

Overview of the EUMETSAT Operational Aerosol Processors

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EUMETSAT **Remote Sensing & Products / *Cloud & Aerosol* (RSP/CLA)**

1) *EUMETSAT*

2) *Rhea Systems GmbH*

3) *Vision Space Technologies*

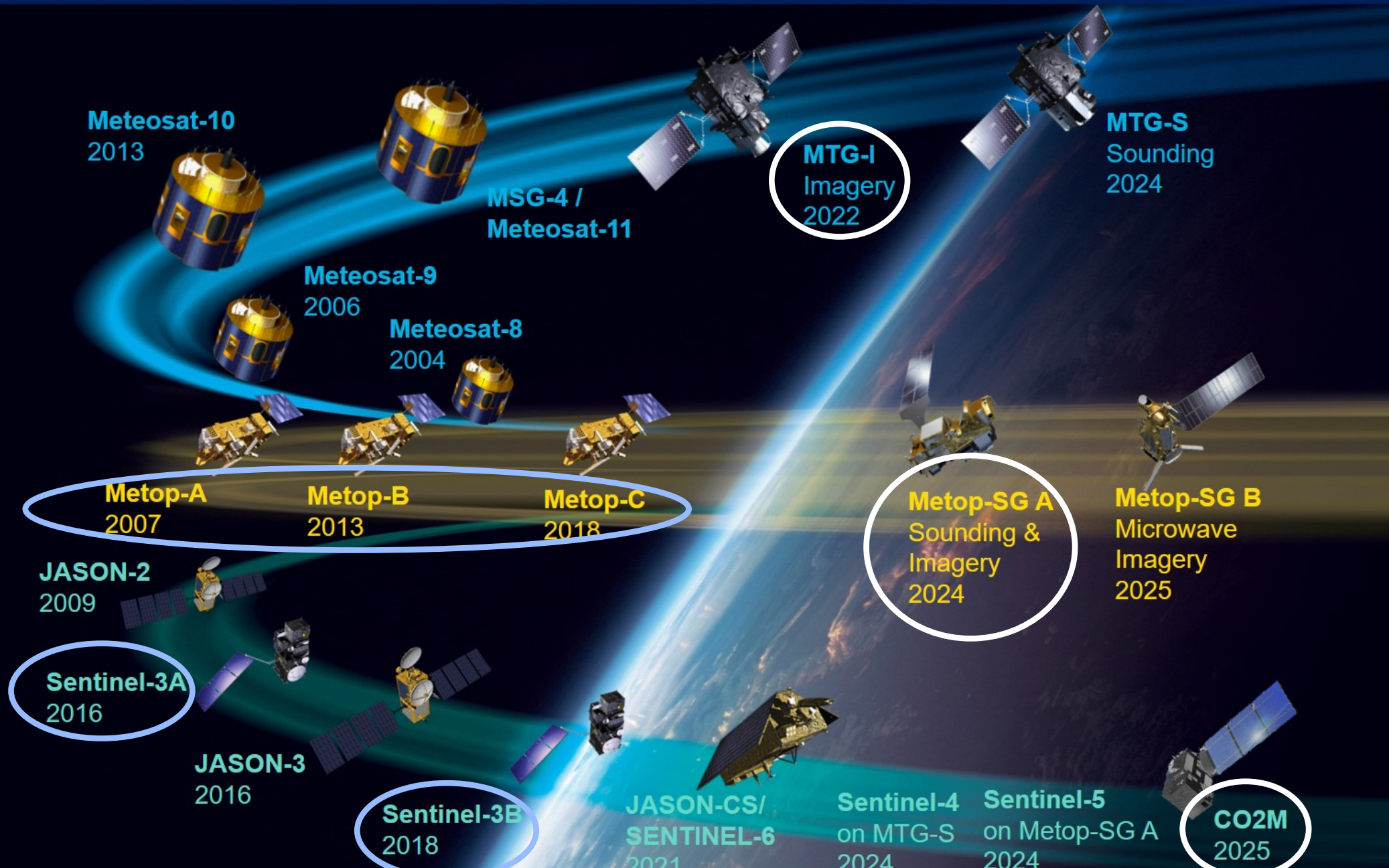
November 2023



- Introduction about Aerosol Operational Processors in EUMETSAT
- Operational processors EPS/PMAp
- Operational processors S3/OSSAR-CS3
- Processor under preparation & development
- Conclusion



EUMETSAT Missions – *Current and Future*





Operational products:

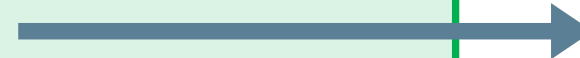
- **O1: EPS/PMAp** : Synergistic combination of instruments
- **O2: S3/SLSTR** : Dual-view radiometer



This is now !!!

Under preparation:

- **P1: EPS-SG/3MI**: Multidirectional polarimeter
- **P2: EPS-SG/MAP**: Synergistic use of 4 instruments (inc. 3MI)
- **P3: CO2M/MAP**: Multiview polarimeter
- **P4: S3/SYN and S3-NG**: Synergy with Multispectral Pushbroom
- **P5: MTG/FCI** : Geostationary imagers



See Thursday 9th 9:10

See Friday 10th 9:30

See Thursday 9th 8:50



- “Operational product” ?
 - Dissemination to operational users
 - Near real time delivery (<3:00h from sensing time)
 - Robustness (availability)
 - Documented performance (validation report)
 - Stability of the performance
 - Monitoring of the performance
 - In general continuous improvements
 - Product tailored to user needs
- Scientific developments are needed to support these definitions and improvements
 - Some adaptation from the scientific development are needed to convert into an operational processor
 - Tailor the products to user needs (core parameters, performance, additional information...)

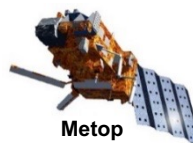
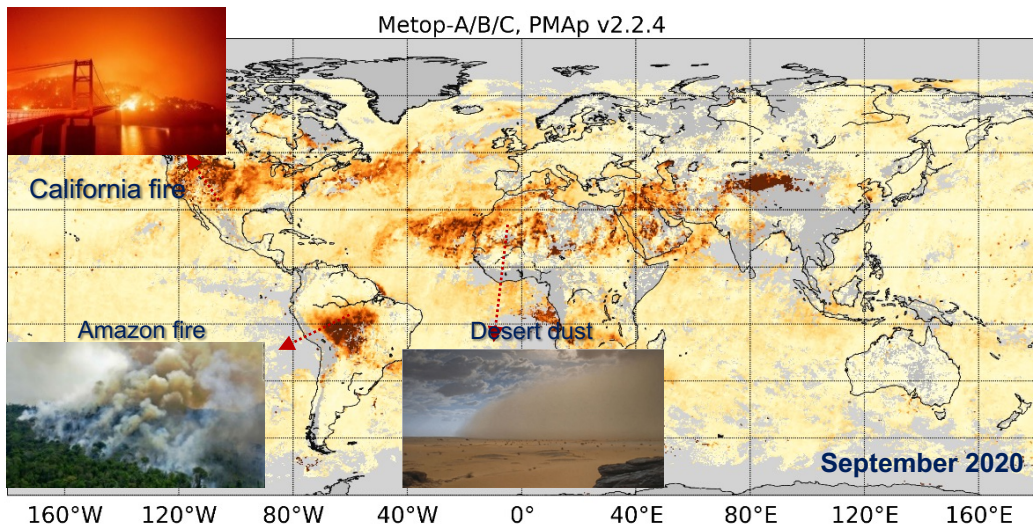
Operational NRT Aerosol processors

01 - EPS/PMAp

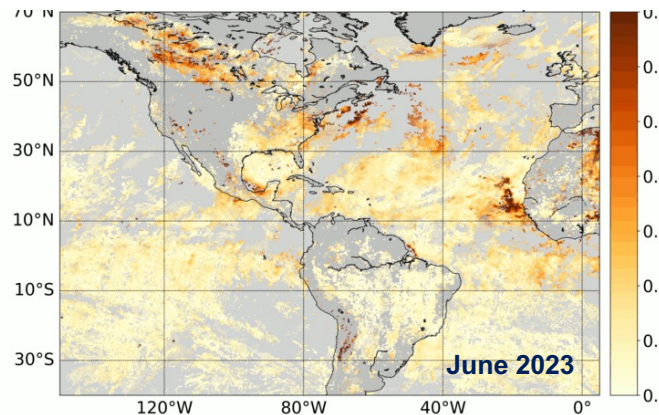


Polar Multi-sensor Aerosol product (PMAp)

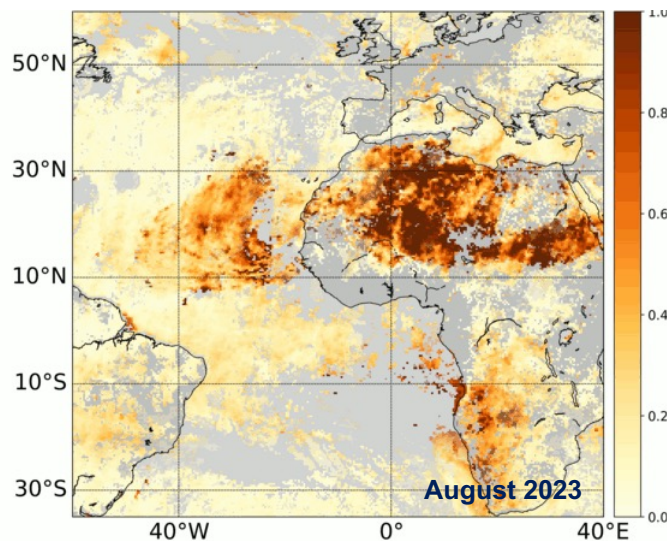
Near Real Time **Aerosol Optical Depth** at 550 nm and **Aerosol Type**



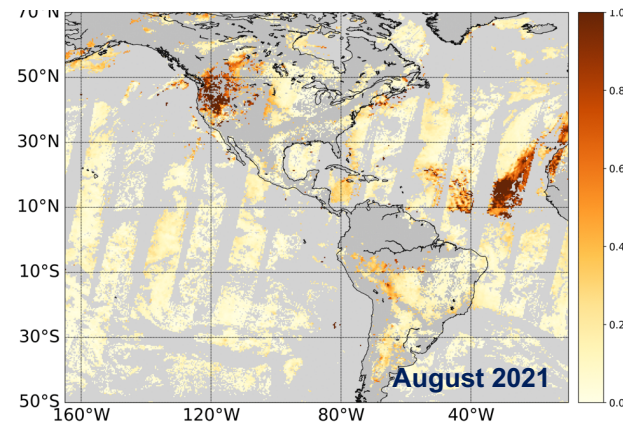
PMAp v2.2, daily aerosol AOD, Metop (B+C)



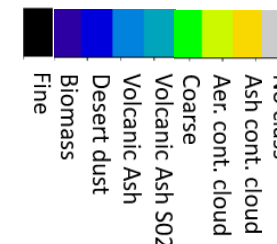
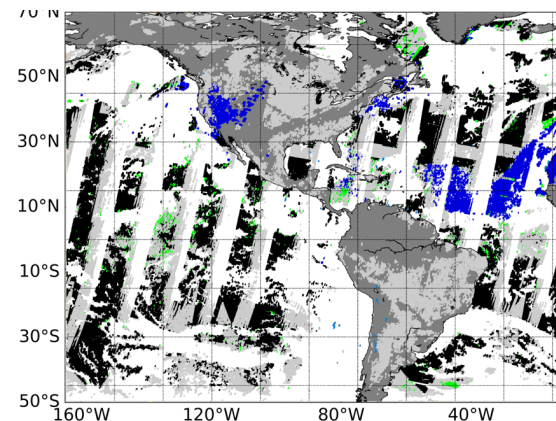
PMAp v2.2, daily aerosol AOD, Metop (B+C)



PMAp v2.2, daily AOD, Metop (A+B+C)



PMAp v2.2, daily aerosol type, Metop (A+B+C)

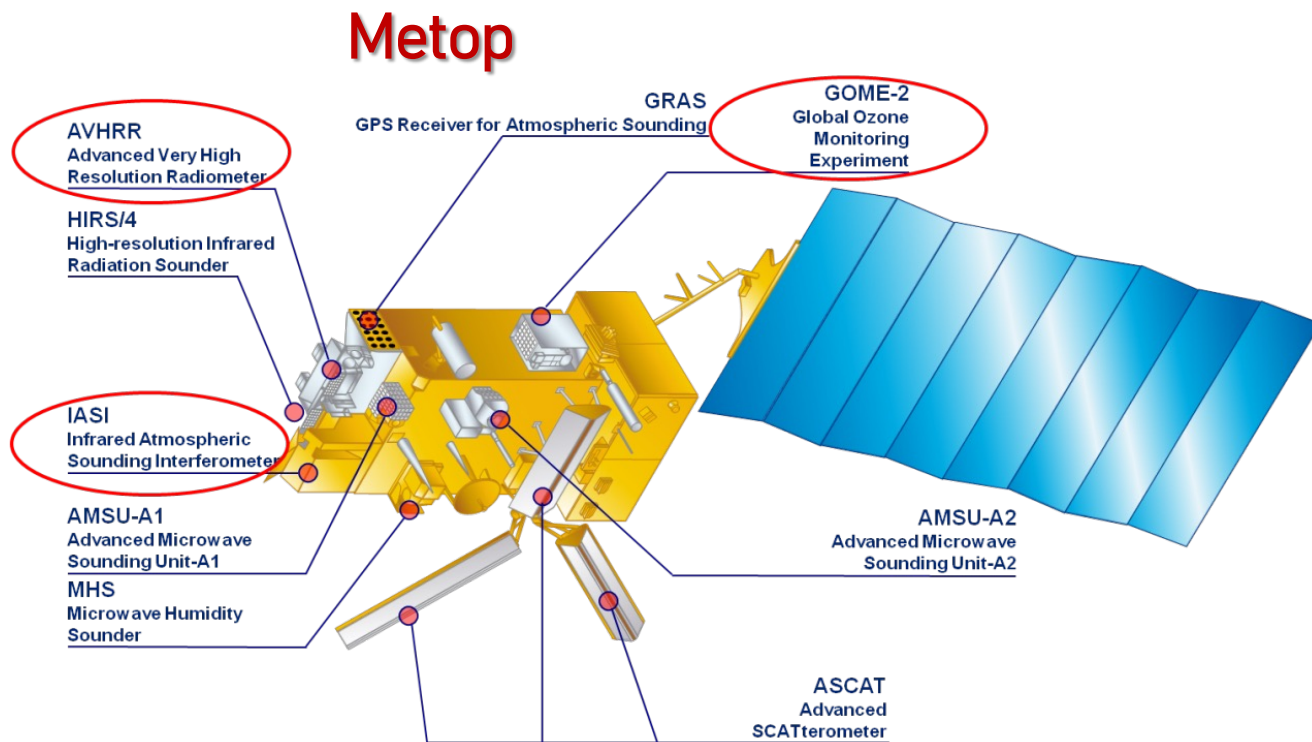


- PMAp is an operational **synergistic** aerosol product retrieved from sensors on-board **Metop** (AVHRR, IASI and GOME-2) from **EUMETSAT** Polar System (EPS).
- 25 years of operation Metop-A/2006–2021, Metop-B/2012, Metop-C/2018.
- Dissemination of PMAp started over ocean since April 2014, over land since April 2016.
- Latest version: February 2023.

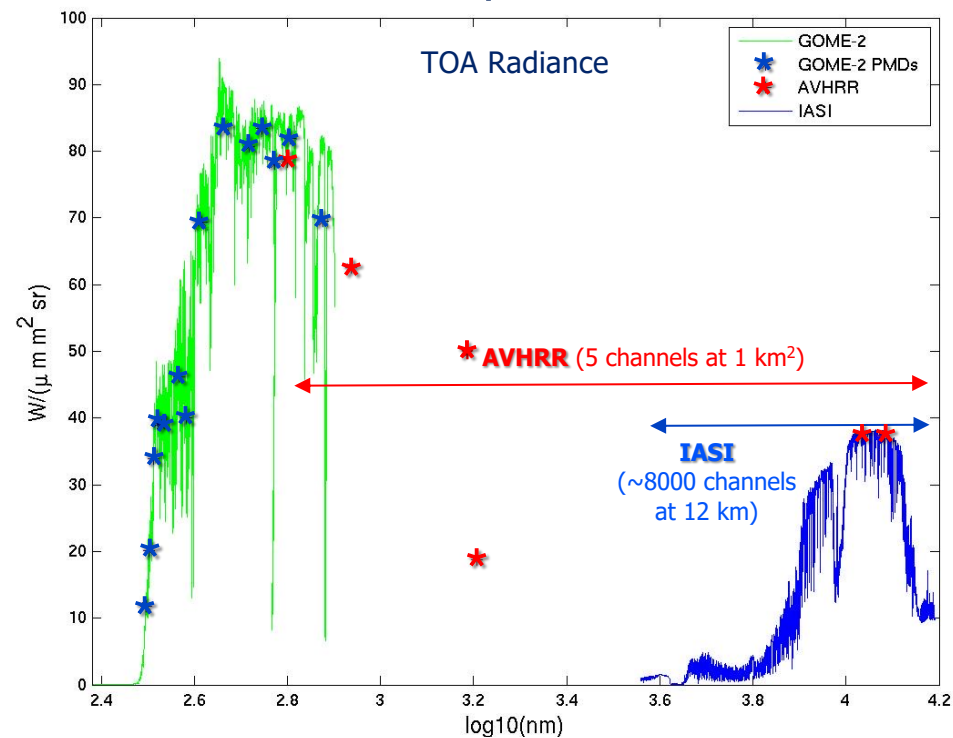


PMAp: Synergy concept

www.eumetsat.int



Multi-sensor spectral information

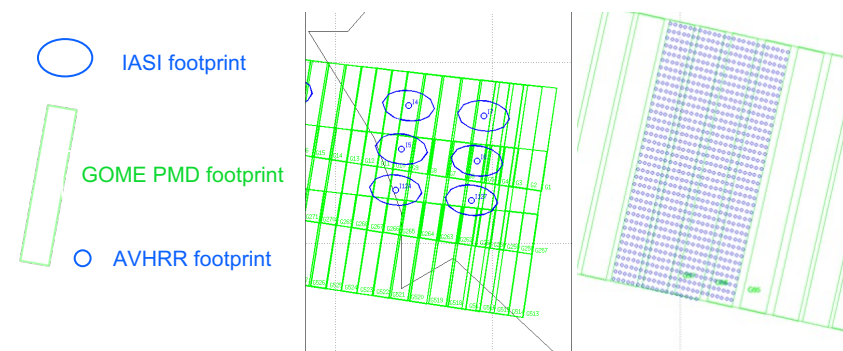


Merging hyper-spectral and high spatial information from GOME-2, AVHRR and IASI

Instruments	Spatial resolution	Spectral range	Polarisation
GOME-2 PMD	10x40 km ²	311 nm – 803 nm (15 bands)	Q/I
AVHRR	1.08 x 1.08 km ²	580 nm – 12500 nm (5 bands)	-
IASI	12 km (circular)	3700 nm – 15500 nm (resolution 0.5 cm ⁻¹)	-

Multi-sensor co-location

IASI spot and AVHRR pixel into the GOME footprint





PMAp Synergy retrieval algorithm design – Version 2.2

Cloud / Aerosol Discrimination

- Volcanic Ash Detection
10 set of thresholds tests **AVHRR + IASI** BTDs tests → Ash presence
 - Desert Dust Detection
IASI dust index → Desert dust presence
 - Clouds' Detection & Correction
clouds detection and cloud fraction calculation (CF)
cloud free PMD Reflectance .OR. PMD Reflectance Correction (for CF < 0.65; partly cloudy pixels)
 - Preliminary Aerosol Type
if Ash presence → aerosol type = ash
if Dust presence → aerosol type = dust
VIS/NIR test for Coarse/Fine mode determination
- } list of preselected aerosol types

Instruments	Purpose
GOME-2 PMD	AOD, Aerosol Type, Absorption, Polarisation
AVHRR	Clouds, Scene heterogeneity, Dust/ash detection
IASI	Volcanic ash detection, Desert dust detection, Aerosol height

Retrieve AODs

- AODs retrieval from **GOME2** for all possible aerosol models in the LUT
over water PMD 12 (640 nm)
over land PMD 7 (414 nm) or PMD 8 (463 nm)

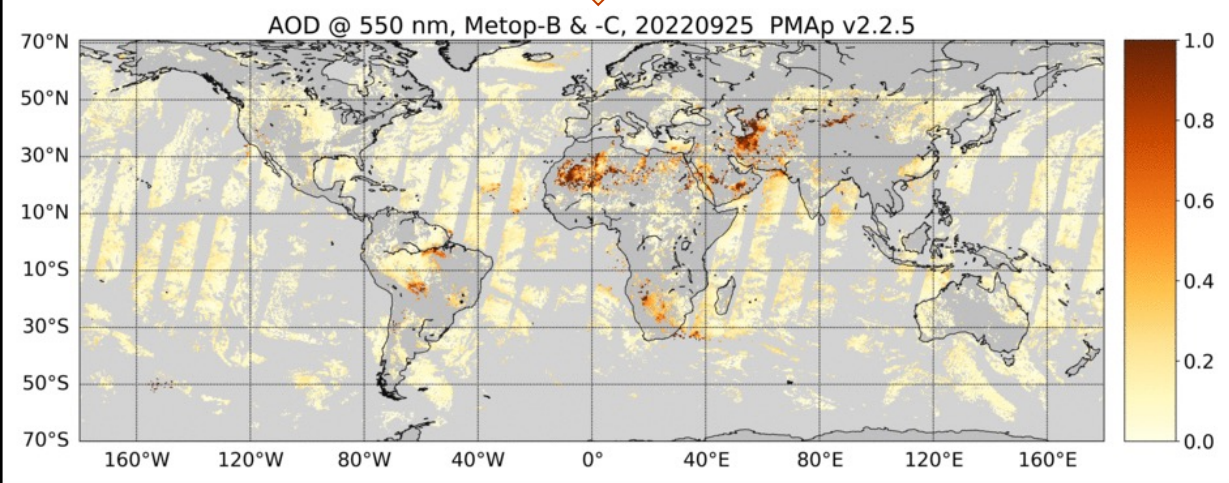
best fit selection – model then AOD

- Microphysics fit : χ^2 minimization of AODs and Models
based on Reflectance and Q fraction for bands in 414 to 799nm
if cloud free: list of preselected aerosol types } → best {AOD, aerosol type}
if partly cloud: all aerosol models
- Estimation of error on AOD

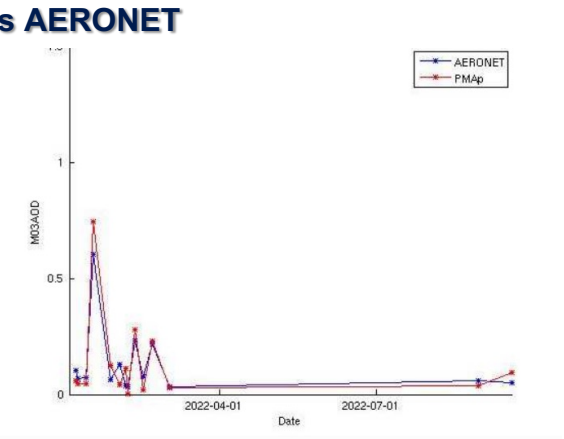
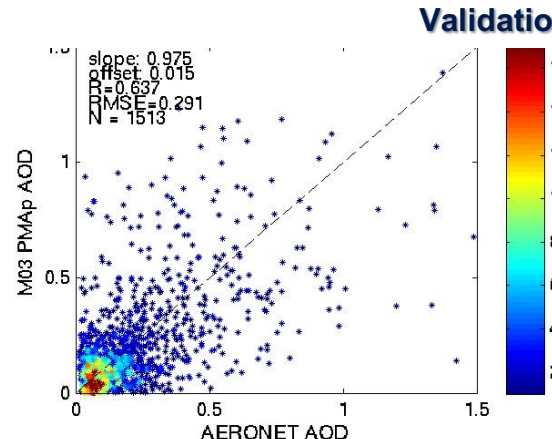
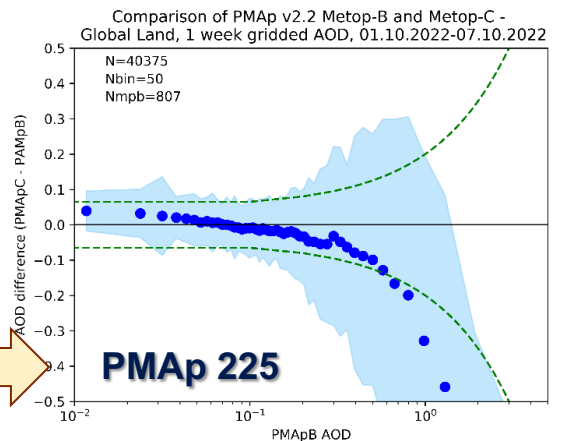
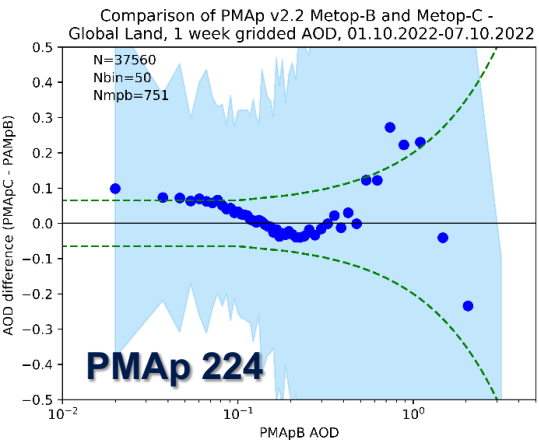
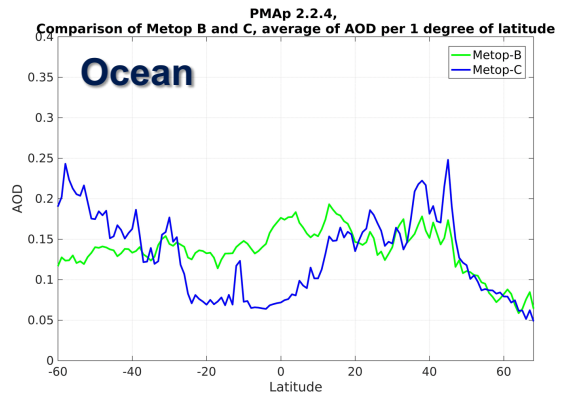
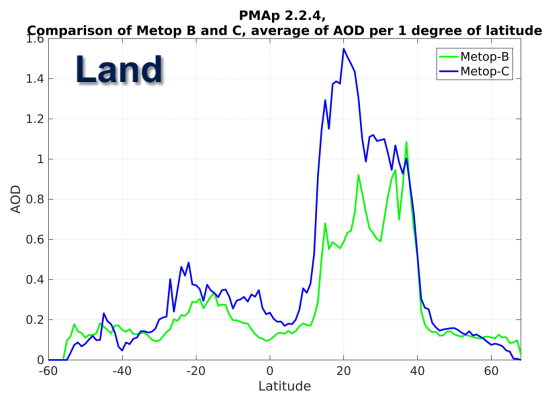
detailed in Grzegorski et al., Remote Sensing, 2022

To address the known limitations of PMAp 2.2.4:

- 1) Update of degradation correction to account for the aging of GOME-2 sensor;
- 1) Calculation of Radiometric adjustment for Metop-C;
- 2) Update of the radiometric adjustment for Metop-B;
- 3) Use of Mode-LER instead of Min-LER (ongoing analysis).



- Increasing the consistency between PMAp-B & -C
- Overall performance of PMAp-C improved.

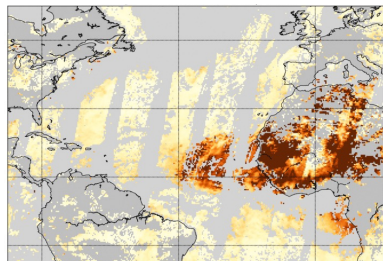
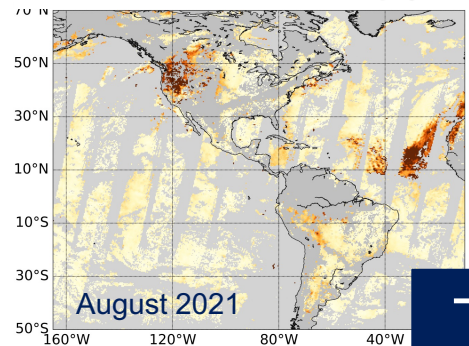




PMAp: validation

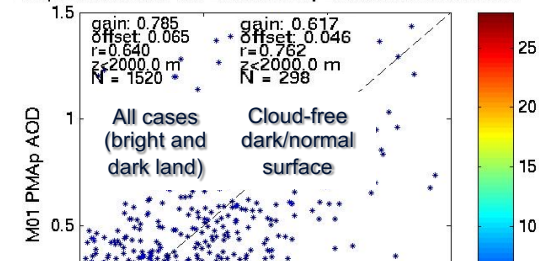
Comparison of PMAp to satellite AOD products

Metop (A+B+C), PMAp v 2.2

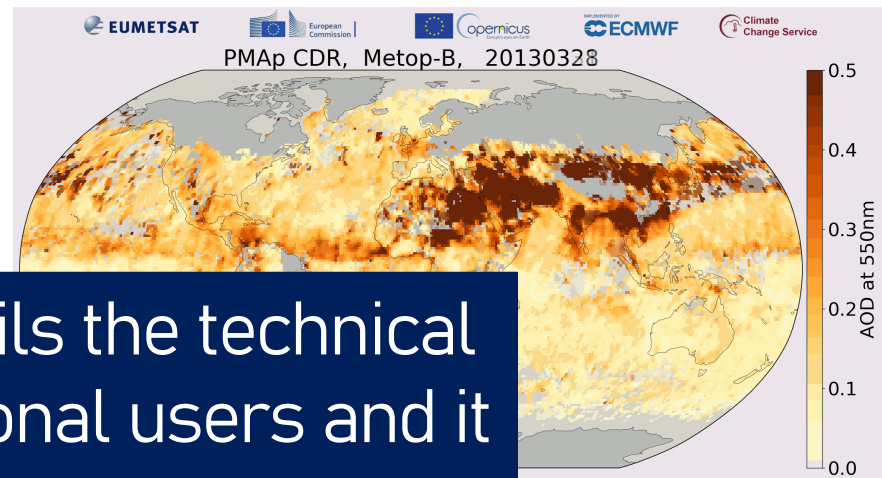


Validation of PMAp vs AERONET

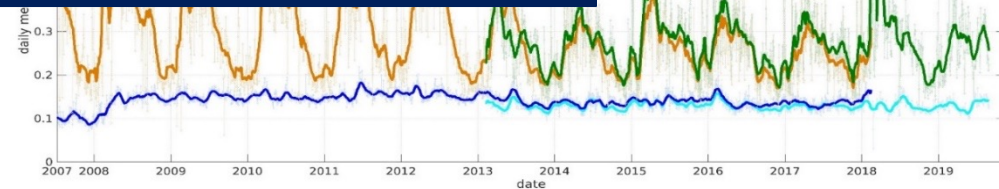
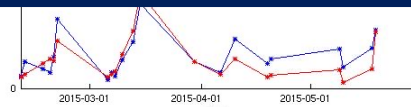
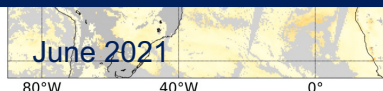
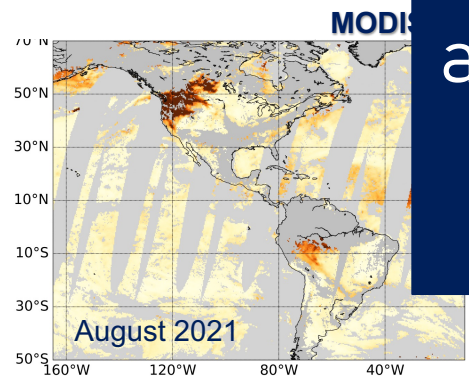
PMAp M01/Aeronet 01-Feb-2015 to 30-May-2015 ΔT: 30min Rad: 30 km



Reprocessing PMAp to create a climate data record (CDR) in the context of Copernicus Climate Change Service (C3S)

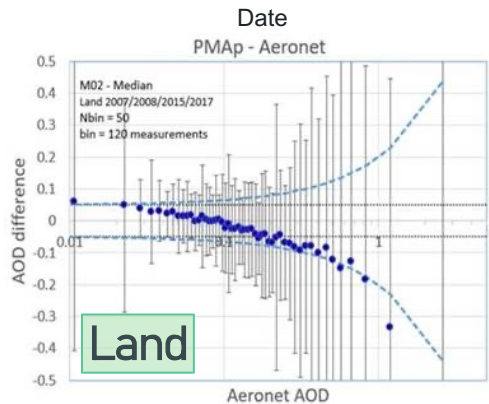
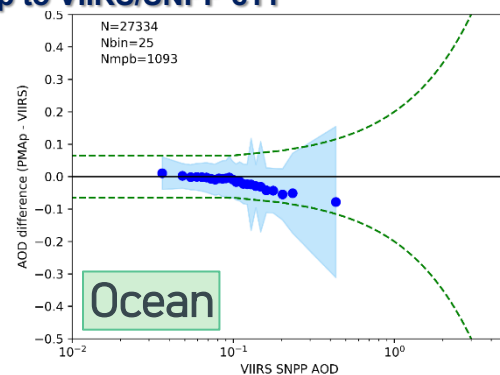
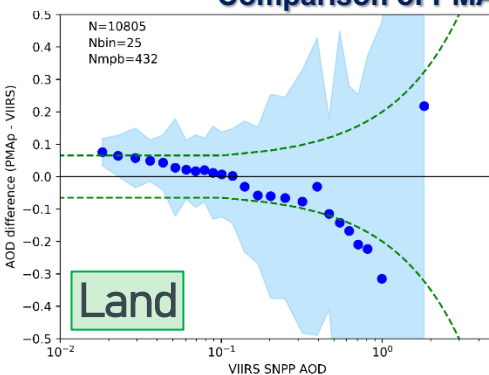


The overall performance of PMAp fulfils the technical and scientific requirements of operational users and it will be used as a baseline for development of next generation of synergy product: MAP

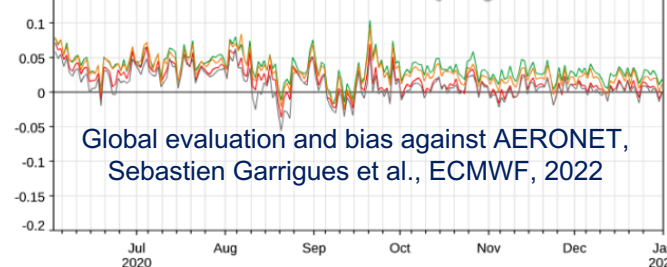


Global AOD in 2007-2019

Comparison of PMAp to VIIRS/SNPP c11



Assimilation of PMAp by CAMS



- PMAp v2.2:
 - Operational since 6th May 2021 with updates in February 2023: (<https://www.eumetsat.int/new-version-metop-pmap-product-released-soon>)
 - significant improvements compared to the previous operational version in terms of aerosol loading, spatial and temporal distribution, especially over land.
 - known limitations of PMAp 2.2.4 being addressed in PMAp 2.2.5.
 - High consistency between the two Metops (-B & -C) is achieved in PMAp 2.2.5
- Now published in Grzegorski et al., Multi-sensor Retrieval of Aerosol Optical Properties for Near-Real-Time Applications Using the Metop Series of Satellites: Concept, Detailed Description and First Validation, *Remote Sensing*, 2022
- The update of GOME-2 surface database to a new version and the relevant limitations of current version are under investigation. A minor update of PMAp is foreseen in coming year. Further improvement will be considered based on requests and feedbacks from users.
- New development will mostly be carried on the follow-on synergistic product EPS-SG/MAP see presentation on Friday:
“Towards the next generation of synergy product: Multi-sensor Aerosol Product (MAP) from sensors on-board the EPS-SG satellites”, by Bertrand Fougnie and Soheila Jafariserajehlou.

Operational NRT Aerosol processors

02 – Sentinel-3/OSSAR-CS3

Copernicus NRT Sentinel-3 aerosols

3 years PRE-operational

Status, lessons learned & planned evolution
towards operational scientific maturity

Julien Chimot¹, Edouard Martins¹, Bertrand Fougne¹, Jaap Onderwater¹, Bojan Bojkov¹

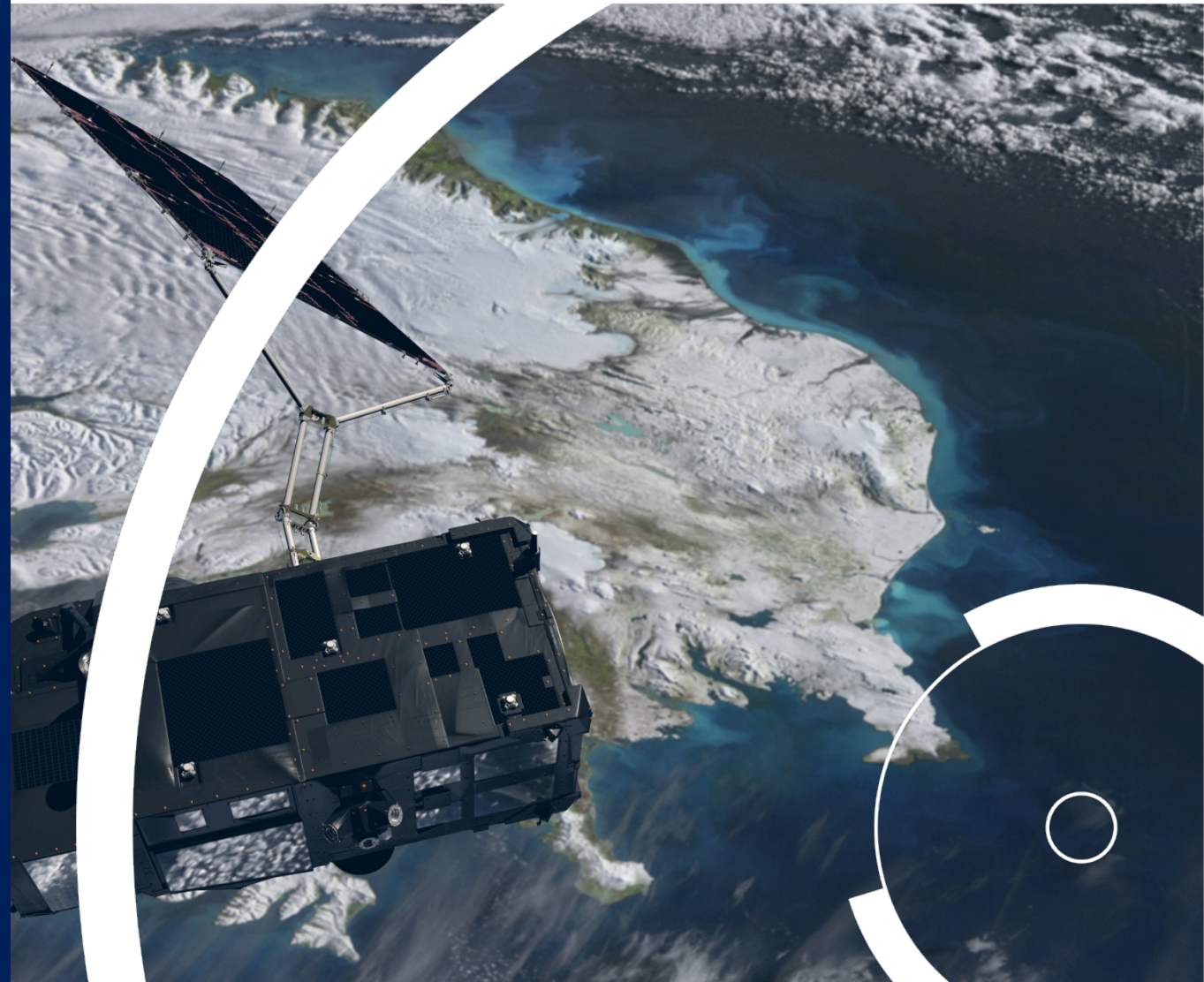
Acknowledgements to:

Swansea U.: Peter North, Kevin Pearson

ECMWF/CAMS: Sebastien Garrigues, Melanie Ades, Enza di Tomaso

ICAP, 9th November 2023

1: EUMETSAT, Darmstadt, Germany

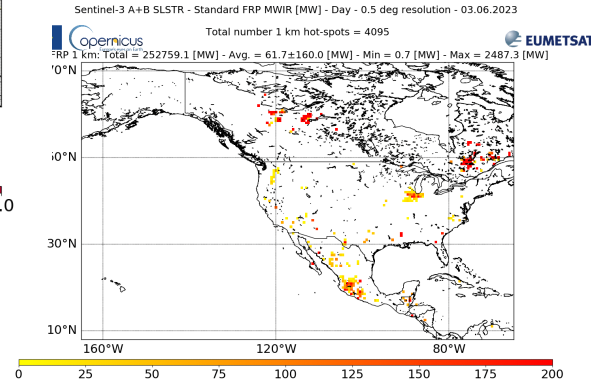
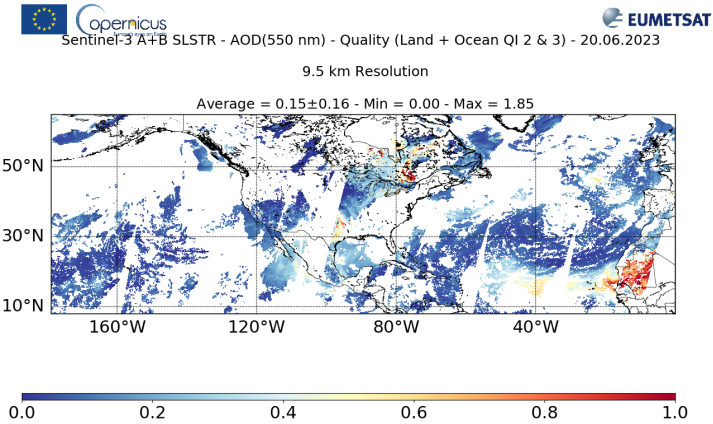
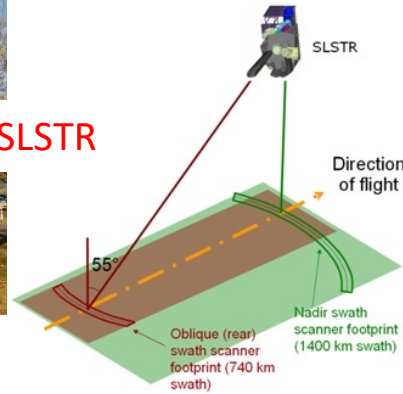




NRT Aerosols from Copernicus Imagery led by EUMETSAT Central Facility since 2020

- 2 NRT products: Aerosol Properties (AOD) & Sources (fires, volcanoes, industrial gas flares - FRP)
- High capability diversity: Imagery (high resolution) - Mono + Dual View – Spectral Synergy - Constellation
- Preparing path towards safe assimilation by operational air quality & climate services with ECMWF & NWP
- **Developments, Calibration, Validation, and Evolutions directly led in-house** supported by key European expertise hired on dedicated topics – NRT (<< 3h), 7/7 days, 24h led by EUM operators & System Engineers.

Sentinel-3 Satellites



Sentinel-3 A, B, C, D (2016 -)

Sentinel-3 New Generation Optical (NGO) – Under preparation (~2035)

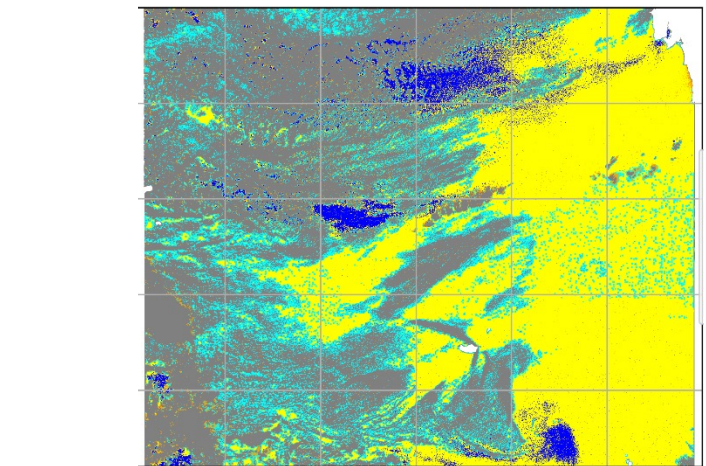
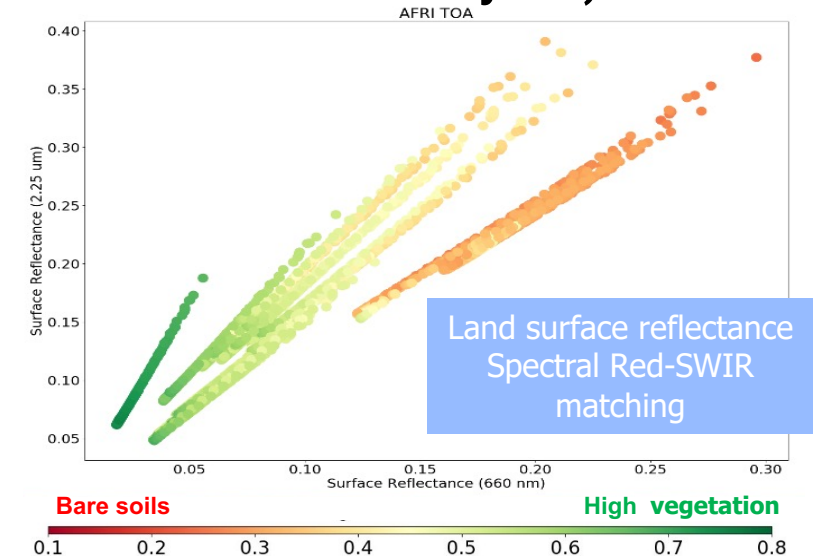
Aerosol User Communities



Volcanic Ash Advisory Centres (VAACs)

Joint surface & aerosol retrieval weighted by the actual ICA (Information Content Analyses)

- **Level 1 radiance correction** (vicariously)
- **Level 1 pixel classification - Naïve Probabilistic algorithm (EUMETSAT)**
 - Dust/Ash mask - Synergy Red-NIR-SWIR-TIR Decision tree: 4 probabilistic schemes + Radiance vicinity + aerosol restoral
 - Glint + Snow/Ice detection
- **Ocean:**
 - Dual-view retrieval
 - Ocean surface pre-computed (not retrieved) :
- **Land:**
 - **Land surface reflectance 1st guess:** a spectral model built upon the AFRI vegetation index & Red-SWIR spectral matching
 - **Weighted joint aerosol+Land surface:** high weight for unfavourable dual-view geometry & vegetation = f(dual scattering angle, land cover type).
- 35 mixtures of aerosol types interpolated between dust, sea salt, weakly & strongly absorbing (Kinne *et al.*, 2006)
- Log(AOD)
- *A posteriori* diagnostic Quality Indicators (QI 1, 2, 3): AOD spatial uniformity, spectral residuals (sediments, melted ice, missed Polar stratospheric clouds), bright deserts (*e.g.* Sahara)



- surely not cloudy
- probably not cloudy
- probably cloudy
- surely cloudy
- lands+borders
- sun-glint
- cloud-vicinity

Naïve Probabilistic CLA Mask
North Atlantic 31.01.2022



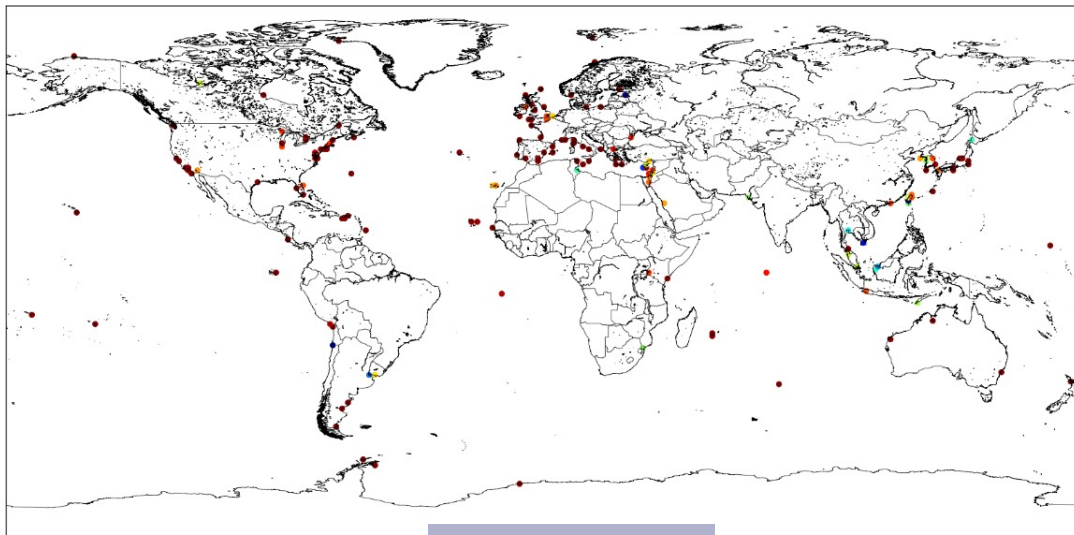
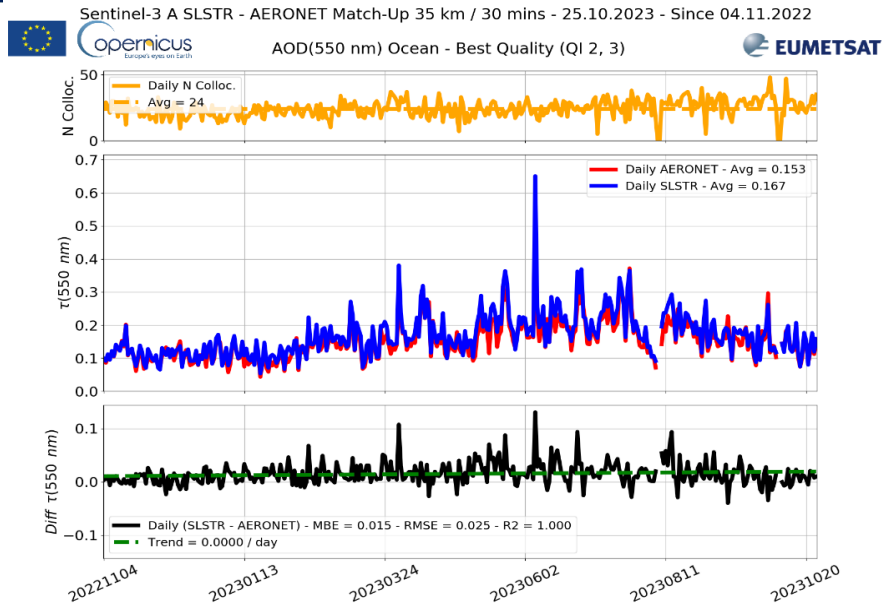
Ocean Validation – Daily AOD(550 nm)

“Ocean” AOD(550 nm) Validation

- Mean bias ~0.015
- GCOS fraction > 60%
- S3A and B very consistent (B slightly larger by 0.03)

Open questions:

- Low negative bias in dark remote waters.
- Over-estimated AOD uncertainty & Fine Mode.

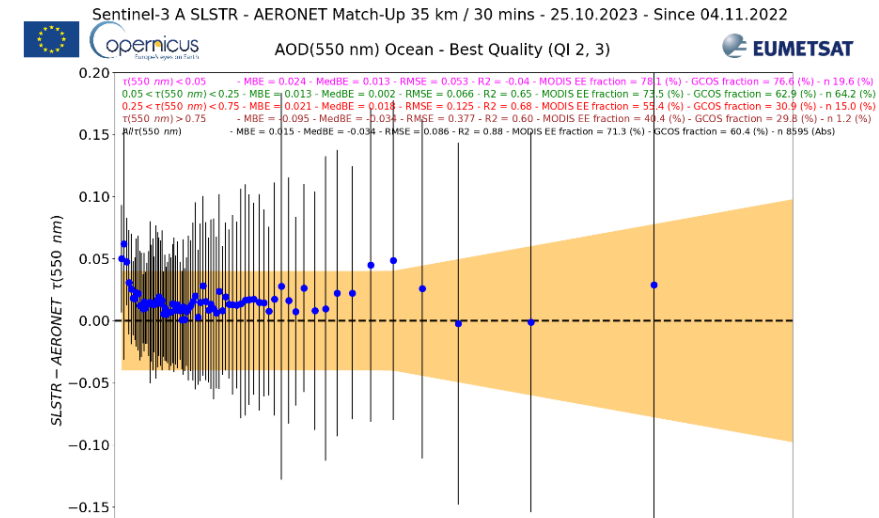


SLSTR-A

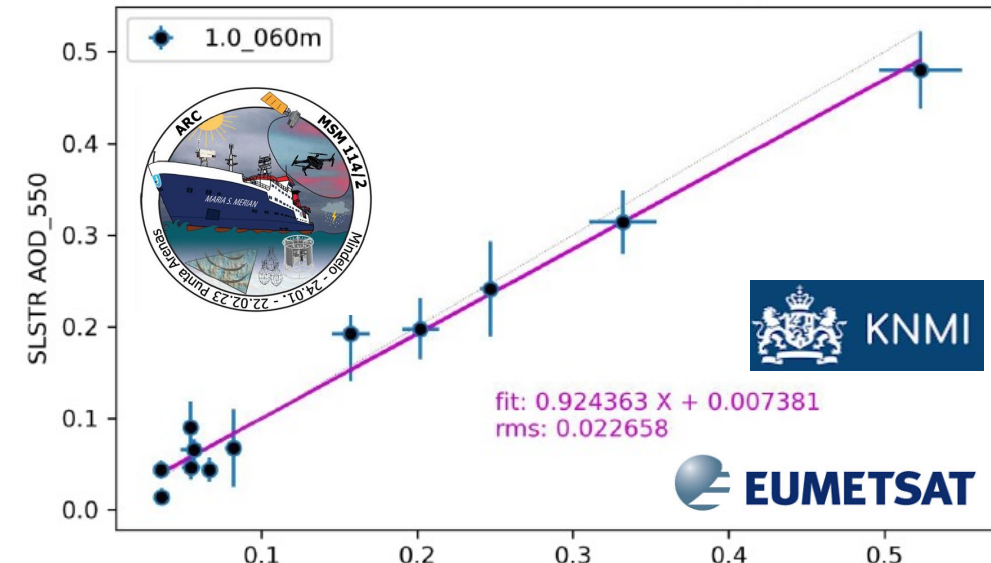
All AERONET Stations

Mainly Coastal

Complete NRT Coll 3.0



Colocated Calitoo AOT540 vs SLSTR AOD_550 / ID: 0108



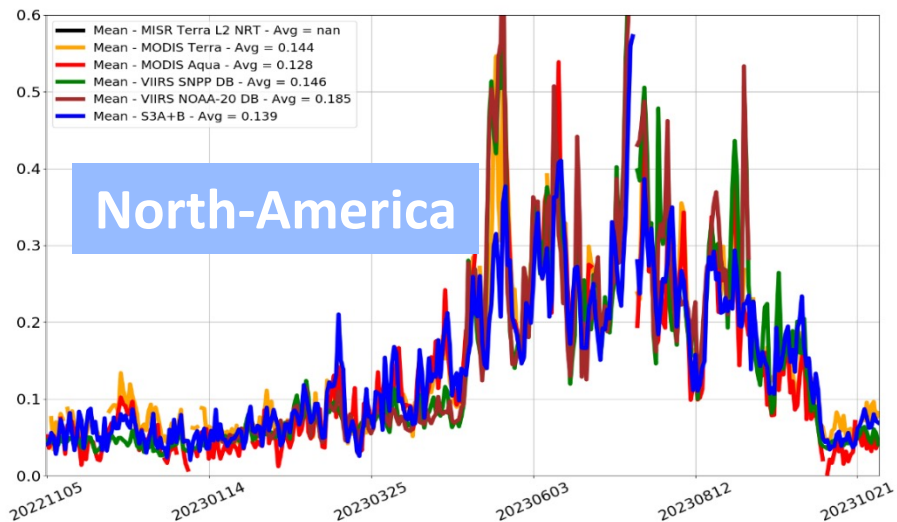
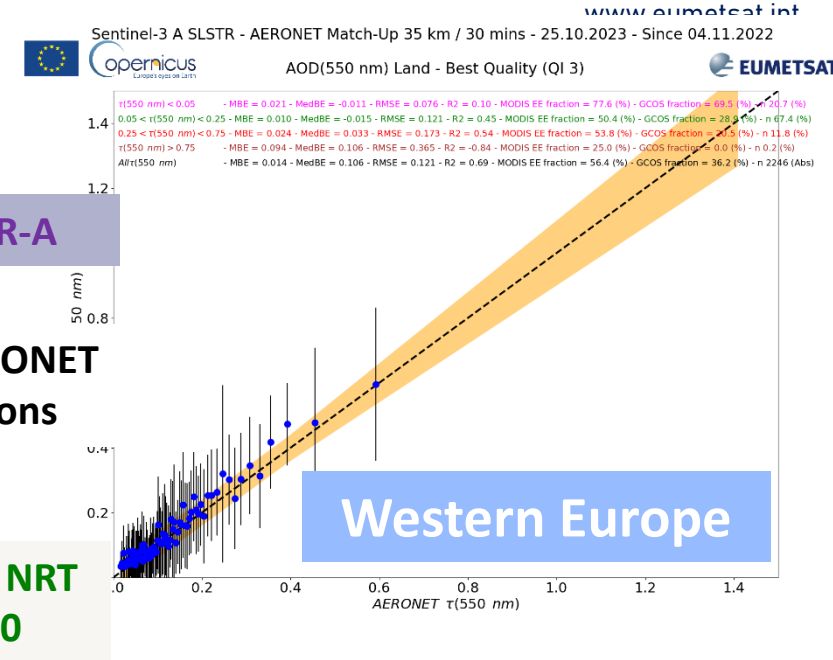
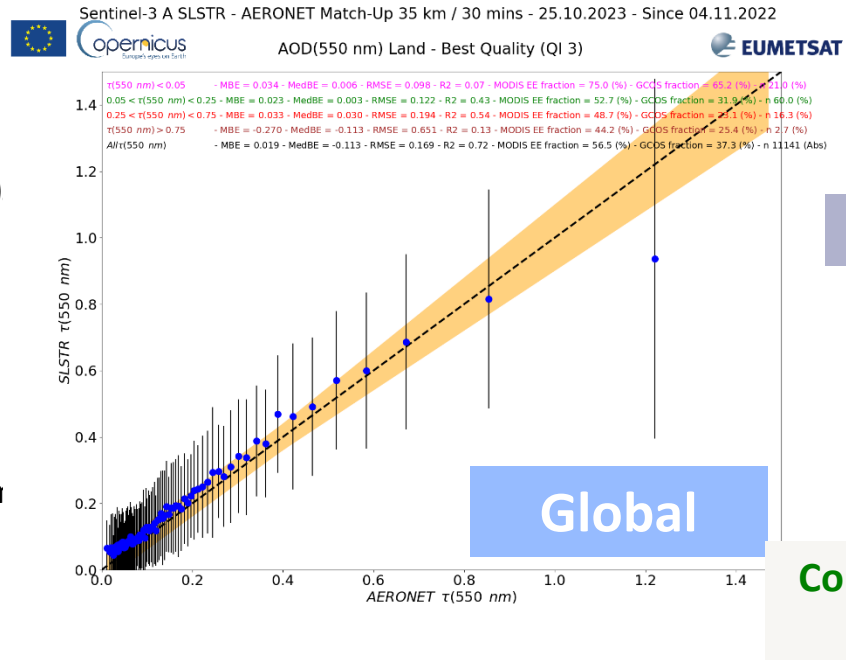
Ship Campaign Jan-March 2023 – Atlantic – RV. Maria S. Merian
 Credits KNMI (P. Stammes, O. Tuinder, P. Wang) – MPI (S. Kinne), TROPOS (S. Bley)



Land Validation – Daily AOD(550 nm)

Global Lands.

- Major improvements with Collection 3.
- GCOS fraction ~40% globally (25% -60% regionally)
- High consistency S3 A/B.
- **Open questions:**
- MODIS & VIIRS (NASA) = lower biases & RMSE.
- Efforts on Aerosol / land surface disentangle continue.
- S3B shows higher bias (~+0.015)

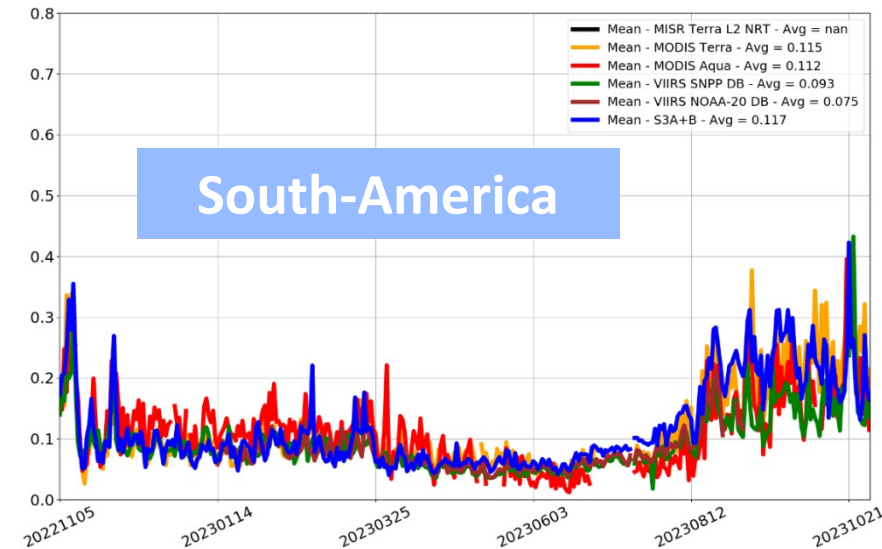


NRT Sentinel-3

MODIS Terra / Aqua

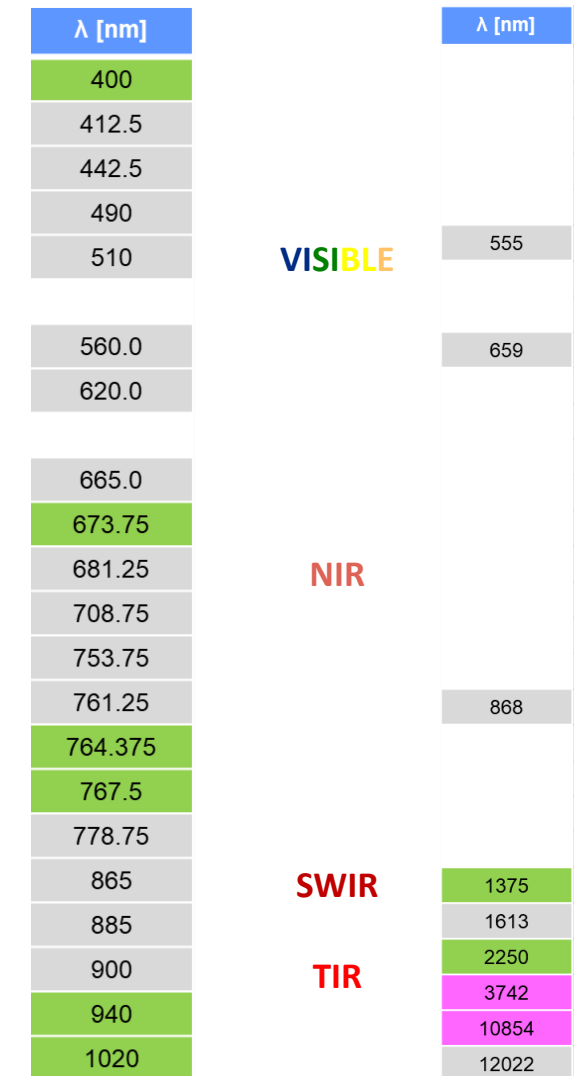
VIIRS SNPP Deep Blue (NASA)

VIIRS NOAA-20 Deep Blue (NASA)



Current Processor = Preliminary OPE

- **Major lessons learned show the need to move towards a new algorithm baseline**
 - Sentinel-3 information content is highly diverse
 - Higher resiliency needed based on Optimized constraints.
- **Days-2/3 developments have kicked-off:**
 - New EUMETSAT S3 Ground-Segment (PDP) – Validated – ready in Nov 2023.
 - New auxiliary Sentinel-3 Optical Land Surface Reflectivity (LSR).
 - **Extended aerosol portfolio:** Aerosol Layer Height (ALH), Dust in progress.
 - **NRT SYnergy Sentinel-3** (lessons learned from PMAP / EPS-SG – MAP)
=> based on EUMETSAT NRT L1 SYnergy (under development).
 - Days-2-3 ITT planned next months
 - Long term – Preparing for S3- New Generation Optical (NGO)
- **New: Reprocessing campaign of Coll 3.0** – Further news in the next months...



Sentinel-3 SYnergy (OLCI + SLSTR)



- **Public visualisations (maps) available** <https://metis.eumetsat.int/aod/index.html>
- **Websites (under major updates in the next weeks):**
 - EUMETSAT SLSTR Aerosol studies (and all documents): <https://www.eumetsat.int/science-studies>
 - OSSAR-CS3 processor: <https://www.eumetsat.int/S3-AOD>
 - NRT Aerosols Collection 2: <https://www.eumetsat.int/S3-nrt-l2-aerosol-product-collection-2-released-soon>
 - Sentinel-3 Atmospheric composition (NRT): <https://www.eumetsat.int/atmospheric-composition>
 - METIS – Daily maps: <https://metis.eumetsat.int/aod/index.html>

Peer-review manuscripts :

Fougnie *et al.*, 2020: Geometry information content for mono, dual & multi-view.
 Garrigues *et al.*, 2022 => Multi satellite (NRT) analyses

Optimized Simultaneous Surface-Atmosphere Retrieval from Copernicus Sentinel-3 (OSSAR-CS3) - Algorithm Theoretical Basis Document (ATBD)

ATBD L2 v1.0
V2.0 in preparation
(CAMS comments)

Doc.No. : EUMSEK0000211243792
 Issue : V1
 Date : 3 September 2021
 WBSQBS :

Sentinel-3 Product Notice – SLSTR Level-2 (L2) Near Real Time (NRT) Aerosol Optical Depth (AOD)

Mission	Sentinel-3A & Sentinel-3B
Sensor	SLSTR & SLSTR-B
Product	<ul style="list-style-type: none"> Near Real Time (NRT) Level-2 (L2) Aerosol Optical Depth (AOD) <ul style="list-style-type: none"> Operations: <ul style="list-style-type: none"> SL2_AOD at Near Real Time (NRT) timeliness exclusively. Granules of 5 minutes. Reprocessed: <ul style="list-style-type: none"> SL2_AOD based on Level-1B (L1B) Near Real Time (NRT) timeliness exclusively. Granules of 5 minutes. Several months of 2020 & 2021. Full reprocessing to complete historic mission timeline in progress.
Approval	EUMETSAT Mission Management

User Product Notice

Summary

This is the Product Notice (PN) for the public release of Copernicus Sentinel-3 (S3-A and S3-B) Sea and Land Surface Temperature Radiometer (SLSTR) Level-2 (L2) Near Real Time (NRT) Aerosol Optical Depth (AOD) product. Baseline Collection (BC) 2, Processing Baseline (PB) 2.0 with the EUMETSAT L2 Instrument Processing Facility (IPF) v3.0 deployed on 20/10/2021 in the EUMETSAT S3 Ground-Segment (GS) centre. The reference processor is the Optimized Simultaneous Surface Aerosol Retrieval for Copernicus S3 (OSSAR-CS3) [see ATBD written by J. Chmou et al., v1] under

Day-2 study developments:



Sentinel-3 Optical pre-calculated Land Surface Reflectivity (LSR) auxiliary product

Project funded by Copernicus, initiated and procured by EUMETSAT under contract EUM_CO_22_4600002703_JCh



Sentinel-3 OLCI O₂-A Aerosol Layer Height (ALH) Prototype – OLCOAH

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Thank you for your contribution !