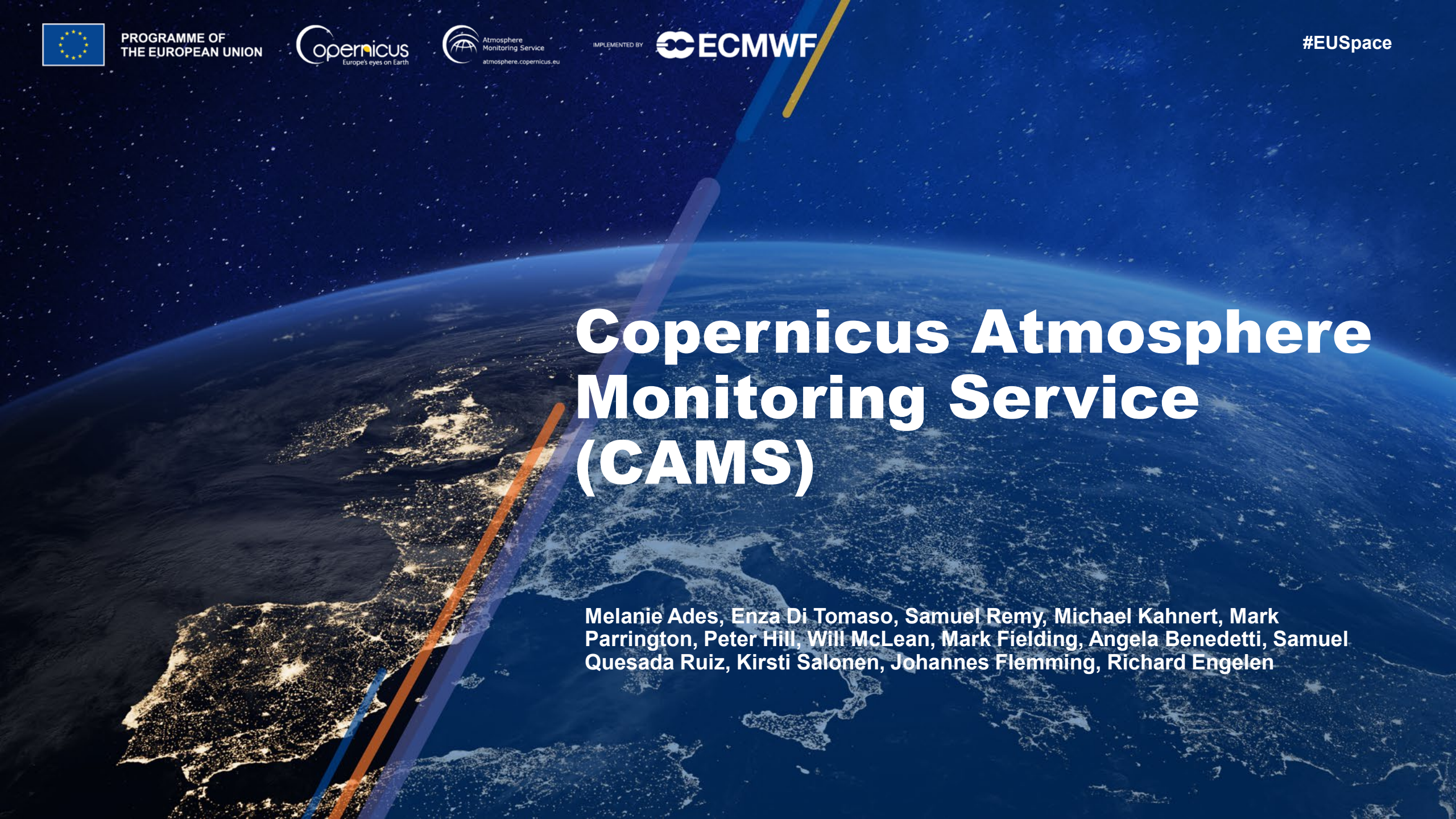
PROGRAMME OF
THE EUROPEAN UNION
Copernicus
Europe's eyes on Earth
Atmosphere
Monitoring Service
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IMPLEMENTED BY
ECMWF
#EUSpace
Copernicus Atmosphere Monitoring Service (CAMS)
Melanie Ades, Enza Di Tomaso, Samuel Remy, Michael Kahnert, Mark Parrington, Peter Hill, Will McLean, Mark Fielding, Angela Benedetti, Samuel Quesada Ruiz, Kirsti Salonen, Johannes Flemming, Richard Engelen

Aerosols at ECWMF

The CAMS team works on the aerosol forecast production, but aerosols also form part of the research done by other scientists at ECMWF

CAMS

Melanie Ades
Aerosol data assimilation
Background errors
Dust assimilation

Enza Di Tomaso
Aerosol data assimilation
AOD Observation updates
GFAS fire assimilation

Michael Kahnert
Lidar/ceilometer assimilation
Dust inversion

Johannes Flemming
Team Leader
Air quality

Mark Parrington
Outreach/event monitoring
Fire assimilation

Roberto Ribas, Chris Kelly, Emmanuele Russo and others

HYGEOS

Samuel Remy
Aerosol model developments
CAMAERA lead

Thierry Elias
Aerosol model developments

Rose-Cloé Meyer
Aerosol model developments

Angela Benedetti
Infrared Team Leader
CAMEO WP lead for radiance assimilation

Mark Fielding
EarthCARE cloud and aerosol assimilation lead

Will McLean
EarthCare backscatter assimilation

Samuel Quesada Ruiz
Aerosol radiance assimilation (CAMEO)

Kirsti Salonen
Aeolus assimilation

Peter Hill
Radiation

IFS-COMPO Aerosol Model

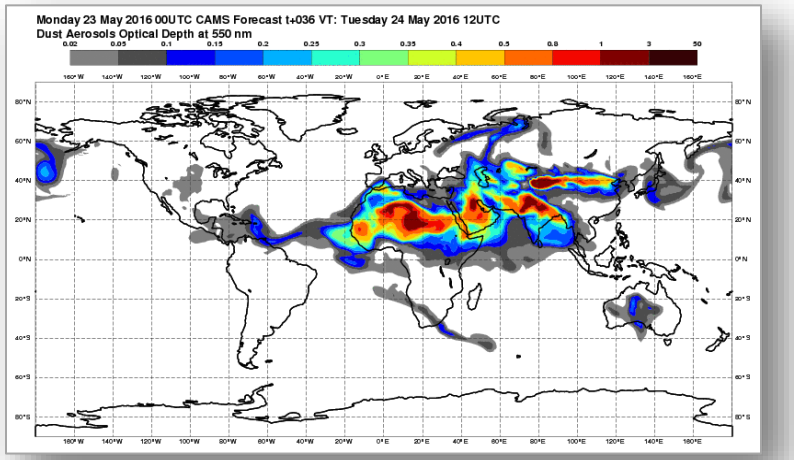
- 8 species considered:
  - Desert dust (DD): 3 tracers
  - Sea-salt aerosol (SS): 3 tracers
  - Organic Matter (OM): 2 tracers
  - Black carbon (BC): 2 tracers
  - Sulfate (SO4) + precursor SO2 when running uncoupled from chemistry
  - Nitrate: 2 tracers (from gas/particle partitioning, and from het. reactions)
  - Ammonium: 1 tracer
  - SOA: 2 tracers (biogenic and anthropogenic)
- Bulk/bin approach : bulk for OM/BC/SO4, 3 size bins for SS/DD
- For OM and BC, hydrophobic (fresh) and hydrophilic (aged) components are considered
- Sea-salt aerosol and Sulfate are also hydrophilic
- 16 tracers representing dry aerosol mass mixing ratio **except for sea-salt aerosol: mass mixing ratio at 80% RH**
- Assimilation minimises based on a **total aerosol variable** and AOD observations. The calculated increment is redistributed back into the 16 tracers based on their proportions in the first guess

Current AOD satellite data usage in IFS

Land & Ocean

- EOS-Terra/MODIS
- EOS-Aqua/MODIS
- S-NPP/VIIRS
- NOAA-20/VIIRS

Global CAMS forecasting system



40km Globe (twice daily, d+5)

Ocean only

- Metop-C/PMAp
- Metop-B/PMAp
- Sentinel-3A/SLSTR
- Sentinel-3B/SLSTR

Model updates since 2024

CY50R1:

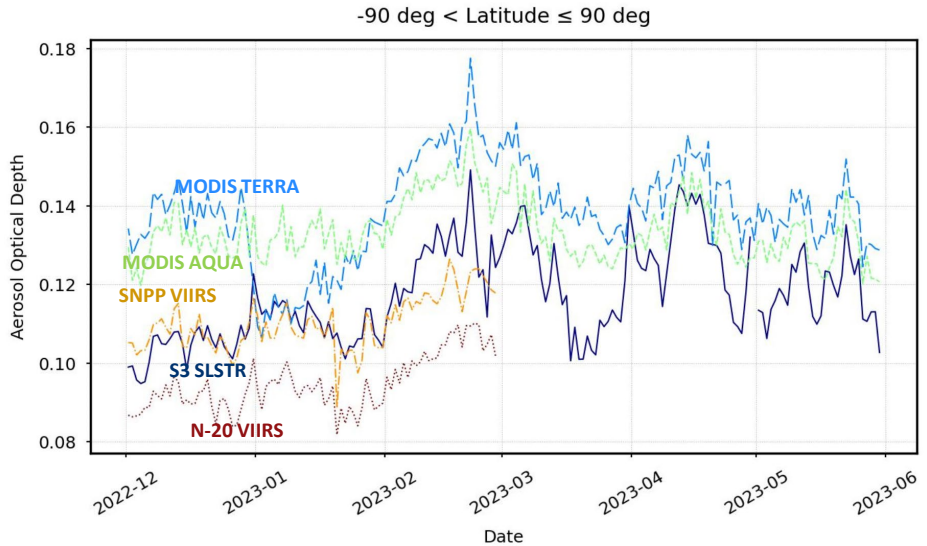
- Online BVOC emissions
- Weekly cycle in emissions
- Update het. chem in troposphere
- Sedimentation velocity from Stokes formula
- Updated SOA/Am/Nitrate growth factors

Latest model version (CY50R1) to be implemented Q1 2026

Observation updates since 2024

Sentinel-3A/B SLSTR AOD (550 nm; OSSAR-CS3 NRT) assimilation will be activated over ocean in the next cycle upgrade of IFS-COMPO (cy50R1; Q1 2026)

- retrievals are filtered for best quality (ocean QI 2,3)
- the product is spatially aggregated before data assimilation to better match retrievals (9.5 km) and model (~40 km / 0.35 degrees) resolution.
  - (+) observations more representative of the model grid box
  - (-) finer scale information is smeared out due to the averaging
- Assimilated observations are bias corrected within the variational assimilation procedure
  - NOAA-20 VIIRS anchor



Ocean-only retrievals
Reprocessed data for the reanalysis

Thanks to Enza Di Tomaso

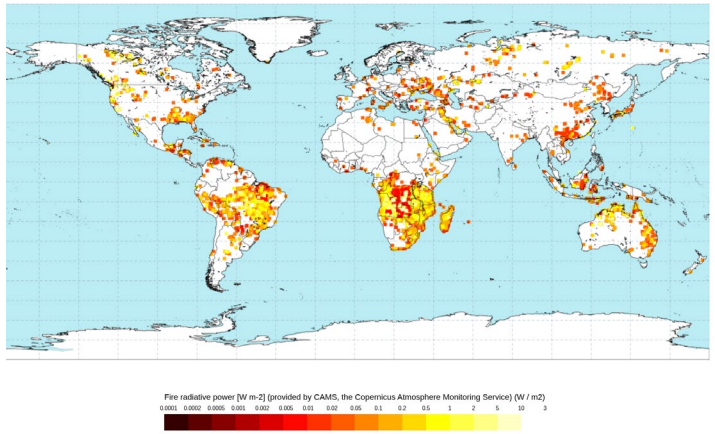
Fire emission updates since 2024

Operationally assimilated

EOS-Terra/MODIS

EOS-Aqua/MODIS

Global Fire Assimilation System (GFAS)
Fire activity on Sep 2, 2025



Additional sensors

S-NPP/VIIRS + together with new spurious signal mask

Plan to activate it from next cycle upgrade (cy50R1)

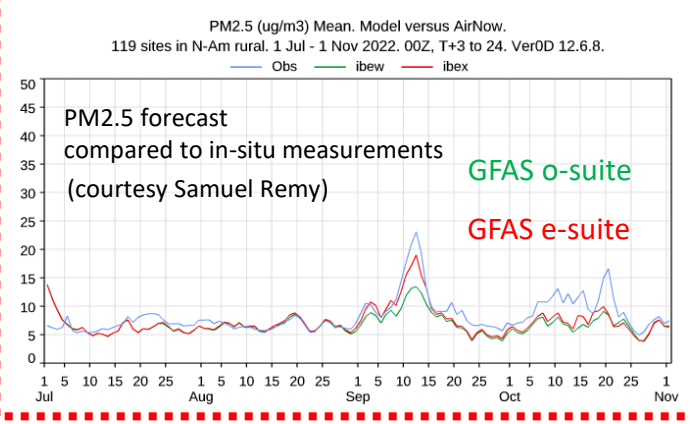
NOAA-20-21/VIIRS

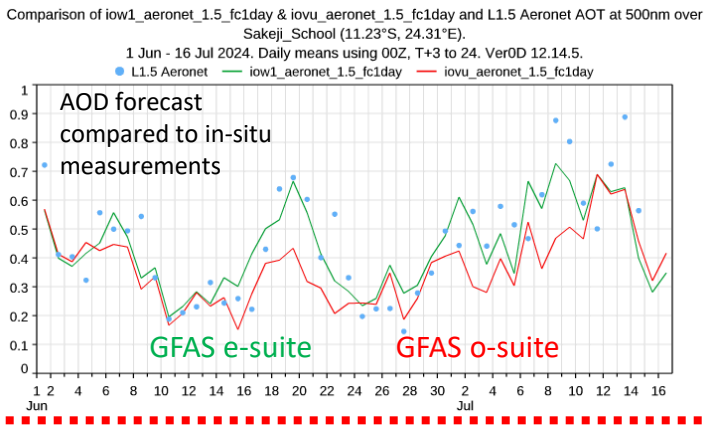
Integration work started (due soon)

Sentinel-3/SLSTR

Integration work will start in autumn 2025

GFAS e-suite (exp 9925) running for cy50r1 preparation

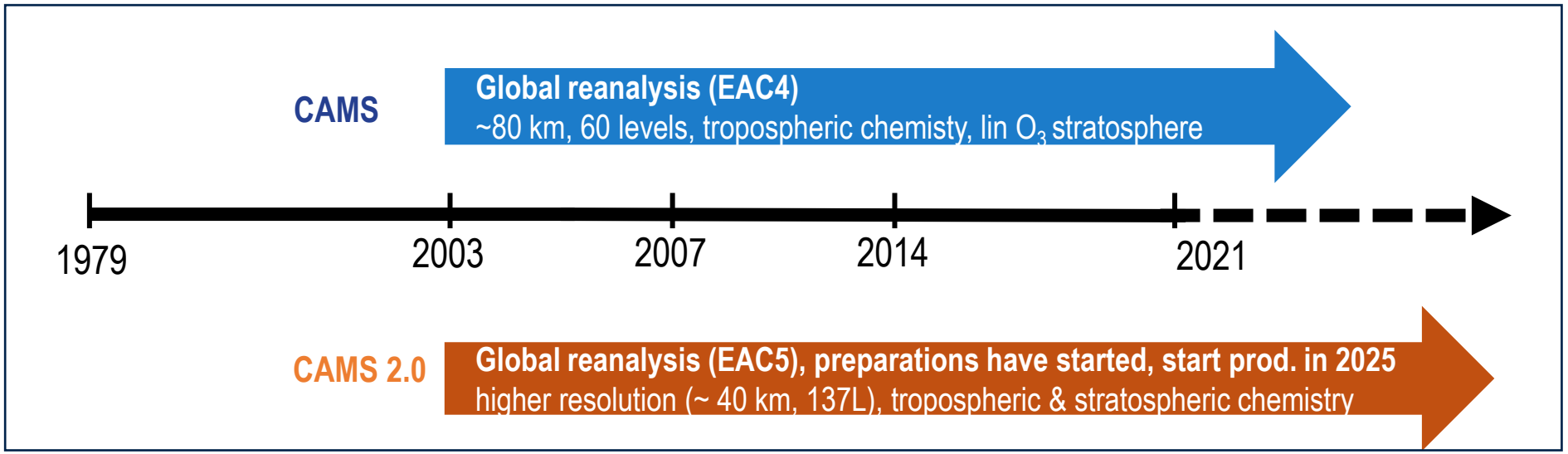




Thanks to Enza Di Tomaso

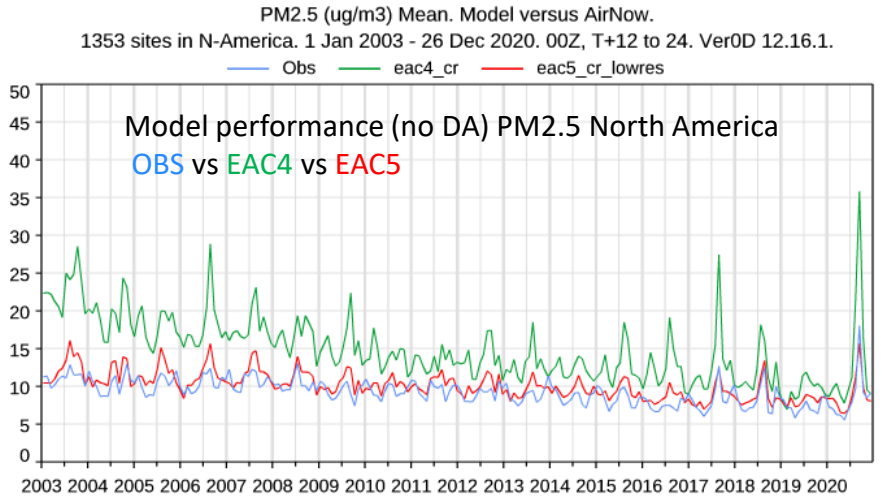
A new CAMS reanalysis (EAC5) in prep

Production period (2026-2028)



Innovations of EAC5 (w.r.t. EAC4)

- Increased resolution (137 vertical levels, 40 km, 1-h output)
- Model updates:
  - BASCOE stratospheric chemistry added
  - Nitrate, Ammonium and SOA added
  - New emissions including online biogenic emissions
  - Many more model updated (Cycle 49r2)
- **New and reprocessed observation (S5P, VIIRS, S3)**



S.Remy

PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

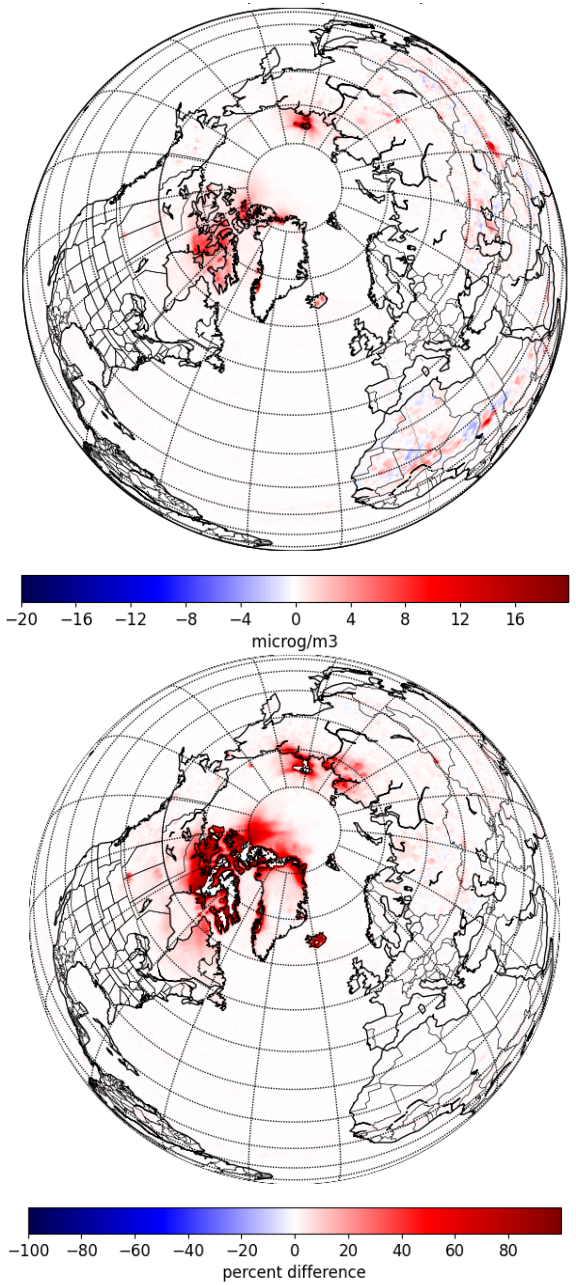
Atmosphere Monitoring Service atmosphere.copernicus.eu

IMPLEMENTED BY ECMWF

Current and future research

51R1 proposed “dust package”

- 6 bin dust scheme : [0.03 – 0.5 – 0.9 – 2.5 – 5 – 10 – 20] micron radius
- New dust emissions scheme from CAMAERA WP5 – adapted from SILAM + threshold velocity from remote sensing (Pu et al 2020)
- Dust emission size distribution from Meng et al 2022 (update of Kok11)
- Possible use of dust emission scaling factors from offline dust inversion (CAMAERA WP1)
- High latitude dust specific development – source maps and threshold velocity
- Updated fraction of dust into PM to account for difference between geometric and aerodynamic diameter (used in PM inlets) following Zhang et al 2025. the aerodynamic diameter of 2.5 µm corresponds to the geometric diameter of 1.7 µm for particles with aspect ratio of 1.7.

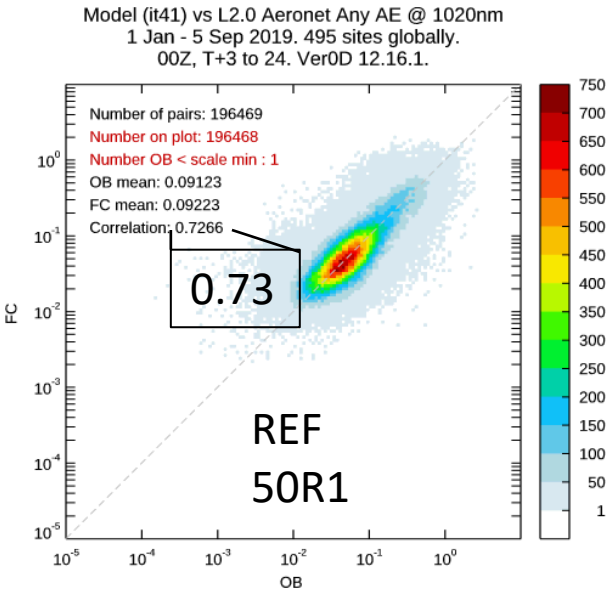


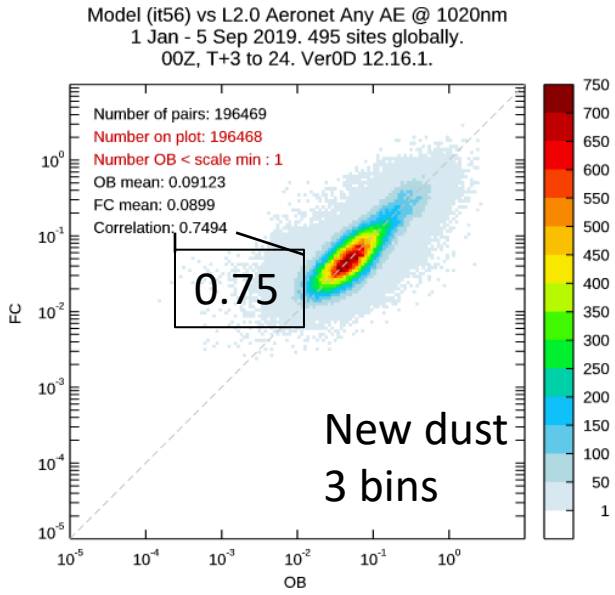
July 2019 simulated PM10 with the new dust emission scheme : absolute (top) and relative, in percentage (bottom) difference of the specific high latitude developments as compared to the version that doesn’t include these developments

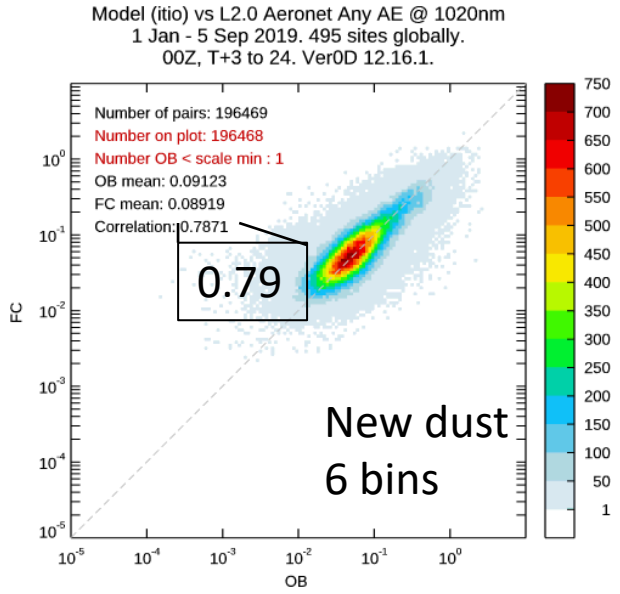
Thanks to Samuel Remy

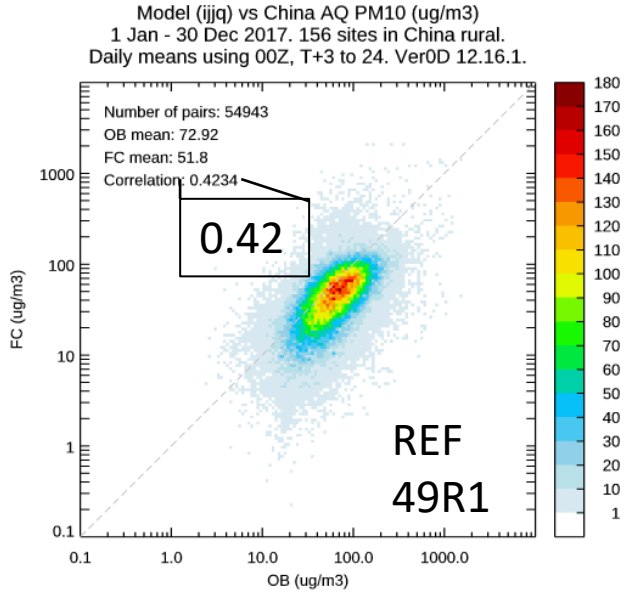
51R1 proposed “dust package” – eval

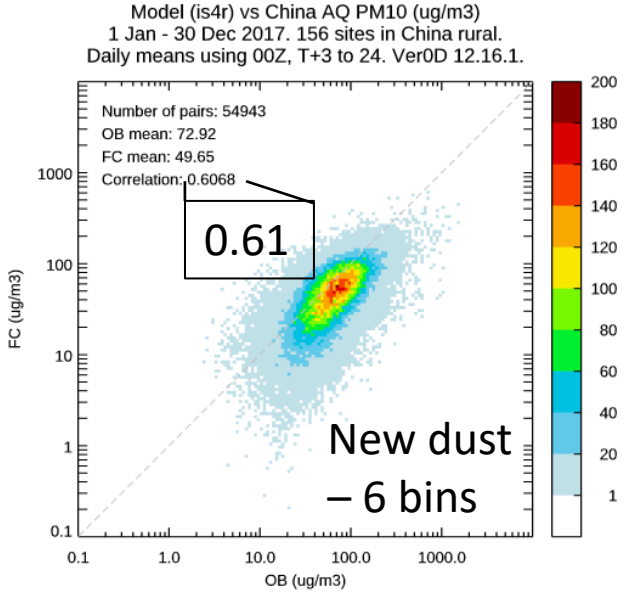
- Currently being tested as a 51R1 contribution in fc only
- Tests with data assimilation done in 49R1 – to be done in 50R1









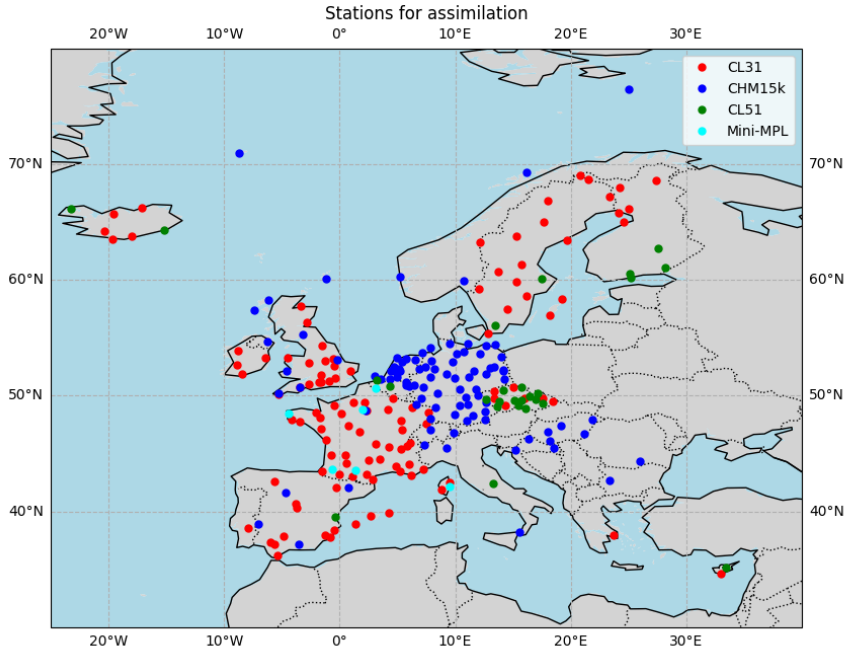


Thanks to Samuel Remy

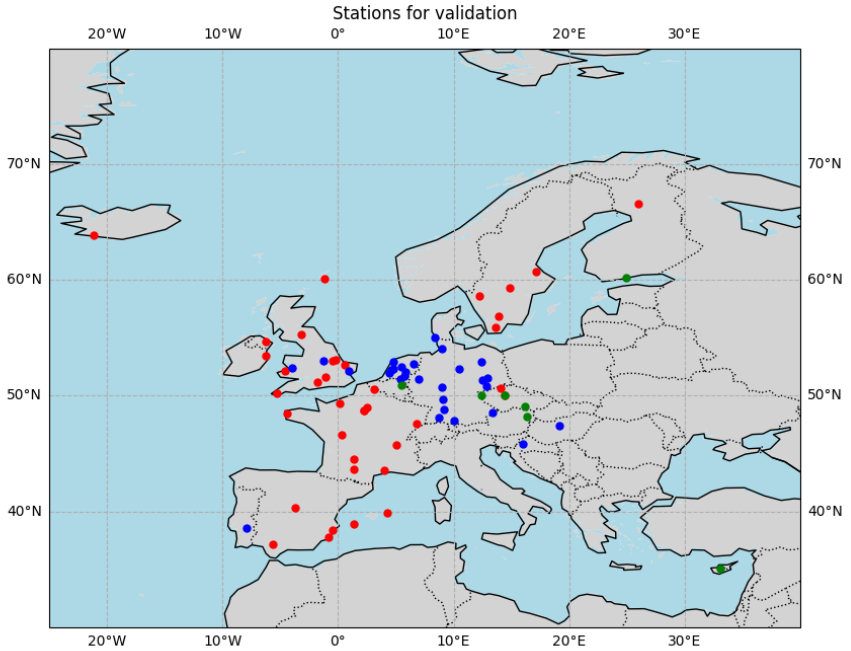
E-PROFILE (CAMAERA HE)

- Pre-processing of raw E-PROFILE data to remove clouds, fog, precipitation and noise
- New observation operator at 910nm introduced including water vapour effects
- Effect of asphericity for dust
- Background and observation errors

CAMAERA is a **H**orizon **E**urope CAMS advancement project which aims to **enhance the quality of the aerosol products** delivered by CAMS through improvements of the modelling capabilities and data assimilation aspects of the CAMS regional and global systems.

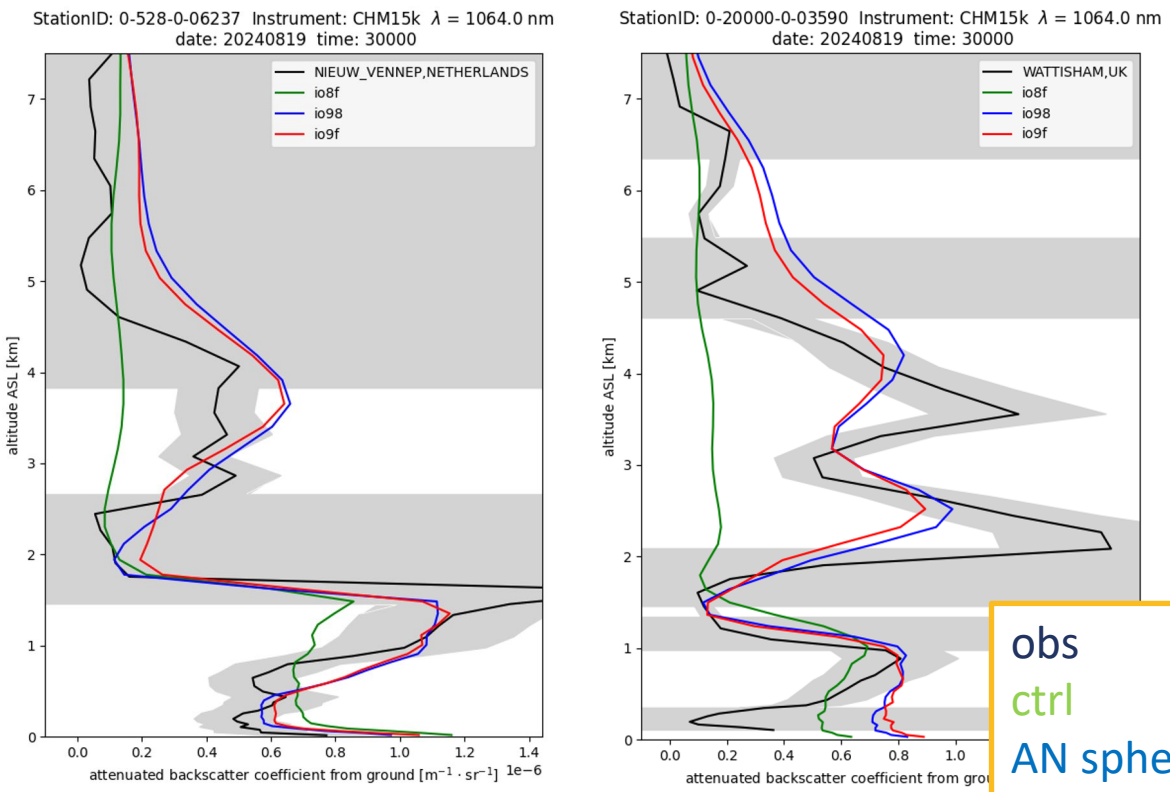


Assimilated lidar/ceilometer stations

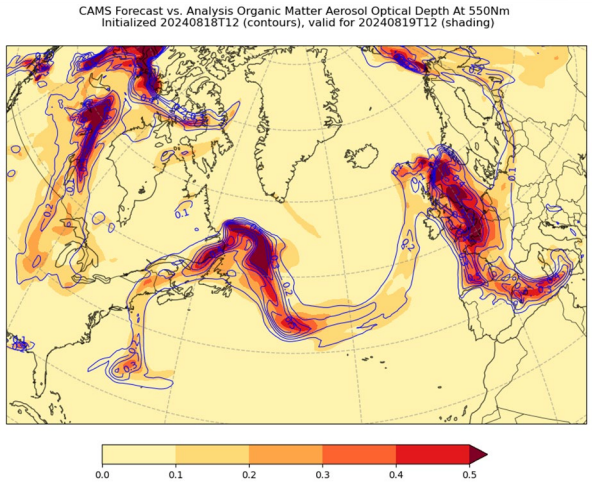


Withheld ceilometer stations

Thanks to Michael Kahnert



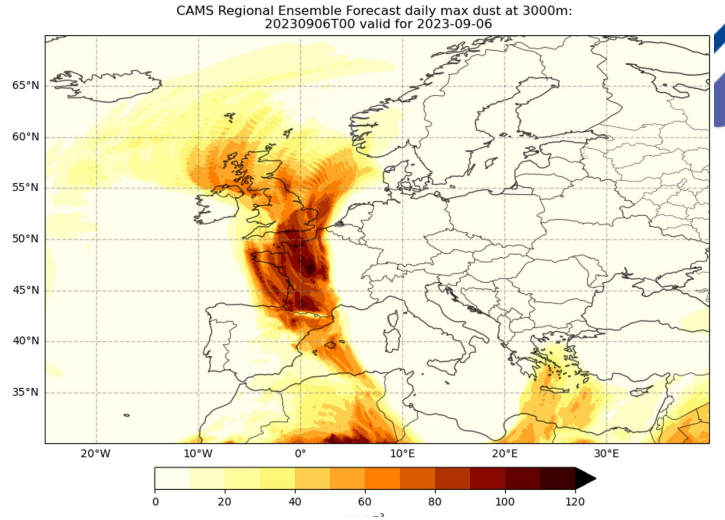
obs
ctrl
AN spheres
AN spheroids

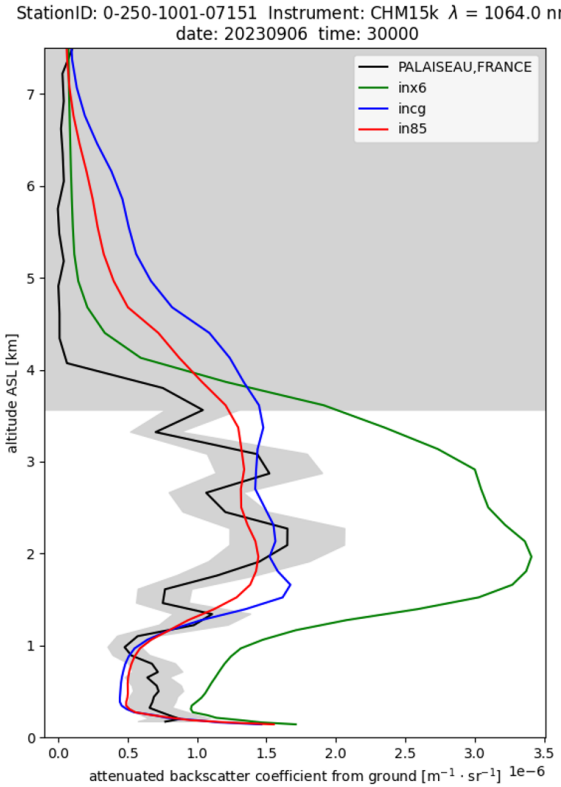


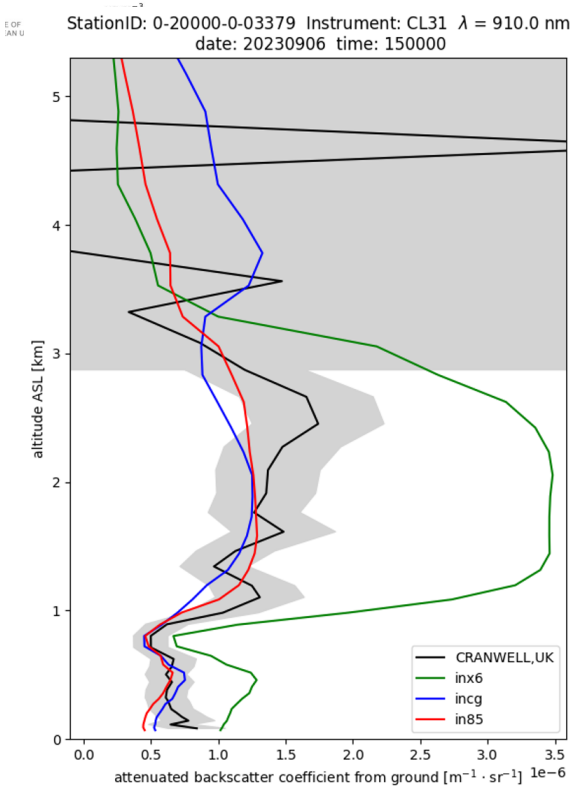
Canadian wildfires,
August 2024

NO AOD assimilation!

Saharan dust storm,
September 2023







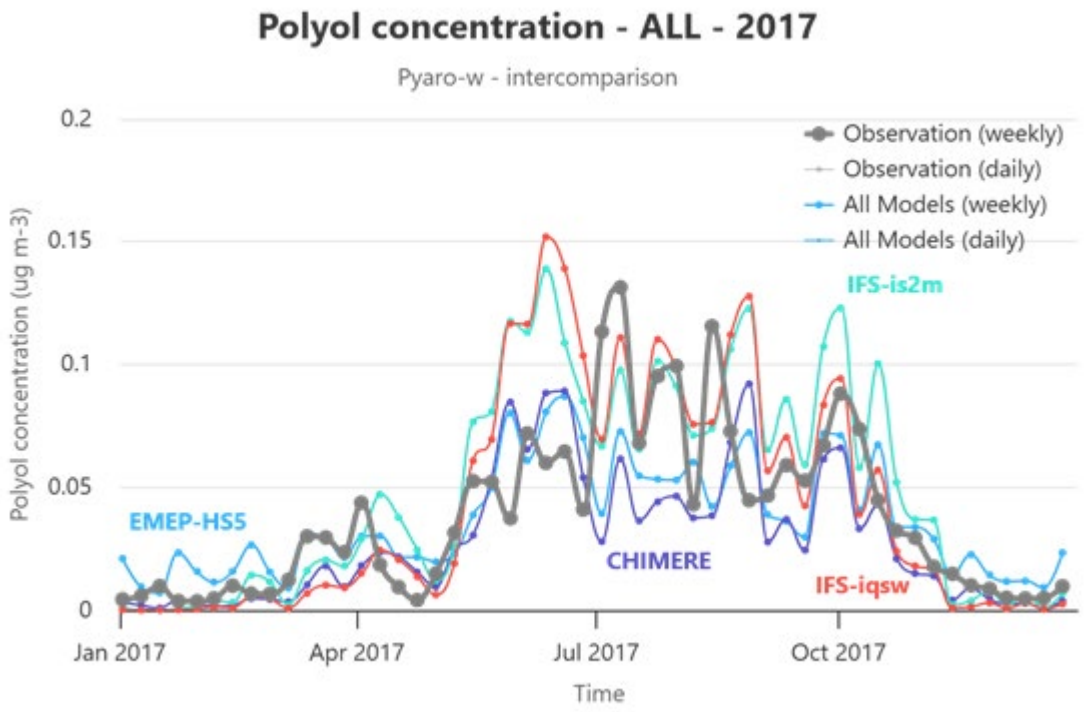
Thanks to Michael Kahnert

Implementation of fungal spores (CAMAERA HE)

A first, simple implementation of fungal spores in IFS-COMPO and EMEP, with different emission schemes.

- Direct evaluation is hard: sparse observations – at first order, the seasonal cycle and general features of fungal spores surface concentration seem to be broadly represented.
- More complex features (peaks in Autumn, etc.) are not well represented: limitation of single-tracer approach
- All parameterizations rely heavily on LAI

- The impact on simulated PM10 is generally positive in summertime



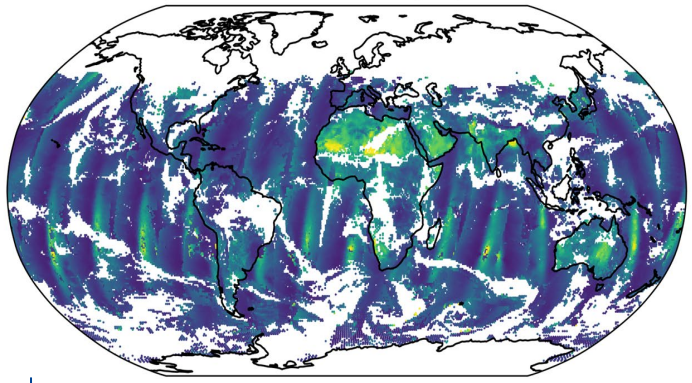
Intercomparison of simulated polyol surface concentration (proxy for fungal spores) over Europe
(**EMEP**, **CHIMERE**, and **IFS-COMPO1/IFS-COMPO2**)

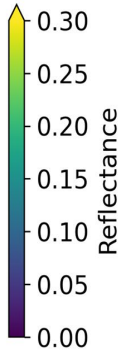
Thanks to Samuel Remy

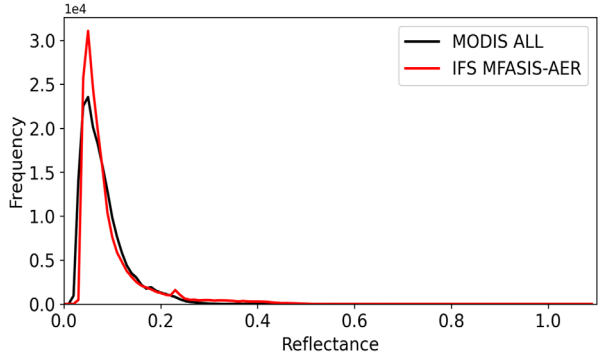
Visible aerosol reflectance assimilation (CAMEO HE)

ALL

Observation MODIS AQUA/TERRA



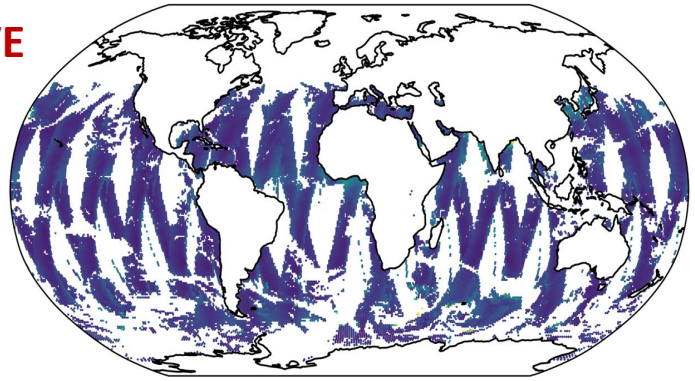


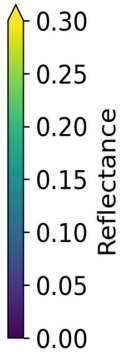


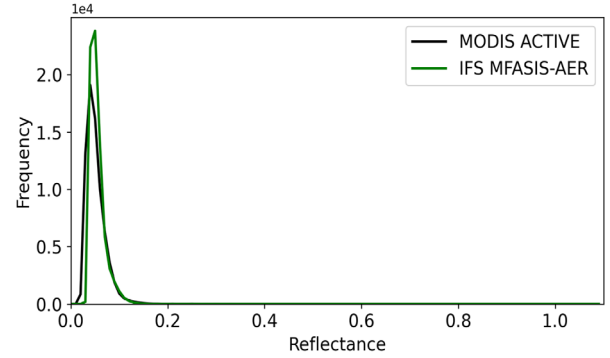
Ocean only
Sunglint
Sea ice
Large solzen/satzen angles
Large departures
…

ACTIVE

Observation MODIS AQUA/TERRA





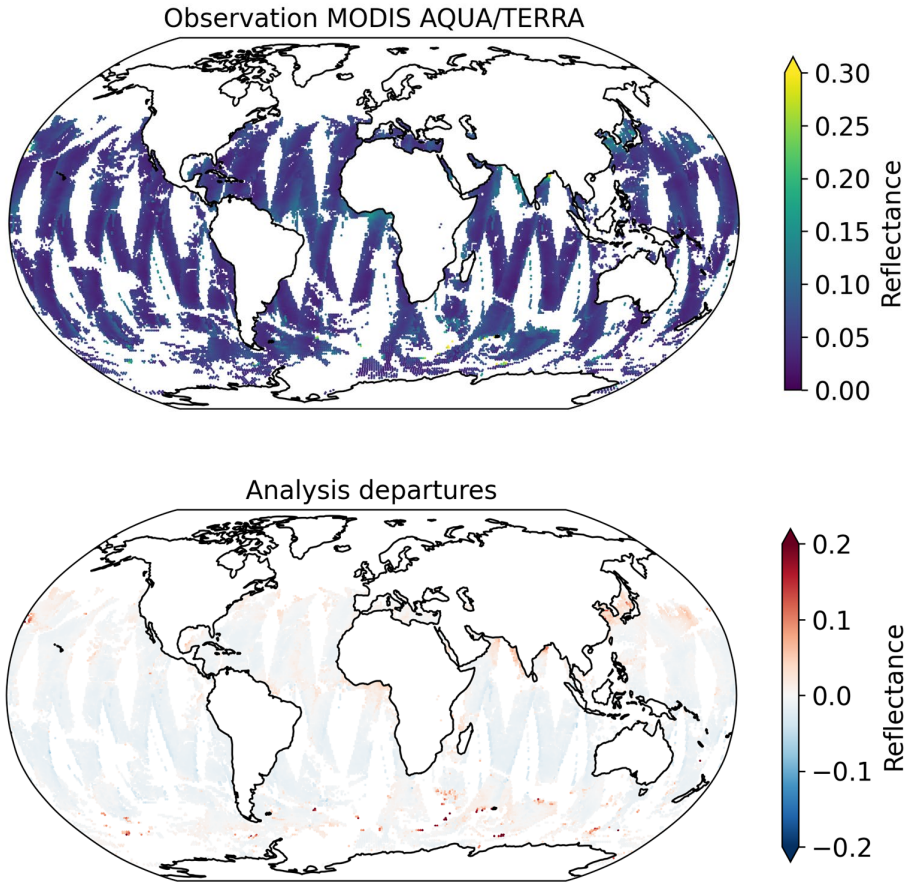


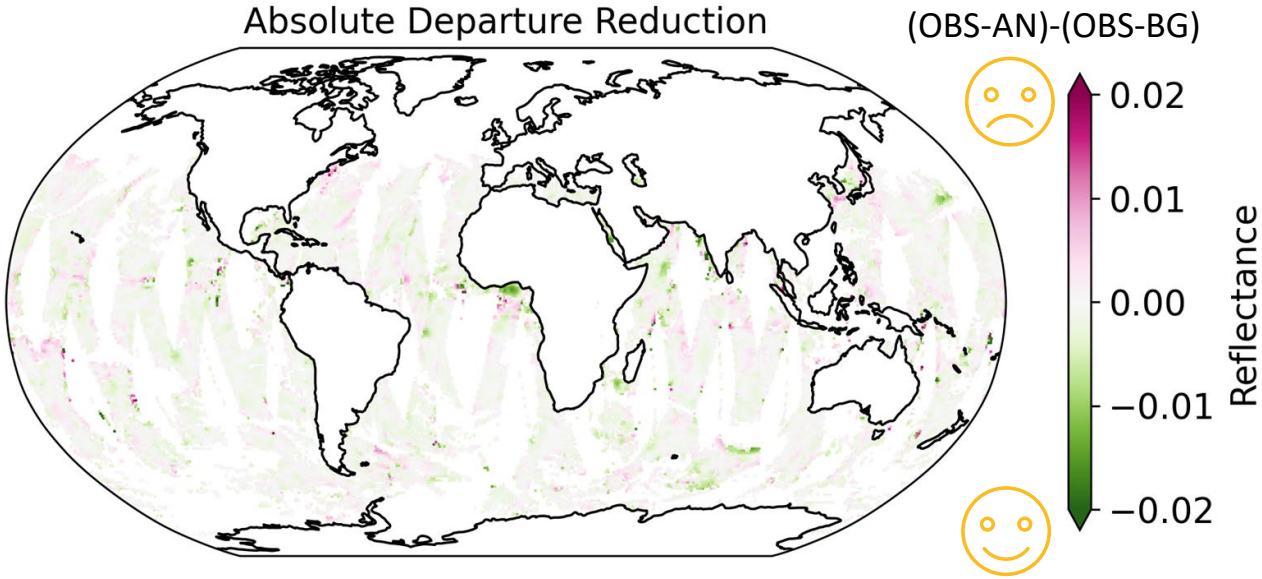
CAMEO is a **H**orizon **E**urope CAMS advancement project which aims to **enhance the quality and efficiency of the CAMS service** and help CAMS to better respond to policy needs such as air pollutant and greenhouse gas monitoring.

- RTTOV is used for radiance assimilation in the infrared and microwave in the IFS.
- *RTTOV-14 includes visible assimilation for clouds in CY50r1, which will be monitored.*
- RTTOV-14.1 (CY51r1) will include MFASIS-Aerosols -> direct reflectance assimilation for aerosols
- **Direct assimilation of reflectances requires cloud screening the observations - use MODIS L2 cloud-cleared aerosol visible reflectances**

Thanks to Samuel Quesada Ruiz and Angela Benedetti

Visible aerosol reflectance assimilation (CAMEO HE)

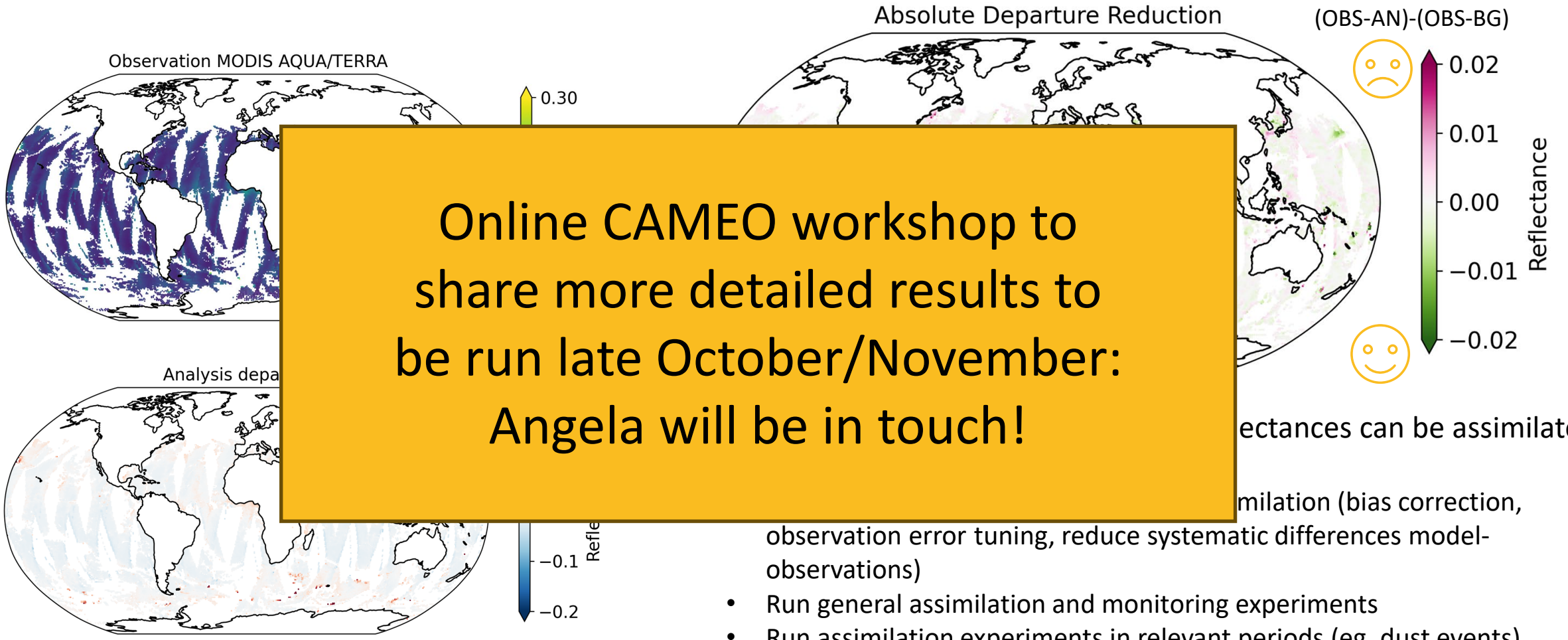




- **PROOF OF CONCEPT** – technically the reflectances can be assimilated
- Next steps:
  - Refine the aerosol visible reflectance assimilation (bias correction, observation error tuning, reduce systematic differences model-observations)
  - Run general assimilation and monitoring experiments
  - Run assimilation experiments in relevant periods (eg. dust events)

Thanks to Samuel Quesada Ruiz and Angela Benedetti

Visible aerosol reflectance assimilation (CAMEO HE)



Online CAMEO workshop to share more detailed results to be run late October/November: Angela will be in touch!

ectances can be assimilated

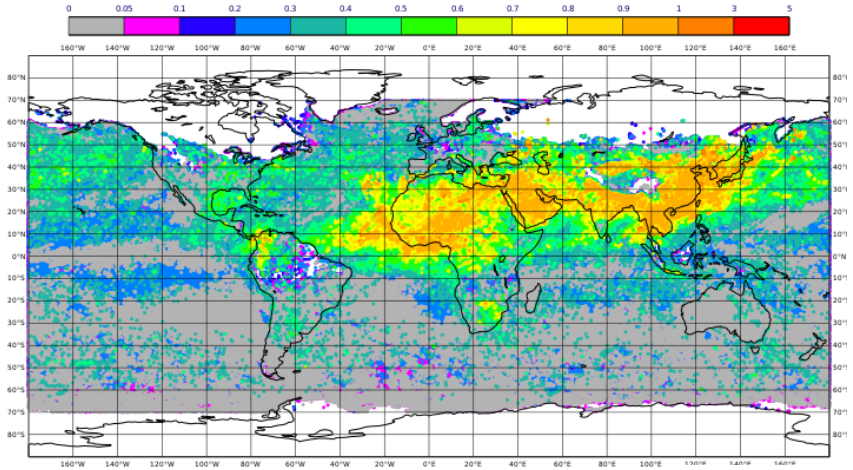
milation (bias correction, observation error tuning, reduce systematic differences model-observations)

- Run general assimilation and monitoring experiments
- Run assimilation experiments in relevant periods (eg. dust events)

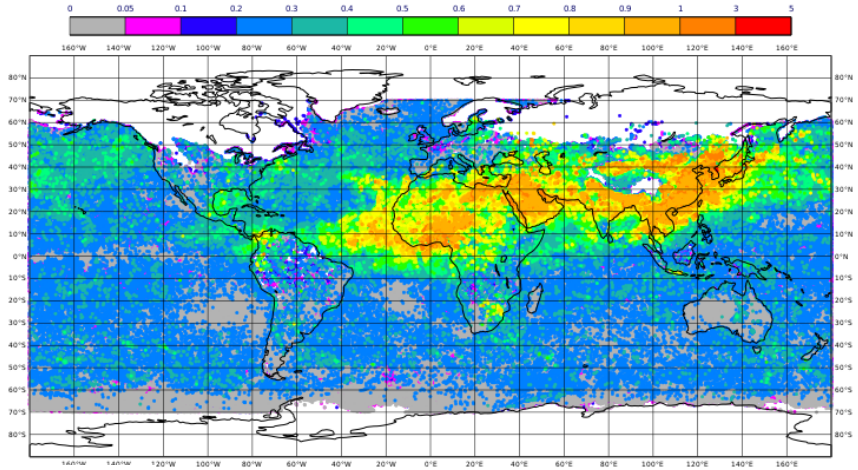
Thanks to Samuel Quesada Ruiz and Angela Benedetti

3MI (CAMEO HE +)

Terra MODIS

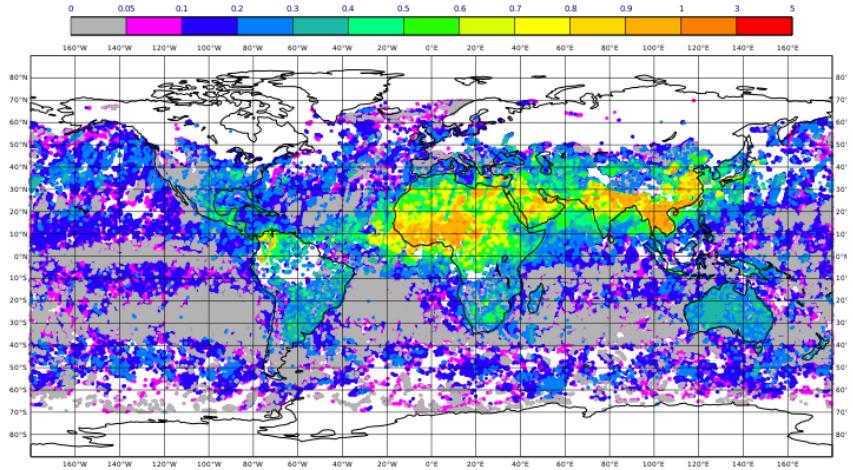


Aqua MODIS

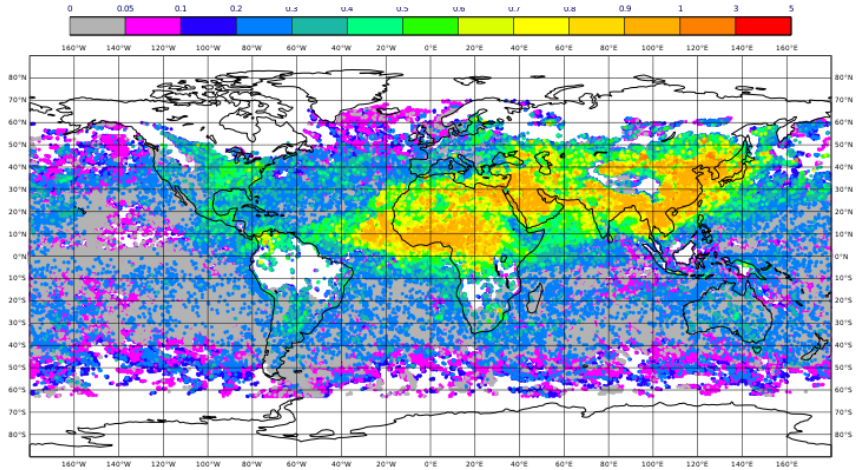


March 2008

AATSR



3MI (pseudo)

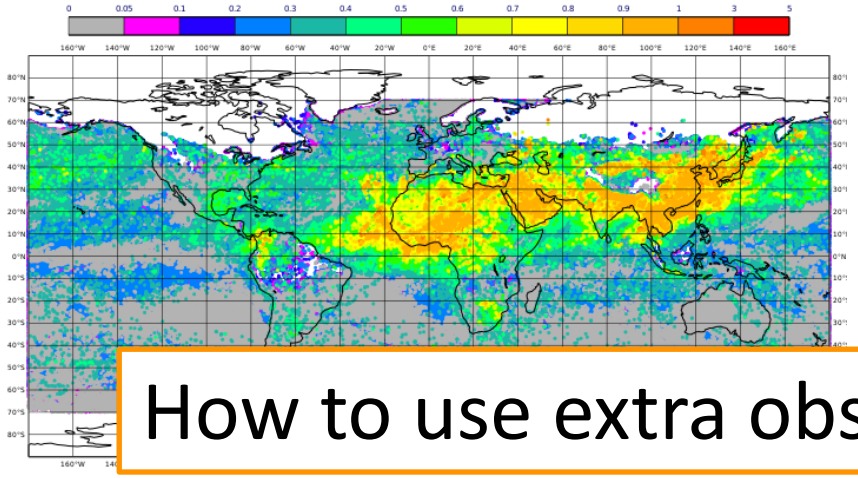


- MetOp-SG-A1 was launched on the 13th August 2025 carrying 3MI
- A task under the CAMEO project was to align the representation of aerosols in models and the GRASP retrieval that will be used for 3MI
- Updated pseudo 3MI observations using POLDER (Parasol)

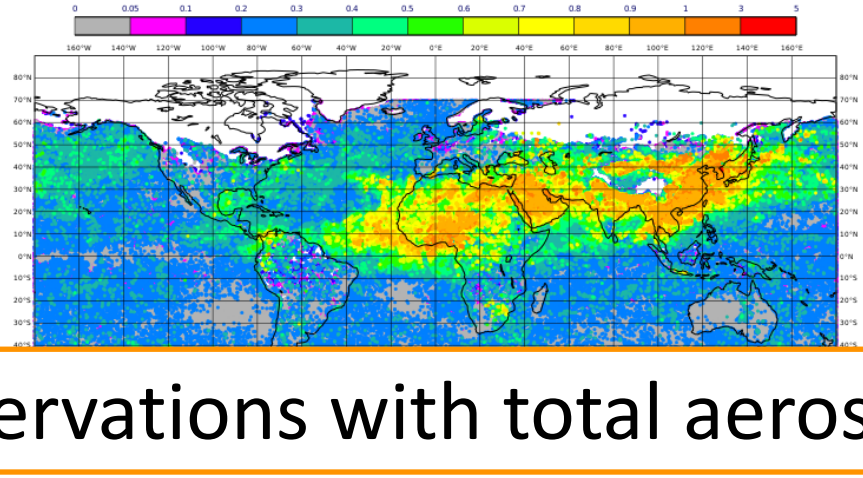
3MI (CAMEO HE +)

AOD (total, fine & coarse)
AAOD (total, fine & coarse)
SSA (total, fine & coarse)
AE

Terra MODIS



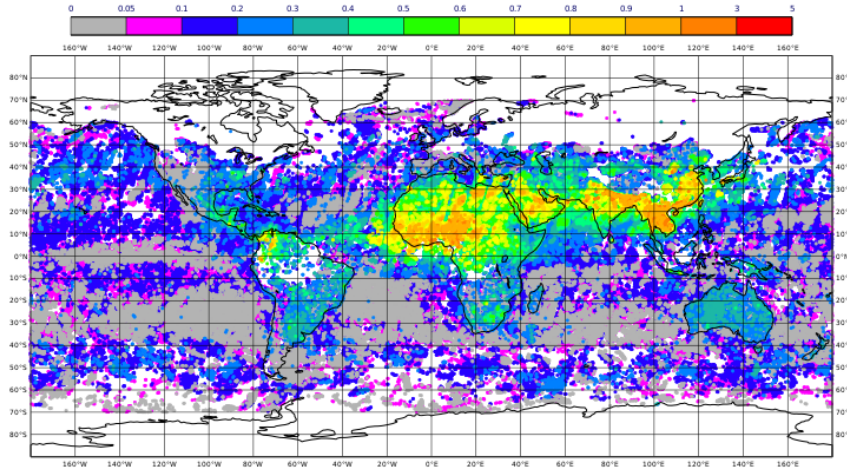
Aqua MODIS



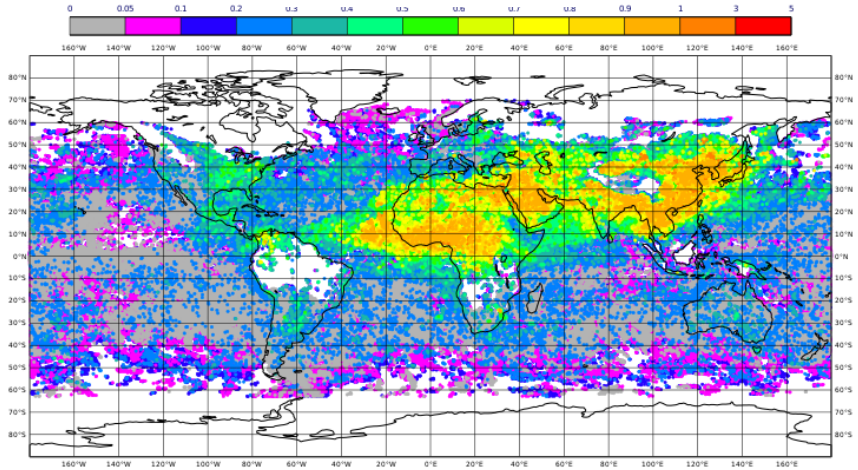
- MetOp-SG-A1 was launched on the 13th August 2025 carrying 3MI

How to use extra observations with total aerosol control variable?

AATSR **March 2008**



3MI (pseudo)



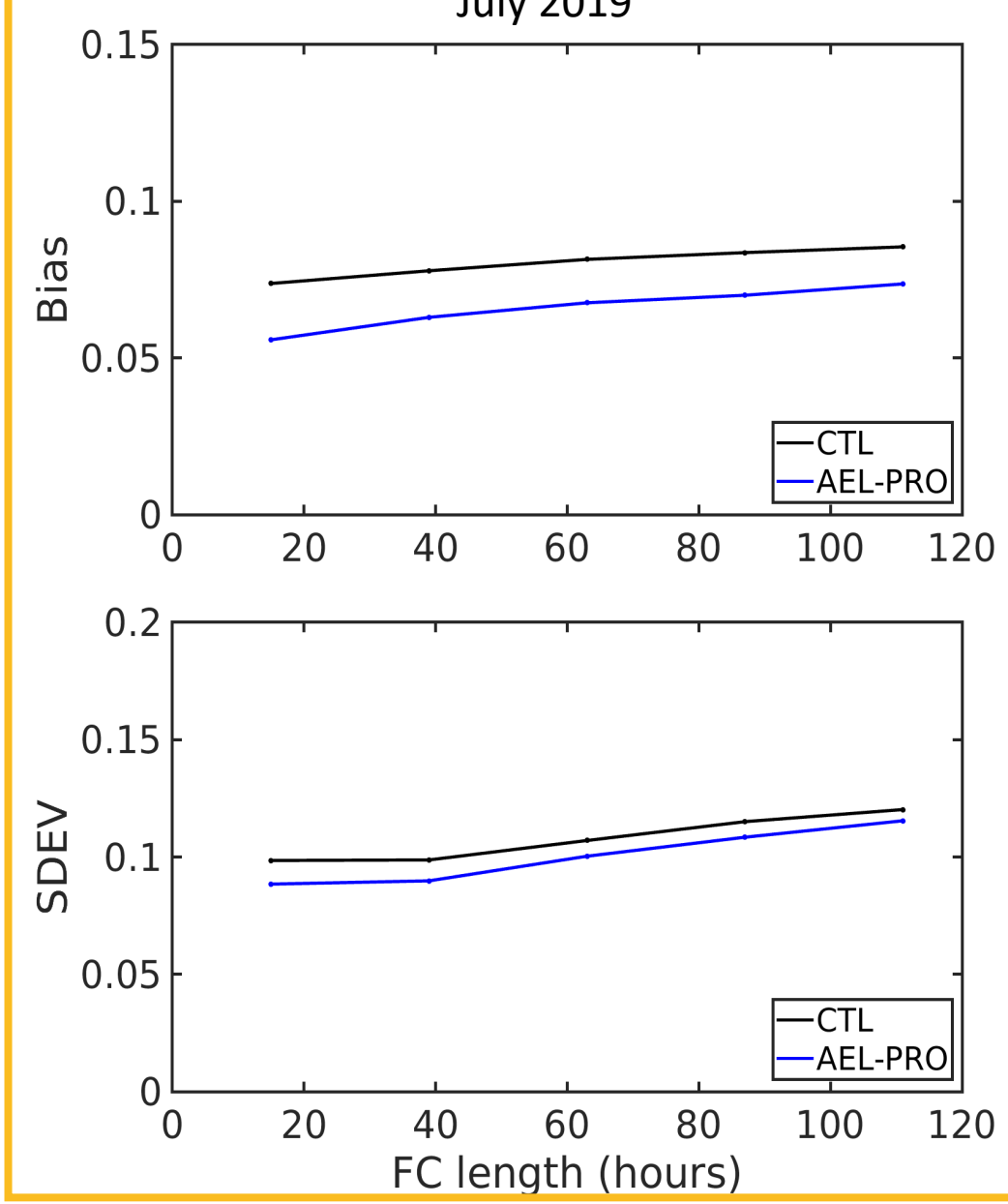
of aerosols in models and the GRASP retrieval that will be used for 3MI

- Updated pseudo 3MI observations using POLDER (Parasol)

AEOLUS (Aeolus DISC)

- Aeolus DISC project assesses the quality and impact of reprocessed L2A lidar backscatter Aeolus data, as input to EarthCARE + possible future Aeolus 2 missions
  - Standard Correct Algorithm (SCA; original Aeolus L2A algo)
  - Maximum Likelihood Estimation (MLE; improved product)
  - AEL-PRO adapted from ATLID algorithms
- The AEL-PRO product with feature mask (aerosol or cloud) shows best potential when used in the CAMS system
  - Clear positive impact on the forecasts when verified against Aeronet observations over Europe (July 2019).
- Feature mask is essential to distinguish cloud and aerosol signal and assimilate aerosol signal only.
- Ongoing work to test feasibility of assimilation of cloud and aerosol signal together (with EarthCARE ATLID obs).

Thanks to Kirsti Salonen



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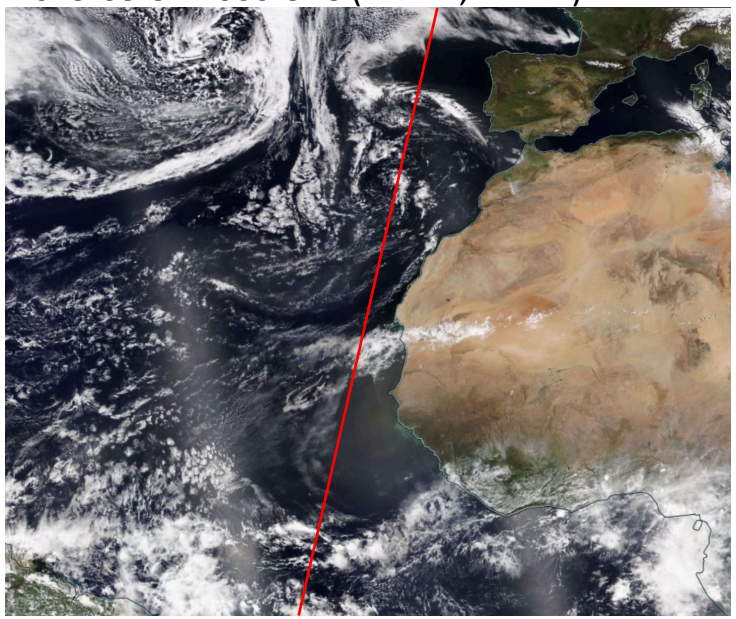
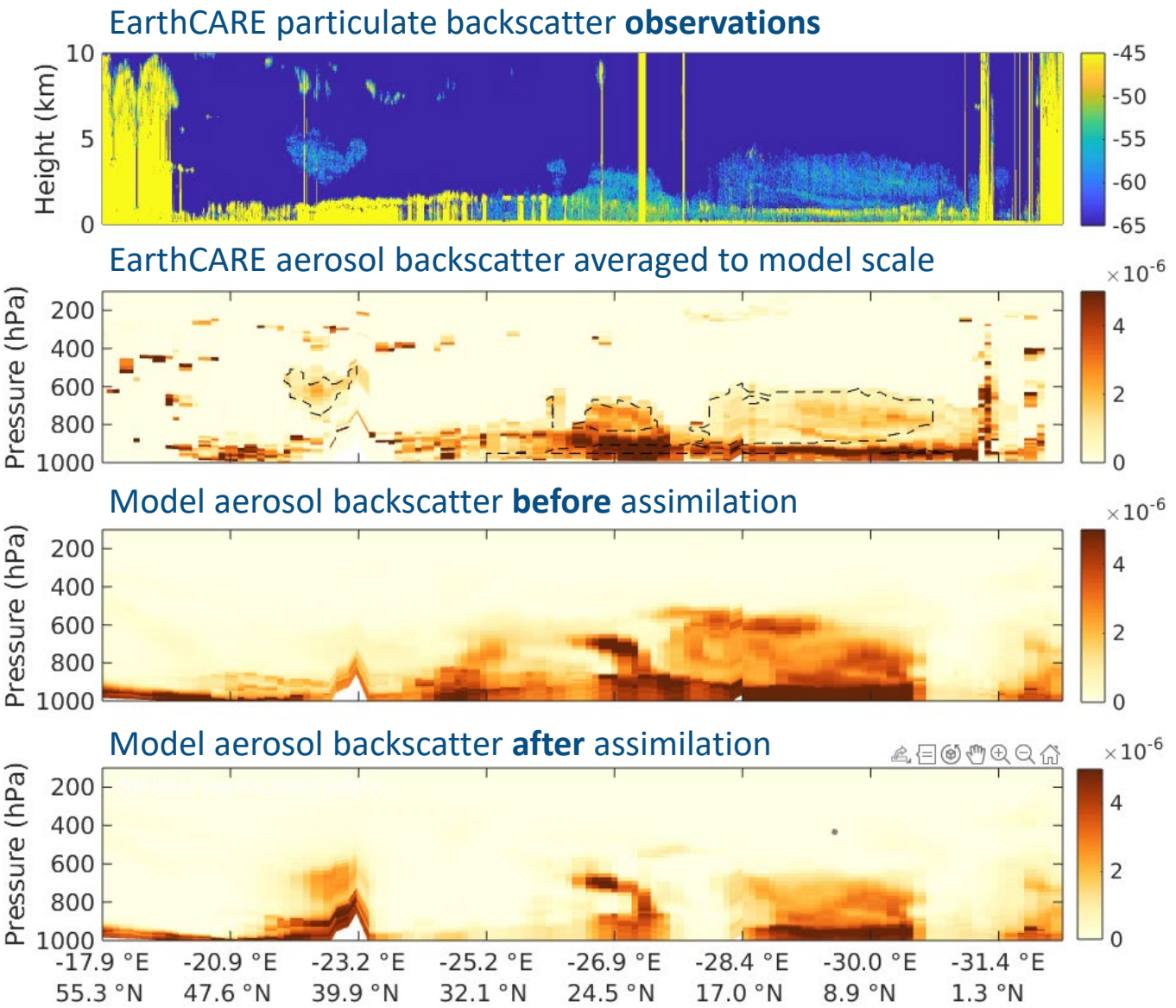
EarthCARE

- ATLID **aerosol backscatter** provides a new vertical constraint on aerosol profiles for atmospheric composition models in both day and night.
- As part of EarthCARE DISC, feasibility studies are being performed for monitoring and assimilation of L2 aerosol products.

2025-03-31 1600 UTC (4772D, 4772E)

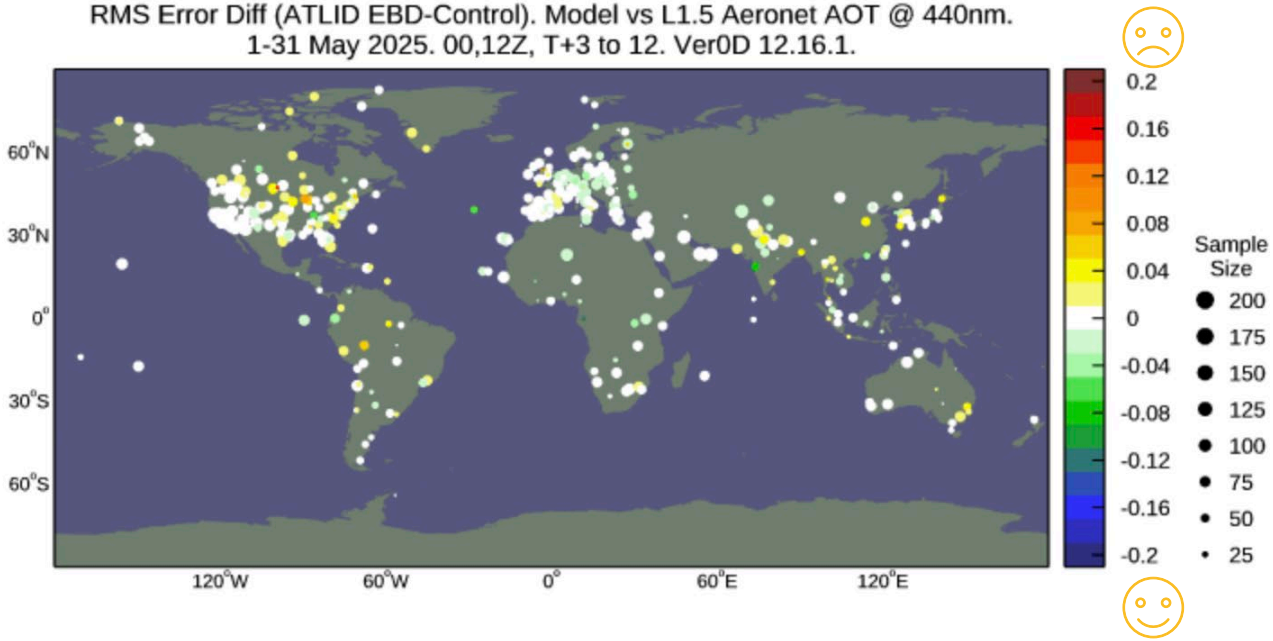


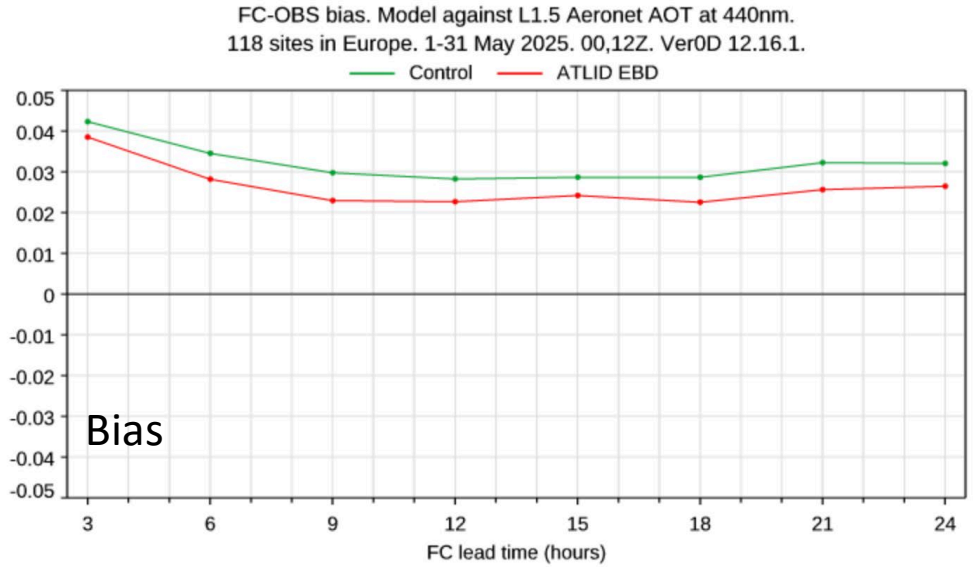


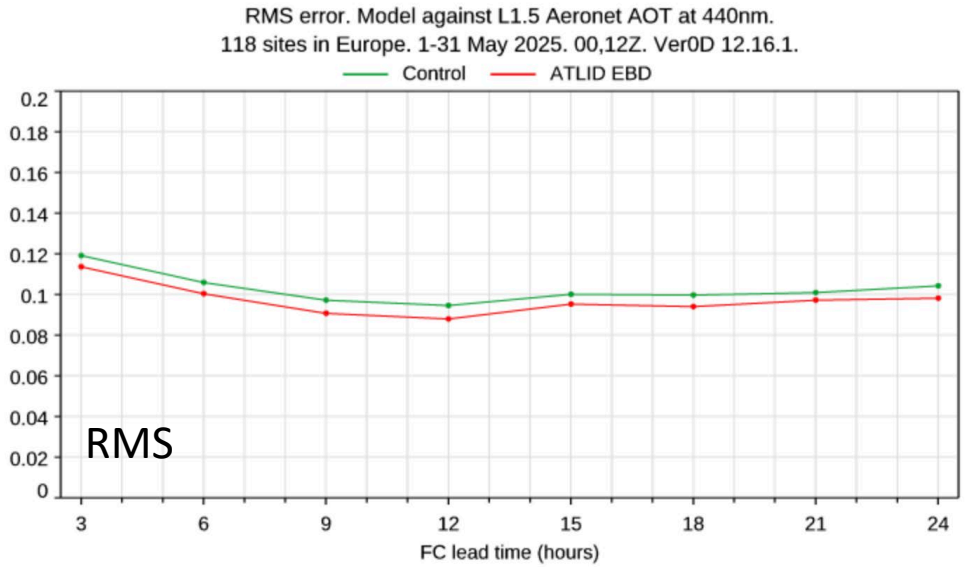
Thanks to Will McLean and Mark Fielding

EarthCARE

- Experiments performed in IFS-COMPO-like assimilation system for May 2025.
- Assimilating EarthCARE helps to reduce overall short-range analysis bias and improve RMS error compared to AERONET stations over Europe.
- This is a first attempt! Tuning of observation errors and screening are underway.



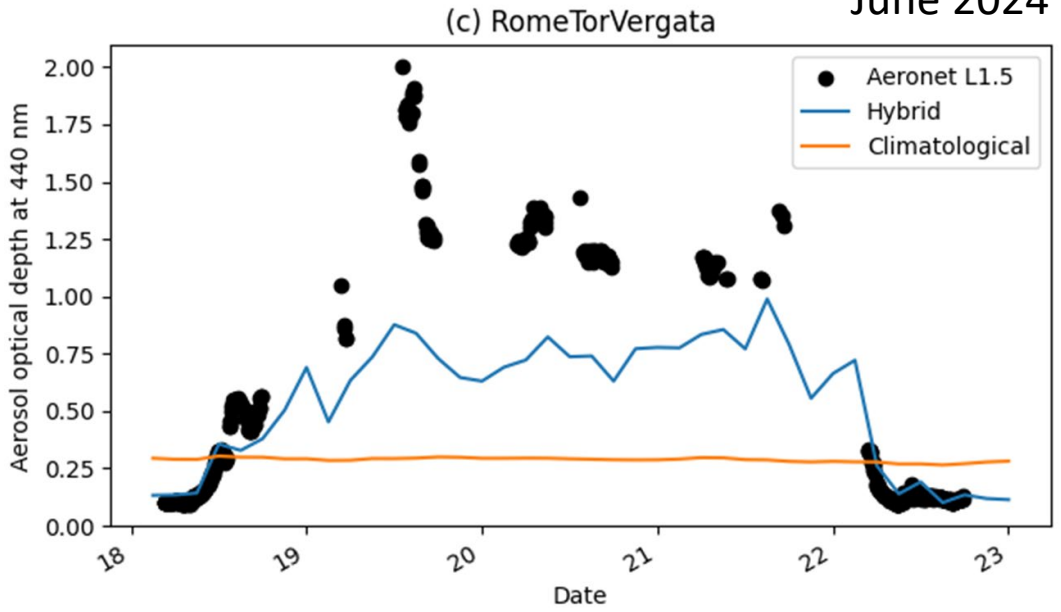


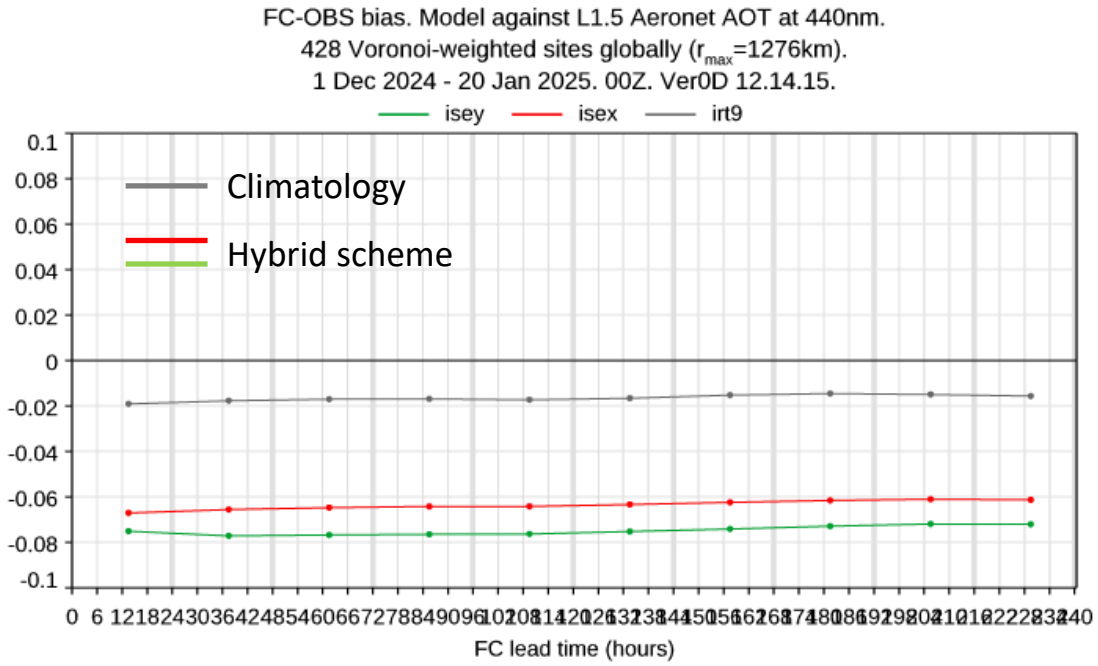


Thanks to Will McLean and Mark Fielding

Aerosols for NWP

- Currently NWP use an aerosol climatology in their setup of the IFS
- Research into a hybrid aerosol scheme: dust, black carbon and organic matter are prognostic, all other species use climatology. No chemistry.
- Consistently does very well for dust outbreak case studies, with good performance against Aeronet observations and increased skill for TOA SW radiation compared to satellite measurements.
- For broader statistics the hybrid scheme performs worse than climatology.
  - Climatological aerosols in hybrid come from old climatology (43r2)
  - Prognostic aerosols use latest version of model (49r1)
  - Inconsistency leads to AOD bias and hence increased RMS errors and larger temperature errors (not shown).





EarthCARE evaluation

Aerosols for NWP

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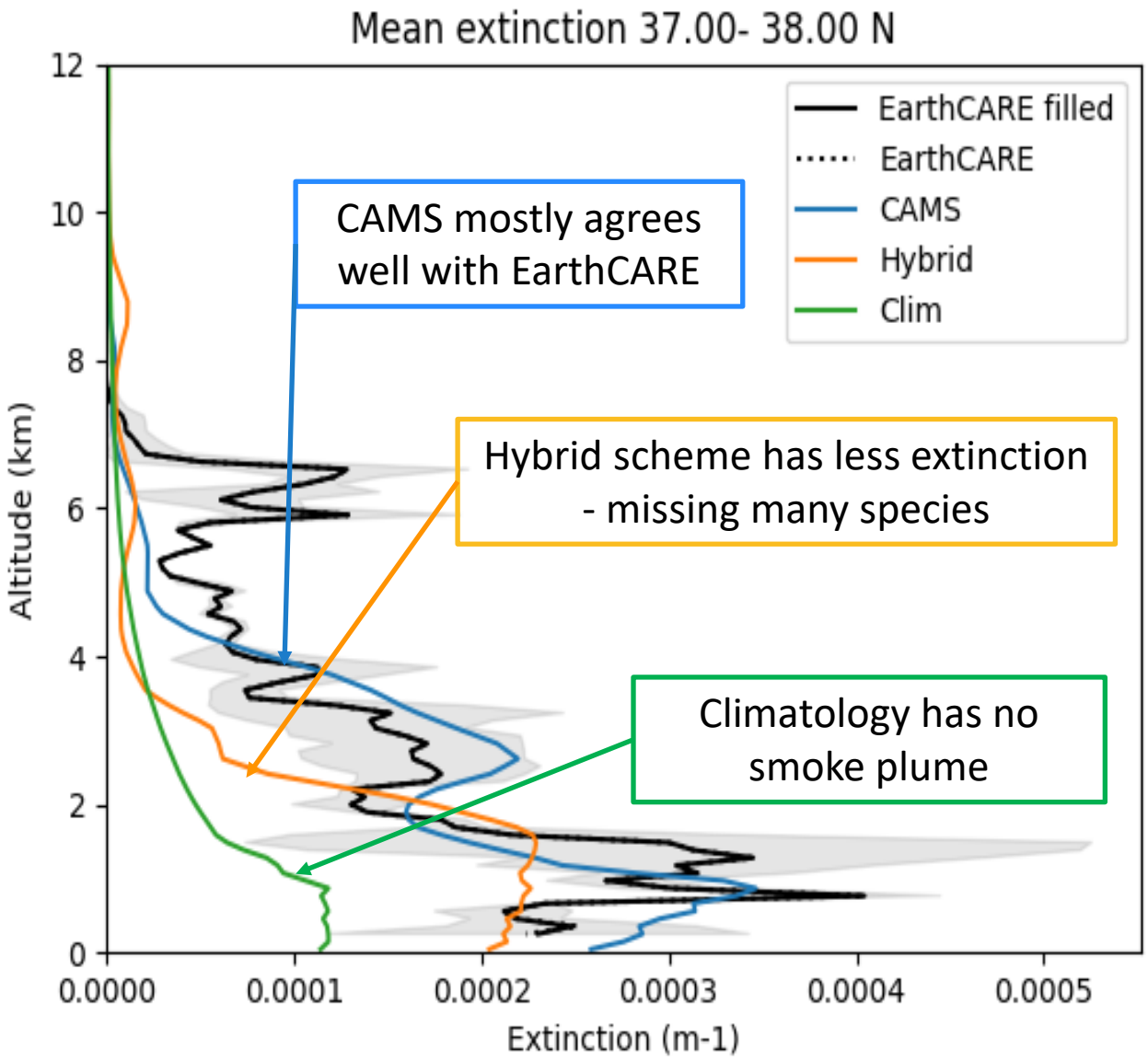

Canadian wildfires 16th August 2024.

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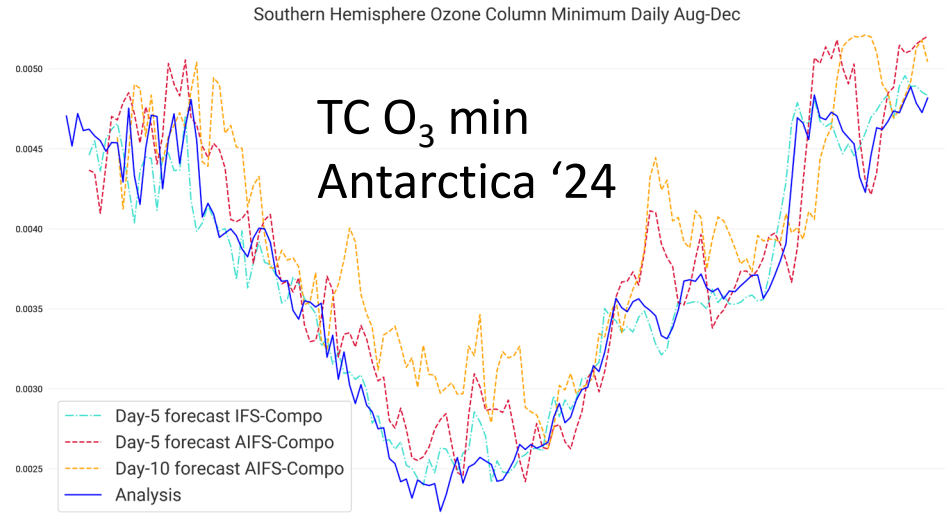
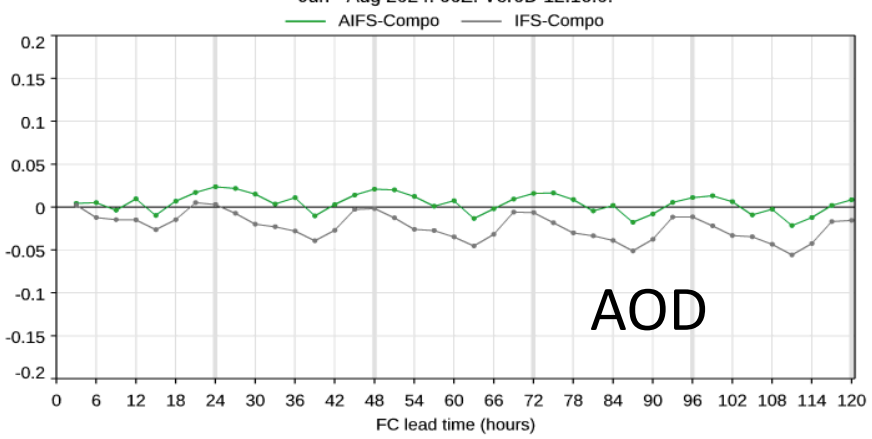
Enza to talk in more detail tomorrow

Machine Learning: AIFS-COMPO





AIFS-COMPO IFS-COMPO o-suite

- AIFS-COMPO follows method of AIFS (graph neural network encoder-decoder with a sliding window transformer processor)
- AIFS COMPO is trained on EAC4 reanalysis (an) and fine tuned with CAMS o-suite (an and fc)
- Currently, AIFS-COMPO can more or less match the forecast performance of the CAMS o-suite for AOD, PM, surface ozone, NO_2, SO_2 and TCO_3
- AIFS-COMPO forecast performance for AOD and PM2.5 exceeds IFS-COMPO
- NRT prototype with 10-day lead time planned (CAMS o-suite is 5 days)

Thanks to Paula Harder

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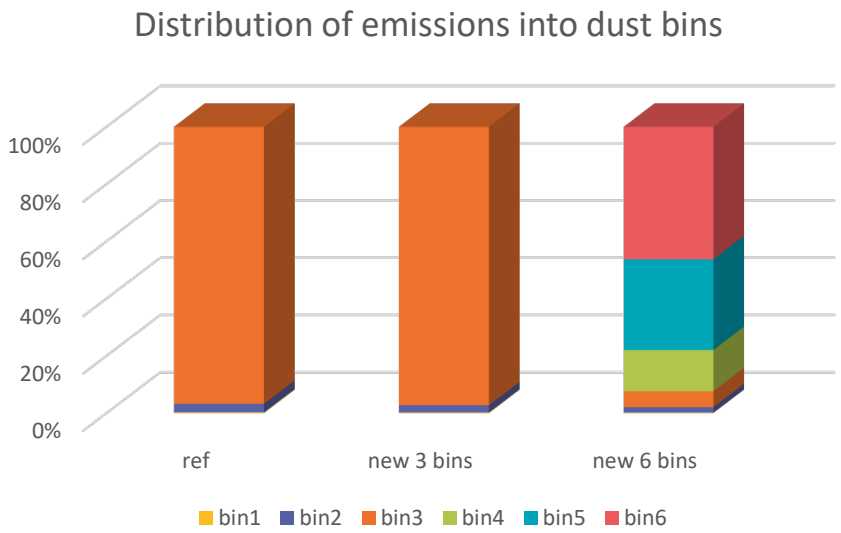
IMPLEMENTED BY ECMWF

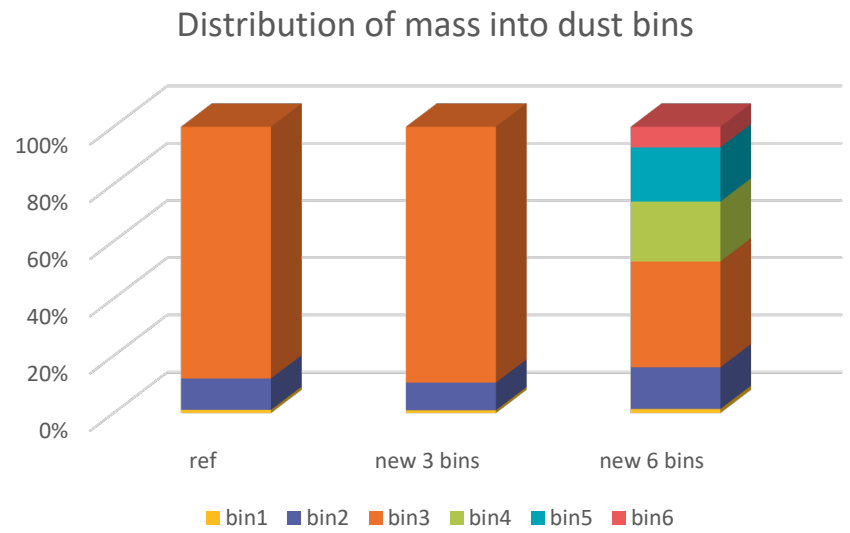
#EUSpace

Thank you

Why 6 dust bins?

- Better distribution of dust mass and emissions into bins
  - 3 bins : 90% of mass and more than 95% of emissions into bin 3
- Better representation of sedimentation – crucial for transport of larger particles





Thanks to Samuel Remy