



S5P Mission Performance Centre Aerosol Layer Height [L2__AER_LH] Readme



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¹ The S5PVT AO project summaries can be found at
<https://earth.esa.int/eogateway/news/announcement-of-opportunity-for-s5pvt>

CHANGE LOG

Reason for change	Issue	Revision	Date
Cloud mask is based on VIIRS ECM product (instead for VICMO) since OFFL orbit 12432 (see section 4.2)	1	2	11/03/2020
Table 2: addition of version 01.04.00	1	3	02/12/2020
<ul style="list-style-type: none"> Table 2: Adapting to V02.02.00 of the processor. Section 3.2: Validation results shortened, pointing to the routine Validation reports. 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 02.02.00. 	2	0	05/07/2021
<ul style="list-style-type: none"> Table 2: addition of version 02.03.01 Section 4.1: Added 'Data in <code>snow_ice_flag</code> variable for pixels with SZA > 88° Section 4.2: Added 'Geolocation co-added when they should not be (solved in 02.03.01)' 	2	1	17/11/2021
<ul style="list-style-type: none"> Table 2: addition of version 02.04.00. 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 5: Added radiometric calibration of L1B and new LER surface database information. 	2	2	20/07/2022

1 Summary

This is the Product Readme file (PRF) for the Copernicus Sentinel 5 Precursor Tropospheric Monitoring Instrument (S5P/TROPOMI) Aerosol Layer Height (L2__AER_LH) Level 2 product and is applicable for both the Near Real-Time (NRTI) and Offline (OFFL) timeliness data products.

Product Identifier: **L2__AER_LH**

Example filename:

S5P_OFFL_L2__AER_LH_20210908T001010_20210908T015140_20226_02_020200_20210909T165109.nc

S5P_NRTI_L2__AER_LH_20210908T002709_20210908T003209_20226_02_020200_20210908T013221.nc

The OFFL data product has the following Digital Object Identifier (DOI): <http://doi.org/10.5270/S5P-7q4iapn>

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 data file contains the `aerosol_mid_pressure` and `aerosol_mid_height` which provide the air pressure at the center of the aerosol layer and the height at the center of the aerosol layer relative to the geoid, respectively. The aerosol layer mid pressure is computed for pixels that are free of ice, snow, and clouds. The maximum allowed cloud fraction is 2%, except if the UVAI is larger than 1.0, those pixels are always processed. The latter is to avoid volcanic ash and dust plumes mistakenly being filtered as clouds. As a user guideline, it is recommended to use only those pixels that contain no sunglint. The `sun_glint_warning` flag is available to filter those ALH pixels that are possibly sunglint contaminated. In general, the data quality is indicated by a `qa_value`. Pixels with a `qa_value` below 0.5 are not recommended for use.

Note: Starting from this processor version 2.4.0, new improved Level 1b version 2.1 data products are used as input [RD04].

The TROPOMI L2__AER_LH product is a relatively new product, released in September 2019, with little heritage. Aerosol vertical profile products exist from other satellite instruments, e.g. active measurements from Calipso onboard CALIPSO, and multi-angle measurements from MISR onboard Terra.

First validation efforts by Sentinel-5 Precursor (S5p) Mission Performance Centre (MPC) Cal/Val experts and the S5p Validation Team (S5PVT) show that the ALH is stable and shows good overall agreement with Calipso retrievals, with Calipso generally retrieving higher ALH than TROPOMI for ocean scenes. A statistical pixel-by-pixel comparison of Calipso and S5P layer height retrievals from three desert dust cases and one smoke plume showed good correlation between the retrievals (regression slope 1.00), but on average Calipso retrievals were 0.53 km higher in altitude than S5P ALH. This is likely due to the different sensitivity, which for Calipso is to the top of the plume, while S5P is sensitive to the centroid of the layer altitude. This was confirmed by a study which compared smoke plume heights over Canada from S5P and those retrieved by Calipso and MISR. The latter uses stereoscopic viewing to retrieve plume top height. The systematic difference between S5P TROPOMI ALH and MISR aerosol plume height is about 600 m. This is again due to differences in the sensitivity of the instruments and the differences in the algorithms (centroid vs. top retrieval).

Over land, TROPOMI ALH becomes unreliable for increasing surface albedo. Consequently, the difference between the plume height observed by TROPOMI and CALIOP depends significantly on the thickness of the plume. Thicker plumes seem to be better captured by TROPOMI and the mean difference reduces with the thickness of the plumes, the mean difference between the TROPOMI and CALIOP mid aerosol layer is just 50 m for very thick plumes (>3 km). The main reason is the insensitivity to the surface bias for thick plume in S5P ALH.

There is a notable difference between the NRTI and OFFL cloud-free scene selections as of version 2.0.0 (see section 4.1).

These above-mentioned studies and up to date validation results are available in the Routine Operations Consolidated Validation Reports (ROCVR) that are accessible through the MPC Validation Data Analysis Facility (VDAF) website at <http://mpc-vdaf.tropomi.eu>. The ROCVR reports are issued quarterly, and reports released after September 2021 include validation results based on processor version 2.x.x.

The target uncertainty requirements for ALH are defined in the S5p Calibration and Validation Plan [RD01] and summarized in Table 1. The ALH is compliant with the requirements over oceans and dark land surfaces.

Parameter	Data product	Vertical Resolution	Bias	Random
ALH	Aerosol Layer Height	Total column	<100hPa (1 Km)	<50hPa

Table 1: ALH data product requirements extracted from the S5p Calibration and Validation Plan [RD01]

2 Processing baseline description

Table 2 contains the history of the ALH processor versions. Note that the processor version for ALH is changing when there is a change to any of the products belonging to the NL-L2 processor suite (NO2, CO, CH4, AI, ALH, O3 PR) even if the change is not affecting the ALH product.

Processor Version	In operation starting from	In operation until	Relevant Improvements
02.04.00	NRTI: orbit 24697, 2022-07-20 OFFL: orbit 24655, 2022-07-17	Current version	<ul style="list-style-type: none"> - Introduction of S5P/TROPOMI-based LER surface database (see section 5) - Minor format changes (see section 6.1) <p>Note: Starting from this processor version, new improved Level 1b version 2.1 data products are used as input [RD04] (with updated L1b radiance calibration)</p>
02.03.01	NRTI: orbit 21223, 2021-11-17 OFFL: orbit 21188, 2021-11-14	Orbit 24697, 2022-07-20 Orbit 24654, 2022-07-17	Minor format changes: text changed in attribute description for two fields (see section 6.1)
02.02.00	NRTI: orbit 19308, 2021-07-05 OFFL: orbit 19258, 2021-07-01	Orbit 21222, 2021-11-17 Orbit 21187, 2021-11-14	<ul style="list-style-type: none"> - The pixel selection scheme has been updated. The Enterprise Cloud Mask (ECM) cloud mask is now the primary cloud filter for OFFL, FRESCO cloud mask for NRTI, with the aerosol index used to add pixels that have both a too high cloud fraction and a high UV Aerosol Index (UVAI) value. These are likely thick aerosol events where the cloud mask considers this a cloud. Full details on the new pixel selection scheme are provided [RD02] - Changes in format (see section 6.1) <p>Note: Starting from this processor version, new improved Level 1b version 2.0 data products are used as input [RD04].</p>
01.04.00	NRTI: orbit 16259, 2020-12-02 OFFL: orbit 16213, 2020-11-29	Orbit 19306, 2021-07-05 Orbit 19257, 2021-07-01	No changes with respect to previous version

01.03.02	NRT: orbit 10171, 2019-09-30 OFFL: orbit 8815, 2019-06-26	Orbit 16256, 2020-12-02 Orbit 16212, 2020-11-29	No changes with respect to previous version
01.03.01	RPRO: orbit 2818, 2018-04-30 OFFL: orbit 7907, 2019-04-23	Orbit 7424, 2019-03-20 Orbit 8814, 2019-06-26	No changes with respect to previous version
01.03.00	OFFL: orbit 7425, 2019-03-20	Orbit 7906, 2019-04-23	Initial version

Table 2: History of ALH processor versions

3 Product Quality

3.1 Recommendations for data usage

The ALH is very sensitive to cloud contamination. However, aerosols and clouds can be difficult to distinguish, and ALH is computed for all FRESCO effective cloud fractions smaller than 0.04 (NRTI) and VIIRS cloud fractions smaller than 0.02 (OFFL). Cloud flags are available from FRESCO and VIIRS, and are strongly recommended to filter for residual clouds. A sunglint mask is also available to screen sunglint regions, which are not filtered beforehand. These and other sources of uncertainties are indicated with the `qa_value`. Use of pixels with a `qa_value` below 0.5 is not recommended.

The variables `aerosol_mid_pressure_precision` and `aerosol_mid_height_precision` can also be further used to diagnose the quality of the ALH.

For further details, data users are encouraged to read the Product User Manual (PUM) [RD03] and Algorithm Theoretical Basis Document (ATBD) [RD02] associated with this data product, available on <https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms>.

3.2 Validation results

The data are validated for reprocessed data using the data processor up to version 01.04.00, see section 1. These data were selected using high UV AI. Version 02.xx.xx will include more data: all pixels with sufficiently low cloud fraction. The UV AI is only used to avoid cloud filtering for thick plumes of smoke and volcanic ash, which are important to include in the retrieval. The validation results are valid for all versions, since the retrieval was not changed markedly in version 2. However, the selection of pixels is now based on different cloud filters in NRTI and OFFL. Details on the consequences of this and up to date validation results are available in the Routine Operations Consolidated Validation Reports (ROCVR) that are accessible through the MPC Validation Data Analysis Facility (VDAF) website at <http://mpc-vdaf.tropomi.eu>. The ROCVR reports are issued quarterly, and reports released after September 2021 include validation results based on processor version 2.x.x.

4 Data Quality Remarks

Currently, the following data quality issues are known and should be kept in mind when looking at the Aerosol Layer Height product and also at validation results.

4.1 Known Data Quality Issues

Bias to clouds

As mentioned, the ALH is very sensitive to clouds, and the height will be strongly biased towards the cloud height for partially clouded pixels.

High surface albedo

It is known that high surface albedos negatively influence the ALH, biasing the ALH towards the surface. In general, the ALH over (dark) oceans is considered reliable to within the requirement of 1000 m or 100 hPa. Over land, especially bright surfaces, the accuracy may be lower, and the use of the ALH product over bright surfaces like deserts is not advisable.

Difference in NRTI and OFFL cloud-free scene selections (since version 2.0.0)

There is a notable difference between the NRTI and OFFL cloud-free scene selections as of version 2.0.0. During OFFL processing the VIIRS Enterprise Cloud Mask (ECM) cloud mask is used to select cloud-free scenes for ALH processing. However, during NRTI processing the VIIRS ECM information is not yet available, and the S5P/FRESCO cloud mask is used to select cloud-free scenes. Since the FRESCO cloud mask represents a (radiative) effective cloud fraction and the VIIRS ECM a geometric cloud fraction, differences between the cloud masks can be significant, which results in a notable different selection of cloud-free pixels. This is not an error, but for ALH purposes the VIIRS ECM cloud filter is considered to be superior to the FRESCO cloud mask. For pixels which were marked cloud-free by either cloud filter, the difference in retrieved ALH from NRTI and OFFL processing was very small.

4.2 Solved Data Quality Issues

Data in `snow_ice_flag` variable for pixels with $SZA > 88^\circ$ (solved in version 02.04.00)

The `snow_ice_flag` value for ground pixels with $SZA > 88^\circ$ is incorrectly set to 255, the NISE flag for "ocean", rather than the FillValue 254 (the NISE flag for an error). Since ground pixels with $SZA > 88^\circ$ are not processed, these pixels do not have ALH column data, hence the ALH data quality is not affected. This has been corrected in version 02.04.00.

Geolocation co-added when they should not be (solved in version 02.03.01)

In version 02.02.00, the geolocation of pixels near the pole show a shift of up to 300 meters due to a co-addition activity performed by mistake. This has been corrected in version 02.03.01.

Metadata/Attributes (solved in version 02.02.00)

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/Attributes fields related to the spatial resolution, remained **unchanged** (hence not aligned to the improved resolution). These fields have been updated with the activation of Level 2 processors version 02.02.xx.

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)

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.

New cloud mask for S-NPP used during OFFL ALH processing

NOAA no longer supports the VIIRS cloud mask (VCM or VICMO) product, which is discontinued (second quarter 2020) in favour of the Enterprise Cloud Mask (ECM). An update to the S5P-NPP L2 processor (to version 01.01.00) has happened (orbit 12432, date 07-03-2020) to ingest the new cloud mask. 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. Therefore, values in the cloud/clear counts used to calculate the cloud fraction for the filtering of the OFFL AER_LH product are now different. Please note that the NRTI AER_LH does not use this cloud mask and is not affected.

The change in cloud fractions (sign and magnitude) are dependent on the day and location. However, the current thresholds for cloud filtering (which are the same for CH4) do not affect the AER_LH product, i.e., cloudy scenes are filtered properly. The new cloud mask values available to users are expected to perform better than before and the user is encouraged to use the available cloud masks to filter for residual clouds. Full assessment of data quality will come after the new processor has been running long enough.

4.4 Mission Operations Changes

A change in the Copernicus Sentinel 5P operations scenario increasing the spatial resolution from 7.0 km to 5.5 km along track for all measurements, became operational starting from 6 August 2019, orbit 9388.

5 Algorithm Change Record

For a detailed description of the L2__AER_LH algorithm, please refer to the ATBD [RD02].

Version 02.04.00

The following improvements have been implemented with respect to the previous version of the data:

- The Level 1B radiometric calibration of the radiance data has improved. For ALH the implications are small.
- New surface reflectance information is used, from the Lambertian Equivalent Reflectivity (LER) database, based on TROPOMI data. Previously a LER database was used based on GOME-2 data. The implications on ALH are considerable, especially the higher resolution of the new database ($0.125^{\circ} \times 0.125^{\circ}$ instead of $0.25^{\circ} \times 0.25^{\circ}$) and TROPOMI-based data benefits the ALH retrieval. However, the biases over land remain large and are not resolved with the use of the new surface database.

6 Data Format

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

For OFFL data the product is stored as a single file per satellite orbit, for NRTI data the product is stored as multiple files per orbit.

Please note that consecutive data granules of the NRTI product show an overlap of about 12 scan lines. Details of the data format are provided in the Product User Manual (PUM) [RD03].

6.1 Data format changes

6.1.1 Version 02.04.00

New fields added

/METADATA/QA_STATISTICS/number_of_thermal_instability_warning_occurrences

In variable:

/PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/processing_quality_flags

Added element to attribute 'flag_meanings': [success, radiance_missing, irradiance_missing, input_spectrum_missing, ..., **thermal_instability_warning**]

Added element to attribute 'flag_masks': [255, 255, 255, ..., **1073741824**]

Added element to attribute 'flag_values': [0, 1, 2, 3, 4, ..., **1073741824**]

6.1.2 Version 02.03.01

Renamed fields

/PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/wavelength_calibration_irradiance_offset
attribute 'long_name' → text changed (from 'wavelength offset' to '**irradiance wavelength offset**')

/PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/wavelength_calibration_irradiance_offset
attribute 'ancillary_variables' → text changed (from 'wavelength_calibration_offset_precision' to '**wavelength_calibration_irradiance_offset_precision**')

6.1.3 Version 02.02.00

New fields added

/PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/aerosol_mid_pressure_not_clipped

/PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/aerosol_optical_thickness attribute

comment /PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/aerosol_optical_thickness

attribute radiation_wavelength

/METADATA/QA_STATISTICS attribute number_of_missing_scanlines

/METADATA/QA_STATISTICS attribute number_of_max_num_outlier_exceeded_error_occurrences

/METADATA/GRANULE_DESCRIPTION attribute CollectionIdentifier

Removed fields

/METADATA/ISO_METADATA/gmd:identificationInfo/gmd:spatialResolution

Renamed fields

/PRODUCT/qa_value attribute valid_min_
→ /PRODUCT/qa_value attribute valid_min

/PRODUCT/qa_value attribute valid_max_
→ /PRODUCT/qa_value attribute valid_max

/METADATA/QA_STATISTICS attribute number_of_aai_warning_occurrences
→ /METADATA/QA_STATISTICS attribute number_of_AAI_warning_occurrences

/PRODUCT/SUPPORT_DATA/DETAILED_RESULTS/aerosol_optical_thickness attribute
proposed_standard_name
→ standard_name

7 Product Availability

All S5P/TROPOMI data are available on the Copernicus Open Data Hub <https://scihub.copernicus.eu>.

The list of major mission data gaps due to acquisition faults or satellite/instrument disruption is available at <https://sentinel.esa.int/web/sentinel/missions/sentinel-5p/mission-status>. For those periods the data are permanently lost.

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.

8 References

- [RD01] Sentinel-5 Precursor Calibration and Validation Plan for the Operational Phase
source: ESA; **ref:** ESA-EOPG-CSCOP-PL-0073;
url: <https://sentinel.esa.int/documents/247904/2474724/Sentinel-5P-Calibration-and-Validation-Plan.pdf>
- [RD02] Sentinel-5 precursor/TROPOMI Level 2 Algorithm Theoretical Basis Document of the Aerosol Layer Height
source: KNMI; **ref:** S5P-KNMI-L2-0006-RP;
url: <https://sentinels.copernicus.eu/documents/247904/2476257/Sentinel-5P-TROPOMI-ATBD-Aerosol-Height>
- [RD03] Sentinel-5 precursor/TROPOMI Level 2 Product User Manual Aerosol Layer Height
source: KNMI; **ref:** S5P-KNMI-L2-0026-MA;
url: <https://sentinel.esa.int/documents/247904/2474726/Sentinel-5P-Level-2-Product-User-Manual-Aerosol-Layer-Height>
- [RD04] Algorithm theoretical basis document for the TROPOMI L01b data processor
source: KNMI; **ref:** S5P-KNMI-L01B-0009-SD;
url: <https://sentinels.copernicus.eu/documents/247904/2476257/Sentinel-5P-TROPOMI-Level-1B-ATBD>
- [D01] VIIRS Calibration Support Team (VCST). (2017). VIIRS/NPP Day/Night Band 6-Min L1B Swath SDR- 750m NRT [Data set]. NASA LANCE MODIS at the MODAPS. https://doi.org/10.5067/viirs/vnp02dnb_nrt.001
- [D02] Winker, D. (2016). CALIPSO LID L1 ValStage1 HDF File - Version 3.40 [Data set]. NASA Langley Atmospheric Science Data Center DAAC. https://doi.org/10.5067/caliop/calipso/cal_lid_l1-valstage1-v3-40

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>.

Abbreviations and acronyms

(A)AI	(Absorbing) Aerosol Index
ALH	Aerosol Layer Height
ATBD	Algorithm Theoretical Basis Document
BIRA-IASB	Royal Belgian Institute for Space Aeronomy
DLR	German Aerospace Center / Deutsches Zentrum für Luft- und Raumfahrt
DOI	Digital Object Identifier
ECM	Enterprise Cloud Mask
ESA	European Space Agency
ESL	Expert Support Laboratory
KNMI	Royal Netherlands Meteorological Institute / Koninlijk Nederlands Meteorologisch Instituut
LER	Lambertian-Equivalent Reflectivity
MPC	Mission Performance Centre
NASA	National Aeronautics and Space Administration
NRTI	Near Real Time (timeliness of products)
OFFL	Offline (timeliness of products)
OMI	Ozone Monitoring Instrument
OMPS	Ozone Mapper and Profiling Suite
PRF	Product Readme File
PUM	Product User Manual
QWG	Quality Working Group
ROCVR	Routine Operations Consolidated Validation Report
S5P	Sentinel-5 Precursor
S5PVT	Sentinel-5 Precursor Validation Team
TCCON	Total Carbon Column Observing Network
TROPOMI	Tropospheric Monitoring Instrument
UVAI	UV Aerosol Index
VCM	VIIRS Cloud Mask
VDAF	Validation Data Analysis Facility