

Coherence of Sentinel-5p Tropospheric NO₂ columns validation using MAX-DOAS and Pandora direct-sun measurements

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Abstract

The quality of nitrogen dioxide (NO₂) Sentinel-5p TROPOMI products throughout the mission has been assessed within the MPC-ATM and the S5p Validation Team (AO project NIDFORVAL). In this presentation, tropospheric NO₂ products up to version 02.04.00 are verified through comparison with ground-based UV-Visible multi-axis DOAS (MAX-DOAS) and direct-sun PANDORA remote sensing measurements, updating the in-depth validation work presented in Verhoelst et al. (2021) until March 2020 and the specific improvements of v2.2 discussed in van Geffen et al. (2022).

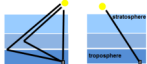
Owing to the multiple pointing geometries, the DOAS technique is sensitive to total, tropospheric and stratospheric NO₂ content. MAX-DOAS measurements also provide coarse information on the vertical distribution of NO₂ in the lower troposphere, of high relevance to assess the validity of a-priori NO₂ vertical profiles used in satellite retrievals. Our study makes use of 30 MAX-DOAS stations operated by the NIDFORVAL consortium partners. Complementary to MAX-DOAS, Pandora direct-sun instruments provide accurate measurements of the total NO₂ columns. Data from the Pandonia Global Network (PGN) are automatically ingested in the MPC CaVal VDAF webserver (<http://mpc-vdaf-server.tropomi.eu/no2>) for the routine validation of S5p total NO₂ columns. About 44 stations contribute to the server.

Here we investigate the consistency between the tropospheric NO₂ validation results obtained using MAX-DOAS and direct-sun PGN instruments. Tropospheric NO₂ columns are derived from PGN total NO₂ values by subtracting the stratospheric column available from the S5p NO₂ product (see Pinardi et al., 2020). A special focus is put on ground-based data comparisons, for stations where both MAX-DOAS and Pandora measurements are performed (such as Uccle, Bremen, Athens, Yokosuka, Mexico city, ...). Whenever possible, standardized data products such as those generated within PGN and the FRM4DOAS project are being used.

GB Data

NO₂ VCDs data from NIDFORVAL AO project (S5pVT) and MPC-ATM:

- MAXDOAS (tropospheric NO₂): 30 stations, 8 also processed by FRM4DOAS centralized facility
- PGN DirectSun (total NO₂): 44 stations



S5p data

OFFL tropospheric NO₂ data from ESA Expert HUB: mix of versions

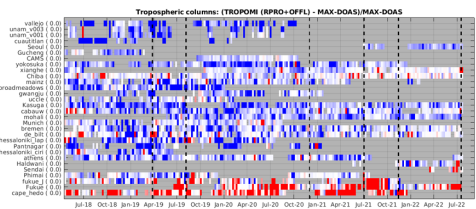
01.02.00	2836, 2018-05-01	5235, 2018-10-17
01.02.00	5236, 2018-10-17	5832, 2018-11-28
01.02.00	5840, 2018-11-29	7424, 2019-03-20
01.03.00	7425, 2019-03-20	7906, 2019-04-23
01.03.01	7907, 2019-04-23	8814, 2019-06-26
01.03.02	8815, 2019-06-26	16212, 2020-11-29
01.04.00	16213, 2020-11-29	19257, 2021-07-01
02.02.00	19258, 2021-07-01	21187, 2021-11-14
02.03.01	21188, 2021-11-14	24654, 2022-07-17
02.04.00	24655, 2022-07-17	current version

Main changes happened for:

- v01.04 (FRESCO-S cloud retrieval improvements)
- v02.02 (Adjustment of surf. albedo in NO₂ window); see also Van Geffen et al., 2022
- Current version: v02.04 (S5p DLER climatology).

2. Operational validation results

Regular updates, see latest ROCVRs #16
Check the evolution of the versions:



A subset of these sites is included in the routine automated CaVal VDAF webserver (<http://mpc-vdaf-server.tropomi.eu/no2>)

Colocations:

Consider for each day S5p valid pixels (QA>0.75) over the station (or its LOS); use the interpolated/closer over ±1h value of gb measurements around S5p overpass. See method description in Verhoelst et al., 2021.

1. Comparison method

4. Compare NIDFORVAL and FRM4DOAS processings

All original data

Biases:

Disclaimer/known differences:
- Athens and Mainz stations have several viewing directions, treated within FRM4DOAS but not within NIDFORVAL.
- When a MAXDOAS LOS is provided (default in FRM4DOAS, not often in NIDFORVAL dataset), this is used for the collocation with S5p pixels -> change in SAT pixels selection!
- some FRM4DOAS data are missing in this exercise.
-> results need to be consolidated!

Common times

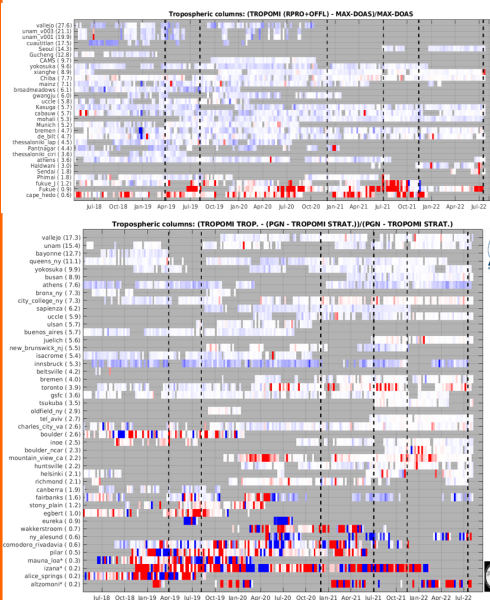
Ongoing:
- more quantitative analysis should be performed - the underlying ground-based datasets also need to be compared in detail. E.g., Uccle:

Note that FRM4DOAS internal consistency is checked by inter-comparing MMF and MAPA algorithms. Validation was done by comparing them to other state-of-the-art profiling tools and ancillary data (Frieis et al. 2019, Tirpitz et al., 2021, FRM4DOAS VR (<https://frm4doas.aeronomie.be>))

Preliminary results!!!

3. MAXDOAS vs PGN

PGN tropo contribution can be estimated by subtracting S5p VCDstrato, as in Pinardi et al. (2020). Comparisons at the network level:

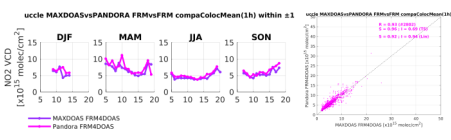


Both networks present a positive bias for clean stations (i.e. tropospheric VCD <1.8 Pmol_{eq}/cm² for MAX-DOAS stations), and a negative bias for more polluted stations.

The MAX-DOAS network is heavily biased towards stations with significant tropospheric column, with a lack of stations in the 2 to 3 Pmol_{eq}/cm² range compared to the PGN network

Some sites host both instrument types: Unam, Uccle, Bremen, Athens, Yokosuka (Cabauw)
-> some are quite coherent in their median GB VCD_{tropo}: Uccle (5.8 & 5.9 Pmol_{eq}/cm²), Bremen (4.7 & 4 Pmol_{eq}/cm²) -> some present apparent inconsistencies: Unam (19.9 and 21.1 Pmol_{eq}/cm², depending on the MAX-DOAS viewing directions & 15.4 Pmol_{eq}/cm²), Athens (3.6 & 7.6 Pmol_{eq}/cm², but MAX on a hill).
Impact of different spatio-temporal sampling and specific-site conditions that could explain part of these differences, should be studied in more details.

PANDORA also perform off-axis scans, that can be included in the FRM4DOAS processing. E.g., in Uccle and comparison to the BIRA MAXDOAS:



Conclusions

Routine validation:

- NO₂ ground-based data points to a negative bias of S5p tropospheric columns, reduced by about 10% with the new v2.x dataset (van Geffen et al., 2022).
- See all results for total, tropo and strato NO₂ VCD (+more in-depth investigations) in the ROCVRs: effect of profile (smoothing of MAXDOAS profile with S5p AVK), influence quantities; impact of the different versions; comparisons with other satellites, ...: <https://mpc-vdaf.tropomi.eu/index.php/nitrogen-dioxide> (+ online automated comparisons: <https://mpc-vdaf-server.tropomi.eu/no2>)

Comparisons with PGN data:

- Network-level comparison is coherent, with positive bias wrt S5p for clean sites and negative bias for more polluted sites.
- The MAX-DOAS network is heavily biased towards stations with significant tropospheric column, with a lack of stations in the 2 to 3 Pmol_{eq}/cm² range compared to the PGN network.
- More in-depth comparisons of the underlying ground-based dataset are needed at the sites where both type of instruments are present (Uccle, Bremen, Athens, Yokosuka, Mexico city).
- Good coherence of first comparisons of Pandora off-axis measurements and MAX-DOAS columns in Uccle (FRM4DOAS processing).

Comparisons with FRM4DOAS:

- Preliminary comparisons results are quite similar to those obtained with the NIDFORVAL dataset. Further consolidation is needed as the provision of LOS information is changing the selected S5p pixels!
- FRM4DOAS is providing profiles in the low troposphere, while only a small subset of NIDFORVAL sites (15 over 30) is providing them.