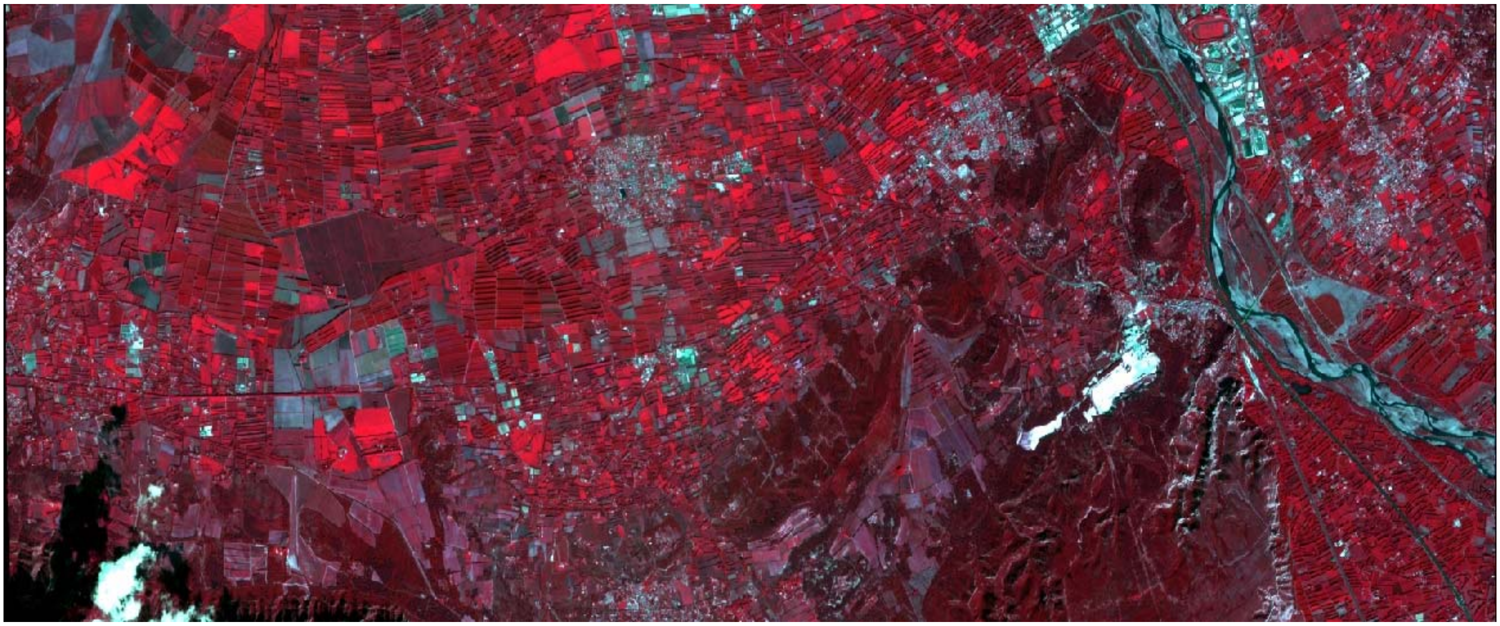
European Commission

JRC TECHNICAL REPORTS



New sensors benchmark report on SPOT 7

Geometric benchmarking over Maussanne test site for CAP purposes

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AIRBUS DEFENCE & SPACE

2014

Report EUR 27063

Joint Research Centre

European Commission
Joint Research Centre
Institute for Environment and Sustainability

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

JRC93987

EUR 27063

ISBN 978-92-79-45053-2

ISSN 1831-9424

doi:10.2788/17914

Luxembourg: Publications Office of the European Union, 2015

Abstract

The main objective of the present study is to assess whether SPOT7 sensor can be qualified for Control with Remote Sensing program (CwRS), in Common Agriculture Policy (CAP).

The benchmarking presented herein aims at evaluating the usability of SPOT7 for the CAP checks through an estimation of its geometric (positional) accuracy, as well as measuring the influence of different factors (viewing angle, number of GCPs, software implementation) on this accuracy. For that purpose, the External Quality Control of SPOT7 orthoimagery conforms to the standard method developed by JRC and follows a procedure already adopted in the validation of previous high (HR) and very-high resolution (VHR) products.

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List Of abbreviations used in the report

PAN	Image panchromatic
PSH	Image pansharpenend
MSP	Image multspectral
RMSE	Root mean square error
CwRS	Control with Remote Sensing
CAP	Common Agriculture Policy
RPC	Rational Polynomials coefficiants
RPF	Rational Polynomial Functions
REF3D	Reference 3DHR: High Tesolution
VHR	Very Higt Resolution
DEM	Digital Elevation Model
DSM	Digital Surface Model
DTM	Digital Terrain Model
ICP	Independent Check Point
GCP	Ground Control Point
UTM	Universal Transverse Mercator
AOI	Area Of Interest
RPC	Rational Polynomial Coefficients
RPF	Rational Polynomial Functions

1 Introduction

The main objective of the present study is to assess whether SPOT7 sensor can be qualified for Control with Remote Sensing program (CwRS), in Common Agriculture Policy (CAP).

The benchmarking presented herein aims at evaluating the usability of SPOT7 for the CAP checks through an estimation of its geometric (positional) accuracy, as well as measuring the influence of different factors (viewing angle, number of GCPs, software implementation) on this accuracy. For that purpose, the External Quality Control of SPOT7 orthoimagery conforms to the standard method developed by JRC and follows a procedure already adopted in the validation of previous high (HR) and very-high resolution (VHR) products.
With SPOT 6 and SPOT 7, Airbus DS not only secures mission continuity of the SPOT series, which has been collecting an archive of more than 30 million of scenes since 1986: this new generation of optical satellites also features technological improvements and advanced system performance that increase reactivity and acquisition capacity as well as simplifying data access.
The first 'twins' in the SPOT family, SPOT6 and SPOT 7, are 180-degree phased, enabling a revisit at least once a day for any point on Earth. [1]

1.1 SPOT 6/7:

1.1.1 Unique Accessibility

SPOT 6 and SPOT 7 deliver 1.5m high resolution products with five spectral bands (Pan/R/G/B/NIR), fully superimposable, as they are always acquired simultaneously.
Standard products are delivered application-ready: pan-sharpened and orthorectified imagery in natural colour.
Individual per-AOI-ordering and North-South acquisitions secure easy data handling.
An extensive and attractive tasking offer allows users to select the service most suitable for their specific requirements.
Airbus DS's innovative online portal www.geostore.com enables 24/7 tasking, ordering and delivery.

1.1.2 Ultimate Reactivity

Multiple tasking plans per day allow for integration of short-notice requests in the tasking plan, thus securing optimized acquisitions. Fully automatic processing and immediate (online) delivery, even via data streaming, ensure rapid availability.

1.1.3 Large Collection Capacities

SPOT 6-7 benefit from a large swath, enabling a daily acquisition capacity of 6 million sqkm per satellite. SPOT 6 and SPOT 7 are specifically designed to efficiently provide large-area coverages, making them particularly suitable to serve cartographic and monitoring applications.
While nominal acquisitions are available within 60km x 600km strips, multi-strip acquisitions can be recorded in a single path and non-North-South-oriented acquisitions are also possible.

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[1] for SPOT6/7 characteristics, please refer to Annex B

The high agility minimizes conflicts and enables automatic, rapid reaction to changing (weather) conditions, thus maximizing the number of successful acquisitions.
SPOT7 orthoimagery benchmarking test follows the benchmarking procedure of SPOT6 orthoimagery conducted in 2013.[2]
The geometric validation of SPOT7 ortho products for use in CAP checks is based on the External Quality Control of orthoimages as an assessment of their planimetric accuracy, and will follow strict guidelines announced by JRC.[3]

[2] see reference document [4]
[3] see reference document [2]

2 Benchmarking methodology

In order to fulfil CwRS requirements, it has been proposed to assess the geometric accuracy of **a part of SPOT7 products distributed commercially**. Indeed panchromatic and pansharpened products share the same geometry, therefore only pansharpened (from these two) will be used for this test. Namely the following spectral combinations:

Pansharpened products (PSH: 1,5m).

Multispectral products (MSP: 6m).

Considering that SPOT7 is the identical twin of SPOT6, for which a complete quality control was done, it is planned to perform only a light test:

1. Validation of MSP and PSH primary products (processing level closest to the image acquired by the sensor, ready for orthorectification) through the benchmarking of derived orthocorrected products,
2. Direct validation of ready orthorectified PSH products as distributed by Astrium (georeferenced, ortho generated using in-house Airbus DS Reference 3D dataset).[4]

Likewise previous benchmarking/validation processes, the scope of the benchmarking performed during validation of primary products comprises the following:

- 1 primary image with a viewing angle of more than 20 degrees.
- The orthocorrection is performed on two independent image processing platforms: ERDAS IMAGINE 2011, PCI Geomatica OrthEngine 2014 version, providing distinct implementations of RPC models.
- The orthocorrection is also performed on the Pixel Factory with physical model and using REF3D (DEM and Orthoreference).
- Concerning the GCPs used for modelling the orthocorrection process, 2 different input configurations are considered, with 3 and 4 GCP(s) respectively. Exactly the same set of CPs is used for the generation of the various orthorectified products on the different software platforms.
- Same points as SPOPT6 quality tests phase when possible.
- A single highly accurate raster DEM is used.
- Well-defined ICPs with precision at least as accurate as the GCPs will be considered for the evaluation of image correction performance.

[4] see Annexe C Automatic orthorectification with Ref3D DEM or SRTM DEM

Hereunder are presented 2 tables showing the initial suggestion of JRC and the final number of orthoproducts

Products / images	DEM	GCP #	model	erdas	PCI	Pixel factory
MSP						
03/10/2014 image - 20.35° off-nadir viewing angle						
	ADS40	3 (derived (*))	rpc	1	1	
	ADS40	4 (derived)	rpc	1	1	
				4		
PSH						
03/10/2014 image - 20.35° off-nadir viewing angle						
	ADS40	3	rpc	1	1	
	ADS40	4	rpc	1	1	
				4		
ortho product						
03/10/2014 image - 20.35° off-nadir viewing angle						
	Reference3D	0				1
				1		
TOTAL				**9**		

Table 1: Benchmarked ortho products: initially proposed by JRC. For every test case, an orthoimage is produced

Products / images	DEM	GCP #	Model (with polynomial order)	erdas	PCI	Pixel factory	delivered
MSP							
03/10/2014 image - 20.35° off-nadir viewing angle							
	ADS40	3 (located)	rpc (0)	1	1		2
	ADS40	3 (located)	rpc (1)		1		1
	ADS40	4 (located)	rpc (0)	1	1		2
	ADS40	4 (located)	rpc (1)	1	1		2
	ADS40	3 (derived	rpc (0)	1	1		2
	ADS40	3 (derived	rpc (1)		1		1
	ADS40	4 (derived)	rpc (0)	1	1		2
	ADS40	4 (derived)	rpc (1)		1		1
				13			13
PSH							
03/10/2014 image - 20.35° off-nadir viewing angle	ADS40	3	rpc ordre polynomial 0	1	1		2
	ADS40	4	rpc ordre polynomial 0	1	1		2
	ADS40	3	rpc ordre polynomial 1		1		1
	ADS40	4	rpc ordre polynomial 1	1	1		2
				7			7
ortho product							
03/10/2014 image - 20.35° off-nadir viewing angle	Reference3D					1	1
				1			1
TOTAL				**21**	**21**		**22**

Table 2: Benchmarked ortho products: finally delivered. For every test case, an orthoimage is produced

Further it was initially suggested to validate all products by using one unique set of GCPs.

PSH product – image coordinates of GCPs were taken directly from the PSH mage (ie. Classical approach)

MSP product – two different approaches:

- The set of GCPs were independently and directly estimated over the MSP products (‘located' GCPs).
- A set of GCPs estimated over the PAN products ('derived' GCPs) to calculate an error (derived-native)

The localisation of the MS derived GCPs was generated by a downsampling of the GCPs localisation from the PSH products.

- The PAN and PSH products, using one unique set of GCPs estimated over the P products,
- The MS products using either the previous set of GCPs independently and directly estimated over the MS products (native GCPs).

3 Input data

For the various test cases to be elaborated, it is required to use in input one single primary image acquired with a 20° viewing angle over a well-known area, and a set of well-defined ancillary data covering that same area: Digital Elevation Model and Ground Control Points. The input data used in the benchmarking are presented in this section.

3.1 Selection of AOI over Maussane test site

The test site of Maussane, located in France, has been selected for benchmarking by JRC as it offers sufficient ancillary and reference data (GCPs, DEM) with a validated quality [1].
Following, one AOI has been identified for SPOT7 as for:

- the AOI covers an extent of 19x18 km with UL corner at position (648800 E, 4836500 N) in EPSG 32631 (UTM - zone 31°N - ellipsoid WGS84) reference system.
- With dense coverage by existing CPs datasets,
- Covered by the footprint of the acquisition provided by Airbus DS (20.35° off-nadir viewing angle).

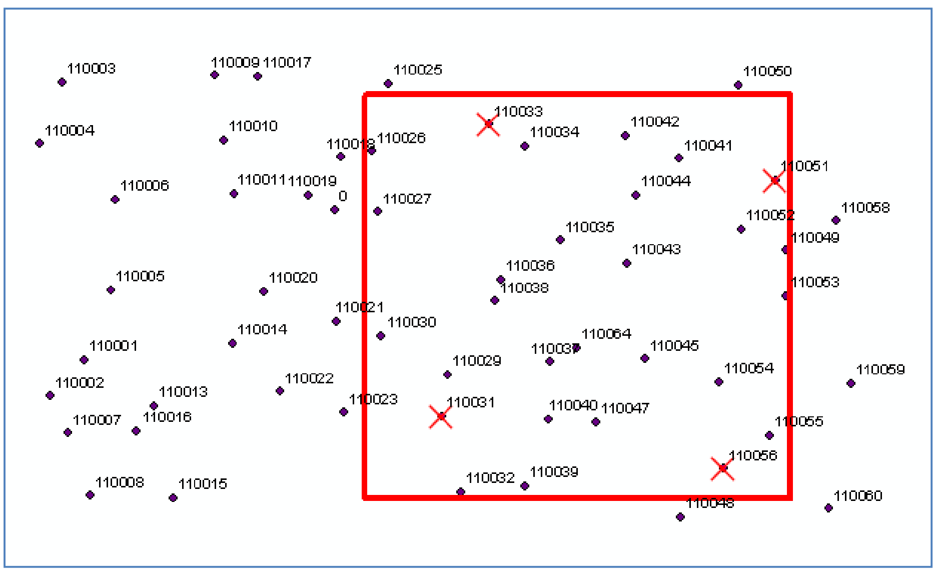


Figure 1: The AOI selected for SPOT 6 and SPOT 7 tests is represented as a bold red frame (18*19 km).
Red crosses correspond for the GCPs selected in the dataset of ADS40 available over this area.

3.2 Primary images

As stated before, one single image has been acquired for geometric benchmarking over Maussane AOI on the 3rd of October 2014 with angle of around 20.35° (Figure 4).
This image was generated in MSP and PSH products.

3.3 **Ancillary data**

3.3.1 GCP

Control Points (simply denoted CPs) serve for the orthocorrection of the images and the geometric quality validation of the derived orthoimages, provided the fulfilment of the accuracy requirements of JRC guidelines [2, Section 7.1]:
"GCPs [and ICPs] should be at least 3 times (5 times recommended) more precise than the target specification for the ortho."
Likewise the validation of SPOT6 data, 4 CPs coming from one dataset are considered [3, 1]: ADS40 dataset.
As mentioned in section 4.3, the ortho-guideline requirements are met when considering the properties of the CPs, as for the positional accuracy $RMSE_{1D:}$

- with ADS40 CPs, $RMSE_{1D}$ (East] < 5 cm and $RMSE_{1D}$ [North] =10 cm

The reader is also referred to [3, 4] for further information regarding the considered CPs database.

3.3.2 DEM

A high-resolution/high-precision raster DEM with ellipsoidal heights is used for benchmarking:

- spatial grid of 2 * 2m,
- vertical (height) accuracy of $RME_Z \leq 0.6$m.

The original DEM was produced from digital airborne stereo image pairs (Leica Geosystem) of GSD of 50 cm in the frame of ADS40 project [1]. From that DEM, a subset is extracted so that a 400m-wider scope area than Maussane AOI is enclosed in the DEM AOI. Within the context of SPOT 7 validation, this DEM meets the requirements of JRC guidelines for orthocorrection [2, p.15].

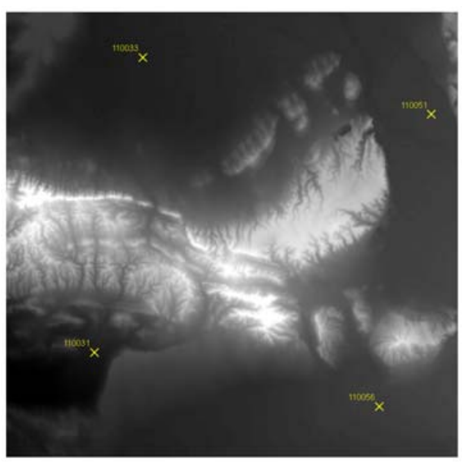


Figure 2: JRC ancillary data available over Maussane AOI: DEM and GCP selected

3.3.3 AERIAL ORTHOMOSAICS

Aerial orthomosaics were used to locate the GCP and ICP in this test (see annex A Description of the CPs used as ancillary/auxiliary data)

4 Orthocorrection process

In order to leverage the SPOT7 images for applications such as GIS, it is necessary to orthorectify the images. A geometric model, ground control points (GCPs) and digital elevation models (DEM) are required. The Rational Function Method (RFM) has been the most popular geometric correction method in orthorectifying high resolution images. This method uses the RPCs provided with the satellite data to perform orthorectification.
Since the SPOT7 primary product is provided with RPCs, RFM can be used to orthorectify the data. RPC model is used for the orthorectification with PCI and ERDAS.
The physical model is used for standard products with REF 3D [Appendix C]. Please note that accuracies of GCPs and DSM are lesser than ADS40 data.

4.1 Ancillary modeling data preparation

In total, 4 GCPs are selected over the product and are used in two different spatial configurations for benchmarking: see Figures 3 and Table 3. See also Tables 4 and5 in Annex A. These GCPs are derived from 1 of the prior mentioned CPs datasets (see also Section 3.3), namely [1]:

- 4 GCPs are taken from ADS40 database.

GCPs used for Spot6 tests campaign were kept, except Point G7010 of Cartosat-2 data, which did not cover SPOT7 image.

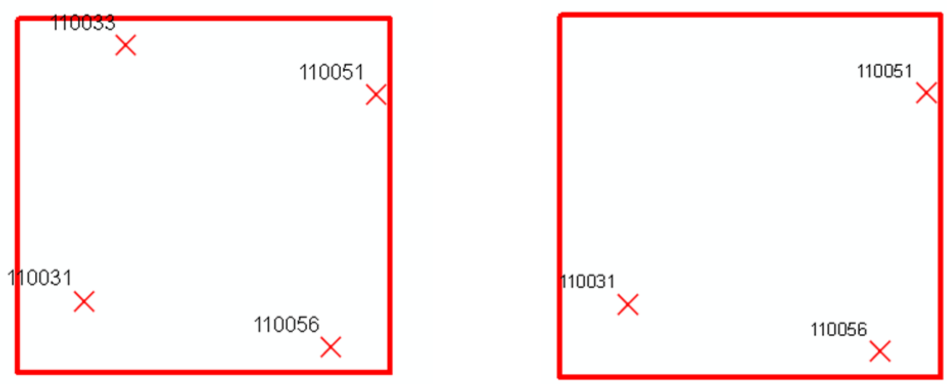


Figure 3: GCPs (Red Cross) spatial configuration: 3 and 4 GCP(s) selected

		GCPs	
#	ID	3	4
1	110033		√
2	110051	√	√
3	110031	√	√
4	110056	√	√

Table 3: GCPs selection for the creation of the orthos-products.

4.2 Remarks regarding the orthocorrection process

It was impossible to use the polynomial 1 order to perform orthocorrection with 3 GCPs on ERDAS. A refinement with a polynomial order of 0 (from ERDAS) was used.
For the Orthocorrection with 4 GCPS the residuals of the modelisation did not seem coherent. In a first time, the product was realized in the same conditions as the orthocorrection with 3 GCPs. In a second time, an ortho product with 4 GCPs was realized with a polynomial order of 1 and provided to the JRC.
For PCI software, a polynomial order of 1 and 0 were used in the both cases, 3 and 4 GCPS.

5 External geometric quality control (Airbus DS)

The external quality control of the ortho-rectified product (geometric) accuracy is done by measuring the misregistration of Independent Check Points, using one parameter: the maximum permissible planimetric error RMSE1D. The results output by this procedure are presented in this section.

5.1 Auxiliary validating data preparation

- 4 ICPs used in dataset ADS 40 (see tables 6 and 7, Annex A)
- Only PSH products were controlled

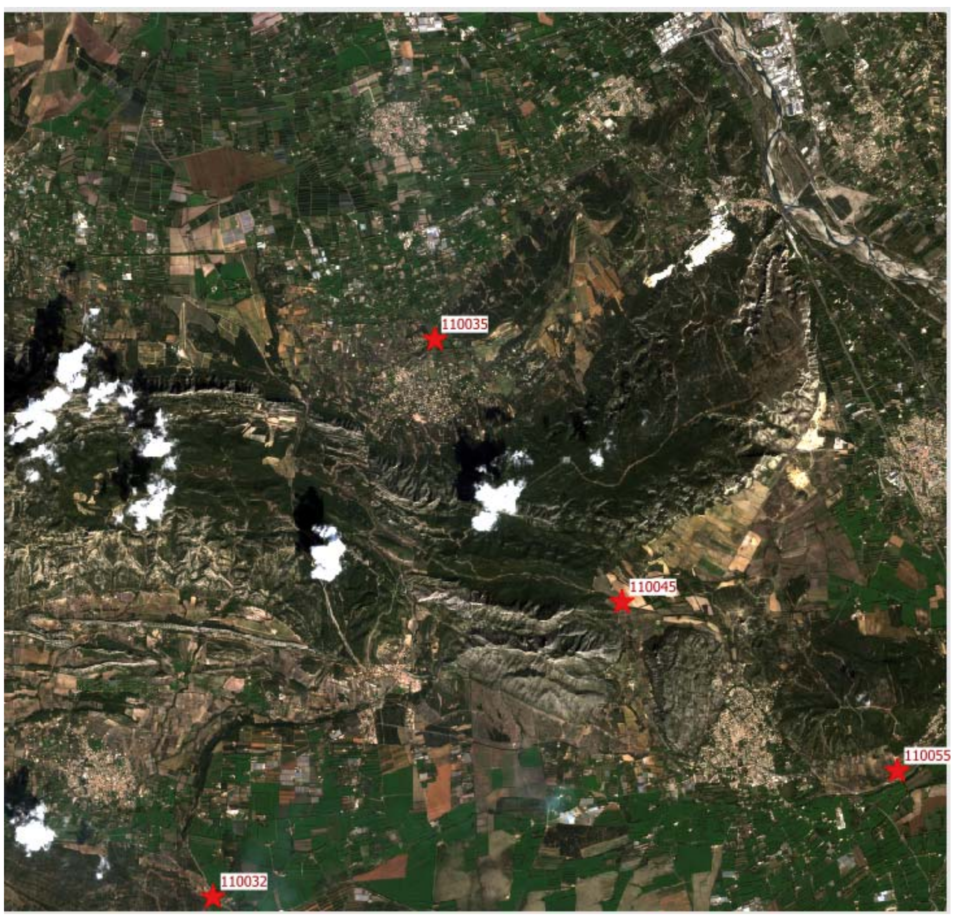
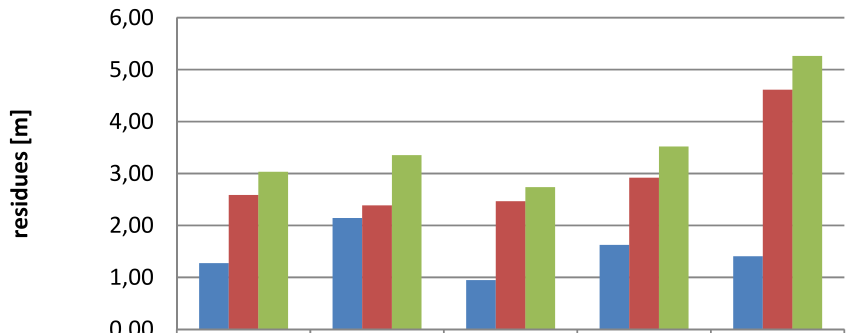


Figure 4 : ICPs (red stars) spatial configuration (see annexe A)

5.2 Overall results



	3,00 PCI	4 PCI	3 ERDAS	4 ERDAS	ref3D PF
North [m]	1,28	2,14	0,95	1,63	1,40
East [m]	2,59	2,39	2,47	2,92	4,62
RMS 2D [m]	3,03	3,35	2,74	3,52	5,26

Figure 5: Planimetric measurements per software suite.
The residual bias in Easting, Northing and RMSEs combined 2D directions are presented all together for PCI, ERDAS and Pixel Factory software. The East (resp., North and 2D) columns store the RE1D [East] (resp., RE1D [North] and RE2D) errors expressed in meters.

Comments:
It is to be noted that we made the checks on pansharpened orthos with only 4 ICPs (polynomial order 1 for PCI and polynomial order 10 for ERDAS (We observed that there is a systematic bias in West direction, but which stays compliant with JRC's specifications.
The x bias is higher than the y one.
The results are better with 3 GCPs than 4 GCPs on ERDAS and PCI.
REF3D results are different because we are on a 5 m precision and resolution standard products with REF3D (see annexe D).

Remarks regarding the orthorectification process managed cy Airbus DS GEO SA:

- The first difficulty in this test was the placement of the points on the primary image. The location of the points used, although accurate, was not always adapted to the resolution of SPOT7 sensor.
- At the beginning the test, there is not specification for the use of polynomial order. For PCI, polynomial order 1 was used for the orthocorrection with 3 and 4 GCP But for ERDAS software option with polynome 0 is only possible. In order to ensure a good comparison of software we have reproduced orthoimages with a polynomial 0 and 1 when possible.

6 Conclusion

On the one hand, the quality control managed by Airbus DS GEO SA shows that the geometric accuracy of PSH ortho products meets the requirement of 3m RMSE1D corresponding to the HR prime profile.

RMSE1D≤ 5m is fulfilled by Reference3D based PSH ortho image (Pixel Factory).

With limitations of the control that we realized. it seems that the use of three points is preferred for better acurracy of orthoimages that this is with PCI software or ERDAS software.

Annexes

A Description of the CPs used as ancillary/auxiliary data

- *the GCPs provided for ortho-rectification,*
- *the ICPs employed in the EQC, and locate them in - ortho resp.* - images.

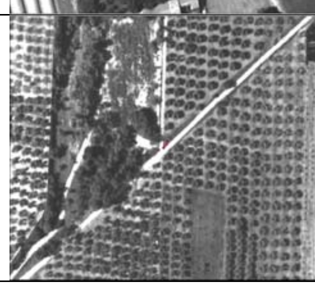
#CP	ID	source	Screen shot	Ground camera shot
4	110033	Ads40		
3;4	110051	Ads40		
3;4	110056	Ads40		
3;4	110031	Ads40		

Table 4: GCPs selection over Maussane site.

GCPs from (see Section 3.3) were selected and positioned on the primary imagery based on the available visual information (ground camera shots and image screenshot

		Ground position [m]		Height [m]		Image location [pixels]	
#CP	**ID**	**North**	**East**	**Ellips.**	**Ortho.**	**X**	**Y**
4	110033	4853129,599	654379,179	98,271	N/A	3531,439	-1158,089
3;4	110051	4850624,772	667097,535	135,407	85,157	10969,591	-2234,569
3;4	110056	4837771,413	664787,963	137,112	87,074	9436,813	-9556,029
3;4	110031	4840147,739	652245,853	92,137	42,117	2094,671	-8534,261

Table 5: Ground position, height and image location of selected GCPs.
In-situ measured GPS (North, East) coordinates in EPSG 32631 reference system and respective heights. (column,row) image coordinates (X; Y) in PAN image are identified by a human operator (1 digit precision, i.e. a tenth of a pixel).

#CP	ID	source	Screen shot	Ground camera shot
	110032	Ads40		
	110035	Ads40		
	110045	Ads40		
	110055	Ads40		

Table 6: ICPs selection over Maussane site.
ICPs from (see Section 3.3) were selected and positioned on the primary imagery based on the available visual information (ground camera shots and image screenshots).

		Ground position [m]	
#CP	ID	North	East
4	110033	4836736,827	653074,884
3;4	110051	4847961,5	657527,887
3;4	110056	4842666,759	661320,451
3;4	110031	4839273,292	666859,315

Table 7: Ground position, of selected ICPs.
In-situ measured GPS (North, East) coordinates in EPSG 32631 reference system. (column,row).

B Description of the Spot Products

	SPOT 6/7	SPOT 5	SPOT 4	Spot 1, 2, 3
Products / Mode/ Bands	➢ Pan 1.5m (1 band) ➢ Pan-sharpened 1.5m (3 or 4 bands) ➢ MS 6m (4 bands) ➢ Bundle: Pan 1.5m + MS 6m (5 bands)	➢ 2.5m Pan (1 band) ➢ 2.5m Pan-sharpened (3 bands) ➢ 5m Pan (1 band) ➢ 5m Pan-sharpened (3 bands) ➢ 10m MS (4 bands)	➢ 10m Pan (1 band) ➢ 10m Pan-sharpened (4 bands) ➢ 20m MS (4 bands)	➢ 10m Pan (1 band) ➢ 20m MS (3 bands)
Footprint (nadir angle)	Up to 60 km x 600 km	60 km x 60 km	60 km x 60 km	60 km x 60 km
Revisit interval	1 day with extended angles	2 to 3 days	2 to 3 days	-
Viewing angle	-45° to +45°	-27° to +27°	-27° to +27°	-27° to +27°
Location accuracy	~12m CE90	Less than 30m CE90	Less than 350m CE90	Less than 350m CE90
Ortho location accuracy - CE 90 (with Ref3D)	6-10m	10m	10m	10m
Image Dynamics	12 bits	8 bits	8 bits	8 bits

Table 8: Characteristics of the sensors of the Spot Satellite Family

C Automatic orthorectification with Ref3D DEM or SRTM DEM [5]

Standard Ortho

The Ortho product is a georeferenced image in Earth geometry, corrected from acquisition and terrain off-nadir effects. The Ortho is produced as a standard, with fully automatic processing.

The Standard Ortho product is an image that has been corrected (viewing angle and ground effects) so that it may be superimposed on a map. On top of radiometric and geometric adjustments, a geometric process using a relief model (known as orthorectification) eliminates the perspective effect on the ground (not on buildings), restoring the geometry of a vertical shot. The Ortho Product is optimal for simple and direct use of the image. It can be used and ingested directly into a Geographic Information System. This processing level facilitates the management of several layers of products, from the same sensor or others, while reducing localization gaps that can be caused by different viewing angles or relief between the various layers. The standard 3D model used for ground corrections is the worldwide Reference3D dataset, which is part of Astrium's Elevation30 suite.

The product is extracted from one to several contiguous strip acquisitions: single ortho or mosaic. Support for this extraction is a polygonal region of interest in WGS84 coordinates.

The Ortho product inherits geometric corrections from the Primary product, with additional adjustments:

- Planimetric reset: On request, if ground reference data is available, the location is reset on Ground Control Points (Reference3D Ortho layer[5])
- Altimetric reset: correction of the panoramic effects induced by the off-nadir incidence angles over the relief thanks to a Digital Elevation Model (DEM). By default, the Reference3D DEM layer is used where available, otherwise SRTM is used.
- Map projection or geographic projection

The Ortho product inherits radiometric corrections from the Primary product, with additional adjustments:

- Pixel sampling at Shannon Sampling (optimized bicubic kernel) at a fixed resolution of 6 m for Multispectral products and 1.5 m for Panchromatic and Pan-sharpened products

The final format includes:

- Masking of pixels (black fill) outside the region of interest polygon and raster trim to the region of interest bounding box
- Physical tiling: images beyond a certain size are split into several files The user selects:
- The possibility to reset the location on Ground Control Points if available

The spectral band combination: Panchromatic, Pan-sharpened 3-Band Natural Color, Pansharpened, 3-Band False Colour, Pan-sharpened 4-Band, Multispectral 4-Band, Bundle The bit-depth: 12-bit native (4096 values) or reduced to 8 bits (adjusted to 256 values) for screen display without adaptation.

- The raster file format: JPEG 2000, with Optimized or Regular compression, or GeoTIFF

[5] See annexe D

D REF 3D [6]

Ref 3d derived from optical satellite data (HRS sensor on board SPOT 5), merged with radar data especially over cloudy areas, Elevation30 features a greater coverage, independent of terrain characteristics and weather conditions (80 Million km^2 Available (end 2014)). The models include “first surface” elevation, including vegetation and man-made structures.

<u>Key Benefits</u>

Up to 8m vertical accuracy

- Based on DTED level 2 standards
- Available over 80 million km^2 worldwide (end 2014)
- Rapid delivery
- Ideal for defence, mapping and terrain modelling applications

Elevation30 ortho-images provide ground control points with an accuracy better than 10m CE90, hence accurate enough to ensure GPS compatibility:
They can be used to orthorectify imagery from most Earth observation satellites (Pléiades, the SPOT family, FORMOSAT-2, the DMC-Constellation, WorldView-1 to -3, QuickBird, IKONOS,Kompsat-2, TerraSAR-X, GeoEye, Landsat, Radarsat, Envisat, etc...) when positional data is not available.

	Reference3D	SPOTDEM Precision	SPOTDEM
Layers			
DEM	DTED level 2 HRS DEM	DTED level 2 HRS DEM	DTED level 2 HRS DEM
Image Data	GPS-compatible HRS Orthoimage	n/a	n/a
Metadata	• Quality indicators for data sources • References and footprints for DEMs and orthoimages • Description of processing for DEMs (masks) • Accuracy estimates	Per pixel information: • Absolute horizontal and vertical accuracy • Source data • Production processes • All corrections and checks	n/a
Accuracy*	• Absolute elevation accuracy: 10m @ 90% for slope <20° • Absolute planimetric accuracy (DEM and ortho-image): 10m @ 90%	• Vertical accuracy - LE90 – 10m - RMS – 7m • Horizontal accuracy - CE90 – 10m - RMS – 7m	• Horizontal accuracy** < 10m • Vertical accuracy** (slope < 20%) < 10m
Size	geographic tiles of 1°x 1° covering emerged land areas and aligned along parallels and meridians. The surface area of a tile, equivalent to 111 km x 111 km at the equator, decreases as the latitude increases.	match the perimeters of your Area of Interest. With a price per square kilometre.	The SPOT DEMs can be framed to match the perimeters of your area of interest. With a price per square kilometre, you will be able to optimize your budget.
Sampling	DEM: Sampling step: 1 second of arc (~ 30m at the equator, varying according to latitude) Ortho-image: Sampling step: 1/6 second of arc (~ 5m at the equator, varying according to latitude)	Gridded file with step sizes of 1 second of arc (30 m on the equator, E/W dimensions vary according to the latitude). Resampling to 20 m available.	Gridded file with step sizes of 1 second of arc (30m on the equator, E/W dimensions vary according to the latitude). Resampling to 20m is available.
Availability	80 million km²	80 million km²	80 million km²
Datum and Projection	• Vertical Datum: EGM96 • WGS84	• WGS84 • UTM WGS84 other projection on request	• WGS84 • UTM WGS84 other projection on request
Format / Delivery	**DIMAP format**	**DIMAP format** (or DTED as an option)	**DIMAP format** (or DTED as an option)

* Accuracy values guaranteed with 90% confidence

** for areas not covered by Reference3D and/or <7,200 km², accuracies of the SPOT DEM are reduced to < 30m (horizontal) and < 20m (vertical)

Table 9: Characteristics of DEM products realized from HRS sernsor

E Modeling results for PCI and ERDAS software

No. Of GCPs		**GCP RMS Residuals [meters]**					
		PCI			**ERDAS**		
Nb GCP	**PSH**	**RMS X**	**RMS Y**	**RMS2D**	**RMS X**	**RMS Y**	**RMS2D**
4	1st order	0,3	1,07	1,11	0,16	0,69	0,70
4	0 order	0,72	1,58	1,74	0,49	1,06	1,16
3	1st order	0,11	0,56	0,57			
3	0 order	0,32	1,35	1,39	0,20	0,91	0,93
	MSP (located)						
4	1st order	3,3	4,68	5,73	0,00	0,78	0,78
4	0 order	3,78	4,74	6,06	0,63	0,79	1,01
3	1st order	3,54	3,72	5,14			
3	0 order	4,02	3,9	5,60	0,67	0,65	0,93
	MSP (derived)						
4	1st order	0,72	1,38	1,56	0.04	0.16	0.17
4	0 order	0,84	1,44	1,67	0.14	0.241	0.278
3	1st order	0,36	1,08	1,14			
3	0 order	0,36	1,2	1,25	0.06	0.199	0.21

Table 10: Modeling results during the orthorectification process with ERDAS and PCI software

References

[1] J. Nowak Da Costa and P.A. Tokarczyk, \Maussane test site auxiliary data: existing datasets of the Ground Control Points", Tech. Rep. 56257, JRC IPSC, 2010.

[2] D. Kapnias, P. Milenov, and S. Kay, \Guidelines for best practice and quality checking of ortho imagery", Tech. Rep. 48904, JRC IPSC, 2008, Available at http://mars.jrc.ec.europa.eu/mars/content/download/1231/7140/file/Orthoguidelines_v3_final.pdf ; wiki available at http://marswiki.jrc.ec.europa.eu/wikicap/index.php/Guidelines_for_Best_Practice_and_Quality_Checking_of_Ortho_Imagery.

[3] C. Lucau and J. Nowak Da Costa, \Maussane GPS field campaign: method- ology and results", Tech. Rep. 56280, JRC IPSC, 2009, Available at http://publications.jrc.ec.europa.eu/repository/bitstream/111111111/14588/1/pubsy_jrc56280_fmp11259_sci-tech_report_cl_jn_mauss-10-2009.pdf.

[4] J. Grazzini, S and P. Åstrand, \External quality control of SPOT6 orthoimagery , "Geometric benchmarking over Maussane test site for positional accuracy assessment", Tech. Rep., JRC IES, 2013.

[5] User guide SPOT6 and SPOT7 : http://www.geo-airbusds.com/spot6userguide/

[6] REF3D : http://www.geo-airbusds.com/en/118-elevation30-worldwide-3d-geographic-reference-database-for-all-global-coverage-needs and http://www.geo-airbusds.com/en/6073-elevation30-products

APPENDIX to the New sensor benchmark report on SPOT 7

EXTERNAL QUALITY CONTROL OF SPOT 7 ORTHOIMAGERY REPORT

Contents

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This external quality control (EQC) report on the SPOT 7 optical satellite ortho-product is a part of the "New sensor benchmark report on SPOT 7". References in this annex therefore refer to the concrete chapters of that report which is in this context called just the "benchmarking report" or to its list of references.

JRC as an independent entity performs a validation phase of the benchmarking workflow methodology used for verifying of a satellite's ortho product compliance with the geometric quality criteria set up for the Control with Remote Sensing program (CwRS), in Common Agriculture Policy (CAP). The workflow follows the Guidelines for Best Practice and Quality Checking of Ortho Imagery (Kapnias et al., 2008) [2], also described in the chapter 2. Benchmarking methodology (benchmarking report) or [4].

Since SPOT 7 sensor has the same characteristics (design and technical specification) as SPOT 6 (i.e. an identical twin), only a light test of satelite's ortho products geometric accuracy was performed. Results and subsequent conclusions of this report are to be considered as a follow up to the External quality control of SPOT 6 orthoimagery (J. Grazzini and P. Astrand, 2013)[4].

The report therefore summarizes the results coming from the geometric quality assessment of the SPOT 7 orthoimagery (precisely 21 orthoimages altogether) derived only from one SPOT 7 scene captured under the viewing angle of 20.35˚.

The tested orthoimages were provided by the Framework (FW) Contractor Airbus.

The sensor orientation and the orthorectification process were carried out with PCI Geomatics 2014, Intergraph ERDAS Imagine 2011 software, using Rational Polynomial Functions (RPFs) model with Rational Polynomial Coefficients (RPCs) supplied with the imagery metadata, applying 3 and 4 ground control points (GCPs) refinement.

The main objectives of the geometric accuracy assessment are as follows:

1. To determine whether the orthorectified imagery of SPOT 7 sensor complies with the accuracy criteria defined for CwRS, in CAP and consequently whether the optical sensor can be qualified for the following profiles:
   - F0.HR prime - CwRS profile: 1D RMSE <1.5x GSD i.e ~3m for PSH, 9m for MSP image, spatial resolution requirements: GSD≤25m (MSP), GSD≤5m(PSH)
   - F1.HHR prime - CwRS profile: 1D RMSE <1.5x GSD (MSP) i.e. 9m for MSP image and 1D RMSE <5m (PAN), , spatial resolution requirements: GSD≤12m (MSP), GSD≤3m (PAN).
   - F2.HHR prime - CwRS profile [ORTHO]: 1D RMSE <1.5x GSD (MSP) i.e. 9m for MSP image and 1D RMSE <5m (PAN, PSH), , spatial resolution requirements: GSD≤12m (MSP), GSD≤3m (PAN, PSH).
   - E. VHR backup profile: 1D RMSE <5m, spatial resolution requirements: GSD≤12m (MSP), GSD≤3m (PSH, PAN)
2. To assess the influence of some factors entering into the satellite image orientation and orthorectification phase on the final horizontal accuracy of ortho products.

1. Method for external quality checks of ortho images

The method for the external quality checks strictly follows the Guidelines for Best Practice and Quality Checking of Ortho Imagery (Kapnias et al., 2008) [2].

1.1 Independent check points (ICPs) - selection, distribution, registration

For the evaluation of the geometric accuracy of the SPOT 7 orthoimagery, 20 independent ICPs were selected by a JRC operator. Both GCPs and ICPs were retrieved from already existing datasets of differential global positioning system (DGPS) measurements over Maussane test site. These datasets are updated and maintained by JRC. Considering the accuracy, distribution and recognisability on the given images, points from the four datasets were decided to be used for the EQC. The intention was to spread the points evenly across the whole image while keeping at least the minimum recommended number of 20 points (Kapnias et al., 2008). JRC for the location of the ICPs took into account the distribution of the GCPs determined by the FW Contractor and provided to JRC together with the products.
Regarding the positional accuracy of ICPs, according to the Guidelines (Kapnias et al., 2008)[2] the ICPs should be at least 3 times (5 times recommended) more precise than the target specification for the ortho, i.e. in our case of a target 3.0m RMS error the ICPs should have a specification of 1m (0.60m recommended). All ICPs that have been selected fulfil therefore the defined criteria (Table 1).

Dataset	RMSEx [m]	RMSEy [m]	Number of points
ADS40 GCP_dataset_Maussane 2003	0,05	0,10	7
Dataset prepared for Cartosat-1 2006	0,55	0,37	1
Dataset prepared for Cartosat-2 2009	0,90	0,80	4
Dataset prepared for Formosat-2	0,88	0,72	3
Maussane GNSS field campaign 2012	< 0,15	< 0,15	5

Table 1: Identical check points specifications

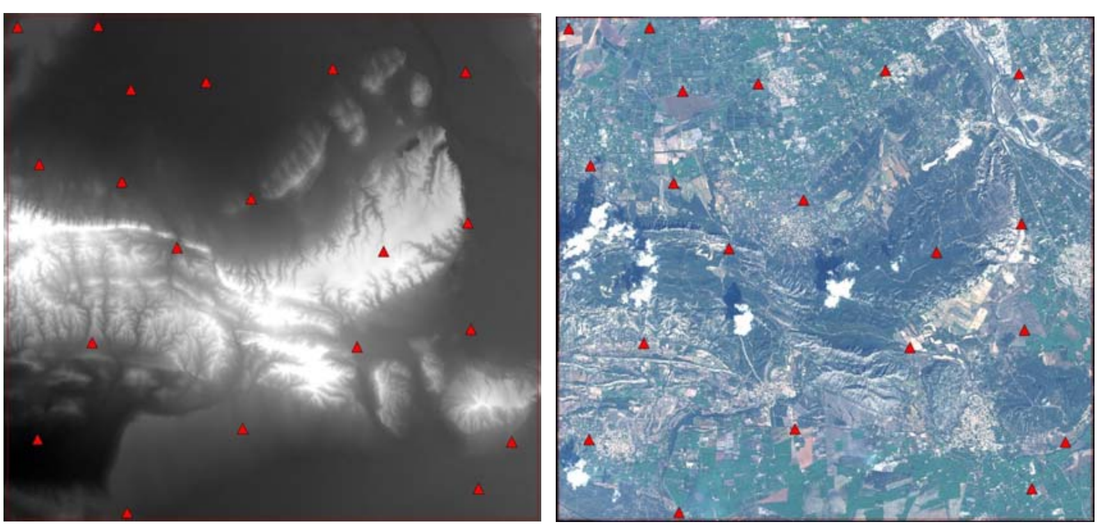


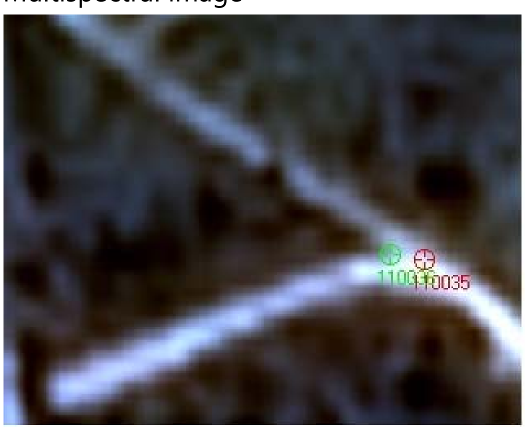
Figure 1: ICPs dataset used by JRC in the EQC of SPOT 7 ortho imagery.
Left: ICPs displayed over the ADS40 DEM. Right: ICPs are displayed over the SPOT 7 acquisition of Maussane.

Photo taken at the place (2003)

Image chip – ADS40 aerial orthomosaic (2003)

Multispectral image

Pan-sharpened image



Airbus “in house” orthoproduct

Figure 2: Example of the ICP localization on the orthoimage

Red symbol: ground true coordinates of the point, green symbol: derived coordinates of the point on the image

ID	E [m]	N[m]	3 GCPs	4GCPs
			Off nadir angle 20.35˚	
110032	653074.88	4836736.83	x	x
110034	655919.78	4852145.33	x	x
110035	657527.89	4847961.50	x	x
110036	654872.14	4846211.49	x	x
110042	660443.40	4852612.64	x	x
110045	661320.45	4842666.76	x	x
110055	666859.32	4839273.29	x	x
330022	665677.15	4837589.86	x	x
G7005	649147.07	4854111.53	x	x
G7036	652891.98	4848575.53	x	x
G7037	649931.03	4849197.97	x	x
G7039	652042.88	4854152.73	x	x
550004	665218.41	4852494.39	x	x
550005	651828.92	4842826.64	x	x
550010	662267.24	4846078.67	x	x
C5R5	649866.17	4839369.32	x	x
C6R2B	653220.31	4851876.09	x	x
C7R5NEW	657221.13	4839746.71	x	x
C9R3	665299.15	4847111.38	x	x
C9R4	665398.41	4843299.01	x	x

Table 2: ICPs overview for each ortho image

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

1.2 Geometric quality assessment – measurements and calculations

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

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

where $X,Y_{REG(i)}$ are orthoimagery derived coordinates, $X,Y_{(i)}$ are the ground true coordinates, n express the overall number of ICPs used for the validation.
This geometric accuracy representation is called the positional accuracy, also referred to as planimetric/horizontal accuracy and it is based on measuring the residuals between coordinates detected on the orthoimage and the ones measured in the field or on a map of an appropriate accuracy.

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

All measurements presented in this annex were carried out in Integraph ERDAS Imagine 2014 software, using Metric Accuracy Assessment tool for quantitatively measuring the accuracy of an image which is associated with a 3D geometric model. Protocols from the measurements contain other additional indexes like mean errors or error standard deviation that can also eventually help to better describe the spatial variation of errors or to identify potential systematic discrepancies. (Kapnias et al., 2008) [2].

2. Outcome and discussion about ECQ

2.1 Overall results

			MSP				PSH			
			ERDAS		PCI		ERDAS			PCI
Off-nadir angle	Number of GCPs	Direction	0 p. order RMSE [m]	1st p.order RMSE [m]	0 p. order RMSE [m]	1 p.order RMSE [m]	0 p. order RMSE [m]	1st p.order RMSE [m]	0 p. order RMSE [m]	1st p.order RMSE [m]
20°	3 "derived"	East	4,60	n/a	5,29	5,22	n/a	n/a	n/a	n/a
		North	4,24	n/a	2,86	2,93	n/a	n/a	n/a	n/a
	4 "derived"	East	4,48	n/a	5,17	4,93	n/a	n/a	n/a	n/a
		North	3,02	n/a	2,68	2,58	n/a	n/a	n/a	n/a
	3 "located"	East	4,86	n/a	5,68	5,96	1,98	n/a	1,70	2,05
		North	4,24	n/a	4,59	4,99	1,35	n/a	1,36	2,26
	4 "located"	East	4,58	8,13	6,04	7,39	2,33	2,69	1,74	2,33
		North	3,68	3,68	3,28	4,32	1,69	2,23	1,26	1,71
	n/a			n/a				PIXEL FACTORY RMSE [m]		
		East						4,54		
		North						2,14		

Table 3: Results of $RMSE_{1D}$ measurements in JRC ICPs dataset.

The results are presented altogether for the different software, number of GCPs used for orthorectification process modelling.

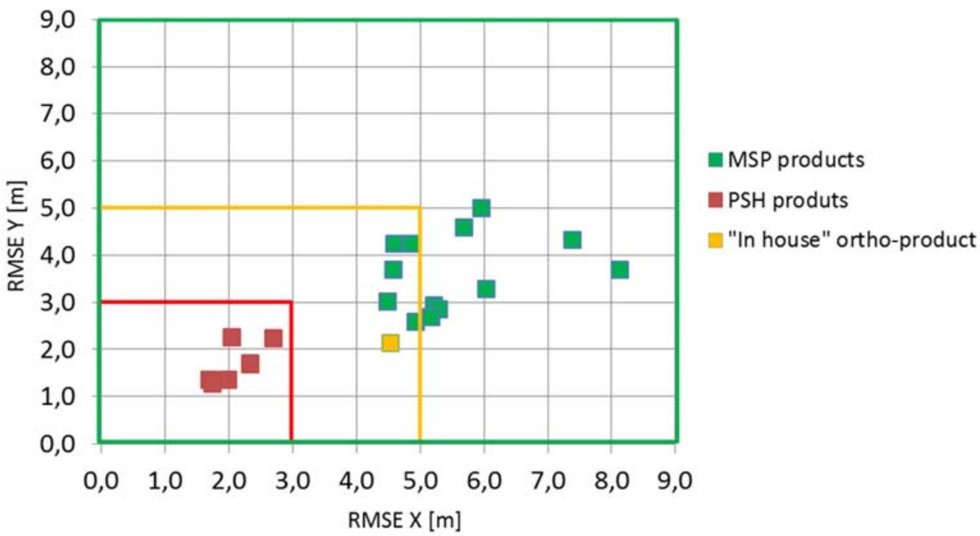
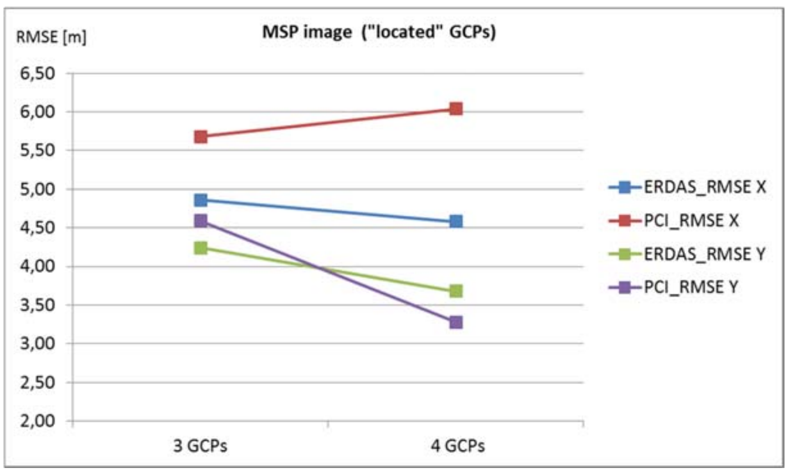


Figure 3: Point representation of all planimetric $RMSE_{1D}$ errors measured in JRC ICPs dataset

2.2 Discussion on software usage factor

To compare algorithms implemented in different COTS, ERDAS IMAGINE 2011, and PCI Geomatica 2014 software were used to derive the corresponding ortho products from the acquired scene.
From the Figure 4, which displays the results for multispectral products, could be concluded the following:

- Regardless the character of GCPs ("located" or "derived") used for the modelling phase ERDAS software gives better RMSEs in the Easting direction. The differences are substantial and vary within 0.70-1.46m.
- Concerning the RMSEs in the Northing direction, using "derived" GCPs the software PCI performs better however with the increasing number of GCPs the performance of both software is similar. Regarding the "located" GCPs the results are inconclusive but no significant differences were observed (0.30m - 0.40m).



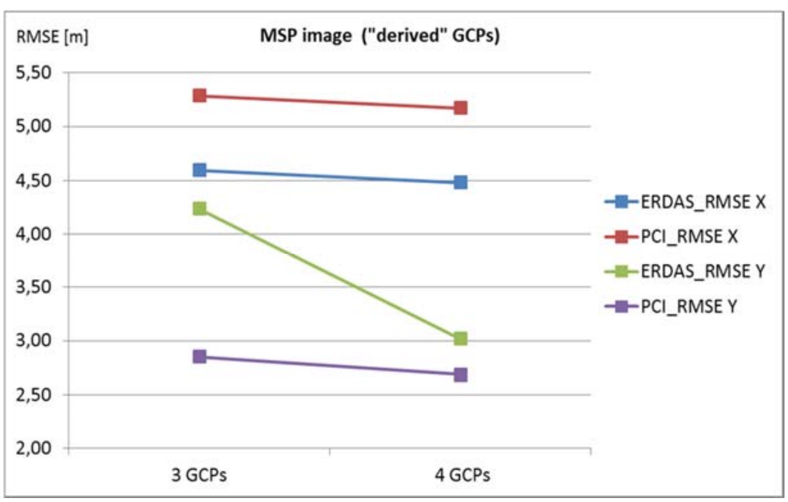


Figure 4: 1-D RMSEs measured on the MSP orthoimages derived using 0 order RPC, as a function of the number of GCPs used for modelling, displayed separately for PCI and ERDAS software.

From up to down: MSP orthoimage- "located" GCP used form modelling, MSP orthoimage – "derived" GCPs used for modelling.

Looking at the Figure 5 which represents the results retrieved from pansharpened products we could conclude the following:

- Products generated with PCI software prove better positional accuracy than orthoimages produced by ERDAS software.

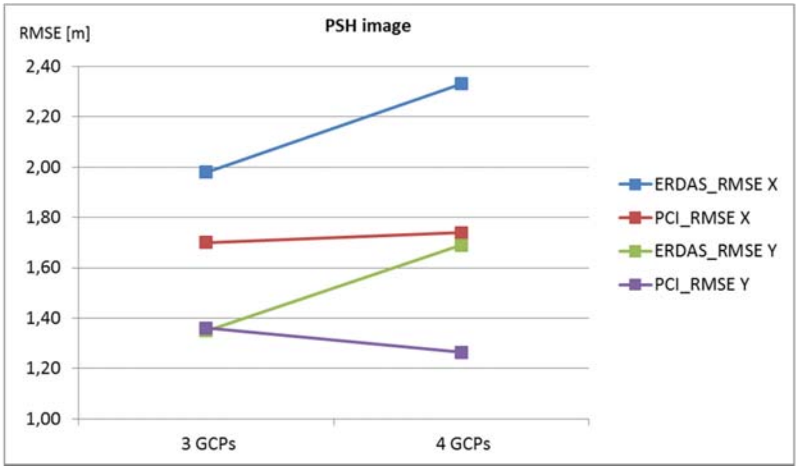


Figure 5: 1-D RMSEs measured on the PSH orthoimages derived using 0 order RPC, as a function of the number of GCPs used for modelling, displayed separately for PCI and ERDAS software.

2.3 Discussion on the number of GCPs used for the modeling

The Figure 4 and Figure 5 above could be also used to describe a change of RMSEs behaviour with the increasing number of GCPs:

- RMSEs of MSP products have in general tendency to decrease or remain equal with the increasing number of GCPs.
- As for the PSH products, the correlation depends on the software used for the production of ortho products. Erdas Imagine software is sensitive to the number of GCPs, with increasing number of GCPs the positional accuracy of ortho photos decreases. PSH products of PCI Geomatics software gives more equilibrates results, sensitivity to the number of GCPs is not so obvious, RMSEs are slightly lower when more GCPs were applied for the modelling.

2.4 Discussion on 'located" and "derived" GCPs

The tested MSP products were generated using two different sets of GCPs. The "located" set of GCPs, directly estimated over the MSP images and the "derived" set of GCPs obtained through a grid down-sampling of their positions in the corresponding PAN images. For detailed explanation see the chapter 2 Benchmarking methodology (benchmarking report). The charts below represent a comparison of both methods.

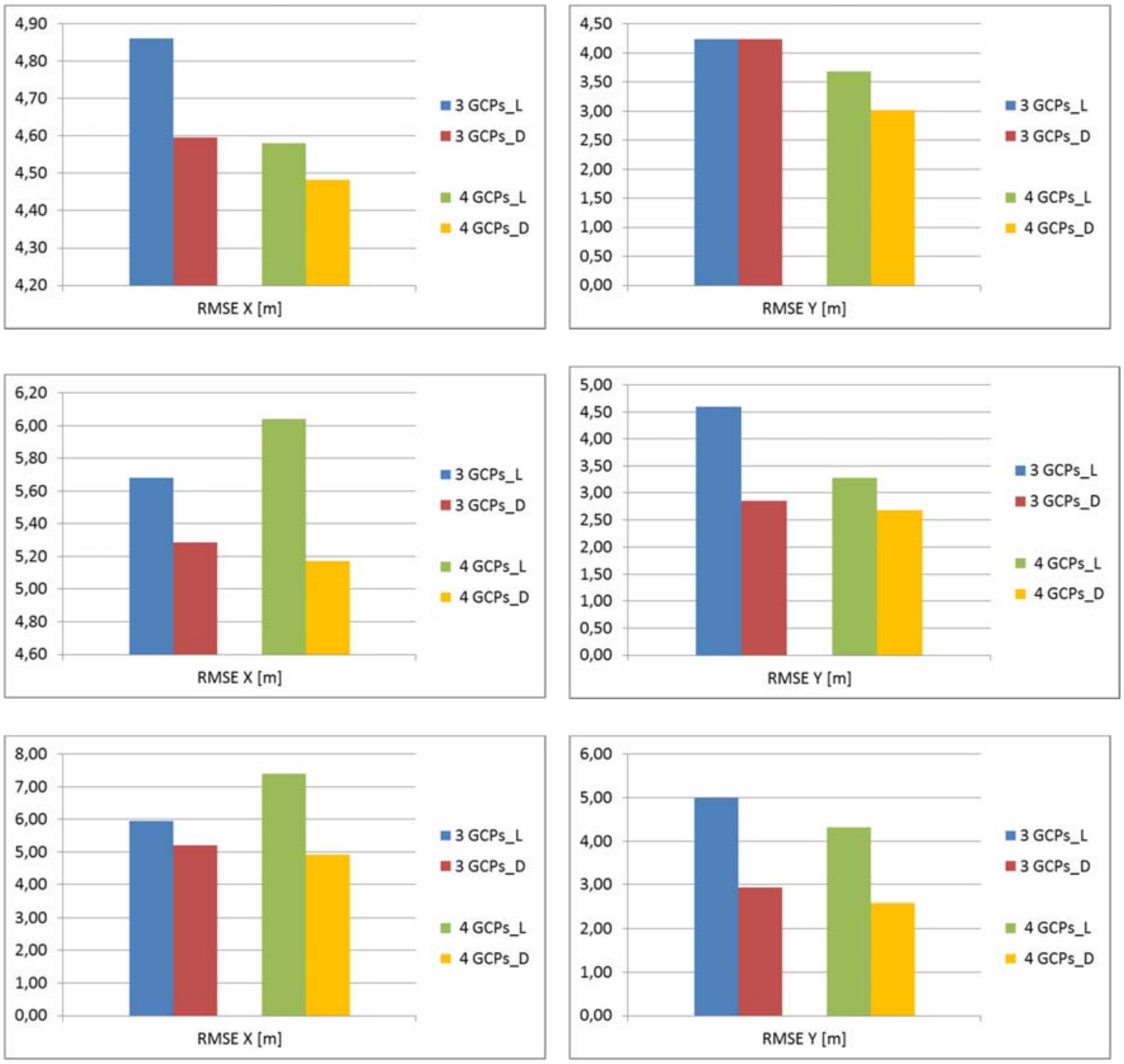


Figure 6: Graph representation of RMSEs comparison between orthoimages derived using "located" and "derived" GCPs

From up to down: 1st.line - MSP orthoimages produced by Erdas software ,0 polynomial order
2nd line - MSP orthoimages produced by PCI software, 0 polynomial order
3rd line - MSP orthoimages produced by PCI software, 1st polynomial order

Comparing the results displayed in the Figure 6 we can summarise the following finding:

- There is the clear evidence that applying "derived" GCPs during the modelling phase results in a better positional accuracy (i.e. lower RMSEs) of the final ortho products regardless of the number of GCPs or software used for the orthorectification.

2.5 Discussion on the polynomial order used for the image geometry refinement

As already mentioned in the chapter 4 Orthorectification process (benchmarking report), the orientation phase was carried out using Rational Polynomial Functions (RPFs) model with Rational Polynomial Coefficients (RPCs) supplied with the imagery metadata. Three and four GCPs were considered and two possible orientation refinements were performed, based on a shift (0 order) and an affine (1st order) transformation.

Charts below compare values measured on orthoimages produced with PCI Geomatics software[1].

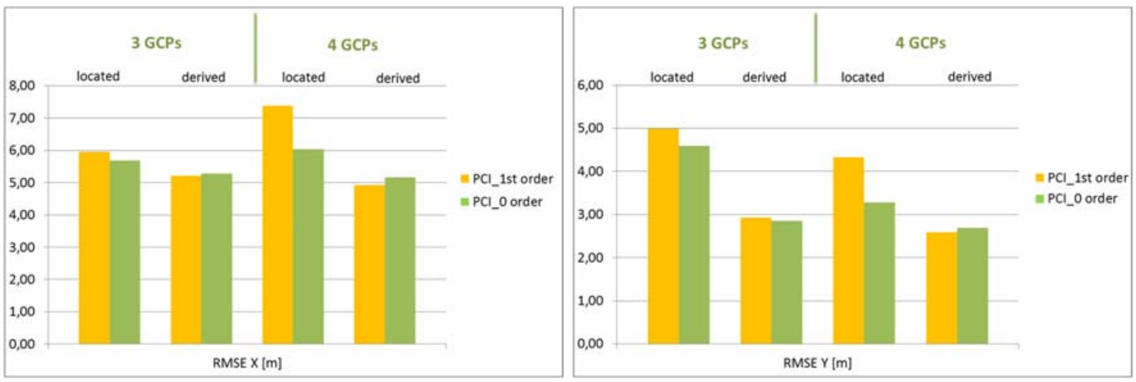


Figure 7: Graph representation of RMSEs comparison between 0 and 1st polynomial order refinement of MSP images

RMSEs measured on MSP images produced by PCI Geomatics software. From left to right: RMSEs in the easting direction, RMSEs in the Northing direction

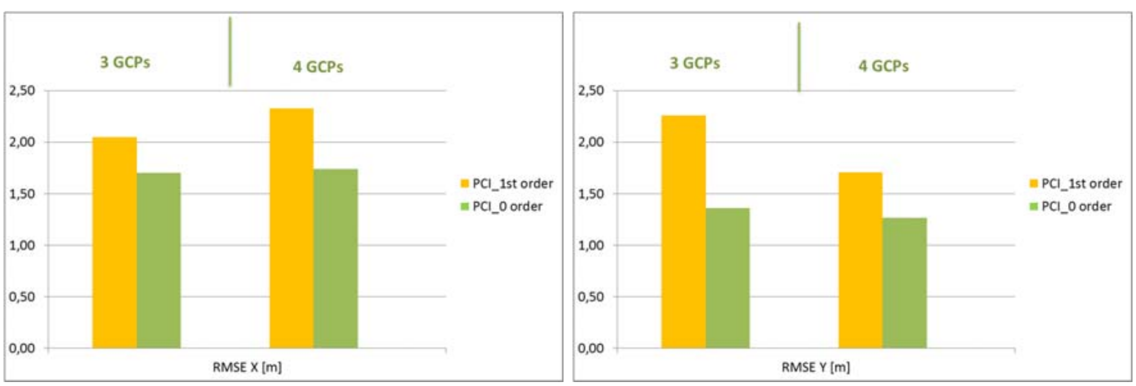


Figure 8: Graph representation of RMSEs comparison between 0 and 1st polynomial order refinement of PSH images

RMSEs measured on PSH images produced by PCI Geomatics software. From left to right: RMSEs in the easting direction, RMSEs in the Northing direction

[1] Software Erdas Imagine does not allow to use affine transformation refinement with only 3 GCPs.

Looking at the charts representing comparison between both refinement models, we can summarise the following conclusions:

- Regarding the MSP images generated with “local” GCPs, better positional accuracy is reached applying the shift refinement. More GCPs are used (i.e 3->4) for refinement the bigger differences between these two models are observed (around 1m in both directions).
- As for the MSP images generated with ”derived” GCPs, the results are very similar. The RMSEs seems not to be sensitive to the model used for the refinement.
- Better geometric accuracy of PSH ortho products is reached with the shift refinement model, regardless the number of GCPs or axis direction. The differences between the shift and affine transformation range within 0.45-0.90m.

3. Conclusions

The conclusions of this report are based on a limited sample of one image scene and should be considered as a follow up to the External quality control of SPOT 6 orthoimagery (J. Grazzini and P. Astrand, 2013)[4].

Following the findings presented in this report it is asserted that:

- The SPOT 7 MSP orthoimagery geometric accuracy meets the requirement of 9m 1D RMSE (GSD≤25m) corresponding to the F0.HR prime CwRS profile defined in the HR profile based technical specifications, on condition that RPC model and at least 3 GCPs are applied to generate the ortho product.

- The SPOT 7 MSP orthoimagery geometric accuracy meets the requirement of 9m 1D RMSE (GSD≤12m) corresponding to the F1.HHR prime CwRS profile defined in the HR profile based technical specifications, on condition that RPC model and at least 3 GCPs are applied to generate the ortho product.

- The SPOT 7 PAN orthoimagery geometric accuracy meets the requirement of 5m 1D RMSE (GSD≤3m) corresponding to the F1.HHR prime CwRS profile defined in the HR profile based technical specifications, on condition that RPC model and at least 3 GCPs are applied to generate the ortho product.

- The SPOT 7 PSH orthoimagery geometric accuracy meets the requirement of 3m 1D RMSE (GSD≤5m) corresponding to the F0.HR prime CwRS profile defined in the HR profile based technical specifications, on condition that RPC model and at least 3 GCPs are applied to generate the ortho product.

- The SPOT 7 PSH (PAN) orthoimagery geometric accuracy meets the requirement of 5m 1D RMSE (GSD≤3m) corresponding to the E. VHR backup profile defined in the VHR profile based technical specifications, on condition that RPC model and at least 3 GCPs are applied to generate the ortho product.

- The SPOT 7 Reference3D based PSH orthoimagery (Astrium's "in house" product produced with Pixel Factory software) geometric accuracy meets the requirement of 5m 1D RMSE (GSD≤3m) corresponding to the F2.HHR prime CwRS [ORTHO] profile defined in the HR profile based technical specifications.

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

- With respect to CAP checks purposes, both software packages (PCI Geomatics and ERDAS Imagine) suite for the orthoimage generation.

- The tested ortho products fulfil the CAP requirements as soon as at least 3 GCPs is applied. The increasing number of GCPs does not have any substantial effect on the positional accuracy of ortho products.

- There is clear evidence that the exploitation of a high resolution PAN band to localise a position of GCPs on a MSP image improves the final geometric accuracy of the product. It is therefore recommended to fully benefit from the high-resolution spatial information of bundle (PAN+MSP) products and use "derived" GCPs

- It appears that having 3 or 4 GCPs, RPF model together with a shift refinement is more suitable for an ortho-correction process of SPOT 7 images than RPF model in combination with an affine transformation. However the decision on which polynomial order use for the refinement very depends on the number of GCPs available, their quality and distribution over the whole scene.

All above mentioned findings and conclusions are in accordance with the External quality control of SPOT 6 orthoimagery (J. Grazzini and P. Astrand, 2013)[4] and confirm that SPOT 7 products fit to various technical profiles (details above) defined within the CAP checks.

European Commission
EUR 27063 – Joint Research Centre – Institute for Environment and Sustainability

Title: Benchmarking report on SPOT 7 sensor

Authors: Vincent Parage, Blanka Vajsova, Nathalie Faget, Pär Johan Åstrand

Luxembourg: Publications Office of the European Union

2015 – 36 pp. – 21.0 x 29.7 cm

EUR – Scientific and Technical Research series – ISSN 1831-9424

ISBN 978-92-79-45053-2

doi:10.2788/17914

LB-NA-27063-EN-N

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ISBN 978-92-79-45053-2

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