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New sensors benchmark report on PlanetScope

Geometric benchmarking test for Common Agricultural Policy (CAP) purposes

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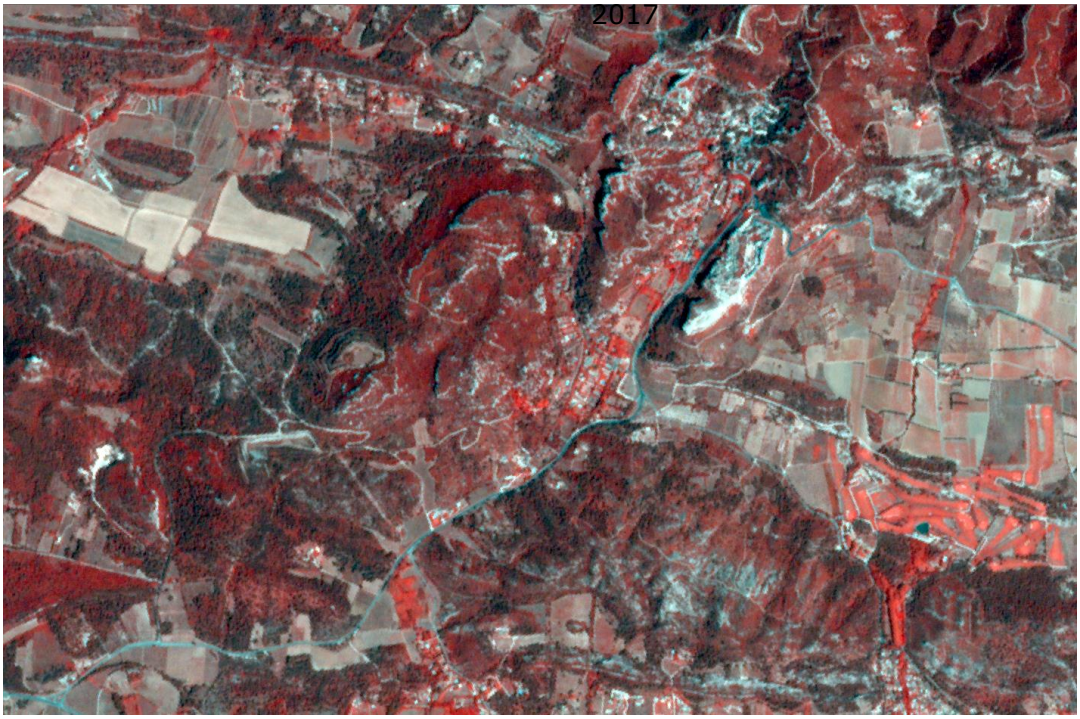

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Contents

Abstract

The main objective of the report is to assess whether images produced by the PlanetScope sensors are suitable for usage in CwRS programme, specifically in the Common Agricultural Policy (CAP). The benchmarking presented herein aims at evaluating the usability of PlanetScope images for the CAP checks through an estimation of its geometric (positional) accuracy. The tests have been performed on the PlanetScope Analytic Ortho Tile product data.

For that purpose, the External Quality Control of PlanetScope 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 Agricultural Policy (CAP) uses the "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 the fulfilment of the 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 Dove satellites [iv], forming the PlanetScope constellation.

1.1 Objective

The aim of this report is to summarize the outcome of the geometric quality testing of the PlanetScope images acquired over several test zones over Europe.

The objective of this study is twofold:

- to evaluate the planimetric accuracy of the orthorectified PlanetScope imagery;
- to check if the orthorectified imagery of the PlanetScope constellation meets the CAP checks programme technical requirements.

Namely, the sensor requirement implies that the planimetric accuracy of the orthoimagery, expressed as the 1D Root-Mean-Square Error (RMSE) in Easting and Northing directions, should not exceed 1.5xGSD(3,95m)[1]=5,925 m to fulfil the geometric requirements and specifications of the HHR ortho profile defined in the HR profile based technical specifications for the CAP checks [iii]. In our case the average GSD has been derived from the GSD's of the PlanetScope Basic Scenes covering the AOI as is shown in the table below:

Table 1 Average GSD over Maussane test site

Acquisition date	Scene 1 GSD [m]	Scene 2 GSD [m]	Scene 3 GSD [m]
17/06/2017	3,9351	3,9349	3,9348
18/06/2017	3,9492	3,9491	3,9490
23/06/2017	3,9348	3,9347	3,9346
04/07/2017	3,9144	3,9143	3,9143
12/07/2017	3,9137	3,9137	n/a
29/07/2017	3,9701	3,9702	3,9703
02/08/2017	4,0092	4,0093	n/a
05/09/2017	4,0072	4,0071	n/a
Average GSD [m]	**3,9510**		

Eight overlapping multispectral PlanetScope Analytic Ortho Tile products over the Maussane AOI (acquisitions between 17/6/2017-5/9/2017) have been analysed to evaluate their absolute positional accuracy with respect to the GNSS points over Maussane. Furthermore, the relative accuracy over two LPIS QA zones (located in Greece and Sweden) have been analysed as well as relative positional accuracy over the Maussane AOI.

[1] Average GSD of the all Basic scenes over the Maussane AOI (see table 1)

1.2 PlanetScope mission

The single PlanetScope satellite, so called Dove, is based on the "3U" CubeSat[2] form factor (10 cm by 10 cm by 30 cm). The PlanetScope satellite constellation consists of multiple launches of groups of individual Dove satellites (flocks[3]) [iv]. Therefore, in-orbit capacity is constantly improving in capability or quantity, with technology improvements deployed at a rapid pace. The most recent development is the so called Build 13. Each new build of the satellite contains improvements compared with the previous build. To image the entire World it is necessary to employ a constellation of more than 120 satellites (equating to a daily collection capacity of 150 million km²/day) [iv]. Basic characteristics of the PlanetScope Satellite constellation and Sensor specifications are shown on the Figure 1.

The normal operations cycle for a flock is launch, deployment, commissioning, operations, and decommissioning. Expected life time of a single Dove satellite is 2-3 years.

Figure 1 PlanetScope Constellation and Sensor Specifications

Mission Characteristic	Sun Synchronous Orbit
Orbit Altitude (reference)	475 km (~98° inclination)
Max/Min Latitude Coverage	±81.5° (depending on season)
Equator Crossing Time	9:30 - 11:30 am (local solar time)
Sensor Type	Three-band frame Imager or four-band frame Imager with a split-frame NIR filter
Spectral Bands	Blue 455 - 515 nm Green 500 - 590 nm Red 590 - 670 nm NIR 780 - 860 nm
Ground Sampling Distance (nadir)	3.7 m (at reference altitude 475 km)
Swath Width	24.6 km x 16.4 km (at reference altitude)
Maximum Image Strip per orbit	20,000 km²
Revisit Time	Daily at nadir (early 2017)
Image Capture Capacity	150 million km²/day (early 2017)
Camera Dynamic Range	12-bit

The traditional "tasking model" is not applied for imagery collection. The Dove satellites are continuously collecting imagery of the sunlit portion of the Earth's surface. The satellites have a very simple concept of operations i.e. the satellite takes an nadir-oriented image when is over the land.

Historical Planet Launches of the Dove satellites as flocks [xi]:

- Flock-1 as a fleet of 28 nanosatellites (CubeSats) (launched 9/1/2014)
- Flock 2e, consisting of 20 nanosatellites (CubeSats) (launched 23/3/2016)

[2] A type of miniaturized satellite for space research that is made up of multiples of 10×10×10 cm cubic units
[3] The flock is a constellation of a number of satellites

- Flock-2p, consisting of 12 Dove satellites (launched 22/6/2016), and
- Flock 3p, consisting of 88 Dove satellites (launched 15/2/2017, *Flock 3p* was the largest satellite fleet ever launched)
- Flock 2k, consisting of 48 Dove satellites, launched on 14 July 2017
- Flock 3m, consisting of just 4 Dove satellites, was launched in 31 October 2017
- Flock 3p', consists of four Dove satellites and was launched on 12 January 2018

Currently, there are more than 175 operational satellites.

1.3 PlanetScope product generation

PlanetScope satellite imagery is captured as a continuous strip of single frame images known as "scenes."

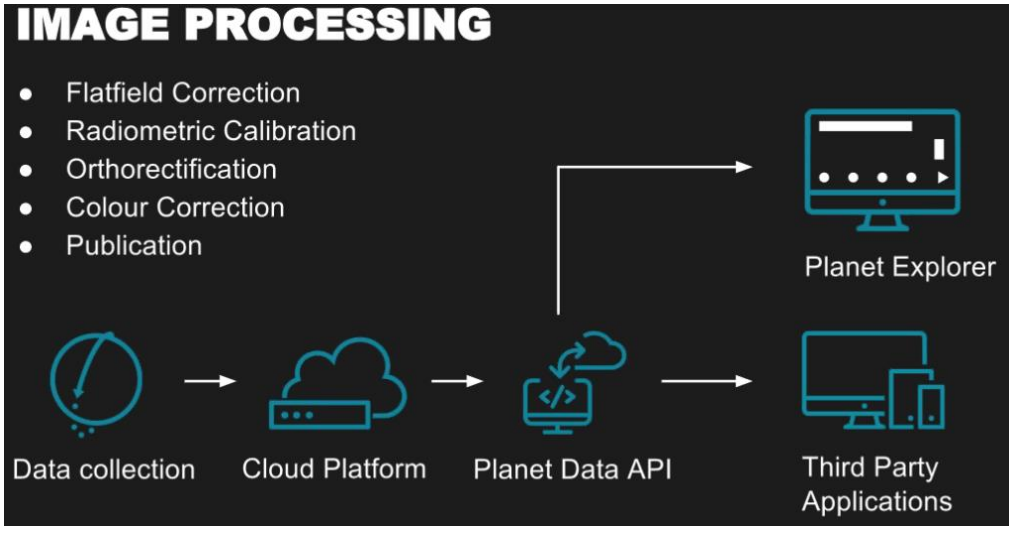
Scenes are acquired in four spectral bands (R, G, B, Near Infrared) using a split-frame Imager [vii].

PlanetScope imagery products are provided as:

- a Basic Scene product (level 1B),
- an Ortho Scene product (level 3B) , and
- an Analytic Ortho Tile product (level (3A).

The Basic Scene product is a scaled Radiance and sensor-corrected product [vii]. The Basic Scene product is designed for users with advanced image processing and geometric correction capabilities. The product is not orthorectified or corrected for terrain distortions. Ortho Scenes represent the single-frame image captures (24 km x 7 km) as acquired by a Dove satellite with additional post processing applied. Analytic Ortho Tiles are multiple orthorectified scenes in a single strip that have been merged and then divided according to a UTM grid (25 km x 25 km with 1 km overlap) [vii].

Figure 2 Image processing chain



For all details regarding the satellite design, specifications, products and formats see Planet's website [iv].

2 Testing scenario

2.1 Methodology

For external geometric quality assessment of PlanetScope imagery both absolute and relative geometric accuracy have been assessed.

Absolute geometric accuracy is based on ICPs that were measured directly in field by GNSS device (Maussane, France) [v].

Relative geometric accuracy is calculated on basis of residuals that are measured on ICPs retrieved from another already orthorectified image of known positional accuracy (VHR Worldview-2 orthorectified image and VHR Worldview-4 orthorectified image). This positional accuracy expressed by RMSE as well as a pointing error that could encumber retrieved coordinates must be taken into account when assessing the final results.

The identification of control points has been carried out within the multispectral image in two ways:

- manual selection of the well visible details
- the automated cross-correlation technique (APM – automatic point measurement) implemented in Erdas IMAGINE 2016 AutoSync™3. After the automatic identification of the tie-points (four points were identified manually), a manual refinement was necessary for all points to eliminate outliers.

2.2 PlanetScope Geometric Quality Requirements

According to the PlanetScope Analytic Ortho Tile Product Specification [vii] the requirements on geometric quality is designed for a wide variety of applications that require imagery with an accurate geolocation and cartographic projection. The positional accuracy declared is less than 10 m RMSE (2D).

2.3 Test sites

For the purposes of the benchmarking, the traditional test site Maussane has been chosen as well as two LPIS QA 2016 sites. The positional accuracy of the orthophoto product depends on auxiliary data such as digital elevation model, ground control points and their distribution and the quality of the orthophoto should be homogeneous throughout the entire area.

ESA has analysed a number of overlapping multispectral PlanetScope Analytic Ortho Tile products to evaluate their positional accuracy both with respect to the DWH_MG2b_CORE_03[4] and to the CSCDAP VHR_IMAGE_2015 Level 3 (Ortho) datasets[5]. The PlanetScope products have been acquired over 5 different European countries (Norway, Poland, Austria, Corsica and Spain) at different latitudes and are characterised by different landscapes and topography and by a variable overlapping area with respect to DWH_MG2b_CORE_03 and to VHR_IMAGE_2015 datasets [viii].

According to the ESA report [viii], different values of relative position accuracy have been achieved over five geographically remote locations. This was also one of the reasons why two additional LPIS QA zones were chosen.

[4] The DWH_MG2b_CORE_03 dataset has been built by using the Optical very high resolution multispectral images SPOT-5 at 2.5m pan-sharpened, SPOT-6 at 1.5m pan-sharpened and FORMOSAT-2 at 2m pansharpened.

[5] The CSCDAP VHR_IMAGE_2015 dataset has been built by using Pléiades 1A & 1B, WorldView-2, WorldView-3, GeoEye-1, Deimos-2 and Dubaisat-2 Optical VHR multispectral and panchromatic products over Europe.

2.3.1 Maussane test site

The geometric quality assessment of the PlanetScope image data was performed over a standard test site of Maussane (indicated with the number 1 at the Figure 3), located in the French commune Maussane-les-Alpilles in the Provence-Alpes-Cote d'Azur region in southern France.

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

Absolute and relative positional accuracy have been calculated over this zone.

2.3.2 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 imagery (GSD<50cm, ELA>80°, haze and cloud free), and that's why it was decided to re-use such ortho-image datasets for the extra geometry benchmarking purposes as basis for ICPs extraction, in addition to the Maussane site.

In total, 2 images were selected from the 2016 LPIS QA Image Campaign (one from Sweden indicated with the number 2 in the Figure 3, and one from Greece indicated with the number 3 in the Figure 3) to serve as reference images for ICPs selection. The criteria for the site selection was the availability of two geographically remoted PlanetScope zones with minimal cloud cover to check the behaviour of the relative position accuracy depending on the geographic location.

Figure 3 Location of tested sites

3 Input datasets

3.1 ICPs used for test

3.1.1 Datasets used over the test site Maussane

3.1.1.1 JRC dataset of points

ICPs were retrieved from datasets of differential global positioning system (DGPS) measurements over the Maussane test site (Figure 4), which are updated and maintained by the JRC.

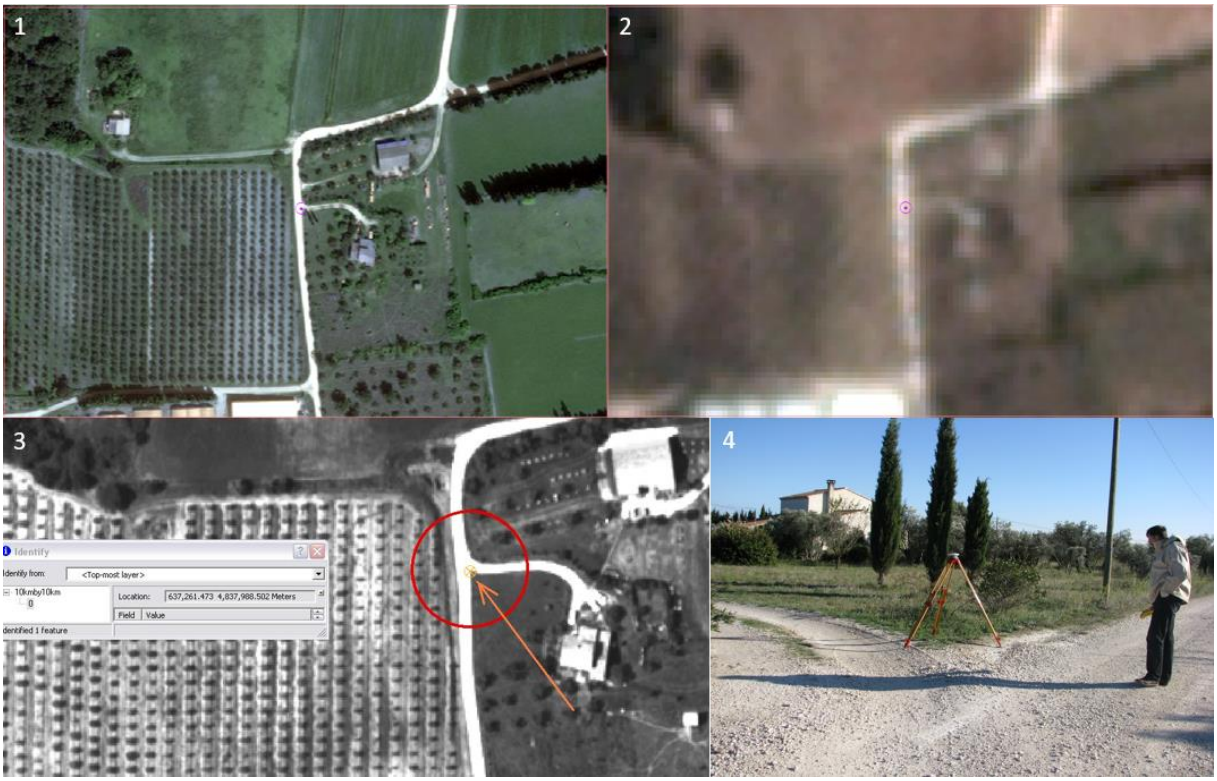
Figure 4 Available GNSS points over the Maussane AOI (81 points overlay on PlanetScope Ortho Tile product))

For the benchmarking, the following general principles for the GCPs selection have been adopted:

- the points should represent a prominent feature
- the points should be well identified features
- the points should be well identified in the image
- the points should be well distributed over the AOI
- the objects that represent vertical displacements should not be used.

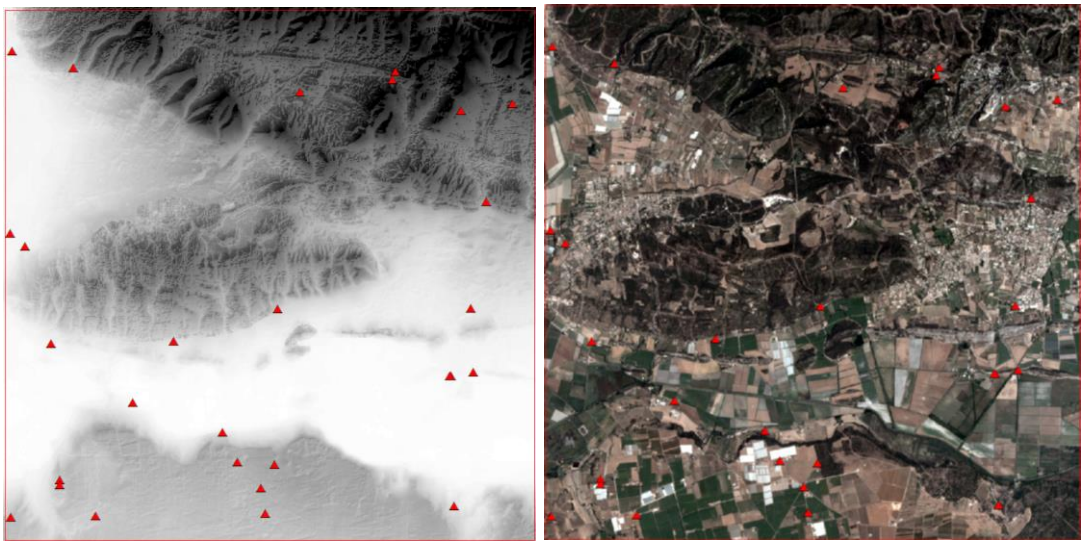
Following the criteria listed above, a number of GCPs have been checked for the visibility and suitability for the benchmarking. The first step in this respect was to identify the point on the image of the high resolution and then to check whether this GCP is visible on the PlanetScope Analytic Ortho Tile product. The imagettes and field photos made during the GNSS campaign supported the selection of the points (figure 5).

Figure 5 Selection of the appropriate GCP's for the benchmarking – (1) high resolution image and identification of the GCP supported with the imagettes (3) and field photo during the GNSS campaign (4), (2) PlanetScope image and verifying whether the GCP is possible to identify



For the evaluation of the absolute geometric accuracy of the PlanetScope ortho imagery 28 independent ICPs (GNSS points) were used as shown in the Figure 6 and listed in Tables 2 and 3.

Figure 6 ICPs (28) dataset selected by JRC over Maussane test site to calculate the absolute geometric accuracy of PlanetScope ortho imagery (left: overlay on DEM, right: overlay on PlanetScope Ortho Tile product)



In addition, the Guidelines for Best Practice and Quality Checking of Ortho Imagery [i] specifies the accuracy requirements for GCPs i.e. ''GCPs should be at least 3 times (5 times recommended) more precise than the target specification for the ortho, e.g. in the case of a target 2.5m RMSE, the GCPs should have a specification of 0.8m RMSE or better''.

According to the Guidelines for the positional accuracy of ICPs the ICPs should be at least 3 times more precise than the target specification of the orthoproduct (Kapnias et al., 2008) [i], i.e. in our case with a target of 5.925 m RMS error, the ICPs should have a specification of 1.9-2.0m (recommended 1.2m). All ICPs that have been selected fulfil this criteria.

For the evaluation of the absolute geometric accuracy of the PlanetScope ortho imagery 28 independent ICPs (GNSS points) were used as shown in the Figure 6 and listed in Tables 2 and 3.

Table 2 Ground Control Points selected for the Maussane test site with the metadata

Dataset	Point ID	RMSEx [m] easting direction	RMSEy [m] northing direction	Number of points
GPS measurement for ADS40 project (2003)	11XXXX	0,05	0,10	5
GPS measurement for Vexel (2005)	44XXX	0,49	0,50	4
GCP dataset for multiuse (2009)	66XXX	0,30	0,30	16
GNSS field campaign 2012	CxRx	0,15	0,15	3

Table 3 The list of the ICPs and their coordinates

ID	x [m] - East	y [m] - North
110001	636327,86	4842638,67
110005	637518,94	4845752,92
110013	639418,26	4840602,35
110016	638647,34	4839449,61
110022	645030,50	4841227,21
440004	643544,23	4845535,28
440005	645815,17	4845076,11
440016	637104,55	4840553,20
440023	641060,73	4837826,92
66004	636363,62	4846077,52
66007	641804,02	4845298,88
66010	643598,10	4845690,29
66011	644844,93	4844945,47
66016	636347,01	4837279,93
66020	637261,09	4837987,96

66021	637265,48	4837886,81
66022	637947,95	4837300,70
66023	640624,49	4838320,52
66024	641320,70	4838276,56
66025	641380,52	4841215,07
66031	644655,96	4839947,67
66035	644717,26	4837489,03
66039	636607,21	4842393,70
66046	641148,67	4837348,79
66064	644632,99	4839952,34
C3R5new	640341,36	4838887,55
C4R4	645317,64	4843233,64
C4R5new	645079,24	4840015,39

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

3.1.1.2 ICPs retrieved from WV4 ortho image

The relative geometric accuracy results are calculated based on the coordinates measured on the WV4 ortho image over the Maussane AOI

The following ortho product was used as reference data (Table 4):

Table 4 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
WV4	PSH	05/04/2017	8.8°	RPC, 9GCPs maxRMSE<2m pixel size 0.5m

Figure 7 ICPs dataset used by JRC over Maussane test site to calculate the relative geometric accuracy of PlanetScope ortho imagery (85 points overlay on WV4 orthoimage)

The list of the ICPs and their coordinates used for the relative geometric accuracy test can be found in the Annex B at the end of this report. The projection and datum details of the above-mentioned data are UTM 31N zone, WGS 84 ellipsoid.

3.1.2 Datasets used over LPIS QA zones 2016

Over these zones only the relative geometric accuracy was calculated.

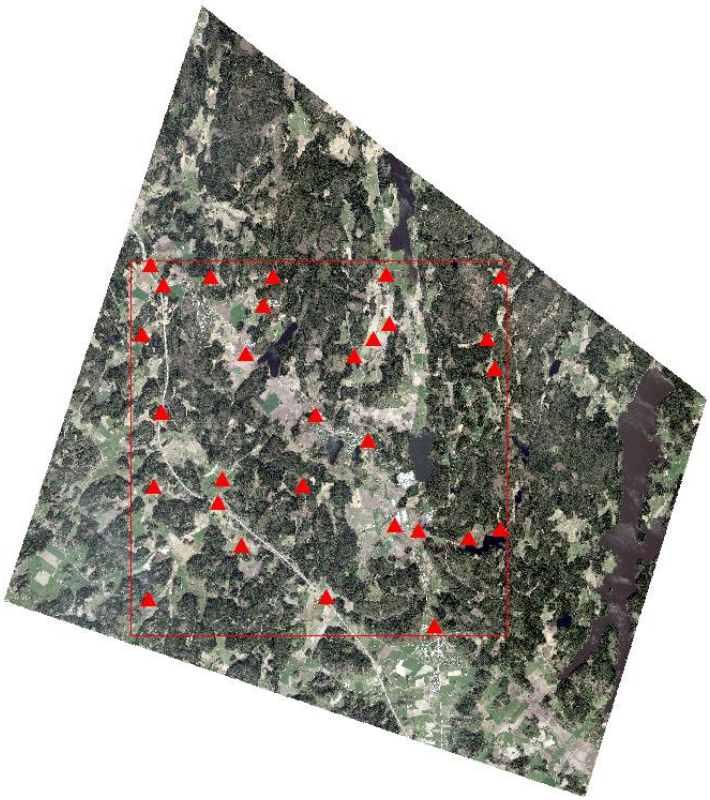
The following ortho products were used as reference data:

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

Table 5 Basic metadata of reference image data used for relative geometric accuracy calculation

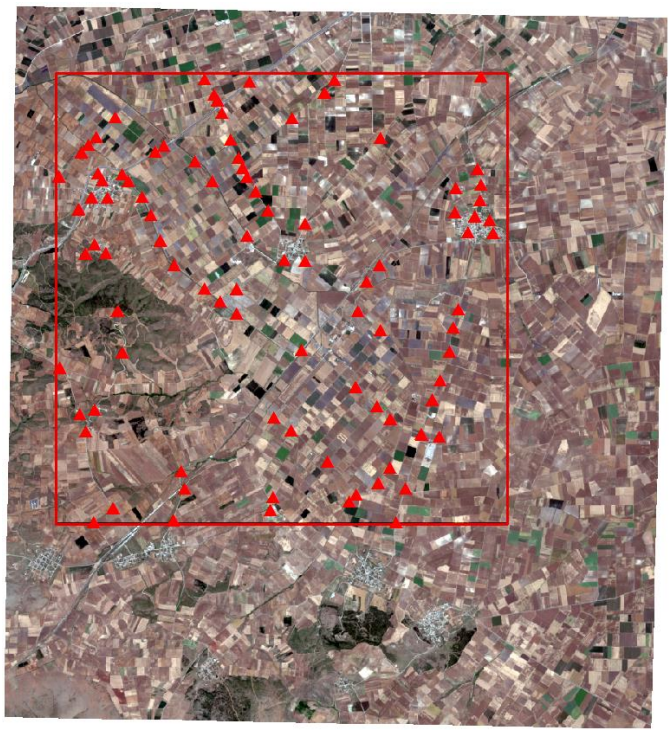
Sensor	Product	Name	Area [km^2]	Collection date of the original image	Off nadir angle of the original image
WV2	PSH	SE_3-2	225	07/05/2016	9.4°
WV2	PSH	EL_2	225	31/05/2016	6.7°

Figure 8 ICPs datasets used by JRC over chosen LPIS QA 2016 SE-3-2 site to calculate the relative geometric accuracy of PlanetScope ortho imagery (overlay on WV2 orthoimage).



The list of the ICPs and their coordinates used for the relative geometric accuracy test can be found in the Annex B at the end of this report. The projection and datum details of the above-mentioned data are UTM 32N zone, WGS 84 ellipsoid.

Figure 9 ICPs datasets used by JRC over chosen LPIS QA 2016 EL-2 site to calculate the relative geometric accuracy of PlanetScope ortho imagery (overlay on WV2 orthoimage)



The list of the ICPs and their coordinated used for the relative geometric accuracy test can be found in the Annex B at the end of this report. The projection and datum details of the above-mentioned data are UTM 34N zone, WGS 84 ellipsoid.

3.2 PlanetScope data tested

3.2.1 PlanetScope data for the absolute positional accuracy test

The PlanetScope data has been selected based on the following search criteria:

- The data is covering the AOI (Maussane) 100%,
- The acquisition dates are between June 2017 and September 2017
- The images are 100% cloud free

After definition of the area of interest (AOI), the request for the PlanetScope data has been sent to Planet Lab.

For each of the following acquisition dates: 17/06/2017, 18/06/2017, 23/06/2017, 04/07/2017, 12/07/2017, 29/07/2017, 02/08/2017 and 05/09/2017 a set of the products over the Maussane AOI have been delivered as a time series of data:

- Basic Product, level 1B (Figure 10)
- Ortho Scene Product, level 3B (the shapes are the same as for the Basic product)
- Analytic Ortho Tile Product, level 3A (Figure 11)

Subject for the benchmarking of PlanetScope data are the Analytic Ortho Tile products which are radiometrically calibrated multispectral imagery, orthorectified as individual 25 km by 25 km tiles referenced to the UTM image tile grid system including an overlap of 1 km with the neighbouring OrthoTile product.

The metadata and the full list of the files can be found in the Annex A at the end of the document.

Figure 10 Three PlanetScope Basic scene products (25x8.5km each, green, magenta and blue shapes) selected covering the Maussane AOI (red shape).

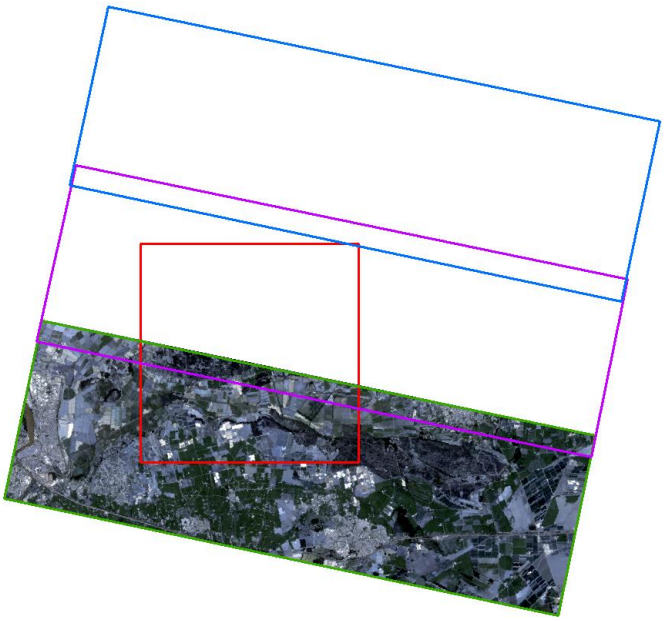
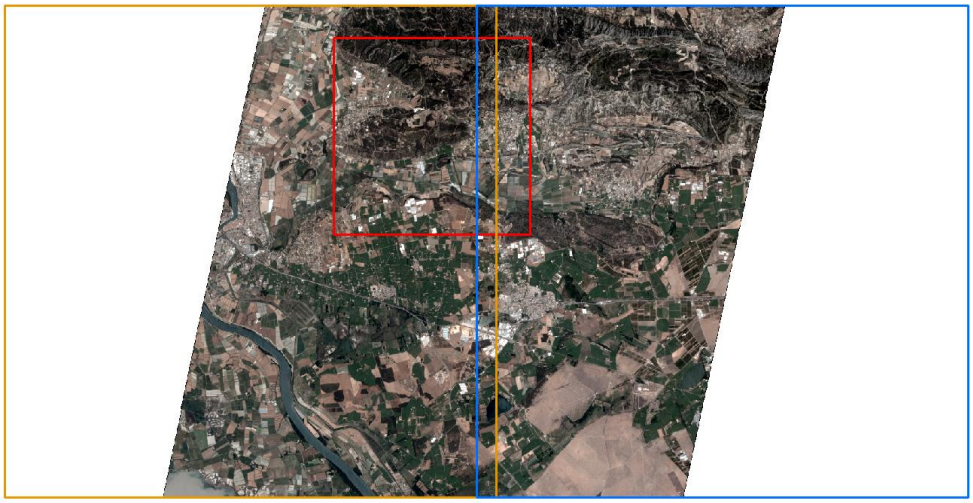


Figure 11 Two Analytic Ortho Tile products (25x25km each, orange and blue shapes) covering the Maussane AOI (red shape)



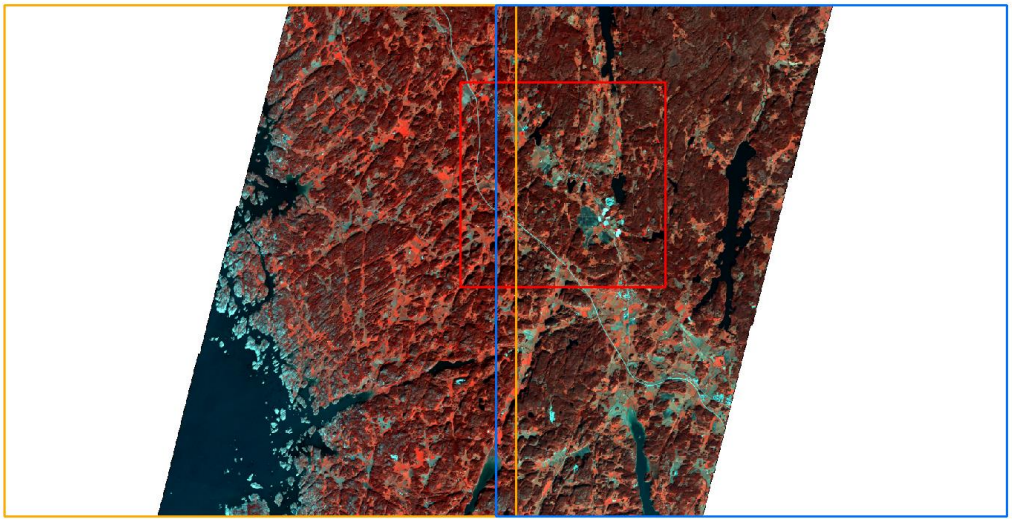
3.2.2 PlanetScope data for the relative positional accuracy test

For the relative positional accuracy test the following PlanetScope data have been used:

- For the Maussane AOI the Analytic Ortho Tile product has been selected for the relative accuracy test with the acquisition date from 17/06/2017 (figure 11):
    - Analytic Ortho Tile Product, level 3A
        - 556609_3159220_2017-06-17_1026_BGRN_Analytic (check Annex A for metadata)
        - 556609_3159221_2017-06-17_1026_BGRN_Analytic (check Annex A for metadata)
- For the LPISQA zone SE3-2 (Sweden) the Analytic Ortho Tile product has been used for the relative positional accuracy test with the acquisition date from 9/10/2017:

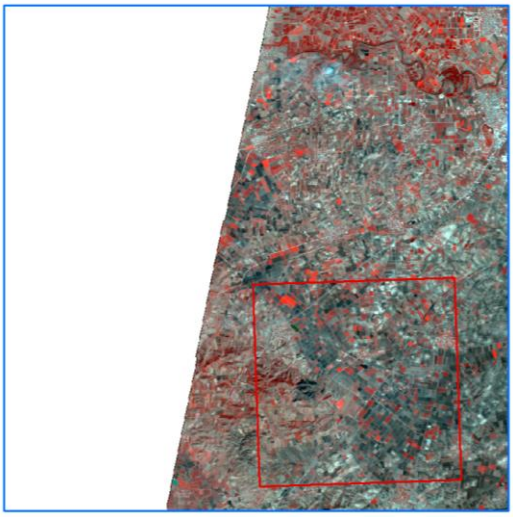
- Analytic Ortho Tile Product, level 3A
  - 823423_3266120_2017-10-09_101f_BGRN_Analytic (check Annex A for metadata)
  - 823423_3266121_2017-10-09_101f_BGRN_Analytic (check Annex A for metadata)

Figure 12 Two Analytic Ortho Tile products (25x25km each, orange and blue shapes) covering the Sweden AOI (red shape)



- For the LPISQA zone EL-2 (Greece), the Analytic Ortho Tile product has been used with the acquisition date from 10/10/2017 (see Annex A for metadata):
  - Analytic Ortho Tile Product, level 3A
    - 825802_3457319_2017-10-10_1034_BGRN_Analytic

Figure 13 Analytic Ortho Tile product (25x25km, blue shape) covering the Greece AOI (red shape)



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 expresses 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 [ix].

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).

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

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:

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

Unlike the values obtained from the field measurements (in our case with GPS device), which are of 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 considered 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 the Annex D) were carried out in ESRI ArcMap and ERDAS Imagine 2016 software, using Auto Sync toolbox.

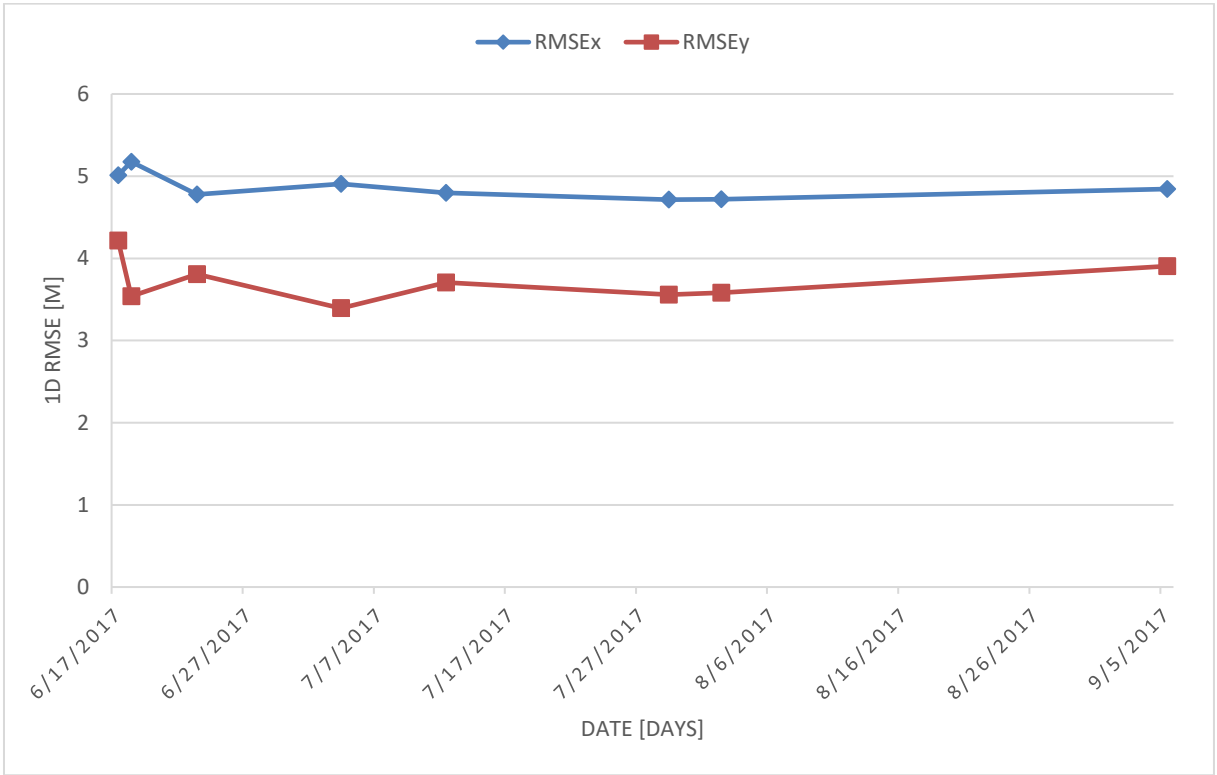
5 Outcome

5.1 Absolute geometric accuracy

Table 6 Results of the absolute $RMSE_{1D}$ calculations based on GNSS measurements over the Maussane test site (June-September)

Date	Satellite serial_ID	RMSEx [m]	RMSEy [m]	CE(90) [m]
17/06/2017	1026	5,01	4,21	9,93
18/06/2017	1036	5,18	3,53	9,51
23/06/2017	1041	4,77	3,81	9,27
04/07/2017	1033	4,90	3,39	9,05
12/07/2017	1040	4,80	3,71	9,20
29/07/2017	1028	4,71	3,56	8,96
02/08/2017	1002	4,72	3,58	8,99
05/09/2017	1013	4,84	3,90	9,44

Figure 14 Behaviour of absolute RMSEs for the 8 Analytic Ortho Tile images checked



5.2 Relative geometric accuracy

5.2.1 Relative accuracy based on WV2 image over LPISQA 2016 zone – Sweden

Table 7 Results of relative $RMSE_{1D}$ calculations based on WV2 ortho image measurements over the LPISQA 2016 zone - Sweden (29 ICP's measured within the ESRI ArcGIS)

date	Serial_ID	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
09/10/2017	101f	SSO	1,50	1,74	3,49

5.2.2 Relative accuracy based on WV2 image over LPISQA 2016 zone – Greece

Table 8 Results of relative $RMSE_{1D}$ calculations based on WV2 ortho image measurements over the LPISQA 2016 zone - Greece (93 ICP's measured within the ESRI ArcGIS)

date	Serial_ID	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
10/10/2017	1034	SSO	2,11	2,32	4,75

5.2.3 Relative accuracy based on WV4 image (Maussane)

Table 9 Results of relative $RMSE_{1D}$ calculations based on WV4 ortho image measurements over Maussane (16 ICP's measured within the ERDAS Imagine 2016 AutoSync)

date	Serial_ID	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
17/06/2017	1026	SSO	2,34	2,36	5,05

Table 10 Results of relative RMSE1D calculations based on WV4 ortho image measurements over Maussane (85 ICP's measured within ESRI ArcGIS)

date	Serial_ID	orbit	RMSEx [m]	RMSEy [m]	CE(90) [m]
17/06/2017	1026	SSO	1,50	2,45	4,36

Erdas Imagine 2016 and its toolbox AutoSync uses the Automatic Point Measurement (APM engine) and the technology of automatic matching and measurement of the corresponding points at two raster files. According to the ERDAS Imagine User manual, the difference in resolution (pixel size) between input raster file and reference file should not be more than 6 times, i.e. in our case the reference file resolution is 50cm (VHR image) and the input file resolution is 3,125m (PlanetScope Analytic Ortho Tile). The table above (9) shows the results after the checking of the results obtained with the APM method, i.e. all automatically measured points were either removed or refined (moved to the proper position), so the process ended up with only 16 points.

5.3 Discussion

The geometric benchmarking of the Analytic Ortho Tile has been performed.

According to the Guidelines for Best Practice and Quality Checking of Ortho Imagery [i] the resampling should be carried out to best accommodate a 1:1 ratio of acquired GSD vs. delivered output pixels. The resolution of the Analytic Ortho Tile product (3,125 m) does not correspond to the resolution of the sensor (3.79-3.99 m) as it is specified in the Product specification [vii] i.e. the pixel size of the orthorectified Analytic Ortho Tile product is oversampled compared to the native (Basic) product.

The selection of the GCP's suitable for comparison was made with special care since the Analytic Ortho Tile product resolution did not always allow identification of the points due to the coarser GSD. Hence, only the points that could be well identified on the Ortho product (such as crunching routes, well-visibility details etc.) have been selected for the benchmarking.

In the individual measurements that have been conducted, there were greater differences observed (more than 10m in a north or south direction) over only three points (id 66016, id 110005 and id 440005, coloured in red in Annex D Residuals obtained by measurements on GCP's over Maussane for the absolute positional accuracy test). The reason for the higher deviations on these points lies indeed in the fact that it is an HHR profile product where the resolution does not allow detailed identification.

The tests performed on the Analytic Ortho Tile dataset (acquired between June and September 2017) over the JRC test Maussane did not show any systematic deviation along any track directions, and the achieved deviations obtained in geometric quality were fully in line with the requirements (see chapter 2.2. PlanetScope Geometric Quality Requirement) in the Specifications of the PlanetScope products [vii].

The relative geometric accuracy values supported these good absolute geometric accuracy results.

It should be noted that for the relative geometric accuracy test over Maussane measurements were performed using two different methods. First, by using the fully manual measurements method within the ArcGis platform (85 measured points) and second by using the AutoSync module within the ERDAS Imagine 2016 platform. In the first step, four manual points were selected and then automatic point matching was performed by software. All automatically measured points have been either refined (manually) or rejected as unacceptable. Finally, the measurement performed within the ERDAS ended up with a total of only 16 points.

Looking at all figures we can summarize that the geometry accuracy performance (from June 2017 till October 2017) is compliant with the requirements for the CAP checks.

6 Conclusions and prospects

The geometry benchmarking over three sites has been performed. In particular, the absolute positional accuracy test as well as relative positional accuracy test have been checked. The absolute positional accuracy test has been performed on the Planet Analytic Ortho Tile products comparing image coordinates and coordinates of ground control points (GCPs) measured directly in the field with the GNSS device. The relative positional accuracy test has been performed by the comparison with VHR orthorectified imagery with known metadata.

The following conclusions are derived from the dataset (June-September 2017) examined.

The geolocation performance of the PlanetScope's Level 3A product is good and the absolute geolocation performance is set by:

- max RMSEx=5.18m and max RMSEy=4.21m
- max CE(90)=9.93m

The relative geolocation performance over three sites in France (Maussane), in Sweden and in Greece is set by:

- max RMSEx=2.34m and max RMSEy=2.45m
- max CE(90)=5.05m

As far as the validation of the PlanetScope Analytic Ortho Tile product (Level 3a), is concerned, based on the achieved results, the following conclusion is made for the CAP Checks:

- **The PlanetScope Analytic Ortho Tile product geometric accuracy meets the requirement of (1.5xGSD) 1D RMSE corresponding to the HHR prime profile defined in the HR profile based technical specifications.**

It should also be emphasized that after the fulfilment of these geometric requirements it is suggested to perform the control of the radiometric quality of the products. This is especially true to clarify the relation between bandwidth and calibration to other satellite data such as Sentinel-2, Landsat, and SPOT. This is important since any mis-calibration will have an effect on derived vegetation indices (e.g. NDVI) which are going to be used extensively in the new "area monitoring system" envisaged to be used for checking the fulfilment of land use and land cover related CAP requirements in the CAP 2020+[x].

The PlanetScope data are available via a Planet's explorer API:

https://www.planet.com/explorer/

References

i. Kapnias, D., Milenov, P., Kay, S. (2008) Guidelines for Best Practice and Quality Checking of Ortho Imagery. Issue 3.0. Ispra https://g4cap.jrc.ec.europa.eu/g4cap/Portals/0/Documents/10133.pdf?ver=2016-03-31-115702-183

ii. JRC IES, VHR image acquisition specifications for the CAP checks (Monitoring and LPIS QA), VHR profile-based specifications including VHR+ profiles (2018), available at

https://g4cap.jrc.ec.europa.eu/g4cap/Portals/0/Documents/22345_VHR_final.pdf?ver=2018-03-22-152037-607

iii. JRC IES, HR image acquisition specifications for the CAP checks (Monitoring), HR profile-based specifications (2018), available at

https://g4cap.jrc.ec.europa.eu/g4cap/Portals/0/Documents/22346_HR_final.pdf?ver=2018-03-22-152114-067

iv. https://www.planet.com/docs/spec-sheets/sat-imagery/

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

vi. Nowak Da Costa, J., Tokarczyk P., 2010. Maussane Test Site Auxiliary Data: Existing Datasets of the Ground Control Points.

vii. https://www.planet.com/products/satellite-imagery/files/Planet_Combined_Imagery_Product_Specs_December2017.pdf

viii. Copernicus data Quality Control (2017) – A Posteriori Report, PA assessment of PlanetScope Analytic Ortho Tile (test) dataset: Summary, Issue:2.2, ESA (European Space Agency)

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

x. Documents on the introduction of monitoring to substitute OTSC -

https://marswiki.jrc.ec.europa.eu/wikicap/images/c/cb/JRC112918.pdf

https://marswiki.jrc.ec.europa.eu/wikicap/images/b/b9/JRC112913.pdf

xi. https://en.wikipedia.org/wiki/Planet_Labs

List of abbreviations and definitions

AOI	Area of Interest
API	Application Programming Interface
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 (SRS Imagery)
HHR	High High resolution (SRS Imagery)
IOCR	In-Orbit Commissioning Review
ICP	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
UTM	Universal Transverse Mercator
VHR	Very High Resolution (SRS Imagery)
WGS 84	World Geodetic System 1984
1-D	One-dimensional

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Annex A Basic Metadata of tested PlanetScope images

MAUSANNE

17/06/2017

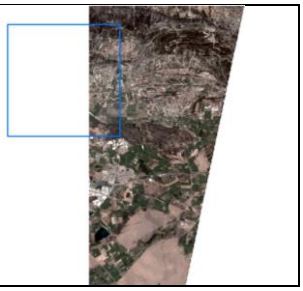
Image id (internal image id)	556609_3159220_2017-06-17_1026_BGRN_Analytic.tif
Product level	Level 3A
Product Type	MSP (BGRN)
Collection date	17/06/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	TIF
Bits Per Pixel	16

Image id (internal image id)	556609_3159221_2017-06-17_1026_BGRN_Analytic.tif
Product level	Level 3A
Product Type	MSP (BGRN)
Collection date	17/06/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	TIF
Bits Per Pixel	16

18/06/2017

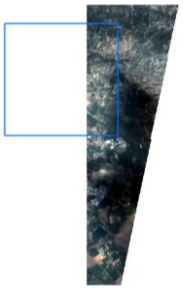
Image id (internal image id)	558260_3159220_2017-06-18_1036_BGRN_Analytic.tif
Product level	Level 3A
Product Type	MSP (BGRN)
Collection date	18/06/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	TIF
Bits Per Pixel	16

Image id (internal image id)	558260_3159221_2017-06-18_1036_BGRN_Analytic.tif
Product level	Level 1C
Product Type	MSP (BGRN)
Collection date	18/06/2017
Ellipsoid Type/Projection	WGS-84/UTM, N31
Format	TIF
Bits Per Pixel	16



23/06/2017

Image id (internal image id)	572147_3159220_2017-06-23_1031_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	23/06/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

Image id (internal image id)	572147_3159221_2017-06-23_1031_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	23/06/2017	
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Format	TIF	
Bits Per Pixel	16	

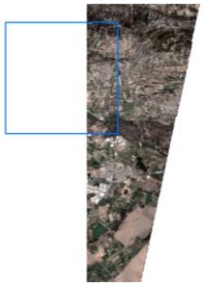
04/07/2017

Image id (internal image id)	599120_3159220_2017-07-04_1033_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	04/07/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

Image id (internal image id)	599120_3159221_2017-07-04_1033_BGRN_Analytic.tif	

12/07/2017

Image id (internal image id)	617015_3159220_2017-07-12_1040_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	12/07/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

Image id (internal image id)	617015_3159221_2017-07-12_1040_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	12/07/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

29/07/2017

Image id (internal image id)	653876_3159220_2017-07-29_1028_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	29/07/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

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Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	29/07/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

02/08/2017

Image id (internal image id)	662717_3159220_2017-08-02_1002_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	02/08/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

Image id (internal image id)	662717_3159221_2017-08-02_1002_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	02/08/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

05/09/2017

Image id (internal image id)	735166_3159220_2017-09-05_1013_BGRN_Analytic.tif	
Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	05/09/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

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Product level	Level 3A	
Product Type	MSP (BGRN)	
Collection date	05/09/2017	
Ellipsoid Type/Projection	WGS-84/UTM, N31	
Format	TIF	
Bits Per Pixel	16	

SE3-2 - LPISQA 2016 zone over SWEDEN

Image id (internal image id)	823423_3266120_2017-10-09_101f_BGRN_Analytic.tif
Product level	Level 3A
Product Type	MSP (BGRN)
Collection date	09/10/2017
Ellipsoid Type/Projection	WGS-84/UTM, N32
Format	TIF
Bits Per Pixel	16

Image id (internal image id)	823423_3266121_2017-10-09_101f_BGRN_Analytic.tif
Product level	Level 3A
Product Type	MSP (BGRN)
Collection date	09/10/2017
Ellipsoid Type/Projection	WGS-84/UTM, N32
Format	TIF
Bits Per Pixel	16

EL-2 - LPISQA 2016 zone over GREECE

Image id (internal image id)	825802_3457319_2017-10-10_1034_BGRN_Analytic.tif
Product level	Level 3A
Product Type	MSP (BGRN)
Collection date	10/10/2017
Ellipsoid Type/Projection	WGS-84/UTM, N34
Format	TIF
Bits Per Pixel	12

Annex B ICPs selected over VHR images as basis for the relative positional accuracy tests

Maussane – manually selected points

ID	x [m] - East	y [m] - North
1ref	638879,69	4836871,50
2ref	640552,62	4836976,37
3ref	641249,45	4837139,94
4ref	642095,37	4836942,07
5ref	645347,08	4837033,24
6ref	644814,26	4837270,59
7ref	637560,05	4837721,41
8ref	639771,61	4837608,97
9ref	644606,56	4837673,70
10ref	638542,48	4838208,22
11ref	640292,94	4837885,51
12ref	642452,52	4838106,52
13ref	645039,03	4838640,01
14ref	638758,82	4838609,07
15ref	644675,68	4839492,64
16ref	638645,91	4839271,63
17ref	644948,74	4839818,94
18ref	644218,90	4840461,98
19ref	637520,47	4840731,51
20ref	640525,53	4840752,34
21ref	644786,27	4840596,12
22ref	643919,23	4840964,12
23ref	642573,66	4841193,90
24ref	641885,42	4841002,59
25ref	641317,90	4841089,03
26ref	639326,80	4840914,97
27ref	638370,59	4841080,53
28ref	636932,68	4840843,46
29ref	636251,19	4841337,01
30ref	641576,74	4841293,02
31ref	643083,91	4841397,22
32ref	645931,53	4841315,42
33ref	645199,11	4841620,89
34ref	644081,16	4841555,38
35ref	643382,19	4841797,38
36ref	637967,49	4841918,57
37ref	646018,53	4841730,90
38ref	646101,33	4842088,47
39ref	645924,29	4842327,80
40ref	643183,49	4842357,91

41ref	636409,42	4842670,28
42ref	639698,54	4842945,47
43ref	642087,33	4842881,00
44ref	644511,47	4842950,15
45ref	645619,33	4842859,62
46ref	644265,76	4843181,92
47ref	642981,47	4843541,89
48ref	641955,92	4843318,06
49ref	638151,47	4843299,95
50ref	636993,26	4843319,12
51ref	636300,05	4843416,54
52ref	637432,24	4843866,29
53ref	638713,79	4843940,43
54ref	639655,20	4843778,00
55ref	640375,77	4843937,17
56ref	643201,40	4843893,89
57ref	645080,28	4843918,60
58ref	646130,69	4843872,72
59ref	646194,37	4844445,72
60ref	644948,99	4844704,12
61ref	639412,52	4844593,21
62ref	638647,24	4844768,50
63ref	636794,87	4844830,75
64ref	636936,42	4845395,76
65ref	637445,00	4845388,76
66ref	637929,73	4845453,27
67ref	642486,69	4845706,00
68ref	643149,62	4845627,93
69ref	645481,79	4845488,63
70ref	644923,98	4845750,14
71ref	639396,52	4845818,68
72ref	638560,04	4845859,80
73ref	637253,02	4845964,10
74ref	646208,64	4846022,71
75ref	636506,61	4846241,00
76ref	646127,67	4846497,91
77ref	643820,50	4846738,41
78ref	643206,40	4846807,74
79ref	643043,42	4846692,64
80ref	636405,57	4846542,75
81ref	639464,45	4846814,43
82ref	638995,66	4846773,37
83ref	638114,33	4846754,32
84ref	637251,39	4846640,99
85ref	636383,42	4846605,58

LPIS QA 2016 Sweden zone SE-3-2

ID	x [m] - East	y [m] - North
p1	642303,73	6500619,44
p2	642656,01	6500066,29
p3	643914,00	6500283,10
p4	648594,64	6500354,62
p5	651637,30	6500298,48
p6	651264,84	6498643,22
p7	651472,97	6497845,28
p8	644092,36	6494257,35
p9	646988,19	6491754,82
p10	644846,99	6498243,46
p11	642085,37	6498764,26
p12	644224,77	6494901,89
p13	642243,46	6491704,48
p14	646713,36	6496616,32
p15	645315,69	6499512,93
p16	648249,36	6498650,44
p17	642591,05	6496684,46
p18	642380,87	6494686,11
p19	648810,80	6493678,20
p20	646367,49	6494716,40
p21	649868,68	6490978,24
p22	649434,25	6493512,09
p23	644721,31	6493121,01
p24	648095,03	6495926,18
p25	648684,63	6499034,48
p26	645564,46	6500306,48
p27	651624,50	6493544,88
p28	650777,94	6493337,65
p29	647742,00	6498192,11

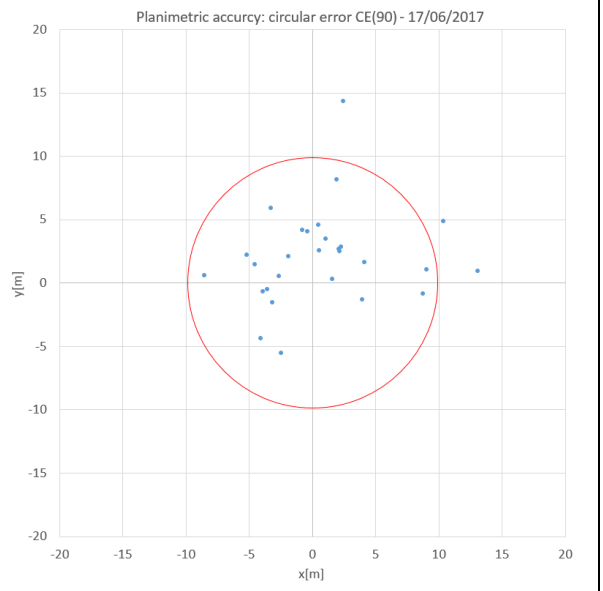
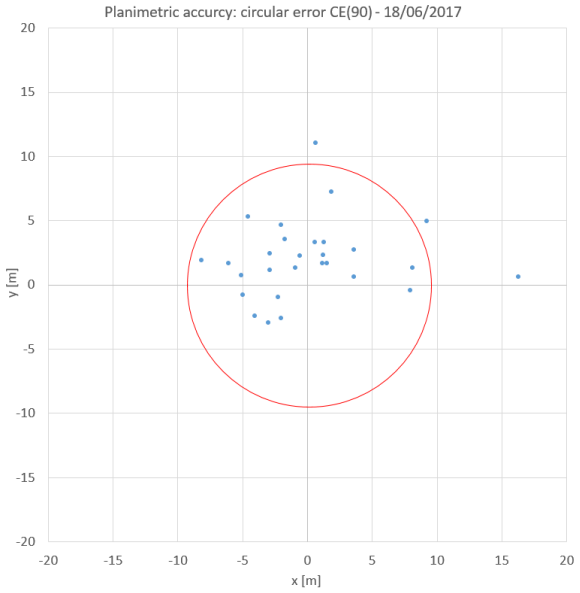
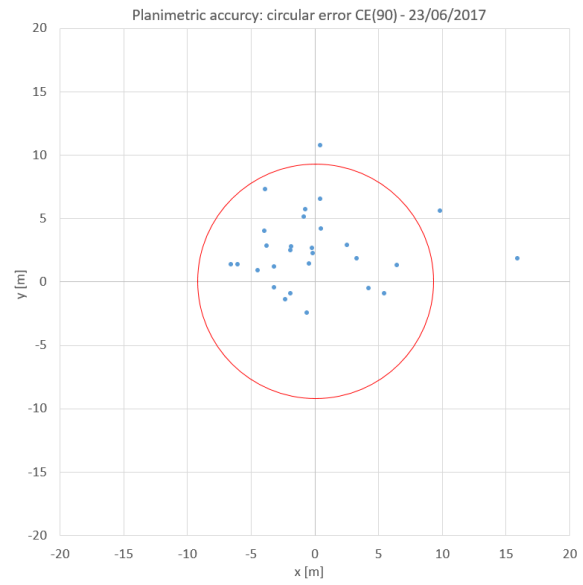
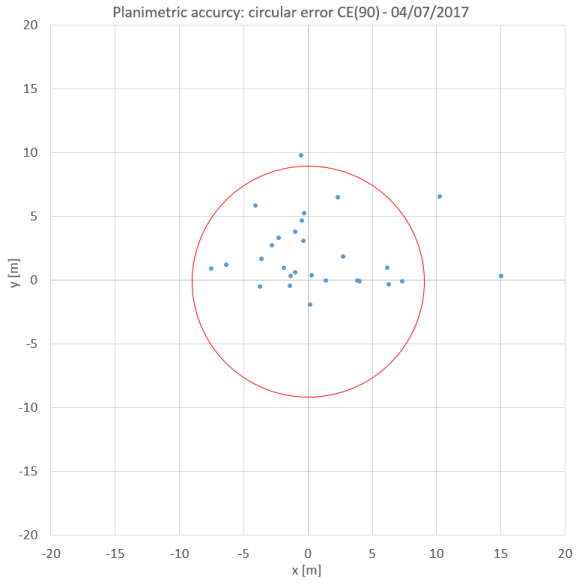
LPIS QA 2016 zone Grece EL-2

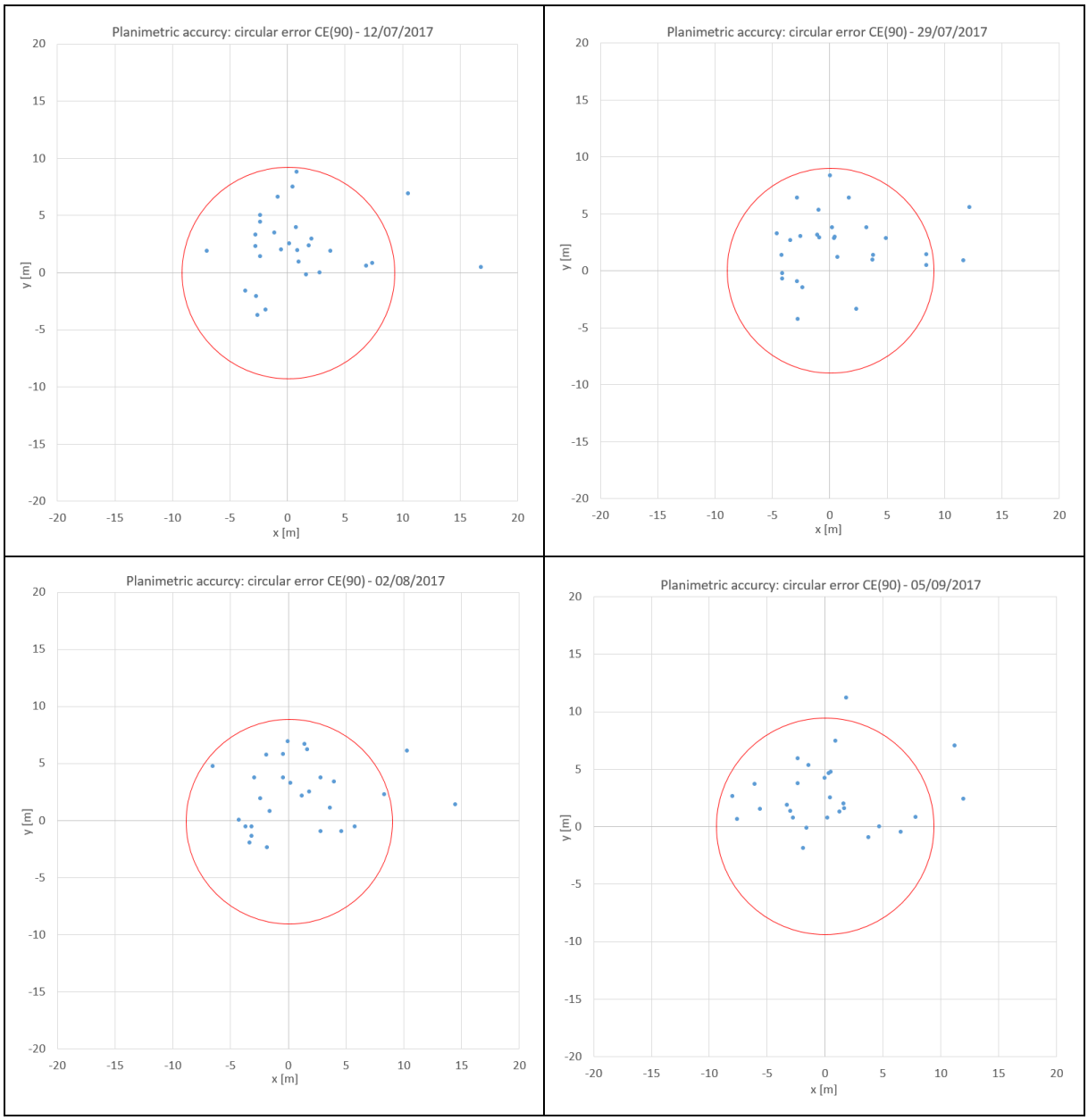
ID	x [m] - East	y [m] - North
p1	357273,31	4377942,44
p2	351569,80	4373194,16
p3	351195,78	4375385,86
p4	350172,83	4372848,21
p5	350927,64	4369426,67
p6	352684,80	4369467,68
p7	357621,28	4369416,42
p8	354834,88	4369683,98
p9	356735,25	4370039,18
p10	356582,46	4369876,79

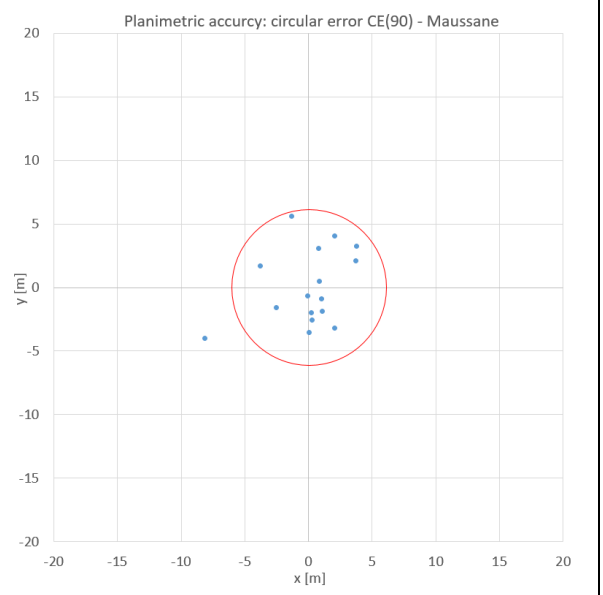
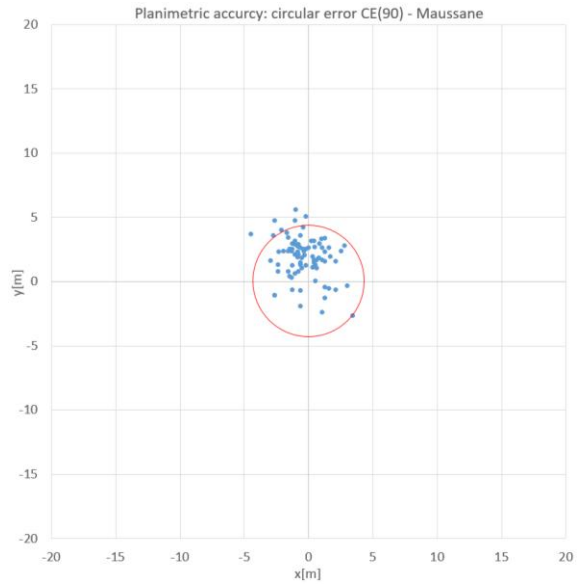
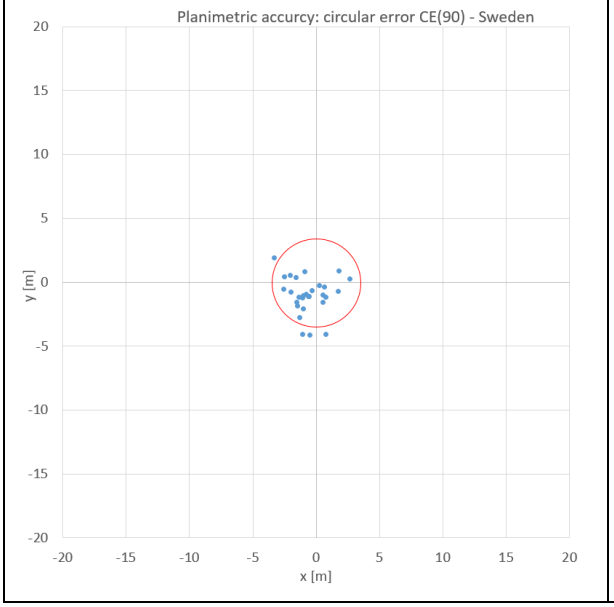
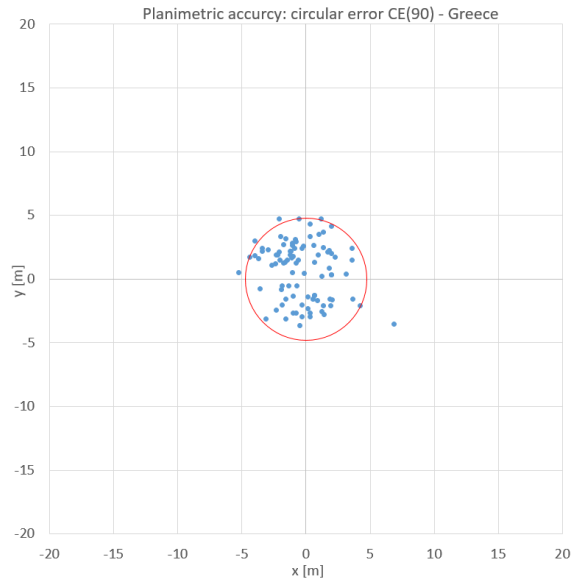
p11	354908,30	4369976,01
p12	351361,55	4369734,25
p13	352940,13	4370163,20
p14	357229,03	4370290,20
p15	357839,23	4370178,75
p16	357480,39	4370632,18
p17	356103,89	4370757,53
p18	352871,34	4370559,75
p19	350755,66	4371432,55
p20	355308,15	4371454,04
p21	358190,13	4371368,38
p22	358580,73	4371315,47
p23	357498,25	4371702,75
p24	354911,28	4371736,16
p25	350617,08	4371822,15
p26	350948,80	4371916,07
p27	357202,24	4371999,42
p28	358430,24	4372138,32
p29	356731,28	4372413,16
p30	358591,97	4372564,63
p31	358812,57	4373199,64
p32	355538,01	4373238,99
p33	357268,72	4373677,54
p34	358891,61	4373746,66
p35	359011,00	4374138,38
p36	356779,90	4374105,83
p37	354087,76	4374053,25
p38	353724,62	4374310,89
p39	351457,47	4374106,83
p40	353385,95	4374599,28
p41	354090,74	4374593,66
p42	356968,09	4374757,04
p43	357264,75	4375129,11
p44	355608,79	4375222,05
p45	355147,09	4375239,58
p46	352717,55	4375119,52
p47	350748,05	4375368,56
p48	350948,14	4375578,91
p49	352410,96	4375667,54
p50	354326,22	4375768,74
p51	355609,78	4376045,90
p52	359206,47	4375852,09
p53	359776,64	4375831,25
p54	359700,25	4376122,63
p55	359368,85	4376203,32

p56	358925,68	4376282,70
p57	354792,88	4376319,41
p58	352192,68	4376235,07
p59	350595,92	4376358,11
p60	350881,67	4376616,07
p61	351234,22	4376620,04
p62	352005,82	4376637,24
p63	354518,04	4376747,37
p64	359485,60	4376567,46
p65	359508,75	4376908,77
p66	358941,55	4376821,46
p67	354318,61	4377075,46
p68	353560,11	4376971,28
p69	351697,25	4376987,81
p70	351116,15	4376999,39
p71	350160,34	4377084,72
p72	351032,29	4377146,11
p73	351568,59	4377135,98
p74	353173,95	4377428,68
p75	354225,01	4377276,54
p76	359420,45	4377249,42
p77	354132,99	4377493,04
p78	352479,75	4377758,42
p79	352290,27	4377639,80
p80	350667,25	4377621,22
p81	350823,13	4377792,81
p82	350981,55	4377957,51
p83	353954,81	4377898,31
p84	355317,08	4378371,59
p85	353772,91	4378491,97
p86	351402,57	4378402,35
p87	353596,63	4378888,85
p88	353673,69	4378771,11
p89	356041,38	4378942,43
p90	359498,50	4379296,64
p91	356256,36	4379224,87
p92	354384,58	4379181,32
p93	353385,28	4379249,89

Annex C Circular errors calculated at 90% level of confidence CE(90)

Absolute positional accuracy	
	
	


Planimetric accurcy: circular error CE(90) - 12/07/2017
Planimetric accurcy: circular error CE(90) - 29/07/2017
Planimetric accurcy: circular error CE(90) - 02/08/2017
Planimetric accurcy: circular error CE(90) - 05/09/2017
x [m]
y [m]

Relative positional accuracy	
	
	

Annex D Measurement residuals

Residuals obtained by measurements on GCP's over Maussane (absolute positional accuracy test)

	17/06/2017		18/06/2017		23/06/2017		04/07/2017		12/07/2017		29/07/2017		02/08/2018		05/09/2017	
Point Nr.	dN	dE	dN	dE	dN	dE	dN	dE	dN	dE	dN	dE	dN	dE	dN	dE
110001	1,46	-4,57	-0,78	-5,00	0,91	-4,47	-1,91	0,22	-1,62	-3,64	-0,68	-4,11	-0,54	-3,18	0,68	-7,56
110005	0,94	13,09	0,63	16,28	1,87	15,89	0,33	15,07	0,47	16,83	0,94	11,68	1,40	14,49	2,41	11,99
110013	1,08	9,06	1,32	8,13	1,31	6,44	-0,09	7,38	0,86	7,39	1,43	8,42	2,27	8,33	0,85	7,85
110016	-4,37	-4,10	-2,96	-3,01	-0,43	-3,21	0,98	6,18	2,34	1,87	-3,33	2,34	-0,53	5,75	-1,86	-1,86
110022	2,65	2,13	1,67	1,52	2,23	-0,18	-0,11	4,05	1,87	3,74	3,83	3,21	3,76	2,79	-0,01	4,69
440004	8,15	1,94	7,28	1,87	6,54	0,46	6,49	2,33	7,48	0,47	6,42	1,68	6,70	1,41	7,47	0,93
440005	4,88	10,38	4,95	9,20	5,62	9,82	6,56	10,29	6,89	10,48	5,60	12,17	6,07	10,28	7,02	11,22
440016	2,57	0,55	2,42	-2,92	2,81	-1,87	2,75	-2,77	3,51	-1,15	2,92	-0,90	3,75	-0,46	3,74	-2,35
440023	-5,50	-2,49	-2,57	-2,04	1,44	-0,46	-0,44	-1,40	-3,27	-1,87	-0,91	-2,81	-1,35	-3,18	1,34	-3,00
66004	0,31	1,58	1,33	-0,94	-2,46	-0,63	0,34	0,30	2,55	0,17	3,15	-1,10	0,81	-1,57	1,28	1,23
66007	-0,86	8,72	-0,43	7,95	-0,92	5,46	-0,33	6,34	0,61	6,86	0,48	8,41	-0,94	4,62	-0,47	6,53
66010	2,10	-1,87	2,26	-0,60	1,85	3,30	-0,03	1,42	0,92	0,97	1,39	3,80	1,10	3,60	1,61	1,67
66011	3,48	1,07	2,34	1,19	-0,94	-1,90	3,76	-0,96	3,95	0,76	-1,45	-2,37	-1,93	-3,31	4,21	-0,01
66016	14,33	2,46	11,09	0,63	10,74	0,46	9,80	-0,48	8,78	0,83	8,38	0,06	6,92	-0,03	11,20	1,87
66020	-1,34	3,94	0,64	3,58	-0,48	4,21	-0,06	3,87	0,02	2,79	0,96	3,73	-0,93	2,79	-0,93	3,74
66021	-0,66	-3,94	-0,94	-2,28	1,22	-3,21	0,28	-1,33	-2,08	-2,73	-0,19	-4,15	0,05	-4,26	0,75	-2,74
66022	1,65	4,10	2,72	3,60	2,92	2,55	1,85	2,74	2,93	2,08	2,84	4,93	3,40	3,96	1,98	1,62
66023	2,52	2,18	1,68	1,13	2,66	-0,24	3,10	-0,32	-0,19	1,64	1,22	0,70	2,17	1,17	0,77	0,24
66024	4,57	0,47	3,54	-1,74	4,22	0,49	4,68	-0,45	1,93	0,84	2,88	0,37	3,29	0,19	4,65	0,36
66025	2,21	-5,21	1,70	-6,06	1,40	-6,55	1,20	-6,32	3,28	-2,77	3,02	-2,57	3,74	-2,92	1,51	-5,63
66031	-1,55	-3,19	-2,42	-4,04	-1,38	-2,31	0,97	-1,84	-3,74	-2,57	-4,23	-2,80	-2,34	-1,85	-0,12	-1,61
66035	4,08	-0,40	3,31	0,56	5,72	-0,73	5,25	-0,26	6,64	-0,82	3,83	0,23	6,19	1,65	4,78	0,48
66039	0,57	-8,56	1,94	-8,15	1,39	-6,07	0,92	-7,47	1,89	-6,99	3,30	-4,63	4,72	-6,52	2,66	-7,97
66046	-0,48	-3,60	0,77	-5,07	4,02	-3,95	-0,54	-3,69	2,31	-2,76	1,37	-4,17	-0,53	-3,70	3,70	-6,05
66064	0,55	-2,65	1,14	-2,91	2,81	-3,75	1,65	-3,58	1,41	-2,33	2,69	-3,45	1,95	-2,41	1,88	-3,27
C3R5new	2,82	2,26	3,31	1,26	2,49	-1,92	0,61	-0,98	2,03	-0,52	2,97	0,42	2,50	1,84	2,51	0,44
C4R4	5,93	-3,25	5,33	-4,55	7,28	-3,86	5,85	-4,07	5,01	-2,36	6,42	-2,83	5,73	-1,90	5,95	-2,37
C4R5new	4,18	-0,82	4,67	-2,03	5,16	-0,84	3,28	-2,25	4,42	-2,35	5,36	-0,94	5,84	-0,47	5,36	-1,40

List of 29 coordinates and residuals – relative accuracy test (PlanetScope vs WV4 over Maussane)

Point Nr.	X [m] - EAST	Y [m] - NORTH	dX	dN
1ref	638879,69	4836871,50	-4,50	3,70
2ref	640552,62	4836976,37	-0,21	5,08
3ref	641249,45	4837139,94	1,58	2,64
4ref	642095,37	4836942,07	-1,48	2,54
5ref	645347,08	4837033,24	2,51	2,38
6ref	644814,26	4837270,59	-1,32	2,38
7ref	637560,05	4837721,41	-2,75	3,60
8ref	639771,61	4837608,97	-0,99	5,62
9ref	644606,56	4837673,70	-1,06	4,76
10ref	638542,48	4838208,22	-1,69	3,81
11ref	640292,94	4837885,51	-2,12	4,02
12ref	642452,52	4838106,52	-1,06	2,12
13ref	645039,03	4838640,01	-1,59	3,44
14ref	638758,82	4838609,07	-1,59	2,38
15ref	644675,68	4839492,64	0,40	1,19
16ref	638645,91	4839271,63	1,27	1,59
17ref	644948,74	4839818,94	2,12	-0,64
18ref	644218,90	4840461,98	-1,27	2,54
19ref	637520,47	4840731,51	-0,85	2,75
20ref	640525,53	4840752,34	0,21	3,18
21ref	644786,27	4840596,12	-0,85	1,91
22ref	643919,23	4840964,12	-1,27	2,96
23ref	642573,66	4841193,90	-0,64	-1,90
24ref	641885,42	4841002,59	-1,48	0,42
25ref	641317,90	4841089,03	-1,27	1,27
26ref	639326,80	4840914,97	-1,06	0,64
27ref	638370,59	4841080,53	3,44	-2,65
28ref	636932,68	4840843,46	-1,06	3,18
29ref	636251,19	4841337,01	-2,65	-1,06
30ref	641576,74	4841293,02	-2,38	0,79
31ref	643083,91	4841397,22	-1,59	0,79
32ref	645931,53	4841315,42	-1,98	2,38
33ref	645199,11	4841620,89	0,50	0,05
34ref	644081,16	4841555,38	-0,79	0,79

35ref	643382,19	4841797,38	1,06	-2,38
36ref	637967,49	4841918,57	1,27	-0,42
37ref	646018,53	4841730,90	-0,85	2,33
38ref	646101,33	4842088,47	-2,38	1,32
39ref	645924,29	4842327,80	-2,64	-1,06
40ref	643183,49	4842357,91	0,53	1,32
41ref	636409,42	4842670,28	-0,66	-0,66
42ref	639698,54	4842945,47	0,79	1,85
43ref	642087,33	4842881,00	-0,33	2,05
44ref	644511,47	4842950,15	1,65	1,98
45ref	645619,33	4842859,62	1,27	-1,27
46ref	644265,76	4843181,92	0,42	3,18
47ref	642981,47	4843541,89	-1,27	-0,63
48ref	641955,92	4843318,06	-2,98	1,65
49ref	638151,47	4843299,95	0,85	2,96
50ref	636993,26	4843319,12	-0,42	4,23
51ref	636300,05	4843416,54	0,33	1,98
52ref	637432,24	4843866,29	-0,64	3,60
53ref	638713,79	4843940,43	-0,66	1,32
54ref	639655,20	4843778,00	2,11	1,58
55ref	640375,77	4843937,17	-1,32	0,33
56ref	643201,40	4843893,89	0,32	1,11
57ref	645080,28	4843918,60	-2,32	2,32
58ref	646130,69	4843872,72	0,64	1,69
59ref	646194,37	4844445,72	-0,66	2,65
60ref	644948,99	4844704,12	0,64	1,06
61ref	639412,52	4844593,21	0,48	2,70
62ref	638647,24	4844768,50	-1,06	2,91
63ref	636794,87	4844830,75	1,27	3,39
64ref	636936,42	4845395,76	2,98	-0,33
65ref	637445,00	4845388,76	-0,64	1,48
66ref	637929,73	4845453,27	2,78	2,78
67ref	642486,69	4845706,00	-0,79	2,12
68ref	643149,62	4845627,93	-0,21	2,54
69ref	645481,79	4845488,63	-0,21	1,27
70ref	644923,98	4845750,14	0,42	1,48
71ref	639396,52	4845818,68	-0,53	1,85

72ref	638560,04	4845859,80	-1,06	2,12
73ref	637253,02	4845964,10	-0,79	2,91
74ref	646208,64	4846022,71	1,06	1,69
75ref	636506,61	4846241,00	-0,42	2,54
76ref	646127,67	4846497,91	1,27	2,33
77ref	643820,50	4846738,41	-0,40	2,38
78ref	643206,40	4846807,74	1,06	2,64
79ref	643043,42	4846692,64	-0,53	1,06
80ref	636405,57	4846542,75	0,42	1,69
81ref	639464,45	4846814,43	0,99	3,31
82ref	638995,66	4846773,37	1,59	-0,53
83ref	638114,33	4846754,32	0,00	2,65
84ref	637251,39	4846640,99	-2,64	4,76
85ref	636383,42	4846605,58	-0,85	2,12

29 points –relative accuracy test WV2 vs PlanetScope over LPISQA 2016 Sweden

Point Nr.	X [m] - EAST	Y [m] - NORTH	dX	dN
p1	642303,73	6500619,44	0,79	-1,19
p2	642656,01	6500066,29	1,77	0,88
p3	643914,00	6500283,10	-1,08	-1,24
p4	648594,64	6500354,62	-0,64	-1,11
p5	651637,30	6500298,48	-3,33	1,91
p6	651264,84	6498643,22	0,26	-0,26
p7	651472,97	6497845,28	-1,29	-2,79
p8	644092,36	6494257,35	-0,52	-4,13
p9	646988,19	6491754,82	-0,53	-1,13
p10	644846,99	6498243,46	-1,55	-1,55
p11	642085,37	6498764,26	0,64	-0,36
p12	644224,77	6494901,89	-1,48	-1,85
p13	642243,46	6491704,48	-2,07	0,52
p14	646713,36	6496616,32	2,65	0,25
p15	645315,69	6499512,93	-1,98	-0,79
p16	648249,36	6498650,44	-0,33	-0,66
p17	642591,05	6496684,46	-1,09	-4,08
p18	642380,87	6494686,11	-2,52	0,45
p19	648810,80	6493678,20	-1,36	-1,19
p20	646367,49	6494716,40	-1,59	0,40
p21	649868,68	6490978,24	-1,03	-1,03
p22	649434,25	6493512,09	0,52	-1,55
p23	644721,31	6493121,01	-2,58	-0,52
p24	648095,03	6495926,18	-1,03	-2,07
p25	648684,63	6499034,48	0,74	-4,07
p26	645564,46	6500306,48	0,56	-1,01
p27	651624,50	6493544,88	1,76	-0,71
p28	650777,94	6493337,65	-0,79	-0,95
p29	647742,00	6498192,11	-0,87	0,83

93 points –relative accuracy test WV2 vs PlanetScope over LPISQA 2016 Greece

Point Nr.	X [m] - EAST	Y [m] - NORTH	dX	dN
p1	357273,31	4377942,44	-1,21	1,87
p2	351569,80	4373194,16	-0,33	-2,98
p3	351195,78	4375385,86	-1,02	-1,34
p4	350172,83	4372848,21	4,20	-2,10
p5	350927,64	4369426,67	-1,05	2,83
p6	352684,80	4369467,68	1,96	4,13
p7	357621,28	4369416,42	1,16	4,73
p8	354834,88	4369683,98	-2,06	1,48
p9	356735,25	4370039,18	-2,10	4,73
p10	356582,46	4369876,79	1,32	3,70
p11	354908,30	4369976,01	0,33	4,30
p12	351361,55	4369734,25	-2,98	2,32
p13	352940,13	4370163,20	-0,79	2,91
p14	357229,03	4370290,20	3,11	0,40
p15	357839,23	4370178,75	3,58	2,38
p16	357480,39	4370632,18	1,01	3,49
p17	356103,89	4370757,53	1,35	2,44
p18	352871,34	4370559,75	-1,14	1,64
p19	350755,66	4371432,55	0,64	-1,27
p20	355308,15	4371454,04	-0,61	1,48
p21	358190,13	4371368,38	-1,20	2,17
p22	358580,73	4371315,47	1,69	2,12
p23	357498,25	4371702,75	1,24	-2,58
p24	354911,28	4371736,16	3,61	1,47
p25	350617,08	4371822,15	-1,75	1,27
p26	350948,80	4371916,07	-1,85	-0,53
p27	357202,24	4371999,42	1,98	1,98
p28	358430,24	4372138,32	-0,51	-3,65
p29	356731,28	4372413,16	1,81	0,88
p30	358591,97	4372564,63	2,27	1,73
p31	358812,57	4373199,64	-1,48	1,48
p32	355538,01	4373238,99	0,32	3,33
p33	357268,72	4373677,54	0,32	-2,96
p34	358891,61	4373746,66	0,67	-1,26
p35	359011,00	4374138,38	1,21	0,20
p36	356779,90	4374105,83	-0,32	-2,01

p37	354087,76	4374053,25	3,67	-1,57
p38	353724,62	4374310,89	0,33	-2,65
p39	351457,47	4374106,83	-0,99	-2,65
p40	353385,95	4374599,28	-2,10	2,10
p41	354090,74	4374593,66	0,15	-1,39
p42	356968,09	4374757,04	-3,57	-0,79
p43	357264,75	4375129,11	-1,86	-2,05
p44	355608,79	4375222,05	1,98	0,33
p45	355147,09	4375239,58	-0,99	1,76
p46	352717,55	4375119,52	1,98	0,33
p47	350748,05	4375368,56	-2,33	-2,43
p48	350948,14	4375578,91	6,87	-3,55
p49	352410,96	4375667,54	1,42	-2,77
p50	354326,22	4375768,74	-3,97	2,98
p51	355609,78	4376045,90	0,66	1,32
p52	359206,47	4375852,09	-0,76	1,23
p53	359776,64	4375831,25	-1,59	3,18
p54	359700,25	4376122,63	1,80	2,21
p55	359368,85	4376203,32	0,58	2,67
p56	358925,68	4376282,70	-1,97	3,31
p57	354792,88	4376319,41	-1,25	2,16
p58	352192,68	4376235,07	2,06	-1,61
p59	350595,92	4376358,11	-3,15	-3,15
p60	350881,67	4376616,07	-1,76	2,70
p61	351234,22	4376620,04	-0,30	2,40
p62	352005,82	4376637,24	-0,73	-0,53
p63	354518,04	4376747,37	-0,84	3,11
p64	359485,60	4376567,46	-0,15	0,42
p65	359508,75	4376908,77	1,85	-1,59
p66	358941,55	4376821,46	-3,44	2,19
p67	354318,61	4377075,46	-1,57	-3,15
p68	353560,11	4376971,28	-4,37	1,72
p69	351697,25	4376987,81	1,91	-2,12
p70	351116,15	4376999,39	-2,35	1,86
p71	350160,34	4377084,72	-3,44	2,38
p72	351032,29	4377146,11	0,14	-2,33
p73	351568,59	4377135,98	0,52	-1,57

p74	353173,95	4377428,68	-1,32	-0,53
p75	354225,01	4377276,54	-1,65	1,32
p76	359420,45	4377249,42	0,92	1,88
p77	354132,99	4377493,04	0,88	-1,68
p78	352479,75	4377758,42	-2,21	1,89
p79	352290,27	4377639,80	-1,91	-0,85
p80	350667,25	4377621,22	-0,22	2,59
p81	350823,13	4377792,81	-3,97	1,85
p82	350981,55	4377957,51	-2,65	1,06
p83	353954,81	4377898,31	1,32	-2,12
p84	355317,08	4378371,59	-1,06	0,53
p85	353772,91	4378491,97	0,52	-1,57
p86	351402,57	4378402,35	-0,79	-2,65
p87	353596,63	4378888,85	-3,67	1,57
p88	353673,69	4378771,11	-0,52	4,72
p89	356041,38	4378942,43	-1,59	-1,59
p90	359498,50	4379296,64	-1,05	2,62
p91	356256,36	4379224,87	-0,90	2,38
p92	354384,58	4379181,32	-2,38	1,19
p93	353385,28	4379249,89	-5,26	0,53

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