S5P MPC

Sentinel-5p Operational Validation

Status, lessons and perspectives for GEO-AQ and Sentinel-5

Jean-Christopher Lambert

Royal Belgian Institute for Space Aeronomy (BITRA-IASB)

+ many collaborators from:

TROPOMI

Sentinel-5p Operational Validation: The people

- Product Validation Coordinators: 8
- Core team: 24
- Regular contributors: 45

Citation	Quarterly Validation Report of the Copernicus Sentinel-5 Precursor Operational Data Products – #03: July 2018 – May 2019. Lambert, J.-C., A. Keppens, D. Hubert, B. Langerock, K.-U. Eichmann, Q. Kleipool, M. Sneep, T. Verhoelst, T. Wagner, M. Weber, C. Ahn, A. Argyrouli, D. Balis, K.L. Chan, S. Compernolle, I. De Smedt, H. Eskes, A.M. Fjæraa, K. Garane, J.F. Gleason, F. Goutail, J. Granville, P. Hedelt, K.-P. Heue, G. Jaross, ML. Koukouli, J. Landgraf, R. Lutz, S. Niemeijer, A. Pazmiño, G. Pinardi, J.-P. Pommereau, A. Richter, N. Rozemeijer, M.K. Sha, D. Stein Zweers, N. Theys, G. Tilstra, O. Torres, P. Valks, C. Vigouroux, and P. Wang. S5P MPC Routine Operations Consolidated Validation Report series, Issue #03, Version 03.0.1, 126 pp., June 2019.	
Approval Record		
Checked by:	J.-C. Lambert (BIRA-IASB) Q. L. Kleipool (KNMI) D. Loyola (DLR) J. P. Veefkind (KNMI) A. Dehn (ESA)	MPC ESL-VAL Lead MPC ESL-L1 Lead MPC ESL-L2 Lead MPC Technical Manager MPC Project Officer
Approved by:	A. Dehn (ESA)	ESA Data Quality Manager

Cal/Val Organisation for the Sentinels

SENTINEL VALIDATION TEAM : *The validation team complete the MPC activities by providing independent validation measurements or independent analysis. The team members are selected through an open call process. The intention of this call is to create scientific validation teams to provide structured coordination of international activities that contribute to Sentinel validation across the entire mission (i.e. Phase E1 and E2).*

The Mission Performance Center

*The Mission Performance Center is in charge of the **operational** and **overall validation** providing the synthesis of the results.*

MPC S1, MPC S2, MPC S3, MPC S5P have been set up.

Quality Working Group QWG | ***ESA Data Quality Manager***

*The information is then discussed, further processed in the **Quality Working Groups** which provide synthetic results to the **Mission Managers**, used for improving the products quality and the products knowledge.*

ESA Validation Data Centre

The Sentinel Validation Teams (SVT):

The validation team complete the MPC activities by providing independent validation measurements or independent analysis.

S2VT, S3VT, S5PVT have been set up.

Fiducial Reference Measurements providers

*Specific activities need to be put in place for providing mandatory FRMs (e.g. for **atmospheric FRMs**: PANDONIA/PGN, FRM4DOAS, FRM4GHG)*

User Community and international forum:

The validation program benefits from the feedback from:

- *Workshops/conferences (ESA or international)*
- *Bilateral relation (NASA, NOAA, CNES, DLR, UKSA, JRC, EUMETSAT etc.)*
- *Coordination within **CEOS WGCV** and **CEOS VCs***

S5P Mission Performance Centre (MPC)

Funding: EC/ESA + national NL/NSO, D/DLR, BE/BELSPO

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and th Environment

DLR

SRON Netherlands Institute for Space Research

iup

aeronomie.be

MAX-PLANCK-GESELLSCHAFT

NILU Norsk institutt for luftforskning Norwegian Institute for Air Research

s[&]t

RAL Space

Objectives + Responsibilities

Routine Quality Control
Level 1 and Level 2

Long-Term Monitoring
TROPOMI instrument sensor and ageing

In-flight calibration
TROPOMI instrument on-board S5P – meet product quality requirements

Geophysical Validation of Products
Using external and independent data sets on a routine basis

Maintenance and evolution
Manage the updates of:
- Calibration algorithms and tools
- L1 and L2 Processor algorithms
- Quality control tools
- Validation algorithms

Communication
S5P/TROPOMI status and products

Sentinel-5p Routine Operations Validation Service

S5P Mission Performance Centre (MPC) to provide service-based solution for Routine Operations validation:

- **Automated**, **routine** comparison of S5P data vs. FRMs
- **S5P validation database** for in-depth MPC studies
- Automated generation of **quick-look comparison reports**

Machine based
⇨ VDAF AVS

- **Monitoring of** S5P products **health**
- Public and MPC **quality information** on S5P products
- Support to L1/L2 **algorithm evolution**
- Synthesis with **S5PVT** results, **ECMWF/CAMS**, literature…

Expertise based
⇨ MPC VAL Team

Validation Data Streams into VDAF

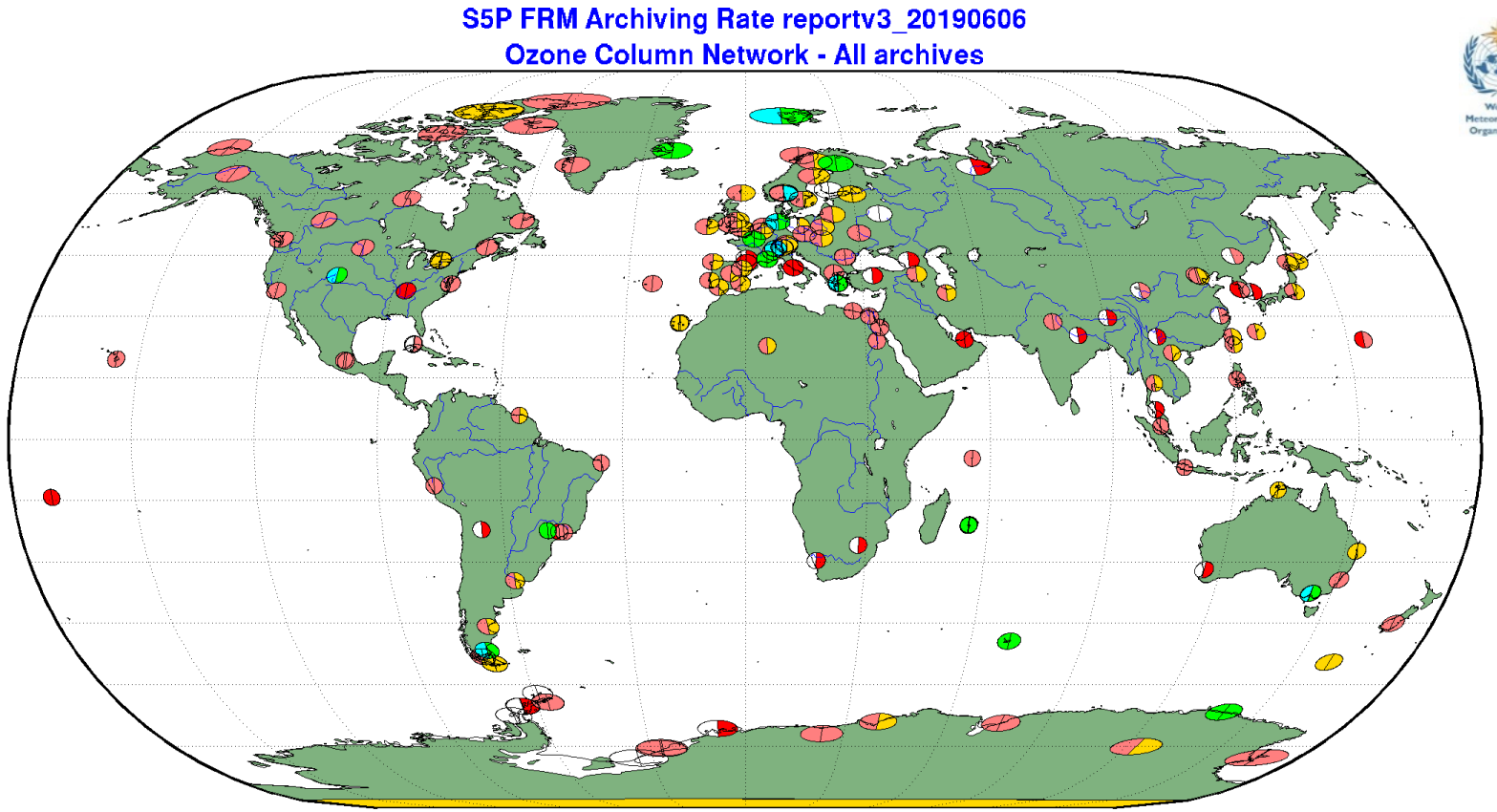
ESA FRM programme + WMO GAW contributing networks

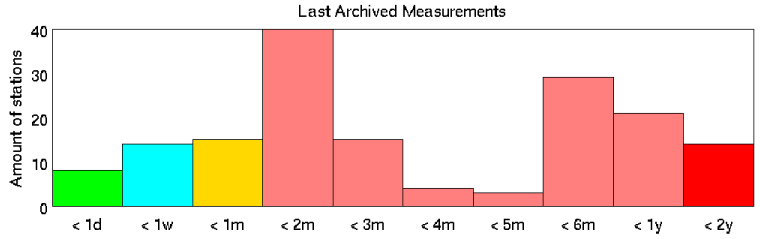
S5P ID	S5P Data Product	Fiducial / Validation Reference Measurements
L2_O3	O_3 total column	**Brewer**, **Dobson**, **ZSL-DOAS**, MAX-DOAS, Pandonia
L2_O3_PR	O_3 profile (incl. troposphere)	ozonesonde, stratospheric DIAL, tropospheric DIAL
L2_O3_TCL	O_3 tropospheric column	ozonesonde
L2_NO2	NO_2 stratospheric column	**ZSL-DOAS**
	NO_2 tropospheric column	MAX-DOAS
	NO_2 total column	**Pandonia**
L2_SO2	SO_2 total column	MAX-DOAS, Pandonia
L2_HCHO	HCHO total column	MAX-DOAS, Pandonia
L2_CO	CO total column	TCCON FTIR (NIR), **NDACC FTIR (MIR)**
L2_CH4	CH_4 total column	TCCON FTIR (NIR), **NDACC FTIR (MIR)**
L2_CLOUD	Cloud Fraction	*not available*
	Cloud Height (pressure)	**Cloudnet lidar/radar**
	Cloud Optical Thickness	*not available*
L2_AER	UV Aerosol Absorbing Index	*not available*
	Aerosol Layer Height	EARLINET aerosol lidar, EUMETNET/ALC ceilometer

Colour code: **automated, full stream** automated, partial stream ready/manual not ready

Status of FRM / Validation Data Streams

O3 column data from LATMOS_RT (ZSL-DOAS/SAOZ), NDACC DHF (ZSL-DOAS) and WMO/GAW WOUDC (Brewer, Dobson, ZSL-DOAS) collected via CORR-2/Multi-TASTE (BIRA-IASB) and EVDC (NILU)

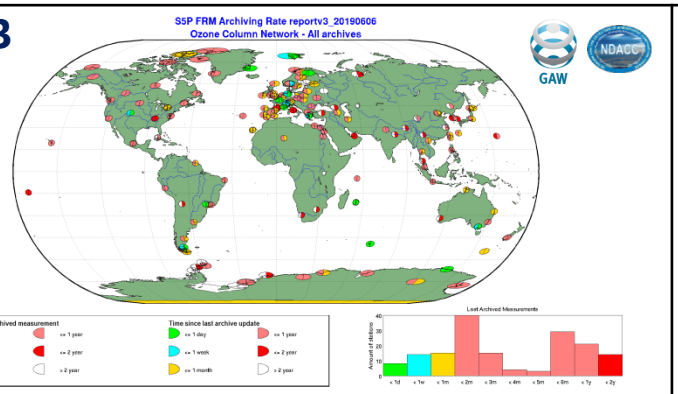




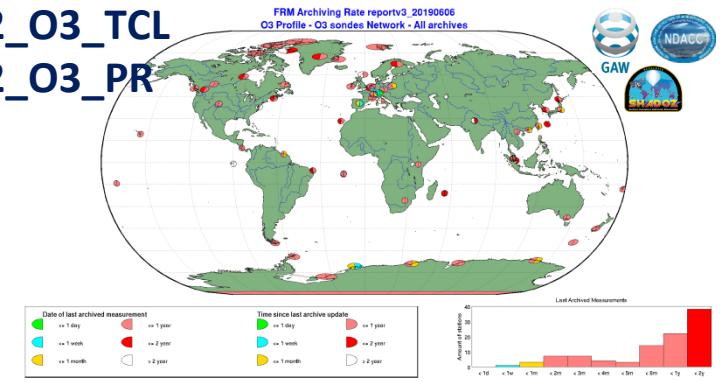
Status of FRM and other Validation Data Streams

from NDACC, PGN, SHADOZ, TCCON and WOUDC collected via CORR-2 (BIRA-IASB) and EVDC (ESA/NILU)

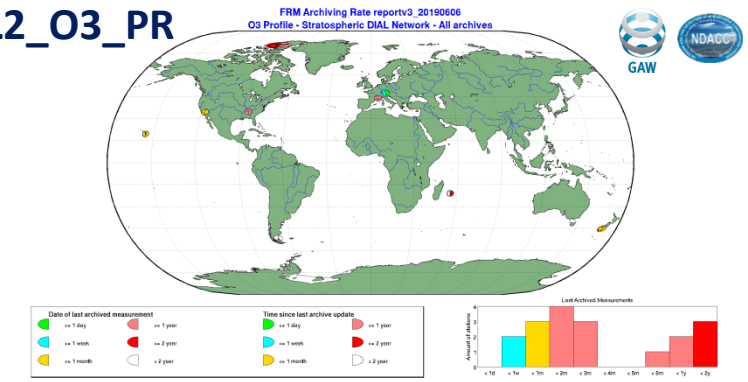
L2_O3



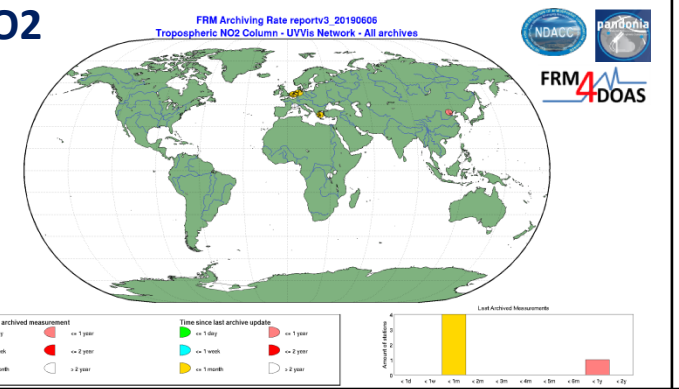
L2_O3_TCL
L2_O3_PR



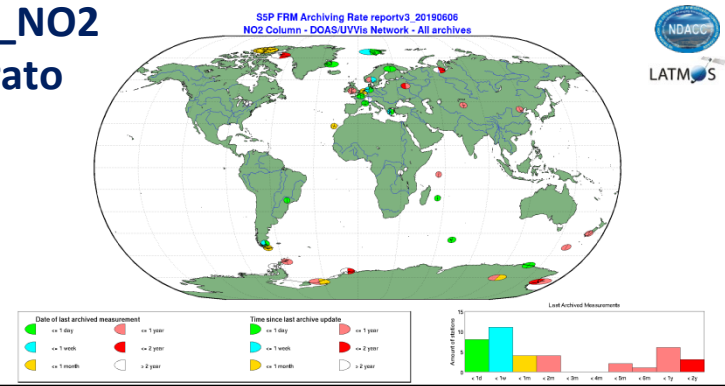
L2_O3_PR



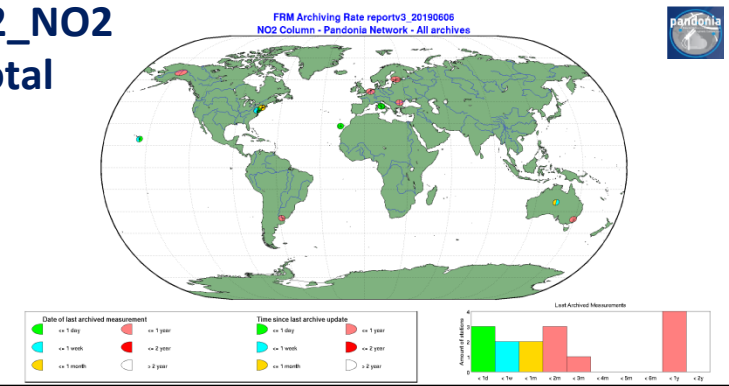
L2_NO2 tropo



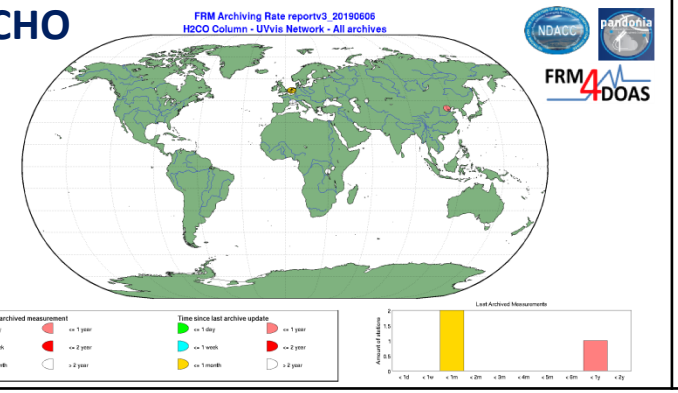
L2_NO2 strato



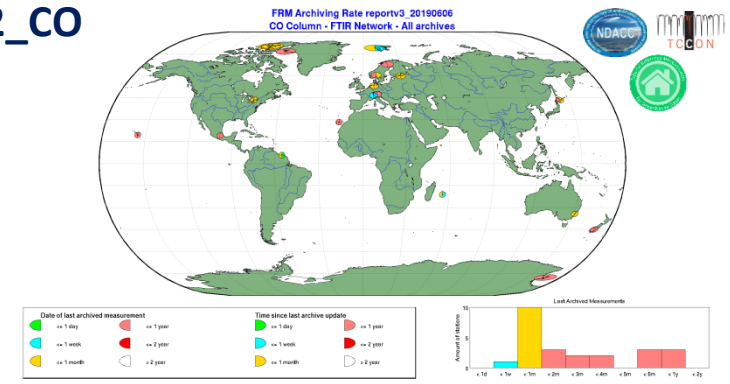
L2_NO2 total



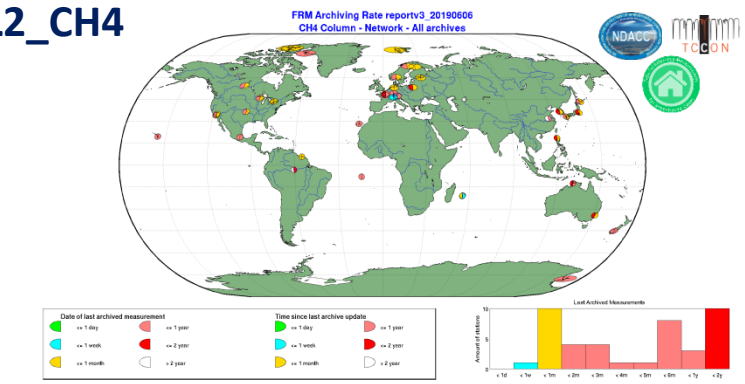
L2_HCHO



L2_CO



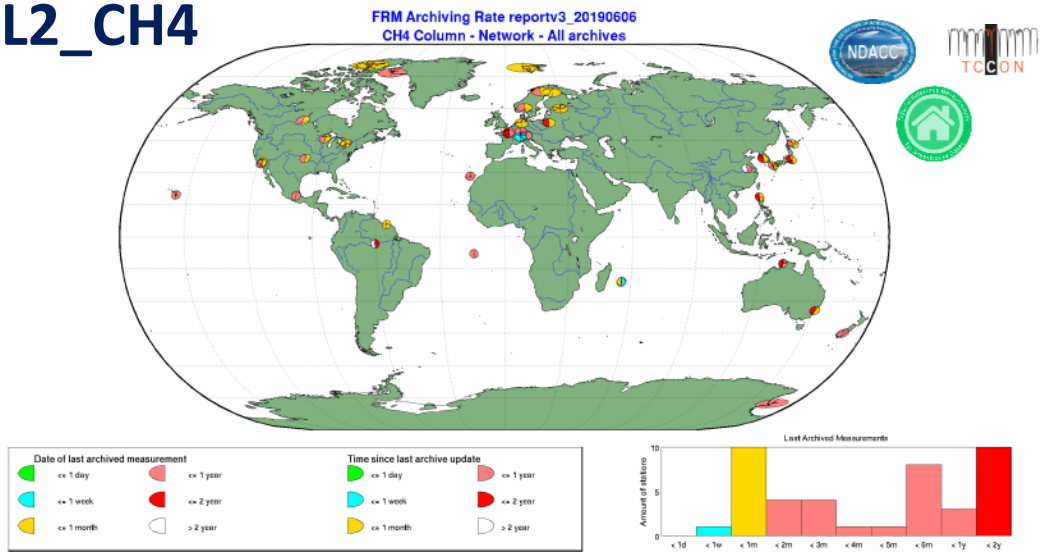
L2_CH4

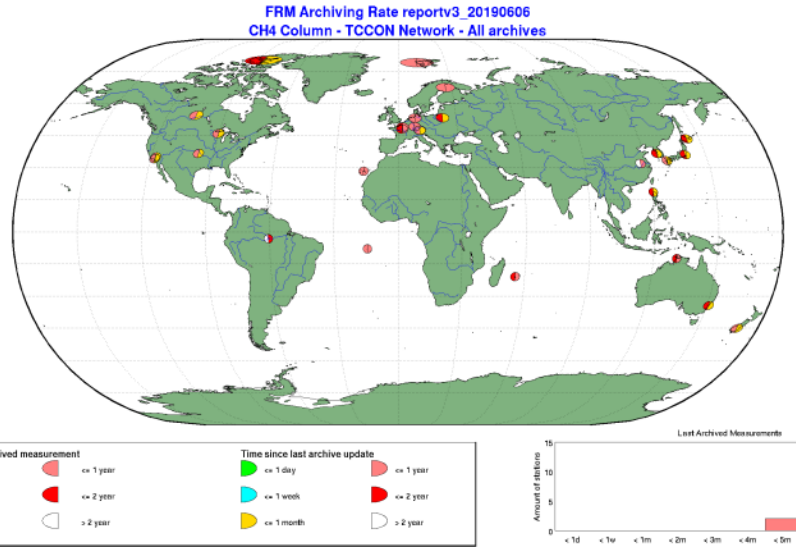


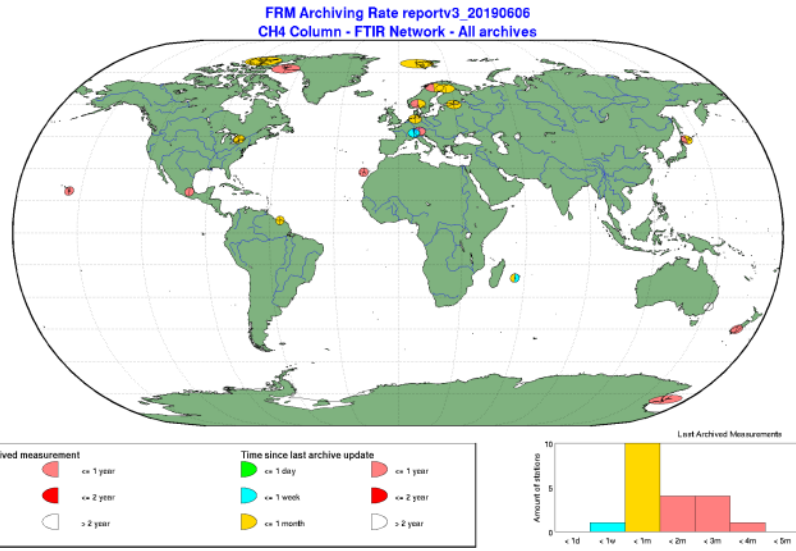
Details of CH_4 Validation Data Streams

from NDACC DHF and TCCON via CORR-2 (BIRA-IASB) and EVDC (ESA/NILU)

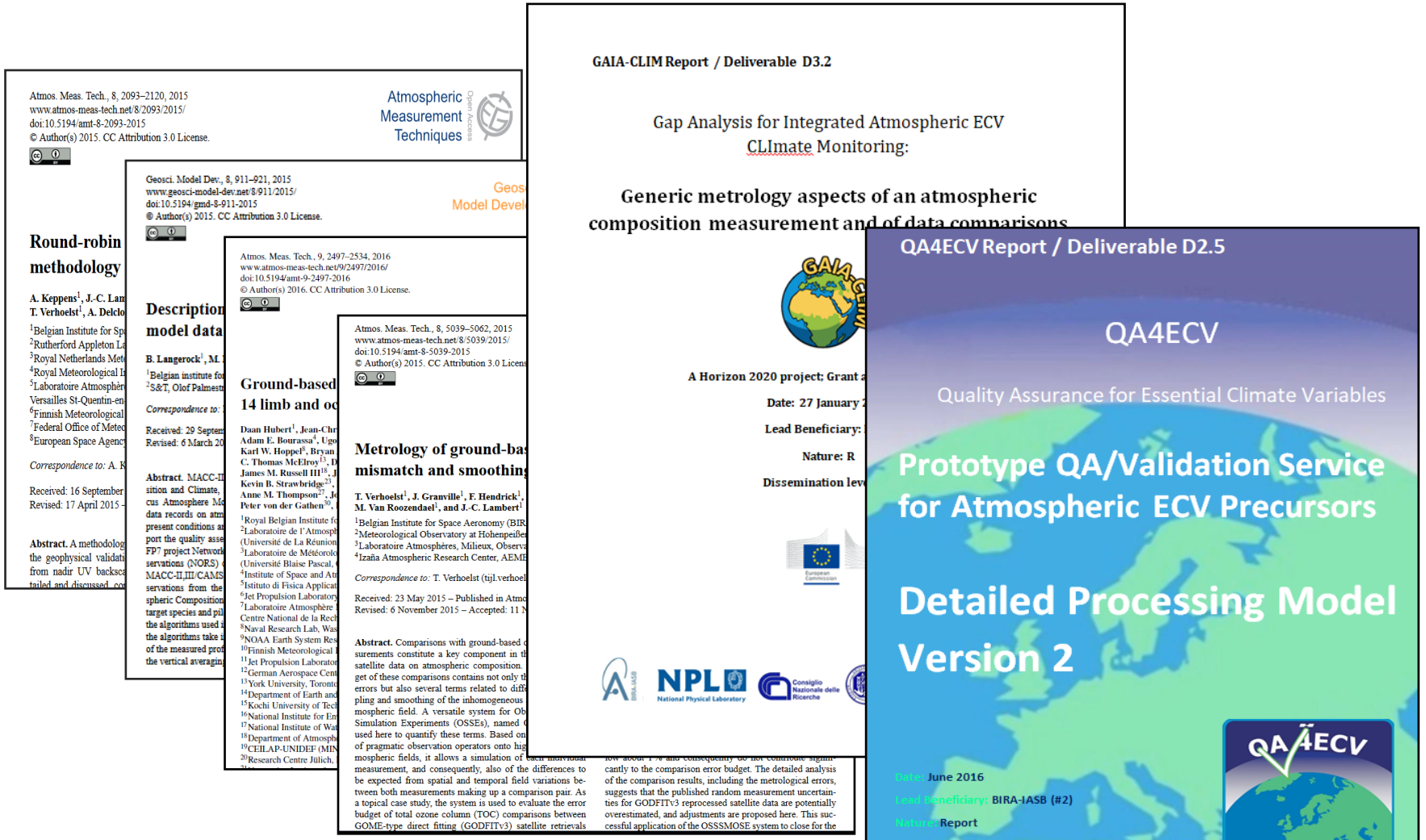
L2_CH4







Generic validation chain, state-of-the-art co-locators, harmonized terminology, agreed metrics…



WGCV-28/…/31

Cross GEOSS EO Cal/Val Harmonization

Prototyping in ESA Multi-TASTE and CCI_Ozone

ACC-8/…/11

Community feedback / endorsement

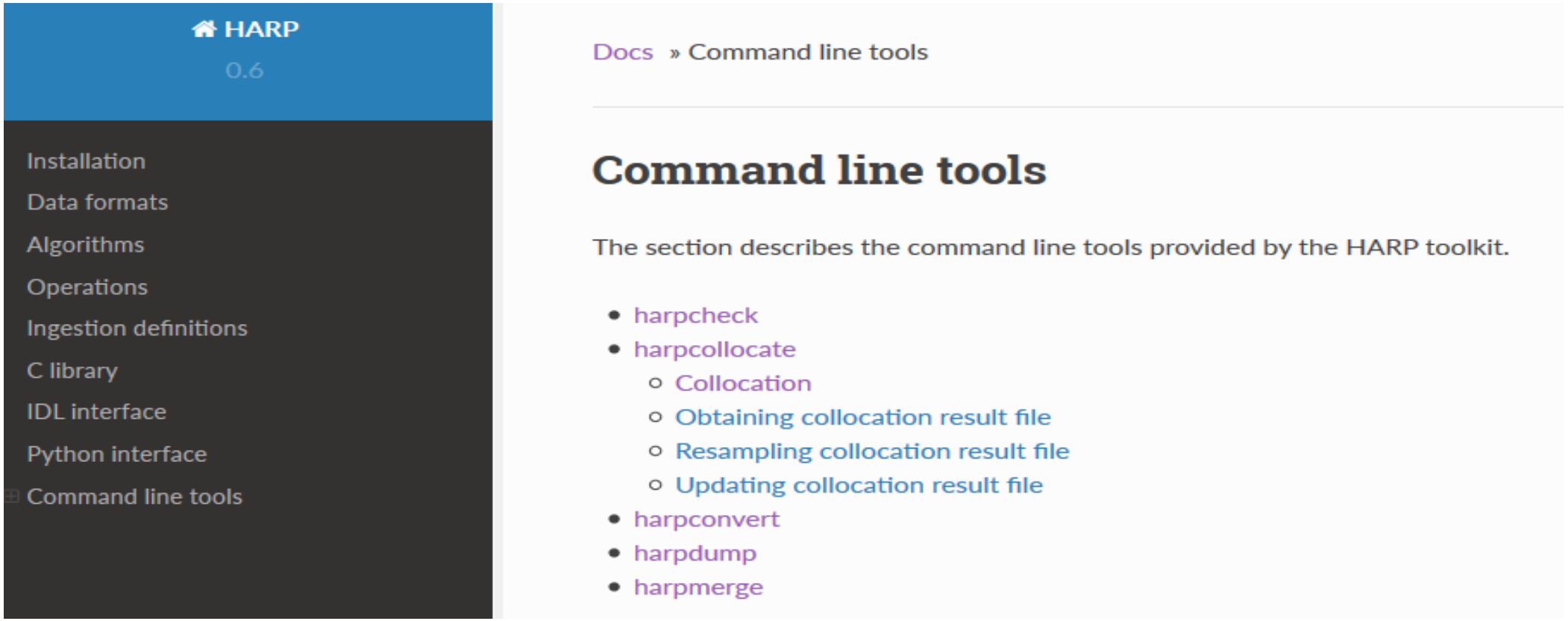
Implemention in FP7 QA4ECV-AVS, H2020 GAIA-CLIM, C3S_312#ozone, S5P MPC VDAF, CAMS-NDACC, CCI+

Data Handling, Co-location and Comparison Toolset

HARP

BASIC ENVISAT ATMOSPHERIC TOOLBOX

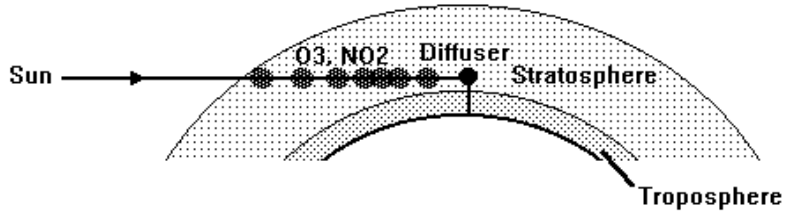
harp documentation https://cdn.rawgit.com/stcorp/harp/master/doc/html/index.html



s[&]t

S5P Data Streams into MPC VDAF

- Overpass data extractor in S5P PDGS
- Based on 3D Observation Operators
- Correction for NO_2 diurnal cycle
- Optimization of data volumes



T. Verhoelst et al.: Co-location mismatch and smoothing issues of total ozone data comparisons AMT 2015

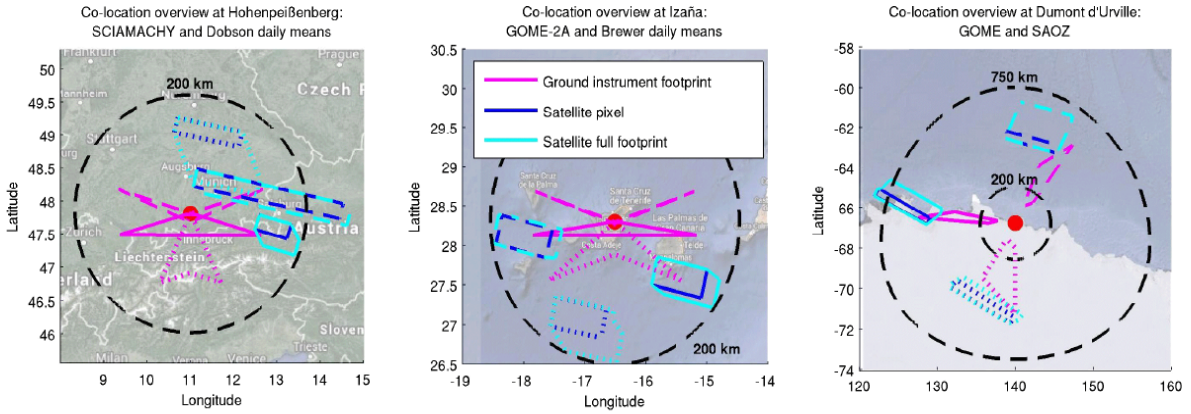
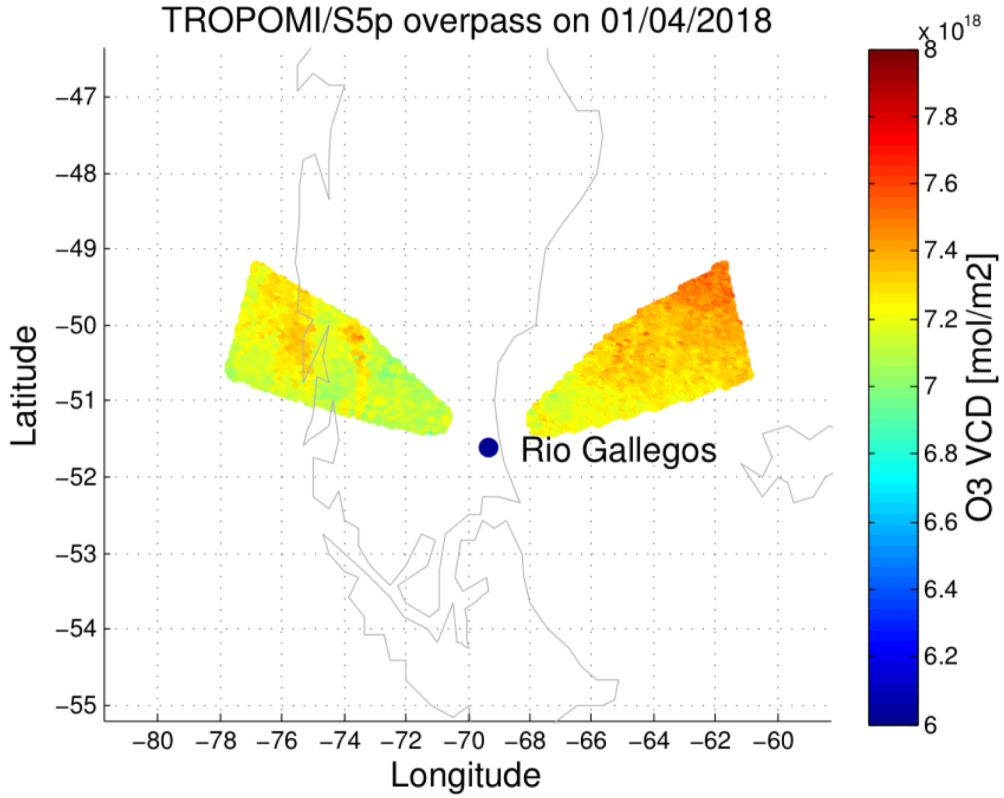
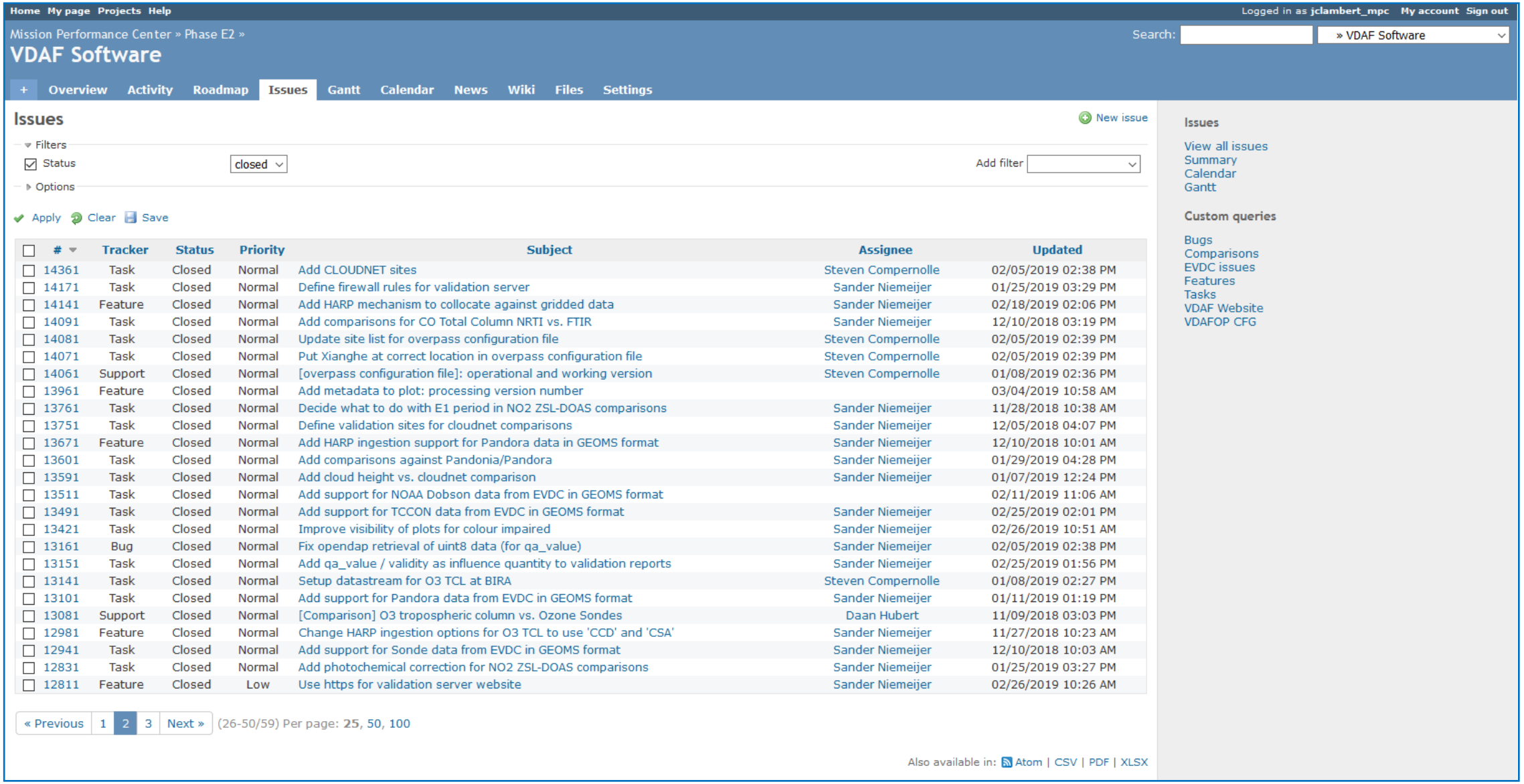


Figure 4. Co-located ground-satellite measurement pairs near summer and winter solstice (dashed and dotted lines, respectively) and near the autumn and spring equinox (solid line). The station is indicated by a red dot, the ground observation operators in magenta, the satellite pixel in dark blue and the full satellite observation operator in cyan.



The (long) way from Scientific Systems to an Operational Facility…



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VDAF Software

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Issues

New issue

Filters

Status closed — Add filter

Options

Apply Clear Save

#	Tracker	Status	Priority	Subject	Assignee	Updated
14361	Task	Closed	Normal	Add CLOUDNET sites	Steven Compernolle	02/05/2019 02:38 PM
14171	Task	Closed	Normal	Define firewall rules for validation server	Sander Niemeijer	01/25/2019 03:29 PM
14141	Feature	Closed	Normal	Add HARP mechanism to collocate against gridded data	Sander Niemeijer	02/18/2019 02:06 PM
14091	Task	Closed	Normal	Add comparisons for CO Total Column NRTI vs. FTIR	Sander Niemeijer	12/10/2018 03:19 PM
14081	Task	Closed	Normal	Update site list for overpass configuration file	Steven Compernolle	02/05/2019 02:39 PM
14071	Task	Closed	Normal	Put Xianghe at correct location in overpass configuration file	Steven Compernolle	02/05/2019 02:39 PM
14061	Support	Closed	Normal	[overpass configuration file]: operational and working version	Steven Compernolle	01/08/2019 02:36 PM
13961	Feature	Closed	Normal	Add metadata to plot: processing version number		03/04/2019 10:58 AM
13761	Task	Closed	Normal	Decide what to do with E1 period in NO2 ZSL-DOAS comparisons	Sander Niemeijer	11/28/2018 10:38 AM
13751	Task	Closed	Normal	Define validation sites for cloudnet comparisons	Sander Niemeijer	12/05/2018 04:07 PM
13671	Feature	Closed	Normal	Add HARP ingestion support for Pandora data in GEOMS format	Sander Niemeijer	12/10/2018 10:01 AM
13601	Task	Closed	Normal	Add comparisons against Pandonia/Pandora	Sander Niemeijer	01/29/2019 04:28 PM
13591	Task	Closed	Normal	Add cloud height vs. cloudnet comparison	Sander Niemeijer	01/07/2019 12:24 PM
13511	Task	Closed	Normal	Add support for NOAA Dobson data from EVDC in GEOMS format		02/11/2019 11:06 AM
13491	Task	Closed	Normal	Add support for TCCON data from EVDC in GEOMS format	Sander Niemeijer	02/25/2019 02:01 PM
13421	Task	Closed	Normal	Improve visibility of plots for colour impaired	Sander Niemeijer	02/26/2019 10:51 AM
13161	Bug	Closed	Normal	Fix opendap retrieval of uint8 data (for qa_value)	Sander Niemeijer	02/05/2019 02:38 PM
13151	Task	Closed	Normal	Add qa_value / validity as influence quantity to validation reports	Sander Niemeijer	02/25/2019 01:56 PM
13141	Task	Closed	Normal	Setup datastream for O3 TCL at BIRA	Steven Compernolle	01/08/2019 02:27 PM
13101	Task	Closed	Normal	Add support for Pandora data from EVDC in GEOMS format	Sander Niemeijer	01/11/2019 01:19 PM
13081	Support	Closed	Normal	[Comparison] O3 tropospheric column vs. Ozone Sondes	Daan Hubert	11/09/2018 03:03 PM
12981	Feature	Closed	Normal	Change HARP ingestion options for O3 TCL to use 'CCD' and 'CSA'	Sander Niemeijer	11/27/2018 10:23 AM
12941	Task	Closed	Normal	Add support for Sonde data from EVDC in GEOMS format	Sander Niemeijer	12/10/2018 10:03 AM
12831	Task	Closed	Normal	Add photochemical correction for NO2 ZSL-DOAS comparisons	Sander Niemeijer	01/25/2019 03:27 PM
12811	Feature	Closed	Low	Use https for validation server website	Sander Niemeijer	02/26/2019 10:26 AM

« Previous 1 2 3 Next » (26-50/59) Per page: 25, 50, 100

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Validations a

L2__CH4

L2__CLC

Sentinel-

TROPOMI

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Reference datas

This validation is available

Bauru (latmos_rt)

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S5P Validation Server

https://mpc-vdaf-server.tropomi.eu/no2

Sentinel-5P MPC Validation Server

TROPOMI

Home / L2__NO2___ (NO2) / NO2 stratospheric column OFFL vs ZSL-DOAS (sunset) / Kerguelen (latmos_rt)

NO_2 stratospheric column | SAOZ (LATMOS-RT) at Kerguelen Islan

Baseline | Diurnal corrected | Properties

Comparison

Preliminary and unverified validation results, please visit the main S5P MPC validation websit

NO2 stratospheric column at K

Settings

Y-axis variable

NO2 - difference (SAT-REF)

X-axis variable

solar zenith angle (satellite)

surface albedo (satellite)

solar zenith angle (satellite)

solar azimuth angle (satellite)

sensor zenith angle (satellite)

sensor azimuth angle (satellite)

.300°E,10m)

Produced by S5P MPC Validation Server

ep 2018 | Nov 2018 | Jan 2019 | Mar 2019 | May 2019

Time

		SAOZ (LATMOS-RT)
		3.0121 Pmolec cm-2
		0.047590 Pmolec cm-2
Std. dev.	0.77937 Pmolec/cm2	0.70908 Pmolec cm-2

Baseline | Diurnal corrected | Properties

Properties

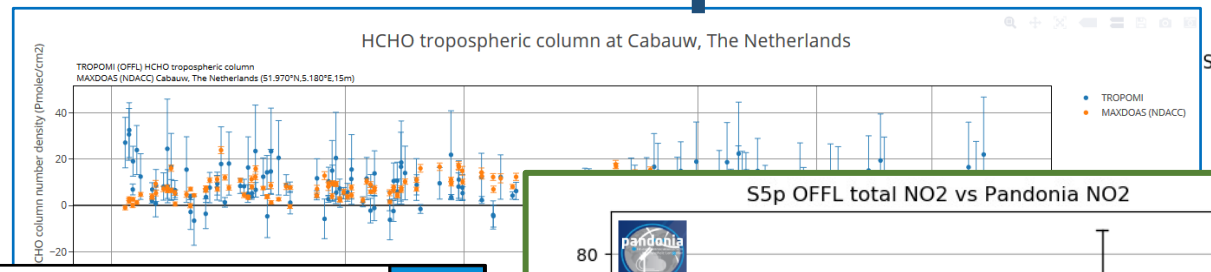
Processing traceability

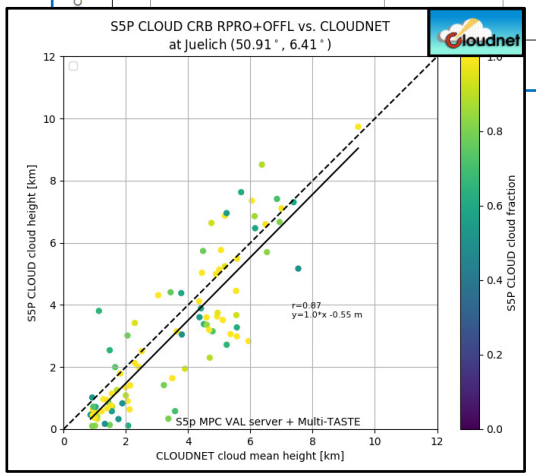
satellite product selection	((product_type == "S5P_L2VONO2_OFFL" and s5p.processor_version>=10200) or (product_type == "S5P_L2VONO2_RPRO" and s5p.processor_version==10202)) and s5p.orbit >= 2818 and location.name == "kerguelen_sunset"	
reference product selection	product_type == "harp_corr2_no2_saoz_latmos_rt" and validity_stop > 2018-04-30 and location.name == "corr2_kerguelen"	
collocation criteria	point-in-area-xy	true
	datetime	12 [h]
satellite pre-collocation	tropospheric_NO2_column_number_density_validity > 75	

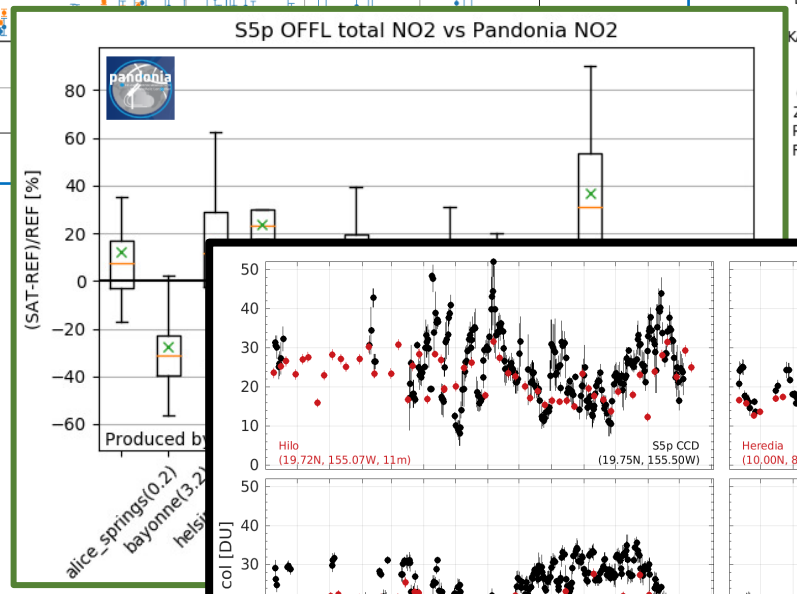
To ensure traceability, the set of data manipulations (selection, filtering, co-location, harmonization, etc.) applied to S5P and FRM data before they are compared, is provided here in yaml format:

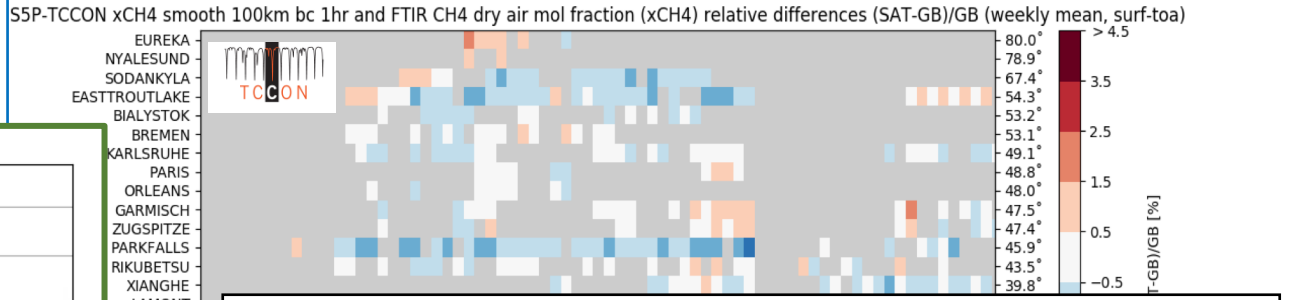
- comparison

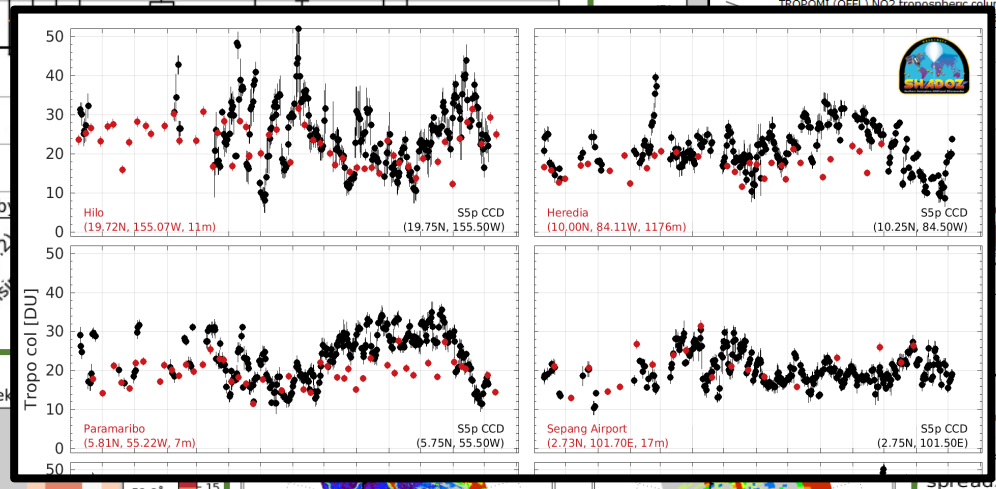
S5P Routine Operations Validation Analysis

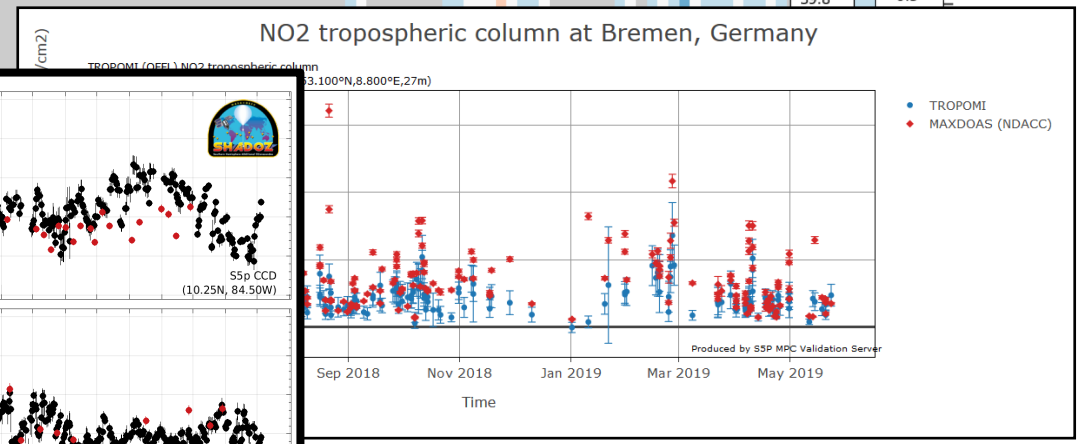


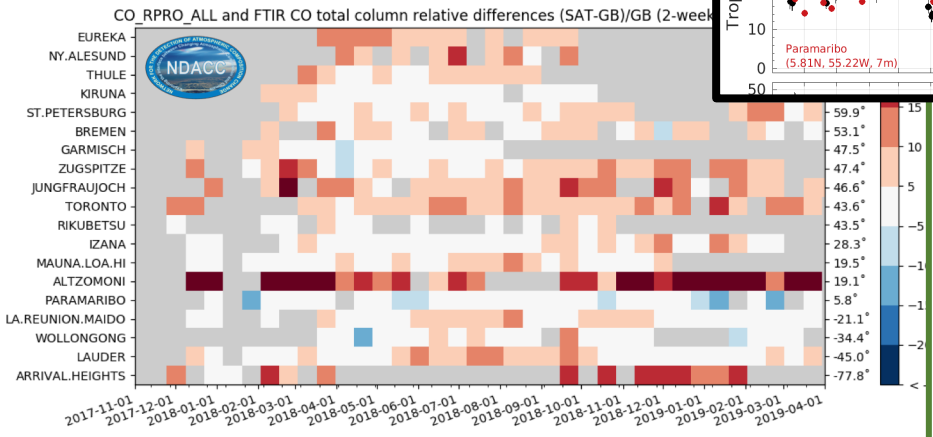


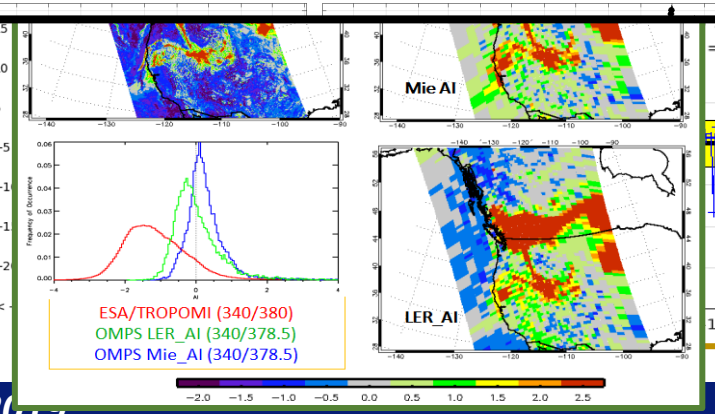


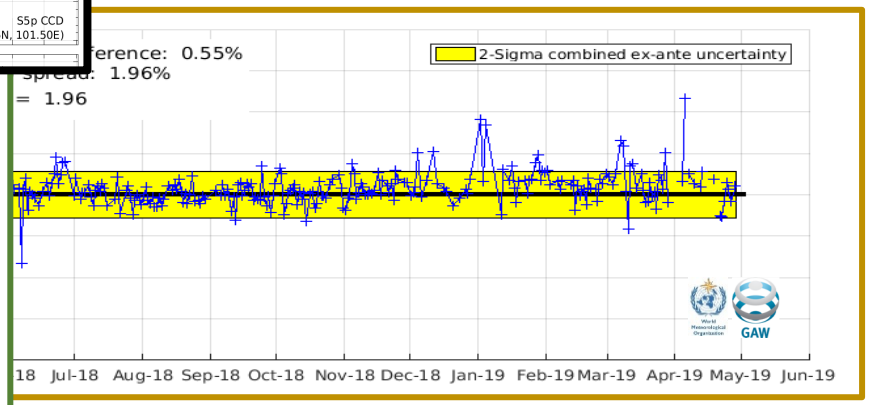




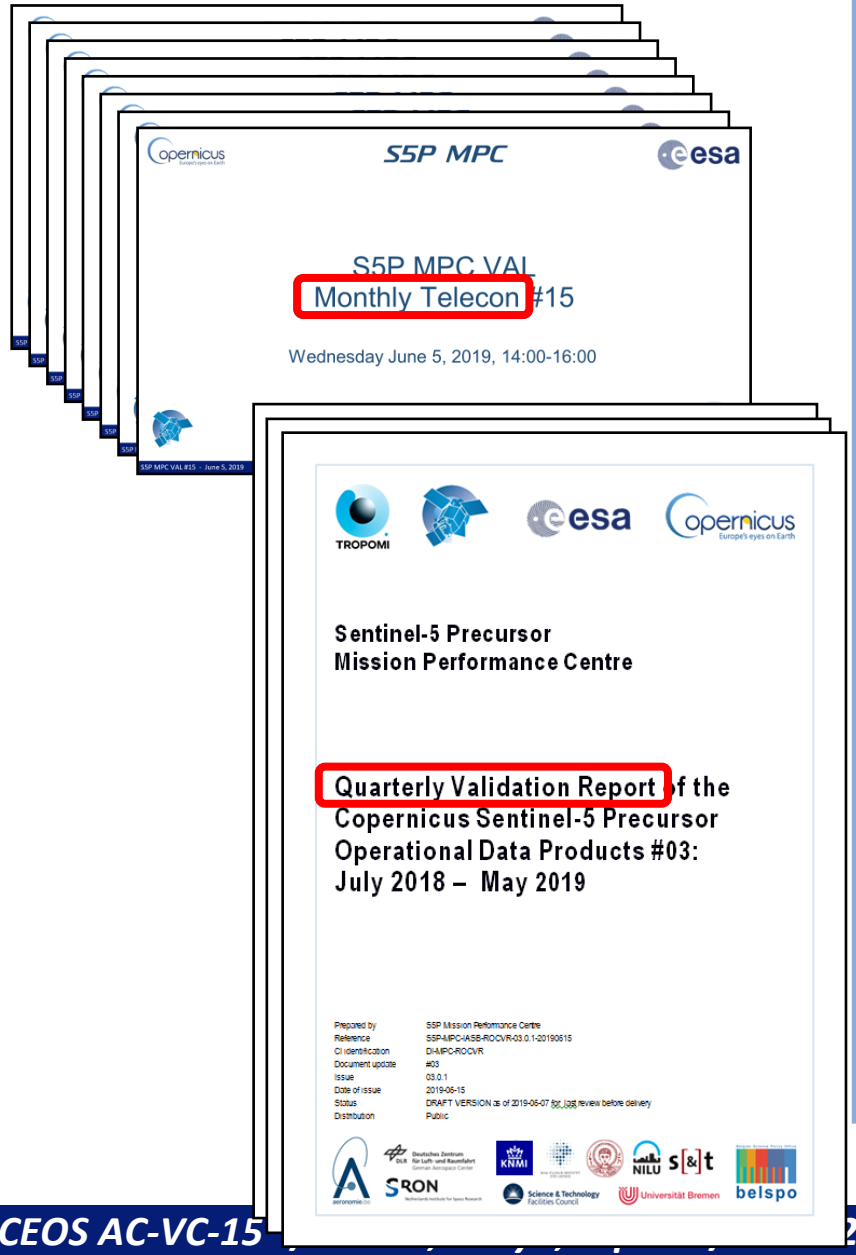


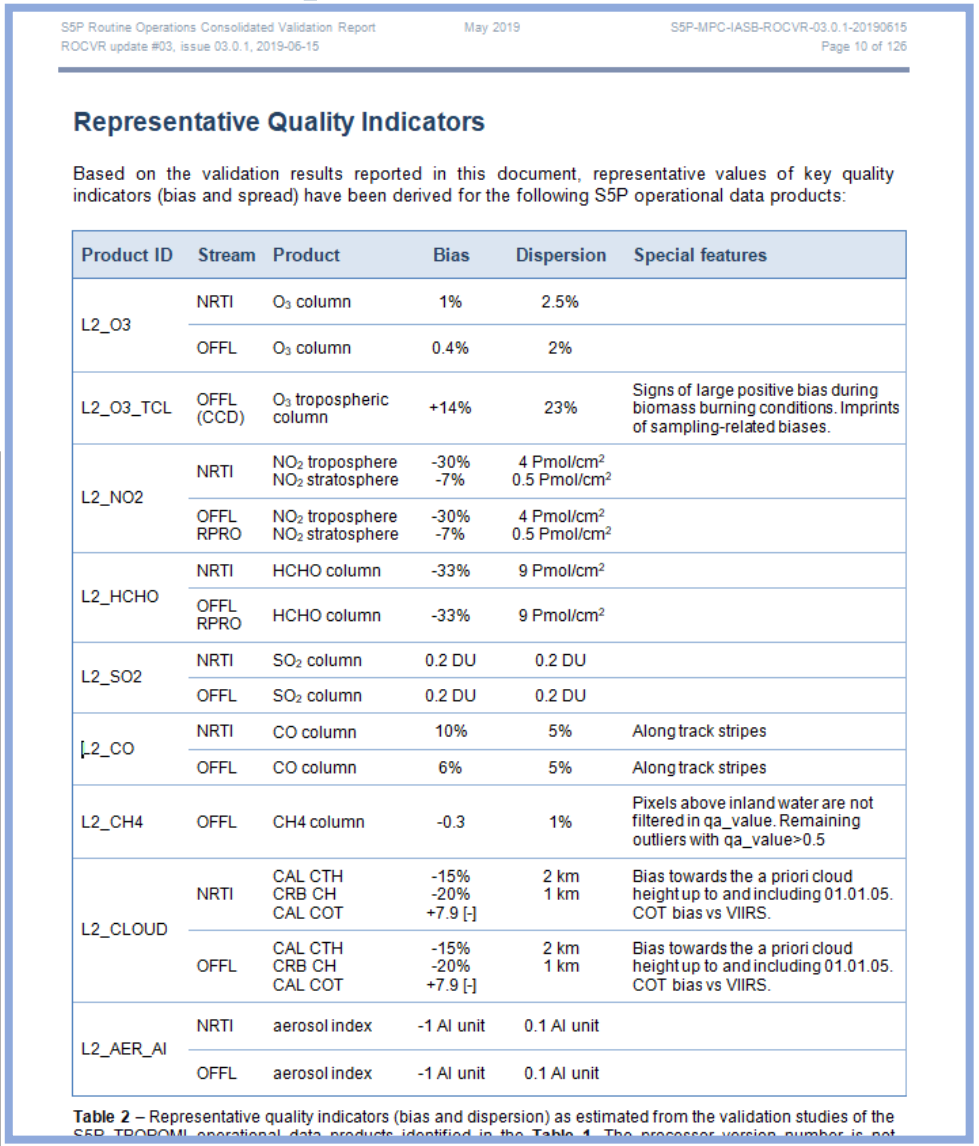






Public and Internal Outputs





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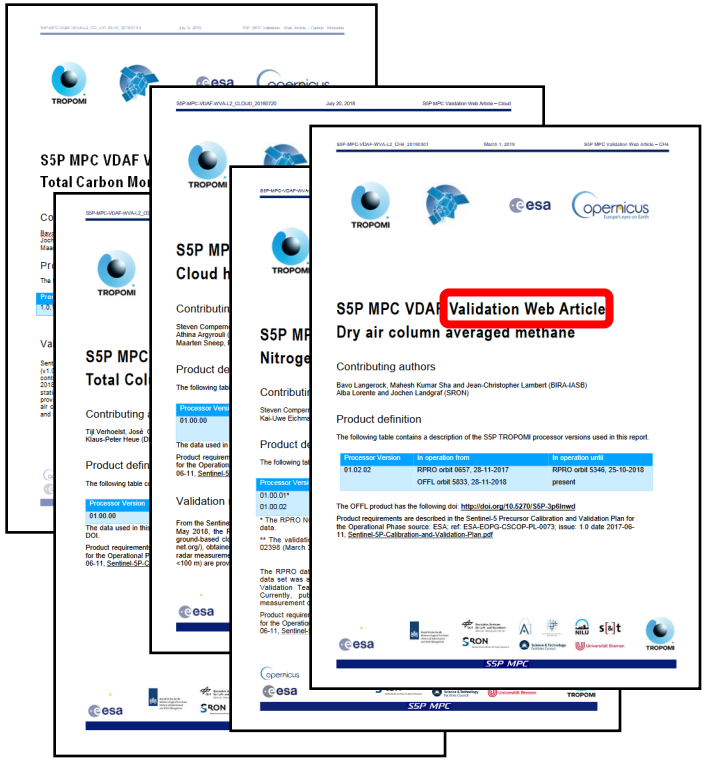
Representative Quality Indicators

Based on the validation results reported in this document, representative values of key quality indicators (bias and spread) have been derived for the following S5P operational data products:

Product ID	Stream	Product	Bias	Dispersion	Special features
L2_O3	NRTI	O_3 column	1%	2.5%	
	OFFL	O_3 column	0.4%	2%	
L2_O3_TCL	OFFL (CCD)	O_3 tropospheric column	+14%	23%	Signs of large positive bias during biomass burning conditions. Imprints of sampling-related biases.
L2_NO2	NRTI	NO_2 troposphere NO_2 stratosphere	-30% -7%	4 Pmol/cm^2 0.5 Pmol/cm^2	
	OFFL RPRO	NO_2 troposphere NO_2 stratosphere	-30% -7%	4 Pmol/cm^2 0.5 Pmol/cm^2	
L2_HCHO	NRTI	HCHO column	-33%	9 Pmol/cm^2	
	OFFL RPRO	HCHO column	-33%	9 Pmol/cm^2	
L2_SO2	NRTI	SO_2 column	0.2 DU	0.2 DU	
	OFFL	SO_2 column	0.2 DU	0.2 DU	
L2_CO	NRTI	CO column	10%	5%	Along track stripes
	OFFL	CO column	6%	5%	Along track stripes
L2_CH4	OFFL	CH4 column	-0.3	1%	Pixels above inland water are not filtered in qa_value. Remaining outliers with qa_value>0.5
L2_CLOUD	NRTI	CAL CTH CRB CH CAL COT	-15% -20% +7.9 [-]	2 km 1 km	Bias towards the a priori cloud height up to and including 01.01.05. COT bias vs VIIRS.
	OFFL	CAL CTH CRB CH CAL COT	-15% -20% +7.9 [-]	2 km 1 km	Bias towards the a priori cloud height up to and including 01.01.05. COT bias vs VIIRS.
L2_AER_AI	NRTI	aerosol index	-1 AI unit	0.1 AI unit	
	OFFL	aerosol index	-1 AI unit	0.1 AI unit	

Table 2 – Representative quality indicators (bias and dispersion) as estimated from the validation studies of the S5P TROPOMI operational data products identified in the Table 1. The processor version number is not



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Search engine to browse results by processor versions, networks etc.

To the Automated Validation Server

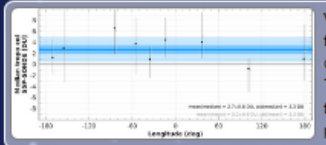
VALIDATION FACILITY

SENTINEL 5P MISSION PERFORMANCE CENTER

Ozone · O3 profile · Nitrogen dioxide · Sulfur Dioxide · Formaldehyde · Surface UV-B · Aerosols · Carbon Monoxide · Methane · Cloud

Results and resources by product

Most recent contributions



Validation against SHADOZ ozonesonde data confirms that the TROPOMI/S5p OFFL tropospheric O3 (L2_O3_TCL) data product meets mission requirements.
This web article summarizes the results of the validation of the first year of S5P OFFL tropospheric ozone column data products (v01.01.05, v01.01.06 and v01.01.07) against co-

First comparison results for the S5P CH4 product based on correlative reference measurements acquired by FTIR instruments contributing to NDACC and TCCON networks.

First validation results for Sentinel-5p NO2 column data.
This report describes initial validation results for Sentinel-5p TROPOMI L2_NO2 tropospheric column, stratospheric

A first validation against NDACC and WOUDC ground-based data confirms that the TROPOMI/S5p NRTI total O3 (L2_O3) product meets mission requirements. Initial Sentinel-5p TROPOMI

Preliminary comparison of TROPOMI/S5p RPRO CLOUD CAL cloud top height and CRB cloud height against ground-based CLOUDNET data.

First comparison results for the S5P CO product based on correlative reference measurements acquired by FTIR instruments contributing to NDACC and TCCON networks.

ROCVR Reports

Quarterly Validation Report of the Sentinel-5 Precursor Operational Data

Quarterly Validation Report of the Sentinel-5 Precursor Operational Data

Quarterly Routine Validation Reports

Validation Web Articles produced by S5P MPC in collaboration with S5PVT AO projects

TROPOMI
TROPOspheric Monitoring Instrument

esa DLR Deutsches Zentrum für Luft- und Raumfahrt German Aerospace Center KNMI NILU s[&]t SRON belspo

Status and Lessons Learnt

- S5P MPC Routine Operations validation facility VDAF in service
- In operation: Automated Validation Server, validation analysis consortium, portfolio of outputs, internal and public web-based facilities
- Approach of complementing MPC VDAF/VAL with S5PVT AO activities successful
- Valuable synergies/convergence between Copernicus space (MPC), FRM procurement and (CAMS/C3S) service components
- Enhanced coordination desired for approach to/funding for FRM gap analysis, deployment, data generation and delivery

Perspectives for S-5 and GEO-AQ

Critical elements (for single missions):

- FRM data streams: availability, relevance, timeliness, sustainability
- Harmonized, state-of-the-art, fit-for-purpose validation methods
- Propagation of uncertainties, closure of comparison error budget
- Definition and implementation of quality compliance criteria…
- Operationalization and service set-up

Additional challenges for GEO-AQ:

- Change in paradigm wrt LEO: diurnal cycle, VZA/SZA, BRDF…

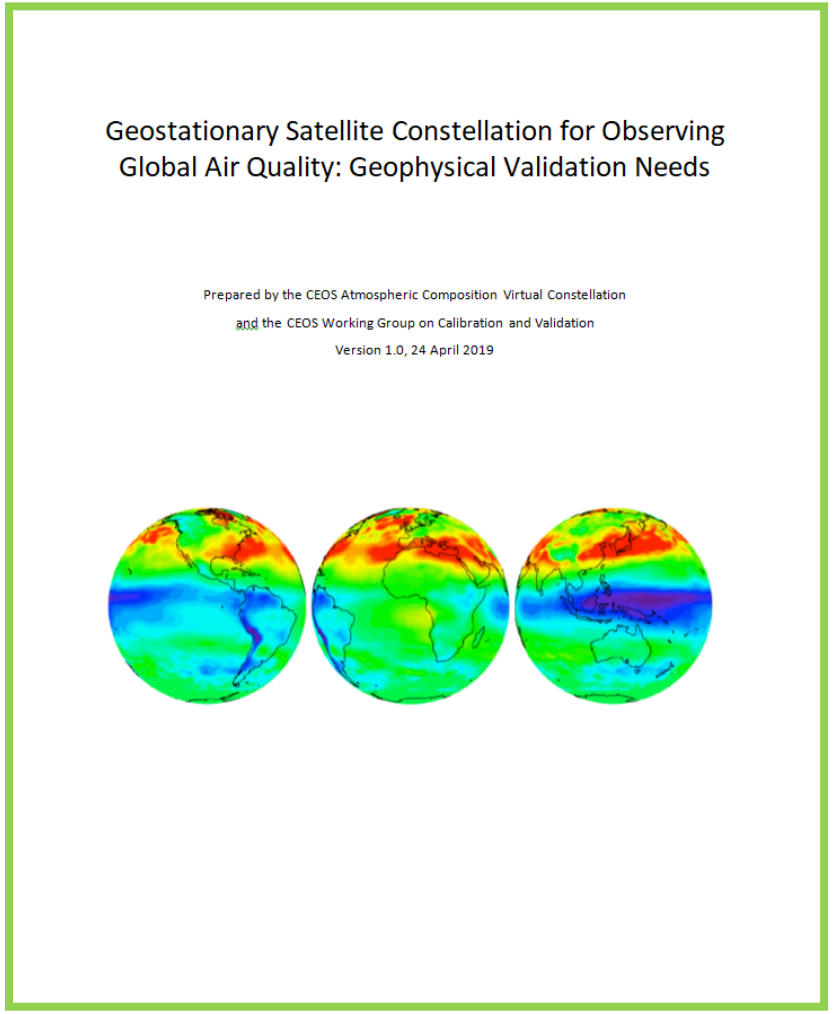
Additional challenges for any constellation:

- Inter-mission consistency of validation: methods, metrics, FRMs, AKs…

Perspectives for GEO-AQ

Recommendations

1. Consistently perform intensive campaigns dedicated to the validation of the capability of the Geo-AQ missions to observe the diurnal cycle of the target species. Such campaigns are conducted at several supersites within each Geo-AQ mission domain where a comprehensive suite of correlative reference measurements is made and a comprehensive set of auxiliary data from a variety of sources is exploited.
2. Conduct joint validation campaigns with exchange of reference airborne and ground-based instruments.
3. Further develop and eventually apply approaches to the radiometric inter-calibration of the Geo-AQ missions, based on comparisons of Earth radiance data acquired over known targets, precise and approximate ray matching between GEO and LEO pairs of missions, and by taking the LEO missions as a travelling standard. These activities should be pursued within the frame of the WMO GSICS initiative.
4. Further develop and eventually apply approaches to the inter-calibration of the Level-2 products of the Geo-AQ missions. These approaches include the comparison of products with inter-calibrated ground-based network data, cross-validation of Level-2 algorithms by exchanging Level-1b data, comparing zonal mean values of the stratospheric sub-column in the Level-2 ozone products, and taking validated LEO missions as a travelling standard.
5. Systematically process the Level-2 Constellation Products of the Geo-AQ missions, using one selected common algorithm per Constellation Product.
6. Further pursue the harmonization of the reference data used for validation and inter-mission consistency verification of Level-2 products, aiming at common measurement protocols, common QA protocols, common data formats, harmonized data policy and open access.
7. Implement a data centre for storage and exchange of all validation data collected for the Geo-AQ missions. Make these data accessible to the entire community involved in the validation of the Geo-AQ mission products and their inter-mission consistency, very soon after acquisition.
8. Implement a coordinating unit for ensuring consistent validation approach and metrics for the Geo-AQ mission products and their inter-mission consistency.



Thank you !

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Website: mpc-vdaf.tropomi.eu