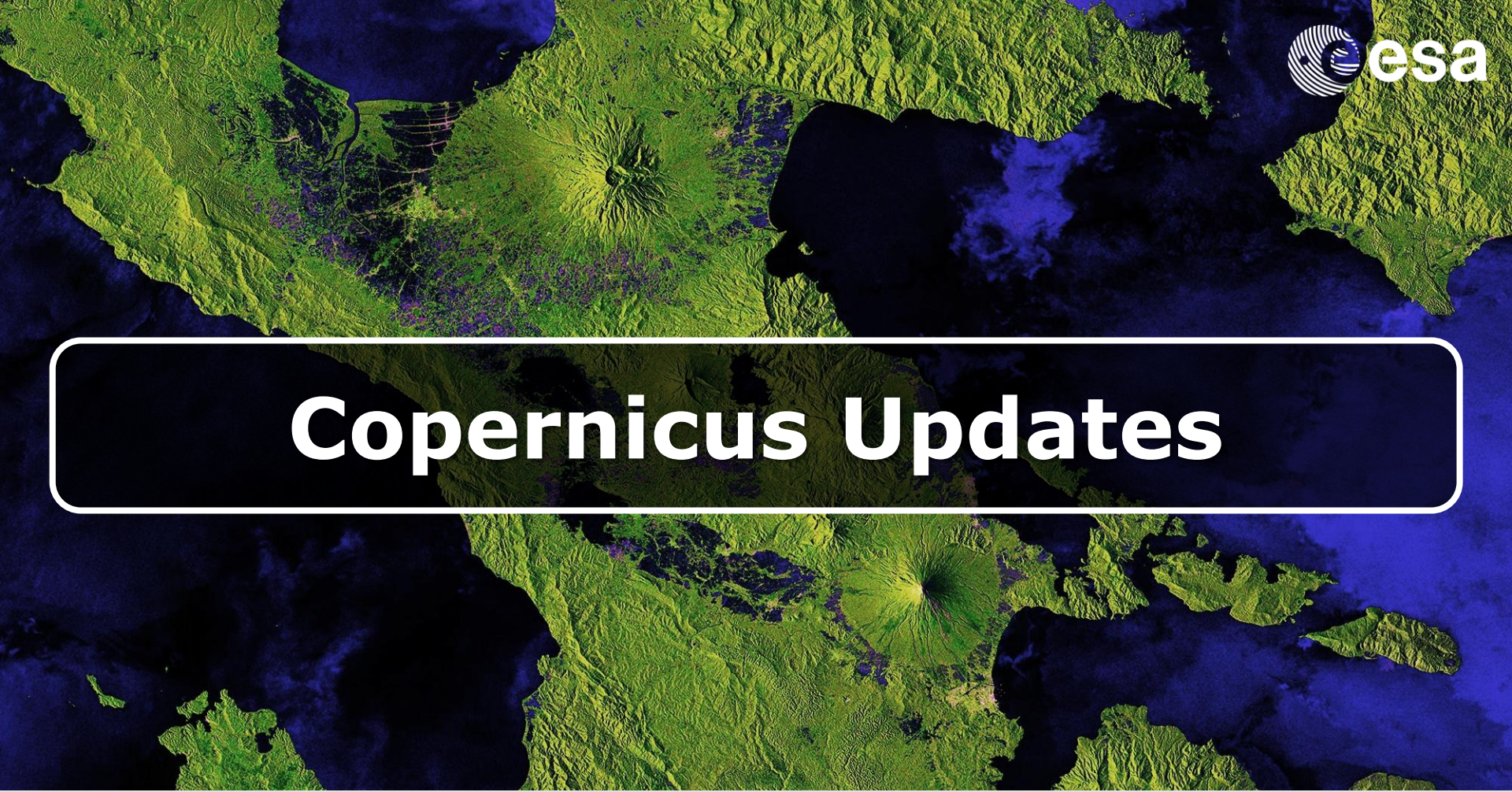
Updates on Copernicus and the Validation of Sentinel data

7th COPERNICUS CZECH NATIONAL USER FORUM

07 June 2018, GSA, Prague

Simon Jutz, ESA
Head of the Copernicus Space Office
Directorate of Earth Observation Programmes

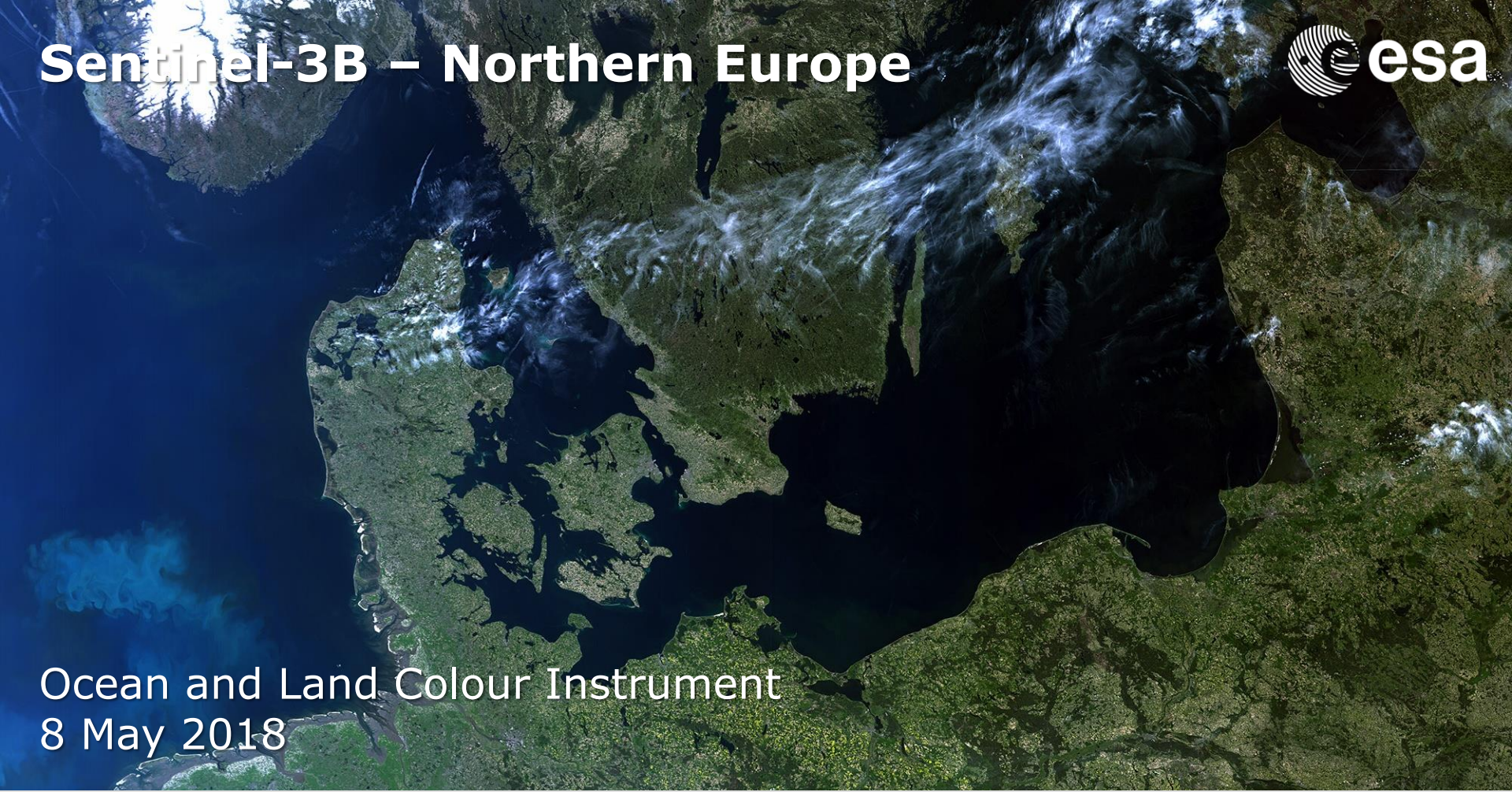

esa
Copernicus Updates

2 Successful Launches

Sentinel-3B – Antarctic Sunset

First Image Ocean and Land Colour Instrument
7 May 2018

Sentinel-3B – Northern Europe



Ocean and Land Colour Instrument
8 May 2018

Sentinel Status

- ✓ **7 successful launches** in a row with Soyus, Vega, Rockot
- ✓ **Instruments** better than specified with excellent results
- ✓ **Unprecedented User Uptake**, >145.000 self-registered data user, and many more Copernicus users
- ✓ **Largest and most comprehensive Earth Observation Programme worldwide**

S-1

Radar

A
3 Apr.

B
25 Apr. 2

C
2022/23

D
> 2022/23

S-2

D
> 2022/23

S-5

S-6

Altimetry

A
2020

B
2025

The Copernicus Revolution

Largest producer of EO data in the world

Public

Science

Start-ups

Large ICT Companies

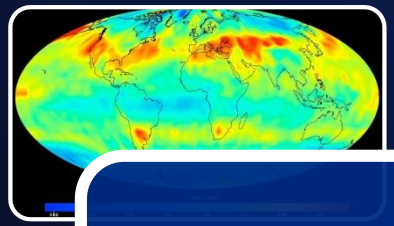
Copernicus Services

Copernicus revolutionises EO

Offers huge potential for Europe

Sentinel Expansion (7 to 12)

High Priority Candidate Missions



Anthropogenic CO_2

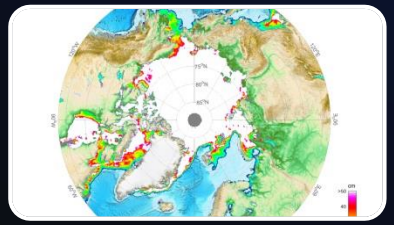
Applications

Climate Change (Causes)

Status: Phase A/B1 system studies

Polar Ice & Snow Topography

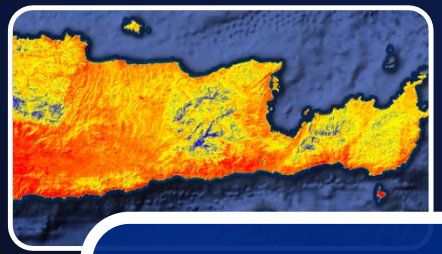
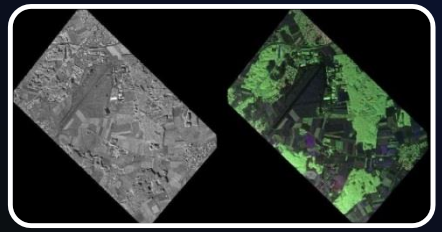
Climate Change (Effects)



Passive Microwave Imaging

Sea Surface Temperature & Sea Ice Concentration

Sentinel Expansion (7 to 12)

High Priority Candidate Missions	Applications
 High Resolution Land Surface Temperature	Agriculture & Urban Management Services
 Hyperspectral Imaging	& Food Security, Soil & Mineral Resources
 L-band SAR	Soil, Vegetation, Food Security & Ground Motion

Status: Phase A/B1 system studies

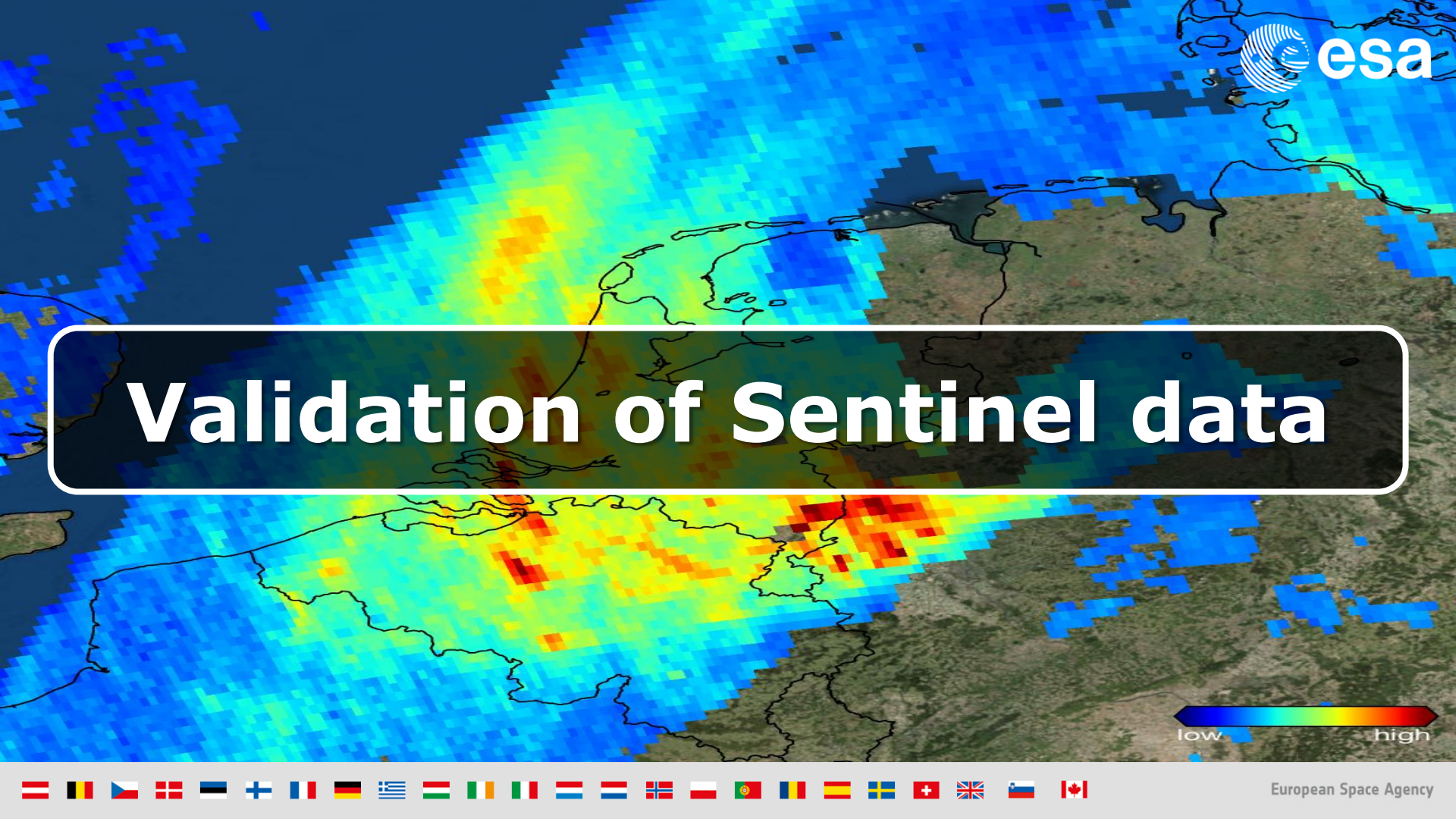
Regulatory Framework

2 May 2018 – European Commission released its **proposal for the next Multiannual Financial Framework (MFF):**

- 7 years (from 2021 to 2027)
- 16 B€ for the European Space Programme

7 June 2018 – European Commission's proposal for the **European Space Programme Regulation** expected to be released today, on 7 June 2018:

- Defining rules and roles of the European Space Programme
- Distributing the budget between Copernicus, Galileo, SST, Govsatcom…
- Establishing the European Union Agency for the Space Programme


esa
Validation of Sentinel data
low
high
European Space Agency

Validation Approach

The validation activities have two main goals:

- **to provide products with documented and associated traceable error bars**
- **to gain knowledge in the algorithm and sensor characteristics in order to improve their quality and reliability**

The accuracy in the uncertainties has a long term impact for most EO applications and in particular for climate applications.

The validation activities

- are a key component of a Mission, as it is the foundation for user credibility into the mission data
- require continuous effort during and after the mission life time

CEOS Definition: Calibration is the process of quantitatively defining a system's responses to known, controlled signal inputs. Validation, on the other hand, is the process of assessing, by independent means, the quality of the data products derived from those system outputs.

Validation Approach

A validation program is composed by a set of different complementary activities bringing elements that need to be combined together in order to produce consolidated and confident validation results.

In a generic manner the different components for a validation program are the following:

- Validation against precise Fiducial Reference Measurements (FRM): few points but precise,
- Validation against in-situ: more points less precise,
- Validation against others sources: inter-satellite comparison,
- Validation against models: data assimilation rejection statistics, integrated model analyses…,
- Validation using Level 3 data (i.e. merged data): statistical comparison between various Level 3 from various sensors constitutes an extremely useful tool (mean, median, sd, bias, RMS…. for selected zones, transects, latitudinal bands, seasonal trends…) for a cross-validation of the products,
- Validation using monitoring tools: statistics, trend, systematic quality control, etc.

All the components are important and necessary; the first point (FRM) is of particular importance because it gives a reference properly characterised and traceable to a standard on which the Validation results can be anchored.

Sentinel Validation Organisation

For each Sentinel mission, the **validation plan** constitutes the baseline description for the validation activities. The activities are implemented by different contributors who interact all together under the responsibility and coordination of the Mission Data Quality Manager.

~~SENTINEL~~ VALIDATION TEAM : *The validation team completes the MPC activities by providing independent validation measurements and/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 validation across the entire mission operations (i.e. Phase E1 and E2).*

Mission Performance Centre (MPC)

The Mission Performance Centre is in charge of the overall validation providing the synthesis of the results.

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

Mission Quality Working Group (QWG) | ***Mission Data Quality Manager***

*The information are 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.*

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 (ex: BOUSSOLE, Infra-Red radiometers…etc…

User community and international forum:

The validation program benefits from the feedback from:

- *Workshops/conferences (ESA or international)*
- *Bilateral relations (NASA, NOAA, CNES, DLR, UKSA, JRC, EUMETSAT…etc…)*
- *Coordination within **CEOS WGCV (WG on Cal/Val)***

** For the specific case of Sentinel-3, EUMETSAT coordinates together with ESA the validation activities and also provides validation infrastructures and internal expertise which complement the MPC/SVT approach.*

Fiducial Reference Measurements

"The suite of independent ground measurements that provide the maximum Return On Investment (ROI) for a satellite mission by delivering, to users, the required confidence in data products, in the form of independent validation results and satellite measurement uncertainty estimation, over the entire end-to-end duration of a satellite mission."

Following the QA4EO principles, the defining **mandatory characteristics** for FRM are:

- FRM measurements have ***documented SI traceability*** (e.g. via round-robin characterisation and regular (pre-and post deployment) calibration of instruments) using metrology standards,
- FRM measurements are ***independent*** from the satellite geophysical retrieval process,
- An ***uncertainty budget*** for all FRM instruments and derived measurements is available and maintained,
- FRM ***measurement protocols, procedures*** and community-wide management practices (measurement, processing, archive, documents etc.) are defined, published openly and adhered to by FRM instrument deployments,
- FRM are ***accessible*** to other researchers allowing independent verification of processing systems,
- FRM are ***required*** to determine the on-orbit uncertainty characteristics of satellite geophysical measurements via independent validation activities.

FRM4 projects

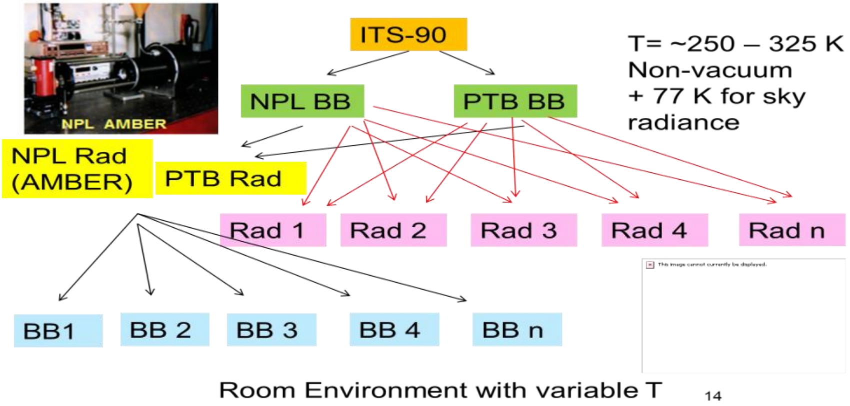
A number of projects have been initiated within ESA EOEP program for FRMs qualification.

Based on generic model:

Laboratory
Laboratory Calibration Exercise (LCE) →
SI traceability
Necessary for all participants to assess biases to SI under laboratory conditions

Field campaigns
Field Inter-comparison Calibration Exercise (FICE)

Analysis
Analysis
Discussion, Workshop
Publications



JOURNAL OF ATMOSPHERIC AND OCEANIC TECHNOLOGY VOLUME 21

The Miami2001 Infrared Radiometer Calibration and Intercomparison. Part II: Shipboard Results

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(Manuscript received 27 August 2002, in final form 6 May 2003)

ABSTRACT

The second calibration and intercomparison of infrared radiometers (Miami2001) was held at the University of Miami's Rosenstiel School of Marine and Atmospheric Science (RSMAS) during a workshop held from May to June 2001. The radiometers targeted in these two campaigns (laboratory-based and at-sea measurements) are those used to validate the skin sea surface temperatures and land surface temperatures derived from the measurements of imaging radiometers on earth observation satellites. These satellite instruments include those on currently operational satellites and others that will be launched within two years following the workshop. The experimental campaigns were completed in one week and included laboratory measurements using blackbody calibration targets characterized by the National Institute of Standards and Technology (NIST), and an intercomparison of the radiometers on a short cruise on board the R/V *F. G. Walton Smith* in Gulf Stream waters off the eastern coast of Florida. This paper reports on the results obtained from the shipborne measurements.

Seven radiometers were mounted alongside each other on the R/V *Walton Smith* for an intercomparison under seagoing conditions. The ship results confirm that all radiometers are suitable for the validation of land surface temperature, and the majority are able to provide high quality data for the more difficult validation of satellite-derived sea surface temperature, contributing less than 0.1 K to the error budget of the validation. The measurements provided by two prototype instruments developed for ship-of-opportunity use confirmed their potential to provide regular reliable data for satellite-derived SST validation. Four high quality radiometers showed agreements within 0.05 K confirming that these instruments are suitable for detailed studies of the dynamics of air–sea interaction at the ocean surface as well as providing high quality validation data. The data analysis confirms the importance of including an accurate correction for reflected sky radiance when using infrared radiometers to measure SST. The results presented here also show the value of regular intercomparisons of ground-based instruments that are to be used for the validation of satellite-derived data products—products that will be an essential component of future assessments of climate change and variability.

Pilot projects FRM4 (funded by ESA EOEP)

http://www.frm4sts.org/	fiducial reference temperature measurements	Preparing ground truth radiometers and drifting buoy as FRM (SI Traceability) → SST, LST
https://frm4soc.org	fiducial reference measurements for satellite ocean colour	Preparing above water radiometers and vicarious infrastructure in Europe for Ocean Colour FRM (SI Traceability) → OC
http://www.frm4alt.eu/	FIDUCIAL REFERENCE MEASUREMENTS FOR ALTIMETRY FRM4ALT	Procedures and approached to maintain ground transponders with SI Traceability) → Topography
http://frm4ghg.aeronomie.be/		The focus of the "FRM Ground-Based FTIR Greenhouse Gas Observations" (FRM4GHG) project is the intercomparison of instruments and harmonization of products and retrievals from ground based FTIR systems → Greenhouse Gas
http://frm4doas.aeronomie.be/	FRM4DOAS	The "FRM for Ground-Based DOAS Air-Quality Observations" (FRM4DOAS) project aims at the harmonization of the retrievals from UV-Visible ground based spectrometers, e.g., MAXDOAS or Pandora, in view of reaching the standards of FRMs for NO2 and ozone.
FRM4SAR (web site tbd)		Best practice for deploying an a site (and analysis) for accurate geometric calibration.

Validation projects (funded by Copernicus)

A number of validation activities started to provide FRMs:

Boussole: Vicarious calibration system. Buoy in the Mediterranean Sea. Continuous measurements + campaigns.	Sentinel-2/3
AMT4SentinelFRM: high quality Fiducial Reference Measurements (FRM) to validate satellite data during the Atlantic Meridional Transect (AMT)	Sentinel-1/2/3
FRP Vicarious Calibration for Fire Channels	Sentinel-3
SAR Radiometric/Polarimetric calibration campaigns over the DLR calibration site	Sentinel-1
CINDI-2 campaign: coordinated operation of a large number of DOAS and MAXDOAS instruments from all over the world.	Sentinel-5P
Permanent calibration station for altimeters in Crete with microwave transponder	Sentinel-3
Infra-Red Radiometers FRM	Sentinel-3
VAL4VEG: Sentinel Land Core Products Validation	Sentinel-2/3

Additional activities (aerosol, LST, WV, Atmospheric Product Validation…etc…) plan to start in 2018/2019

Conclusion

- A validation approach has been defined for the Sentinel missions
- In line with QA4EO guidelines and CEOS WGCV
- Validation plans are implemented involving: Mission Performance Centres and Validation Teams
- Plans are in place for Fiducial Reference Measurement (FRM) qualification
- Activities started or will start to provide with FRMs
- Validation results indicate very good performances for the Sentinel missions
- Fine tuning and algorithm improvements are still needed (in particular for Sentinel-3 optical products (Fire products, Aerosol products))
- Sentinel Performance Reports are on line: Cyclic reports
  → http://sentinel.esa.int
- Cal/Val information, FRM projects:
  → https://earth.esa.int/web/sppa/home

Air Pollution Monitoring

Sentinel-5P

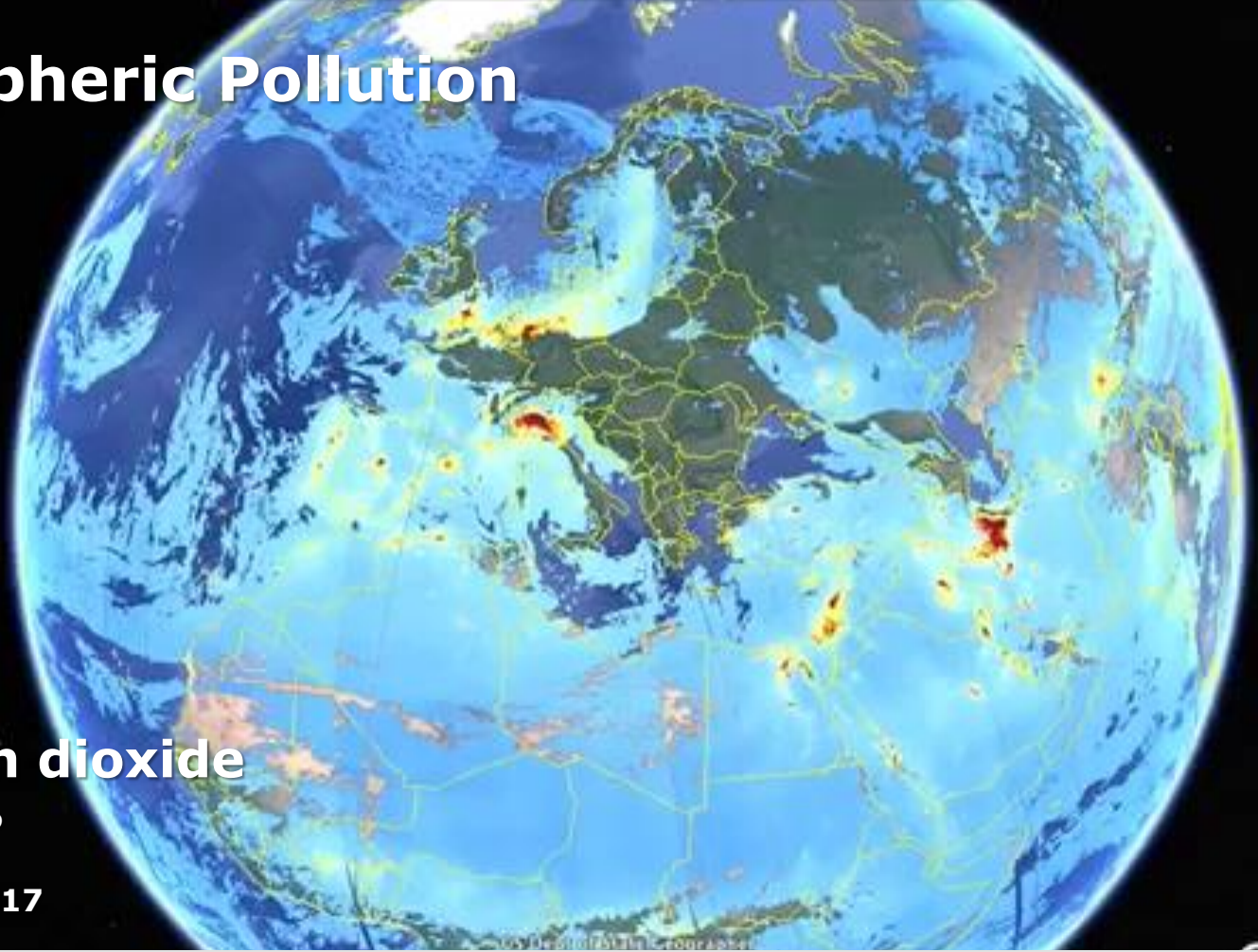
Mean NO_2 Concentrations Europe

19 April 2018

Air pollution causes around 467,000 **premature deaths** in Europe every **year**

EEA 2016 Report

Atmospheric Pollution



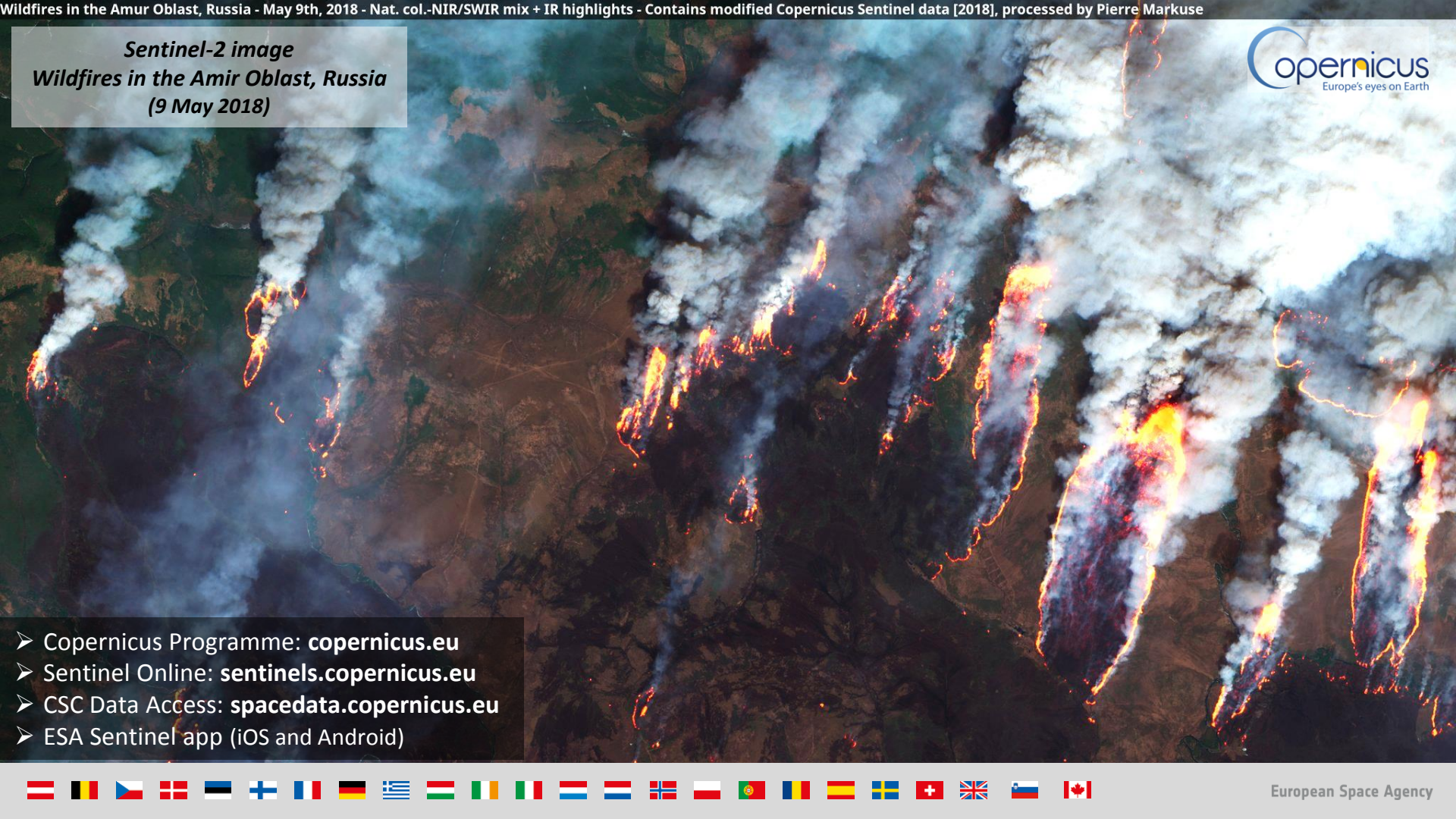
Nitrogen dioxide

Sentinel-5P
KNMI
November 2017

Hawaii Earthquake

Eruption and earthquake near Kilauea volcano, Hawaii

Wildfires in the Amur Oblast, Russia - May 9th, 2018 - Nat. col.-NIR/SWIR mix + IR highlights - Contains modified Copernicus Sentinel data [2018], processed by Pierre Markuse



European Space Agency

Backup Slides

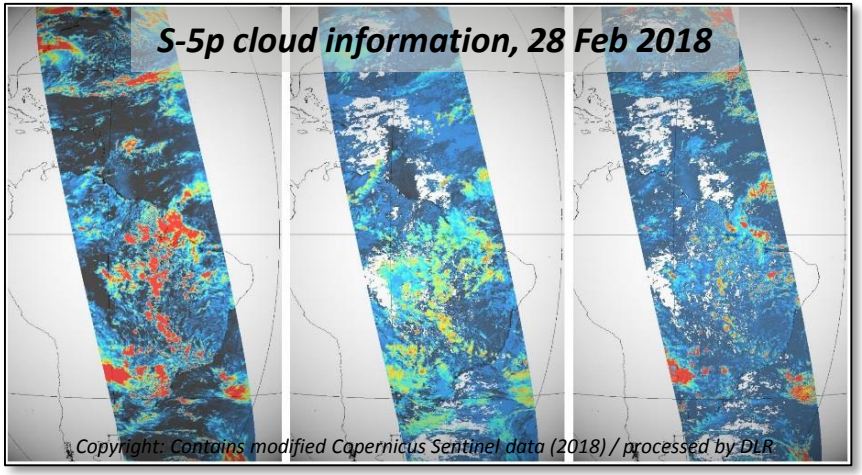
Sentinel-5 Precursor (S5p) mission status

The Sentinel-5p In-Orbit Commissioning Review (IOCR) successfully took place on 24 April 2018.

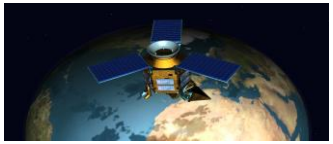
The hand-over to the Mission Manager took place on the same day.

- The nominal operations baseline with a **360 orbit repeat cycle** has started with orbit 2818 on 30 April.

- Since March 2018, the **Cal/Val teams** have access to S-5p sample products via the S-5p Expert Data Hub.
- In **July 2018**, **first S-5p products will be released** to all users including Level-1B products and Level-2 CO products (NTC delivery time) and Level-2 O3, NO2, and cloud & aerosol information (NRT delivery time).
- By end 2018, all S-5p products should be available to users.



Sentinel-5 Precursor mission status



S5P Mission

- ✓ Funded by **EC/ESA** + **national NL/NSO, D/DLR, BE/BELSPO**
- ✓ First operational mission on **air quality** & **climate change**
- ✓ Earth **global daily coverage**, at 13.30 Solar Local Time at Ascending Node

TROPOMI (TROPOspheric Monitoring Instrument)

- ✓ Nadir viewing instrument, UV-VIS-NIR–SWIR spectral ranges (270-500, 675-775, 2305-2385 nm)
- ✓ Spatial resolution (Km^2): **3.5 x 7** (across x along track); 7x7 SWIR

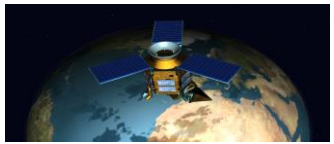
Data products: Total column (O_3, NO_2, CO, SO_2, CH_4, HCHO); Tropospheric column (O_3, NO_2); O_3 Profile; UV Aerosol Index and Layer Height; Clouds

Main Users: CAMS (Copernicus Atmospheric Monitoring Service); **C3S** (Copernicus Climate Change Service)

S5P Mission status

- ✓ Launched on **13th Oct 2017** from Plesetsk (*at 11:27 local time*) - Rockot launcher
- ✓ LEOP (Launch and Early Operations Phase) in record time (33 hours) with **no** single **anomaly**
- ✓ In Commissioning Phase (E1) (*since 16th Oct 2017*) 6 months duration - progressing **nominally**
  - ➢ After decontamination period (*16th Oct - 7th Nov 2017*), earth radiance (science) measurements started
  - ➢ Successful start of solar irradiance measurements (*15th Nov 2017*)
  - ➢ Solar diffuser-1 (QVD-1) bidirectional reflectance characterization campaign (*9th Jan – 6th Feb 2018*) – preliminary results show nominal degradation. Solar diffiuser-2 (QVD-2) on-going (*started 26th Feb 2018*)
- ✓ Implementation of enhancements for the processors deliveries at end of Phase E1 - Ongoing
- ✓ Data access: Only phase E1 support teams & algorithm developers. Cal/Val teams (mid-March)

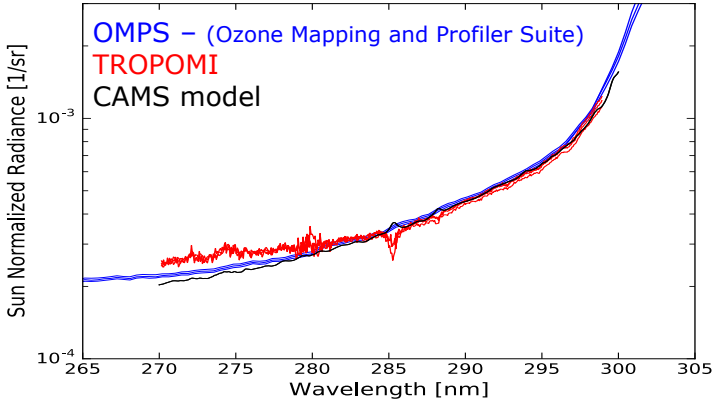
Sentinel-5 Precursor Cal/Val status



S5P CAL/VAL activities: **MPC** (Mission Performance Centre) x Cal/Val (operational by end of Phase E1); **S5PVT** (S5P Validation Team) x independent contribution to Validation.

Calibration status: overall in good shape. Current focus on:

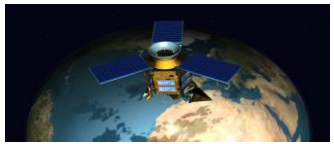
- ✓ Reflectance: band 1 seems too high (see plot)
- ✓ Radiance: occasional saturation over cloudy scenes on tropical areas. Possible change in along-track resolution: **7 → 5.5 Km**
- ✓ NIR Out Of Band (OOB) stray light: correction in place, but accuracy to be validated during Phase E1



Validation status: **Preliminary results** within Phase E1 team tasks. Activities by MPC & S5PVT starting Mid March 2018.

- ✓ UV Aerosol Index: no outstanding issues
- ✓ Aerosol Layer Height: known issues (pixel selection to be improved)
- ✓ O_3 Profile: known issues (bias identified)
- ✓ NO_2: Known issues (FRESCO cloud pressures, DOAS fit iterations)
- ✓ CO: Known issues (minor stripes, differences with prototype algorithm)
- ✓ CH_4: known issues (data filtering problem)
- ✓ Clouds: impact of stray light and inter-band co-registration ongoing
- ✓ O_3: (OFFL) performance improvement ongoing; (NRT) production starting mid-March
- ✓ Tropospheric column O_3: no outstanding issues
- ✓ SO_2: no outstanding issues
- ✓ HCHO: no outstanding issues
- ✓ Suomi NPP Clouds: no outstanding issues

Sentinel-5 Precursor Products Release Plan



S5P Data Provision plan to the public

- ✓ **Launch +8 months** - Level-1B; Total Columns of Ozone (O_3), Sulphur Dioxide (SO_2), Nitrogen Dioxide (NO_2), Carbon Monoxide (CO); Cloud & Aerosol information
- ✓ **Launch +10 months** - Total Columns of Tropospheric Ozone (O_3), Formaldehyde (HCHO)
- ✓ **Launch +12 months** - Total Columns of Methane (CH_4)
- ✓ **Launch +14 months** - Aerosol Layer Height, Ozone (O_3) Profiles

Quality Working Group (QWG)

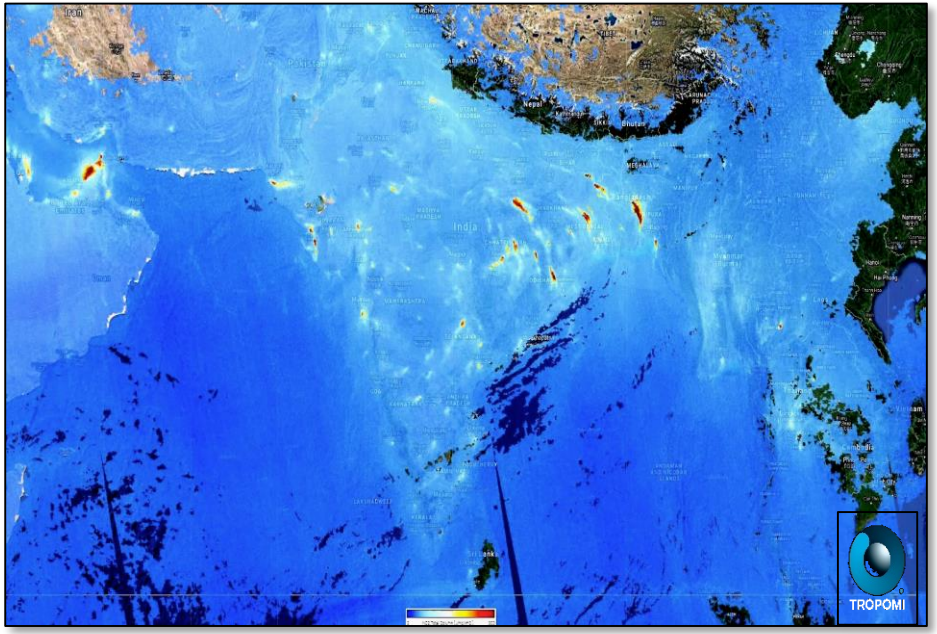
- ✓ Kicked-Off (KO): 7th February 2018
- ✓ First meeting: 25th-26th June 2018, focused on products of first release (Launch + 8 months)

Sentinel-5 Precursor (S5p) mission status

Air Quality monitoring / Climate monitoring

Air Quality Monitoring:

Nitrogen Dioxide (NO2) over India (17-28 Feb. 2018)



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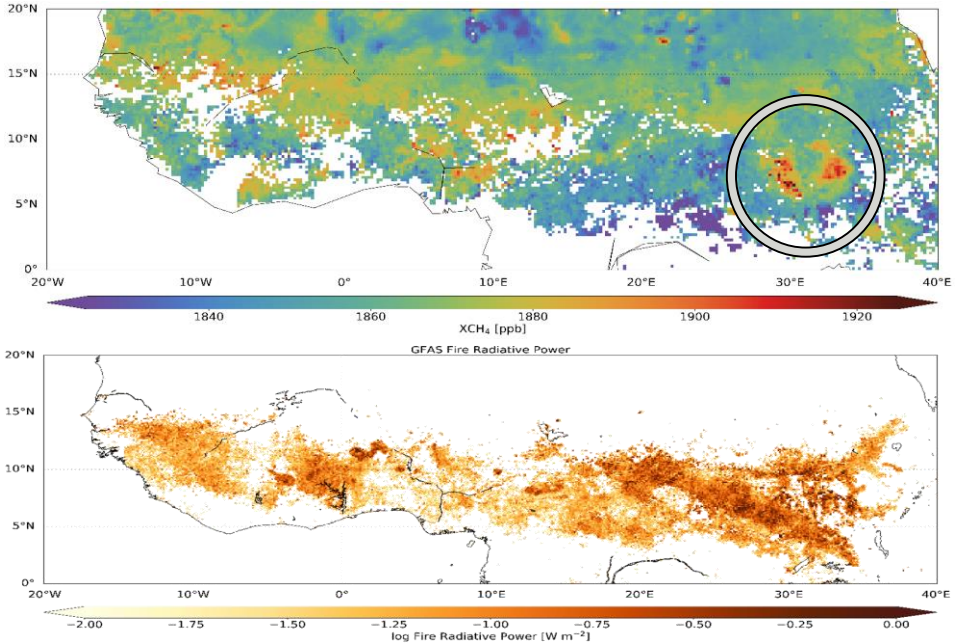
Climate Monitoring:

Methane emissions by fires and wetlands (circle) over Africa



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TROPOMI CO vertical column densities (averaged from 9.11 - 22.11.2017)