Technical Note on Quality Assessment for Dove-R

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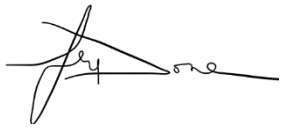
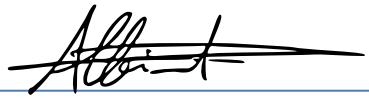
Approval:  ***Fay Done***
Task 1 Lead

Accepted:  ***Clement Albinet***
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AMENDMENT RECORD SHEET

The Amendment Record Sheet below records the history and issue status of this document.

ISSUE	DATE	REASON
0.1	26 02 2020	Draft version for ESA review
0.2	03 03 2020	Updated draft version for ESA review – updated maturity matrix (Table 3-1) to account for not public information
0.3	26 05 2020	Updated draft version for ESA review – minor updates (comments received 15/05/2020)
1.0	07 02 2022	First issue.

TABLE OF CONTENTS

1. EXECUTIVE SUMMARY

The primary purpose of the activity performed with PlanetScope data has been to ensure that the product conforms to the declared quality.

As shown in the visual inspection activity (Section 5.4), compared to DOVE, at least two major design updates to DOVE-R have contributed to the significantly improved product quality, more particularly image quality: the Bayer pattern filter and pass band filter have been replaced by a high-performance filter.

There remains some room for improvement in terms of the metadata content and quality assurance information of DOVE-R products. This study shows that the geometric accuracy of DOVE-R requires careful monitoring. Furthermore, the quality mask exists but its description, content and the consistency of information given should be improved.

The geometric accuracy of ortho products varies in a scene, depending on the stripe. The georeferencing model of one scene is refined with block adjustment over all previous and following stripes.

The model estimates boresight angles for a two-dimensional array, causing inevitable geometric shift between two image stripes. It has been shown in geometric activity (Section 5.6) that the accuracy of the geometric model is fair, however, the analysis demonstrates that the accuracy of the image's internal geometry is degraded. The situation is magnified when terrain relief becomes slightly hilly (100 m height in footprint area).

The inter-band registration is quite good over flat terrain but becomes degraded over hilly terrain. The parallax effect caused by Earth targets not seen at the same time by the different bands remains very important and cannot be corrected by the sensor model that should account for inner orientation of each detector in the two-dimensional array. As a conclusion, the geometric specification of DOVE-R data remains in the operational performance requirements if, and only if, observations are done over flat terrain relief.

The Signal-to-Noise Ratio (**SNR**) of the system has been assessed. The results indicate stability, across several products, and are in agreement with the SNR specifications disclosed by the data provider.

The analysis presented herein highlights systematic effects observed in all bands of all DOVE-R products, i.e. the SNR increases at the beginning of each image scene causing regular banding in the scene (vertical line). This issue should be seen as an artefact and it does not impact significantly the overall image quality.

2. INTRODUCTION

This document is the Technical Note describing the Quality Assessment of the PlanetScope (DOVE-R) mission.

The quality assessment consists of a series of checks on the product format and metadata, and on the geometric and radiometric performance of a limited number of products. Note that it is possible that these products were updated since the quality assessment described in this document was carried out.

The quality assessment performed here is in line with the assessment guidelines provided in the Earthnet Data Assessment Pilot (**EDAP**) project [RD-1] and the guidelines tailored for optical missions [RD-2].

2.1 Reference Documents

The following is a list of reference documents with a direct bearing on the content of this proposal. Where referenced in the text, these are identified as [RD-n], where 'n' is the number in the list below:

RD-1. EDAP.REP.001 Generic EDAP Best Practice Guidelines,1.1 23 May 2019

RD-2. EDAP.REP.002 Optical Mission Quality Assessment Guidelines, 1.0, 16 October 2019.

RD-3. Planet Imagery Product Specifications, June 2020, https://assets.planet.com/docs/Planet_Combined_Imagery_Product_Specs_letter_screen.pdf

RD-4. Analysis Ready Data for Land, product family specification Surface Reflectance (CARD-4L SR), 08/06/2020 http://ceos.org/ard/files/PFS/SR/v5.0/CARD4L_Product_Family_Specification_Surface_Reflectance-v5.0.pdf

RD-5. S. Bahoul, A. Jumpsaut, I; Zuleta, 'PLANET L1 data quality report Q4 2019 Report', Status of calibration and data quality for the Planetscope constellation, December 31th, 2019.

RD-6. Zanoni, "IKONOS Signal-to-Noise Ratio Estimation", March 25-27, 2002, JACIE Workshop, 2002 https://ntrs.nasa.gov/search.jsp?R=20040004380

RD-7. CEOS, RadCalNet Quick Start Guide. July 2018 https://www.radcalnet.org/resources/RadCalNetQuickstartGuide_20180702.pdf

RD-8. EDAP.REP.007, TN on Quality Assessment for PlanetScope (DOVE), 1.0, January 2020

RD-9. Planet L1 Data Quality Report Q2 2019 – Status of calibration and Data Quality for the PlanetScope Constellation

RD-10. NEXTMap World 30 Digital Surface Model, Intermap (083013v3)

RD-11. Clyde R. Greenwalt and Melvin E. Shultz, “Principles of Error Theory And Cartographic Applications”, Aeronautical Chart and Information Center, 1968.

RD-12. Joshua Greenberg, “On-Orbit Radiometric Calibration and Validation of Planet’s Constellation”, JACIE conference, 2018

RD-13. Nicholas Wilson, Joshua Greenberg, Arin Jumpasut, Alan Collison and Horst Weichelt, “Absolute Radiometric Calibration of Planet Dove Satellites, Flocks 2p & 2e, 2014

RD-14. CDS-TPZ-03-00077-TR, 19/09/2017, Issue 1.0

2.2 Glossary

The following acronyms and abbreviations have been used in this Report.

ATBD	Algorithm Theoretical Basis Document
BRDF	Bidirectional Reflectance Distribution Function
CEOS	Committee on Earth Observation Satellites
EDAP	EARTHNET Data Assessment Pilot
GSD	*Ground Sampling Distance*
HR	High Resolution
JACIE	*Joint Agency Commercial Imagery Evaluation*
MTF	*Modulation Transfer Function*
NPL	National Physical Laboratory
PDI	Product Data Item
PHR	Pleiades High Resolution
ROI	Region Of Interest
S2	Sentinel-2
SNR	Signal-to-Noise Ratio
TN	Technical Note
TOA	Top-Of-Atmosphere
UDM2	Usable Data Mask
VHR	Very High Resolution

3. EDAP QUALITY ASSESSMENT

3.1 EDAP Maturity Matrix

The preliminary assessment was performed following the EDAP quality assessment guidelines written by the National Physical Laboratory (**NPL**) [RD-1], with the summary in Section 3 (see Table 3-1) and detailed in Section 4. It is considered as a 'preliminary assessment' as it was prepared using a limited number of Dove-R products over specific calibration sites.

Table 3-1: DOVE-R Quality Maturity Matrix

Product Information	Product Generation	Ancillary Information	Uncertainty Characterisation	Validation
Product Details	Sensor Calibration & Characterisation Pre-Flight 🔒	Product Flags	Uncertainty Characterisation Method 🔒	Reference Data Representativeness
Product Availability & Accessibility	Sensor Calibration & Characterisation Post-Launch 🔒	Ancillary Data	Uncertainty Sources Included 🔒	Reference Data Quality
Product Format	Retrieval Algorithm Method		Uncertainty Values Provided 🔒	Validation Method
User Documentation	Retrieval Algorithm Tuning		Geolocation Uncertainty 🔒	Validation Results
Metrological Traceability Documentation	Additional Processing			

Key
Not Assessed
Not Assessable
Basic
Intermediate
Good
Excellent

🔒 Information not public

3.2 Summary of Quality Assessment

The summary of the activities performed for DOVE-R products listed in APPENDIX B is shown in Table 3-2.

Table 3-2: Executive Summary

Assessment	Results
Product details and visual assessment	The image does not show evidence of image artefacts or anomalies, detectable through visual assessment. The general image quality of DOVE-R is better when compared to DOVE. The documentation on the Usable Data Mask (**UDM**, UDM 2) [RD-4] should be updated to reflect the content of the UDM. The UDM provides information, which is very useful for filtering inconsistent pixel values, but of this information (e.g. cloud, lost detector) is not consistent.
Geometric accuracy	The geometric calibration of DOVE-R ortho tile products has been validated. In this context, three critical validation items have been checked - the absolute accuracy, the multi-temporal accuracy, and the inter-band registration accuracy. For all these considered validation items, the results found are in agreement with the accuracy specifications given by the data provider in [RD-3] and the quality report [RD-5].
Radiometric accuracy	The radiometric accuracy assessment, performed on only two DOVE-R products, is based on a commonly used absolute calibration methodology; the radiometric calibration of the DOVE-R data is estimated against in-situ data, which are permanently recorded with the La Crau station (France) as part of the RadCalNet network. Furthermore, the same methodology is applied with a Sentinel-2B product acquired on the same date / time as the DOVE-R data. The assessment results of the first product indicate conformance with the radiometric performance specification but the results for the second product do not.
Image quality	By using a bright / uniform site, it has been possible to compute the SNR for a full image. The study demonstrates that the SNR results are stable between two dates. In addition, the study demonstrates that the SNR level is compliant with the Planet specification.

4. DETAILED EDAP QUALITY ASSESSMENT

The sub-section assessment of the mission quality maturity matrix includes:

- Product Information
- Product Generation
- Ancillary Data
- Uncertainty Characterisation
- Validation

The sub-section assessment relies on a grading scale (key), namely 'Not Assessable, Not Assessed, Basic, Intermediate, Good and Excellent'.

4.1 Product Information

This sub-section covers top-level product descriptive information, product format, and supporting documentation.

The product information in the product metadata is listed in the table below, with parameter values given when available. There is some of the minimum set of required information missing (e.g. stated measurement quality) so the associated EDAP grade is "*Basic*".

Product Details	
Sensor Name	*PlanetScope – DOVE-R, PS2*
Sensor Type	*Optical Multispectral (VNIR)*
Product Version Number	*The version of the product is tagged by the processing date together with the processor name.*
Processor Name / Version	*CMO Processor / 4.1.4*
Product ID	*<CatalogueID>_<TileID>_<AcquisitionDate>_<SatelliteID>* *Example: 2037910_3159122_2019-01-19_1010* *Full list of products used in this document is reported in APPENDIX B*
Processing level of product	*PlanetScope Basic Scene Product (Level 1B)* *PlanetScope Ortho Scene Product (Level 3B)* *PlanetScope Ortho Tile Product (Level 3A)*
Measured Quantity Name	*Not available in the metadata* *(Radiance / Top of Atmosphere Reflectance / Surface Reflectance)*
Measured Quantity Units	*Not available in the metadata* *(DN / W sr^{-1} m^{-2} μm^{-1})*
Stated Measurement Quality	*Unavailable*
Spatial Resolution	*Given in term of Sensor Resolution and Ground Sampling Distance (**GSD**). The GSD is defined with the following formula:* $$GSD = \frac{detector_{pitch} * altitude}{Focal\ length}$$ *where* • $detector_{pitch}$ = 5.5 μm,

	• $Focal\ length = 0.7\ m$ *(effective)* • $altitude$ *is the altitude of the platform varying between 450 km (orbit perigee) and 510 km (orbit apogee).* *With this formula, the GSD is always within 3.50 m and 4.0 m.* *This parameter is to be understood as "the pixel resolution" of Level 3A / Level 3B images that does not change and is respectively 3.125 m / 3.0 m as indicated in the product metadata.* *The term "Sensor Resolution", set to 3.0 m, is also not appropriate.*
Spatial Coverage	*The spatial coverage is given in the metadata file, the geographical coordinates of the product footprint (corners) are given.* *(For information a standard scene is about 25 km x 16 km Frame)*
Temporal Resolution	*The temporal resolution is not indicated as metadata information.*
Temporal Coverage	*The temporal coverage understood as the scene time duration is also indicated in the product metadata.* *(For information it is within 1 day accounting for the overall constellation)*

Based on INSPIRE metadata, recommended information is also given in the product metadata as:

- Point of contact (*www.planet.com)*
- Licence (*20160101 - https://assets.planet.com/docs/20160101_Inc_SingleUser.txt)*

As part of recommended information, the following information is missing:

- Product abstract (summary of resource) is missing,
- Product locator (DOI).

Other information, as number of satellites involved in the constellation (25 DOVE-R), the sun-synchronous orbit characteristics (Two Line elements, NORAD ID, Ascending / Descending orbit) is not indicated.

Regarding the product availability & accessibility, the data meets many of the FAIR principles and there is no data management plan. The EDAP grade is '*Intermediate'.*

As shown in the table below, the data are in a standard file format, meeting community naming convention standards. The CARD4L-SR threshold (minimum) requirements are partially met. For these reasons the EDAP grade is *'Good'.*

Product Format	
Product File Format	*Data encoding is standard GeoTiff with GeoJSON metadata file and XML metadata file*
Metadata Conventions	*xsi:schemaLocation="http://schemas.planet.com/ps/v1/planet_product_metadata_geocorrected_level http://schemas.planet.com/ps/v1/planet_product_metadata_geocorrected_level.xsd"* *xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"*

	xmlns:xs="http://www.w3.org/2001/XMLSchema" *xmlns:xlink="http://www.w3.org/1999/xlink"* *xmlns:opt="http://earth.esa.int/opt"* *xmlns:gml="http://www.opengis.net/gml"* *xmlns:eop="http://earth.esa.int/eop"* *version="1.2.1"* *planet_standard_product_version="1.0"*
Analysis Ready Data?	*The CARD4L-SR threshold (minimum) requirements (RD-4) for the general metadata and the per-pixel metadata are mostly met. There are some exceptions; as deviations one can cite the following 'non compliancy':* • *Algorithms are not identified in the metadata;* • *Auxiliary data are not identified in the metadata.* *SR images are provided in the Level 3B products.*

The user documentation covers two fundamental aspects, the availability of a product user guide and the availability of an Algorithm Theoretical Basis Document (**ATBD**). In the user guide, there is ATBD-type information (in the user guide, in the workshop presentation), but absence of a formal ATBD(s). The user guide is very detailed *[RD-3].* For these reasons, the EDAP grade is *'Intermediate'.*

User Documentation		
Document	*Reference*	*QA4ECV Compliant*
Product User Guide	*Product specification document is available online (last accessed 10/01/2020),* The d*ocument is updated regularly*	*Partially – user cases and validation missing.*
ATBD	*Not available to users*	-

There is no traceability chain documented. For this reason, the EDAP grade for metrological traceability is *'Not Assessable'.*

4.2 Product Generation

This sub-section covers the processing steps undertaken to produce the data. As mentioned previously, the data provider delivered L1 and L2 data products.

There is only one document found regarding pre-flight calibration and it is in the form of a presentation given at a JACIE conference. It demonstrates that pre-flight activities have been performed. However, this material is not sufficient to assess pre-flight calibration approach(es). For this reason, the EDAP grade is *'Not Assessable'.*

Sensor Calibration & Characterisation – Pre-Flight	
Summary	*Public presentation at the Joint Agency Commercial Imagery Evaluation (**JACIE**) workshop: the presented pre-flight calibration consists of calculation of the Modulation Transfer Function (**MTF**) Flat field noise and it was estimated the RSR over a few percent of the total number of DOVE satellites.*

References	*1. https://calval.cr.usgs.gov/apps/sites/default/files/jacie/JACIE-Presentation-Pre-launch-Calibration-of-the-Planet-Labs-PlanetScope-Constellation-1.pdf*

The post-launch calibration and characterisation activities are regularly performed and the method is described into a dedicated document. The analysis covers important aspects of the sensor behaviour. In addition, Planet is using appropriate community infrastructure (CEOS PICS, RADCALNET) to perform analysis. For these reasons, the EDAP grade is *'Intermediate'.*

Sensor Calibration & Characterisation – Post-Launch	
Summary	*The calibration is performed by cross-calibration between DOVE-R and RapidEye [RD-13]. RapidEye is well calibrated to ±2.5% [RD-12]. The most recent calibration performed by Planet was in the period 2019-02-12 to 2019-02-26.*
References	*[RD-12], [RD-13]*

The data provider is delivering surface reflectance product, derived from the standard Planet Analytic (Radiance) product, that is processed to TOA reflectance and then atmospherically corrected to BOA reflectance (surface reflectance). Planet uses the 6S radiative transfer model with ancillary data from MODIS to account for atmospheric effects on the observed signal at the sensor for the PlanetScope Dove-R constellation [RD-3]. In [RD-3], the limitations of the proposed processing are well documented. Moreover, the values of the atmospheric parameters (AOT, Ozone content …) are reported in the GeoTiff metadata.

Also, regarding the 'Retrieval Algorithm Method', with respect to the method shortly described in [RD-3], the retrieval method is reasonable and judged to be "fit for purpose". For these reasons, the EDAP grade of 'Retrieval Algorithm Method' is *'Intermediate'.*

Finally, there is no material allowing us to evaluate 'Retrieval Algorithm Tuning' and 'Additional Processing' so the EDAP grade for them is '*Not Assessable'*.

4.3 Ancillary Information

The product UDM contains a comprehensive set of well documented product flags, with full gradation where appropriate and many provided or calculable at pixel level. The EDAP grade is therefore '*Excellent'.*

Product Flags	
Product Flag Documentation	*Unusable Data Mask band (UDM).* *New Usable data mask (UDM2) available but not present in products analysed. Specifications are found in the Planet product specification document.*
Comprehensiveness of Flags	*Cloud mask, detector failure mask*

Furthermore, it is considered that all ancillary data is provided to define measurement. The relative spectral response function and other information can be requested from the user service. The EDAP grade is therefore *'Basic'.*

Ancillary Data	
Ancillary Data Documentation	*Partially available to the user in the data product. The other information needs to be requested (i.e. not available to users).*
Comprehensiveness of Data	*N/A*
Uncertainty Quantified	*N/A*

4.4 Uncertainty Characterisation

This sub-section evaluates the methodology used to estimate uncertainty values for a given mission, the extent of the mission's analysis and how the values are provided.

The Planet team perform regular uncertainty characterisation activities as illustrated in the quarterly data quality report [RD-4]. The quarterly report is not public and has only been shared with the EDAP team under a non-disclosure agreement.

Based on a representative dataset and comparison with other sensors, the quarterly report proposes a comprehensive analysis of the most common product performance quality items. Furthermore, a full breakdown is proposed. For these reasons, the EDAP grade is *'Good'*.

Uncertainty Characterisation Method	
Summary	*Planet provides uncertainty on Geometric performance and Radiometric performance.* *A broad range of quality items are addressed. The associated methods are not fully described but the essential is reported.*
Reference	[RD-4]

The uncertainty sources are specifically discussed for the geometric calibration method (reference data). There is no similar discussion regarding the other method. For this reason, the EDAP grade is 'Basic'.

Uncertainty Sources Included	
Summary	*The Planet report partially documents the uncertainty sources related to geometry and not radiometry. Furthermore, the uncertainty related to the estimate of image quality parameter (SNR, Relative Edge Response).*
Reference	[RD-4]

The uncertainty values are never provided in the EO data product. However, the main uncertainty values, given in [RD-4], are provided for subsets of data (e.g. subsets of data for a given period). Furthermore, the DOVE-R constellation is processed as a whole and there is no breakdown depending on the satellite. However, inter-calibration measurements in order to assess mission to mission variations (DOVE / DOVE-R and

Super Dove) are proposed. In addition, the uncertainty values are in most cases expressed in different metrics, which is very helpful for the user.

For all of these reasons, EDAP grade is '*Intermediate*'. This grade is applicable to the two following maturity matrix box 'Uncertainty Values Provided' and 'Geolocation Uncertainty'. The tables below summarise the uncertainty values gathered from the existing documentation and covering the subset of data observed in the Q4 2019 period. These values have been used as input of the EDAP quality assessment, as is also written at the beginning of each corresponding quality assessment section (when relevant).

Uncertainty Values Provided: Radiometric Calibration Uncertainty	
Summary	*The following mean / standard deviation (STD) cross-calibration gains are given:* • *BLUE: 1.015 / 0.036* • *GREEN: 1.025 / 0.041* • *RED: 1.005 / 0.038* • *NIR: 0.999 / 0.042* *The validation methodology compares DOVE-R with reference mission as Landsat 8 / OLI and Sentinel-2A / MSI, Sentinel-2B / MSI.*
Reference	*[RD-4]*

Uncertainty Values Provided: Signal to Noise Ratio	
Summary	*The following SNR are given:* • *BLUE: 224.501 / 204* • *GREEN: 162.298 / 166* • *RED: 235.57 / 144* • *NIR: 183.144 / 437* *For each band, the SNR value and its corresponding average reference radiance* $W.sr^{-1}m^{-2}$ *are given. The reference radiance measurements associated with these measurements correspond to 50% of the dynamic range for each band (12-bit).* *The SNR is computed for each scene, an average value is given here.*
Reference	*[RD-4]*

Uncertainty Values Provided: Relative Edge Response	
Summary	*The Relative Edge Response (RER) is calculated on the Green band for all images with sharp edges overlapping 5000 specified airport sites worldwide.*

<table>
<tr><td></td><td>
<table>
<tr><td></td><td colspan="2">RER green
Across Track</td><td colspan="2">RER green
Along Track</td></tr>
<tr><td></td><td>native</td><td>Normalized to 3 m GSD</td><td>native</td><td>Normalized to 3 m GSD</td></tr>
<tr><td>Four-stripe DOVE-R</td><td>0.345</td><td>0.261</td><td>0.363</td><td>0.276</td></tr>
</table>
</td></tr>
<tr><td>Reference</td><td>[RD-4].</td></tr>
</table>

Applicable to all geolocation uncertainty items, Planet proposes “overall” geolocation uncertainty metrics, which consider as input the uncertainty associated to each product. With this approach, the following metrics are given:

- Average RMSE,
- 90th Percentile of the radial RMSE,
- STD of RMSE.

The table below details the geolocation uncertainty results.

<table>
<tr><th colspan="2">Geolocation Uncertainty</th></tr>
<tr><td>Summary</td><td>The product accuracy results (L3A,L3B), reported by the quality control team, and considered as EDAP input specifications are given in [RD-4] and can be summarised as follows:
• The absolute geolocation accuracy is 3.79 m / 2.00 m (Mean / STD RMSE accuracy), this average accuracy is computed based on 903 products,
• The multi-temporal geolocation accuracy is 2.68 m / 2.60 m (Mean / STD RMSE accuracy), this average accuracy is computed based on 903 products,
• The Inter-band registration accuracy (Mean / STD RMSE Accuracy) is summarised as follow:
BLUE - GREEN : 2.38 m / 2.75 m
BLUE - RED : 1.89 m / 2.03 m
BLUE - NIR : 2.04 m / 1.54 m
GREEN - RED : 1.21 m / 1.36 m
GREEN - NIR : 2.31 m / 2.14 m
RED -/ NIR : 1.74 m / 1.27 m
This average accuracy is computed based on 983 products.</td></tr>
<tr><td>Reference</td><td>[RD-4].</td></tr>
</table>

4.5 Validation

The below validation items related to activities conducted by the EDAP Team (not Planet).

Reference measurements are assessed to be somewhat representative of the satellite measurements, covering a limited range of satellite measurements. For this reason, the EDAP grade is '*Basic'.*

Reference Data Representativeness	
Summary	*There is good data representativeness but the sample of data is small as input of the EDAP methodology.*
Reference	*None. Note that this report provides results of such a validation.*

The reference data used by EDAP comes with a single uncertainty for the entire dataset. For this reason, the EDAP grade is '*Intermediate'.*

Reference Data Quality	
Summary	*The Sentinel-2 mission is used as reference, the radiometric accuracy of MSI is high and well documented. Considering both satellites, the absolute calibration uncertainties is within 2-3 %.* *The radiometric calibration method used also the RadCalNet data and MODIS data, given with a respective uncertainty of 2% and 3%.* *Regarding the absolute geolocation, the method used as reference a GCP set derived from a GPS test field survey. The uncertainties of the field measurement is within 30 cm.*
Reference	*https://sentinel.esa.int/documents/247904/685211/Sentinel-2_User_Handbook* *https://www.usgs.gov/land-resources/nli/landsat/landsat-8-data-users-handbook* *MODIS Data, RadCalNet :[RD-7]*

The EDAP methodology assess satellite measurements providing a simple uncertainty estimated e.g. from statistical point of view. For this reason, the EDAP grade is '*Intermediate*'.

Validation Method	
Summary	*Absolute geolocation accuracy is validated with GCPs located in the image space by using a semi-automatic method. The uncertainty related to the GCP pointing accuracy is within 0.5 pixel.* *The geometric calibration accuracy is validated using image matching techniques, which involve image grid comparisons that are very accurate (uncertainty of about 0.1 pixel).* *The radiometric calibration accuracy is validated using RadCalNet data and MODIS data.* *The Image quality is validated based using methods presented at the JACIE Workshop [RD-6].*

Reference	*See section 5.*

The EDAP validation results shows good agreement between satellite and reference measurements, and agreement within uncertainties claimed by the data provider. Furthermore, the EDAP analysis has been performed independently from the satellite mission owner. As result, the EDAP grade is "*Good*".

Validation Results	
Summary	*Given into this document summary.*
Reference	*See Section 5 for the analysis.* *See Section 6 for the conclusions.*

5. DETAILED DOVE-R QUALITY ASSESSMENT

5.1 Goals

Considering the innovative and often challenging technology associated with Very High Resolution (**VHR**) and High Resolution (**HR**) data, this Technical Note (**TN**) reports the results of the performed quality assessment with respect to the following validation aspects:

- Product documentation;
- Product format;
- Image quality;
- Geometric calibration quality;
- Radiometric calibration quality;

5.2 Product Documentation Evaluation

The PlanetScope constellation includes three generations of satellites: DOVE (PS2), DOVE-R (PS2.SD) and SUPER DOVE (PSB.SD). The Planet product specification documentation [RD-3] describes the specificities of these three generations of satellites, in particular the type of sensor that is different, as shown in Figure 5-1.

The Planet imagery product specifications document is available online [RD-3] and deals with the Planet constellation, including the PlanetScope constellation and the SkySat constellation.

The product specifications document [RD-3] addresses a broad category of topics such as constellations / satellites, sensors, products, formats, product processing. Also, the following document breakdown is adopted:

- Planet constellation and sensor
- PlanetScope imagery products
- RapidEye imagery Products
- SkySat imagery products
- Product processing
- Product metadata
- Product delivery

It is worth noting that there is no accuracy specification provided, except the geolocation accuracy. Any references related to accuracy specification is available in [RD-4].

In this section, a comparison of the Planet user guide documentation and the Sentinel-2 user guide documentation is provided. Documents and or any information available for Sentinel-2 not listed in this section can be considered unavailable for PlanetScope products.

Mission overview

Planet provides an initial section with the mission overview including the main satellite and sensor parameters.

CONSTELLATION OVERVIEW: PLANETSCOPE			
Mission Characteristics	Sun-synchronous Orbit		
Instrument	**PS2**	**PS2.SD**	**PSB.SD**
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	Four-band frame Imager with a split-frame VIS+NIR filter	Four-band frame imager with butcher-block filter providing blue, green, red, and NIR stripes	Eight-band frame imager with butcher-block filter providing coastal blue, blue, green I, green II, yellow, red, red-edge, and NIR stripes
Spectral Bands	Blue: 455 - 515 nm Green: 500 - 590 nm Red: 590 - 670 nm NIR: 780 - 860 nm	Blue: 464 - 517 nm Green: 547 - 585 nm Red: 650 - 682 nm NIR: 846 - 888 nm	Coastal Blue 431-452 nm* Blue: 465-515 nm Green I: 513. - 549 nm Green II: 547. - 583 nm* Yellow: 600-620 nm* Red: 650 - 680 nm Red-Edge: 697 - 713 nm NIR: 845 - 885 nm *(* avail. after 8-band release)*
Ground Sample Distance (nadir)	3.7 m (approximate)		
Frame Size	24 km x 8 km (approximate)	24 km x 16 km (approximate)	32.5 km x 19.6 km (approximate)
Maximum Image Strip per orbit	20,000 km²		
Revisit Time	Daily at nadir		
Image Capture Capacity	200 million km²/day		
Imagery Bit Depth	12-bit		

Figure 5-1: Example of PlanetScope document table. Mission overview.

The overview section of the Sentinel-2 User guide contains a similar table, with the comparison to heritage missions. The table contains less parameters compared to PlanetScope products. However, all the parameters listed in the PlanetScope mission overview are explained in specific sections in the Sentinel-2 user guide, whereas there are no further details for some of the fields present in the table depicted in Figure 5-2.

Products type

The Planet product description document continues with the different products available. Planet provides the L1A, L3A and L3B PlanetScope products to the users.

As shown with the table below, PlanetScope product levels are not immediately comparable to Sentinel-2 products for the following reasons:

PLANETSCOPE SATELLITE IMAGE PRODUCT PROCESSING LEVELS

Name	Description	Product Level
PlanetScope Basic Scene Product	Scaled Top of Atmosphere Radiance (at sensor) and sensor corrected product. The Basic Scene product is designed for users with advanced image processing and geometric correction capabilities. This product has scene based framing and is not projected to a cartographic projection. Radiometric and sensor corrections applied to the data.	Level 1B
PlanetScope Ortho Scene Product	Orthorectified, scaled Top of Atmosphere Radiance (at sensor) or Surface Reflectance image product suitable for analytic and visual applications. This product has scene based framing and projected to a cartographic projection.	Level 3B
PlanetScope Ortho Tile Product	Radiometric and sensor corrections applied to the data. Imagery is orthorectified and projected to a UTM projection.	Level 3A

Name	**High-level description**	**Production & Distribution**	**Data Volume**
Level-1B	Top-of-atmosphere radiances in sensor geometry	Systematic generation and on-line distribution	27 MB (each 25x23 km^2)
Level-1C	Top-of-atmosphere reflectances in cartographic geometry	Systematic generation and on-line distribution	500 MB (each 100x100 km^2)
Level-2A	Bottom-of-atmosphere reflectances in cartographic geometry (prototype product	Generation on user side (using Sentinel-2 Toolbox	600 MB (each 100x100 km^2)

Figure 5-2: Comparison of Planet DOVE-R (top) and Sentinel-2 (bottom) products available to users.

The major differences can be summarised as follow:

- The Sentinel-2 Level 1B products are not proposed to the user in a straightforward way, unlike the PlanetScope Level 1B products available from the catalogue. In both cases, image is corrected from systematic effect and expressed into the corresponding instrument grid.
- The PlanetScope Level 3B image is a one frame observation (24.6 km x 16.4 km) corresponding to a full swath image, due to the size, there is no S2 product embedding full swath image.
- The PlanetScope Level 3A / Level 3B image is corrected from systematic effects, co-registered to common reference map (ALOS / PRISM Reference), corrected from

effect due to terrain relief (Intermap, [RD-10]). The raster / elevation reference used for processing are not the same as for the Sentinel-2 processing. However, starting from the Level 1B processing level, the Sentinel-2 raster / elevation reference data can be involved, resulting in an improved geometric co-registration accuracy between both Sentinel-2 and PlanetScope ortho images.

- As for the Level 3B image, the Level 3A image is expressed in to a Universal Transverse Mercator (**UTM**) geographic grid. This grid is defined in 25 km by 25 km tiles referenced based on the UTM number. This referential is different from the Military Grid Reference System (**MGRS**) (adopted for Sentinel-2.
- The Level 3B product include calibrated physical data expressed in two different forms: Top-Of-Atmosphere (**TOA**) reflectance and Surface Reflectance (**SR**) measurements. For this purpose, the Sentinel-2 approach distinguishes two processing levels - Level 1C and Level 2A.

In the Planet product description document, the basic characteristics of each PlanetScope product type are listed and explained. For Sentinel-2, a separate document for the Product specification is provided that encompasses all aspects of the product, from product definitions to a full detailed description of each Product Data Item (**PDI**). The fields present in each PlanetScope product were compared to the Product specification document and they resulted compliant to the specifications.

As for the Sentinel-2 documentation, all the fields present in a PlanetScope product metadata are listed and explained. The product structure is summarised in a table and each file delivered in a PlanetScope product is summarised and explained.

Notably, Planet introduced a new Usable Data Mask (**UDM2**) in their products. This additional band has the function of a quality band and gives information regarding clouds, shadows, snow and other field of view obstruction elements (e.g. haze).

Product processing

The product description document provided by Planet continues with a section relative to the processing chain. The section is mainly composed of a table and a graph that summarise the processing steps performed and the differences between the products processing levels. The level of details of that section informs the users about the processing blocks (e.g. radiometric calibration, geometric corrections) expected for each product type but does not reach the completeness of an Algorithm Theoretical Basis Document (**ATBD**) which is distributed for Sentinel-2 products.

Data delivery options

The document concludes explaining the different delivery options available for the users, namely the API and the GUI with the links to their platform.

5.3 Product Format Evaluation

As discussed just here before and described in [RD-3], Planet delivers the three following PlanetScope product types:

- PlanetScope Basic Scene Product (Level 1B);
- PlanetScope Ortho Scene Product (Level 3B);

- PlanetScope Ortho Tile Product (Level 3A).

This breakdown is adopted for DOVE (PS2), DOVE-R (PS2.SD) and SUPER DOVE (PSB.SD) data. The Table 5-1 list content of each product type selected as part of the EDAP Test Data Set (TDS). In addition, the processing applied is also indicated. Note that the Level 1B is not geocoded. Alternatively, an RPC file associated to the image is available and is essential for the geometric processing (ortho processing).

Unlike the Level 3A, the Level 3B includes both TOA and Bottom-of-Atmosphere (**BOA**) images. A framing is applied to Level 3B images: the geographical extent of Level 3B image covers a tile of 25 km x 25 km fully included within the Level 3A image extent.

A JSON file is also available at the root of the product directory.

Table 5-1: Content and processing of PlanetScope product type.

Product Type	Component and Format	Map projected	TOA	Resampling	BOA	Framing
PlanetScope Basic Scene Product (Level 1B)	Image File – GeoTIFF format Metadata File – XML format Rational Polynomial Coefficients - XML format Thumbnail File – GeoTIFF format Unusable Data Mask (UDM) file – GeoTIFF format Usable Data Mask (UDM2) file - GeoTIFF format	N	Y	N	N	N
PlanetScope Ortho Scene Product (Level 3A),	Image File – GeoTIFF format Metadata File – XML format Thumbnail File – GeoTIFF format Unusable Data Mask (UDM) file – GeoTIFF format Usable Data Mask (UDM2) file - GeoTIFF format	Y	Y	Y	N	N
PlanetScope Ortho Tile Product (Level 3B).	Image File – GeoTIFF format Metadata File – XML format Thumbnail File – GeoTIFF format Unusable Data Mask (UDM) file – GeoTIFF format Usable Data Mask (UDM2) file - GeoTIFF format	Y	N	Y	Y	Y

In the DOVE study [RD-8], the format check of the metadata file and the JSON file have been performed and results are report. Procedure has been played back for DOVE-R data, there is no difference. So, for in depth analysis, please refer to [RD-8].

In general, the product format of the XML DIMAP file is detailed and conforms to the various OGC standards. Regarding the content of the metadata files, the fields are well documented with comments written into the XML.

5.4 Image Quality: Visual inspection

5.4.1 Activity Description Sheet

Table 5-2: Activity description sheet for image quality visual inspection

Visual inspection
Inputs
Set of Level 3A / Level 3B PlanetScope DOVE-R data observed over “La Crau”, “Libya 4”, site (set of products is listed in APPENDIX B)
Description
The visual inspection tasks include analysis of the quick look images, analysis of the full resolution images and analysis of the mask. In case of DOVE-R, and more generally in case of Planet, as shown before, there are different product types and also different radiometric processing (BOA and TOA values). In this context, the main tasks undertaken within this activity are: • Check of the Unusable Data Mask (UDM1), • Check of the Usable Data Mask (UDM2), • Check of BOA images • Qualitative evaluation of Image interpretability Regarding the last points, a particular interest has been paid on the comparison between DOVE / DOVE-R.
Outputs
Qualitative assessment of the image data information. Image interpretability report Analysis report on data mask

5.4.2 Introduction

The visual inspection addresses three product components; the quicklook, the mask and the full-resolution image. This section starts with a discussion on the consistency of the data mask accompanying image data. For this purpose, any data mask images of the input test dataset have been extracted from UDM / UDM2 and analysed from visual and quantitative point of view.

In addition, as Planet delivers BOA images, it has been the opportunity to compare both Sentinel 2 and DOVE-R surface reflectance images.

Finally, an image interpretability method has been performed, with main objective to compare DOVE & DOVE-R data.

5.4.3 Unusable data Mask

The unusable data mask file provides information on areas of unusable data within an image (e.g. cloud and non-imaged areas). The content of the unusable data mask image is explained in [RD-3]. The value of each pixel in the UDM is coded on 1 byte and is seen as a bit sequence, each bit set to 0 or 1 depending on the flagging rule. The UDM image pixel value is broken as follow:

- Bit 0: Identifies whether the area contains backfill in all bands.
- Bit 1: Identifies whether the area is cloud covered.
- Bit 2: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in band 1.
- Bit 3: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in band 2.
- Bit 4: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in band 3.
- Bit 5: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in band 4.
- Bit 6 is set to “0”.
- Bit 7 is set to “0”.

In this analysis, we focused on the quality of UDM information with visual inspection and statistical tasks. All UDM masks in the test dataset have been processed. The following remarks can be listed as follow, these are documented just here after:

- Level 3A / Level 3B UDM – Missing or suspects pixel flag: even if product is from the same date / time, the information in the UDM differs depending on the processing level.
- UDM – Missing or suspects pixel flag: the identification of suspects / missing is not clear because a lot of pixels are correct and are flaged as ‘suspects’
- UDM – Cloud and false detection: there is an excessive number of false positive cloudy pixels. This is due to cloud 1.0 detection algorithm. It should be fixed with cloud 2.0 detection algorithm, as confirmed with Planet (communication 08-12-2020).
- UDM – format: The format of UDM mask is not in agreement with the format defined [RD-3], as confirmed with Planet (communication 08-12-2020). It is a minor issue related to the document of bit ordering.

Level 3A / Level 3B UDM – Missing or suspects pixel flag

For a same reference product, same location, the content of the UDM is different depending on the processing level. The ortho tile UDM (Level 3A) includes always more information compared to the ortho scene UDM (Level 3B). In particular, the frame boundaries can be indicated in the Level 3A UDM for certain band, as shown in Figure 5-3.

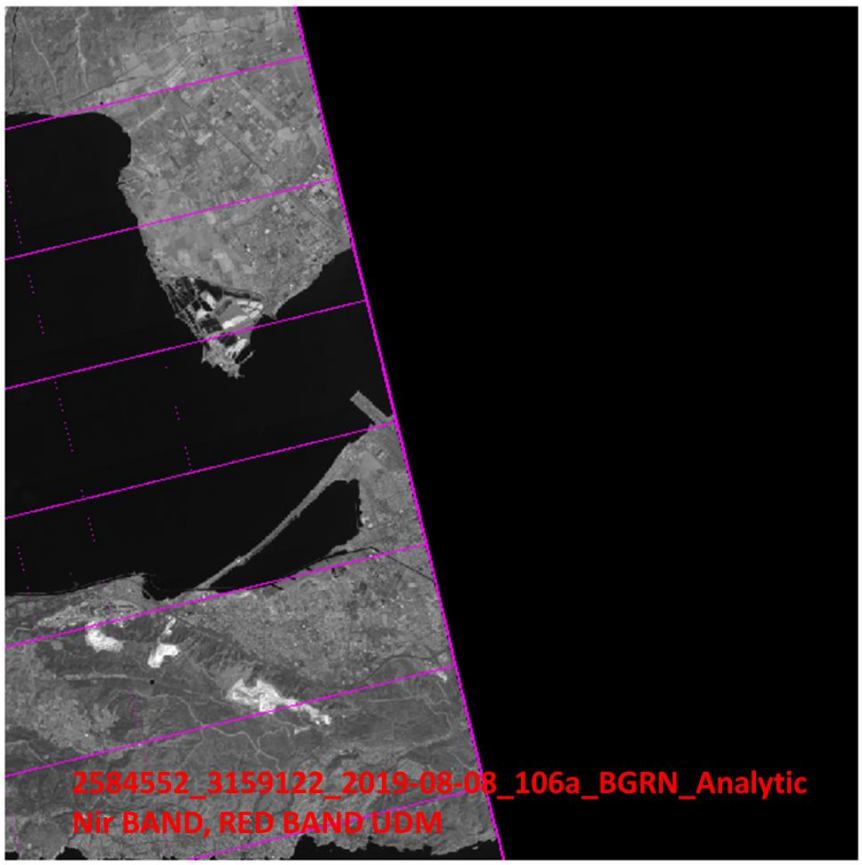


Figure 5-3: Usable data mask (Level 3A)

Checking images, in most cases, no anomaly is observed.

UDM – Missing or suspects pixel flag

This study does not confirm the fidelity of the UDM: image anomalies are in most cases not flagged in the UDM images. Conversely, there are a lot of false detection as shown in the Figure 5-4. This figure is extracted from the Libya 4 image (Id 16), Blue band image. The geographical coordinates of the ROI are indicated at the bottom left of the figure. The small image of the full scene is overlays the main figure, in lower right corner. Note that a radiometric stretch has been applied to the image in order to highlight anomalies.

The BGRN images have been analysed, and agreement between image and UDM information has been verified. Referring to the Figure 5-4, the following anomalies can be observed:

- A vertical line (1) in the right of figure corresponding to detector sensitivity lost contaminated the input image (from top to bottom) and is not flagged in the UDM,
- A horizontal line (2) in the middle of the image, that might be due to equalisation issue between the two consecutive stripe (dark field correction), (it also been observed in the La Crau images),
- A vertical line (3) in the left of the figure corresponding to flagged pixel in UDM for the Red band, by checking this band, no anomaly has been observed.

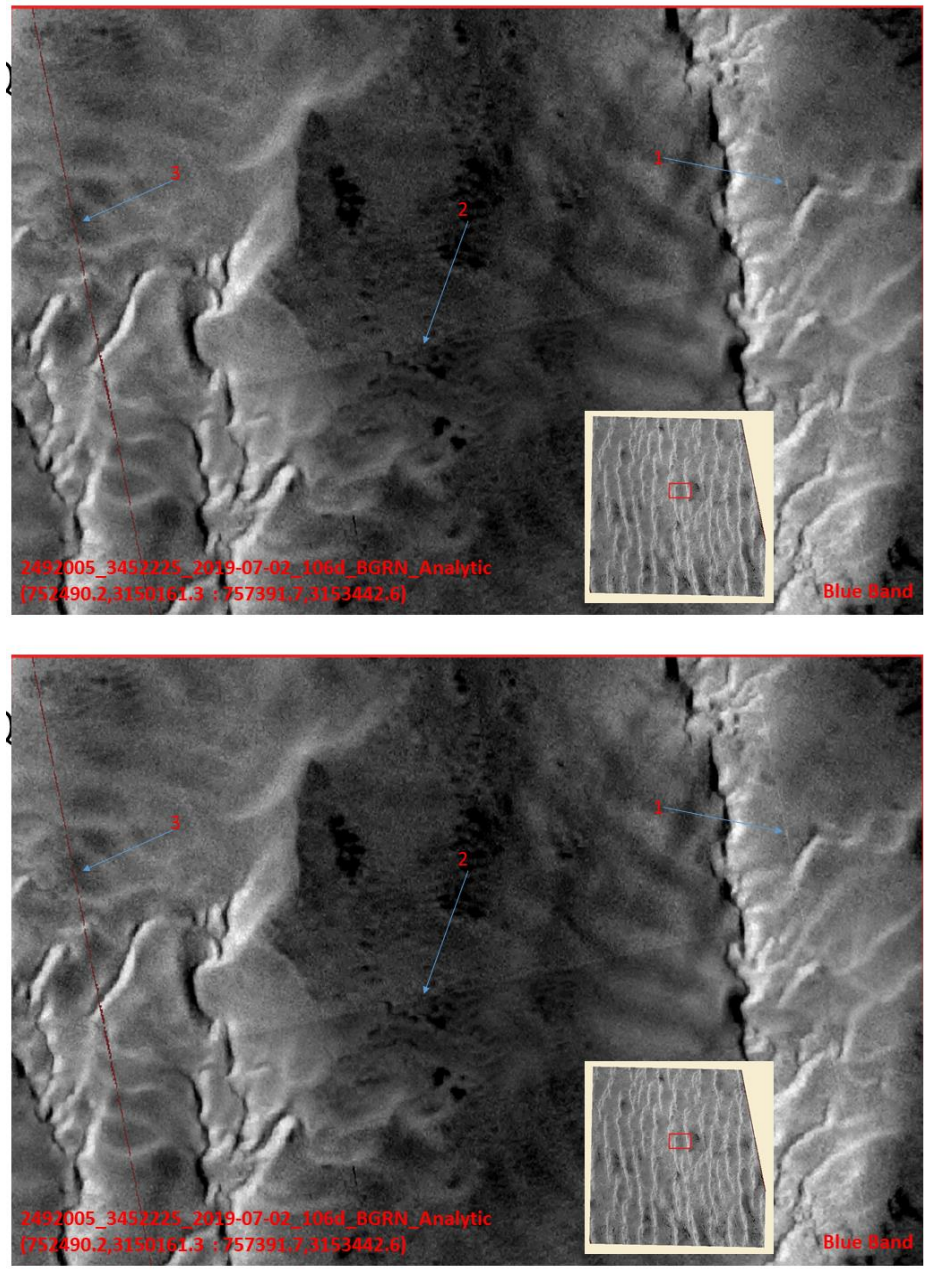


Figure 5-4: Usable data mask, false detection (ID 16).

Some anomalies are correctly flagged. However, even if very few pixels are contaminated in the image, it is all the corresponding pixels issued from the same detector array that are flagged as contaminated, as shown in Figure 5-5 where the same RGB image with (left figure) and without (right figure) the lost pixel mask as additional layer are compared. In this small region with the ortho scene full image (Level 3B), there are two groups of corrupted pixels:

- one group on the left side (Red circle) that is flagged (pink straight line) by the UDM
- a second group on the right side is not flagged by the UDM.

Even if there is few number of contaminated pixels, all pixels under the pink line are flagged as not valid pixels.

Figure 5-5: Usable data mask, over detection, false detection, no detection (ID 11).

UDM – Cloud and false detection

The UDM cloud information is inconsistent: pixels flagged as cloudy are finally valid. The Figure 5-6 shows an RGB composition of images from the four La Crau Ortho Tiles (Left), mosaicking applied.

This RGB composition is overlaid with cloud mask image extracted from UDM (pink). The UDM Cloud mask images have been mosaicked. The brown line (horizontal / vertical) indicated the boundary of each tile. A Red rectangle defines the region of the zoom.

The small images from this region are shown on the right of the same figure. Comparing the top image (with mask) and the bottom image (without), it demonstrates that pixels from vegetation cover are flagged as cloudy.

In addition, the left images (RGB composition) shows that the spatial distribution of the cloud mask is strongly dependant of the strip boundary. Also, anomaly in the UDM cloud mask might dependent on the strip processing. On scene required to stitch several strips of image.

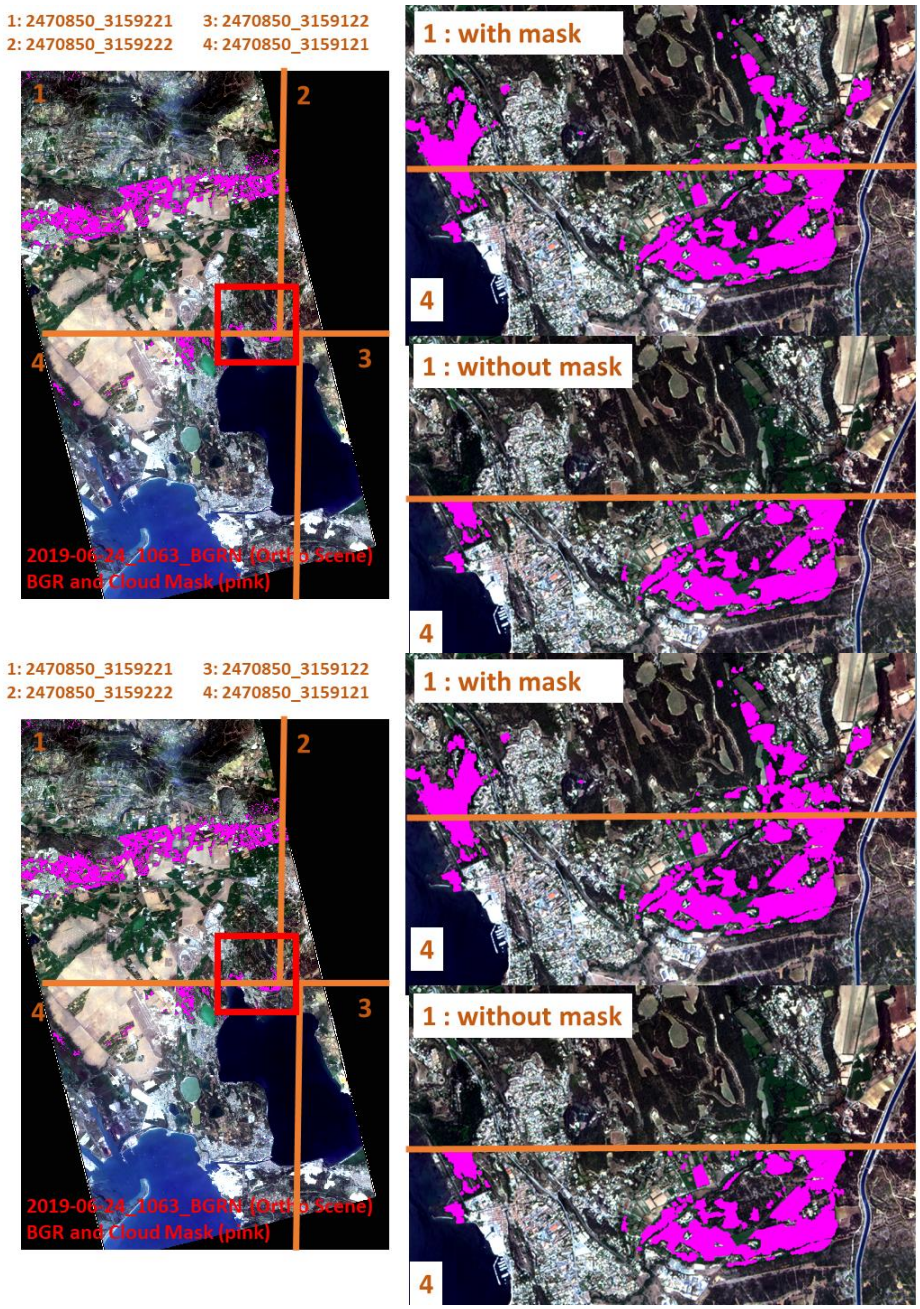


Figure 5-6: Usable data mask, cloud detection (ID 2, ID 3, ID 4, ID 5).

UDM format

The UDM content has been checked from quantitative point of view. As found with EDAP analysis, the bit order of the UDM byte is explicitly defined as “blackfill, cloud, Blue, Green,

Red, Red edge, NIR, other". The documentation, [RD-3] (pp 10), states that the order is "as blackfill, cloud, Blue, Green, Red, NIR, Red edge, other". This issue is minor.

5.4.4 Usable data Mask

As mentioned in [RD-3], "The usable data mask file provides information on areas of usable data within an image (e.g. clear, snow, shadow, light haze, heavy haze and cloud).". The UDM is a raster image having the same dimensions as the image product, comprised of 8 bands, where each band represents a specific usability class mask. The usability masks are mutually exclusive, and a value of one indicates that the pixel is assigned to that usability class.

● Band 1: clear mask (a value of "1" indicates the pixel is clear, a value of "0" indicates that the pixel is not clear and is one of the 5 remaining classes below)

- Band 2: snow mask,
- Band 3: shadow mask,
- Band 4: light haze mask,
- Band 5: heavy haze mask,
- Band 6: cloud mask.

● Band 7: confidence map (a value of "0" indicates a low confidence in the assigned classification, a value of "100" indicates a high confidence in the assigned classification)

● Band 8: unusable data mask "

The usable data mask of ID 3 product has been investigated. The images observed in August are mostly clear sky. However, as shown in Figure 5-7 , the clear mask indicates that some pixels are not clear due to snow, which is a priori not possible in this summer period. The flags are not activated for Band 3, Band 4, Band 5 and Band 6.It should be interesting to confirm that it is effectively proposed to the user.

Furthermore (Figure 5-7), the band 8 is a copy of the unusable data mask including inconsistencies previously discussed. There is also a confidence mask link to the classification. The confidence values are varying, the meaning of this information is not evident and we do not found description. A confidence of 99 is attached to pixel contaminated with snow.

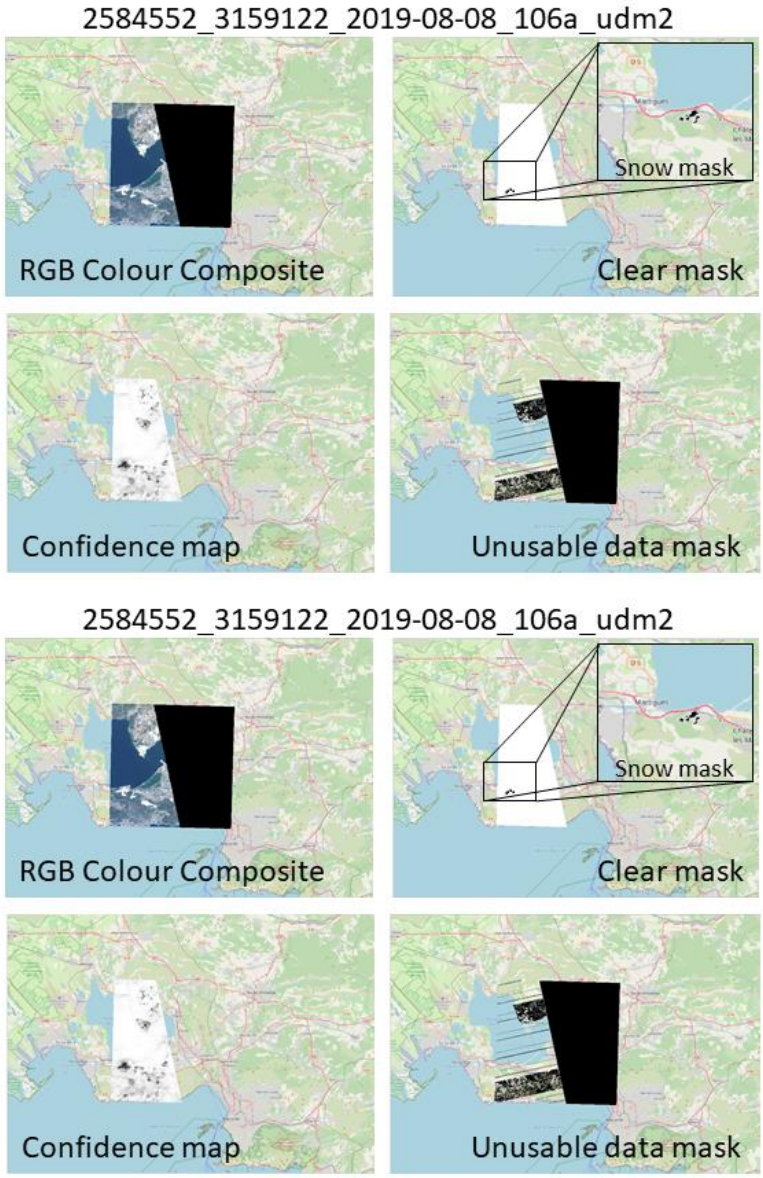


Figure 5-7: Usable data mask information (ID 3).

5.4.5 Surface reflectance product

For one specific Level 3B product, aberrations in the image have been detected, as shown in Figure 5-8. The problem is due to cirrus cloud not detected by the Planet atmospheric correction processing. In the UDM image, the cirrus area is flagged as ‘clear’. This limitation is discussed in the Planet user note [RD-3].

Figure 5-8: Artefact in the Surface Reflectance colour composite image, ID 1 product.

This latter statement is confirmed with a comparison between the Planet Level 3B images (ID 1 product) and one Sentinel-2 Level 2A images, acquired at the same date / time (there are 13 minutes lags between the two observations).

As shown in Figure 5-9, the existing cirrus cloud (depicted with the Red circle) visible in the Planet image (right) has been totally corrected in the Sentinel-2B image (left). Beside this limitation, due to atmospheric corrections, the figure demonstrates that, from qualitative point of view, a good radiometric calibration agreement between DOVE-R and Sentinel-2 MS is reached.

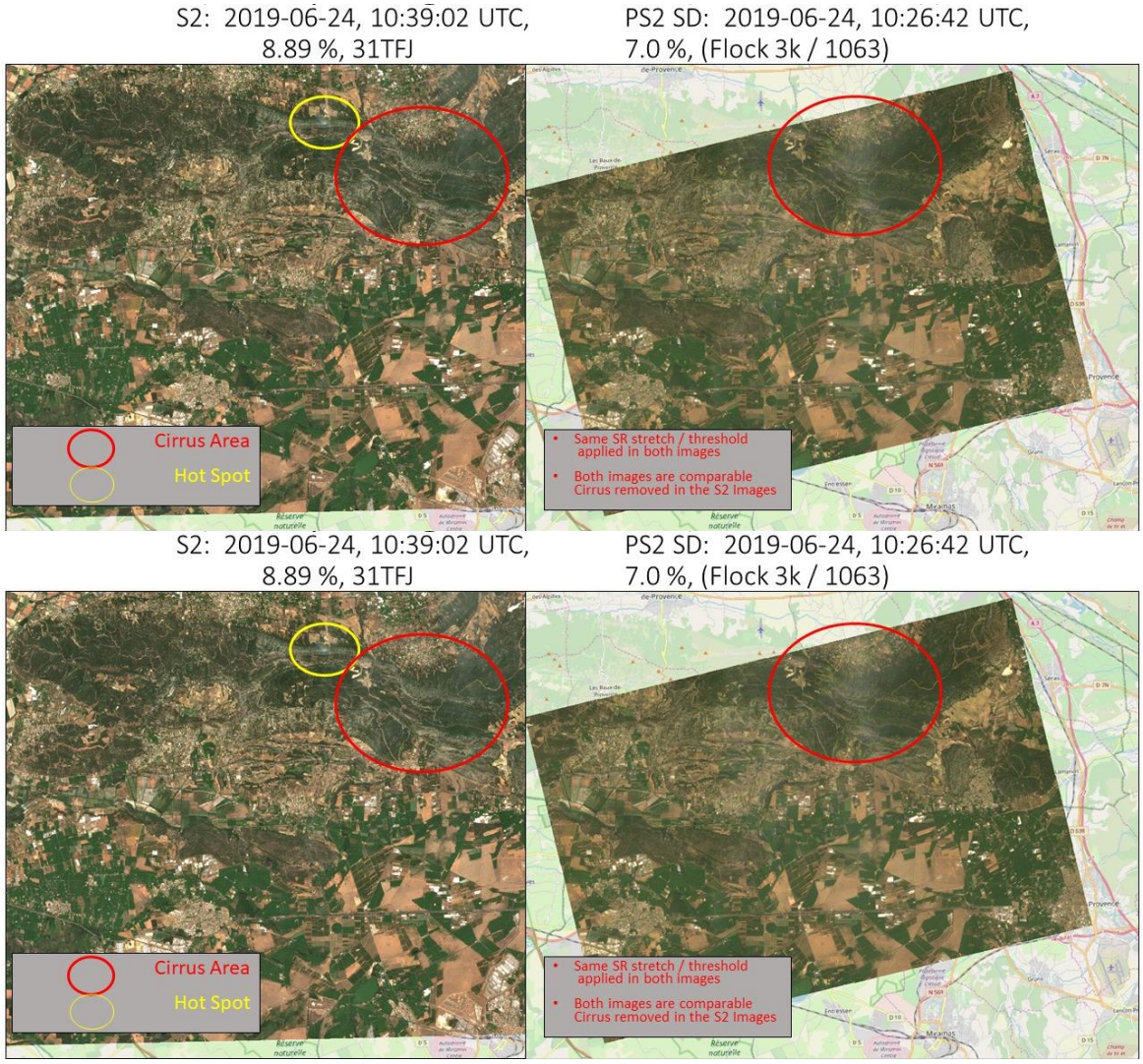


Figure 5-9: Surface reflectance corrections; Sentinel-2B Level 2A RGB image (left) compaRed with the DOVE-R Level 3B RGB image (right), ID 1 product.

5.4.6 Image interpretability

The planet image is resampled to a pixel resolution of 3.125 m. The pixel resolution of the image is often considered as the same parameter as the Ground Sampling Distance (**GSD**) of the system. It is not necessarily true. It depends on the data provider's approach. The Planet "initial" image GSD is varying depending on the altitude of the platform and is estimated to be on the order of 3.8 m. The GSD parameter is sufficient but not enough to appreciate the ability of the sensor to discriminate objects. In the community, some experts are using the term Effective Ground Sampling Distance in order to account for the quality of the acquisition system: the more the effective GSD is close to the GSD, the better the image quality is.

Herein, it is not intended to estimate the effective GSD. We just used an image interpretability technique to compare how well object extraction is by considering DOVE image, DOVE R image and Pleiades HR image.

Our intention is to show an improvement between DOVE and DOVE-R and also to show that the image quality of Planet data may exhibit some limitations in some specific configurations.

A main input to this analysis is the definition of objects (object database) and reference data. Reference data is from an optical multi spectral data of higher quality. Pleiades High Resolution (**PHR**) data.

The object database relies on POIs selected for their characteristics: manmade objects / natural objects. Within the deliveRed dataset, data observed over Salon-de-Provence and dated of October 5 2019 has been selected. Figure 5-10 shows the distribution of Points of Interest (**POI**) in a Green Band image.

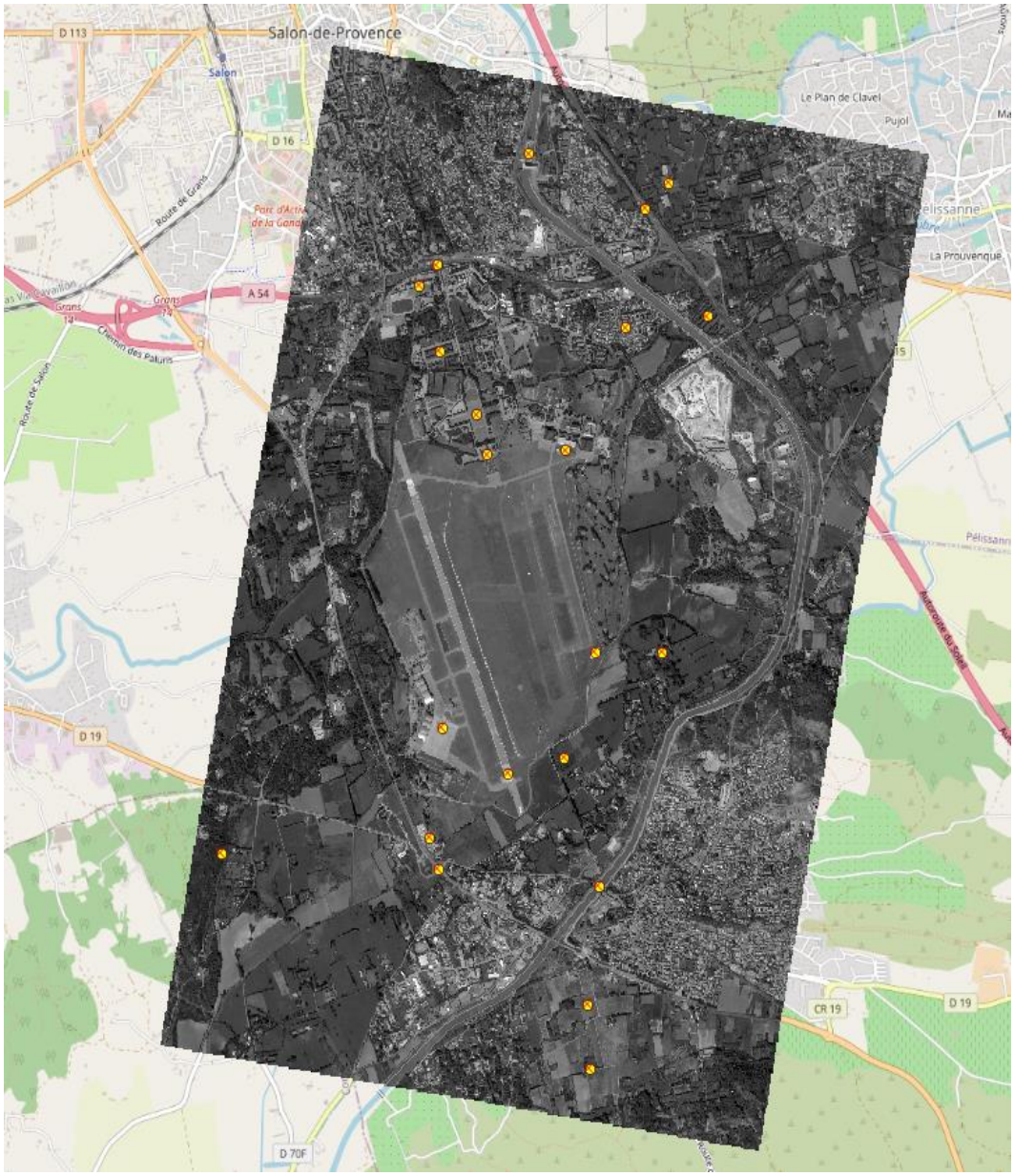


Figure 5-10: POI over Green Band image observed over Salon-de-Provence.

The method consists of clipping input images (all bands) within a 100 x 100 pixels window centred on the POI.

In this document, the full resolution image windows processed with the same pixel resolution (3.125 m) are displayed. By comparing images from the various missions, it is possible to assess the capability of each mission to capture image details.

The Table 5-3 below lists the POIs used in this assessment, a short description of each is given.

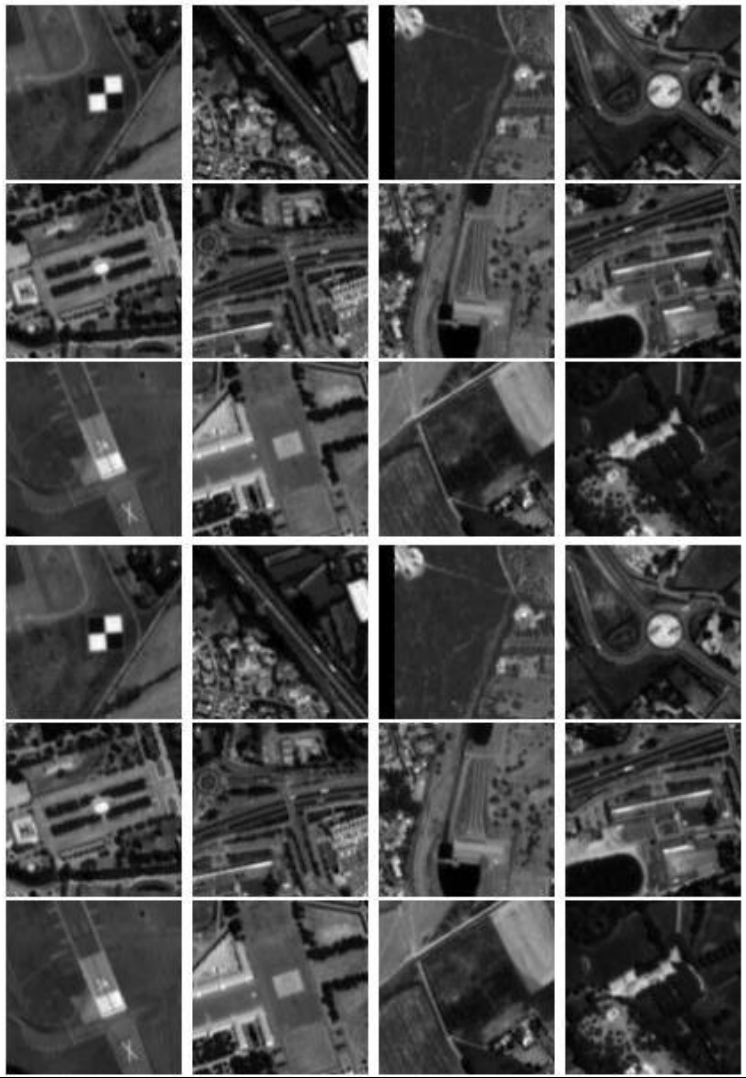
Table 5-3: POI over the Salon scene

wkgt_geom (UTM 31)	Id	Description
Point (671090.3105554151115939 4830278.58671295549720526)	1	Modulation Transfer Function target
Point (671364.24309313111007214 4833044.0252351425588131)	2	Motor way / sharp transition (45° NE)
Point (668580.81736886233557016 4828965.45189037173986435)	3	Forest
Point (670056.62237295764498413 4828905.08180973120033741)	4	Roundabout / parking lot
Point (669985.90922565956134349 4832120.72269264236092567)	5	Elevated tree
Point (669956.03863696497865021 4832655.53592716064304113)	6	Motor way / roundabout
Point (670564.24590074480511248 4833363.40447467099875212)	7	The dam
Point (669836.88448120269458741 4832528.00618595350533724)	8	Big building (shadow)
Point (670518.95015854423400015 4829513.56928175128996372)	9	Landing track - 34
Point (670249.72702971810940653 4831735.0312919020652771)	10	Floor Painting
Point (670900.38168655894696712 4829617.21182315889745951)	11	Crop fields / sparse
Point (671548.0352310094749555 4830292.1131860688328743)	12	Broadleaved woodland
Point (671099.93821095407474786 4828090.14610077627003193)	13	Crop fields
Point (671156.44116920174565166 4828825.77096180152148008)	14	Bridge and water
Point (671120.4438803291413933 4827691.31545618735253811)	15	Crop fields
Point (670328.31568091106601059 4831489.30539688002318144)	16	Building / EA 15
Point (671516.86161747551523149 4833207.41657157335430384)	17	Greenhouse

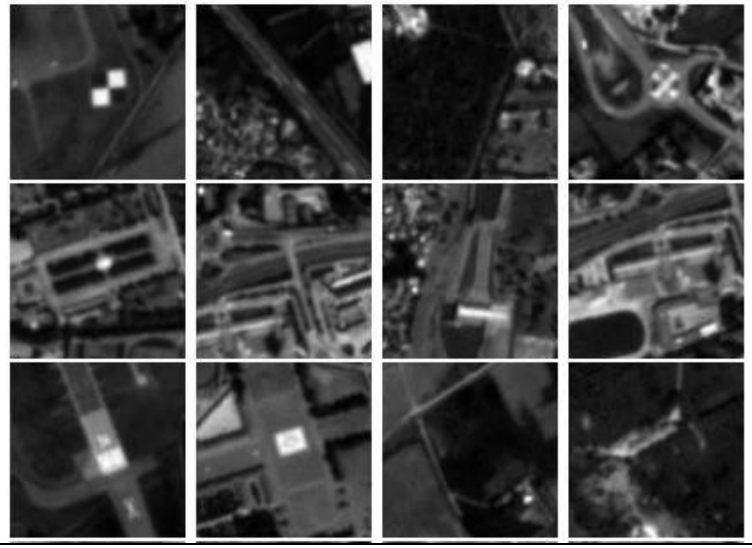
wkgt_geom (UTM 31)	Id	Description
Point (669996.87127304612658918 4829099.09009433817118406)	18	Parking lot
Point (670062.87681329366751015 4829781.35287734866142273)	19	Plane parking
Point (670860.46870227111503482 4831527.10888031311333179)	20	Plane hangar
Point (671802.47347140731289983 4832385.40385554917156696)	21	Small crop fields
Point (671246.59432400949299335 4832300.03732818737626076)	22	Urban city

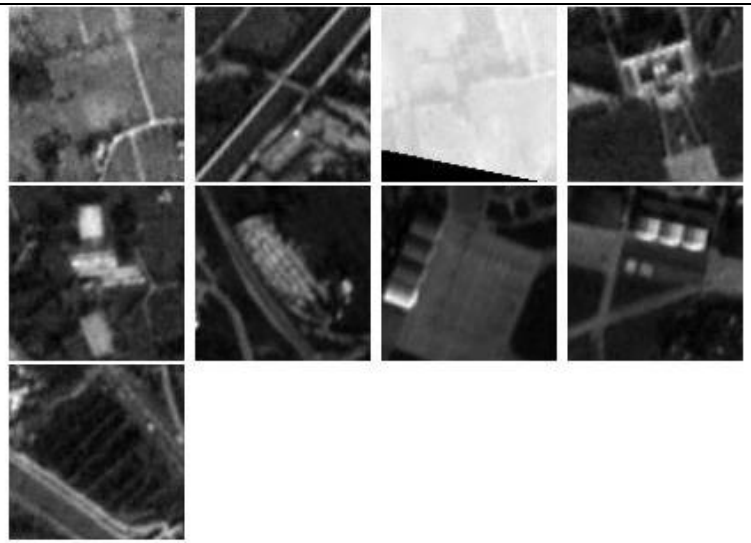
The **Error! Reference source not found.** shows the POI images observed with DOVE, DOVE R and PHR missions. The image comparison allows us to issue the following remarks:

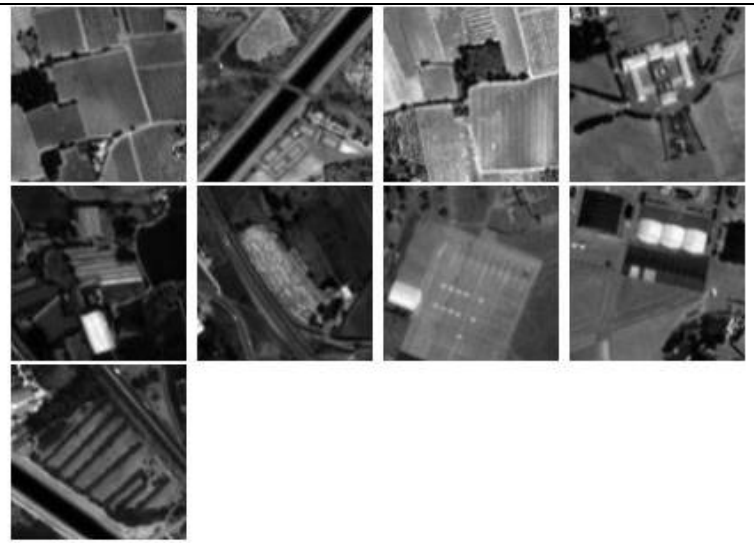
- Significant image quality Improvements between DOVE and DOVE-R;
- For a same pixel resolution, the DOVE-R image allows to better delineate objects compared to DOVE images;
- At the pixel resolution of 3.125 m, in some cases objects which are visible in the PHR images, are not visible in the DOVE-R images (traffic lane, cars, airport runway letter);
- The contrast of the NIR image is low, for DOVE and DOVE-R data.



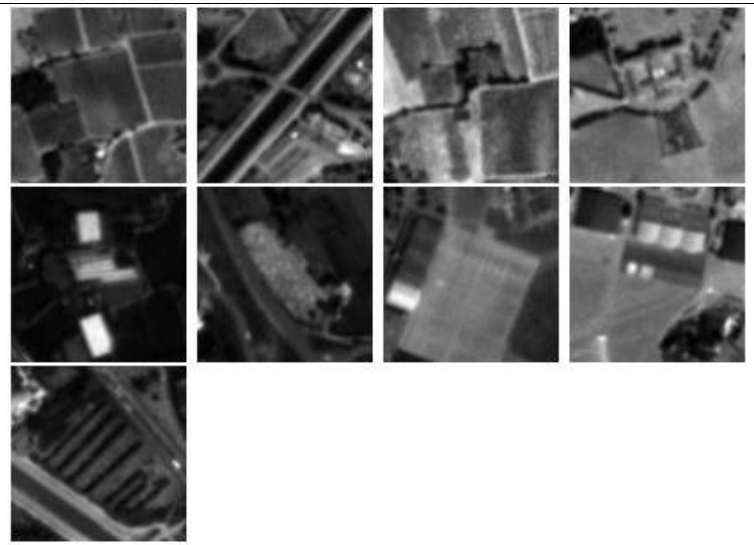
DOVE	PHR
BLUE BAND (POI 1 => POI 12)	DOVE-R

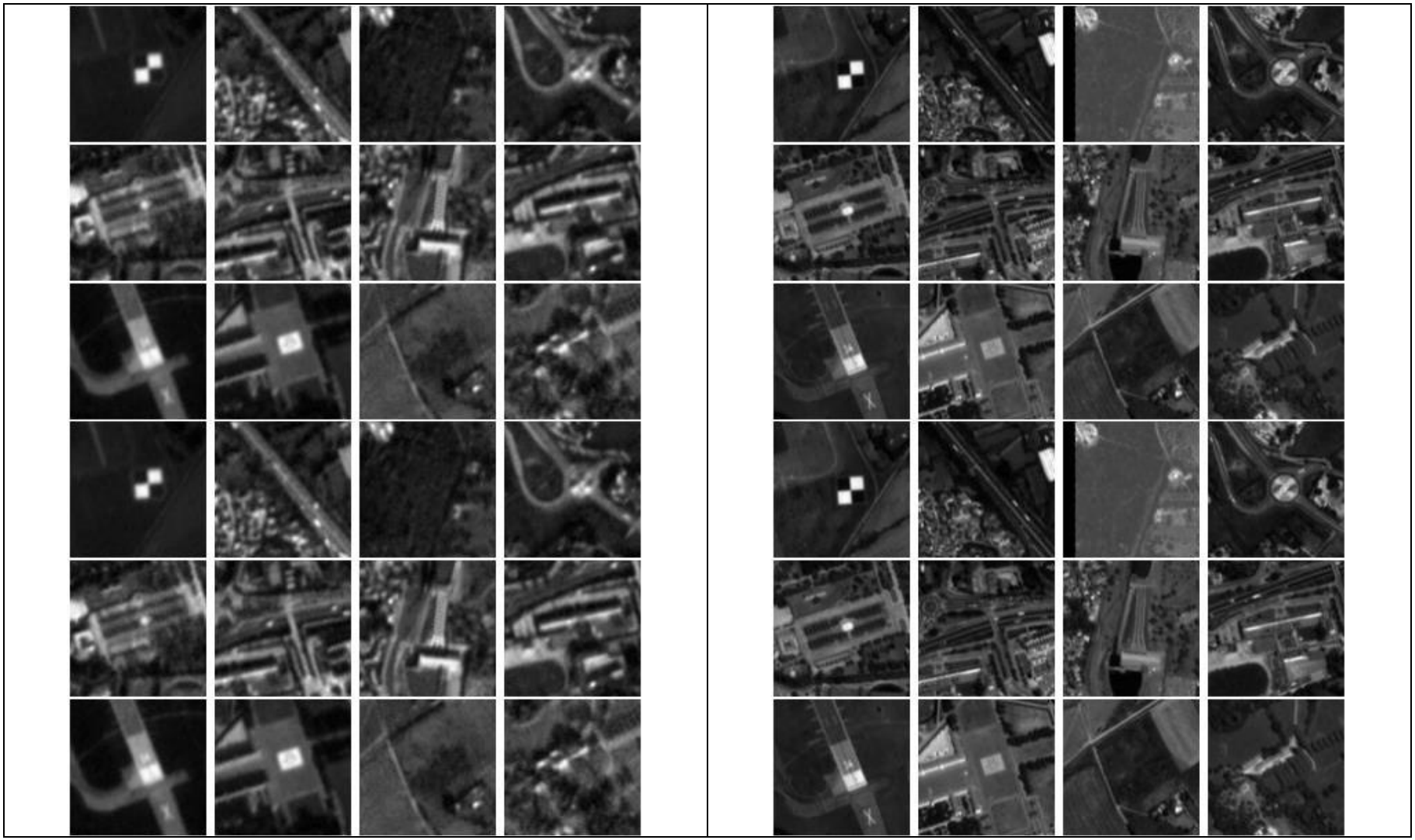




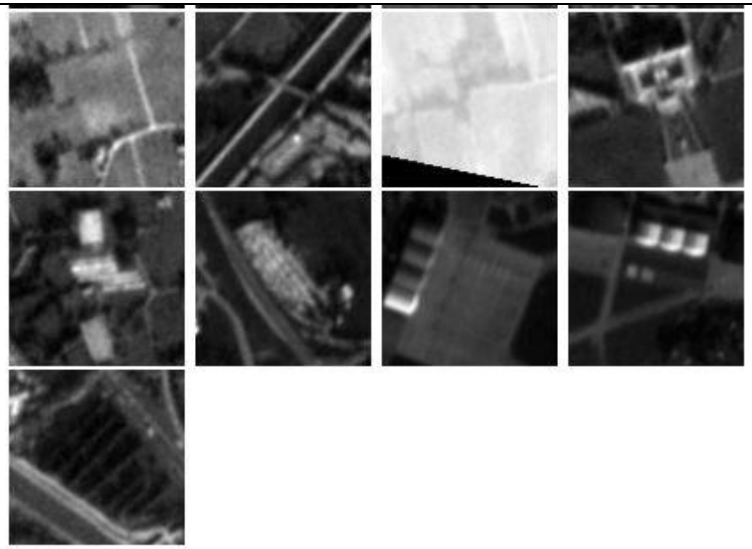


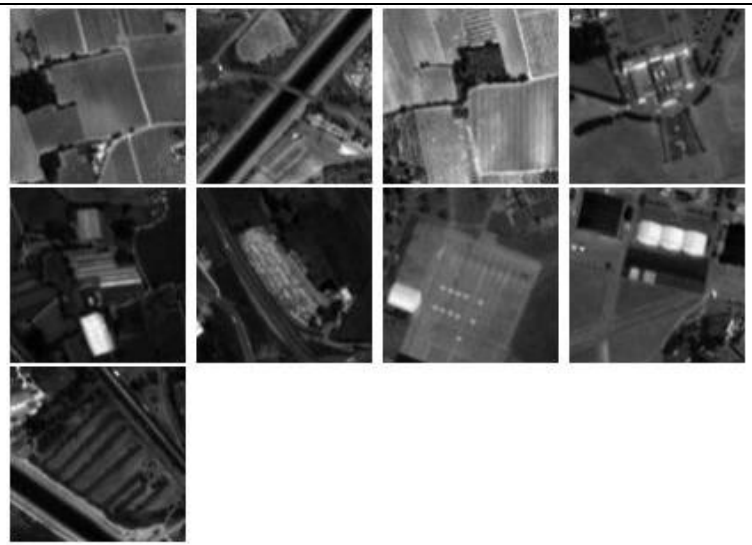
DOVE	PHR
BLUE BAND (POI 13 => POI 21)	DOVE-R



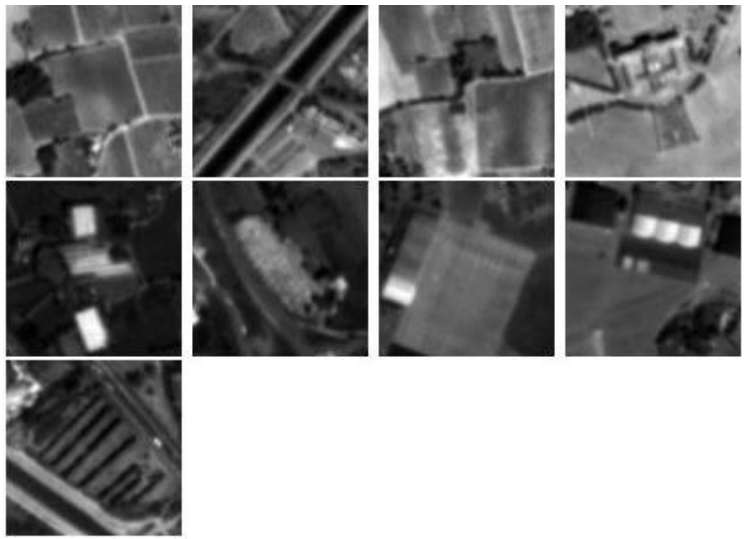


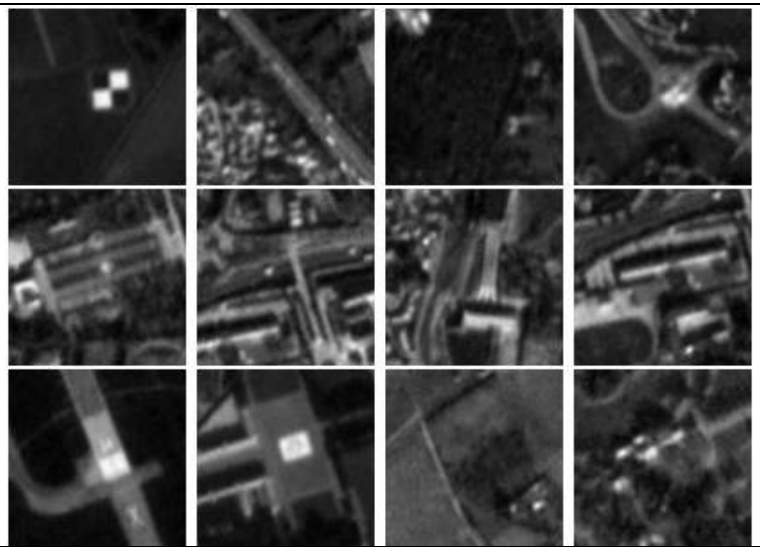
DOVE	PHR
GREEN BAND (POI 1 => POI 12)	DOVE-R



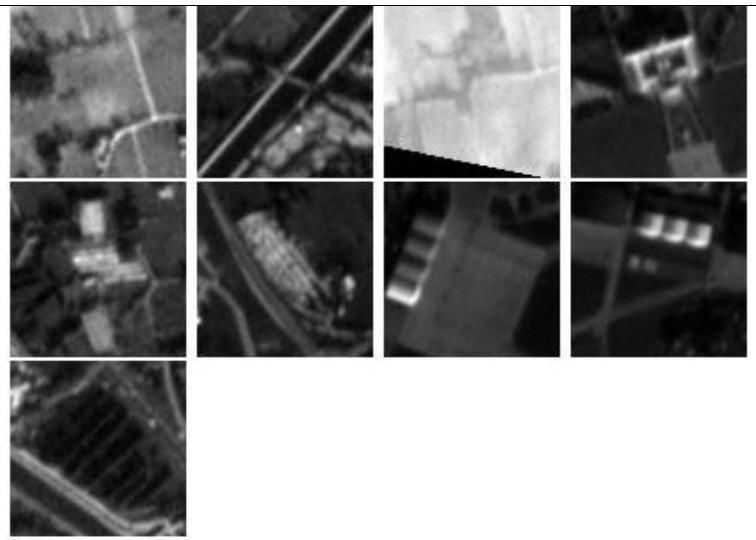


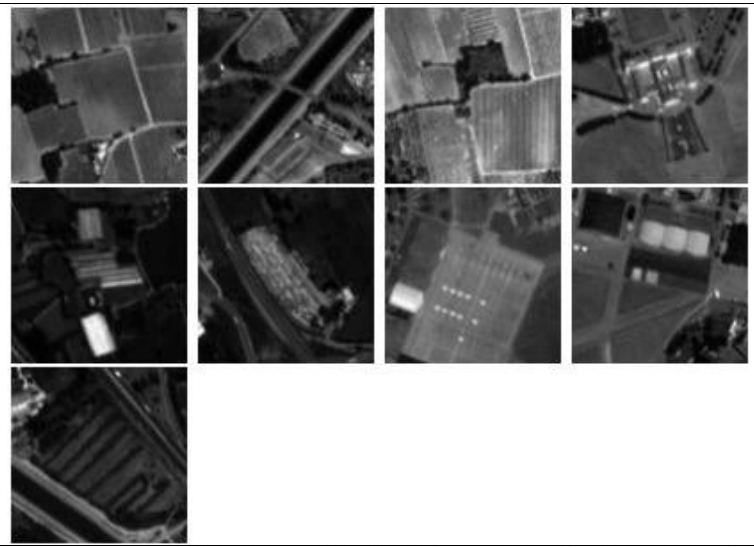
DOVE	PHR
GREEN BAND (POI 13 => POI 21)	DOVE-R



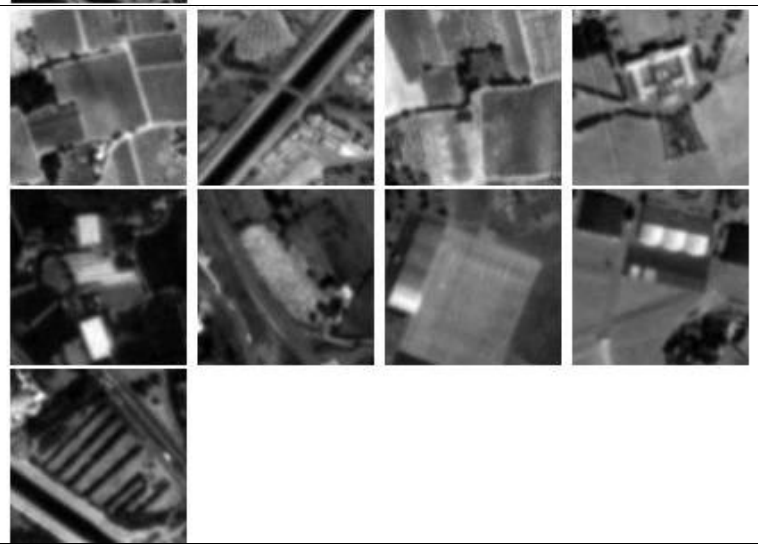


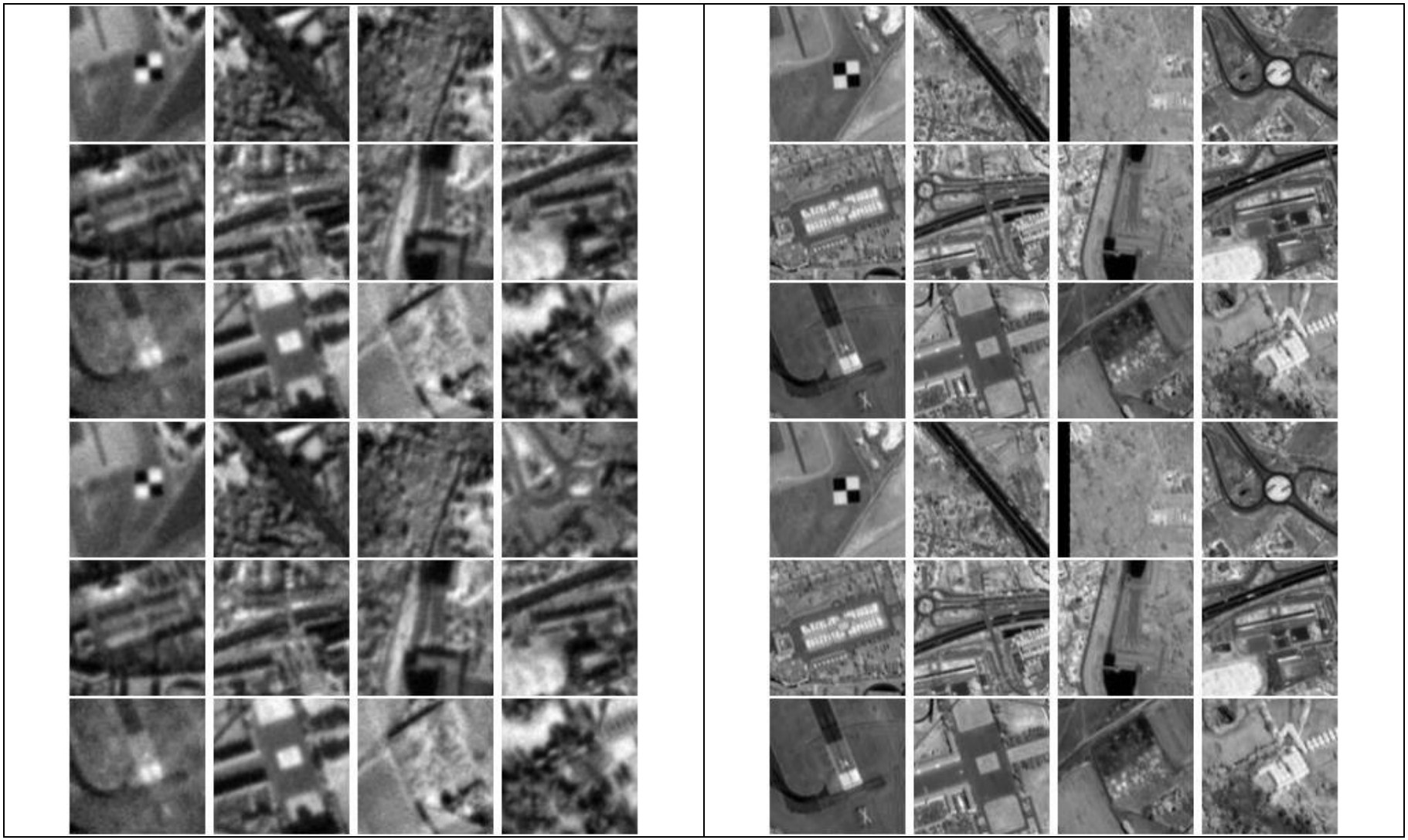
DOVE	PHR
RED BAND (POI 1 => POI 12)	DOVE-R



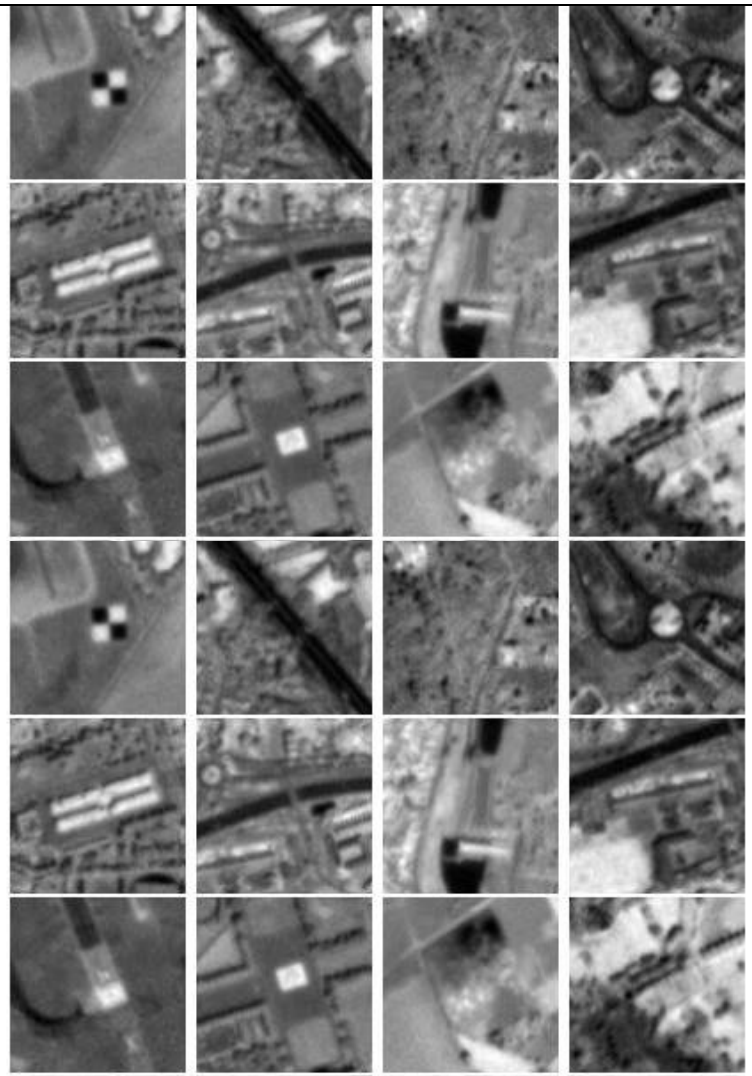


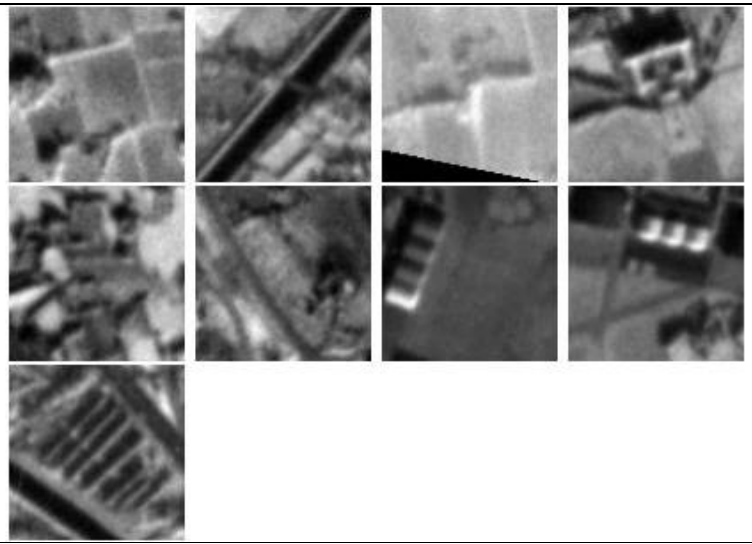
DOVE	PHR
RED BAND (POI 13 => POI 21)	DOVE-R

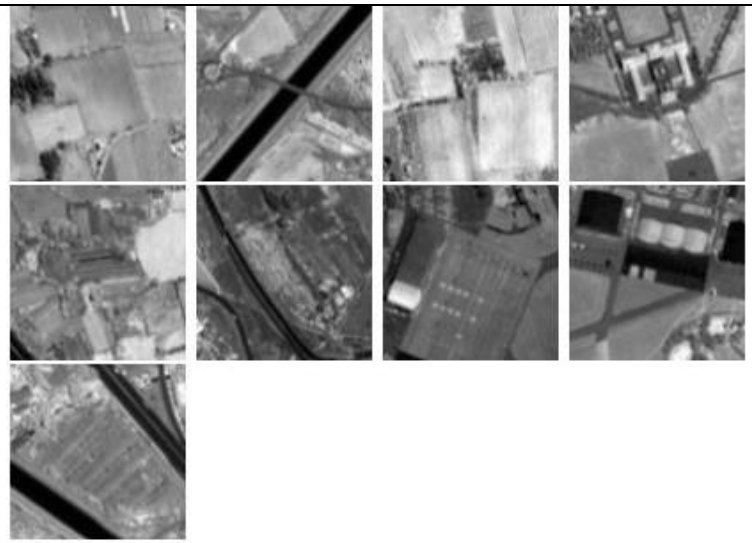




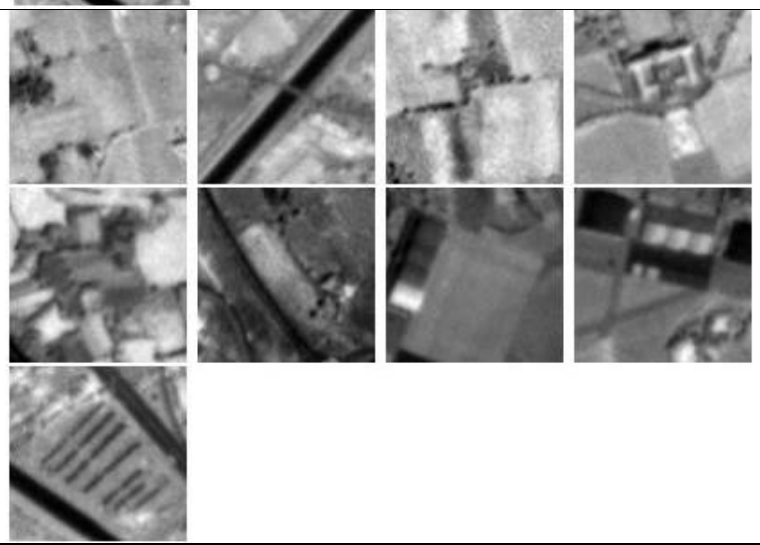
DOVE	PHR
NIR BAND (POI 1 => POI 12)	DOVE-R







DOVE	PHR
NIR BAND (POI 13 => POI 21)	DOVE-R



5.4.7 Results

The results have been provided within the respective sub-sections here before. A quick summary can rely on the following points:

- The data masks (UDM, UDM2) show significant inconsistencies and anomalies;
- The quality of surface reflectance images is correct, processing is not operating as expected within some specific configurations (cirrus) and creates image artefacts;
- The spatial resolution (not the pixel resolution) of DOVE-R is better than DOVE.

5.5 Image Quality: Signal-to-Noise Ratio

5.5.1 Activity Description Sheet

SNR Accuracy Validation
Inputs
Set of Level 3A PlanetScope DOVE-R data observed over PICS “Libya-4” site (set of products is listed in APPENDIX B)
Description
The SNR has been estimated for each spectral band. The data has been evaluated for a reference radiance corresponding to those of the Libya 4 desert site for the concerned spectral bands. The product accuracy results (L3A, L3B), report by the quality control team, and considered as EDAP input specifications are given in [RD-4] and can be summarised as follow: • BLUE: 224.501 / 204 • GREEN: 162.298 / 166 • RED: 235.57 / 144 • NIR: 183.144 / 437 For each band, the SNR value and its corresponding average reference radiance $W.sr^{-1}m^{-2}$ are given.
Outputs
SNR measurement associated to each band

5.5.2 Introduction

The SNR is an important image quality indicator. Visual interpretation of image does not require high SNR data: even in presence of noise an operator is able to identify objects. However, multispectral image processing requires high SNR values in order to control as much as possible uncertainties in the measurement.

The method proposed here is simple and is used with two DOVE-R product files of the same area. The products are from two different dates, acquired with two different satellites.

- 11 August 2019: 2591943_3452225_2019-08-11_106b
- 2 July 2019: 2492005_3452225_2019-07-02_106d

5.5.3 Methods and Tools

The SNR is a measure of the mean signal to noise ratio. In the community, there are two types of SNR typically measured; the temporal SNR and the spatial SNR. The basic formulation of the SNR is given by:

$$SNR = \frac{\mu}{\sigma}$$

Where:

- μ is the mean signal,
- σ is the standard deviation of the signal.

The proposed method estimates the spatial SNR considering statistical over a set of "small windows" (9 x 9 pixels), where by referring to the previous mathematical relationship:

- The "mean signal" is defined as the spatial average of a group of pixels in the "small window";
- Noise is typically defined as the standard deviation of a region of pixels in the "small window".

Each spectral band image (radiance measurement) is processed with the modified algorithm initially proposed in [RD-6]. The algorithm has been modified to allow the selection of small windows of uniform image intensity (condition 1), and the selection of small windows mostly located over regions with a flat terrain relief (condition 2).

For conducting the SNR analysis, a uniform / bright scene has to be selected and Libya-4 appears to be appropriate for this purpose. The site uniformity increases over small areas, and this is the reason for which small windows are selected. However, the spatial high frequency image content still exists, specifically at locations of sharp transition (e.g. desert dune summit). To overcome this issue, a dedicated image processing is applied in order to detect high frequency content and filter small windows (image window processing with Sobel operator).

As consequences, to fulfil both conditions, the proposed algorithm considers as input:

- Edge image, obtained with image processing (Sobel operator) to discard area with high frequency content;
- Digital Elevation Model data.

The different steps of this algorithm can be summarised as follows:

1. Create SNR image, considering as input, image converted to radiance measurements, and iterating on "small windows" to compute SNR;
2. Compute local statistics over 9 pixels x 9 pixels sliding window on the terrain relief data and the image edge response (Sobel Operator);
3. Select the set of "small windows" displaying uniform content and located in flat area;

4. Compute the statistical distribution (histogram) of "small windows" $\frac{\mu}{\sigma}$;
5. Location of the peak in the histogram is a measure of the system SNR;
6. Report the SNR value at the peak and the corresponding mean radiance value.

Input images are with a radiometric calibration applied. 16-bit DN pixel values correspond to radiance values which is particularly convenient for SNR computation.

5.5.4 Region of interest

The region of interest is within the Libya 4 site, and defined within the full image extent. The background values are discarded from the selection, and this region is common to both product observation data and the dimension is about 3000 pixels x 300 pixels.

5.5.5 Data

5.5.5.1 Planet Data acquisition date

- 2 July 2019: 2492005_3452225_2019-07-02_106d (Id 16)
- 11 August 2019: 2591943_3452225_2019-08-11_106b (Id 17)

5.5.6 Results

As shown in Table 5-4, although the data have been acquired by two different Dove-R satellites, the SNR results do not change. A variation within 10 (SNR is unitless) of the specification is acceptable: the SNR depends on the considered radiance value.

The last column of the table indicates the SNR specifications disclosed by the Copernicus data Quality Control Service[1] (specification disclosed by the data provider). The reference radiance associated to these specifications are not provided. The comparison with EDAP results is not straightforward. However, one can notice that SNR results are very close to the specifications.

Table 5-4: SNR results

	2492005_3452225_2019-07-02_106d		2591943_3452225_2019-08-11_106b		SNR Specification (Planet)
	Mean Radiance (W.m-².str-1)	SNR	Mean Radiance (W.m-².str-1)	SNR	
BLUE	143,68	148	153	144	170
GREEN	184,04	155,9	195,26	145,9	170
RED	213,54	156,9	222,73	144,9	170
NIR	163,75	100,1	171,24	97,1	90

The figure below shows the $\frac{\mu}{\sigma}$, histogram computed for each spectral band where the peak in the histogram is a measure of the system SNR.

[1] *CDS-TPZ-03-00077-TR, 19/09/2017, Issue 1.0*

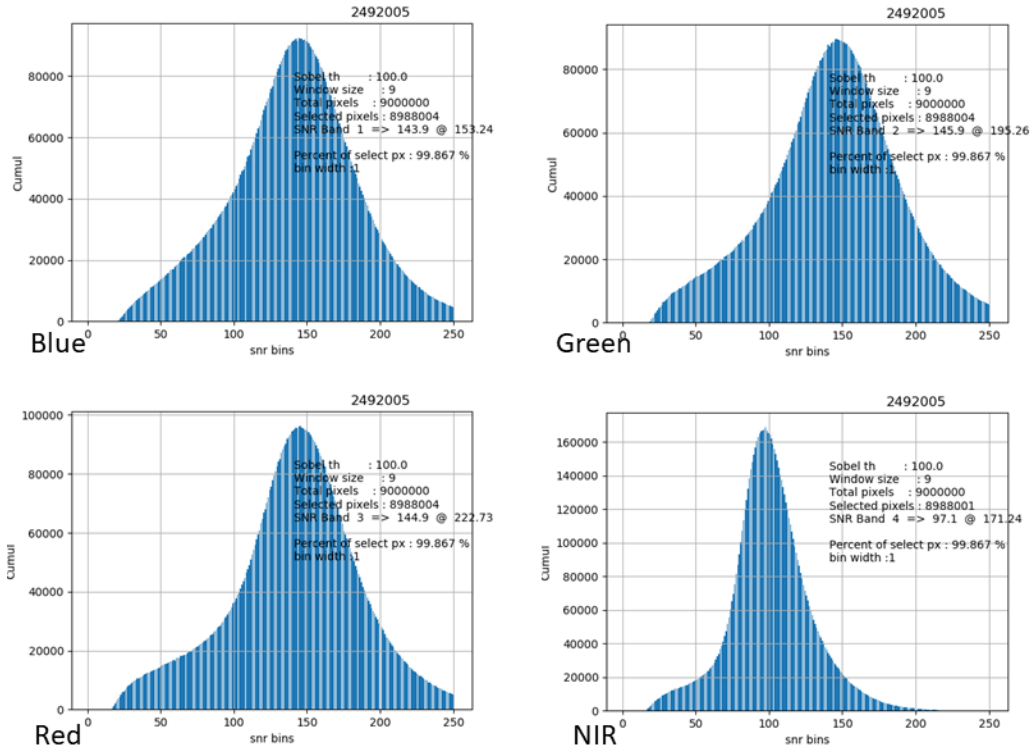


Figure 5-11: The $\frac{\mu}{\sigma}$, histogram images for SNR computation.

In addition, the analysis has allowed to detect image quality artefacts contaminating systematically all the DOVE-R images in the input SNR TDS. As shown in the Figure 5-12, Figure 5-13, in all bands the SNR increase for some locations in the select sub-image (stripes). These locations are periodic in the image and should correspond to transition areas between two DOVE-R stripes (overlap).

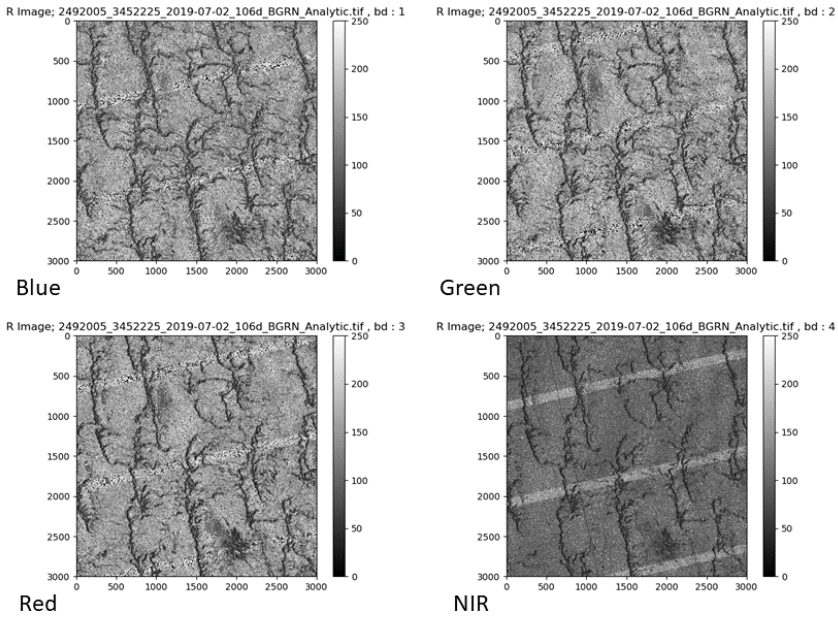


Figure 5-12: The $\frac{\mu}{\sigma}$, images (Id 16).

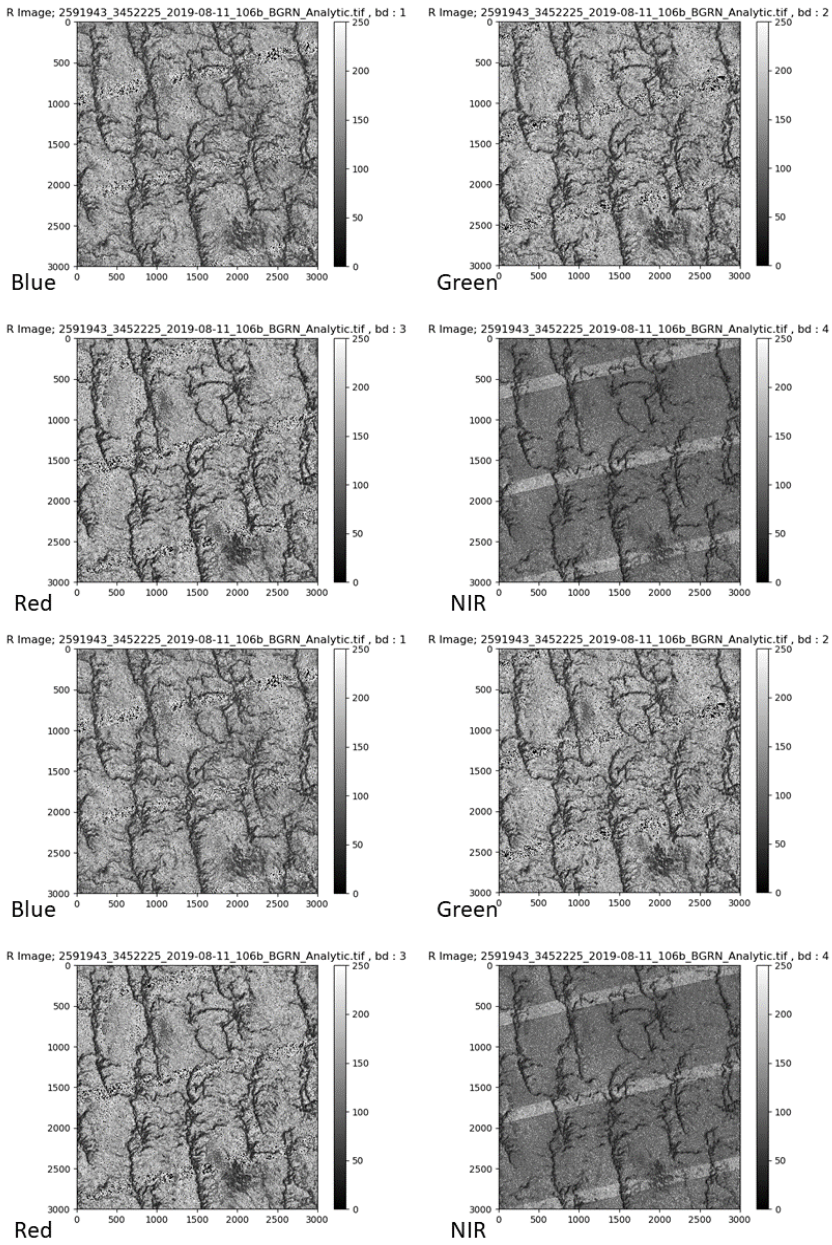


Figure 5-13: The $\frac{\mu}{\sigma}$, images (Id 17).

Note that this issue affects all spectral bands and all products. This artefact arises systematically on Planet DOVE-R data.

5.6 Geometric Calibration / Validation

5.6.1 Activity Description Sheet

Geometric Accuracy Validation: Absolute / Multitemporal / Inter-band registration
Inputs
Set of Level 1B / Level 3A / Level 3B PlanetScope DOVE-R data observed over La Crau (France) and Piedmont (Italy) sites (set of products is listed in APPENDIX B) GCP Reference Vector layer (La Crau)
Description
Estimation of the geometric accuracy of DOVE-R products including absolute accuracy, multi temporal accuracy and inter-band registration accuracy. Verification that measured geometric accuracy is within the product specification accuracy, as stated in the product specification document [RD-3] and regularly monitored by Planet in the quarterly report [RD-4]. The input product specifications (L1B, L3A, L3B) related to geometry is given in [RD-3] and is focused on the positional accuracy; *"The positional accuracy is less than 10.0 m RMSE".* The geometry differs depending on the processing level. Also it is expected that the accuracy of Ortho product is better. The product accuracy results (L3A, L3B), report by the quality control team, and considered as EDAP input specifications are given in [RD-4] and can be summarised as follow: • *The absolute geolocation accuracy is 3.79 m / 2.00 m (Mean / STD RMSE accuracy), this average accuracy is computed based on 903 products,* • *The multi temporal geolocation accuracy is 2.68 m / 2.60 m (Mean / STD RMSE accuracy), this average accuracy is computed based on 903 products,* • *The Inter-band registration accuracy (Mean / STD RMSE Accuracy) is summarised as follow:* *BLUE - GREEN : 2.38 m / 2.75 m* *BLUE - RED : 1.89 m / 2.03 m* *BLUE - NIR : 2.04 m / 1.54 m* *GREEN - RED : 1.21 m / 1.36 m* *GREEN - NIR : 2.31 m / 2.14 m* *RED -/ NIR : 1.74 m / 1.27 m* *This average accuracy is computed based on 983 products.*
Outputs
Geometric accuracy metrics

5.6.2 Introduction

In this section dedicated to the analysis of geometry, there are three accuracy assessments performed: absolute accuracy, multi temporal accuracy and inter-band accuracy.

Results from additional qualitative checks are given in the last part.

5.6.3 Absolute Geolocation Accuracy

5.6.3.1 Methods

The analysis performed for estimating the absolute geometric accuracy considered as input Level 3A products (ortho tile). The approach consists in identifying GCPs in the input image. The GCP set is from several GPS Test field surveys performed in 2004.

The ortho tiles images (Level 3A) observed in La Crau (2019-06-24) are stitched together to create a single image with a greater geographical extent. As shown in Figure 5-14, the input image is a mosaic of 25 km x 25 km image tiles. Furthermore, the spatial distribution of GCPs allows to cover 70 % of the image, the northern is not covered.

The main drawback of mosaicking several image tiles is that the relative accuracy between tiles might not be correct. The overall accuracy that is computed herein includes the uncertainty related to the tile relative registration (the GCP set is spread over different tiles).

5.6.3.2 Data

The input to this assessment is DOVE-R Level 3A products. The Level 3A images are already corrected from systematic and non-systematic effects. Also, as mentioned by Planet and reported in the metadata, the image is co-registered to a reference map and a digital elevation model is used for ortho processing.

As input data, only one reference date is used. It is data collected in the La Crau site (France) listed in APPENDIX B, ID 2 / ID 3 / ID 4 / ID 5.

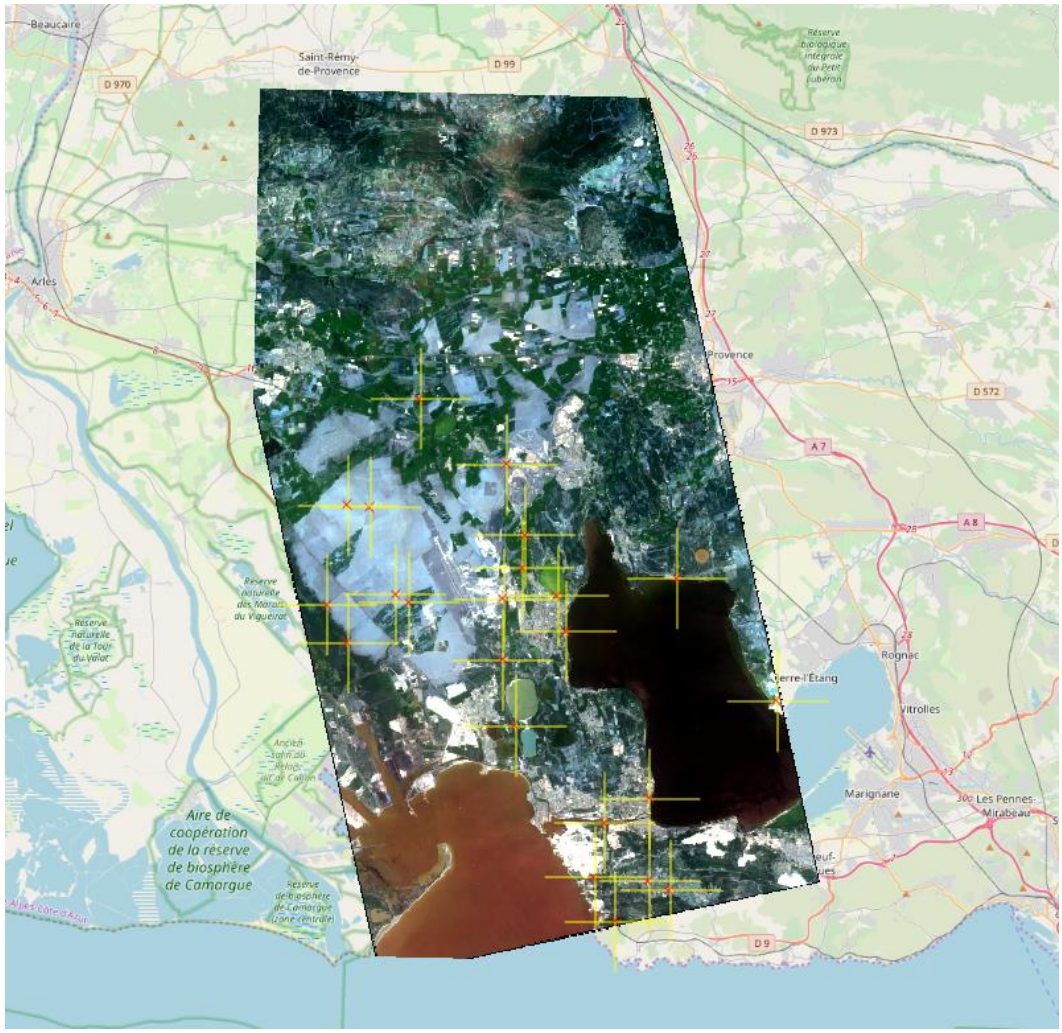


Figure 5-15: Geometric Accuracy – Composite Level 3A Tile products with Ground Control point set added (La Crau).

The reference data is vector data type, a GCP corresponds to GPS point recorded in the field. The GPS measurements are from recording with a professional device (Thales). It is consolidated measurements by using differential GPS techniques. The accuracy of these measurements is about 25 cm.

5.6.3.3 Results

As given in the activity description sheet, the DOVE-R absolute geolocation accuracy claimed by the data provider, is estimated to be 3.79 m / 2.00 m (Mean / STD RMSE accuracy), this average accuracy is computed based on 903 products. The Planet validation is using notably ALOS / PRISM data as reference, with an uncertainty of 5.00 m. Including the uncertainty of the reference data, the absolute RMSE accuracy of Planet DOVE-R data is within a range of 5.3 m and 7.65 m.

Accounting uncertainty due to relative registration of tiles, our RMSE accuracy is about 8.35 m and is therefore very close to the Planet specification.

The Table 5-5 reports our absolute geolocation accuracy results. The following points can be underlined:

- The image quality is correct for identifying the GCPs on the image, the pointing accuracy is with precision of the method and one can be confident on results,
- In north / south direction, there are basically two group of GCPs originated from different tiles
- There is a large degradation of precision in the east/west direction that might be attributed to terrain relief.
- The observed bias (mean error) might be due to the reference involved in the ortho processing.

Table 5-5: Planimetric Accuracy Results (Absolute, in meter unit).

Reference	GCP Set
Working Image (RED)	Image mosaic of ID 2 / ID 3 / ID 4 / ID 5
Sample (#GCP)	23
Easting Error Mean (m)	1,65
Northing Error Mean (m)	4,77
Easting Error STD (m)	3,70
Northing Error STD (m)	4,64
Easting Root Mean Square Error (m)	**5,05**
Northing Root Mean Square Error (m)	**6,65**
Root Mean Square Error (m)	**8,35**
Circular Error @ 90 Percentile (m)	**10,68**

(Error = REF – WORK)

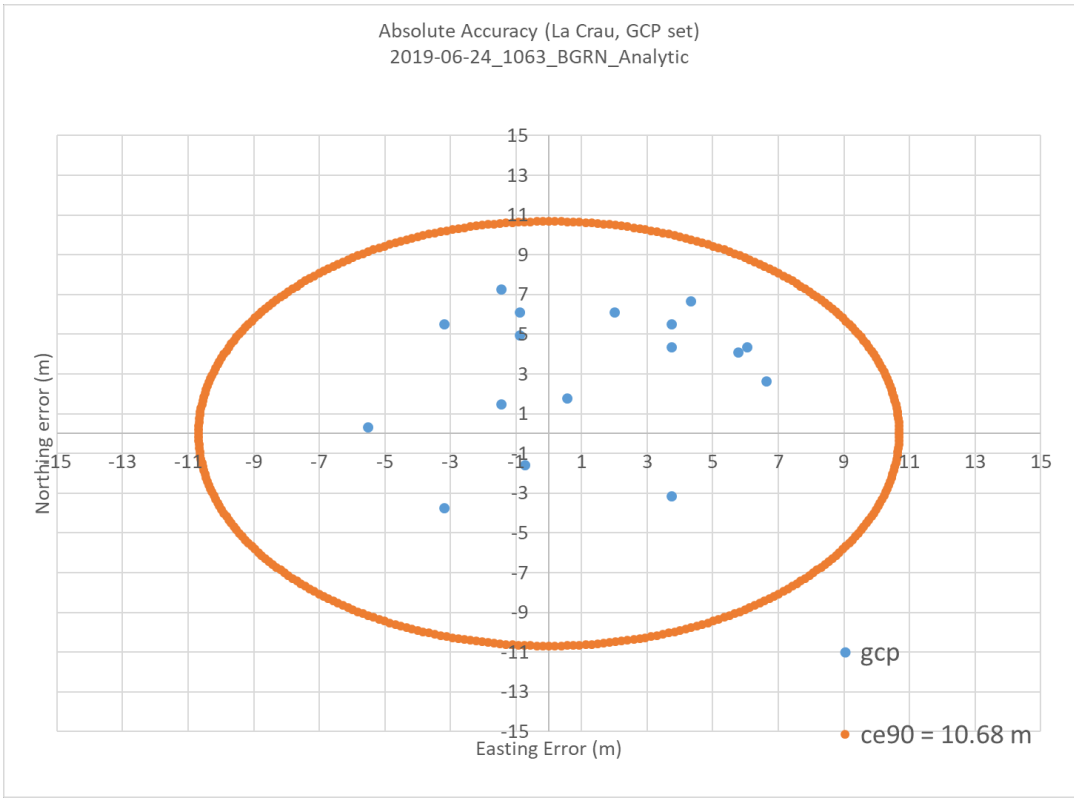


Figure 5-16: Absolute Geometric Accuracy - Circular Error Plot (La Crau).

5.6.4 Multi-temporal Geolocation Accuracy

5.6.4.1 Methods

For the multi-temporal assessment, the geometric grids of two images acquired at a different time and with two different DOVE-R satellites are compared. The products involved in this assessment are given just here after.

The grid comparison is performed by using a classic image matching approach relying on an intensity-based method. The method performs statistical analysis of the image matching outputs: the geometric displacements between the two image grids computed for each pixel are analysed. The accuracy of the method is within 0.1 pixel.

A drawback of this method is the selection of the most confident measurements involved in the accuracy analysis, discarding in particular noisy results, and cloudy pixels.

The analysis is performed on the RED band images and results report accordingly. The RED band image offers a better contrast and a higher SNR. Also, information to be matched is increased.

About the other BLUE, GREEN, NIR images, the results on inter-band registration given later in the document can then be used to derive the multi temporal accuracy for the other spectral bands.

5.6.4.2 Data

The input to this assessment is DOVE-R Level 3A products. The Level 3A images are already corrected from systematic and non-systematic effects. Also, as mentioned by Planet and reported in the metadata, the image is co-registered to a reference map and a digital elevation model is used for ortho processing.

The input data is from two observation dates. It is data collected in the Piedmont site listed in APPENDIX B, ID 12 / ID 13 and ID 14 / ID 15. There are two Level 3A products per date. As previously explained, the two Level 3A images have been stitched together to create a larger image as shown in Figure 5-18 illustrating an RGB colour composite of ID 12 / ID 13 images (2019-07-05) and the related tile footprints (Red). On can note an overlapping areas of 1 km between the two tiles.

The time lag between the two products observation dates is three days. Different satellites (1069 / 1065) have been used. The viewing angle at the satellite nadir for the two observations (2019-07-05, 2019-07-02) is respectively 2° and 5°. It is very close and it should minimise any artefacts due to terrain relief parallax.

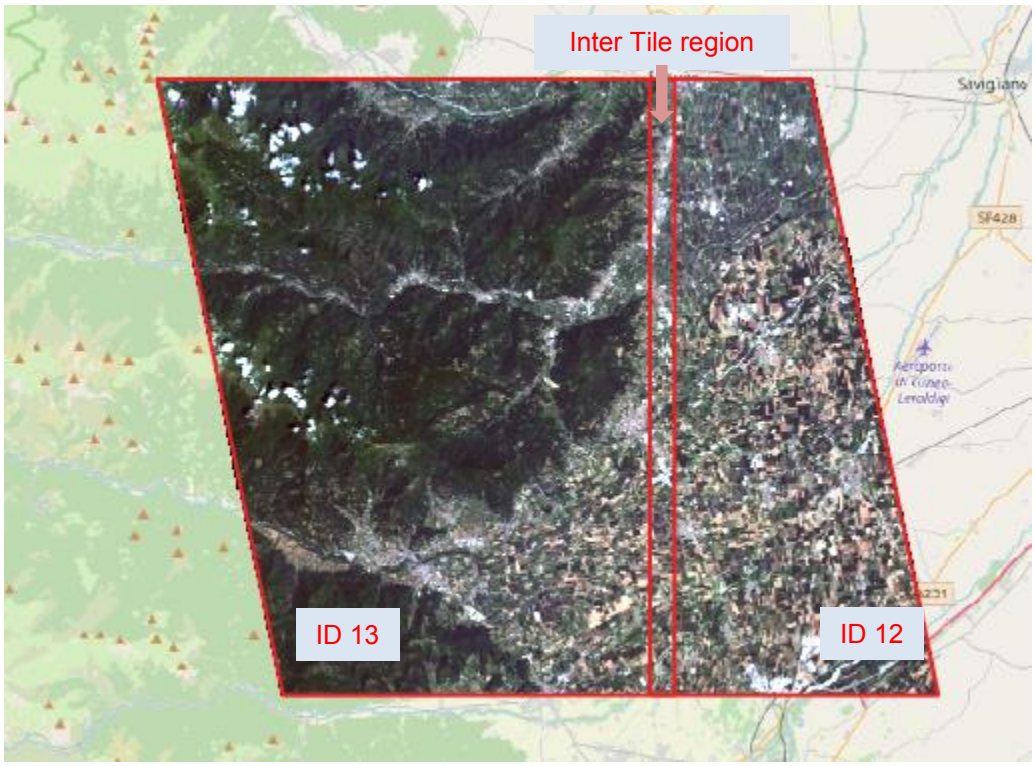


Figure 5-17: (ID 12 / ID 13) mosaic image, RGB image composite (Piedmont site).

For cross checking, the same procedure has been applied to the following Level 3A data collected in the La Crau site (France) and listed in APPENDIX B,

- ID 2 / ID 3 / ID 4 / ID 5, observed in 2019-06-24
- ID 6 / ID 7 / ID 8 / ID 9, observed in 2019-09-08.

Visual inspection of results has been performed but no quantitative measurement is report herein.

5.6.4.3 Results

As given in the activity description sheet, the multi temporal geolocation accuracy, claimed by the data provider, is estimated to be 2.68 m / 2.60 m (Mean / STD RMSE accuracy), this average accuracy is computed based on 903 products. The EDAP uncertainty results (RMSE) should be within 0.1 m and 5.28 m.

As shown in Table 5-6, due to the quantity of successful matches (186289) for the given confidence threshold (0.95), the image matching results are very consistent and reliable.

The same table shows that the uncertainty (RMSE) is estimated to be 3.23 m. It is within the accuracy specification given by the data provider (below 5.28 m).

The empirical circular error at 90th percentile (CE90) is estimated to be 5.10 m.

On can note that there are 1.30 m difference (about 1/3 pixel, pixel resolution is 3.125 m) between Easting Error RMSE (1.56 m) and Northing Error RMSE (2.82 m).

As mentioned before, the accuracy is correct in both Easting / Northing directions, mean error is within 1.3 m. However, the STD errors are high in the Northing direction (2.82 m). Also, a major contributor to the overall RMSE uncertainty is the error STD (precision).

Table 5-6: Multi-temporal Geolocation Accuracy Results (in meter unit).

Reference Image (RED)	Image mosaic of ID 12 / ID 13
Working Image (RED)	Image mosaic of ID 14 / ID 15
Sample (#Pixel)	624827
Correlation Confidence	0.95
Easting Error Mean (m)	-0.06
Northing Error Mean (m)	1.31
Easting Error STD (m)	1.56
Northing Error STD (m)	2.50
Easting Root Mean Square Error (m)	1.56
Northing Root Mean Square Error (m)	2.82
Root Mean Square Error (m)	3.23
Circular Error @ 90 Percentile (m)	5.10
(Error = REF – WORK)	

Linked to accuracy statistics listed in table just here before, the Figure 5-18 shows the statistical distribution of displacement errors in both line direction (left graphics) and pixel direction (right graphics).

By convention, the line direction (x) is the same as the Northing direction and the pixel direction (y) is the same as the Easting directions.

In both histograms, based on mean / STD error value, a normal distribution curve is added (Red). Visually, it shows that the distribution does not follow a Gaussian law: errors are not normally distributed in each the x- and y-component. Furthermore, the error for the x-component is not equal to and independent of error for the y-component, the factor of 2.146 cannot be applied to compute circular error at the 90% confidence level, as discussed in ([RD-11)]. It is confirmed with a normality test that is rejected by the process.

In both cases, the statistical distributions show that a significant part of measurements is far from the mean value.

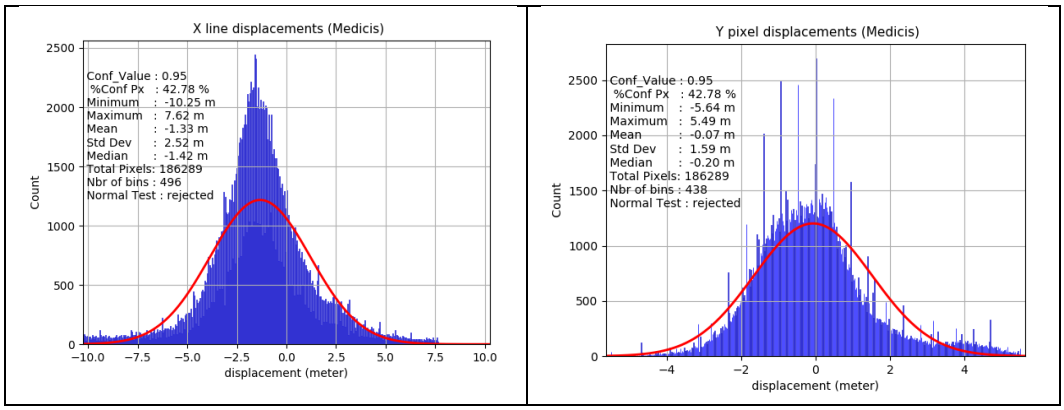


Figure 5-18: Multi-temporal Geolocation Accuracy – histograms of displacement errors; in line direction (X) / in pixel direction (Y), respectively graphics on the left / right.

With the visual inspection of the matching results (image of displacements in both directions) the following points are raised:

- The error is mostly pronounced in the line direction due to a relative rotation between the two images
- Parallax due to terrain relief and due to difference in viewing angles is not totally corrected by the ortho processing (effect due to terrain relief is a non-systematic effect),
- One tile is the composite of several frames, matching of two image tiles observed at two different dates, highlights the boundaries of each frame. The internal geometry of each tile is changing depending on the frame number.
- The geometry of images is stable within the inter tile region (Figure 5-17).

As explained in [RD-4]:

“Dove-R L1 composite images, both 3-band and 4-band, are produced by an image registration process involving up to four frames ahead and four frames behind the anchor frame. There is a typical time interval of ~0.5 seconds and a spatial baseline of ~3.8 km between consecutive frames.”

The Figure 5-17: (ID 12 / ID 13) mosaic image, RGB image composite (Piedmont site). shows the DOVE-R (ID-12.ID-13) NIR images. Regarding the landscape, the left part of the image displays a hilly terrain relief (below 400 m elevation height) and the right part of the image displays the shores of the Po.

The Figure 5-19 shows the radial error image, defined as quadratic sum of displacements in both directions. A quick cross checking with the image Figure 5-16 confirms that radial error magnitude is strongly correlated with terrain relief: over mountainous terrain relief, the error is above 2 pixels.

Furthermore, the Figure 5-19 shows horizontal strips corresponding to the frame boundaries. The radial error image, as displacement errors between the two DOVE-R image grids, demonstrates that the geometry of a single image is not spatially stable, and is changing along the image line. The figure shows that for some frames the error can be up to 3.0 pixels.

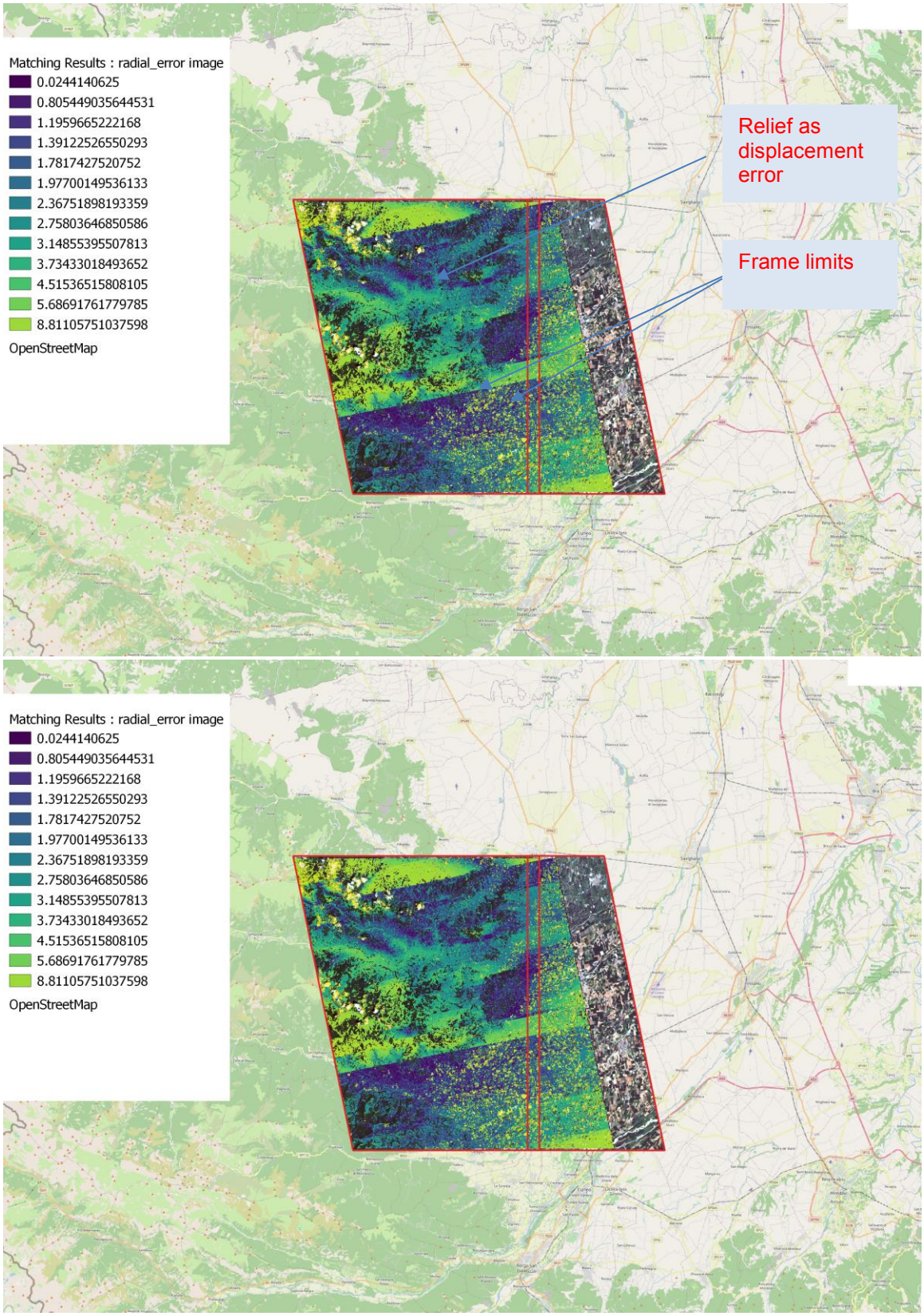


Figure 5-19: Multi-temporal Geolocation Accuracy - Radial Error Image (pixel) by comparing the two Red spectral band images.

As mention in 5.6.4.2, for comparison purposes the same procedure has been applied to another TDS observed in the “La Crau” site. The quantitative results are not report herein. However, it confirms that frame alignment issues found in Piedmont images are also observed in La Crau images, even if the satellites involved are different.

Checking the radial error image, shown in Figure 5-19, it is confirmed that the width of the stripe (between two frame limits) is about ~ 3.7 km and it corresponds to a frame length.

Furthermore, the multi temporal analysis has been the opportunity to investigate another anomaly. The Figure 5-20 shows the correlation confidence image. The confidence image is used to filter matching output results. A low confidence is associated to image location where the information content is poor. In Figure 5-20, black banding patterns are distinguished. It corresponds to area for which confidence value is very low. In the image, these areas are blurred and image difficult to match. It is located just between or over two consecutive frames, the term inter-frame anomaly is appropriate. This observation is to be correlated with the SNR results.

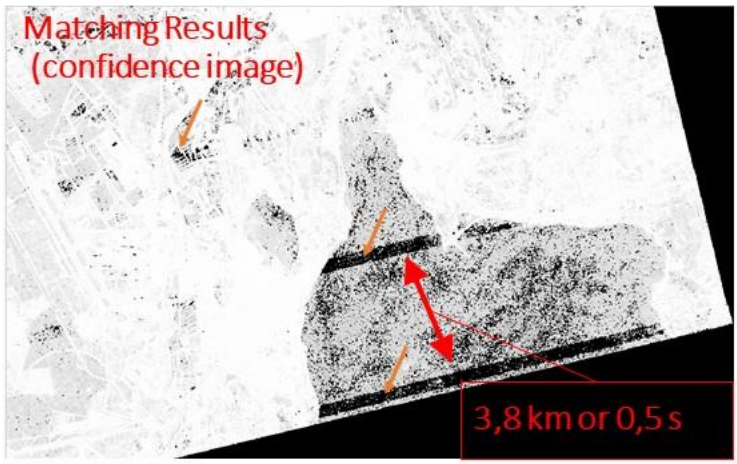


Figure 5-20: Inter Frame anomaly – investigation on ‘La Crau’ results.

5.6.5 Inter-band Geolocation Accuracy

5.6.5.1 Methods

Our objective is to assess the co registration between bands. For a given product, several band twins are considered, namely (BLUE, GREEN), (GREEN, RED), (RED, NIR), (NIR, BLUE) and geometry of the two image grids in the twin are compared. The grids are compared by using dense image matching technic: for any pixel location in the image space, a displacement, D, in both line (y) / pixel (x) direction is computed.

The post processing of image matching result is an essential stage before producing accuracy statistics and the related error budget.

Regarding the error budget, the rule is that per pixel displacement errors are transitive across all band twins. By summing displacement for these twins (B, G), (G, R), (R, N), the result is in the same order of displacement for the twin (B, N), as shown in the equation below.

$$D_{B,N} \cong D_{B,G} + D_{G,R} + D_{R,N}$$

Where $D_{B,N}$ stands for displacement between the BLUE band and the NIR band, in line or pixel direction.

By comparing this estimate against the true value obtained with matching, the error budget of the method is computed.

With reference to the previous DOVE study [RD-8], the La Crau site is appropriate site for computing inter-band registration and one product observed over this site has been analysed.

5.6.5.2 Data

The input to this assessment is DOVE-R Level 3B products (ID 1).

5.6.5.3 Results

As given in the activity description sheet, the inter-band registration accuracy, claimed by the data provider, depends on the band twin. We do not assess accuracy of all band twins. It is expected that the accuracy results found is below Mean RMSE + STD RMSE. This information is added in Table 5-7 and comes in the table row with text written bold type.

Table 5-7 below provides inter-band accuracy results. For each band twins (Reference Band/ Working Band) the geometric uncertainties derived from statistical processing is provided.

From statistics point of view, the centring accuracy is correct. The STD is always within 2.0 m in both Easting and Northing directions. All RMSE values are below the proposed specification.

Table 5-7: Inter-band registration results.

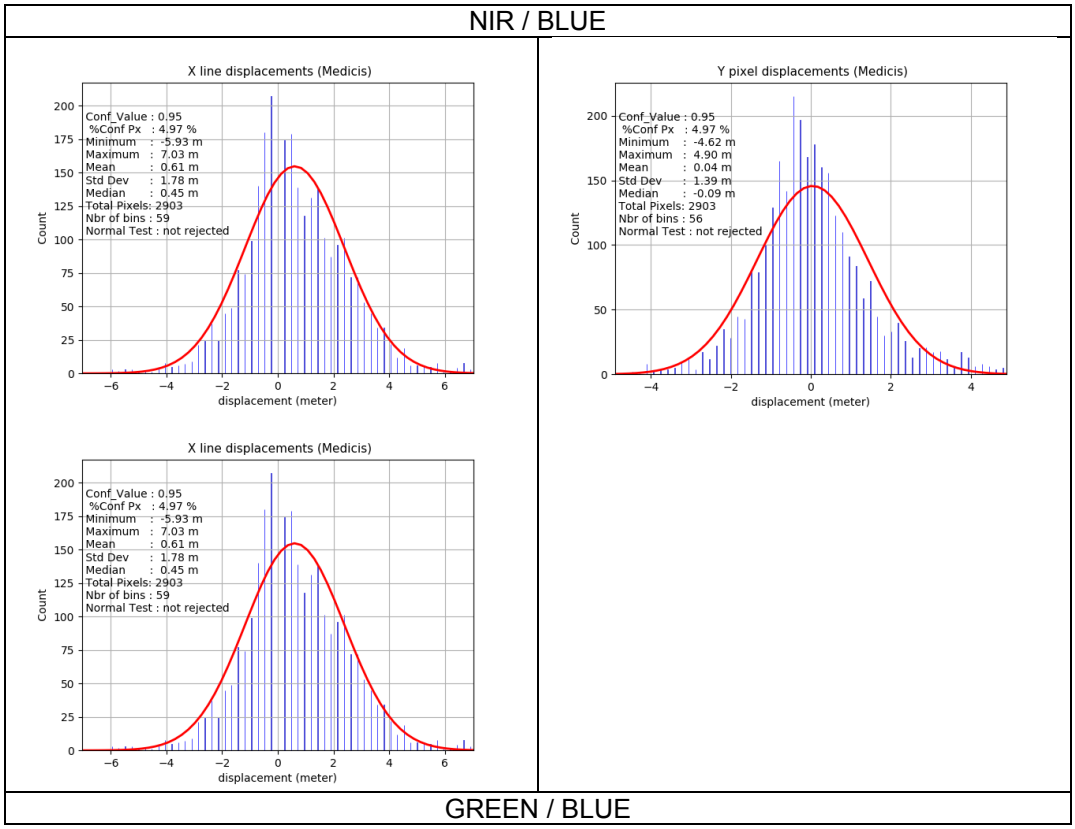
Reference Band	BLUE	GREEN	RED	NIR
Working Band	NIR	BLUE	GREEN	RED
Sample (#Pixel)	58413	110548	135369	8110
Easting Error Mean (m)	-0,04	0,14	-0,12	0,02
Northing Error Mean (m)	0,61	-0,63	0,22	-0,16
Easting Error Std (m)	1,39	0,74	0,57	1,15
Northing Error Std (m)	1,78	1,97	1,03	1,35
Easting Error RMS (m)	1,39	0,75	0,58	1,15
Northing Error RMS (m)	1,89	2,07	1,06	1,36
Root Mean Square Error (m)	2,34	2,20	1,20	1,78
Inter-band accuracy (m) << SPECIFICATION FROM [RD-3]	**3,58**	**5,13**	**2,57**	**3,01**
Circular Error @ 90 Percentile (m)	3,74	3,77	1,94	2,93
(Error = REF - WORK)				

The Figure 5-21 shows the corresponding statistical distribution of errors for the concerned band twins. The statistical distribution of NIR / BLUE and NIR / RED are mostly correct. One can observe greater asymmetry regarding the GREEN / BLUE and RED / GREEN distribution. Furthermore, in the GREEN / BLUE distribution (line displacement) an isolated peak is detected. It demonstrates that mean geometric displacement of a significant number of pixels is about 3.7 m.

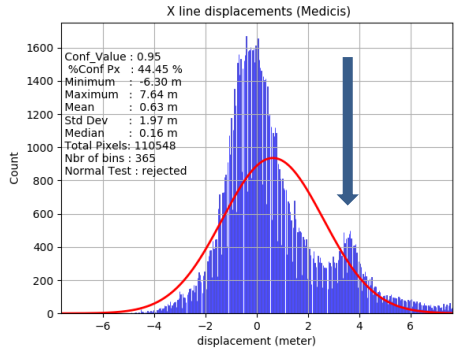
This issue is confirmed when viewing the radial error image, shown in Figure 5-22 and Figure 5-23 respectively about RED / GREEN and RED / BLUE displacement errors.

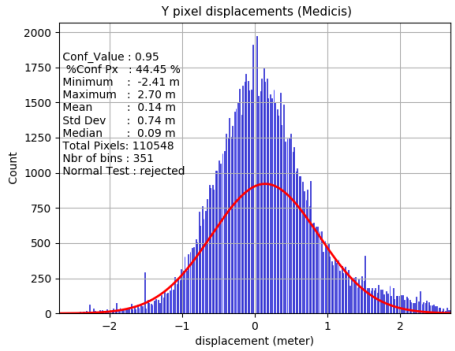
A DOVE-R image is a composite of several scenes. The **Error! Reference source not found.** and **Error! Reference source not found.** demonstrate that for some location in the image one frame in the RED image is not well co-registered to the corresponding scene in the GREEN image and in the BLUE image. It is worth noting that for a given geographical location, the BLUE, GREEN, RED, NIR frames (array) is not recorded at the same time.

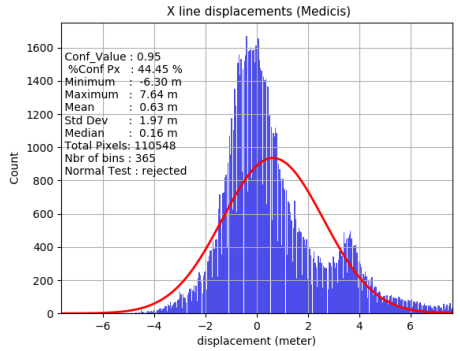
NIR / BLUE

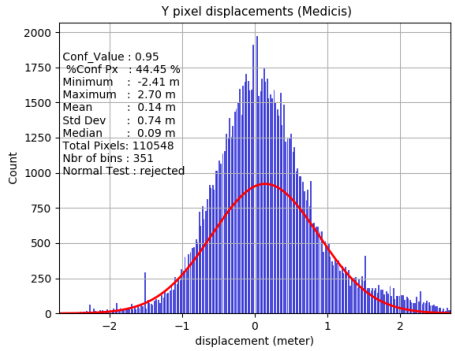


GREEN / BLUE

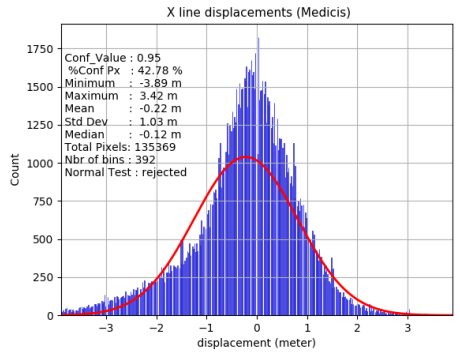


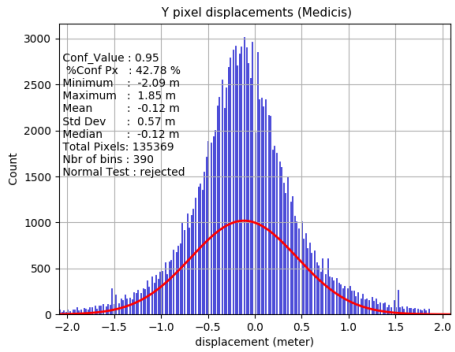


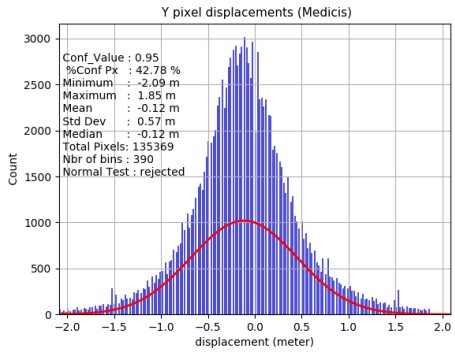




RED / GREEN







NIR / RED

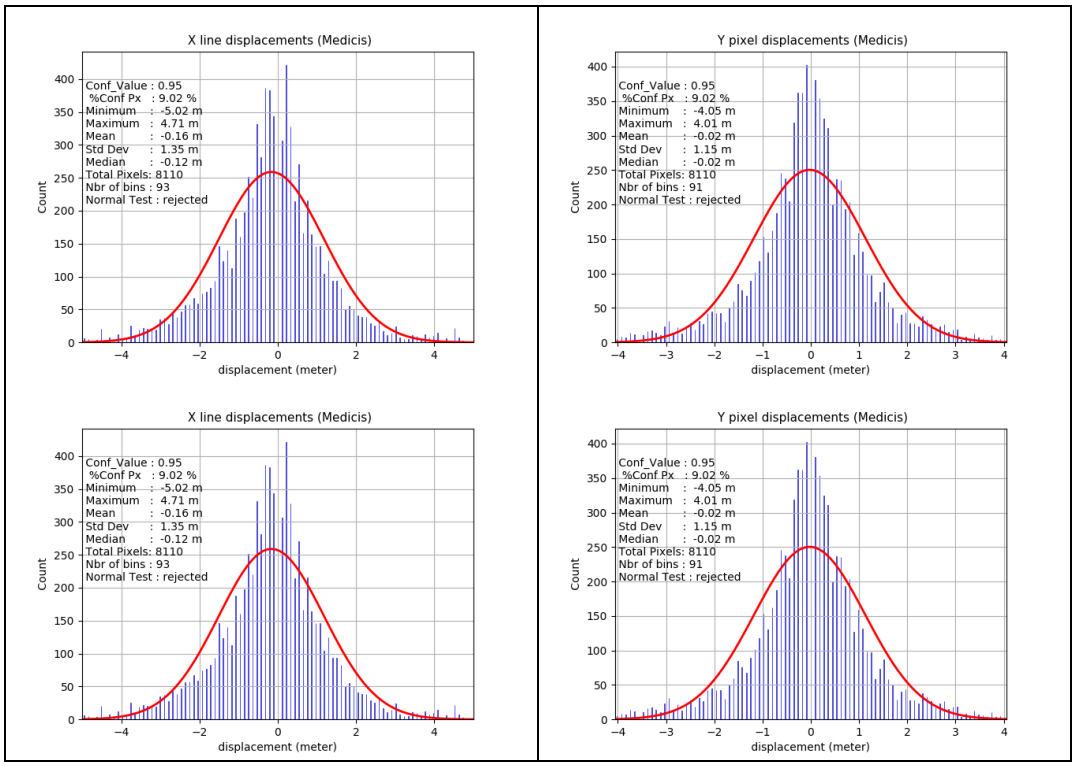


Figure 5-21: Inter-band Geolocation Accuracy – histograms of displacement errors; in line direction (X) / in pixel direction (Y), respectively graphics on the left / right.

The figures below show radial error images as geometric difference between spectral band images from the same product. It observed that mis-registration error between two consecutive scenes exist. This issue is band dependant. In this case, it is the GREEN band that is contaminated with geometric distortions arising in the eastern part of the image.

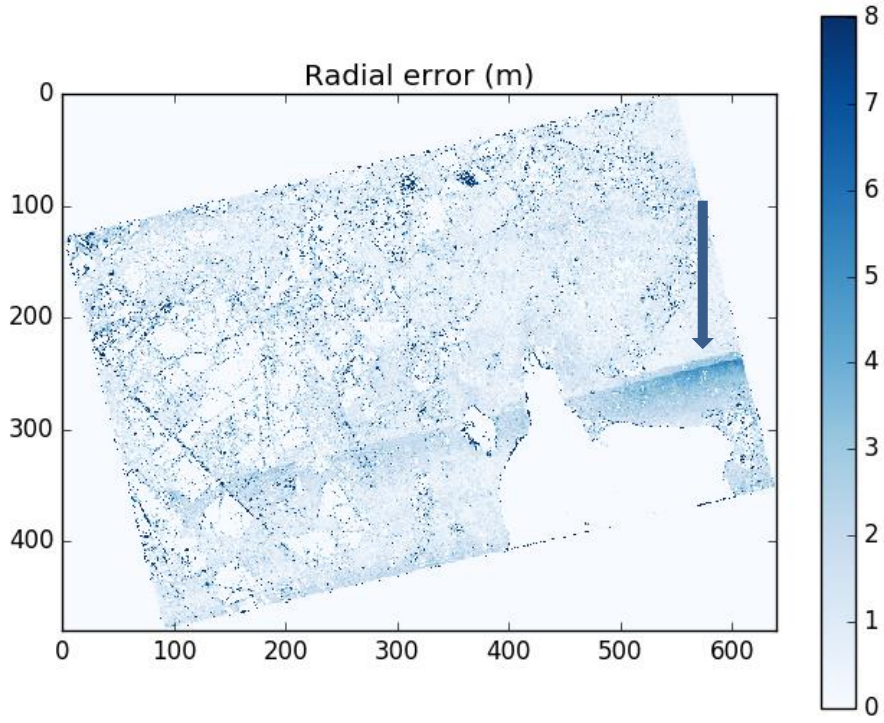


Figure 5-22: Inter-band Geolocation – GREEN / RED Radial error (m).

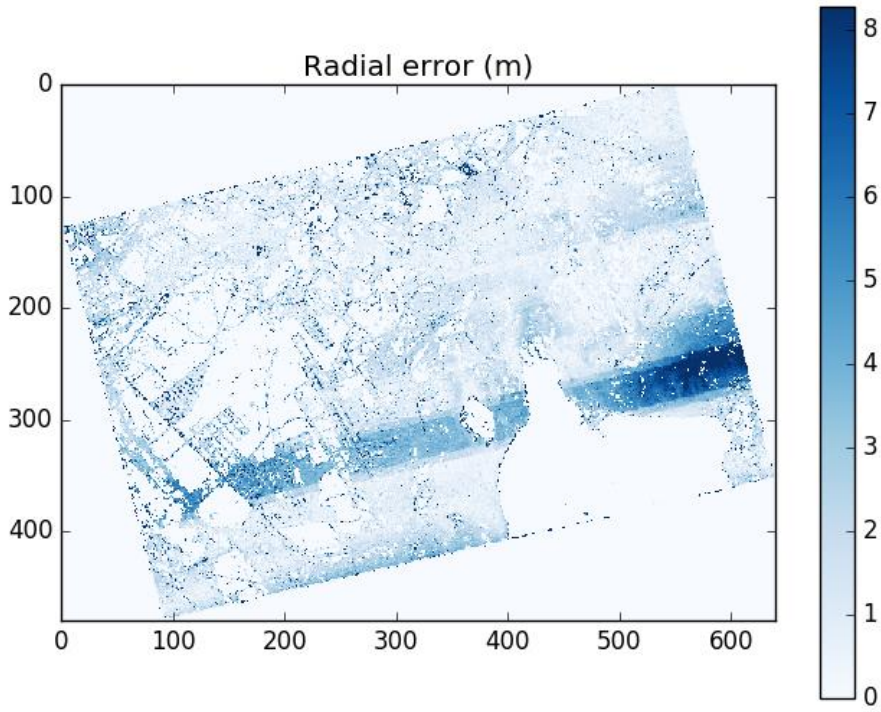


Figure 5-23: Inter-band Geolocation – BLUE / GREEN Radial error (m).

5.6.6 Results

Results have been provided within the respective sub-sections here before. A quick summary can rely on the following points:

- The results of absolute accuracy are not within product specification accuracy claimed by the data provider ([RD-5]) but remain below 10.0 m as written into [RD-3].
- The results of multi-temporal accuracy and interband accuracy are within product specification accuracy claimed by the data provider ([RD-5]).
- The STD error is generally high because of effects due to terrain relief and effects due to mis-registration between consecutive scenes.

5.7 Radiometric Calibration / Validation: Absolute calibration of DOVE-R by using RadCalNet

5.7.1 Activity Description Sheet

Radiometric Accuracy Validation
Inputs
Set of Sentinel-2 (**S2**) Level 1C data (MSI instrument) Set of Level 3B PlanetScope DOVE-R data observed over “La Crau” (set of products is listed in APPENDIX B) RadCalNet data at the overpass date / time
Description
The scope is to estimate the absolute calibration with in flight method. The RadCalNet La Crau station measurements recorded in the period of satellite over pass and delivered as TOA measurements are the calibration reference. The method process PlanetScope DOVE-R data and compared results against TOA RadCalNet measurements. A same method is also applied with Sentinel-2B MSI data. The radiometric uncertainty of DOVE-R is report in [RD-4] through validation approach. The calibration is performed with crossover method by using cross calibration between DOVE-R and RapidEye [RD-13]. RapidEye is well calibrated to ±2.5% [RD-12]. The most recent calibration performed by Planet was in the period 2019-02-12 to 2019-02-26. In [RD-4], validation exercise report that the following mean / STD cross calibration gain, comparing with reference mission as Landsat 8 / OLI and Sentinel-2A / MSI, Sentinel-2B / MSI. • BLUE: 1.015 / 0.036 • GREEN: 1.025 / 0.041 • RED: 1.005 / 0.038 • NIR: 0.999 / 0.042 This assessment results, present herein, are checked against this validation results [RD-4] defined at 1 σ.
Outputs
Absolute calibration ratio for DOVE-R and Sentinel-2 data. An absolute calibration ratio Q is defined for a given band, and is used to express a statistical linear relationship between an input DOVE-R TOA reflectance and a reference TOA reflectance.

5.7.2 Introduction

RadCalNet is an initiative of the Committee on Earth Observation Satellites (**CEOS**) Working Group on Calibration and Validation. The RadCalNet service provides satellite operators with SI-traceable TOA spectrally-resolved reflectances over some specific sites to aid in the post-launch radiometric calibration and validation of optical imaging sensor

data. The free and open access service provides a continuously updated archive of TOA reflectances derived over a network of sites, with associated uncertainties, at a 10 nm spectral sampling interval, in the spectral range from 380 nm to 2500 nm and at 30-minute intervals.

5.7.3 Methods and Tools

The method used for this exercise consists of different processing stages as shown in Figure 5-24.

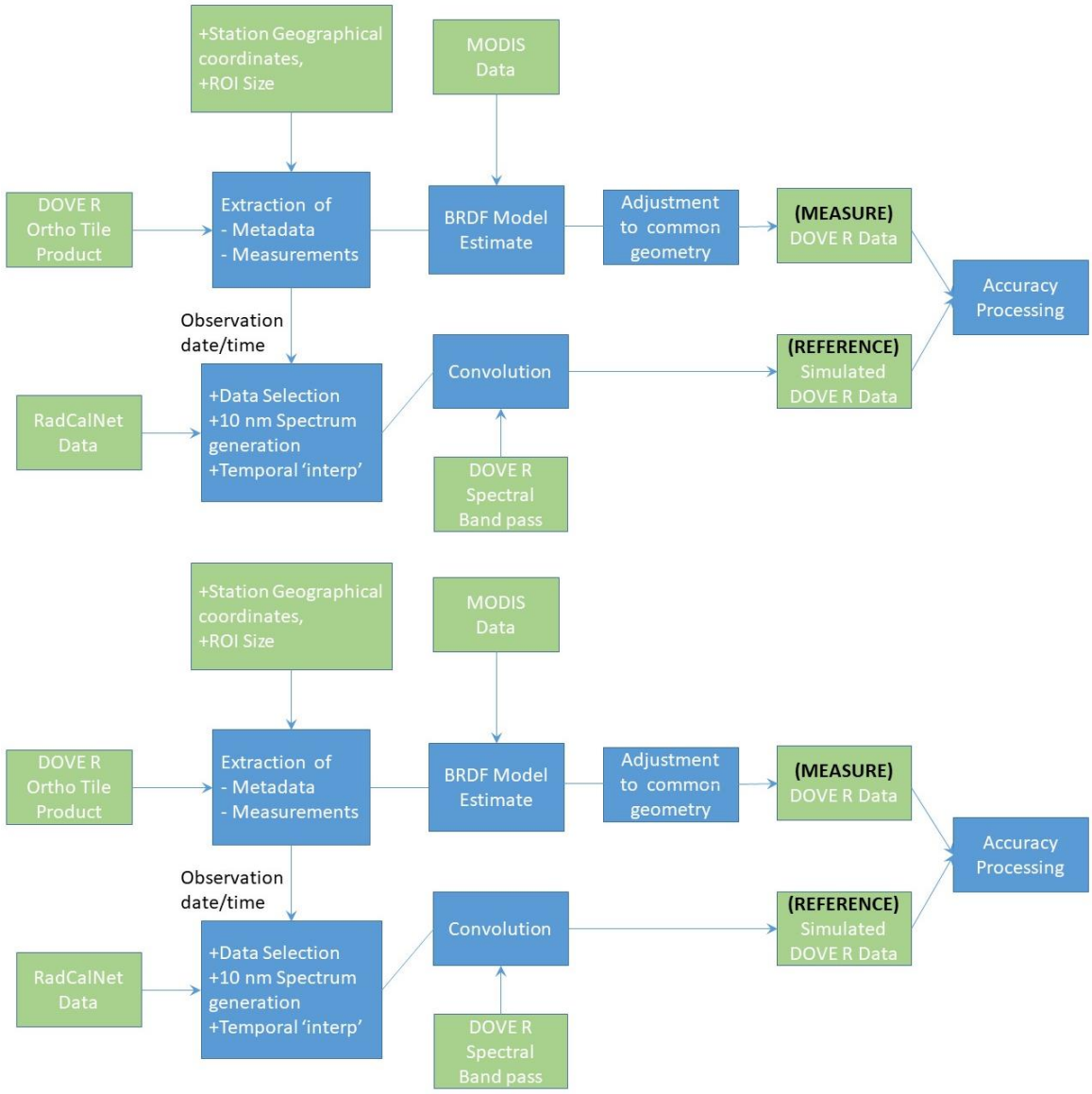


Figure 5-24: The workflow of absolute radiometric calibration using RadCalNet data.

These different processing stages can be summarised as follows:

- Extracting multispectral TOA measurements from the DOVE-R Level 3B product recorded over the La Crau RadCalNet station. The measurement is spatially integrated over a window of size 60 m by 60 m. Note that the dimension of the ROI is a parameter, the sensitivity of this parameter to measurement has been tested and results are shown in Figure 5-26.
- Retrieving from the RadCalNet portal the TOA measurements recovered by the station. It is not possible to get data at the exact observation date / time of the DOVE-R product. Therefore, temporal interpolation of data is performed to overcome this issue.
- Convolving the RadCalNet 10 nm TOA spectrum with the DOVE-R spectral band pass in order to get a reference measurement for each sensor spectral band.
- Adjusting the DOVE-R measurement to the RadCalNet geometry (Nadir viewing and 0° Azimuth Angle). This transformation is based on the use of MODIS Albedo / Bidirectional Reflectance Distribution Function (**BRDF**) (MCD43) for what concerns the BRDF weights f_{iso} , f_{vol} , f_{geo} predicted at the exact observation date / time. The BRDF kernels consider observation geometries (sun angles, viewing angles) given in the product metadata with interpolation, because the geographic location of the La Crau station in the scene does not necessary correspond to the scene centre, image location to which related product metadata parameters are referring to.
- Computing the calibration ratio, Q, between BRDF Corrected DOVE-R Mean TOA (over the Region Of Interest (**ROI**)) and RadCalNet TOA and also computing the percentage difference as follows:

$$\%Difference = \frac{100 * (TOA\_Measure - TOA\_Reference)}{TOA\_Reference}$$

Where:

- $TOA\_Measure$ is the measurement processed from the DOVE-R product
- $TOA\_Reference$ is the measurement processed from RadCalNet data.

Note that the method is also applied for the Sentinel-2B data for which viewing angle is greater. As the calibration accuracy of the Sentinel-2B MSI instrument is well known, it allows validation of the proposed process.

Note that MODIS data pixel spacing is 500.0 m and therefore largely above the area covered with station (30 m radius). As the area is uniform, as shown in Figure 5-25, by experience the BRDF characterisation remains valid in the context of this validation.

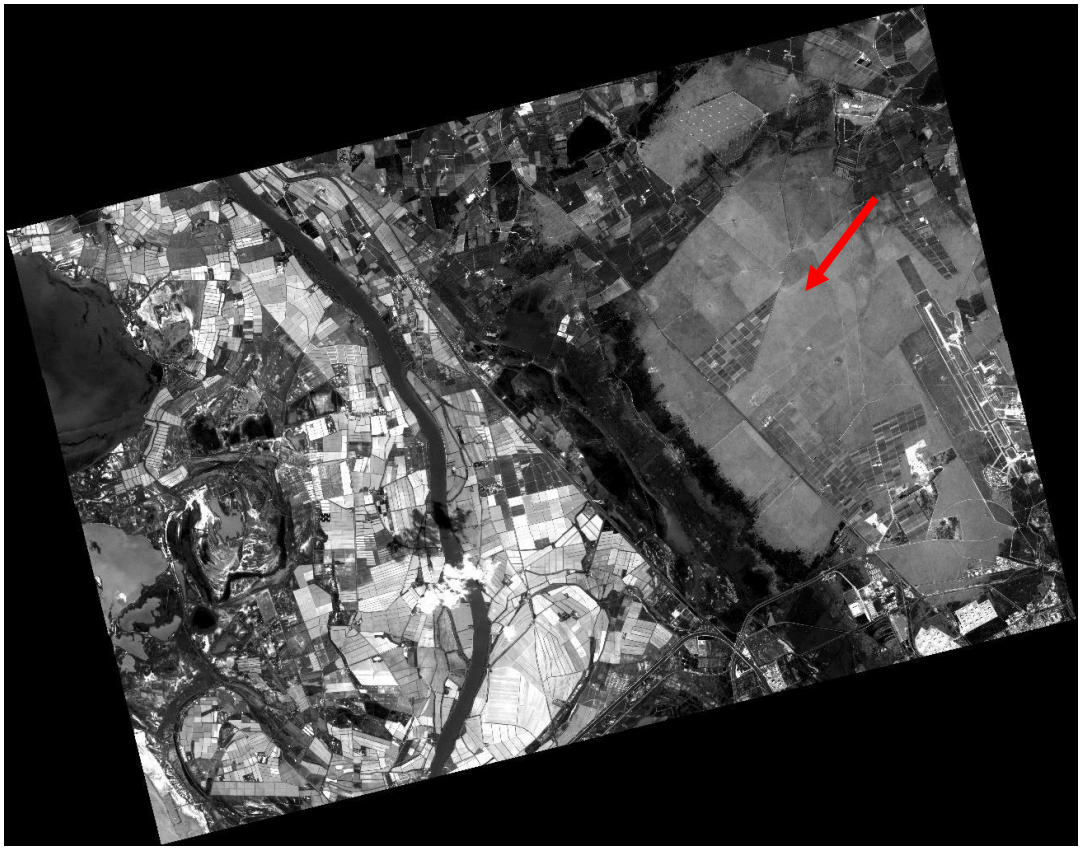


Figure 5-25: PlanetScope DOVE-R ID 10 NIR Image, and RadCalNet station location in the western part of the image (Red arrow).

On the window dimension parameter

The previous assumption made on surface homogeneity of the target is basically confirmed. The Figure 5-26 shows mean TOA measurement for each band. There are several measurements for a given band because the mean TOA value is computed for an ROI of varying dimensions: from 1 x 1 pixel up to 19 x 19 DOVE-R pixels. We observed that TOA value becomes stable when the window size reach 10 x 10 DOVE-R pixels window. Note that the same behaviour is observed with Sentinel-2B data. Beside the DOVE-R values, for each band a brighter dot depicts the measured RadCalNet TOA value.

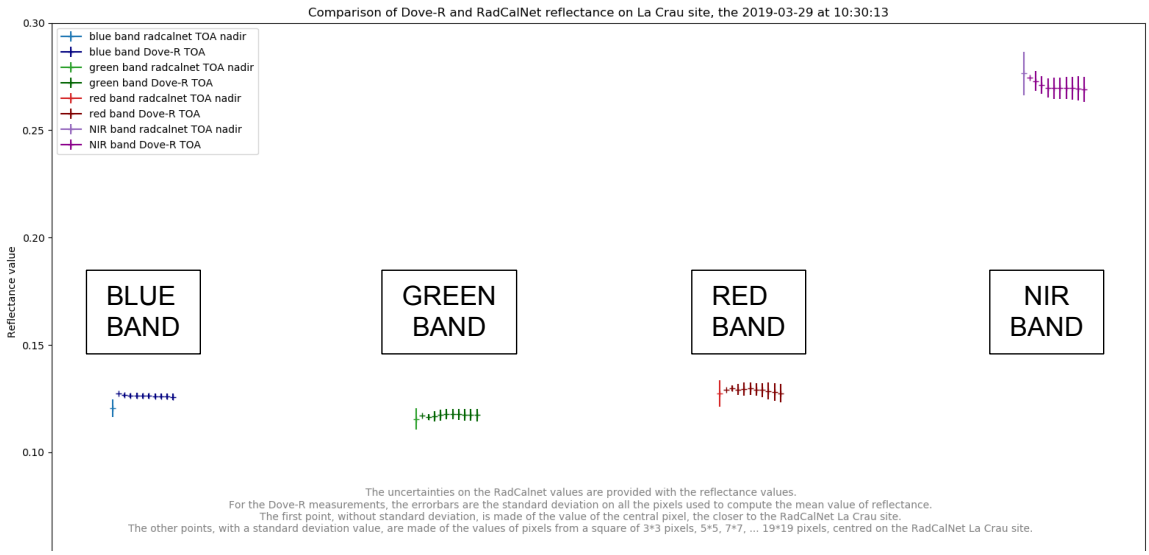


Figure 5-26: DOVE-R TOA Reflectance over RadCalNet LaCrau site, varying the size of the ROI, from one pixel up to 19 x 19 pixels (DOVE-R pixel size).

5.7.4 Region of interest

As detailed in [RD-7], the top-of-atmosphere reflectance spectra over the La Crau RadCalNet site (https://www.radcalnet.org/#!/sites/LCFR) are representative of a disk of 30 m radius centred on latitude 43.55885 degrees and longitude 4.864472 degrees. The site is shown in Figure 5-27.

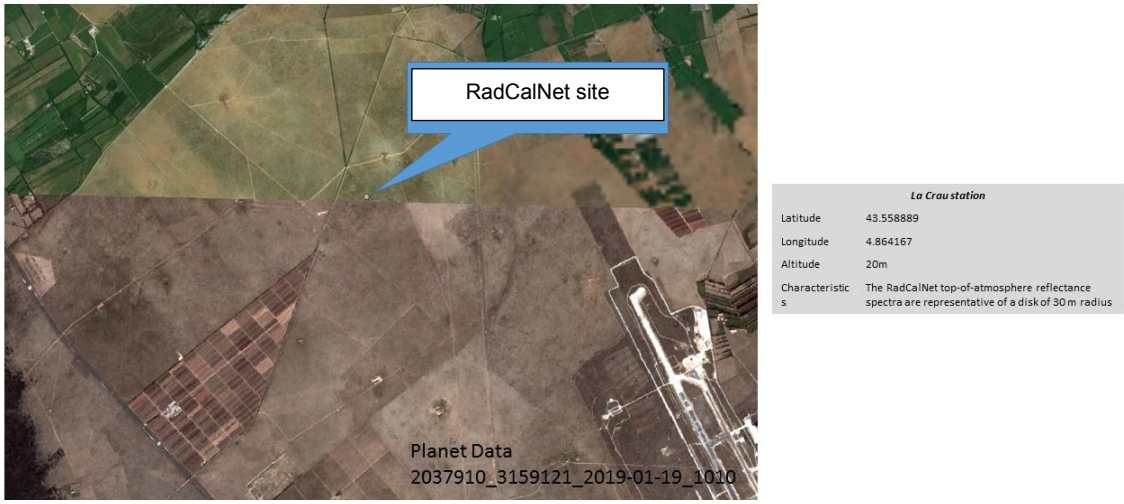


Figure 5-27 : La Crau station location, (RadCalNet)

5.7.5 Data

5.7.5.1 Planet Data

The input to this assessment is DOVE-R Level 3B with the following ID and observation data time (UTC):

- ID 10: 2019-03-29T10:30:13+00:00
- ID 11: 2019-01-21T10:33:54+00:00

5.7.5.2 Sentinel 2 Data

The Sentinel-2B L1C product (31TFJ) has been downloaded from the ESA ONDA and is dated of 2019-03-29T10:48:51.950452

5.7.5.3 Modis Data

The two MODIS products (MCD43A1 - MODIS/Terra + Aqua BRDF/Albedo Model Parameters Daily L3 Global - 500m) are from LAADS DAAC[2] (NASA) with following reference:

- MCD43A1.A2019088.h18v04.006.2019099171714
- MCD43A1.A2019024.h18v04.006.2019036201050

5.7.6 Results

The Table 5-8 lists the DOVE-R radiometric calibration results of EDAP assessment. Two parameters discussed before are report, the calibration ratio Q and the $\%Difference$. These parameters are both given for the two observation dates. The two table columns on the left are the 1-σ specification, EDAP results should be included within the interval $[Q_{min}, Q_{max}]$, specification interval defined with results given in [RD-4] as discussed previously. For table cells reporting results, one used the Green as a cell colour in order to highlight that EDAP calibration value found is within the specification claimed by the data provider.

The table shows that the results depend on the products, each one from a different satellite. The ID 10 product is well calibrated and within the defined specification. The ID 11 is not within the specification except for the RED band. The ID 10 calibration is good because within 5 % for all bands. The ID 11 calibration is degraded because above 7% except for the RED band.

Table 5-8: Absolute calibration results (RadCalNet) – DOVE-R.

		DOVE-R Observation date				SPECIFICATION	
		21-01-2019		29-03-2019			
		Q	% DIFF	Q	% DIFF	Q Min	Q Max
SPECTRAL BANDS	BLUE	1,074	7,38%	1,049	4,88%	0,979	1,051
	GREEN	1,092	9,22%	1,022	2,18%	0,984	1,066
	RED	1,034	3,40%	1,008	0,81%	0,967	1,043
	NIR	1,139	13,91%	0,978	-2,21%	0,957	1,041

[2] https://ladsweb.modaps.eosdis.nasa.gov/missions-and-measurements/products/MCD43A1

When processing the Sentinel-2B data with the same method (comparison with RadCalNet data), the final results are very close to the DOVE-R results, except for the RED band where percent differences between SENTINEL-2B and RadCalNet is about 4.45%. This difference should be investigated and might be due to our method. Results are shown in Table 5-9 and demonstrates that the proposed method is accurate within 5%.

Table 5-9: Absolute calibration results (RadCalNet) – DOVE-R / Sentinel-2B.

		DOVE-R		SENTINEL 2B	
		29-03-2019		29-03-2019	
		Q	% DIFF	Q	% DIFF
SPECTRAL BANDS	BLUE	1,049	4,88%	1,039	3,94%
	GREEN	1,022	2,18%	1,025	2,49%
	RED	1,008	0,81%	1,045	4,45%
	NIR	0,978	-2,21%	1,002	0,22%

6. CONCLUSIONS

This analysis has focused on a sample of DOVE-R L1C products observed in summer 2019, with satellites from the Flock-3k (1063,106z,106b,106d,1065). These products have been processed in August 2019, 15 with the processor "*CMO Patch Processor"* version 4.1.4.

The quality of the mission data has been evaluated from the data product point of view. Aside, product documentation and product format, a specific attention has been paid to investigate fundamental data quality aspects: the image quality, the geometry and the radiometric accuracy.

Both qualitative aspects and quantitative aspects of image quality have been assessed with respectively the visual inspection activity and the computation of quality metrics; Signal To Noise Ratio (SNR).

The geometry of L1C images have been analysed from three point of views; the absolute accuracy, the multi temporal accuracy and the band co registration accuracy.

Finally, the radiometric calibration accuracy has been analysed from absolute point of view by using RadCalNet in situ data.

6.1 Product Documentation Evaluation

The PlanetScope constellation includes three generation of satellites: DOVE (PS2), DOVE-R (PS2.SD) and SUPER DOVE (PSB.SD). The Planet product specification documentation, [RD-3] describes specificities of these three generations of satellites, in particular the type of sensor that is different.

The Planet product specification is very clear. The document proposes an overview for a broad category of topics. The document provides useful information regarding constellations / satellites, sensors, products, formats, product processing. This document is not specific to DOVE-R. The scientific algorithms are not discussed. This document does not reach completeness of any Sentinel-2 documents.

It is worth noting that there is no accuracy specification provided in [RD-3], except the geolocation accuracy. Any references related to accuracy specification is available in [RD-4].

6.2 Product Format Evaluation

The DOVE, DOVE-R product format is harmonised, and has already been analysed in the EDAP DOVE Report [RD-8]. The metadata (JSON, XML) include a minimal set of information. As part of metadata information, it might be interesting to add information about auxiliary / reference data involved in the processing (raster reference, terrain elevation reference) version. Furthermore; it might be interesting to add quality assurance information such as geometric accuracy of the L1C product.

The product includes usability data masks associated to each image band. It has been shown that this mask includes inconsistencies both regarding cloud detection and detector anomaly flagging, notably false detection. This aspect might be improved.

6.3 Image quality: Visual Inspection

The DOVE-R image quality represents a significant improvement when compared with the DOVE image. The DOVE-R images show good contrast with very few saturated data. There is no major radiometric anomaly except small part of image including over saturated / degraded value.

Regarding the DOVE-R Level 2, comparison with the Sentinel-2 images, observed the same day has been performed. Qualitatively, it has been shown that the radiometry of the two products match well. However, as mentioned in the Planet documentation, the atmospheric corrections do not account for cirrus cloud. Consequently, in this latter case, in cirrus areas the radiometry of the image is locally distorted.

6.4 Image quality: SNR

By using bright / uniform site, it has been possible to compute the SNR for a full image. The study demonstrates that the SNR results are stable between two dates. In addition, the study demonstrates that the SNR level is compliant with the Planet specification.

Nonetheless, the study shows also that the SNR is not stable in an image: SNR values are changing nearby transition between two frames or within inter frame area. This problem is systematic, all products are affected. The SNR is high within inter frame areas. It is particularly visible in the NIR band. Root causes of this anomaly might be investigated more in depth.

6.5 Geometric calibration

The geometric calibration of DOVE-R ortho tile products has been validated. In this context, three critical validation items have been checked: the absolute accuracy, the multi-temporal accuracy, and the inter-band registration accuracy.

For all these considered validation items, the results found are in agreement with the accuracy specifications given by the data provider in [RD-3] and the Q4 quality report [RD-5]. Only one difference exists, it is regarding the Absolute geolocation accuracy.

The absolute geolocation accuracy remains below 10.0 m as stated in [RD-3] but is not in agreement with corresponding results given in [RD 4], as shown in the table below.

Table 6-1: Planet / EDAP – comparison of Uncertainty Results.

	Inter-band Accuracy [m], RMS	Absolute Accuracy [m], RMS	Multi-temporal Accuracy [m], RMS
EDAP Results	Blue-Green: 2.34 Green-Blue:2.20 Red-Green: 1.20 NIR-Red: 1.78	8.35	4.62
Planet Q4 quality report [RD 4], pp 5.	Blue-Green: 3.58 Green-Blue:5.13 Red-Green: 2.57	3.79 / 2.00 **	2.68 / 2.6***

	NIR-Red: 3.04*		

* These results are actually a mean of RMSE accuracy, it is computed based on 970 products, the STD is within 2.0 m.

* These results are actually a mean / STD of RMSE accuracy, it is computed based on 903 products,

** These results are actually a mean / STD of RMSE accuracy, it is computed based on 884 products,

There are several explanations to explain differences regarding absolute location accuracy:

- EDAP considered only one product as composite of several tiles
- The absolute accuracy of the Planet reference used to validate the production is 5.0 m (1 sigma), [RD-5] pp.7). The absolute accuracy claimed by the data provider does not account for the uncertainty associated to this reference. Also, if this uncertainty is accounting for, the EDAP results are equivalent to the Planet one.

Also, the EDAP results capture the precision lost observed in Planet Dove-R images due to geometric distortions occurring inside the image, as shown in this Technical Note. The precision is an essential contributor to uncertainty: even if the overall accuracy is generally correct, the image suffers with a loss of precision.

6.6 Radiometric assessment

The validation of the radiometric uncertainty is regularly performed by Planet. For simultaneous observations (called “crossover”), a cross calibration method compares DOVE-R TOA measurements and Sentinel-2 and Landsat 8 TOA measurements. Results indicate that DOVE-R agrees at 1-sigma within 6% with Sentinel-2 mission and Landsat 8 mission ([RD-4]). Results are better for the RED and NIR bands (4 %).

The Planet method provides, a robust estimate of the DOVE-R per band calibration gain (mean, standard deviation) since the gain value is computed for any crossovers and hundreds of thousands of crossovers are computed.

It is worth noting that the input statistical sample is not break into different categories depending on the mission, although Landsat 8 and Sentinel-2 inter calibration might be around 3% for the BLUE / RED bands due to differences in the spectral bandwidth definition. Furthermore, as mentioned in[3], a cross calibration offset on the order of 1% - 2% between S2A / S2B exists. This difference affects the visible through near-infrared (VNIR) bands which are in the warm focal plan of the instrument.

The herein assessment is based on an absolute calibration methodology. Only two DOVE-R products are used. The radiometric calibration of the DOVE-R data is estimated against

[3] *Revel, Charlotte, Vincent Lonjou, Sébastien Marcq, Camille Desjardins, Bertrand Fougnie, Céline Coppolani-Delle Luche, Nicolas Guilleminot, et al. « Sentinel-2A and 2B absolute calibration monitoring ». European Journal of Remote Sensing 52, no 1 (1 janvier 2019): 122 37. https://doi.org/10.1080/22797254.2018.1562311*

in-situ data, which are permanently recorded with the La Crau station (France) as part of the RadCalNet network.

Furthermore, the same methodology is applied with a Sentinel-2B product acquired on the same date / time as the DOVE-R data.

To account for directional effects, a model derived with the MODIS product parameters for products observed in a same period has been set up and applied to both DOVE-R and Sentinel-2B data.

The comparison performed by using in situ measurements as reference shows that results are different depending on the DOVE-R satellite involved. Also, whilst a very good accuracy is achieved with the first product (below 5%), a strong deviation is observed for the second one (about 10%).

The first product is also in agreement with Sentinel-2B measurements for the concerned similar spectral bands: the percent difference results are mainly below 3% and, therefore, are fully within the error budget of the method 5%.

On can conclude that for the first product the results are conformed with the radiometric performance specification and that for the second product, it is not the case. The temporal stability of the radiometric calibration should be investigated.

APPENDIX A PLANETSCOPE MISSION

Since the launch of the demonstration satellites “DOVE 1” and “DOVE 2” in April 2013, Planet Labs has successfully deployed more than one hundred CubeSats to form the PlanetScope satellite constellation. Ensuring close flight frequency, and operating an almost continuous image collection, the constellation achieves full global coverage every day with 3-5 m spatial resolution optical data. The PlanetScope satellite constellation includes three generation of satellites: DOVE, DOVE-R and SUPER DOVE.

Dove-R Instrument Design and difference with Dove

Comparing with the Dove (PS2) satellite, main differences exist in the spectral filter: the Dove-R (PS2.SD) satellites does not used any more the Bayer pattern filter and pass-band filters. These have been replaced with a high-performance butcher-block filter. The main consequences, is the effective GSD that has been increased. The Bayer filter requires to interpolate the missing pixels.

Also, the PS2.SD instrument is made of 4 individual pass band filters, that separate the light into each of the Blue, Green, Red and NIR spectral bands, as show in Figure 6-1. It is worth noting that the physical unit of the pixel size is micrometre (μm). This value should correspond to the dimension of the detector (pitch) in the focal plan (5.5 μm).

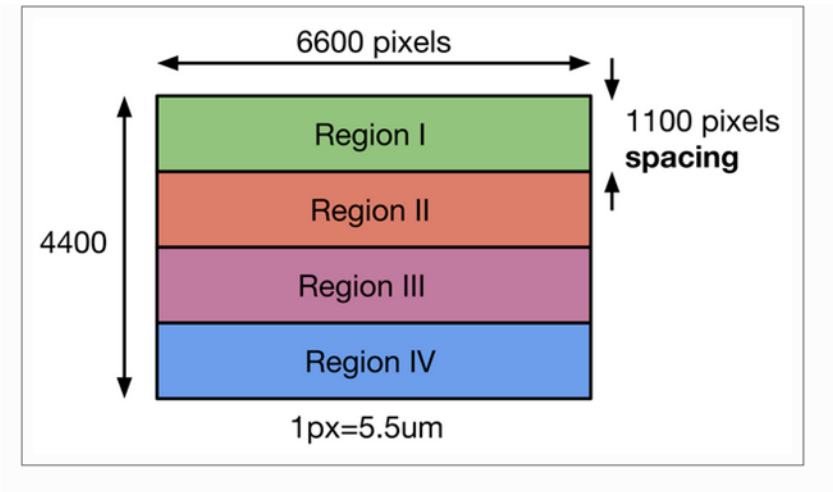


Figure 6-1: The PS2 SD instrument on board DOVE-R (Planet documentation).

Each frame acquired by the PS2.SD instrument is comprised of 4 stripes, one for each band. In order to generate a final image scene for each band, image stripes are stitched together.

As discussed in the Planet L1 data quality report (pp9, RD-4), the Dove-R sensor plane consists of four separate stripes organized vertically along the track of the flight path. Each one of the stripes corresponds to the separate spectral components GREEN, RED, Near-Infrared and BLUE, with no CFA array. Dove-R L1 composite images, both 3-band and 4-band, are produced by an image registration process involving up to four frames ahead and four frames behind the anchor frame. There is atypical time interval of ~0.5 seconds and a spatial baseline of ~3.8 km between consecutive frames.

APPENDIX B List of DOVE-R products used

Depending on the EDAP assessment, three different product types (described in [RD-3]) have been assessed:

- Level 1B, PlanetScope_Basic_Scene,
- Level 3A, PlanetScope_Ortho_Tile,
- Level 3B, PlanetScope_Ortho_Scene.

The PlanetScope_Basic_Scene and PlanetScope_Ortho_Scene are gathered into a same product and therefore are part of a same delivery.

The use of Level 1B processing level has been restricted to the validation of RPCs file: the scope was to validate that RPCs file associated with image provides a consistent georeferencing model.

The table below lists the TDS content. A table column indicates into which section the quality of this product is discussed. Moreover, the following trigram is used to indicate the validation process applied:

- IMQ for Image Quality Quality,
- RAD for RADdiometry,
- GEO for GEOmetry.

Table 6-2: DOVE-R Analysis: Input Test Data Set.

ID	$	Ass	Site	Processing Level	Product Identifier
1	5.4,5.6.5	IMQ GEO	La_Crau	Level 3B	20190624_102640_58_1063
2	5.4,5.6.3	IMQ GEO	La_Crau	Level 3A	2470850_3159121_2019-06-24_1063
3	5.4,5.6.3	IMQ GEO	La_Crau	Level 3A	2470850_3159122_2019-06-24_1063
4	5.4,5.6.3	IMQ, GEO	La_Crau	Level 3A	2470850_3159221_2019-06-24_1063
5	5.4,5.6.3	IMQ, GEO	La_Crau	Level 3A	2470850_3159222_2019-06-24_1063
6	5.4,5.6.3	IMQ, GEO	La_Crau	Level 3A	2584552_3159121_2019-08-08_106a
7	5.4,5.6.3	IMQ, GEO	La_Crau	Level 3A	2584552_3159122_2019-08-08_106a
8	5.4,5.6.3	IMQ, GEO	La_Crau	Level 3A	2584552_3159221_2019-08-08_106a
9	5.4,5.6.3	IMQ, GEO	La_Crau	Level 3A	2584552_3159222_2019-08-08_106a
10	5.7	RAD	La_Crau	Level 3B	20190329_103013_29_1063

ID	$	Ass	Site	Processing Level	Product Identifier
11	5.7	RAD	La_Crau	Level 3B	20190121_100720_1040
12	5.6.4	GEO	Piedmont	Level 3A	2498153_3259610_2019-07-05_1065
13	5.6.4	GEO	Piedmont	Level 3A	2498153_3259609_2019-07-05_1065
14	5.6.4	GEO	Piedmont	Level 3A	2492076_3259609_2019-07-02_1069
15	5.6.4	GEO	Piedmont	Level 3A	2492076_3259610_2019-07-02_1069
16	5.5	IMQ	Libya 4	Level 3A	2492005_3452225_2019-07-02_106d
17	5.5	IMQ	Libya 4	Level 3A	2591943_3452225_2019-08-11_106b

These products have been processed in August 2019, 15 with the processor "*CMO Patch Processor"* version 4.1.4 as indicated into the metadata file. These products have been downloaded from the Planet Catalogue.

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