

DOCUMENT

Sentinel-5 Precursor

Level 1b and Level 2 Numbered Validation Requirements

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1 AIM OF THIS DOCUMENT

This document shall summarise the validation requirements for all Sentinel 5 Precursor Level 2 products. These will be used in the compilation of the Science Validation Implementation Plan in order to allow a tracing between the validation projects and the validation needs, identifying potential synergies and gaps.

2 REFERENCE DOCUMENTS

Identifier	Description	Version
Processors		
[ATBD-UVAI]	TROPOMI ATBD of the aerosol index, S5P-KNMI-L2-0008-RP	0.13.0
[ATBD-ALH]	TROPOMI ATBD of the Aerosol Layer Height product, S5P-KNMI-L2-0006-RP	0.11.0
[ATBD-CH4]	ATBD for Sentinel-5 Precursor methane retrieval, SRON-S5P-LEV2-RP-001	0.12.00
[ATBD-Cloud]	S5P/TROPOMI ATBD Cloud Products, S5P-DLR-L2-ATBD-400I	0.12.0
[ATBD-CO]	Algorithm Theoretical Baseline Document for Sentinel-5 Precursor: Carbon Monoxide Total Column Retrieval, SRON-S5P-LEV2-RP-002	0.11.1
[ATBD-HCHO]	S5P/TROPOMI HCHO ATBD, S5P- BIRA-L2-ATBD-400F	0.13.0
[ATBD-L1]	Algorithm theoretical basis document for the TROPOMI Lo1b data processor, S5P-KNMI-Lo1B-0009-SD	5.0.0
[ATBD-NO2]	TROPOMI ATBD of the total and tropospheric NO2 data products, S5P-KNMI-L2-0005-RP	0.11.0
[ATBD-NPPC]	S5P-NPP Cloud Processor ATBD, S5P-NPPC-RAL-ATBD-0001	0.11.0
[ATBD-O3P]	TROPOMI ATBD Ozone profile and tropospheric profile, S5P-KNMI-L2-0004-RP	0.11.0
[ATBD-O3TOT]	S5P/TROPOMI Total Ozone ATBD, S5P-L2-DLR-ATBD-400A	0.11.0
[ATBD-O3TRO]	TROPOMI/S5P ATBD of tropospheric ozone data products, S5P-DLR-IUP-L2-400C	0.11.0
[ATBD-SO2]	S5P/TROPOMI SO2 ATBD, S5P-BIRA-L2-400E-ATBD	0.12.0
[ATBD-UV]	TROPOMI/S5P UV Product ATBD, S5P-FMI-UV-0003 (in preparation)	0.02
[GEOP-VAL]	Requirements for the Geophysical Validation of Sentinel-5 Precursor Products, S5P-RS-ESA-SY-164	21/05/14

Identifier	Description	Version
[Sys-Req]	GMES Sentinel-5 Precursor – S5p System Requirement Document (SRD), S5p-RS-ESA-SY-0002	4.1

3 VALIDATION REQUIREMENTS

3.1 Generic Validation Requirements

The generic validation requirements cover issues common to most products. In some cases the specific validation requirements are further specifying the validation needs of a product.

3.1.1.1 Temporal Validation Requirements

- [VAL-Gen-01] Validation cover the full seasonal cycle.
- [VAL-Gen-02] Long-loop time series.

3.1.1.2 Spatial Validation Requirements

- [VAL-Gen-03] Global scale validation.
- [VAL-Gen-04] Validation measurement representative of the product horizontal resolution.

3.1.1.3 Geolocation

- [VAL-Gen-05] Validation of the geolocation information.

3.1.1.4 Observation conditions

The validation activities shall be done under varying observation conditions. These include:

- [VAL-Gen-06] Different illumination conditions, e.g., a wide range of solar-zenith-angle conditions.
- [VAL-Gen-07] Complete observation swath, i.e., off-nadir viewing geometry.
- [VAL-Gen-08] Variable cloud conditions.
- [VAL-Gen-09] Variable aerosol conditions.

3.1.1.5 Retrieval Requirements

- [VAL-Gen-10] Validation of a-priory information (e.g. Surface Albedo, trace gas profiles, etc.).
- [VAL-Gen-11] Validation of Numerical Model Atmosphere/Background (thermodynamic, trace gases) input to the retrievals.
- [VAL-Gen-12] Verification of Averaging Kernels and retrieval diagnostics.

3.2 Level 2 Accuracy and Precision Product Requirements

The accuracy and precision requirements for the Sentinel-5 Precursor Level 2 products have been assessed by the Level 2 Working Group and agreed with the Sentinel-5 Precursor Mission Advisory Group and are provided in the table below. It needs to be stressed that these requirements are not strictly derived from the analysis performed in the definition of the atmospheric Sentinel missions, but are the best assessment of the expected mission performance to be met. Note that ‘Product Accuracy’ is defined as the mean deviation from the truth and ‘Product Precision’ is the 1-sigma variation due to random processes such as instrument noise. The values in the table are under the assumption that the L1B data meet the requirements from the SRD.

Parameter	Data Product	Vertical Resolution	Accuracy	Precision
Ozone	Ozone Profile	6 km	10-30%	10%
	Total Ozone	total column	3.5-5%	1.6-2.5%
	Tropospheric Ozone	trop column	25%	10%
NO ₂	Stratospheric NO ₂	strat column	<10%	0.5×10 ¹⁵ mol/cm ²
	Tropospheric NO ₂	trop column	25-50%	0.7×10 ¹⁵ mol/cm ²
SO ₂	SO ₂ enhanced	total column	30%	0.15-0.3 (0.06-0.12) DU
	Total SO ₂	total column	30-50%	1-3 (0.4-1.2) DU
Formaldehyde	Total HCHO	total column	40-80%	1.2×10 ¹⁶ mol/cm ²
CO	Total CO	total column	15%	<10%
Methane	Total CH ₄	total column	1.5%	1%
Cloud	Cloud Fraction	total column	<20%	0.05
	Albedo (Optical Thickness)	total column	<20%	0.05 (10)
	Cloud Height (Pressure)	total column	<20%	<0.5 km (<30hPa)
Aerosol	Aerosol Layer Height	total column	<100hPa	<50hPa
	UV Aerosol Index	total column	~1 UVAI	<0.1 UVAI
S5P-SNPP Cloud	VIIRS Cloud Classification	N/A	TBD	TBD
	Mean VIIRS M7 Radiance (865 nm)	N/A	TBD	TBD
	Mean VIIRS M9 Radiance (1.378 μm)	N/A	TBD	TBD
	Mean VIIRS M11 Radiance (2.25 μm)	N/A	TBD	TBD
Surface UV	Surface UV Radiance	N/A	20%	20% for UV Index > 1

3.3 Specific Validation Requirements

In addition to the product requirements, the Level 2 algorithm teams are also identifying specific validation requirements for the respective products. This includes validation of parameters related to the

- algorithm and processing itself, e.g., input data, intermediate products, algorithm assumptions;
- spatial validation requirements, e.g., global, over land, tropics, urban;
- temporal validation requirements, e.g., long time series, seasonal cycle;
- special validation requirements, e.g., arctic vortex, natural emission regimes.

The requirements have been extracted from [GEOP-VAL] and the ATBDs for the different products. Validation requirements common to several or all products are covered in a dedicated section below.

3.3.1 Ozone Profile (O3Pr)

3.3.1.1 Accuracy and Precision

[VAL-O3Pr-01] Accuracy: 10-30%

[VAL-O3Pr-02] Precision: 10%

3.3.1.2 Algorithm Parameter

None specific identified.

3.3.1.3 Spatial Validation Requirements

[VAL-O3Pr-03] Measurement representativeness 50x50 km².

[VAL-O3Pr-04] Vertical resolution higher than 6 km.

3.3.1.4 Temporal Validation Requirements

No specific requirement.

3.3.1.5 Special Validation Requirements

[VAL-O3Pr-05] Stratospheric intrusions conditions.

[VAL-O3Pr-06] Biomass burning conditions.

[VAL-O3Pr-07] Ozone hole conditions.

3.3.2 Total Ozone Column (O₃TC)

3.3.2.1 Accuracy and Precision

[VAL-O₃TC-01] Accuracy: 3.5-5%

[VAL-O₃TC-02] Precision: 1.6-2.5%

3.3.2.2 Algorithm Parameter

[VAL-O₃TC-03] Validation of a-priori vertical O₃ profile.

[VAL-O₃TC-04] Validation of retrieved effective temperature.

3.3.2.3 Spatial Validation Requirements

[VAL-O₃TC-05] Measurement representativeness 10x10 km².

3.3.2.4 Temporal Validation Requirements

No specific requirement.

3.3.2.5 Special Validation Requirements

[VAL-O₃TC-06] High SZA/Polar regions

[VAL-O₃TC-07] Ozone hole conditions.

3.3.3 Tropospheric Ozone (O₃Tr)

3.3.3.1 Accuracy and Precision

[VAL-O₃Tr-01] Accuracy: 25%

[VAL-O₃Tr-02] Precision: 10%

3.3.3.2 Algorithm Parameter

[VAL-O₃Tr-03] Validation of vertical O₃ profile.

[VAL-O₃Tr-04] Validation of stratospheric O₃ assumption

3.3.3.3 Spatial Validation Requirements

[VAL-O₃Tr-05] Validation in the Tropics (for Convective-Cloud-Differential method, CCD).

[VAL-O₃Tr-06] Global validation (for Cloud-slicing-Algorithm, CSA)

[VAL-O₃Tr-07] Measurement representativeness 50x50 km².

3.3.3.4 Temporal Validation Requirements

No specific requirement.

3.3.3.5 Special Validation Requirements

No specific requirement.

3.3.4 NO₂ Total and Tropospheric Column (NO₂)

3.3.4.1 Accuracy and Precision

3.3.4.1.1 Stratospheric Column

- [VAL-NO2-01] Accuracy: <10%
[VAL-NO2-02] Precision: 0.5×10^{15} mol/cm²

3.3.4.1.2 Tropospheric Column

- [VAL-NO2-03] Accuracy: 25-50%
[VAL-NO2-04] Precision: 0.7×10^{15} mol/cm²

3.3.4.2 Algorithm Parameter

- [VAL-NO2-05] Validation of vertical NO₂ profile in the PBL (for tropospheric NO₂)
[VAL-NO2-06] Validation of vertical NO₂ column stratosphere.
[VAL-NO2-07] Validation of a-priori NO_x emissions.

3.3.4.3 Spatial Validation Requirements

- [VAL-NO2-08] Validation Representative for zonal bands for stratospheric NO₂.
[VAL-NO2-09] Validation in polluted conditions (anthropogenic).
[VAL-NO2-10] Validation in presence of natural emissions, e.g., biomass burning, microbial soil activity and lightning.
[VAL-NO2-11] Validation in clean/background conditions.
[VAL-NO2-12] Validation under partly cloudy conditions.

3.3.4.4 Temporal Validation Requirements

- [VAL-NO2-13] Validation information covering the diurnal cycle.

3.3.4.5 Special Validation Requirements

- [VAL-NO2-14] Near Arctic Vortex (break-up conditions, i.e., late winter/early spring) (for stratospheric NO₂).
[VAL-NO2-15] Validation in areas with horizontal gradients at scales on the order of the satellite pixel.
[VAL-NO2-16] Validation collocated with aerosol profile information.

3.3.5 Total and enhanced Sulphur Dioxide Total Column (SO₂)

3.3.5.1 Accuracy and Precision

3.3.5.1.1 Enhanced Total Column

- [VAL-SO2-01] Accuracy: 30%
- [VAL-SO2-02] Precision: 0.15-0.3 (0.06-0.12) DU

3.3.5.1.2 Total Column

- [VAL-SO2-03] Accuracy: 30-50%
- [VAL-SO2-04] Precision: 1-3 (0.4-1.2) DU

3.3.5.2 Algorithm Parameter

- [VAL-SO2-05] Validation of a-priori vertical tropospheric SO₂ profile.

3.3.5.3 Spatial Validation Requirements

No specific requirements.

3.3.5.4 Temporal Validation Requirements

No specific requirements.

3.3.5.5 Special Validation Requirements

- [VAL-SO2-06] Validation in volcanic plume environment (degassing and eruptive volcanoes) in particular plume height.
- [VAL-SO2-07] Regions with significant SO₂ pollution.
- [VAL-SO2-08] Nominal and high SO₂ load conditions to validating all algorithm branches
- [VAL-SO2-09] Validation under aerosol loading with optical properties in the UV.
- [VAL-SO2-10] Validation in areas with horizontal SO₂ gradients [of the order of a pixel size]

3.3.6 Formaldehyde Total Column (HCHO)

3.3.6.1 Accuracy and Precision

[VAL-HCHO-01] Accuracy: 40-80%

[VAL-HCHO-02] Precision: 1.2×10^{16} mol/cm²

3.3.6.2 Algorithm Parameter

[VAL-HCHO-03] Validation of a-priori vertical HCHO profile, in particular first three kilometres.

3.3.6.3 Spatial Validation Requirements

[VAL-HCHO-04] Validation in presence of natural emissions (biogenic emissions).

[VAL-HCHO-05] Validation under biomass burning conditions.

[VAL-HCHO-06] Validation in polluted conditions (urban and sub-urban areas).

[VAL-HCHO-07] Global validation.

3.3.6.4 Temporal Validation Requirements

[VAL-HCHO-08] Validation of the diurnal cycle.

3.3.6.5 Special Validation Requirements

[VAL-HCHO-09] Validation collocated with aerosol measurements.

3.3.7 Carbon Monoxide Total Column (CO)

3.3.7.1 Accuracy and Precision

[VAL-CO-02] Accuracy: 15%
[VAL-CO-03] Precision: <10%

3.3.7.2 Algorithm Parameter

[VAL-CO-04] Validation of the vertical CO profile.
[VAL-CO-05] Validation of the water vapour column
[VAL-CO-06] Validation of effective cloud height

3.3.7.3 Spatial Validation Requirements

[VAL-CO-07] Polluted conditions.
[VAL-CO-08] Background conditions.

3.3.7.4 Temporal Validation Requirements

No specific requirement.

3.3.7.5 Special Validation Requirements

[VAL-CO-09] Humid atmospheric conditions.
[VAL-CO-10] Dry atmospheric conditions.
[VAL-CO-11] High albedo conditions.
[VAL-CO-12] Low albedo conditions.

3.3.8 Methane Total Column (CH₄)

3.3.8.1 Accuracy and Precision

[VAL-CH₄-01] Accuracy: 1.5%
[VAL-CH₄-02] Precision: 1%

3.3.8.2 Algorithm Parameter

[VAL-CH₄-03] Validation of the vertical CH₄ profile.
[VAL-CH₄-04] Validation of H₂O and CO columns
[VAL-CH₄-05] Validation of cirrus cloud detection, in particular in the tropics.

3.3.8.3 Spatial Validation Requirements

[VAL-CH₄-06] Global over land.

3.3.8.4 Temporal Validation Requirements

No specific requirement

3.3.8.5 Special Validation Requirements

[VAL-CH₄-07] Humid atmospheric conditions
[VAL-CH₄-08] Dry atmospheric conditions
[VAL-CH₄-09] High albedo conditions.
[VAL-CH₄-10] Low albedo conditions.

3.3.9 Clouds

3.3.9.1 Accuracy and Precision

3.3.9.1.1 Cloud Fraction

[VAL-Cloud-01] Accuracy: <20%

[VAL-Cloud-02] Precision: 0.05

3.3.9.1.2 Albedo (Optical Thickness)

[VAL-Cloud-03] Accuracy: <20%

[VAL-Cloud-04] Precision: 0.05 (10)

3.3.9.1.3 Cloud Height (Pressure)

[VAL-Cloud-05] Accuracy: <20%

[VAL-Cloud-06] Precision: <0.5 km (<30 hPa)

3.3.9.2 Algorithm Parameter

[VAL-Cloud-07] Validation of Cloud Fraction.

[VAL-Cloud-08] Validation of Cloud Height (Pressure).

[VAL-Cloud-09] Validation of COT and Cloud Albedo.

3.3.9.3 Spatial Validation Requirements

[VAL-Cloud-10] Validation over snow/ice.

3.3.9.4 Temporal Validation Requirements

No specific requirement.

3.3.9.5 Special Validation Requirements

[VAL-Cloud-11] Different cloud types.

3.3.10 S5P-SNPP Cloud product

3.3.10.1 Algorithm Parameter

[VAL-NCloud-01] Cloud Fraction.

3.3.10.2 Spatial Validation Requirements

No specific requirement.

3.3.10.3 Temporal Validation Requirements

No specific requirement.

3.3.10.4 Special Validation Requirements

[VAL-NCloud-02] All cloud types.

[VAL-NCloud-03] Cloud scenes with large variability.

3.3.11 Aerosol Layer Height

3.3.11.1 Accuracy and Precision

[VAL-ALH-01] Accuracy: <100 hPa

[VAL-ALH-02] Precision: <50 hPa

3.3.11.2 Algorithm Parameter

[VAL-ALH-03] Validation at retrieval wavelength of 760 nm

[VAL-ALH-04] Validation of a-priori aerosol parameters (SSA, phase function)

[VAL-ALH-05] Validation of a-priori chlorophyll fluorescence assumption.

[VAL-ALH-06] Validation of secondary AOT product

3.3.11.3 Spatial Validation Requirements

No specific requirements.

3.3.11.4 Temporal Validation Requirements

No specific requirements.

3.3.11.5 Special Validation Requirements

[VAL-ALH-07] Validation using high resolution aerosol extinction profiles providing high accuracy and precision (e.g., Lidar)¹

¹ The forward model used in the Lidar retrieval should ideally be the same as the forward model used for S5P ALH retrieval, which is DISAMAR (see TROPOMI ATBD Aerosol Height, S5P-KNMI-L2-0006-RP).

3.3.12 [UV] Aerosol Index

3.3.12.1 Accuracy and Precision

[VAL-AAI-01] Accuracy: ~ 1 UVAI

[VAL-AAI-02] Precision: < 0.1 UVAI

3.3.12.2 Algorithm Parameter

[VAL-AAI-03] Validation of aerosol parameter profiles (e.g., SSA, asymmetry, extinction).

[VAL-AAI-04] Validation of AOT and ALH.

3.3.12.3 Spatial Validation Requirements

No specific requirements.

3.3.12.4 Temporal Validation Requirements

No specific requirements.

3.3.12.5 Special Validation Requirements

[VAL-AAI-05] Sahara/Desert Dust outflow regions

[VAL-AAI-06] Biomass burning outflow regions

3.3.13 Surface UV Product

The UV product includes UV irradiances at specific wavelengths and as weighted by biological action spectra such as the erythemal weighting function for sunburn of human skin. Moreover, the surface UV is provided for the satellite overpass time, local noon, and as daily doses. The local noon UV product is based on the assumption that the cloud conditions at local noon equal those during overpass. Therefore, validation efforts should primarily focus on overpass time and daily doses, which are considered more representative for examining the algorithm performance.

3.3.13.1 Accuracy and Precision

- [VAL-UV-01] Accuracy: 20%
- [VAL-UV-02] Precision: 20% for conditions when UV Index > 1

3.3.13.2 Algorithm Parameter

- [VAL-UV-03] UV irradiance at Earth's surface.
- [VAL-UV-04] UV doses at Earth's surface.

3.3.13.3 Spatial Validation Requirements

- [VAL-UV-05] Validation of all climatological regions ('global').

3.3.13.4 Temporal Validation Requirements

- [VAL-UV-06] Validation at Satellite Overpass time.

3.3.13.5 Special Validation Requirements

- [VAL-UV-07] Validation of daily UV doses

3.4 Level 1b Validation

The spectral and radiometric validation of the Level 1b products, radiance and irradiance, by independent means is an important contribution to the overall S5P characterisation. The comparison can be performed with data from ground-based sites, air- or spaceborne instruments, and RT models. The S5P performance requirements are covered in the System Requirements Document [Sys-Req], the actual instrument performance is established in the on-ground and in-flight calibration. In order to allow a tracking between the S5PVT proposals and the Level 1b products, high level Level 1b requirements are established, basically indicating the requirement for spectral and radiometric validation of the radiances and solar irradiance for the different Level 1b products.

- [VAL-L1b-01] Validation of the UV radiance products (Band 1/2, full spectral range 267–332 nm).
- [VAL-L1b-02] Validation of the UV-Vis radiance products (Band 3/4, full spectral range 303-499 nm).
- [VAL-L1b-03] Validation of the NIR radiance products (Band 5/6, full spectral range 660-784 nm).
- [VAL-L1b-04] Validation of the SWIR radiance products (Band 7/8, full spectral range 2299 - 2390 nm).
- [VAL-L1b-05] Validation of the UV-Vis-NIR solar irradiance product.
- [VAL-L1b-06] Validation of the SWIR solar irradiance product.