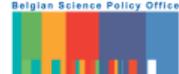




S5P Mission Performance Centre NPP Cloud [L2__NP_BDx] Readme



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CHANGE LOG

Reason for change	Issue	Revision	Date
Cloud mask is based on VIIRS ECM product (instead for VICMO) since processor version 01.01.00 (see Table 1)	1	4	11/03/2020
<ul style="list-style-type: none"> Table 1: adapting to version 01.03.00 of the processor Section 4.1 & section 4.2: some text moved from section 4.1 (Known Data Quality Issues) to section 4.2 (Solved Data Quality Issues) Section 6.1: added format changes related to version 01.03.00 	1	5	05/07/2021
<ul style="list-style-type: none"> Table 1: addition of version 02.00.01 Table 1: addition of a note on REPRO orbit for version 01.03.00 Section 6.1: removed old changes and added detailed format changes related to version 02.00.01 in the newly created ANNEX section (Section 9). Added a note on the addition of new variables based on additional VIIRS level 2 data products. Section 7: Replaced Open Data Hub with CDSE 	1	6	29/11/2023

1 Summary

This is the Product Readme File (PRF) for the Copernicus Sentinel 5 Precursor Tropospheric Monitoring Instrument (S5P/TROPOMI) NPP-Cloud auxiliary/support data product and is applicable for the Offline (OFFL) timeliness data product (there are no Near Real Time products).

A change in the Copernicus Sentinel 5P operations scenario, towards an increased spatial resolution from 7.0 km to 5.5 km along track for all measurements, became operational starting from 6 August 2019, orbit 9388. Obviously, this is also affecting the NPP-Cloud product, which is essentially a re-gridding of the operational VIIRS L1 and cloud mask products from NOAA to the TROPOMI resolution.

Product Identifier : **L2__NP_BDx** (Where **x** indicates a specific TROPOMI band)

Example filename :

S5P_OFFL_L2__NP_BD3_20180704T133421_20180704T151550_03748_01_010000_20180710T125313.nc

The data product has the following DOI: <https://doi.org/10.5270/S5P-c8b3899>

The Readme file describes the current processing baseline, product and quality limitations, and product availability status. More information on this data product is available from the Sentinel product webpage:

<https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms>,

and from the TROPOMI product webpage <http://www.tropomi.eu/data-products>.

The S5p NPP Cloud product contains information on cloud and scene homogeneity for TROPOMI scenes, derived from operational products from the Visible Infrared Imaging Radiometer Suite (VIIRS) on board the Suomi NPP platform. S5p operates in loose formation orbit with NPP, so that measurements from VIIRS are well co-located with TROPOMI, with a time difference of about 3.5 minutes. There is no specific validation of auxiliary products within the S5p Mission Performance Centre.

2 Processing baseline description

Table 1 contains the history of the S5p S-NPP Cloud processor versions.

Processor Version	In operation from	In operation until	Relevant improvements
02.00.01	OFFL: orbit 31705, 2023-11-26	Current version	- Addition of new variables based on additional VIIRS level 2 cloud data
01.03.00	OFFL: Orbit 19258, 2021-07-01 RPRO: Orbit 25163, 2022-08-21	Orbit 31704, 2023-11-26 Orbit 25276, 2022-08-30	- Changes to some metadata - Enable code to read NOAA re-processed VIIRS ECM data - RPRO data: Users are recommended to use the RPRO data in the period 21-30 August 2022 because those products were generated with an optimal configuration of the auxiliary files (unlike the OFFL data).
01.01.00	OFFL: Orbit 12432, 2020-03-07	Orbit 19257, 2021-07-01	- Cloud mask is now based on VIIRS ECM product (instead for VICMO) (see section 4). - A bug fix affecting small sub-sections of some orbits leading to missed cloudy mask counts was implemented - Added <code>qa_value</code> parameter
01.00.02	OFFL: Orbit 5236, 2018-10-17 RPRO: Orbit 2818, 2018-04-30	Orbit 12431, 2020-03-07 Orbit 3660, 2018-06-28	Correction of the <code>max_value</code> attribute assigned to the cloud flag counts, which was too low (see section 4)
01.00.00	OFFL: Orbit 3661, 2018-06-28	Orbit 5234, 2018-10-17	Initial version

Table 1: History of S5p S-NPP Cloud processor versions

3 Product Quality

3.1 Recommendations for data usage

The product contains statistics of the VIIRS measured radiances and cloud mask, aggregated over the S5p footprints. Included in the data are counts of the number of valid VIIRS observations in a given S5p scene and these should be used to confirm that VIIRS data is actually present and valid for a given S5p scene.

The product does not give cloud fraction directly, but reports the number of VIIRS pixels within an S5p scene which are flagged in four classes: confidently cloudy, probably cloudy, probably clear and confidently clear. The user can compute fraction from these by (a) summing the number of pixels in the class(es) of interest (e.g. confidently + probably cloudy) and (b) normalizing by the total number of VIIRS cloud flag value, obtained by summing the counts for all four classes.

In version 2 of the processor additional variables are made available based on the VIIRS cloud height (“VIIRS JPSS Granule CloudHeight EDR”), VIIRS cloud phase (“VIIRS JPSS Granule CloudPhase EDR”), and VIIRS cloud DCOMP (daytime cloud optical and microphysical properties, “VIIRS JPSS Granule CloudDCOMP EDR”). The product user manual contains a full list of added variables, each marked with the source of the variable as listed in parentheses in the previous list. Note that the processor itself is capable to ingest additional VIIRS products, but these are not used operationally. The cloud mask data that was available in previous versions has been enhanced by the addition of variables that are marked “VIIRS JPSS Granule CloudMask EDR” in the product user manual.

For further details, data users are encouraged to read the Product User Manual (PUM) and Algorithm Theoretical Basis Document (ATBD) associated with this data product, available on the ESA S5p Document library (<https://sentinel.esa.int/web/sentinel/user-guides/sentinel-5p-tropomi/document-library>).

3.2 Validation results

The NPP product is essentially a re-gridding of the operational VIIRS L1 and cloud mask products from NOAA. The fidelity of the re-gridding algorithm was confirmed during the development of the S5P-NPP product and S5p commissioning by (a) comparing results between the prototype and operational versions of the processor; (b) comparing the re-gridded VIIRS radiances to S5p measurements in comparable spectral bands.

The quality of the geophysical quantities which are re-gridded (cloud mask and Level 1 radiances) is covered by documentation and other resources from NASA and NOAA, including the references given in section 8 below.

4 Data Quality Remarks

4.1 Known Data Quality Issues

To date there are no known major issues with the S5P-NPP product. The algorithm appears to reliably re-grid the input products. Availability and quality of information is limited by that of input VIIRS data and timeliness/completeness of transfer to the S5p ground segment. This has not led to significant gaps of coverage so far, though the NPP product can only be generated within about 2 days delay from real time, due to the need to wait for all required input product to be acquired from NOAA.

The assumptions made about the S5p spatial response may limit the validity of the S5p data for quantitative use (beyond e.g. simply flagging cloud presence). E.g. the product provides most information for quadrilateral areas which are related to the S5p spatial response. Radiances are also reported as averages weighted by the spatial response, however variations in spatial response as a function of spectral pixel within band are not accounted for. The S5p L1 geolocation information is also assumed to be correct. Details related to these assumptions are provided in the ATBD.

The user should also be aware of the few minutes difference between S5p and VIIRS measurements. In extreme circumstances (very high winds), cloud motion could introduce some error into the NPP derived cloud fraction for TROPOMI. The sensing time difference is reported in the NPP files, and cloud information is reported for scenes (“scaled fields of view”) which are larger than the S5p footprint. This enables scenes which might be affected by cloud motion or small errors in geolocation to be identified.

4.2 Solved Data Quality Issues

Too low value of `max_value` (solved in version 01.00.02)

It should be noted that for version 01.00.00 (in operations from 2018-06-28 to 2018-10-17) the `max_value` attribute assigned to the cloud flag counts (e.g. `vcm_confidently_cloudy`) is set to a value which is too low (the value can be exceeded towards the edge of the TROPOMI swath). Users should ignore the `max_value` attribute and treat all values in the cloud counts as valid. This problem is solved in version 01.00.02, in operations since 17 October 2018.

Missing cloudy scene counts due to faulty identification of valid cloud mask (solved in version 01.01.00)

An issue was found with the previous version (01.00.02) of the S5P NPP processor which affects small (contiguous) orbit sections within about 1.5% of all orbits processed to date. The issue led to “cloudy” mask values not being counted in a section of orbit (while “clear” mask values continue to be counted in the same section). This is evident as cloud-related spatial structure appearing in maps of the total number of cloud-mask counts (i.e. the total of `vcm_confidently_clear` + `vcm_probably_clear` + `vcm_probably_cloudy` + `vcm_confidently_cloudy`). While the issue is visibly evident in such a plot, it is not possible to properly estimate cloud fraction or know which of the affected scenes are fully cloud-free. This occurs due to an error in the way the processor interpreted the cloud mask validity. In all identified cases the issue arose when there was also missing data in the VIIRS channel 9. Therefore, it is possible to screen out affected scenes (in version 01.00.02 products) by not using data for which the variable `band09_srf_coverage` < 0.9. This will have the side-effect of also screening out cloud mask values (which are valid) at the beginning and end of the orbit where band09 radiances are missing because the VIIRS solar zenith angle is very high (>~85 degrees). Version 01.01.00 (and following ones) products are not affected by this issue.

Metadata/Attributes (solved in version 01.03.00)

The spatial resolution of the TROPOMI measurements is improved by bringing the along track ground pixel size from 7.0 to 5.5 Km starting on 6th August 2019. Note that, after this operations change, the metadata/Attribute field related to the spatial resolution, remain **unchanged** (hence not aligned to the improved resolution).

4.3 Data Features

This section describes some characteristics of the data that might seem anomalous, however they are physically correct and not related to any problem.

Pixel geolocation around North Pole (feature of S5p)

The solar irradiance is measured on a daily basis over the North Pole at a reference azimuth angle to remove seasonal effects on the measurements. To this end, a yaw manoeuvre is executed when the instrument is still in radiance mode, causing possible distortion on the scanlines observed during this manoeuvre (i.e. crossing scanlines, “bow-tie” ground pixel shape instead of rectangular). This occurs at most during the last 26 seconds of radiance measurements in few orbits (7-9 per week). Though this may seem anomalous, it is physically correct, and not related to any problem on the data geolocation.

Change to input VIIRS cloud mask

Up to version 01.00.02, the S5P NPP processor ingested and summarised the VIIRS cloud mask (VCM or VICMO) product (as well as level 1 radiances). The VCM product is no longer supported by NOAA and will be discontinued. From version 01.01.00, the processor will be applied to the newer (supported) VIIRS enterprise cloud mask (ECM) products. The ECM provides an estimated probability of each VIIRS scene being cloudy, which can be used to classify scenes in a manner analogous to VCM (“confidently cloudy”, “probably cloudy”, “probably clear” and “confidently clear”). The S5P-NPP processor has been modified to ingest the new ECM product, but the format of the output product is unchanged. It should, however, be noted that there are significant differences between the cloud mask fields themselves: E.g. compared to VCM, ECM tends to indicate fewer confidently clear scenes over land, but more over sea. More information on the two VIIRS cloud mask products can be found here:

VCM:

https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/D0001-M01-S01-011_JPSS_ATBD_VIIRS-Cloud-Mask_E.pdf

ECM: https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/ATBD_EPS_Cloud_Mask_v1.1.pdf

Note that the cloud mask input which was used in a specific S5P NPP product can be identified from the `VIIRS_CloudMask_files` attribute in the `ALGORITHM_SETTINGS` group. The main variable names for the cloud mask counts are still prefixed “`vcm_`”, irrespective of the source of the cloud mask input.

5 Algorithm Change Record

For a detailed description of the L2__NP_BDx algorithms, please refer to the ATBD [RD01].

There are no algorithm changes to report respect to the previous version of this PRF.

6 Data Format

The product is stored as NetCDF4 file. The NetCDF4 file contains both the data and the metadata for the product.

Details of the data format are provided in the Product User Manual (PUM) [RD02].

6.1 Data format changes

The data format changes of processor version 02.00.01 respect to the previous version 01.03.00 are highlighted in the ANNEX. Changes concern the addition of new variables based on CloudDCOMP, CloudHeight, and CloudPhase, as well as a few additional CloudMask variables. The new variables are also clearly marked in the product user manual.

7 Product Availability

All S5P/TROPOMI data are available on the Copernicus Data Space Ecosystem <https://dataspace.copernicus.eu>

Information on data handling tools is available from the web page <http://www.tropomi.eu/tools>

For further questions regarding S5P/TROPOMI data products please contact EOSupport@Copernicus.esa.int.

The access and use of any Copernicus Sentinel data available through the Copernicus Sentinel Data Hub is governed by the Legal Notice on the use of Copernicus Sentinel Data and Service Information and is given here:

https://sentinels.copernicus.eu/documents/247904/690755/Sentinel_Data_Legal_Notice.

Auxiliary data are available respecting the terms of the source data including the S5p VIIRS (value-added) auxiliary cloud products. This data provided in line with NASA's data policy that ensures that all NASA data are available fully, openly, and without restrictions <https://earthdata.nasa.gov/nasa-data-policy>.

8 References

- [RD01] S5P-NPP Cloud Processor ATBD: source: RAL **ref:** S5P-RAL-ATBD-001; url: <https://sentinel.esa.int/documents/247904/2476257/Sentinel-5P-NPP-ATBD-NPP-Clouds>
- [RD02] Sentinel-5 precursor/TROPOMI Level 2 Product User Manual, NPP Cloud **source:** RAL; **ref:** S5P-RAL-PUM-001; **url:** <https://sentinel.esa.int/documents/247904/2474726/Sentinel-5P-Level-2-Product-User-Manual-NPP-Cloud-product>
- [RD03] Joint Polar Satellite System (JPSS) VIIRS Cloud Mask (VCM) ATBD **source:** NASA; **ref:** 474-00033 revision E; **date:** 2014-08-05; **url:** https://www.star.nesdis.noaa.gov/jpss/documents/ATBD/D0001-M01-S01-011_JPSS_ATBD_VIIRS-Cloud-Mask_E.pdf
- [RD04] VIIRS Cloud Mask IP Release, Validation Stage 2 Data Quality. Read-me for Data Users, http://www.class.ngdc.noaa.gov/notification/pdfs/ReadMe_VCM_CLASS_validated_maturity_stage2.pdf
- [RD05] VIIRS SDR Release: Validated Data Quality, March 1, 2014; **url :** http://www.class.ngdc.noaa.gov/notification/pdfs/VIIRS_SDR_Validated_Release_README_CLASS_cc_rev1_SDR_rm.pdf
- [RD06] Keith D. Hutchison, Andrew K. Heidinger, Thomas J. Kopp, Barbara D. Iisager & Richard A. Frey (2014) Comparisons between VIIRS cloud mask performance results from manually generated cloud masks of VIIRS imagery and CALIOP-VIIRS match-ups, International Journal of Remote Sensing, 35:13, 4905-4922, DOI: [10.1080/01431161.2014.932465](https://doi.org/10.1080/01431161.2014.932465)

More information on this data product is available from the Sentinel product webpage:

<https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms>,

and from the corresponding TROPOMI product webpage <http://www.tropomi.eu/data-products>.

The NPP VIIRS official website is <https://www.jpss.noaa.gov/viirs.html>

Abbreviations and acronyms

ATBD	Algorithm Theoretical Basis Document
BIRA-IASB	Royal Belgian Institute for Space Aeronomy
DLR	German Aerospace Center / Deutsches Zentrum für Luft- und Raumfahrt
ECM	Enterprise Cloud Mask
ESA	European Space Agency
ESL	Expert Support Laboratory
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
JPSS	Joint Polar Satellite System
KNMI	Koninklijk Netherlands Meteorologisch Instituut – Royal Dutch Meteorological Institute
MPC	Mission Performance Centre
NASA	National Aeronautics and Space Administration
NOAA	National Oceanic and Atmospheric Administration
NRTI	Near Real Time
OFFL	OFFLine
PRF	Product Readme File
PUM	Product User Manual
RAL	Rutherford Appleton Laboratory
S5P	Sentinel-5 Precursor
S5PVT	Sentinel-5 Precursor Validation Team
SRON	Netherlands Institute for Space Research
Suomi NPP	Suomi National Polar-orbiting Partnership
TROPOMI	Tropospheric Monitoring Instrument
VCM	VIIRS Cloud Mask
VIIRS	Visible Infrared Imaging Radiometer Suite

9 ANNEX

Items added in this release

The following variables have been added to BAND7_NPPC/STANDARD_MODE/VIIRSDATA:

```
float cloudmicrovisod(time, scanline, ground_pixel) ;
ubyte cloudmicrovisod_srf_coverage(time, scanline, ground_pixel) ;
float cloudmicroeffrad(time, scanline, ground_pixel) ;
ubyte cloudmicroeffrad_srf_coverage(time, scanline, ground_pixel) ;
float cloudmicrolwp(time, scanline, ground_pixel) ;
ubyte cloudmicrolwp_srf_coverage(time, scanline, ground_pixel) ;
float cloudmicroiwp(time, scanline, ground_pixel) ;
ubyte cloudmicroiwp_srf_coverage(time, scanline, ground_pixel) ;
float cldtopemss(time, scanline, ground_pixel) ;
ubyte cldtopemss_srf_coverage(time, scanline, ground_pixel) ;
float cldtoptemp(time, scanline, ground_pixel) ;
ubyte cldtoptemp_srf_coverage(time, scanline, ground_pixel) ;
float cldtoppres(time, scanline, ground_pixel) ;
ubyte cldtoppres_srf_coverage(time, scanline, ground_pixel) ;
float cldtophght(time, scanline, ground_pixel) ;
ubyte cldtophght_srf_coverage(time, scanline, ground_pixel) ;
ubyte cloudmask_confclr(time, scanline, ground_pixel) ;
ubyte cloudmask_probclr(time, scanline, ground_pixel) ;
ubyte cloudmask_probclld(time, scanline, ground_pixel) ;
ubyte cloudmask_confclld(time, scanline, ground_pixel) ;
ubyte cloudmask_srf_coverage(time, scanline, ground_pixel) ;
float cloudprobability(time, scanline, ground_pixel) ;
ubyte cloudprobability_srf_coverage(time, scanline, ground_pixel) ;
ubyte cloudphase_clear(time, scanline, ground_pixel) ;
ubyte cloudphase_liquid_water(time, scanline, ground_pixel) ;
ubyte cloudphase_supercooled_liquid_water(time, scanline, ground_pixel) ;
ubyte cloudphase_mixed_phase(time, scanline, ground_pixel) ;
ubyte cloudphase_ice(time, scanline, ground_pixel) ;
ubyte cloudphase_not_determined(time, scanline, ground_pixel) ;
ubyte cloudphase_srf_coverage(time, scanline, ground_pixel) ;
```