
PROGRAMME OF
THE EUROPEAN UNION
Copernicus
Europe's eyes on Earth
Atmosphere
Monitoring Service
atmosphere.copernicus.eu
IMPLEMENTED BY
ECMWF
#EUSpace
Welcome from CAMS and ECMWF
Johannes Flemming
Reactive Gases and Aerosols team lead

The strength of a common goal

ECMWF celebrated its 50th Anniversary in 2025

ECMWF became a multi-site organization in 2021.

ECMWF was founded to address the critical and most difficult research **problems in medium-range NWP** that no one country could tackle on its own.

Since 2014, ECMWF implements the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S) as Entrusted Entity of the European Commission DG DEFIS, and is contractor for the Copernicus Emergency Management Service (CEMS)

CAMS Thematic Areas

CAMS mandate is to deliver consistent and quality-controlled information related to **the chemical composition of the atmosphere**, its drivers (**air pollutants and GHG**) and its impact on air quality and health, solar energy, climate forcing, in Europe and everywhere in the world.

Air quality

Policy tools

Dust Storms impacts

Solar energy

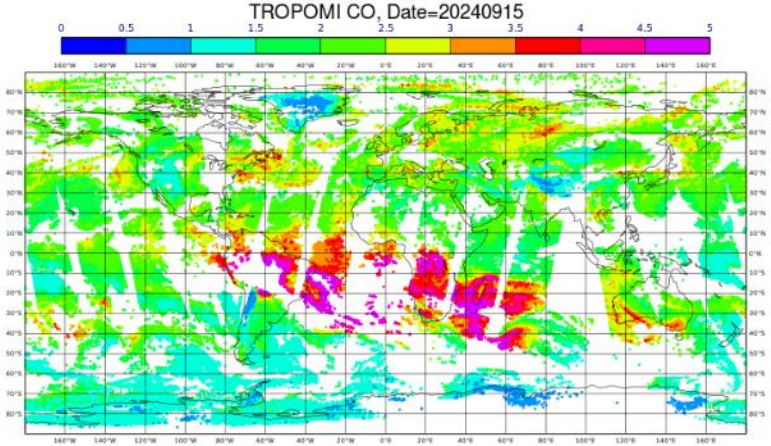
Ozone layer and UV radiation

Emissions and surface Fluxes

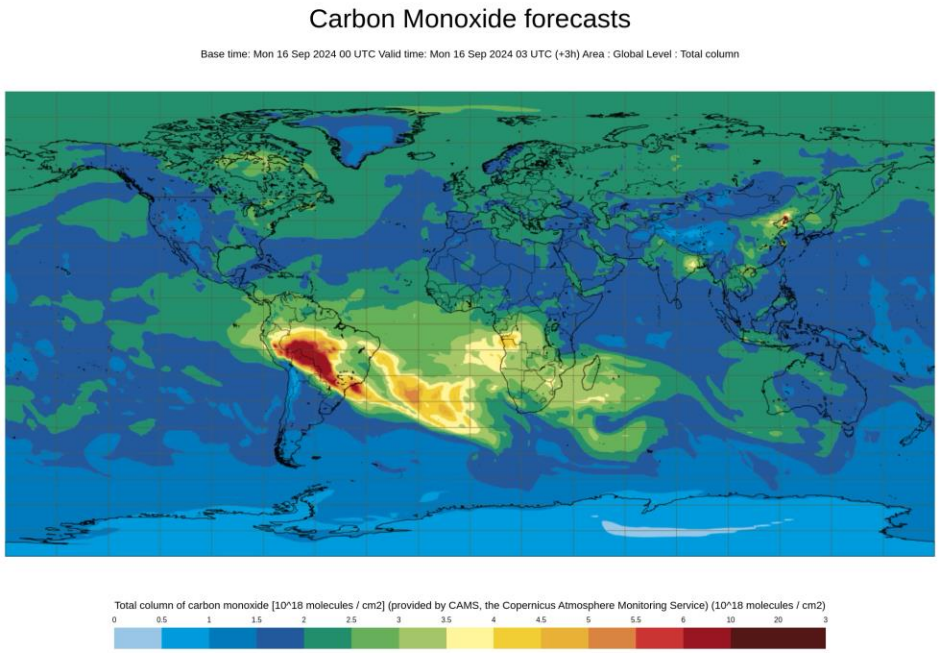
Wildfires impacts

Climate forcing

CAMS global : IFS-Compo and IFS-GHG



Satellite observations (S-5p, MOPITT & IASI)



Data assimilation

Medium-range forecast

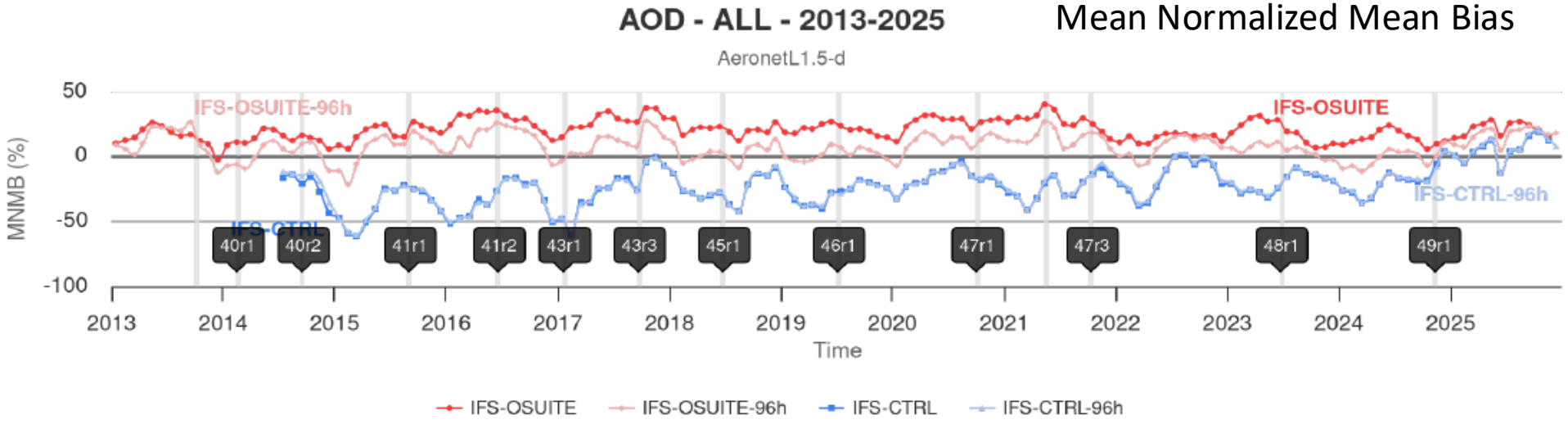
Forecast → **Analysis** → **Forecast** → **Analysis** → • • •

Analyses (and reanalysis) are initial conditions for forecast and reference datasets for trends analyses and for training ML forecast systems

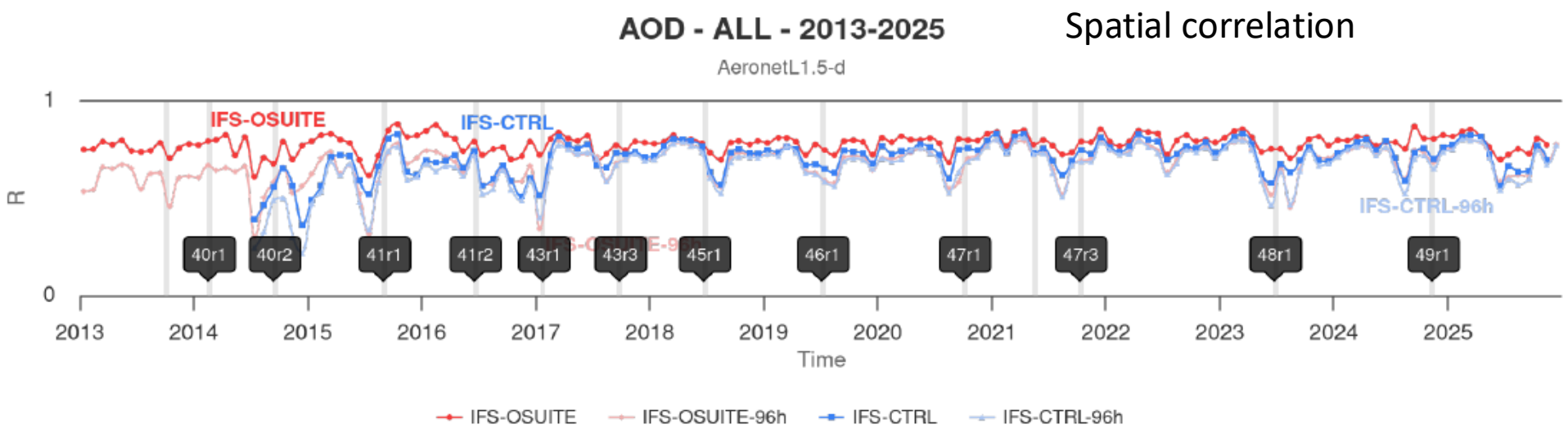
Long term Performance

CAMS vs AERONET AOD

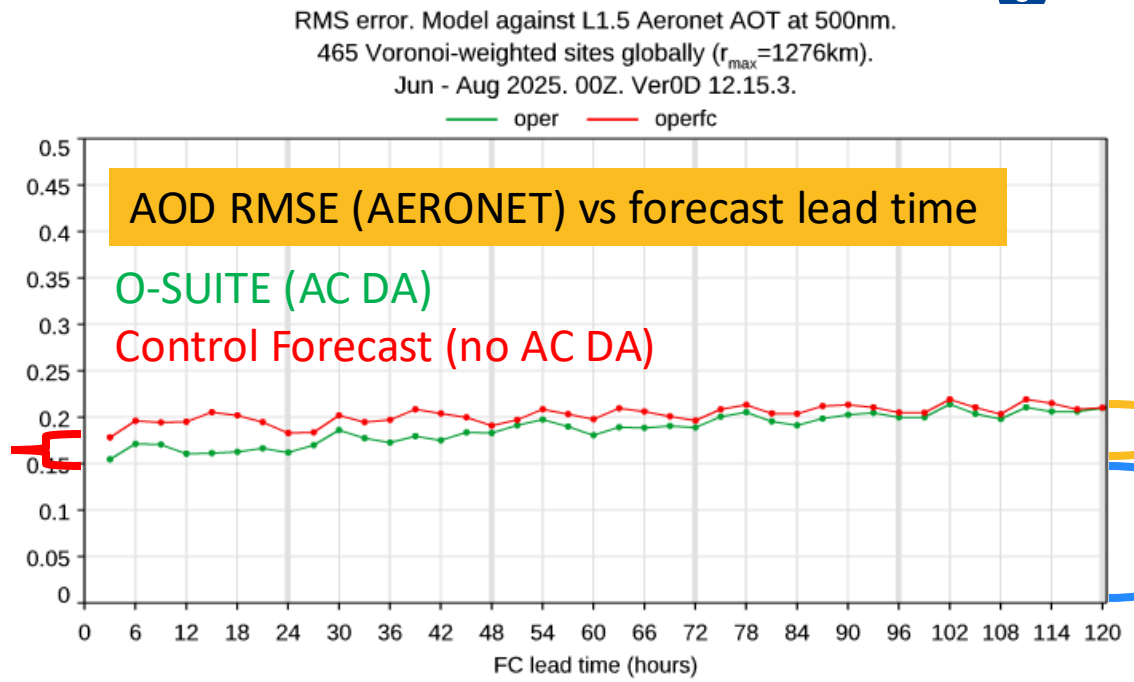
Mean Normalized Mean Bias



Spatial correlation



What to focus on … average perspective



Data Assimilation gain

Forecast error

Base line error

Forecast error is small compared to base line error

- Mainly caused by weather forecast error -
- Improved by AIFS-COMPO (ML)
- GFAS fire emissions forecast …

Data assimilation gain is small compared to base line error

- to be improved by
  - DA of new instruments (S5, S4, 3MI …)
  - better DA methods (4DVAR and ML)
  - emissions inversion DA

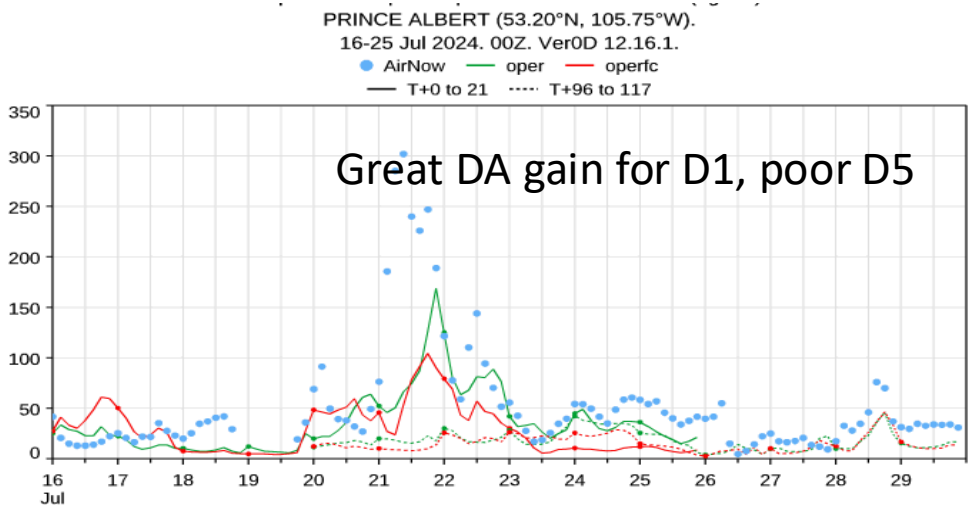
Base line error dominates total error for most CAMS variables

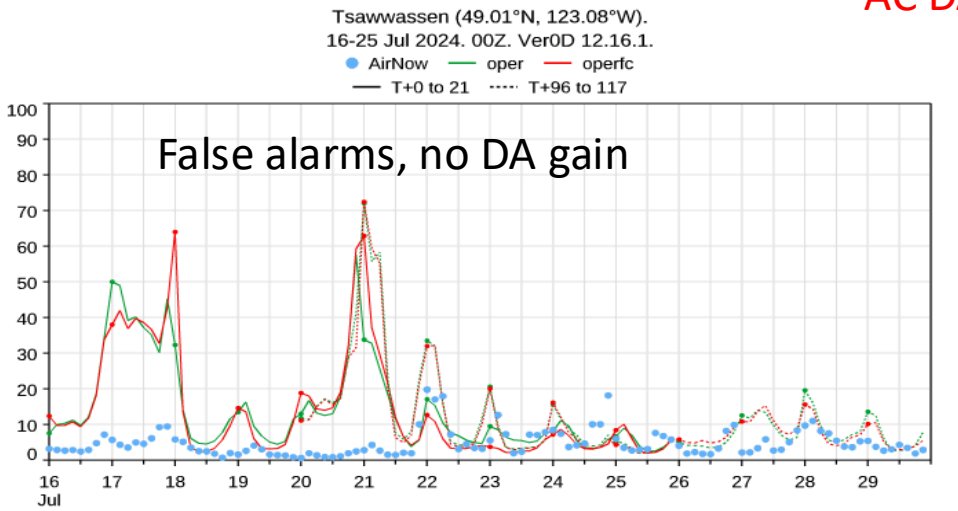
- caused by model and emissions errors (+ representativeness of observations)
- to be improved by
  - Larger DA gain
  - better modelling and emissions
  - higher resolution

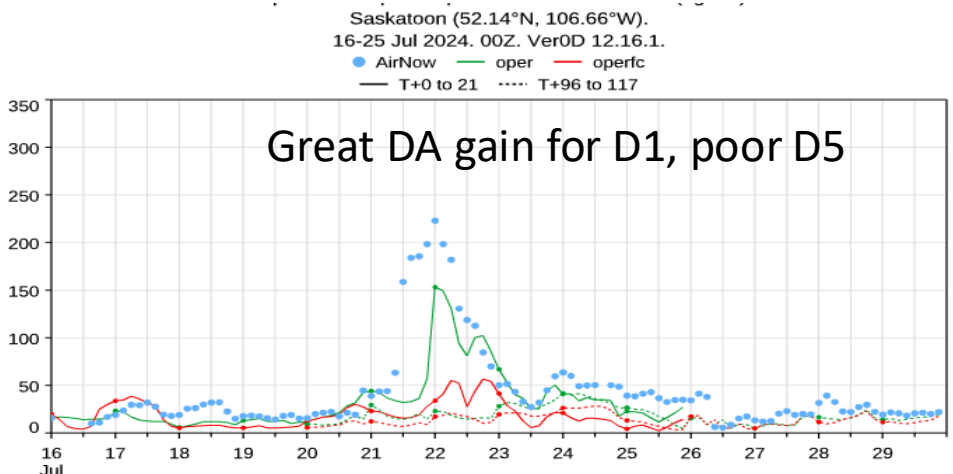
What to focus on … event perspective

PM25 during 2024 NA wild-fire episode

O-SUITE (AC DA)
Control Forecast (no AC DA)







C. Li, ECMWF

- Increase DA impact for longer lead times - emission update by inversion
- Focus on emissions prediction (GFAS) using ML
- **Quantification of event performance required (WMO/GAFIS effort)**

Challenges of AOD retrieval assimilation

	No vertical information	Speciation	Biases (inter instrument)	Accuracy
Now:	• Vertical background error profile (NMC)	• Proportional increments	• Variational bias correction (BC) and anchoring	• QC flagging
Work in progress	• Tuning vertical background errors • E-Profile assimilation • EarthCARE assimilation	• Dust-AOD (IASI) assimilation • Coarse and fine mode AOD DA from 3MI	• Review of BC predictors and anchors	• Testing new retrievals products • Harmonisation of optical properties

Improving global CAMS forecasts and analysis

- Respond to user needs
- Track quality and monitor progress of service

- Prepare CAMS DA for **new retrievals** from new instruments
- Advance **emissions inversion** capacity
- Improve AC **DA methods**

- Improve chemistry, aerosol and online emissions **modelling** - process evaluation
- Use better anthropogenic emissions **inventories**

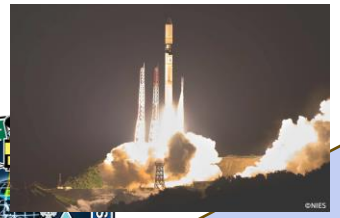
- **Apply AI/ML** for faster and better forecasts, downscaling, bias correction, learning from observations,

2025 : a key milestone for EO

12/08/2025

26/07/2025

01/07/2025



29/06/2025

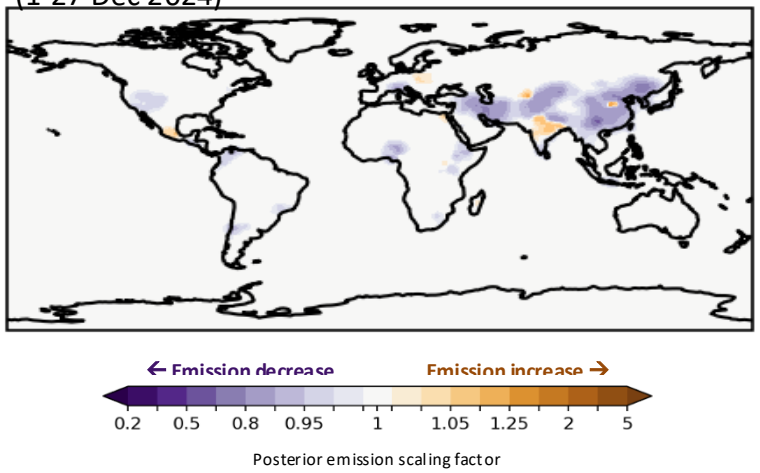
New-generation missions will provide unprecedented datasets.

Waiting for the CO2M constellation

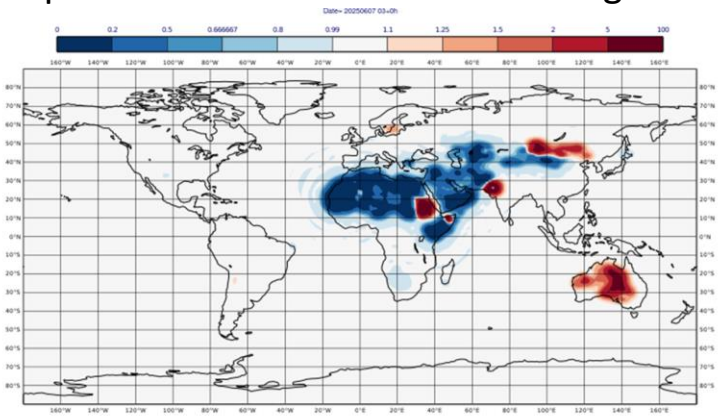
Maximising use of EO

Inversion of emissions & MMR DA

Anthropogenic CO emission scaling factor
(1-27 Dec 2024)



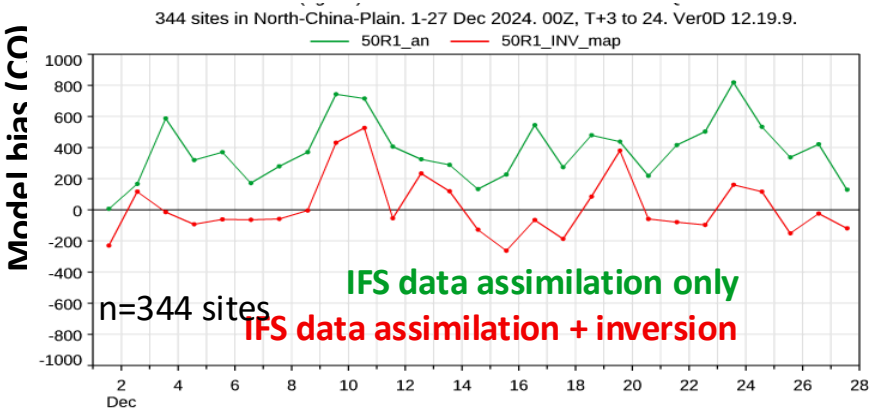
Super Coarse Dust emissions scaling factors



CAMS development for CO2VMS – online emissions monitoring for GHG based on EO

IFS-COMPO for 51r1 will contain emissions inversion capacity for shortlived species (scaling factors)

IFS bias against independent surface CO observations (China AQ) in the North China Plain



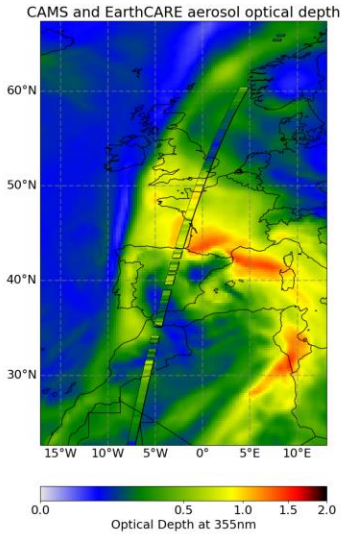
Assimilation of AOD at 10µm from IASI on Metop B/C
Use multiplicative correction factor for coarse dust as extended control variable

M. Kahnert

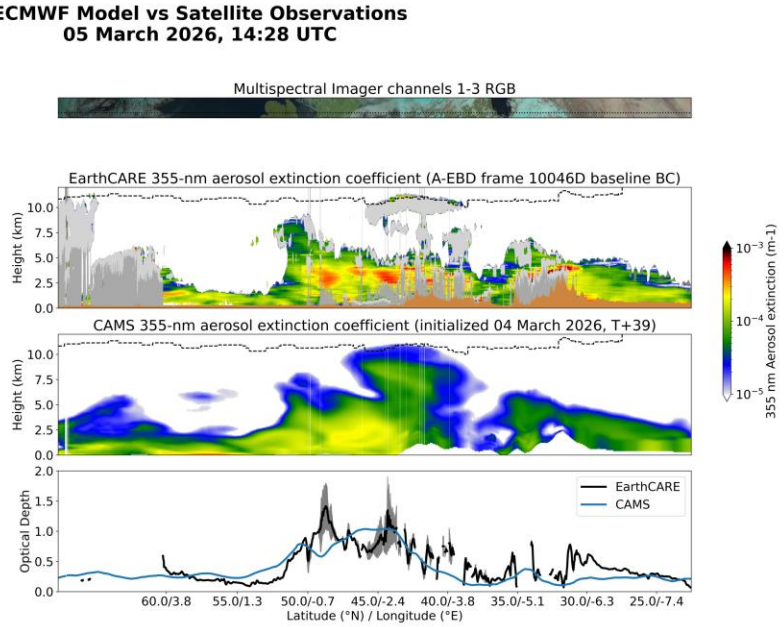
Work in progress for online dust and isoprene emissions

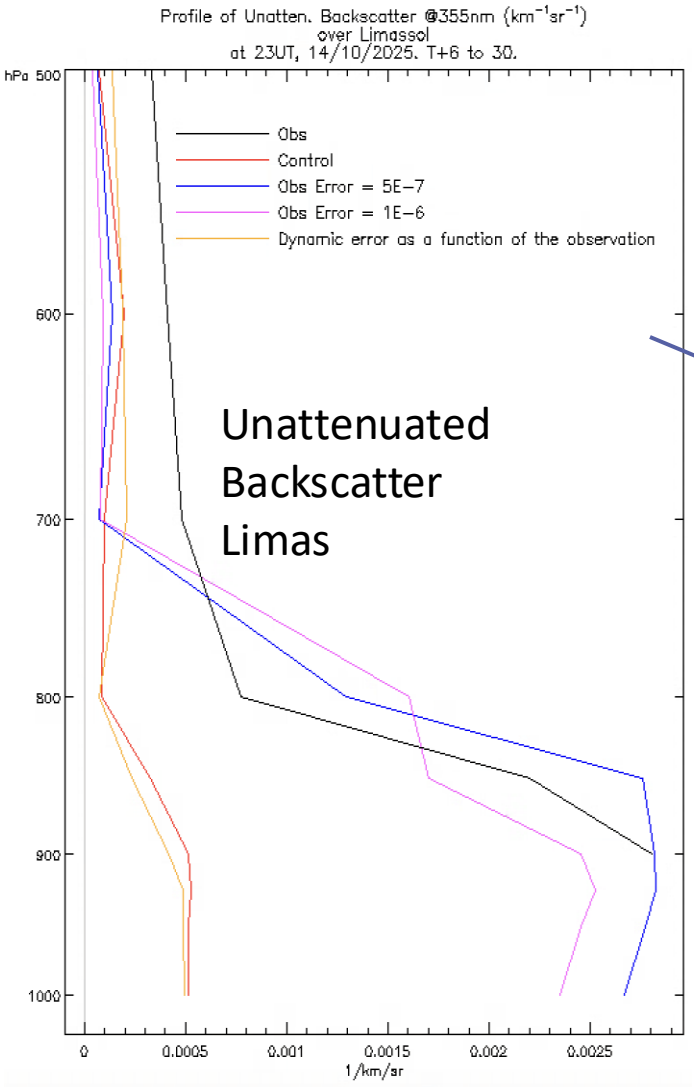
Aiming at improved analysis and better forecast skill for Aerosols and Reactive Gases

EarthCARE for Evaluation and Assimilation

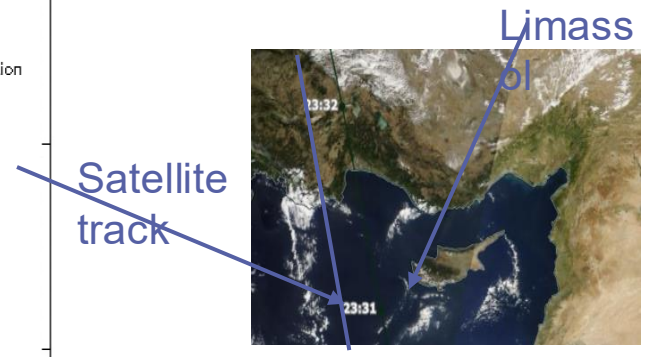


Peter Hill



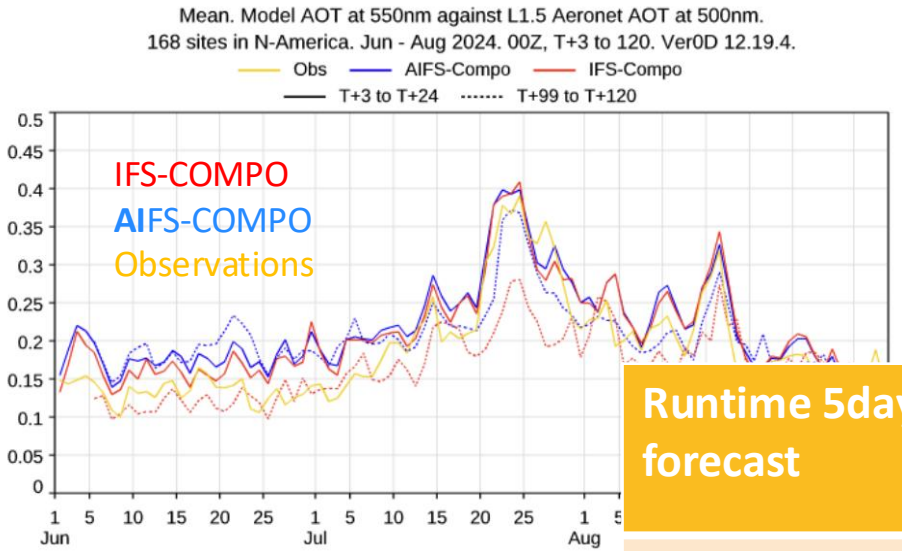


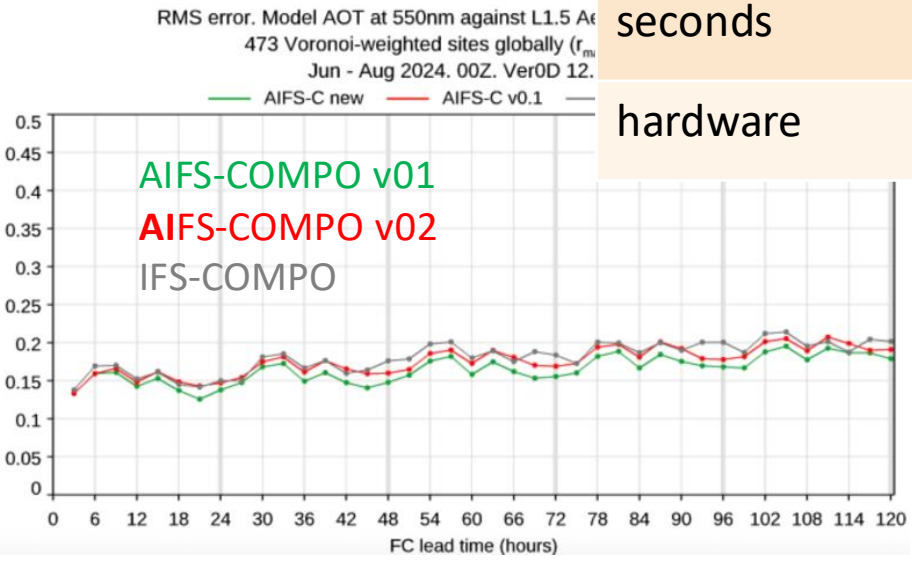
William McLean

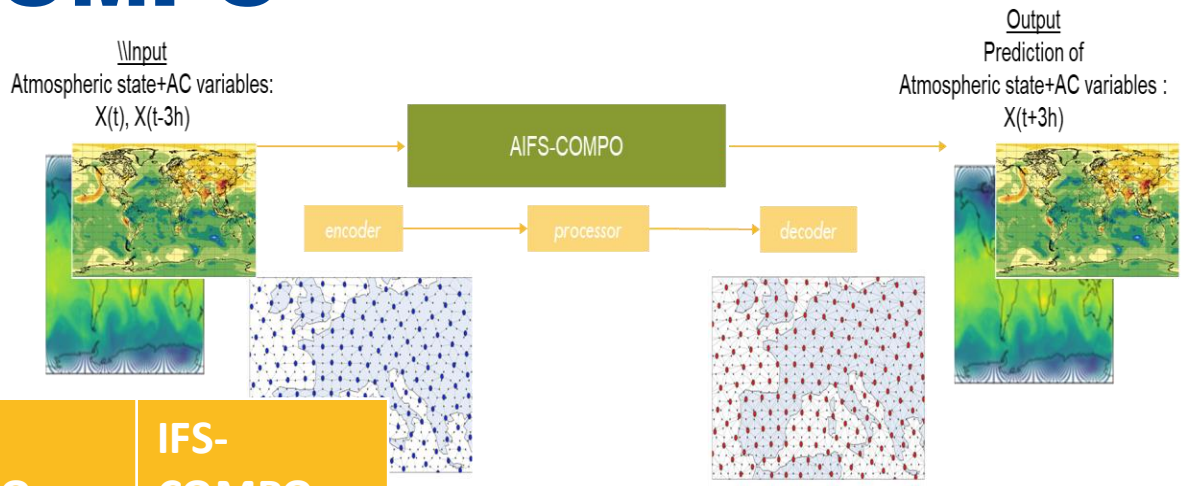


No.	Error
1	N/A
2	5×10^{-7}
3	1×10^{-6}
4	Dyn err

Machine Learning: AIFS-COMPO







Runtime 5day forecast	AIFS-COMPO	IFS-COMPO
seconds	50	1000
hardware	1GPU	8000CPU

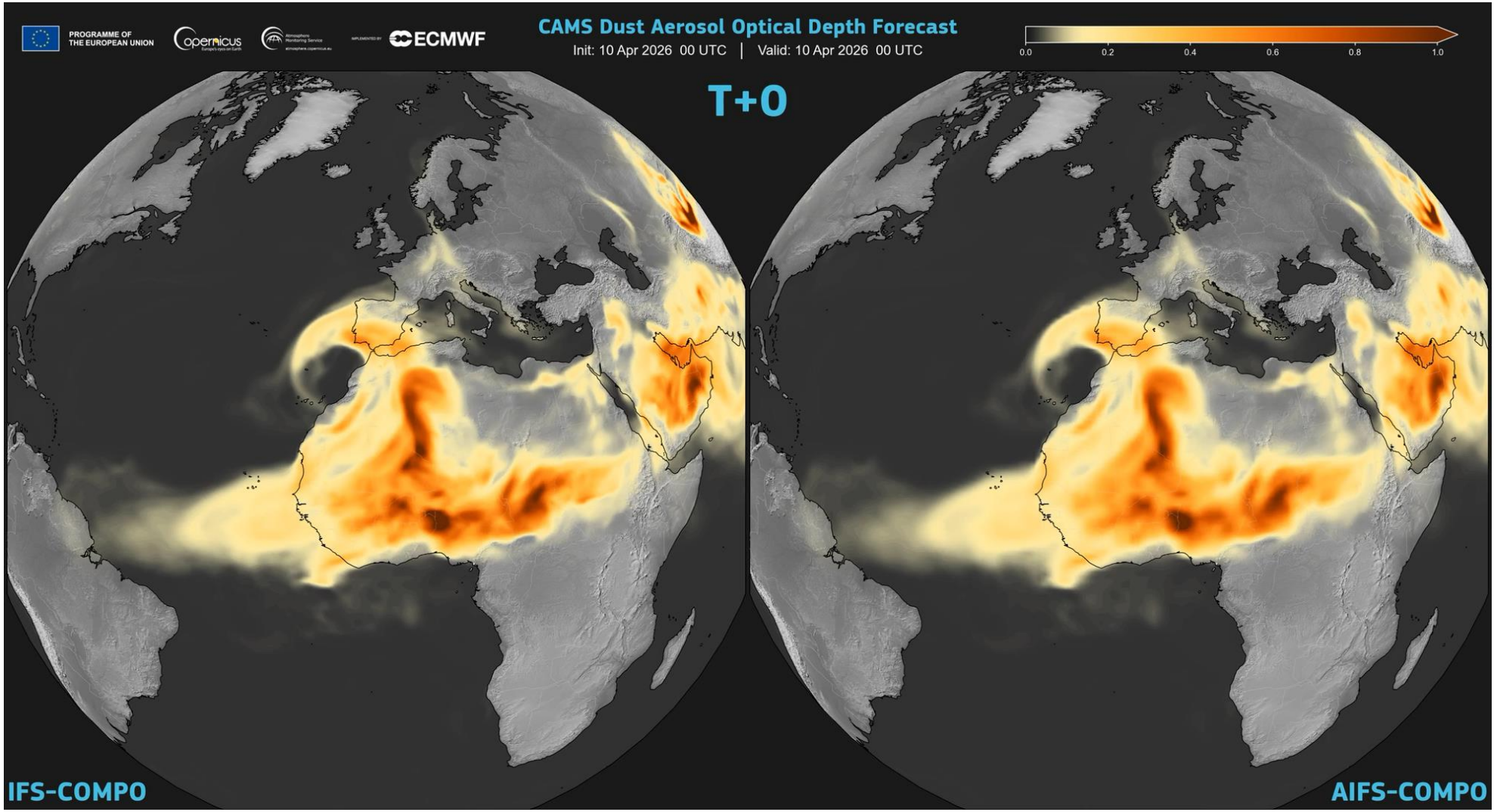
…od of AIFS (graph neural network encoder-…dow transformer processor)

…EAC4 reanalysis and fine tuned with CAMS o-suite

- 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
- AIFS-COMPO uses AC analysis from IFS-COMPO as IC

Paula Harder arXiv:2604.0330

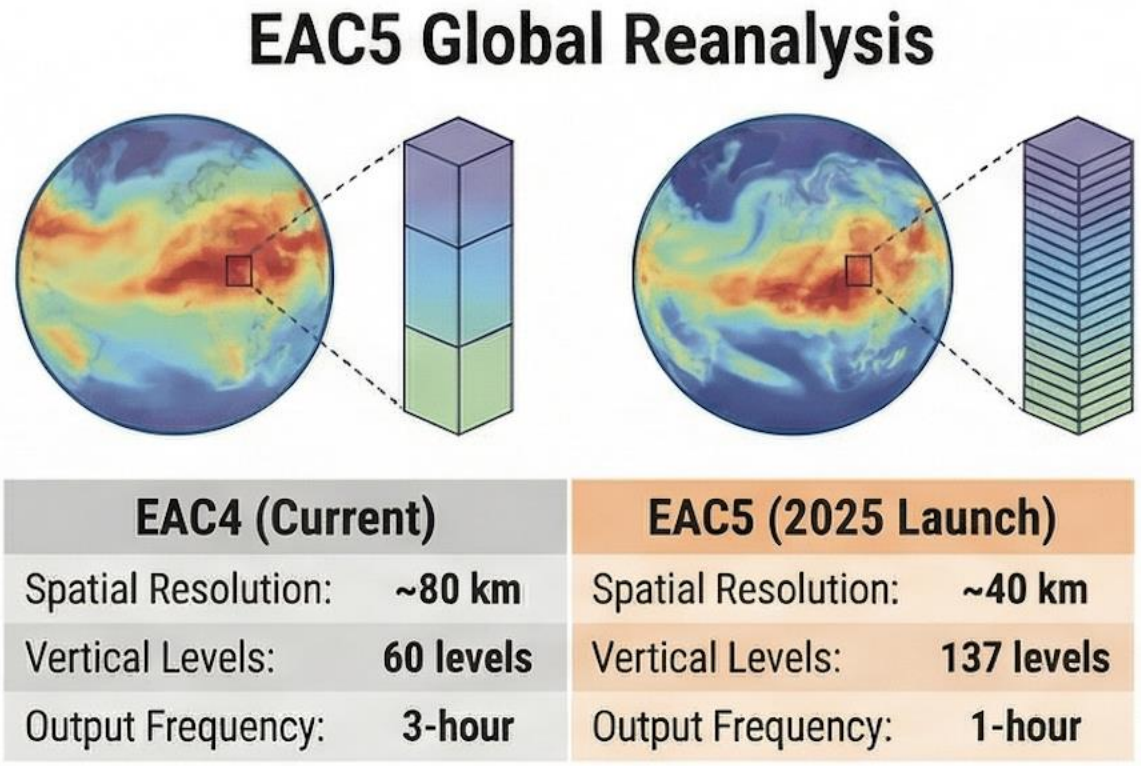
Results: AOD Day 3 forecast



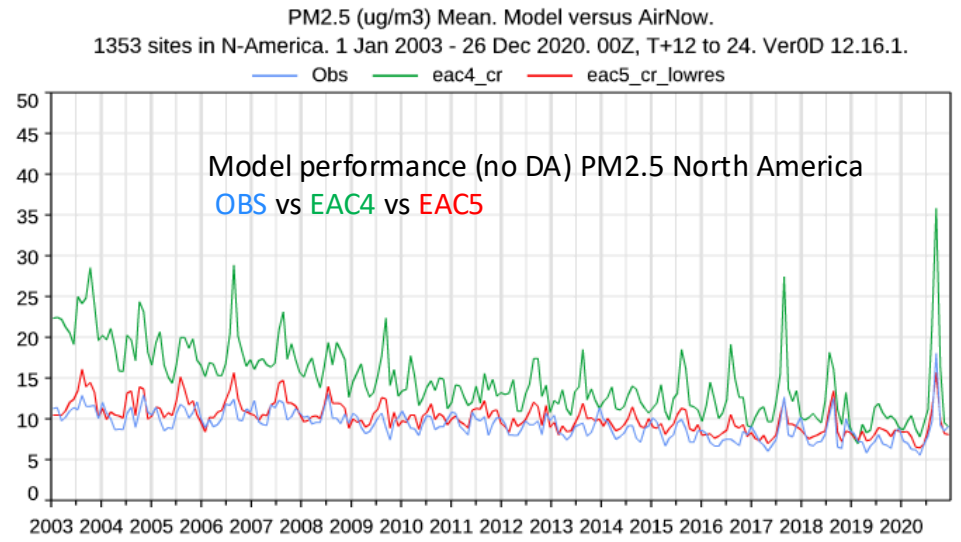
AI/ML

A new CAMS reanalysis (EAC5) in prep

Production period (Q3/2026-2028)



- Model updates:
  - **BASCOE stratospheric chemistry added**
  - **Nitrate, Ammonium and SOA added**
  - New emissions
  - Many more model updates (Cycle 49r2)
- **New and reprocessed observations (S5P, VIIRS, S3)**



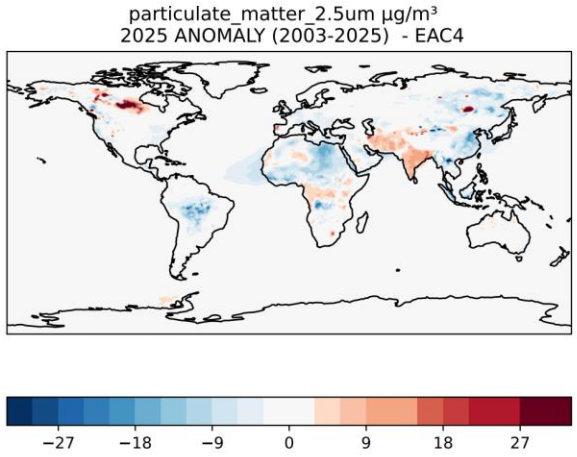
CAMS RA and Control (No AOD DA) – trends

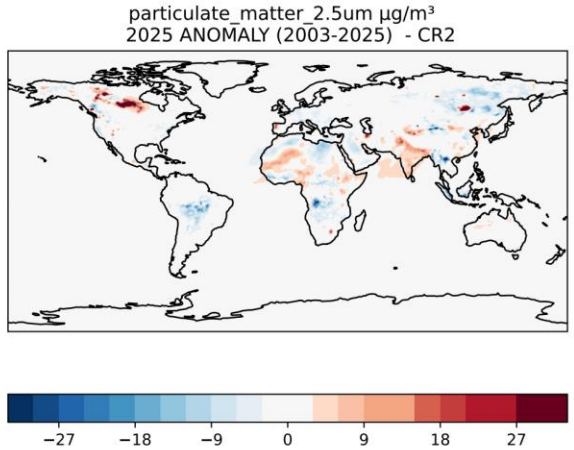
CAMSRA EAC4

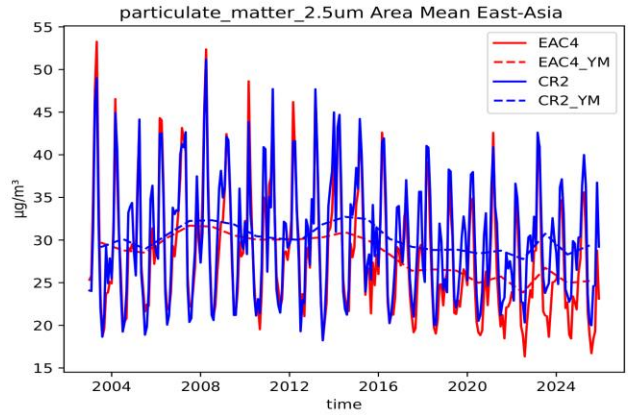
CR

MM time series over East Asia

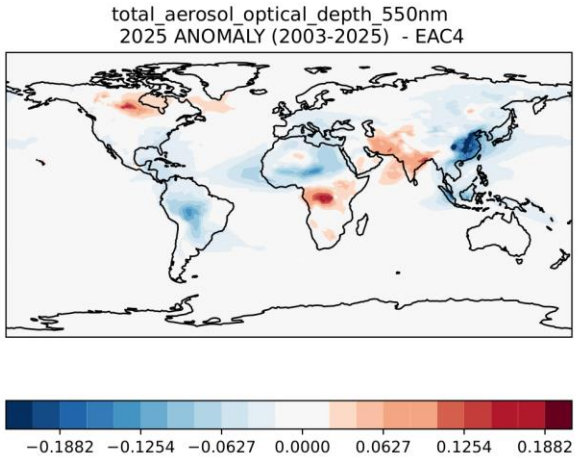
PM2.5

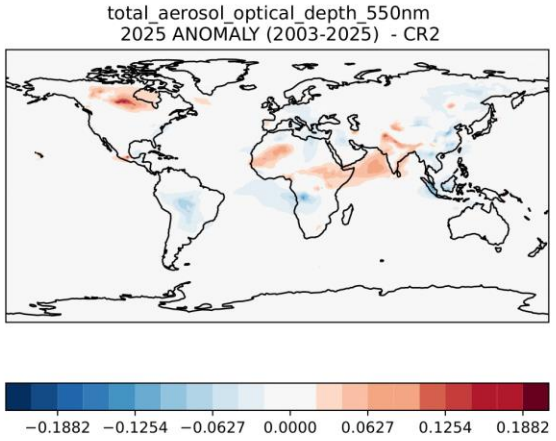


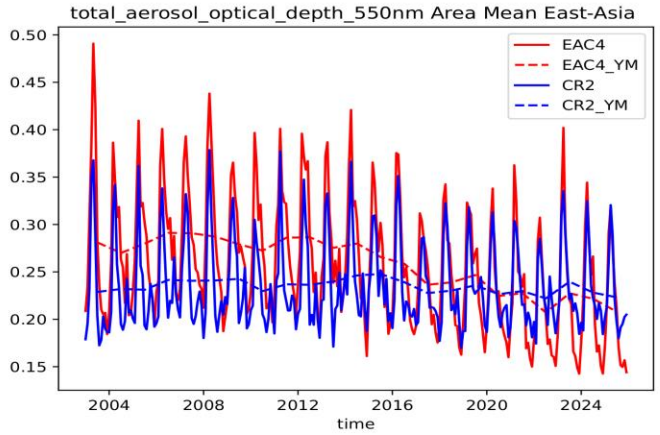




AOD

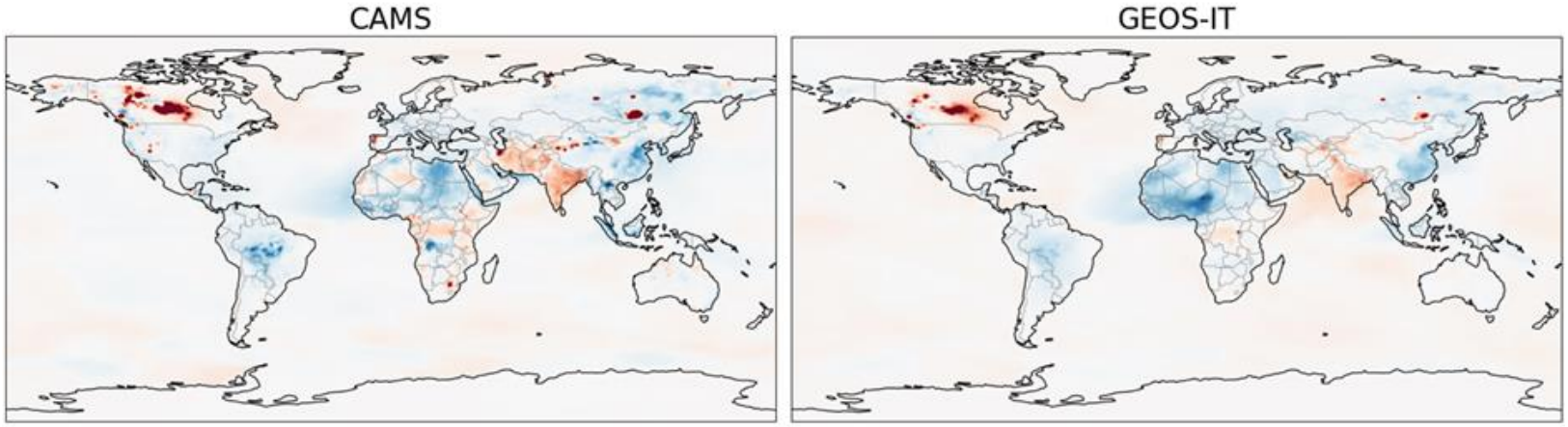






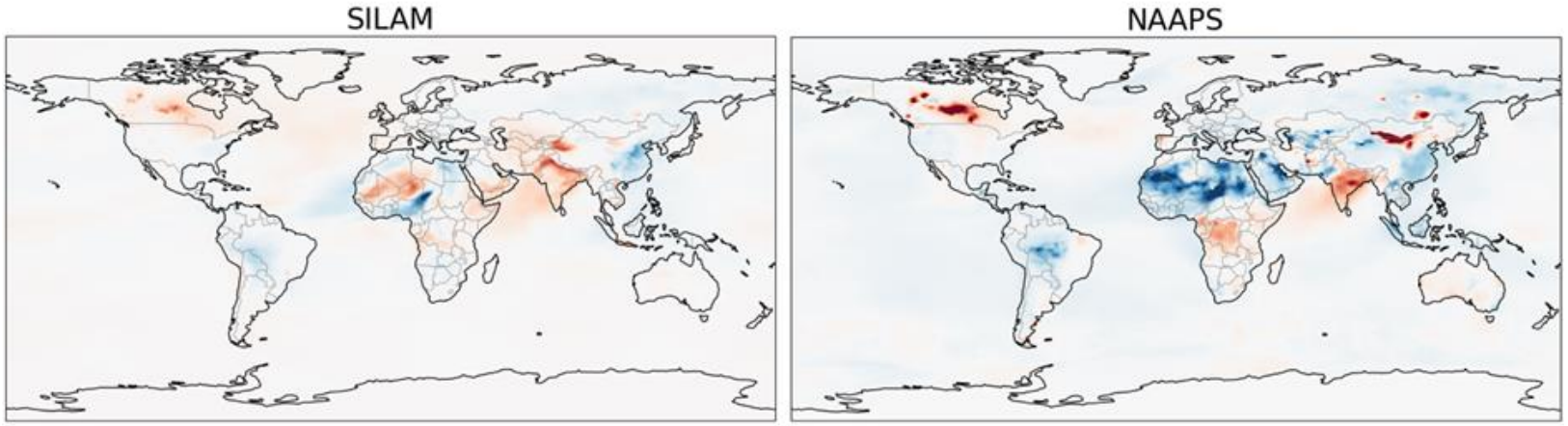
PM2.5 2025 Anomaly from different systems

AOD-DA

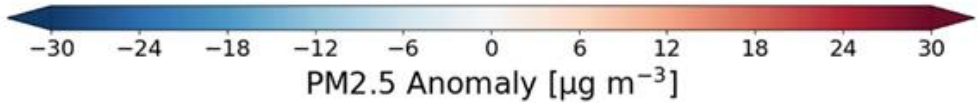


AOD-DA

No DA



AOD-DA



PM25 AOD anomalies from various systems

Colaraco et al. for GAW Air Quality and Climate bulletin

PROGRAMME OF THE EUROPEAN UNION

opernicus

Atmosphere Monitoring Service

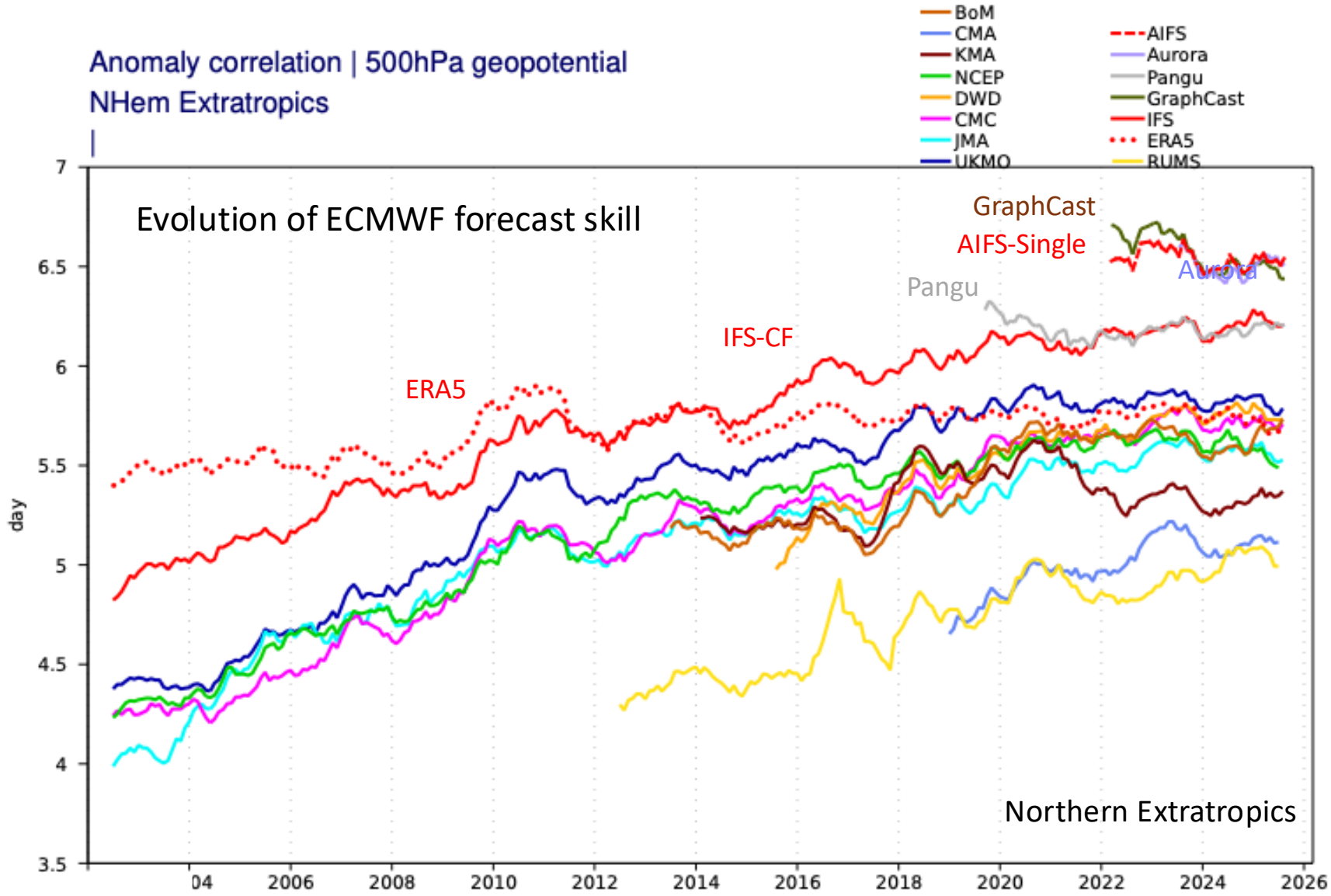
IMPLEMENTED BY ECMWF

Welcome ICAP 26 in Bonn

Source: BMV
Facility design: SL/A Architekten
Visualisation: renderstudios

New ECMW building
Planned opening end of 2027

Anomaly correlation of 500 hPa geopotential reaching 85%



ML models

Physics-based models

- Aurora, GraphCast and AIFS very close
- IFS has slightly increased lead on most other centres