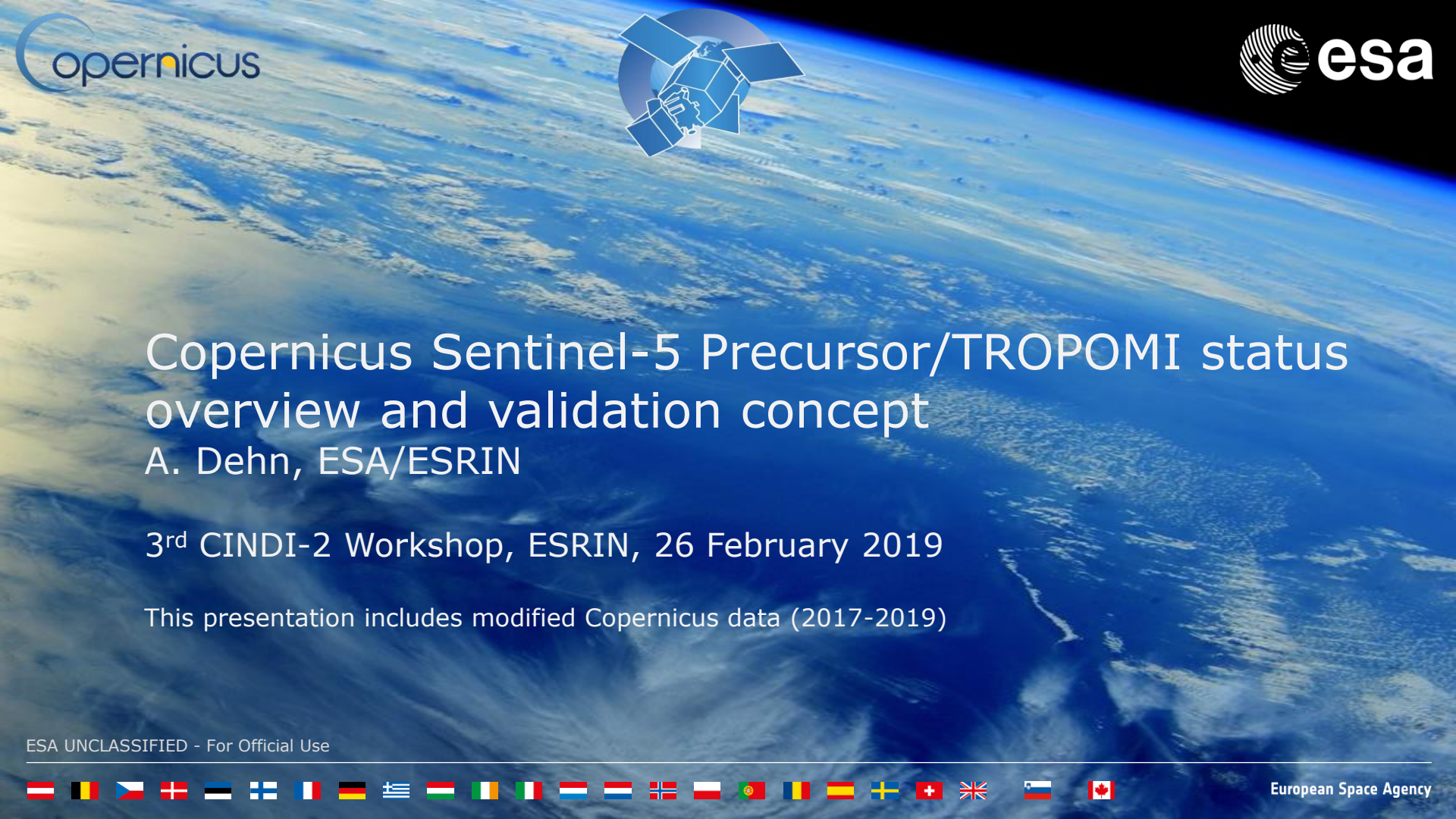

Copernicus Sentinel-5 Precursor/TROPOMI status overview and validation concept

A. Dehn, ESA/ESRIN

3rd CINDI-2 Workshop, ESRIN, 26 February 2019

This presentation includes modified Copernicus data (2017-2019)

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Copernicus Programme

European Earth Observation System

- Led by the EU
- EU-ESA Collaboration

European response to global needs:

- to manage the environment
- to mitigate effects of climate change
- to ensure civil security

European independence, contribution to GEOSS

Copernicus Sentinel Missions

S-1	S-2	S-3	S-4	S-5P	S-5	S-6
Radar	High Resolution Optical	Medium Resolution Optical & Altimetry	Atmospheric Chemistry (GEO)	Atmospheric Chemistry (LEO)	Atmospheric Chemistry (LEO)	Altimetry
A 3 Apr. 2014	A 23 Jun. 2015	A 16 Feb. 2016	A 2021	A 13 Oct. 2017	A 2021	A 2020
B 25 Apr. 2016	B 6 Mar. 2017	B 25 Apr. 2018	B 2027		B 2027	B 2025

Sentinel-5 Precursor

COPERNICUS ATMOSPHERE MISSION IN POLAR ORBIT

The Sentinel-5 Precursor (S5p) is the first **atmospheric Sentinel** mission focusing on global observations of the atmospheric composition for **air quality** and **climate monitoring**. Launched on **Oct. 13 2017** with a **7 years** design lifetime.

The TROPOspheric Monitoring Instrument (**TROPOMI**) is the payload of the S5P mission and was jointly developed by **The Netherlands and ESA**. Polar synchronous orbit at a height of about 820 km. Global coverage within 1 day (swath of 2600 km). Ground-pixel spatial resolution of 7 x 3.5 km. Open data access following the Copernicus Data Policy.

S5p Commissioning Phase Outcome - follow up during Ramp-up Phase

Level-1 B Enhancements:

- Solve Band 2/3 radiometric inconsistency: ongoing – improved Level 1 product release planned during mid 2019
- Handle pixel blooming (in case of saturated pixels): flagged in Level 2 QA value (using the slant column fit)

TROPOMI Operations: shorter along-track spatial resolution of 5.5 km (25% more observations) – investigations have been performed on possible Level 2 quality impact and implementation feasibility, proposed TROPOMI operations changes were approved by COM, new TROPOMI operations planned during mid 2019

Spacecraft Operations: fill the small gap over the equator (by using an off-nadir measurement scenario) – investigation have been performed and discussed within the QWG (27 June 2018), First Steering Group Meeting Decision (10 July 2018): TROPOMI will remain in nadir viewing operations and this proposed change will not be implemented

Mission Status and Data Quality Reporting:
https://sentinel.esa.int/web/sentinel/missions/sentinel-5p/mission-status **- Reports covering a time period of 2 weeks**

http://www.tropomi.eu/mission-status **- L1 Portal, L2 Data Quality, Routine Validation**

Information about Products and Algorithms:
https://sentinels.copernicus.eu/web/sentinel/technical-guides/sentinel-5p/products-algorithms

S5p – Ground_Segment (PDGS)

- **Mission Operations: controlled by ESOC supported by the OSF at KNMI (defining TROPOMI operations)**
- **Post Launch Support Office (PLSO) ESTEC: in-orbit mission performance monitoring - no major anomaly reported so far**
- **Data Acquisition: Inuvik and Svalbard ground-stations**
- **Mission Commanding: Kiruna ground-station**
- **Level 1 Prototype Development: at KNMI (supported by SRON)**
- **Level 2 Prototype: at KNMI (supported by SRON) & at DLR (supported by BIRA/IASB and RAL)**
- **Operational Level 1 and Level 2 Product Processing – Payload Data Ground Segment (PDGS): at DLR**
- **Cal/Val: MPC (operational) and S5PVT (science - AO projects)**

Sentinel-5P Level 1 Product Requirements

Mission Requirement Traceability Document

EOP-SM/2413/BV-bv

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esa

estec

European Space Research
and Technology Centre
Keplerlaan 1
2201 AZ Noordwijk
The Netherlands
Tel. (31) 71 5656565
Fax (31) 71 5656040
www.esa.int

DOCUMENT

GMES SENTINELS 4 AND 5 MISSION REQUIREMENTS
TRACEABILITY DOCUMENT

Example: absolute radiometric accuracy (UVN) –> 2-3%

Wavelength range [nm]	Accuracy
270-275	max [0.5%(G) / 2%(T) S_{ref}(275 nm), 2%(G) / 3%(T) S]
275-280	max [0.5%(G) / 2%(T) S_{ref}(280 nm), 2%(G) / 3%(T) S]
280-285	max [0.5%(G) / 2%(T) S_{ref}(285 nm), 2%(G) / 3%(T) S]
285-290	max [0.5%(G) / 2%(T) S_{ref}(290 nm), 2%(G) / 3%(T) S]
290-295	max [0.5%(G) / 2%(T) S_{ref}(295 nm), 2%(G) / 3%(T) S]
295-300	max [0.5%(G) / 2%(T) S_{ref}(300 nm), 2%(G) / 3%(T) S]
300-305	max [0.5%(G) / 2%(T) S_{ref}(305 nm), 2%(G) / 3%(T) S]
305-310	max [0.5%(G) / 2%(T) S_{ref}(310 nm), 2%(G) / 3%(T) S]
310-315	max [0.5%(G) / 2%(T) S_{ref}(315 nm), 2%(G) / 3%(T) S]
315-320	max [0.5%(G) / 2%(T) S_{ref}(320 nm), 2%(G) / 3%(T) S]
320-325	max [0.5%(G) / 2%(T) S_{ref}(325 nm), 2%(G) / 3%(T) S]
325-330	max [0.5%(G) / 2%(T) S_{ref}(330 nm), 2%(G) / 3%(T) S]
330-425	max [0.5%(G) / 2%(T) S_{ref}(425 nm), 2%(G) / 3%(T) S]
425 - 429.16	max [0.5%(G) / 2%(T) S_{ref}(429.16 nm), 2%(G) / 3%(T) S]
429.16 -433.33	max [0.5%(G) / 2%(T) S_{ref}(433.33 nm), 2%(G) / 3%(T) S]
433.33 – 437.50	max [0.5%(G) / 2%(T) S_{ref}(437.50 nm), 2%(G) / 3%(T) S]
437.50 – 441.66	max [0.5%(G) / 2%(T) S_{ref}(441.66 nm), 2%(G) / 3%(T) S]
441.66 – 445.83	max [0.5%(G) / 2%(T) S_{ref}(445.83 nm), 2%(G) / 3%(T) S]
445.83 – 450	max [0.5%(G) / 2%(T) S_{ref}(450 nm), 2%(G) / 3%(T) S]
450 – 500	max [0.5%(G) / 2%(T) S_{ref}(500 nm), 2%(G) / 3%(T) S]
710-775	max [1% S_{ref}(750 nm), 2%(G) / 3%(T) S]

Sentinel-5P Level 2 Product Requirements

Parameter	Data Product	Vertical Resolution	Bias	Random
Ozone	Ozone Profile	6 km	10-30%	10%
	Total Ozone	total column	3.5-5%	1.6-2.5%
	Tropospheric Ozone	trop column	25%	10%
NO_2	Stratospheric NO_2	strat column	<10%	0.5e15
	Tropospheric NO_2	trop column	25-50%	0.7e15
SO_2	SO_2 enhanced	total column	30%	0.15-0.3 (0.06-0.12) DU
	Total SO_2	total column	30-50%	1-3 (0.4-1.2) DU
Formaldehyde	Total HCHO	total column	40-80%	1.2e16 (4e15)
CO	Total CO	total column	15%	<10%
Methane	Total CH_4	total column	1.5%	1%
Cloud	Cloud Fraction	total column	<20%	0.05
	Albedo (Optical Thickness)	total column	<20%	0.05 (10)
	Cloud Height (Pressure)	total column	<20%	<0.5 km (<30hPa)
Aerosol	Aerosol Layer Height	total column	<100hPa	<50hPa
	Aerosol Type	total column	~1 AAI	<0.1 AAI
Surface UV	Provided by FMI in frame of the Finnish Sentinel Collaborative Ground Segment			

Sentinel-5P Cal/Val Organization

S5P Mission Performance Centre (MPC)

The Mission Performance Centre is in charge of the operational calibration/validation.
(see J-C. Lambert presentation)

ESA atmospheric Validation Data Centre (EVDC)

Quality Working Group (QWG)
chaired by ESA Data Quality Manager

*The information is then discussed, further processed in the **Quality Working Groups** which provide synthetic results to the S5P Mission Manager, used for improving the products quality and the products knowledge.*

S5P Validation Teams (S5PVT)

The validation team complements the MPC activities by providing independent validation measurements and independent analysis.

Fiducial Reference Measurements (FRM) providers

Specific activities to enable the provision for mandatory FRMs (suite of independent, fully characterized, and traceable ground measurement)

User Community and international forum:

Feedback from:
- Workshops/conferences (ESA or international)
- Bilateral relation (NASA, NOAA, DLR, EUMETSAT…)
*- Coordination within **CEOS WGCV and AC-VC***

AO call for the Sentinel-5 Precursor Validation Team is permanently open
https://earth.esa.int/aos/S5PVT

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Sentinel-5P Mission Performance Center (MPC)

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

Royal Netherlands Meteorological Institute
Ministry of Infrastructure and the 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

S5P MPC – routine validation

- Based on Fiducial Reference Measurements (FRMs)

ID	S5P Data Product	FRM Data
A	O_3 total column	Brewer, Dobson, ZSL-DOAS, MAX-DOAS, Pandonia
B	O_3 profile (incl. troposphere)	ozonesonde, stratospheric DIAL, tropospheric DIAL
C	O_3 tropospheric column	ozonesonde
D	NO_2 stratospheric column	ZSL-DOAS
	NO_2 tropospheric column	MAX-DOAS
	NO_2 total column	Pandonia
E	SO_2 total column	Pandonia
F	HCHO total column	MAX-DOAS, Pandonia
G	CO total column	TCCON FTIR (NIR), NDACC FTIR (MIR)
H	CH_4 total column	TCCON FTIR (NIR), NDACC FTIR (MIR)
I	Cloud Fraction	not available
	Cloud Height (pressure)	Cloudnet
	Cloud Optical Thickness	not available
J	Aerosol Absorbing Index	not available
	Aerosol Layer Height	EARLINET

Source: S5P MPC routine Cal/Val plan (version June 2018)

Dedicated S5P MPC validation tool (VDAF):

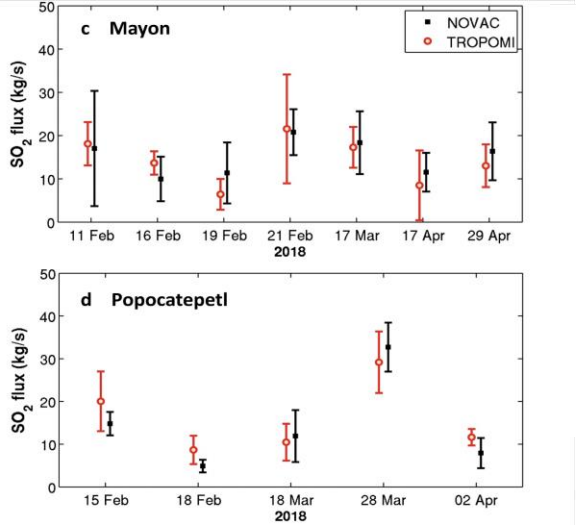
- Automated overpass extraction S5P L2 and FRM ground based data sets
- Automated generation of data comparisons, tables, plots
- MPC Product experts interpreting results

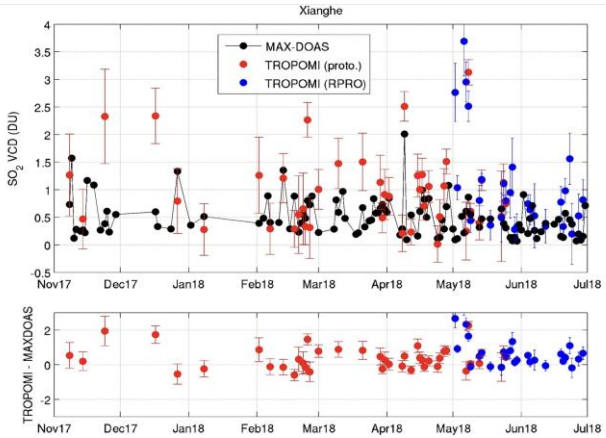
- MPC validation results at: http://mpc-vdaf.tropomi.eu/

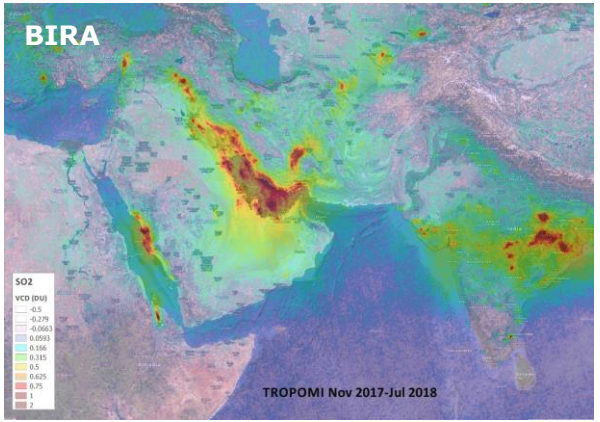
Level 2 products validation example

➢ SO2 product performance

- TROPOMI – OMPS comparisons for volcanic cases: excellent agreement is found (only 5 % differences in the 85% of the cases)
- NOVAC: differences <30-50%
- MAXDOAS: <50% within requirement (30-50%); VCDs are low (at limit of S5p detection)







rce: S5p MPC, BIRA, from 2nd Release meeting, 28-Sep-2018

S5P – ESA Fiducial Reference Measurements (FRM)

FRM4DOAS http://frm4doas.aeronomie.be

Team: BIRA-IASB (lead), IUP-Bremen, IUP-Heidelberg, MPIC, KNMI, BKScientific

- Harmonization of retrievals from UV-Vis ground based spectrometers (e.g. MAXDOAS):
  - Specification of best practices for instrument operation
  - Support to preparation of the CINDI-2 campaign
  - Round Robin comparison of algorithms
  - Development of centralised processing system

- Target products:
  tropospheric & stratospheric NO_2 vertical profiles, total O_3 and tropospheric formaldehyde profiles.

- Operational implementation planned: 2019

FRM4DOAS talk by F. Hendrick, BIRA-IASB

S5P – ESA Fiducial Reference Measurements (FRM)

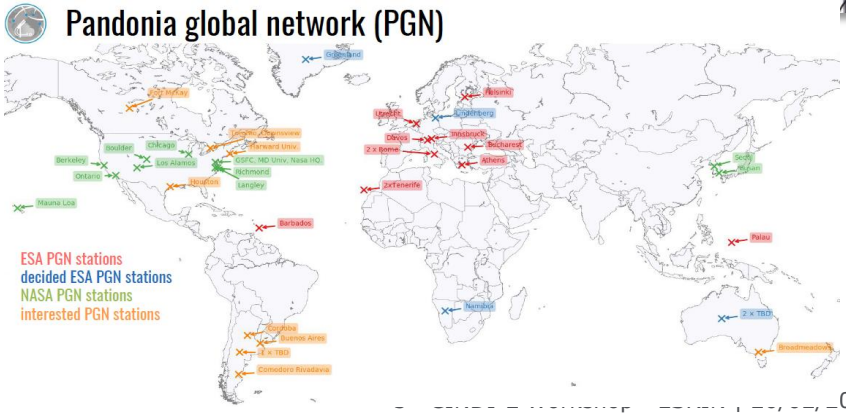
PGN FRM (Pandonia Global Network) http://pandonia.net

LuftBlick, Austria *moving to ->*http://pgn.nasa.esa.int/

- Ground-based remote sensing network using Pandora-2S and Pandora spectrometers
- Target products, total & tropospheric column: O_3, NO_2 ; additional products: SO_2, formaldehyde

- Network instruments officially being added, starting Q4 2018, NO2 initially
- PGN ESA/NASA collaboration

- Data availability real time ca. 10 min after measurements



S5P – ESA Fiducial Reference Measurements (FRM)

FRM4GHG http://frm4ghg.aeronomie.be

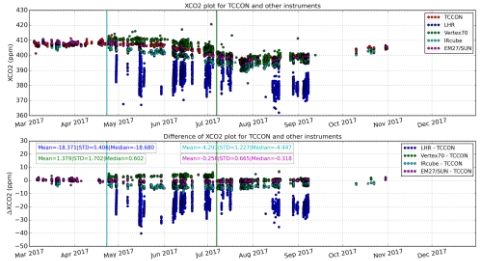
Team: IUP Bremen (lead), BIRA-IASB, KIT, FMI, Uni Groningen, Uni Wollongong, RAL

Phase 1 during 2016/2017

- Inter-comparison of ground based transportable FTIR systems with reference to TCCON as standard system – measurement campaign in Sodankyla/Finland
- Target Products: CO, CH4

Phase 2 during 2018/2019

- campaign in 2018 (March to October) in Sodankyla/Finland
- continued and extended the measurements campaign
- provide a guideline for further development of new observation sites to complement the TCCON network
- Specific S5P/TROPOMI validation task



Sentinel-5P Validation Team – S5PVT

ESA AO (Announcement of Opportunity) call in fall 2014
to engage experts for the Calibration & Validation of S5P:

1st S5PVT workshop October 2015

- ✓ S5P AO Call summaries of current proposals available:
  https://earth.esa.int/aos/S5PVT

2nd S5PVT workshop 5/6 February 2018

- ✓ Validation teams to present new or updated Cal/Val proposals
  - ✓ Coordination of Cal/Val AO projects and identification of gaps
  - ✓ Feedback on tools and test data from the Validation teams

3rd S5PVT workshop 25/26 June 2018
First Products released

Next S5PVT workshop:
11-15 November 2019 in ESRIN, Frascati

The AO call for The Sentinel-5 Precursor Validation Team is permanently open
https://earth.esa.int/aos/S5PVT

EVDC - ESA atmospheric Validation Data Centre

Official ESA repository for validation and campaign datasets, including FRM.

S5P MPC to access FRM and other validation data sets via the EVDC.

S5PVT to upload AO validation data sets to the EVDC.

New portal ***https://evdc.esa.int*** since August 2017 including new features:

- Overpass predictor and Orbit Tool;
- Satellite data sub-setting:
  - Sentinel 5P as demo currently
    - to become available Q1 2019
  - S5P, ADM-Aeolus for operational Phase
  - EarthCare in the future

Further evolution on-going, based on user requirements – including S5PVT

Product release status summary

Product	NRT	NTC (OFFL)
Level 1B	N/A	✓
Ozone (O_3) total vertical column	✓	✓
Ozone (O_3) tropospheric vertical column	N/A	✓
Ozone (O_3) full vertical profile	⚠	⚠
Nitrogen dioxide (NO_2) vertical column	✓	✓
Sulphur dioxide (SO_2) vertical column	✓	✓
Carbon monoxide (CO) total column	✓	✓
Methane (CH_4) vertical column	N/A	✓
Formaldehyde (CH_2O) vertical column	✓	✓
Cloud parameters	✓	✓
Aerosol index product	✓	✓
Aerosol layer height product	🔍	🔍

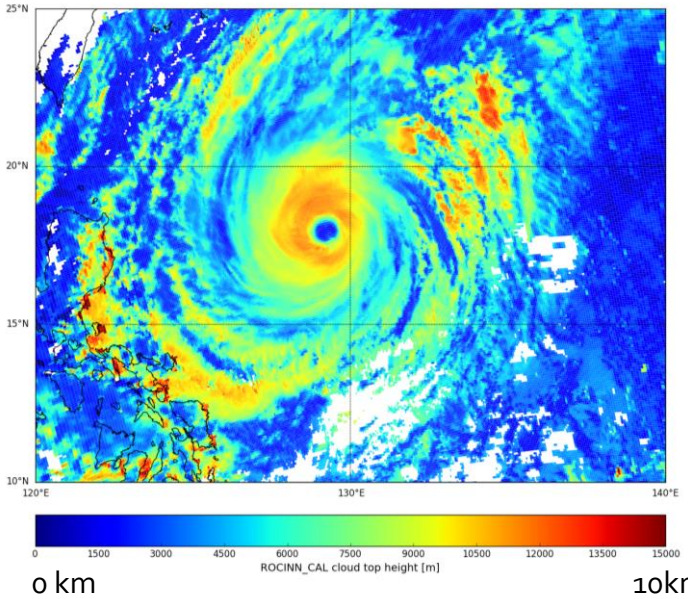
✓ Released on PreOperations Hub

🔍 Validation starting end March 2019

⚠ Pending L1B Reprocessing for inter-band calibration

L1B Product (Radiances/Irradiances), Aerosol & Cloud information – released to the public during July 2018

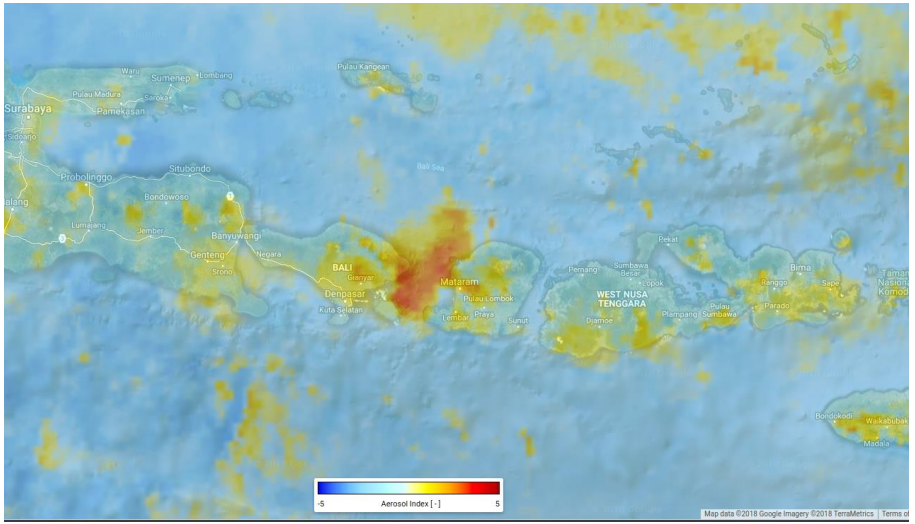
TROPOMI/S5P Cloud Height



0 km 10km

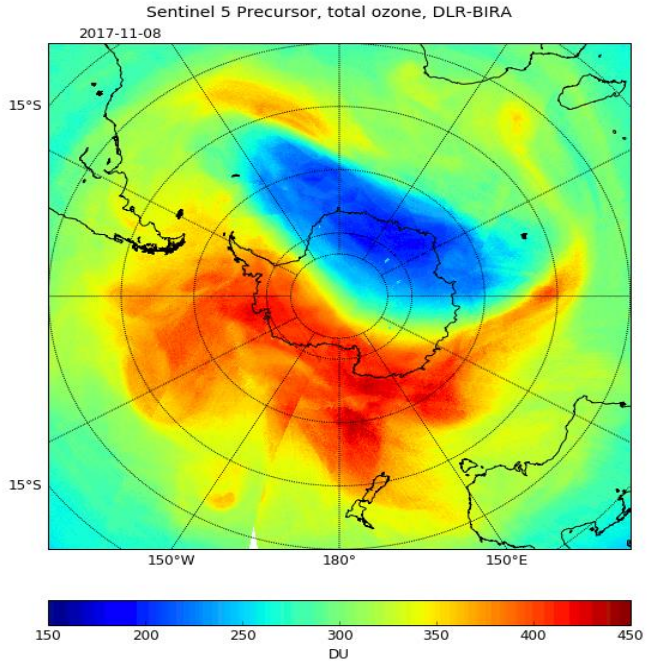
S5p – Typhoon Yutu, Phillipines, 28th October 2018

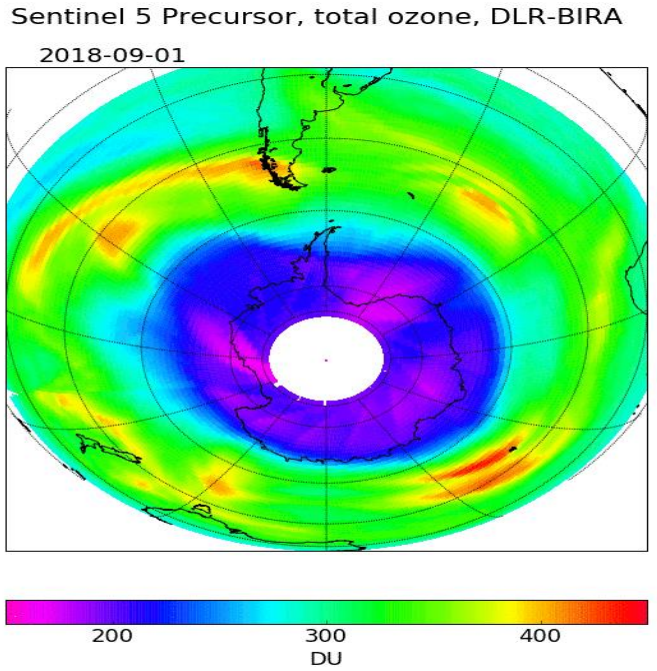
S5p Aerosol Absorbing Index



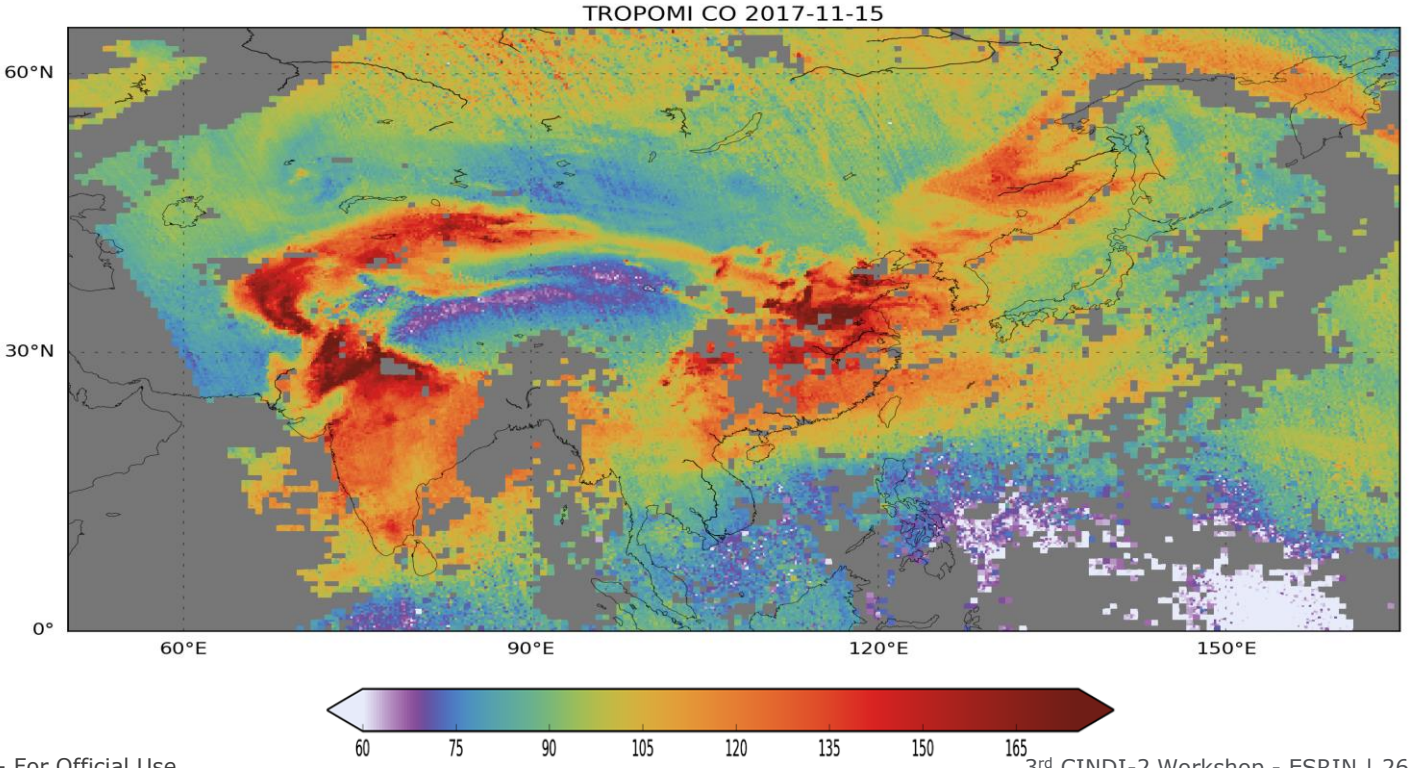
Agung Volcanic Eruption, 27 Nov 2017

S5p/TROPOMI Total Ozone (DLR)

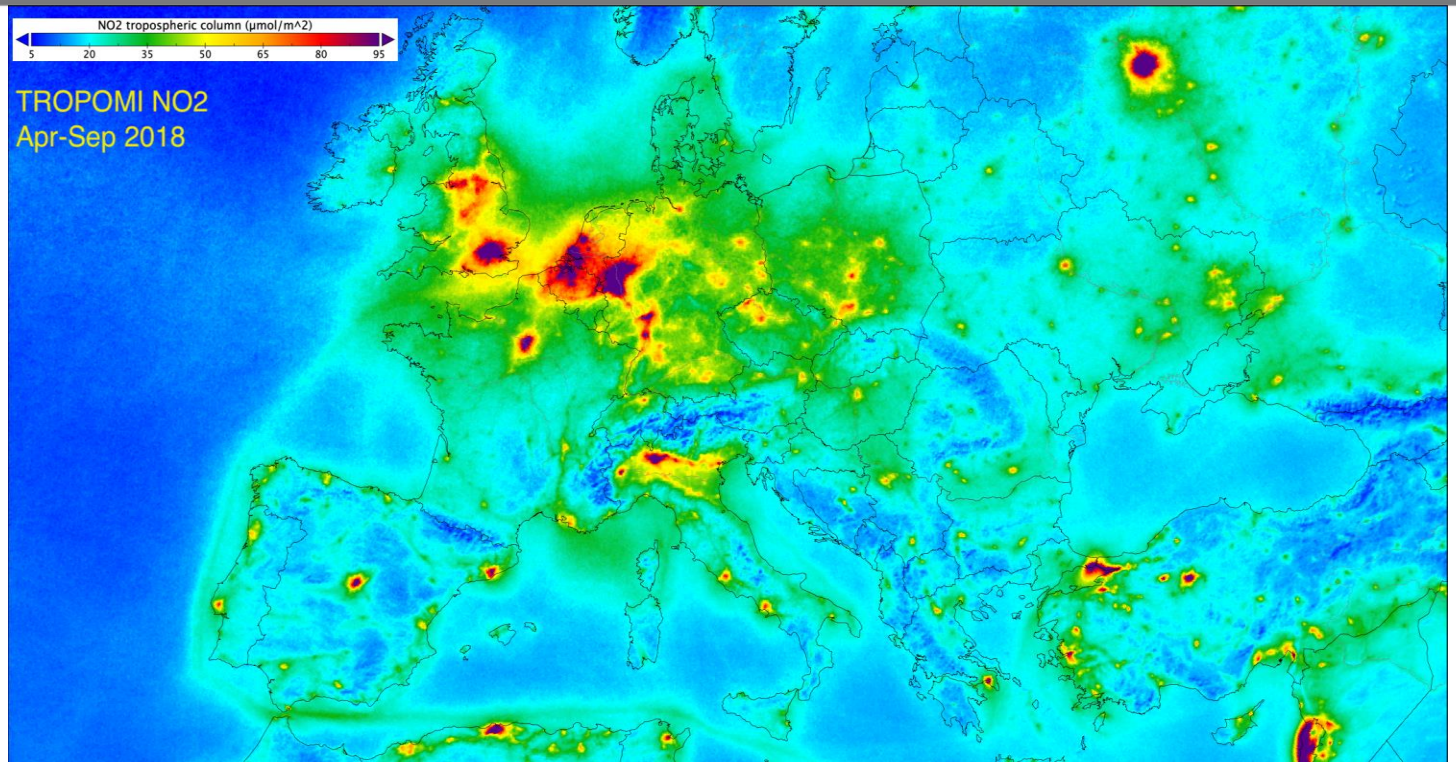




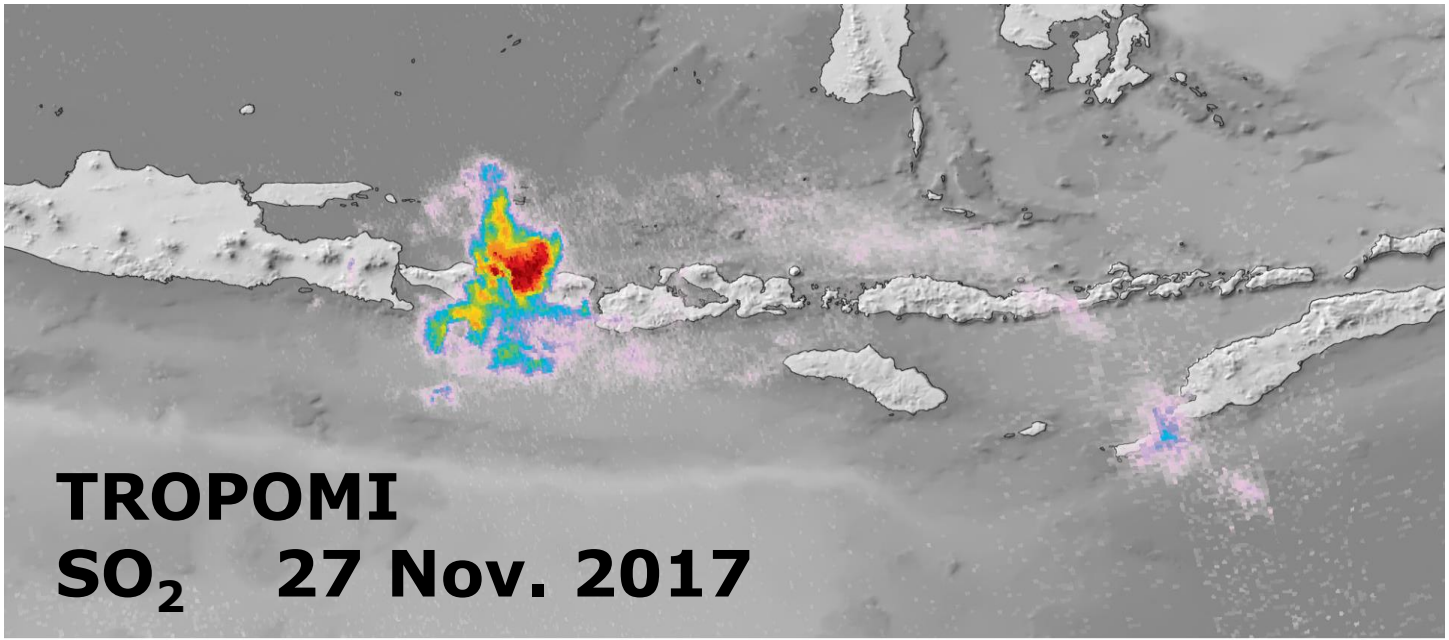
S5p/TROPOMI Carbon Monoxide November 2017 (SRON)



S5p/TROPOMI NO_2 trop. column densities
(6 months average - 2018) - KNMI



S5p/TROPOMI Sulphur Dioxide (BIRA/IASB)



MPC - S5PVT

- Mission Performance Centre (MPC): operational Cal/Val - http://www.tropomi.eu/data-products/mission-performance-centre
- 54 projects in the S5p Validation Team (earth.esa.int/aos/S5PVT)
- Dedicated webpage http://s5pvt.skytek.com/group/s5pvt-qwg to exchange documentation and information
- S5PVT Workshop planned during 11-15 Nov. 2019 at ESRIN (has still to be announced)