30	2.81	6.27	2.32

	shift transformation				affine transformation			
	SISAR							
	CS 258		CS 313		CS 258		CS 313	
No. of GCPs	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	0.96	1.17	1.40	1.69	1.13	1.60	1.43	1.76
6	1.01	1.18	1.50	1.57	1.28	1.05	1.45	1.73
9	1.02	1.24	1.59	1.65	1.24	1.08	1.66	1.75
	Geomatica (PCI Geomatics)							
4	0.98	1.19	1.31	1.75	1.38	1.54	1.32	1.80
6	1.14	1.21	1.39	1.58	1.51	1.07	1.37	1.77
9	1.10	1.25	1.49	1.66	1.44	1.09	1.44	1.77
	ERDAS Imagine 2011							
4	0.96	1.17	1.40	1.69	1.13	1.60	1.43	1.76
6	1.01	1.18	1.50	1.57	1.28	1.05	1.45	1.73
9	1.02	1.24	1.59	1.65	1.24	1.08	1.66	1.75

When GCPs were considered, two possible orientation refinements were performed, based on a shift (zero order) and an affine (first order) transformation.

The results lead to the following main conclusions:

- for all software, the orientation accuracy without any refinement ranges from 2 to more than 7 m, therefore is not suited at all for the orthoimage generation
- according to all software, the orientation accuracy with the shift and the affine refinements ranges between 1.0 and 1.8 m, with good results even with 4 GCPs and better performances for the shift transformation; even in the worst case, the orientation accuracy appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component

11. Cosenza COSE_MODE_1- Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients generated with SISAR

The same orientation tests as before were carried out, now using the RPCs generated with SISAR. In fact, SISAR includes a tool devoted to RPCs generation based on its Rigorous model, following the so-called *independent terrain scenario*; the generated RPCs are organized in a standard format file which can be used by whatever commercial software.
In this case, the RPCs were generated with the Rigorous model using the set with 6 GCPs.

The results lead to the following main conclusions:

- all software have the same behaviour in all the orientation tests
- the orientation accuracy without any refinement ranges from 1.3 to 1.9 m, due to the fact that the imagery were oriented with the Rigorous model before the RPCs generation; even in the worst case, the orientation accuracy appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component
- the orientation accuracy with the shift and the affine refinements ranges between 1.5 and 2.9 m; this accuracy level is worse than the one reached with the Rigorous model

Table 11.1. Results (RMSE-CPs) for the RPFs models with SISAR RPCs

SISAR - no refinement				
	CS 258		**CS 313**	
No. of GCPs	East [m]	North [m]	East [m]	North [m]
0	1.32	1.93	1.85	1.70
Geomatica (PCI Geomatics) - no refinement				
0	1.32	1.93	1.85	1.70
ERDAS Imagine 2011 - no refinement				
0	1.32	1.93	1.85	1.70

	shift transformation				**affine transformation**			
	SISAR							
	CS 258		**CS 313**		**CS 258**		**CS 313**	
No. of GCPs	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]	East [m]	North [m]
4	1.62	2.06	1.45	1.82	1.91	2.84	1.55	1.82
6	1.55	1.97	1.54	1.77	1.56	2.00	1.55	1.72

9	1.46	1.94	1.58	1.82	1.33	1.92	1.73	1.78
	Geomatica (PCI Geomatics)							
4	1.60	2.05	1.47	1.81	1.95	2.73	1.49	1.83
6	1.54	1.97	1.55	1.77	1.51	2.00	1.52	1.72
9	1.46	1.93	1.59	1.82	1.33	1.92	1.44	1.77
	ERDAS Imagine 2011							
4	1.62	2.06	1.45	1.82	1.91	2.84	1.55	1.82
6	1.55	1.97	1.54	1.77	1.56	2.00	1.55	1.72
9	1.46	1.94	1.58	1.82	1.33	1.92	1.72	1.78

12. Conclusions about Cosenza COSE_MODE_1 orientation tests

The best orientation accuracy is reached with the Rational Polynomial Functions model using the Rational Polynomial Coefficients supplied with the imagery metadata and applying a shift refinement even with 4 GCPs.
The accuracy is practically software independent, ranges between 1.0 and 1.8 m and appears suited for the orthoimage generation with accuracy better than 2.5 m in each horizontal component.

13. Cosenza COSE_MODE_3 - Orientation tests with the Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata

The conclusion about Maussane and Cosenza COSE_MODE_1 orientation tests highlights that the best accuracy was obtained using Rational Polynomial Functions models with Rational Polynomial Coefficients supplied with the imagery metadata and applying a shift refinement; therefore only this model was used for the geolocation of all the scenes of Cosenza COSE_MODE_3 test. The orientation was performed with SISAR, Geomatica (PCI Geomatics) and ERDAS Imagine, and also in this test the results obtained with SISAR software were just equal to those obtained with ERDAS Imagine. The orientation tests were carried out with the sets including 4 and 6 well distributed GCPs; due to the low GPs number for each scene and a good accuracy level obtained using 4 or 6 GCPs, the orientation tests with 9 GCPs were not carried out.

Analysing the results, in particular for 556 and 557 scenes, it is noted that the accuracy in North component halves in both adjustments when 6 GCPs are used in respect to the accuracy obtained with 4 GCPs; this apparently strange behaviour is due to the low CPs number (from 7 to 14) used to assess the accuracy when the image is oriented with 6 GCPs; then, both the accuracies with 4 and 6 GCPs get close if they are evaluated on the same CPs.
The sets of 4 GCPs used to orient each scene are summarized in the following table and

The results lead to the following main conclusions:

- all software display the same behaviour in all the orientation tests
- the orientation accuracy with the shift refinement ranges between 0.6 and 1.9 m; this accuracy level gets worse slightly with affine transformation and it ranges between 0.7 and 2.4 m

Table 13.1. GCPs sets (upper: orientations with 4 GCPs only) used for Cosenza COSE_MODE_3

Image ID	555	556	557	593	594	595	596	597	598
set of GCPs	16	32	99	93	61	101	17	17	98
	99	67	104	208	96	102	101	98	106
	100	100	105	211	111	218	103	105	107
	104	103	109	1164	302	1160	202	106	108
	66	31	52	206	220	209	22	20	14
	731193	62	27	214	222	217	1219	74502	28

Figure 13.1. Set with 4 GCPs Cosenza Test Site – COSE_MODE_3

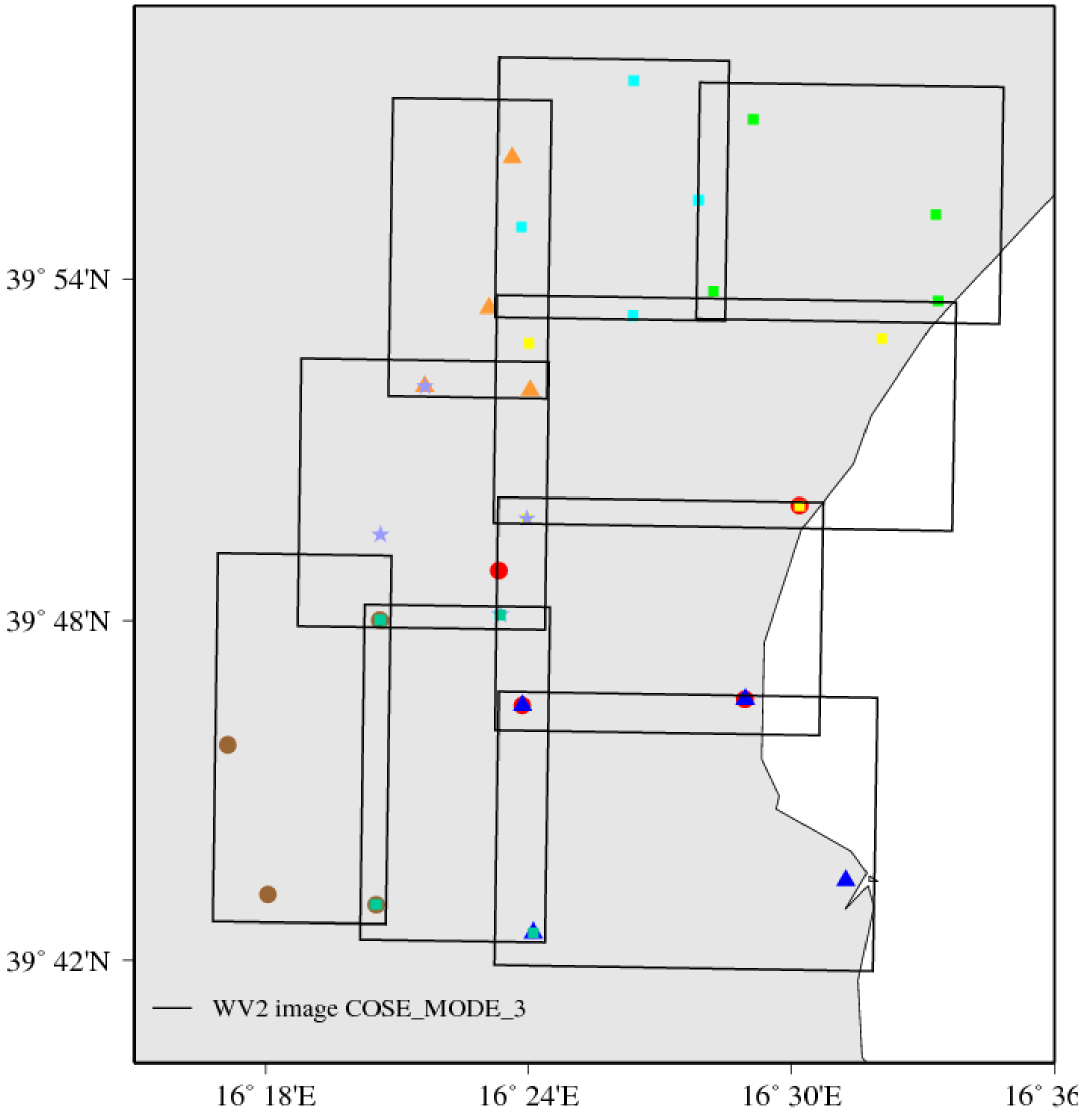


Table 13.2. Results (RMSE-CPs) for the RPFs models with metadata RPCs

Geomatica (PCI Geomatics)							
Image ID	off-nadir angle [°]	No. of GCPs	No. of CPs	shift transformation		affine transformation	
				East [m]	North [m]	East [m]	North [m]
555	18.3	4	7	0.88	1.36	1.32	1.29
		6	5	0.72	1.58	1.42	1.52
556	18.4	4	10	1.57	1.02	2.12	1.15
		6	8	1.58	0.68	2.20	1.02
557	18.1	4	7	0.87	1.17	1.06	1.29
		6	5	0.97	0.63	1.08	0.72
593	18.7	4	11	1.47	1.38	1.72	1.50
		6	9	1.52	1.50	1.72	1.64
594	18.5	4	8	1.06	1.18	1.34	1.11
		6	6	1.00	1.31	1.39	1.19
595	24.2	4	9	1.74	1.63	2.04	1.45
		6	7	1.94	1.86	2.37	1.69
596	24.0	4	14	1.01	1.71	1.28	2.09
		6	12	1.02	1.85	1.22	1.82
597	23.7	4	13	1.36	1.49	1.37	1.49
		6	11	1.36	1.32	1.42	1.24
598	23.8	4	9	1.53	1.82	1.40	1.89
		6	7	1.79	1.42	1.62	1.56

ERDAS Imagine 2011							
Image ID	off-nadir angle [°]	No. of GCPs	No. of CPs	shift transformation		affine transformation	
				East [m]	North [m]	East [m]	North [m]
555	18.3	4	7	0.75	1.38	0.93	1.56
		6	5	0.64	1.57	0.95	1.81
556	18.4	4	10	1.35	1.14	1.76	1.14
		6	8	1.43	0.68	1.87	1.01
557	18.1	4	7	0.81	1.04	0.94	1.17
		6	5	0.89	0.59	0.92	0.70
593	18.7	4	11	1.32	1.31	2.03	1.50
		6	9	1.62	1.48	1.93	1.63
594	18.5	4	8	0.86	1.17	1.35	1.20
		6	6	0.90	1.32	1.42	1.33
595	24.2	4	9	1.84	1.70	2.08	1.43
		6	7	1.95	1.91	2.29	1.68
596	24.0	4	14	1.21	1.72	1.06	1.72
		6	12	1.01	1.84	1.09	1.82
597	23.7	4	13	1.28	1.38	1.29	1.45
		6	11	1.38	1.32	1.39	1.28
598	23.8	4	9	1.36	2.01	1.60	1.99
		6	7	1.62	1.47	1.79	1.45

Table 13.3. Results (RMSE-CPs) for the RPFs models with metadata RPCs using the same CPs

Geomatica (PCI Geomatics)							
Image ID	off-nadir angle [°]	No. of GCPs	No. of CPs	shift transformation		affine transformation	
				East [m]	North [m]	East [m]	North [m]
555	18.3	4	5	0.80	1.56	1.46	1.46
		6	5	0.72	1.58	1.42	1.52
556	18.4	4	8	1.72	0.81	2.35	0.99
		6	8	1.58	0.68	2.20	1.02
557	18.1	4	5	0.97	0.94	1.18	1.12
		6	5	0.97	0.63	1.08	0.72
593	18.7	4	9	1.59	1.52	1.86	1.66
		6	9	1.52	1.50	1.72	1.64
594	18.5	4	6	1.14	1.29	1.49	1.22
		6	6	1.00	1.31	1.39	1.19
595	24.2	4	7	1.94	1.85	2.27	1.63
		6	7	1.94	1.86	2.37	1.69
596	24.0	4	12	1.02	1.84	1.26	2.10
		6	12	1.02	1.85	1.22	1.82
597	23.7	4	11	1.40	1.46	1.42	1.45
		6	11	1.36	1.32	1.42	1.24
598	23.8	4	7	1.72	1.71	1.57	1.83
		6	7	1.79	1.42	1.62	1.56

ERDAS Imagine 2011							
Image ID	off-nadir angle [°]	No. of GCPs	No. of CPs	shift transformation		affine transformation	
				East [m]	North [m]	East [m]	North [m]
555	18.3	4	5	0.65	1.56	0.95	1.78
		6	5	0.64	1.57	0.95	1.81
556	18.4	4	8	1.49	0.92	1.95	0.97
		6	8	1.43	0.68	1.87	1.01
557	18.1	4	5	0.87	0.83	0.98	1.00
		6	5	0.89	0.59	0.92	0.70
593	18.7	4	9	1.46	1.44	2.15	1.65
		6	9	1.62	1.48	1.93	1.63
594	18.5	4	6	0.96	1.29	1.50	1.34
		6	6	0.90	1.32	1.42	1.33
595	24.2	4	7	2.02	1.93	2.32	1.61
		6	7	1.95	1.91	2.29	1.68
596	24.0	4	12	1.17	1.85	1.09	1.82
		6	12	1.01	1.84	1.09	1.82
597	23.7	4	11	1.35	1.38	1.37	1.44
		6	11	1.38	1.32	1.39	1.28
598	23.8	4	7	1.49	1.88	1.73	1.83
		6	7	1.62	1.47	1.79	1.45

14. Conclusions about Cosenza COSE_MODE_3 orientation tests

Only orientation accuracy with the Rational Polynomial Functions model using the Rational Polynomial Coefficients supplied with the imagery metadata applying shift and affine refinements were carried out and the best accuracy was achieved applying a shift refinement with 4 GCPs.
The accuracy is software independent, ranges between 0.7 and 1.9 m and appears suited for the orthoimage generation with accuracy better than 2.5 m in each horizontal component.

15. Conclusion towards orthoimages production

Considering the results obtained, for the final quality check the following orthoimages, were produced, with regards to the most significant tests in practice and the best ones highlighted.
It is remembered that the orthoimages are generated only with Geomatica (PCI Geomatics) and ERDAS Imagine 2011 software.

The orthoimages produced for Maussane test are the following ones:

- 5 orthoimages with SISAR RPCs, 0 GCPs with ERDAS Imagine 2011
- 5 orthoimages with metadata RPCs, 4 GCPs and shift transformation with ERDAS Imagine 2011
- 5 orthoimages with metadata RPCs, 9 GCPs and affine transformation with ERDAS Imagine 2011
- 5 orthoimages with SISAR RPCs, 0 GCPs with Geomatica (PCI Geomatics)
- 5 orthoimages with SISAR RPCs, 9 GCPs and affine transformation with Geomatica (PCI Geomatics)
- 5 orthoimages with Rigorous model with Geomatica (PCI Geomatics)

The orthoimages produced for Cosenza test COSE_MODE_1 are the following ones:

- 2 orthoimages with metadata RPCs, 4 GCPs and shift transformation with ERDAS Imagine 2011
- 2 orthoimages with metadata RPCs, 4 GCPs and shift transformation with Geomatica (PCI Geomatics)

Maussane orthoimages and Cosenza (COSE_MODE_1) orthoimages were sent by DHL Express the 02/05/2011.
The orthoimages produced for Cosenza test COSE_MODE_3 are the following ones:

- 9 orthoimages with metadata RPCs, 4 GCPs and shift transformation with ERDAS Imagine 2011
- 9 orthoimages with metadata RPCs, 4 GCPs and shift transformation with Geomatica (PCI Geomatics)

The Cosenza orthoimages (COSE_MODE_3) were uploaded on AGG-URS ftp site the 16/06/2011.

16. Maussane test site- Outcome of the external quality control

The JTC performed the external quality control on each of the orthoimage produced (with ERDAS, LPS and PCI Geomatics) for each image correction variant of the WorldView-2. The number and distribution of the ICPs is constant (20). The result are summarised in the following table:

Table 16.1 The 1-D RMS errors obtained for img 052299009030_01 during the external quality control of the orthoimages.

Maussane_15jan 36deg_052299009030_01	NUMBER OF CPs	RMSE_E	RMSE_N
ERDAS_RPCSISAR_0GCP (ms_15jan36deg_erdas_rpcsisar_0gcp)	20	0.85	1.03
ERDAS_RPCvendors_4GCPshift (ms_15jan36deg_erdas_rpcvendors_4gcpshift)	20	1.01	0.68
ERDAS_RPCvendors_9GCPaffine (ms_15jan36deg_ERDAS_RPCvendors_9GCPaffine)	20	0.92	0.78
PCI_Rigorous_9GCP (ms_15jan36deg_PCI_Rigorous_9GCP)	20	0.85	1.06
PCI_RPCSISAR_0GCP (ms_15jan36deg_PCI_RPCSISAR_0GCP)	20	0.89	1.00
PCI_RPCSISAR_9GCP_affine (ms_15jan36deg_PCI_RPCSISAR_9GCP_affine)	20	0.68	0.86

Table 16.2 The 1-D RMS errors obtained for img 052299009040_01 during the external quality control of the orthoimages.

Maussane_22jan21deg_052299009040_01	NUMBER OF CPs	RMSE_E	RMSE_N
ERDAS_RPCSISAR_0GCP (ms_22jan21deg_ERDAS_RPCSISAR_0GCP)	20	1.11	0.65
RPC shift Vendors 4GCP Erdas (ms_22jan21deg_RPC shift Vendors 4GCP Erdas)	20	0.60	0.70
ERDAS_RPCvendors_9GCPaffine (ms_22jan21deg_ERDAS_RPCvendors_9GCPaffine)	20	0.58	0.77
PCI_Rigorous_9GCP (ms_22jan21deg_PCI_Rigorous_9GCP)	20	0.64	0.48
PCI_RPCSISAR_0GCP (ms_22jan21deg_PCI_RPCSISAR_0GCP)	20	1.03	0.70
PCI_RPCSISAR_9GCP_affine (ms_22jan21deg_PCI_RPCSISAR_9GCP_affine)	20	0.91	0.72

Table 16.3 The 1-D RMS errors obtained for img 052299009050_01 during the external quality control of the orthoimages.

Maussane_28jan10deg_052299009050_01	NUMBER OF CPs	RMSE_E	RMSE_N
ERDAS_RPCSISAR_0GCP (ms_28jan10deg_ERDAS_RPCSISAR_0GCP)	20	0.58	0.75
ERDAS_RPCvendors_4GCPshift (ms_28jan10deg_ERDAS_RPCvendors_4GCPshift)	20	0.32	0.62
ERDAS_RPCvendors_9GCPaffine (ms_28jan10deg_ERDAS_RPCvendors_9GCPaffine)	20	0.40	0.83
PCI_Rigorous_9GCP (ms_28jan10deg_PCI_Rigorous_9GCP)	20	0.60	0.60
PCI_RPCSISAR_0GCP (ms_28jan10deg_PCI_RPCSISAR_0GCP)	20	0.69	0.76
PCI_RPCSISAR_9GCP_affine (ms_28 jan10deg_PCI_RPCSISAR_9GCP_affine)	20	0.40	0.72

Table 16.4 The 1-D RMS errors obtained for img 052299009060_01 during the external quality control of the orthoimages.

Maussane_28jan31deg_052299009060_01	**NUMBER OF CPs**	**RMSE_E**	**RMSE_N**
ERDAS_RPCSISAR_0GCP (ms_28jan31deg_ERDAS_RPCSISAR_0GCP)	20	0.59	1.02
ERDAS_RPCvendors_4GCPshift (ms_28jan31deg_ERDAS_RPCvendors_4GCPshift)	20	0.40	0.87
ERDAS_RPCvendors_9GCPaffine (ms_28jan31deg_ERDAS_RPCvendors_9GCPaffine)	20	0.60	0.89
PCI_Rigorous_9GCP (ms_28jan31deg_PCI_Rigorous_9GCP)	20	0.44	0.81
PCI_RPCSISAR_0GCP (ms_28jan31deg_PCI_RPCSISAR_0GCP)	20	0.62	0.87
PCI_RPCSISAR_9GCP_affine (ms_28jan31deg_PCI_RPCSISAR_9GCP_affine)	20	0.45	0.92

Table 16.5 The 1-D RMS errors obtained for img 052299009070_01 during the external quality control of the orthoimages.

Maussane_31jan26deg_052299009070_01	**NUMBER OF CPs**	**RMSE_E**	**RMSE_N**
ERDAS_RPCSISAR_0GCP (ms_31jan26deg_ERDAS_RPCSISAR_0GCP)	20	0.47	0.92
ERDAS_RPCvendors_4GCPshift (ms_31jan26deg_ERDAS_RPCvendors_4GCPshift)	20	0.48	0.86
ERDAS_RPCvendors_9GCPaffine (ms_31jan26deg_ERDAS_RPCvendors_9GCPaffine)	20	0.48	0.86
PCI_Rigorous_9GCP (ms_31jan26deg_PCI_Rigorous_9GCP)	20	0.52	0.50
PCI_RPCSISAR_0GCP (ms_31jan26deg_pci_rpcsisar_0gcp)	20	0.64	1.03
PCI_RPCSISAR_9GCP_affine (ms_31jan26deg_PCI_RPCSISAR_9GCP_affine)	20	0.40	0.74

16.1. Discussion about Maussane external quality control

Figure 16.1 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the off nadir angle after WV2 2A single scene correction based on RPC parameters delivered by provider and DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points).

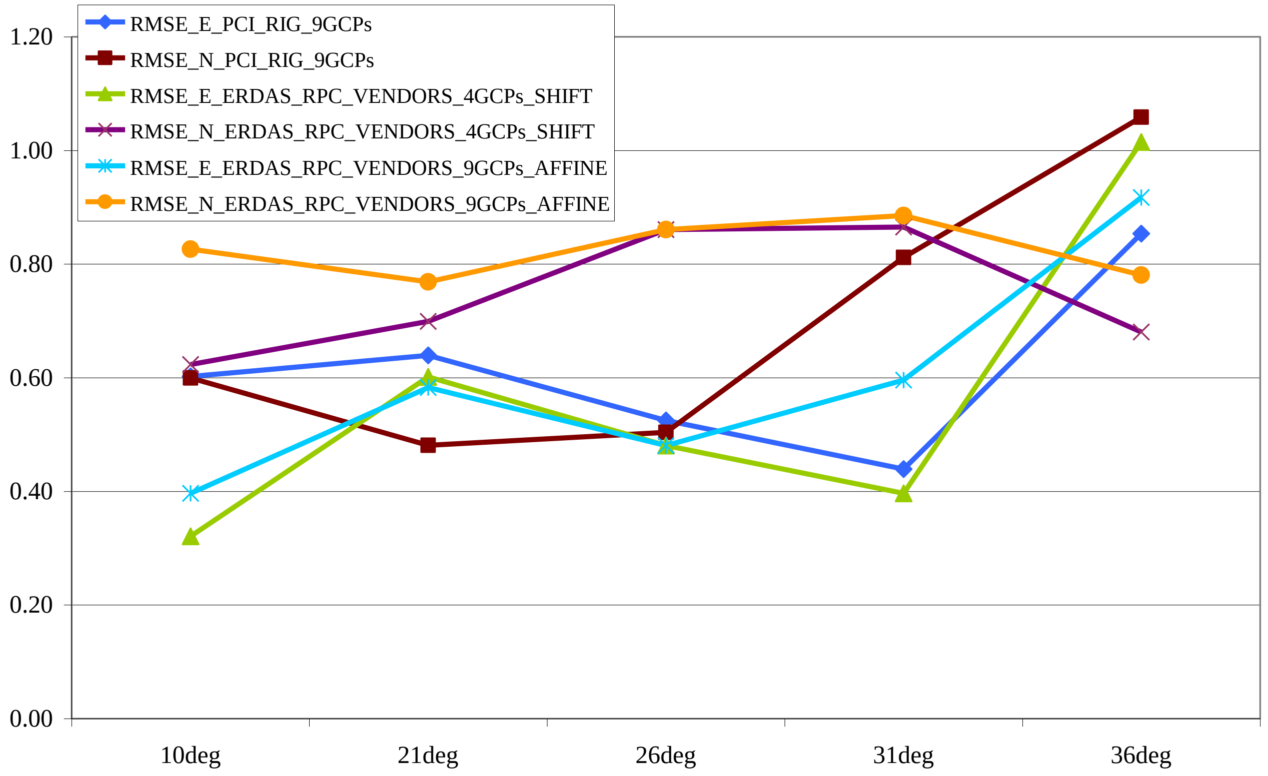


Figure 16.2 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the off nadir angle after WV2 2A single scene correction based on RPC parameters calculated based on SISAR software and DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points).

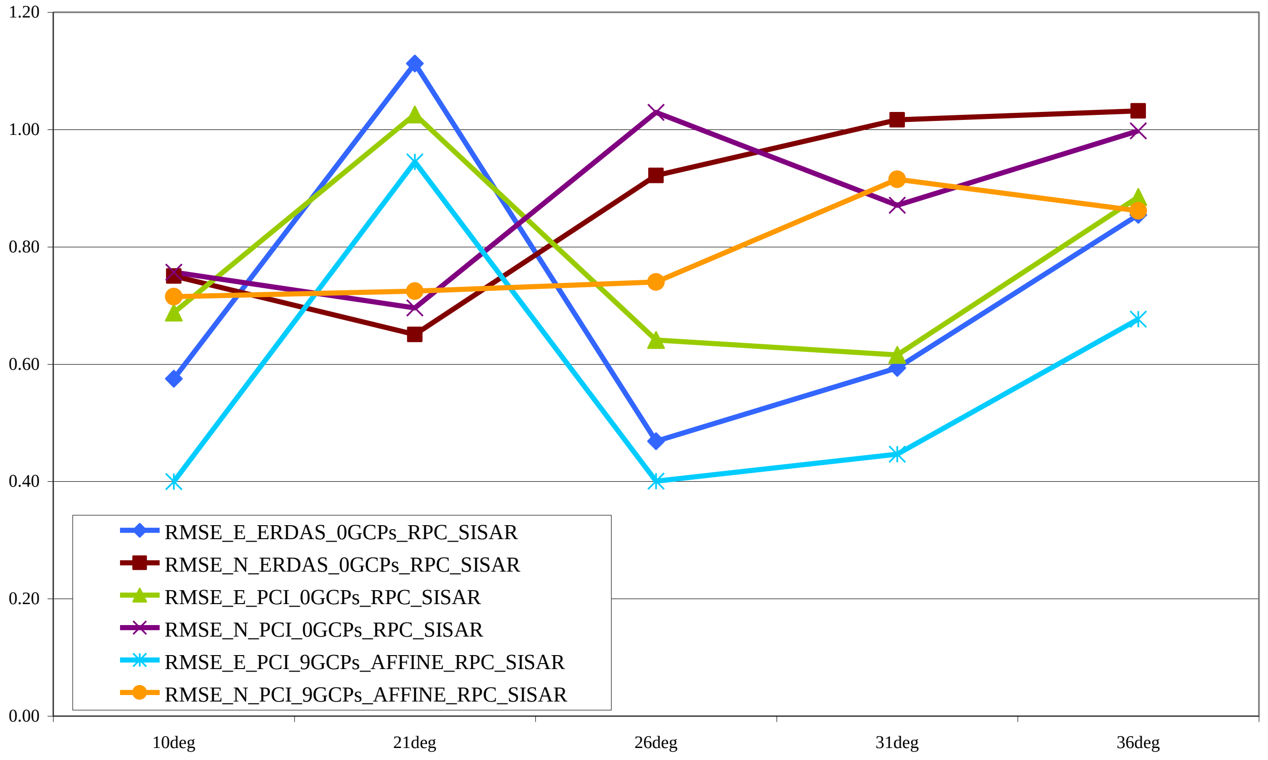
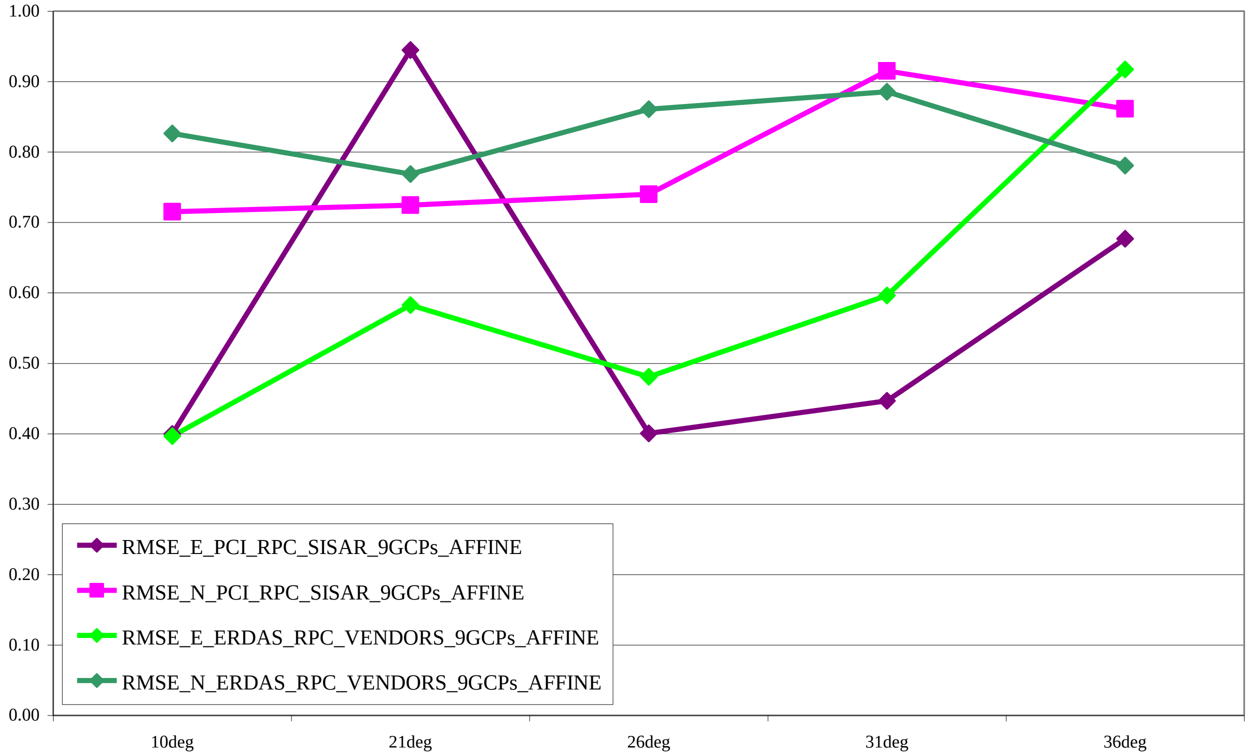


Figure 16.3 1-D RMSE_ICP [m] measured on the final orthoimage as a function of the off nadir angle after WV2 2A single scene correction based on RPC parameters provider and calculated in SISAR software, DTM with 0.6m vertical accuracy (ADS40). The number and distribution of the ICPs is constant (20 points).



16.2. Summary of Key Issues

1) The 1-D RMS error based on the manual measurement of 20 well distributed Independent Check Points (ICPs) is well below the 2.5 [m] for each analyzed case (this is in adherence with the EC Services – “Guidelines for Best Practice and Quality” http://mars.jrc.ec.europa.eu/mars/Bulletins-Publications/Guidelines-for-Best-Practice-and-Quality-Checking-of-Ortho-Imagery-v-3.0)
2) The 1-D RMS error based on the manual measurement of 20 well distributed Independent Check Points (ICPs) is sensitive to the off-nadir angle. The 1-D RMS increases with increasing off-nadir angle. This concerns orthos created based on RPC delivered by producer, 1-D error is from the range 0.40-1.10 [m].
3) In the case of orthos produced with RPC calculated by the sw suite SISAR the same trend is not visible. For those orthos 1-D RMS error behave less stable than the 1-D error calculated for above orthos based on RPCs delivered by provider and reaches a max value of slightly above 1.20 [m].

17. COSE test site - Outcome of the external quality control

We performed the external quality control of the WorldView-2 (level 2A) orthoimages produced (with ERDAS, LPS and PCI Geomatics) for COSE_MODE_1 (two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file) and COSE_MODE_3 (each strip provided as a set of overlapping sub-scenes, accompanied by metadata files, each with separate RPC file). The results are summarized in the following table:

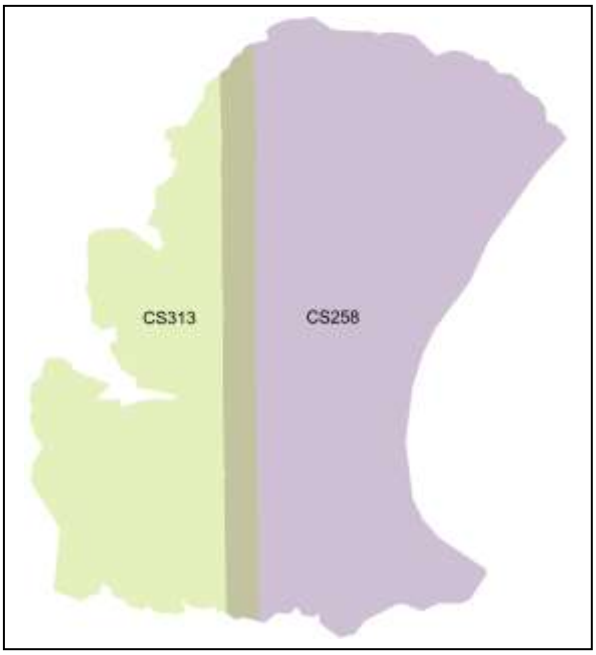
Table 17.1 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 (two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file) correction by 0 order Rational Polynomial using ERSAS LPS and PCI Geomatics based on 4 GCPs.

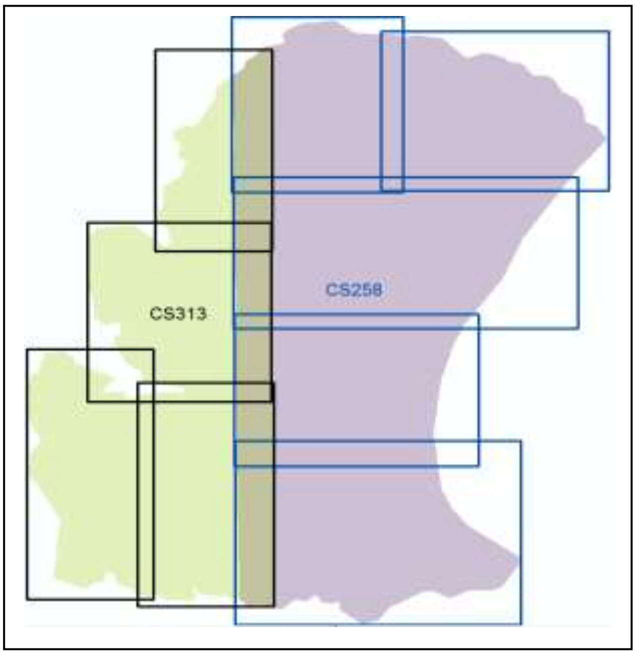
ID_ORTHO COSE_MODE_1	NUMBER OF CPs	RMSE_ E	RMSE_N	off nadir angle
cs_258_ERDAS_RPCvendors_4GCPshift	14	1.68	3.94	18.3
cs_258_PCI_RPCvendors_4GCPshift	14	2.09	3.88	18.3
cs_313_ERDAS_RPCvendors_4GCPshift	11	1.62	4.65	24.0
cs_313_PCI_rpcvendors_4gcpshift	11	1.13	4.42	24.0

Table 17.2 1-D RMSE_ICP [m] measured on the final orthoimage after the WV2 (each strip provided as a set of overlapping sub-scenes, accompanied by metadata files, including one RPC file) correction by 0 order Rational Polynomial using ERSAS LPS and PCI Geomatics based on 4 GCPs.

ID_ORTHO COSE_MODE_3	NUMBER OF CPs	RMSE_ E	RMSE_N	off nadir angle
ERDAS_ RPCvendors_4GCPshift (analogue to the cs 258)	14	1.53	4.29	18.4
PCI_ RPCvendors_4GCPshift (analogue to the cs 258)	14	2.05	4.08	18.4
ERDAS_ RPCvendors_4GCPshift (analogue to the cs 313)	11	1.58	4.91	24.0
PCI_ RPCvendors_4GCPshift (analogue to the cs 313)	11	1.38	4.39	24.0

Figure 17.1. The extent of the sample of WorldView-2 images: product level 2A. On the left side two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file.
On the right side each strip provided as a set of overlapping sub-scenes, accompanied by metadata files, each with separate RPC file





17.1. Discussion about COSE external quality control

Figure 17.2. On the left side 1-D RMSE_ICP [m] measured on the final orthoimage produced by ERDAS LPS. On the right side 1-D RMSE_ICP [m] measured on the final orthoimage produced by PCI Geomatics.
1-D RMSEs_ICP [m] measured on the final orthoimage produced with two strips provided as Mosaic Tiled product accompanied one single RPC file are marked in blue and red (COSE_MODE_1).
1-D RMSE_ICP [m] measured on the final orthoimage where each strip consists of sets overlapping sub-scenes (each sub-scene accompanied by RPC file) are marked in green and purple (COSE_MODE_3).

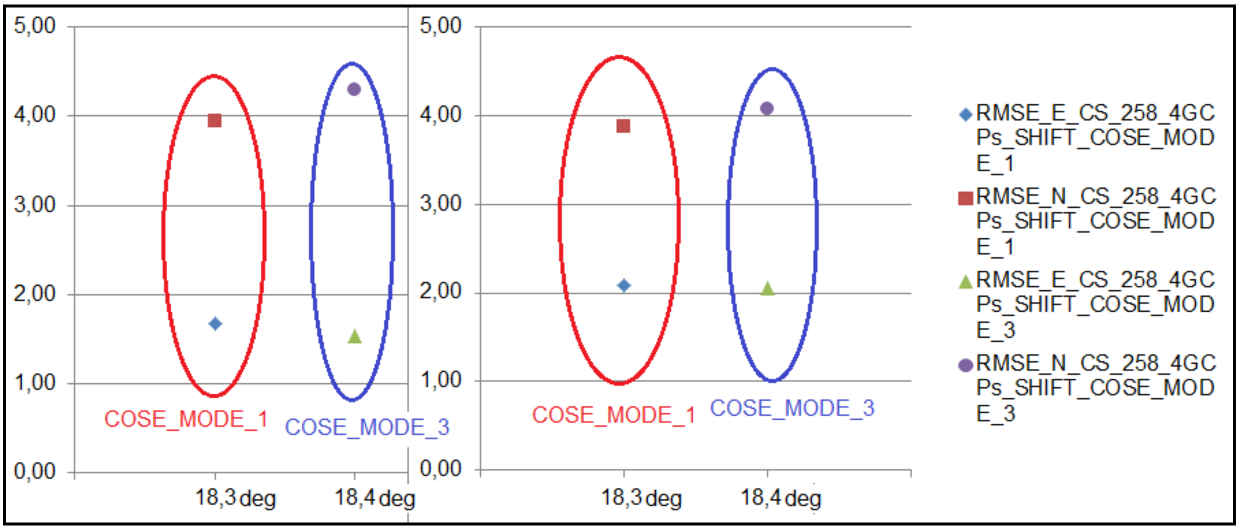


Figure 17.3. On the left side 1-D RMSE_ICP [m] measured on the final orthoimage produced by ERDAS LPS. On the right side 1-D RMSE_ICP [m] measured on the final orthoimage produced by PCI Geomatics.
1-D RMSEs_ICP [m] measured on the final orthoimage, where two strips are provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file are marked in blue and red (COSE_MODE_1)..
1-D RMSE_ICP [m] measured on the final orthoimage where each strip consists of sets overlapping sub-scenes (each sub-scene accompanied by RPC file) are marked in green and purple (COSE_MODE_3).

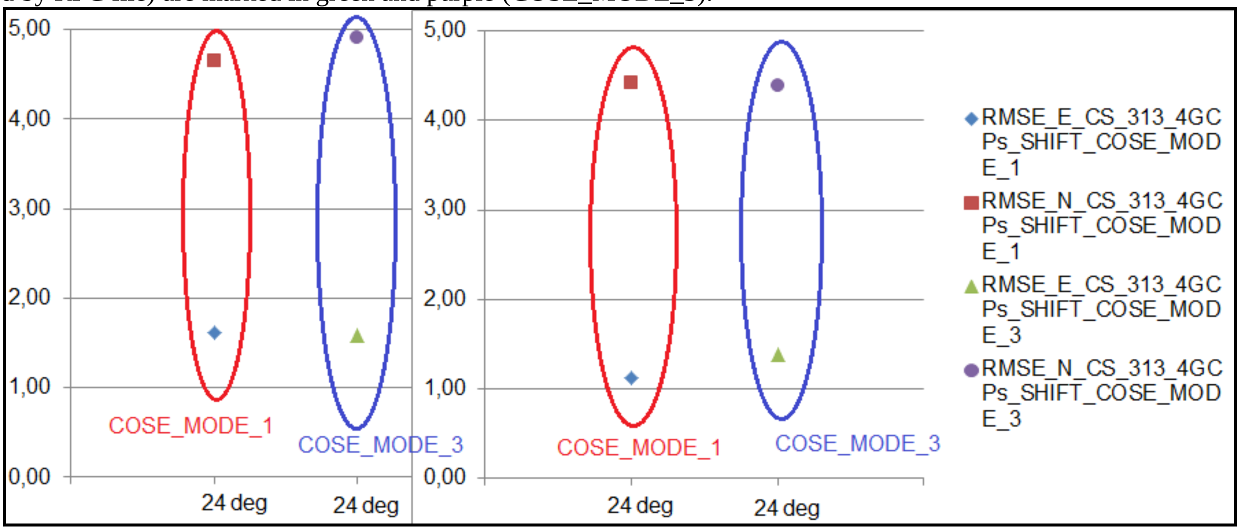
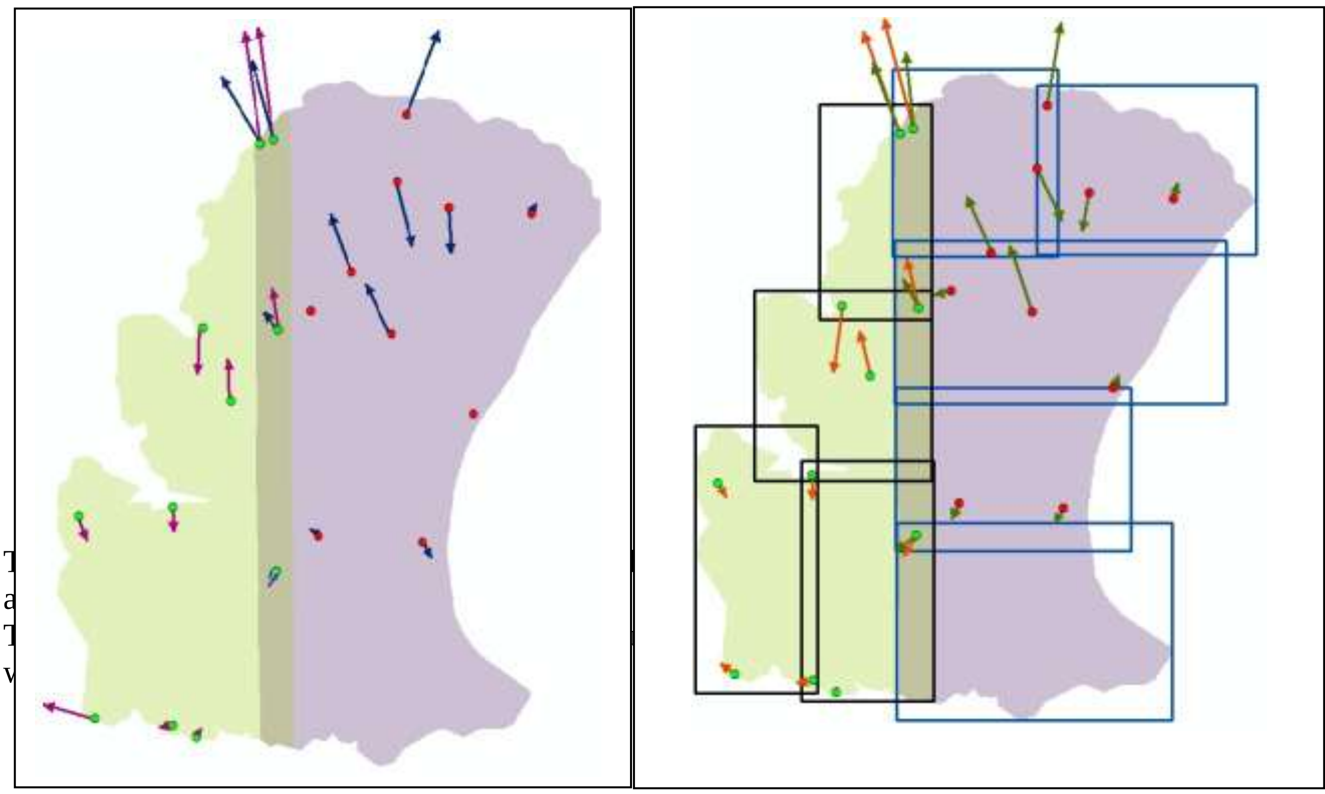


Figure 17.4 Comparison of the distribution 1-D RMSE (ERDAS LPS, shift transformation, 4 GCPs). On the left the case with two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file. On the right- each strip provided as a set of overlapping sub-scenes, accompanied by metadata files, each with separate RPC file.



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17.2 Summary of key issues:

1) 1-D RMSE [m] was calculated (based on 11ICPs, off nadir angle 24deg for the left strip (CS313), 14ICPs, off nadir angle 18.4deg for the right (CS258)) for two cases:
   - COSE_MODE_1 (two strips provided as Mosaic Tiled product accompanied by one single set of support files, including one single RPC file),
   -COSE_MODE_3 (each strip provided as a set of overlapping sub-scenes, accompanied by metadata files, including one separate RPC file).
   Based on 4GCPs and shift transformation with two software (ERDAS LPS, PCI Geomatica),
2) The average 1-D RMSE for the WorldView-2 product are 1,60m and 4.30m for Easting and Northing direction respectively.
3) 1-D RMSE have similar values for both cases COSE_MODE_1 and COSE_MODE_3 (i.e. no better values in dataset divided in sub-scene with separate RPC file).
4) Direction of ICP residuals are similar for COSE_MODE_1 and COSE_MODE_3.

18. Conclusions

Firstly, as regards the orientation, on the basis of the presented results, some general conclusions can be drawn:

- the orientation accuracy displays a significant dependence on the off-nadir angle (higher accuracy for lower off-nadir angle)
- the best orientation accuracy is reached with the Rational Polynomial Functions model using the Rational Polynomial Coefficients supplied with the imagery metadata and applying a shift refinement even with 4 GCPs
- overall the accuracy is practically software independent and appears suited for the orthoimage generation with an accuracy better than 2.5 m in each horizontal component
- concerning Cosenza Test Site appears more convenient to process the two long strips (up to 28 km) (COSE_MODE_1) instead of the separate 9 scenes (COSE_MODE_3), since the accuracy is practically the same whereas the number of the required GCPs is much lower

Secondly, as regards the orthoimages validation some general conclusions can be drawn:

- the goal stated by the EC Services - "Guidelines for Best Practice and Quality", that is one-dimensional RMS error below 2.5 meter, can be reached, provided a good quality DSM is used
- all the orthoimages satisfy the previous requirement for Maussane Test Site
- for Cosenza Test Site, both for COSE_MODE_1 and COSE_MODE_3, there are quite similar bad results in the North component. This fact can be explained considering the satellite azimuths of the both acquisitions, that are nearly along the North-South direction; in fact the largest residuals regard only the mountainous area (where the used DSM probably displays the largest error) and they are aligned along the mean line of sight

19. Possible future prospects

Considering the drawn conclusions two possible items for further investigations could be the following:

- longer strips have to be considered in order to assess the upper length limit to fulfil the accuracy requirements
- low resolution global DSMs should be tested, provided the large availability of this kind of product (for example the pretty well known SRTM and ASTER DEM are available all over the large part of the world including Europe)
- the mean accuracy of the used DSM should be always assessed considering the available GPs and possible bias should be removed
- the appropriate DSMs accuracy has to be assessed, in order to obtain results that satisfy the EC Services guidelines using WorldView-2 imagery

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European Commission
EUR 24973 – Joint Research Centre – Institute for Environment and Sustainability

Title: Sensitivity of the WorldView-2 satellite orthoimage horizontal accuracy with respect to sensor orientation method, number and distribution of ground control points, satellite off-nadir angles, and strip length

Author(s): Mattia Crespi, Francesca Fratarcangeli, Francesca Pieralice, Agnieszka Walczynska, Joanna Krystyna Nowak Da Costa, Pär Johan Åstrand

Luxembourg: Publications Office of the European Union

2012 – 49 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424 (online)

ISBN 978-92-79-21600-8 (pdf)

DOI: 10.2788/83426

Abstract:
Imagery acquired by the WorldView-2 (WV2) sensor is of potential interest to the Control with Remote Sensing (CwRS) Programme of the European Commission and therefore needs to be assessed. In details, the horizontal accuracy of the orthoimages which can be derived from WV2 imagery have to be concerned, recalling that in order to qualify WV2 as a Very High Resolution (VHR) prime sensor (i.e. a sensor suitable for measuring parcel areas to the accuracy requested by the Common Agriculture Policy - CAP regulation), the CwRS guidelines requires that the one-dimensional RMSE error (i.e. in the East and North components) measured on the external Check Points - CPs for any orthoimage should not exceed 2.5 m. This report summarizes the results regarding the orientation tests of the five WorldView-2 Panchromatic (WV2 PAN) images acquired over the JRC Maussane Test Site (Provence, Southern France), two Pan-sharpened (WV2 PANSHP) images (COSE_MODE_1) acquired over Cosenza Test Site (Southern Italy) and 9 Pan-sharpened (WV2 PANSHP) scenes (COSE_MODE_3) acquired over Cosenza Test Site (Southern Italy), carried out with Geomatica (PCI Geomatics), ERDAS Imagine 2011 and SISAR software, using both Rigorous model and Rational Polynomial Functions (RPFs) model with Rational Polynomial Coefficients (RPCs).
The Hold-Out-Validation accuracy assessment method (HOV) was considered, computing the Root Mean Square Error (RMSE) of the residuals between the estimated and the reference positions of the Check Points (CPs) for each horizontal component (East, North) varying the number of the GCPs. In addition the Leave-One-Out Cross Validation (LOOCV) method was been used to identify possible outliers.

LB-NA-24973-EN-N

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ISBN 978-92-79-21600-8

9 789279 216008