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New sensors benchmark report on Sentinel-2B

Geometric benchmarking test for CAP purposes

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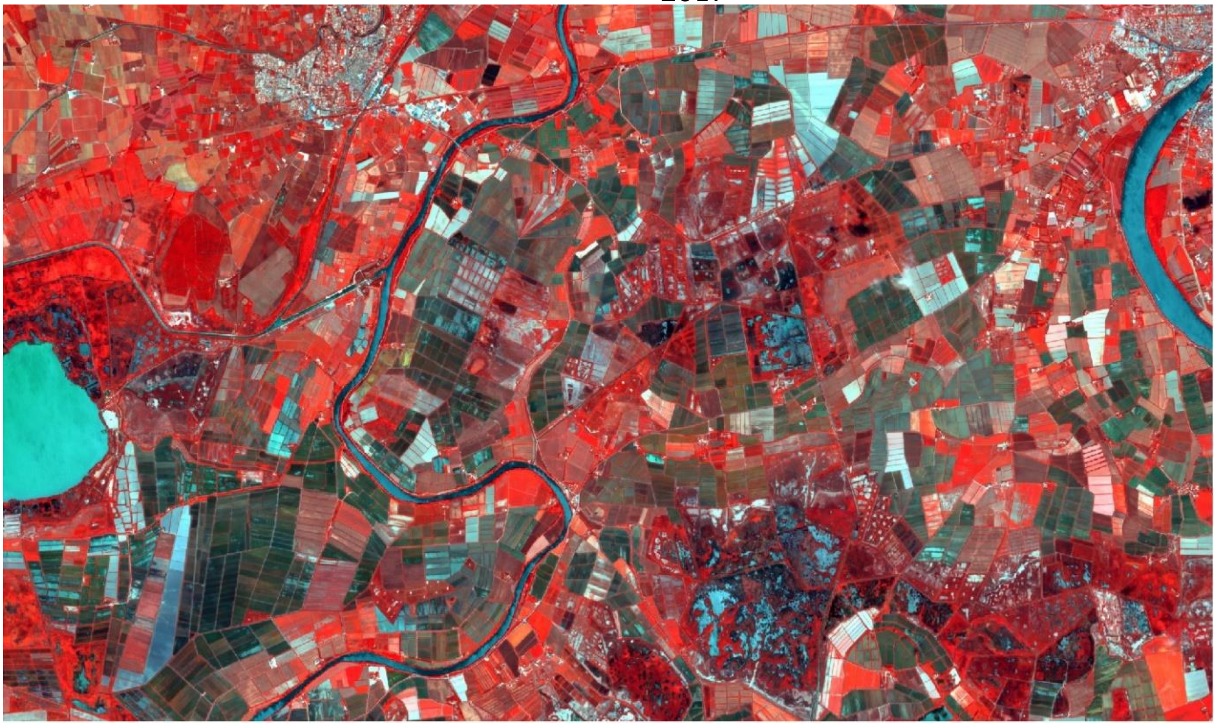
2017



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Contents

Abstract

The main objective of the report is to assess whether images produced by Sentinel-2B sensor are suitable for usage in Control with Remote Sensing programme, specifically in the Common Agriculture Policy (CAP). The benchmarking presented herein aims at evaluating the usability of Sentinel-2B images for the CAP checks through an estimation of its geometric (positional) accuracy. Tests have been performed on Sentinel-2B data from the first pre-operational phase (June 2017), subsequently on data from the pre-operational hub (July 2017). See chapter 2.1.

For that purpose, the External Quality Control of Sentinel-2B orthoimagery conforms to the standard method developed by JRC and follows a procedure already adopted in the validation of previous high and very-high resolution products.

1 Introduction

The Common Agriculture Policy (CAP) uses the "Controls with Remote Sensing" (CwRS) as one of control systems to check whether aids given to European farmers are correctly granted.

Each newly launched satellite which is going to provide image data for the purpose of CAP checks has to pass a validation test to prove a fulfilment of CwRS requirements [ref. ii, iii]. This geometric validation is based on the External Quality Control (EQC) of the orthoimagery and follows strict guidelines described by JRC in the so-called "Guidelines for Best Practice and Quality Checking of Ortho Imagery" [i].

Within this context, the purpose of the current technical report is to perform a quality assessment with respect to the capabilities of the newly launched Sentinel-2B satellite, which is an identical twin of Sentinel-2A [iv]. This report is therefore a continuation of New sensors benchmark report on Sentinel-2A where all details about the Sentinel-2 mission are mentioned including satellite characteristics and products [xiii].

1.1 Objective

The aim of this report is to summarize the outcome of the geometric quality testing of the Sentinel-2B images acquired over several testing zones over Europe.

The objective of this study is twofold:

- to evaluate the planimetric accuracy of the orthorectified Sentinel-2B imagery;
- to check if the orthorectified imagery of the Sentinel-2B meet the CAP CwRS Programme technical requirements.

Namely, the sensor requirement implies that the planimetric accuracy of the orthoimagery, expressed as the Root-Mean-Square Error (RMSE) in Easting and Northing directions, should not exceed 1.5xGSD=15m to fulfil the geometric requirements and specifications of HR prime profile and HHR ortho profile defined in the HR profile based technical specifications for the CAP checks [iii].

1.2 Sentinel-2 mission

Sentinel-2B satellite is a duplication of Sentinel-2A satellite. For all details regarding the satellite design, specifications, products and formats see ESA's website [iv] or New sensors benchmark report on Sentinel-2A [xiii].

2 Testing scenario

2.1 Timeline

- First Sentinel-2B image was acquired on 15/03/2017.
- In-Orbit Commissioning Review (IOCR) passed successfully on 15/6, i.e. operations were passed on from launch to mission managers
- Sentinel-2B pre-operational data were made available on the 31st of May to QWG members for a preliminary evaluation and feedback
- S2B public dissemination started in July 2017. From mid July, the S2B acquisition pattern is supposed to be equivalent to the current S2A

The first part of the geometric assessment consists of an evaluation performed on imagery coming from a very early pre-operational phase. This preliminary benchmark covers products that were made available to QWG members in June 2017.

Results from the preliminary study based on June's products were presented at the 3rd Sentinel-2 Quality Working Group held at ESA-ESRIN, 20th and 21st of June 2017.

Starting from July 2017 Sentinel-2B products have been available for download from Sentinel-2B Pre-operational Hub: pre-operational access point for all users to Sentinel-2B [xiv]. Products acquired during July make a second part of the geometric benchmarking test.

2.2 Methodology

For external geometric quality assessment of Sentinel-2B imagery both absolute and relative geometric accuracy were assessed.

Relative geometric accuracy is calculated on basis of residuals that are measured on ICPs retrieved from another already orthorectified image of known positional accuracy. This positional accuracy expressed by RMSE as well as a pointing error that could encumber retrieved coordinates has to be taken into account when assessing the final results.

Absolute geometric accuracy is based on ICPs that were measured directly in a field by GNSS device.

2.3 Sentinel-2 Geometric Quality Requirements

According the Sentinel-2 Calibration and Validation Plan for the Operational Phase [viii] the requirements on geometric quality are following:

- A priori absolute geolocation uncertainty:

  The a priori uncertainty of image location (i.e. before performing any processing) shall be better than 2km (3σ)

- Absolute geolocation uncertainty of Level-1B data :

  The geo-location uncertainty of Level-1B data with respect to a reference ellipsoid shall be better than 20 m at 2σ confidence level without the need of any GCP.

- Absolute geolocation uncertainty of Level-1C data :

  The geo-location uncertainty of Level-1C data with respect to a reference map shall be better than 12.5 m at 2σ confidence level with the need of GCPs.

2.4 Test sites

Figure 1. Location of tested sites

2.4.1 Maussane test site

The geometric quality assessment of the Sentinel-2B image data was performed over a standard test site of Maussane, located in French commune Maussane-les-Alpilles in the Provence-Alpes-Cote d'Azur region in southern France.

The site has been used by JRC for the geometric benchmarking of High Resolution (HR) and Very High Resolution (VHR) imagery since 1997.

Both absolute and relative accuracy were calculated over this zone.

2.4.2 Selected LPIS QA zones from 2016

Satellite imagery is supplied by the Commission to the Member States for use within the 'On The Spot Checks' (OTSC) of direct payment claims made by farmers, and for the LPIS Quality Assurance (QA). There are high quality requirements on LPIS QA, GSD<50cm, ELA>80°, haze an cloud free, and that's why it was decided to re-use such orhto-image datasets for geometry benchmarking purposes as basis for ICPs extraction.

In total 3 images were picked from the 2016 LPIS QA Image Campaign to serve as such reference images for ICPs selection. The only criteria for the site selection was the availability of Sentinel 2B data with a minimal cloud cover.

3 Input datasets

3.1 ICPs used for test

3.1.1 Datasets used over the test site Maussanne

3.1.1.1 JRC dataset of points

For the evaluation of the geometric accuracy of the Sentinel-2B ortho imagery, the same 20 independent ICPs were used as for Sentinel-2A assessment. That was done for best comparison of results.

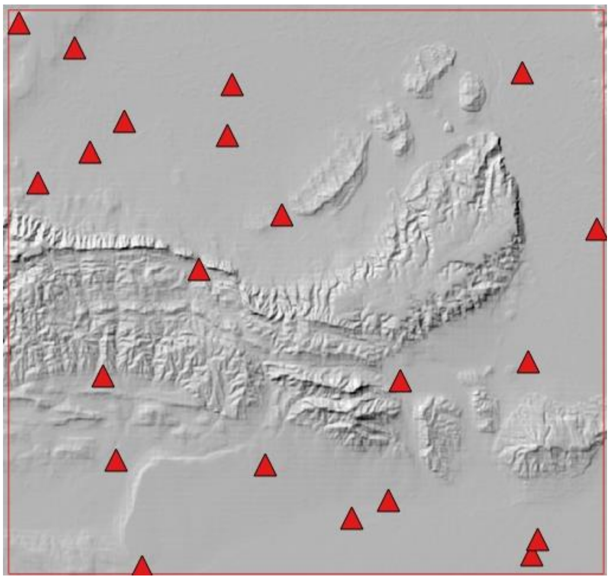
ICPs were retrieved from datasets of differential global positioning system (DGPS) measurements over Maussane test site, which are updated and maintained by JRC.

Table 1 Ground Control Points available for the Maussane test site

Dataset	Point ID	RMSEx [m]	RMSEy [m]	Number of points
GPS measurement for ADS40 project (2003)	11XXXX	0,05	0,10	7d
GPS measurement for Cartosat-1 project (2006)	33XXX	0,55	0,37	2
GCP dataset for Formosat-2 project (2007)	7XXX	0,88	0,72	5
GCP dataset for Cartosat-2 project (2009)	55XXX	0,90	0,76	5
GNSS field campaign 2012	CxRx	<0,15	<0,15	1

As regards to the positional accuracy of ICPs, according to the Guidelines (Kapnias et al., 2008) [i] the ICPs should be at least 3 times more precise than the target specification of the orthoproduct, i.e. in our case of a target 15 m RMS error the ICPs should have a specification of 5.0m (3m recommended). All ICPs that have been selected therefore fulfil the defined criteria (Table 1).

Figure 2.ICPs dataset used by JRC over Maussane test site to calculate the absolute geometric accuracy of Sentinel-2B ortho imagery



3.1.1.2 ICPs retrieved from SPOT 7 ortho image

To support the absolute geometric accuracy results calculated on the basis of ground true coordinates (measured in the field), also the relative geometric accuracy was considered.

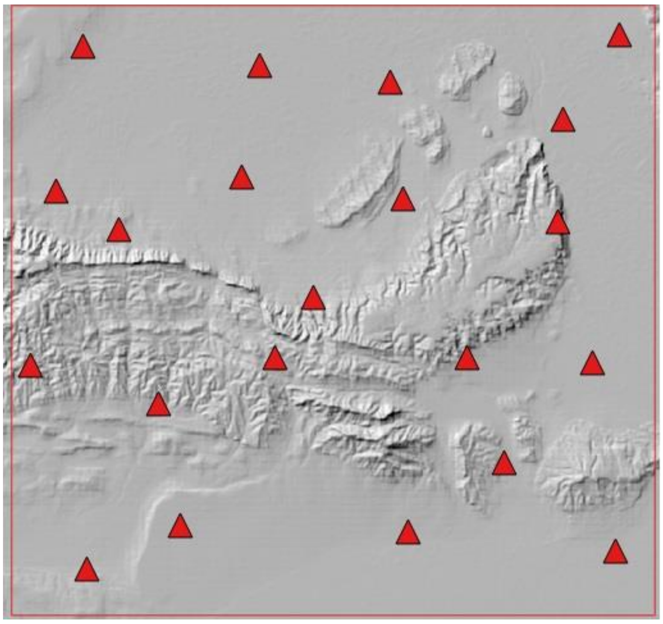
The following ortho product was used as reference data:

- SPOT 7 ortho image of max RMSE of 4.50m and pixel size of 1.5m.

Table 2: Basic metadata of reference image data used for relative geometric accuracy calculation

Sensor	Product	Collection date of the original image	Off nadir angle of the original image	Method used to orthorectify the original image
SPOT 7	PSH	03/10/2014	20.35˚	RPC, 4GCPs

Figure 3.ICPs dataset used by JRC over Maussane test site to calculate the relative geometric accuracy of Sentinel-2B ortho imagery



Due to comparative reasons also for relative accuracy calculations the same image and the same points were applied as for the Sentinel-2A geometry benchmark.

3.1.2 Datasets used over LPIS QA zones 2016

Over these zones only relative geometric accuracy was calculated.

The following ortho products were used as reference data:

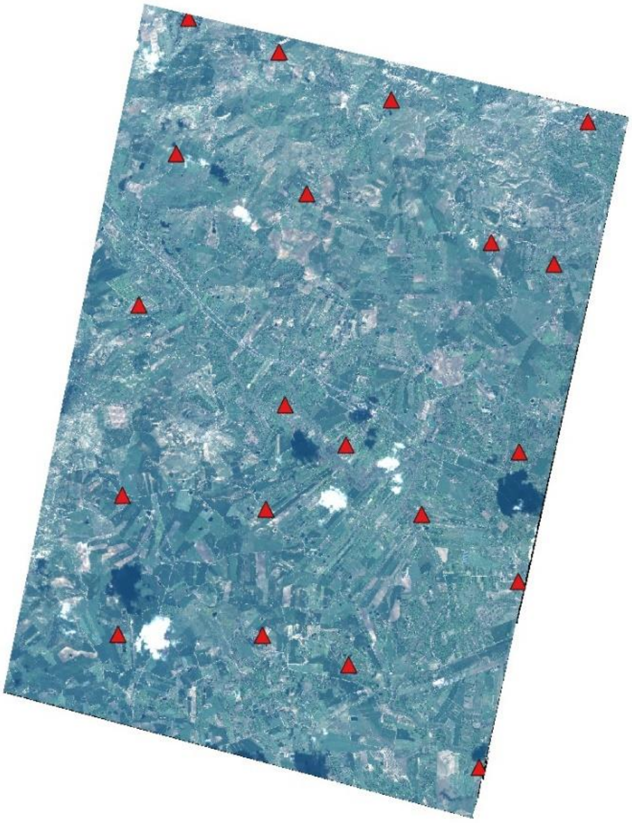
- WV2 ortho image of max RMSE of 1.25m and pixel size of 0.5m.

Table 3: Basic metadata of reference image data used for relative geometric accuracy calculation

Sensor	Product	Name	Area [km^2]	Collection date of the original image	Off nadir angle of the original image
WV2	PSH	HU_3	225	02/07/2016	88.5°
WV2	PSH	IT_1	225	01/03/2016	79°
WV2	PSH	IT_4	225	18/03/2016	87.5°

Figure 4.ICPs datasets used by JRC over chosen LPIS sites to calculate the relative geometric accuracy of Sentinel-2B ortho imagery.

From up to down: HU_3, IT_1, IT_4



3.2 Sentinel-2B data tested

Samples of the Sentinel-2B imagery used for testing were collected in June 2017 (sample for a preliminary evaluation) and July 2017 (after in orbit corrections), however during the satellite's pre-operational phase. For more details, see chapter 5.4.

Altogether 13 image scenes in the L1C product have been downloaded and tested. Basic metadata of each image can be found in the Annex A at the end of the document.

4 Quality characteristics

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

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

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

where $X,Y_{REG(i)}$ are ortho imagery derived coordinates, $X,Y_{(i)}$ are the ground true coordinates, n express the overall number of ICPs used for the validation.

This geometric accuracy representation is called the positional accuracy, also referred to as planimetric/horizontal accuracy and it is therefore based on measuring the residuals between coordinates detected on the orthoimage and the ones measured in the field or on a map of an appropriate accuracy [xii].

According to ISO 19157, the circular error at 90% CE(90) significant level (or confidence interval) is defined as a radius describing a circle, in which the true point location lies with the probability of 90 %. It is also known as CMAS (circular map accuracy standard).

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

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

$$\mathrm{CE}(90) = 2{,}146 * RMSE_{(East)} \quad \text{or} \quad \mathrm{CE}(90) = 2{,}146 * RMSE_{(North)}$$

Unlike the values obtained from the field measurements (in our case with GPS device) which are of the defined accuracy the coordinates registered from the involved 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 were carried out in ERDAS Imagine 2016 software, using Metric Accuracy Assessment. Protocols from the measurements contain other additional indexes like mean errors or error standard deviation that can also eventually help to better describe the spatial variation of errors or to identify potential systematic discrepancies [i].

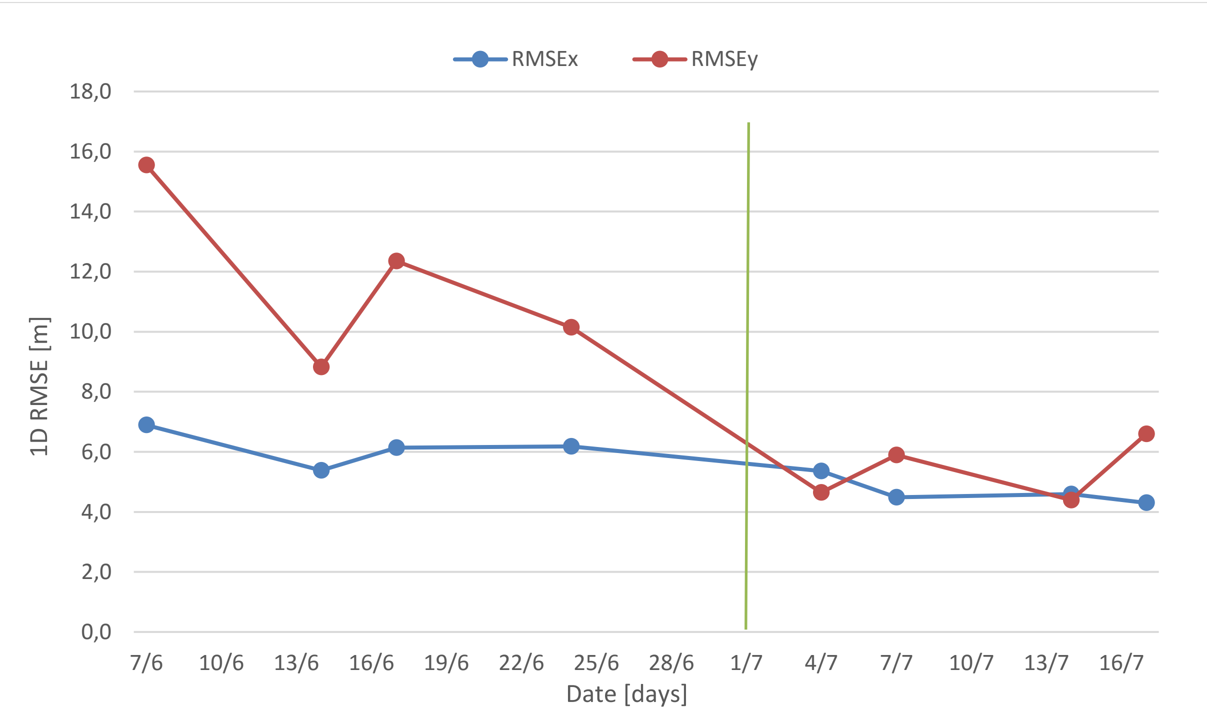
5 Outcome

5.1 Absolute geometric accuracy

Table 4 Results of absolute $RMSE_{1D}$ calculations based on GNSS measurements over the Maussane test site (June-July)

Date	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
07/06/2017	R008	6,89	15,55	25,81
14/06/2017	R108	5,38	8,82	15,67
17/06/2017	R008	6,14	12,36	20,94
24/06/2017	R108	6,18	10,15	18,03
04/07/2017	R108	5,36	4,64	10,76
07/07/2017	R008	4,49	5,90	11,24
14/07/2017	R108	4,59	4,39	9,64
17/07/2017	R008	4,30	6,60	11,95
24/07/2017	R108	Image too cloudy		

Figure 5 Behaviour of absolute RMSEs in function of time



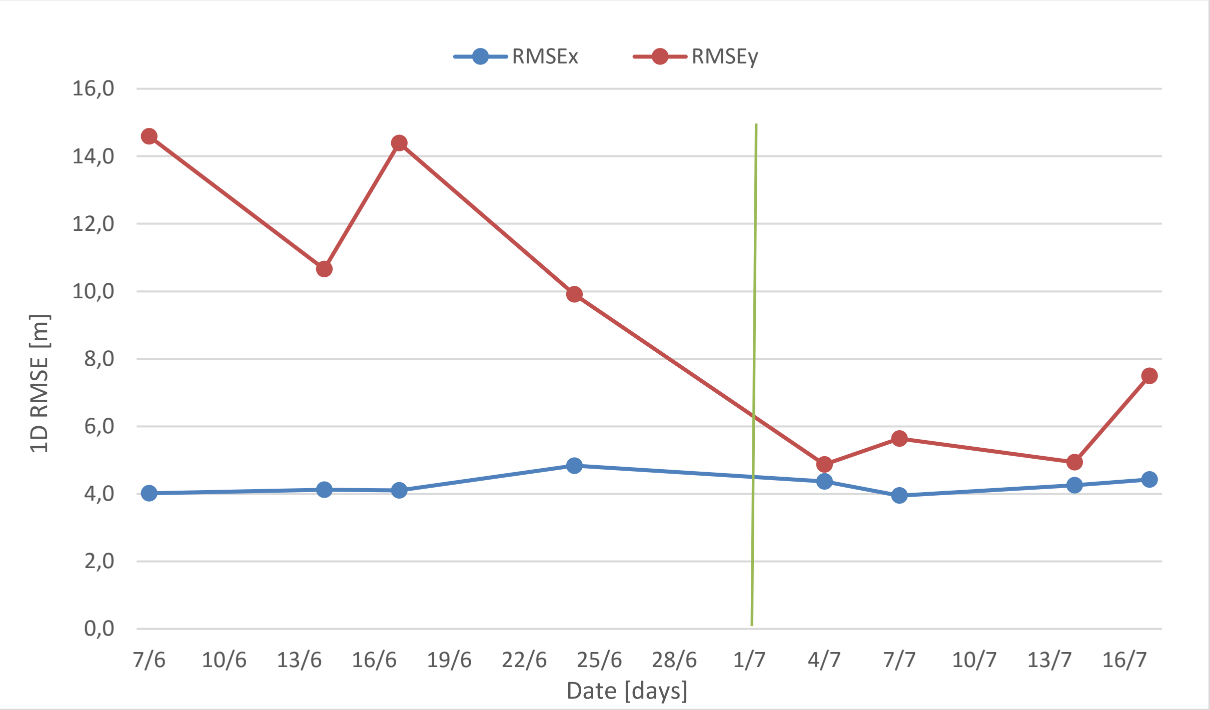
5.2 Relative geometric accuracy

5.2.1 Relative accuracy based on SPOT 7 image

Table 5 Results of relative $RMSE_{1D}$ calculations based on SPOT 7 ortho image measurements over the Maussane test site (June-July)

date	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
07/06/2017	R008	4,01	14,59	22,97
14/06/2017	R108	4,12	10,66	17,34
17/06/2017	R008	4,11	14,39	22,70
24/06/2017	R108	4,84	9,91	16,74
04/07/2017	R108	4,37	4,87	9,92
07/07/2017	R008	3,95	5,64	10,44
14/07/2017	R108	4,25	4,93	9,88
17/07/2017	R008	4,42	7,50	13,21

Figure 6 Behaviour of relative RMSEs in function of time



5.2.2 Relative accuracy based on WV2 images

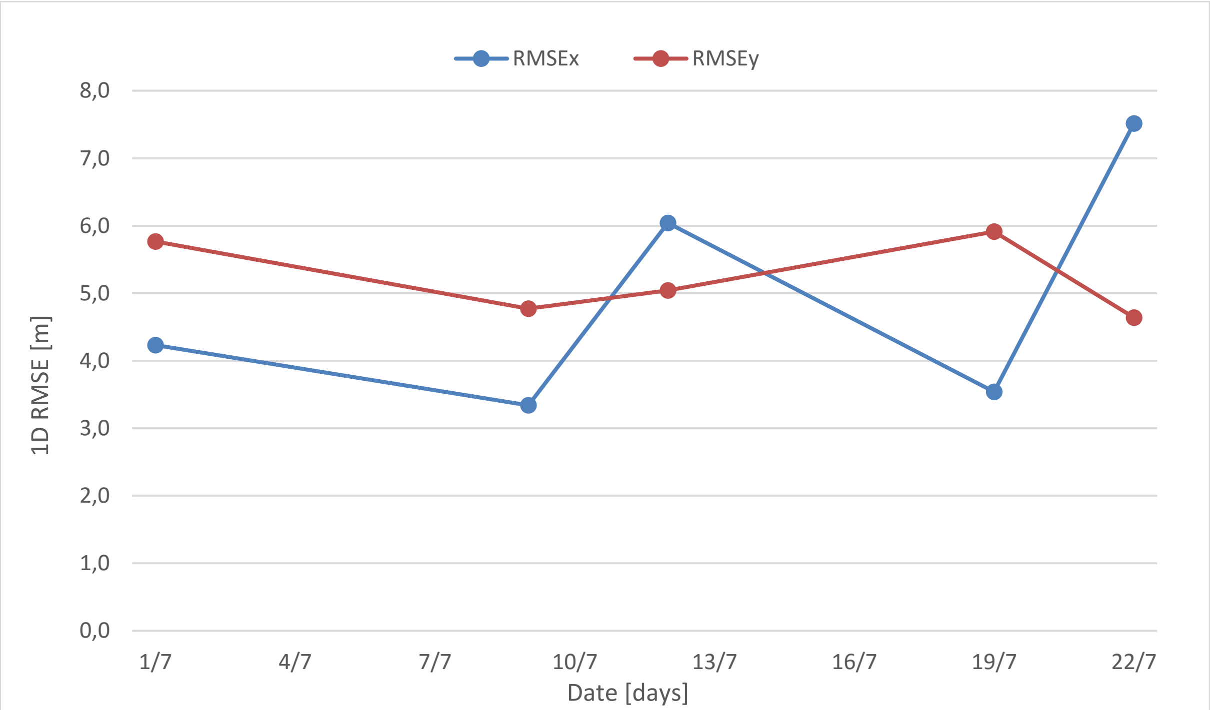
Table 6 Results of relative $RMSE_{1D}$ calculations based on WV2 ortho images measurements over selected 2016 LPIS sites (July only)

		LPIS zone 2016 IT_4 (WV2)		
date	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
12/07/2017	R079	6,04	5,04	11,94
22/07/2017	R079	7,52	4,64	13,40

		LPIS zone 2016 IT_1 (WV2)		
date	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
01/07/2017	R065	4,23	5,77	10,85

		LPIS zone 2016 HU_3 (WV2)		
date	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
09/07/2017	R036	3,34	4,77	8,84
19/07/2017	R036	3,54	5,91	10,46

Figure 7 Behaviour of relative RMSEs in function of time



5.3 Comparison with Sentinel-2A

Figure 8 Comparison of absolute RMSEs between Sentinel-2A and Sentinel-2B

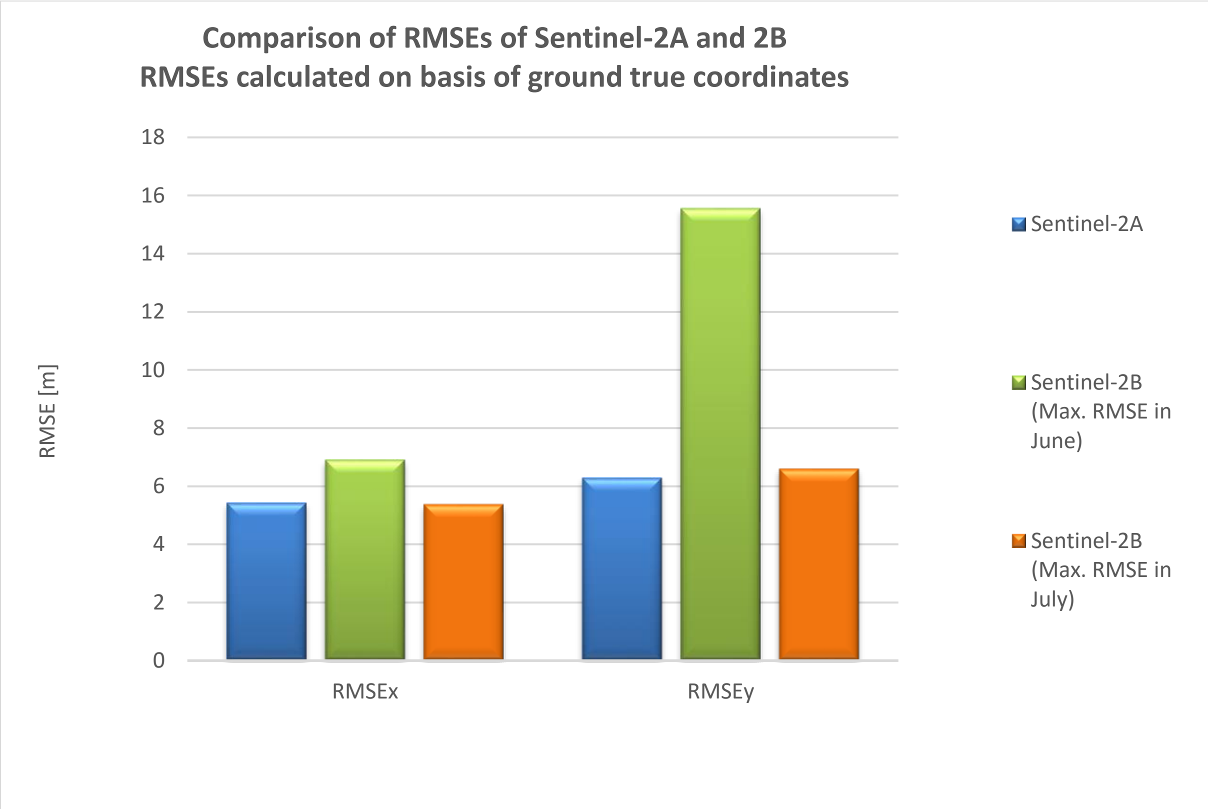
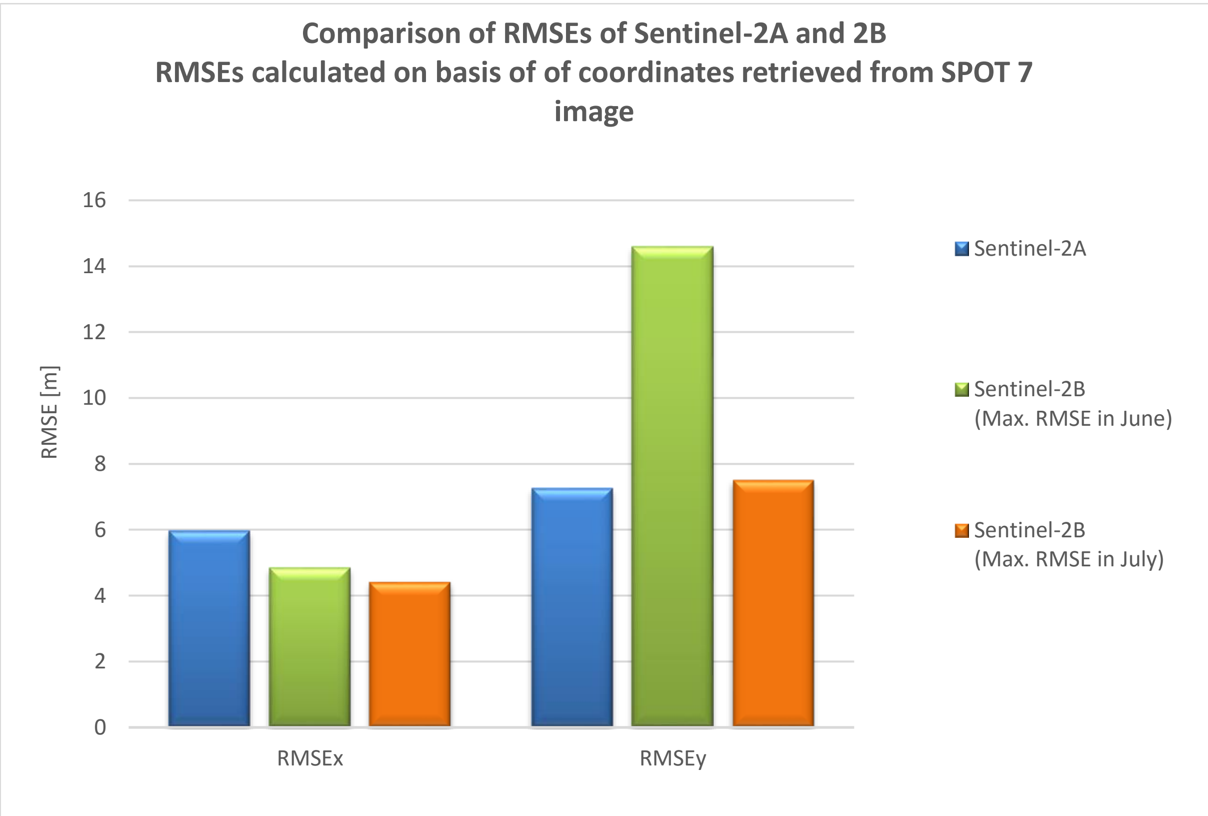
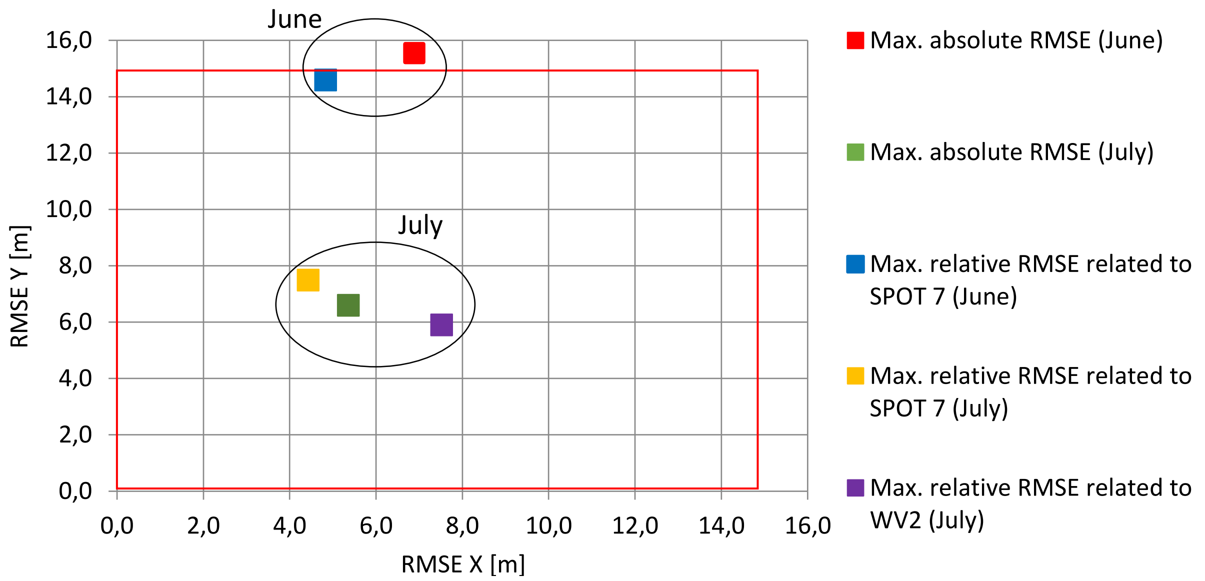


Figure 9 Comparison of relative RMSEs between Sentinel-2A and Sentinel-2B



5.4 Discussion



Sentinel-2B geometric accuracy performed on the early pre-operational dataset acquired in June and tested over the JRC test Maussane was showing a systematic larger deviation along track direction. This slight deviation of geometric quality was not fully in line with the high geometric accuracy reported at IOCR however still in line with the Sentinel-2 MRD [xvi] requirements. After reporting to ESA at QWG meeting on 20-21/06/2017 and their further investigation it was found that the reason of this geolocation deviation comes from the evolution of the instruments pitch and roll (both in time and as a function of latitude). The small deviations observed by JRC and confirmed by MPC showed that more frequent updates of the processing chain settings are required than initially foreseen [xv].

After such optimization (end of June), another set of images acquired in July was tested. All RMSEs calculated for this dataset resulted below one pixel. The relative geometric accuracy values supported these good absolute geometric accuracy results.

Looking at figures **Figure 8** and **Figure 9** we can summarize that the geometry accuracy performance (July) is comparable and at the same level as Sentinel-2A.

6 Conclusions and prospects

The following conclusions are derived from July's dataset.

The geolocation performance of the Sentinel-2B's L1C product is good. The absolute geolocation performance (see Table 4) is set by

- max RMSEx=5.36m and max RMSEy=6.60m
- max CE(90)=11.95m

As far as the validation of the Sentinel-2B, L1C product, is concerned, based on the presented results, following conclusion are made for the CAP CwRS:

- The Sentinel-2B, L1C product geometric accuracy meets the requirement of (1.5xGSD) 15 m 1D RMSE corresponding to the HR prime profile defined in the HR profile based technical specifications.

- The Sentinel-2B, L1C product geometric accuracy meets the requirement of (1.5xGSD) 15 m 1D RMSE corresponding to the HHR ortho multispectral profile defined in the HR profile based technical specifications.

The Sentinel-2B data are available to all users via a dedicated pre-operational S2B data Hub: https://scihub.copernicus.eu/

As mentioned in Data Quality Report (01/01/2017)[xvii] "the attitude reference bias of Sentinel-2B is still evolving as a result of post-launch effect. This evolution must be compensated by regular updates of the geometric calibration". As Sentinel-2B is not yet stabilised, its geolocation performance is not officially reported by ESA yet. A first performance estimate is planned for the next issue of the Data quality Report (DQR in September).

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List of abbreviations and definitions

AOI	Area of Interest
CAP	The Common Agricultural Policy
CE90	Circular Error of 90%
DEM	Digital Elevation Model
DQR	Data Quality Report
DSM	Digital Surface Model
EO	Earth Observation
EPSG	European Petroleum Survey Group
EQC	External Quality Control
ESA	European Space Agency
GCP	Ground Control Point
GNSS	Global Navigation Satellite System
GRI	Global Reference Image
GPS	The Global Positioning System
GSD	Ground Sample Distance
HR	High resolution
IOCR	In-Orbit Commissioning Review
IPC	Independent Check Point
JRC	Joint Research Centre
LE90	Linear Error of 90%
LPIS	Land Parcel Information System
LPIS QA	Land Parcel Information System Quality Assurance
LVLH	Local Vertical/Local Horizontal
MPC	Mission Performance Centre
MRD	Mission Requirements Document
MS	Multispectral
MSI	Multispectral Imager
OD	Orbit Determination
ONA	Off Nadir Angle
PAN	Panchromatic
POD	Precision Orbit Determination
RMSE	Root Mean Square Error
RPC	Rational Polynomial Coefficient
S2B	Sentinel-2B
UTM	Universal Transverse Mercator
VHR	Very High Resolution
WGS 84	World Geodetic System 1984
1-D	One-dimensional

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Annex A Basic Metadata of tested Sentinel-2B images

Image id (internal image id)	S2B_MSIL1C_20170607T104019_ N0205_R008_T31TFJ	
Product level	Level 1C	
Product Type	MSP	
Collection date	07/06/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	JPEG 2000	
Bits Per Pixel	12	

Image id (internal image id)	S2B_MSIL1C_20170614T103019_ N0205_R108_T31TFJ	
Product level	Level 1C	
Product Type	MSP	
Collection date	14/06/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	JPEG 2000	
Bits Per Pixel	12	

Image id (internal image id)	S2B_MSIL1C_20170617T104019_ N0205_R008_	
Product level	Level 1C	
Product Type	MSP	
Collection date	17/06/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	JPEG 2000	
Bits Per Pixel	12	

Image id (internal image id)	S2B_MSIL1C_20170624T103019_ N0205_R108_T31TFJ	
Product level	Level 1C	
Product Type	MSP	
Collection date	24/06/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	JPEG 2000	
Bits Per Pixel	12	

Image id (internal image id)	S2B_MSIL1C_20170704T103019_ N0205_R108_T31TFJ	
Product level	Level 1C	
Product Type	MSP	
Collection date	04/07/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	JPEG 2000	
Bits Per Pixel	12	

Image id (internal image id)	S2B_MSIL1C_20170707T104019_N0205_R008_T31TFJ
Product level	Level 1C
Product Type	MSP
Collection date	07/07/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	JPEG 2000
Bits Per Pixel	12

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Product level	Level 1C
Product Type	MSP
Collection date	14/07/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	JPEG 2000
Bits Per Pixel	12

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Product level	Level 1C
Product Type	MSP
Collection date	17/07/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	JPEG 2000
Bits Per Pixel	12

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Product level	Level 1C
Product Type	MSP
Collection date	12/07/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	JPEG 2000
Bits Per Pixel	12

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Product Type	MSP
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Ellipsoid Type/Projection	WGS-84/UTM, N31
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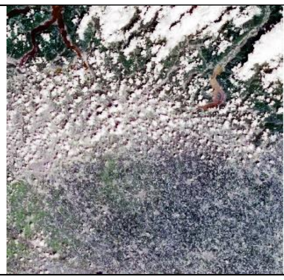
Image id (internal image id)	S2B_MSIL1C_20170701T102029_ N0205_R065_T32TNR	
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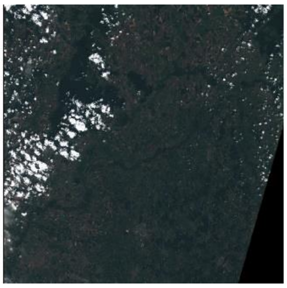
Image id (internal image id)	S2B_MSIL1C_20170709T094029_ N0205_R036_T34UEU	
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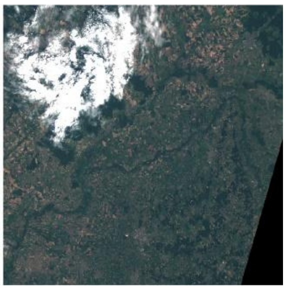
Image id (internal image id)	S2B_MSIL1C_20170719T094029_ N0205_R036_T34UEU	
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Annex B Circular errors calculated at 90% level of confidence CE(90)

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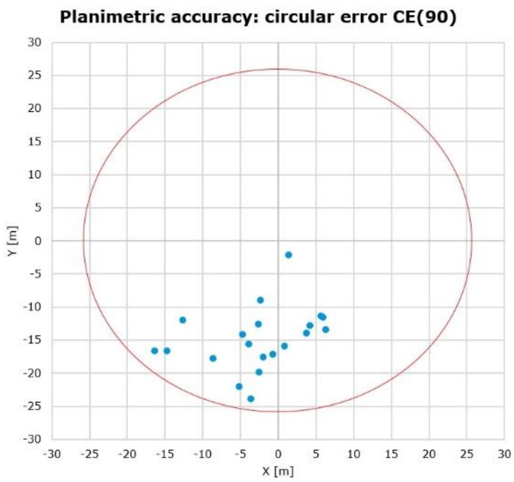
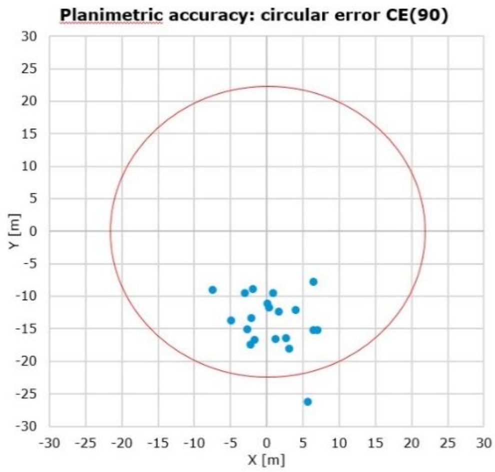
<tr><td>
</td><td>
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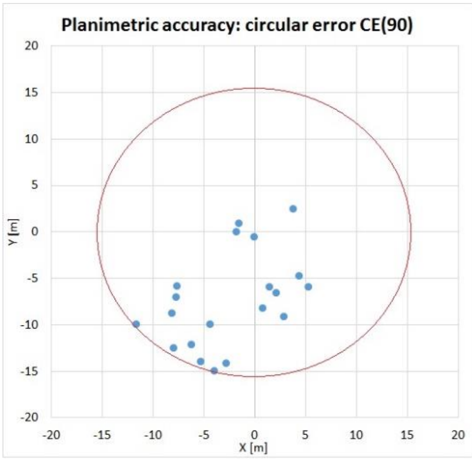
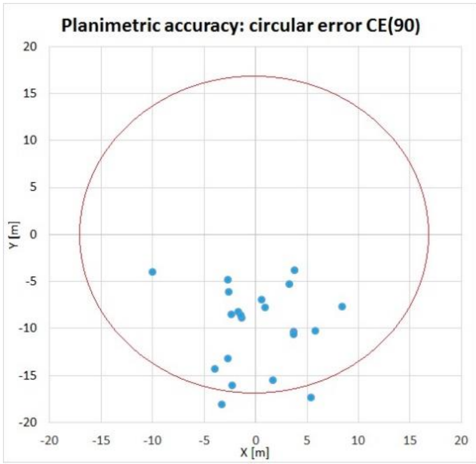
<tr><td>
</td><td>
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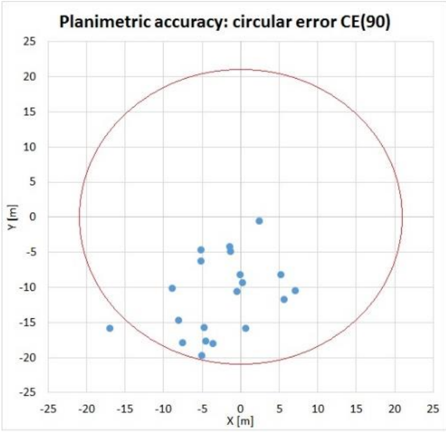
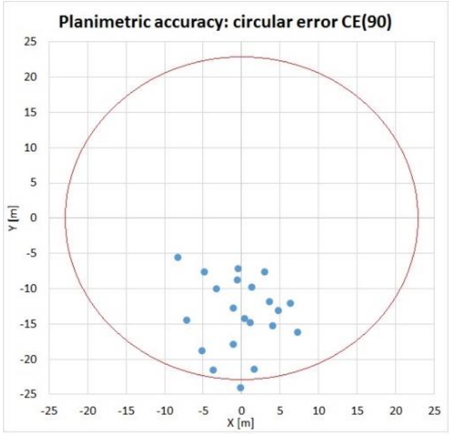
GNSS measurements	SPOT 7 as reference image
17/06/2017	
see below	see below
24/06/2017	

17/06/2017 — GNSS measurements



17/06/2017 — SPOT 7 as reference image



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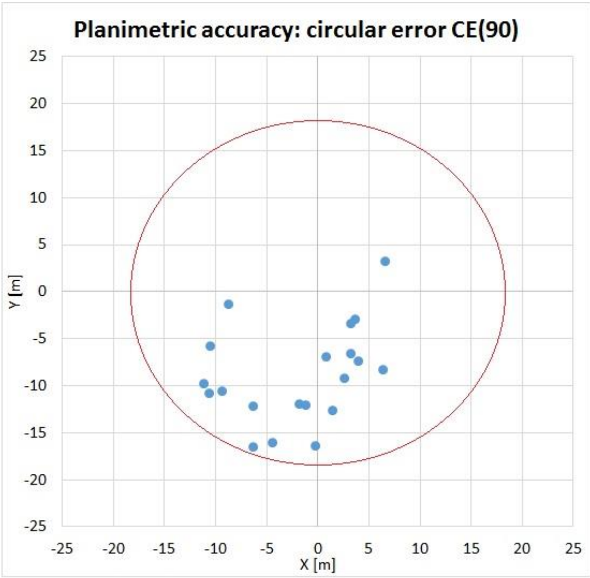

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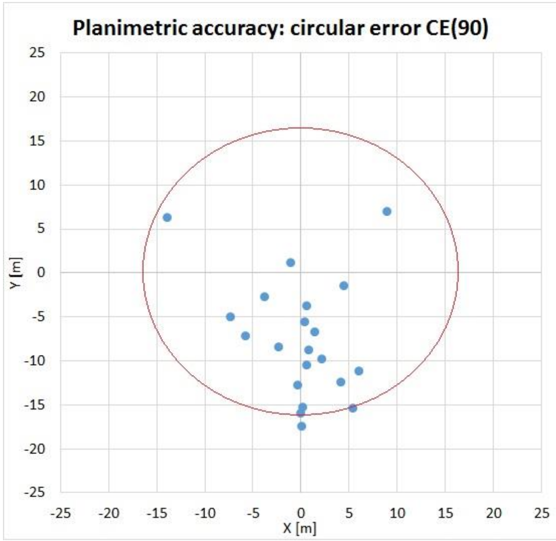

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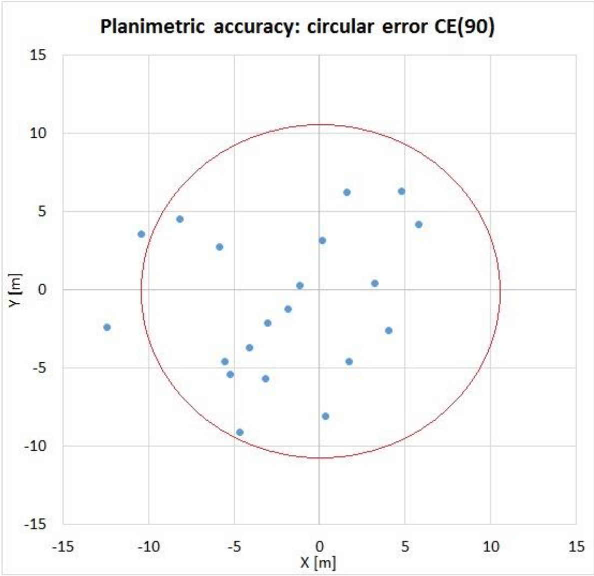
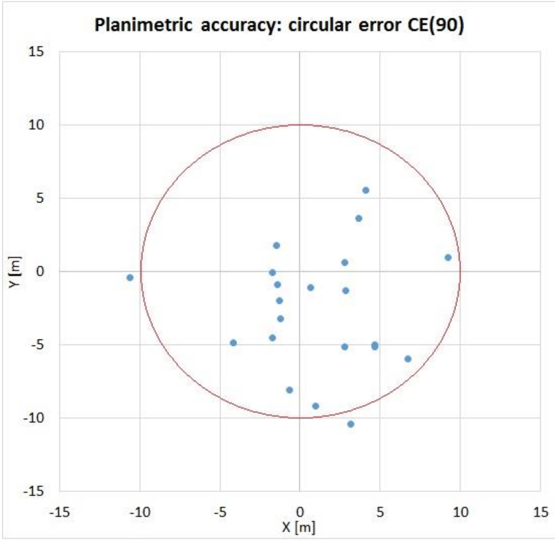
<tr><td>
</td><td>
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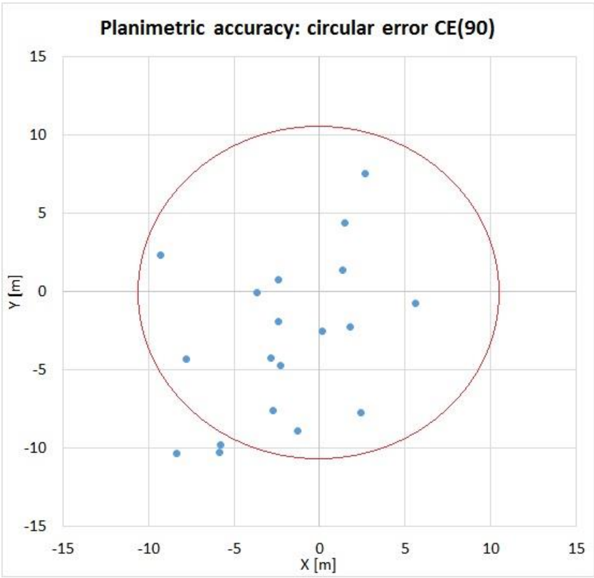
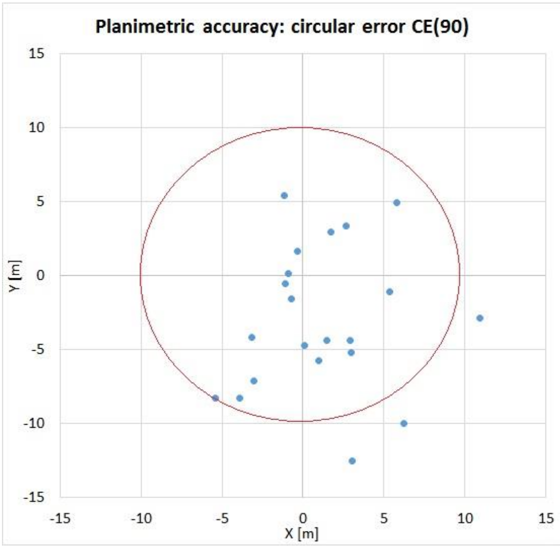
<tr><td>
</td><td>
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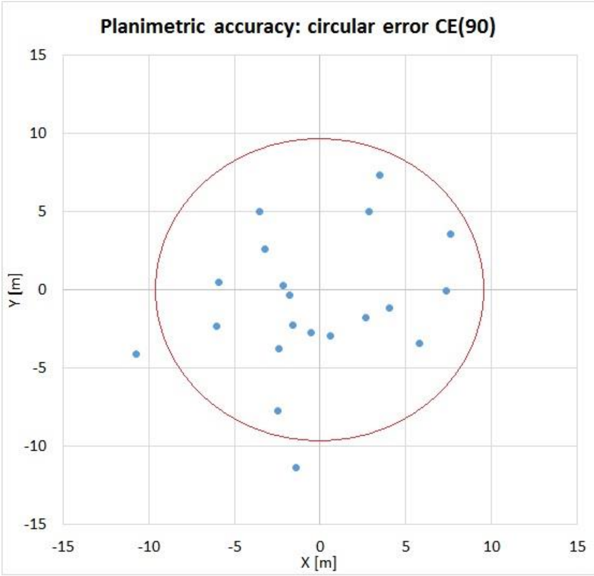
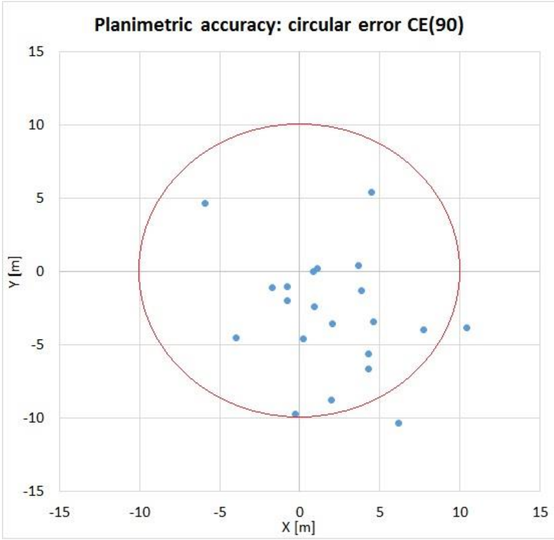
<tr><td>
</td><td>
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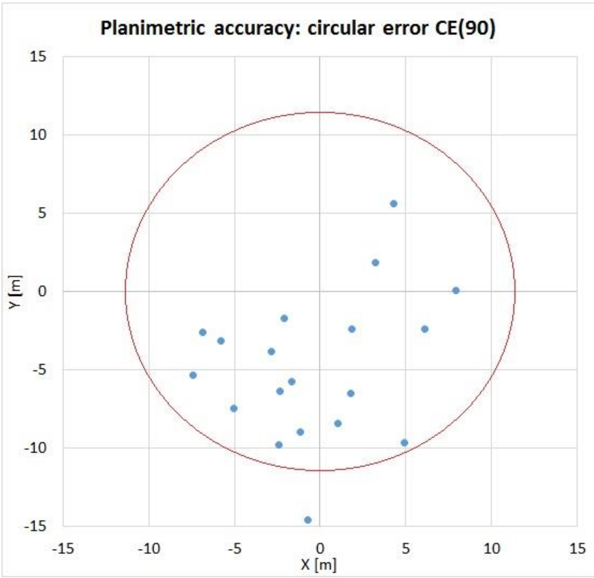
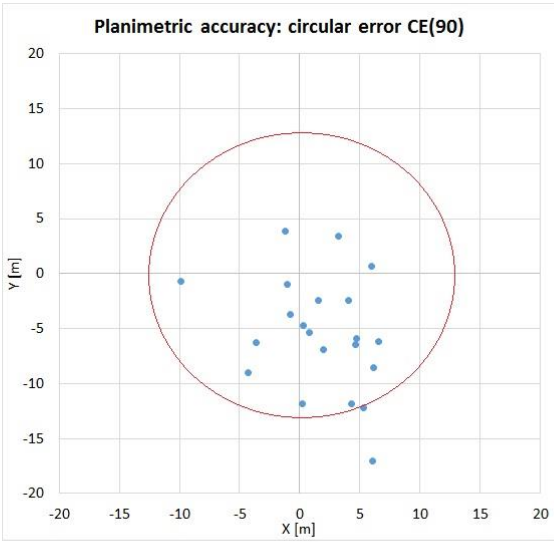
<tr><td>
</td><td>
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	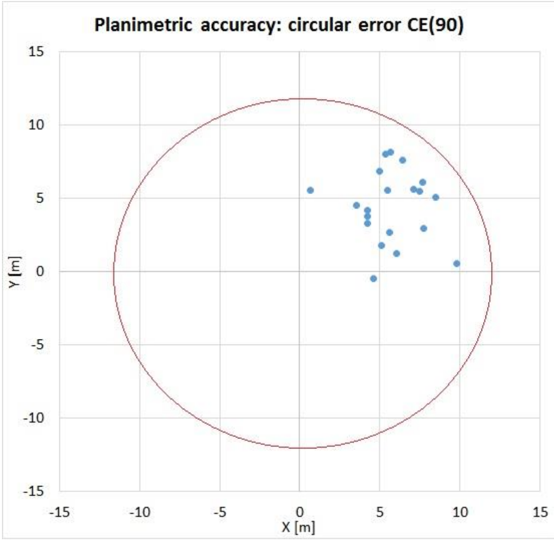
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	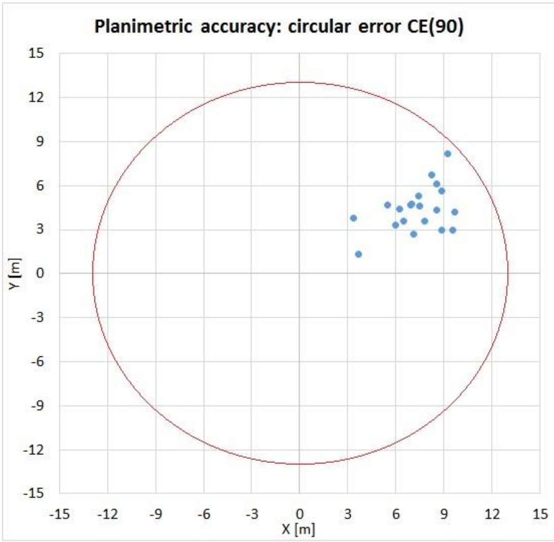

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	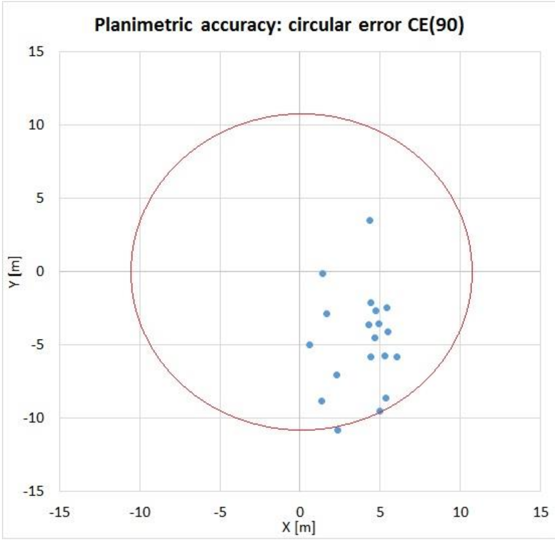
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	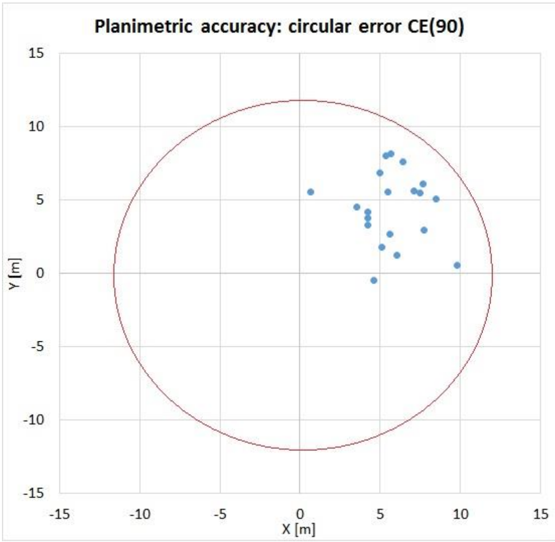

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	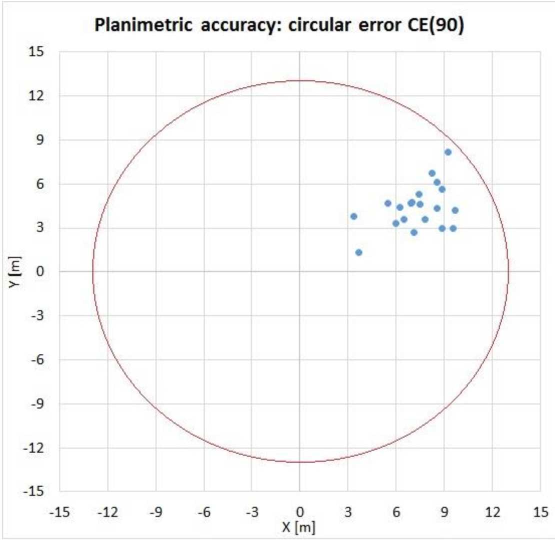

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