Technical Note on Quality Assessment for SuperDove

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TABLE OF CONTENTS

1. INTRODUCTION

This document is the Technical Note on Quality Assessment for the PlanetScope SuperDove (**SD**) mission. SuperDove is the third instrument in the PlanetScope mission, following on from Dove and Dove-R. The instruments are micro-satellites, with several usually being launched in 'flocks'. More information is given in the Appendix: PlanetScope Mission.

In the EarthNet Data Assessment Pilot (**EDAP**) project, the quality assessment relies on the two following pillars:

- **The EDAP quality assessment** that follows guidelines written by the National Physical Laboratory (**NPL**) [RD-1], tailored for optical missions [RD-2]. See Section 3 for full information.
- **The EDAP validation / data quality control** which consist of a series of checks on the product format and metadata, and on the geometric and radiometric performance of a limited number of products.

The main output of these analyses is a product quality evaluation matrix, the so-called **maturity matrix;** see Table 2-1: SuperDove Quality Maturity Matrix**.**

1.1 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, dated June 2020, for this report [recently updated February 2021], https://assets.planet.com/docs/Planet_Combined_Imagery_Product_Specs_letter_screen.pdf

RD-4. 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. [not publicly available]

RD-5. Zanoni, "IKONOS Signal-to-Noise Ratio Estimation", March 25-27, 2002, JACIE Workshop, 2002 https://ntrs.nasa.gov/search.jsp?R=20040004380

RD-6. CEOS, RadCalNet Quick Start Guide. July 2018 https://www.radcalnet.org/resources/RadCalNetQuickstartGuide_20180702.pdf

RD-7. EDAP.REP.016, TN on Quality Assessment for Dove-R, 2.0, December 2020.

RD-8. The Spectral Response of Planet Doves: Pre-launch Method and Results, C. Pritchett *et al*., CALCON 2020: https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1399&context=calcon

RD-9. EDAP.MEM.016 EDAP SuperDove Visual Inspection Report, v1.0, 01 April 2021.

RD-10. SPOT Image Quality Performances, CNES C443-NT-0-296-CN, https://www.intelligence-airbusds.com/files/pmedia/public/r438_9_spot_quality_performances_2013.pdf

RD-11. 2020-Q3 Planet L1 Data Quality Report PlanetScope, Planet L1 Data Quality Q3 2020 Report - Status Of Calibration And Data quality For The Planetscope constellation [not publicly available]

RD-12. 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-13. Bouvet, M.; Thome, K.; Berthelot, B.; Bialek, A.; Czapla-Myers, J.; Fox, N.P.; Goryl, P.; Henry, P.; Ma, L.; Marcq, S.; Meygret, A.; Wenny, B.N.; Woolliams, E.R. RadCalNet: A Radiometric Calibration Network for Earth Observing Imagers Operating in the Visible to Shortwave Infrared Spectral Range. Remote Sens. 2019, 11, 2401, https://doi.org/10.3390/rs11202401

RD-14. CEOS, RadCalNet Quick Start Guide. July 2018 https://www.radcalnet.org/resources/RadCalNetQuickstartGuide_20180702.pdf

RD-15. ESA Sentinel-2 Data Quality Reports, https://sentinel.esa.int/web/sentinel/data-product-quality-reports

RD-16. National Image Interpretability Rating Scales, https://fas.org/irp/imint/niirs.htm

RD-17. https://calval.cr.usgs.gov/apps/sites/default/files/jacie/JACIE-Presentation-Pre-launch-Calibration-of-the-Planet-Labs-PlanetScope-Constellation-1.pdf

1.2 Glossary

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

ATBD	Algorithm Theoretical Basis Document
BOA	bottom of atmosphere
CEOS	Committee on Earth Observation Satellites
DN	digital number
EDAP	EarthNet Data Assessment Pilot
HR	High Resolution
JACIE	Joint Agency Commercial Imagery Evaluation
MTF	Modulation Transfer Function
NIIRS	National Imagery Interpretability Rating Scale

NPL	National Physical Laboratory
PHR	Pleaides High-Resolution
POI	Points of Interest
QL	quick looks
RMSE	Root Mean Square Error
ROI	Region of Interest
S2	Sentinel-2
SD	SuperDove
SNR	signal-to-noise ratio
TN	Technical Note
TOA	top of atmosphere
UDM2	Usable Data Mask
VHR	Very High Resolution

2. EXECUTIVE SUMMARY

The EDAP quality assessment relies primarily on documentation disclosed by the data provider (e.g. [RD-3], [RD-4], [RD-11]), including information on the product format specification, processing and validation. The EDAP quality assessment also relies on more specific, technical documentation available online, including conference proceedings, peer review papers (e.g. [RD-8]), etc.

The EDAP data quality assessment, EDAP validation (Section 4), was performed using a small sample of SD Ortho Tile (Level 3A) products, from numerous different SD satellites, acquisitioned between February and September 2020. Please note these products were data quality assessed in the last quarter of 2020.

The results of the aforementioned assessments are captured by the maturity matrix, given in Table 2-1, and a summary is given below.

Product Information

The SuperDove mission, products and format are well documented and the data easily accessible. Note the product format does not include information on the measurement data quality and there is no documentation, or it is not shared, on the processing algorithms (i.e. ATBD-like information) used and metrological traceability.

Product Generation

The processing steps undertaken to produce the data are documented, from the user's point of view, with very limited details, some of which can be found online (e.g. [RD-8]), on the processing itself. Regarding the in-flight calibration activities, there are few documents showing that Planet is using appropriate community infrastructure to undertake these activities. These documents might be updated more regularly.

Ancillary Information

The Planet product includes some useful ancillary information; set per pixel, product flags are mostly binary (unusable mask data). The product format includes a lot of information in general. However, the format does not address ancillary data origin, ancillary data type, and uncertainties. Note other valuable information (e.g. relative spectral response) are shared by the Planet Team.

Uncertainty Characterisation

The Planet data quality report [RD-4] is evidence that the quality of the products is regularly monitored. The quarterly report proposes a comprehensive analysis of the most common product performance quality items. There is some room for improvement regarding uncertainty sources because these are, except for the geometry, not really discussed.

Validation

- *Product details and visual assessment:* The product images do not show image artefacts or image anomalies that are detectable from visual assessment. The data mask associated with the image is consistent. Image analysis shows that compliance with the National Image Interpretability Rating Scales (**NIIRS**) Category 3 (2.5 – 4.5 m) is reached.

- *Geometric accuracy*: The validation shows that Level 3A absolute and temporal geolocation accuracy are in agreement with the claimed specification (<10.0 m RMSE) (i.e. by the data provider). The interband registration accuracy is also in agreement with the claimed specification.
- *Radiometric accuracy*: The absolute radiometric calibration of products is estimated to be within 5%, which is totally in agreement with the claimed specification. Day-to-day variations, depending on the satellite involved, are observed and should be characterised and explained.
- *Image quality:* The image quality, assessed via sharpness and signal-to-noise ratio (**SNR**) analyses, is acceptable and within the claimed specifications.

Table 2-1: SuperDove 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. DETAILED EDAP QUALITY ASSESSMENT

3.1 Product Information

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

The product format is consistent and informative, and the parameters included in the metadata format are listed in the Appendix: PlanetScope Mission (Table 4-16). This information can be complemented with information from the product description report and quality control report (not publicly available).

The overall information available in the product format or in the on-demand documentation is relevant. Therefore, the EDAP grade for Product Information is "*Intermediate*".

There is some room for improvement, mainly concerning the product metadata into which information on measurement quality is missing, and traceability of ancillary data used is missing. The full product description is available in [RD-3]. Some required information is missing from publicly available documentation (e.g. the stated measurement quality [RD-11]). Regarding product availability and accessibility, the dataset meets many of the FAIR principles. As there is no publicly available data management plan showing progress toward FAIR principles, the EDAP grade for **Product Availability and Accessibility** is '*Intermediate'.* The Planet data product includes encoded GeoTiff images with a GeoJSON metadata file and XML metadata file. The product format is well documented and meets community naming conventions standards. The compliancy to CARD4L-SR requirements is not reached because processing algorithms and auxiliary data are not identified in the metadata. For these reasons, the EDAP grade for **Product Format** is *'Good'.*

The user documentation covers two fundamental aspects, the availability of a product user guide and the availability of the Algorithm Theoretical Basis Document (**ATBD**). In the Planet user guide [RD-3], there is existing ATBD-type information, but absence of a formal ATBD. The user guide is very detailed. In addition, several conference presentations are accessible elsewhere. For these reasons, the EDAP grade for **User Documentation** is *'Intermediate'.*

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

3.2 Product Generation

This section covers the processing steps undertaken to produce the data. As mentioned previously, the data provider delivers products with three distinct processing chains: Level L1A, Level 3A and Level 3B. In the context of the EDAP analysis, the Level 3A 'ortho tile' products have been assessed.

There are conference documents (public) available detailing pre-flight calibration, demonstrating that pre-flight activities have been performed. However, this material is not sufficient to assess the pre-flight calibration approach. For this reason, the EDAP grade for **Pre-Flight Sensor Calibration and Characterisation** is *'Not Assessable'.* However, the reader can refer to the Joint Agency Commercial Imagery Evaluation (**JACIE**) presentation on PlanetScope (2016) [RD-17].

Post-launch calibration and characterisation activities are regularly performed and the method is described in a dedicated document [RD-11]. The analysis covers important aspects of the sensor behaviour, and is quite comprehensive, although not publicly available. In addition, Planet is using appropriate community infrastructure (Committee on Earth Observation Satellites (**CEOS**) PICS, RADCALNET) to perform analysis. For these reasons, the EDAP grade for **Post-Launch Sensor Calibration and Characterisation** is *'Intermediate'.*

Note, as mentioned in [RD-11], the radiometric calibration campaigns are done based on a cross calibration method using Sentinel-2 and Landsat-8. Many thousands of crossover events are used for this calibration activity. [RD-11] also includes calibration / validation results on absolute geolocation accuracy, interband registration, absolute radiometric accuracy and signal to noise ratio.

Furthermore, the data provider can deliver surface reflectance products derived from the standard Planet Analytic (Radiance) Product that is processed to top of atmosphere (**TOA**) reflectance and then atmospherically corrected to bottom of atmosphere (**BOA**) or surface reflectance. As discussed in [RD-3], 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 constellation. The retrieval method is reasonable and judged to be "fit for purpose". For these reasons, the EDAP grade of **'Retrieval Algorithm Method'** is *'Intermediate'.* There is no material allowing us to evaluate 'Retrieval Algorithm Tuning'. For these reasons, the EDAP grade for **Retrieval Algorithm Tuning** is '*Not Assessable'*.

In the case of Planet products, the additional processing item within the EDAP Maturity matrix refers to the geometric processing including several critical steps. These steps are partially documented in [RD-3], in particular any information regarding sensor modelling and ortho-processing. However, information to fully understand product geometry is not available. For this reason, the EDAP grade for **Additional Processing** is *'Basic'*.

3.3 Ancillary Information

Contained within the Usable Data Mask (UDM1, UDM2), detailed in [RD-3], is a comprehensive set of product flags and many are provided at pixel level; see Figure 4-25 and Figure 4-26. The product flags are well documented, but these flags are binary by nature. For this reason, the EDAP grade for **'Product Flags'** is '*Intermediate'.*

The following information is available in the UDM:

- Usable mask: clear / snow / shadow / light haze / heavy haze / cloud mask / confidence map / unusable data mask,
- Unusable mask: blackfill / cloud covered / missing or suspect for each of the product bands in turn.

One may wonder if all ancillary data is provided to define the measurement. Some information is available via the metadata, e.g. illumination angles, but some is not, e.g. sensor altitude. The relative spectral response is available via the web documentation. When relevant, additional information such as meteorological data is reported. These data are generally not given together with uncertainty quantified. The EDAP grade for **Ancillary Data** is therefore *'Basic'*.

3.4 Uncertainty Characterisation

This section of the mission quality assessment 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 performs regular uncertainty characterisation activities as illustrated in the quarterly data quality report [RD-11]. The quarterly report is not public but has been shared with the EDAP team under non-disclosure agreement.

Based on representative datasets 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 for **Uncertainty Characterisation Method** is *'Good'*.

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

The uncertainty values are not provided in the product. However, the main uncertainty values, given in [RD-11], are provided for subsets of data (i.e. samples of data for a given period). The 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 included. In addition, the uncertainty values are in most cases expressed using different metrics, which is very helpful for the user.

For the reasons given above, the EDAP grade for **Uncertainty Values Provided** is '*Intermediate*'. This grade is applicable to the two maturity matrix boxes: 'Uncertainty Values Provided' and 'Geolocation Uncertainty'.

Table 3-1 summarises the uncertainty values gathered from the existing documentation and covering subsets of data observed in the Q3 2020 period. These values have been used as input to the EDAP quality assessment, as written at the beginning of each corresponding quality assessment section, unless data were readily publicly available.

Table 3-1: Uncertainty Values Provided

Uncertainty Values Provided: Radiometric Calibration Uncertainty	
Summary	*Mean / STD cross-calibration gains are given:* • *BLUE: 1.075 / 0.046* • *GREEN: 0.970 / 0.046* • *RED: 0.954 / 0.031* • *NIR: 0.920 / 0.046* *The validation methodology compares SuperDove with reference missions such as Landsat 8 / OLI and Sentinel-2A / MSI, Sentinel-2B / MSI.*
Reference	*[RD-8], [RD-11]*

Uncertainty Values Provided: Signal-to-Noise Ratio	
Summary	*The Planet pre-launch Signal-to-Noise ratio can be seen in [RD-8]. In-flight data can be seen in [RD-11], and values are also given in web documentation.* *From [RD-11], for bands, R, G, B, Red_edge and NIR:* *SuperDove - 299.384 /188.565 / 286.159 / 233.546 / 249.424* *Reference wavelength: 338 / 385 / 565 / 1233 / 1460*
Reference	*[RD-8], [RD-11], https://developers.planet.com/docs/apis/data/sensors/*

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.* *Relative edge response numbers are given in post-launch QC information for 8-stripe SuperDove:* *RER green across track: 0.299 (native);* *0.22 (Normalized to 3 m Ground Sampling Distance (**GSD**))* *RER green along track: 0.318 (native);* *0.234 (Normalized to 3 m GSD)*
Reference	*[RD-11]*

For geolocation uncertainty, the following metrics are available from Planet:

- Average RMSE for positional accuracy comprising all bands;
- Mean and STD of RMSE for temporal and interband geolocation accuracy.

Table 3-2 details the geolocation uncertainty results.

Table 3-2: Geolocation Uncertainty

Geolocation Uncertainty	
Summary	*The accuracy results reported by the Planet quality control team, and considered as EDAP input specifications are summarised:* • *The GSD for the five-band product is given as 3 – 6 m (3.7 m average at reference altitude 475 km). The pixel size is given as 3.7 - 4.1 m (altitude-dependent GSD). The positional accuracy is given as < 10 m RMSE [RD-3].* • *The temporal geolocation accuracy is 11.0 m / 5.4 m (Mean / STD RMSE accuracy); this average accuracy is computed based on 992 products [RD-11].* • *The Interband registration accuracy is [RD-11]:*

	<table><tr><th>Band Combination</th><th>Sample Size</th><th>Average RMSE rad [m]</th><th>STD(RMSE rad) [m]</th></tr><tr><td>Blue - Green</td><td>1093</td><td>3.0</td><td>2.6</td></tr><tr><td>Blue - Red</td><td>1095</td><td>1.9</td><td>1.5</td></tr><tr><td>Blue - RE</td><td>1087</td><td>4.0</td><td>3.2</td></tr><tr><td>Blue -NIR</td><td>1046</td><td>5.2</td><td>3.8</td></tr><tr><td>Green - Red</td><td>1095</td><td>2.4</td><td>1.8</td></tr><tr><td>Green - RE</td><td>1090</td><td>1.6</td><td>1.3</td></tr><tr><td>Green - NIR</td><td>1085</td><td>4.3</td><td>2.6</td></tr><tr><td>Red - RE</td><td>1088</td><td>3.0</td><td>2.5</td></tr><tr><td>Red - NIR</td><td>1053</td><td>5.3</td><td>3.6</td></tr><tr><td>RE - NIR</td><td>1093</td><td>3.4</td><td>2.0</td></tr></table>
Reference	*[RD-3], [RD-11]*

3.5 Validation

Note that the validation items are related to independent validation 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 of **Reference Data Representativeness** is '*Basic'.*

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

Table 3-3: Reference Data Quality

Reference Data Quality	
Summary	*The Sentinel-2 mission is used as reference as the radiometric accuracy of MSI is high and well documented.* *The radiometric calibration method used globally accepted RadCalNet data.* *Regarding absolute geolocation, the method used SPOT-5 data (accurate to 2.5 m) as reference.*
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* *RadCalNet: [RD-13], [RD-14]*

The EDAP methodology assesses satellite measurements providing a simple uncertainty estimated from a statistical point of view. For this reason, the EDAP grade of **Validation Method** is ‘*Intermediate*’.

Table 3-4: Validation Method

Validation Method	
Summary	*Absolute geolocation accuracy is validated against SPOT-5 data. The uncertainty associated with SPOT-5 is less than 1 SuperDove pixel.* *Radiometric calibration accuracy is validated by using RadCalNet and Sentinel data.* *Image quality / SNR is validated based on methods presented at the JACIE Workshop [RD-5] and updated in-house methods.*
Reference	*See Section 4*

For any analysis, the compliance between the validation results and data provider specification is shown in Table 3-5. Validation demonstrates an overall agreement between satellite and reference measurements and agreement is generally within uncertainties claimed by the data provider.

All EDAP validation reports are in Section 4. Furthermore, the EDAP assessments have been performed independently from the satellite mission owner. As a result, the EDAP grade of **Validation Results** is “*Good*”.

Table 3-5: Validation Analysis Results.

EDAP Validation Analysis	Compliance (Y / N)
Image Quality / Visual Inspection	Y
Image Quality / Signal To Noise Ratio	Y
Image Quality / Sharpness	Y
Geometric Calibration Quality / Absolute Geolocation	Y
Geometric Calibration Quality / Temporal Registration	Y
Geometric Calibration Quality / Interband Registration	Y
Radiometric Quality / Calibration	Y

4. EDAP Validation

4.1 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:

- Image quality
- Geometric calibration quality
- Radiometric calibration quality

4.2 Image Quality

4.2.1 Activity Description Sheet

Table 4-1: Activity Description Sheet for Image Quality

Image Quality
Inputs
Level 3A OrthoTile PlanetScope SuperDove product(s) (listed in APPENDIX B): • *Visual Inspection: [PSD.4], [PSD.9]* • *Image Interpretability: [PSD.6]* • *SNR: [PSD.4], [PSD.10]* • *Sharpness Analysis: [PSD.20], [PSD.21]*
Description
The qualitative and quantitative image quality assessments of input product imagery include: • *Check content of product image quick looks / check content of product quality masks* • *Image Interpretability: Assess the ability to interpret surface features or objects in imagery, using a selection of points of interest, and compare to imagery from a reference sensor. Also, assess imagery against NIIRS.* • *The Signal-to-Noise Ratio (SNR) was estimated for each band in the two products. The five-band SuperDove products were evaluated for radiances characteristic of those of the Libya-4 desert site. Libya-4 is a PICS (Pseudo-Invariant Calibration Site) location, defined by the CEOS WGCV and IVOS, and has demonstrated over many decades its suitability for calibration and validation.* • *Sharpness Analysis was performed based on a set of images showing sharp transitions (Maricopa fields region). Estimation of the width of the selected feature and associated noise was made from histograms of the mean and standard deviation BOA reflectances.*
Outputs

Image Quality
• *The visual inspection assessment of imagery and masks showed the test products to conform to expectations with regard to regions of interest, with no obvious anomalies.* • *The results of image interpretability showed that the points of interest were easily identifiable and could be classified according to NIIRS Category 3 (2.5 – 4.5 m).* • *SNR values for each band for two different products are computed and results showed the SNR values to be within the Planet specification.* • *The results of the sharpness assessment displayed some lack of specific detail about areas of natural contrast, depending on the band observed, but estimates of the feature were within the stated GSD.*

4.2.2 Introduction

The image quality assessments of SuperDove products is performed by using distinct approaches for the following:

- Visual inspection of Image and Data Mask
- Image Interpretability
- Signal-to-Noise Ratio
- Image Sharpness

4.2.3 Visual Inspection

4.2.3.1 Methods

The processing implemented for the generation of the standard basic scene, ortho tile products include full-resolution GeoTIFF imagery with band data quantified as TOA measurements. A usable data mask (udm2) accompanies the latter imagery, within which there is an unusable data mask (as bits set within Band 8 of udm2), allowing additional quality assurance information per full-resolution pixel.

In addition, work has focused on the quality of the usable data mask. The usable data mask (udm2) proposes a classification of each pixel according to the following classes: clear, snow, cloud, shadow, light / heavy haze, classification confidence percentage, and the unusable data mask (udm), as detailed in the product documentation.

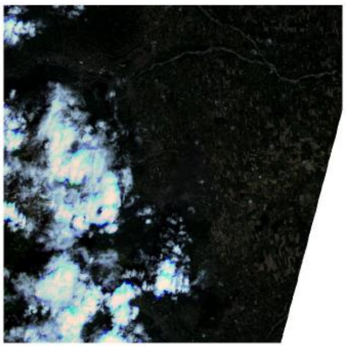
Figure 4-25 displays SuperDove udm2 band information, and Figure 4-26 displays the udm bit information. This information was taken from the Planet Developers centre at https://developers.planet.com/docs/data/udm-2/.

4.2.3.2 Results

The product image quicklooks (**QL**) have been assessed and their quality is nominal, no artefacts or anomalies have been detected. Note the standard supplied QLs from Planet were viewed for some of the products in the test dataset (APPENDIX B). Examples are shown in Table 4-2.

Table 4-2: Quick look examples from the SuperDove TDS

Product / Location	Quicklook	Comment
PSD.1 Wellington, South Africa		Clear, detailed QL Good contrast
PSD.4 Libya		Desert site QL very dark but dune tops can be seen
PSD.14 La Crau, France		Reasonably clear QL Contrast between land and sea can be seen

Product / Location	Quicklook	Comment
PSD.19 Piedmont, Italy		Bright clouds lead to dark imagery over the land

Product Analysis #1

Information from the data mask of the following product is shown in this section:

- 3346039_3159222_2020-04-25_2263_BGREN_Analytic [PSD.9]

Figure 4-1 shows the red band image from PSD.9, with the scaling slightly saturated to display the clouds and their shadows. This product was chosen specifically due to the cloudiness of the image.

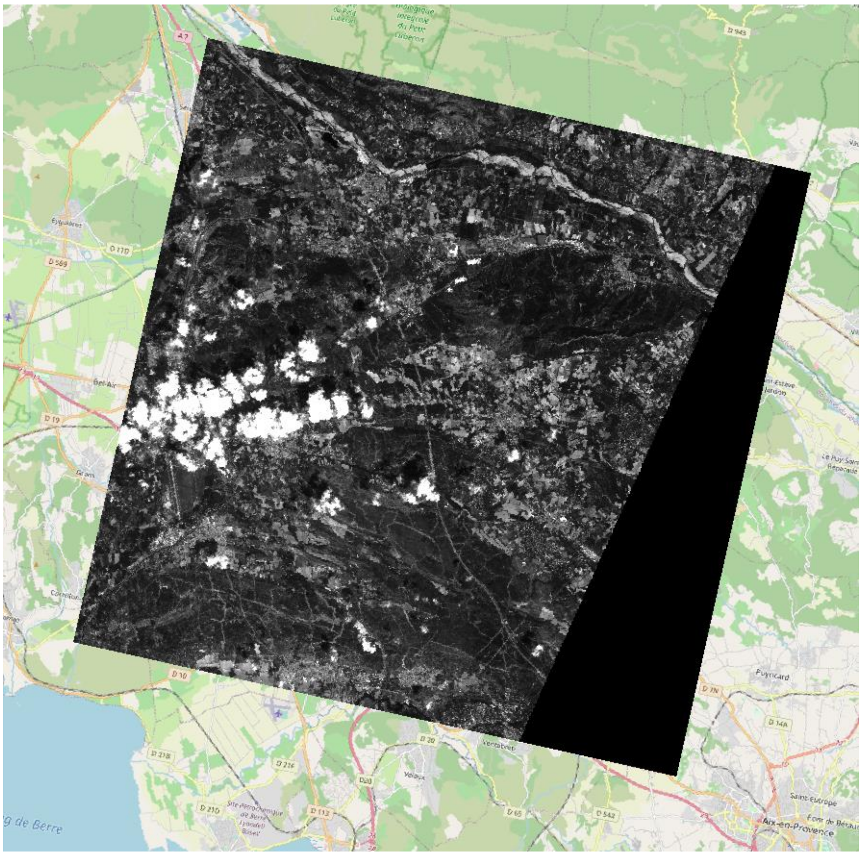


Figure 4-1: Red band image of PSD.9 over La Crau.

Examples of udm2 information for PSD.9 over La Crau are shown in Figure 4-2 and Figure 4-3. Examples of udm information for PSD.9 are shown in Figure 4-4 and Figure 4-5. It can be noted that PSD.9 contained 8% unclear pixels.

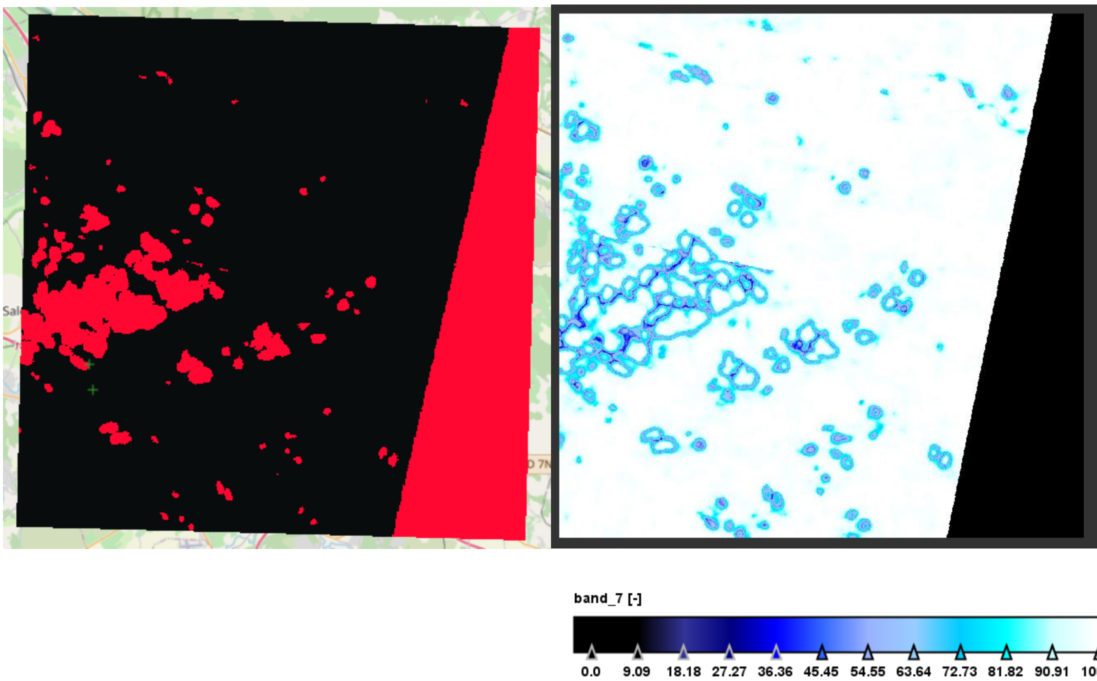


Figure 4-2: Usable data mask (udm2) information from SuperDove product PSD.9. Left: Band 1, where red=not clear [QGIS viewer]. Right: Band 7 confidence map, where darker blue values show less confidence in the classification [SNAP viewer]

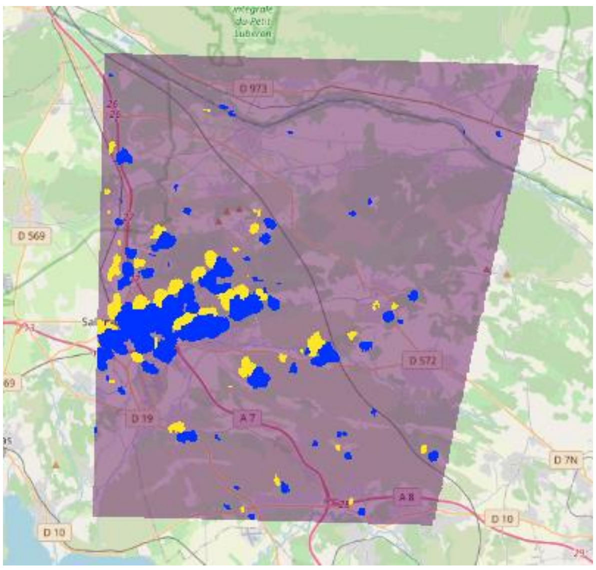


Figure 4-3: Usable data mask (udm2) information from SuperDove product PSD.9. Band 1: clear, shaded box; Band 3: shadow, yellow pixel; Band 6: cloud, blue pixel. (No other bands are active in this product.)

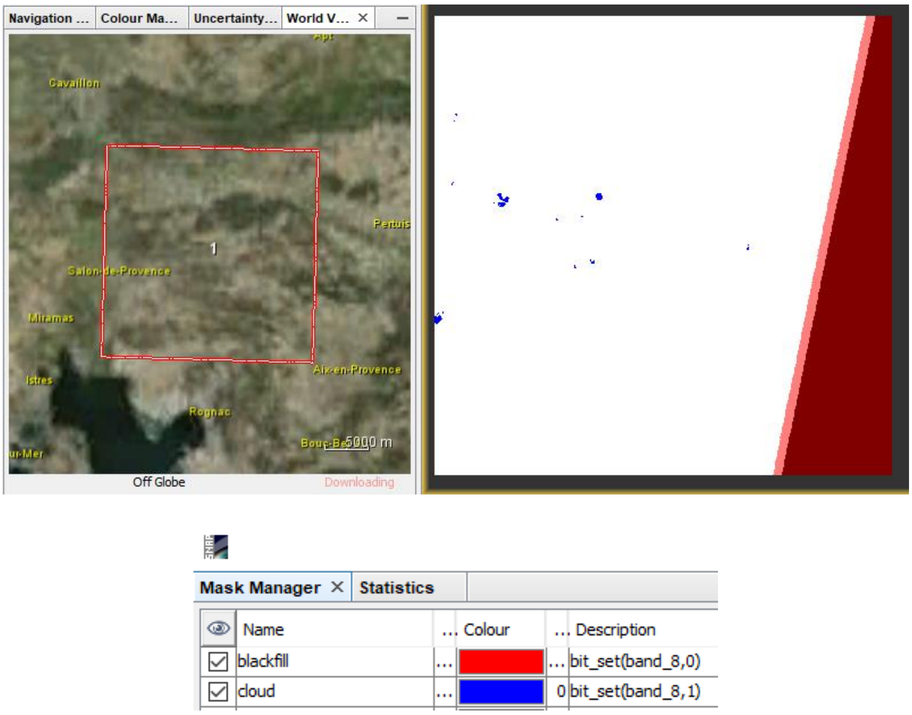


Figure 4-4: Bits set in Band 8 for PSD.9, showing the unusable data mask (udm). Left: area of interest in the red box. Right: udm data showing blackfill (red) and cloud (dark blue). [SNAP viewer]

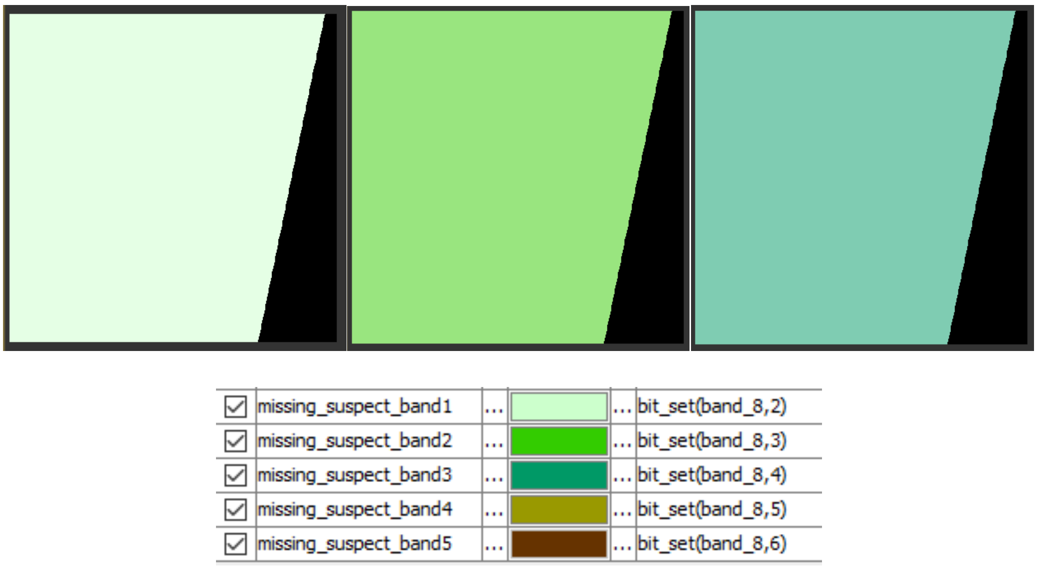


Figure 4-5: Bits set in Band 8 for PSD.9, showing the unusable data mask (udm). Left – right: missing_suspect information for Bands 1, 2 and 3, respectively. There were no bits set for missing_suspect information in Bands 4 and 5. [SNAP viewer]

From the information given above, we conclude that the data mask information corresponds to the visual features noted.

Product Analysis #2

Information from the data mask of the following product is shown in this section:

- 3441792_3452224_2020-05-30_2271_BGREN_Analytic [PSD.4]

The SNR Analysis carried out in Section 4.2.5 highlighted some discontinuities within the product. Figure 4-6 shows the blue band radiance (left), and udm2 band 7 (confidence_analysis; right). White pixels in the radiance image are dune tops in the Libya-4 region. A discontinuity within this figure can be seen in the confidence_analysis display (within the oval).

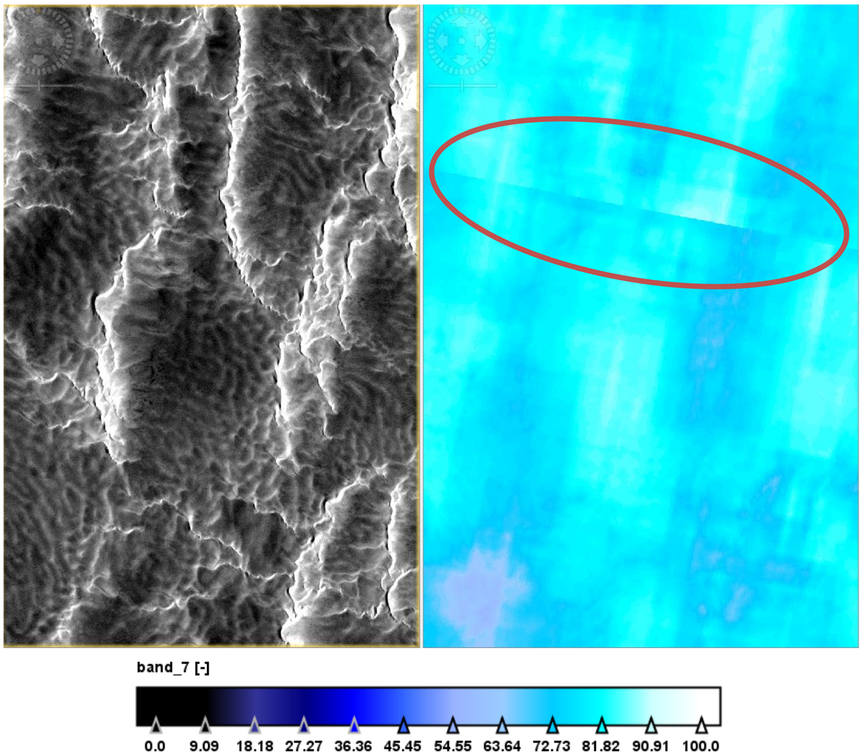


Figure 4-6: Left: PSD.4 blue band radiance; right: PSD.4 udm2 band 7 confidence_analysis, where darker blue values show less confidence in the classification [SNAP viewer].

It can be surmised that this is an "echo" of the splicing of the different frames imaged at different times as seen, for example, in Figure 4-27. The conclusion is that the joining of the frames is successful, in that the trace shown in Figure 4-6 is very subtle.

4.2.4 Image Interpretability

4.2.4.1 Methods

The image interpretability of optical sensor imagery is an important aspect of image quality (originating from the actual sensor or image processing), especially in terms of their practical use or application. This is commonly assessed, subjectively, using a well-defined procedure that is based on the successful interpretation of features or objects of interest (i.e. points of interest) according to the National Imagery Interpretability Rating Scale (**NIIRS**) category in which the sensor belongs [RD-16]. This well-defined procedure also importantly allows for the cross-comparison of image quality from similar sensors.

The method used to assess image interpretability consists of clipping 100 x 100 pixel windows from the sensor's imagery (for each band), centred on the points of interest (**POI**) identified. Note reference imagery is processed in order to ensure the pixel size matches that of this sensor's imagery.

Pleiades High-Resolution (**PHR**) imagery, reduced to 3 m pixel size, were used as a reference for SuperDove around 22 POI. The POI are deemed suitable for **NIIRS Category 3 (2.5 – 4.5 m)** and **NIIRS Category 5 (0.75 – 1.2 m GSD).**

The SuperDove Visual Inspection Report [RD-9] details the POI and presents all histogram and image comparisons for every POI and for every instrument band.

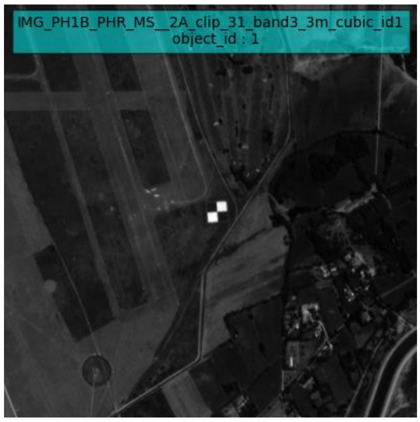
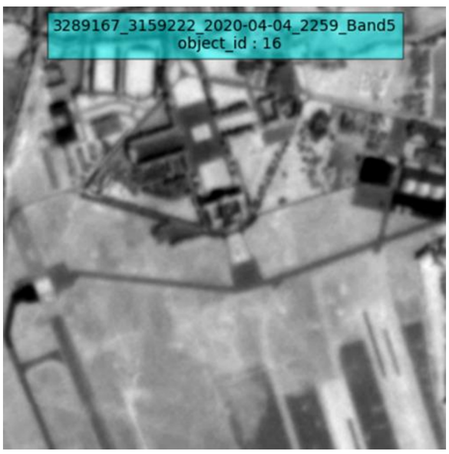
4.2.4.2 Results

PHR has superior image quality compared with SuperDove for all POI, even though PHR has been downsampled to 3 m (to match the product pixel size of 3.125 m). In part, this is because the GSD for some bands is not 3.7 m but closer to 6 m for the NIR (see Figure 4-31). The visual non-clarity in some respects can also be ascribed to SuperDove conversion (from 16-bit to 8-bit imagery encompassing the whole range of data), and the fact that over many of the POI, the SuperDove histogram is skewed, therefore converting around the mean results in an image that is either saturated in parts or too dark. Without any conversion, SuperDove images generated using this process are usually too dark with the exception of the NIR band.

Note that the presence of noise in SuperDove blue band imagery is likely due to atmospheric contamination. Also, one can note the degradation of the resolution in SuperDove NIR band (due to the quantum efficiency law).

Table 4-3: Examples of image comparison between SuperDove and Pleiades

Description	id	SuperDove	Pleiades
MTF target, **blue** band	1	Blurry and saturated in the white part of the target 	Detailed image and the target is clearly resolved 

Description	id	SuperDove	Pleiades
MTF target, **red** band *Data conversion relaxed to try to avoid saturation over the target*	1	This is achieved but the image is now overly dark 	A darker image for PHR also but the target is still clear 
Building, **green** band	16	Saturation seen in a few regions, details on road not seen clearly 	Good contrast, features seen in roads, building at right saturated 
Building, **NIR** band	16	NIR imagery not seen as clearly as the green band imagery above 	(no comparison)

4.2.5 Signal-to-Noise Ratio

4.2.5.1 Methods

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

The basic formulation of SNR is:

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

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

The method proposed for this assessment allows for the estimation of (spatial) SNR, based on the aforementioned equation and the following assumption:

- The mean signal is defined as the spatial average of a group of pixels observing a spatially varying scene and the noise is defined as the standard deviation of this signal for the same group of pixels.

The method, modified since it was initially proposed in [RD-5], is performed for each spectral band, whose imagery has been converted from digital numbers to radiance, in the following way:

1. Compute the local statistics of a small (e.g. 3 x 3 pixels) sliding window applied to the imagery being assessed. Select only the "best" small windows for the next steps.
    a. The selection of small windows ensures that increased site uniformity is generally maintained (if not, where spatially high frequencies exist, e.g. sharp transitions seen as a dune summits, dedicated image processing is applied in order to detect this and filter).
2. Compute the statistical distribution (histogram), between the minimum and maximum radiance of the whole scene, of the selected "best" small windows – the signal is defined as the peak (i.e. mean radiance) of this statistical distribution and the noise is defined as the standard deviation of this statistical distribution about the mean.
3. Estimate the signal-to-noise-ratio(s).

The most accurate estimations of signal-to-noise ratios are derived from statistical distributions that are of a normal (i.e. Gaussian) nature.

The region of interest defined for this assessment is 3k x 3k pixels, instead of 8k x 8k (entire product image), over PICS Libya-4. This is illustrated in Figure 4-7.

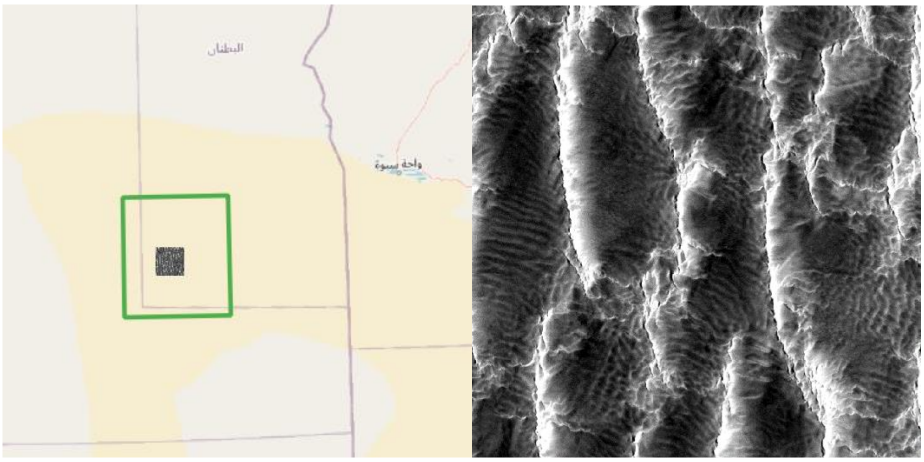


Figure 4-7: Left: SuperDove product placement (image) within PICS Libya-4 (green box); right: ROI for SNR assessment for PSD.4 (blue band).

4.2.5.2 Results

The results of this assessment, detailed in Table 4-4, indicate the SNR values are generally better than the Planet in-flight SNR values taken from [RD-8].

it is important to note the Planet reference radiances (L_{ref}) for each band (except the blue band) are not closely aligned with the mean radiance values analysed over Libya-4. SNR values are highly dependent upon the reference radiance.

Table 4-4: SuperDove Signal-to-Noise Ratio

Band	3441792_3452224_2020-05-30_2271 [PSD.4]		3356390_3452224_2020-04-29_2257 [PSD.10]		L_{ref} ($W\ sr^{-1}\ \mu m^{-1}\ m^{-2}$) (Planet)	SNR @ L_{ref} (Planet)
	Mean radiance ($W\ m^{-2}\ sr^{-1}$)	SNR	Mean radiance $W\ m^{-2}\ sr^{-1}$)	SNR		
Blue	130	196	130	201	130	170
Green	168	198	166	206	130	150
Red	200	183	200	163	130	138
Red-Edge	159	208	188	251	70	57
NIR	159	210	153	198	130	137

An example of the analysis output from the products is given in Figure 4-8 for PSD.4, blue band.

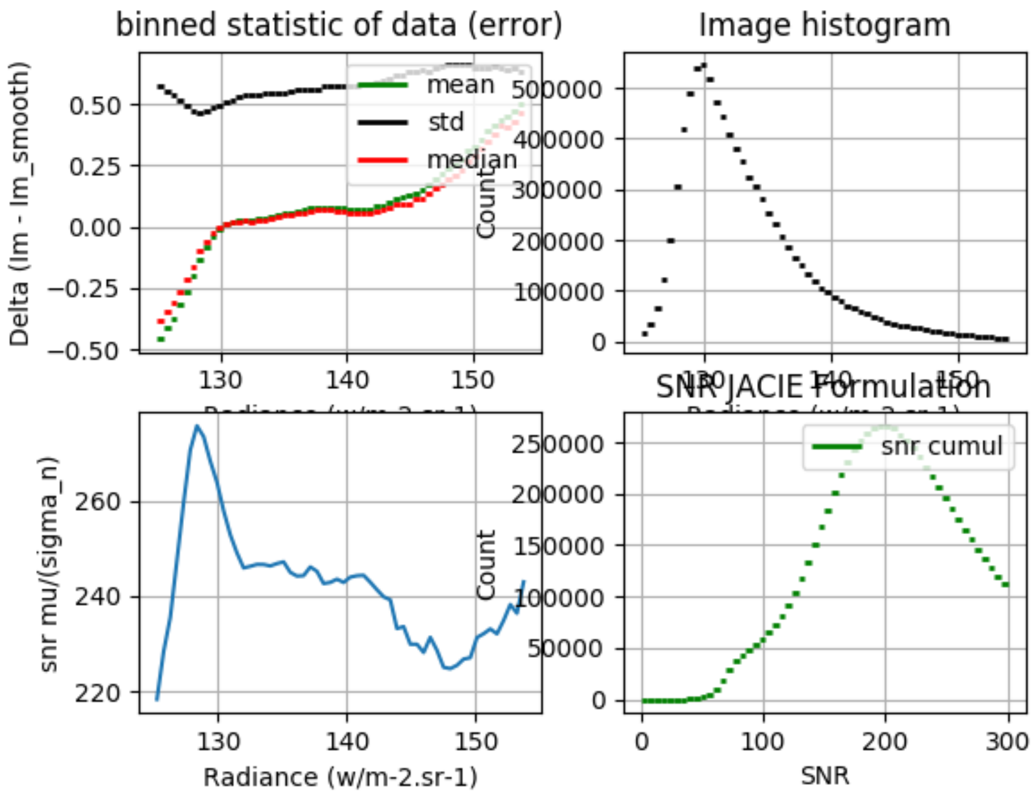


Figure 4-8: PSD.4, blue band SNR analysis outputs. Top left: scene statistics, top right: scene radiance histogram, bottom left: SNR vs radiance, bottom right: SNR.

4.2.6 Sharpness Analysis

4.2.6.1 Methods

Artificial Modulation Transfer Function (**MTF**) targets, such as those at Salon-de-Provence (France) (see Table 4-3), can be too small to give a fair assessment of imagery from satellites with the GSD of SuperDove. In this instance, therefore, we have chosen to conduct a sharpness analysis using the Maricopa fields in Arizona, USA. The agricultural fields at Maricopa provide a natural target for sharpness analysis.

Shapefiles of the Maricopa fields were constructed and used to select regions of interest within the products.

The original data products were clipped about the Region of Interest (**ROI**), and the values were converted to TOA reflectance by multiplication of the digital number (**DN**) with the TOA reflectance coefficient, for each band, given in the product metadata xml file.

4.2.6.2 Results

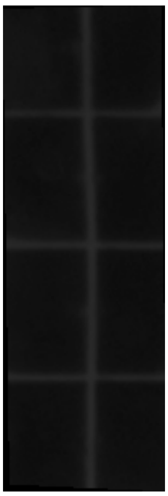
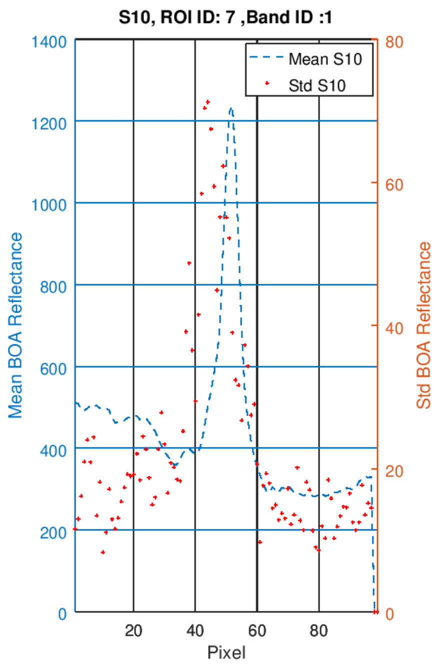
Table 4-5 displays reflectance images and sharpness assessments for ROI 7, blue band 1 (PSD.21); and ROI 6, blue, green, red and NIR Bands 1–4 (PSD.20).

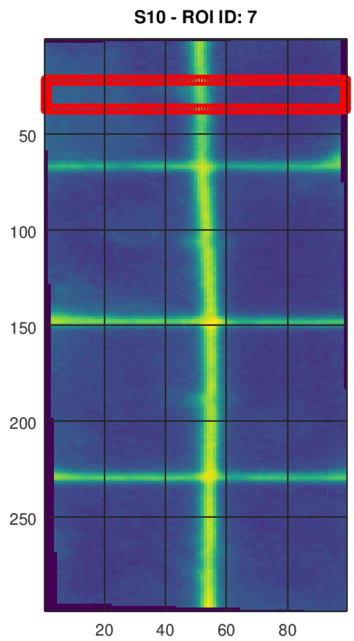
The red box in the sharpness analysis image marks the interval over which the mean and standard deviation TOA reflectances were calculated.

The main findings that can be deduced from the results are:

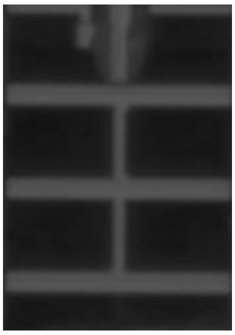
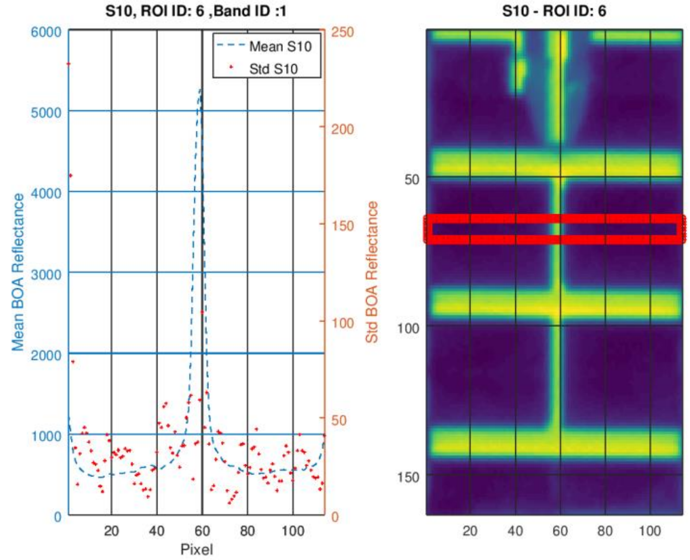
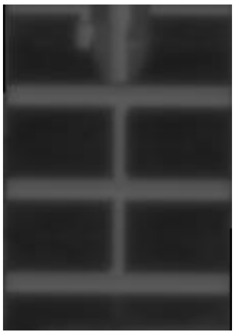
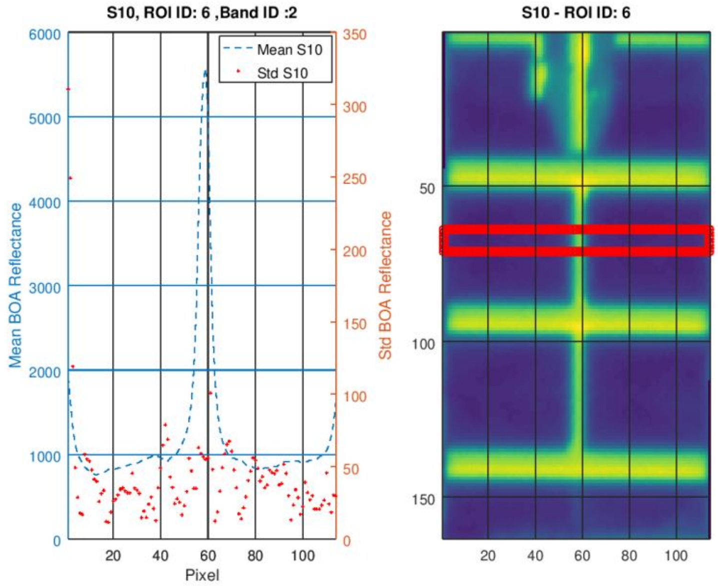
1. Both images and different bands display the FWHM to be ~6 pixels, translating to ~18 m at SuperDove GSD of 3 m.
2. Google Map comparisons show the features assessed to be ~15 m, at maximum.
3. Differences between bands (PSD.20) can be seen in terms of noise in both the sharpness images and the standard deviation of the histogram plots.
4. Noise differences between the products for the blue band 1 comparison display the lack of contrast available for ROI 7 when compared with ROI 6.

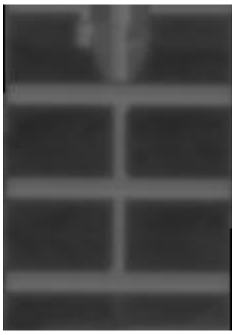
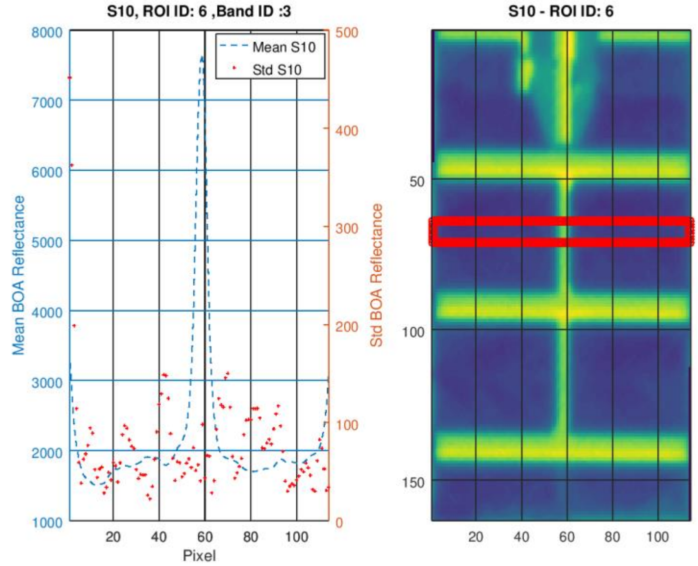
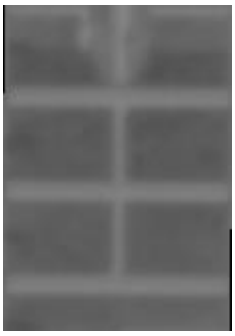
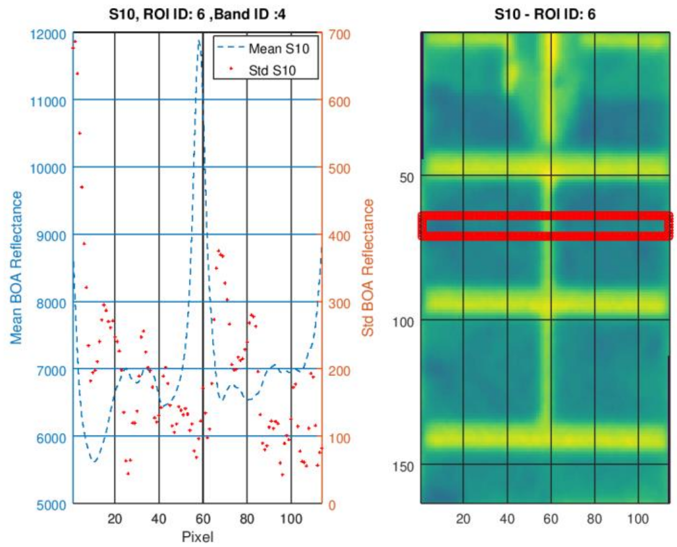
Table 4-5: Images for sharpness analysis over Maricopa fields

<table>
<tr><th>Product /
ROI /
Band</th><th>Sharpness analysis</th></tr>
<tr><td>PSD.21
ROI 7
Band 1 (blue)
</td><td>


</td></tr>
<tr><td>Comment</td><td>The dashed Mean line in the reflectance pixel plot has a FWHM (full width, half maximum) estimated to be ~6 pixels. (Slightly less than one-third of 20 pixels.) In terms of SuperDove GSD, this translates to ~18 m.

The apparent distortion in the product image of the straight lines is confirmed to be real (Bing Maps, Google Maps), and is not an artefact of the SuperDove image.</td></tr>
</table>

PSD.20 **ROI 6** **Band 1 (blue)** 	
Comment	The dashed Mean line in the reflectance pixel plot has a FWHM (full width, half maximum) estimated to be ~6 pixels. (Slightly less than one-third of 20 pixels.) In terms of SuperDove GSD, this translates to ~18 m.
PSD.20 **ROI 6** **Band 2 (green)** 	

PSD.20 **ROI 6** **Band 3 (red)** 	
PSD.20 **ROI 6** **Band 4 (NIR)** 	
	Google Maps in this location (W. Harmon Road, Arizona, U.S.A) provides an estimate of the width of the relevant band to be ~15 m maximum.

4.2.7 Results / Conclusions

The image quality components have been addressed in both qualitative and quantitative ways.

The visual inspection and interpretability of imagery was assessed, qualitatively, and the results indicate there were no obvious anomalies or artefacts present and the interpretability can be as acceptable.

The results of the quantitative assessment of sharpness indicate some blurring when assessing natural high-contrast sites in the USA, and the results of the quantitative assessment of SNR showed values for all bands to be within the stated Planet in-flight values.

4.3 Geometric Calibration Quality

4.3.1 Activity Description Sheet

Table 4-6: Activity Description Sheet for Geometric Calibration Quality

Geolocation: Absolute / Temporal / Interband / Relative Accuracy
Inputs
Level 1 PlanetScope SuperDove OrthoTile products (listed in APPENDIX B): [PSD.15], [PSD 16], [PSD.17]
Description
Estimate the accuracy of SuperDove products, including absolute accuracy, temporal accuracy and interband registration accuracy. Verify that measured accuracy is within the product specification accuracy stated in [RD-3]. *Note the GSD for the five-band product is given as 3 – 6 m (3.7 m average at reference altitude 475 km). The geolocation accuracy, referred to as the positional accuracy by Planet, is given as < 10 m RMSE.*
Outputs
*For absolute geolocation accuracy against SPOT-5 reference (2.5 m accuracy): it is confirmed that the product Root Mean Square Error (**RMSE**) accuracy is of the order of 10 m.* *For temporal accuracy between three different satellites, there is reasonable alignment between one pairing (<8 m RMSE), but the two other pairings are aligned at >10 m RMSE.* *For interband accuracy, the B, G and R band alignments are of the order of 1 pixel. For RE and NIR, the alignment is between 1 and 3 pixels.*

4.3.2 Introduction

The objective of the EDAP analysis is to assess all core aspects of data quality, which includes geometric calibration, against the sensor and product data requirements or specifications, using the sample of products provided.

This section is dedicated to the analysis of geometry, and there are the following four accuracy assessments performed: absolute and relative geolocation accuracy, temporal geolocation accuracy and interband registration accuracy.

4.3.3 Absolute Geolocation Accuracy

4.3.3.1 Methods

The absolute geolocation accuracy is assessed for Level 3A products (OrthoTile). The approach consists of using SPOT-5 as a reference. Due to the GSD of the SuperDove image, it is not possible to identify well-defined GCPs measured in the field (GPS campaign). Rather, the approach has been to qualify the raster reference (SPOT-5) with the GCPs collected in the field, and then use the SPOT-5 raster to assess the accuracy of the SuperDove image.

RD-10 gives some information on the *a priori* geolocation performance of SPOT-5 data. The input SPOT-5 image was delivered as free from systematic errors and as free from non-systematic errors (due to terrain relief). The absolute accuracy of this data, assessed by means of the GCP set previously discussed, is estimated to be within 2.5 m (RMSE). This assessment showed that the precision of the SPOT-5 image is very good; the main contributor to lowered accuracy being actually a systematic bias of about 1.5 m. This information is of importance when analysing geometric registration errors between SPOT-5 and the SuperDove image.

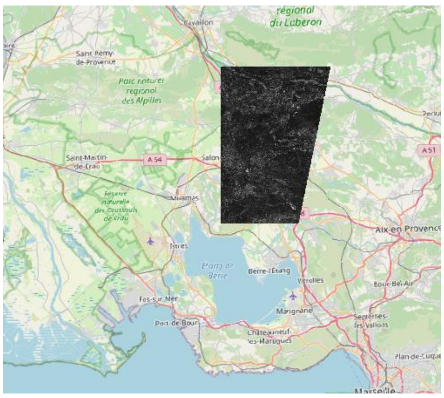
Before comparing with SPOT-5 red-band data, red band (Band 3) images from the following SuperDove products were isolated:

- 3427705_3159222_2020-05-25_2271_BGREN_Analytic [PSD.15]
- 3427705_3159221_2020-05-25_2271_BGREN_Analytic [PSD 16]
- 3427705_3159121_2020-05-25_2271_BGREN_Analytic [PSD.17]

The SuperDove orthotile image extent is relatively small, so to widen the geometry over a full image swath, the products above, from the same time (25 May 2020) and the same satellite (2271), were merged and converted from 16-bit to 8-bit quantification (stretching).

Figure 4-9 shows the footprints of the three individual products.

Figure 4-10 shows the SPOT-5 reference image (larger tile) with the merged SuperDove product superimposed.

PSD.15	

PSD.16	
PSD.17	

Figure 4-9: The three separate products contributing to the merged SuperDove image.

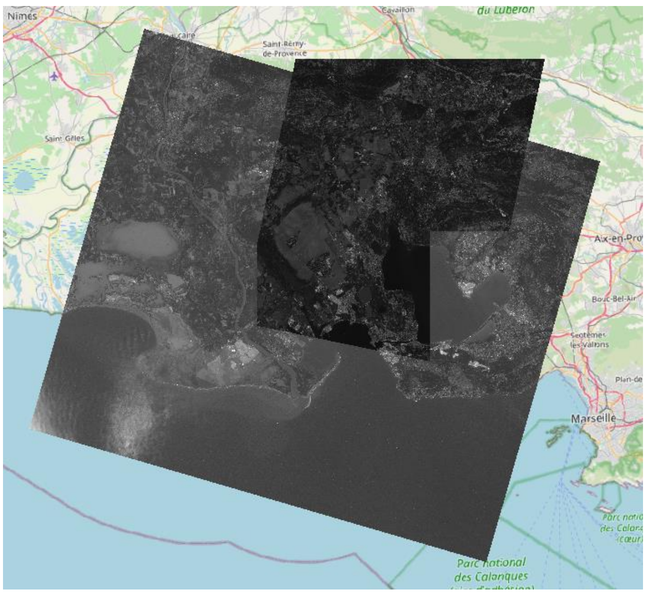


Figure 4-10: SPOT-5 reference image (large tile) with the merged SuperDove image superimposed.

4.3.3.2 Results

Table 4-7 displays the statistical results from intensity-based image matching at a 95% confidence level. The results show that the SuperDove RMSE is within the accuracy stated in the Product Specification [RD-3].

Figure 4-11 shows the 95% confidence analysis results.

Table 4-7: Image-matching statistics at 95% confidence levels for the merged SuperDove product against the SPOT-5 reference image

Parameter	Confidence level
	95%
Total valid pixels	16353
Number of matched pixels	1059
Mean Easting error (m)	-3.1
Mean Northing error (m)	-2.7
Easting error standard deviation (m)	5.8
Northing error standard deviation (m)	5.3
Circular Error @90 (m)	13.7
Easting RMSE (m)	6.6
Northing RMSE (m)	5.9
RMSE (m)	**8.9**
Planet stated RMSE (m)	<10

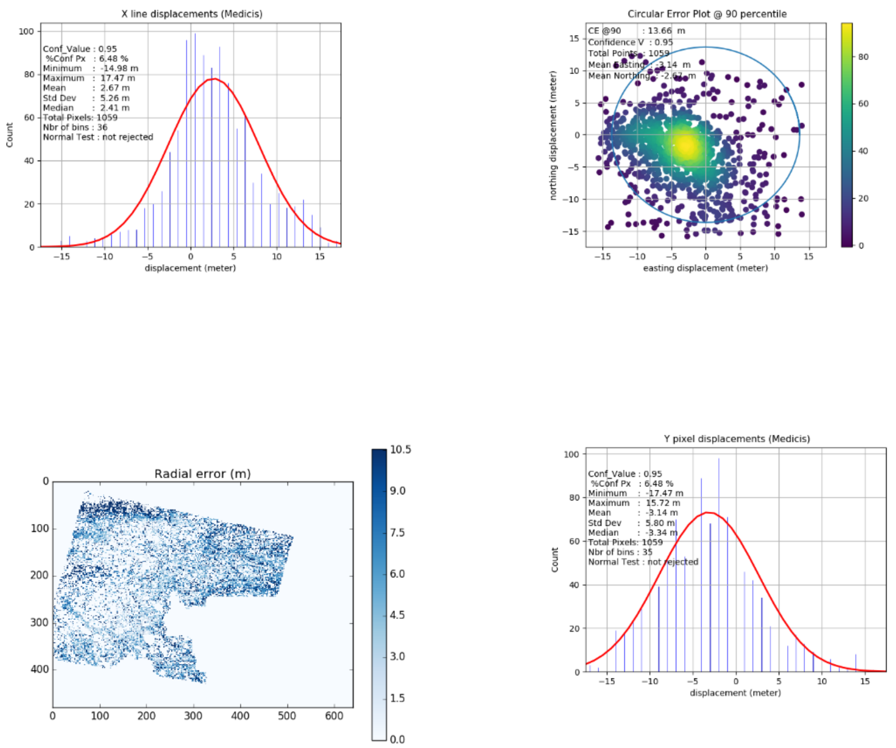


Figure 4-11: Image-matching results at a 95% confidence level. Top left: Northing displacements; top right: Circular Error; bottom left: Radial error; Bottom right: Easting displacements.

The results show:

1. The mean easting and northing differences are ~3 m, which is of the order of one SuperDove pixel.
2. The RMSE is 8.9 m (not accounting for SPOT-5 accuracy) and so is in within that defined by Planet.
3. Large differences in the top left corner in the radial error results can likely be attributed to the natural terrain of the Parc Naturel Regional des Alpilles.

4.3.4 Relative Geolocation Accuracy

4.3.4.1 Methods

This method was introduced as a way of generating a quick and early assessment of SuperDove geolocation when compared to an existing basemap. It is a qualitative assessment.

SuperDove band images were imprinted with a checkerboard pattern (of image and black/transparent squares) so that the resulting image could be overlaid on an independent basemap using QGIS. Use of available QGIS transparency functions then enabled the viewing and matching of permanent structures, e.g. roads and bridges, from each set of data. Care was taken to view at the applicable scale for SuperDove data (1:10,000).

The independent basemap used was Bing Maps (Bing Aerial subset) available from the OpenLayers Plug-In on QGIS.

Grey-scale imagery is SuperDove and colour imagery is Bing Maps. Views over Wellington (South Africa) and La Crau (France) are shown.

4.3.4.2 Results

4.3.4.2.1 PSD.11

Figure 4-12 and Figure 4-13 show the relative geolocation for bands 1 and 2 of Product PSD.11 over Wellington, South Africa.

The continuation of the roads and the sports pitch lines show a good relative geolocation between SuperDove and the underlying image from Bing Maps, especially in the vertical checkerboard direction. It may be that the horizontal placing is a little less coincident (see red, circled areas in Figure 4-12).

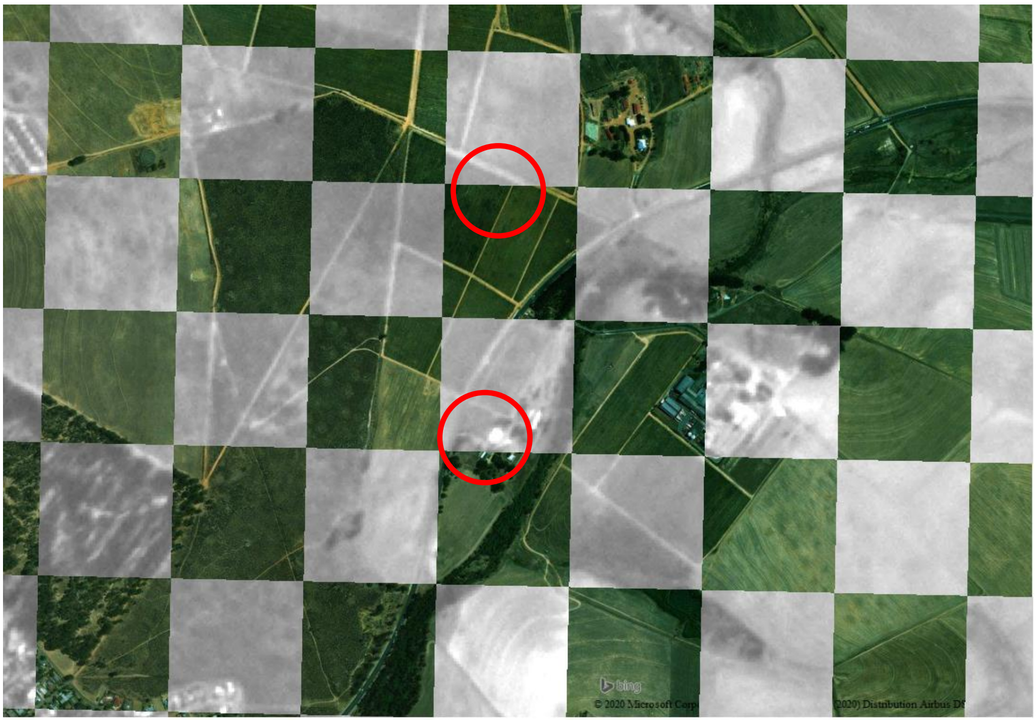


Figure 4-12: PSD.11 Blue band 1 checkerboard geolocation over roads and sports pitches near Wellington, South Africa.

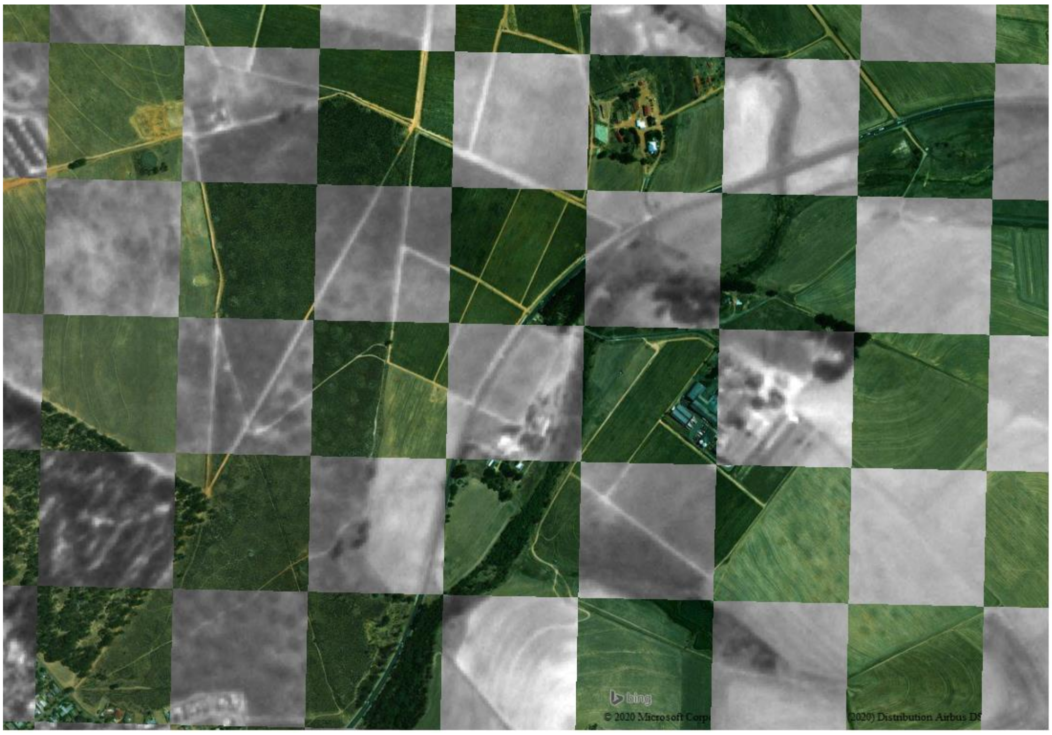


Figure 4-13: PSD.11 Green band 2 checkerboard geolocation over roads and sports pitches near Wellington, South Africa.

4.3.4.2.2 PSD.16

Figure 4-14 and Figure 4-15 show the relative geolocation for bands 3 and 5 for Product PSD.16 over La Crau, France.

The continuation of the motorways and the junction structure show a good relative geolocation between SuperDove and the underlying image from Bing Maps. The field boundaries also show good agreement.

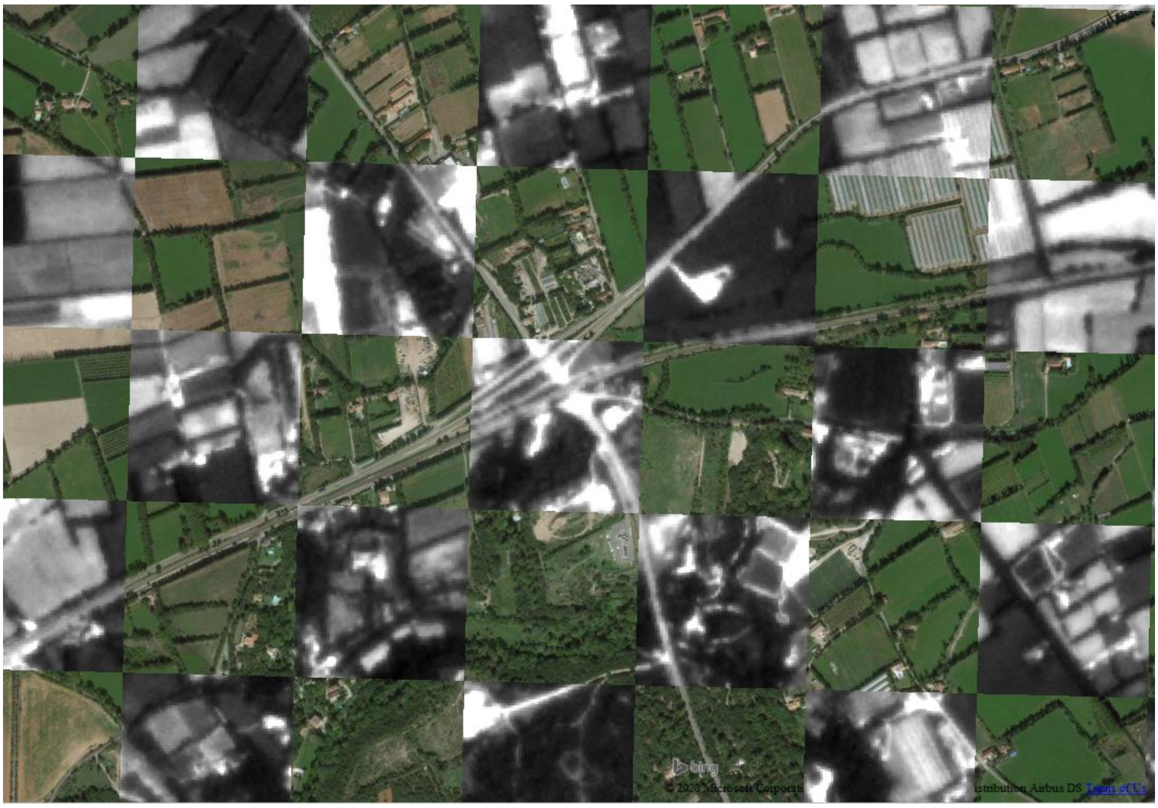


Figure 4-14: PSD.16 Red band 3 checkerboard geolocation over a motorway junction near La Crau.

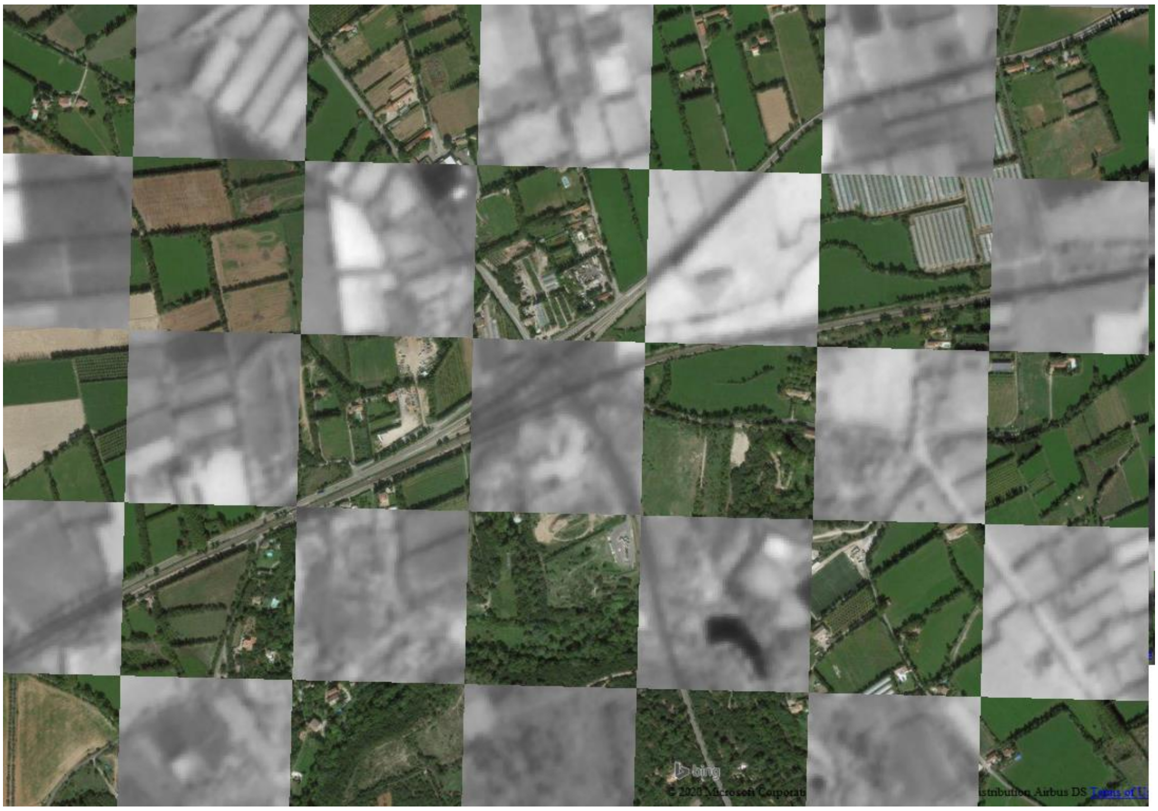


Figure 4-15: PSD.16 NIR band 5 checkerboard geolocation over a motorway junction near La Crau.

4.3.5 Temporal Geolocation Accuracy

4.3.5.1 Methods

Three Level 3A products (OrthoTile) over La Crau were inspected for the temporal assessment. The dates analysed were:

- 4 April 2020
- 25 April 2020
- 18 May 2020

Near infrared (NIR, Band 5) images from the SuperDove products were converted from 16-bit to 8-bit data, and compared with each other in turn. The products assessed are given below:

- 3289167_3159222_2020-04-04_2259_BGREN_Analytic [PSD.6]
- 3346039_3159222_2020-04-25_2263_BGREN_Analytic [PSD.9]
- 3407231_3159222_2020-05-18_2277_BGREN_Analytic [PSD.13]

Green figures are the relevant product date; orange figures give the satellite number, so it can be seen that the assessment is also between different satellites. The physical reality of the SuperDove flock and requirement for clear-sky analysis means that temporal analysis of only one satellite would not be realistic to achieve.

4.3.5.2 Results

Table 4-7 displays the statistical results from the intensity-based image-matching, at 95% confidence level, for the three products.

Table 4-8: Temporal Geolocation Accuracy: Image-matching (CL@95%)

Parameter	Product		
	PSD.6 vs PSD.9 21 days	PSD.6 vs PSD.13 44 days	PSD.9 vs PSD.13 23 days
Total valid pixels	14233	12174	14845
Number of matched pixels	5403	3272	5914
Mean Easting error (m)	-2.5	-1.5	1.1
Mean Northing error (m)	5.5	4.1	0.5
Easting error STD (m)	5.0	5.1	5.1
Northing error STD (m)	6.3	7.8	5.3
Circular Error @90 (m)	14.5	15.2	11.7
Easting RMSE (m)	5.6	5.3	5.2
Northing RMSE (m)	8.4	8.8	5.3
RMSE (m)	**10.1**	**10.3**	**7.5**

For the temporal analysis, viewing with different satellites, the following can be noted:

1. The mean easting errors are sub-pixel for all product-pairs.
2. The mean northing errors are of the order of one to two pixels for the first two product-pairs in Table 4-7, while for PSD.9 vs PSD.13 they are sub-pixel. Therefore, there is some inconsistency between satellites.
3. The RMSE for the temporal product-pair comparisons is of the order of 10 m, however PSD.9 and PSD.13 show better agreement at 7.5 m. This indicates that there may be an issue with PSD.6.

The potential issue with PSD.6 was investigated by performing an image-matching comparison with SPOT-5 reference data. Due to the smaller common area, image-matching at a 90% confidence level was carried out. Results are shown in Table 4-9, and the circular error plot is given in Figure 4-16.

Table 4-9: Image-matching statistics at CL@90% for PSD.6 against the SPOT-5 reference image.

Parameter	PSD.6 vs SPOT-5
Total valid pixels	5905

Parameter	PSD.6 vs SPOT-5
Number of matched pixels	1272
Mean Easting error (m)	-0.7
Mean Northing error (m)	-0.9
Easting error standard deviation (m)	6.2
Northing error standard deviation (m)	5.6
Circular Error @90 (m)	13.3
Easting RMSE (m)	6.2
Northing RMSE (m)	5.7
RMSE (m)	**8.4**
Planet stated RMSE (m)	< 10

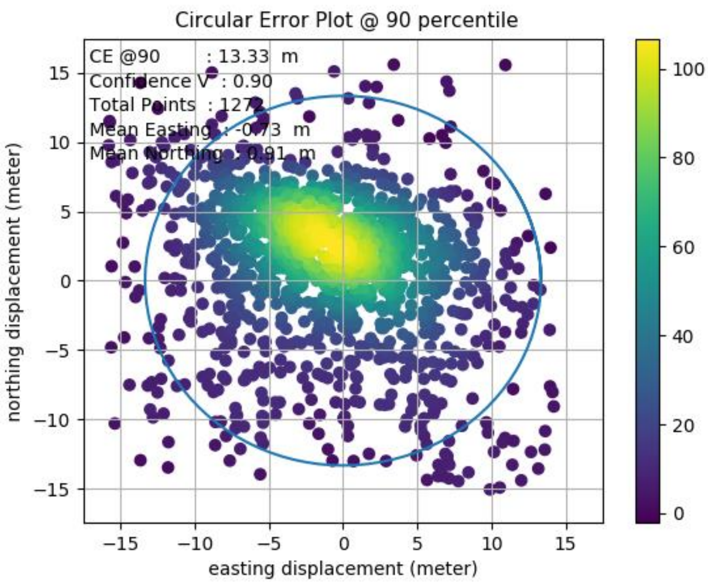


Figure 4-16: Circular Error plot for PSD.6 vs SPOT-5 at 90% confidence level.

The results for PSD.6 when image matched against SPOT-5 do not show any significant degradation from the comparison of the merged product (Section 4.3.3) or against the Planet product specification. On this basis, we may state that PSD.6 does not display any particular anomalies, rather we could say that PSD.9 and PSD.13 are well harmonised.

4.3.6 Interband Registration Accuracy

4.3.6.1 Methods

The interband registration accuracy assessment is intended to analyse the consistency of the registration between different bands within one product. The product analysed was from a La Crau product:

- 3427705_3159221_2020-05-25_2271_BGREN_Analytic [PSD.16]

The intensity-based image-matching algorithm is applied to each band pair (consecutive bands): for any pixel location in the image space, a displacement, D, in both line (y) / pixel (x) direction is computed.

In addition to the above, the error budget is calculated, and is based on the rule that per pixel displacement errors are transitive across all band twins. By summing displacement for the twins (B, G), (G, R), (R, RE), (RE, N), (N, B), the result is in the same order of displacement for the twin (B, N), as shown in the equation below.

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

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 image-matching, the error budget of the method is computed.

With reference to the DOVE-R study [RD-7], the La Crau site is an appropriate site for computing interband registration; one product over this site was analysed.

4.3.6.2 Results

Table 4-10 displays the statistical results from the image-matching, at a 95% confidence level, for the bands of PSD.16.

As given in the activity description sheet, the interband registration accuracy claimed by the data provider depends on the band pair. We did not assess the accuracy of all band pairs. It is expected that the accuracy results found are below Planet's Mean RMSE + STD RMSE, which is also included in Table 4-10.

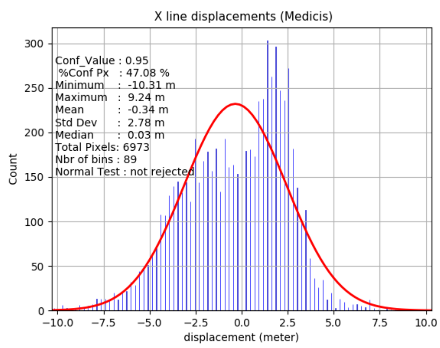
Table 4-10: Image-matching (CL@95%) Statistics for PSD.16 Bands

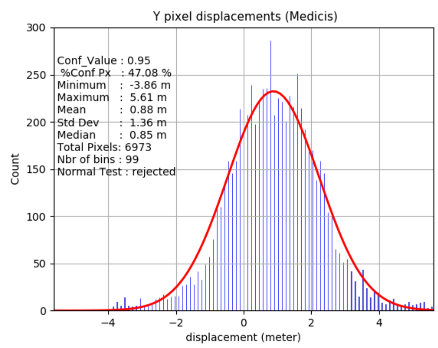
Parameter	Interband comparisons					
	Blue Band 1	Green Band 2	Red Band 3	Red-Edge Band 4	Near IR Band 5	
	Green Band 2	Red Band 3	Red-edge Band 4	NIR Band 5	Blue Band 1	
Total valid pixels	14810	15881	15846	8756	5208	
Number of matched pixels	6973	7534	6700	1935	535	**Error budget**
Mean Easting error (m)	0.9	-0.4	0.2	-1.4	1.6	-0.28
Mean Northing error (m)	-0.3	-0.6	-0.8	-1.2	1.8	0.33
Easting error STD (m)	1.4	1.2	1.9	5.5	6.3	

Parameter	Interband comparisons				
	Blue Band 1	Green Band 2	Red Band 3	Red-Edge Band 4	Near IR Band 5
	Green Band 2	Red Band 3	Red-edge Band 4	NIR Band 5	Blue Band 1
Northing error STD (m)	2.3	2.1	3.2	5.2	6.3
Circular Error @90 (m)	4.9	3.7	5.9	13.5	14.9
Easting RMSE (m)	1.7	1.3	1.9	5.7	6.5
Northing RMSE (m)	2.3	2.2	3.3	5.3	6.6
RMSE (m)	**2.9**	**2.5**	**3.8**	**7.8**	**9.2**
Planet in-flight RMSE (Mean / STD) [RD-11]	3.0 / 2.6	2.4 / 1.8	3.0 / 2.5	3.4 / 2.0	5.2 / 3.8

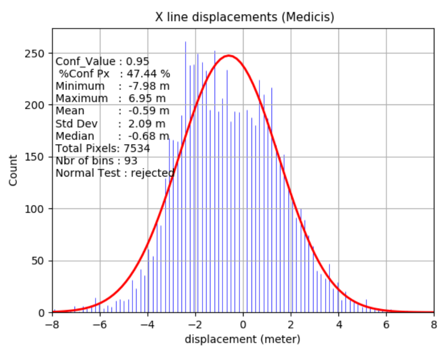
Figure 4-17 shows the statistical distribution of errors for the band pairs. The distributions are largely normal, however there is an indication that the northing in-line error (x line displacement) is somewhat bi-modal in the comparisons that involve the blue band.

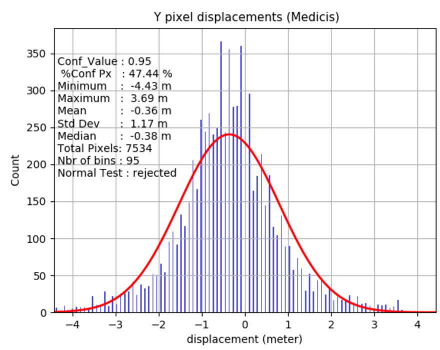
BLUE / GREEN





GREEN / RED





RED / RED-EDGE

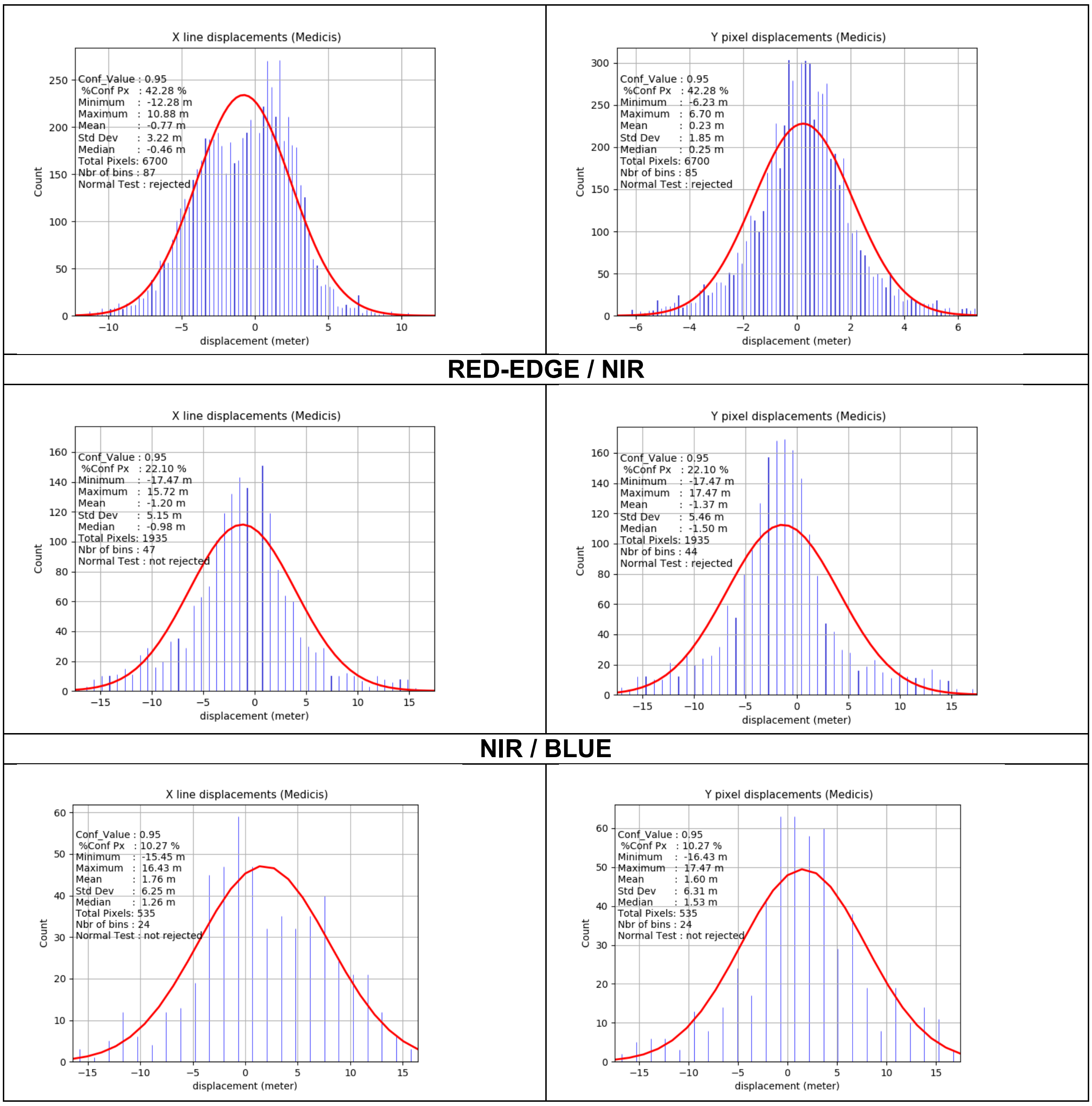


Figure 4-17: Interband geolocation accuracy: histograms of displacement errors. Left: northing in-line direction (X); Right: easting in-pixel direction (Y).

For the interband analysis, the following can be noted:

1. Consistent image-matching between the blue, green and red bands can be seen, with RMSE ~3 m.
2. The larger GSDs of the red-edge and NIR bands show up in the image-matching statistics.

4.3.7 Results / Conclusions

With regard to the SuperDove OrthoTile products, [RD-3] states that the GSD for the five-band product is 3 – 6 m (3.7 m average at reference altitude 475 km). The positional accuracy is given as < 10 m RMSE.

Absolute geolocation accuracy was undertaken, using image-matching with SPOT-5 data as a reference. Results showed the RMSE to be slightly above the stated specification of 10 m. These results were supported by the relative geolocation accuracy (but can be some query as to whether the accuracy in the relative horizontal direction is not as good as in the relative vertical direction).

Temporal geometric accuracy using image matching between SuperDove products showed some variation between products. Mean errors were sometimes less than one pixel, but not always, however the RMSE ranged from 7.5 to 10.3 m. These results indicate some inconsistency between satellites.

Interband registration accuracy using image matching showed good agreement between blue, green and red bands, but some distancing for the red-edge and NIR bands. There is a signal of a bi-modal error distribution in the northing in-line pixel direction.

4.4 Radiometric Calibration Accuracy

4.4.1 Activity Description Sheet

Table 4-11: Activity Description Sheet: Absolute Radiometric Accuracy

Absolute Radiometric Accuracy
Inputs
PlanetScope SuperDove Level 3A OrthoTile Product(s) (listed in APPENDIX B): *La Crau: 3427705_3159221_2020-05-25_2271_BGREN_Analytic [PSD.16]* *Libya-4: 3356390_3452224_2020-04-29_2257_BGREN_Analytic [PSD.10]* *Libya-4: 3441792_3452224_2020-05-30_2271_BGREN_Analytic [PSD.4]* ***Sentinel-2 (S2) MSI Level 2A Product(s):*** *The S2 surface reflectance products are from observations performed during 2019 / 2020 and correspond to the MGRS tile 34RGS.* ***RadCalNet Data:*** *Information on RadCalNet can be found in [RD-13]. The following dataset was downloaded from the RadCalNet site at La Crau: LCFR01_2020_146_v03.02.output.*
Description
The scope is to estimate the absolute calibration with in flight method. *The absolute radiometric accuracy is assessed using a method (i.e. method 1) that compares RadCalNet TOA data and processed PlanetScope SuperDove TOA data (i.e. performing conversions from DN to TOA). Note Planet's product specification [RD-3] states "Analytic products are scaled to Top of Atmosphere Radiance. Validation of radiometric accuracy of the on-orbit calibration has been measured at 5% using vicarious collects in the Railroad Valley calibration site for PlanetScope products."* *Planet's Data Quality Report [RD-11] states the following radiometric accuracies, which have been validated against Sentinel-2A, Sentinel-2B and Landsat 8, for SuperDove:*

Absolute Radiometric Uncertainty: 7.5 % (B), 3.0 % (G), 4.6 % (R) and 8 % (N). (in-flight results obtained using high quantities of crossover data). *The absolute radiometric accuracy is assessed using another method (i.e. method 2) that compares Sentinel-2B (MSI) PICS Libya-4 TOA data with SuperDove TOA data.*
Outputs
The EDAP analysis provides the absolute calibration ratio for • SKS and RadCalNet (Method 1), • SKS and Sentinel-2 (Method 2) *An absolute calibration ratio Q is provided for each band, and is used to express a statistical linear relationship between an input SuperDove TOA reflectance and a reference TOA reflectance (using RadCalNet or Sentinel-2).* First method shows that the calibration accuracy is within 2% and the second method shows that the calibration accuracy is mostly within 5%. These outputs agree with *Product Specification (stated calibration accuracy is 5%).*

4.4.2 Introduction

The first method uses data from RadCalNet, an initiative of the Working Group on Calibration and Validation of CEOS [RD-13]. The RadCalNet service provides satellite operators with SI-traceable TOA spectrally resolved reflectances 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.

The second method uses PICS Libya-4 using Sentinel-2 as reference mission. This site is categorised as a “bright” site and is characterised by high reflectance in conjunction with low aerosol loading and a predominance of clear skies that reduces the impact of atmospheric errors.

The spectral bands of SuperDove and their comparison with Sentinel-2 bands are shown in APPENDIX C SuperDove Spectral Response (Figure 4-29).

4.4.3 RadCalNet Method (Method 1)

4.4.3.1 Method description

The method used for this exercise consists of different processing stages as shown in Figure 4-18.

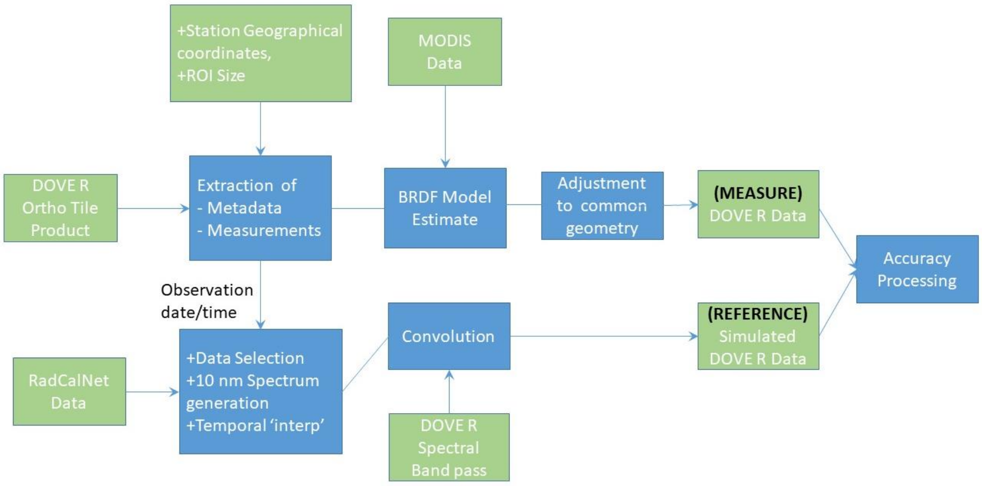


Figure 4-18: The workflow of absolute calibration using RadCalNet data.

These different processing stages can be summarised as follows:

- Extract multispectral TOA measurements from the SuperDove Level 3A 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 was tested for Dove-R [RD-7].
- Retrieve 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 SuperDove product. Therefore, temporal interpolation of data is performed to overcome this issue.
- Convolve the RadCalNet 10 nm TOA spectrum with the SuperDove spectral bandpass in order to get a reference measurement for each sensor spectral band.
- Adjust the SuperDove measurement to the RadCalNet geometry (nadir viewing and 0° Azimuth Angle), this transformation is based on the use of MODIS Albedo / BRDF products (MCD43) for what concerned the BRDF weights f_{iso} , f_{vol} , f_{geo} predicted at the exact observation date / time. The BRDF kernels considered observation geometries (sun, viewing) given in the product metadata with interpolation because the geographic location of the La Crau station in the scene does not necessarily correspond to the scene centre, image location to which related product metadata parameters are referring to.
- Compute the calibration ratio between BRDF Corrected SuperDove Mean TOA (over ROI) and RadCalNet TOA and compute the percent difference as follows:

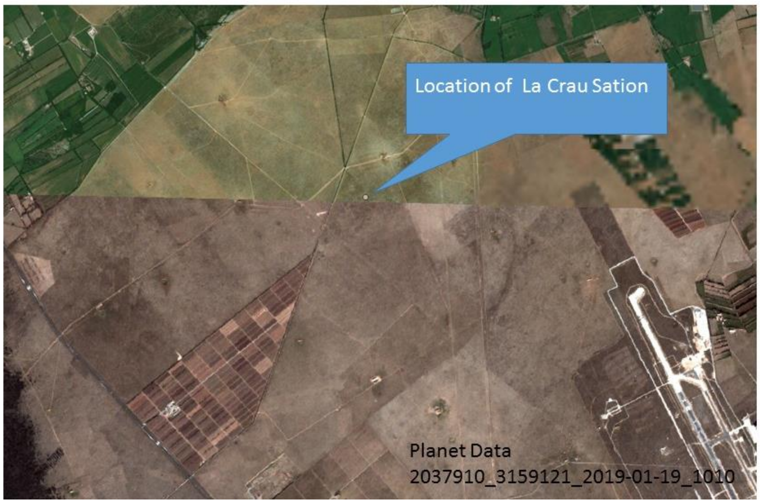
$$\%Difference = \frac{100 * (TOA\_Measure - TOA\_Reference)}{TOA\_Reference}$$

Where $TOA\_Measure$ is the measurement processed from the SuperDove product and $TOA\_Reference$ is the measurement processed from RadCalNet data.

Note that the method is also applied for the Sentinel 2B data for which the viewing angle is greater. As the calibration accuracy 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, by experience the BRDF characterisation remains valid in the context of this validation.

As detailed in [RD-6], 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 4-19.



La Crau station	
Latitude	43.558889
Longitude	4.864167
Altitude	20m
Characteristics	The RadCalNet top-of-atmosphere reflectance spectra are representative of a disk of 30 m radius

Figure 4-19 : RadCalNet La Crau Station Location

4.4.3.2 Results

Table 4-14 displays the TOA reflectances for SuperDove at the RadCalNet La Crau site, and the corresponding time-interpolated RadCalNet TOA values.

Table 4-12: TOA reflectances for SuperDove, RadCalNet

Data	TOA Reflectance				
	Blue	Green	Red	Red-Edge	NIR
La Crau, 25 May 2020					
SuperDove	0.1175	0.1178	0.1197	0.1532	0.2719
RadCalNet	0.1150	0.1183	0.1212	0.1560	0.2752

Table 4-15 shows the percentage difference in TOA reflectance for each SuperDove band against both RadCalnet.

Table 4-13: Calibration results for SuperDove vs RadCalNet.

Site / comparison	TOA Reflectance Difference (%)				
	Blue	Green	Red	Red-Edge	NIR
La Crau / RadCalNet 25 May 2020	2.2%	0.5%	1.2%	1.7%	1.2%
Planet in-flight [RD-11]	7.5%	3.0%	4.6%	N/A	8.0%

RadCalNet comparisons show the reflectance difference to be less than 2.2%.

4.4.4 PICS Method (Method 2)

4.4.4.1 Method description

The method used for this exercise consists of different processing stages as shown in Figure 4-20.

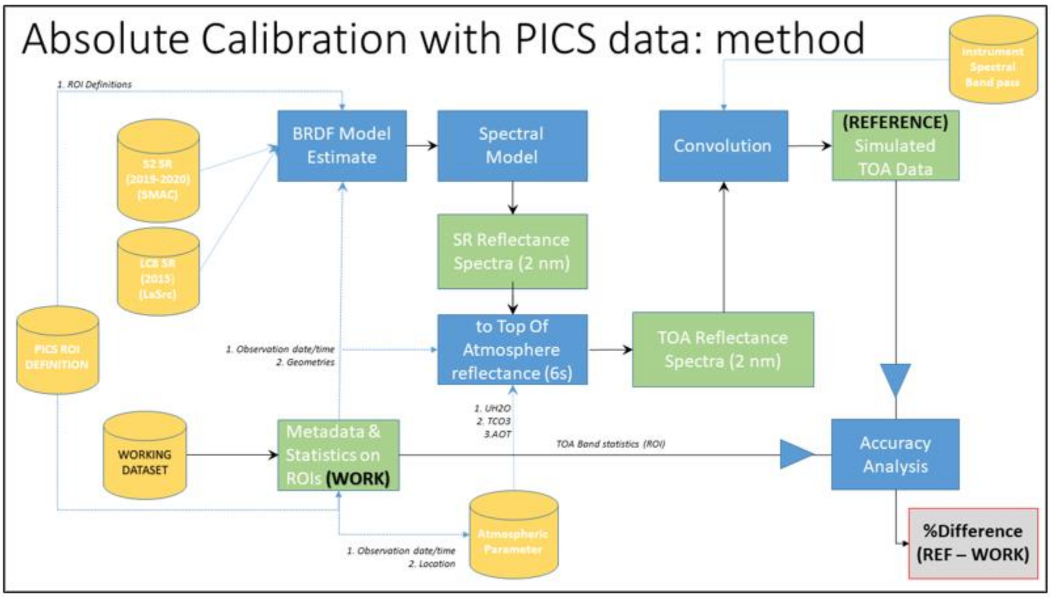


Figure 4-20: The workflow of absolute radiometric calibration using PICS data.

The method is based on two main processing stages, explained in the figure above:

- Estimate the reference top of atmosphere spectra by using the calibration reference (Sentinel-2 data)
- Use the reference spectra to simulate the reference measurements depending on the sensor to be evaluated.

The S2 surface reflectance products are from observations performed during 2019 / 2020 and correspond to the MGRS tile 34RGS.

The different processing stages can be summarised as follows:

1. Create Surface BOA reflectance time series (*S2 BOA TS*) at the ROI location
2. Assess S2 TS directional effects, output a model and correct data
3. Consider the observation geometry of SuperDove data, and estimate the BOA reflectance for each S2 band
4. Apply spectral interpolation of the BOA reflectance set given at each S2 band central wavelength (*BOA_Spectrum*), with a step of 2 nm
5. Considering the observation date, observation geometry (*OBS*), the location of the ROI, collect atmospheric parameters (*ATMS_P*) by using data from Copernicus Atmospheric Monitoring Service (CAMS)
6. Use *OBS, ATMS_P* and *BOA_Spectrum* as input of SIXS to generate the corresponding *TOA_Spectrum*

7. Assemble relevant SuperDove products
8. Extracting at the ROI location, the multi spectral TOA measurements from the SuperDove images ($TOA\_Measured$): image DN is converted to TOA by using the coefficient provided in the metadata
9. Convolve the *TOA_Spectrum, w*ith the SuperDove spectral response to obtain simulated TOA values at SuperDove band central wavelengths $TOA\_Simulated$
10. Compute the calibration ratio, Q, and calibration per cent difference between simulated and product TOA as follows:

$$\%Difference = \frac{100 * (TOA\_Simulated - TOA\_Measured)}{TOA\_Simulated}$$

Where:

- $TOA\_Measure$ is the measurement processed from the SuperDove product.
- $TOA\_Simulated$ is the measurement processed from PICS data (Sentinel-2A).

The SuperDove product footprint over the Libya-4 PICS site was used as the ROI. See Figure 4-7 (left, image tile).

4.4.4.2 Results

Table 4-14 also shows TOA reflectances at the Libya-4 site, along with Sentinel-2 values. Note the two SuperDove Libya products are from different satellites.

Table 4-14: TOA reflectances for SuperDove, Sentinel-2

Data	TOA Reflectance				
	Blue	Green	Red	Red-Edge	NIR
Libya, 29 April 2020					
SuperDove	0.2520	0.3503	0.4902	0.5087	0.6196
Sentinel-2	0.2650	0.3432	0.4779	0.4986	0.5891
Libya, 30 May 2020					
SuperDove	0.2487	0.3483	0.4938	0.5206	0.6263
Sentinel-2	0.2666	0.3468	0.4829	0.5062	0.5939

Figure 4-21 and Figure 4-22 display the simulations of the top of atmosphere reflectance values at the SuperDove central wavelengths for PSD.10 and PSD.4, respectively.

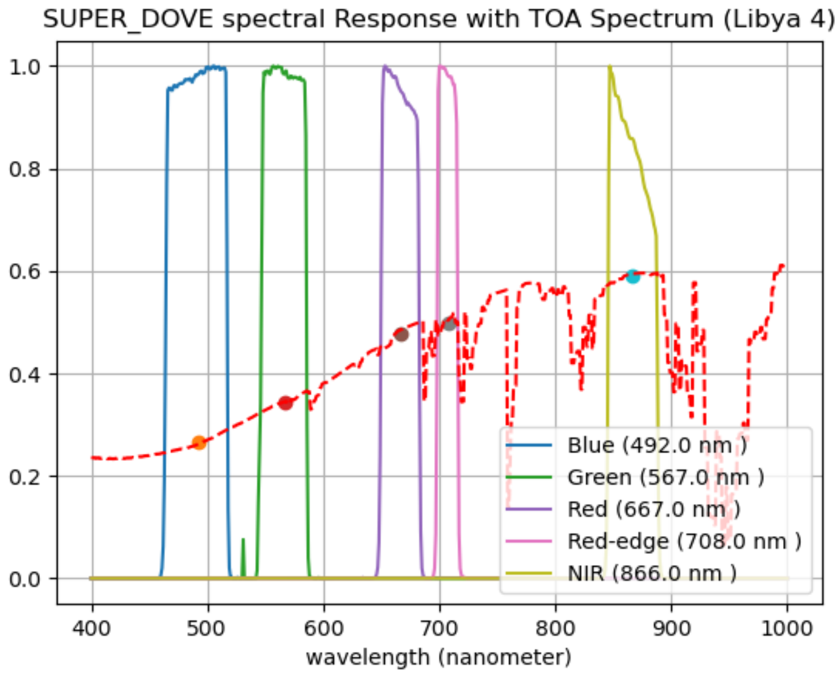


Figure 4-21: Simulation of the top of atmosphere reflectance values at the SuperDove central wavelengths for PSD.10.

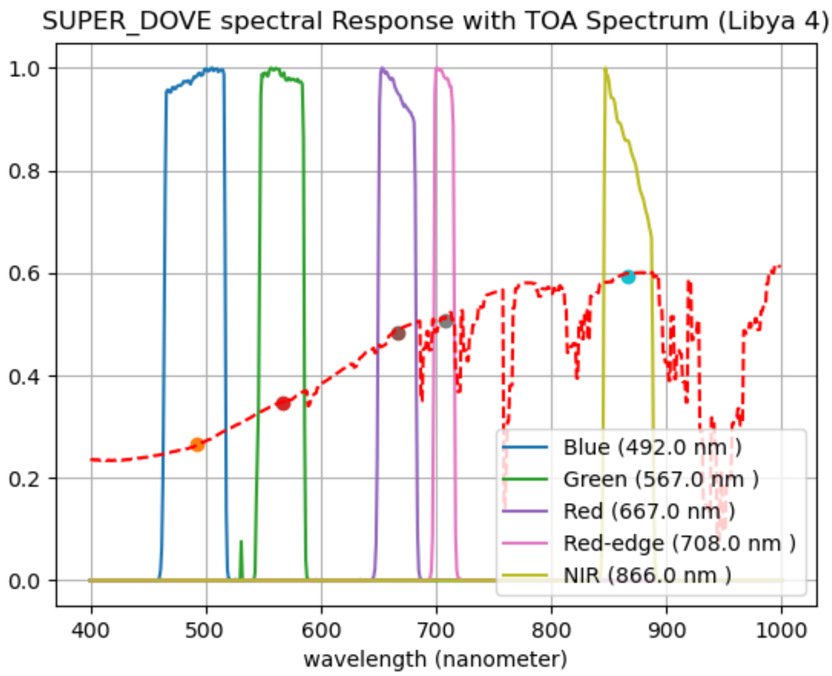


Figure 4-22: Simulation of the top of atmosphere reflectance values at the SuperDove central wavelengths for PSD.4.

Table 4-15 shows the percentage difference in TOA reflectance for each SuperDove band against both RadCalnet and Sentinel-2 over Libya. Sentinel-2 MSI data is considered to be accurate to 5% +/- 2% in May 2020 [RD-15].

Table 4-15: Calibration results for SuperDove vs RadCalNet and Sentinel-2. Planet in-flight values are also shown

Site / comparison	TOA Reflectance Difference (%)				
	Blue	Green	Red	Red-Edge	NIR
Libya / Sentinel-2 29 April 2020	4.9%	2.1%	2.6%	2.0%	5.2%
Libya / Sentinel-2 30 May 2020	6.7%	0.4%	2.3%	2.8%	5.5%
Planet in-flight [RD-11]	7.5%	3.0%	4.6%	N/A	8.0%

For the Libya PICS site comparisons, taking into account the accuracy of the method (within 5%) and based on a limited number of data, the analysis shows some variations between the two products, particularly in the blue and green bands.

4.4.5 Results / Conclusions

The radiometric calibration error of SuperDove data was estimated straightforwardly using *in-situ* data, recorded at the La Crau station as part of the RadCalNet network, as well as using comparisons with Sentinel-2 data obtained over the Libya-4 PICS site.

The product specification stated a reflectance error within 5%, which was achieved for the RadCalNet comparison. More detailed in-flight values within the Planet QC report [RD-11] showed separate errors for each band, rather than one generic value; the PICS site comparison results showed that the products were within these in-flight errors.

APPENDIX A PLANETSCOPE MISSION

SuperDove Mission Information

The PlanetScope constellation includes three generations of satellites: Dove (PS2), Dove-R (PS2.SD) and SuperDove (PSB.SD). The Planet product specification document is available online [RD-3], covering all PlanetScope satellites, and includes important information on the following:

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

Mission overview

Planet provides an initial section with the mission overview including the main satellite and sensor parameters; see Figure 4-23. Note that these sections are regularly updated and the information presented below may not be in the product specification when accessed later.

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 blue, green, 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	Blue: 457.5 - 522.5 nm Green: 542. - 577.5 Red: 650 - 680 Red-Edge: 697.5 - 712.5 NIR: 855 - 875
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		
Camera Dynamic Range	12-bit		

Figure 4-23: Example of PlanetScope document table. Mission overview.

Product type

Planet can provide users with L1B, L3B and L3A PlanetScope products and a description of these are detailed in Figure 4-24.

In the Planet product description document, the basic characteristics of each PlanetScope product type are listed and explained. Note the test dataset used for these assessments comprise the PlanetScope SuperDove Ortho Tile product (Level 3A) only and their product format consists of the following:

- Image file in tif format
  - 3427705_3159222_2020-05-25_2271_BGREN_Analytic.tif
- Data mask file in tif format
  - 3427705_3159222_2020-05-25_2271_udm2.tif
- Metadata file in XML format
  - 3427705_3159222_2020-05-25_2271_BGREN_Analytic_metadata.xml

Each file is standard and easy to read with appropriate viewers.

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

Figure 4-24: PlanetScope product type descriptions.

The product metadata contents are explained within the Product Specification, but note that its html <gsd> parameter is fixed to 3.125 m, denoting the pixel size, rather than the approximate GSD of each of the bands, or even the highlighted average (3.7 m). As such, the metadata contents can be not specific to the requirements of any band or product.

Notably, Planet SuperDove include a Usable Data Mask (**UDM2**) with 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 summarises 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**).

Data delivery options

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

SuperDove Product Information

Table 4-16 displays the information available in the product metadata. The product xml contains more information (see [RD-3]).

Table 4-16: Product Information

Product Details	
Product Name	*PlanetScope Basic Scene Product (Level 1B)* *PlanetScope Ortho Scene Product (Level 3B)* *PlanetScope Ortho Tile Product (Level 3A)*
Sensor Name	*PlanetScope – SuperDove (PSB.SD)*
Sensor Type	*Optical MultiSpectral (VNIR)*
Mission Type	*Flock*
Mission Orbit	*LEO-SSO*
Product Version Number	*Planet Standard product version 1.0*
Processor Name / Version	*CMO Patch Processor / 4.1.4*
Product ID	*<CatalogueID>_<TileID>_<AcquisitionDate>_<SatelliteID>* *Example: 3427705_3159221_2020-05-25_2271*
Processing level of product	*Level 1B / Level 3B / Level 3A*
Measured Quantity Name	*Digital number to* • *Radiance* • *Top of Atmosphere Reflectance (SI)*
Spatial Resolution	*Detector Pitch is 5.5 µm* *Ground Spatial Resolution of the image (projection of the detector field of view over the ground surface) depends on the satellite height and pointing and is 3.7 m for SuperDove products considered here (5-band only).* *The pixel spacing of the Level 3 image (orthorectified product) grid is 3.125 m.*
Spatial Coverage	*As indicated in the product metadata:* *Image Frame: 8880 pixels / 5280 lines (Level 1B).* *Image Ortho Tile: 8000 pixels / 8000 lines (Level 3A).*
Satellite / Sun angles configuration	*These parameters are reported in the XML metadata and are given at the scene centre.*
Orbit Type	*SSO Ascending / Descending Orbit*
Point of Contact	*www.planet.com*
License	*20160101 - Inc - Single User* *https://assets.planet.com/docs/20160101_Inc_SingleUser.txt*
Product Abstract	*A summary of resource is provided in the beginning of metadata part.*

SuperDove Usable data mask information

Figure 4-25 and Figure 4-26 display the information available in the usable data mask (UDM2) and the unusable data mask (UDM), respectively.

UDM2 Bands

Band	Description	Pixel Value Range	Interpretation
Band 1	Clear map	[0, 1]	0: not clear, 1: clear
Band 2	Snow map	[0, 1]	0: no snow or ice, 1: snow or ice
Band 3	Shadow map	[0, 1]	0: no shadow, 1: shadow
Band 4	Light haze map	[0, 1]	0: no light haze, 1: light haze
Band 5	Heavy haze map	[0, 1]	0: no heavy haze, 1: heavy haze
Band 6	Cloud map	[0, 1]	0: no cloud, 1: cloud
Band 7	Confidence map	[0-100]	percentage value: per-pixel algorithmic confidence in classification
Band 8	Unusable pixels	--	Equivalent to the `UDM` asset: see Planet's Imagery Specification for complete details

Figure 4-25: The usable data mask (udm2) bands for SuperDove.

- Bit 0: Identifies whether the area contains blackfill in all bands (this area was not imaged). A value of "1" indicates blackfill.
- **Bit 1**: Identifies whether the area is cloud covered. A value of "1" indicates cloud coverage. Cloud detection is performed on a decimated version of the image (i.e. the browse image) and hence small clouds may be missed. Cloud areas are those that have pixel values in the assessed band (Red, NIR or Green) that are above a configurable threshold. This algorithm will:
  - Assess snow as cloud
  - Assess cloud shadow as cloud free
  - Assess haze as cloud free
- Bit 2: Identifies whether the area contains missing (lost during downlink) or suspect (contains down-link errors) data in band 1. A value of "1" indicates missing/suspect data. If the product does not include this band, the value is set to "0".
- Bit 3: Identifies whether the area contains missing (lost during downlink and hence blackfilled) or suspect (contains downlink errors) data in the band 2. A value of "1" indicates missing/suspect data. If the product does not include this band, the value is set to "0".
- Bit 4: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in the band 3. A value of "1" indicates missing/suspect data. If the product does not include this band, the value is set to "0".

- Bit 5: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in band 4. A value of "1" indicates missing/suspect data. If the product does not include this band, the value is set to "0".
- Bit 6: Identifies whether the area contains missing (lost during downlink) or suspect (contains downlink errors) data in band 5. A value of "1" indicates missing/suspect data. If the product does not include this band, the value is set to "0".
- Bit 7: Is currently set to "0".

Figure 4-26: The unusable data mask (udm), set as bits within Band 8 of the usable data mask (udm2).

Instrument Design for SuperDove

SuperDove is the third instrument in the SuperDove PlanetScope mission. Planet states (https://developers.planet.com/docs/data/sensors/) that the new PSB.SD (SuperDove) instrument comprises the next-generation "PSBlue" telescope with a larger 47-megapixel sensor and the same filter response as PS2.SD (Dove-R) in the Red, Green, Blue and NIR bands.

The SuperDove payload has been extended, giving an eight-band frame imager with butcher-block filter providing blue, green, red, red-edge, and NIR stripes; see Figure 4-27. The five spectral bands within the products tested in this analysis are stated as:

- Blue: 457.5 – 522.5 nm
- Green: 542. – 577.5 nm
- Red: 650 – 680 nm
- Red-Edge: 697.5 – 712.5 nm
- NIR: 855 – 875 nm

There is a larger sensor on the PSB.SD payload, meaning that the framing of scene products is larger in both directions when compared to Dove-R and Dove scene products.

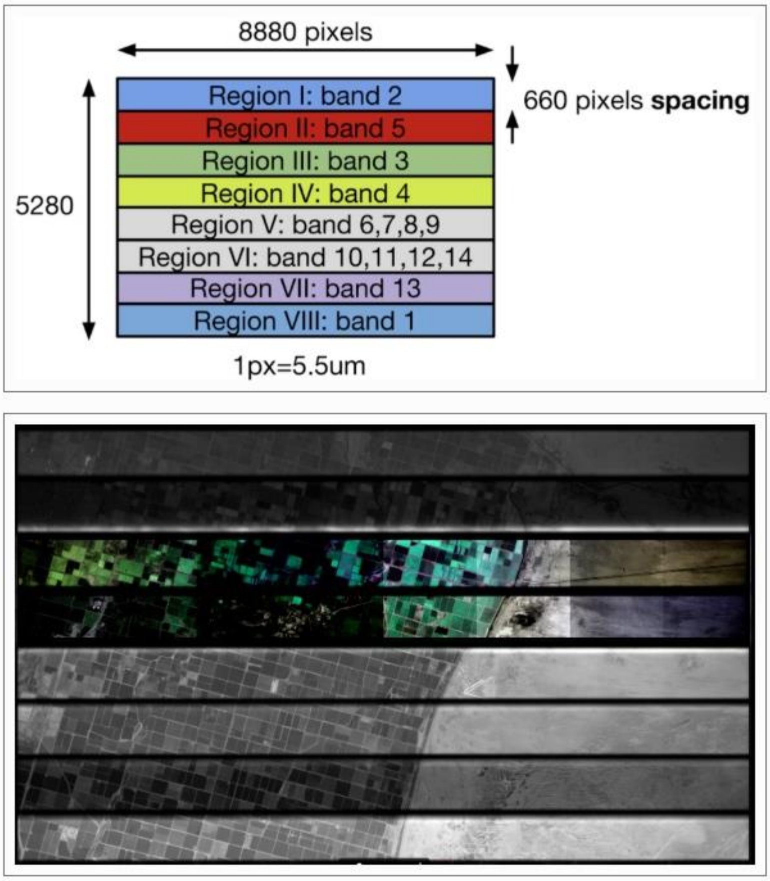


Figure 4-27: The PSB.SD instrument on board SuperDove (Planet documentation).

The PS2.SD (Dove-R) instrument configuration can be seen in Figure 4-28 for comparison. The PS2.SD filter is made of four individual pass-band filters that separate the light into each of the blue, green red and NIR spectral bands. Each frame acquired by the PS2.SD instrument comprises four stripes, one for each band. In order to generate a final image scene for each band, image stripes are stitched together.

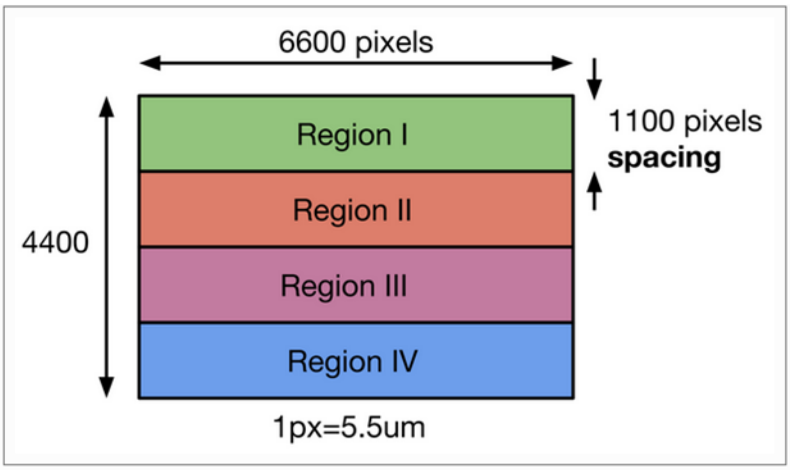


Figure 4-28: The PS2 SD instrument on board DOVE-R (Planet documentation), shown for comparison.

APPENDIX B SUPERDOVE TEST DATASET

The table below list the TDS used for this EDAP analysis. All products assessed were 'OrthoTile', Level 3A.

ID	Site	Used in section	Product_Identifier
PSD.1	Wellington	N/A	3122863_3423606_2020-02-10_2257
PSD.2	Piedmont	N/A	3297561_3259609_2020-04-07_2212
PSD.3	Piedmont	N/A	3297561_3259709_2020-04-07_2212
PSD.4	Libya	4.2.3,4.2.5, 4.4	3441792_3452224_2020-05-30_2271
PSD.5	Wellington	N/A	3272263_3423606_2020-03-29_2271
PSD.6	La Crau/Salon	4.3.4	3289167_3159222_2020-04-04_2259
PSD.7	La Crau/Salon	N/A	3308849_3159222_2020-04-11_2304
PSD.8	Wellington	N/A	3325034_3423606_2020-04-17_2275
PSD.9	La Crau/Salon	4.2.3, 4.3.4	3346039_3159222_2020-04-25_2263
PSD.10	Libya	4.2.5, 4.4	3356390_3452224_2020-04-29_2257
PSD.11	Wellington	4.3.4	3381931_3423606_2020-05-09_2277
PSD.12	Wellington	N/A	3404200_3423606_2020-05-17_2257
PSD.13	La Crau/Salon	4.3.4	3407231_3159222_2020-05-18_2277
PSD.14	La Crau	4.2.3	3407231_3159121_2020-05-18_2277
PSD.15	La Crau/Salon	4.3.3	3427705_3159222_2020-05-25_2271
PSD.16	La Crau	4.3.3, 4.3.4, 4.3.6, 4.4	3427705_3159221_2020-05-25_2271
PSD.17	La Crau	4.3.3	3427705_3159121_2020-05-25_2271
PSD.18	Piedmont	N/A	3462790_3259609_2020-06-06_2257
PSD.19	Piedmont	4.3.3	3462790_3259709_2020-06-06_2257
PSD.20	Maricopa	4.2.6	3699011_1254112_2020-09-03_2271
PSD.21	Maricopa	4.2.6	3699011_1254113_2020-09-03_2271

APPENDIX C SUPERDOVE SPECTRAL RESPONSE

Information on spectral bands and comparison with Sentinel-2 imagery is given in Figure 4-29.

Spectral response information was taken from https://developers.planet.com/docs/data/sensors/ on 10/6/2020, and plotted for ease of viewing in Figure 4-30.

The PSB.SD payloads extend on this capability so that in addition to the four bands that are identical to the PS2.SD spectral bands above (Red, Green II, Blue and NIR), there is also an additional band. Specifically, Red Edge, which is meant to be interoperable with Sentinel-2 band 5. Please refer to the table below in this section to see absorption range for each band.

Band	Name	Wavelength (fwhm)	Interoperable with Sentinel-2
1	Blue	490 (50)	Yes - with Sentinel-2 band 2
2	Green II	565 (36)	Yes - with Sentinel-2 band 3
3	Red	665 (31)	Yes - with Sentinel-2 band 4
4	Red edge I	705 (15)	Yes - with Sentinel-2 band 5
5	NIR	865 (40)	Yes - with Sentinel-2 band 8a

Please refer to this CSV for spectral response within absorption ranges.

Figure 4-29: SuperDove spectral bands and wavelengths.

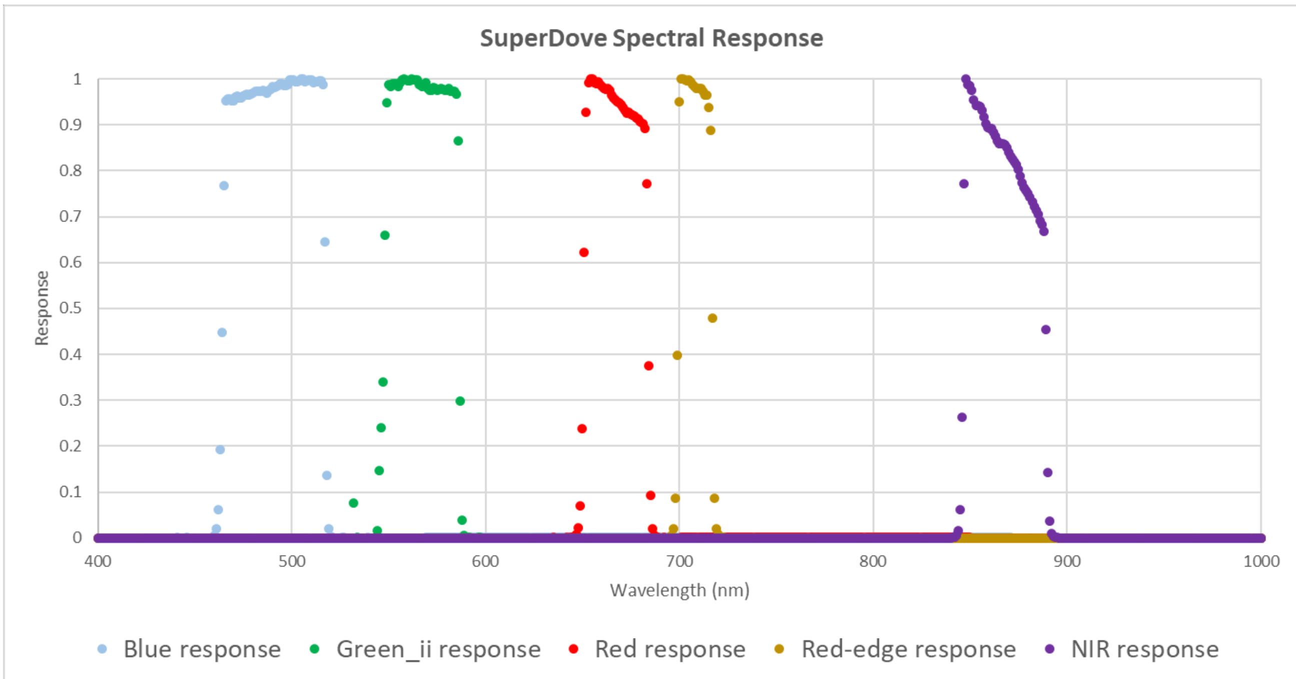


Figure 4-30: SuperDove Spectral Response plots for the five bands commonly used in this analysis.

Band	Name	Notes	Wavelength (fwhm)	spatial sampling	GSD (m)	L_{ref} (W sr-^{1}um^{-1} m^{-2})	SNR @ L_{ref} (t=10ms)*
1	Coastal Blue	core visible bands	443 (20)	0.25x	12	130	193
2	Blue		490 (50)	1x	3	130	170
3	Green I		531 (36)	1x	3	130	150
4	Green II		565 (36)	1x	3	130	154
5	Red		665 (31)	1x	3	130	138
6	Yellow	sediments, PC	610 (20)	1x	6	70	63
10	Red edge I	important for data compatibility with Sentinel-2	705 (15)	0.5x	6	70	57
13	NIR	narrow NIR	865 (40)	0.5x	6	130	137

Figure 4-31: SuperDove spatial sampling, GSD and SNR information from Planet [RD-8].

[END OF DOCUMENT]