PROBA-V COLLECTION 2 PRODUCTS USER MANUAL

v1.0

Reference: *PROBA-V Products User Manual Collection 2*
Author(s): Erwin Wolters, Carolien Toté, Wouter Dierckx, Martine Paepen and Else Swinnen
Date: 27/03/2023

DOCUMENT CONTROL

Signatures

Authors	Erwin Wolters, Carolien Toté, Wouter Dierckx, Martine Paepen and Else Swinnen
Reviewers	Dennis Clarijs
Approvers	Dennis Clarijs (VITO), Fabrizio Niro (ESA), Roberto Biasutti (ESA)
Issuing authority	VITO, authorized by ESA

Change record

Release	Date	Updates	Approved by
Collection 2, v1.0	27/03/2022	Major updates with regard to Collection 2 reprocessing: • Short overview of the algorithms changes and references to detailed documention added • Included information on the CEOS-ARD metadata standard • Updated information on Product Data access.	Dennis Clarijs

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS

Acronym	Explanation
6S	Second Simulation of a Satellite Signal in the Solar Spectrum
AC	Atmospheric Correction
ACIX	Atmospheric Correction Intercomparison eXercise
ALE	Absolute Location Error
API	Application Programming Interface
AOT	Aerosol Optical Thickness
ArcGIS	Aeronautical Reconnaissance Coverage Geographic Information System
AU	Astronomical Unit
C1	Collection 1
C2	Collection 2
CARD4L	CEOS Analysis Ready Data for Land
CEOS	Committee on Earth Observation Satellites
CF	Climate and Forecast
CGS	Collaborative Ground Segment
CGLS	Copernicus Global Land Service
COG	Cloud Optimized Geotiff
CRS	Coordinate Reference System
DC	Dark Current
DCC	Deep Convective Clouds
DEM	Digital Elevation Model
DN	Digital Number Count
ECMWF	European Centre For Mid-Range Weather Forecasts
ENVI	Environment for Visualizing Images
EOS	Earth Observing System
ERDAS	Earth Resources Data Analysis System
ESA	European Space Agency
FCOVER	Fraction of green Vegetation Cover
FOV	Field of View
FWHM	Full Width at Half Maximum
GDAL	Geospatial Data Abstraction Layer
GeoTiff	Geospatial Tagged Image File Format
GIS	Geographic Information System
GLSDEM	Global Land Survey Digital Elevation Model
GNU	GNU's Not Unix
GUI	Graphical User Interface
GZIP	GNU Zip
HDF	Hierarchical Data Format
ICP	Instrument Calibration Parameters
IDL	Interactive Data Language
IGFOV	Instantaneous Geometric Field Of View
IQC	Image Quality Center
JSON	JavaScript Object Notation
LAI	Leaf Area Index
Lref	Top-of-Atmosphere Reference Irradiance
LSB	Least Significant Bit

LTDN	Local Time of Descending Node
MATLAB	MATrix LABoratory
MEP	Mission Exploitation Platform
MERRA-2	Modern-Era Retrospective analysis for Research and Applications, version 2
MLP	Multi-Layer Perceptron
MSB	Most Significant Bit
MVC	Maximum Value Composite
NASA	National Aeronautics and Space Administration
NDVI	Normalized Difference Vegetation Index
NetCDF	Network Common Data Form
NIR	Near-Infrared
NWP	Numerical Weather Prediction
OGC	Open Geospatial Consortium
OSCAR	Optical Sensor CAlibration with simulated Radiance
PROBA-V	Project for On-Board Autonomy - Vegetation
PV	Physical Value
QGIS	Quantum GIS
QWG	Quality Working Group
RoI	Region of Interest
RTM	Radiative Transfer Model
S1	1-day Synthesis Products
S10	10-day Synthesis Products
SAA	Solar Azimuth Angle
SLP	Sea Level Pressure
SMAC	Simplified Model for Atmospheric Correction
SNAP	Sentinel Application Platform
SNR	Signal-To-Noise Ratio
SPOT-VGT	Satellite Pour l'Observation de la Terre – Végétation
SRF	Spectral Response Function
SSH	Secure Shell
SWIR	Short-Wave Infrared
SZA	Solar Zenith Angle
SZIP	Shrink Zigzag Inline Package
TDS	Test Data Set
TOA	Top-Of-Atmosphere
TOC	Top-Of-Canopy
TOMS	Total Ozone Monitoring Spectrometer
USGS	United States Geological Survey
UTC	Universal Time Coordinate
VAA	Viewing Azimuth Angle
VM	Virtual Machine
VNIR	Visible and Near-InfraRed
VZA	Viewing Zenith Angle
WGS84	World Geodetic System 1984
WKT	Well-Known Text
WMS	Web Mapping Service
WMTS	Web Map Tile Service
WRS-2	Worldwide Reference System V2

1. Introduction

1.1. Document objectives

This document describes the PROBA-V mission and Collection 2 data. It describes the various PROBA-V processing levels, the applied algorithms for the Collection 2 full archive (October 2013 – June 2020) reprocessing, and the data product content. Finally, a new data dissemination channel, metadata standard, search catalogue are highlighted.

The PROBA-V Collection 2 reprocessing was performed to increase the data product quality with respect to the following topics:

- Radiometric calibration
- Cloud, cloud shadow, and snow/ice detection
- Atmospheric correction
- Harmonization of compositing for all product resolutions
- Data format update
- Data dissemination

1.2. Related sources of documentation

We have attempted to keep the document concise and comprehensible. Interested users on the various PROBA-V topics highlighted in this document are referred to the scientific publications presented in Table 1 below. Additionally, concise descriptions of the mission, the data products and access can be found on the VITO Remote Sensing Terrascope documentation portal.

Table 1: Reference documents

Document name	Major topics covered	Download location
Dierckx, W. et al. (2014). PROBA-V mission for global vegetation monitoring: standard products and image quality. *Int. J. Remote Sens*, 35, 2589 – 2614, doi: 10.1080/01431161.2014.883097	PROBA-V mission, data quality, data compression, cloud detection, spectral response in relation to SPOT-VGT	http://proba-v.vgt.vito.be/sites/default/files/dierckx_etal_2014.pdf
Sterckx, S., et al. (2014). The PROBA-V mission: image processing and calibration. *Int. J. Remote Sens.*, *35*(7), 2565 – 2588, doi: 10.1080/01431161.2014.883094	PROBA-V mission, detailed processing chain overview, radiometric and geometric calibration, product distribution	http://proba-v.vgt.vito.be/sites/default/files/sterckx_etal_2014.pdf
Francois, M., et al. (2014). The PROBA-V mission: The space segment. *Int. J. Remote Sensing*, 35, 2548 – 2564, doi:10.1080/01431161.2014.883098	PROBA-V flight segment, instrument design, technology payloads, geometry and radiometry	http://proba-v.vgt.vito.be/sites/default/files/francois_etal_2014.pdf

Table 2 lists the reference documentation for PROBA-V collection 2.

Table 2: Reference documentation for PROBA-V collection 2

Document ID	Document and link
PV C2 Algorithm Change Document	PROBA-V C2 Algorithm Change Document https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Algorithm_Change_Document.pdf
PV C2 Validation Report	Validation report of PROBA-V Collection 2 https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Evaluation.pdf
ATBD AC	Algorithm Theoretical Basis Document of the Atmospheric Correction of PROBA-V C2 https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Atmospheric_Correction_ATBD.pdf
VR AC	Validation report of the Atmospheric Correction of PROBA-V C2 https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Atmospheric_Correction_Validation_Report.pdf
ATBD PC	Algorithm Theoretical Basis Document of the Pixel Classification of PROBA-V C2 https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Cloud_Mask_ATBD.pdf
VR PC 1 km	Validation report of the Pixel Classification of PROBA-V C2 at 1 km https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Cloud_Mask_1km_Validation_Report.pdf
VR PC 300 m	Validation report of the Pixel Classification of PROBA-V C2 at 300 m https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Cloud_Mask_300m_Validation_Report.pdf
VR PC 100 m	Validation report of the Pixel Classification of PROBA-V C2 at 100 m https://proba-v.vgt.vito.be/sites/probavvgt/files/downloads/PROBA-V_C2_Cloud_Mask_100m_Validation_Report.pdf

Users can find the most recent updates on product quality and known issues on the PROBA-V Quality Website (http://proba-v.vgt.vito.be/en/quality/quality).

2. The PROBA-V mission

2.1. PROBA-V mission overview

The PROBA-V satellite was launched on 6 May 2013 and was designed to bridge the gap in space-borne vegetation measurements between SPOT-VGT (March 1998 – May 2014) and the Sentinel-3A and B satellites, launched on 16 February 2016 and 25 April 2018, respectively. The mission objective was to ensure continuity with the SPOT-VGT mission's heritage. PROBA-V had a platform performance (LTDN evolution, payload performance, etc.) well within the requirements beyond its 5 year designed lifetime. Therefore the operational mission was extended through June 2020, with a further extension into an experimental phase, including only observations over Europe and Africa, until 31 October 2021.

PROBA-V flies at an altitude of 820 km in a sun-synchronous orbit and had a local overpass time at launch of 10:45 h. Because the satellite has no onboard propellant, the overpass time gradually, but accelerating over time, decreased as a result of increased atmospheric drag. Figure 1 presents the Local Time of Descending Node (LTDN) evolution from launch through 16 September 2021.

The VEGETATION instrument has a Field Of View of 102°, resulting in a swath width of 2295 km. This swath width ensures a near-global daily coverage (90%), whereas total global coverage is achieved every 2 days. The central camera observes at 100 m nominal resolution, which covers a swath of about 517 km that ensures global coverage every 5 days.

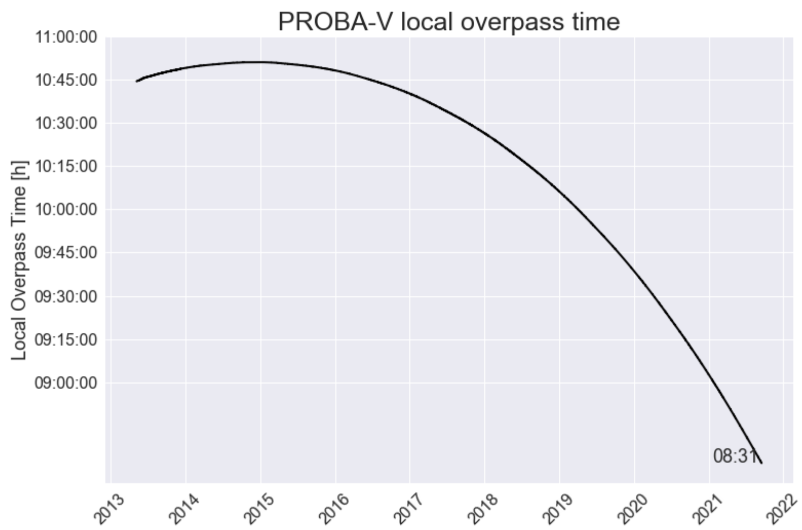

Figure 1: PROBA-V local overpass time evolution from 6 May 2013 (launch date) through 16 September 2021. The time indicates the last known LTDN

PROBA-V observes in four spectral bands: BLUE (centered at 0.463 µm), RED (0.655 µm), NIR (0.837 µm), and SWIR (1.603 µm). Observations are taken at resolutions between 100 and 180 m at nadir and up to 350 m and 660 m at the swath extremes for the VNIR and SWIR channels, respectively (Francois et al., 2014). Final PROBA-V products are disseminated at 100 m, 300 m, and 1 km resolution. The instrument and spectral characteristics will be explained in more detail in Section 2.2. The flight and payload characteristics are summarized in Table 3.

Table 3: PROBA-V payload and flight characteristics

Altitude [km]	819 – 827
Local overpass time at launch [h]	10:45
Inclination [°]	98.7
Daily coverage [%]	90 (100 for latitudes > ±35°)
Payload Mass [kg]	33.3
Payload Dimensions [m]	0.2 × 0.8 × 0.35
Instantaneous geometric field of view (IGFOV) [m]	96.9 for VNIR (BLUE, RED, NIR), 193.8 for SWIR

2.2. Instrument characteristics

The optical design of PROBA-V consists of three cameras. Each camera has two focal planes, one for the short wave infrared (SWIR) and one for the visible and near-infrared (VNIR) bands. The VNIR detector consists of four lines of 5,200 pixels. Three spectral bands were implemented, comparable with SPOT-VGT: BLUE, RED, and NIR. The SWIR detector is a linear array composed of three staggered detectors of 1,024 pixels. Each used detector line is labelled as a strip. Therefore each camera has 6 strips. The instrument plane layout is shown in Figure 2.

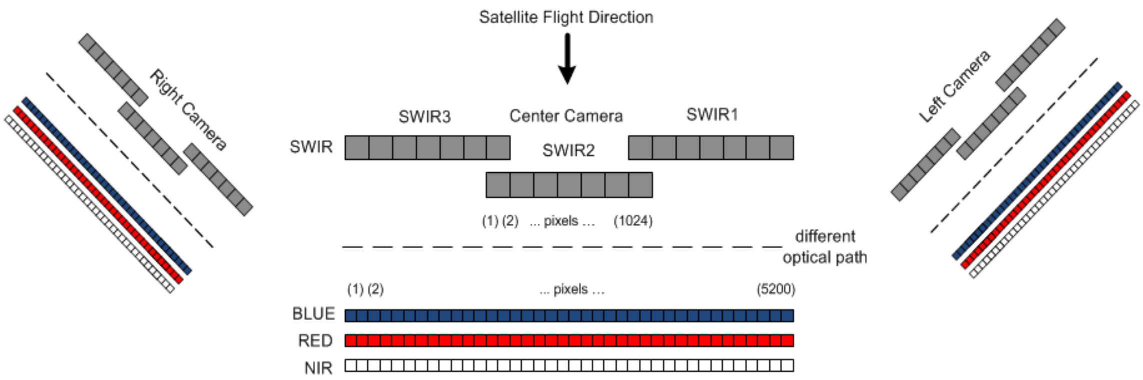

Figure 2: The PROBA-V instrument design

The instrument has been designed such that the NIR band observes the Earth first, followed by the RED, BLUE, and SWIR bands. As a result, an observation time difference of 12 s exists between the NIR and SWIR bands. This difference is accounted for in surface observations. Table 4 lists the radiometric characteristics of the PROBA-V spectral bands.

Table 4: PROBA-V spectral and radiometric characteristics. L_{ref} refers to the TOA irradiance at the respective spectral band. FWHM = Full Width at Half Maximum, SNR = Signal to Noise Ratio

Band name	Centre wavelength [µm]	Spectral range @FWHM [µm]	SNR @L_{ref} [W m^{-2}sr^{-1} µm^{-1}] at 300 m resolution
BLUE	0.464	0.440 – 0.487	177 @111
RED	0.655	0.614 – 0.696	598 @110
NIR	0.837	0.772 – 0.902	574 @106
SWIR	1.603	1.570 – 1.635	720 @20
Radiometric performance			
Absolute accuracy [%]	< 5		
Inter-channel accuracy [%]	< 3		
Stability [%]	< 3		

Figure 3 presents the spectral response functions (SRFs) for the PROBA-V BLUE, RED, NIR, and SWIR channels (solid lines), SPOT-VGT1 (dashed lines), and SPOT-VGT2 (dotted lines). It can be seen that the PROBA-V and SPOT-VGT SRFs differ and that differences are largest for the SWIR band. Note that the spectral responses for PROBA-V represent the center camera and that slight differences between the left, center, and right cameras exist. Appendix A shows detailed plots with spectral responses for all PROBA-V cameras.

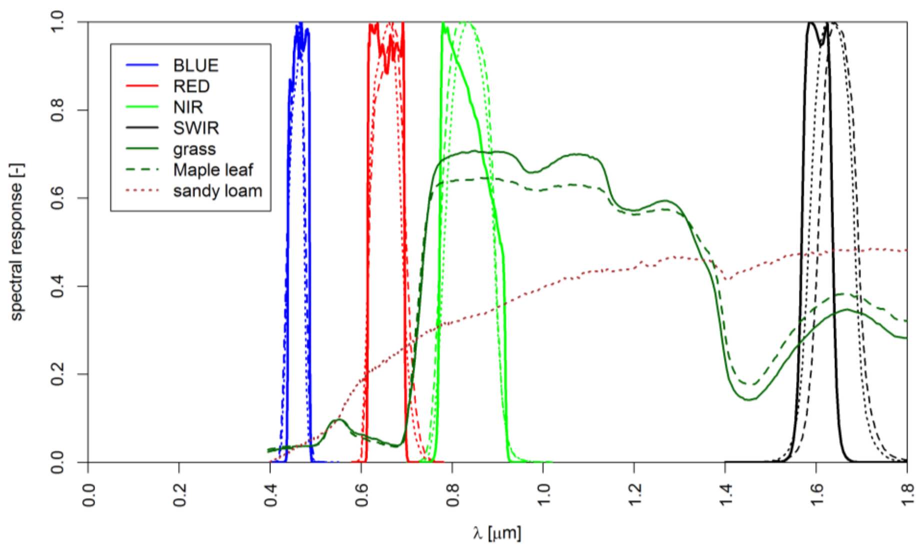

Figure 3: Spectral response functions for SPOT-VGT1 (dashed lines), SPOT-VGT2 (dotted lines), and PROBA-V (solid lines) for the BLUE, RED, NIR, and SWIR channels. Typical vegetation spectra for grass (solid dark green line), maple leaf (dashed dark green line), and bare soil (sandy loam, dotted brown line) are plotted for reference.

2.3. PROBA-V data products

The PROBA-V products are similar to the ones of SPOT-VGT in terms of file structure and comprise the following elements:

- **Segment products (Level-1C and Level-2A, both consisting of TOA reflectances)**
  The Level-1C product contains the raw, non-projected observations in segments, as well as calibration information, while the Level-2A (L-2A) products contain the projected segment data. The latter were named “P products” for SPOT-VGT.

- **Synthesis products (Level-3, both TOA and TOC)**
  These products contain daily (S1, available at all resolutions) and multi-daily (S5 for 100 m) TOA reflectances that are composed of cloud, shadow, and snow/ice screened observations. Additionally, Top-of-Canopy (TOC) reflectance and Normalized Difference Vegetation Index (NDVI) products are corrected for atmospheric reflectance contributions, such as aerosols and gaseous absorption. For the TOC reflectances, also 10-daily composites are available (S10 for 300 m and 1 km) next to the S1 (for all resolutions) and 5-daily (S5) for the 100 m products. Synthesis products were previously known as S products for SPOT-VGT.

Figure 4 shows the flowchart of the product processing chain. The separate products and algorithms will be further described in Section 2.4.

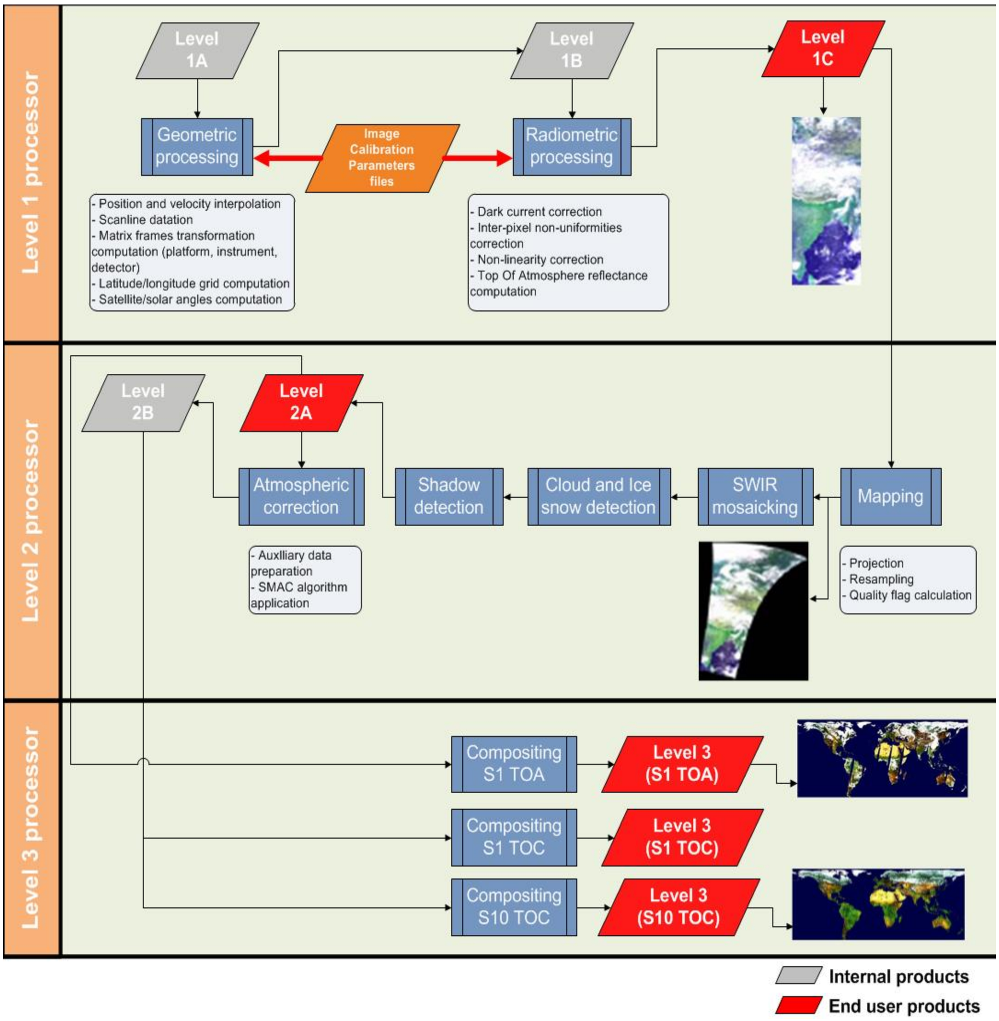

Figure 4: PROBA-V processing chain flowchart for the S1 and S10 products

2.4. Collection 2 reprocessing campaign

In 2020, it was decided to replace Collection 1 with a follow-up Collection 2, reflecting the latest scientific and operational progress on the various PROBA-V processing algorithms. After elaborate discussions in the PROBA-V Quality Working Group (QWG), the following improvements were implemented:

- Updated radiometric calibration
- Updated geomodelling
- A new and better cloud detection method and improved cloud shadow detection
- An improved atmospheric correction
- Compositing harmonization among the resolutions
- Product format update
- CEOS-ARD compliant metadata for the surface reflectance products
- A new data distribution catalogue

More information on the algorithm changes can be found in the PROBA-V Collection 2 Algorithms Changes Document.
The Collection 2 data set was fully validated, and the results of the validation can be found in the PROBA-V Collection 2 Validation report.

3. Products description

This Section describes the various PROBA-V products. First, the various algorithms that are applied to the raw image data are explained, followed by an explanation of the compositing rules to arrive at the Level-3 synthesis products. Finally, for all product types an overview of the information content is given.

A summary of the changes and improvements that were implemented for Collection 2 are given in Section 2.4.

3.1. Level-1 algorithm and data

The upper part of Figure 4 (*'Level-1 processor'*) shows the subsequent processing steps, which are performed to obtain the Level-1C product. The two main processing steps are:

- Geometric processing
- Radiometric processing

These processing steps are explained in further detail in the following subsections.

3.1.1. Geometric processing

Using the Level-1A raw and uncompressed data, a geolocation step is performed for each satellite position to determine the latitude and longitude of the observed pixel. The satellite position and velocity are interpolated for each scan line using an orbital propagation model. The geolocation accuracy is refined using the geometric Instrument Calibration Parameters (ICP) file (see also Figure 4). The ICP file contains the variation in detector viewing direction relative to the time out of eclipse and the Sun beta angle. The geometric processing model additionally calculates the viewing and solar zenith angles (VZA and SZA, respectively), which are required for further processing. The geometric processing output is the Level-1B data. The user is referred to Sterckx et al. (2014) for further details on the geometric processing model. More information can also be found on the website.

3.1.2. Radiometric processing

The radiometric processing converts the digital number count at a certain spectral band (DN) into physical TOA reflectance values. First, the DN number is corrected for detector non-linearities, dark currents, and inter-pixel non-uniformities. Second, these numbers are converted to at-sensor radiance L [W m^{-2} µm^{-1} sr^{-1}], using the band-specific calibration coefficients derived from the radiometric ICP file. Finally, the TOA radiance L at a given spectral band is converted into TOA band reflectance using:

$$R_{TOA} = \frac{\pi d^2 L}{E_o cos(\theta_s)}$$

With R_{TOA} the obtained TOA reflectance value [-], d the Earth – Sun distance [AU], E_o the mean exo-atmospheric irradiance at the specific spectral band [W m^{-2} µm^{-1}], with values from Thuillier et al. (2003), and θ_s the solar zenith angle [°]. The output of the radiometric processing is the Level-1C data.

For Collection 2, the following modifications were implemented:

- Application of a 2nd degree polynomial model for observed radiometric change (both increase and decrease of responsivity)
- Correction for small negative bias for the BLUE LEFT and SWIR RIGHT cameras
- Updates to the SWIR equalization/multi-angular calibration coefficients based on yaw maneuver data (pixel-dependent changes)

More details can be found in the PROBA-V Collection 2 Algorithm Changes Document.

3.2. Level-2 algorithm and data

The Level-1C data are used as input for further processing in the Level-2 processor, which consists of the following steps:

- Mapping and SWIR mosaicking
- Snow/ice detection
- Cloud and cloud shadow detection
- Atmospheric correction

The separate processing steps are explained in the following subsections.

3.2.1. Mapping and SWIR mosaicking

In the mapping procedure, the Level-1C data are mapped onto a World Geodetic System (WGS) 84 geographic lat/lon projection, using a procedure proposed by Riazanoff (2004). An inverse model is used to calculate the original Level-1 *(p, l)* coordinates from the Level-2 *(x, y)* coordinates, with x being the longitude, y the latitude, p the pixel-in-line, and l the line number. This mapping is explained in Figure 5.

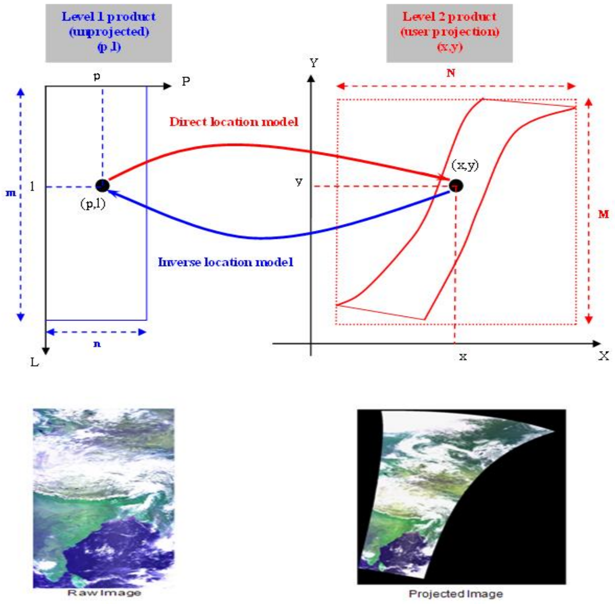

Figure 5: The Level-2 mapping procedure

The mapping operation is carried out twice, at 0 m and 5000 m above sea level, thereby resulting in two *(p, l)* coordinate sets. The *(p, l)* coordinates at a given altitude are then linearly interpolated from these two datasets. Orthorectification is performed using the Global Land Survey Digital Elevation Model (GLSDEM) from the National Aeronautics and Space Administration (NASA)/United States Geological Survey (USGS). The GLSDEM resolution is ~90 m and are available in Worldwide Reference System version 2 (WRS-2) format or in degree tiles for the latitudinal range 56ºS – 83ºN.

In the final step, the Level-2 pixel values are mapped to an *(x,y)* grid using a stretched bi-cubic interpolation filter (see Dierckx et al., 2014). This interpolation technique was found to be more accurate for PROBA-V compared to the standard bi-cubic interpolation used for SPOT-VGT1 and SPOT-VGT2 (Dierckx et al., 2014). The SWIR detector per camera consists of three strips (see Figure 2). After the mapping, there are still three separately projected SWIR strips. Therefore a mosaicking step is applied to compose a single SWIR band image. In the overlapping regions, the pixel radiometric Status Map is taken into account to select the best pixel (see Figure 6). More information on the Status Map dataset is given in Section 6.

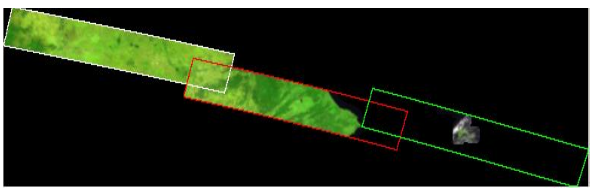

Figure 6: Example of the mosaicking algorithm result on the three SWIR strips

3.2.2. Cloud, cloud shadow, and snow/ice detection

The newly designed algorithm for cloud detection in PROBA-V data introduces major changes w.r.t. the algorithm used in Collection 1. It uses a Multi-Layer Perceptron (MLP) neural network algorithm. A single global model per resolution was established and validated. The training and validation data have been gathered on a much larger scale compared to Collection 1, and final performance is greatly improved compared to both Collection 0 and Collection 1. The method also removed the dependency on auxiliary input data, which was a major issue in Collection 1. For a detailed description of the method, please consult the Algorithm Theoretical Basis Document.

The new cloud detection method was validated for each resolution separately and the results of this validation are summarized in [VR PC 300 m] for the 300 m products, in [VR PC 1 km] for the 1 km products and in [VR PC 100 m] for the 100 m products. The validation is performed with a manually selected pixel collection and by comparison of the different cloud flags in randomly selected PROBA-V images.

The validation showed that the new cloud detection method has a very good performance. The issues found in C1 are largely solved and a good separation between cloud and snow/ice is found. Some trade-offs were made, resulting in some overestimation of clouds over salt lakes and urban areas, 50% of the thin semi-transparent clouds are detected, and sparse snow or melting ice is often not detected.

The cloud shadow detection was improved by removing the 1-pixel border between cloud and cloud shadow, which was present in the previous collections.

Interested readers are referred to the PROBA-V Collection 2 Cloud Detection Validation Report.

3.2.3. Atmospheric correction

Pixels that are not marked as “cloud-covered” or “contaminated” are considered for atmospheric correction. TOC directional reflectance estimates are obtained by applying the Simplified Method for Atmospheric Correction (SMAC, Rahman and Dedieu, 1994).

The choice for SMAC is supported by the following arguments:

- It is an operational algorithm and is widely used in the land surface research community.
- It is a robust and generic algorithm, thus minimizes sensor-dependency, which makes it well suitable for generating multi-sensor time series with limited biases.

SMAC is based on the Second Simulation of a Satellite Signal in the Solar Spectrum (6S, Vermote et al., 1997) Radiative Transfer Model (RTM), where all the pertinent radiative quantities are parameterized as a function of auxiliary data:

- Gas content (mainly ozone and water vapor for the PROBA-V spectral channels)
- Aerosol content and type
- Molecular scattering, mainly driven by the Sea Level Pressure (SLP) and surface elevation

The atmospheric correction is performed for each band separately and auxiliary data are used to compute the total gaseous transmission T_g, the atmospheric path radiance R_{atm}, the atmospheric spherical albedo s_{atm} and the total downward and upward scattering transmissions T_{sca}.

SMAC is a parameterization of 6S, which has a commonly agreed 1% accuracy. The SMAC approximation to 6S is also claimed to be within 1% for most situations, under the assumption of a Lambertian, i.e. isotropic, surface. However, for anisotropic surfaces, SMAC could be quite inaccurate to several percent, especially for high atmospheric turbidity, i.e., high AOT loads. Neither adjacency effects nor terrain slope corrections are applied, however, such effects are mostly secondary at the PROBA-V spatial resolutions.

Finally, it is noted that SMAC becomes rather unreliable for SZA and/or VZA > 60º (see Proud et al., 2010). Therefore, TOC reflectances at such large angles (PROBA-V observed at SZA up to 87.3º) should be considered with caution. Observations at extremely high SZA (> 80º) are only included in the Level-2A TOA data. See Table 6 for information on the TOA and TOC products' geographical extents.

More information on the SMAC methodology, AOT input, and uncertainty component formulations can be found in the Atmospheric Correction Algorithm Theoretical Base Document (AC ATBD). The atmospheric correction was validated according to the ACIX approach (Doxani et al., 2018), and the results can be found in the PROBA-V Collection 2 Atmospheric Correction Validation Report.

3.3. Level-3 algorithm and data: compositing

The compositing into synthesis images is performed by the Level-3 Processor (see Figure 4). The aim is to optimally combine multiple observations into a single and cloud-free synthesis image. Atmospherically uncorrected (Level-2A) or corrected (Level-2B) data are the basis for the TOA and TOC synthesis products, respectively. Cloud coverage is minimized through discarding pixels that were labeled as "cloud" by the cloud detection algorithm. In addition, angular variations are minimized, while global coverage is maximized. The S10 compositing is applied to avoid spatial coverage gaps resulting from clouds and the non-global daily swath coverage in the tropical areas.

Atmospherically corrected segment files are combined into a global Level-3 synthesis through application of a Maximum Value Composite (MVC) technique (see among others Holben, 1986 and Tarpley et al., 1984). This technique selects the maximum TOA NDVI (which is additionally calculated within the compositing algorithm) pixel values. The following synthesis products are generated:

- S1 (1-day syntheses): TOA and TOC
- S10 (10-day or dekad syntheses): TOC, with starting days at the 1st, 11th, or 21st day of a month. For months having 28, 29 or 31 days the S10 of the third dekad comprises the remaining days of that month.
- For the 100 m product, also S5 TOA and TOC data files are available, with starting days at the 1st, 6th, 11th, 16th, 21st and 26th day of a month. PROBA-V 100 m S5 products are

comparable with full-coverage 300 m S1 products and are not real syntheses. Due to the narrow swath of the 100 m camera, there is only overlap in observations for latitudes > ~40°. This means that only poleward of this latitude the compositing rules can be applied and that within the latitudes ~40°S – 40°N the single reflectance observed at one of the five days is given.

The TIME grid dataset in the synthesis files provides per pixel information at which day observations were taken. This information is provided in minutes since the start of the synthesis period (day 1, 00:00 UTC). Figure 7 indicates the 100 m observation coverage after 5 days.

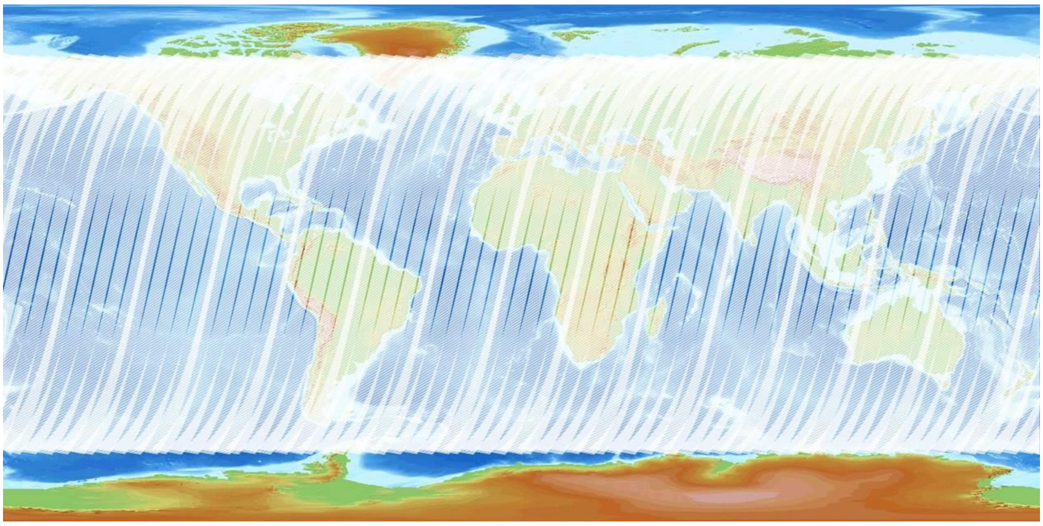

Figure 7: Overview of the 100 m coverage after 5 days. The brighter white areas indicate overlapping observations.

The compositing rules applied consecutively for syntheses at all resolutions are as follows:

1. Observations covered by all spectral bands are preferred over observations covered by less spectral bands.
2. Observations for which the SZA and VZA are less than a configured limit threshold (szaLimit and vzaLimit in the table below) are preferred over observations that exceed the limit angle value.
3. Observations with a good pixel quality indicator for the BLUE, RED, and NIR bands are preferred over lower-quality observations. Depending on the quality of a spectral band, a "score" is calculated (where RED=10, NIR=10, BLUE=5, SWIR=0). A pixel with higher score is preferred over a lower-score observation.
4. The quality of the observation (quality order from good to bad: 0=<good> 1=ice/snow 2=shadow 3=cloud 4=undefined) is checked and the observation with the smallest score is selected. In other words, cloud-free observations are preferred over ice/snow, which in turn are preferred over shadow, which in turn are preferred over cloud, which in turn are preferred over undefined observations.

5. In case two observations satisfy the rules above, the VZA and SZA are used to distinguish optimal from less optimal observations. 'Threshold' angle constraints on viewing and solar angles (szaThreshold and vzaThreshold in the table below) are checked and the observation that satisfies the angle constraints is selected.
6. In case two or more observations are still of equal quality, the observation yielding the maximum TOA NDVI value is preferred.

Table 5: SZA and VZA threshold values in the synthesis processing.

Rule	Limit	Threshold
Solar Zenith Angle (SZA)	90°	60°
Viewing Zenith Angle (VZA)	75°	40°

With respect to Collection 1, the compositing rules in Collection 2 are consistently applied throughout all product resolutions, while for Collection 1 a difference between the 100 m and 300 m versus 1 km composite resolutions existed. The difference was that in Collection 1 for 1 km composites, only a good radiometric quality for BLUE, RED, and NIR was imposed upon pixel selection, while for 100 m and 300 m additionally a good radiometric quality for SWIR was required. In Collection 2, the same compositing rules are applied across resolutions.

3.4. Data projection and geographical extents

All PROBA-V data products are projected in a standard WGS84 projection (also known as the Plate Carrée projection), similar as for the SPOT-VGT products. The spatial resolution of the 1 km Plate Carrée projection is defined as 1/112°, with the latitude and longitude coordinates defined at the pixel centre. This implies that the pixel boundaries extend ±1/224° for both latitude and longitude at the pixel corners. For example, if we consider the pixel corresponding to [lon, lat]=[-180°, 75°], the upper left corner of this pixel represents [lon, lat]=[-180° - 1/224°, 75° + 1/224°].

For the 300 m products, it seems logical to define a projection that contains 336 pixels per degree, such that 3 × 3 pixels would map onto a single 1 km pixel. However, users should note that due to the pixel coordinate definition (which applies to both 1 km and 300 m), no direct aggregation of 300 m to 1 km can be performed at the minimum and maximum latitude and longitude, while such an aggregation can be done within these boundaries (see the solid grids in Figure 8). Likewise, caution should be taken with the aggregation of 100 m pixels onto the 300 m grid.

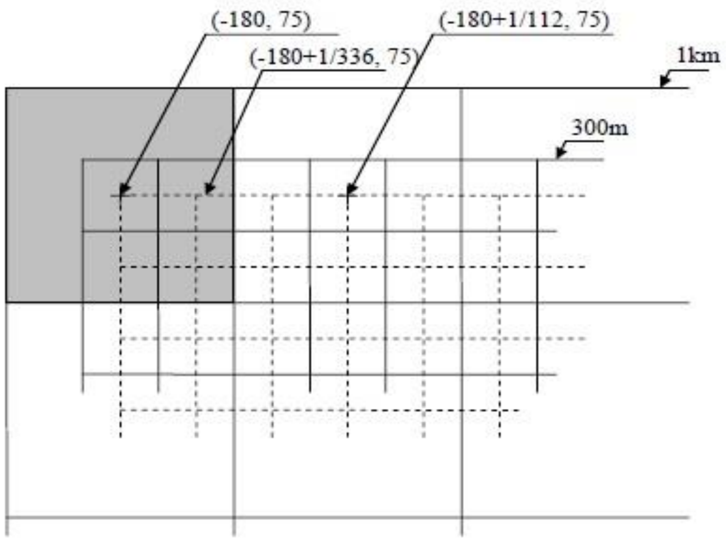

Figure 8: Depiction of the Plate-Carrée 1 km and 300 m projection grids. Solid lines indicate grids with coordinates representing the pixel centre, while for the dashed grid these represent the pixel upper-left corner.

Table 6 contains information on the geographical extents of the PROBA-V data products at the 21 June and 21 December solstices.

Table 6: Maximum northern latitude [°] for the PROBA-V data products at the summer and winter solstice dates

Date	Level-2A	S1 TOA	S1 TOC	S5/S10 TOC
21 June	79.3	75	75	75
21 December	65.9	65.9	65.9	66.0/66.2

The larger geographical coverage for the Level-2A (TOA) products results from a decision to extend the observations to SZA = 87.3°N to provide additional observations for snow cover mapping. This was implemented from second half of 2015 onwards. The extended observations are not included in the synthesis TOC products, due to the inaccurate atmospheric correction by SMAC at these large SZA (see Section 3.2.3).

4. Product data access and user support

4.1. Catalogue webservice and data access

On Terrascope, the Belgian Collaborative Ground Segment (CGS), which is a platform with as main aim making value-added Copernicus satellite data easily accessible, PROBA-V Collection 2 data has been made available for the EO user community. The viewer provides a way to do manual searches but when you are a developer and you program yourself, you can use the web service or Python Client. The openSearch web service or Python client interface allows users to search, select and download PROBA-V Collection 2 data products for specific areas and/or time periods.

The PROBA-V C2 products from all the collections meaning L1C (HDF format), L2A (HDF and COG format) and L3 syntheses (HDF and COG format) are available in the Catalogue.

Some examples of Catalogue search queries for PROBA-V Collection 2 collections and products are given in Table 7. The results are returned as Javascript Object Notation (JSON) files.

Table 7: Examples of Catalogue web service requests

Search request	TerraCatalogue search query
List all PROBA-V collections, including the collection 2 collections This query can be used to find the parentIdentier for searching on products within a collection.	https://services.terrascope.be/catalogue/collections?platform=PROBA-V
List all PROBA-V collections with a resolution of 1KM	https://services.terrascope.be/catalogue/collections?platform=PROBA-V&resolution=1000
List all collection 2 PROBA-V S10 300 m data in COG format for 2020/06/01 – 2020/06/10 in the area 50º – 60º N, 0º – 20º E	https://services.terrascope.be/catalogue/products?collection=**urn:eop:VITO:PROBAV_S10_TOC_333M_COG_V2**&start=2020-06-01T00%3A00%3A00&end=2020-06-10T23%3A59%3A59&bbox=0.00,50.00,20.00,60.00
List all collection 2 PROBA-V S10 300 m data in COG format for 2020/06/01 – 2020/06/10 in the area 50º – 60º N, 0º – 20º E, and provide the file locations on the Terrascope (or MEP) platform which simplifies	https://services.terrascope.be/catalogue/products?collection= urn:eop:VITO:PROBAV_S10_TOC_333M_COG_V2&start=2020-06-01T00%3A00%3A00&end=2020-06-10T23%3A59%3A59&bbox=0.00,50.00,20.00,60.00&**accessedFrom=MEP**

file access when running the application on the Terrascope (or MEP) VM	

More information on the Catalogue web service and additional sample requests can be found on the Terrascope documentation portal.

The openSearch catalogue response includes download locations for downloading the data products and/or the metadata. Download is only possible after authentication.

Examples of download urls:

- The Blue band of a PROBA-V TOC 10-daily synthesis in GeoTIFF format:

https://services.terrascope.be/download/PROBAV/C2/COG/PROBAV_L3_S10_TOC_333M/2020/20200601/PROBAV_S10_TOC_20200601_333M_V201/PROBAV_S10_TOC_X18Y01_20200601_333M_BLUE_V201.TIFF

- The HDF file for a PROBA-V TOC 10-daily product:

https://services.terrascope.be/download/PROBAV/C2/HDF/PROBAV_L3_S10_TOC_333M/2020/20200601/PROBAV_S10_TOC_20200601_333M_V201/PROBAV_S10_TOC_X18Y01_20200601_333M_V201.HDF5

Authentication is required. You can use your Terrascope or EGI account.

4.2. PROBA-V Viewer

Collection 2 data have been ingested into a new catalogue client instead of the legacy Product Distribution Portal, phased out in July 2023. Catalogue search API (see Section 4.1) is used in the backend, as it proves to be very stable. In addition, a new PROBA-V viewer (https://viewer.probav.vito.be/probav/) was developed. It contains similar functionalities as the former Mission Exploitation Platform (MEP) applications: Time series export, viewing capabilities, authentication, etc.

The targeted user groups for this viewer range a wide spectrum, supporting both expert users with GIS experience and non-expert users mainly interested in viewing the available data and comparing different layers.

All PROBA-V L3 synthesis collection 2 can be explored in the PROBA-V viewer in GeoTIFF format. The viewer provides several components to further explore and exploit the available data. Next to the general viewing capabilities it is possible to export what you see as an image format, compare different dates and/or layers and download data products and its metadata after authentication.

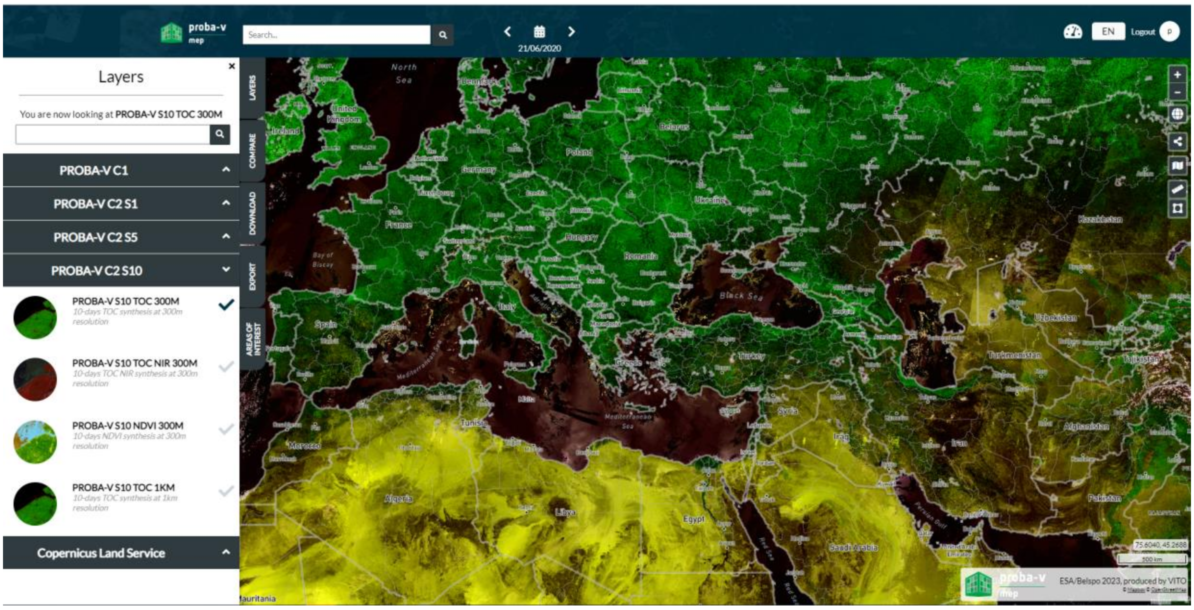

Figure 9: PROBA-V Viewer

4.3. PROBA-V data in Virtual Machine environment

PROBA-V data can also be accessed directly on the Terrascope/PROBA-V MEP platform. Once having registered as a Terrascope user, you can apply for a free User Virtual Machine (VM). This free VM comes with standard 8 GB of virtual memory and 80 GB of disk storage. For more information on registering as a Terrascope user, applying for a VM application, and how to use it see the Terrascope documentation portal.

In the Virtual Machine environment, the PROBA-V HDF5 and COG data products can be found in directories with naming:
/data/MTDA/PROBAV_C2/<data format>/<Collection>/YYYY/MM/YYYYMMDD/<product name>

With:
- <data format> being 'COG' or 'HDF',
- <Collection> referring to the collection, being:
    - PROBAV_L1C (only in the HDF folder)
    - PROBAV_L2A_1KM
    - PROBAV_L2A_100M
    - PROBAV_L2A_333M
    - PROBAV_L3_S1_TOA_1KM
    - PROBAV_L3_S1_TOA_100M
    - PROBAV_L3_S1_TOA_333M
    - PROBAV_L3_S1_TOC_1KM

- PROBAV_L3_S1_TOC_100M
- PROBAV_L3_S1_TOC_333M
- PROBAV_L3_S1_TOC_NDVI_100M
- PROBAV_L3_S5_TOA_100M
- PROBAV_L3_S5_TOC_100M
- PROBAV_L3_S5_TOC_NDVI_100M
- PROBAV_L3_S10_TOC_1KM
- PROBAV_L3_S10_TOC_333M
- PROBAV_L3_S10_TOC_NDVI_1KM
- PROBAV_L3_S10_TOC_NDVI_333M

4.4. User support

User questions (both technical and scientific) can be addressed to the VITO Remote Sensing Helpdesk:
helpdeskticket@vgt.vito.be

Please note that it can take up to two working days upon receiving an answer.

Alternatively, questions can be addressed at:
info@terrascope.be

5. Data and metadata formats

5.1. HDF5 EOS File Format

PROBA-V data products are disseminated as HDF5 files (Hierarchical Data Format, Version 5, for more information see http://www.hdfgroup.org/HDF5/), which comprises a set of file formats and libraries designed to store and organize large amounts of numerical data. The structure within an HDF5 file mainly has two major object types:

- Datasets, which are multi-dimensional arrays of a homogeneous type
- Groups, which are container structures that can contain other datasets and groups

The HDF5 file format is hierarchical and is built up like a file system. See for example Figure 10, which shows the various Datasets and Groups for a PROBA-V Level-3 S1 TOA file, as well as the BLUE and RED bands opened as images. In HDF5, attributes with additional information are attached to the Datasets and Groups (see Appendix B1, B2 and B3).

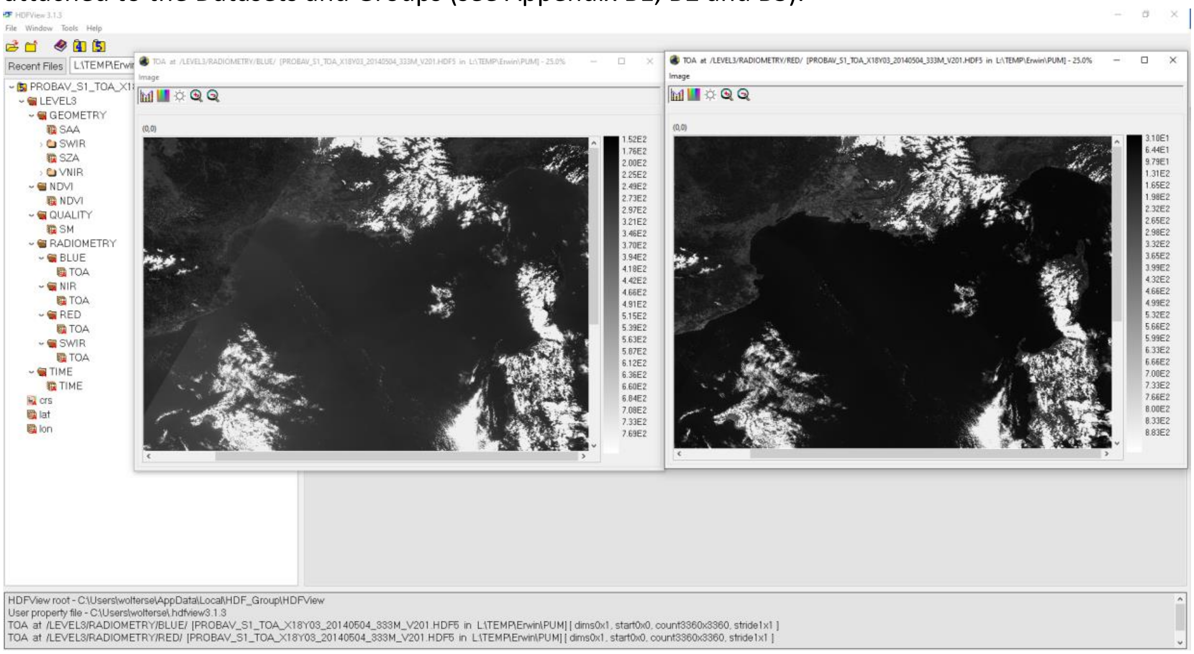

Figure 10: Overview of the Datasets, Groups, and images of the BLUE and RED spectral bands within the PROBA-V Level-3 S1 TOA HDF5 file for 4 May 2014, tile X18Y03

The HDF5 files are produced using the SZIP (de)compression software. SZIP is a stand-alone software library that ensures lossless compression of scientific data and is superior in both compression rate and (de)compression times during I/O as compared to e.g. GZIP.

Most software packages that can read HDF5 files have the SZIP library included. However, users are referred to the following links to obtain more detailed information on the SZIP performance and to download the SZIP library pre-compiled source code when necessary:

http://www.hdfgroup.org/doc_resource/SZIP/
https://www.hdfgroup.org/downloads/hdf5/

5.2. Cloud Optimized GeoTiff (COG) format

The Cloud optimized GeoTIFF (COG) format will enable fast access to PROBA-V data. COG (https://www.cogeo.org/) is the new standard, replacing the standard GeoTIFF format. The COG format is backward compatible with GeoTIFF. By offering COGs, handling of files in cloud environments and visualization of the data will get easier in the future.

The GeoTagged Image File Format (GeoTiff) is a metadata standard that allows for including georeferencing information (ellipsoids, projection, datums, etc.) to a TIFF raster file. The GeoTiff format has become the standard format for most GIS applications, including QGIS, ArcGIS, ERDAS Imagine, etc. GeoTiff images can be properly read by any program/script that is built on the Geospatial Data Abstraction Library (GDAL).

Table 8 shows the COG filenames and data content. All intermediate Level-2A data for all resolutions and all Level-3 composite products are available in COG format.

Table 8: PROBA-V Cloud Optimized GeoTiff (COG) filenames and content

Filename	Content
*BLUE_V201.TIFF	BLUE band spectral reflectances
*RED_V201.TIFF	RED band spectral reflectances
*NIR_V201.TIF	NIR band spectral reflectances
*SWIR_V201.TIFF	SWIR band spectral reflectances
*GEOMETRY.TIFF	Geometry data: SAA, SZA, VNIR VAA, VNIR VZA, SWIR VAA, and SWIR VZA Band 1: SZA Band 2: SAA Band 3: VAA SWIR detector Band 4: VZA SWIR detector Band 5: VAA VNIR detector Band 6: VZA VNIR detector
*SM.TIFF	Status Map information
*TIME.TIFF	Time Grid data
*NDVI.TIFF	Normalized Difference Vegetation Index

5.3. CEOS Analysis Ready Data (CEOS-ARD) compliant metadata

In Collection 1, all product metadata were CF-1.6-compliant. To further facilitate the access for non-experienced users, the Committee on Earth Observation Satellites (CEOS) developed the CEOS

Analysis Ready Data (CEOS-ARD) standard. In addition, this CEOS-ARD standard allows for immediate creation of Data Cubes and subsequent analyses to further improve the data ease-of-use and which enhances the interoperability among EO datasets. Collection 2 TOC data have CEOS-ARD compliant metadata. The PROBA-V Level 3 TOC products have been evaluated as CEOS-ARD compliant at the Threshold level.

CEOS-ARD is defined such that at minimum the products' time series analysis and data interoperability are supported.

More information on CEOS-ARD, the completed CEOS-ARD self-assessment and the peer review outcome document can be found at https://ceos.org/ard/.

5.4. Algorithm Version Information

The PROBA-V product version number in the filename has three digits, which consists of two parts: the first digit indicates the collection number, with '2' for Collection 2. The second and third digit together represent a processing counter for the number of iterations a certain collection has taken till completion. Generally, these numbers will not change once a Collection has been completed and for Collection 2 the version numbering is 'V201' for all Collection 2 product files.

The various algorithms within the processing chain have an irregular change in versioning. Table 9 presents these algorithms, while Table 10 contains information on the Collection 2 algorithms' version numbers. The latter information is found in the Level-3 Group metadata attributes.

Table 9: Definition of the various PROBA-V processing algorithms

Metadata Field	Description
PROCESSINGINFO_GEOMODELLING	Identifier for the algorithm and version of the geometric processing step.
PROCESSINGINFO_RADIOMODELLING	Identifier for the algorithm and version of the radiometric processing step.
PROCESSINGINFO_MAPPING	Identifier for the algorithm and version of the projection step.
PROCESSINGINFO_MOSAIC	Identifier for the algorithm and version of the mosaic processing step.
PROCESSINGINFO_CLOUDICESNOWDETECTION	Identifier for the algorithm and version of the cloud/snow/ice detection processing step.
PROCESSINGINFO_ SHADOWDETECTION	Identifier for the algorithm and version of the shadow detection processing step.
PROCESSINGINFO_ATMOSPHERIC_ CORRECTION	Identifier for the algorithm and version of the atmospheric correction processing step.
PROCESSINGINFO_COMPOSITING	Identifier for the algorithm and version of the compositing processing step.

Table 10: Processing algorithm versions for Collection 1 data

Metadata Field	Value	Description
PROCESSINGINFO_GEOMODELLING	PROBAV_GEOMODELLING_V1.0	Initial version of the geometric modelling algorithm
PROCESSINGINFO_ RADIOMODELLING	PROBAV_RADIOMODELLING_V1.0	Initial version of the radiometric modelling algorithm
PROCESSINGINFO_MAPPING	PROBAV_MAPPING_V1.0	Initial version of the Geometric

		modelling algorithm
PROCESSINGINFO_MOSAIC	PROBAV_MOSAIC_V1.0	Initial version of the mosaicking algorithm
PROCESSINGINFO_ CLOUDICESNOWDETECTION	PROBAV_ CLOUDICESNOWDETECTION_V3.0	Contains the MLP cloud and snow/ice detection
PROCESSINGINFO_ SHADOWDETECTION	PROBAV_ SHADOWDETECTION_V1.1	Part of the MLP cloud and snow/ice detection
PROCESSINGINFO_ATMOSPHERIC_ CORRECTION	PROBAV_ATMCORR_ SMAC_V2.0	New version of SMAC, contains uncertainty propagation and improved aerosol characterization
PROCESSINGINFO_COMPOSITING	PROBAV_COMPOSITING_MVC_V2.1	Same as PROBAV_COMPOSITING_MVC_V2.0, but with the following changes: Fixed time grid (minutes since start of the synthesis).

5.5. PROBA-V Product Files Description

5.5.1. Level-1C Product File Naming and Content

The file format for the Level-1C products is as follows:

PROBAV_L1C_*<DATE>*_*<TIME>*_*<CAMERA>*_**V***<VERSION>***.HDF5**

In which:

<DATE> start date of the segment identifier (format: YYYYMMDD).
<TIME> Segment start time (hhmmss).
<CAMERA> camera identifier
1: left camera (descending orbit, east)
2: central camera
3: right camera (descending orbit, west)
<VERSION> version identifier, ‘V201’ for all Collection 2 product files

Example: the filename *PROBAV_L1C_20140517_121832_1_V201.HDF5* represents the data that were observed from 17 May 2014 12:18:32 UTC onwards with the LEFT camera.

The segment files contain the following dataset structure:

- **LEVEL-1A**
  This group contains the raw uncompressed digital number per pixel. It also contains the Platform information provided by the spacecraft. These data are not publicly available.

- **LEVEL-1B**

This group gives the geometric processing output. It contains the geographical coordinates (latitude, longitude) for each pixel at heights of 0 and 5000 m above sea level. It also contains the viewing and illumination geometry per pixel. These data are not publicly available.

- **LEVEL-1C**
  Contains the radiometrically corrected TOA reflectance value per pixel. It also contains a quality indicator, which gives information per pixel on the reliability of the value.

The above Levels have the following datasets:

- BLUE
- NIR
- RED
- SWIR1
- SWIR2
- SWIR3

The respective datasets contain the Digital Number counts for the respective spectral bands, with attributes providing information on the scale and offset values required to convert the DN to physical reflectance values. Figure 11 displays the dataset structure of an Level-1C file. Further, each of the Levels contains additional HDF5 Attribute Tables in which detailed information on geolocation, processing, etc. is stored. Detailed explanations of the entire dataset structure for the Level-1C files are given in Appendix B1.

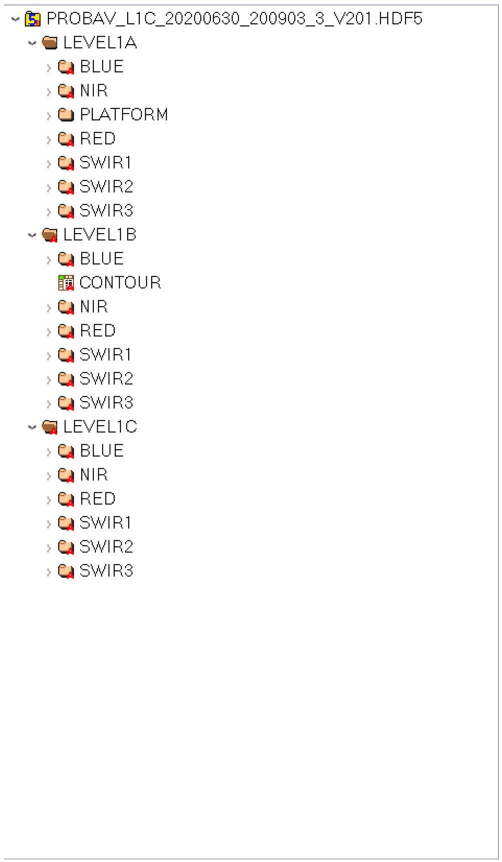

Figure 11: Dataset structure of a Level-1C product file

5.5.2. Level-2A Product File Naming and Content

The file format for Level-2A product files is as follows:

PROBAV_L2A_*<DATE>***_***<TIME>*_*<CAMERA>***_***<RESOLUTION>*_**V***<VERSION>***.HDF5**

In which:

<DATE>	start date of the segment identifier (format: YYYYMMDD).
<TIME>	start time (UTC) of the segment (format: hhmmss).
<CAMERA>	camera identifier 1: left camera (descending orbit, east) 2: central camera 3: right camera (descending orbit, west)
<VERSION>	version identifier, ‘V201’ for all Collection 2 product files

Example: the filename *PROBAV_L2A_20160210_105508_1_1KM_V201.HDF5* represents data that were collected from observations using the left camera, starting 10 February 2016 at 10:55:08 UTC.

Figure 12 shows the dataset structure of a Level-2A HDF5 file.

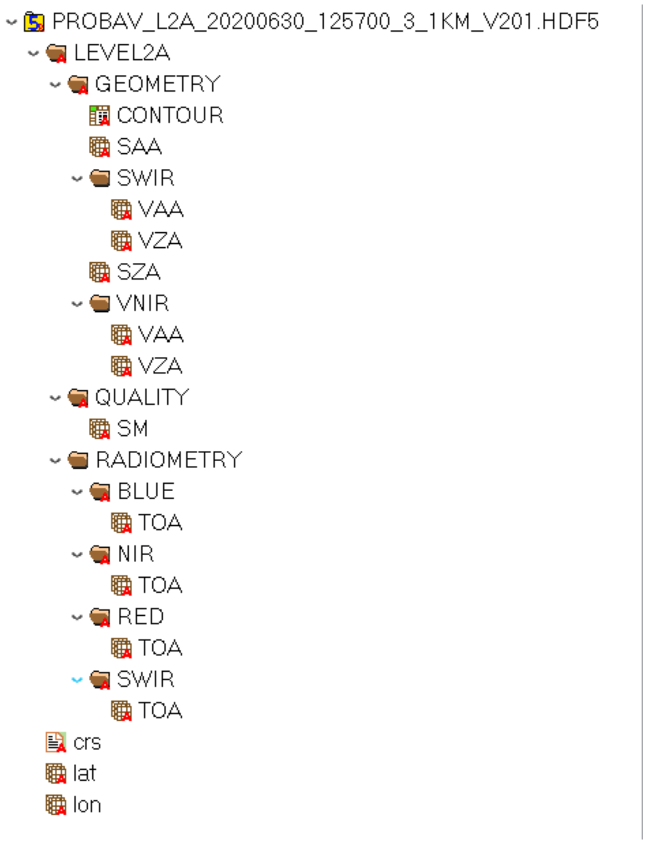

Figure 12: Dataset structure of a Level-2A product file

The dataset structure is built around the Level-2A Main Group. Within this Main Group, the following Groups can be distinguished:

- **GEOMETRY**
  Contains the viewing and illumination geometry per pixel.

- **QUALITY**
  Contains a quality indicator per pixel, consisting of an observation indicator (clear, cloud, ice, shadow, undefined), a land/sea flag, and a radiometric quality indicator. The pixel quality is set to ‘undefined’ if the per-pixel cloud detection or atmospheric correction fails.

- **RADIOMETRY**
  Contains the reflectance value per pixel at TOA.

Detailed explanations of the dataset structure, dataset contents, and data types for the Level-2A files are given in Appendix B2.

5.5.3. Synthesis Product File Naming and Content

The file format for the synthesis products (S1, S5, and S10) is as follows:

PROBAV_<*TYPE*> **_**<*TILE-ID*>**_**<*DATE*>**_**<*GRID*>**_V**<*VERSION*>**.HDF5**

In which:

<*TYPE*>	product type ('S1_TOA', 'S1_TOC' or 'S10_TOC')
<*TILE ID*>	tile identifier. 'X00Y00' is the identifier for the top-left tile, numbering increases in eastward and southward direction for X and Y, respectively. See Figure 13 for the tile numbering.
<*DATE*>	start date of the synthesis (YYYYMMDD)
<*GRID*>	spatial resolution (300 m or 1 km)
<*VERSION*>	version identifier, 'V201' for all Collection 2 product files

Example: The top-left tile of the third 1 km S10 of September 2013 has filename: **PROBAV_S10_TOC_X00Y00_20130921_1KM_V201.HDF5.**

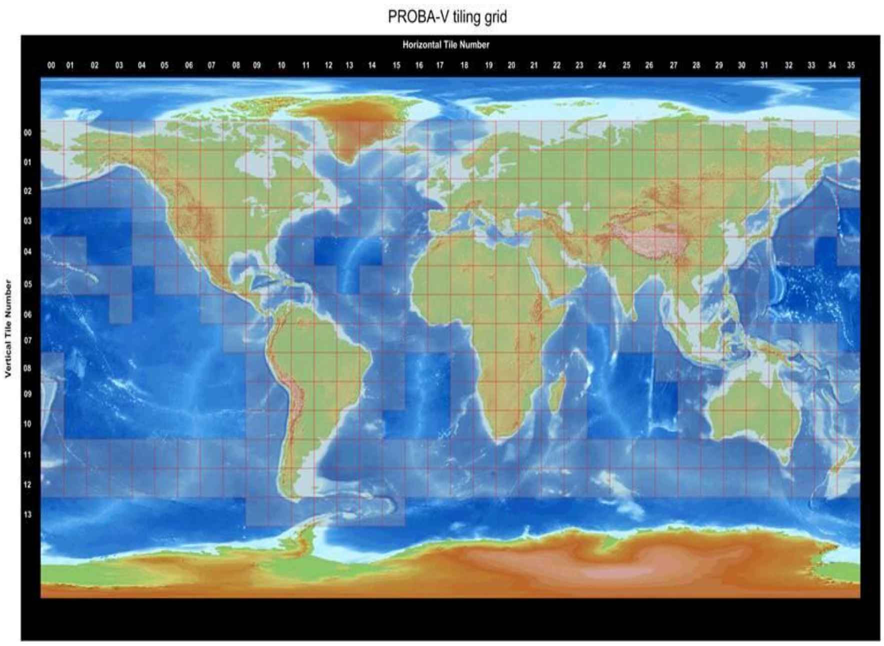

Figure 13: PROBA-V tile numbering

Figure 13 explains the tile numbering (tiles have 10° × 10° dimensions). The top-left tile is numbered 'X00Y00' (having top-left coordinates 180°E, 75°N), with the X and Y tile numbers increasing eastward and southward, respectively.

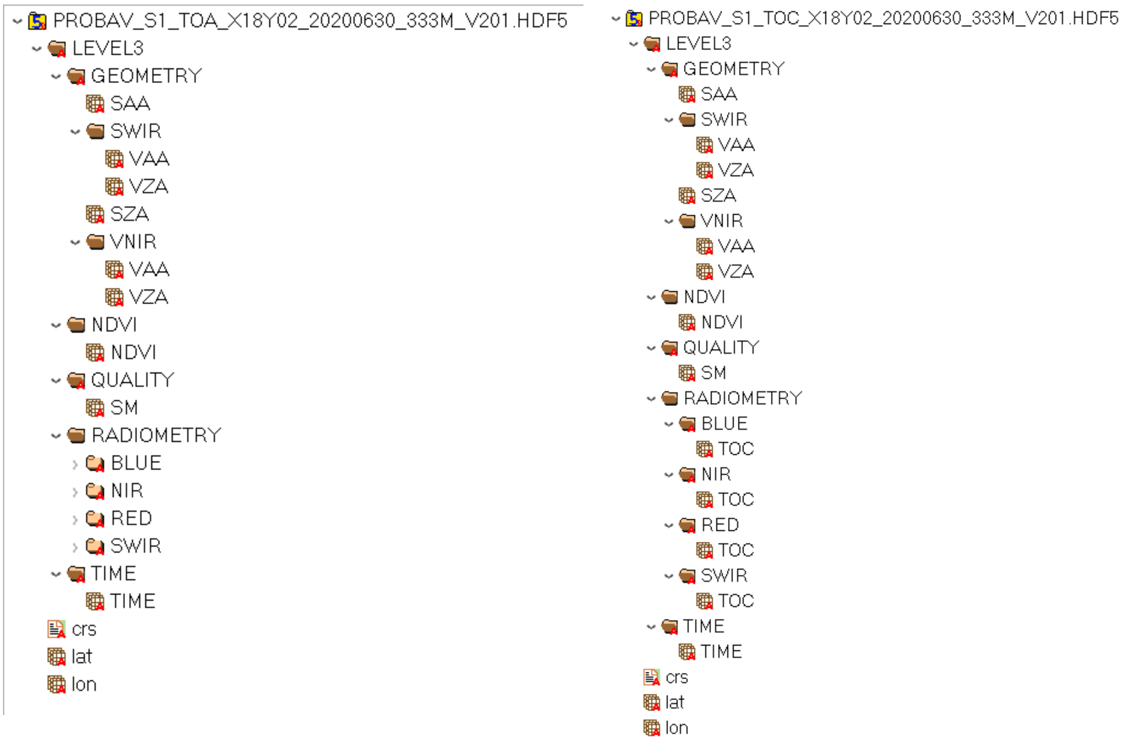

Figure 14: Dataset structure of S1 TOA (left) and TOC (right) product files

The dataset structure is built around the Level-3 Main Group. Within this Main Group, the following Groups can be distinguished:

- **GEOMETRY**
  Contains the viewing and illumination geometry for each product pixel.

- **NDVI**
  Contains the Normalized Difference Vegetation Index (NDVI) for each product pixel.
  The NDVI is calculated from the RED and NIR TOA (S1 TOA) or TOC (S1 TOC) reflectances:

  $$NDVI = \frac{R_{NIR} - R_{RED}}{R_{NIR} + R_{RED}} \qquad \text{(Eq. 1)}$$

  The conversion from digital values in the synthesis files to physical values is done as follows:

  $$PV = DN * \ scale\_factor - add\_offset \qquad \text{(Eq. 2)}$$

  In which PV is the physical value and *DN* is the digital value. For NDVI, the *add_offset* and *scale_factor* values are -0.08 and 0.004, respectively, giving a valid physical range of [-0.08, 0.92] for a DN range of [0, 250]. Observations for which the NDVI underruns or exceeds the lower or upper limits are given DN values 0 and 250, respectively. An overview of scale, offset, and no data values for all dataset types is provided in Section 5.6.1. Note that the

PROBA-V metadata contain two sets of scale and offset values. One set contains the CF-compliant values (see Section 5.3) and are named *scale_factor* and *add_offset*, which are the values to be used in the conversion of Eq. 2. The other set contains the inverted scale and offset values (denoted SCALE and OFFSET). Conversion to Physical Values using the latter values is done using Eq. 3.

$$PV = \frac{(DN - OFFSET)}{SCALE} \qquad \text{(Eq. 3)}$$

- **QUALITY**
  Contains a quality state indicator per pixel, consisting of an observation indicator (clear, cloud, ice, shadow, undefined), a land/sea flag, and a radiometric quality indicator. The pixel quality is set to 'undefined' if the per-pixel cloud detection or atmospheric correction fails.

- **RADIOMETRY**
  Contains the TOA or TOC reflectance value per pixel.

- **TIME**
  Contains the date and time of observation, expressed as the number of minutes since the beginning of the synthesis period in UTC. It is noted that the value for 'no data' in the TIME grid is set to '0', which can also be a real value. Therefore users should check the Status Map for additional information to ascertain whether the TIME grid pixel carries indeed a 'no data' value.

Figure 14 presents the entire dataset structure for the TOA and TOC Synthesis products. Detailed information on the Groups, Attributes, and Datasets is given in Appendix B3.

5.6. Data viewing and handling

The HDF5 file format is readable for most data interpretation languages, such as IDL, R, and Python. Further, applications (such as QGIS) exist to quickly view the data as images and to perform these basic calculations.

5.6.1. DN to PV value scaling

The reflectances that are provided in the Level-1C, Level-2A, and Level-3 data files are presented as Digital Count Numbers (DN). In order to obtain reflectance values a conversion is necessary, which is done using the formula below:

$$PV = DN * \ scale\_factor - add\_offset$$

With DN the Digital Count Number and PV the Physical Values, respectively. The various scales and offset values can be found in the respective dataset attributes (reflectances, zenith and azimuth angles, NDVI, Status Map, and Time grid) in the Level-1C, Level-2A, and Level-3 files, with attribute names *scale_factor* and *add_offset*. Note that in the HDF5 files, additionally *SCALE* and *OFFSET* are listed, which are the reciprocals of *scale_factor* and *add_offset*, respectively. Table 11 contains the scale, offset, and no data values for each of these dataset types. Note that for the Level-1C files the SWIR channel data contain the observations for each of the three strips.

Table 11: Scale, offset, and no data values for the PROBA-V dataset types

Product type	scale_factor	SCALE	add_offset	OFFSET	No data
Reflectances	0.0005	2000	0.0	0.0	-1.0
Azimuth Angles	1.5	0.66667	0.0	0.0	255.0
Zenith Angles	0.5	2.0	0.0	0.0	255.0
NDVI	0.004	250	-0.08	20	255.0
Status Map	1.0	1.0	0.0	0.0	2.0
Time	1.0	1.0	0.0	0.0	0.0

Note that the names listed refer to the HDF5 conversion factors and that SCALE and OFFSET are the reciprocals of scale_factor and add_offset. The No data value is stored in the NO_DATA and _FillValue attributes.

5.6.2. Opening HDF5 in R

The example program below shows how to open a PROBA-V S10 synthesis HDF5 file and how to read the data in R, using the `h5r` package.

```
read_hdf5 <-function(){
    require(h5r)

    filename <- "PROBAV_S1_TOA_X11Y07_20140607_300 m_V201.hdf5"

    #extract the HDF5 dataset
    h5 <- H5File(filename,'r')
    dblu  <- getH5Dataset(h5, "/LEVEL3/RADIOMETRY/BLUE/TOA")

    #get the image values and store into 3360 x 3360 matrix
    blue  <- array(readH5Data(dblu), c(3360, 3360))
}
```

Note that alternative packages (such as `rhdf5`) exist; the syntax to open and read the HDF5 file will be slightly different. An example script using `rhdf5` is shown below and evidently data are more conveniently extracted using this package.

```
read_hdf5_alt <-function(){
    require(rhdf5)

    filename <- "PROBAV_S1_TOA_X11Y07_20140607_300 m_V201.hdf5"

    #extract the TOA reflectances for the four spectral bands
    d_red <- h5read(h5file, "LEVEL3/RADIOMETRY/RED/TOA") / 2000
    d_nir <- h5read(h5file, "LEVEL3/RADIOMETRY/NIR/TOA") / 2000
    d_blu <- h5read(h5file, "LEVEL3/RADIOMETRY/BLUE/TOA") / 2000
```

```
    d_swi <- h5read(h5file, "LEVEL3/RADIOMETRY/SWIR/TOA") / 2000
}
```

5.6.3. Opening HDF5 in Python

The example program below shows how to open a PROBA-V S1 synthesis HDF5 file in Python, using the `h5py` and `numpy` packages.

```
#Import h5py library
import h5py

#Open HDF5 file with h5py, read-write mode
h5f = h5py.File('PROBAV_S1_TOA_X11Y07_20140607_300m_V201.HDF5','r+')

#Use Python dictionary syntax to explore the HDF5 structure
h5f.keys()

#Get dimensions
h5f['/LEVEL3/RADIOMETRY/BLUE/TOA'].shape

#Get data type
h5f['/LEVEL3/RADIOMETRY/BLUE/TOA'].dtype

#Get value array for the BLUE TOA data layer
toa_b = h5f['/LEVEL3/RADIOMETRY/BLUE/TOA'].value
```

5.6.4. Opening HDF5 in QGIS

Below a short description on how to open a PROBA-V HDF5 file in QGIS version 3.18 is given.

In the Quantum GIS main screen, select the 'Open Raster' icon. A dialog box to select the raster file is opened, see Figure 15. Once the HDF5 file is opened, another dialog box for selecting one or more bands is opened, see Figure 16. In this example, the BLUE band is selected for further viewing. After band selection, the proper coordinate reference system needs to be chosen, which is presented in Figure 17. Once these three steps have been completed, the band image is loaded and further actions can be performed.

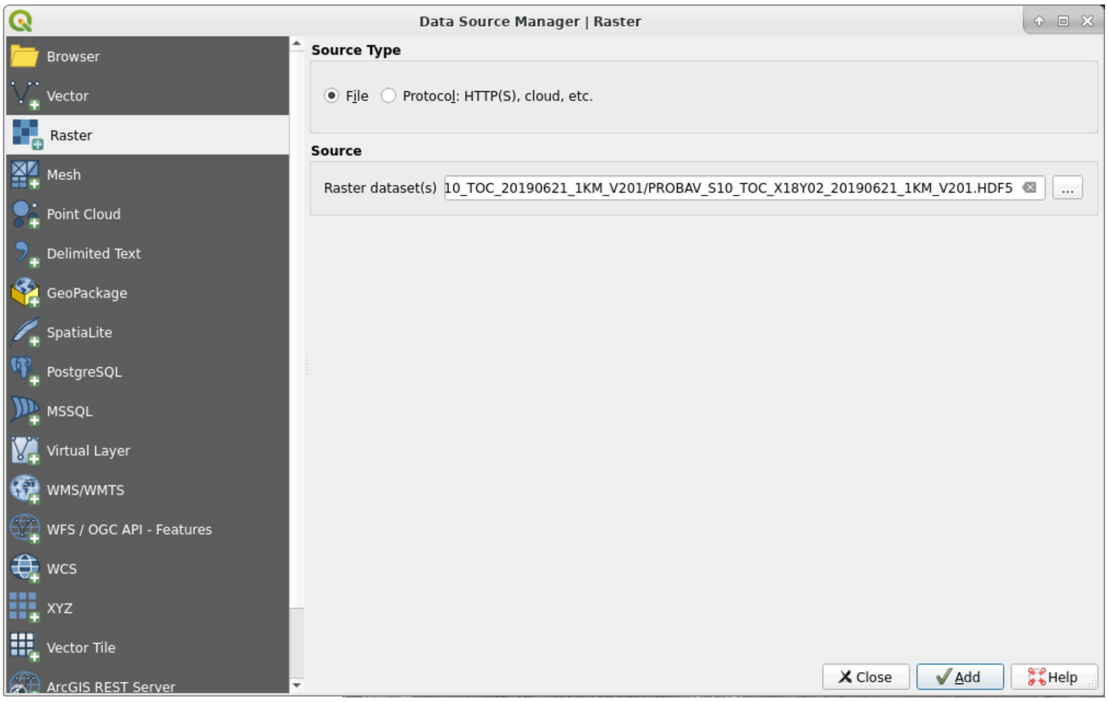

Figure 15: Dialog box for opening a raster file in QGIS 3.18

Here, we select a Collection 2 HDF5 S10 TOC 1 km file for 21/06/2019, tile X18Y04, and we choose the NIR TOC band, see Figure 16.

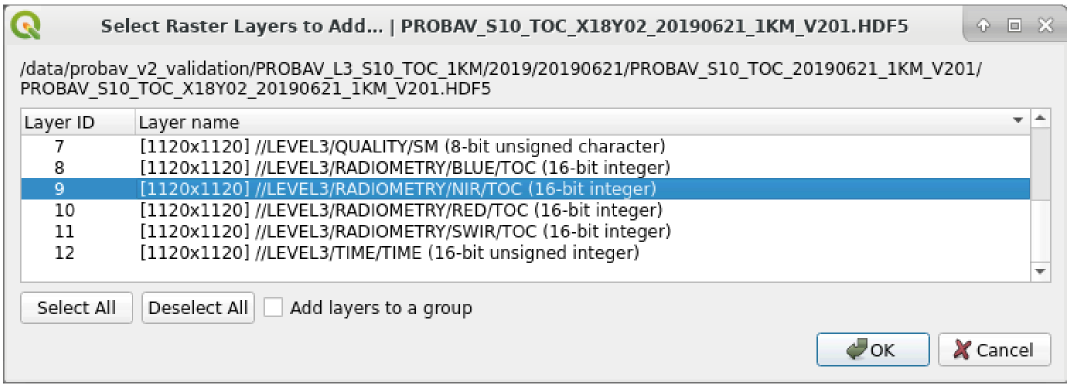

Figure 16: Selection of the NIR TOC band

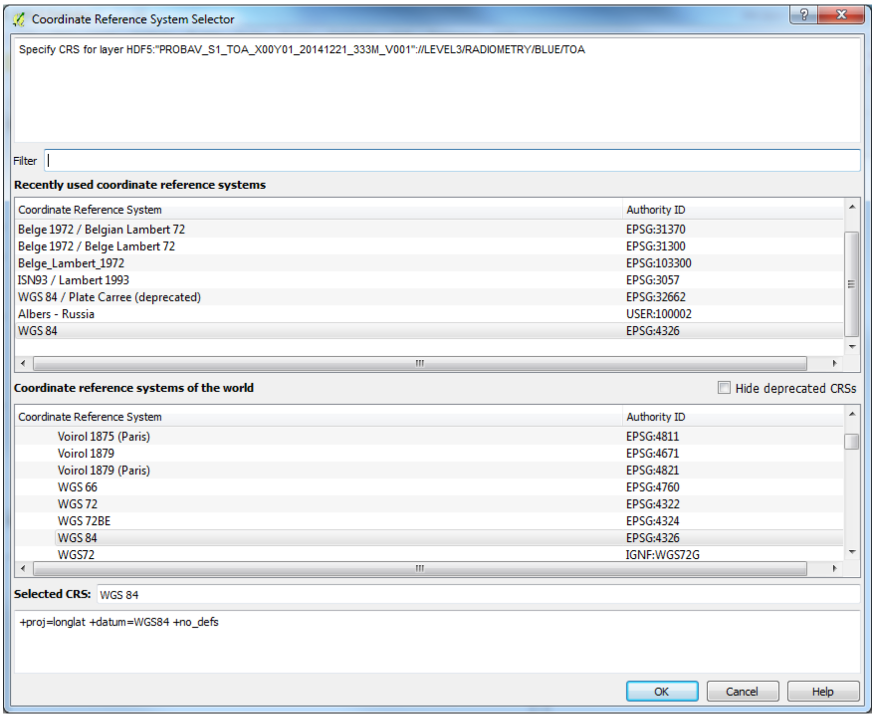

Figure 17: Selection of the WGS84 Coordinate Reference System (CRS)

An example of the visualization of NDVI, using a customized color table is shown in Figure 18.

Figure 18: Example of the NDVI for 21 - 30 June 2019 shown in QGIS 3.18

It is noted that HDF5 data layers are shown in image coordinates, due to a discrepancy between the QGIS and HDF5 Geotiepoint definitions. To obtain proper overlays with e.g. vector files, users are advised to download PROBA-V images in GeoTiff format or to open the HDF5 in GIS programs that are compliant with the HDF5 Geotiepoint definition.

5.6.5. Sentinel Application Platform (SNAP) PROBA-V Toolbox

The Sentinel Application Platform (SNAP) comprises a set of Toolboxes that facilitate the analysis, processing, and visualisation of the Sentinel-1, -2, and -3 satellite data. As part of the Sentinel Toolboxes, a first version of the PROBA-V Toolbox was released in January 2017. The PROBA-V Toolbox enables users to conveniently access, analyse, and visualise PROBA-V Level-2A and Level-3 data.

The Sentinel Toolboxes can be downloaded from http://step.esa.int/main/download/ and the PROBA-V Toolbox v1.0 release notes are available at https://github.com/senbox-org/probavbox/blob/1.x/ReleaseNotes.md.

6. Quality assurance

Both the Segment and Synthesis product files are delivered with quality indicators. Below these indicators are shortly explained. Reference is made to Appendices C1 – C4 for detailed descriptions of the Segment and Synthesis metadata.

6.1. Level-1C files

For Level-1C files, the quality is indicated by the Q Dataset, which is located in the LEVEL-1C STRIP Group (see Appendix C1 for more details). The pixel quality for the Level-1C data is decoded as 8-bit unsigned integers, the values and their meaning are given in Table 12. These pixel quality indicators are replaced by the Status Map from Level-2 onwards (see below). Saturated pixels will have reflectances above 1.

Table 12: Explanation of the pixel quality indicators in the Level-1C Product

Status	Explanation
0	'Correct': no quality issues encountered
1	'Missing': the pixel value is missing due to a bad detector
2	'WasSaturated': the DN value of the pixel is equal to 4095 (coded in 12 bits =2^{12}-1)
3	'BecameSaturated': during the calculation of the TOA reflectance the value became higher than 4095
4	'BecameNegative': during the calculation of the TOA reflectance the value became lower than 0
5	'Interpolated': the value of the pixel radiance was interpolated using the neighboring pixels
6	'BorderCompressed': the pixel quality is uncertain due to on-board compression artefacts

6.2. Level-2A and synthesis product files

In the Level-2A, S1, S5, and S10 product files, the quality indicator is located in the SM (Status Map) Dataset within the QUALITY Group. The SM Dataset contains a quality state indicator per pixel, consisting of an observation indicator (clear, cloud, ice, shadow, undefined), a land/sea flag, and a radiometric quality indicator. Table 13 lists the various quality values. Please note that bits 8 – 11, containing additional information on the observational coverage for each band, are only available for Level-2A data.

Due to 'blind' detectors in the imaging system, along track stripes of pixels are labelled with 'bad' radiometric quality in the SWIR band. In the Level-1 image processing, observations given by these detectors are ignored and replaced by interpolated observations from the neighbouring detectors. Depending on the application, users can opt to ignore the SWIR radiometric quality flag, as these can lead to a striping effect in the application outcomes. Also in Level-3 compositing, the SWIR quality flag is ignored (see §3.3).

Table 13: Explanation of the pixel quality indicators in the Status Map Dataset. Bits indicated with * are only available for Level-2A data.

Bit (LSB to MSB)	Description	Value	Key
0-2	Cloud/Ice Snow/Shadow Flag	000 001 010 011 100	Clear Shadow Undefined Cloud Ice
3	Land/Sea	0 1	Sea Land
4	Radiometric quality SWIR flag	0 1	Bad Good
5	Radiometric quality NIR flag	0 1	Bad Good
6	Radiometric quality RED flag	0 1	Bad Good
7	Radiometric quality BLUE flag	0 1	Bad Good
8*	SWIR coverage	0 1	No Yes
9*	NIR coverage	0 1	No Yes
10*	RED coverage	0 1	No Yes
11*	BLUE coverage	0 1	No Yes

The Status Map information can be easily read in most programming languages. Below we present how to read and extract the various flags for bits 0 – 2 (see Table 13) from the Status Map Level-2A data for R and Python.

R

The ‘`rhdf5`’ package is used to extract the Status Map dataset from the Level-2A file, while ‘`R.utils`’ contains the ‘`intToBin`’ function, which is used to convert the Status Map integer values to binary. Comments are highlighted in red.

```
require(rhdf5)
require(R.utils)

L2_file     <- 'C:\PROBAV_L2A_20150506_085613_3_1KM_V201.HDF5'
SM          <- h5read(L2_file, "LEVEL2A/QUALITY/SM")

#convert the Status Map integers to binary values
b_SM <- intToBin(SM)

#extract the 3 rightmost bits (in Level-2A, 8 bits in Level-3 data) and assign
clear, shadow, undefined, cloudy, and snow/ice
clr  <- which(substr(b_SM, 10, 12) == "000")
shw  <- which(substr(b_SM, 10, 12) == "001")
und  <- which(substr(b_SM, 10, 12) == "010")
cld  <- which(substr(b_SM, 10, 12) == "011")
ice  <- which(substr(b_SM, 10, 12) == "100")
```

Python

In Python, the `h5py` library conveniently handles the opening, reading, and extraction of HDF5 datasets. The `numpy` library in this example contains the '`where`' statement, which returns those array indices that fulfill a certain criterion. Bitwise operations are used here, with '`&1`', '`&2`', and '`&4`' indicating evaluations of the 3 least significant bits.

```
import h5py
import numpy as np

L2_file = 'C:\PROBAV_L2A_20150506_085613_3_1KM_V201.HDF5'
h5 = h5py.File (L2_file,'r+')
SM = h5['/LEVEL2A/QUALITY/SM'].value

#Evaluate the three least significant bits for 'clear', 'shadow', 'undefined',
'cloud', and 'snow/ice' and assign the outcome to variables
clr = np.where((SM&1 == 0) & (SM&2 == 0) & (SM&4 == 0))
shw = np.where((SM&1 != 0) & (SM&2 == 0) & (SM&4 == 0))
und = np.where((SM&1 == 0) & (SM&2 != 0) & (SM&4 == 0))
cld = np.where((SM&1 != 0) & (SM&2 != 0) & (SM&4 == 0))
ice = np.where((SM&1 == 0) & (SM&2 == 0) & (SM&4 != 0))
```

6.3. PROBA-V Quality Webpage

A Quality Webpage is available at http://proba-v.vgt.vito.be/en/quality/quality and provides information on the Quality Assessment and the various methods applied to maintain PROBA-V's data quality at the highest possible level, from the raw satellite observations through the value-added products available at the PROBA-V Data Portal.

The following topics are highlighted:

- Radiometric and geometric calibration
- Platform status
    - Geolocation accuracy
    - Spectral Response Functions
    - Quarterly Image Quality Reports
- Product evaluation: Access to PROBA-V and SPOT-VGT Evaluation Reports
- Product and Algorithm Information: PROBA-V reference documentation
- Known issues
- PROBA-V Quality Working Group
    - Introduction, objectives, and composition
    - Members
    - Contact Point

REFERENCES

Dierckx, W., S. Sterckx, I. Benhadj, S. Livens, G. Duhoux, T. Van Achteren, M. Francois, K. Mellab, and G. Saint, 2014: PROBA-V mission for global vegetation monitoring: standard products and image quality. *Int. J. Remote Sens*, **35**, 2589 – 2614, DOI: 10.1080/01431161.2014.883097.

Doxani G., E. Vermote, J.-C. Roger, F. Gascon, S. Adriaensen, D. Frantz, O. Hagolle, A. Hollstein, G. Kirches, F. Li, J. Louis, A. Mangin, N. Pahlevan, B. Pflug, Q. Vanhellemont, 2018: Atmospheric Correction Inter-Comparison Exercise, *Remote Sens*. 10(2):352. https://doi.org/10.3390/rs10020352.

Francois, M., S. Santandrea, K. Mellab, D. Vrancken, and J. Versluys, 2014: The PROBA-V mission: The space segment. *Int. J. Remote Sensing*, **35**, 2548 – 2564, doi: 10.1080/01431161.2014.883098.

Gómez-Chova, L., G. Matteo-García, J. Muñoz-Marí, and G. Camp-Valls, 2017: Cloud detection machine learning algorithms for PROBA-V, available from https://arxiv.org/pdf/2012.10396.pdf.

Holben, B. N., 1986: Characteristics of maximum-value composite images from temporal AVHRR data. *Int. J. Remote Sens.*, **7**, 1417 – 1434.

Plummer S., J. Chen, G. Dedieu, and M. Simon, 2003: GLOBCARBON Detailed Processing Model GLBC-ESL-DPM-V1.3, 202 pp.

Proud, S. R., Rasmussen, M. O., Fensholt, R., Sandholt, I., Shisanya, C., Mutero, W., Mbow, C., & Anyamba, A. (2010). Improving the SMAC atmospheric correction code by analysis of Meteosat Second Generation NDVI and surface reflectance data. Remote Sensing of Environment, 114(8), 1687–1698. https://doi.org/10.1016/j.rse.2010.02.020

Rahman, H., and G. Dedieu, 1994: SMAC: a simplified method for the atmospheric correction of satellite measurements in the solar spectrum. *Int. J. Remote Sens.,* **15**, 123 – 143.

Riazanoff, S., 2004: SPOT1-2-3-4-5 Satellite Geometry Handbook, *GAEL-P135-DOC-001,* **1**, Revision 4, 82 pp.

Stelzer, K., M. Paperin, M., and U. Lange, 2019: *PROBA-V CLOUD (C2) Validation report,* Brockmann Consult.

Sterckx, S. S. Adriaensen, W. Dierckx, and M. Bouvet, 2016: In-Orbit Radiometric Calibration and Stability Monitoring of the PROBA-V Instrument. *Remote Sens.*, **8**, 546, doi:10.3390/rs8070546.

Sterckx, S., I. Benhadj, G. Duhoux, S. Livens, W. Dierckx, E. Goor, S. Adriaensen, W. Heyns, K. Van Hoof, K., G. Strackx, K. Nackaerts, I. Reusen, T. Van Achteren, J. Dries, T. Van Roey, K. Mellab, R. Duca, and J. Zender, 2014: The PROBA-V mission: image processing and calibration. *Int. J. Remote*

Sens., ***35*****(7)**, 2565 – 2588, doi: 10.1080/01431161.2014.883094.

Tarpley, J. D., S.R. Schneider, and R.L. Money, 1984: Global vegetation indices from the NOAA-7 meteorological satellite. *J. Clim. Appl. Meteorol*, **23**, 491 – 494.

Thuillier, G., M. Hersé, T. Foujols, W. Peetermans, D. Gillotay, P.C. Simon, H. and Mandel 2003: The solar spectral irradiance from 200 to 2400 nm as measured by the SOLSPEC spectrometer from the ATLAS and EURECA missions. *Sol. Phys.*, **214**, 1 – 22, doi: 10.1023/A:1024048429145.

Vermote, E. F., D. Tanré, J.L. Deuze, M. Herman, and J.J. Morcette, 1997: Second simulation of the satellite signal in the solar spectrum, 6S: An overview, *IEEE T. Geosci. Remote*, **35**, 675 – 686.

APPENDICES

Appendix A: PROBA-V Spectral Response Functions (SRF) per camera

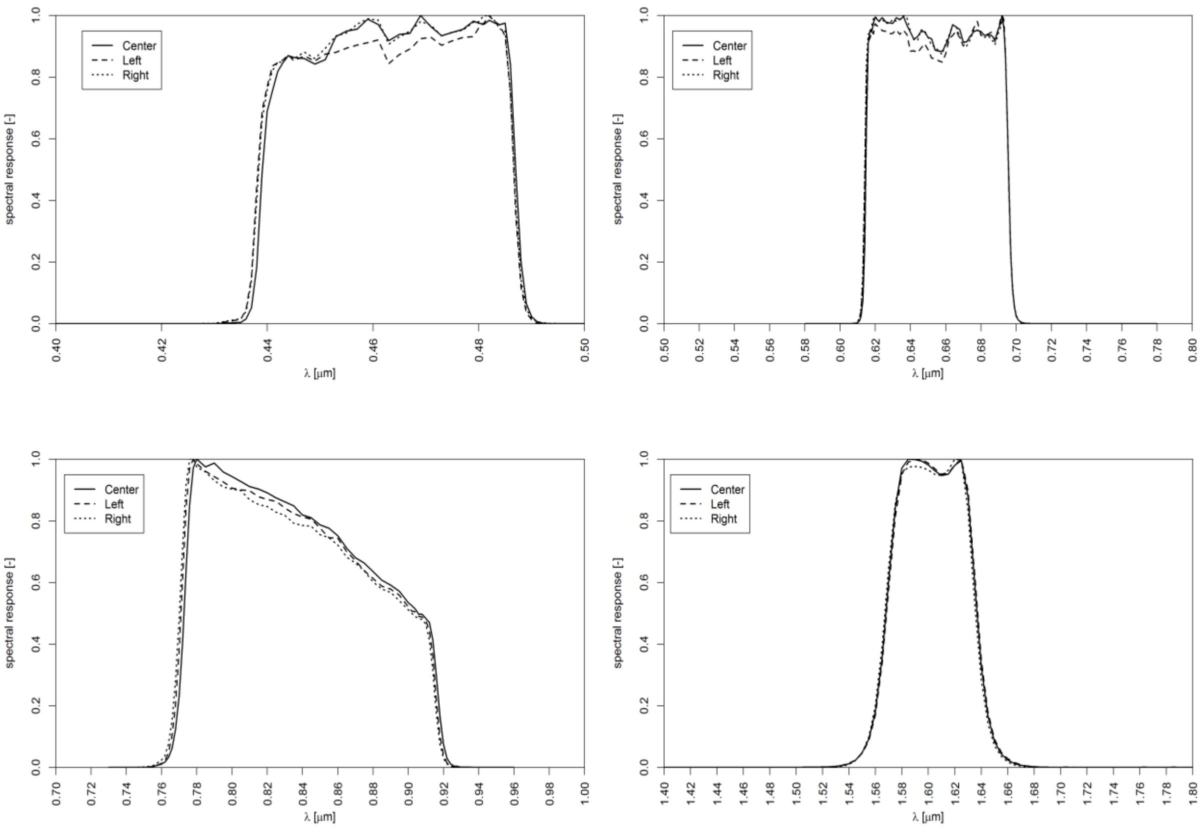

Figure 19: Spectral response functions per camera (solid=center camera, dashed=left camera, and dotted=right camera) for the BLUE (upper left), RED (upper right), NIR (lower left) and SWIR (lower right) channels.

The Spectral Response Functions data are available online at http://proba-v.vgt.vito.be/en/quality/platform-status-information/spectral-response-functions.

Appendix B1: Detailed Level-1C HDF5 Product file description

Below a detailed description of the Segment Product (LEVEL-1C) files is given. Reference is made to Figure 11, which presents the dataset structure of the file.

Table 14: HDF5 structure of LEVEL-1C product file

Type	Name	Description	Data type
HDF5 Group	LEVEL1A	HDF5 group containing the Level1A data and metadata. The structure and content of this group is elaborated in Table 15.	See Table 15
HDF5 Group	LEVEL1B	HDF5 group containing the Level1B data and metadata. The structure and content of this group is elaborated in Table 16.	See Table 16
HDF5 Group	LEVEL-1C	HDF5 group containing the LEVEL-1C data and metadata. The structure and content of this group is elaborated in Table 17.	See Table 17
HDF5 Attribute	ACQUISITION_STATION	Identifier for the data reception station (i.e., Kiruna or Fairbanks).	String
HDF5 Attribute	BOTTOM_LEFT_LATITUDE	The latitude of the bottom-left point of the bounding box [º].	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_LONGITUDE	The longitude of the bottom-left point of the bounding box [º].	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_LATITUDE	The latitude of the bottom-right point of the bounding box [º].	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_LONGITUDE	The longitude of the bottom-right point of the bounding box [º].	32-bit floating-point
HDF5 Attribute	CAMERA	Camera identifier. Possible values are: “LEFT” for the left camera (camera 1), “CENTER” for the center camera (camera 2), “RIGHT” for the right camera (camera 3)	String
HDF5 Attribute	DATELINE_CROSSING	Flag indicating whether or not the segment is crossing the dateline (180° border).	String
HDF5 Attribute	DAY_NIGHT_FLAG	Indicating whether or not the segment is a day segment or taken at night.	String
HDF5 Attribute	DEFECT_PIXELMAP_ID	Field identifying the defect pixel map.	32-bit integer
HDF5 Attribute	DESCRIPTION	Short description of the file content, i.e. “PROBA-V LEVEL-1C product”.	String
HDF5 Attribute	INSTRUMENT	Short name for the instrument, i.e. VEGETATION.	String
HDF5 Attribute	NORTHPOLE_INDICATOR	Flag indicating whether or not the segment is covering the north pole.	String
HDF5 Attribute	NUMBER_OF_STRIPS	The number of strips this product contains. This value is typically set to 6.	32-bit integer

Type	Name	Description	Data type
HDF5 Attribute	OBSERVATION_END_DATE	The observation end date (UTC) of the segment. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_END_TIME	The observation end time (UTC) of the segment. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	OBSERVATION_START_DATE	The observation start date (UTC) of the segment. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_START_TIME	The observation start time (UTC) of the segment. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	OVERPASS_NUMBER	The overpass number.	32-bit integer
HDF5 Attribute	PLATFORM	Short name for the platform and its serial number, i.e. PROBA-1.	String
HDF5 Attribute	PROCESSING_DATE	The date the product was generated. The format is: YYYY-MM-DD.	String
HDF5 Attribute	PROCESSING_TIME	The time the product was generated. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	PRODUCT_REFERENCE	A unique textual reference to the product (type: string). This string has following syntax: RawSegment_PROBAV#<CAMERA>_<YYYYMMDD><hhmmss>_LEVEL-1C_V<VERSION> Where: <CAMERA>: identifier for the camera (1, 2 or 3) <YYYYMMDD>: the observation start date <hhmmss>: the start observation start time <VERSION>: the version identifier (three digits)	String
HDF5 Attribute	ROI_IDENTIFIER	Identifier for the Region Of Interest. If the LEVEL-1C product is a full swath product, it contains the value “FULL_SWATH”.	String
HDF5 Attribute	SOUTHPOLE_INDICATOR	Flag indicating whether or not the segment is covering the south pole.	String
HDF5 Attribute	TOP_LEFT_LATITUDE	The latitude of the top-left point of the bounding box [°].	32-bit floating-point
HDF5 Attribute	TOP_LEFT_LONGITUDE	The longitude of the top-left point of the bounding box [°].	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_LATITUDE	The latitude of the top-right point of the bounding box [°].	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_LONGITUDE	The longitude of the top-right point of the bounding box [°].	32-bit floating-point

Table 15: HDF5 structure of LEVEL1A Group

Type	Name	Description
HDF5 Group	PLATFORM	HDF5 group containing the platform data and ancillary data that is applicable for

Type	Name	Description
		this segment. The content and structure of this group is elaborated in Table 16.
HDF5 Group	BLUE	HDF5 group containing the instrument data and metadata for the BLUE strip.The structure and content of this group is elaborated in Table 17.
HDF5 Group	NIR	HDF5 group containing the instrument data and metadata for the NIR strip. The structure and content of this group is elaborated in Table 17.
HDF5 Group	RED	HDF5 group containing the instrument data and metadata for the RED strip. The structure and content of this group is elaborated in Table 17.
HDF5 Group	SWIR1	HDF5 group containing the instrument data and metadata for the SWIR1 strip. The structure and content of this group is elaborated in Table 17.
HDF5 Group	SWIR2	HDF5 group containing the instrument data and metadata for the SWIR2 strip. The structure and content of this group is elaborated in Table 17.
HDF5 Group	SWIR3	HDF5 group containing the instrument data and metadata for the SWIR3 strip. The structure and content of this group is elaborated in Table 17.

Table 16: HDF5 structure of PLATFORM Group

Type	Name	Description	Data type
HDF5 Table	ATT	Table containing the attitude-related data with a frequency of 4 Hz. The table consists of the following fields: • MJD: the Modified Julian Date in TAI (Temps Atomique International). • QW: the first quaternion (BodyFixed frame (BOF) to Celestial frame (CEL). • QX: the second quaternion (BodyFixed frame (BOF) to Celestial frame. • QY: the third quaternion (BodyFixed frame (BOF) to Celestial frame. • QZ: the fourth quaternion (BodyFixed frame (BOF) to Celestial frame. The table contains following attributes: • FREQUENCY: the frequency [Hz] at which the ATT data is generated. • VERSION: the version number. Every field of the table contains following attributes: • DESCRIPTION: short description of the field content • NAME: the name of the field • UNITS: the units or "-" in case no units are available.	64-bit floating point 64-bit floating point 64-bit floating point 64-bit floating point 64-bit floating point 32-bit floating point String String String string
HDF5 Table	OBET_ GPS	Table containing the time correlation data between on Board Elapsed Time (OBET) and GPS with a frequency of 1 Hz. The table consists of following fields: • OBET: the OBET time [s] • GPS_WEEK: the GPS week • GPS_SECONDS: the GPS second time [s]	64-bit floating point 64-bit floating point 16-bit integer 64-bit floating

		The table contains the following attributes: • FREQUENCY: the frequency [Hz] at which the time correlation related data is generated. • VERSION: the version number. Every field of the table contains the following attributes: • DESCRIPTION: short description of the field content • NAME: the name of the field • UNITS: the units or "-" in case no units are available.	point 32-bit floating point String String String String
HDF5 Table	OBET_VI	Table containing the time correlation data between OBET and VI (Vegetation Instrument) with a frequency of 1 Hz. The table consists of following fields: • OBET: the OBET time [s]. • VI: the VI time [s]. The table contains following attributes: • FREQUENCY: the frequency [Hz] at which the time correlation related data is generated. Every field of the table contains following attributes: • DESCRIPTION: short description of the field content . • NAME: the name of the field. • UNITS: the units or "-" in case no units are available.	64-bit floating point 64-bit floating point 32-bit floating point String String string
HDF5 Table	PRM	Table including any housekeeping telemetry generated by the Vegetation Instrument. The data has a frequency of 1 Hz. The table consists of following fields: • MJD: the Modified Julian Date in TAI [d] (Temps Atomique International, data type: 64-bit floating-point). • TIME_OUT_ECLIPSE: the time since out of eclipse (delta) [s]. The special value 0 means in eclipse and the value -1 means NO VALUE. • VI_1 : VI Temperature TMA of left spectral imager. • VI_2 : VI Temperature TMA of central spectral imager. • VI_3 : VI Temperature TMA of right spectral. • VI_4 : VI parameter 4 TBD. • VI_5: VI parameter 5 TBD. • VI_6: VI parameter 6 TBD. • VI_7: VI parameter 7 Temperature: Optical bench near star tracker. • VI_8: VI parameter 8 Temperature: Left SWIR detector. • VI_9: VI parameter 9 Temperature: Central SWIR detector. • VI_10: VI parameter 10 Temperature: Right SWIR detector. • VI_11: VI parameter 11 Temperature: Left VNIR detector. • VI_12: VI parameter 12 Temperature: Central VNIR detector. • VI_13: VI parameter 13 Temperature: Right VNIR detector • VI_14: VI parameter 14 Temperature: Left flexure. • VI_15: VI parameter 15 Temperature: Central flexure	32-bit unsigned integer (through SPARE_8)

		• VI_16:VI parameter 16 Temperature: Right flexure • SPARE_1: spare parameter TBD. • SPARE_2: spare parameter TBD. • SPARE_3: spare parameter TBD. • SPARE_4: spare parameter TBD. • SPARE_5: spare parameter TBD. • SPARE_6: spare parameter TBD. • SPARE_7: spare parameter TBD. • SPARE_8: spare parameter TBD. • SPARE_9: spare parameter TBD. • SPARE_10: spare parameter TBD. • SPARE_11: spare parameter TBD. • SPARE_12: spare parameter TBD. • SPARE_13: spare parameter TBD. • SPARE_14: spare parameter TBD. • SPARE_15: spare parameter TBD. • SPARE_16: spare parameter TBD. The table contains following attributes: • FREQUENCY: the frequency [Hz]. • PACKET_EDITION: the packet edition. • VERSION: the current version. Every field of the table contains following attributes: • DESCRIPTION: short description of the field content . • NAME: the name of the field. • UNITS: the units.	64-bit unsigned integer (through SPARE_16) 32-bit unsigned integer 32-bit unsigned integer String String String string
HDF5 Table	PV	Table containing the position and velocity related data with a frequency of 1 Hz. The table consists of the following fields: • MJD: the Modified Julian Date in TAI (Temps Atomique International). • PX: the position in the X direction in the Terrestrial frame (TER) [m]. • PY: the position in the Y direction in the Terrestrial frame (TER) [m]. • PZ: the position in the Z direction in the Terrestrial frame (TER) [m]. • VX: the velocity in the X direction in the Terrestrial frame (TER) [m s^{-1}]. • VY: the velocity in the Y direction in the Terrestrial frame (TER) [m s^{-1}]. • VZ: the velocity in the Z direction in the Terrestrial frame (TER) [m s^{-1}]. The table contains following attributes: • FREQUENCY: the frequency [Hz] at which the PV data is generated. • VERSION: the version number. Every field of the table contains following attributes: • DESCRIPTION: short description of the field content. • NAME: the name of the field.	64-bit floating point (through VZ) 32-bit floating point String String

		• UNITS: the units.	String string

Table 17: HDF5 structure of LEVEL1A STRIP (BLUE, RED, NIR, SWIR1, SWIR2, and SWIR3) Groups

Type	Name	Description	Data type
HDF5 Table	BLOCKDATA	Table containing the block related data. The table consists of following fields: • MJD: the Modified Julian Date in TAI (Temps Atomique International), [d]. • INTEGRATION_TIME: the integration time [s] • TEMPERATURE: the temperature [º C] () • DARK_PIXEL_1: the dark pixel value for pixel 3 • DARK_PIXEL_2: the dark pixel value for pixel 4 • DARK_PIXEL_3: the dark pixel value for pixel 5997 • DARK_PIXEL_4: the dark pixel value for pixel 5998 Each field contains following attributes: • DESCRIPTION: short description of the field content • NAME: the name of the field • UNITS: the units **Note:** there are no BLOCKDATA dataset for the SWIR strips (SWIR1, SWIR2, SWIR3)	 64-bit floating-point 32-bit floating point 32-bit floating-point 16-bit integer 16-bit integer 16-bit integer 16-bit integer string string string

HDF5 Table	LINEDATA	Table containing the line related data. The table consists of the following fields:
		• MJD: the Modified Julian Date in TAI (Temps Atomique International) [d] associated with the centre of the integration period.
		• LINE_QUALITY: line flag indicating whether a line is :
		  ▪ good (flag = 0)
		  ▪ bad (flag = 1)
		  ▪ missing (flag = 2)
		• INTEGRATION_TIME: the integration time [s]
		• TIME_OUT_ECLIPSE: the time since out of eclipse (delta) [s]. The special value “0” means in eclipse and the value “-9999” means NO_DATA.
		• TEMPERATURE: the temperature [º C] (NO_DATA = -9999)
		
		Further, every field of the table contains following attributes:
		• DESCRIPTION: short description of the
			
			64-bit floating-point
			
			32-bit integer
			
			32-bit floating-point
			32-bit integer
			
			32-bit floating-point
			
			String

Type	Name	Description	Data type
		field content (data type: string) • NAME: the name of the field NO_DATA: the "no data" value. This attribute is optional in case no "no data" value is applicable for the field. • UNITS: the used units	String NO_DATA: 32-bit integer or float string
HDF5 Dataset	DN	Dataset containing the digital numbers (extracted from the raw data). Table 18 lists the metadata items attached to this dataset.	16-bit integer
HDF5 Attribute	COMPRESSION_RATIO	The used compression ratio.	32-bit floating-point
HDF5 Attribute	DETECTOR	Identifier for the detector. Possible values are: VNIR, SWIR	String
HDF5 Attribute	GAIN_FACTOR	The gain factor.	32-bit floating-point
HDF5 Attribute	LINE_END	The end line of the bottom-right pixel value in the image.	32-bit integer
HDF5 Attribute	LINE_START	The start line of the top-left pixel value (0, 0) in the image. In case the image contains the full swatch, this value is set to 0.	32-bit integer
HDF5 Attribute	OBSERVATION_END_DATE	The observation end date (UTC), i.e. the date of the last line of the strip. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_END_TIME	The observation end time (UTC), i.e., the time of the last line of the strip. The format is: hh:mm:ss.μμμμμμ.	String
HDF5 Attribute	OBSERVATION_START_DATE	The observation start date (UTC), i.e., the date of the first line of the strip. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_START_TIME	The observation start time (UTC), i.e., the time of the first line of the strip. The format is: hh:mm:ss.μμμμμμ.	String
HDF5 Attribute	PIXEL_END	The end index of the bottom-right pixel value in the image. In case the image contains the full swath, this value is set to: 5199 for the VNIR strips 1023 for the SWIR strips	32-bit integer
HDF5 Attribute	PIXEL_START	The start index of the top-left pixel value (0, 0) in the image. In case the image contains the full swatch, this value is set to 0.	32-bit integer
HDF5 Attribute	STRIP	Identifier for the strip. Possible values are: BLUE, RED, NIR, SWIR1 (left SWIR strip), SWIR2 (center SWIR strip), SWIR3 (right SWIR strip)	String

Table 18: HDF5 metadata items for DN datasets

Type	Name	Description	Data type
HDF5 Attribute	DESCRIPTION	Description of the DN dataset name.	String
HDF5 Attribute	MAPPING	The mapping information, consisting of following values: • **<proj_id>**: the projection ID (e.g. "Geographic	String

Type	Name	Description	Data type
		Lat/Lon") • **<x_m>**: A value indicating whether the map X coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<y_m>**: A value indicating whether the map Y coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<x_start>**: the X coordinate of the upper-left pixel. • **<y_start>**: the Y coordinate of the upper-left pixel. • **<x_res>**: the spatial resolution in the X direction. • **<y_res>**: the spatial resolution in the Y direction. • **<datum>**: the projection's datum (in case of unprojected image, the value is '-'). • **<units>**: the projection's unit (in case of an unprojected image, the value is '-'). Note that his is an optional attribute. If not provided, it is assumed that no geographical information is attached to the dataset.	
HDF5 Attribute	NO_DATA	Indicates the "no data" value of the dataset. See §5.6.1 for the no data values.	32-bit floating-point
HDF5 Attribute	OFFSET	OFFSET values (see SCALE attribute)	32-bit floating-point
HDF5 Attribute	SCALE	The coding information, indicating that the pixels have been scaled with a given scale and offset according to following formula: DN = OFFSET + (PV * SCALE) • The scale factor • The offset factor The physical value is determined as PV = (DN-OFFSET) / SCALE.	32-bit floating-point

Table 19: HDF5 structure of LEVEL1B group

Type	Name	Description	Data type
HDF5 Table	CONTOUR	Table containing the contour points of the segment. The table contains two fields: • The longitude values of the segment's contour. • The latitude values of the segment's contour. This contour is the contour that encloses all the strip contours.	32-bit floating point
HDF5 Group	BLUE	HDF5 group containing the instrument data and metadata for the BLUE strip. The structure and content of this group is elaborated in Table 20.	See Table 20
HDF5 Group	NIR	HDF5 group containing the instrument data and metadata for the NIR strip. The structure and content of this group is elaborated in Table 20.	See Table 20
HDF5 Group	RED	HDF5 group containing the instrument data and metadata for the RED strip. The structure and content of this group is elaborated in	See Table 20

Type	Name	Description	Data type
		Table 20.	
HDF5 Group	SWIR1	HDF5 group containing the instrument data and metadata for the SWIR1 strip. The structure and content of this group is elaborated in Table 20.	See Table 20
HDF5 Group	SWIR2	HDF5 group containing the instrument data and metadata for the SWIR2 strip. The structure and content of this group is elaborated in Table 20.	See Table 20
HDF5 Group	SWIR3	HDF5 group containing the instrument data and metadata for the SWIR3 strip. The structure and content of this group is elaborated in Table 20.	See Table 20
HDF5 Attribute	ICP_REFERENCE	Reference to the used geometric ICP file. This string has the following syntax: PROBAV_ICP_GEOMETRIC#{LEFT|RIGHT|CENTER}_<StartDate>_V<Revision>	String
HDF5 Attribute	LEAPSECONDS	Leap second =TAI-UTC [s].	32-bit floating point
HDF5 Attribute	POLARMOTION_ DELTA_UT1	The difference between UT1 and UTC (UT1-UTC), [s].	32-bit floating point
HDF5 Attribute	POLARMOTION_X	The X position of the Celestial Intermediate Pole (CIP) and the Celestial/Terrestrial Ephemeris Origins (CEO, TEO) in the Geocentric Celestial Reference System (GCRS) and International Terrestrial Reference System (ITRS) [sec].	32-bit floating point
HDF5 Attribute	POLARMOTION_Y	The Y position of the Celestial Intermediate Pole (CIP) and the Celestial/Terrestrial Ephemeris Origins (CEO, TEO) in the Geocentric Celestial Reference System (GCRS) and International Terrestrial Reference System (ITRS) [sec].	32-bit floating point
HDF5 Attribute	PROCESSINGINFO_ GEOMODELLING	Reference to the used geo-modelling tool, e.g. “GEOMODELLING V1.0”.	String
HDF5 Attribute	SUN_BETA_ANGLE	The sun beta angle [°].	32-bit floating point

Table 20: HDF5 structure of LEVEL1B STRIP (BLUE, NIR, RED, SWIR1, SWIR2, and SWIR3) Groups.

Type	Name	Description	Data type
HDF5 Table	CONTOUR	Table containing the contour points of the strip. The table contains: • Longitude, the longitude values of the segment's contour • Latitude, the latitude values of the segment's contour	32-bit floating point
HDF5 Dataset	LN1	Dataset containing the longitude at 0 m altitude. Table 21 lists the metadata items specific for this dataset.	32-bit floating-point
HDF5 Dataset	LN2	Dataset containing the longitude at 5000 m altitude. Table 21 lists the metadata items specific for this dataset.	32-bit floating-point
HDF5 Dataset	LT1	Dataset containing the latitude at 0 m altitude. Table 21 lists the metadata items specific for this dataset.	32-bit floating-point
HDF5 Dataset	LT2	Dataset containing the latitude at 5000 m altitude. Table 21 lists the metadata items specific for this dataset.	32-bit floating-point
HDF5 Dataset	SAA	Dataset containing the solar azimuth angles. Table 21 lists the metadata items specific for this dataset.	8-bit unsigned integer
HDF5 Dataset	SZA	Dataset containing the solar SZA. Table 21 lists the metadata items specific for this dataset.	8-bit unsigned integer
HDF5 Dataset	VAA	Dataset containing the viewing azimuth angles. Table 21 lists the metadata items specific for this dataset.	8-bit unsigned integer
HDF5 Dataset	VZA	Dataset containing the VZA. Table 21 lists the metadata items specific for this dataset.	8-bit unsigned integer
HDF5 Attribute	BOTTOM_LEFT_ CORNER_ LATITUDE	The latitude of the bottom-left corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_ CORNER_ LONGITUDE	The longitude of the bottom-left corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_ CORNER_X	The X position of the bottom-left corner point of the strip.	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_ CORNER_Y	The Y position of the bottom-left corner point of the strip.	32-bit floating-point
HDF5 Attribute	BOTTOM_ RIGHT_CORNER_ LATITUDE	The latitude of the bottom-right corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_ CORNER_ LONGITUDE	The longitude of the bottom-right corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	BOTTOM_ RIGHT_CORNER_ X	The X position of the bottom-right corner point of the strip.	32-bit floating-point
HDF5 Attribute	BOTTOM_ RIGHT_CORNER_Y	The Y position of the bottom-right corner point of the strip.	32-bit floating-point
HDF5 Attribute	CENTER_ LATITUDE	The latitude of the center point of the strip [°].	32-bit floating-point
HDF5 Attribute	CENTER_ LONGITUDE	The longitude of the center point of the strip [°].	32-bit floating-point
HDF5 Attribute	CENTER_X	The X position of the center point of the strip.	32-bit floating-point
HDF5 Attribute	CENTER_Y	The Y position of the center point of the strip.	32-bit floating-point
HDF5 Attribute	DETECTOR	Identifier for the detector. Possible values are: VNIR, SWIR	String
HDF5 Attribute	OBSERVATION_ END_DATE	The observation end date (UTC), i.e., the date of the last line of the strip. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_	The observation end time (UTC), i.e. the time of the last	String

Type	Name	Description	Data type
	END_TIME	line of the strip. The format is: hh:mm:ss.μμμμμμ.	
HDF5 Attribute	OBSERVATION_ START_DATE	The observation start date (UTC), i.e., the date of the first line of the strip. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_ START_TIME	The observation start time (UTC), i.e., the time of the first line of the strip. The format is: hh:mm:ss.μμμμμμ.	String
HDF5 Attribute	STRIP	Identifier for the strip. Possible values are: BLUE, RED, NIR, SWIR1 (left SWIR strip), SWIR2 (center SWIR strip), SWIR3 (right SWIR strip).	String
HDF5 Attribute	TOP_LEFT_ CORNER_ LATITUDE	The latitude of the top-left corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	TOP_LEFT_ CORNER_ LONGITUDE	The longitude of the top-left corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	TOP_LEFT_ CORNER_X	The X position of the top-left corner point of the strip.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_ CORNER_Y	The Y position of the top-left corner point of the strip.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_ CORNER_ LATITUDE	The latitude of the top -right corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_ CORNER_ LONGITUDE	The longitude of the top-right corner point of the strip [°].	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_ CORNER_X	The X position of the top-right corner point of the strip.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_ CORNER_Y	The Y position of the top-right corner point of the strip.	32-bit floating-point

Table 21: HDF5 metadata items for L1B datasets

Type	Name	Description	Data type
HDF5 Attribute	DESCRIPTION	Description of the dataset.	String
HDF5 Attribute	MAPPING	The mapping information, consisting of following values: • **<proj_id>**: the projection ID (e.g. "Geographic Lat/Lon") • **<x_m>**: A value indicating whether the map X coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<y_m>**: A value indicating whether the map Y coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<x_start>**: the X coordinate of the upper-left pixel. • **<y_start>**: the Y coordinate of the upper-left pixel. • **<x_res>**: the spatial resolution in the X direction. • **<y_res>**: the spatial resolution in the Y direction. • **<datum>**: the projection's datum (in case of unprojected image, the value is '-'). • **<units>**: the projection 's unit (in case of unprojected image, the value is '-'). Note that his is an optional attribute. If not provided, it is assumed that no geographical information is attached to the dataset.	String
HDF5 Attribute	NO_DATA	Indicates the "no data" value of the dataset.	String

Type	Name	Description	Data type
		Typically, this value is set to "-9999". This attribute is optional, meaning that in case the attribute is not present, no "no data" value is applicable for the dataset.	
HDF5 Attribute	OFFSET	OFFSET values (see SCALE attribute)	32-bit floating-point
HDF5 Attribute	SCALE	The coding information, indicating that the pixels have been scaled with a given scale and offset according to following formula: DN = OFFSET + (PV * SCALE) • The scale factor • The offset factor The physical value is determined as PV = (DN - OFFSET)/SCALE.	32-bit floating-point
HDF5 Attribute	UNIT	Unit type of the dataset (if not applicable the values '-' is used)	String

Table 22: HDF5 structure of LEVEL-1C group.

Type	Name	Description	Data type
HDF5 Group	BLUE	HDF5 group containing the instrument data and metadata for the BLUE strip. The structure and content of this group is elaborated in Table 23.	See Table 22.
HDF5 Group	NIR	HDF5 group containing the instrument data and metadata for the NIR strip. The structure and content of this group is elaborated in Table 23.	See Table 22.
HDF5 Group	RED	HDF5 group containing the instrument data and metadata for the RED strip. The structure and content of this group is elaborated in Table 23.	See Table 22.
HDF5 Group	SWIR1	HDF5 group containing the instrument data and metadata for the SWIR1 strip. The structure and content of this group is elaborated in Table 23.	See Table 22.
HDF5 Group	SWIR2	HDF5 group containing the instrument data and metadata for the SWIR2 strip. The structure and content of this group is elaborated in Table 23.	See Table 22.

HDF5 Group	SWIR3	HDF5 group containing the instrument data and metadata for the SWIR3 strip. The structure and content of this group is elaborated in Table 23.	See Table 22.
HDF5 Attribute	ICP_REFERENCE	Reference to the used radiometric ICP file. This string has following syntax: PROBAV_ICP_RADIOMETRIC#{LEFT|RIGHT|CENTER}_<StartDate>_V<Revision>	String
HDF5 Attribute	PROCESSINGINFO_RADIOMODELLING	Reference to the used radio modelling tool.	String

Table 23: HDF5 structure of LEVEL-1C STRIP (BLUE, NIR, RED, SWIR1, SWIR2, and SWIR3) Groups

Type	Name	Description	Data type
HDF5 Dataset	Q	Dataset containing the quality indicator values. Every pixel is decoded in an 8-bit integer value. • status = 0 'Correct': no issues • status = 1 'Missing': the pixel value is missing due to a bad detector • status = 2 'WasSaturated' : the value DN of the pixel is equal to 4095 (coded in 12 bits = 2^12-1) • status = 3 'BecameSaturated' : during the calculation of the TOA reflectance, the value becomes higher than 4095 • status = 4 'BecameNegative' : during the calculation of the TOA reflectance, the value becomes lower than 0 • status = 5 'Interpolated' : the value of the radiance of the pixel is interpolated using the neighbour pixels • status = 6 'BorderCompressed': the quality of theses pixels of a strip are uncertain due to on-board compression artefacts. Table 24 lists the metadata items specific for this dataset.	See Table 24
HDF5 Dataset	TOA	Dataset containing the Top-Of-Atmosphere (TOA) reflectance values. Table 24 lists the metadata items specific for this dataset.	16-bit integer
HDF5 Attribute	DETECTOR	Identifier for the detector. Possible values are: VNIR, SWIR	String
HDF5 Attribute	OBSERVATION_END_DATE	The observation end date (UTC), i.e. the date of the last line of the strip. The format is: YYYY-MM-DD.	String

Type	Name	Description	Data type
HDF5 Attribute	OBSERVATION_END_TIME	The observation end time (UTC), i.e. the time of the last line of the strip. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	OBSERVATION_START_DATE	The observation start date (UTC), i.e. the date of the first line of the strip. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_START_TIME	The observation start time (UTC), i.e. the time of the first line of the strip. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	SOLAR_IRRADIANCE	The solar Top-Of-Atmosphere irradiance [W m^{-2}].	32-bit floating point
HDF5 Attribute	STRIP	Identifier for the strip. Possible values are: BUE, RED, NIR, SWIR1 (left SWIR strip), SWIR2 (center SWIR strip), SWIR3 (right SWIR strip)	String

Table 24: HDF5 metadata items for the LEVEL-1C attributes

Type	Name	Description	Data type
HDF5 Attribute	DESCRIPTION	Short description of the dataset.	String
HDF5 Attribute	MAPPING	The mapping information, consisting of following values: • **<proj_id>**: the projection ID (e.g. “Geographic Lat/Lon”) • **<x_m>**: A value indicating whether the map X coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<y_m>**: A value indicating whether the map Y coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<x_start>**: the X coordinate of the upper-left pixel. • **<y_start>**: the Y coordinate of the upper-left pixel. • **<x_res>**: the spatial resolution in the X direction. • **<y_res>**: the spatial resolution in the Y direction. • **<datum>**: the projection‘s datum (in case of unprojected image, the value is ‘-’). • **<units>**: the projection ‘s unit (in case of unprojected image, the value is ‘-’). Note that his is an optional attribute. If not provided, it is assumed that no geographical information is attached to the dataset.	String
HDF5 Attribute	NO_DATA	The no data value.	32-bit floating-point
HDF5 Attribute	OFFSET	The offset factor. The physical value (PV) is calculated as PV = (DN-offset)/scale (DN = digital number)	32-bit floating-point
HDF5 Attribute	SCALE	The scale factor. The physical value (PV) is calculated as PV = (DN-offset)/scale (DN = digital number)	32-bit floating-point
HDF5 Attribute	UNITS	The units.	String

Appendix B2: Detailed Level-2A HDF5 Product file description

Below follows a detailed description of the various Groups, Datasets, and Attributes of Level-2A files is given. Reference is made to Figure 12, in which the HDF5 dataset structure is visualised.

Table 25: HDF5 structure of Level-2A file

Type	Name	Description	Data type
HDF5 Group	LEVEL-2A	HDF5 “root” group containing the Level-2A TOA/TOC data and metadata. The structure and content of this group is elaborated in Table 33.	-
HDF5 Attribute	ACQUISITION_ STATION	Name of the acquisition station, default value is ‘Kiruna’.	String
HDF5 Attribute	CAMERA	Camera identifier. Possible values are: “LEFT” for the left camera (camera 1), “CENTER” for the center camera (camera 2), “RIGHT” for the right camera (camera 3)	String
HDF5 Attribute	DATELINE_ CROSSING	Flag indicating whether or not the segment is crossing the International Dateline.	String
HDF5 Attribute	DAY_NIGHT_FLAG	Indicating whether or not the segment is a day segment or taken at night.	String
HDF5 Attribute	DESCRIPTION	Short description of the file content, e.g. PROBA-V Level2A S1 Top-Of-Atmosphere product at 1 km	String
HDF5 Attribute	INSTRUMENT	Short name for the instrument, i.e., VEGETATION.	String
HDF5 Attribute	MAP_PROJECTION_ FAMILY	The family to which the projection belongs.	String
HDF5 Attribute	MAP_PROJECTION_ NAME	The full name of the projection.	String
HDF5 Attribute	MAP_PROJECTION_ REFERENCE	A unique reference (EPSG code) of the projection. An example is EPSG:4326.	String
HDF5 Attribute	MAP_PROJECTION_ UNITS	The units of the projection. Possible values are: DEGREES, METERS	String
HDF5 Attribute	MAP_PROJECTION_ WKT	The projection WKT string.	String
HDF5 Attribute	NORTHPOLE_ INDICATOR	Flag indicating whether or not the segment is covering the north pole.	String
HDF5 Attribute	OBSERVATION_ END_DATE	The observation end date (UTC) of the segment. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_ END_TIME	The observation end time (UTC) of the segment. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	OBSERVATION_ START_DATE	The observation start date (UTC) of the segment. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_ START_TIME	The observation start time (UTC) of the segment. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	OVERPASS_ NUMBER	The overpass number since launch.	32-bit integer

Type	Name	Description	Data type
HDF5 Attribute	PLATFORM	Short name for the platform and its serial number, i.e. PROBA-1.	String
HDF5 Attribute	PROCESSING_DATE	The date the product was generated. The format is: YYYY-MM-DD.	String
HDF5 Attribute	PROCESSING_TIME	The time the product was generated. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	PRODUCT_ REFERENCE	A unique textual reference to the product. This string has following syntax: Segment_PROBAV#<YYYYMMDDhhmmss>_<LEVEL>_<RESOLUTION>_V<VERSION> Where: <YYYYMMDDhhmmss> is the start observation date and time; <LEVEL> is L2A, <RESOLUTION> is the spatial resolution of the data, and <VERSION> is the version identifier (three digits).	String
HDF5 Attribute	SYNTHESIS_PERIOD	The synthesis period. Following values are possible: 1: for a daily synthesis, 10: for a 10-day synthesis	32-bit integer
HDF5 Attribute	SOUTHPOLE_INDICATOR	Flag indicating whether or not the segment is covering the south pole.	String

Table 26: HDF5 structure of LEVEL-2A Root Group

Type	Name	Description	Data type
HDF5 Group	GEOMETRY	HDF5 group containing the geometry data for the segment. The structure and content of this group is elaborated in Table 34.	
HDF5 Group	QUALITY	HDF5 group containing the quality data for the segment. The structure and content of this group is elaborated in Table 36.	
HDF5 Group	RADIOMETRY	HDF5 group containing the radiometry data for the segment. The structure and content of this group is elaborated in Table 37.	
HDF5 Attribute	GEOMETRIC_ICP_REFERENCE	Reference to the used geometric ICP file. This string has the following syntax: PROBAV_ICP_GEOMETRIC#{LEFT|RIGHT|CENTER}_<StartDate>_V<Revision>	String
HDF5 Attribute	PROCESSINGINFO_ CLOUDICESNOW_ DETECTION	Reference to the used cloud, snow and ice detection algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ GEOMODELLING	Reference to the used geo modelling algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ MAPPING	Reference to the used mapping algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ MOSAIC	Reference to the used mosaicking algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ RADIOMODELLING	Reference to the used radio modelling algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ SHADOWDETECTION	Reference to the used shadow detection algorithm version.	String

Type	Name	Description	Data type
HDF5 Attribute	RADIOMETRIC_ICP_REFERENCE	Reference to the used radiometric ICP file. This string has following syntax: PROBAV_ICP_RADIOMETRIC#{LEFT|RIGHT|CENTER}_<StartDate>_V<Revision>	String

Table 27: HDF5 structure of GEOMETRY group

Type	Name	Description	Data type
HDF5 Group	SWIR	HDF5 group containing the data and metadata for the SWIR detector. This group contains two datasets: • **VAA**: dataset containing the viewing azimuth angles. Every pixel is decoded in an 8-bit unsigned integer value. • **VZA**: dataset containing the viewing zenith angles. Every pixel is decoded in an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset.	-
HDF5 Group	VNIR	HDF5 group containing the data and metadata for the VNIR detector. This group contains two datasets: • **VAA**: dataset containing the viewing azimuth angles. Every pixel is decoded in an 8-bit unsigned integer value. • **VZA**: dataset containing the viewing zenith angles. Every pixel is decoded in an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset	-
HDF5 Dataset	CONTOUR	Compound dataset containing latitude and longitude information.	
HDF5 Dataset	SAA	Dataset containing the solar azimuth angles. Every pixel is decoded as an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset.	-
HDF5 Dataset	SZA	HDF5 dataset containing the SZA. Every pixel is decoded as an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset.	-
HDF5 Attribute	BOTTOM_LEFT_LATITUDE	The latitude of the bottom-left point of the segment.	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_LONGITUDE	The longitude of the bottom-left point of the segment.	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_X	The X coordinate of the bottom-left point of the cartographic bounding	32-bit floating-point

Type	Name	Description	Data type
		box of the segment.	
HDF5 Attribute	BOTTOM_LEFT_Y	The Y coordinate of the bottom-left point of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_LATITUDE	The latitude of the bottom-right point of the segment.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_LONGITUDE	The longitude of the bottom-right point of the segment.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_X	The X coordinate of the bottom-right point of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_Y	The Y coordinate of the bottom-right point of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	CENTER_LATITUDE	The latitude of the center point of the geographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	CENTER_LONGITUDE	The longitude of the center point of the geographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	CENTER_X	The center point in X direction of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	CENTER_Y	The center point in Y direction of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_LATITUDE	The latitude of the top-left point of the segment.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_LONGITUDE	The longitude of the top-left point of the segment.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_X	The X - coordinate of the top-left point of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_Y	The Y - coordinate of the top-left point of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_LATITUDE	The latitude of the top-right point of the segment.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_LONGITUDE	The longitude of the top-right point of the segment.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_X	The X - coordinate of the top-right point of the cartographic bounding box of the segment.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_Y	The Y - coordinate of the top-right point of the cartographic bounding box of the segment.	32-bit floating-point

Table 28: HDF5 structure of QUALITY Group

<table>
<tr><th>Type</th><th>Name</th><th>Description</th><th>Data type</th></tr>
<tr><td>HDF5 Dataset</td><td>SM</td><td>Dataset containing the quality flags and status pixels.
<table>
<tr><th>Bit (LSB to MSB)</th><th>Description</th><th>Value</th><th>Key</th></tr>
<tr><td>0-2</td><td>Cloud/Ice Snow/Shadow Flag</td><td>000
001
010
011
100</td><td>Clear
Shadow
Undefined
Cloud
Ice</td></tr>
<tr><td>3</td><td>Land/Sea</td><td>0
1</td><td>Sea
Land</td></tr>
<tr><td>4</td><td>Radiometric quality SWIR flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>5</td><td>Radiometric quality NIR flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>6</td><td>Radiometric quality RED flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>7</td><td>Radiometric quality BLUE flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>8</td><td>SWIR coverage</td><td>0
1</td><td>No
Yes</td></tr>
<tr><td>9</td><td>NIR coverage</td><td>0
1</td><td>No
Yes</td></tr>
<tr><td>10</td><td>RED coverage</td><td>0
1</td><td>No
Yes</td></tr>
<tr><td>11</td><td>BLUE coverage</td><td>0
1</td><td>No
Yes</td></tr>
</table>
Table 36 lists the metadata items specific for this dataset.</td><td>8-bit unsigned integer</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE _CLOUD</td><td>The percentage cloud.</td><td>32-bit floating-point</td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE _SNOW</td><td>The percentage snow.</td><td>32-bit floating-point</td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE _LAND</td><td>The percentage land.</td><td>32-bit floating-point</td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE _MISSING_ DATA</td><td>The percentage missing data.</td><td>32-bit floating-point</td></tr>
</table>

Table 29: HDF5 structure of RADIOMETRY Group

Type	Name	Description
HDF5 Group	BLUE	HDF5 group containing the radiometry data for BLUE band of the segment. The structure and content of this group is explained in Table 30.
HDF5 Group	NIR	HDF5 group containing the radiometry data for NIR band of the segment. The structure and content of this group is explained in Table 30.
HDF5 Group	RED	HDF5 group containing the radiometry data for RED band of the segment. The structure and content of this group is explained in Table 30
HDF5 Group	SWIR	HDF5 group containing the radiometry data for SWIR band of the segment. The structure and content of this group is explained in Table 30.

Table 30: HDF5 structure of band groups in the RADIOMETRY Group

Type	Name	Description	Data type
HDF5 Dataset	TOA	Dataset containing the TOA reflectances. Table 31 lists the metadata items specific for this dataset.	16-bit integer
HDF5 Attribute	DETECTOR	Identifier for the detector. Possible values are: VNIR, SWIR	String
HDF5 Attribute	GAIN_FACTOR	The gain factor.	32-bit floating-point
HDF5 Attribute	OBSERVATION_END_DATE	The observation end date (UTC), i.e. the date of the last line of the band. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_END_TIME	The observation end time (UTC), i.e. the time of the last line of the band. The format is: hh:mm:ss.μμμμμμ .	String
HDF5 Attribute	OBSERVATION_START_DATE	The observation start date (UTC), i.e. the date of the first line of the band. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_START_TIME	The observation start time (UTC), i.e. the time of the first line of the band. The format is: hh:mm:ss.μμμμμμ.	String
HDF5 Attribute	SOLAR_IRRADIANCE	The solar irradiance at TOA for the respective band.	32-bit floating-point

Table 31: HDF5 metadata items for the L2A datasets

Type	Name	Description	Data type
HDF5 Attribute	DESCRIPTION	Short description of the dataset.	String
HDF5 Attribute	DIMENSION_ LABEL	Lat, lon	String
HDF5 Attribute	DIMENSION_ LIST	Arrays with object references to other datasets.	Variable-length of Object reference
HDF5 Attribute	MAPPING	The mapping information, consisting of following values: • **<proj_id>**: the projection ID (e.g. "Geographic Lat/Lon") • **<x_m>**: A value indicating whether the map X coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<y_m>**: A value indicating whether the map Y coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<x_start>**: the X coordinate of the upper-left pixel. • **<y_start>**: the Y coordinate of the upper-left pixel. • **<x_res>**: the spatial resolution in the X direction. • **<y_res>**: the spatial resolution in the Y direction. • **<datum>**: the projection's datum (in case of unprojected image, the value is '-'). • **<units>**: the projection 's unit (in case of unprojected image, the value is '-'). Note that his is an optional attribute. If not provided, it is assumed that no geographical information is attached to the dataset.	String
HDF5 Attribute	NO_DATA	The no data value. See §5.6.1 for the no data values.	32-bit floating-point
HDF5 Attribute	_FillValue	Same as the NO_DATA attribute.	32-bit floating-point
HDF5 Attribute	OFFSET	The scale factor. The physical value (PV) is calculated as PV = (DN-offset)/scale (DN = Digital Number Count)	32-bit floating-point
HDF5 Attribute	SCALE	The scale factor. The physical value (PV) is calculated as PV = (DN-offset)/scale (DN = Digital Number Count)	32-bit floating-point
HDF5 Attribute	UNITS	The units of the dataset.	String

Appendix B3: Detailed Synthesis (S1/S5/S10) HDF5 product file description

Below follows the detailed description of the various Groups, Datasets, and Attributes of the Synthesis product files. Reference is made to Figure 14, in which the HDF5 dataset structure is visualized.

Table 32: HDF5 structure of Synthesis file

Type	Name	Description	Data type
HDF5 Group	LEVEL3	HDF5 "root" group containing the Level3 TOA/TOC data and metadata. The structure and content of this group is elaborated in Table 33.	-
HDF5 Attribute	DESCRIPTION	Short description of the file content, e.g. PROBA-V Level3 S1 Top-Of-Atmosphere product at 1km	-
HDF5 Attribute	INSTRUMENT	Short name for the instrument, i.e., VEGETATION.	-
HDF5 Attribute	MAP_PROJECTION_FAMILY	The family to which the projection belongs.	String
HDF5 Attribute	MAP_PROJECTION_NAME	The full name of the projection.	String
HDF5 Attribute	MAP_PROJECTION_REFERENCE	A unique reference (EPSG code) of the projection. An example is EPSG:4326.	String
HDF5 Attribute	MAP_PROJECTION_UNITS	The units of the projection. Possible values are: DEGREES, METERS	String
HDF5 Attribute	MAP_PROJECTION_WKT	The projection string.	String
HDF5 Attribute	PLATFORM	Short name for the platform and its serial number, i.e. PROBA-1.	String
HDF5 Attribute	PROCESSING_DATE	The date the product was generated. The format is: YYYY-MM-DD.	String
HDF5 Attribute	PROCESSING_TIME	The time the product was generated. The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	PRODUCT_ REFERENCE	A unique textual reference to the product. This string has following syntax: Synthesis_PROBAV_<YYYYMMDD>_<LEVEL> _ <GRID>_V<VERSION> Where: <YYYYMMDD> is the start observation date; <LEVEL> is 'S1_TOA', 'S1_TOC' or 'S10_TOC'; <GRID> is the spatial resolution; <VERSION> is the version identifier (three digits)	String
HDF5 Attribute	VERSION	Denotes the product version	32-bit integer
HDF5 Attribute	SYNTHESIS_PERIOD	The synthesis period. Following values are possible: 1: daily synthesis, 5: 5-day synthesis, 10: 10-daily synthesis	32-bit integer

Table 33: HDF5 structure of LEVEL3 Root Group

Type	Name	Description	Data type
HDF5 Group	GEOMETRY	HDF5 group containing the geometry data for the synthesis. The structure and content of this group is elaborated in Table 34.	-
HDF5 Group	NDVI	HDF5 group containing the NDVI (Normalized Difference Vegetation Index) data for the synthesis. The structure and content of this group is elaborated in Table 35.	-
HDF5 Group	QUALITY	HDF5 group containing the quality data for the synthesis. The structure and content of this group is elaborated in Table 36.	-
HDF5 Group	RADIOMETRY	HDF5 group containing the radiometry data for the synthesis. The structure and content of this group is elaborated in Table 37.	-
HDF5 Group	TIME	HDF5 group containing the timing data for the synthesis. The structure and content of this group is elaborated in Table 39.	-
HDF5 Attribute	PROCESSINGINFO_ CLOUDICESNOW_ DETECTION	Reference to the used cloud, snow and ice detection algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ COMPOSITING	Reference to the used compositing algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ GEOMODELLING	Reference to the used geo modelling algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ MAPPING	Reference to the used mapping algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ MOSAIC	Reference to the used mosaicking algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ RADIOMODELLING	Reference to the used radio modelling algorithm version.	String
HDF5 Attribute	PROCESSINGINFO_ SHADOWDETECTION	Reference to the used shadow detection algorithm version.	String

Table 34: HDF5 structure of GEOMETRY group

Type	Name	Description	Data type
HDF5 Group	SWIR	HDF5 group containing the data and metadata for the SWIR – detector. This group contains two datasets: • **VAA**: dataset containing the viewing azimuth angles. Every pixel is decoded in an 8-bit unsigned integer value. • **VZA**: dataset containing the viewing zenith angles. Every pixel is decoded in an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset.	
HDF5 Group	VNIReserved	HDF5 group containing the data and metadata for the VNIR detector. This group contains two datasets: • **VAA**: dataset containing the viewing azimuth angles. Every pixel is decoded in an 8-bit unsigned integer value. • **VZA**: dataset containing the viewing zenith angles. Every pixel is decoded in an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset	
HDF5 Dataset	SAA	Dataset containing the solar azimuth angles. Every pixel is decoded as an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset.	
HDF5 Dataset	SZA	HDF5 dataset containing the SZA. Every pixel is decoded as an 8-bit unsigned integer value. Table 40 lists the metadata items specific for this dataset.	
HDF5 Attribute	BOTTOM_LEFT_LATITUDE	The latitude of the bottom-left point of the synthesis.	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_LONGITUDE	The longitude of the bottom-left point of the synthesis.	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_X	The X coordinate of the bottom-left point of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	BOTTOM_LEFT_Y	The Y coordinate of the bottom-left point of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_LATITUDE	The latitude of the bottom-right point of the synthesis.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_LONGITUDE	The longitude of the bottom-right point of the synthesis.	32-bit floating-point
HDF5 Attribute	BOTTOM_RIGHT_X	The X coordinate of the bottom-right point of the cartographic bounding	32-bit floating-point

Type	Name	Description	Data type
		box of the synthesis.	
HDF5 Attribute	BOTTOM_RIGHT_Y	The Y coordinate of the bottom-right point of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	CENTER_LATITUDE	The latitude of the center point of the geographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	CENTER_LONGITUDE	The longitude of the center point of the geographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	CENTER_X	The center point in X direction of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	CENTER_Y	The center point in Y direction of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_LATITUDE	The latitude of the top-left point of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_LONGITUDE	The longitude of the top-left point of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_X	The X - coordinate of the top-left point of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_LEFT_Y	The Y - coordinate of the top-left point of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_LATITUDE	The latitude of the top-right point of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_LONGITUDE	The longitude of the top-right point of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_X	The X - coordinate of the top-right point of the cartographic bounding box of the synthesis.	32-bit floating-point
HDF5 Attribute	TOP_RIGHT_Y	The Y - coordinate of the top-right point of the cartographic bounding box of the synthesis.	32-bit floating-point

Table 35: HDF5 structure of NDVI Group

Type	Name	Description	Data type
HDF5 Dataset	NDVI	Dataset containing the NDVI (Normalized Difference Vegetation Index). Table 40 lists the metadata items specific for this dataset.	8-bit unsigned integer

Table 36: HDF5 structure of QUALITY Group

<table>
<tr><th>Type</th><th>Name</th><th>Description</th><th>Data type</th></tr>
<tr><td>HDF5 Dataset</td><td>SM</td><td>Dataset containing the quality flags and status pixels.
<table>
<tr><th>Bit (LSB to MSB)</th><th>Description</th><th>Value</th><th>Key</th></tr>
<tr><td>0-2</td><td>Cloud/Ice Snow/Shadow Flag</td><td>000
001
010
011
100</td><td>Clear
Shadow
Undefined
Cloud
Ice</td></tr>
<tr><td>3</td><td>Land/Sea</td><td>0
1</td><td>Sea
Land</td></tr>
<tr><td>4</td><td>Radiometric quality SWIR flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>5</td><td>Radiometric quality NIR flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>6</td><td>Radiometric quality RED flag</td><td>0
1</td><td>Bad
Good</td></tr>
<tr><td>7</td><td>Radiometric quality BLUE flag</td><td>0
1</td><td>Bad
Good</td></tr>
</table>
Table 40 lists the metadata items specific for this dataset.</td><td>8-bit unsigned integer</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE_ CLOUD</td><td>The percentage cloud.</td><td>32-bit floating-point</td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE_ SNOW</td><td>The percentage snow.</td><td>32-bit floating-point</td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE_ LAND</td><td>The percentage land.</td><td>32-bit floating-point</td></tr>
<tr><td>HDF5 Attribute</td><td>PERCENTAGE_ MISSING_ DATA</td><td>The percentage missing data.</td><td>32-bit floating-point</td></tr>
</table>

Table 37: HDF5 structure of RADIOMETRY Group

Type	Name	Description
HDF5 Group	BLUE	HDF5 group containing the radiometry data for BLUE band of the synthesis. The structure and content of this group is explained in Table 38.
HDF5 Group	NIR	HDF5 group containing the radiometry data for NIR band of the synthesis. The structure and content of this group is explained in Table 38.
HDF5 Group	RED	HDF5 group containing the radiometry data for RED band of the synthesis. The structure and content of this group is explained in Table 38.
HDF5 Group	SWIR	HDF5 group containing the radiometry data for SWIR band of the synthesis. The structure and content of this group is explained in Table 38.

Table 38: HDF5 structure of band groups in the RADIOMETRY Group

Type	Name	Description	Data type
HDF5 Dataset	TOA or TOC	Dataset containing the Top-Of-Atmosphere reflectance values (TOA) or Top-Of-Canopy reflectance values (TOC). Table 40 lists the metadata items specific for this dataset.	16-bit integer
HDF5 Attribute	DETECTOR	Identifier for the detector (type: string). Possible values are: VNIR, SWIR	String
HDF5 Attribute	GAIN_FACTOR	The gain factor (type: float).	32-bit floating-point
HDF5 Attribute	OBSERVATION_END_DATE	The observation end date (UTC), i.e. the date of the last line of the band (type: string). The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_END_TIME	The observation end time (UTC), i.e. the time of the last line of the band (type: string). The format is: hh:mm:ss.µµµµµµ .	String
HDF5 Attribute	OBSERVATION_START_DATE	The observation start date (UTC), i.e. the date of the first line of the band (type: string). The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_START_TIME	The observation start time (UTC), i.e. the time of the first line of the band (type: string). The format is: hh:mm:ss.µµµµµµ.	String
HDF5 Attribute	SOLAR_IRRADIANCE	The solar irradiance at TOA.	32-bit floating-point

Table 39: HDF5 structure of TIME Group

Type	Name	Description	Data type
HDF5 Dataset	TIME	Dataset containing the start acquisition time of the selected segment, expressed in minutes since the beginning of the synthesis period in UTC. Table 40 lists the metadata items specific for this dataset.	16-bit unsigned integer
HDF5 Attribute	OBSERVATION_END_DATE	The observation end date (UTC) of the synthesis. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_END_TIME	The observation end time (UTC) of the synthesis. The format is: hh:mm:ss.	String
HDF5 Attribute	OBSERVATION_START_DATE	The observation start date (UTC) of the synthesis. The format is: YYYY-MM-DD.	String
HDF5 Attribute	OBSERVATION_START_TIME	The observation start time (UTC) of the synthesis. The format is: hh:mm:ss.	String

Table 40: HDF5 metadata items for the datasets

Type	Name	Description	Data type
HDF5 Attribute	DESCRIPTION	Short description of the dataset.	String
HDF5 Attribute	DIMENSION_ LABEL	Lat, lon	String
HDF5 Attribute	DIMENSION_ LIST	Arrays with object references to other datasets.	Variable-length of Object reference
HDF5 Attribute	MAPPING	The mapping information, consisting of following values: • **<proj_id>**: the projection ID (e.g. "Geographic Lat/Lon") • **<x_m>**: A value indicating whether the map X coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<y_m>**: A value indicating whether the map Y coordinates refer to the top-left corner (0.0) or center (0.5) of the pixel. • **<x_start>**: the X coordinate of the upper-left pixel. • **<y_start>**: the Y coordinate of the upper-left pixel. • **<x_res>**: the spatial resolution in the X direction. • **<y_res>**: the spatial resolution in the Y direction. • **<datum>**: the projection's datum (in case of unprojected image, the value is '-'). • **<units>**: the projection 's unit (in case of unprojected image, the value is '-'). Note that his is an optional attribute. If not provided, it is assumed that no geographical information is attached to the dataset.	String
HDF5 Attribute	NO_DATA	The no data value. See §5.6.1 for the no data values.	64-bit floating-point
HDF5 Attribute	_FillValue	Same as the NO_DATA attribute.	32-bit floating-point
HDF5 Attribute	OFFSET	The scale factor. The physical value (PV) is calculated as PV = (DN-offset)/scale (DN = Digital Number Count)	32-bit floating-point
HDF5 Attribute	SCALE	The scale factor. The physical value (PV) is calculated as PV = (DN-offset)/scale (DN = Digital Number Count)	32-bit floating-point
HDF5 Attribute	UNITS	The units of the dataset.	String