PROGRAMME OF THE EUROPEAN UNION

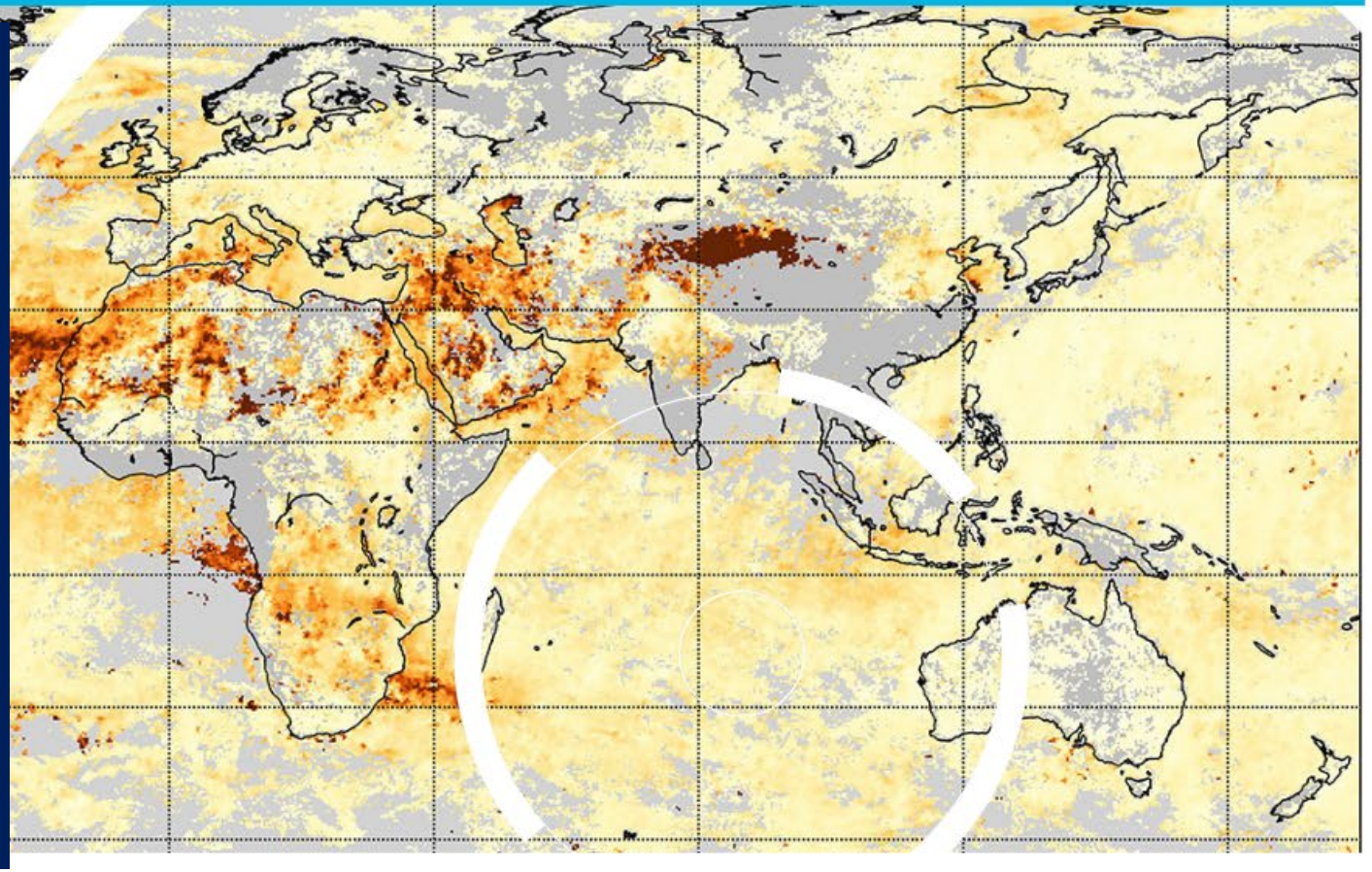
Copernicus Europe's eyes on Earth

Atmosphere Monitoring Service atmosphere.copernicus.eu

IMPLEMENTED BY ECMWF EUMETSAT esa

JOINT TRAINING IN ATMOSPHERIC COMPOSITION

13 -17 OCTOBER 2025, BRUSSELS



Aerosol monitoring from Sentinel-4, Sentinel-5 and 3MI: Instruments overview and data products.

Rasmus Lindstrot

Competence Area Manager – Atmospheric Chemistry

on behalf of EUMETSAT Atmospheric Chemistry and Aerosol Teams

Agenda

Principles of aerosol remote sensing

Copernicus Sentinel-4 and Sentinel-5

Instrument concepts

Aerosol monitoring capabilities

3MI

Instrument concept

Aerosol monitoring capabilities

Synergy opportunities

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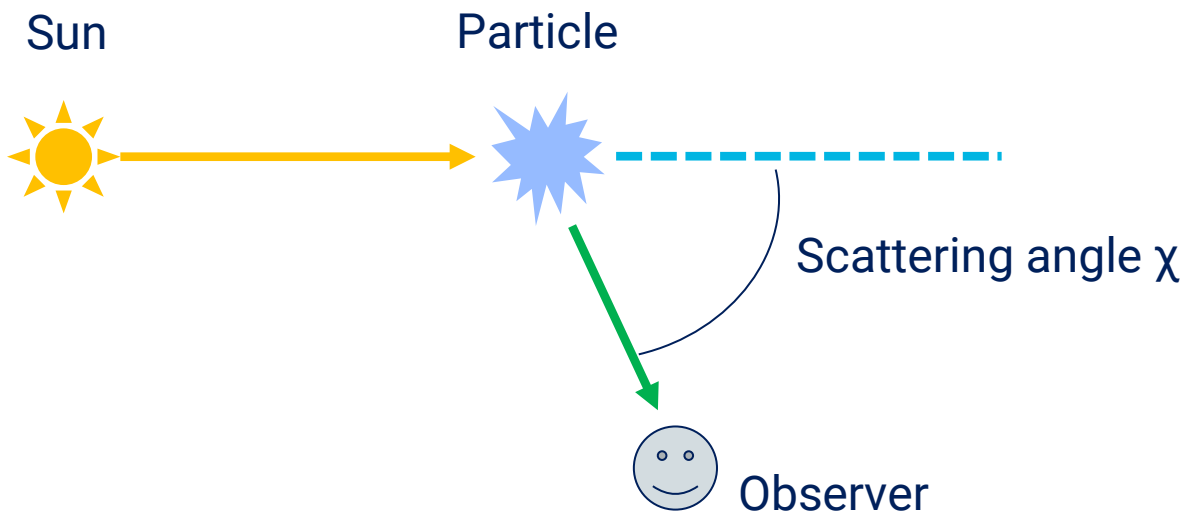
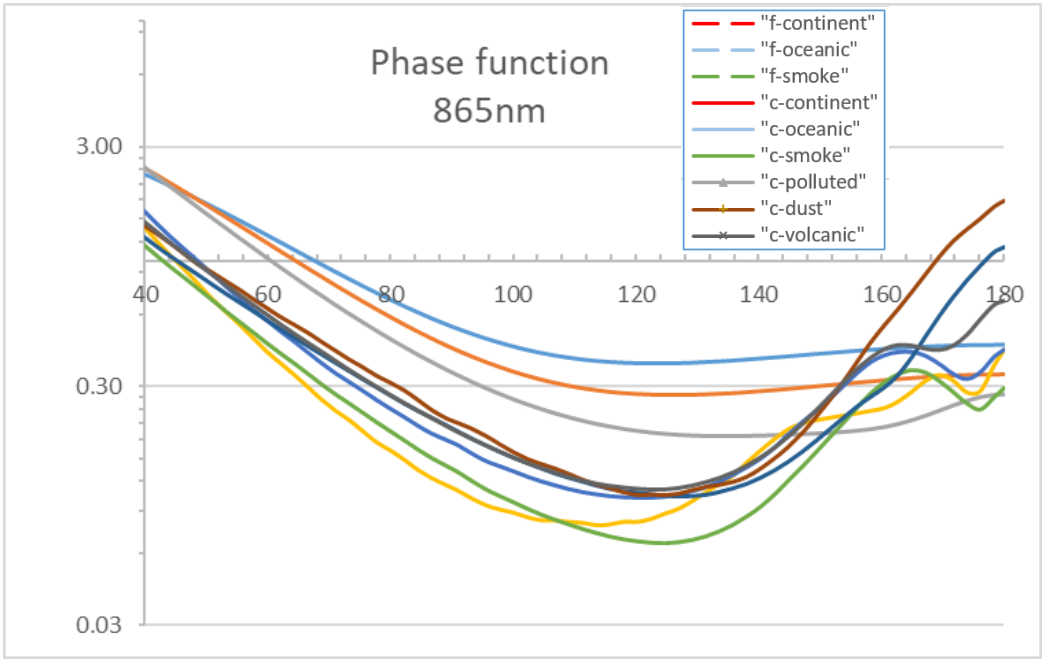
Aerosol remote sensing: Optical properties

- Optically, particles such as aerosol and cloud, reflect and absorb the sunlight
  - 1 aerosol = 1 phase function





$$\text{Observed Signal} \approx \text{SSA} \times \text{AOT} \times \text{PhaseFunction}(\chi)$$

Single Scattering Albedo
= absorption by aerosol

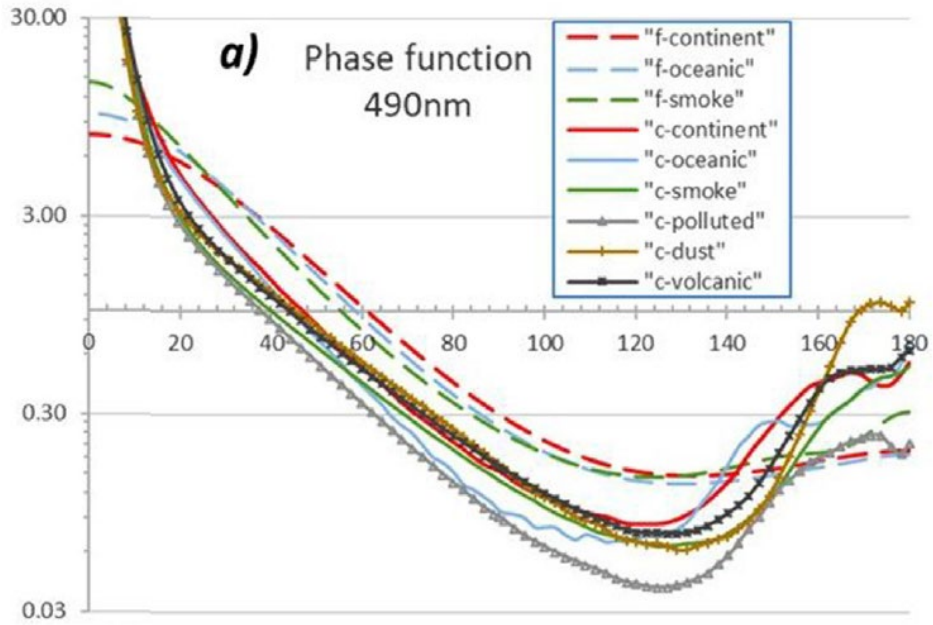
Aerosol Optical Thickness
= quantity of aerosol

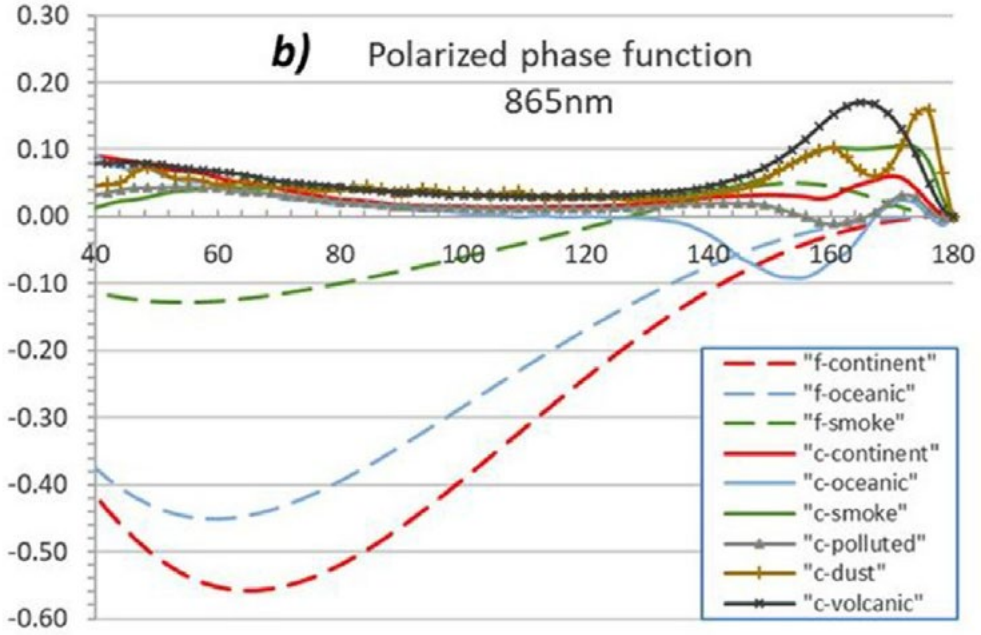
Aerosol Phase Function
= angular distribution of scattering

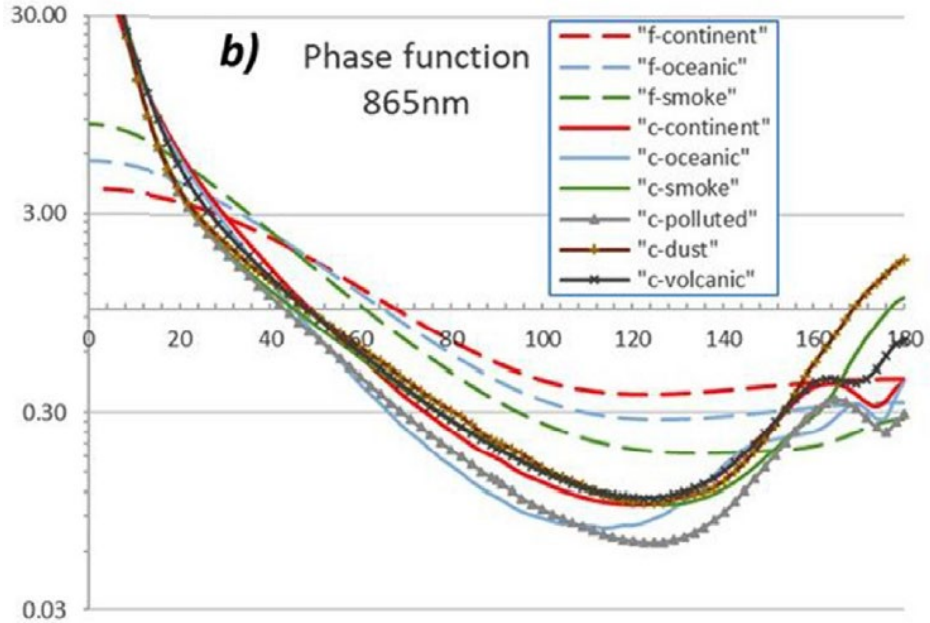
- A measurement = information about both aerosol quantity and aerosol type

Aerosol remote sensing: Optical properties

- Phase function depends on
  - Refractive index: real and imaginary (=absorption)
  - Size distribution
  - Particle shape (non-sphericity)
  - ➔ Nature of the aerosol
- Phase functions also have spectral and polarised dimensions
  - SPECTRAL = colour
  - POLARISATION = preferred plane of vibration







Aerosol information in spectral shape, directionality and polarisation state

Reflective domain of the optical part of the spectrum

- Source = Solar irradiance
- Light reflected / scattered / absorbed by the Earth-Atmosphere system
- 3 main properties of the light after interaction

1/ Spectral

- Refers to the colour (intensity in different bands)

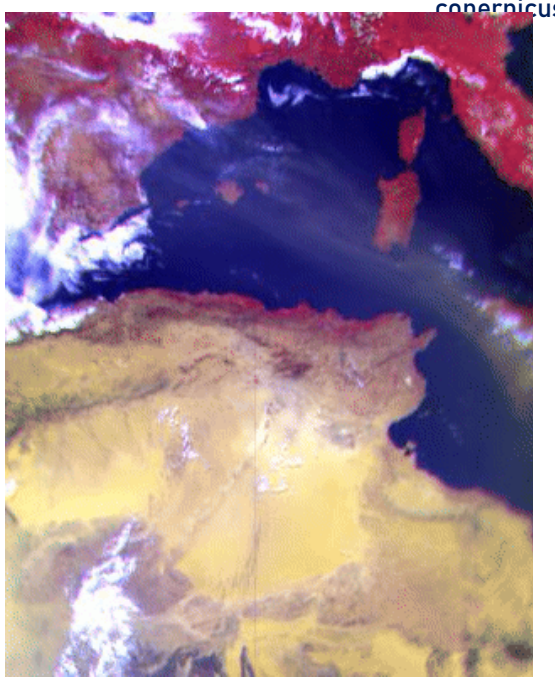
2/ Directionality

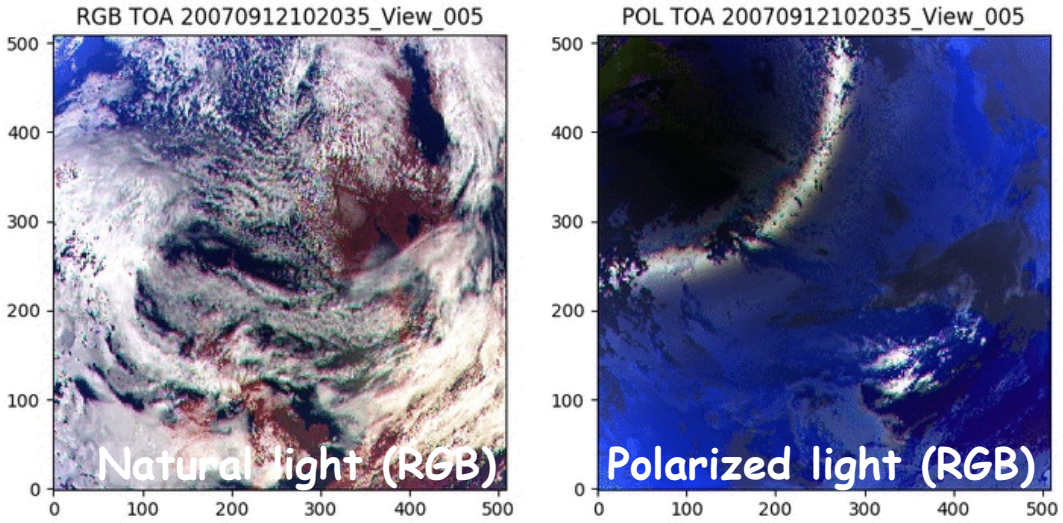
- Variation with angle of observation

3/ Polarisation

- Vibration of the wave in a preferred orientation
- Happens after interaction with particles
- Quantity of Polarisation = Polarised intensity

=> Combination of the 3 signatures





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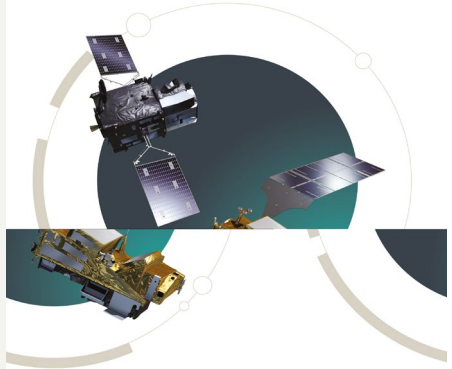
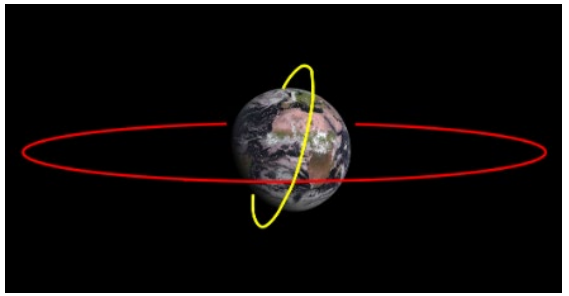


- **Part of the European Earth observation program Copernicus**, developed by ESA and operated by EUMETSAT. Main operational user: CAMS.
- **Objective**: Monitoring atmospheric composition (air quality, ozone layer, trace gases, aerosols).

- **Sentinel-4/UVN** flies aboard the **Meteosat Third Generation Sounder (MTG-S)** satellite in **geostationary orbit**.
  Launch: 1st of July 2025.

- **Sentinel-5/UVNS** flies aboard the **EUMETSAT Polar System – Second Generation (EPS-SG) A** satellite in a **low Earth polar orbit**.
  Launch: 13th of August 2025.



- Together, both missions will form **Europe's operational backbone** for atmospheric composition monitoring. They will provide **complementary data**, enabling both **regional and global insights** into air quality and atmospheric conditions.

EPS-SG

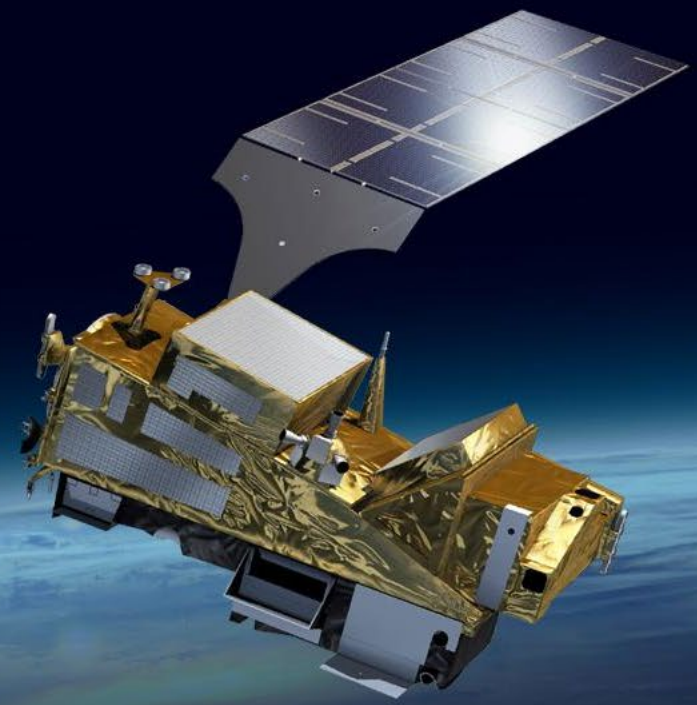
Complete constellation consists of two satellites: Sounding and Optical Imaging (A) and Microwave imaging and sounding (B)

EPS-SG A platform:

- Visible Infrared Imager (METimage)
- Infrared Atmospheric Sounding Interferometer (IASI-NG)
- Microwave Sounder (MWS)
- Multi-Viewing Multi-Channel Multi-Polarisation Imaging (3MI)
- Radio Occultation (RO)
- **Copernicus Sentinel-5/UVNS (S5)**

EPS-SG B platform:

- SCA, MWI, ICI, RO
- Launch: 2026



EPS-SG A / Copernicus Sentinel-5

Copernicus Sentinel-5 will provide operational monitoring of trace gas concentrations for atmospheric chemistry and climate applications from a polar orbit, extending the GOME-2 and Copernicus Sentinel-5P missions into the future.

UVNS spectrometer measuring in

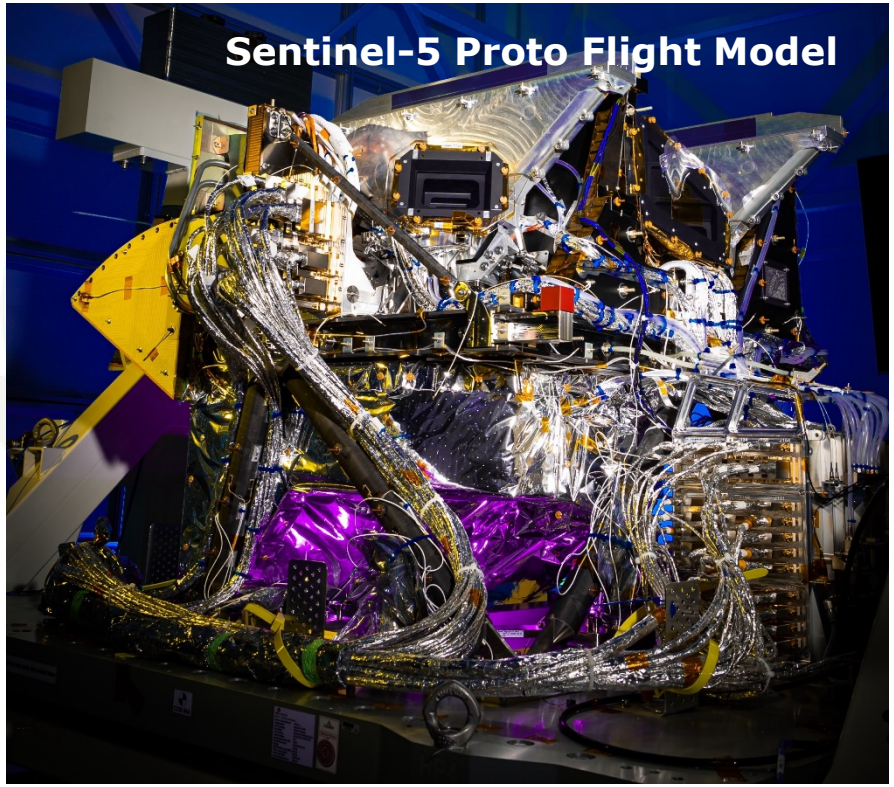
- the ultraviolet (UV: 270–370nm),
- the visible (VIS: 370–500nm),
- the near infrared (NIR: 750–775nm) and
- the shortwave infrared (SWIR: 1590-1675nm, 2305-2385nm),
- spatial sampling distance of around 7km at nadir.

Copernicus Sentinel-5/UVNS

https://www.youtube.com/watch?v=IAAphaUuBLE

Copernicus Sentinel-5 key characteristics

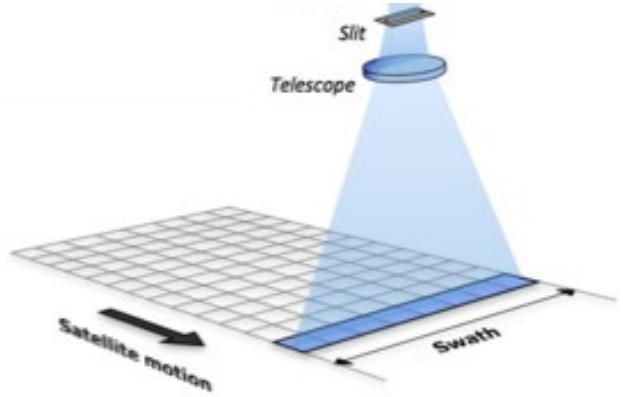
- Type: passive grating imaging spectrometer
- Configuration: Push broom staring (non-scanning) in nadir viewing
- Swath width: 2 670 km
- Spatial sampling: < 50 × < 50 km^2(UV1a), 7.5 × 7.5 km^2 (all other channels)
- Spectral: 5 spectrometers (UV1, UV2VIS, NIR, SWIR1, SWIR3) with spectral resolution between 0.25nm (SWIR) an 1nm (UV1)
- Radiometric accuracy (absolute): 3%, 6%(SWIR) of the measured earth spectral reflectance.
- Design lifetime: 7.5 years
- Power Demand: 300 W
- Generated data volume: 139 Gbits per full orbit.

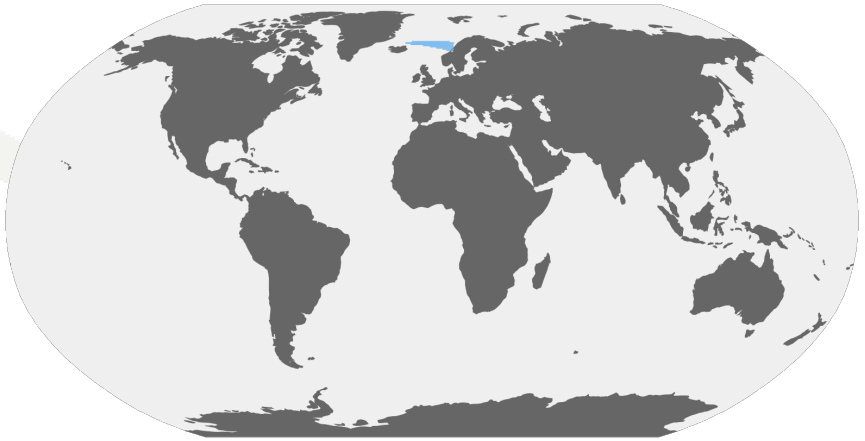


Sentinel-5/UVNS: Pushbroom-Spectrometer

Pushbroom multi-band imaging spectrometer

- The telescope projects the ground scene onto the entrance slit.
- The light entering the slit is collimated and split into several spectral bands.
- Each spectral band is dispersed by a diffraction grating and recorded by a detector.
- The forward motion of the satellite smears the entrance slit in the flight direction.
- Every few hundred milliseconds, the detector is read out. Individual read-outs are co-added.
- This creates a “map” with 7 km × 7 km pixels, in which trace gases are determined.
- Sentinel-5 will observe from a sun-synchronous morning orbit, meaning it will observe every location on Earth at the same local time (9:30 AM).





Meteosat Third Generation

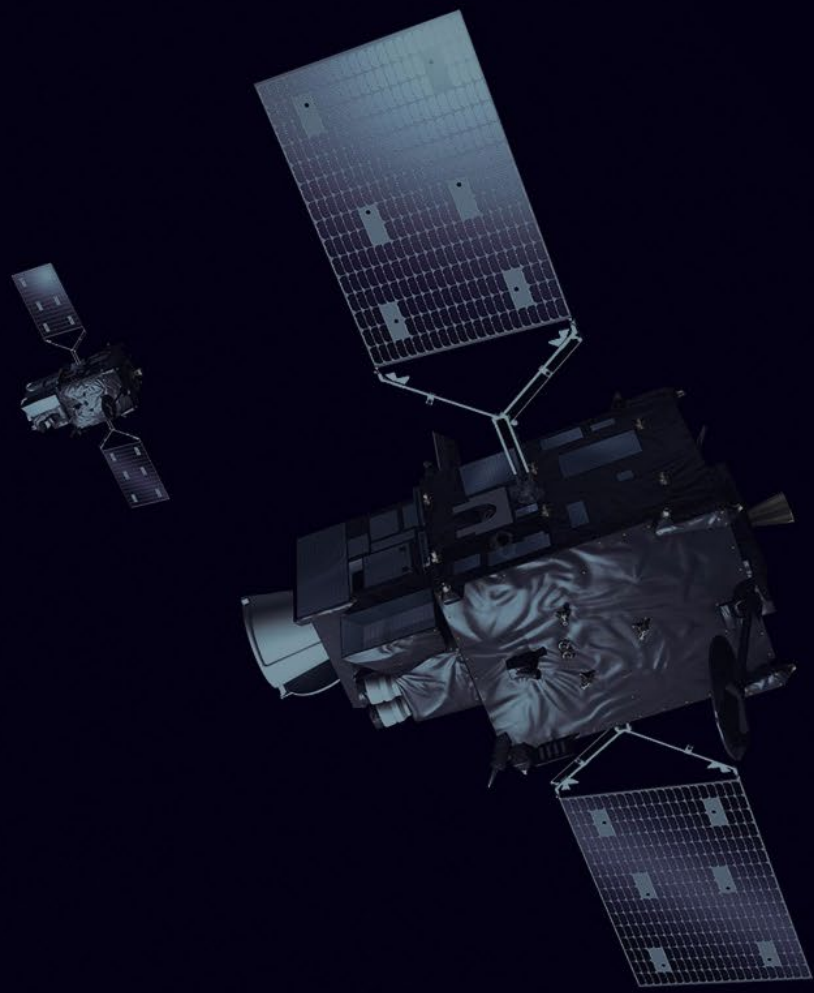
Complete constellation consists of three satellites: two imaging satellites and one sounding satellite

MTG-I platforms:

- Flexible Combined Imager (FCI)
- Lightning Imager (LI)

MTG-S platform:

- InfraRed Sounder (IRS)
- Copernicus Sentinel-4/UVN (S4)

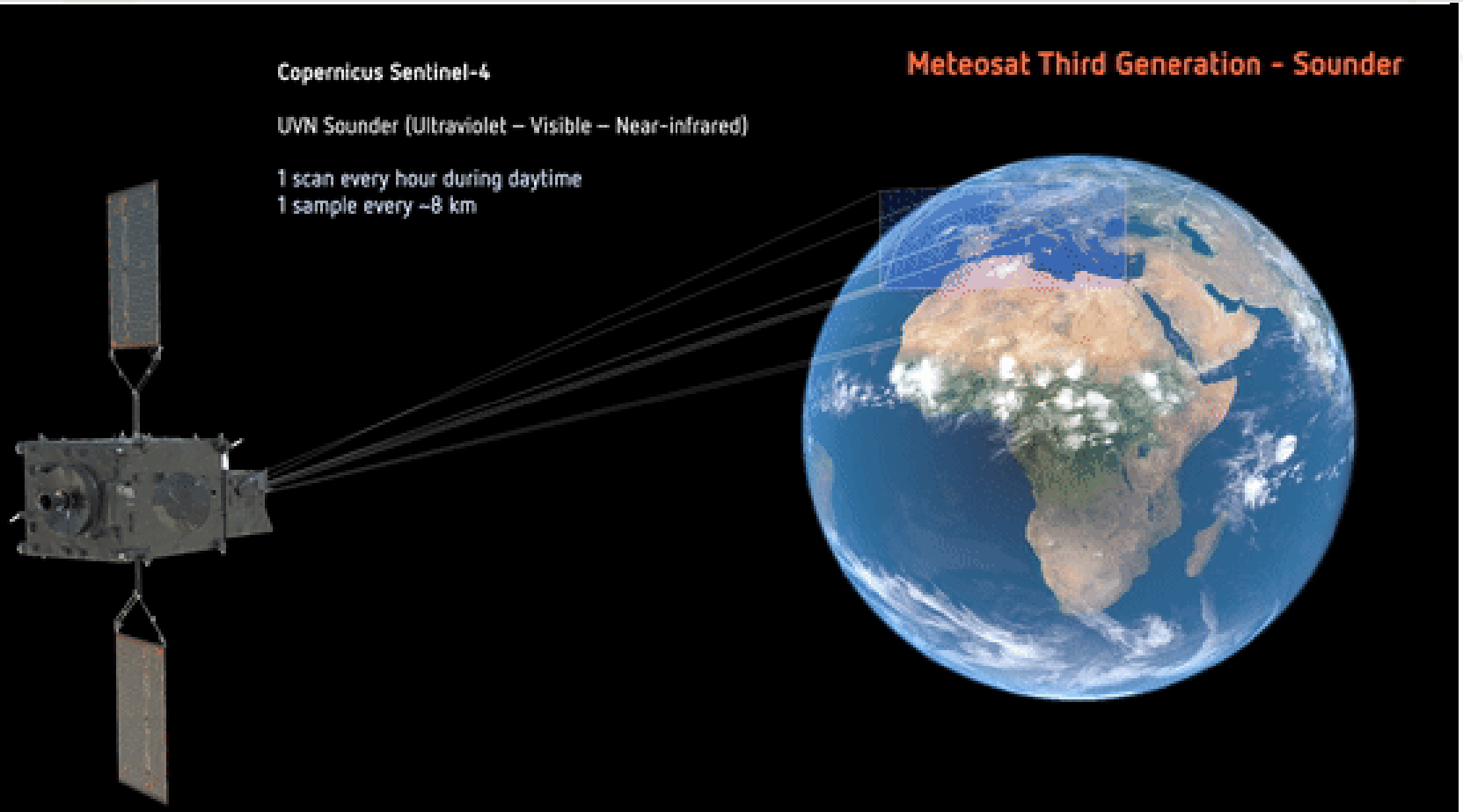


Meteosat Third Generation – Sounder / Copernicus Sentinel-4

Copernicus Sentinel-4 will be the first European Air Quality mission in a geostationary orbit

UVN spectrometer measuring in the ultraviolet (UV: 305–400nm), the visible (VIS: 400–500nm) and the near infrared (NIR: 750–775nm), spatial sampling distance of around 8km.

Observation area from 30 to 65° N in latitude and 30° W to 45° E in longitude. Observation repeat cycle period approximately one hour.



The Sentinel-4 instruments are CFI provided by ESA in the framework of the Copernicus Space Component.

Copernicus Sentinel-4/UVN

https://www.youtube.com/watch?v=FxPljs1ELTk

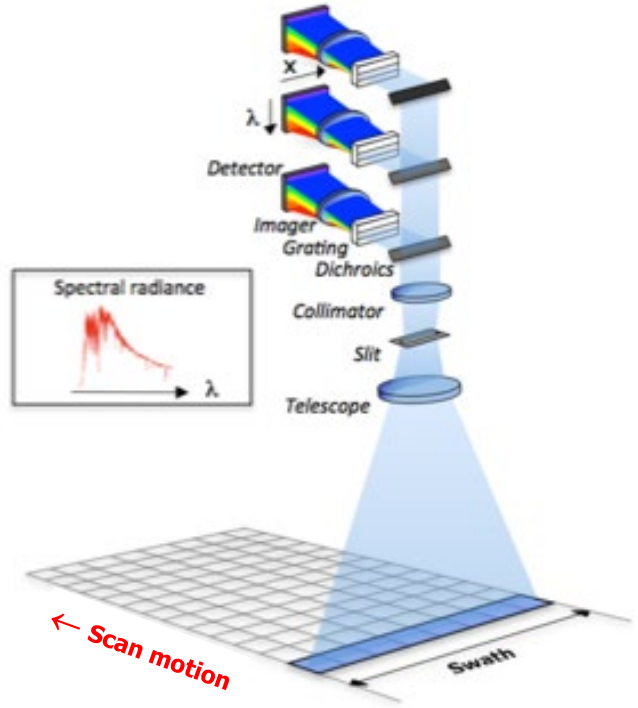
Copernicus Sentinel-4 key characteristics

- N/S Field Of View: 3.85°, E/W Field Of Regard: 11.2°
- Scanning in E/W direction with hourly frequency
- Spatial sampling: 8 × 8 km^2 (degrading towards FoV edges)
- Imaging Spectrometer:
  - Telescope + UV-VIS & NIR spectrographs
  - Full refractive optics except the scan mirror (23 elements / 19 lenses)
- 2 silicon CCD detectors cooled to ≈ 215 K
  - UV-VIS band: 305 – 500 nm with spectral resolution of 0.5nm
  - NIR band: 750 – 775 nm with spectral resolution of 0.12nm
- On board calibration sources: solar diffusers, White light source, LEDs

Sentinel-4/UVN: Pushbroom-Spectrometer

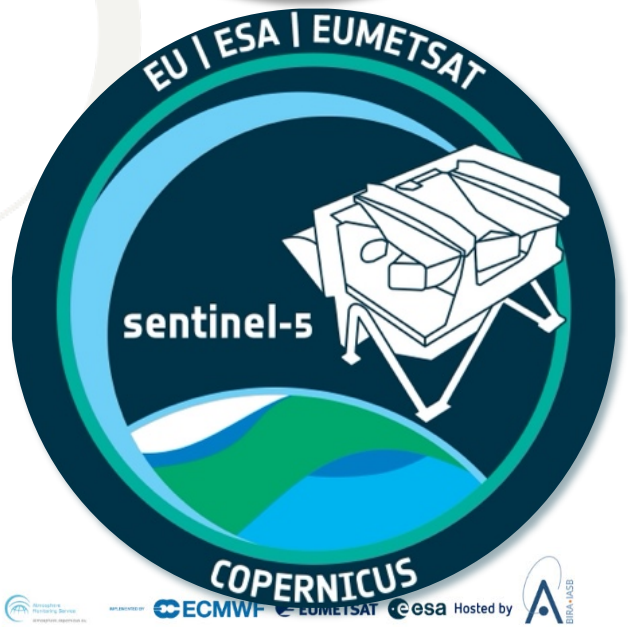
Pushbroom multi-band imaging spectrometer

- The telescope projects the ground scene onto the entrance slit.
- The light entering the slit is collimated and split into spectral bands.
- Each spectral band is dispersed by a diffraction grating and recorded by a detector.
- The motion of the scan mirror smears the entrance slit in the E-W scan direction.
- Every few hundred milliseconds, the detector is read out. Individual read-outs are co-added.
- This creates a “map” with 8 km × 8 km pixels, in which trace gases are determined.
- Sentinel-4 will observe from a geostationary orbit, meaning it will observe every location in Europe multiple times throughout the day (once per hour).
- Due to small wobble/libration effects of the geostationary platform, each scan will come with its own geolocation grid.
- The scan pattern will be adjusted in the morning and evening, limiting the covered area to the sunlit parts.



Sentinel-4 / -5 operational ramp-up timeline

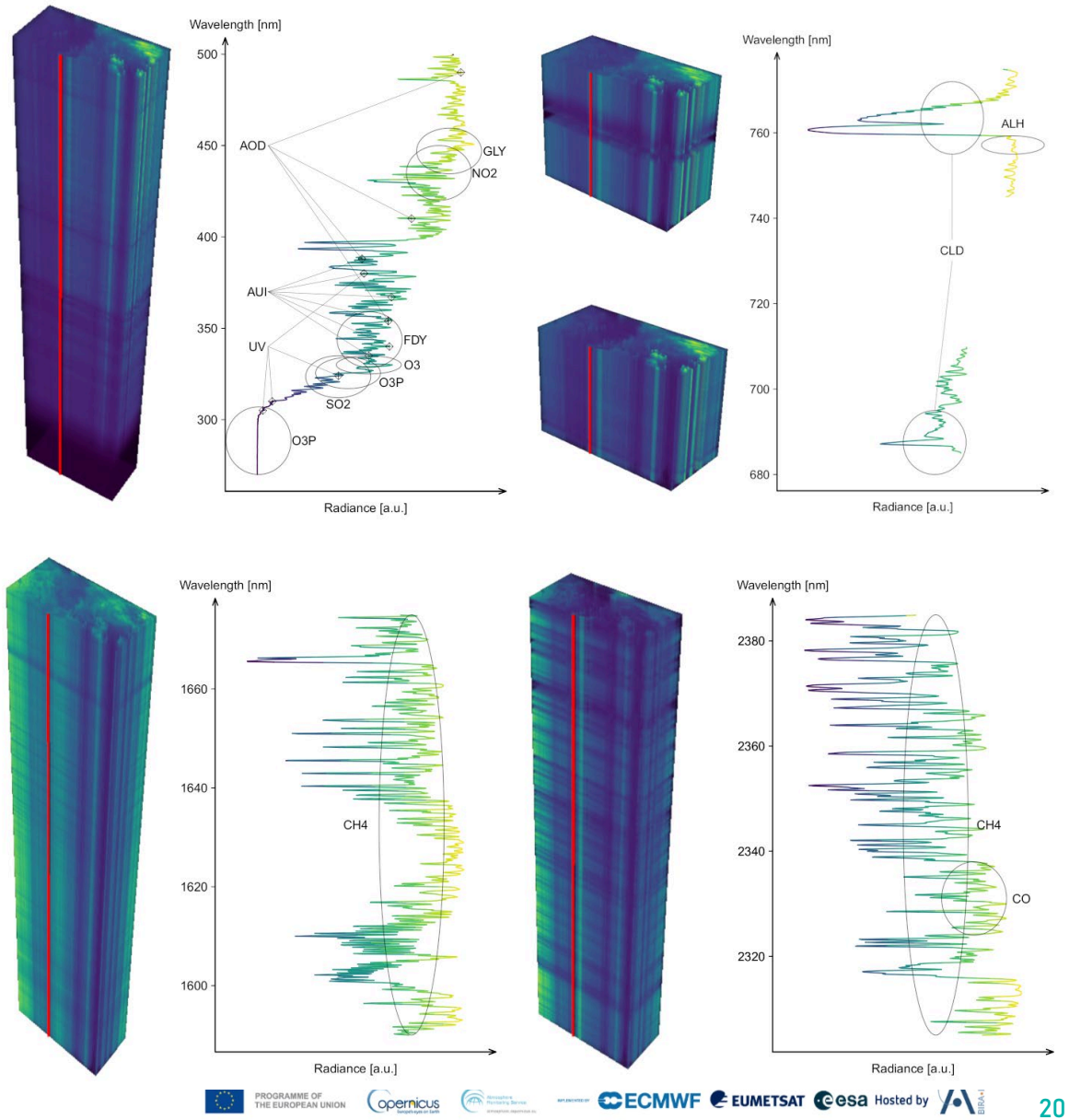
- S4/UVN and S5/UVNS instruments were kept in contamination avoidance mode for several weeks after Launch and Early Operations Phase (LEOP).
- In-orbit verification (IOV) currently ongoing, under responsibility of Airbus / ESA.
- EUMETSAT Cal/Val activities are gradually ramping up from Q4 2025 onwards, as soon as ground segment is ready to generate mission products according to the latest baseline, including IOV findings.
- Cal/Val of the EUMETSAT operational ground segment processing chains is based on
  - in-house expertise, resources, and tooling. This includes arrangements for automated pulling of reference data and operating frameworks for automated monitoring, validation and report generation.
  - off-site support services, exploiting the expertise existing in the Member States, funded by Copernicus.
  - S4 and S5 Validation Team (S4S5VT), a consortium formed in response to a joint Announcement of Opportunity by ESA and EUMETSAT.
- S4 & S5 missions handover ESA → EUMETSAT foreseen around L+12.



Sentinel-4/-5: Copernicus Level-2 Products

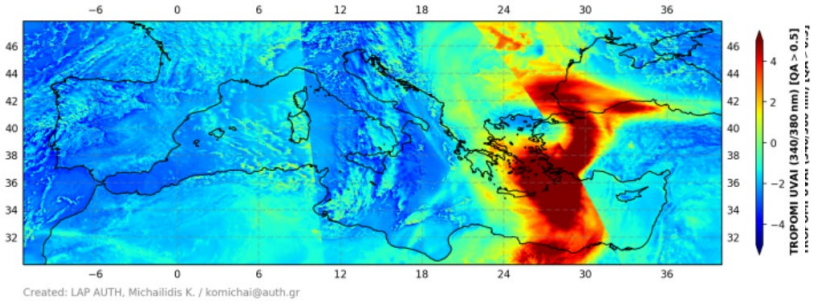
Nitrogen Dioxide (NO_2)
Sulfur Dioxide (SO_2, incl. layer height)
Ozone (O_3) (column + profile)
Formaldehyde (HCHO)
Glyoxal ($C_2H_2O_2$)
Methane (CH_4) (*S5 only*)
Carbon Monoxide (CO) (*S5 only*)
UV index (*S5 only*)
Aerosol Optical Depth
UV Aerosol Index
Aerosol Layer Height
Cloud Pressure
Surface Reflectance

S4/S5 do not provide measurements of polarisation and directionality. But they provide hyperspectral information, which is complementary to that available from other instruments and allows the monitoring of important aerosol properties.

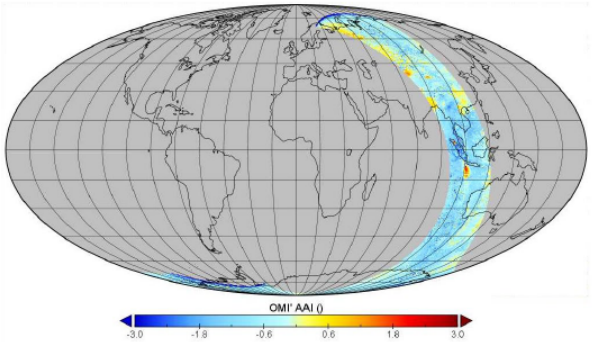


S4/S5 aerosol products: UV Aerosol Index

UV Aerosol Index allows the detection of the presence of elevated absorbing aerosols in the Earth's atmosphere. The aerosol types that are mostly seen in the index are desert dust, biomass burning and volcanic ash.



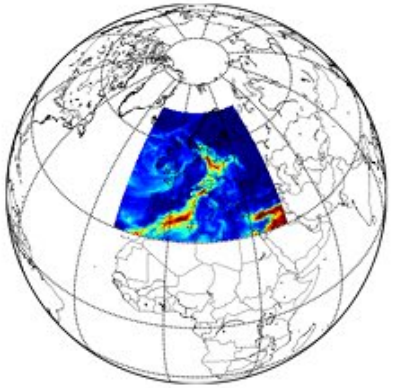
TROPOMI data, figures from Michailidis, et al. (2023)

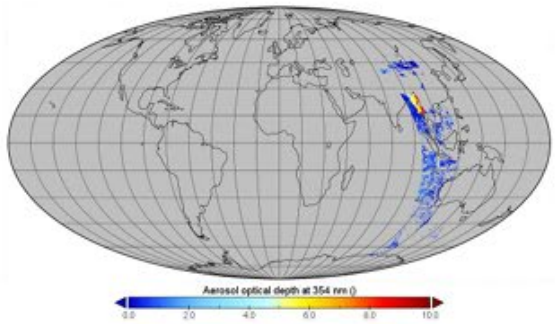


	Sentinel-4/UVN	Sentinel-5/UVNS
Techniques	Radiometric residuals	
Algorithmic and/or secondary products highlights	- 4 wavelengths (two pairs): 340nm-380nm (TOMS) and 354nm-388nm (OMI) - UAI>0 indicates the presence of UV-absorbing aerosols, like dust and smoke	- 6 wavelengths (three pairs): 335nm-367nm (S5); 340nm-380nm (TOMS) and 354nm-388nm (OMI) - UAI>0 indicates the presence of UV-absorbing aerosols, like dust and smoke
Product Developer	KNMI	KNMI

S4/S5 aerosol products: Aerosol Optical Depth

AOD is a dimensionless number that describes the degree to which aerosols absorb or scatter sunlight.
It is an optical quantity, linked to the integrated amount and type of aerosols in vertical column.





	Sentinel-4/UVN	Sentinel-5/UVNS
Techniques	GRASP	OMAER UV+VIS
Algorithmic and/or secondary products highlights	- BRDF land and ocean - Full radiative transfer model - Single and multiple pixel retrieval	- LUT radiative transfer model - Cloud free scenes - Ice/snow free scenes - Surface reflectance climatology (land) and model (ocean)
Product Developer	LOA/Catalysts	KNMI

S4/S5 aerosol products: Aerosol layer height

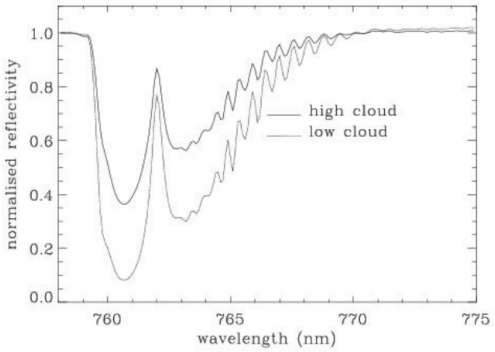
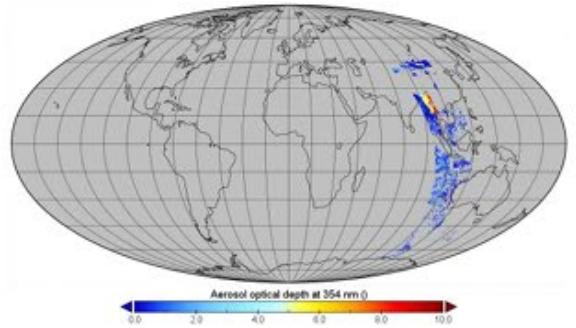


Figure from Stammes et al (2006)

Retrieval exploits the fact that elevated aerosols reflect light back to space, thereby shortening the photon pathlength in the atmosphere, resulting in weaker absorption by oxygen



	Sentinel-4/UVN	Sentinel-5/UVNS
Techniques	O_2 A-Band Optimal estimation	
Algorithmic and/or secondary products highlights	- single homogeneous layer of scattering particles - single scattering albedo - Cloud free scenes - Surface LER and BRDF - NN forward model	- single homogeneous layer of scattering particles - single scattering albedo - Cloud free scenes - LER surface albedo - NN forward model - optical thickness - (O2 B-Band, Surface BRDF)
Product Developer	KNMI	KNMI

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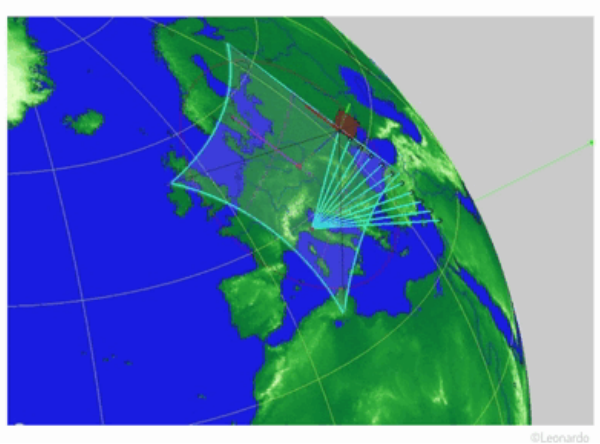
EPS-SG/3MI in a nutshell

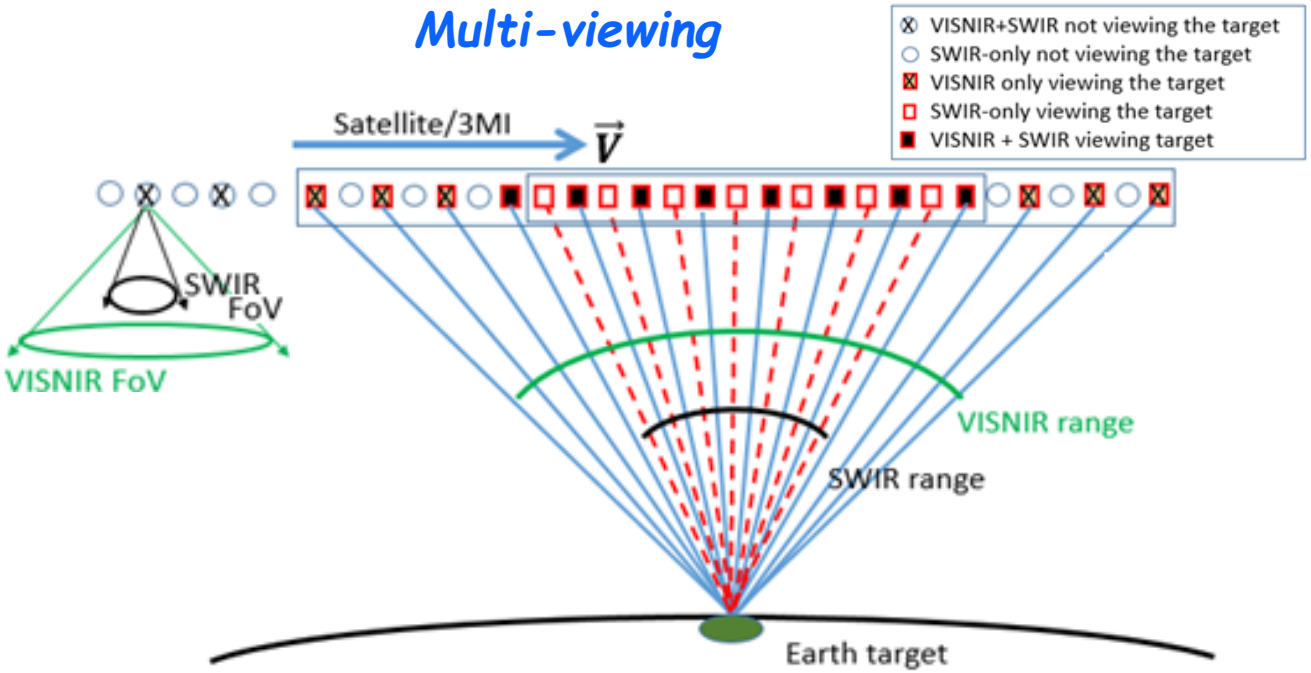
3MI : Multi-viewing Multi-channel Multi-polarisation imager

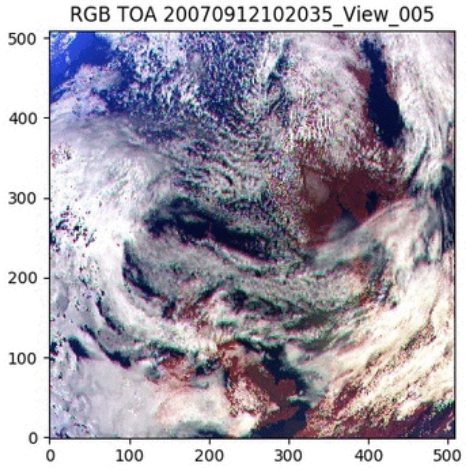
- 3MI is a new instrument
- 12 spectral bands from 410 to 2130nm, inc. 9 with I/Q/U
- 4km nadir – 2200x2200km² swath (for VISNIR)

Filter wheel = spectral and polarization

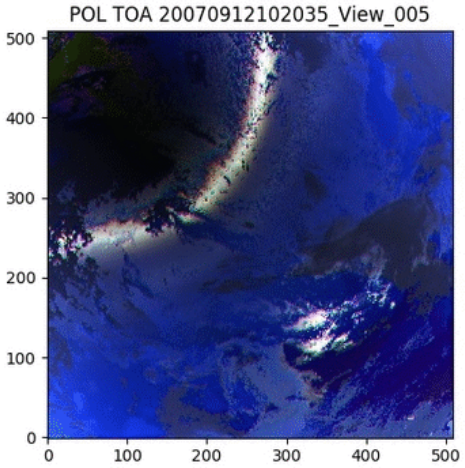


Wide field-of-view = Multi-viewing





Natural light (RGB)



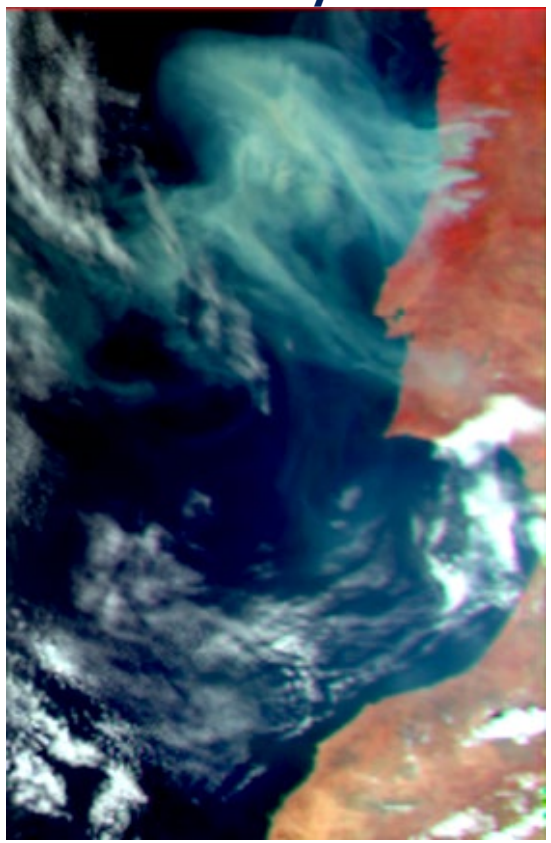
Polarized light (RGB)

Slide by B. Fougnie (EUM)

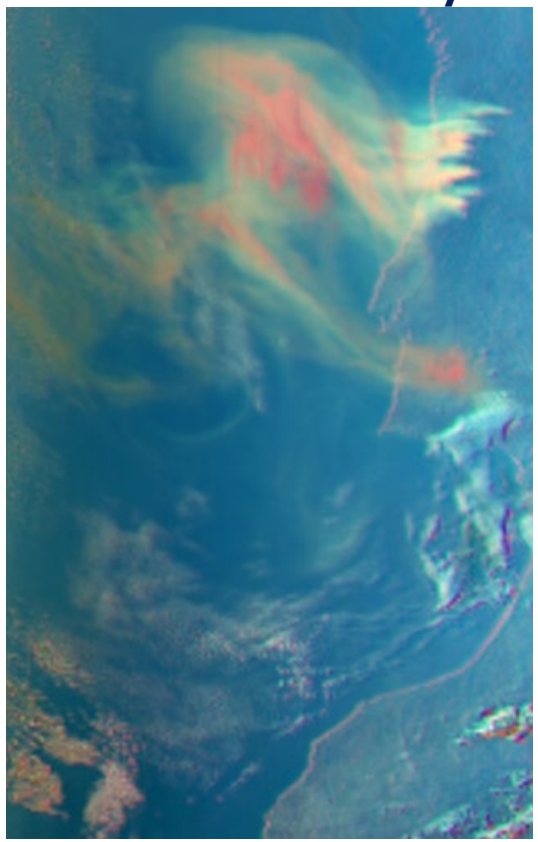
What can one see with polarisation?

16th September 2024 Portugal

Intensity



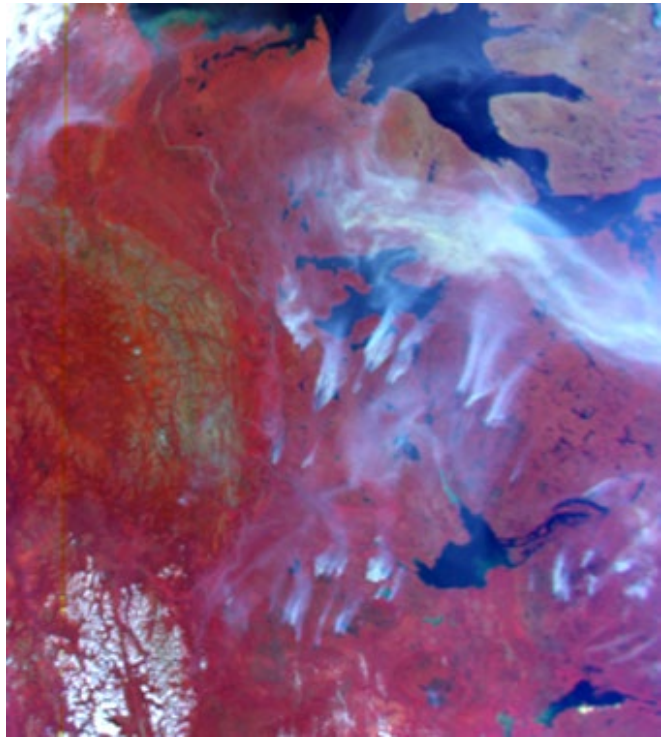
Polarised Intensity



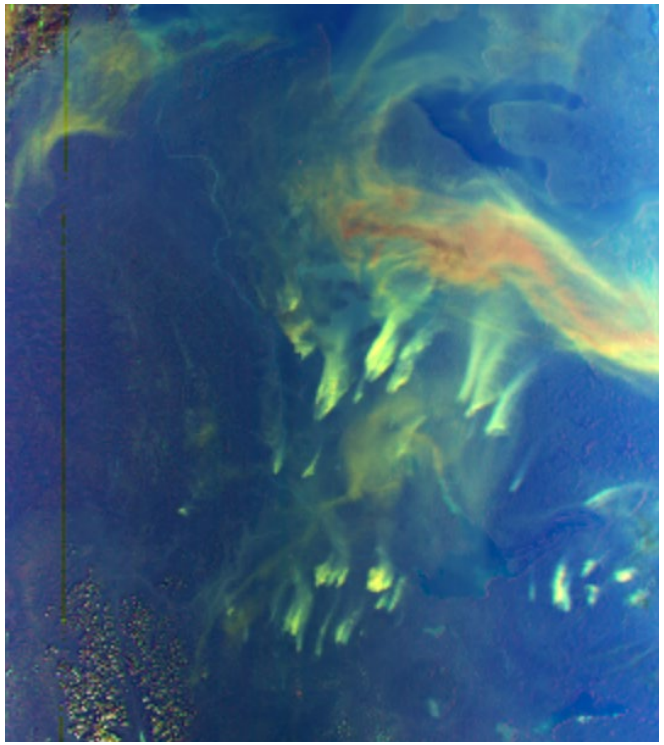
RGB = 865/550/440nm

8th August 2024 Canada

Intensity



Polarised Intensity



RGB = 865/670/440nm

Slide by B. Fougnie (EUM)

What can one see with directional polarisation?

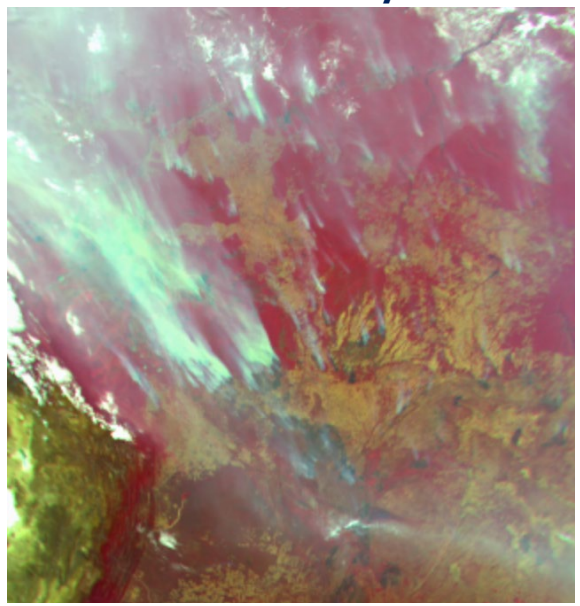
Amazonia

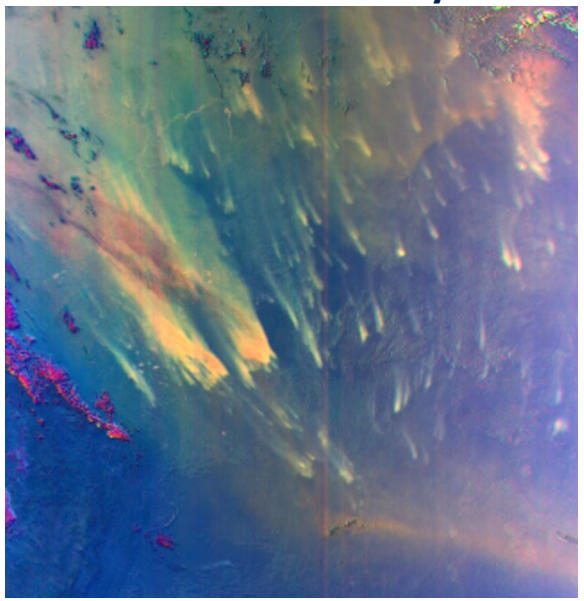
Intensity

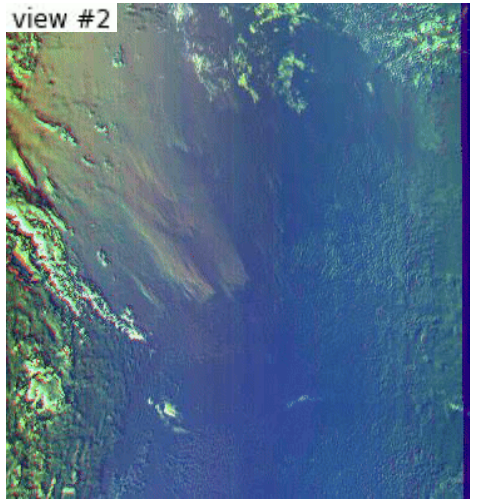
Polarised Intensity

Polarised Intensity

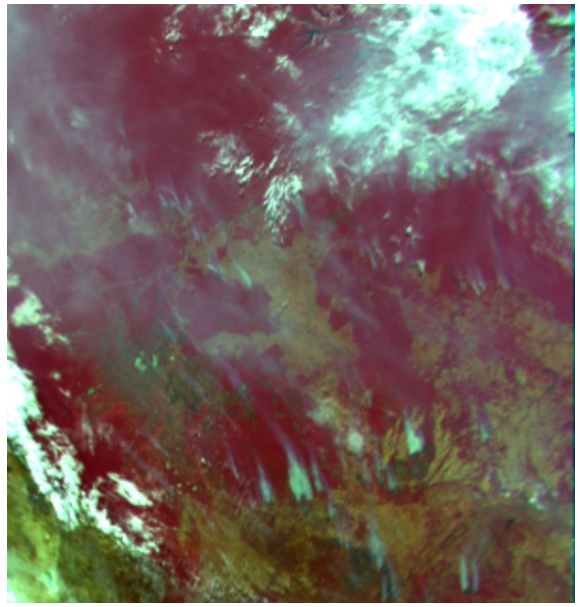
26th August 2024

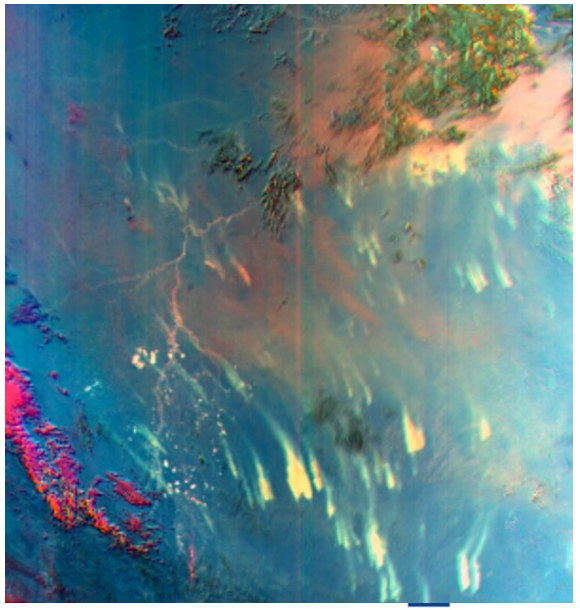


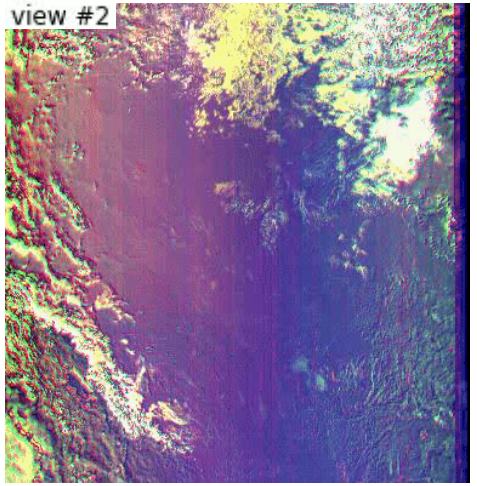




12th August 2024







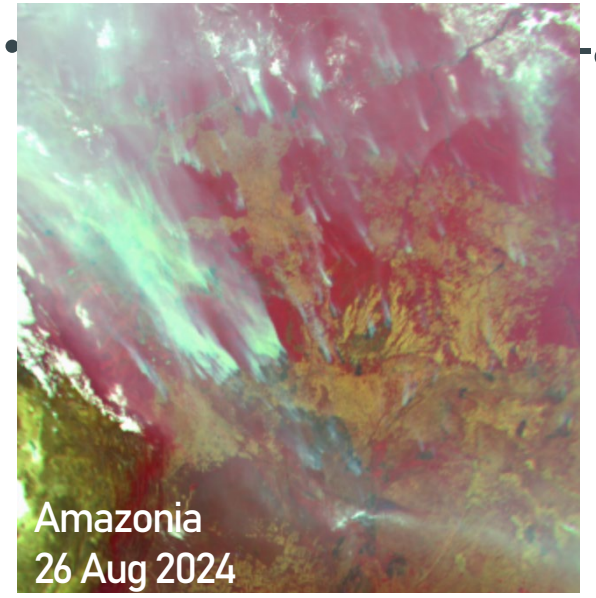
RGB = 865/670/440nm

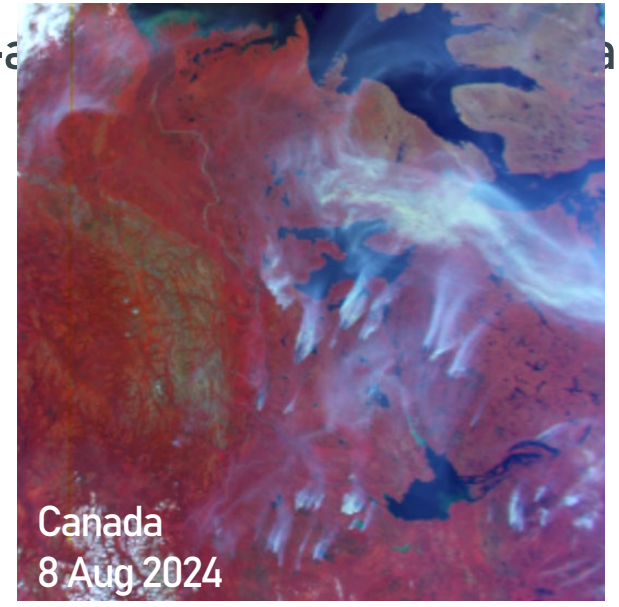
Slide by B. Fougnie (EUM)

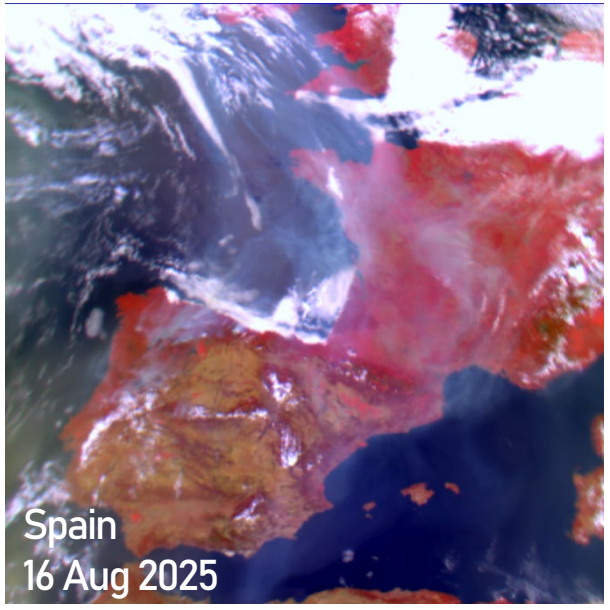
New Generation of Enhanced Aerosol Products

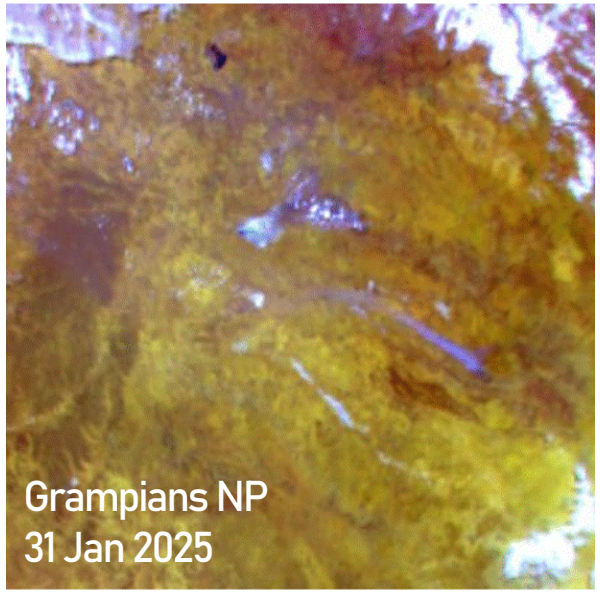
copernicus.eumetsat.int

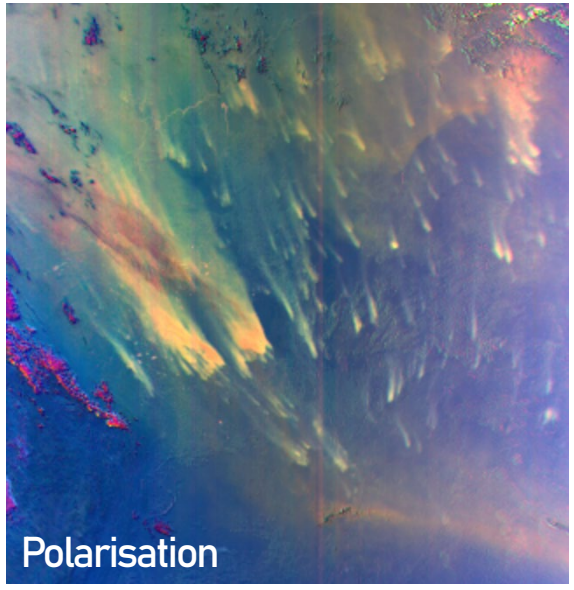
From PACE/HARP2

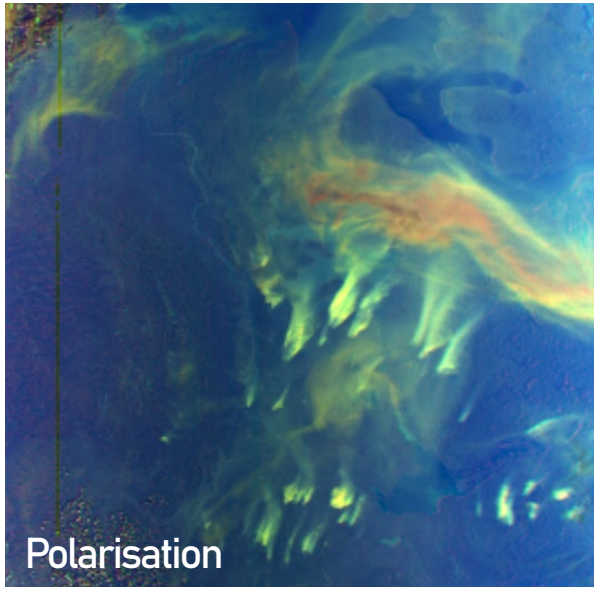


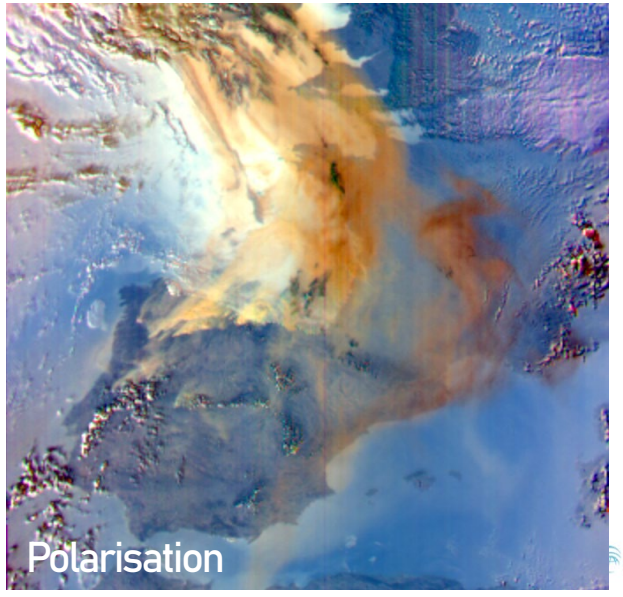


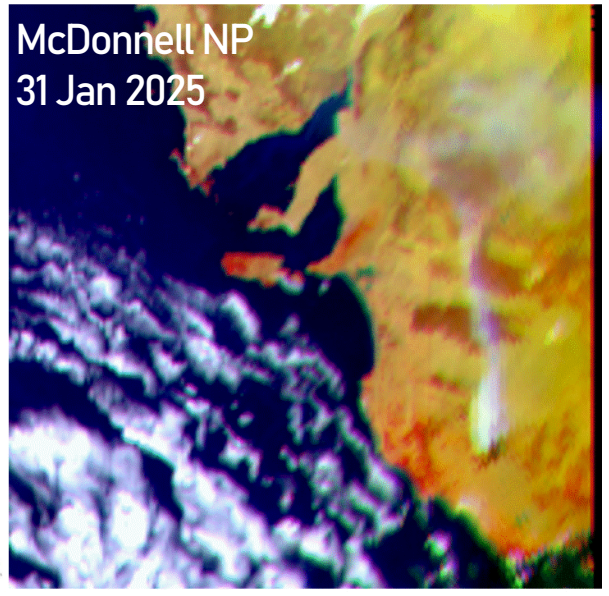








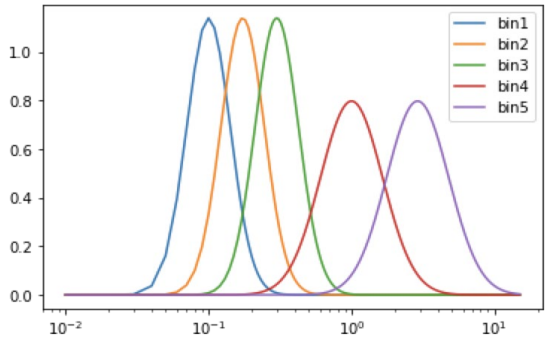




3MI L2 Aerosol Processor – New era of Product

- Aerosol components external mixture in **3 modes** (internal mixture by **Linear Volume Mixture**)
- **Refractive index** from **literature review** (publications 1979-2007)
- Vertical profiling is accounted with aerosol **concentration per mode** (**exponential** one).

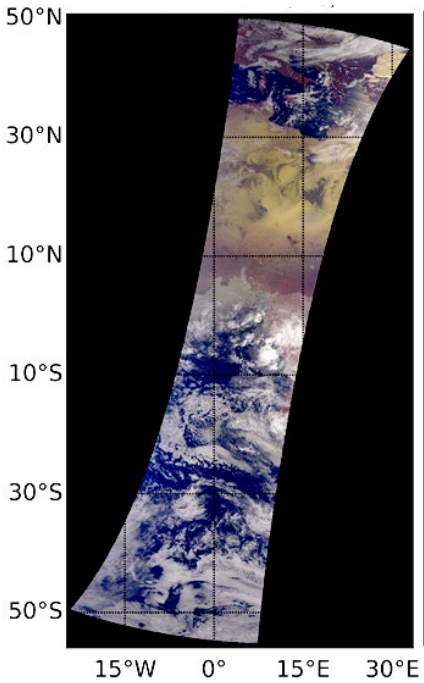
	Size distribution	Volume Concentration	BC	BrC	Quartz	Iron Oxide	Water/ Sulphate	Sea salt
Fine mode	3 LN bins	✓	✓	✓	✓	✗	✓	✗
Coarse mode	2 LN bins	✓	✗	✗	✓	✓	✓	✗
Coarse mode	2 LN bins	✓	✗	✗	✗	✗	✓	✓



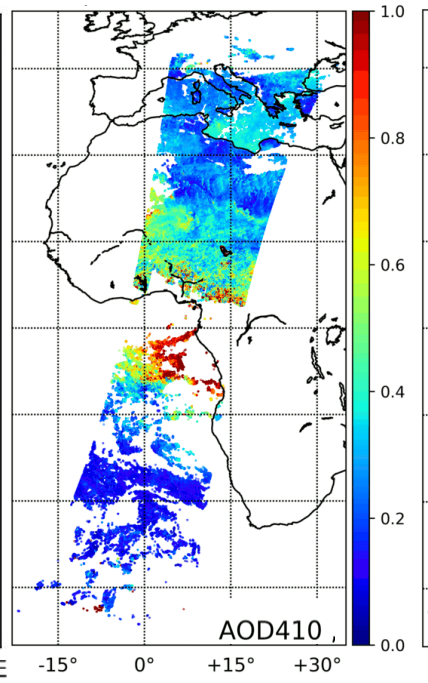
Size
Radius:
mode 1:
bins: 0.1, 0.1732, 0.3 µm
mode 2:
bins: 1., 2.9 µm
mode 3:
bins: 1., 2.9 µm

More parameters

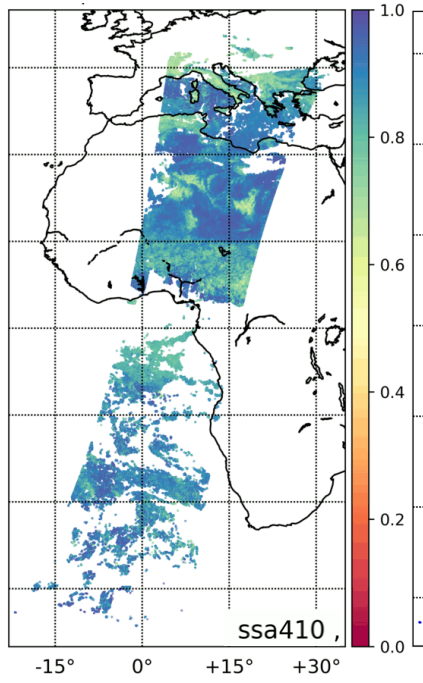
TOA RGB



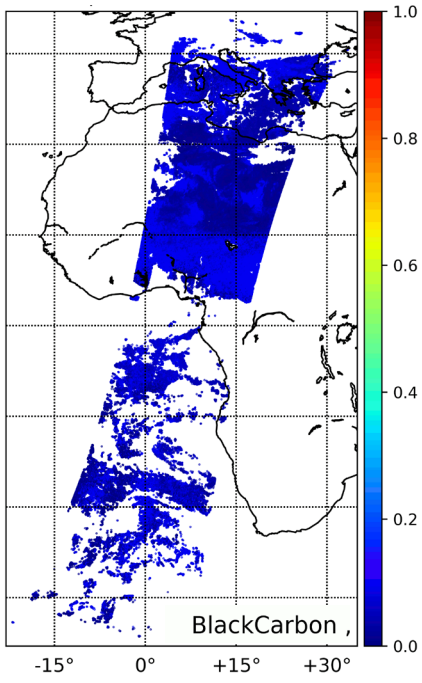
Aerosol Optical Depth



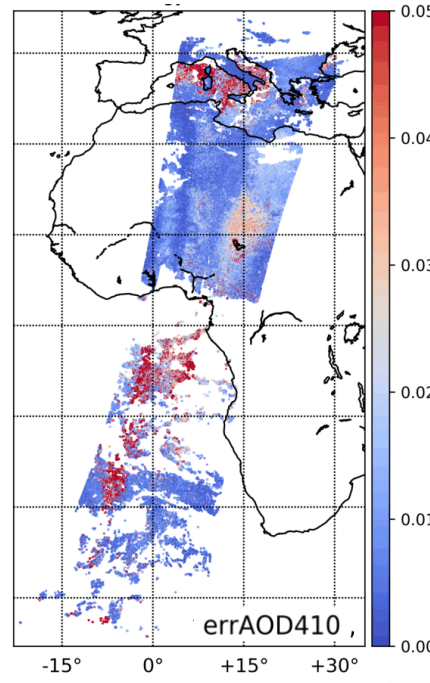
Single Scattering Albedo



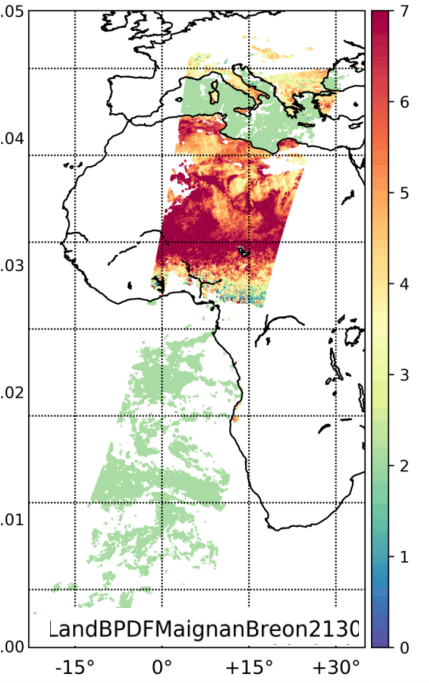
Chemical Components



AOD Error



Surface Polarized Reflectance

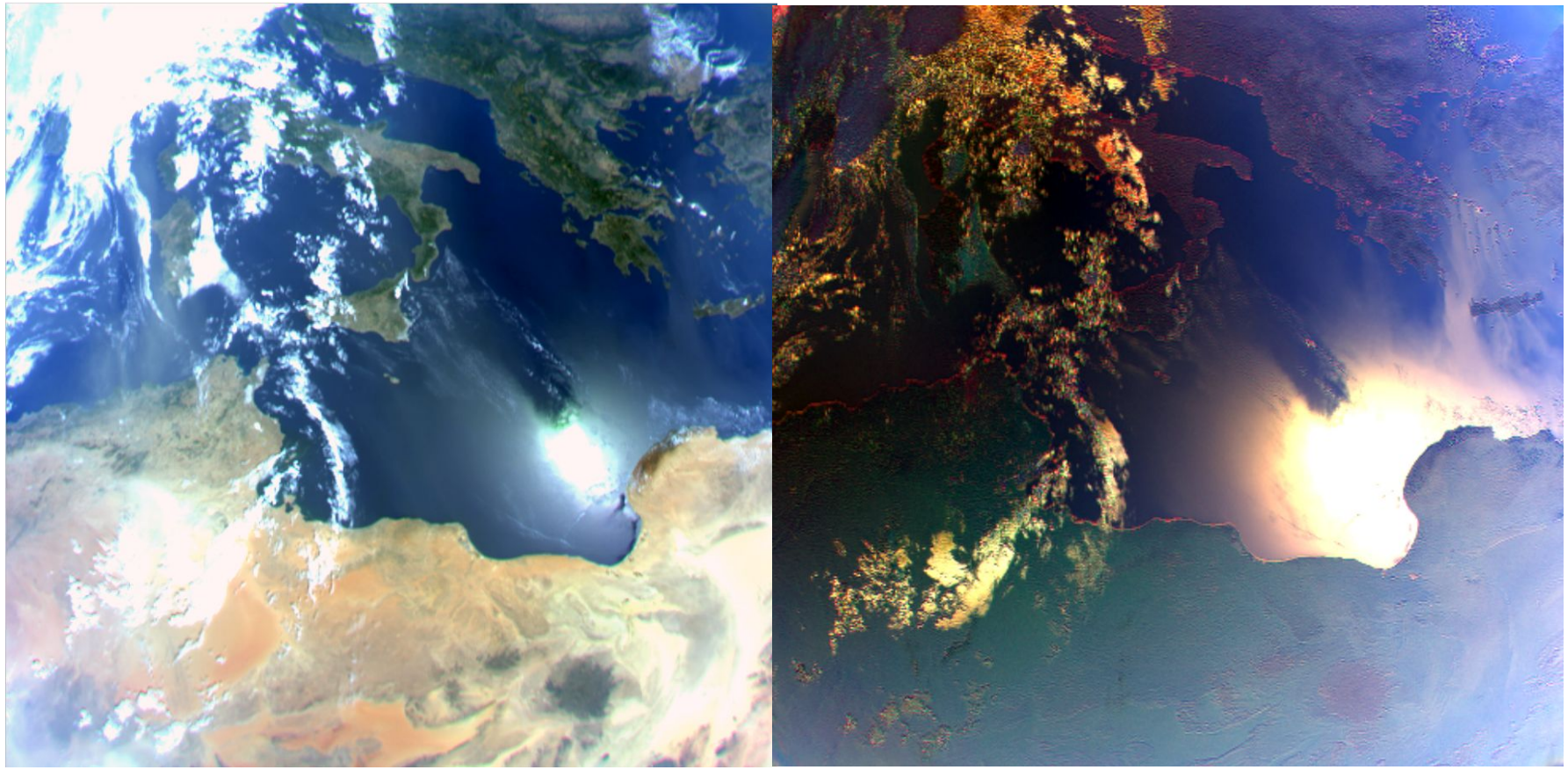


Slide by B. Fougnie (EUM)

3MI first image: 28th Aug 2025 -- 08:59 to 09:03 UTC

Intensity

Polarised intensity



Instrument in de-contamination mode (non-nominal acquisition)

Only VNIR acquired
(443, 670, 865nm presented)

Raw performance
(no radio/geo recalibration)

Image source: L1B1 from ESA GPP + L1B from CNES GPP + RSP in-house processing

Credits: Henda Guermazi and Margarita Vázquez

Agenda

Principles of aerosol remote sensing

Copernicus Sentinel-4 and Sentinel-5

Instrument concepts

Aerosol monitoring capabilities

3MI

Instrument concept

Aerosol monitoring capabilities

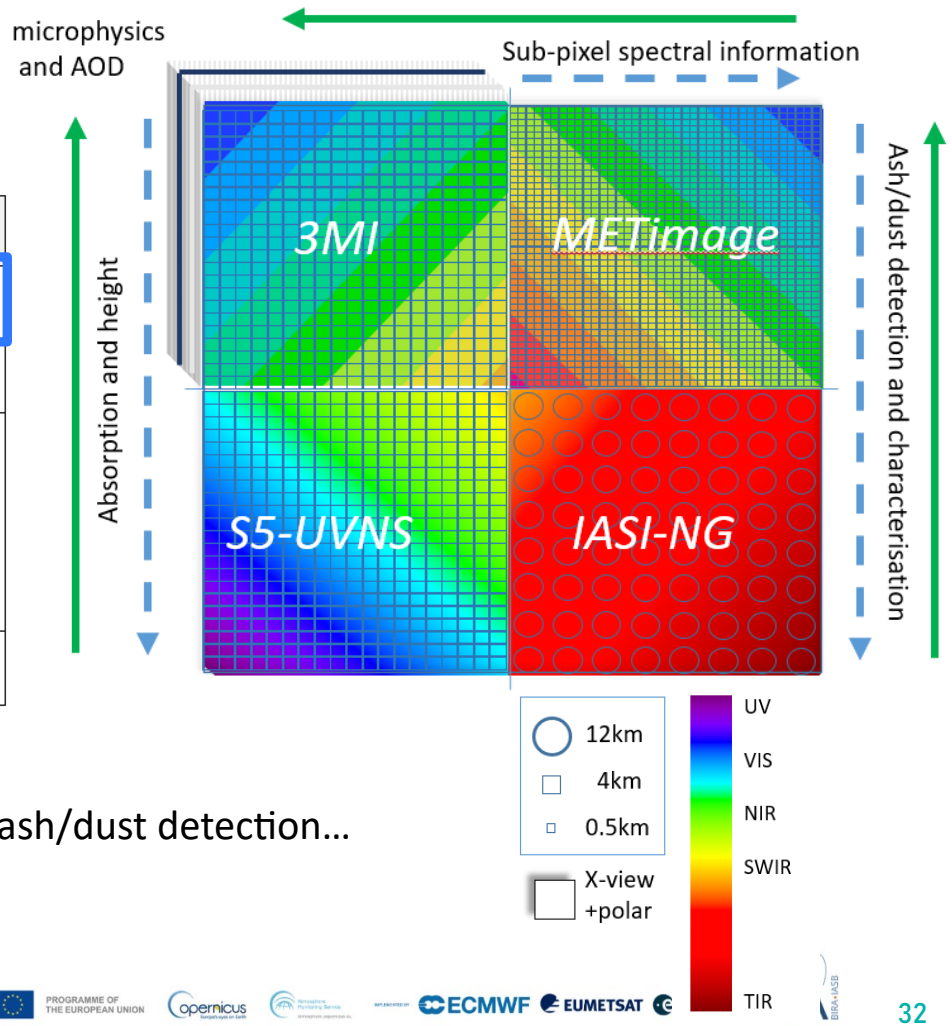
Synergy opportunities

Synergy: EPS-SG Multi-sensor Aerosol Product (MAP)

Next generation of synergy aerosol product from EPS-SG: MAP *(follow-on PMAp on EPS)*

- Retrieval of **aerosol properties** using a hyper-instrument synergy of instruments on-board the platform
  - 3MI - Multi-View, Polarisation, -Spectral Imager;
  - UVNS - UV/Near- and Shortwave Infrared Sentinel-5 spectrometer (Sentinel 5);
  - METimage - Visible Infrared Imager (VII);
  - IASI-NG - Infrared Atmospheric Sounding Interferometer.

Sensor	Spatial resolution	Swath	Spectral type	Spectral bands	Spectral range	Additional capabilities
3MI	4x4 km²	2200 x 2200 km²	VIS/NIR/SWIR	12 bands	410 to 2130nm	14 views Polarisation (I/Q/U)
METimage	0.5x0.5 km²	2670 km	VIS/NIR/SWIR TIR	11 bands 9 bands	443 to 2250nm 3.3 to 13.3µm	
S5-UVN	7.5x7.5 km² 50x50 km² (<300nm)	2670 km	UV/VIS/NIR/SWIR	1669 bands (0.25nm in SWIR to 1nm in UV)	270-300nm 300-370-500nm 685-710nm 755-773nm 1590-1675nm 2305-2385nm	
IASI-NG	12km spot	2000 km	TIR	16921 bands (0.25cm-1)	645 to 2760cm-1	



- Baseline for the design of MAP version 1:
  - PMAP synergy adapted to EPS-SG: colocation, cloud masking, pre-classification, ash/dust detection…
  - AOD and model retrieval from 3MI/GRASP
- Extension to other parameters: improve ash & dust, aerosol height, SSA, PM25?

Thank you!

Questions are welcome.