



TERRASCOPE SENTINEL-2

ALGORITHM THEORETICAL BASE DOCUMENT (ATBD)

S-2 – TOC – V200

Reference: *Terrascope Sentinel-2 Algorithm theoretical base document S-2 – TOC – V200*

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TABLE OF CONTENTS

1. INTRODUCTION.....	9
1.1. Terrascope explained	9
1.2. Scope of Document	9
1.3. Description	10
1.4. Feature added value/use case	12
1.5. Related documents	12
2. INPUT DATA.....	14
2.1. General	14
2.2. Ancillary data and models	15
2.2.1. Pixel classification	15
2.2.2. Atmospheric Correction	15
3. OUTPUT	18
3.1. Product layers	18
3.2. Product version	21
3.3. Product data access.....	21
4. METHODOLOGY	23
4.1. Pixel classification	23
4.1.1. Justification.....	23
4.1.2. Implementation	23
4.1.3. Outlook.....	23
4.2. Atmospheric correction.....	24
4.2.1. Justification.....	24
4.2.2. Implementation	24
4.2.3. Outlook.....	25
5. LIMITATIONS	26
5.1. Pixel classification	26
5.2. Atmospheric correction.....	26
6. QUALITY ASSESSMENT	27
6.1. Terrascope Sentinel-2 v200 vs v102.....	27
6.1.1. SCENECLASSIFICATION layer.....	27
6.1.2. TOC products	28
7. OTHER REFERENCE DOCUMENTS.....	34

LIST OF FIGURES

FIGURE 2.1: S-2-MSI SPECTRAL-BANDS VERSUS SPATIAL RESOLUTION REFERENCE [RD3]	14
FIGURE 2.2 SRTM COVERAGE MAP. THE COLOURS OF THE SWATHS INDICATE THE NUMBER OF TIMES THE AREA WAS IMAGED BY SRTM. FOR LAND, ONE-TIME COVERAGE IS GREEN, TWICE IS YELLOW-GREEN AND SO ON, AS SHOWN IN THE KEY AT LOWER LEFT. OVER WATER, THE COLOUR CODE IS IN SHADES OF BLUE AS SHOWN IN THE KEY AT LOWER RIGHT. AREAS IN RED COULD NOT BE MAPPED. © NASA, HTTPS://WWW2.JPL.NASA.GOV/SRTM/COVERAGE.HTML	16
FIGURE 2.3: LAND SURFACE COVERAGE WITHIN COPERNICUS DEM – GLO-90. THE COVERED AREA IS MARKED IN GREEN. © COPERNICUS - ESA.....	16
FIGURE 3.1: S-2 TOC PRODUCT FILE LIST	18
FIGURE 6.1 FRACTION [%] OF EACH CATEGORY IN THE YEAR 2018 FOR TILE 31UFS. THE BLUE BARS REPRESENT THE RESULTS FOR V102, GREEN BARS FOR V200'	27
FIGURE 6.2: FREQUENCY PLOTS (LEFT) AND BIAS HISTOGRAMS (RIGHT) FOR THE TOC REFLECTANCES (V200 AND V102) OF THE 20 M BANDS CALCULATED OVER THE ENTIRE TIME SERIES.	33

LIST OF TABLES

TABLE 1.1: SUMMARY OF MAIN CHARACTERISTICS BETWEEN DIFFERENT TERRASCOPE VERSIONS.....	10
TABLE 1.2: LIST OF CHANGES BETWEEN TERRASCOPE SENTINEL-2 V200 AND V102.....	11
TABLE 1.3: LIST OF RELATED DOCUMENTS.....	12
TABLE 3.1: SPATIAL AND SPECTRAL CHARACTERISTICS OF THE S-2 TOC PRODUCTS.	19
TABLE 3.2: TECHNICAL INFORMATION ON THE S-2 TOC, AOT, WVP, SZA, VZA, RAA VALUES.....	19
TABLE 3.3: EXPLANATION OF PIXEL CLASSIFICATION VALUES	20
TABLE 6.1: CONFUSION MATRIX OF THE SCENECLASSIFICATION LAYER BETWEEN V102 AND V200	28

LIST OF ACRONYMS

ACRONYM	EXPLANATION
ACIX	Atmospheric Correction Inter-comparison Exercise
AOT	Aerosol Optical Thickness
ATBD	Algorithm Theoretical Base Document
ATLAS	Atmospheric Laboratory for Applications and Science
BENELUX	Belgium – the Netherlands – Luxembourg
CCC	Canopy Chlorophyll Content
CCI	Climate Change Initiative
CMIX	Cloud Masking Inter-comparison Exercise
COG	Cloud-Optimized Geotiff
COP-DEM	Copernicus DEM – Global and European Digital Elevation Model
CWC	Canopy Water Content
DEM	Digital Elevation Model
ESA	European Space Agency
EURECA	European Retrieval CARrier
fAPAR	Fraction of Absorbed Photosynthetically Active Radiation
fCOVER	Fraction of green vegetation Cover
GeoTIFF	Geospatial Tagged Image File Format
iCOR	Image Correction for atmospheric effects
L-1C	Level-1C (Top-Of-Atmosphere) product
L-2A	Level-2A (Top-Of-Canopy) product
LAI	Leaf Area Index
MEP	Mission Exploitation Platform
MSI	Multispectral Instrument
NDVI	Normal Difference Vegetation Index
NRT	Near Real Time
OGC	Open Geospatial Consortium
PDGS	Payload Data Ground Segment
PDP	Product Distribution Portal
PROBA-V	Project for On-Board Autonomy – Vegetation
RAA	Relative Azimuth Angle
RD	Related Document
S-2	Sentinel-2
SAA	Sun Azimuth Angle
SAR	Synthetic Aperture RADAR
Sen2Cor	Sentinel-2 Correction
SOLSPEC	SOLar SPECTrum
SPOT	Satellite Pour l'Observation de la Terre
SRF	Spectral Response Function
SRTM	Shuttle Radar Topography Mission
STEP	Science Toolbox Exploitation Platform

Terrascope Sentinel-2

List of acronyms

SWIR	Short-Wave infrared
SZA	Solar Zenith Angle
TOA	Top-Of-Atmosphere
TOC	Top-Of-Canopy
UTM	Universal Transverse Mercator
VAA	View Azimuth Angle
VITO	Vlaams Instituut voor Technologisch Onderzoek
VNIR	Visible and Near InfraRed
VZA	View Zenith Angle
WGS84	World Geodetic System 1984
WVP	Water Vapour
XML	Extensible Markup Language

1. Introduction

1.1. Terrascope explained

Terrascope is the Belgian platform for Copernicus, PROBA-V, and SPOT-VEGETATION satellite data, products, and services. It provides easy, full, free and open access to all users without restrictions. This allows non-specialist users to explore the wealth of remote sensing information and build value-added products and services.

The following data are included:

- The SPOT-VEGETATION archive
- The PROBA-V archive
- Sentinel-1 SAR data over Belgium and its surroundings
- Sentinel-2 optical data over Europe and soon to be expanded to Africa
- Sentinel-3 optical and thermal Synergy (SYN) – Vegetation (VGT) data

A standard set of biophysical indicators (NDVI, FAPAR, FCOVER, LAI, CCC, CWC) derived from Sentinel-2 data is offered alongside the Sentinel-2 surface reflectance data.

Users have the possibility to build derived information products to their own specification, using the Terrascope processing cluster through provided virtual machines or Notebooks. This eliminates the need for data download (and consequential storage costs), because the cluster holds all data and it is directly accessible. Integration of data or products in your own application is facilitated through Open Geospatial Consortium (OGC) web services.

Terrascope is user centered, so any suggestions for new or enhanced functionality are welcome. Feel free to contact us at info@terrascope.be.

1.2. Scope of Document

This ATBD (Algorithm Theoretical Base Document) describes the origin and generation of Sentinel-2 (S-2) Level2 Top-Of-Canopy (TOC) products embedded in the Terrascope Sentinel-2 v200 processing chain.

The document is organised as following:

- Section 2 provides an overview of all input data needed to feed the processing workflow, including a description of the S-2 Level-1C/Level-2A (L-1C and L-2A, respectively) input data and ancillary data.
- Section 3 explains the data available to users.
- Section 4 provides a detailed description of the different processing algorithms.

- Section 5 discusses the implemented algorithms' limitations.
- Section 6 justifies the overall workflow with a quality assessment.

1.3. Description

The S-2 TOC reflectance product is a geometrically and atmospherically corrected version of the original Copernicus provided data products with additional information on pixel classification, Aerosol Optical Thickness (AOT), water vapour (WVP), and angular information: Solar Zenith Angle (SZA), Viewing Zenith Angle (VZA), and Relative Azimuth Angle (RAA).

S-2 L-2A Top-Of-Canopy (TOC) products [RD1] are systematically generated at the ESA ground segment over Europe since March 2018, and production was extended to the entire globe in December 2018. The Terrascope workflow was adapted accordingly and starts with the download of these L-2A products. When L-2A data is not available, L-1C Top-Of-Atmosphere [RD2] data are downloaded from the collaborative hub or open access hub and processed to TOC using Sen2Cor v2.8 [RD2]. Sen2Cor processing also incorporates a Scene Classification (SC) step, which generates a classification map called Scene Classification Layer (SCL), which includes four different classes for clouds (including cirrus) and six different classifications for shadows, cloud shadows, vegetation, soils/deserts, and water and snow pixels. The output of this workflow encompasses the TOC reflectance for each spectral band, a scene classification layer, AOT, WVP, SZA, VZA, and RAA layers.

This document applies to the Terrascope S-2 v200 processing chain. Table 1.1 summarizes the main characteristics of the different Terrascope versions until v200. The changes between v102 and v200 are listed in Table 1.2. Validation results between both versions are included in Section 6.1.

Table 1.1: Summary of main characteristics between different Terrascope versions.

Version	Main characteristics
V101	Input: L-1C data Atmospheric correction: iCOR Scene classification : Sen2Cor v2.3 Output: TOC, cloud masks, shadow masks, scene classification
V102	Input: L-1C data Atmospheric correction: iCOR with AOT fallback and improved spectral response curves Scene classification: Sen2Cor v2.5.5 Output: TOC, cloud masks, shadow masks, scene classification, AOT
V200	Input: L-2A data (NRT) or L-1C (historic)

Version	Main characteristics
	<p>Atmospheric correction: Ground Segment Sen2Cor version (NRT) or Sen2Cor v2.8 (historic)</p> <p>Scene classification: Sen2Cor v2.8 with CCI auxillary package</p> <p>Output: TOC, scene classification, AOT, WVP, SZA, VZA, RAA</p>

Table 1.2: List of changes between TERRACOPE Sentinel-2 v200 and v102

Adaptations between v200 and V102	Clarification
Scene selection	
Tiles covered with more than 95% clouds are not processed.	To optimise data storage, scenes almost fully covered with clouds will no longer be processed.
Scene classification	
Update of Sen2Cor version (v2.5.5 → v2.8)	On 20.02.2019 a new version of Sen2Cor was released (v2.8).
Atmospheric correction	
Download of Sentinel-2 L-2A Near-Real-Time products	Since March 2018, the Payload Data Ground Segment (PDGS) has processed L-2A products over Europe, and production was extended to global in December 2018. [RD1]
Atmospheric correction with Sen2Cor instead of iCOR.	To be in line with the ESA processing, we switched from iCOR to SEN2COR processing. Both are valid processors and have been included in various inter-comparison exercises (e.g. ACIX-I and ACIX-II).
Output products	
Additional layers at 60 m: <ul style="list-style-type: none"> - WVP - Angles: RAA, VZA, and SZA 	Users can use these layers to derive other products or for quality control.
Removal of the: <ul style="list-style-type: none"> - Cloudmask layers (10m, 20m and 60m) - Shadowmask layers (10m, 20m, 60m) 	This information can also be found in the SCENECLASSIFICATION layer.
Update of the INSPIRE Metadata	The metadata xml file has been updated to be compliant with ISO-19115-2 standards.

Adaptations between v200 and V102	Clarification
Values in dense clouds (indicated as high probability clouds in the scene classification layer) of processed tiles (i.e. cloud% < 95%) are masked with a conservative buffer.	Masking of dense clouds allows an optimised data storage.
Data Archive	
Switch from Product Distribution Portal (PDF) to OpenSearch Catalogue for Remote Sensing, with accompanying GeoJSON metadata information.	The new catalogue is easier to maintain.
Change in folder structure on Terrascope cloud processing platform (Virtual machines and Jupyter notebooks)	The folder structure has been revised, made more concise and user-friendly.

1.4. Feature added value/use case

The atmospheric impact on the observed TOA reflectance differs for each spectral band. In data assessment studies (e.g. band ratios, time series analysis or quantitative studies), atmospheric disturbances and inaccurate geolocation will hamper a good analysis. The Terrascope platform provides a solution to users that want to work with atmospherically corrected Sentinel-2 data by making TOC products available in Cloud-Optimized GeoTIFF format (COG). The TOC products are accompanied with pixel classification layers and AOT, WVP, SZA, VZA, and RAA information. These latter layers are useful for quality control or to derive new value-added products.

1.5. Related documents

Table 1.3 lists the related documents (RD) that are complementary to this ATBD. Other Reference Documents (ORD) are listed in Section 7.

Table 1.3: List of related documents

[RD1]	Louis, J., Devignot, O., Pessiot, L. (2017) S-2 MPC Level 2A Product Format Specification. Ref. S-2-PDGS-MPC-L-2A-PFS-V14.2. https://sentinel.esa.int/documents/247904/685211/Sentinel-2-MSI-L-2A-Product-Format-Specifications.pdf
[RD2]	Gatti, A., Galoppo, A. Castellani, C., Carriero, F. Sentinel-2 Products Specification Document, REF: S-2-PDGS-TAS-DI-PSD issue 14.5,20/03/2018 https://sentinel.esa.int/documents/247904/685211/Sentinel-2-Products-Specification-Document

[RD3]	Mueller-Wilm, U., Devignot, O., Pessiot, L. (2019) S-2 MPC Sen2Cor Software Release Note. Ref. S-2-PDGS-MPC-L-2A-SRN-V2.8.0. http://step.esa.int/thirdparties/sen2cor/2.8.0/docs/S-2-PDGS-MPC-L-2A-SRN-V2.8.pdf
[RD4]	Paepen, M., et al. (2019) Terrascope Sentinel-2 Product User Manual V1.1

2. Input data

2.1. General

The Terrascope processing starts from the S-2 L-1C and L-2A data products that can be freely downloaded from the Copernicus Open Access Hub (<https://scihub.copernicus.eu/dhus/#/home>). The data are distributed in granules, also called tiles, which are 100 × 100 km² ortho-images in Universal Transverse Mercator World Geodetic System 1984 (UTM/WGS84) projection with an overlap of 9.8 km between tiles. The tiling grid can be downloaded from [Sentinel-2 tiling grid.kml](#). The L-1C and L-2A data are TOA and TOC reflectance, respectively, projected in UTM zones of the WGS84 ellipsoid.

S-2 L-1C and L-2A data are distributed by ESA as SENTINEL-SAFE files, which includes image data in JPEG2000 format, quality indicators, auxiliary data, and metadata. The Multispectral Instrument (MSI) on-board S-2 measures the Earth's reflected solar irradiance in 13 spectral bands from the Visible and Near Infra-Red (VNIR) to the Short Wave Infra-Red (SWIR), see Figure 2.1:

- 4 bands at 10 m spatial resolution: blue (490 nm centre wavelength), green (560 nm), red (665 nm) and near infrared (842 nm).
- 6 bands at 20 m spatial resolution: 4 narrow bands for vegetation characterization (705 nm, 740 nm, 783 nm and 865 nm) and 2 larger SWIR bands (1610 nm and 2190 nm) for applications such as snow/ice/cloud detection or vegetation moisture stress assessment.
- 3 bands at 60 m spatial resolution, mainly for cloud screening and atmospheric corrections (443 nm for aerosols, 945 nm for water vapor and 1375 nm for cirrus detection).

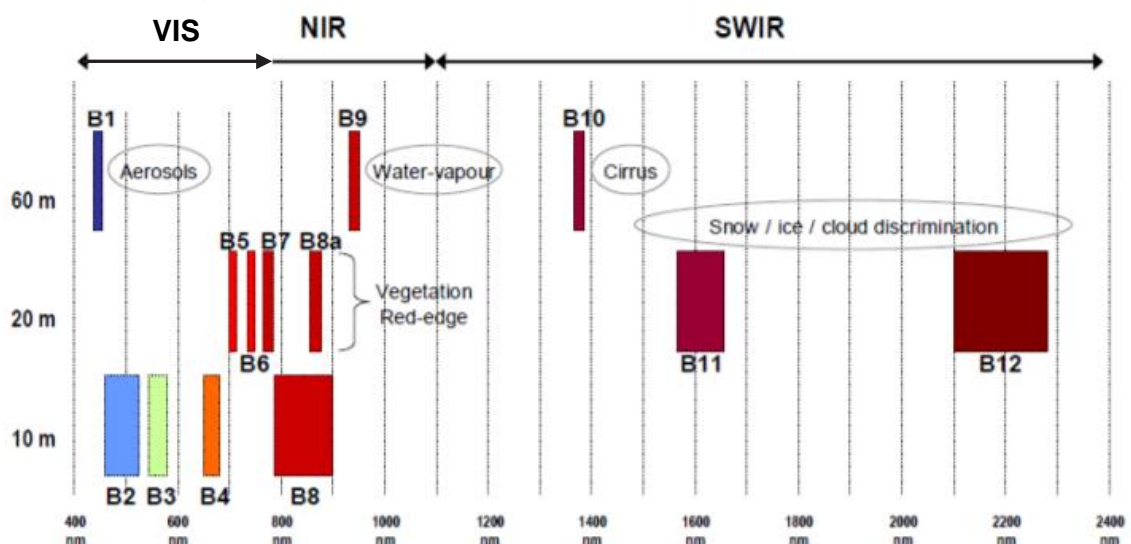


Figure 2.1: S-2-MSI Spectral-Bands versus Spatial Resolution Reference [RD3]

More information on the S-2 data products and tiling strategy is available on <https://sentinel.esa.int/web/sentinel/missions/sentinel-2/data-products>. Detailed information on the S-2 L-1C data products can be found in [RD2]. Detailed information on S-2 L-2A data products can be found in [RD1].

2.2. Ancillary data and models

2.2.1. Pixel classification

Pixel classification in the Terrascope workflow for historic products (no L-2A products available) is performed using the **Sen2Cor v2.8** [RD3] stand-alone version for Linux (release date 20/02/2019). For near-real time products the Terrascope workflow relies on the Sen2Cor version used in the production by the PDGS. The SceneClass Module is used to generate the Scene classification layer. In order to generate this Scene classification, Sen2cor v2.8 uses the surfaces of the **Climate Change Initiative (CCI)** Land Cover data from 2015 (v2.0.7) as auxiliary information [RD2]. This is a package of 24 annual (1992-2016) global 300 m land cover maps. These land cover maps were produced through state-of-the art reprocessing of the National Oceanic and Atmospheric Administration (NOAA)-Advanced Very High Resolution Radiometer (AVHRR), Satellite Pour l'Observation de Terre-Végétation (SPOT-VGT), Environmental Satellite (ENVISAT) Moderate Resolution Imaging Spectrometer (MERIS), and Advanced Synthetic Aperture Radar (ASAR), and Project for On-Board Autonomy – Vegetation (PROBA-V) archives. The use of this auxiliary CCI information is implemented in Terrascope v200 workflow.

More information on the implementation is given in Section 4.1.

2.2.2. Atmospheric Correction

The atmospheric correction algorithm makes use of following ancillary data:

- **Digital Elevation Model (DEM)**

Two DEMs are used in the Sen2Cor atmospheric correction:

- Shuttle Radar Topography Mission (SRTM) is the default DEM embedded in the Sen2Cor processing and has a spatial resolution of 3 arcsec (~90 m). Figure 2.2 shows the global coverage of the SRTM DEM. It covers most of the surface between 60°N and 54°S. (Farr et al., 2007).

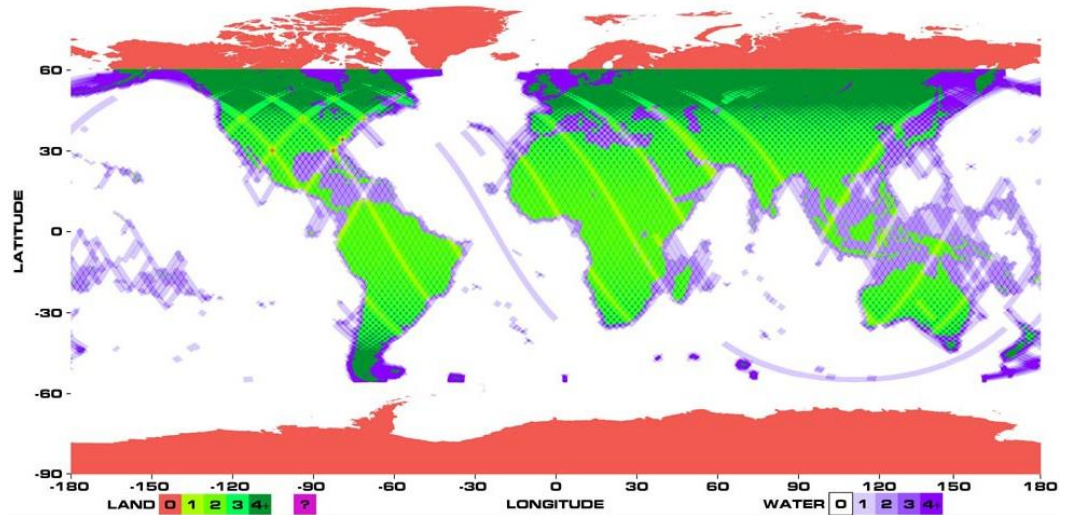


Figure 2.2 SRTM coverage map. The colours of the swaths indicate the number of times the area was imaged by SRTM. For land, one-time coverage is green, twice is yellow-green and so on, as shown in the key at lower left. Over water, the colour code is in shades of blue as shown in the key at lower right. Areas in red could not be mapped. © NASA, <https://www2.jpl.nasa.gov/srtm/coverage.html>.

Tiles located outside the SRTM coverage, i.e. $> 60^{\circ}\text{N}$ are processed using Copernicus DEM – Global and European Digital Elevation Model (COP-DEM), GLO-90 with a spatial resolution of 3 arcsec ($\sim 90\text{ m}$). The global coverage of GLO-90 shown in Figure 2.3 represents the surface of the Earth including buildings, infrastructure and vegetation (Fahrland et al., 2019).

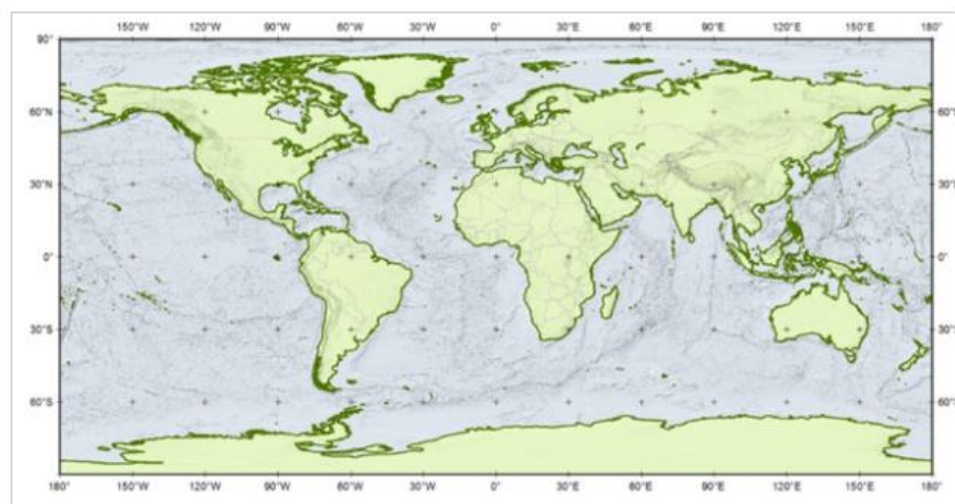


Figure 2.3: Land surface coverage within Copernicus DEM – GLO-90. The covered area is marked in green. © Copernicus - ESA

- **Angle information**

On 06/11/2018 ESA deployed a new Production Baseline (02.07) which includes an accurate detector footprint. With this information, it is possible to link one pixel to one detector and derive Solar Zenith Angle (SZA), View Zenith Angle (VZA) and Relative Azimuth Angle (RAA) for each pixel through a SNAP gpt command.

3. Output

3.1. Product layers

The S-2 TOC products generated and distributed by Terrascope include several files which are the output of the Sen2Cor processor for atmospheric correction and scene classification. Each output file in the TOC product is formatted as a single layer compressed Cloud-Optimized GeoTIFF (COG) file. Figure 3.1 shows the S-2 TOC product file list.

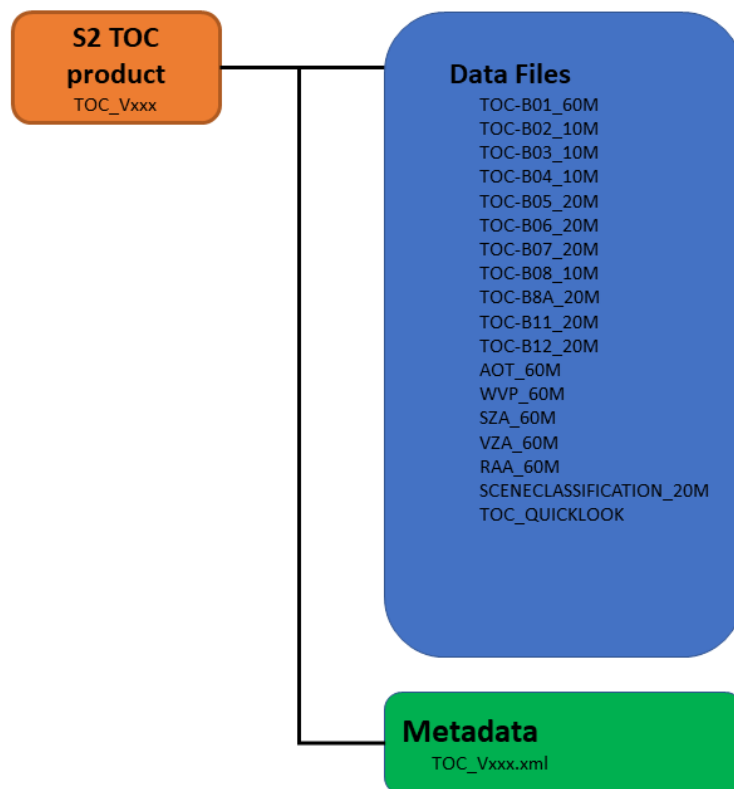


Figure 3.1: S-2 TOC product file list

The S-2 TOC spectral bands span from the visible and the Near Infrared to the Short Wave Infrared in different resolutions. The spatial and spectral characteristics are listed in Table 3.1. Note that B09 and B10 are not delivered, as these contain the water vapor and cirrus bands, respectively.

Table 3.1: Spatial and spectral characteristics of the S-2 TOC products.

Layer	Spatial resolution [m]	S-2A		S-2B	
		Central wavelength [nm]	Bandwidth [nm]	Central wavelength [nm]	Bandwidth [nm]
TOC-B01_60M	60	442.7	21	442.2	21
TOC-B02_10M	10	492.4	66	492.1	66
TOC-B03_10M	10	559.8	36	559.0	36
TOC-B04_10M	10	664.6	31	664.9	31
TOC-B05_20M	20	704.5	15	703.8	16
TOC-B06_20M	20	740.5	15	739.1	15
TOC-B07_20M	20	782.8	20	779.7	20
TOC-B08_10M	10	832.8	106	832.9	106
TOC-B8A_20M	20	864.7	21	864.0	22
TOC-B11_20M	20	1613.7	91	1610.4	94
TOC-B12_20M	20	2202.4	175	2185.7	185

The AOT, WVP, SZA, VZA and RAA are provided in the native 60 m resolution.

The physical pixel values in the S-2 TOC files are converted from floating point values into integers, mainly to reduce the file sizes. Table 3.2 lists the S-2 TOC product metadata, with information necessary to calculate the Physical Values (PV) from the Digital Numbers (DN) available in the files. The physical number can be defined by using the following formula:

$$PV = Scaling * DN + offset$$

Table 3.2: Metadata on the S-2 TOC, AOT, WVP, SZA, VZA, and RAA values

	TOC [-]	AOT [-]	WVP [g cm ⁻²]	SZA [°]	VZA [°]	RAA [°]
Physical min	-1.0	0.00	1	0	0	0
Physical max	2.0	2.5	3.5	80	12	180
Digital number min	-10000	0	100	0	0	0
Digital number max	20000	2500	350	8000	1200	18000
Scaling	0.0001	0.001	0.01	0.01	0.01	0.01
Offset	0.0	0.0	0.0	0.0	0.0	0.0

The output of the Sen2Cor scene classification module provides the Scene Classification at 20 m with values of the pixel classification layers specified as shown in Table 3.3. [RD2]

Table 3.3: Explanation of pixel classification values

Layer	Value	Classification
SCENE	0	NO_DATA
CLASSIFICATION	1	SATURATED_OR_DEFECTIVE
	2	DARK_AREA_PIXELS
	3	CLOUD_SHADOWS
	4	VEGETATION
	5	BARE_SOIL
	6	WATER
	7	UNCLASSIFIED
	8	CLOUD_MEDIUM_PROBABILITY
	9	CLOUD_HIGH_PROBABILITY
	10	THIN_CIRRUS
	11	SNOW

In the Terrascope Virtual Machine environment, the S-2 TOC product data can be found in `/data/MTDA/TERRASCOPE_Sentinel-2/<Product_version>/<Year>/<Month>/<Day>/<Tile_ID>`

The folder structure used on the Terrascope platform is:

1. Product and version - e.g. *TOC_V2*
2. Year - e.g. *2019*
3. Month - e.g. *'04'* for April
4. Day - e.g. *04*
5. Tile_ID - e.g. *S-2B_20190504T105629_31UDS_TOC_V200*

It might happen that some Sentinel-2 products are delivered multiple times. For example, let's take following Sentinel-2 Level-1C products:

- a) S-2B_MSIL-1C_20170829T105019_N0205_R051_T31UFS_**20170829T105021**.zip
- b) S-2B_MSIL-1C_20170829T105019_N0205_R051_T31UFS_**20170829T105633**.zip

Based on the processing timestamp in the filename (highlighted in bold), one can differentiate redelivered products. Both products need to be stitched (mosaicked) in order to become a fully filled tile. This creates a Sentinel-2 mosaic product with the same file naming conventions as Sentinel-2 Level-1C products (see <https://sentinel.esa.int/web/sentinel/user-guides/sentinel-2-msi/naming-convention>), but with the processing timestamp always set to *19700101T000000*, e.g. "S-2B_MSIL-1C_20170829T105019_N0205_R051_T31UFS_**19700101T000000**.zip"

3.2. Product version

Terrascope products are produced in a controlled way. Every product has a version indicator, consistent with the Semantic Versioning 2.0.0 protocols (<https://semver.org/>). The version indicator has three digits: XYZ.

- X is 0 during prototyping and pre-operational use. X is 1 for the first operational setup, and increments when if its results are no longer backward compatible (i.e. any further processing will have to be adapted to deal with e.g. format changes, value scaling, etc.).
- Y is reset to 0 with an X increment. Y increments when functionality is added, but backward compatibility is guaranteed (e.g. when a different approach is taken for atmospheric or geometric correction).
- Z is reset to 0 when Y increments. Z increments when the software is patched (bug fixed) without any functional changes.

The current Terrascope Sentinel-2 TOC workflow version is v200.

Whenever X or Y changes, the impact of the updates will be reported and the new and previous versions of the workflow will be run in parallel, for a 3-4 month period. This allows users to implement changes to their subsequent processing. Users are informed about version changes through the Terrascope newsletter (to subscribe: <https://terrascope.be/en/stay-informed>).

3.3. Product data access

The Terrascope S-2 data products can be accessed through:

- Terrascope viewer: <https://viewer.terrascope.be/en>
For viewing, discovery and data access. The viewer provides fast access to satellite data including most Sentinel satellites. You can easily search, view, and compare various data layers. Via the 'Export' tab you can even download png images, GIF timelapses or the original data in just a few clicks. Would you like to implement your own processing? In that case, you can also directly retrieve the satellite data. You can do so through our data portal.
- Web services: [Web Map Service \(WMS\)](#) and [Web Map Tile Service \(WMTS\)](#):
Protocols for downloading images and integrating them into GIS software
- Notebooks (login required): <https://notebooks.terrascope.be/hub/login>
Programming environment to quickly access and edit data

- Virtual Machines (VM, login required): <https://forum.terrascope.be/en/request-vm>
External computer used to view data and process it in the cloud

The details of each of these access points are described on <https://terrascope.be/en/services>.

4. Methodology

4.1. Pixel classification

4.1.1. Justification

Including a pixel classification in the output facilitates the exploitation of the TOC products in further processing steps. A couple of well-known tools exists, including Sen2Cor (Mueller-Wilm et al, 2018) [RD2] and Fmask (Zhu et al., 2015). In the previous Terrascope S-2 version (v102), it was decided to work with Sen2Cor based on an internal quality assessment study. Also the results of the recent organized Cloud Masking Inter-comparison Exercise (CMIX) were considered. Sen2Cor has been updated to its latest public release (v2.8) and the CCI auxiliary package is implemented.

4.1.2. Implementation

Pixel classification in the Terrascope workflow for historic products (no L-2A products available) is performed using the **Sen2Cor v2.8** [RD3] stand-alone version for Linux (release date 20/02/2019). For near-real time products the Terrascope workflow relies on the Sen2Cor version used in the production by the PDGS. Sen2Cor is freely available online from the ESA STEP (Science toolbox Exploitation Platform) portal. More information on this processor can be found at <http://step.esa.int/main/third-party-plugins-2/sen2cor/>. [RD2]

Sen2Cor consists of two important processing modules, the SceneClass Module and the AtmCorr Module. The AtmCorr Module is implemented to atmospherically correct archive S-2 data, and discussed in Section 4.2. The SceneClass Module allows to detect clouds, snow and cloud shadows and to generate a classification map (so-called scene classification) including also information on dark areas, vegetation, bare soil, water and snow.

Sen2Cor v2.8 is able to use the CCI Land Cover data from 2015 as auxiliary information. This is used in Sen2Cor to improve the accuracy of Sen2Cor classification over water, urban, and bare areas and also to have a better handling of false detection of snow pixels. [RD2]. The use of this auxiliary CCI information is implemented in the Terrascope v200 workflow.

4.1.3. Outlook

Future updates of the Sen2Cor SceneClass module will be evaluated. If the updated version results in a significant improvement, the Terrascope workflow will be updated to include the new version.

4.2. Atmospheric correction

4.2.1. Justification

When electromagnetic radiation passes through the atmosphere it may be transmitted, scattered or absorbed. Using S-2 data for quantitative remote sensing of land or water surfaces requires the removal of atmospheric effects, which is essential to convert radiance measured by the sensors to surface reflectance. Hadjimitsis et al. (2010) argued that atmospheric correction is the most important part of the pre-processing of satellite remotely sensed data. For agricultural applications, any omission of considering the effects of the atmosphere when vegetation indices from satellite images are used, may lead to major discrepancies in the final outcomes. For example, neglecting atmospheric correction when calculating Normalized Difference Vegetation Index (NDVI), a widely used index in agricultural studies, will result in an average error of 18% and the outcomes are then no longer useful for e.g. crop growth monitoring.

The Terrascope v200 downloads atmospherically corrected data (L-2A) from the ESA data science hub. When no L-2A data is available, L-1C data will be downloaded and processed with the Sen2Cor v2.8 atmospheric correction (AtmCorr Module). This in contrast with v102, where the iCOR atmospheric correction method was used (De Keukelaere et al., 2018). Both are valid atmospheric correction processors and have been validated in various efforts, including the Atmospheric Correction Inter-comparison Exercise (ACIX) organized by ESA-NASA (Doxani et al., 2018) and its successor ACIX-II. Switching from iCOR to Sen2Cor was done to be in line with L-2A products provided by the PDGS. More information on the AtmCorr module in Sen2Cor can be found at [RD2].

4.2.2. Implementation

S-2 L-2A products are downloaded directly from the collaborative hub or open access hub and converted into COG files, with accompanying Scene classification layer, AOT, WVP, SZA, VZA, and RAA.

When no L-2A products are available at the collaborative hub, i.e., historic data before March 2018, L-1C products are downloaded and processed into TOC products using the Sen2Cor v2.8 atmospheric correction algorithm. AOT and WVP are additional layers provided by Sen2Cor. The VZA, SZA, and RAA are generated using a SNAP gpt command.

Tiles fully covered by clouds (> 95%) are not downloaded or processed, as their relevance for land surface application is minimal.

4.2.3. Outlook

Future updates of the Sen2Cor atmospheric correction module will be evaluated. If the updated version results in a significant improvement, the Terrascope workflow will be updated to include the new version.

5. Limitations

5.1. Pixel classification

Each new publicly available update of the Sen2Cor scene classification module will be analysed in terms of added value for processing historic products compared to previous versions and the required effort for implementation or update. Only if the cost/benefit analysis is positive, the update will be implemented. For NRT products the version is automatically updated as L-2A products are downloaded.

In line with other pixel classification algorithms, the scene classification of Sen2Cor is imperfect and both commission and omission errors of clouds and cloud shadows occur. Most notable errors are i) over-detection of bright surfaces (e.g. in urban areas) as clouds; ii) false detection of snow in clouds; iii) under-detection of cloud shadows and iv) over-detection of cloud shadows at high solar zenith angles. The implementation of the CCI auxiliary package has improved these errors, yet they can still be a limitation for further usage of the TOC products and processing.

The current version of Sen2Cor is tile-based. As the scene classification module relies on some dynamically adjusted thresholds, scene classification values of the same pixel in overlapping areas between neighbouring tiles might be different.

5.2. Atmospheric correction

Each new publicly available update of the Sen2Cor atmospheric correction module will be analysed in terms of added value for processing historic products compared to previous versions and the required effort for implementation or update. Only if the cost/benefit analysis is positive, the full archive will be reprocessed. For NRT products, the version is automatically updated as L-2A products are downloaded.

The current version of the Sen2Cor atmospheric correction is tile-based, and does not include a fall-back mechanism for AOT. The AOT retrieval from an image can be hampered by the absence of dark dense vegetation. In these situations, Sen2Cor will fix the AOT value at 0.2. Moreover, edge artefacts can occur between different tiles acquired on the same date.

6. Quality assessment

6.1. Terrascope Sentinel-2 v200 vs v102

6.1.1. SCENECLASSIFICATION layer

A new version of Sen2COR (v2.8) is implemented with support of the CCI package. Figure 6.1 and Table 6.1 show the differences in identified classes between v102 and v200. Figure 6.1 show the fraction of each category for a full year of tile 31UFS. v200 detects more 'Cirrus', 'Snow' and 'Clouds medium probability', while the total number of pixels identified as 'Cloud high probability' is lower. The total number of 'vegetated' pixels remains stable. Table 6.1 is a confusion matrix, showing the percentage of pixels of different V102 classes belong to one V200 class. The percentages of the columns sums to 100%. Of all pixels classified in v200 as 'Cloud medium probability', only 61% belonged in v102 in the same category, while 38% of these pixels were classified as 'Cloud high probability' in v102. Most changes occurred in the category 'Snow': from the pixels classified as 'Snow' in V200, 70% were in V102 classified as 'Cloud high probability', 15% as 'Cloud medium probability', only 9% also as 'Snow', and another 4% as 'Unclassified'. Also the increase in 'Cirrus' percentage in v200 is not only linked to one specific category shift. It comprises of pixels classified in v102 as 'Water', 'Cloud high probability', 'Vegetation' and 'Unclassified'.

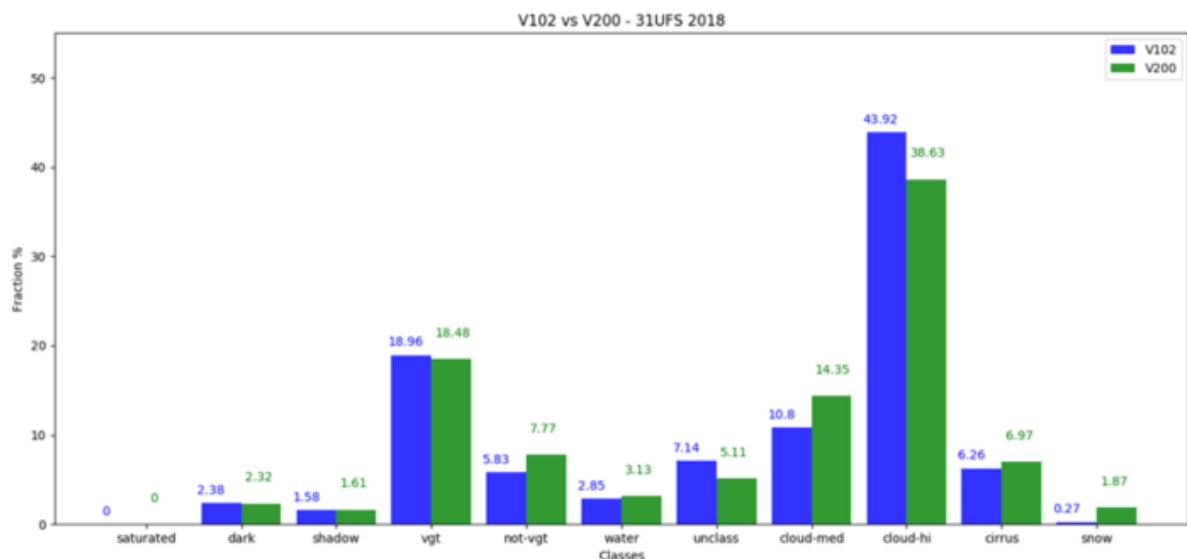


Figure 6.1 Fraction [%] of each category in the year 2018 for tile 31UFS. The blue bars represent the results for v102, green bars for v200 '.

Table 6.1: Confusion matrix of the Scene Classification layer between V102 and V200, expressed in percentages.

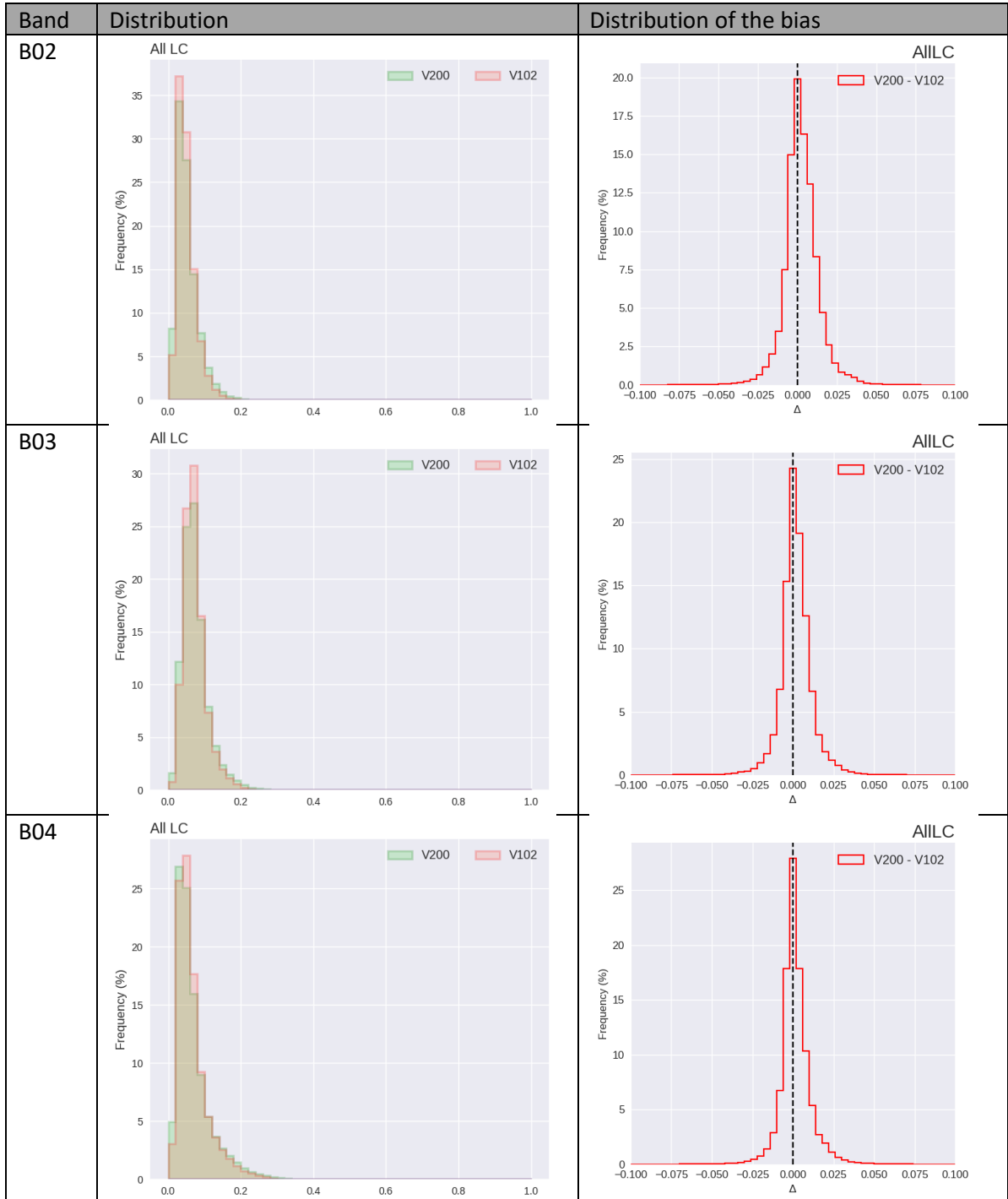
		V200										
		No data	Dark area pixels	Cloud shadow	Vegetation	Bare soil	Water	Unclassified	Cloud medium probability	Cloud high probability	Thin cirrus	Snow
V102	No data	100.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
	Dark area pixels	0.00	84.99	0.01	0.00	0.00	15.63	0.00	0.00	0.00	0.17	0.00
	Cloud shadow	0.00	0.21	99.98	0.00	0.00	13.17	0.00	0.00	0.00	0.14	0.00
	Vegetation	0.00	0.00	0.00	99.98	0.00	0.00	0.00	0.00	0.00	2.37	0.00
	Bare soil	0.00	0.00	0.00	0.00	82.21	0.00	0.00	0.00	0.00	1.32	0.00
	Water	0.00	0.07	0.00	0.00	0.00	62.06	0.00	0.00	0.00	0.32	0.30
	Unclassified	0.00	3.41	0.00	0.00	13.75	8.32	99.88	0.00	0.00	0.30	4.23
	Cloud medium probability	0.00	8.77	0.00	0.00	3.35	0.16	0.01	61.43	0.00	0.56	15.48
	Cloud high probability	0.00	0.92	0.00	0.00	0.66	0.56	0.04	38.55	100.00	4.91	70.13
	Thin cirrus	0.00	0.02	0.01	0.01	0.02	0.00	0.07	0.02	0.00	89.89	0.01
	Snow	0.00	1.62	0.00	0.00	0.00	0.09	0.00	0.00	0.00	0.02	9.86

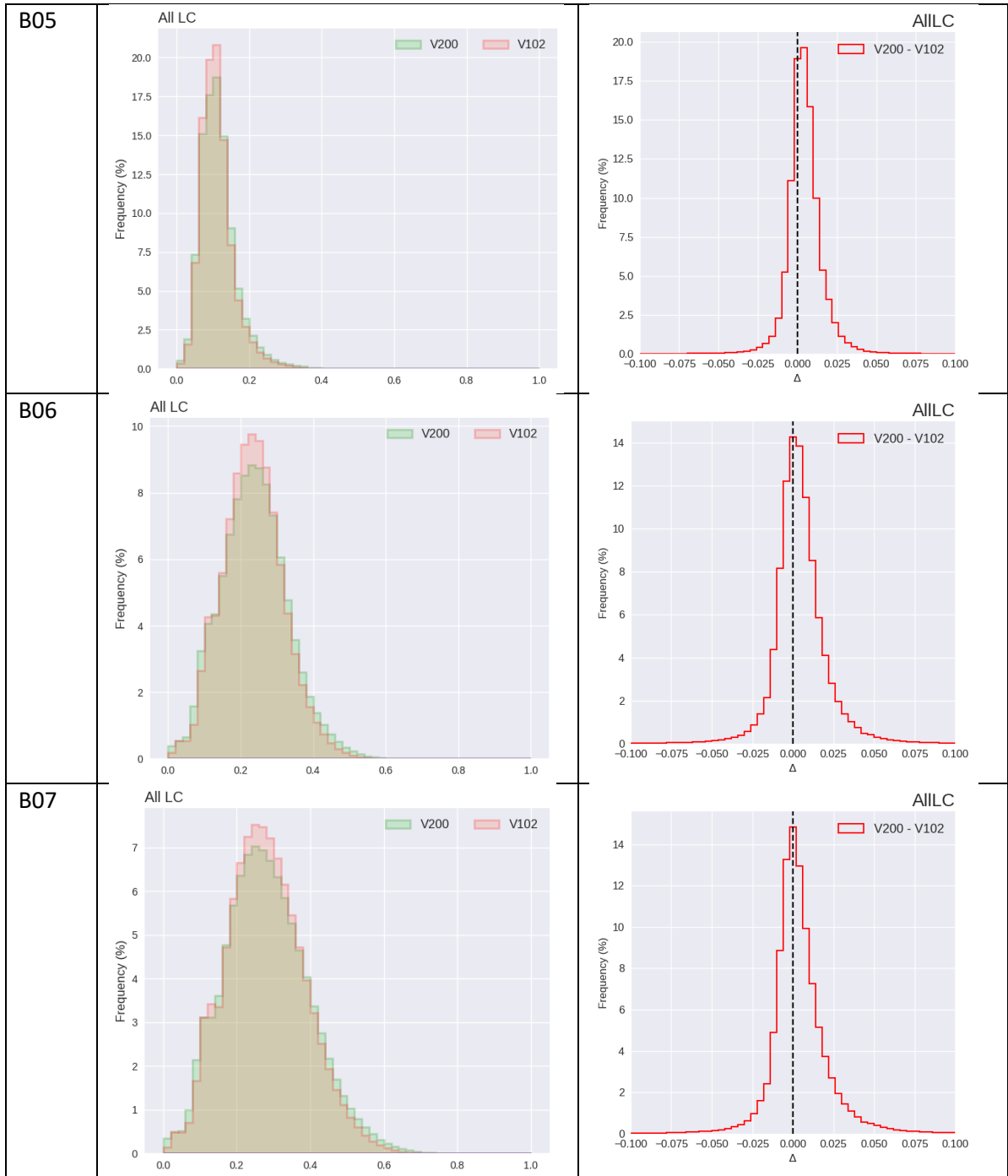
6.1.2. TOC products

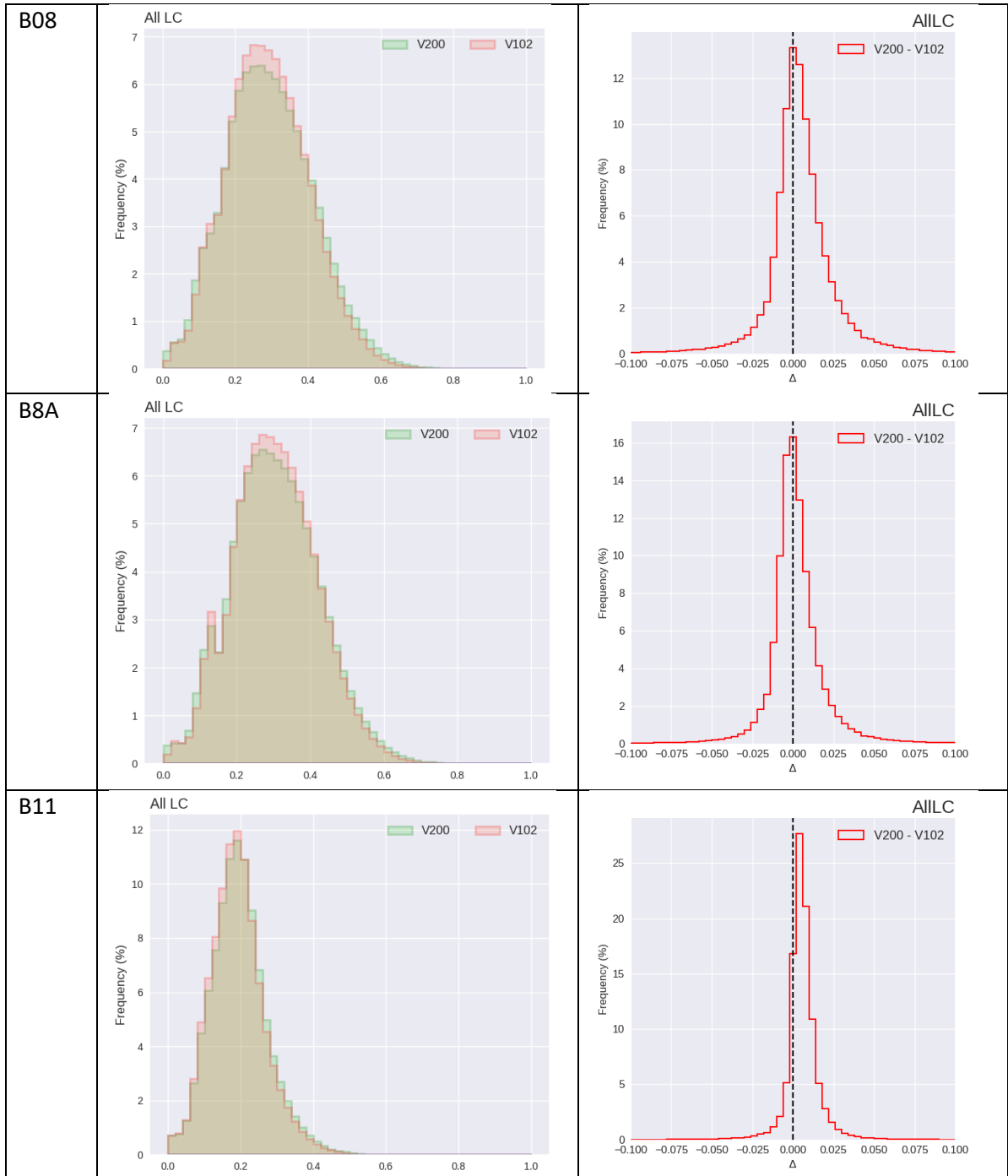
An inter-comparison was done between S-2 V200 and S-2 V102 to show the impact of the changes on the products. A more profound validation of the new products will become available in a validation report, which is currently under construction.

A full time series of Tile 31UFS was processed, ranging from 06/07/2015 to 28/03/2020. Based on the scene classification maps, pixels classified as dark area pixel, vegetation, bare soil, and water were retained in this exercise. The spatial consistency of the time series was tested. Spatial consistency refers to the realism and repeatability of the spatial distribution of retrievals, including the absence of artefacts (e.g., missing data, stripes, unrealistic values, etc.), based on expert knowledge. The analysis is based on spatial distribution of validation metrics at tile level. Figure 6.2 shows frequency and bias histograms for the TOC reflectances (V200 and V102) of the 20 m bands calculated over the entire time series.

The histograms show small differences between both versions. For most observations the bias is <0.025 .







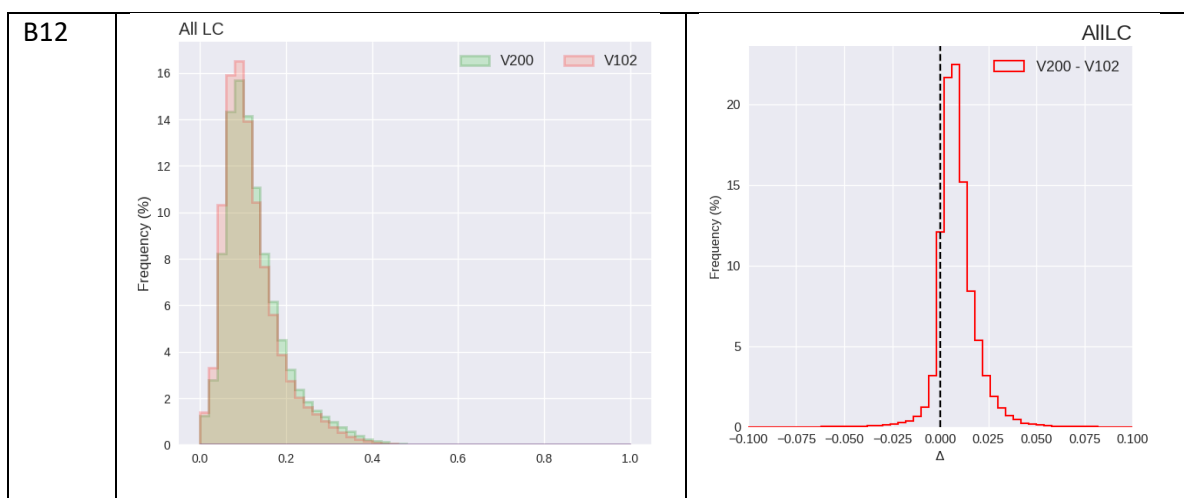


Figure 6.2: Frequency plots (left) and bias histograms (right) for the TOC reflectances (V200 and V102) of the 20 m bands calculated over the entire time series.

7. Other Reference documents

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