Sentinel-5P TROPOMI Cal/Val

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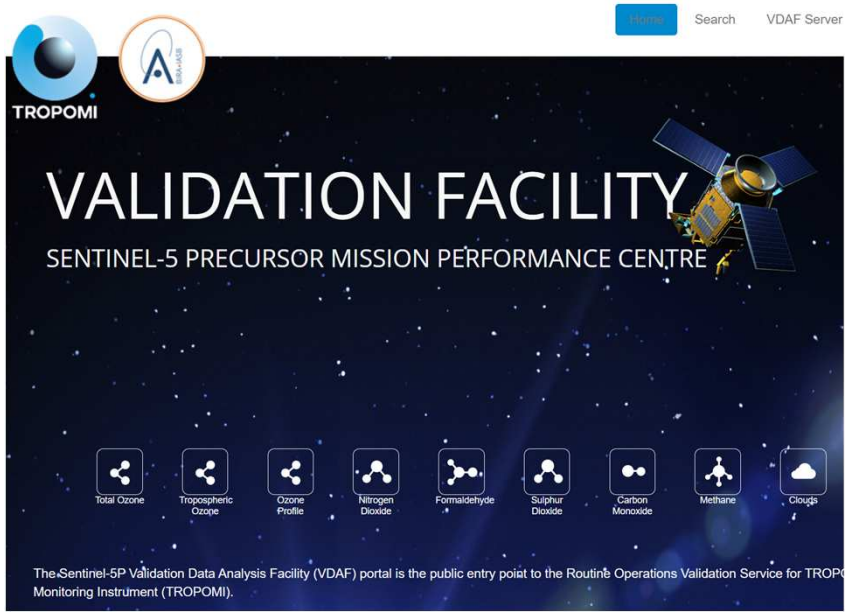
S-5P ATM MPC Routine Validation

- 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

Courtesy: BIRA-IASB, ATM-MPC

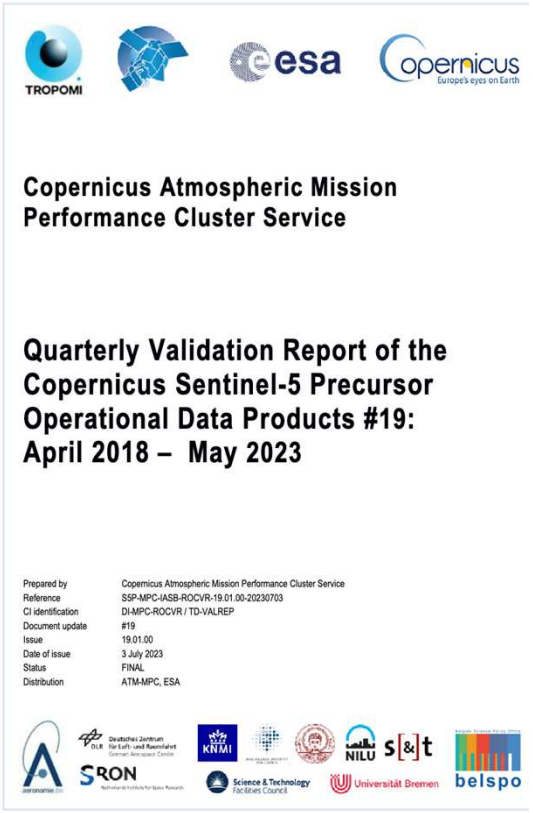
S5P data Product	Mission requirements Systematic	Random	Fiducial Reference Measurements and other ground-based data sources	Satellite data sources
O_3 total column	5%	2.5%	Brewer, Dobson, ZSL-DOAS, PGN	OMI, GOME-2
O_3 vertical profile	30%	10%	ozonesonde, DIAL (strato+tropo)	OMI, GOME-2
O_3 tropospheric column	25%	25%	ozonesonde	OMI, GOME-2
NO_2 stratospheric column	10%	0.5 e15	ZSL-DOAS	OMI, GOME-2
NO_2 tropospheric column	50%	0.7 e15	MAX-DOAS	OMI, GOME-2
NO_2 total column	-	-	PGN	OMI, GOME-2
SO_2 total column	30%	30%	MAX-DOAS, PGN	OMI, GOME-2, OMPS-NP
HCHO total column	80%	1.2 e16	MAX-DOAS, NDACC FTIR, PGN	OMI, GOME-2
CO total column	15%	10%	NDACC/FTIR, TCCON, COCCON	GOSAT-2, OCO-2
CH_4 total column	1.5%	1%	NDACC/FTIR, TCCON, COCCON	GOSAT-2, OCO-2
Cloud Fraction	20%	0.05	*FRM not available*	VIIRS, OMI, GOME-2
Cloud Height (pressure)	20%	0.5 km	CLOUDNET lidar/radar	VIIRS, OMI, GOME-2
Cloud Optical Thickness	20%	0.05	*FRM not available*	VIIRS, OMI, GOME-2
Aerosol Absorbing Index	1 AAI	0.1 AAI	*FRM not available*	OMI, OMPS-NP
Aerosol Layer Height	100 hPa	50 hPa	EARLINET lidar	CALIPSO, VIIRS

Colour code: automated production of S5P QIs by the VDAF-AVS manual data collection and/or validation

FRM not available, quality evaluation mainly via diagnostics and satellite data intercomparisons

New, July 2023: SO_2 Layer Height, Random: 1km breakthrough, 2km threshold

Sentinel-5P Level 2 Product Assessment



Copernicus Atmospheric Mission Performance Cluster Service

Quarterly Validation Report of the Copernicus Sentinel-5 Precursor Operational Data Products #19: April 2018 – May 2023

Prepared by	Copernicus Atmospheric Mission Performance Cluster Service
Reference	S5P-MPC-IASB-ROCVR-19.01.00-20230703
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Date of issue	3 July 2023
Status	FINAL
Distribution	ATM-MPC, ESA

Representative Quality Indicators

Representative values of key quality indicators (bias and dispersion vs. reference measurements, and special features) have been derived for the following S5P operational data products on the basis of the validation results reported in this document:

Product ID	Stream	Product	Bias	Dispersion	Special features
L2_O3	NRTI	O_3 column	0.7 %	2 %	Some increase in dispersion in the comparisons to ground-based measurements at SZA > 70°. Ex-ante uncertainties perhaps slightly too conservative.
	OFFL	O_3 column	1.3 %	2 %	Some increase in dispersion in the comparisons to ground-based measurements at SZA > 70°.
L2_O3_TCL	OFFL RPRO	O_3 tropospheric column (CCD)	+20 %	25 %	Geographical imprints of sampling-related biases. Seasonal change of the bias at Atlantic sites coinciding with biomass burning season.
L2_O3_PR	NRTI	O_3 profile	5-10 %	10-30 %	Mean agreement better than 5 to 10 % in the troposphere and UTLS. Bias goes up to -15 % in the higher stratosphere (35-45 km), but with vertical oscillations. Dispersion of order of 30 % in the troposphere, and 10 to 20 % in the UTLS and upper stratosphere.
	OFFL	O_3 profile	5-10 %	10-30 %	
	RPRO	O_3 profile	5-10 %	10-30 %	
L2_NO2	NRTI	NO_2 troposphere NO_2 stratosphere NO_2 total	-37% -3% 0±50%	2.6 Pmolec/cm² 0.3 Pmolec/cm² -	Bias and dispersion by column amount: Troposphere [<2 Pmolec/cm²] +33% and [>15 Pmolec/cm²] -49%. Total [+/-6 Pmolec/cm²]: +5 % and -19 %.
	OFFL RPRO	NO_2 troposphere NO_2 stratosphere NO_2 total	-28% 3% -6.7%	1.4 Pmolec/cm² 0.3 Pmolec/cm² 1.6 Pmolec/cm²	
L2_HCHO	NRTI OFFL RPRO	HCHO, low HCHO, high	+34 % -37 %	9 Pmolec/cm² 25 Pmolec/cm²	Bias and dispersion depend on column amount: [<2.5 Pmolec/cm²] positive bias, low dispersion, [>8 Pmolec/cm²] negative bias, high dispersion.
L2_SO2	NRTI	SO_2 column	0.2 DU	0.2 DU	Lack of validation stations in areas with high SO_2.
	OFFL	SO_2 column	0.2 DU	0.2 DU	
L2_CO	NRTI	CO column	+2 %	8 %	Along orbit stripes. 4% SZA and 2% seasonal dependence in bias, both within reference measurement uncertainty. Seasonal dependence can be reduced when taking into account the satellite averaging kernels.
	OFFL	CO column	+2 %	8 %	
L2_CH4	OFFL	CH4 column	+0.29%	0.7%	Along orbit stripes. Underestimation at low albedo. Remaining outliers with `qa_value` >0.5. Outlying CH_4 values observed along coastal or mountain regions – e.g., in Greenland.

ATM MPC

http://mpc-vdaf.tropomi.eu/

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

Product ID	Stream	Product	Bias	Dispersion	Special features
L2_CLOUD	NRTI OFFL	CAL CTH (h) CAL CTH (l) CAL CMH (h) CAL CMH (l) CRB CH (h) CRB CH (l)	37 % -15 % 12 % 18 % -20 % -25 %	2 km 0.5 km 1.7 km 0.5 km 2 km 0.5 km	Low clouds (l): CLOUDNET CTH<4km; high clouds (h): CLOUDNET CTH>4km.
L2_AER_AI	NRTI	aerosol index	-1.1 AI unit	0.1 AI unit	
	OFFL	aerosol index	-1.1 AI unit	0.1 AI unit	
L2_AER_LH	OFFL	aerosol layer height	50 hPa	100 hPa	Over ocean only. Larger bias and dispersion expected over land.

Table 2 – Representative quality indicators (bias, dispersion and special features) derived from the validation of the S5P 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

Processor versions up to v02.05.00 OFFL + v02.04.00 RPRO

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

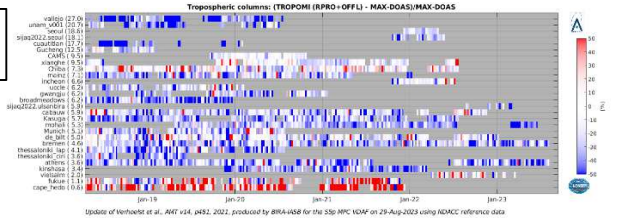
Status of validation activities

- 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 NO_2 retrieval.

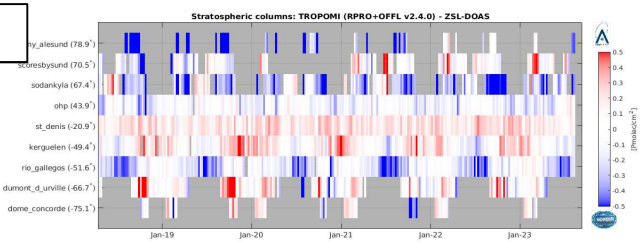
Validation results

- Bias, (Dispersion): **tropospheric** (-28%, 2 Pmolec/cm^2): 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/cm^2); and **total** column (-8.5%, 1.5 Pmolec/cm^2);
- Total **NRTI** roughly 0.5% larger than OFFL; tropospheric **NRTI** 2% with differences of more than 2 Pmolec/cm^2 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 NO_2 biases. Also better agreement with OMI-QA4ECV tropospheric columns;

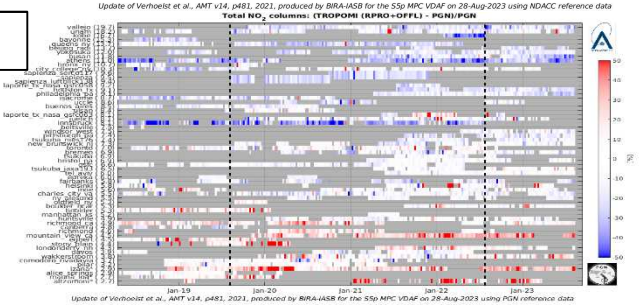
Troposph. NO2 columns: (TROPOMI – MAX-DOAS)/ MAX-DOAS



Stratosph. NO2 columns: (TROPOMI –ZSL-DOAS)



Total NO2 columns: (TROPOMI –PGN)/PGN



Bias is within requirements. Dispersion is also within requirements, except in the troposphere.

L2_HCHO Validation Summary

Validation coordinator: K.-U. Eichmann (IUPB). Contributors: S. Compernolle, I. De Smedt, G.Pinardi, C. Vigouroux (BIRA-IASB)

Status of validation activities

- Fully operational comparison in the VDAF-AVS with 6 **MAX-DOAS,** 30 **PGN**, and 18 **FTIR** instruments.
- Independent validation [**S5P-MPC CCN-5/NIDFORVal** AO208607project]: 28 NDACC **FTIR** stations (*Vigouroux,2020*); 8 **MAX-DOAS** stations, 3 providing Averaging Kernel.
- Comparison to the **QA4ECV OMI** satellite tropospheric HCHO retrieval.

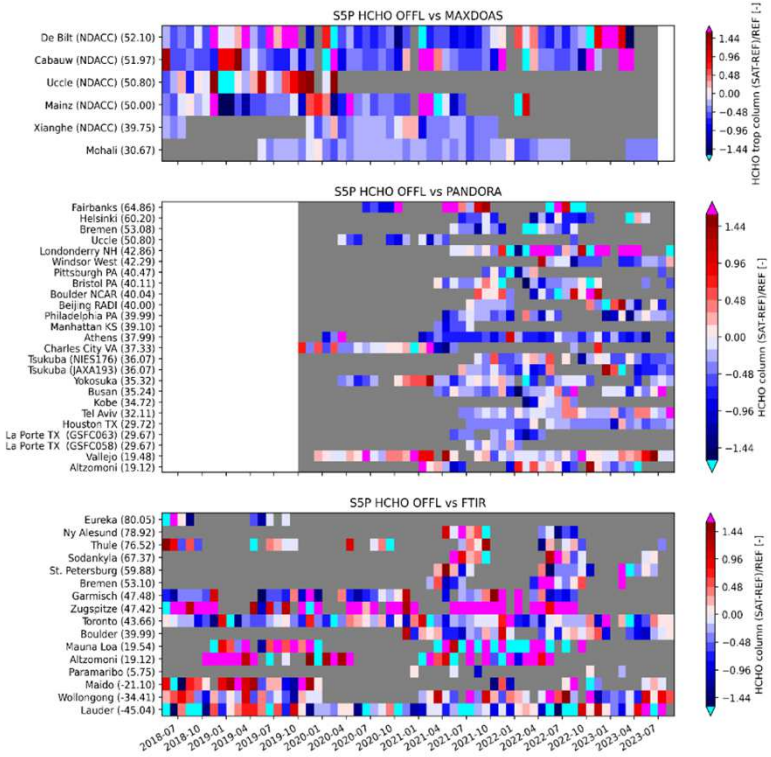
Validation results

- Bias, (Dispersion):
  - FTIR [clean <2.5 Pmolec/cm^2] (34%, 9 Pmolec/cm^2),
    [polluted >8 Pmolec/cm^2] (-30%, 25 Pmolec/cm^2);
  - MAX-DOAS (-33%, <10 Pmolec/cm^2);
  - PGN (-32%, <10 Pmolec/cm^2);
  - OMI [polluted >5 Pmolec/cm^2] (3%, <7 Pmolec/cm^2);
- **NRTI** about 0.5% lower than OFFL;
- Dependence on **influence quantities**: no variations detected w.r.t. SZA, SAA, row index, cloud fraction.
- **Drift**s: 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.

Processor version 02.05.00 OFFL + 02.04.01 RPRO



Bias is within requirements. Dispersion is within requirements at clean sites only.

L2_SO2 Validation Summary

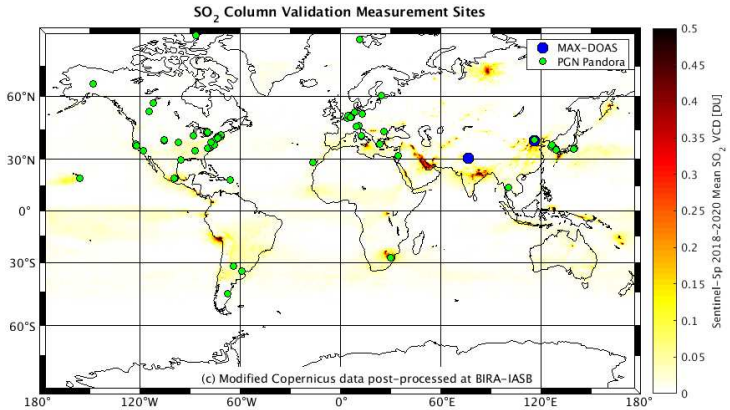
Validation coordinator: T. Wagner (MPI-C)
Contributors: N. Theys, S. Compernolle (BIRA-IASB)

Validation activities & results

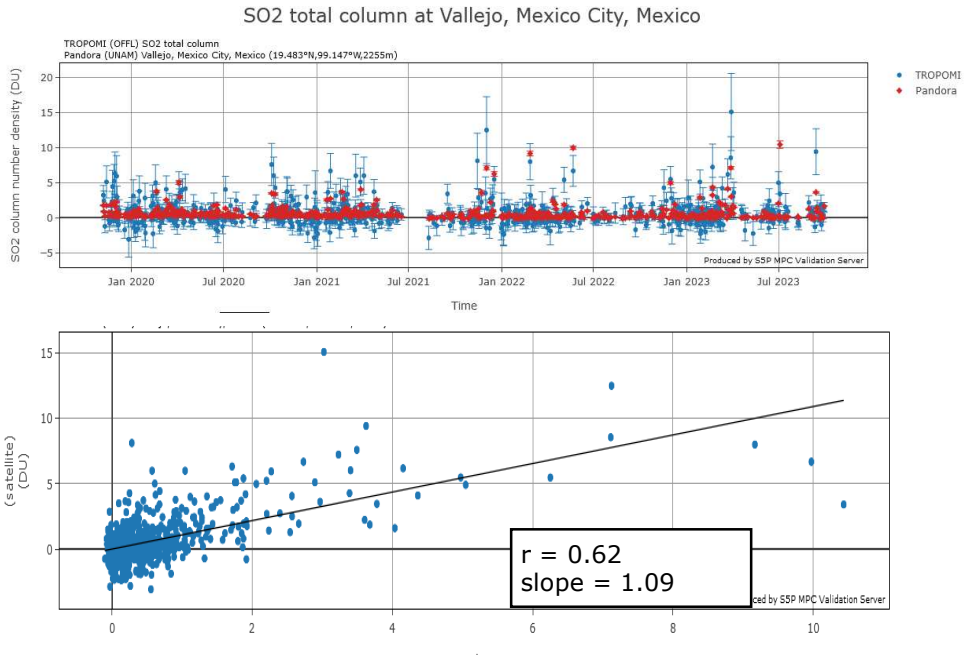
- vs. MAX-DOAS : typical bias 0.2 DU, dispersion 0.2 DU, but larger deviations in winter (NH)
- good qualitative agreement with GOME-2, OMI, OMPS

Highlights & Open issues

- comparisons with ground-based instruments at volcanic sites (e.g., NOVAC) are still needed.



Validation example using routine PGN measurements

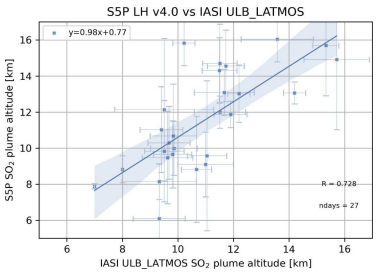


Results from the Sentinel-5P MPC Validation Server

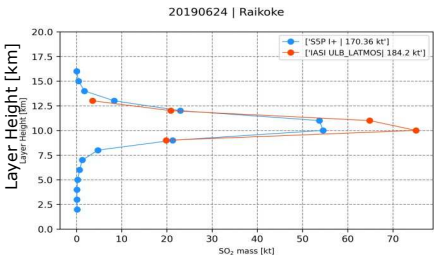
L2_SO2_LH Validation Summary

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

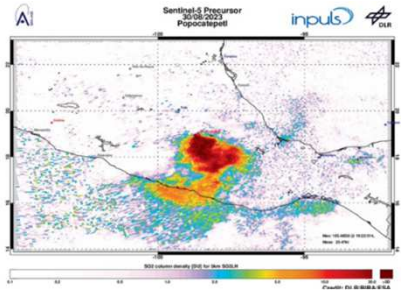
S5P SO2LH vs IASI ULB_LATMOS



Raikoke, 24/06/2019



S5P Popocatepetl, 30/08/2023



Validation activities & results

- This validation activity started in September 2023

Highlights & Open issues

S5P L2 SO_2 LH Validation Tasks:

- The existing end-to-end SO_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:

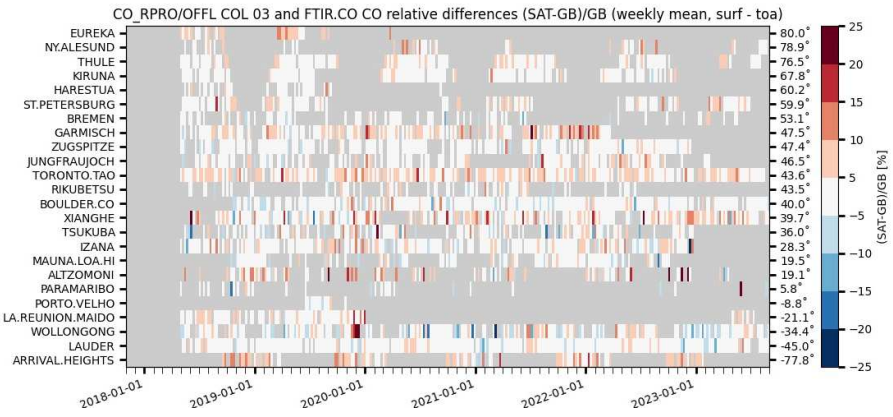
- Direct comparison with respect to the operational IASI SO_2LH product
- Investigation into the possibility of back-trajectory analysis to compensate for spatio-temporal collocation mismatches.
- After development is concluded, all applicable eruptions will be investigated beginning with the September 2023 Popocatepelt, 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

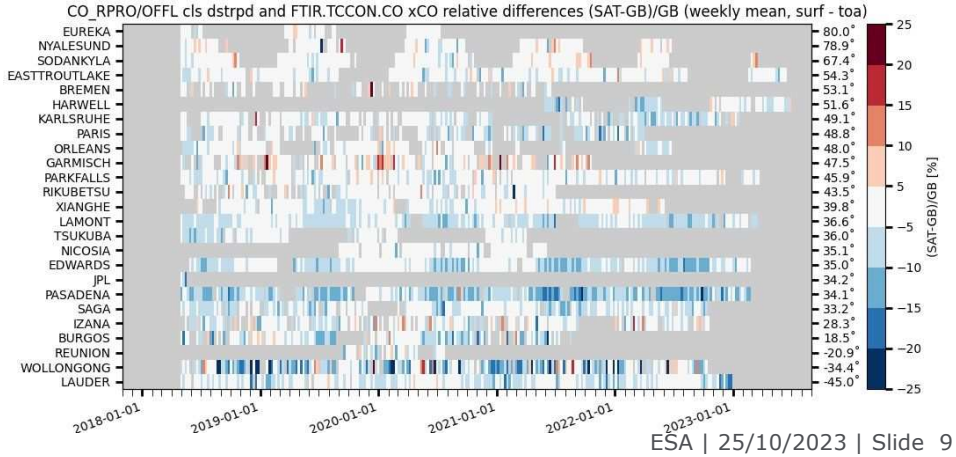
Validation coordinator B. Langerock (BIRA-IASB), Contributor M. K. Sha (BIRA-IASB)

- 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

NDACC



TCCON



L2_CH4 Validation Summary

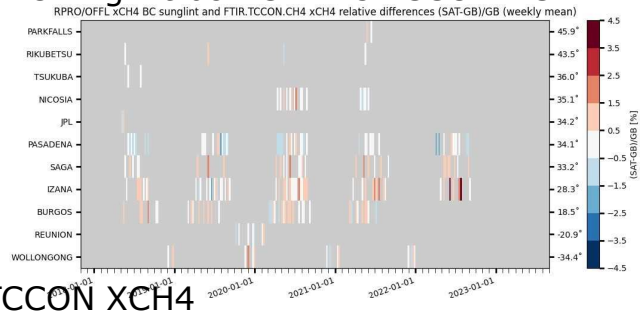
Validation coordinator M. K. Sha (BIRA-IASB), Contributor B. Langerock (BIRA-IASB)

- 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 COCCON

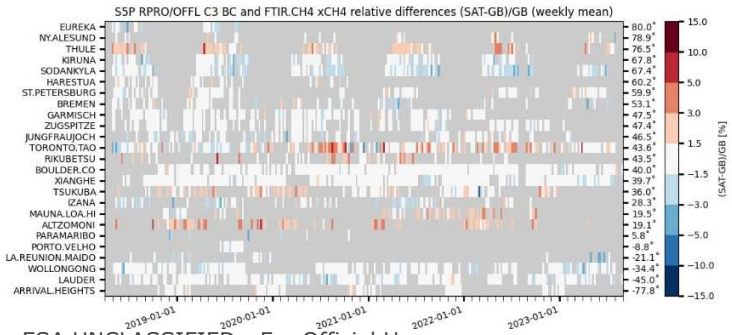
Plans for next updates

- Continuous monitoring of L2 CH4 data,
- update of VAL results using COCCON V2 data

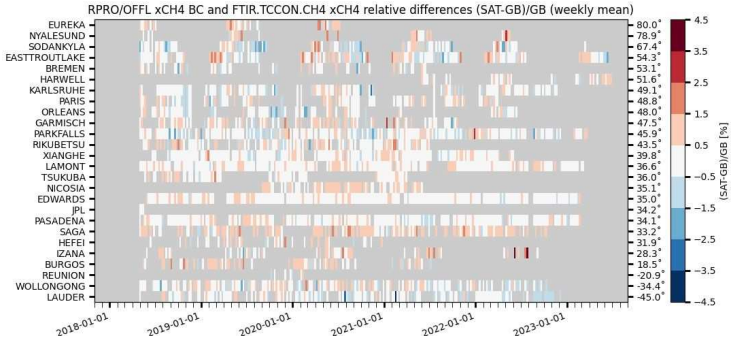
TROPOMI glint bc-XCH4 vs TCCON XCH4



TROPOMI nadir bc-XCH4 vs NDACC XCH4

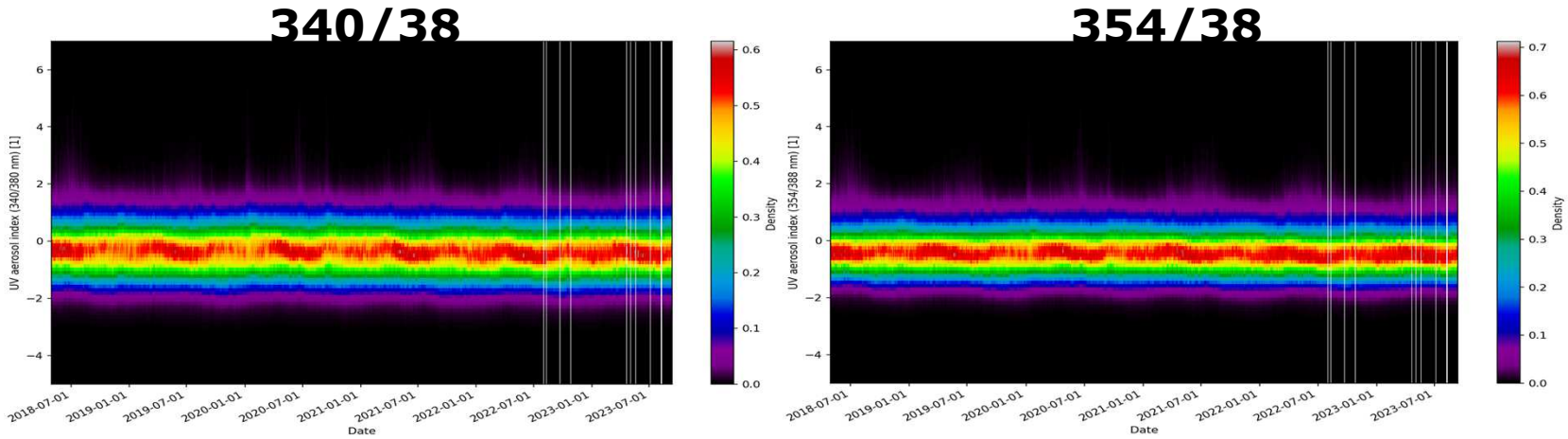


TROPOMI nadir bc-XCH4 vs TCCON XCH4



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

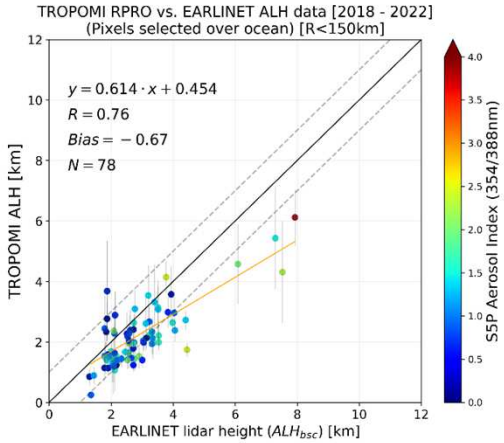
- change of filter (cloud mask) largely increases number of processed pixels
- valuable validation contribution using EARLINET ground-based LIDAR network

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

Validation against ground based EARLINET LIDAR

over ocean



over land