Sentinel-5P TROPOMI Cal/Val

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S-5P ATM MPC Routine Validation

- The routine validation is performed by the Validation Teams using the ATM-MPC VDAF.
- Standardized, rigorous validation techniques applied to an automated validation server.
- Ingests high-quality, ground-based and sonde data for most data products, around the globe with varying timeliness.
- Provides user-interactive visualization and analysis functionality.

https://mpc-vdaf.tropomi.eu/
### Sentinel-5P Processor Level 2 Routine Validation

#### Fiducial Reference Measurements and other validation data

<table>
<thead>
<tr>
<th>SSP data Product</th>
<th>Mission requirements</th>
<th>Fiducial Reference Measurements and other ground-based data sources</th>
<th>Satellite data sources</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Systematic</td>
<td>Random</td>
<td>Brewer, Dobson, ZSL-DOAS, PGN</td>
</tr>
<tr>
<td>O₃ total column</td>
<td>5%</td>
<td>2.5%</td>
<td>O₃ vertical profile</td>
</tr>
<tr>
<td></td>
<td>30%</td>
<td>10%</td>
<td>ozonesonde, DIAL (strato+tropo)</td>
</tr>
<tr>
<td>O₃ tropospheric column</td>
<td>25%</td>
<td>25%</td>
<td>ozonesonde</td>
</tr>
<tr>
<td>NO₂ stratospheric column</td>
<td>10%</td>
<td>0.5 e15</td>
<td>ZSL-DOAS</td>
</tr>
<tr>
<td>NO₂ tropospheric column</td>
<td>50%</td>
<td>0.7 e15</td>
<td>MAX-DOAS</td>
</tr>
<tr>
<td>NOx total column</td>
<td>-</td>
<td>-</td>
<td>PGN</td>
</tr>
<tr>
<td>SO₂ total column</td>
<td>30%</td>
<td>30%</td>
<td>MAX-DOAS, PGN</td>
</tr>
<tr>
<td>HCHO total column</td>
<td>80%</td>
<td>1.2 e16</td>
<td>MAX-DOAS, NDACC FTIR, PGN</td>
</tr>
<tr>
<td>CO total column</td>
<td>15%</td>
<td>10%</td>
<td>NDACC/FTIR, TCCON, COCCON</td>
</tr>
<tr>
<td>CH₄ total column</td>
<td>1.5%</td>
<td>1%</td>
<td>NDACC/FTIR, TCCON, COCCON</td>
</tr>
<tr>
<td>Cloud Fraction</td>
<td>20%</td>
<td>0.05</td>
<td>FRM not available</td>
</tr>
<tr>
<td>Cloud Height (pressure)</td>
<td>20%</td>
<td>0.5 km</td>
<td>CLOUDNET lidar/radar</td>
</tr>
<tr>
<td>Cloud Optical Thickness</td>
<td>20%</td>
<td>0.05</td>
<td>FRM not available</td>
</tr>
<tr>
<td>Aerosol Absorbing Index</td>
<td>1 AAI</td>
<td>0.1 AAI</td>
<td>FRM not available</td>
</tr>
<tr>
<td>Aerosol Layer Height</td>
<td>100 hPa</td>
<td>50 hPa</td>
<td>EARLINET lidar</td>
</tr>
</tbody>
</table>

**New, July 2023:** SO₂ Layer Height, Random: 1km breakthrough, 2km threshold
Sentinel-5P Level 2 Product Assessment

Representative Quality Indicators

Representative values of key quality indicators (bias and dispersion vs. reference measurement, and special features) have been derived for the following Sentinel operational data products on the basis of the validation results reported in this document:

<table>
<thead>
<tr>
<th>Product ID</th>
<th>Stream</th>
<th>Product</th>
<th>Bias</th>
<th>Dispersion</th>
<th>Special features</th>
</tr>
</thead>
<tbody>
<tr>
<td>L2_C5_TOL</td>
<td>O3 profile</td>
<td>&lt;0%</td>
<td>10-30%</td>
<td>Some increase in dispersion in the comparisons to ground-based measurements at SZA &gt; 70°. Eventual corrections for aerosol are conservative.</td>
<td></td>
</tr>
<tr>
<td>L2_C5_PP</td>
<td>O3 profile</td>
<td>5-10%</td>
<td>10-30%</td>
<td>Increase in agreement to 10–15% in the troposphere and TMLS. Bias might be up to +1% in the stratosphere (20–40 km). Dispersion of order of 10% in the troposphere and 10–20% in the TMLS and upper stratosphere.</td>
<td></td>
</tr>
</tbody>
</table>

Quarterly reports contain summary about Quality indicators

- Routine Product Validation by the ATM – Mission Performance Cluster
- Quarterly reports contain summary about Quality indicators

Table 2 – Representative quality indicators (bias, dispersion and special features) derived from the validation of the SP TROPOMI data products listed in the Table 1, valid for all processor versions unless stated differently. CTH: cloud top height; CH: cloud height; COT: cloud optical thickness.
**L2_NO2 Validation Summary**

Validation coordinator: K.-U. Eichmann (IUPB)
Contributors: S. Compernolle, G. Pinardi, and T. Verhoelst (BIRA-IASB), H. Eskes, J. van Geffen (KNMI)

### Status of validation activities
- Fully operational comparison in the VDAF-AVS: **15 SAOZ ZSL-DOAS** (strato), **8 MAX-DOAS** (tropo), and **62 PGN** (total) instruments, with excellent timeliness.
- Complemented with another **26 FTIR**, **9 ZSL-DOAS** and **20 MAX-DOAS** (including contributions through AO NIDFORVAL and former S5P-MPC CCN-5) for a harmonized analysis (Verhoelst, 2021).
- Comparison to the **QA4ECV OMI** satellite tropospheric NO₂ retrieval.

### Validation results
- Bias, (Dispersion): tropospheric (-28%, 2 Pmolec/cm²): positive bias (13%) in clean areas and larger negative bias (-40%) in highly polluted areas; similar behaviour in total column; stratospheric (-3%, 0.3 Pmolec/cm²); and total column (-8.5%, 1.5 Pmolec/cm²);
- Total NRTI roughly 0.5% larger than OFFL; tropospheric NRTI 2% with differences of more than 2 Pmolec/cm² on pixel level possible; stratospheric NRTI about -0.5% lower.
- Dependence on influence quantities: increase in tropospheric bias w.r.t. aerosol optical thickness and cloud fraction.
- Drifts: no drifts detected; Patterns: no patterns detected;
- Effect of processor change V2.4.0: decrease in tropospheric and total NO₂ biases. Also better agreement with OMI-QA4ECV tropospheric columns;

**Bias is within requirements. Dispersion is also within requirements, except in the troposphere.**
**L2_HCHO Validation Summary**


**Status of validation activities**

- Fully operational comparison in the VDAF-AVS with 6 MAX-DOAS, 30 PGN, and 18 FTIR instruments.
- Independent validation [SSP-MPC CCN-5/NIDFORVal AO208607 project]: 28 NDACC FTIR stations (Vigouroux, 2020); 8 MAX-DOAS stations, 3 providing Averaging Kernel.
- Comparison to the QA4ECV OMI satellite tropospheric HCHO retrieval.

**Validation results**

- Bias, (Dispersion):
  - FTIR [clean <2.5 Pmolec/cm²] (34%, 9 Pmolec/cm²), [polluted >8 Pmolec/cm²] (-30%, 25 Pmolec/cm²);
  - MAX-DOAS (-33%, <10 Pmolec/cm²);
  - PGN (-32%, <10 Pmolec/cm²);
  - OMI [polluted >5 Pmolec/cm²] (3%, <7 Pmolec/cm²);
- NRTI about 0.5% lower than OFFL;
- Dependence on influence quantities: no variations detected w.r.t. SZA, SAA, row index, cloud fraction.
- Drifts: no drifts detected; Patterns: no patterns detected;

**Highlights, open issues**

- Enhancement of FRM data provision; Inclusion of new sites: 18 MAX-DOAS; Investigation of ground-based data consistency in Xianghe; Validation results using OMI and MAX-DOAS data (de Smedt, 2021); Mohali DOAS site added in VDAF-AVS.

Bias is within requirements. Dispersion is within requirements at clean sites only.
**L2_SO2 Validation Summary**
Validation coordinator: T. Wagner (MPI-C)
Contributors: N. Theys, S. Compernolle (BIRA-IASB)

**Validation activities & results**
- vs. MAX-DOAS: typical bias 0.2 DU, dispersion 0.2 DU, but larger deviations in winter (NH)
- good qualitative agreement with GOME-2, OMI, OMPS

**Highlights & Open issues**
- comparisons with ground-based instruments at volcanic sites (e.g., NOVAC) are still needed.
L2_SO2_LH Validation Summary

Validation coordinator: T. Wagner (MPI-C)
Contributors: M. Koukouli, A. Pseftogkas, K. Michailidis (AUTH)

Validation activities & results

- This validation activity started in September 2023

Highlights & Open issues

S5P L2 SO\textsubscript{2} LH Validation Tasks:

- The existing end-to-end SO\textsubscript{2} LH AUTH validation system will be updated and automated for this work.
- The existing volcanic alerts automated within the ESA S5P+I: SO2LH project will be integrated in the AUTH validation system to initialize the validation chain.

Validation will include:

- Direct comparison with respect to the operational IASI SO\textsubscript{2}LH product
- Investigation into the possibility of back-trajectory analysis to compensate for spatio-temporal collocation mismatches.
- After development is concluded, all applicable eruptions will be investigated beginning with the September 2023 Popocatepetl, Mexico, eruption and offered as proof-of-concept to the next AMT-MPC Monthly Validation Meeting and be included in the ROCVR.
L2_CO Validation Summary

Validation coordinator B. Langerock (BIRA-IASB), Contributor M. K. Sha (BIRA-IASB)

- Stable performance for the entire time series: up-to-date comparisons with NDACC (operational in VDAF-AVS), ±1 year time lag for TCCON, campaign based for COCCON
L2_CH4 Validation Summary

Validation coordinator M. K. Sha (BIRA-IASB), Contributor B. Langerock (BIRA-IASB)

- Stable performance for the entire time series: up-to-date comparisons with NDACC (operational in VDAF-AVS), ±1 year time lag for TCCON, campaign based for COCCCON

Plans for next updates
• Continuous monitoring of L2 CH4 data,
• Update of VAL results using COCCON V2 data

TROPOMI nadir bc-XCH4 vs NDACC XCH4

TROPOMI glint bc-XCH4 vs TCCON XCH4
L2_AER_AI Validation Summary

Validation coordinator: T. Wagner (MPI-C)
Contributors: D. Stein Zweers (KNMI), O. Torres, C. Ahn (NASA)

Validation activities & results
- new time series plots (histograms)

Highlights
- good agreement of RPRO with OMPS
L2_AER_LH Validation Summary

Validation coordinator: T. Wagner (MPI-C)
Validation contributors: M. de Graaf (KNMI), K. Michailidis, ML. Koukouli (AUTH)

Validation activities & results
- change of filter (cloud mask) largely increases number of processed pixels
- valuable validation contribution using EARLINET ground-based LIDAR network

Highlights & Open issues
- relatively good agreement over ocean, strong underestimation over land (see figure)
- updated version (2.6.0, November 2023) includes surface albedo in inversion as fitted parameter. This largely improves ALH over land