EUMETSAT missions: current and future

Geostationary Programmes
- Meteosat-10 (2013)
- MSG-4/Meteosat-11 (2016)

Mandatory Programmes
- FCI Imagery (2021)
- MTG-I Sounding (2023)

Optional and Third Party Programmes (incl. Copernicus)
- Metop-A (2007)
- Metop-B (2013)
- Metop-C (2019)
- S3 Imagery (2022)
- S3 Imagery (2022)
- JASON-CS/Sentinel-6 (2021)
- JASON-3/Sentinel-5 on Metop-SG A (2022)
- JASON-3/Sentinel-4 on MTG-S (2022)

Polar Programmes
- PMAp
- MAP
- Metop-SG A Sounding & Imagery (2022)
- Metop-SG B Microwave Imagery (2023)
EUMETSAT activities in support to Copernicus

• Legal Framework:
  • EUMETSAT: Third Party Programme foreseen by the Convention approved in October 2014
  • EU: Delegation Agreement foreseen by the Copernicus Regulation signed in November 2014

• Focus: ocean and atmospheric composition monitoring

• Cooperation with ESA on development and operations

• Vision : deliver integrated data streams (from Copernicus, EUMETSAT and third party missions)

• Objective : create synergies with EUMETSAT own infrastructures
Third party programmes in support of Copernicus

**SENTINEL-1:**
- 4-40m resolution, 3 day revisit at equator
- *S1A and 1B in orbit*
- Polar-orbiting, all-weather, day-and-night radar imaging

**SENTINEL-2:**
- 10-60m resolution, 5 days revisit time
- *S2A and 2B in orbit*
- Polar-orbiting, multispectral optical, high-resolution imaging

**SENTINEL-3:**
- 300-1200m resolution, <2 days revisit
- *S3A and S3B in orbit*
- Optical and altimeter mission monitoring sea and land parameters

**SENTINEL-4:**
- 8km resolution, 60 min revisit time
- 1st Launch 2022
- Payload for atmosphere chemistry monitoring on MTG-S

**SENTINEL-5p:**
- 7-68km resolution, 1 day revisit
- *S5P in orbit*
- Mission to reduce data gaps between ENVISAT, and Sentinel 5

**SENTINEL-5:**
- 7.5-50km resolution, 1 day revisit
- 1st Launch 2023
- Payload for atmosphere chemistry monitoring on MetOp 2ndGen

**SENTINEL-6:**
- 10 day revisit time
- 1st Launch 2020
- Radar altimeter to measure sea-surface height globally

**SENTINEL-7:**
- Preparing for launch
- CO2 monitoring
# Third party programmes in support of Copernicus

## SENTINEL-5/UVNS Level-2 products

<table>
<thead>
<tr>
<th>Parameter(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O3</td>
<td>Ozone (O3) total column, tropospheric column, stratospheric vertical profile</td>
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<tr>
<td>NO2</td>
<td>Nitrogen dioxide (NO2) total column, tropospheric column</td>
</tr>
<tr>
<td>SO2</td>
<td>Sulfur dioxide (SO2) total column, layer height (TBC)</td>
</tr>
<tr>
<td>HCHO</td>
<td>Formaldehyde (HCHO) total column</td>
</tr>
<tr>
<td>CHOCHO</td>
<td>Glyoxal (CHOCHO) total column</td>
</tr>
<tr>
<td>CH4</td>
<td>Methane (CH4) total column</td>
</tr>
<tr>
<td>CO</td>
<td>Carbon monoxide (CO) total column</td>
</tr>
<tr>
<td>Cloud</td>
<td>Cloud effective fraction, effective height, cloud mask</td>
</tr>
<tr>
<td>Aerosol</td>
<td>Aerosol UV absorption index, layer height, optical depth (TBC)</td>
</tr>
<tr>
<td>Surface</td>
<td>Surface effective albedo, scene heterogeneity</td>
</tr>
<tr>
<td>UV</td>
<td>UV spectrally resolved irradiance at surface, UV index</td>
</tr>
</tbody>
</table>

## SENTINEL-4 Level-2 products

<table>
<thead>
<tr>
<th>Parameter(s)</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>O3</td>
<td>Ozone (O3) total column, tropospheric sub-column,</td>
</tr>
<tr>
<td>NO2</td>
<td>Nitrogen dioxide (NO2) total column, tropospheric sub-column</td>
</tr>
<tr>
<td>SO2</td>
<td>Sulfur dioxide (SO2) total column</td>
</tr>
<tr>
<td>HCHO</td>
<td>Formaldehyde (HCHO) total column</td>
</tr>
<tr>
<td>CHOCHO</td>
<td>Glyoxal (CHOCHO) total column</td>
</tr>
<tr>
<td>Cloud</td>
<td>Cloud optical thickness, fraction, altitude</td>
</tr>
<tr>
<td>Aerosol</td>
<td>Aerosol column optical thickness, type, layer height, absorbing index</td>
</tr>
<tr>
<td>Surface</td>
<td>Surface and aerosol characteristics</td>
</tr>
</tbody>
</table>
Third party programmes in support of Copernicus
From weather to environmental forecasting

Meteosat 9 IR10.8 20080525 0 UTC

ECMWF Fc 20080525 00 UTC+0h:
### Copernicus data access

<table>
<thead>
<tr>
<th>Service</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>EUMETCast</td>
<td>Multi-service push dissemination via satellite or terrestrial networks</td>
</tr>
<tr>
<td>Copernicus Online Data Access (CODA)</td>
<td>Download service offering all Sentinel-3 span up to 12 months of data.</td>
</tr>
<tr>
<td>Data Long-Term Archive</td>
<td>EUMETSAT's long-term archive of products, including Copernicus Sentinel-3</td>
</tr>
<tr>
<td>EUMETView</td>
<td>Visualisation service allowing users to view EUMETSAT data and Copernicus Sentinel-3</td>
</tr>
<tr>
<td>New: Copernicus WEkEO DIAS</td>
<td>A federated approach: The most up-to-date Copernicus data and an expanding data offer in the future Distributed open architecture concept, federative and scalable, implemented by European industry.</td>
</tr>
</tbody>
</table>
Summary

Heritage and current developments:

- **EPS/PMAp**: Combination of instruments
  - LUT retrieval and spectral combination (Grzegorski et al. in prep)

- **S3/SLSTR**: Dual-view radiometer
  - Aerosol retrieval with a physical based surface model from U. Swansea (North. et al. 1999)

- **S3/OLCI**: Multispectral Pushbroom
  - Simultaneous aerosol / surface retrieval with GRASP (Dubovik et al. 2014)

Next generation of aerosol products:

- **EPS-SG/3MI**: Multi-directional Polarimeter
  - Simultaneous aerosol / surface retrieval with GRASP (Dubovik et al. in prep)

- **EPS-SG/MAP**: Multi-sensor
  - Combination of PMAp and 3MI

- **MTG/FCI**: Geostationary imagers
  - Simultaneous aerosol / surface retrieval with AERUS (Carrer et al. 2014)
Products from sensors currently in-orbit

- **EPS (EUMETSAT Polar System)**
  - 3 instruments for aerosol retrieval
    - GOME-2, AVHRR, IASI → hyper-instrument

- **Sentinel-3 (Copernicus)**
  - 2 LEO satellites: S3-A (2016) and S3-B (2018)
  - 2 instruments for aerosol retrieval
    - SLSTR, and OLCI
EPS sensors – creating a hyper-instrument

**PMAp: Polar Multi-sensor Aerosol product** from GOME-2, AVHRR and IASI

- EPS: Polar orbit at 09:30 ECT – A/2006, B/2012, C/2018
- 3 redundant platform/instrument → 25 y. of operation
- GOME-2, AVHRR, IASI

**Combined Spectral information**

TOA Radiance at 40 by 80 km² (GOME-2) resolution

- AVHRR: 5 channels 1 km² resolution
- IASI: ~8000 channels 12 km resolution
- GOME-2: ~4000 channels
- GOME-2 PMDs: 15 channels

**Spatial sampling** co-location

IASI spot into the GOME footprint

AVHRR pixel

- Product = AOD @550nm + aerosol type classification
- Fully operational product since Oct’14 (over ocean)
- Version 2 since Feb’17 (ocean & land)
- Version 2.2 released soon
PMAp Main Updates

• Operational product, Currently Version 2.1.0 (Feb 2017)
  • Surface homogeneity test
  • Surface elevation correction function for Rayleigh scattering calculation
  • Surface reflectance database (LER v1.6) statically masked for more accurate land/water areas partition
  • Volcanic Ash/\text{SO}_2\text{ class using thermal IR IASI measurement}

• Next Release 2.2 - coming mid-2019
  • GOME-2 PMDs L1 radiance correction for degradation (degradation + offset)
  • Surface reflectance database (LER) now based on MetopA & B
  • Improved detection and AOD quality for thick desert dust - in particular over bright surfaces and discrimination w.r.t. to water clouds (IASI spectrum)

→ Under refinement by EUMETSAT and evaluation by CAMS
  • Very good consistency between Metop-A, -B, and -C
  • The specific case of dust over clouds creates “hotspots” on AOD retrieval : to be discarded or flagged
The Polar Multi-sensor Aerosol Product
Operational near-real time products from EPS/Metop

PMAp V2.1 Metop-C

- **PMAp-C V2.1**
  - PMAp-C activated after the L1 in-flight calibration update of GOME
  - Product quality very similar to PMAp-B
  - Currently in GS1. Pre-operational status: released for Trial dissemination (to Cal/Val partners)

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**V2.1 AOD(550) : MetopC 20190227**

**V2.1 AOD(550) : MetopB 20190227**
The Polar Multi-sensor Aerosol Product
Operational near-real time products from EPS/Metop

PMAp V2.1 → V2.2

AOD @ 550 nm

PMAp v2.2
Adding information for enhancing the capabilities of desert dust detection and tracking
• **Investigation on the HotSpots**
  - IASI detection of dust over ocean
  - This corresponds also to cloudy situations – in V2.2 cloud test skipped because dust event is supposed to be non-cloudy
  - Impact not only hot-spot (saturation of AOD)
  - Update = to force the cloud-test even if dust

**MODIS RGB**

**PMAp Aerosol Optical Depth** 2013081800000 2013081900000

**PMAp Dust type**
Investigation on the HotSpots

- IASI detection of dust over ocean: corresponds sometimes to cloudy situations – in V2.2 cloud test skipped because dust event is supposed to be non-cloudy
- Impact not only hot-spot (saturation of AOD)
- Update in V2.2b = to force the cloud-test even if dust
  - Now identified as cloudy pixel + the aerosol contaminated flag raised (no more AOD value)
The Polar Multi-sensor Aerosol Product
Operational near-real time products from EPS/Metop

PMAp-A/B/C = PMAp-D

- Tristar MetOp configuration → very good complementarity of PMAp A/B/C products
  - Remarkable global daily coverage: complementarity of the ground tracks (low loss due to sunglint)
  - Efficiency of the cloud decontamination, especially over ocean
  - Good consistency over dust events & Better identification of the inter-track residues
The Polar Multi-sensor Aerosol Product
Operational near-real time products from EPS/Metop

- **Tristar MetOp configuration → very good complementarity of PMAp A/B/C products**
  - Remarkable global daily coverage: complementarity of the ground tracks (low loss due to sunglint)
  - Efficiency of the cloud decontamination, especially over ocean
  - Good consistency over dust events & Better identification of the inter-track residues

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**Map of AOD @ 550 nm for 20190619 platform M01 M02 M03 PMAp v2.1**

- Color scale from 0.00 to 1.00
The Polar Multi-sensor Aerosol Product
Operational near-real time products from EPS/Metop

PMAp-A/B Time Series

Feb-May 2015
&
Jun-Sep 2013

3-day averaging
Binning 3x3

Version 2.2
(not yet released)

PMAp L3 (0.50x0.50) Aerosol Optical Depth 01-Feb-2015

Courtesy R. Lang
Products from sensors currently in-orbit

• **EPS (EUMETSAT Polar System)**
  - 3 instruments for aerosol retrieval
    GOME-2, AVHRR, IASI → hyper-instrument

• **Sentinel-3 (Copernicus)**
  - 2 LEO satellites: S3-A (2016) and S3-B (2018)
  - 2 instruments for aerosol retrieval
    SLSTR, and OLCI
**Actual Aerosol Mission: Sentinel-3 sensors**

**Sentinel-3**: Copernicus Mission
- Polar orbit at 10:00 ECT – A in Feb. 2016, B in Apr. 2018
- 2 complementary instruments: OLCI and SLSTR

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<thead>
<tr>
<th>λ center (μm)</th>
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<td>Band 7</td>
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<tr>
<td>Band F1</td>
<td>3.740</td>
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<tr>
<td>Band 8</td>
<td>10.850</td>
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<tr>
<td>Band F2</td>
<td>10.850</td>
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<tr>
<td>Band 9</td>
<td>12.000</td>
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**Sea Land Surface Temperature Radiometer**
- dual view conic scanner, 500m @nadir (1km @nadir for TIR)
- 9 spectral bands

**Ocean Land Colour Imager**
- pushbroom
- Fine resolution 300m@nadir
- Reduced Resolution 1.2 km@nadir
- 21 spectral bands

<table>
<thead>
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<th>λ center (nm)</th>
<th>Width (nm)</th>
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<tr>
<td>400</td>
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<td>940</td>
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<td>1020</td>
<td>40</td>
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</tbody>
</table>
Aerosol Product from Sentinel-3 : SLSTR

• **Sentinel-3 / SLSTR**
  - 5 spectral channels at 554, 659, and 868 nm, and 1.613, 2.255 um – 4.5km resolution
  - dual-view instruments nadir + 50° oblique (ATSR 1&2, AATSR)
  → Retrieval of AOD + model

• **Scientific approach (Univ. Swansea; North. et al. 1999)**
  - Historically applied to dual-view instruments ATSR 1&2, AATSR (ESA CCI_aerosol project)
  - Aerosol retrieval with a physical based surface model - Iterative optimization of AOD, aerosol model & surface reflectance
  - Viewing constraints: multi-angular – dual-view over land, nadir view over ocean

• **Initial algorithm & Processor**
  - Developed in the framework of S3 Mission Performance Centre (ESA contract)
  - Delivered to EUMETSAT (Oct. 2018), now fully in charge of maintenance, long-term evaluation, validation monitoring, evolution, deployment.

• **On-going analyses / validation by EUMETSAT** - necessary evolutions before operational release:
  - Optimal adaptation based on up-to-date knowledge of SLSTR sensor specificities (e.g. geometry, radiometry calibration, etc..)
  - Note: parallel study with Finnish Met. Inst. to consolidate the SLSTR specificities and the expected product performance
Aerosol Product from Sentinel-3: SLSTR

**S5P-Tropomi over Middle Atlantic**

**SLSTR retrieval over Middle Atlantic**
Aerosol Product from Sentinel-3 : SLSTR

**Validation over Ocean**

North Atlantic

South Pacific

**Validation over Land**

S3 A – SLSTR (10:00)

Terra MODIS (10:30)

3 km
Aerosol Product from Sentinel-3 : OLCI

- Sentinel-3 / OLCI
  - 21 bands from 400 to 1020nm for 1700 km nadir swath → Retrieval of AOD
- OLCI : on-going demonstration of GRASP performance for OLCI
  - Simultaneous surface aerosol retrieval (Dubovik et al. 2014)
Aerosol Product from Sentinel-3 : OLCI

- OLCI : on-going demonstration of GRASP performance for OLCI
- Simultaneous surface aerosol retrieval (Dubovik et al. 2014)

**AOD(865) : OLCI-A**

*OLCI retrieval 17 July 2018*

*OLCI retrieval June 2018*
Products from future sensors

• **EPS-SG (EPS Second Generation)**
  - 3 LEO satellites: Metop-SG on LEO at 9:30
  - core instrument for aerosol: 3MI polarimeter
  - 4 instruments for aerosol retrieval
    3MI, Metimage, S5, IASI-NG → hyper-instrument MAP

• **MTG (Meteosat Third Generation)**
  - 3 GEO satellites
  - 1 instrument for aerosol retrieval
    FCI imager
Future Aerosol Mission: EPS-SG - 3MI

2D Push-broom radiometer (2200 km swath, 4 km pixel at nadir)

Provides images of the Earth TOA outgoing radiance using:
- Multi-view (10 to 14 views; angular sampling in the order of 10°)
- Multi-channel (12 channels from 410 to 2130 nm)
- Multi-polarisation (9 channels with -60°, 0°, +60° polarisers)

### 3MI channels

- 410-P ± 10 nm
- 443-P ± 10 nm
- 490-P ± 10 nm
- 555-P ± 10 nm
- 670-P ± 10 nm
- 763 ± 5 nm
- 765 ± 20 nm
- 865-P ± 20 nm
- 910 ± 10 nm
- 1370-P ± 20 nm
- 1650-P ± 20 nm
- 2130-P ± 20 nm

[Diagram of 3MI components: CCD VNIR Detector (509x509 pixels), Filter wheel, VNIR Optical Head, CMOS SWIR Detector (255x499 pixels), SWIR Optical Head, 3MI simulated total radiance, View 01, 3MI simulated polarised radiance, View 01 SWIR]
Aerosol Product from EPS-SG : 3MI

- 3MI = Multi-directional polarimeter
- Added-value information content for aerosol retrieval: 14 views, polarisation, and 12 bands from 410 to 2130nm

Based on simulated 3MI “ideal” dataset
Aerosol Product from EPS-SG : 3MI

- Simultaneous aerosol / surface retrieval with GRASP
- Approach according Dubovik et al., 2014 using all the information content
- Already tested for various sensors (PARASOL, MISR, MODIS, OLCI…)
- Under adaptation for an operational use in EUMETSAT (Near Real Time)

Based on simulated 3MI “ideal” dataset
Aerosol Product from EPS-SG : 3MI

- Simultaneous aerosol / surface retrieval with GRASP
- Already tested for various sensors (PARASOL, MISR, MODIS, OLCI…)
- Under adaptation & evaluation for an operational use in EUMETSAT (Near Real Time)

Input AOD to generate 3MI simulated dataset

AOD retrieved from 3MI simulated dataset

Based on simulated 3MI “ideal” dataset
Aerosol Product from EPS-SG : 3MI

Based on PARASOL data 30th June 2008

AOD(550)

Angström
Aerosol Product from EPS-SG : 3MI

Based on PARASOL data 30th June 2008
Aerosol Product from EPS-SG : toward MAP

• Multi-sensor Aerosol Product (follow-on PMAp)
• All sensors available on the same platform → Hyper-instrument
  • Spectral range (from 270nm to 15 micron)
  • Spectral resolution
  • Spatial resolution (from 500m to 20km)
  • Polarisation and multi-directionality

• Core product based on 3MI
• Additional information content from METimage (sub-pixel information), Sentinel-5 (extension to UV), IASI-NG (TIR sounding)

• Improvement of the accuracy or more parameter retrieved :
  • Aerosol type
  • Aerosol height
  • AOD, SSA, refractive index, fine mode fraction

• Potentiality for PM2.5 estimation
• AOD over clouds
Products from future sensors

- **EPS-SG (EPS Second Generation)**
  - 3 LEO satellites: Metop-SG on LEO at 9:30
  - core instrument for aerosol: 3MI polarimeter
  - 4 instruments for aerosol retrieval
    - 3MI, Metimage, S5, IASI-NG → hyper-instrument MAP

- **MTG (Meteosat Third Generation)**
  - 3 GEO satellites
  - 1 instrument for aerosol retrieval
    - FCI imager
Geostationary sensors – SEVIRI and FCI

**MSG/SEVIRI:**
- full disk every 15’
- 3 reflective solar bands
- 3km@nadir

**MTG/FCI:**
- full disk every 10’
- Rapid scan service (1/4th of full disk every 2.5’)
- 8 reflective solar bands
- 1km@nadir

[(courtesy Météo-France/CNRM)]
Aerosol Product from MSG : SEVIRI

- Simultaneous aerosol / surface retrieval with AERUS-GEO
- Approach according Carrer et al., 2010; 2014
- Daily retrieval for MSG/SEVIRI available in ICARE
- Instantaneous retrieval (up to 96/day) under development
- Planned to be operationally implemented in EUMETSAT for MTG/FCI

Capture of aerosol plume from Etna volcano on April 15th, 2010

Daily AOD at 0.64μm on March 30th, 2010

(Ceamanos et al. 2018)
Aerosol Product from MSG : SEVIRI

- Instantaneous retrieval with i-AERUS
  - good estimation of the AOD
  - reveal the diurnal cycle that may be large
→ comparison to Aeronet and PARASOL (GRASP)
- artefacts : identified limitation in backscattering geometry with the aerosol model (phase function)
Aerosol Product from MSG : SEVIRI

- Instantaneous retrieval with i-AERUS
- Various types of behaviour

**Bright surface Desert dust type**

**Oceanic surface**
Aerosol Product from MSG : SEVIRI

• Instantaneous retrieval with i-AERUS

  Mediterranean basin

  *i-AOD retrieved by i-AERUS-GEO*

  *d-AOD retrieved by d-AERUS-GEO*

  Scores are similar to those of the operational d-AERUS-GEO
Aerosol Product from MSG to MTG

- Instantaneous retrieval with i-AERUS
  - The i-AERUS product is already at a good level of maturity

- Good assessment of the AOD and its diurnal variation

- Clear improvements are identified for:
  - A better consideration of the aerosol type
  - A better consideration of the surface (especially for ocean)

- MTG/FCI will provide more spectral information expected to contribute to a better constrain of the retrieval
Development of Operational Aerosol Products

• Several developments on-going

• EPS PMAp already operational – improvements coming very soon

• Sentinel-3: current development and operational product is expected to arrive soon

• Operational product under preparation for MTG - based on development with MSG
  • Assessment of the diurnal cycle for AOD

• Follow-on MAP based on the core aerosol mission 3MI and other sensors
  • Robust and accurate aerosol characterisation (AOD + other parameters)
Development of Operational Aerosol Products

ありがとうございます