S5P Nitrous Acid [L2__HONO_] Readme

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CHANGE LOG

Reason for change	Issue	Revision	Date
First draft	1	0	16/02/2026
Small fixes	1	1	19/03/2026

1 Summary

This is the Product Readme File (PRF) for the Copernicus Sentinel 5 Precursor Tropospheric Monitoring Instrument (S5P/TROPOMI) nitrous acid Level 2 product and is applicable to Offline (OFFL) products.

The Readme file describes the current processing baseline in section 2. Section 3 explains how to make best use of the data and section 4 points to the limitation of HONO sources detected by TROPOMI. A short overview of the algorithm is given in section 5.

The main variable in the product is `nitrousacid_vertical_column` which gives the total atmospheric column of HONO assuming different plume heights, single scattering albedo and optical thickness of aerosols. Because HONO has a short lifetime, it is only detected for a few TROPOMI pixels. To easily extract the relevant data, the L2 file includes a detection flag (nitrousacid_detection_flag). The vertical column of HONO is calculated only for the pixels for which HONO is detected (nitrousacid_detection_flag>0). For those scenes, smoke aerosols are typically present in large quantities. As the air mass factor used to convert the HONO slant column into vertical column depends a lot on aerosol parameters that are not necessarily available, the vertical column is calculated for a combination of those parameters (namely plume height, single scattering albedo and optical thickness of aerosols). This allows us to cover a wide range of conditions and infer (i.e., interpolate) an HONO vertical column based on third party information on aerosols. Under those specified condition one would be able to also calculate an error for the vertical column by propagating the uncertainties on the input parameters.

2 Processing baseline description

The history of the HONO processor versions is detailed in Table 1. The current document describes the most up-to-date processor version.

Processor Version	In operation from	In operation until	Relevant improvements
01.00.00	28 February 2026 onwards	Initial version	Initial version
01.00.01	19 March 2026 onwards		Bug fixes

Table 1: History of HONO processor versions

3 Product Quality

3.1 Recommendations for data usage

The HONO vertical column depends on many aerosols parameters which are mostly unknown. The difficulty lies in recognizing real HONO sources.

The detection of statistically relevant HONO sources is based on the signal-to-noise ratio (defined as the ratio of the SCD of HONO and its error from the COBRA retrieval, see section 5). If the SNR of a pixel and the SNRs of at least 2 surrounding pixels are above a certain threshold, then the detection is considered as statistically significant, and the flag is activated for the pixel under consideration as well as its surrounding pixels. The flag assigning is as follows:

- 3: high confidence (SNR>16)
- 2: good confidence (SNR>8)
- 1: reasonable confidence (SNR>4) if other data (e.g., AAI, fire radiative power) indicate presence of fires.
- 0: no detection

A simplified qa value has been defined based on the detection quality flag, and can take two values : 0 (nitrousacid_detection_flag==0) or 1 (nitrousacid_detection_flag>0)

Pixels selection:

To get a more consolidated pixels selection It is recommended to use TROPOMI pixels with: solar_zenith_angle<65 & nitrousacid_slant_column_density_precision>2.5e-6 & (25<ground_pixel <426)

For pixels with detection flag=1, it is useful to consolidate the pixels selection by consulting the absorbing aerosol index (smoke plumes have AAI>>2) and/or the retrieved NO_2 values.

After pixel selection, some false positives may still occur due to the large number of TROPOMI pixels. Additional selection that the user might consider: nitrousacid_slant_column_density >4e-5 & nitrogendioxide_slant_column_density_corrected>3x nitrogendioxide_slant_column_density_precision.

HONO to NO2 ratio:

The HONO to NO2 ratio is independent of dilution and is a proxy of the photochemical production rate of HONO.
After pixels selection, recommended variables are nitrousacid_slant_column_density and nitrogendioxide_slant_column_density_corrected. To avoid division by a small number, detectable amounts of NO2 must be considered, e.g. pixels with nitrogendioxide_slant_column_density_corrected>3x nitrogendioxide_slant_column_density_precision.

HONO VCD:

To limit the processing time, the HONO VCD is only provided for pixels with detectable amounts of HONO (i.e., detection flag>0). The HONO VCD is calculated for pre-defined values of:

- plume height (a.g.l): 2 km (tropical conditions, or young plume near the source), 5 km (extra-tropical conditions, or older plume), 12 km (lofted plume representing pyroconvection events).
- single scattering albedo (SSA): 0.7 (highly absorbing/black carbon, pixels in the immediate vicinity of the source), 0.8 (absorbing aerosols, young plume near the source), 0.9 (older plume).
- Aerosol optical depth (AOD): 1, 2 (dispersed plume), 5, 10 (freshly emitted plume).

It is up to the user to select the most appropriate values (or linear combinations) depending on the conditions or external information on plume height and aerosols. As a baseline and in the absence of any information, it is recommended to use the HONO VCD for a plume height of 2km, SSA of 0.8 and AOD of 5.

Table 2 provides an overview of the variables obtained by the retrievals.

Table 2: Slant and vertical column variables, and the air mass factor and the HONO detection flag.

Variable name	Unit	description
nitrogendioxide_slant_column_density	Mol/m^{-2}	NO2 slant column obtained with linear DOAS retrieval
nitrogendioxide_slant_column_density_corrected	Mol/m^{-2}	Background corrected and destriped NO2 SCD
nitrogendioxide_slant_column_density_precision	Mol/m^{-2}	NO2 SCD random error
nitrousacid_air_mass_factor		AMF values for several plume height, single scattering albedo and optical depths for each pixel
nitrousacid_detection_flag		Displays the confidence level of HONO detection. This variable can take the values 0,1,2,3
nitrousacid_slant_column_density	Mol/m^{-2}	For certain conditions the doas retrieval performs better than cobra, this is explained in section 5.
nitrousacid_slant_column_density_cobra	Mol/m^{-2}	SCD HONO retrieved by the cobra method.
nitrousacid_slant_column_density_cobra_precision	Mol/m^{-2}	Error on the SCD HONO by cobra
nitrousacid_slant_column_density_cobra_rms	1	RMS of the cobra retrieval
nitrousacid_slant_column_density_doas	Mol/m^{-2}	SCD HONO retrieved by doas.
nitrousacid_slant_column_density_doas_corrected	Mol/m^{-2}	Background corrected and destriped HONO SCD.
nitrousacid_slant_column_density_doas_precision	Mol/m^{-2}	Random error on the SCD HONO from the doas retrieval
nitrousacid_slant_column_density_precision	Mol/m^{-2}	Random error for nitrousacid_slant_column_density
nitrousacid_vertical_column	Mol/m^{-2}	VCD HONO for different conditions of plume height, SSA and AOD.

For further details, data users are encouraged to read the description associated with this data product, in section 5.

3.2 Validation results

Initial validation results ([RD01], [RD02]) concludes that the TROPOMI HONO columns are of general good quality.

We compare the TROPOMI HONO columns to aircraft observations from the BB-FLUX campaign. When explicitly accounting for aerosols, the satellite and aircraft data are in good agreement albeit with significant comparison uncertainty. We also evaluated the TROPOMI retrievals against HONO columns measured by IASI.

4 Data Quality Remarks

4.1 Known Data Quality Issues

Currently, the data quality issues of the HONO product, not covered by the quality flags, are known and should be kept in mind when looking at the HONO product itself, and also at validation results.

Detection limit

Given the relatively large footprint of TROPOMI, emissions from weak fires will produce an HONO signal which might be too small to detect. Therefore, TROPOMI is limited to large events and statistics or interpretation on the HONO might be biased.

Air mass factor calculation

The smoke masking effect is particularly intense for highly absorbing aerosols as found in freshly emitted plumes. Therefore, the sensitivity of the satellite is typically limited to the upper part of the plume. Because of the presence of smoke aerosols, air mass factors are quite uncertain because there is generally a poor a priori knowledge of crucial parameters for the AMF calculation, notably the vertical profiles of the plume constituents (trace gases and aerosols) and the aerosol optical properties.
Another aspect is the neglect of the effect of smoke on the photochemistry of HONO and how this ultimately affects the satellite AMF.

4.2 Mission Operations Change

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

In this section, we aim at giving a short description of the algorithm.

The HONO retrieval algorithm has been developed as part of the Development and Interpretation of improved Nitrous Acid Retrievals (DINAR) project [ER01] and is fully described in [RD01] and [RD03]. As a starting point, it is useful to remember the main algorithm parts:

1. Slant column density retrievals: after a wavelength calibration step, the measured radiances are analyzed with the Covariance-Based Retrieval Algorithm (COBRA) and Differential Optical Absorption Spectroscopy (DOAS) techniques in the fitting window 337-375 nm. The resulting HONO SCDs from both techniques are combined in a merged product. By default, the COBRA SCD is used as it proves to be more sensitive than DOAS. However, for large signals, COBRA has limitations in representing the observed conditions and the spectral interferences with other trace gases present in the plume. Therefore, for these specific conditions, DOAS is believed to be more accurate than COBRA and is used instead. The DOAS results are also used to derive the NO2 SCD, co-retrieved in the same wavelength range, as it is useful to estimate enhancement ratios of the measured HONO SCD to the NO2 SCD (RHN). Finally, to increase and facilitate the usage of the HONO SCD data, a detection flag is constructed based on the retrieved HONO SCDs and SCD errors. This flag will be further described below.
2. Background correction: to account for possible SCD offsets, the retrieved SCDs are corrected using a dedicated background correction procedure. It is acting separately for each row and is performed using measured SCDs from the same orbit. This is particularly relevant for NO2 as it allows destriping the data and correcting for a NO2 background (including the stratospheric contribution to the SCD).
3. Air mass factor calculations: To convert the SCD into vertical column, air mass factors are calculated for each detection (i.e., for a detection flag larger than zero), for a set of prescribed aerosol parameters (AOD: 1, 2, 5, 10 and single scattering albedo: 0.7, 0.8, 0.9) and plume heights (2, 5, 12 km a.g.l.). The idea is that a wide range of conditions would be covered by the AMFs, and a user could easily infer (i.e., interpolate) an HONO VCD based on third party information (in terms of AOD, single scattering albedo, plume heights). The calculations are performed for cloud-free conditions and a fixed albedo of 0.05

The COBRA algorithm is described in detail in [RD01] and [RD03]. In short, the COBRA scheme starts from the wavelength calibrated radiances and retrieves a single fitted parameter: the HONO slant column:

$$\widehat{SCD} = \left(k^T S^{-1} k\right)^{-1} k^T S^{-1} \left(y - \bar{y}\right) \quad (1)$$

In this expression, k is the row-dependent HONO cross section vector over the fitting range, y is the measurement vector (log intensity radio from radiance and irradiance measurements) of the pixel to be analyzed. S and $\bar{y}$ are the covariance and mean vector of a set of clean (HONO-free) spectra. The idea of COBRA is to select a set of measured HONO free spectra, representative of the background variability of the spectra and use the inverse of the covariance matrix as a weight to optimally retrieve the target species (HONO in this case). Although the method is simple in principle, the algorithm is taking care of calculating separately the covariance matrix (and $\bar{y}$) for each orbit, each row and for 3 scanline segments. A precaution is also implemented to remove the spectra from the clean set that are contaminated by HONO, in the form of an iteration process. Finally, from the fit, it is also possible to calculate a retrieval error (precision estimate) by:

$$\widehat{SCD}_{err} = \chi \,.\, \sqrt{\left(k^T S^{-1} k\right)^{-1}} \qquad (2)$$

with the normalized root-mean-square χ:

$$\chi^2 = \frac{1}{N-1} \,.\, \left(\Delta y^T S^{-1} \Delta y\right) \qquad (3)$$

where $\Delta y = y - \overline{y} - k \,.\, \widehat{SCD}$ (residual) and N being the number of wavelengths in the fitting interval. This variable is typically close to 1, except for conditions of bad fit quality (χ>>1).

In algorithm version, several changes have been applied to the retrieval scheme compared to [RD03]:

a. A better retrieval error estimation based on the normalized root mean square (Eq. 3).

b. Improvement of the detection flag. The flag is based on the signal-to-noise ratio (defined as the ratio of the SCD and its error, Eqs. 1 and 2). If the SNR of a pixel and the SNRs of at least 2 surrounding pixels are above a certain threshold, then the detection is considered as statistically significant, and the flag is activated for the pixel under consideration as well as its surrounding pixels. The flag assigning is as follows:

   • 3: high confidence (SNR>16)

   • 2: good confidence (SNR>8)

   • 1: reasonable confidence (SNR>4) if other data (e.g., AAI, fire radiative power) indicate presence of fires.

   • 0: no detection

c. An improved destriping and background correction is applied to the DOAS SCDs (HONO and NO2) of each orbit. The destriping is based on 2D moving median filter [RD06]with widths of the median window of 70 and 50, in along-track and across-track dimensions, respectively. For the background, the correction is applied per row and consists of subtracting a moving median SCD (with a window of 100 in the along-track direction) to the SCDs.

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. Processing of near-real time (NRTI) data is currently not foreseen.

Product Identifier: **L2__HONO__**

Example filename:

S5P_PAL__L2__HONO___20251007T112301_20251007T130431_41372_03_010000_20260128T151233.nc

Details of the data format are provided in the Product File Specification (PFS) document ([RD04]).

7 Product Availability

The latest product release, version 01.00.01, is currently implemented in the so-called pre-operational environment of the S5P-PAL system ([ER02]). The data will become available through the data portal of the PAL system ([ER03]). Details will be provided in a future update of this document.

8 References

[RD01] Theys, N., Yu, H., Franco, B., Clarisse, L., Volkamer, R., Cha, H., Kim, J., De Smedt, I., Stavrakou, T., van Gent, J., & Van Roozendael, M. (2025). Atmospheric HONO Observed Over Global Biomass Burning Regions Using Satellite Observations of TROPOMI and GEMS. Journal of Geophysical Research: Atmospheres, 130(8). https://doi.org/10.1029/2024jd043163

[RD02] DINAR Validation Report Document, **source**: BIRA; **ref**: DINAR_HONO_VR_v1.2; **issue:** 1.2; **date:** 2024-02-27. https://hono.aeronomie.be/ProjectDir/Documents

[RD03] DINAR Algorithm Theoretical Baseline Document, **source**: BIRA; **ref**: DINAR_HONO_ATBD_v2.0; **issue:** 1.2; **date:** 2024-02-05. https://hono.aeronomie.be/ProjectDir/Documents

[RD04] S5P/TROPOMI HONO Product Format Specification, **source**: BIRA; **ref**: S5P-L2 BIRA-PFS-HONO; **issue:** 1.0; **date:** 2026-02-18.

[RD05] S5p Product Algorithm Laboratory L2 Processor File Format Guidelines. **source:** S&T; **ref:** ST-ESA-S5P_PAL-L2FFG-001; **issue:** 1.4; **date:** 2023-03-27.

[RD06] **Borsdorff, T.; Martinez-Velarte, M.C.; Sneep, M.; ter Linden, M.; Landgraf, J.** *Random Forest Classifier for Cloud Clearing of the Operational TROPOMI* XCH_4 *Product.* **Remote Sensing 2024**, *16*(7), 1208.

[ER01] https://hono.aeronomie.be/

[ER02] https://www.s5p-pal.com/

[ER03] https://data-portal.s5p-pal.com/

Abbreviations and acronyms

AAI	Absorbing Aerosol Index
AMF	Air Mass Factor
AOD	Aerosol Optical Depth
ATBD	Algorithm Theoretical Basis Document
BIRA-IASB	Royal Belgian Institute for Space Aeronomy
COBRA	Covariance-Based Retrieval Algorithm
DINAR	Development and Interpretation of improved Nitrous Acid Retrievals
DOAS	Differential Optical Absorption Spectroscopy
ESA	European Space Agency
HONO	Nitrous acid
IASI	Infrared Atmospheric Sounding Interferometer
L2	Level-2
NO2	Nitrogen dioxide
NRTI	Near-real time
OFFL	Offline
PAL	Product Algorithm Laboratory
PFS	Product Format Specification
PRF	Product Readme File
RHN	Ratio HONO to NO2
SCD	Slant Column Density
SNR	Signal to noise ratio
S5P	Sentinel-5 Precursor
TROPOMI	Tropospheric Monitoring Instrument
VCD	Vertical Column Density