# ESA & EUMETSAT EO Activities

C. Retscher (ESA) & F. Fierli (EUMETSAT)

Fourth Joint School on Atmospheric Composition

**28 Sept – 6 October 2022**



Copernicus Europe's eyes on Earth · ECMWF · Atmosphere Monitoring Service atmosphere.copernicus.eu · EUMETSAT · esa

# Outline

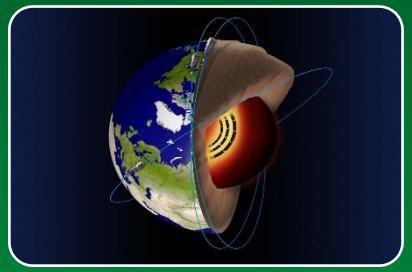
1. Satellite Missions Overview
2. Atmosphere Heritage Instruments
3. Atmosphere Today
4. Future Atmosphere

# 1. Satellite Missions Overview

# ESA EOP builds user-driven Missions

## Member States

### Earth Explorers



Defined by science partners in Member States through Open Calls

## EU

### Copernicus

## EUMETSAT

### Meteorology

## Industry

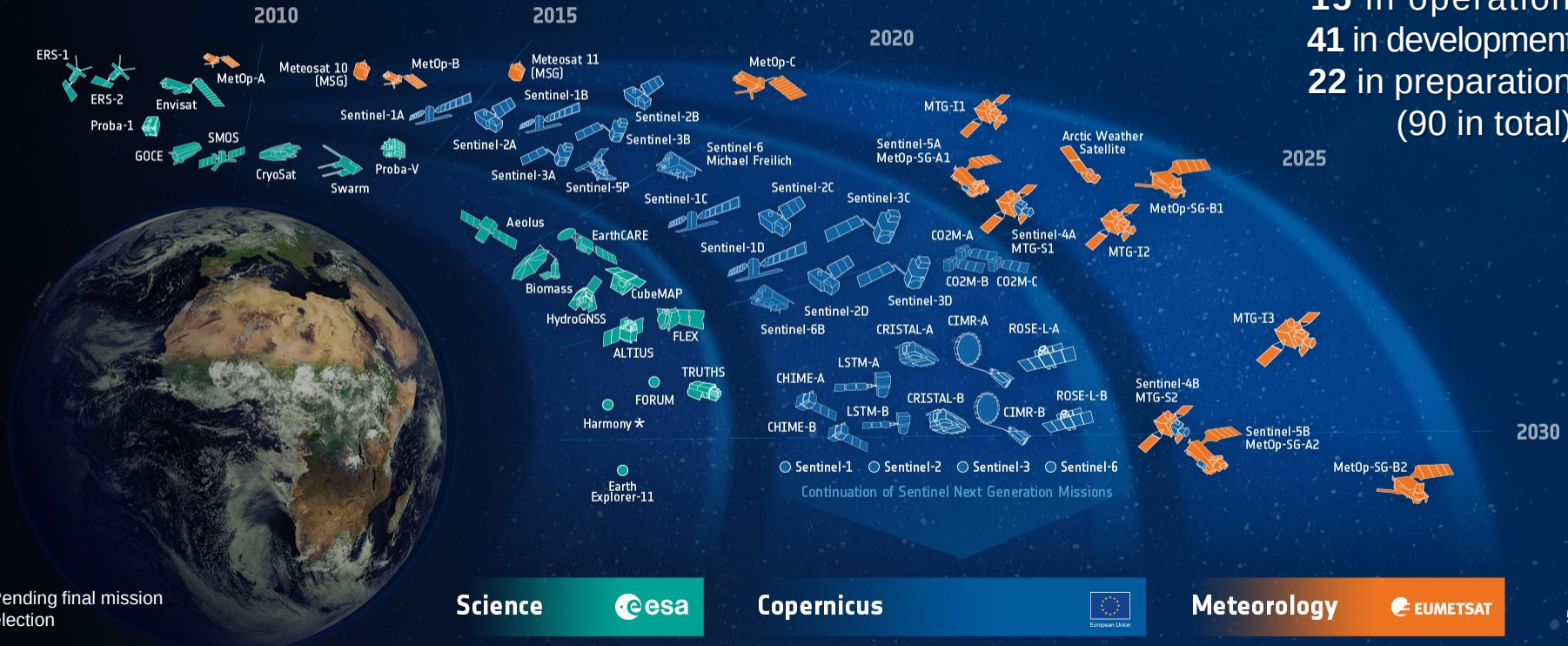
### InCubed

- Objectives come from partners & industry
- Mission Definition by ESA with industry, partners & users involved

# ESA's Earth Observation Mission

## Satellites

**12** in heritage
**15** in operation
**41** in development
**22** in preparation
(90 in total)




*Pending final mission selection

Science esa | Copernicus | Meteorology EUMETSAT



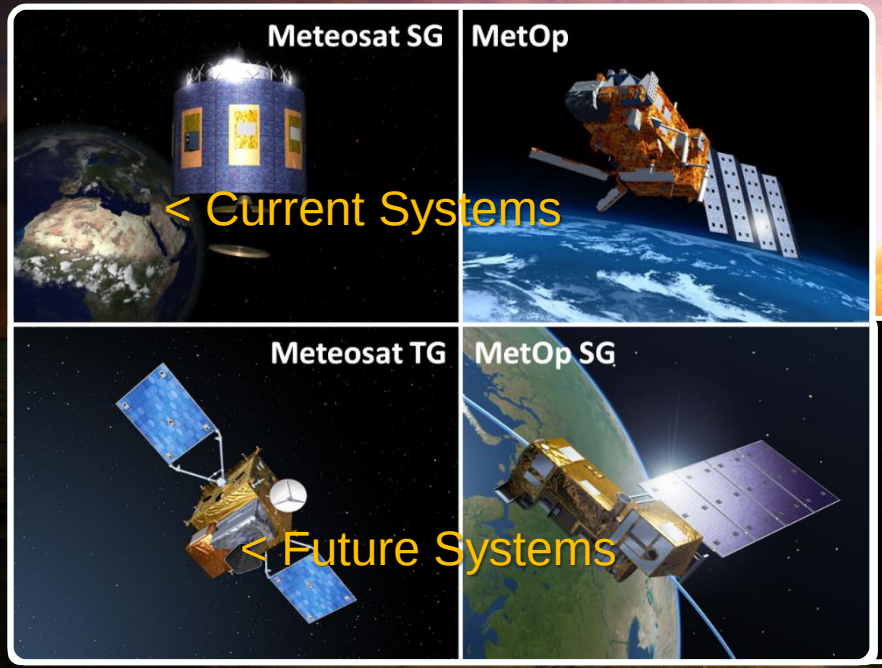
→ THE EUROPEAN SPACE AGENCY

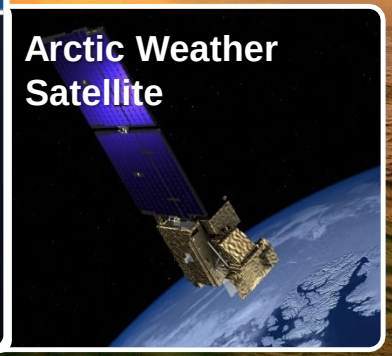
# Earth Explorers


→ THE EUROPEAN SPACE AGENCY

# Meteorology

**Meteosat (GEO) and MetOp-A/B/C (LEO) Series: weather forecasting and climate monitoring**



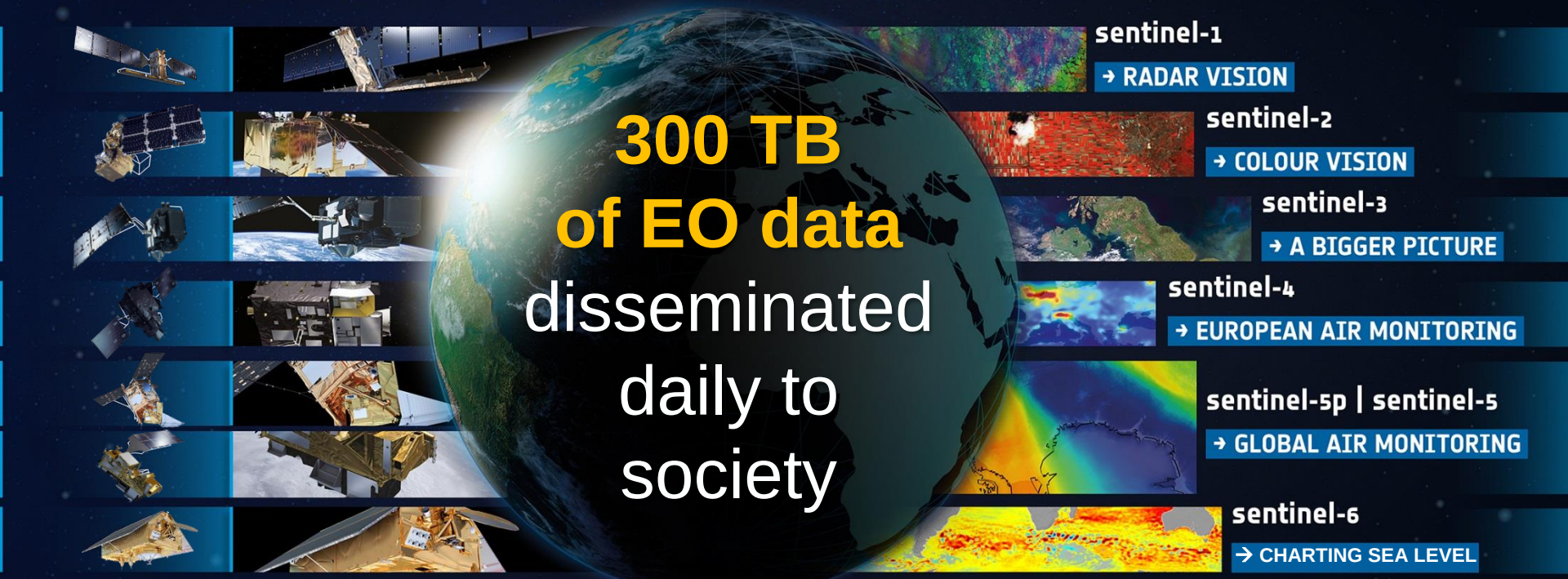

**Metop Second Generation (Expected launch MetOpG-SG A1/B1/A2/B2 2024/25/31/32)**

**Meteosat Third Generation Imaging & Sounding (Expected launch MTG-I1/2/3 2022/25/32 - MTG-S1 2024)**
**Unique combination of novel products for "nowcasting" high impact weather and air quality**

**Arctic Weather Satellite Prototype (Expected launch 2024)**

- **Operational microwave meteorology over polar regions**
- **Improving Arctic and global weather forecasts**

# Copernicus Sentinels (First Generation)



# Initial CSC Evolution

## Current & New Sentinels

**S1** → C-band SAR

**S2**, **S8**, **S10** → MSI (VNIR/SWIR Imaging); TIR Imaging; Hyper-Spectral

**S3** → Altim. + opt. in SSO → OPT, TOPO

**S6** → Reference Altim.

**S9** → Altimetry ice snow

**S4**, **S5P, S5**, **S7** → GEO; LEO; CO2

## Next Generation

C-band SAR NG
L-band SAR
Low-frequ. (eg L/C-band) radiometers
→ **S1 NG**

MSI+TIRI NG
Hyper-spectral NG
OLCI+SLSTR NG
→ **S2+S3 NG**, **GEO**

ALT in SSO NG
ALT reference NG
ALT ice snow NG
→ **TOPO**

LEO / CO2 + …
→ **ATM**

Candidates to be verified through requirements process
(+ observations optimisation through architecture studies)

## EO Capability

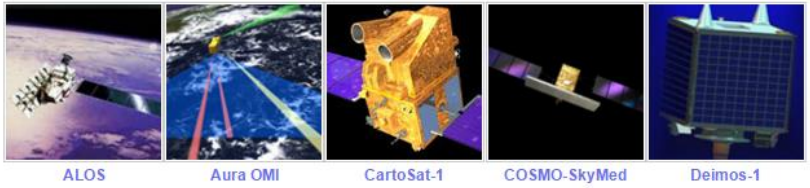
*Earth Microwave (4D) Imaging*

*Earth Optical Imaging*

*Earth Topography by Altimetry*

*Earth Atmosphere by Spectroscopy*

# ESA Third Party Missions


ALOS | Aura OMI | CartoSat-1 | COSMO-SkyMed | Deimos-1

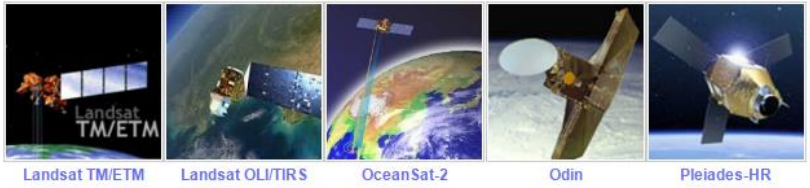

Proba-1 | Proba-V | QuickBird | QuikSCAT | RADARSAT-2


Deimos-2 | GeoEye-1 | GOSAT | GRACE | IKONOS


RapidEye | ResourceSat-1 | ResourceSat-2 | SciSat-1/ACE | SeaSat


IRS-1C | IRS-1D | JERS-1 | KOMPSAT-1 | KOMPSAT-2


SPOT | TerraSAR-X and TanDEM-X | UK-DMC | WorldView-1 | WorldView-2



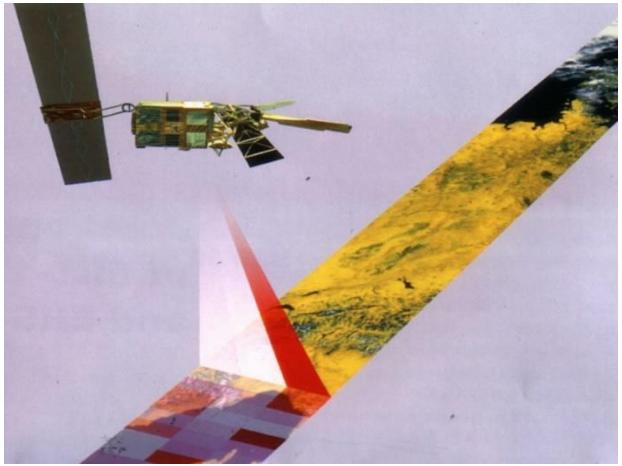
Landsat TM/ETM | Landsat OLI/TIRS | OceanSat-2 | Odin | Pleiades-HR

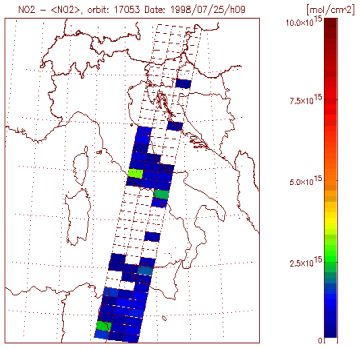

WorldView-3

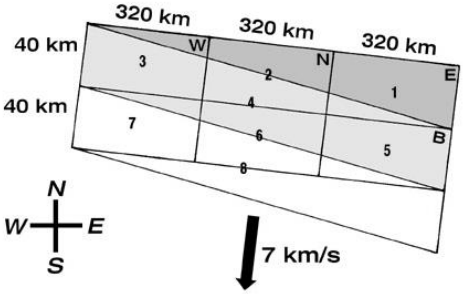
Data access:
https://earth.esa.int/eogateway/search?text=&category=Missions&subFilter=Third%20Party%20Missions

# 2. Atmosphere Heritage

# ERS-2 Global Ozone Monitoring Experiment (GOME)

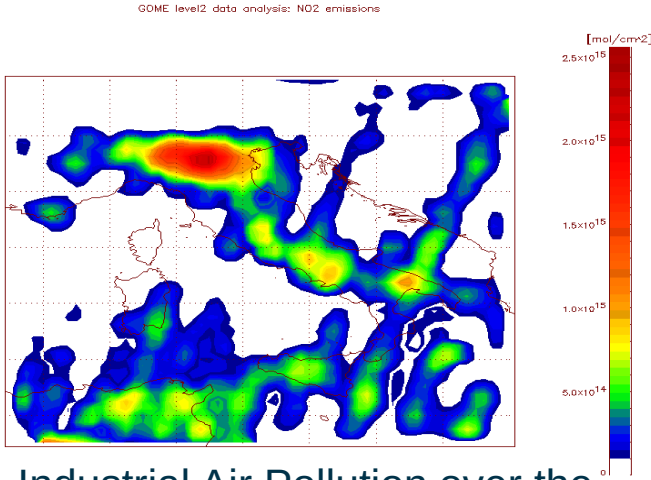





Nadir viewing spectrometer: GOME on ERS-2 **launched 1995** operational for 16 years; later similar instruments are SCIAMACHY and GOME-2

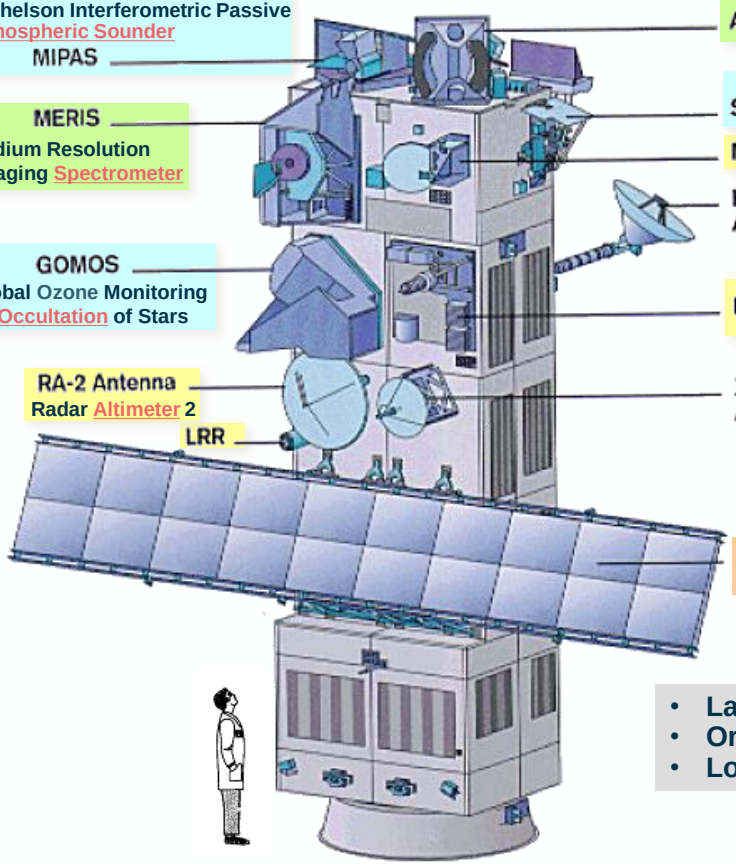
- **Spectral Coverage:** 240 - 790 nm
- **Spatial Resolution:** 40 x 320 km, global coverage 3d




Industrial Air Pollution over the Mediterranean Sea derived from GOME $NO_2$ measurements – Credits: EMPA

- **Single Acquisition (left):** 25/07/1998 NO2
- **3 months average (right):** June - August 1998

# ENVISAT



Michelson Interferometric Passive Atmospheric Sounder
MIPAS

MERIS
Medium Resolution Imaging Spectrometer

GOMOS
Global Ozone Monitoring by Occultation of Stars

RA-2 Antenna
Radar Altimeter 2

LRR

AATSR Advanced Along Track Scanning Radiometer

SCIAMACHY Scanning Imaging Absorption Spectrometer for Atmospheric Cartography

MWR Microwave Radiometer

Ka-band Antenna → *to Data Relay Satellite Artemis*

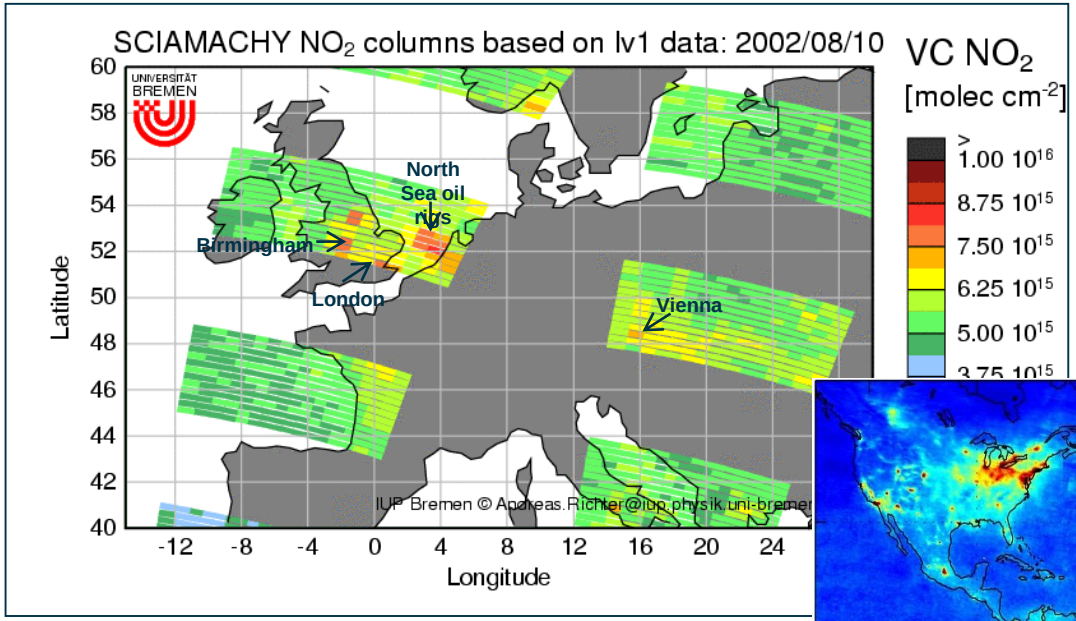
DORIS Doppler Orbitography and Radio-positioning Integrated by Satellite

X-band Antenna → *to Ground Stations*

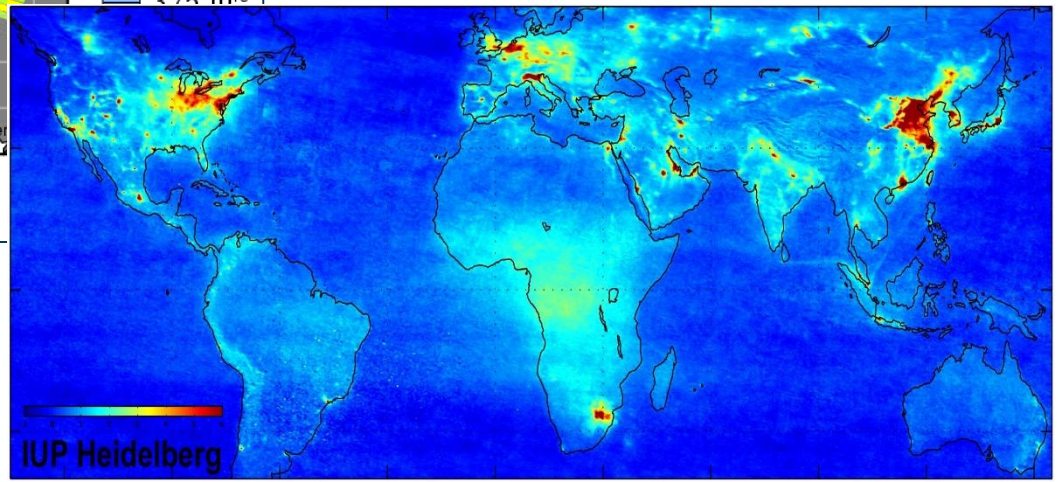
ASAR Antenna Advanced Synthetic Aperture Radar

- **Launch**: 1st **March 2002**
- **Orbit: 800 km**, sun synchronous, 10:00 am, i.e. 30 min. before ERS-2
- **Lost contact in 2012**

# SCIAMACHY $NO_2$ measurements



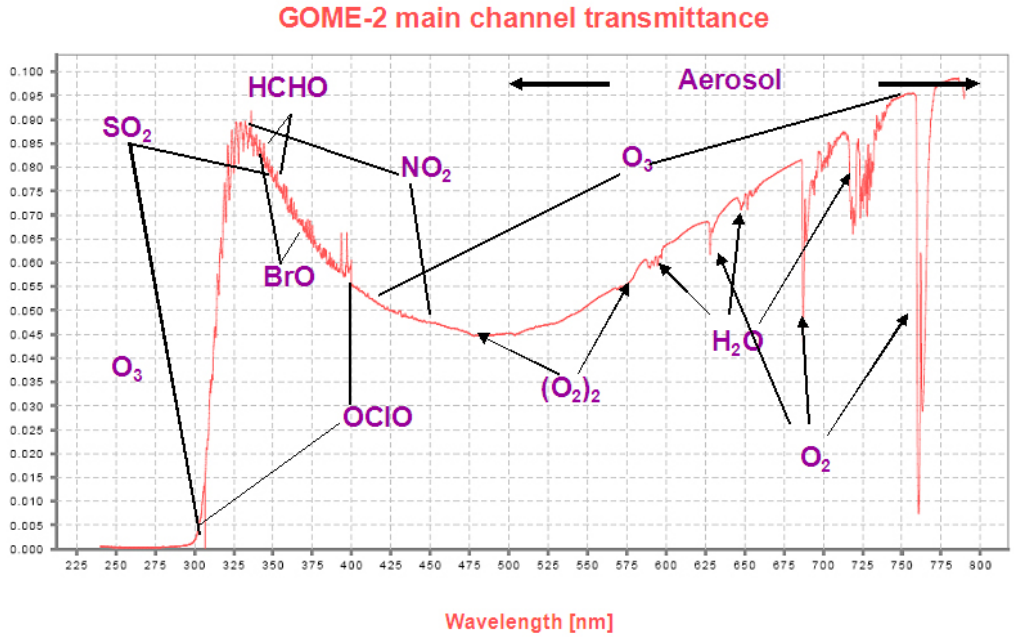

SCIAMACHY Nitrogen Dioxide ($NO_2$) Measurements averaged over 18 months (mid 2002 – end 2003)




**NO2 -> Air pollution**

# Other instruments (still in operation)

- GOME-2 -> EUMETSAT




OMI -> NASA

## Key Facts

OMI is a nadir-viewing wide-field-imaging spectrometer, giving daily global coverage.

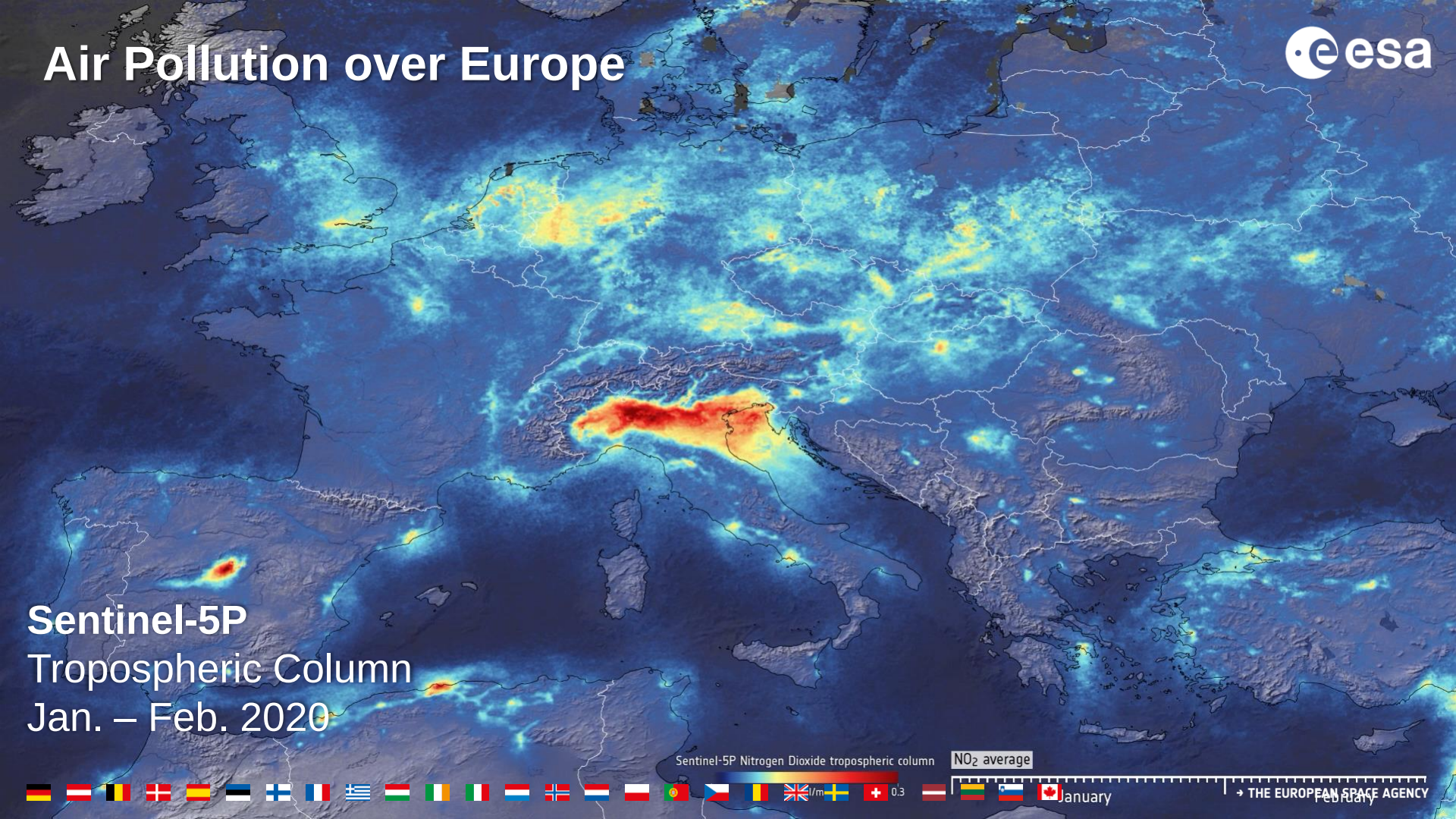
OMI measures the key air quality components such as nitrogen dioxide($NO_2$), sulfur dioxide ($SO_2$), bromine oxide(BrO), OClO, and aerosol characteristics.

OMI provides mapping of pollution products from an urban to super-regional scale.

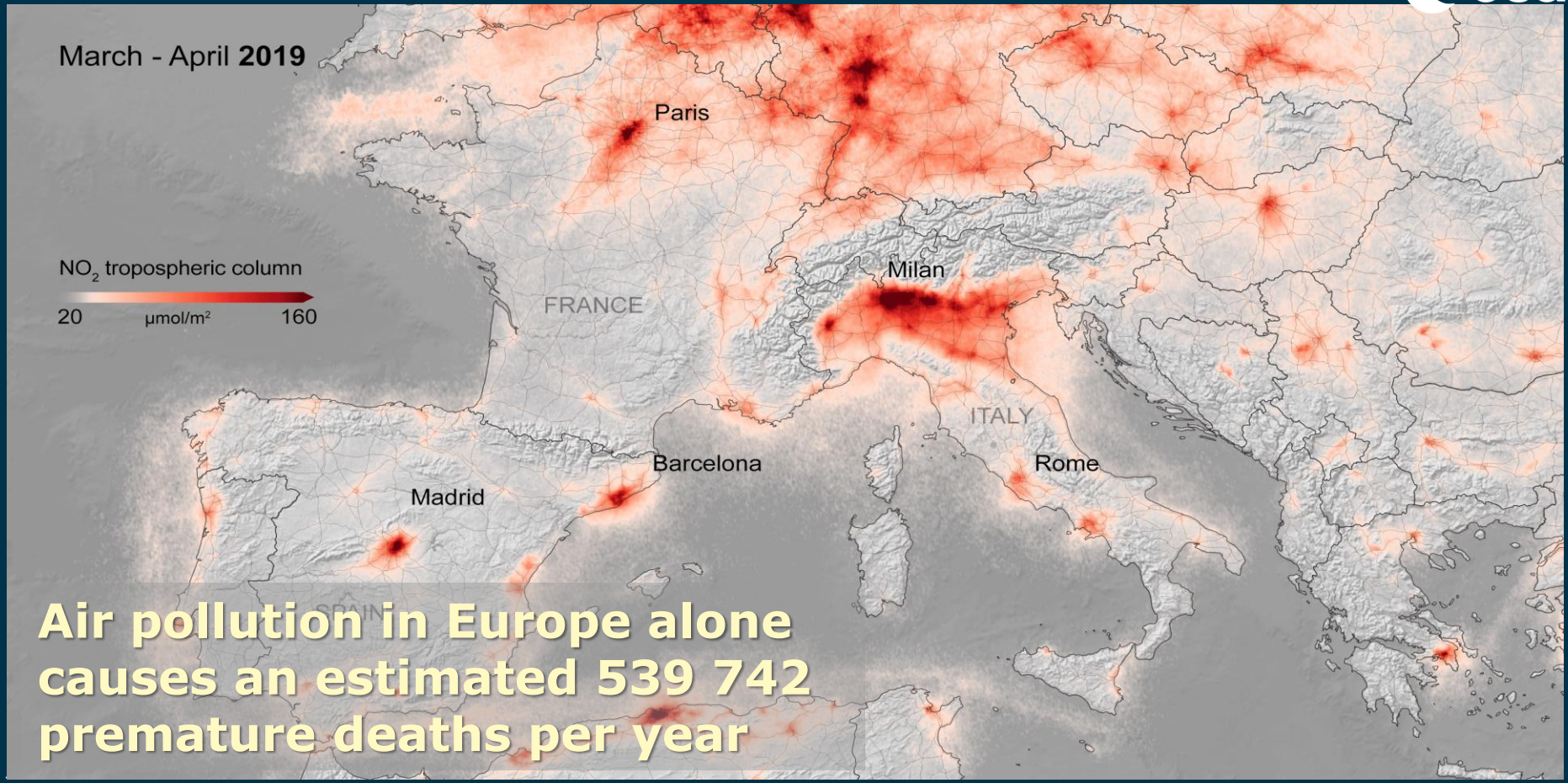
# 3. Atmosphere Today

# Sentinel-5P

- Launched: 13 October 2017
- Single Payload: TROPOMI (co-funded by NL and ESA)
- Hyper-spectral push-broom imaging spectrometer
- Orbit altitude: 820 km
- Daily Global Coverage: 13:30 ascending node crossing time
- Spatial Sampling: in nadir 5.5 x 3.5 km
- Mission Design Life Time: ~7 years


Air Pollution over Europe
esa
Sentinel-5P
Tropospheric Column
Jan. – Feb. 2020
Sentinel-5P Nitrogen Dioxide tropospheric column
$NO_2$ average
0.3
January
February
→ THE EUROPEAN SPACE AGENCY

# AIR POLLUTION

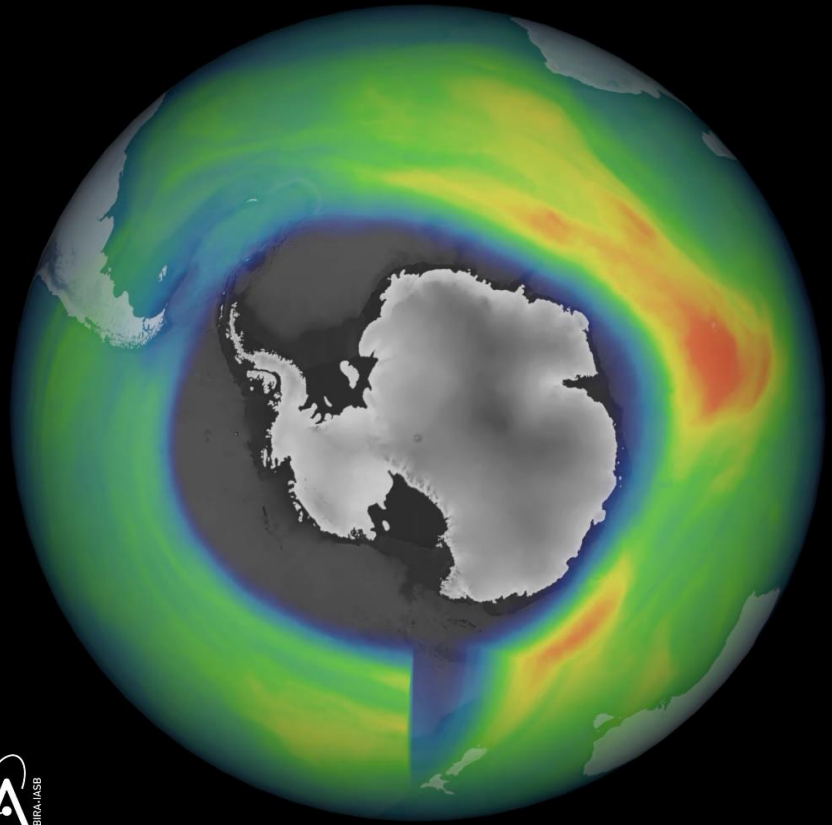



**Air pollution in Europe alone causes an estimated 539 742 premature deaths per year**

# Energy: Large ozone hole over the Antarctic

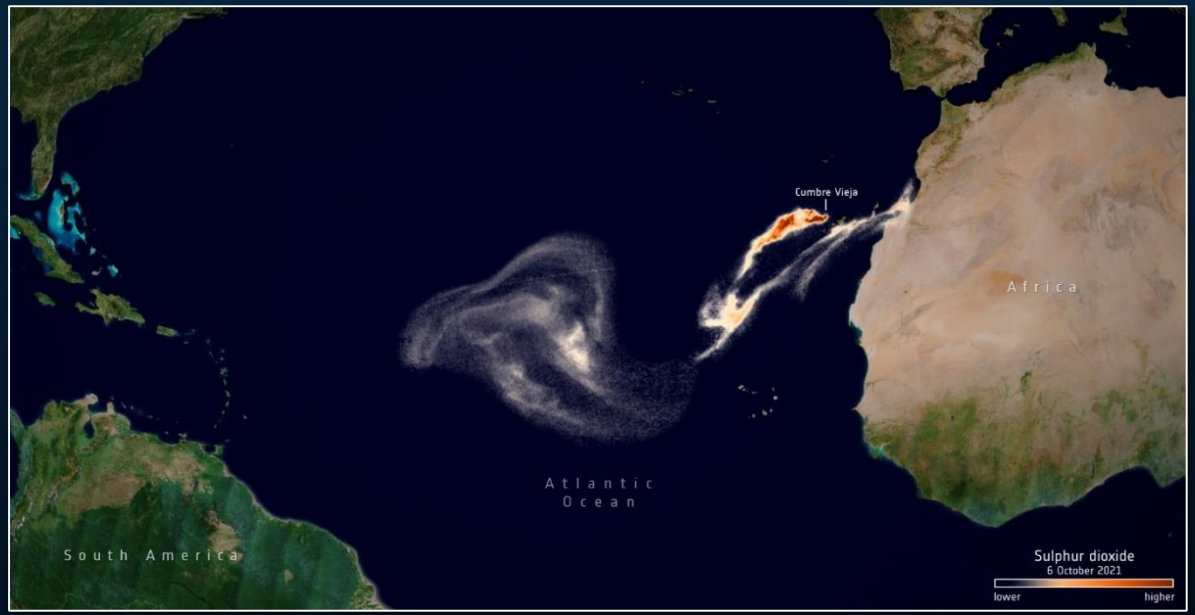
Sentinel 5P
**TROPOMI**
**DAILY OZONE**
25-09-2020

## Sentinel-5P




DLR – Earth Observation Center (EOC)

# Sentinel-5p Applications: Measuring Volcanic SO2 Emission




***Sentinel-5P Volcanic Sulphur Dioxide (SO2) Emission Measurements***
***6 October 2021***

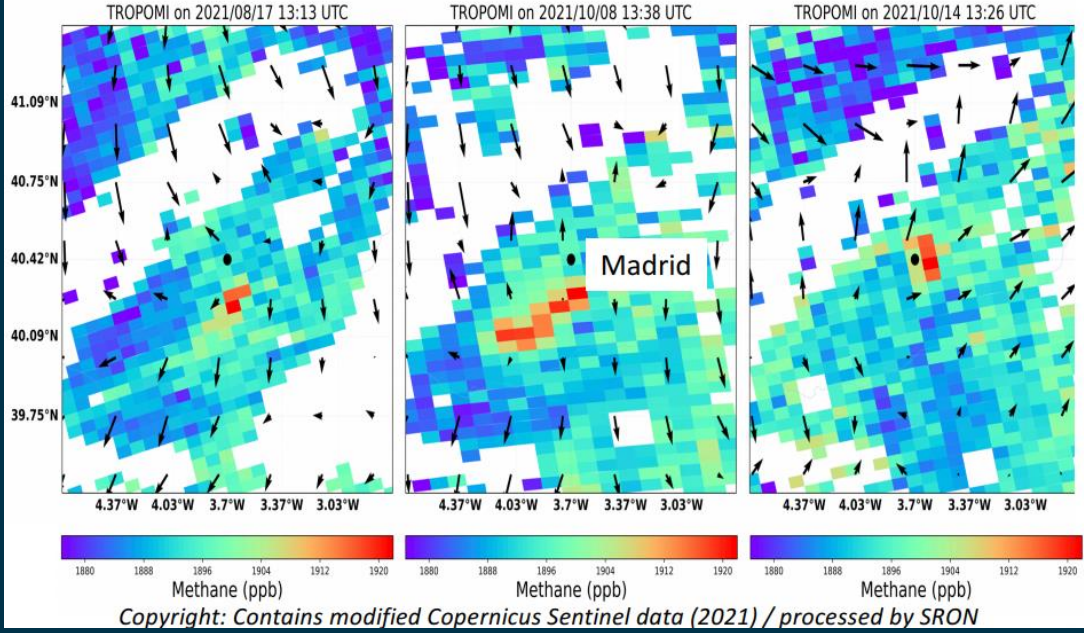
***La Palma volcano: How satellites help us monitor eruptions***

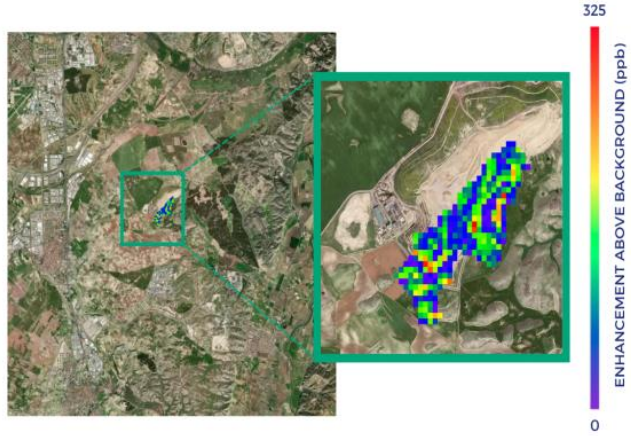
https://www.esa.int/Applications/Observing_the_Earth/Copernicus/La_Palma_volcano_How_satellites_help_us_monitor_eruptions

# Sentinel-5p Applications: Methane (CH4)

## Methane Emissions from land fill close to Madrid

https://www.esa.int/Applications/Observing_the_Earth/Satellites_detect_large_methane_emissions_from_Madrid_landfills

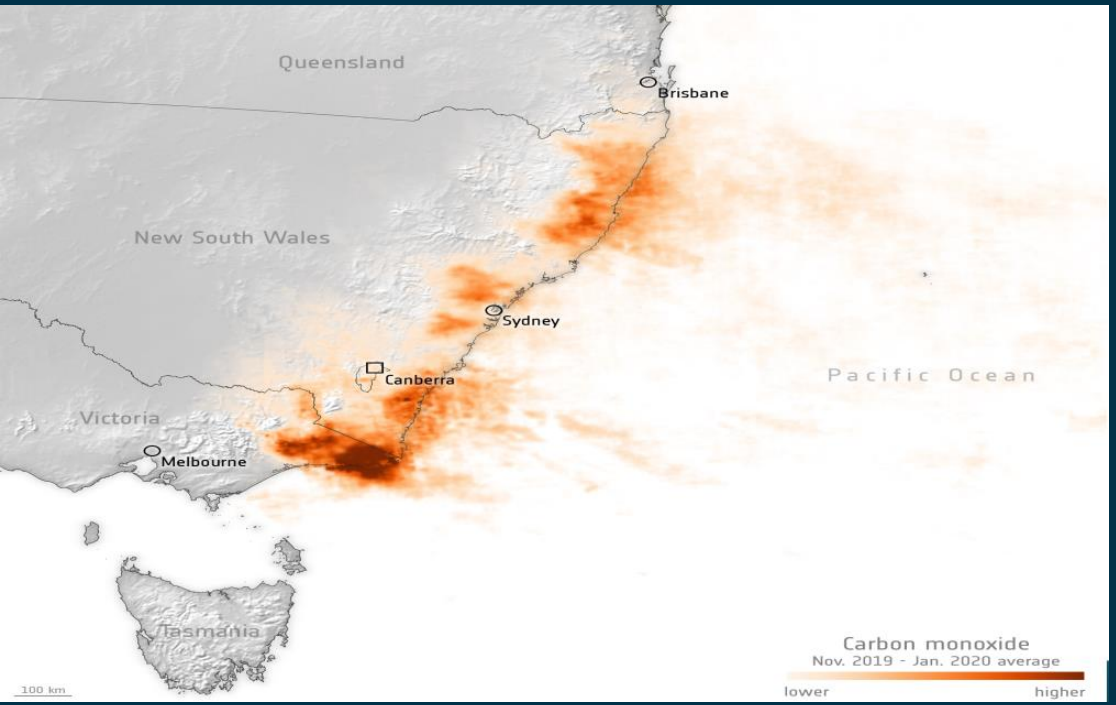



GHGSat Methane Measurements (Oct. 13 2021)
copyright GHGSat

*Copyright: Contains modified Copernicus Sentinel data (2021) / processed by SRON*

# Sentinel-5p Applications: CO




**Bush-Fire Emissions in Australia (Nov. 2019 – Jan. 2020) released CO equivalent to 715 million tonnes of CO2 in just three months**

van der Velde, I.R., van der Werf, G.R., Houweling, S. et al. Vast CO2 release from Australian fires in 2019–2020 constrained by satellite. Nature 597, 366–369 (2021). https://doi.org/10.1038/s41586-021-03712-y

https://www.esa.int/Applications/Observing_the_Earth/Aerosols_released_from_Australian_bushfires_triggers_algal_blooms

# Sentinel-5p+ Innovation: CHOCHO

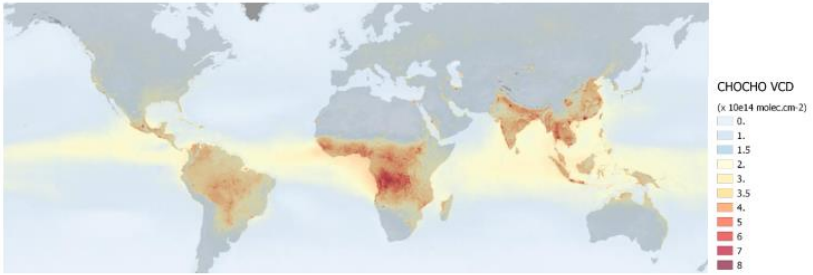
- Glyoxal is a key trace gas in **tropospheric chemistry** primarily due to its potential role of secondary organic aerosols (SOA) precursor, and to a lesser extent as it affects the abundance of tropospheric ozone (O3), a potent greenhouse gas.
- Sources are predominantly secondary, originating in the **oxidation** of **anthropogenic**, **pyrogenic** and **biogenic** volatile organic compound precursors (**VOCs**).
- Measurements from space offer the potential to provide information on **non-methane VOC** emissions at the global scale.
- Algorithm also applied to **OMI**, and **GOME-2A/B**. Excellent inter-satellite consistency vs **TROPOMI**
- Validation with **9 MAX-DOAS** data sets in Europe and Asia

CHOCHO

BIRA-IASB aeronomie·be

Universität Bremen

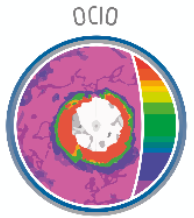
iup



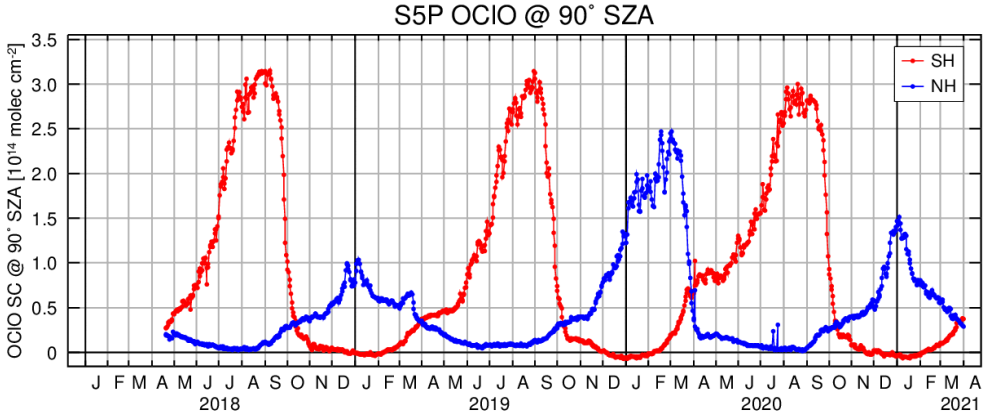

**TROPOMI CHOCHO tropospheric vertical columns – 2018-2020**

Lerot, C. et al., Glyoxal tropospheric column retrievals from TROPOMI – multi-satellite intercomparison and ground-based validation, Atmos. Meas. Tech., 14, 7775–7807, 2021, https://doi.org/10.5194/amt-14-7775-2021

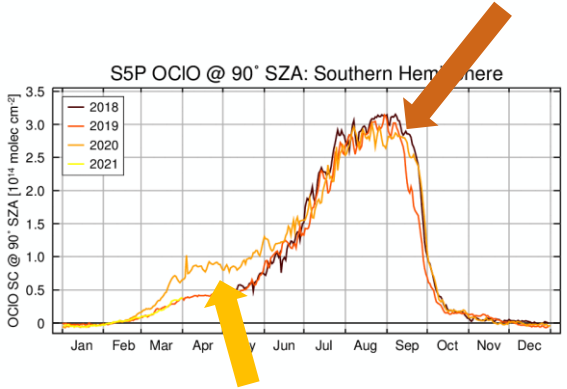
# Sentinel-5p+ Innovation: OClO




- OClO relates to the need to monitor **stratospheric chlorine activation** over time in order to document the continuing **effectiveness** of the measures taken in the **Montreal Protocol** and its amendments.
- While OClO observations do **not** provide a **direct measure** of stratospheric chlorine **concentrations**, they are an **indicator** of stratospheric **chlorine activation**.



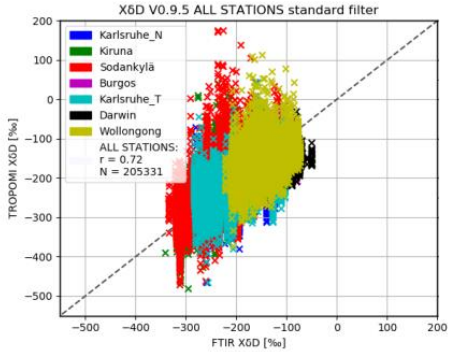

Early deactivation in **2019**

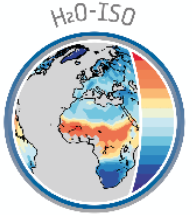



Early activation in **2020**

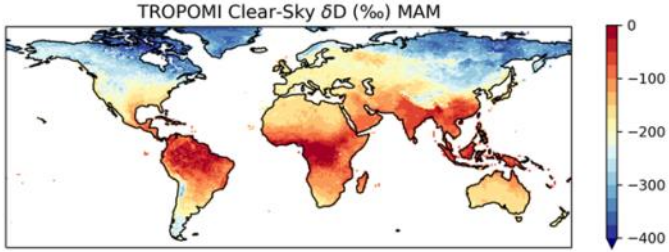
# Sentinel-5p+ Innovation: H2O-ISO

- The **water cycle** is key element of the Earth's climate system and insufficient understanding of **links** between **clouds**, **circulation** and **climate sensitivity** is one of the **grand challenges** in climate research. Water vapour **isotopologues** offer unique **possibilities** for investigating the **tropospheric water cycle**. With their ability to record the condensation and **rain-out history** of air masses, and to some extent **"tag" moisture** as it **travels** through the atmosphere, ocean, biosphere, and cryosphere, water isotopologue ratios provide insights into key circulation processes.
- **Comparisons** to **MUSICA IASI** data shows **no significant bias**;
- **Scientific impact** of H2O-ISO assessed against isotope-enabled models, MUSICA IASI and aircraft. H2O-ISO spatial and temporal coverage is highly useful for deciphering the interrelation of weather situations and the isotopic state of atmospheric water vapour, in particular in combination with other (infrared) satellite products.




Correlation of FTIR and TROPOMI XδD single pixel measurements (left) and daily means (right) with standard filtering around the FTIR stations.




H2O-ISO prototype product (v1.0.1) between June 2018 and May 2019 shown as 3-m averages after quality-filtering.

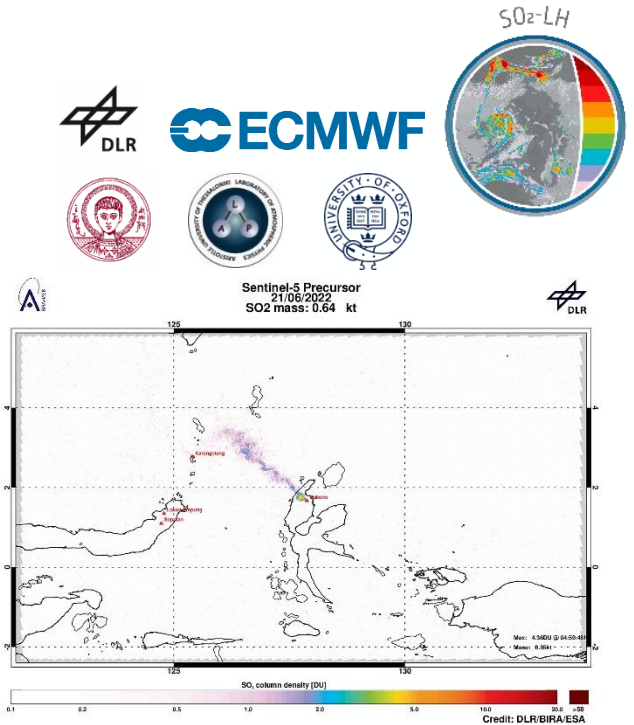
Diekmann, C. et al., A Lagrangian Perspective on Stable Water Isotopes During the West African Monsoon https://doi.org/10.1029/2021JD034895

# Sentinel-5p+ Innovation: SO2-LH

**Accurate determination** of the location, height and loading of **SO2 plumes** emitted by volcanic eruptions is essential for **aviation safety**. SO2-LH is furthermore one of the most critical parameters that determine the **impact** on the climate since SO2 in the atmosphere has **important** impacts on **chemistry** and **climate** at both local and global levels.

- SO2-LH retrieval is applied on an **hourly basis** to latest S5p NRT data
- **Latest results** of ongoing volcanic eruptions are automatically published via twitter: http://twitter.com/dlrso2
- **Excellent agreement** between IASI and TROPOMI $SO_2$ LH results
- Good agreement with CALIOP/CALIPSO LIDAR data
- $SO_2$ LH **assimilation** by **CAMS** yields significantly better $SO_2$ forecasts


- Koukouli, E. et al., Volcanic $SO_2$ layer height by TROPOMI/S5P: evaluation against IASI/MetOp and CALIOP/CALIPSO observations, Atmos. Chem. Phys., 22, 5665–5683, 2022, https://doi.org/10.5194/acp-22-5665-2022
- Inness, A. et al., Evaluating the assimilation of S5P/TROPOMI near real-time $SO_2$ columns and layer height data into the CAMS integrated forecasting system (CY47R1), based on a case study of the 2019 Raikoke eruption, Geosci. Model Dev., 15, 971–994, 2022, https://doi.org/10.5194/gmd-15-971-2022


Enhanced SO2 signal of 4.36DU at a distance of 14.0km Dukono (Indonesia)

# Sentinel-5p+ Innovation: AOD/BRDF

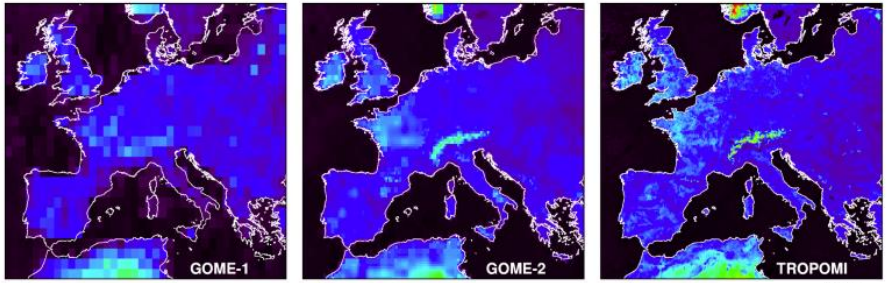
Koninklijk Nederlands Meteorologisch Instituut
Ministerie van Infrastructuur en Waterstaat

GRASP Catalysts
software is our passion

esa AOD-BRDF

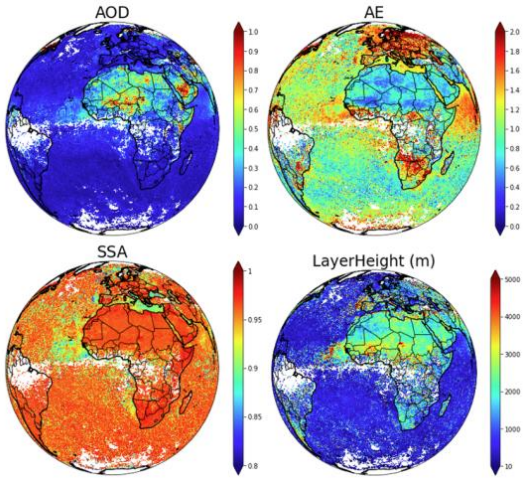
| Algorithms | Spectral range | Products | Coverage | End Users |
|---|---|---|---|---|
| **Heritage AOD** | UV,VIS | *Aerosol*:<br>1. AOD<br>2. SSA | Daily | 1. Aerosol community<br>2. Trace gases community |
| **DLER** | UV, VIS, NIR, SWIR | *Surface*:<br>1. DLER<br>2. LER | Monthly climatological | 1. Trace gases community<br>2. Aerosol and Cloud community<br>3. Earth surface community<br>4. TROPOMI L2 data processor and processing |
| **GRASP** | UV, VIS, NIR, SWIR | *Aerosol*:<br>1. AOD<br>2. AODf and AODc<br>3. AExp<br>3. SSA<br>4. AAOD<br>5. Concentration for four major aerosol type: Biomass Burning, Sulphates, Oceanic and Dust<br><br>*Surface (land and sea/ocean)*:<br>1. Full BRDF<br>2. DHR (Black Sky Albedo)<br>3. BHR_iso (White Sky Albedo) | 1. Instantaneous daily<br>2. Monthly for each year | 1. Aerosol and Cloud community<br>2. Trace gases community (when accurate aerosol and full BRDF is crucial)<br>3. Earth surface cover and climate studies<br>4. Climate studies modelling community |

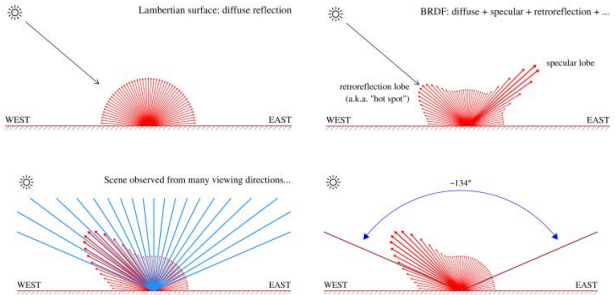
## DLER: 0.125 deg2 spatial resolution




Surface LER in March over Europe according for GOME-1, GOME-2, and TROPOMI

Example of TROPOMI/GRASP products of aerosol characteristics.



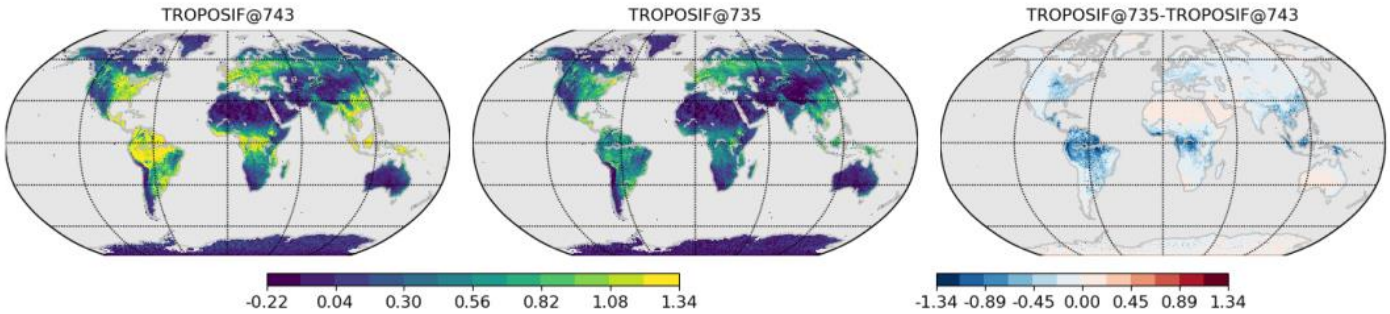




Heritage products

- AOD: OMAERUV and OMAERO 340 – 494 nm, 0.2 nm
- DLER 21 one-nm wide wavelength bins between 328 - 2314 nm

# Sentinel-5p+ Innovation: SIF

- Solar-induced chlorophyll fluorescence (SIF) is signal emitted by the **chlorophyll-a** of assimilating plants: part of the **energy** absorbed by chlorophyll is **not used** for **photosynthesis**, but emitted at longer wavelengths as a two-peak spectrum roughly covering the **650–850 nm spectral range**.
- SIF **responds** to perturbations in **environmental conditions** such as **light** and **water stress**, which makes it a direct proxy for photosynthetic activity.
- TROMPI SIF data at 740 nm and estimated from two fitting windows:
  - 743–758 nm (baseline product, aka Caltech). Very robust results against atmospheric effects (especially cloud contamination).
  - 735–758 nm (experimental product

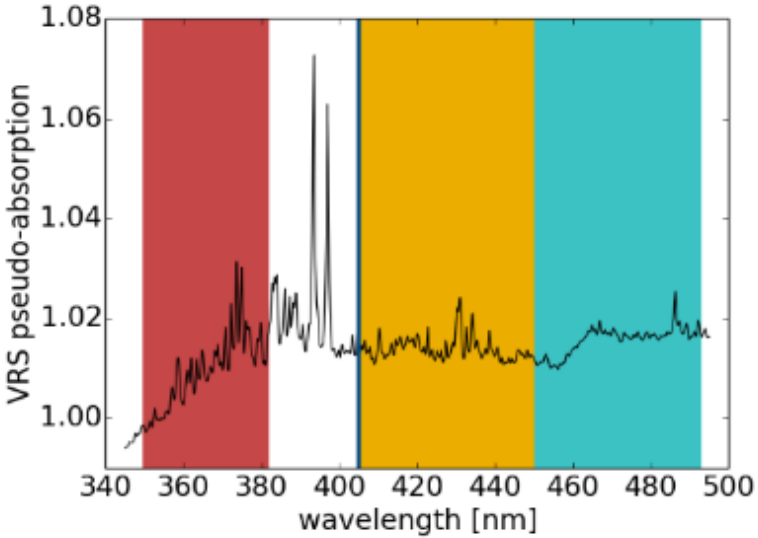




At global scale **very close** agreement of three SIF products. Higher **agreement** between the 2 TROPOMI products (**TROPOSIF** and **Caltech**) than with **OCO-2**, which is partly attributable to similar samplings for the two TROPOMI products and higher number of observations within the binned pixels that reduces the retrieval error. In addition, OCO-2 SIF estimates were found to be in slightly closer agreement with TROPOSIF than with Caltech.

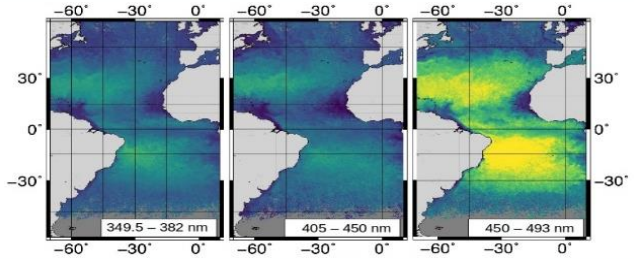
# Sentinel-5p+ Innovation: Ocean Color

- **Highly innovative: First time that KD retrievals for the UV range from satellite data and inversion are developed**
- Algorithm for KD within UV-AB, UV-A and blue light developed for TROPOMI using DOAS method via retrieving vibrational Raman scattering (VRS) and LUT based on coupled ocean-atmospheric RTM
- Uncertainty was assessed via fit error and model error based on retrieval sensitivity
- PP evaluated across the biogeochemical provinces of the Atlantic Ocean with in-situ data and similar (these only provide KD at 490nm!) operational products from OC-CCI and OLCI



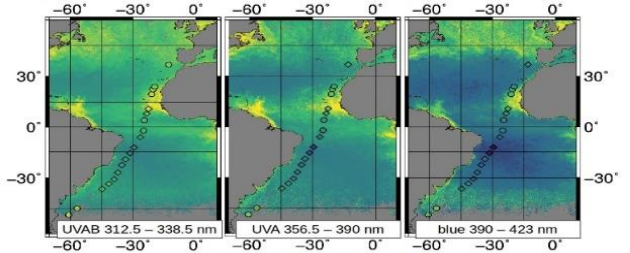

OCEAN COLOUR

**S5P Inelastic Scattering (VRS) in Ocean Water**




LUT (RTM)

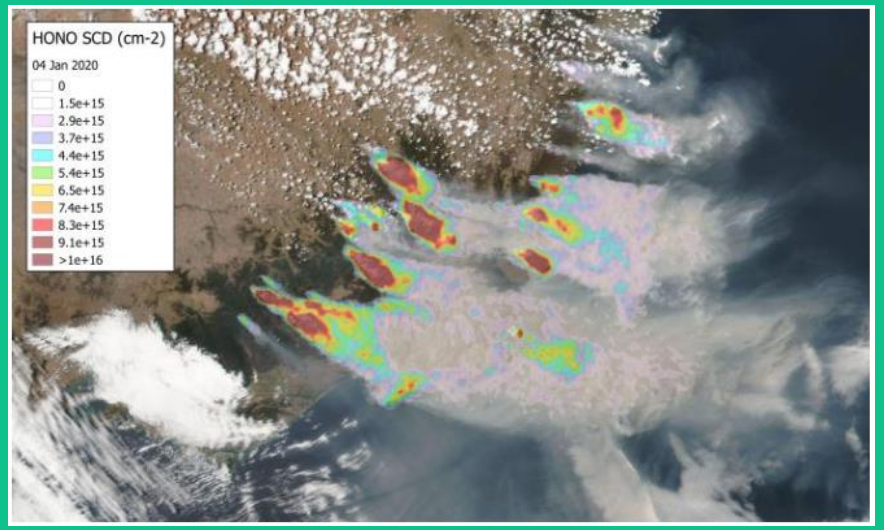
**S5P Diffuse attenuation (KD) in Ocean Water**



# Atmosphere Science Cluster: HONO DINAR

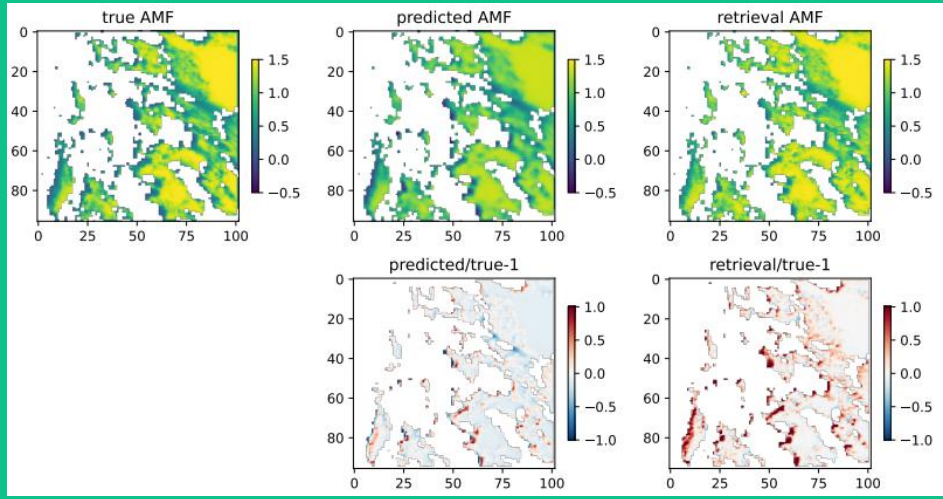
- **Nitrous acid** (HONO) is a key atmospheric species primarily due to its role as a source of **hydroxyl radicals** (OH) through its rapid **photolysis**. OH is the atmosphere's primary oxidant: it plays a central role in **breaking** down **pollutants** and **greenhouse gases**, and at the same time, it is a key ingredient to **photochemical smog** and **ozone** formation;
- The DINAR project addresses the need for highly sensitive, mature and easily accessible **HONO space-based** data. DINAR aims at developing HONO products from multiple and complementary satellite payloads including polar-orbiting and geostationary platforms, operating in the ultraviolet-visible (**TROPOMI**, **OMI**, **GEMS**) and thermal infrared (**IASI**, **GIIRS**) spectral ranges.
- KO 2022/03, 24 m

Example of TROPOMI observations of HONO slant columns from wildfires in Australia on January 4, 2020. The background layer is an RGB image from VIIRS/SuomiNPP.



# Atmosphere Science Cluster: MIT3D -> 3DCTRL
# 3D Cloud Impact Mitigation

- **Explore existing synthetic TROPOMI-S5P** data from a previous ESA study using artificial intelligence;
- **3D radiative transfer** model MYSTIC;
- As input, realistic simulated clouds over Europe and surrounding countries;
- The data-set includes reflectance spectra in the visible range; from 400–500 nm and in the O2A band region around 768 nm;
- The **synthetic data** has been **analyzed** with a **state-of-the-art NO2 retrieval** algorithm;
- The input NO2 vertical column density (VCD) is known, therefore the retrieval error due to cloud scattering could easily be determined;
- **CNN trained** to predict air mass factors (**AMF**) from reflectance data;
- Example that in the **clear regions** the CNN seems to **underestimate** the AMFs. In **cloudy regions** the relative **differences** are slightly **smaller** for the CNN predictions than for the AMFs from the retrieval algorithm;
- Results **can't** be **generalized** so far.

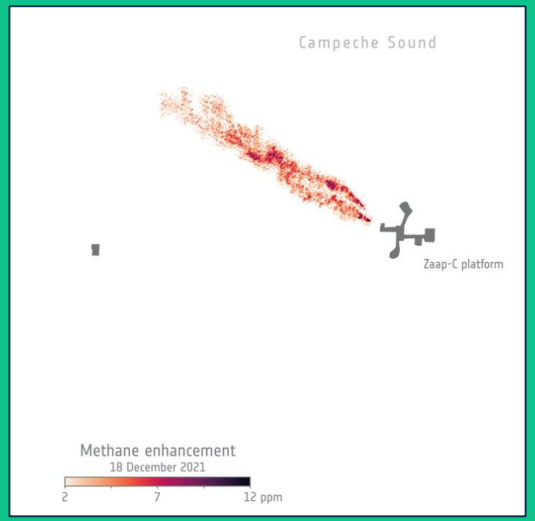



NILU, BIRA

# Atmosphere Science Cluster: HiResCH4

## Methane emissions: offshore platform in the Gulf of Mexico

- Universitat Politècnica de València (UPV), used data from Maxar's **WorldView-3** satellite, obtained through ESA's Third Party Missions Programme, and US **Landsat 8** mission to detect and quantify strong methane plumes from an offshore oil and gas production platform near the coast of Campeche – in one of Mexico's major oil producing fields. 17-day ultra-emission event which amounted to approximately **40 000 tonnes** of methane released into the atmosphere in **December 2021**.
- These emissions are equivalent to around 3% of Mexico's annual oil and gas emissions and this single event would have a similar magnitude to the entire regional annual emissions from Mexico's offshore region.



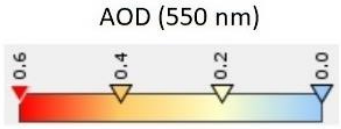

- https://eo4society.esa.int/projects/hiresch4/
- https://www.esa.int/Applications/Observing_the_Earth/Methane_emissions_detected_over_offshore_platform_in_the_Gulf_of_Mexico
- https://www.reuters.com/business/environment/scientists-find-massive-methane-leak-pemex-gulf-mexico-oil-field-paper-2022-06-09/

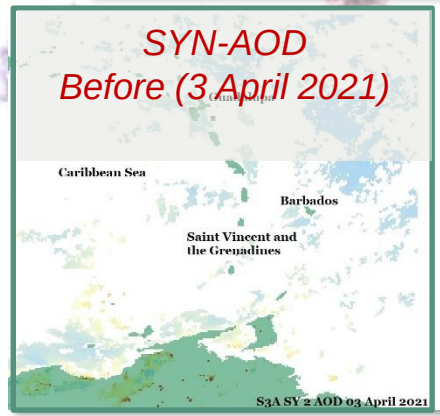
# Aerosols from “La Soufrière” volcano in Saint-Vincent

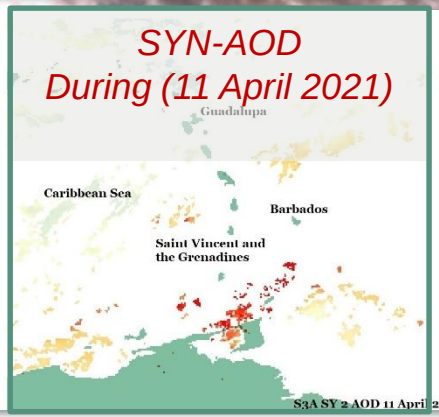
The new **Sentinel-3 SYN-AOD products** are available since 8 April 2021 through the ESA Open Access Hub (for data starting on 19 February 2020)

Data below show the sharp increase of aerosols immediately after the eruption of La Soufrière volcano, and how it diffuses some day later.

Sentinel-3 OLCI image
(11 April 2021)



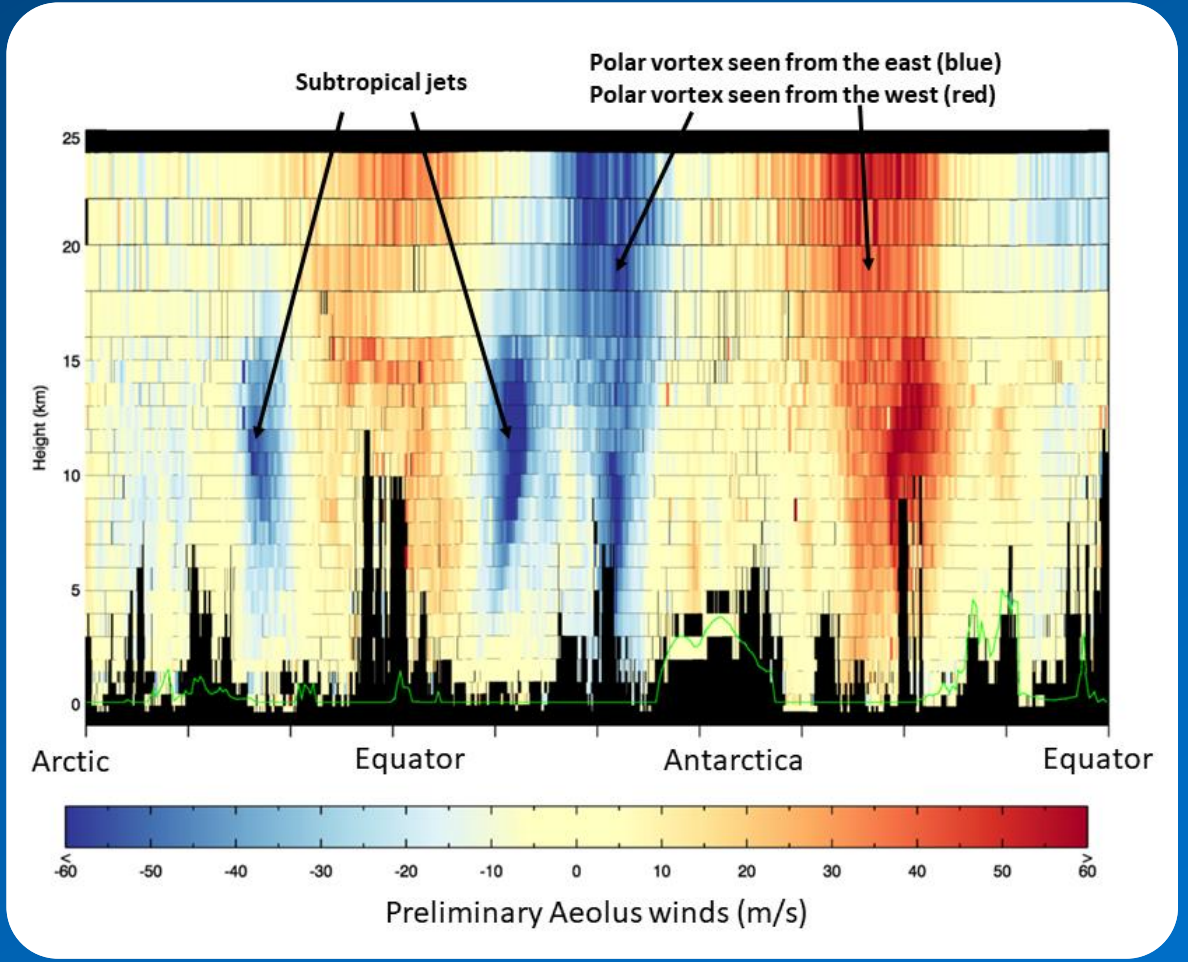




# Earth Explorer Aeolus

| | |
|---|---|
| **Mission** | Wind profiling |
| **Payload** | ALADIN UV lidar |
| **Orbit** | SSO, alt: 320 km<br>LTAN: 18h00 |
| **Consortium** | Prime: ADS-UK<br>Aladin: ADS-FR |
| **Launch date** | 22 Aug. 2018 |
| **Lifetime** | 3 years |

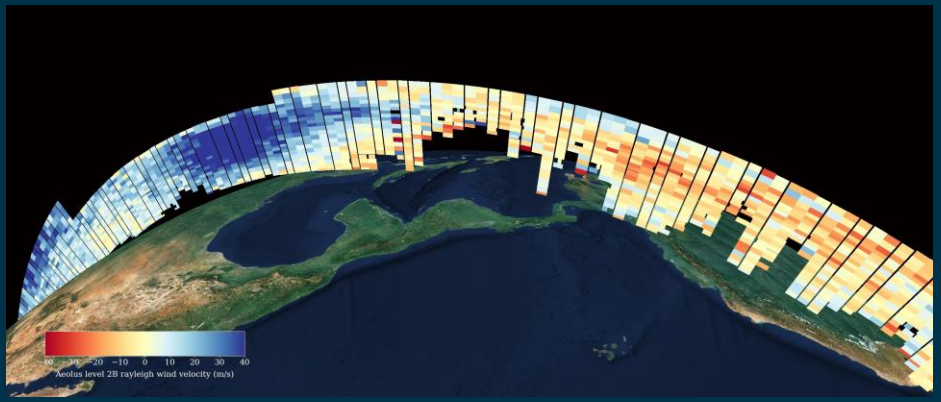
# Aeolus



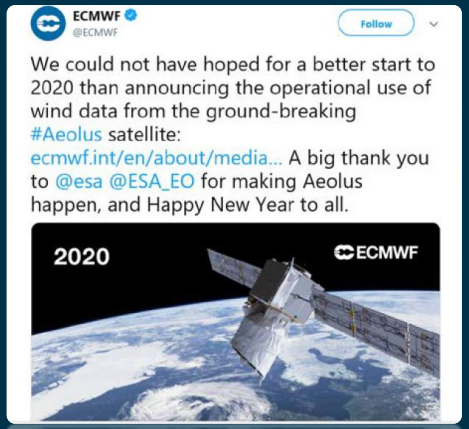

12 September 2018

# Aeolus addresses our ‘Blind Spot’ - Wind

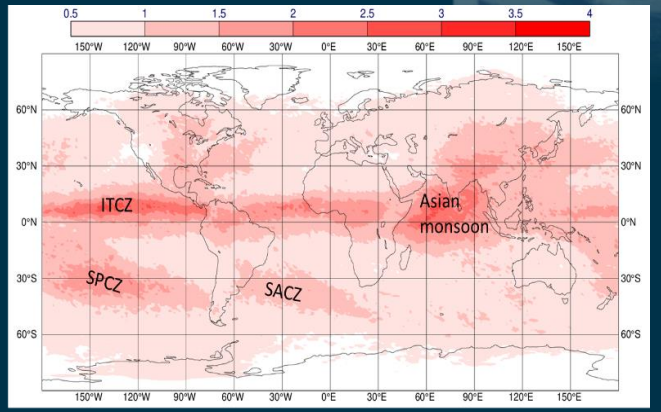





Aeolus gauges hurricane Lota wind velocities 17 November 2020



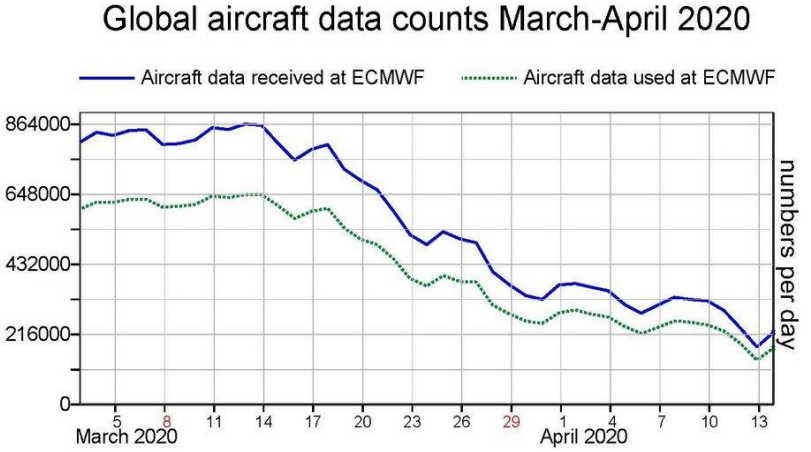

- Improving NWP Models’ forecast accuracy with data now operationally used by ECMWF
- Deepening Understanding of Climate Science
- Spurring insight into the atmospheric energy, water, aerosol and chemistry cycles

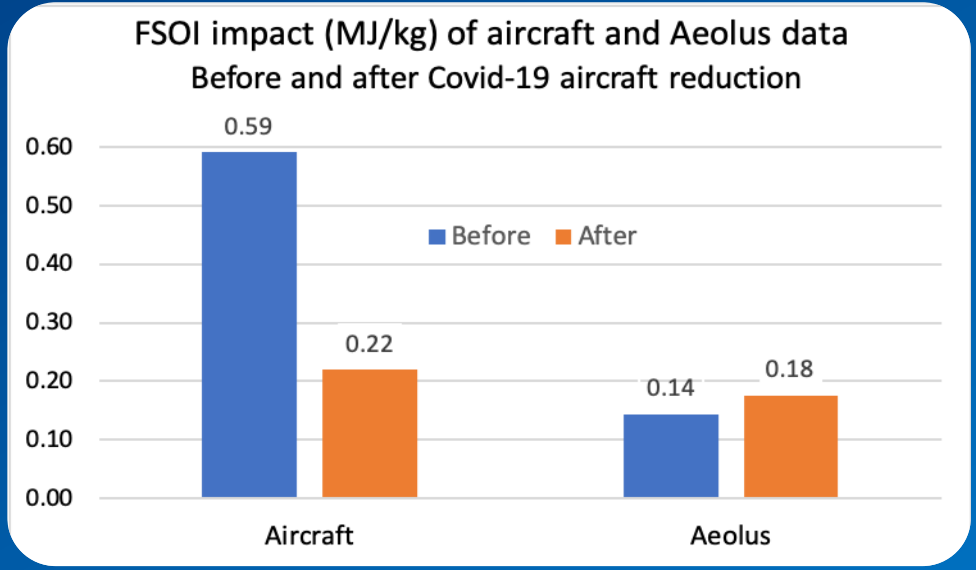



Positive impact (red) when assimilating Aeolus winds from 4 April to 19 August 2020 (M. Rennie – ECMWF)

# Aeolus partially fills weather data observation gap

- With many planes grounded the amount of aircraft data available for NWP at ECMWF has dropped
- Operational use of Aeolus mission data in NWP has helped filling this observation gap; Forecast Sensitivity to Observation Impact (FSIO)



# 4. Future Atmosphere

# Copernicus Missions for Atmospheric Composition

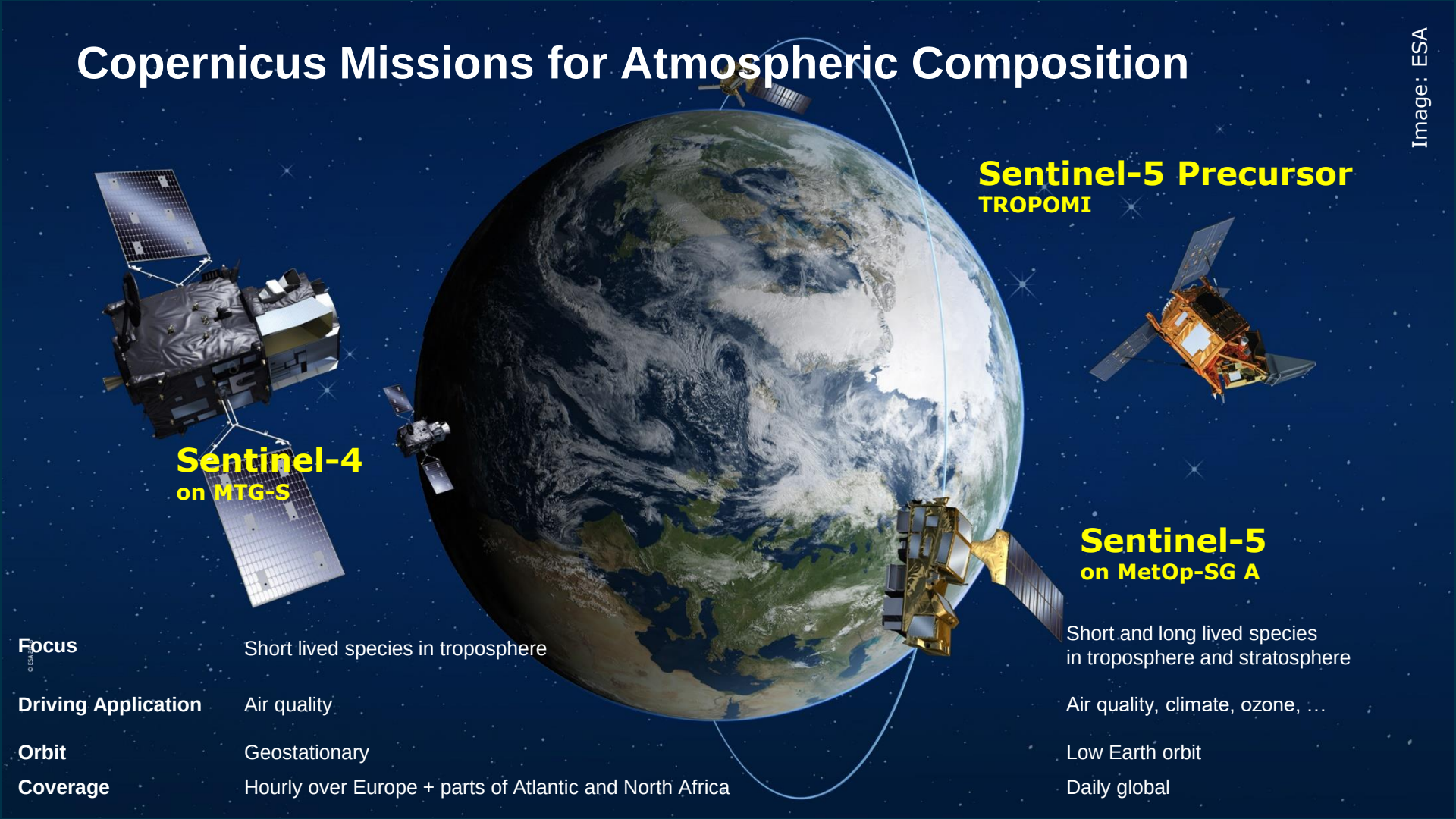


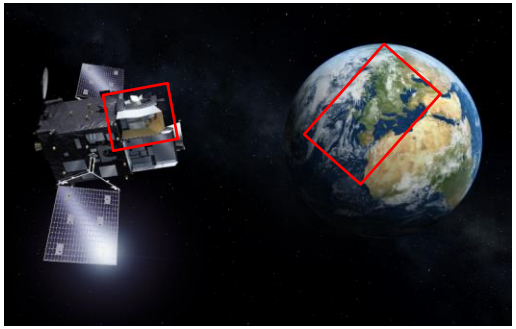

Image: ESA

| | Sentinel-4 on MTG-S | Sentinel-5 Precursor TROPOMI | Sentinel-5 on MetOp-SG A |
|---|---|---|---|
| **Focus** | Short lived species in troposphere | | Short and long lived species in troposphere and stratosphere |
| **Driving Application** | Air quality | | Air quality, climate, ozone, … |
| **Orbit** | Geostationary | | Low Earth orbit |
| **Coverage** | Hourly over Europe + parts of Atlantic and North Africa | | Daily global |

# Sentinel-4 Mission

- Objective: measure from a Geo orbit the atmospheric composition (*) over Europe for the Copernicus Atmosphere Monitoring Service, with **hourly revisit** time and with **8 km spatial resolution**.

  (*) $O_3$ (Ozone), $NO_2$ (Nitrogen dioxide), $SO_2$ (Sulphur dioxide), HCHO (Formaldehyde), CHOCHO (Glyoxal) and the aerosol optical depth
- Procurement Agency: ESA; Prime Contractor: Airbus (DE); GS Operator: EUMETSAT
- Embarked on Meteosat Third Generation sounder satellites (MTG-S).
- Launched on an Ariane 6
- 2 spectrometer instruments (PFM, FM2), covering the UV, Visible and Near IR wavelength bands (305-500 nm; 750 – 775 nm).
- PFM instrument: fully integrated; final calibration: May 2022
- FM2: under integration
- 7.5 years nominal lifetime.
- Launch of the first MTG-S: 2024.



# Copernicus Sentinel-4 Level-2

- Level-2 products cover atmospheric constituents that drive air quality
  - Trace gases: $O_3$ (tropospheric and total column), $NO_2$, HCHO, CHOCHO, $SO_2$
  - Aerosol optical depth, aerosol layer height, UV absorbing index
  - Auxiliary products for handling clouds and surface reflectance, facilitating synergy with FCI, ..

- Operational Processor (L2OP) developed by a consortium led by DLR under responsibility of ESA
  - Verified on synthetic data, testing on data from geostationary GEMS ongoing
  - Uncertainty budget established per product
  - V1 near completion (2 parts delivered, last one expected 3Q2022), V2 after PFM on-ground calibration, V3 after PFM in-orbit verification

- Will be integrated into MTG
  L2 Processing Facility (L2PF) by EUMETSAT

# Sentinel-5 Mission

- Objective: monitoring atmospheric composition from low Earth orbit.
- Provides **daily global** observations of ozone and other trace gases with **7.3 km spatial resolution**.
- It will be embarked on EUMETSAT's MetOp Second Generation (MetOp-SG) satellites type A, part of the space segment of the EUMETSAT Polar System Second Generation (EPS-SG).
- Sentinel-5 development is co-funded by ESA and the European Commission in the frame of the Space Component of the Copernicus Programme.
- G/S operator: EUMETSAT
- 3 instruments under production: PFM, FM2 and FM3 to be flown on three MetOp-SG type A satellites, each with a 7.5 years nominal lifetime.
- Sentinel-5 instruments will be operated and data products will be dissiminated by EUMETSAT.
- Launch of the first MetOp-SG-A type satellite is foreseen in 2024.

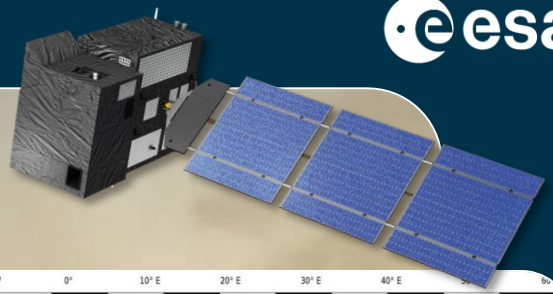

# Copernicus Sentinel-5 Level-2

- Level-2 products cover atmospheric constituents that drive air quality, climate, and ozone/UV
  - Trace gases: $O_3$ (total column and profile), $NO_2$, HCHO, CHOCHO, $SO_2$, CO, $CH_4$
  - Aerosol optical depth, aerosol layer height, UV absorbing index, erythemal UV index, cloud properties
  - Auxiliary products for handling clouds and surface reflectance, facilitating synergy with MetImage, …

- Prototype Processor (L2PP) developed by consortium led by S&T under responsibility of ESA
  - Algorithms verified and tested on synthetic and real data from S5P/TROPOMI
  - Uncertainty budget established per product
  - V1 delivered, V2 after PFM on-ground calibration, V3 after PFM in-orbit verification

- Operational Processor (L2OP) development and integration by EUMETSAT

# Sentinel Expansion Missions: CO2M



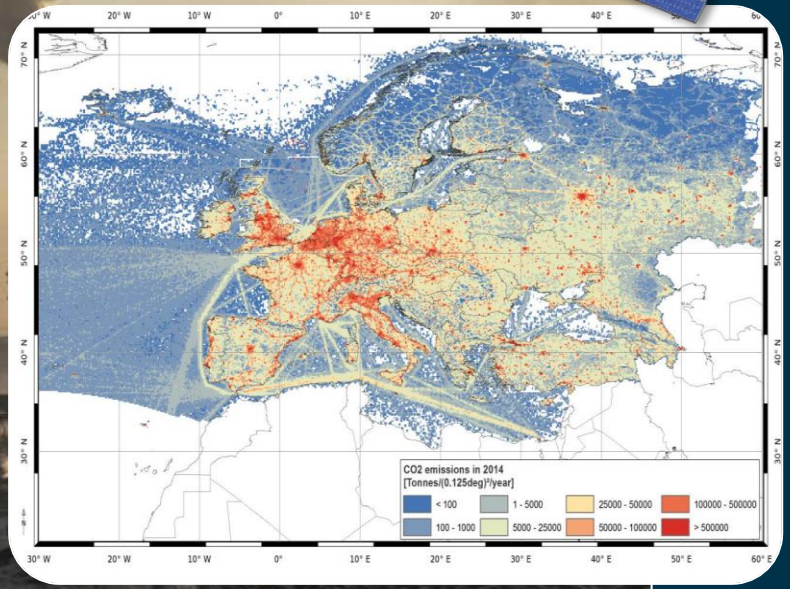
## Anthropogenic $CO_2$ Monitoring Mission

### Europe's first operational CO2 mission

- Analyse man-made $CO_2$ emissions and overall $CO_2$ budget
- At country and regional/megacity scales
- Support Paris Agreement implementation and global stocktake from 2023 to assess the effectiveness of CO2 reduction strategies

### Four instruments for improved detection accuracy of anthropogenic CO2

- A combined CO2/NO2 instrument based on a VIS, NIR and SWIR spectrometer
- A Multi-Angle polarimeter (MAP) based on 4 identical cameras
- A Cloud Imager (CLIM) derived from the ProbaV instrument
- >250Km swath with global coverage in 4 days

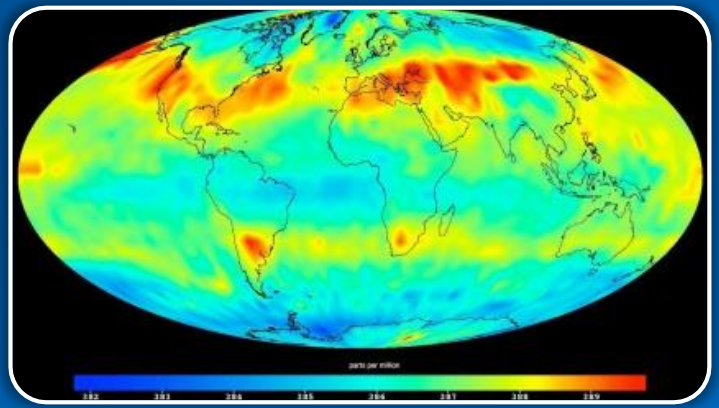


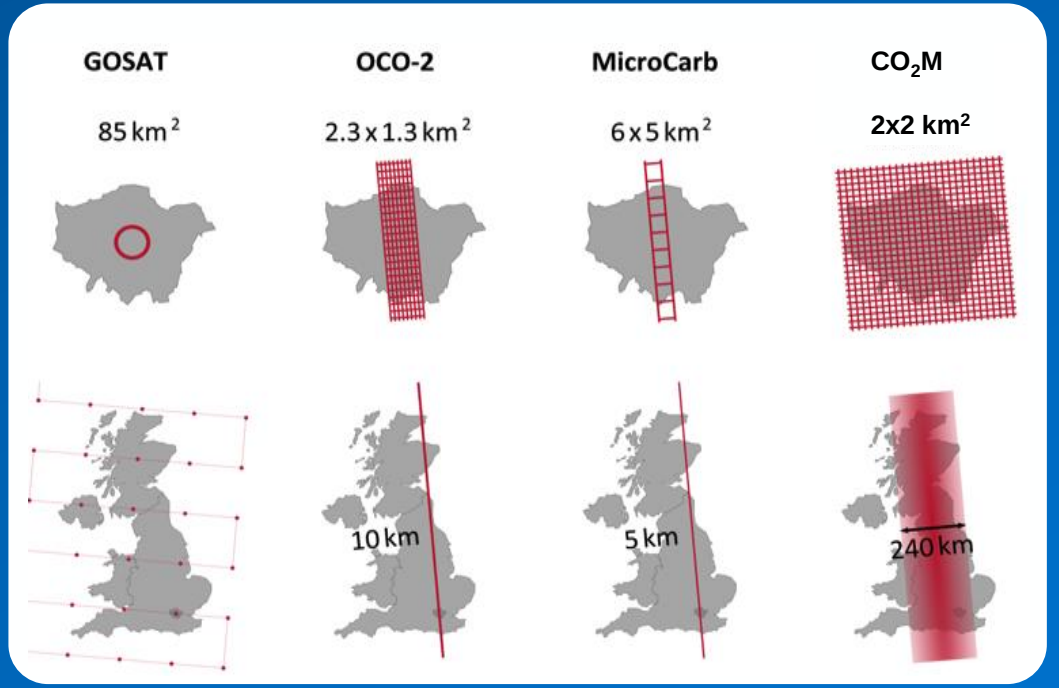

European total $CO_2$ emissions - Kuenen et al., 2014 and 2015

# CO2M

## Designed to measure anthropogenic $CO_2$ emissions

- 4 km² spatial sampling
- Global coverage - revisit
  time 2-3 days @40°N
- XCO2 precision 0.5 – 0.7 ppm
- Systematic bias < 0.5 ppm





# Science: EE6 EarthCARE

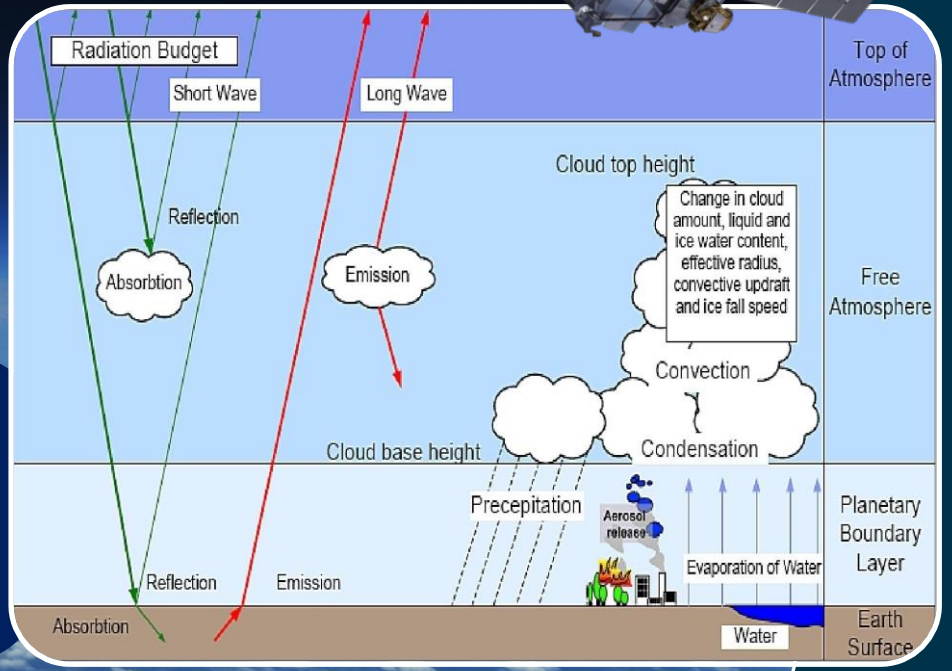
## Study of natural & anthropogenic Climate Change

### Joint ESA/JAXA(NICT) mission

- Building on ESA's ERM (Earth Radiation Mission) and JAXA's ATMOS-B1 satellite projects
- Unique global measurements of vertical profiles of clouds, aerosols, temperature and humidity profiles simultaneously with the Top-of-Atmosphere radiance

### Synergistic active/passive instrument suite for vertical cloud profile retrievals

- UV Lidar for cloud and aerosol optical depth
- Cloud Profiling Radar for micro- and macroscopic properties of clouds
- Broadband Radiometer for top of atmosphere radiance



# Science: EE9 FORUM

## Studying the earth's radiation budget

### Optical mission to improve climate models and climate prediction

- New insight into Earth's radiation budget and how it is controlled
- Detailed picture for more accurate tracking of key atmospheric components

### Measuring far infrared emission spectrum with a hyperspectral sensor

- Step and Stare technique integrates 15km-wide spot for 7 to 8 seconds every 100km
- 6.25 to 100 microns with 0.5 microns sampling resolution (complemented by MetOp-SG IASI)

# Science: ALTIUS

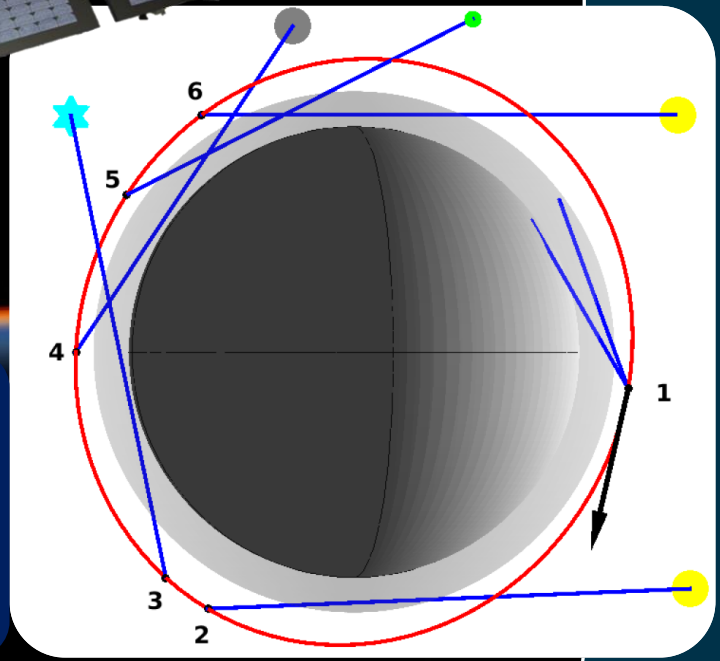
## Monitoring Earth's Ozone layer recovery

### Limb-sounding mission

- Observing O3, NO2, CH4, H2O and aerosols in UTLS
- Global high resolution vertical profiles from 0 to 100 Km
- Complement nadir-looking missions, e.g. S-4, S-5, S-5P
- Study altitude and the horizontal extent of Polar Stratospheric and Polar Mesospheric Clouds

### 3 independent high-resolution imagers

- Ultraviolet, visible and near-infrared channels
- 6 observation geometries in baseline operations:
  (1) backward limb (2) sunset occultation (3) star occultation (4) Moon occultation (5) planet occultation (6) sunrise occultation



# Science: TRUTHS (2028)

## Optical mission for measuring incoming solar and outgoing reflected radiation

### A Metrology lab in space

- UV-VIS-SWIR hyperspectral imager
- Cryogenic Solar Absolute Radiometer replicating the SI-traceable calibration chain and operating at ~220ºC

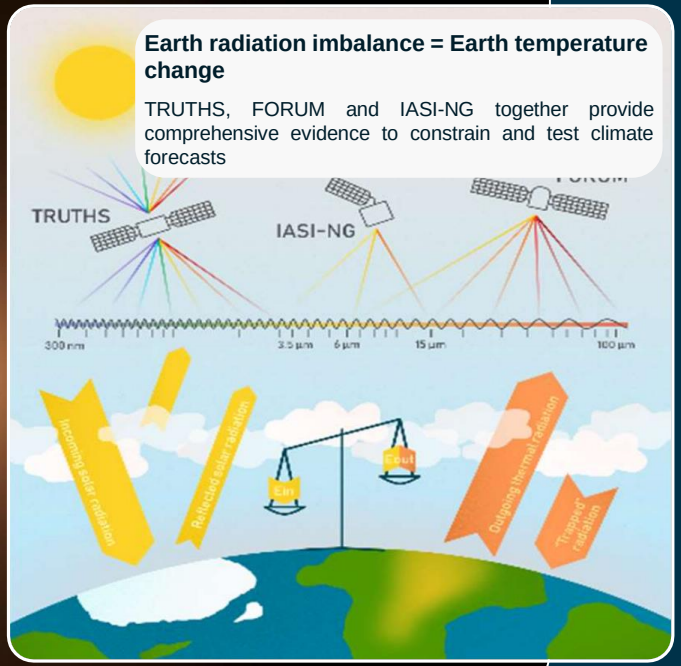
**SI-traceable measurements** of the solar spectrum to address direct science/climate questions.

**Satellites cross-calibration**: Establish a 'metrology laboratory in space' to create a fiducial reference data set to cross-calibrate other sensors and improve the quality of their data anchored to an SI reference in space

**Climate benchmarking** enhances by an order-of-magnitude our ability to estimate the Earth Radiation Budget through direct measurements of incoming & outgoing energy

**Earth radiation imbalance = Earth temperature change**

TRUTHS, FORUM and IASI-NG together provide comprehensive evidence to constrain and test climate forecasts




Thank you