



Sentinel-5p+ Innovation Theme 6: Solar Induced Chlorophyll Fluorescence (SIF)

Product User Manual

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1. Introduction

1.1. Purpose and objective

This document describes the technical characteristics of the Level 2 and Level 2b sun-induced chlorophyll fluorescence (SIF) products derived from the TROPOMI sensor, which were generated in the frame of the [TROPOSIF project](#) within the ESA [Sentinel-5p+ Innovation \(S5p+I\)](#) programme.

This product user manual relates to the TROPOSIF products which were generated according to the retrieval scheme described in the Algorithm Theoretical Baseline Document ([AD1]) and whose validation is documented in the Validation Report ([AD2]).

1.2. Document overview

Section 2 lists references and acronyms. Section 3 recalls the characteristics of the TROPOSIF product. Section 4 describes the format of the TROPOSIF L2 and L2B products.

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2. References, terms and acronyms

[AD1]	TROPOSIF study team. Algorithm Theoretical Baseline Document Sentinel-5 Precursor SIF Retrieval - V4. NOV-FE-0956-NT-042-v4, February 2021
[AD2]	TROPOSIF study team. Validation Report - v2. NOV-FE-0956-NT-017-v2, February 2021

[RD1]	Köhler P., C. Frankenberg, T. S. Magney, L. Guanter, J. Joiner, and J. Landgraf. Global retrievals of solar-induced chlorophyll fluorescence with TROPOMI: First results and intersensor comparison to OCO-2. Geophysical Research Letters, 45(19):10,456–10,463, 2018. doi: 10.1029/2018GL079031.
[RD2]	Robert B. Schmunk; Panoply netCDF, HDF and GRIB Data Viewer. URL http://www.giss.nasa.gov/tools/panoply/ .

OCO-2	Orbiting Carbon Observatory-2
RFL	Reflectance
S5P	Sentinel-5 Precursor
SIF	Sun-Induced Chlorophyll Fluorescence
SZA	Sun Zenith Angle
TOA	Top Of Atmosphere
TROPOMI	TROPOspheric Monitoring Instrument
VZA	View Zenith Angle
WVL	Wavelength

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3. Overview of the TROPOSIF Product

3.1. Product Overview

The retrieval of the L2 TROPOSIF product is based on a linear forward model fitting of TROPOMI Top-Of-Atmosphere (TOA) radiances in the far-red spectral region [AD1]. The fundamental basis for the retrieval is a data driven approach where a series of orthogonal spectral vectors derived from a so-called training set are used to model high spectral frequency features in the spectrum from both solar and atmospheric lines. SIF is estimated through the inversion of the linear model, together with the weights of the singular vectors and the coefficients of a 3rd-order polynomial used to model low spectral frequency variations in the spectrum such as those from varying surface albedo.

The TROPOSIF product consists in SIF data estimated at 740 nm from two fitting windows:

- **743–758 nm.** In this fitting window, SIF estimates have been shown to be very robust against atmospheric effects (especially cloud contamination).
- **735–758 nm.** In this fitting window, SIF estimates are associated with smaller precision errors due to the greater number of spectral points used in the estimation.

The SIF product derived from the **743–758 nm window is the baseline product**, as this retrieval window provides the best compromise between retrieval precision and sensitivity to clouds. This SIF product is also consistent with the one defined in the existing Caltech SIF product [RD1].

3.1.1. L2 and L2B products

- The nominal TROPOSIF product is the L2 product which is provided as ungridded data available for each TROPOMI orbit. Each data file contains the SIF estimates derived from the two fitting windows. The validation of the L2 product is described in [AD2] (also see §3.1.4).
- A more user-friendly L2B product is also available. It consists in ungridded SIF estimates including all orbits within a day, similar to the existing Caltech product [RD1]. The SIF estimates derived from the two fitting windows are provided in separate files, depending on a data screening performed on cloud fraction:
 - the "**all sky**" L2B SIF product corresponds to SIF estimates derived from the **743-758 nm** fitting window, and for observations with cloud fraction below 0.8;
 - the "**clear sky**" L2B SIF product corresponds to SIF estimates derived from the **735-758 nm** fitting window, and for observations with cloud fraction below 0.2. This product also includes TOA reflectance estimates calculated from narrow spectral ranges at atmospheric windows (665, 680, 712, 741, 755, 773, and 781 nm).

The daily files only contain the valid retrievals (quality assurance above 0.5, see §3.1.2).

- The SIF estimates are provided in netCDF4 files. The format and content of these data files are described in §Erreur ! Source du renvoi introuvable..

3.1.2. Quality assurance

A quality value `qa_value` indicating the reliability of each SIF retrieval is included in the L2 and L2B SIF products. This value is a score between 0 and 1 (from lowest to highest quality) calculated through the combination of a series of penalty factors applied in those conditions which are expected to potentially affect the retrieval quality.

The initial `qa_value` is 1.0. It is modified by the different penalty factors as follows:

- $VZA > 60^\circ \rightarrow qa_value = qa_value - 0.5;$

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- $SZA > 70^\circ \rightarrow qa_value = qa_value - 0.5;$
- average TOA radiance $\notin [20, 200] \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1} \rightarrow qa_value = qa_value - 0.5;$
- $\chi_r^2 \notin [0.6, 2] \rightarrow qa_value = qa_value - 1.0$
- $SIF \notin [-10, 10] \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1} \rightarrow qa_value = qa_value - 1.0$

If the final qa_value becomes < 0 , it is reset to 0.

Cloud contamination is not included in the computation of the qa_value . Cloudy observations are included in the generation of the singular vectors used for the forward model so the latter is generally expected to properly represent cloudy spectra. In those cases in which clouds do degrade the fit quality, this will be captured in the χ_r^2 value. Further filtering by cloud fraction is possible for those applications in which only cloud free acquisitions are used.

Only SIF retrievals with at least $qa_value > 0.5$ are recommended for further processing.

3.1.3. Estimation errors

For the L2/L2B products, the 1- σ retrieval error is parameterized as a function of the TOA radiance on a per pixel basis, as described in [AD1].

The L2/L2B SIF data are provided for the instantaneous measurements. User may need to perform spatio-temporal binning of single-sky SIF retrievals. In that case, the estimation error can be represented by the standard error of the mean $\sigma(\overline{SIF})$, where $\overline{SIF}$ is the mean value of the n clear-sky retrievals in a given gridbox and time window, and σ_i is the single-retrieval 1 σ precision:

$$\sigma(\overline{SIF}) = \frac{1}{\sqrt{\sum_{i=1}^n (1/\sigma_i)^2}} \quad \text{Eq. 3-1}$$

3.1.4. Result of the product validation

An evaluation of the baseline TROPOSIF 743-758nm product was undertaken by comparing it against the Caltech product and OCO-2 SIF estimates re-scaled at 740 nm for acquisitions performed over year 2019 ([AD2]). Overall the three products are consistent in terms of level and amplitude of the retrieved SIF, and seasonality, for vegetated surfaces. The closest agreement was found between the two SIF products derived from TROPOMI (Caltech and TROPOSIF) with a root mean square deviation of $0.09 \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1}$.

The mean bias (inferred over vegetation-free areas) both for TROPOSIF-743nm and TROPOSIF-735nm is typically below $0.05 / 0.03 \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1}$ for the daily-corrected SIF, and below $0.08 / 0.04 \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1}$ for the "raw" SIF estimates. The retrieval error for TROPOSIF (estimated from a set of observations over Sahara) is typically $0.5 \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1}$ for the "all sky" product (743-758 nm fitting window) and $0.4 \text{ mW} \cdot \text{m}^{-2} \cdot \text{sr}^{-1} \cdot \text{nm}^{-1}$ for the "clear sky" product (735-758 nm fitting window).

3.2. Data distribution

The TROPOSIF product is available via the project portal (<https://s5p-troposif.noveltis.fr/data-access/>) where the data hosted on SRON FTP server are mirrored (<ftp://ftp.sron.nl/open-access-data-2/TROPOMI/tropomi/sif/>).

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4. Format of the TROPOSIF products

4.1. L2 product

4.1.1. File format

The file format for the L2 TROPOSIF product is netCDF-4/HDF5 as it is being done for other TROPOMI level 2 products.

4.1.2. Repository structure and file name convention

The data files are provided per

```
Year/
  └─ Month/
    └─ Day/
      └─ Orbit
```

The file name format complies with the convention used for the input L1B orbit files. An example of file name is as follows:

```
S5P_OFFL_L2__SIF____20191201T003404_20191201T021534_11047_01_010000_20191201T040519.nc
```

- The first field corresponds to the mission name, always "S5P";
- The second field corresponds to the processing stream, here offline "OFFL";
- The third field corresponds to the product level, here "L2";
- The fourth field corresponds to the product name, here "SIF";
- The fifth field corresponds to the start of granule in UTC as "YYYYMMDDTHHMMSS". The "T" is a fixed character;
- The sixth field corresponds to the end of the granule in UTC as "YYYYMMDDTHHMMSS". The "T" is a fixed character;
- The seventh field is the orbit number;
- The eighth field corresponds to the collection number;
- The ninth field corresponds to the processor version number as "MMmmpp", with "MM" the major version number, "mm" the minor version number, and "pp" the patch level;
- The tenth field corresponds to the time of processing for this granule in UTC as "YYYYMMDDTHHMMSS". The "T" is a fixed character;
- The eleventh field is the file name extension, ".nc" for netCDF-4/HDF5.

4.1.3. Structure of TROPOSIF L2 data files

For consistency with other Sentinel 5P L2 products, the netCDF-4/HDF5 files containing the L2 SIF products correspond to orbit files (with (x,y coordinates and time) as variable dimensions) and the variables inside being structured into groups:

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1. METADATA/ALGORITHM_SETTINGS: It contains information about the processor's configuration variables, such as the spectral fitting window or the thresholds used for data filtering.
2. PRODUCT: It contains the SIF product itself (SIF), the daily-average corrected SIF (SIF_Corr) and the estimated 1- uncertainty (SIF_ERROR) for the two fitting windows.
3. PRODUCT/SUPPORT_DATA/DETAILED_RESULTS: It contains ancillary data fields for the exploitation or interpretation of the SIF retrievals, such as day-length correction factor (DayLength_fac), the reduced χ^2 (χ_r^2) of the fit (redCHI2), the average TOA radiance in the fitting window (TOA_RAD), and the spectral TOA reflectance and corresponding wavelengths at several spectral points (TOA_RFL and WVL_RFL).
4. PRODUCT/SUPPORTDATA/GEOLOCATIONS: It contains data fields describing the acquisition location (latitude and longitude bounds for each retrieval) and geometry (viewing and solar angles).
5. PRODUCT/SUPPOR_DATA/INPUT_DATA: It contains geospatial data used as inputs for the retrieval, such as the cloud fraction from TROPOMI's L2 product (cloud_fraction_L2) and the land cover mask used to separate land and water pixels (LC_mask).

The content of one data file is shown in Figure 1 below:

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Name	Long Name	Type
▼  SSP_OFFL_L2_SIF_20191201T00340...	TROPOMI SIF L2 product	Local File
▼  METADATA	METADATA	—
▶  ALGORITHM_SETTINGS	METADATA/	—
▼  PRODUCT	PRODUCT	—
 delta_time	offset from the reference start time of measurement	1D
 latitude	pixel center latitude	Geo2D
 longitude	pixel center longitude	Geo2D
 SIF_735	retrieved SIF@740 (for clear-sky analysis only)	Geo2D
 SIF_743	retrieved SIF@740	Geo2D
 SIF_Corr_735	daylength-corr SIF@740	Geo2D
 SIF_Corr_743	daylength-corr SIF@740	Geo2D
 SIF_ERROR_735	1-sigma SIF retrieval error	Geo2D
 SIF_ERROR_743	1-sigma SIF retrieval error	Geo2D
▼  SUPPORT_DATA	PRODUCT/	—
▼  DETAILED_RESULTS	PRODUCT/SUPPORT_DATA/	—
 DayLength_fac	Daylength correction factor = $\text{int}(\cos\text{SZA}(t)) / \cos\text{SZA}(tm)$	Geo2D
 Mean_TOA_RAD_735	Mean TOA Radiance in fitting window	Geo2D
 Mean_TOA_RAD_743	Mean TOA Radiance in fitting window	Geo2D
 QA_value_735	Quality flag [0-1]	Geo2D
 QA_value_743	Quality flag [0-1]	Geo2D
 redCHI2_735	Reduced χ^2 value of the fit	Geo2D
 redCHI2_743	Reduced χ^2 value of the fit	Geo2D
 TOA_RFL	TOA Reflectance in far-red atmospheric windows	Geo2D
 WVLRFL	Spectral points at which TOA RFL is calculated	1D
▼  GEOLOCATIONS	PRODUCT/SUPPORT_DATA/	—
 latitude_bounds	latitude bounds	Geo2D
 longitude_bounds	longitude bounds	Geo2D
 solar_azimuth_angle	solar azimuth angle	Geo2D
 solar_zenith_angle	solar zenith angle	Geo2D
 viewing_azimuth_angle	viewing azimuth angle	Geo2D
 viewing_zenith_angle	viewing zenith angle	Geo2D
▼  INPUT_DATA	PRODUCT/SUPPORT_DATA/	—
 cloud_fraction_L2	effective radiometric cloud fraction	Geo2D
 LC_MASK	Land Cover Map	Geo2D
 time	reference start time of measurement	—

Figure 1: Detail of the L2 TROPOMI SIF data file as displayed with the Panoply netCDF viewer.

Among those variables:

- SIF_743 / SIF_735 correspond to instantaneous SIF estimates derived from the 743-758 nm / 735-758 nm windows;
- The SIF_Corr_743/SIF_Corr_735 variables correspond to instantaneous SIF estimates scaled to daily SIF data by means of the day-length scaling factor (DayLength_fac) (see Eq 4-6 in [AD1]);
- SIF_ERROR_743/SIF_ERROR_735 correspond to the 1- σ retrieval errors which are parameterized for the instantaneous SIF estimates (§3.1.3);
- QA_value_743/QA_value_735 correspond to the quality assurance associated with the instantaneous SIF_743 / SIF_735 estimates as defined in §3.1.2.

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A more detailed description of these variable dimensions and attributes is provided below for the same example data file:

```
netcdf file:/home/bsy/TRAVAIL/ESA-
TROPOSIF/DATA/S5P_OFFL_L2__SIF____20191201T003404_20191201T021534_11047_01_010000_20191201T040519.nc
{
  dimensions:
    time = 1;
    ncorner = 4;
    num_bd_rfl = 7;
    ground_pixel = 448;
    scanline = 4172;
  group: METADATA {
    group: ALGORITHM_SETTINGS {
      // group attributes:
      :Polynomial_degree_win-743_nm = 3L; // long
      :Number_SVs_win-743_nm = 4L; // long
      :Fitting_window_win-743_nm_(nm) = 743.0, 758.0; // double
      :Polynomial_degree_win-735_nm = 3L; // long
      :Number_SVs_win-735_nm = 7L; // long
      :Fitting_window_win-735_nm_(nm) = 735.0, 758.0; // double
      :Cloud_fraction_threshold = 0.8; // double
      :SZA_threshold = 70.0; // double
      :VZA_threshold = 60.0; // double
      :Quality_level_threshold = 80L; // long
      :SIF_reference_wavelength_(nm) = 740.0; // double
      :Masked-out_spectral_channels_for_SIF_retrieval_(#) = 179L; // long
      :FWHM_of_macro-channels_for_TOA_reflectance = 3.0, 3.0, 3.0; // double
    }
  }

  group: PRODUCT {
    variables:
      float SIF_743(time=1, scanline=4172, ground_pixel=448);
      :_FillValue = 9.96921E36f; // float
      :units = "mW/m2/sr/nm";
      :standard_name = "retrieved SIF@740 743-758 nm fitting window";
      :long_name = "retrieved SIF@740";
  }
}
```

```

:_ChunkSizes = 1U, 4172U, 448U; // uint

float SIF_Corr_743(time=1, scanline=4172, ground_pixel=448);
:_FillValue = 9.96921E36f; // float
:units = "mW/m2/sr/nm";
:standard_name = "daylength-corr SIF@740 743-758 nm fitting window";
:long_name = "daylength-corr SIF@740";
:_ChunkSizes = 1U, 4172U, 448U; // uint

float SIF_ERROR_743(time=1, scanline=4172, ground_pixel=448);
:_FillValue = 9.96921E36f; // float
:units = "mW/m2/sr/nm";
:standard_name = "1-sigma error 743-758 nm fitting window";
:long_name = "1-sigma SIF retrieval error";
:_ChunkSizes = 1U, 4172U, 448U; // uint

float SIF_735(time=1, scanline=4172, ground_pixel=448);
:_FillValue = 9.96921E36f; // float
:units = "mW/m2/sr/nm";
:standard_name = "retrieved SIF@740 735-758 nm fitting window (for clear-sky analysis
only)";
:long_name = "retrieved SIF@740 (for clear-sky analysis only)";
:_ChunkSizes = 1U, 4172U, 448U; // uint

float SIF_Corr_735(time=1, scanline=4172, ground_pixel=448);
:_FillValue = 9.96921E36f; // float
:units = "mW/m2/sr/nm";
:standard_name = "daylength-corr SIF@740 735-758 nm fitting window";
:long_name = "daylength-corr SIF@740";
:_ChunkSizes = 1U, 4172U, 448U; // uint

float SIF_ERROR_735(time=1, scanline=4172, ground_pixel=448);
:_FillValue = 9.96921E36f; // float
:units = "mW/m2/sr/nm";
:standard_name = "1-sigma error 735-758 nm fitting window";
:long_name = "1-sigma SIF retrieval error";
:_ChunkSizes = 1U, 4172U, 448U; // uint

```

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```
float latitude(time=1, scanline=4172, ground_pixel=448);

:comment = "Latitude of the center of each ground pixel on the WGS84 reference ellipsoid";
:_FillValue = 9.96921E36f; // float
:long_name = "pixel center latitude";
:max_val = 90.0f; // float
:min_val = -90.0f; // float
:standard_name = "latitude";
:bounds = "latitude_bounds";
:units = "degrees_north";
:_ChunkSizes = 1U, 4172U, 448U; // uint
```

```
float longitude(time=1, scanline=4172, ground_pixel=448);

:comment = "Longitude of the center of each ground pixel on the WGS84 reference ellipsoid";
:_FillValue = 9.96921E36f; // float
:long_name = "pixel center longitude";
:max_val = 180.0f; // float
:min_val = -180.0f; // float
:standard_name = "longitude";
:bounds = "longitude_bounds";
:units = "degrees_east";
:_ChunkSizes = 1U, 4172U, 448U; // uint
```

```
float time(time=1);

:comment = "Reference time of the measurements. The reference time is set to yyyy-mm-ddT00:00:00 UTC, where yyyy-mm-dd is the day on which the measurements of a particular data granule start.";
```

```
:long_name = "reference start time of measurement";
:standard_name = "time";
:units = "seconds since 2010-01-01 00:00:00";
:_ChunkSizes = 1U; // uint
```

```
int delta_time(time=1, scanline=4172);

:_FillValue = -2147483647; // int
:comment = "Time difference with time for each measurement";
:long_name = "offset from the reference start time of measurement";
:units = "milliseconds since 2019-12-01 00:00:00";
:_ChunkSizes = 1U, 4172U; // uint
```

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```

group: SUPPORT_DATA {
  group: DETAILED_RESULTS {
    variables:
      float redCHI2_743(time=1, scanline=4172, ground_pixel=448);
      :units = "-";
      :standard_name = "reduced CHI2 743-758 nm fitting window";
      :long_name = "Reduced Chi^2 value of the fit";
      :_ChunkSizes = 1U, 4172U, 448U; // uint

      float redCHI2_735(time=1, scanline=4172, ground_pixel=448);
      :units = "-";
      :standard_name = "reduced CHI2 735-758 nm fitting window";
      :long_name = "Reduced Chi^2 value of the fit";
      :_ChunkSizes = 1U, 4172U, 448U; // uint

      float DayLength_fac(time=1, scanline=4172, ground_pixel=448);
      :units = "-";
      :standard_name = "Day-length_factor";
      :long_name = "Daylength correction factor = int(cosSZA(t)) / cosSZA(tm)";
      :_ChunkSizes = 1U, 4172U, 448U; // uint

      float TOA_RFL(time=1, scanline=4172, ground_pixel=448, num_bd_rfl=7);
      :_FillValue = 9.96921E36f; // float
      :units = "-";
      :standard_name = "TOA Reflectance";
      :long_name = "TOA Reflectance in far-red atmospheric windows";
      :_ChunkSizes = 1U, 2674U, 448U, 7U; // uint

      float Mean_TOA_RAD_743(time=1, scanline=4172, ground_pixel=448);
      :_FillValue = 9.96921E36f; // float
      :units = "mW/m2/sr/nm";
      :standard_name = "TOA Radiance";
      :long_name = "Mean TOA Radiance in fitting window";
      :_ChunkSizes = 1U, 4172U, 448U; // uint

      float Mean_TOA_RAD_735(time=1, scanline=4172, ground_pixel=448);

```

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```

:_FillValue = 9.96921E36f; // float

:units = "mW/m2/sr/nm";

:standard_name = "TOA Radiance";

:long_name = "Mean TOA Radiance in fitting window";

:_ChunkSizes = 1U, 4172U, 448U; // uint

float QA_value_743(time=1, scanline=4172, ground_pixel=448);

:_FillValue = 9.96921E36f; // float

:units = "-";

:standard_name = "Quality flag";

:long_name = "Quality flag [0-1]";

:_ChunkSizes = 1U, 4172U, 448U; // uint

float QA_value_735(time=1, scanline=4172, ground_pixel=448);

:_FillValue = 9.96921E36f; // float

:units = "-";

:standard_name = "Quality flag";

:long_name = "Quality flag [0-1]";

:_ChunkSizes = 1U, 4172U, 448U; // uint

float WVL_RFL(num_bd_rfl=7);

:long_name = "Spectral points at which TOA_RFL is calculated";

:standard_name = "WVL_RFL";

:units = "nm";

:_ChunkSizes = 7U; // uint

}

group: GEOLOCATIONS {

    variables:

        float solar_azimuth_angle(time=1, scanline=4172, ground_pixel=448);

        :comment = "Solar azimuth angle at the ground pixel location on the reference ellipsoid.
Angle is measured clockwise from the North (East = +90, South = -+180, West = -90)";

        :coordinates = "longitude latitude";

        :_FillValue = 9.96921E36f; // float

        :long_name = "solar azimuth angle";

        :max_val = 180.0f; // float

```

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```

:min_val = -180.0f; // float

:standard_name = "solar_azimuth_angle";

:units = "degree";

:_ChunkSizes = 1U, 4172U, 448U; // uint

float latitude_bounds(time=1, scanline=4172, ground_pixel=448, ncorner=4);

:comment = "The four latitude boundaries of each ground pixel.";

:_FillValue = 9.96921E36f; // float

:units = "degrees_north";

:_ChunkSizes = 1U, 4172U, 448U, 4U; // uint

float viewing_zenith_angle(time=1, scanline=4172, ground_pixel=448);

:comment = "Zenith angle of the satellite at the ground pixel location on the reference
ellipsoid. Angle is measured away from the vertical.";

:coordinates = "longitude latitude";

:_FillValue = 9.96921E36f; // float

:long_name = "viewing zenith angle";

:max_val = 180.0f; // float

:min_val = 0.0f; // float

:units = "degree";

:standard_name = "platform_zenith_angle";

:_ChunkSizes = 1U, 4172U, 448U; // uint

float longitude_bounds(time=1, scanline=4172, ground_pixel=448, ncorner=4);

:comment = "The four longitude boundaries of each ground pixel.";

:_FillValue = 9.96921E36f; // float

:units = "degrees_east";

:_ChunkSizes = 1U, 4172U, 448U, 4U; // uint

float viewing_azimuth_angle(time=1, scanline=4172, ground_pixel=448);

:comment = "Azimuth angle of the satellite at the ground pixel location on the reference
ellipsoid. Angle is measured clockwise from the North (East = +90, South = +180, West = -90)";

:coordinates = "longitude latitude";

:_FillValue = 9.96921E36f; // float

:units = "degree";

:long_name = "viewing azimuth angle";

:standard_name = "platform_azimuth_angle";

:max_val = 180.0f; // float

```

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```

:min_val = -180.0f; // float

:_ChunkSizes = 1U, 4172U, 448U; // uint

float solar_zenith_angle(time=1, scanline=4172, ground_pixel=448);

    :comment = "Solar zenith angle at the ground pixel location on the reference ellipsoid.
Angle is measured away from the vertical. ESA definition of day side: SZA less the 92 degrees";

    :coordinates = "longitude latitude";

    :_FillValue = 9.96921E36f; // float

    :long_name = "solar zenith angle";

    :standard_name = "solar_zenith_angle";

    :max_val = 180.0f; // float

    :min_val = 0.0f; // float

    :units = "degree";

    :_ChunkSizes = 1U, 4172U, 448U; // uint

}

group: INPUT_DATA {
    variables:

        float cloud_fraction_L2(time=1, scanline=4172, ground_pixel=448);

            :_FillValue = 9.96921E36f; // float

            :units = "1";

            :long_name = "effective radiometric cloud fraction";

            :source = "cal";

            :comment = "Retrieved effective radiometric cloud fraction using the OCRA/ROCINN CAL
model.";

            :coordinates = "/PRODUCT/longitude /PRODUCT/latitude";

            :_ChunkSizes = 1U, 4172U, 448U; // uint

        ubyte LC_MASK(time=1, scanline=4172, ground_pixel=448);

            :_FillValue = 0UB; // ubyte

            :units = "([ENF=1, EBF=2, DNF=3, DBF=4, MF=5, CS=6, OS=7, WS=8, S=9, G=10, PW=11, C=12,
U=13, CNV=14, SI=15, B=16])";

            :standard_name = "Land Cover Map (MODIS MCD12C1 2018)";

            :long_name = "Land Cover Map";

            :_ChunkSizes = 1U, 4172U, 448U; // uint

    }

```

```

}

}

// global attributes:
:title = "TROPOMI SIF L2 product";
:date_created = "2021-01-28 16:25:58.133348";
}

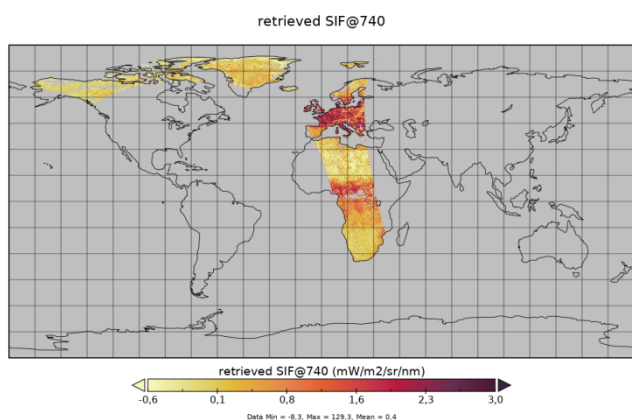
```

The number of columns of variables is 448, which is consistent with those for the L1B_BD6 data files on which the retrieval is based.

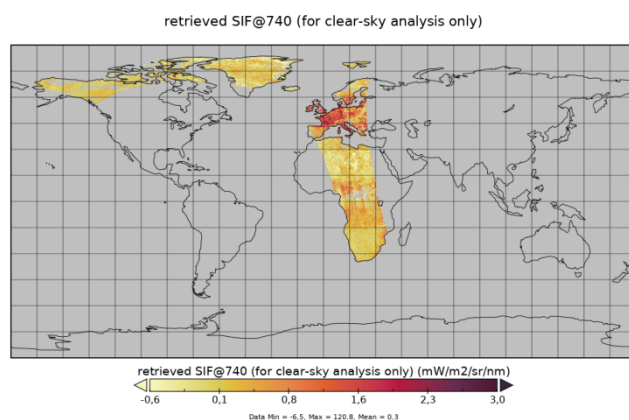
4.1.4. Data product examples

Examples of the L2 TROPOMI SIF product (for one orbit file) projected on a global map are shown in Figure 2. The data have been displayed using the Panoply tool [RD2].

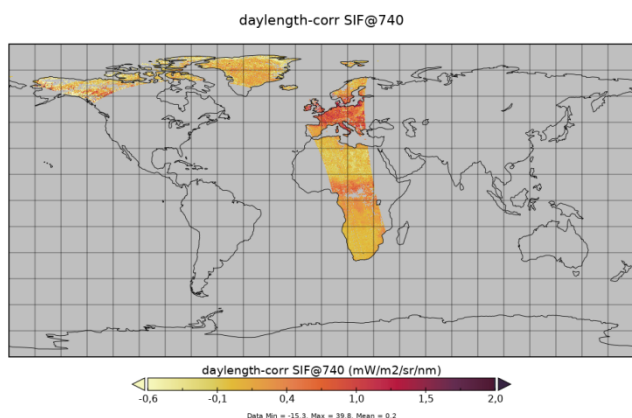
SIF_743



SIF_735



SIF_Corr_743



SIF_Corr_735

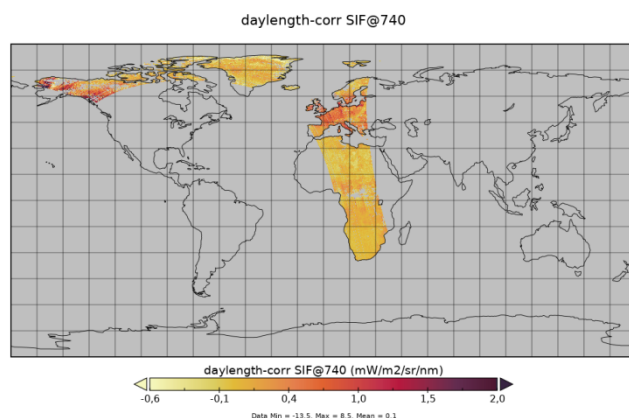


Figure 2: Examples of L2 TROPOMI SIF product estimated for the orbit number 08684 (June 17th 2019) (figures generated by Panoply).

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4.1.5. Data distribution

TROPOSIF L2 data are available through the project website <https://s5p-troposif.noveltis.fr/data-access/>.

4.2. L2B product

4.2.1. File format

As for the L2 product, the file format for L2B TROPOSIF product is netCDF-4/HDF5.

4.2.2. Repository structure and file name convention

The data files are provided per:

```

Year/
├── Month/
│   ├── Day/
│   │   └── Orbit

```

Contrary to the L2 product, the all-sky (SIF 743-758 nm, CF<0.8) and clear-sky (SIF 735-758 nm, CF < 0.2) estimates are provided in separate files.

The file name format complies with the following convention:

TROPOSIF_L2B_productname_YYYY-MM-DD.nc

where:

- Productname is either "all_sky" or "clear_sky";
- YYYY, MM and DD correspond respectively to the year, month and day of acquisition.

4.2.3. Structure of TROPOSIF L2 files

The L2B data correspond to the L2 data of all orbits per day. The data which do comply with the quality assurance have been screened out (i.e. qa_value <= 0.5). As for the L2 TROPOSIF product, the variables are structured into groups.

4.2.3.1. All-sky product

The content of one all-sky data file is shown in Figure 3 below:

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Name	Long Name	Type
▼ TROPISIF_L2B_all_sky_2019-01-01.nc	TROPISIF_L2B_all_sky	Local File
▼ METADATA	METADATA	—
▶ ALGORITHM_SETTINGS	METADATA/	—
▼ PRODUCT	PRODUCT	—
latitude	latitude	1D
longitude	longitude	1D
SIF_743	retrieved SIF@740	1D
SIF_Corr_743	daylength-corr SIF@740	1D
SIF_ERROR_743	1-sigma SIF retrieval error	1D
▼ SUPPORT_DATA	PRODUCT/	—
▼ DETAILED_RESULTS	PRODUCT/SUPPORT_DATA/	—
Mean_TOA_RAD_743	Mean TOA Radiance in 743-758 nm fitting window	1D
QA_value_743	Quality flag [0-1]	1D
▼ GEOLOCATIONS	PRODUCT/SUPPORT_DATA/	—
relative_azimuth_angle	relative azimuth angle	1D
solar_zenith_angle	solar zenith angle	1D
viewing_zenith_angle	viewing zenith angle	1D
▼ INPUT_DATA	PRODUCT/SUPPORT_DATA/	—
cloud_fraction_L2	cloud fraction	1D
LC_MASK	Land Cover Map	1D

Figure 3: Detail of the L2B TROPOMI all-sky SIF file as displayed by the Panoply netCDF viewer.

A more detailed description of these variable dimensions and attributes is provided below for the same example data file:

```
netcdf file:/home/bsy/TRAVAIL/ESA-TROPISIF/DATA/TROPISIF_L2B_all_sky_2019-01-01.nc {
  dimensions:
    ncorner = 4;
    n_elem = 2421884;
    num_bd_rfl = 7;
  group: METADATA {
    group: ALGORITHM_SETTINGS {
      // group attributes:
      :Polynomial_degree_win-743_nm = 3L; // long
      :Number_SVs_win-743_nm = 4L; // long
      :Fitting_window_win-743_nm_(nm) = 743.0, 758.0; // double
      :Polynomial_degree_win-735_nm = 3L; // long
      :Number_SVs_win-735_nm = 7L; // long
      :Fitting_window_win-735_nm_(nm) = 735.0, 758.0; // double
      :Cloud_fraction_threshold = 0.8; // double
      :SZA_threshold = 70.0; // double
      :VZA_threshold = 60.0; // double
      :Quality_level_threshold = 80L; // long
      :SIF_reference_wavelength_(nm) = 740.0; // double
    }
  }
}
```

SENTINEL-5P+ INNOVATION THEME 6: SOLAR INDUCED CHLOROPHYLL FLUORESCENCE (SIF)	Ref	NOV-FE-0956-NT-019		
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```

:Masked-out_spectral_channels_for_SIF_retrieval_(#) = 179L; // long

:FWMH_of_macro-channels_for_TOA_reflectance = 3.0, 3.0, 3.0; // double
}

}

group: PRODUCT {
  variables:

    float SIF_743(n_elem=2421884);
      :units = "mW/m2/sr/nm";
      :standard_name = "retrieved SIF@740 743-758 nm fitting window";
      :long_name = "retrieved SIF@740";
      :_ChunkSizes = 2421884U; // uint

    float longitude(n_elem=2421884);
      :standard_name = "longitude";
      :_ChunkSizes = 2421884U; // uint

    float SIF_Corr_743(n_elem=2421884);
      :units = "mW/m2/sr/nm";
      :standard_name = "daylength-corr SIF@740 743-758 nm fitting window";
      :long_name = "daylength-corr SIF@740";
      :_ChunkSizes = 2421884U; // uint

    float SIF_ERROR_743(n_elem=2421884);
      :units = "mW/m2/sr/nm";
      :standard_name = "1-sigma error 743-758 nm fitting window";
      :long_name = "1-sigma SIF retrieval error";
      :_ChunkSizes = 2421884U; // uint

    float latitude(n_elem=2421884);
      :standard_name = "latitude";
      :_ChunkSizes = 2421884U; // uint

group: SUPPORT_DATA {

```

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```

group: DETAILED_RESULTS {
    variables:

        float Mean_TOA_RAD_743(n_elem=2421884);

            :units = "mW/m2/sr/nm";

            :standard_name = "TOA Radiance";

            :long_name = "Mean TOA Radiance in 743-758 nm fitting window";

            :_ChunkSizes = 2421884U; // uint


        float QA_value_743(n_elem=2421884);

            :standard_name = "Quality flag";

            :long_name = "Quality flag [0-1]";

            :units = "-";

            :_ChunkSizes = 2421884U; // uint


    }


group: GEOLOCATIONS {
    variables:

        float viewing_zenith_angle(n_elem=2421884);

            :standard_name = "viewing zenith angle";

            :_ChunkSizes = 2421884U; // uint


        float solar_zenith_angle(n_elem=2421884);

            :standard_name = "solar zenith angle";

            :_ChunkSizes = 2421884U; // uint


        float relative_azimuth_angle(n_elem=2421884);

            :standard_name = "relative azimuth angle";

            :_ChunkSizes = 2421884U; // uint


    }


group: INPUT_DATA {
    variables:

        float cloud_fraction_L2(n_elem=2421884);

```

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```

:standard_name = "cloud_fraction";

:_ChunkSizes = 2421884U; // uint

ubyte LC_MASK(n_elem=2421884);

:units = "([ENF=1, EBF=2, DNF=3, DBF=4, MF=5, CS=6, OS=7, WS=8, S=9, G=10,
PW=11, C=12, U=13, CNV=14, SI=15, B=16])";

:standard_name = "Land Cover Map (MODIS MCD12C1 2018)";

:long_name = "Land Cover Map";

:_ChunkSizes = 2421884U; // uint

}

}

}

// global attributes:

:title = "TROPOSIF_L2B__all_sky";

:date_created = "2021-01-27 16:08:25.588905";

}

```

4.2.3.2. Clear-sky product

The content of one clear-sky data file is shown in Figure 4 below. Compared to the all-sky product, the clear-sky data file contains the additional Top-Of-Atmosphere reflectance (TOA_RFL) variable.

Name	Long Name	Type
▼  TROPoSIF_L2B_clear_sky_2019-01-01.nc	TROPoSIF_L2B_clear_sky	Local File
▼  METADATA	METADATA	—
▼  ALGORITHM_SETTINGS	METADATA/	—
▼  PRODUCT	PRODUCT	—
 latitude	latitude	1D
 longitude	longitude	1D
 SIF_735	retrieved SIF@740	1D
 SIF_Corr_735	daylength-corr SIF@740	1D
 SIF_ERROR_735	1-sigma SIF retrieval error	1D
▼  SUPPORT_DATA	PRODUCT/	—
▼  DETAILED_RESULTS	PRODUCT/SUPPORT_DATA/	—
 Mean_TOA_RAD_735	Mean TOA Radiance in 735-758 nm fitting window	1D
 QA_value_735	Quality flag [0-1]	1D
 TOA_RFL	TOA Reflectance in far-red atmospheric windows	2D
 WVLRFL	Spectral points at which TOA RFL is calculated	1D
▼  GEOLOCATIONS	PRODUCT/SUPPORT_DATA/	—
 relative_azimuth_angle	relative azimuth angle	1D
 solar_zenith_angle	solar zenith angle	1D
 viewing_zenith_angle	viewing zenith angle	1D
▶  INPUT_DATA	PRODUCT/SUPPORT_DATA/	—
 cloud_fraction_L2	cloud fraction	1D
 LC_MASK	Land Cover Map	1D

Figure 4: Detail of the L2B TROPOMI clear-sky SIF file as displayed by the Panoply netCDF viewer.

```
netcdf file:/home/bsy/TRAVAIL/ESA-TROPoSIF/DATA/TROPoSIF_L2B_clear_sky_2019-01-01.nc {
  dimensions:
    ncorner = 4;
    n_elem = 1188469;
    num_bd_rfl = 7;
  group: METADATA {
    group: ALGORITHM_SETTINGS {
      // group attributes:
      :Polynomial_degree_win-743_nm = 3L; // long
      :Number_SVs_win-743_nm = 4L; // long
      :Fitting_window_win-743_nm (nm) = 743.0, 758.0; // double
      :Polynomial_degree_win-735_nm = 3L; // long
      :Number_SVs_win-735_nm = 7L; // long
      :Fitting_window_win-735_nm (nm) = 735.0, 758.0; // double
      :Cloud_fraction_threshold = 0.8; // double
      :SZA_threshold = 70.0; // double
      :VZA_threshold = 60.0; // double
      :Quality_level_threshold = 80L; // long
      :SIF_reference_wavelength (nm) = 740.0; // double
      :Masked-out_spectral_channels_for_SIF_retrieval (#) = 179L; // long
    }
  }
}
```

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```

:FWHM_of_macro-channels_for_TOA_reflectance = 3.0, 3.0, 3.0; // double
}

}

group: PRODUCT {
  variables:
    float SIF_735(n_elem=1188469);
      :units = "mW/m2/sr/nm";
      :standard_name = "retrieved SIF@740 735-758 nm fitting window";
      :long_name = "retrieved SIF@740";
      :_ChunkSizes = 1188469U; // uint

    float longitude(n_elem=1188469);
      :standard_name = "longitude";
      :_ChunkSizes = 1188469U; // uint

    float SIF_Corr_735(n_elem=1188469);
      :units = "mW/m2/sr/nm";
      :standard_name = "daylength-corr SIF@740 735-758 nm fitting window";
      :long_name = "daylength-corr SIF@740";
      :_ChunkSizes = 1188469U; // uint

    float SIF_ERROR_735(n_elem=1188469);
      :units = "mW/m2/sr/nm";
      :standard_name = "1-sigma error 735-758 nm fitting window";
      :long_name = "1-sigma SIF retrieval error";
      :_ChunkSizes = 1188469U; // uint

    float latitude(n_elem=1188469);
      :standard_name = "latitude";
      :_ChunkSizes = 1188469U; // uint

group: SUPPORT_DATA {
  group: DETAILED_RESULTS {
    variables:
      float TOA_RFL(n_elem=1188469, num_bd_rfl=7);

```

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```

:units = "-";

:standard_name = "TOA Reflectance";

:long_name = "TOA Reflectance in far-red atmospheric windows";

:_ChunkSizes = 1188469U, 7U; // uint

float WVL_RFL(num_bd_rfl=7);

:standard_name = "WVL_RFL";

:long_name = "Spectral points at which TOA_RFL is calculated";

:units = "nm";

:_ChunkSizes = 7U; // uint

float Mean_TOA_RAD_735(n_elem=1188469);

:units = "mW/m2/sr/nm";

:standard_name = "TOA Radiance";

:long_name = "Mean TOA Radiance in 735-758 nm fitting window";

:_ChunkSizes = 1188469U; // uint

float QA_value_735(n_elem=1188469);

:standard_name = "Quality flag";

:long_name = "Quality flag [0-1]";

:units = "-";

:_ChunkSizes = 1188469U; // uint

}

group: GEOLOCATIONS {

variables:

float viewing_zenith_angle(n_elem=1188469);

:standard_name = "viewing zenith angle";

:_ChunkSizes = 1188469U; // uint

float solar_zenith_angle(n_elem=1188469);

:standard_name = "solar zenith angle";

:_ChunkSizes = 1188469U; // uint

float relative_azimuth_angle(n_elem=1188469);

:standard_name = "relative azimuth angle";

```

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```

        :_ChunkSizes = 1188469U; // uint

    }

    group: INPUT_DATA {
        variables:

            float cloud_fraction_L2(n_elem=1188469);

            :standard_name = "cloud_fraction";

            :_ChunkSizes = 1188469U; // uint

            ubyte LC_MASK(n_elem=1188469);

            :units = "([ENF=1, EBF=2, DNF=3, DBF=4, MF=5, CS=6, OS=7, WS=8, S=9, G=10, PW=11, C=12,
U=13, CNV=14, SI=15, B=16])";

            :standard_name = "Land Cover Map (MODIS MCD12C1 2018)";

            :long_name = "Land Cover Map";

            :_ChunkSizes = 1188469U; // uint

        }

    }

}

// global attributes:
:title = "TROPOSIF_L2B__clear_sky";
:date_created = "2021-01-27 16:08:35.332674";
}

```

4.2.4. Data product examples

Examples of the daily L2B TROPOSIF product, as projected on a global map, are provided in Figure 5.

TROPOSIF_L2B_all_sky_2019-06-17.nc

TROPOSIF_L2B_clear_sky_2019-06-17.nc

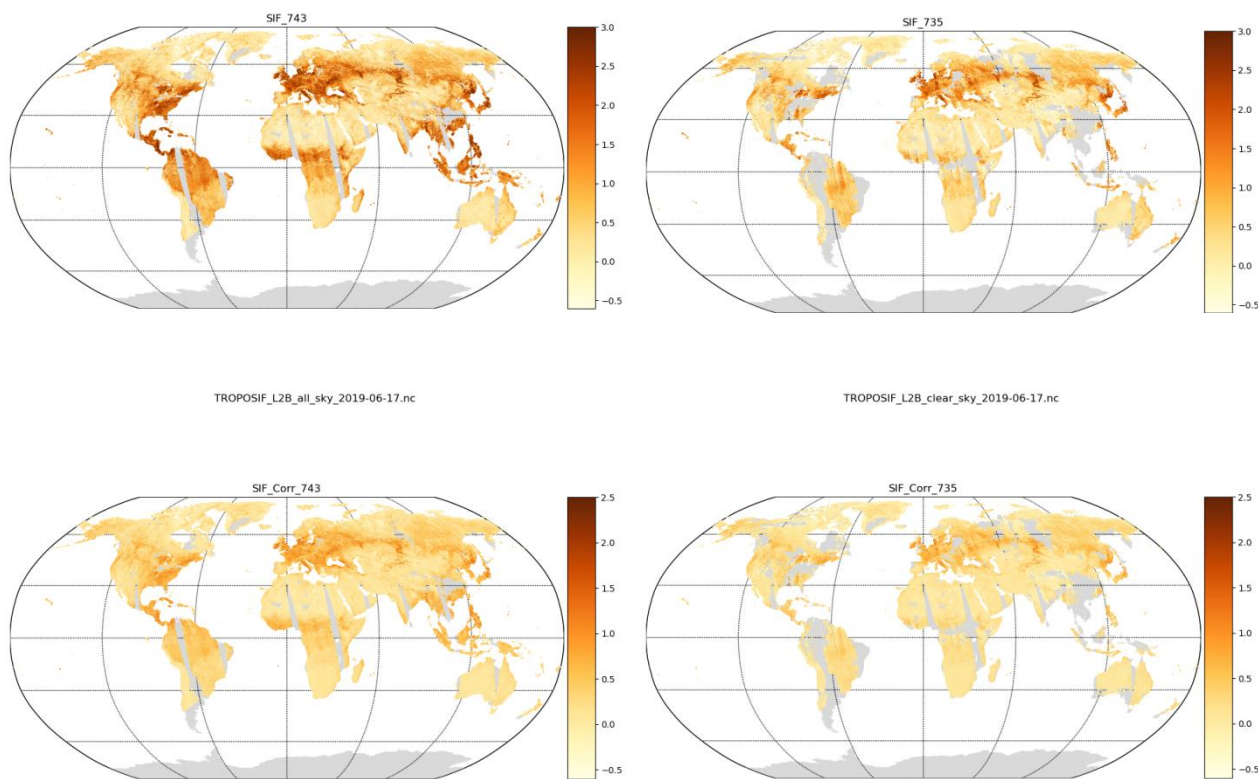


Figure 5: Examples of L2B SIF products estimated on June 17th 2019.

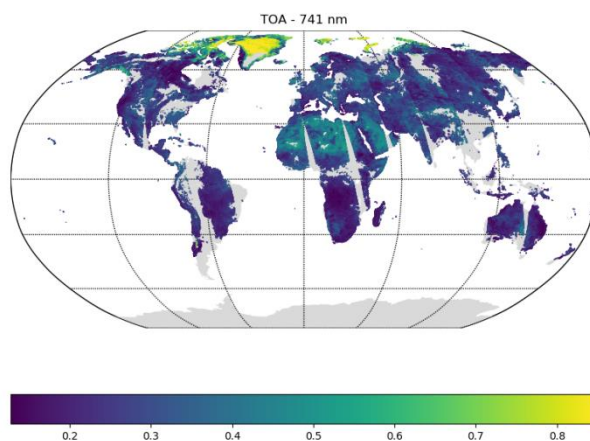


Figure 6: Example of TOA reflectance product (at 741 nm) estimated on June 17th 2019.

4.2.5. Data distribution

TROPOSIF L2 data are available through the project website <https://s5p-troposif.noveltis.fr/data-access/>.