Role of observations in NWP and atmospheric composition forecasts

Laurence Rouïl

Director of the Copernicus Atmosphere Monitoring Service

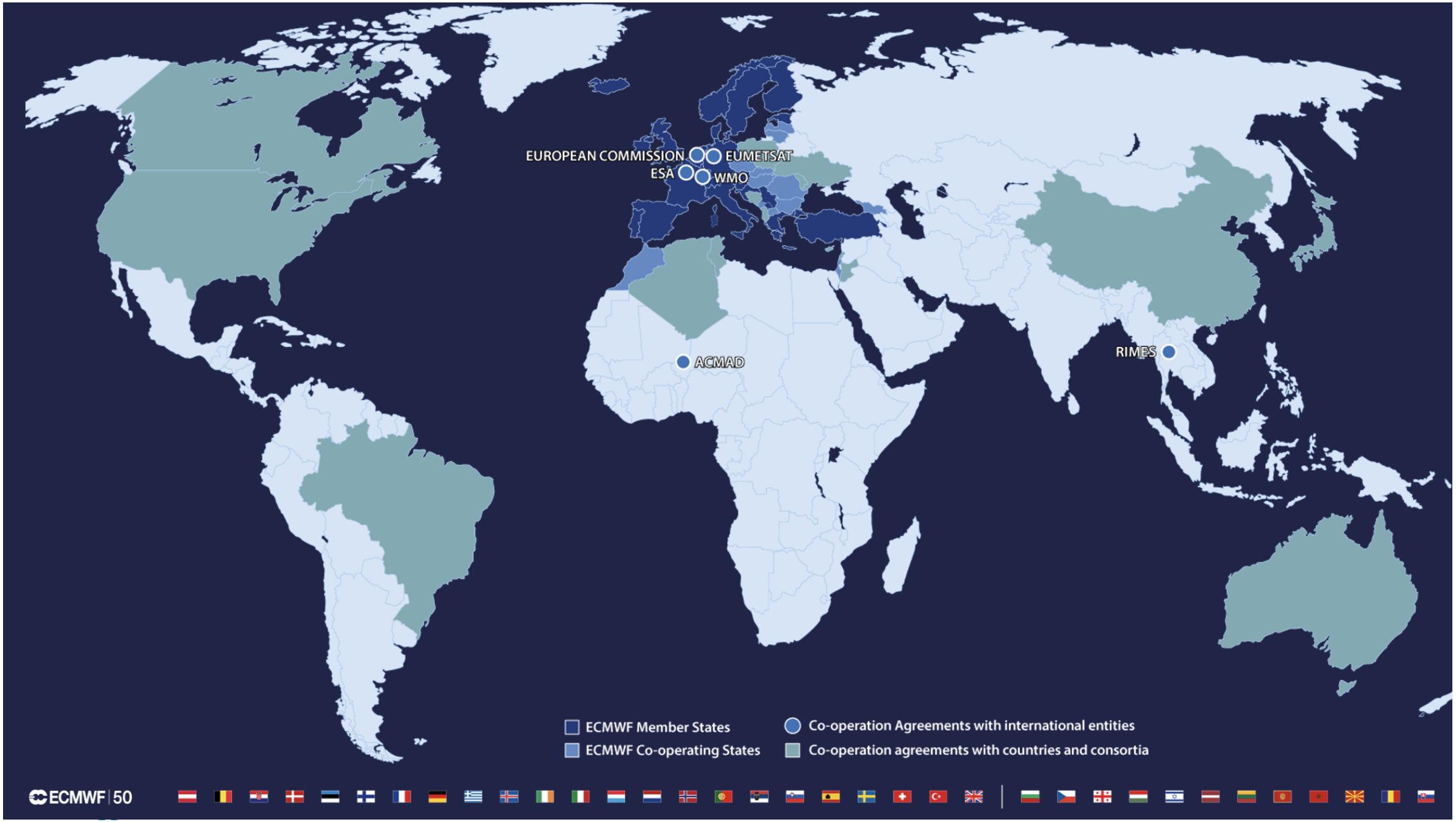
The strength of a common goal

European Centre for Medium-Range Weather Forecasts

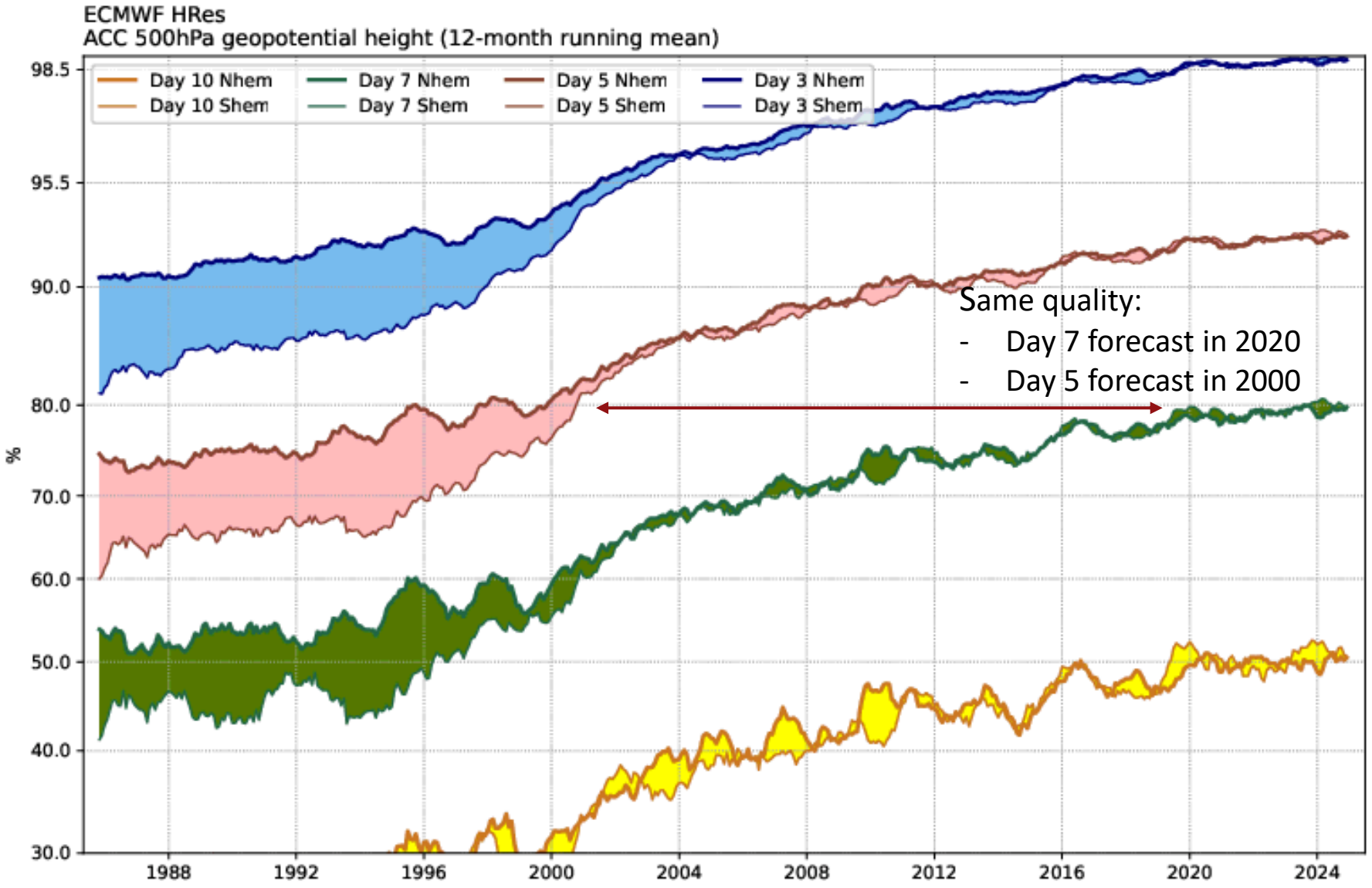
Created 1975
Research, Operations, Data Centre
www.ecmwf.int

23 Member States
12 Cooperating States
>500 staff

HPC + over 1 exabyte of weather and climate data


EUROPEAN COMMISSION
EUMETSAT
ESA
WMO
ACMAD
RIMES
ECMWF Member States
ECMWF Co-operating States
Co-operation Agreements with international entities
Co-operation agreements with countries and consortia
ECMWF 50

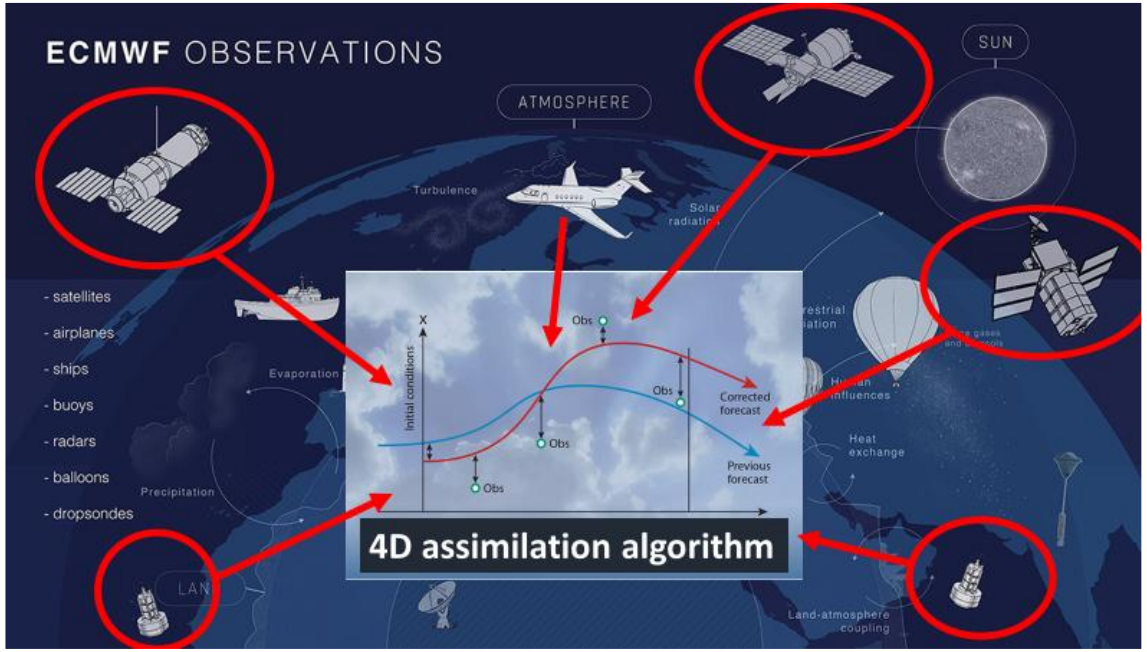
Evolution of the skill of medium-range forecasts

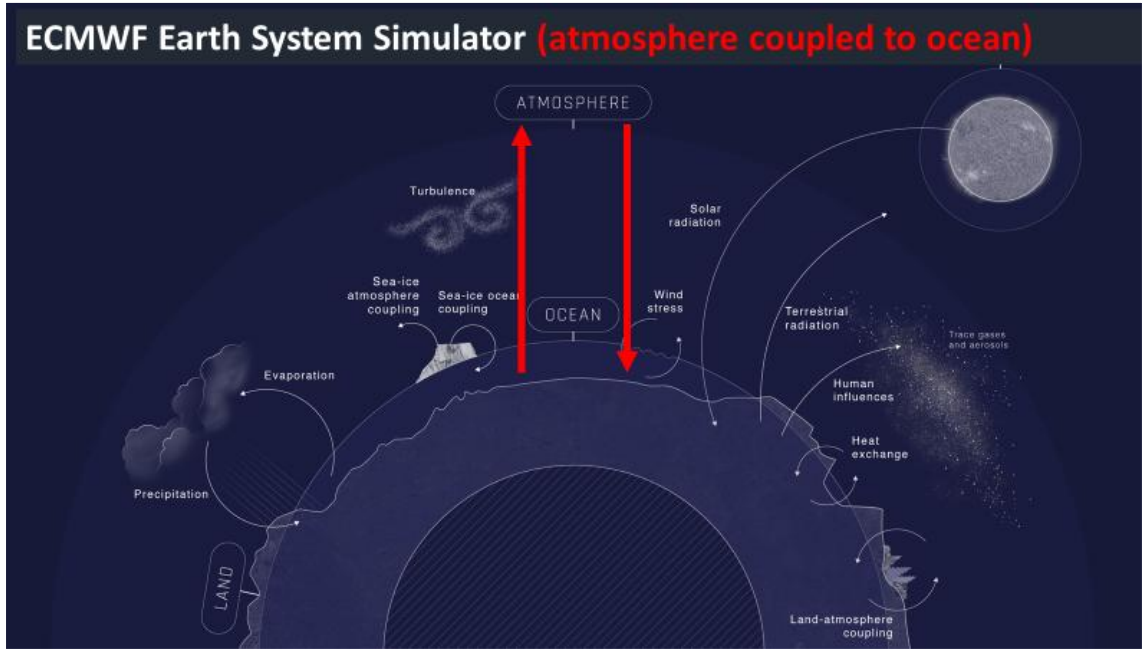


The quiet revolution of numerical weather prediction
(Bauer et al., Nature, 525, 47–55 (2015), https://doi.org/10.1038/nature14956)

Observations in NWP

The Satellites provide the **global initial conditions** (what the atmosphere doing now) needed to forecast many days in the future.

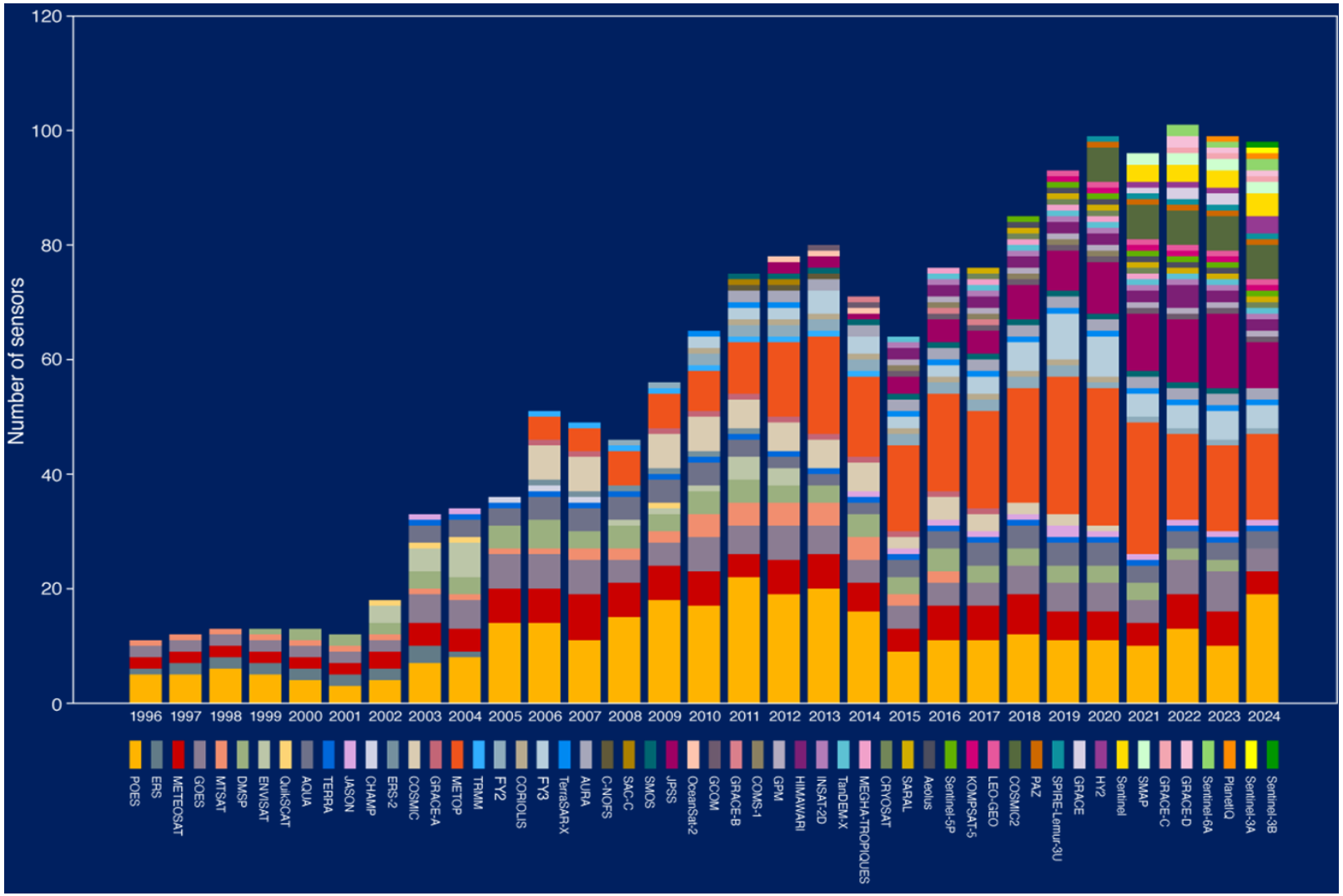




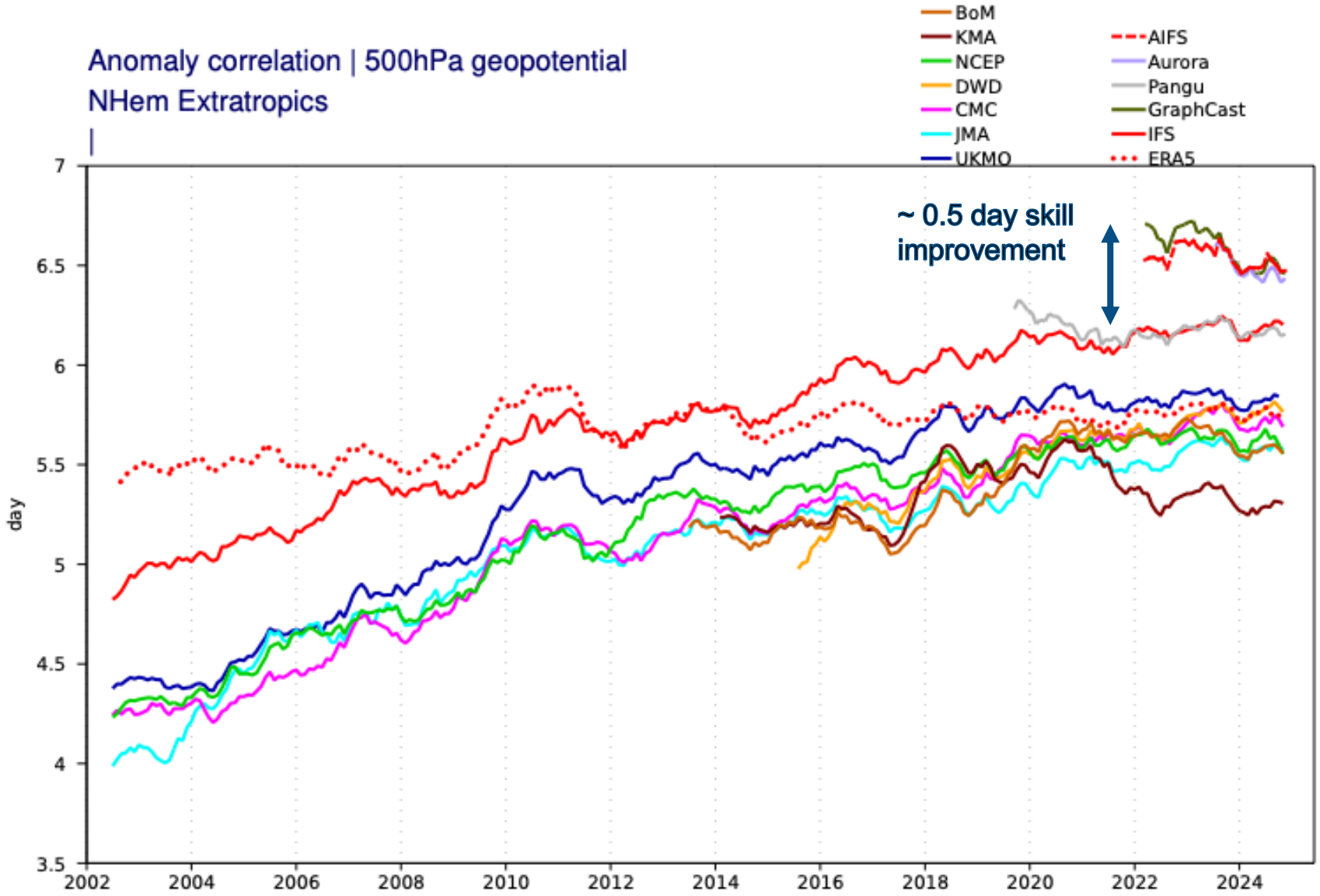
Number of satellite instruments processed and used operationnally at ECMWF

60 million quality-controlled observations absorbed every day by our physics-based **Integrated Forecasting System (IFS).** Around 40,000,000 are satellite observations!

These observations constrain the meteorology, the land surface, the ocean, and atmospheric composition.



And comes AI/ML…



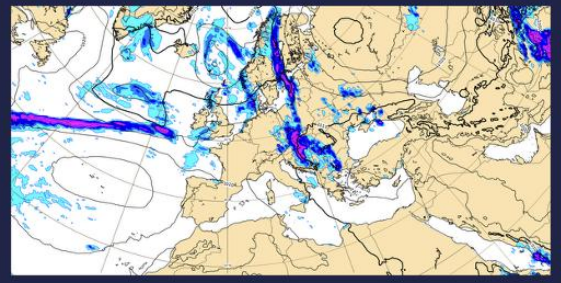
The skill of the best AI/ML systems outperforms physics-based systems particularly for forecasting weather patterns at large scales.

Caveats:

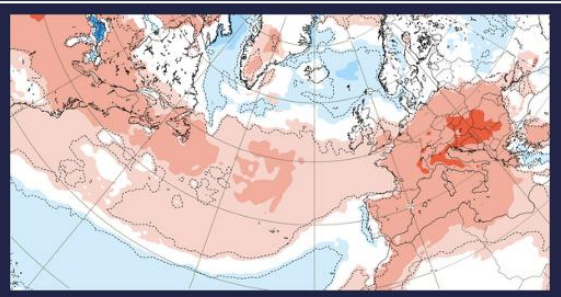
- not all the variables (yet) covered
- generally less well-performing for smaller scale features (best way forward is probably “hybrid”)
- yet requires a reanalysis for training

Beyond the weather forecasts

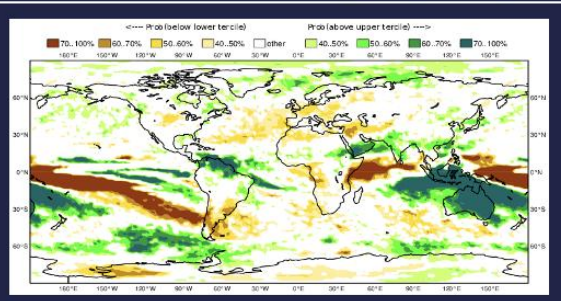
Medium range: up to 2 weeks



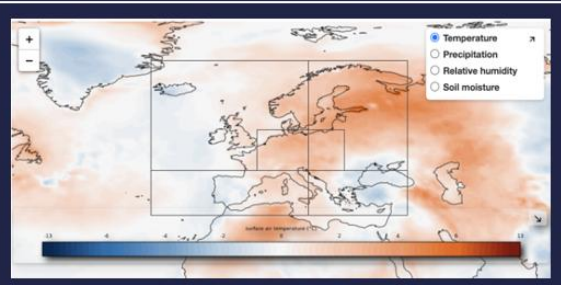
Sub-seasonal range: up to 6 weeks



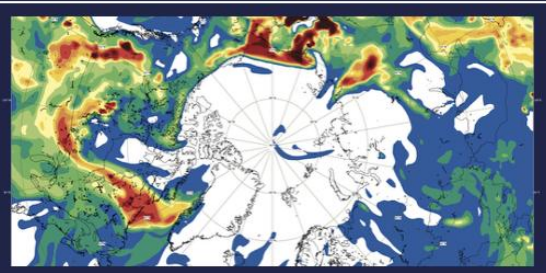
Seasonal range: up to a year



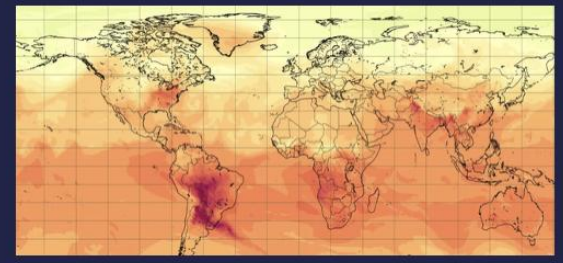
Climate monitoring



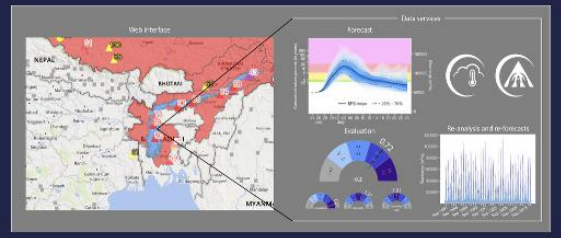
Air quality forecasts



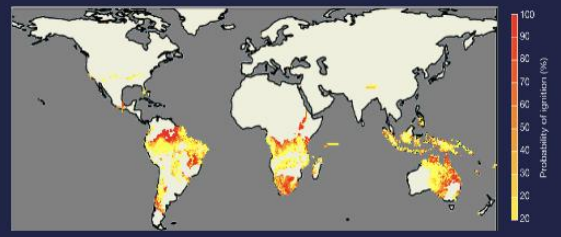
Greenhouse gas forecasts



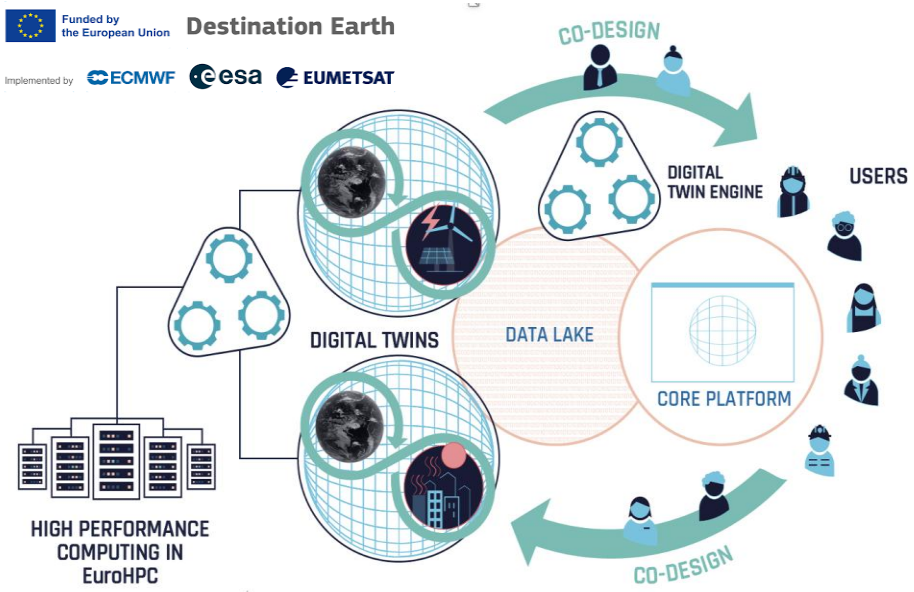
Hydrological forecasts



Wildfires: probability of ignition by lightning



- **Since 1990**s, ECMWF has been involved in EU Reseach and Innovation programmes
- **Since 2014**, ECMWF implements the Copernicus Atmosphere Monitoring Service (CAMS) and the Copernicus Climate Change Service (C3S) as Entrusted Entity of the EC / DG DEFIS, and is contractor for the Copernicus Emergency Management Service (CEMS)
- **Since 2021**, ECMWF implements Destination Earth together with ESA and Eumetsat as Entrusted Entities of the EC / DG CNECT
- **Since 2025**, ECMWF also works with ESA and Eumetsat on a project of the EC / DG INTPA on Space for Early Warnings in Africa (SEWA)



Copernicus Atmosphere Monitoring Service

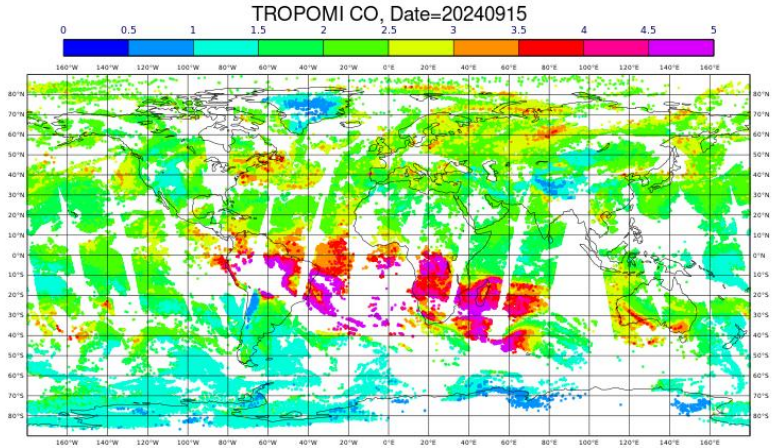
11 years of CAMS operations @ECMWF

https://atmosphere.copernicus.eu/9th-cams-general-assembly-copernicus

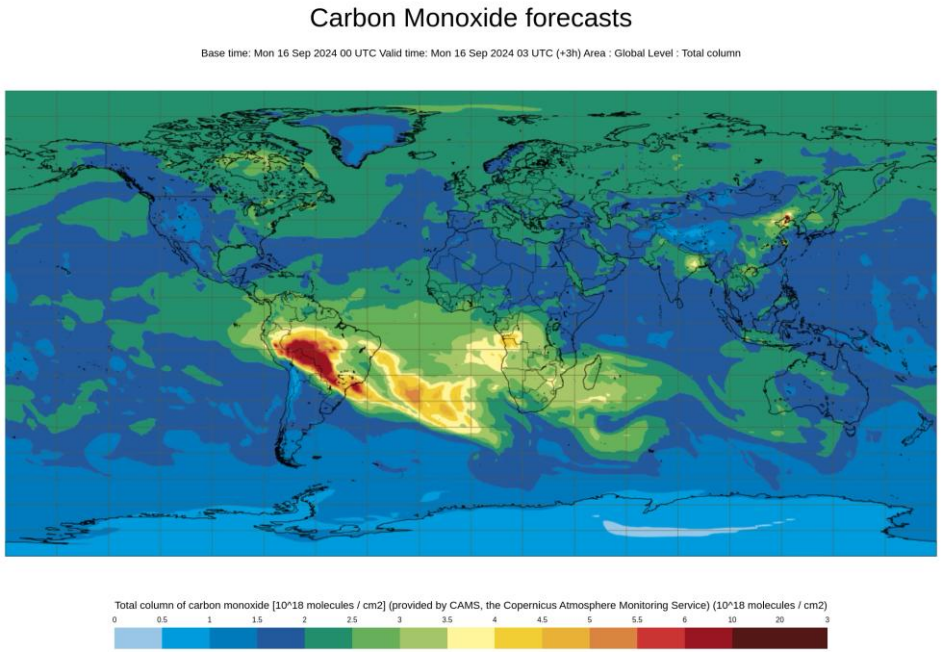
CAMS is the effort of ECMWF and about 200 contractors/partners around Europe. The 2025 General Assembly had more than **400 participants** with 250 attendees in person.

CAMS global: IFS-Compo

40 km resolution
5day AC and NWP forecast at 0 and 12 UTC



Satellite observations



Medium-range forecast

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

Yesterday's forecast is adjusted by today's observations to produce the outlook for tomorrow. Every day.

AC observations used in global NRT CAMS system

Species	Instruments
CAMS NRT	
O_3	**S5P, GOME-2, OMI, OMPS-NP, MLS, OMPS-LP, GEMS, TEMPO**
CO	**S5P, IASI, MOPITT**
NO_2	**S5P, GOME-2, GEMS, TEMPO**
Aerosol	**MODIS, VIIRS, PMAp, S3**
CO_2	**GOSAT, IASI, OCO-2**
CH_4	**GOSAT, IASI, S5P**
SO_2 (volcanic)	**S5P, GOME-2, IASI**
SO_2 (anthropogenic)	**S5P**
HCHO	**S5P, GEMS, TEMPO**
GFAS fire emissions	**MODIS, VIIRS, GOES, S3**

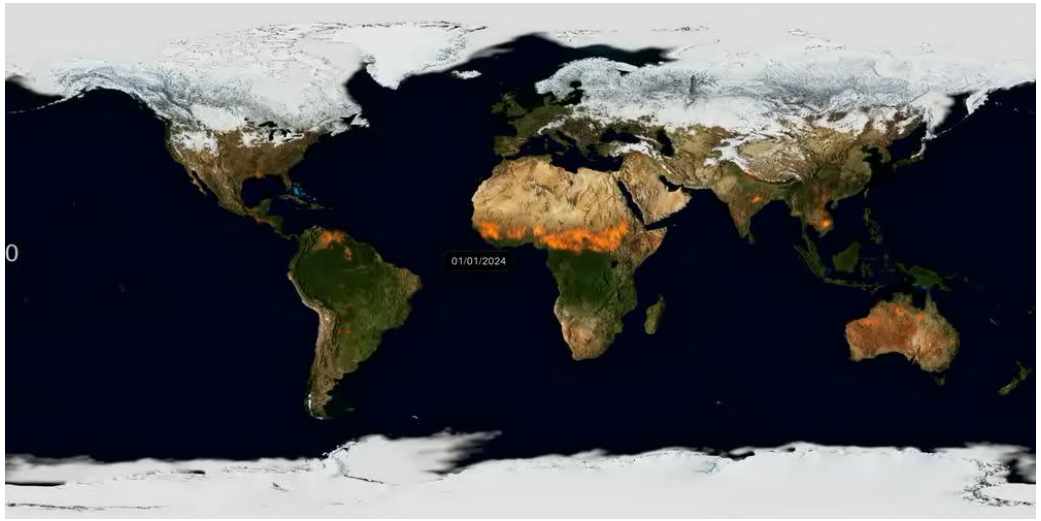
CAMS uses Earth Observation data from many satellites for atmospheric composition and weather (total ~100).

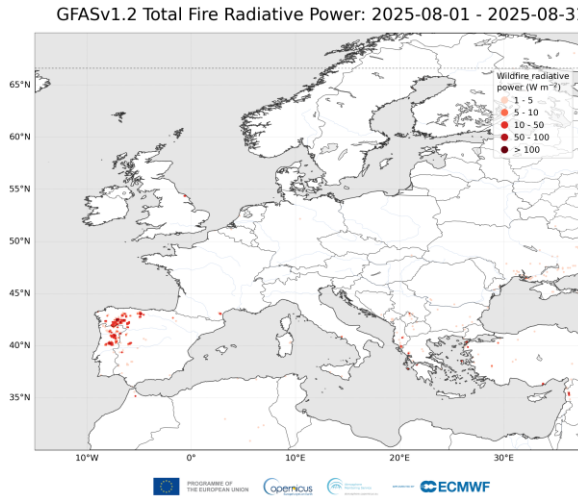
---- Used in operations
---- Undergoing testing
---- Retired since Feb 2025

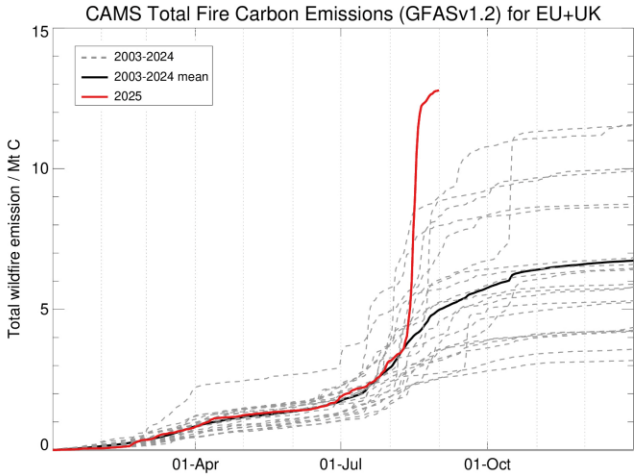
Launch MTG-S1
on 01/07/2025
(Copernicus Sentinel-4)

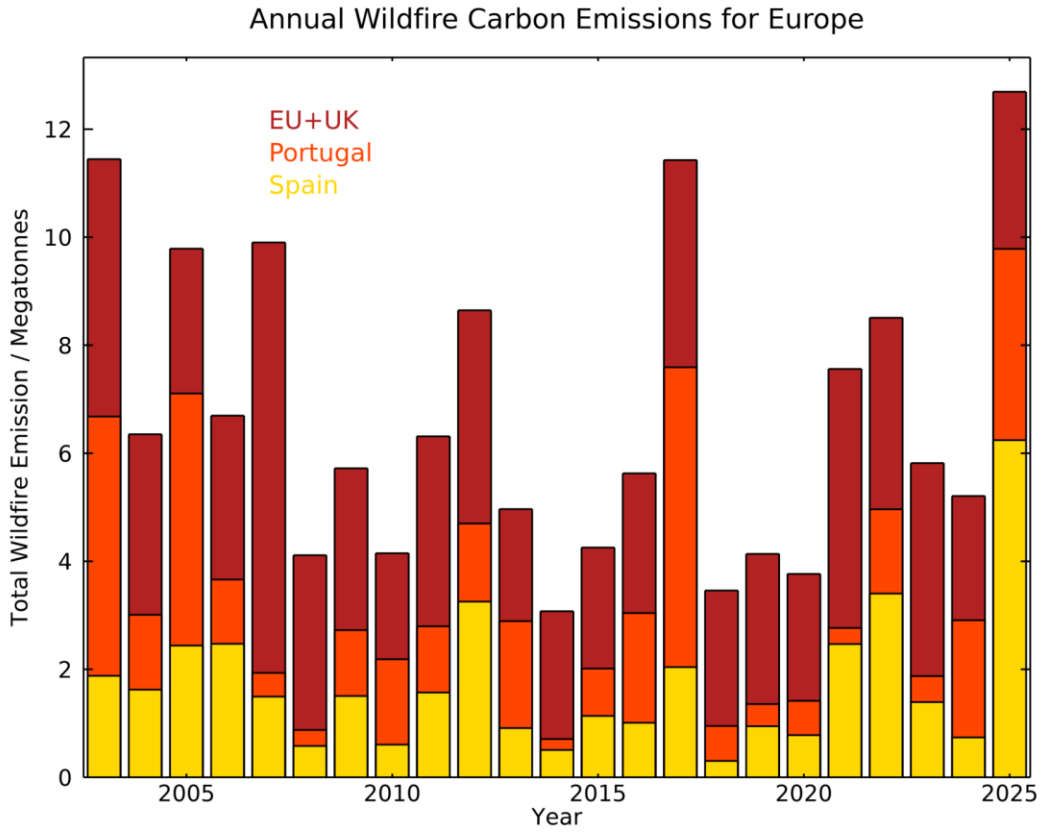
Launch MetOp-SG1
on 12/08/2025
(Copernicus Sentinel-5)

Wildfires monitoring and their impacts on emissions and air pollution

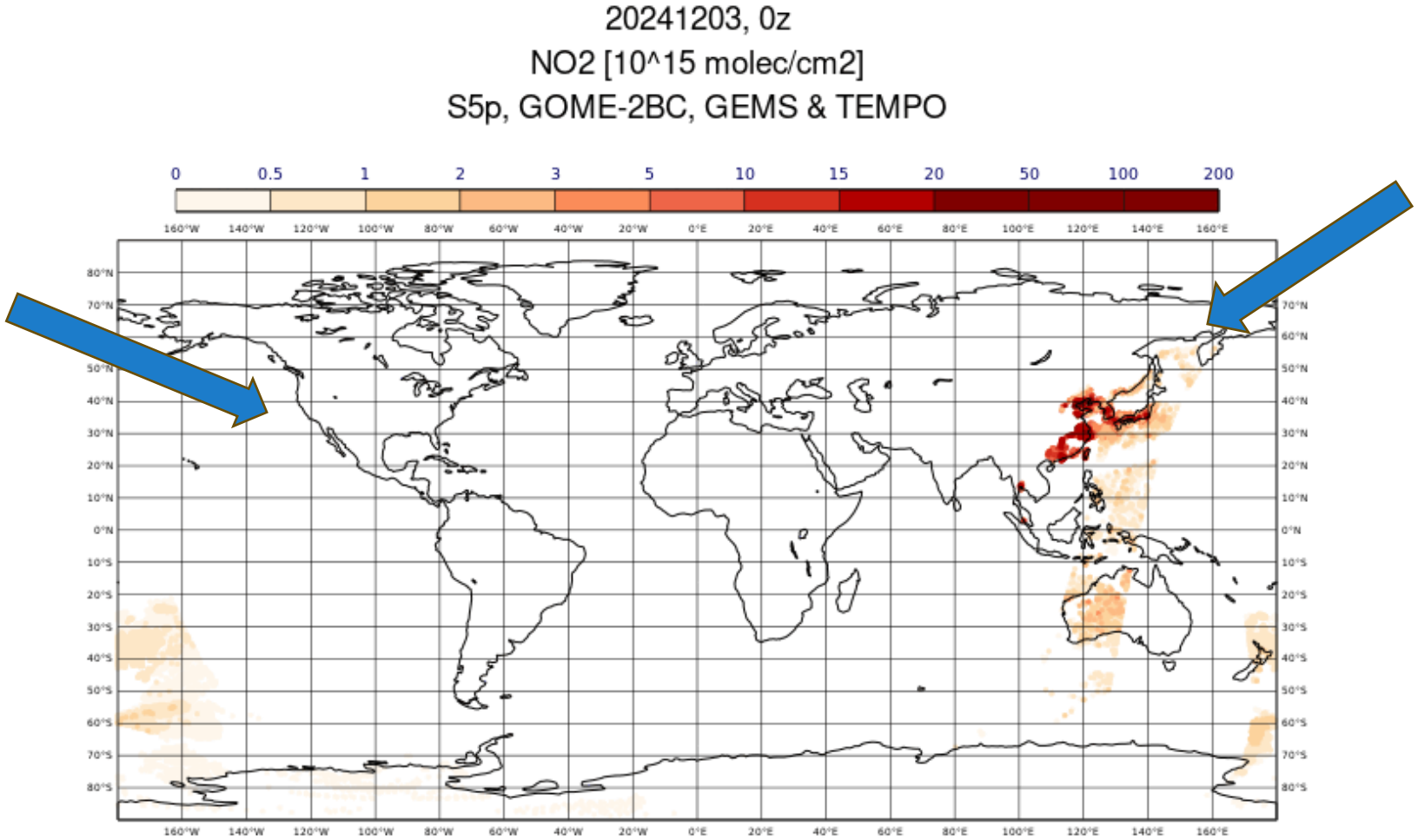








Animation of hourly NO_2 retrievals 20241203



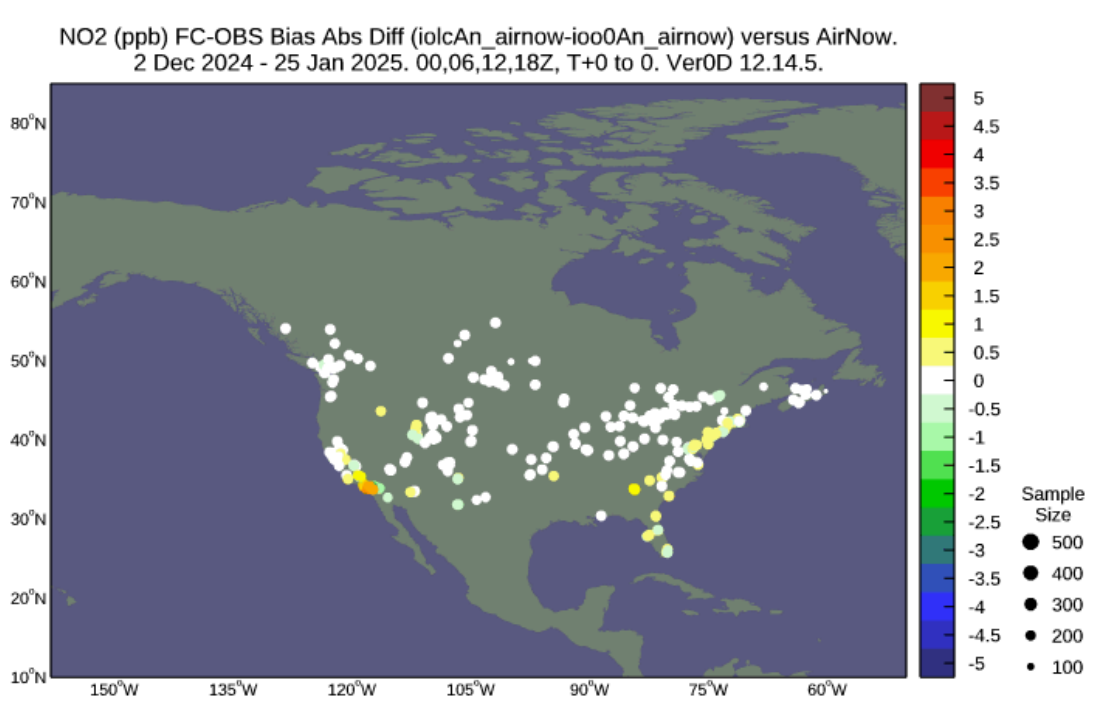
TEMPO
Hourly during daytime

GEMS
Hourly during daytime

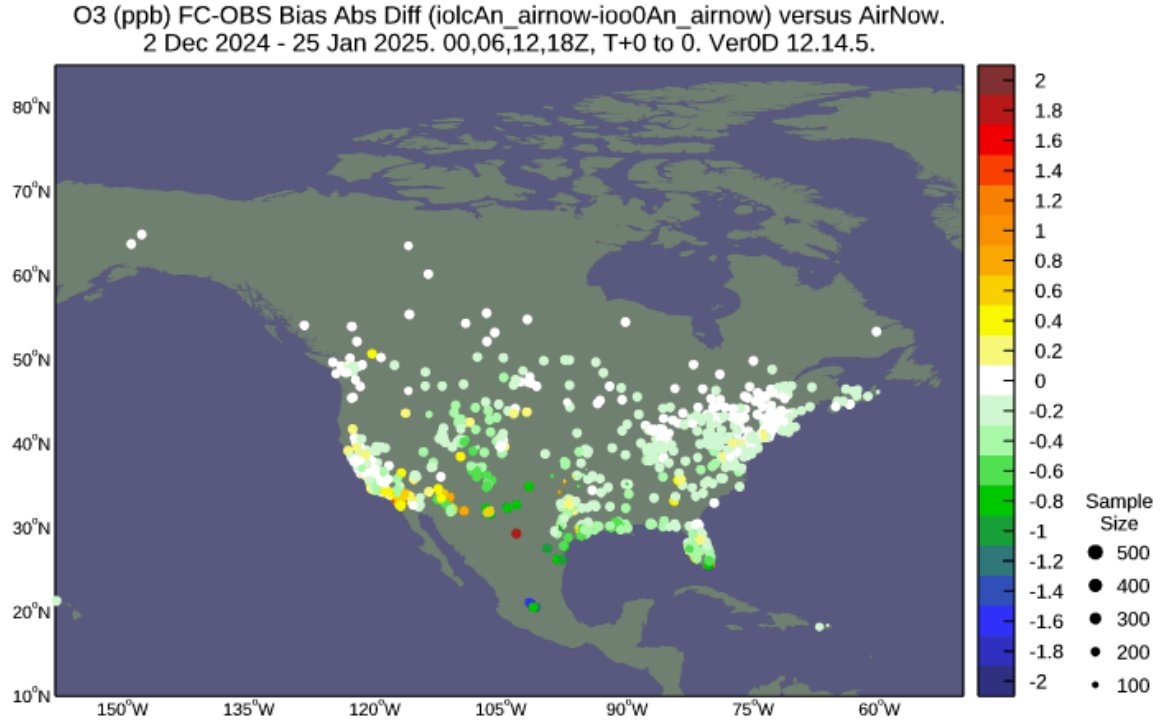
S5p & GOME-2BC polar orbits

NO_2 and OZONE DIFFERENCES (NO_2 ASSIM - CTRL)

ABS BIAS NO_2 (ASSIM – CTRL)



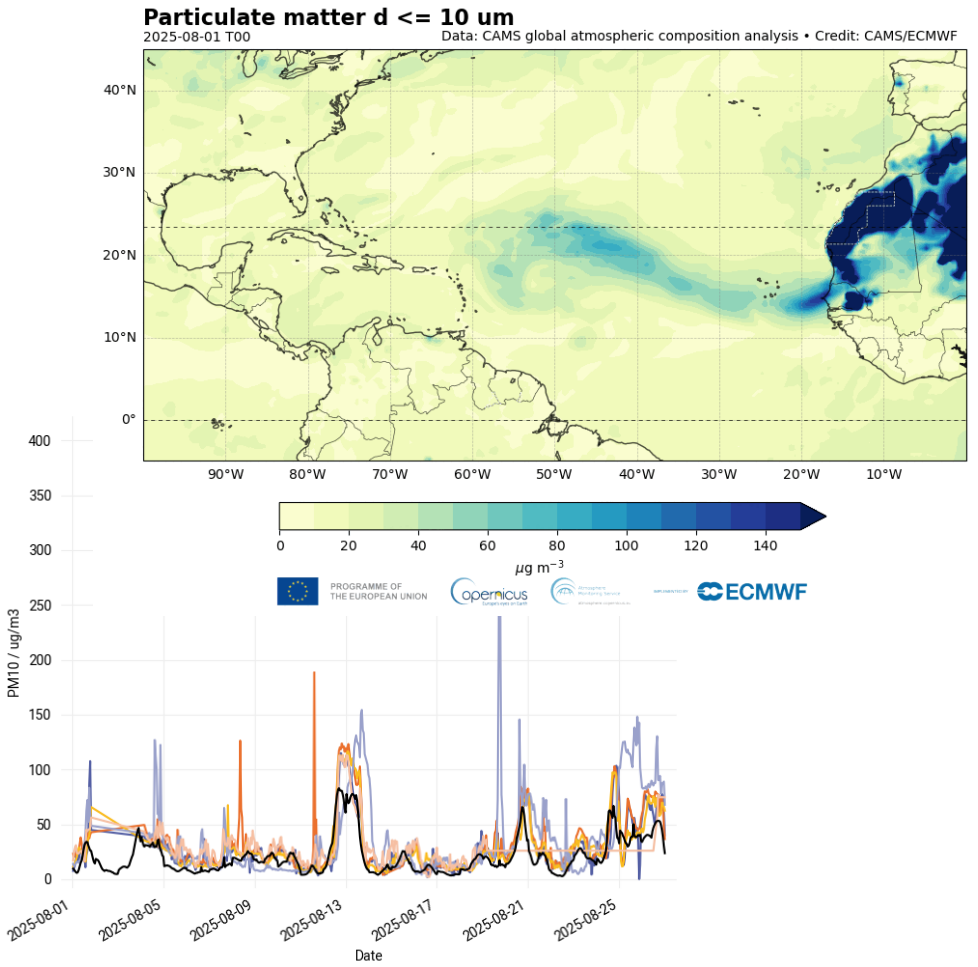
ABS BIAS O_3 (ASSIM – CTRL)



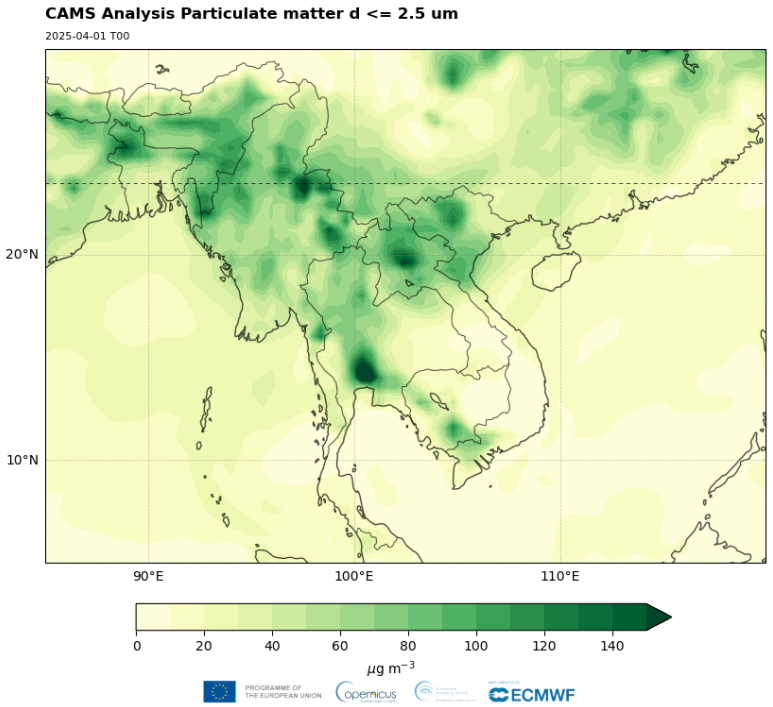
- Comparison with Airnow surface NO_2 and O_3 observations
- Small reduction in O_3 MNMB and RMSE when assimilating TEMPO **NO_2**, especially in central and eastern US

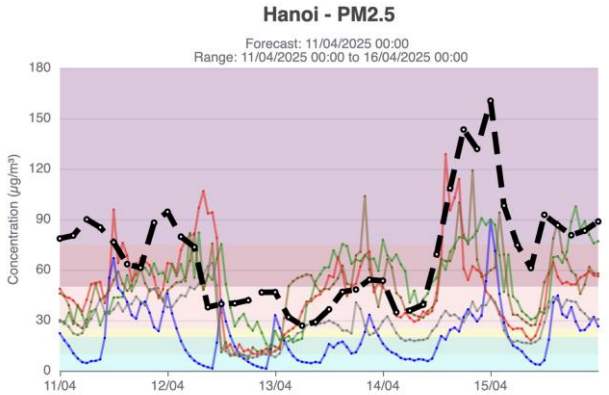
Forecasting air pollution events

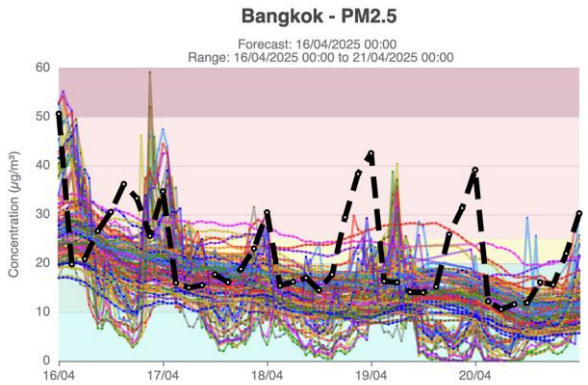
Saharan dust intrusions monitored in Europe and long-range transport across the Atlantic Ocean + impact on PM concentrations



CAMS o-suite versus Gwadair observations







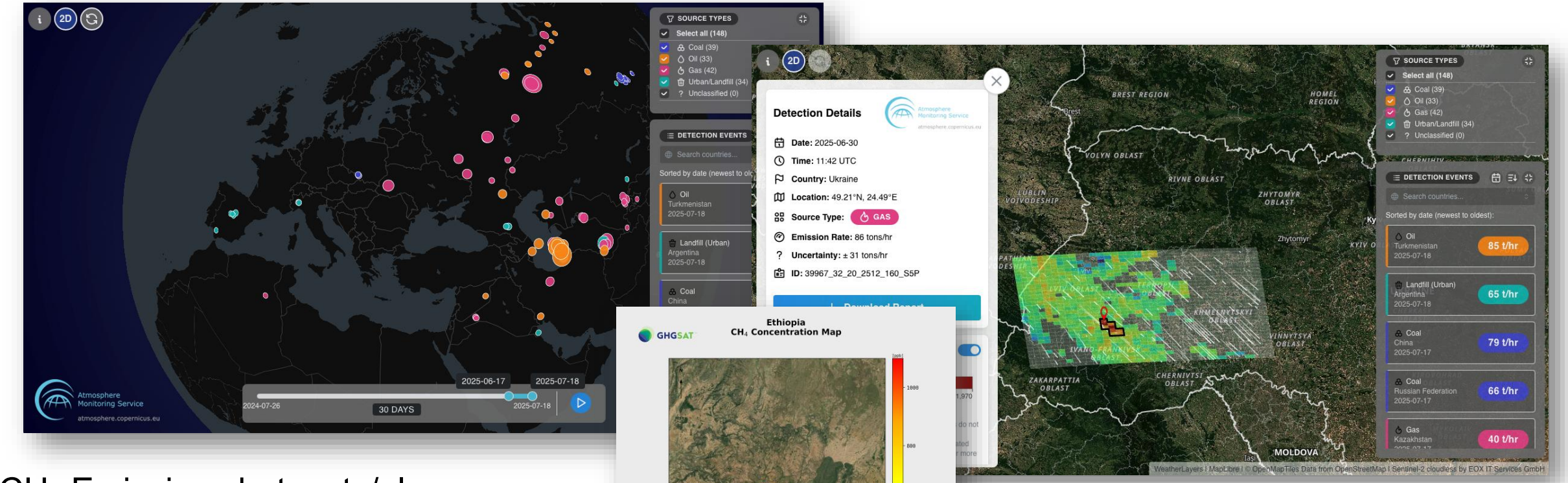
PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

Atmosphere Monitoring Service atmosphere.copernicus.eu

IMPLEMENTED BY ECMWF

CAMS Methane Hotspot Explorer

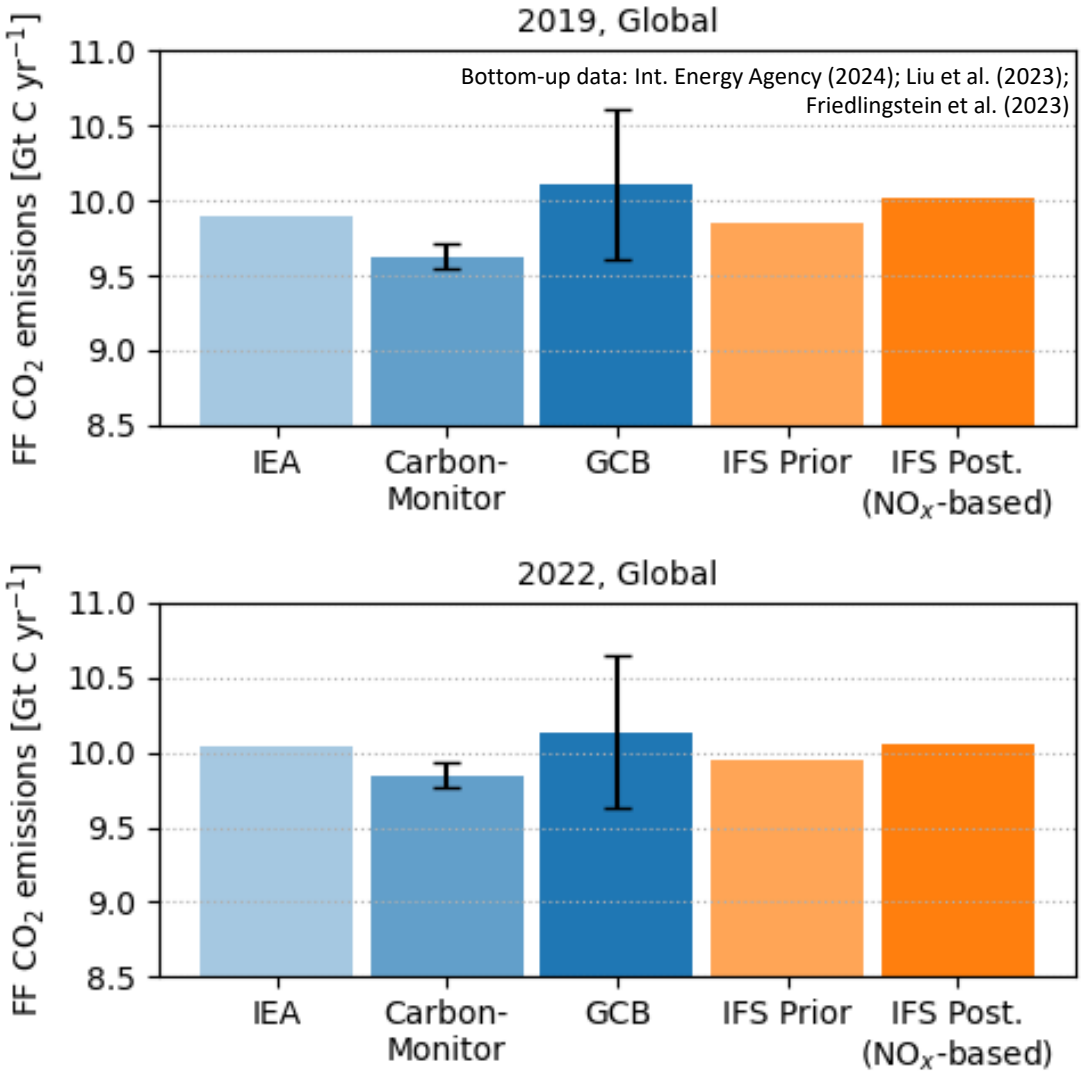


CH_4 Emissions hotspots/plumes detection using Sentine-5P observations. Now also working with companies with high-resolution capabilities.

GHGSAT, Mount Fentale, January 2025

Access the Apps here

CAMS Emissions inversions

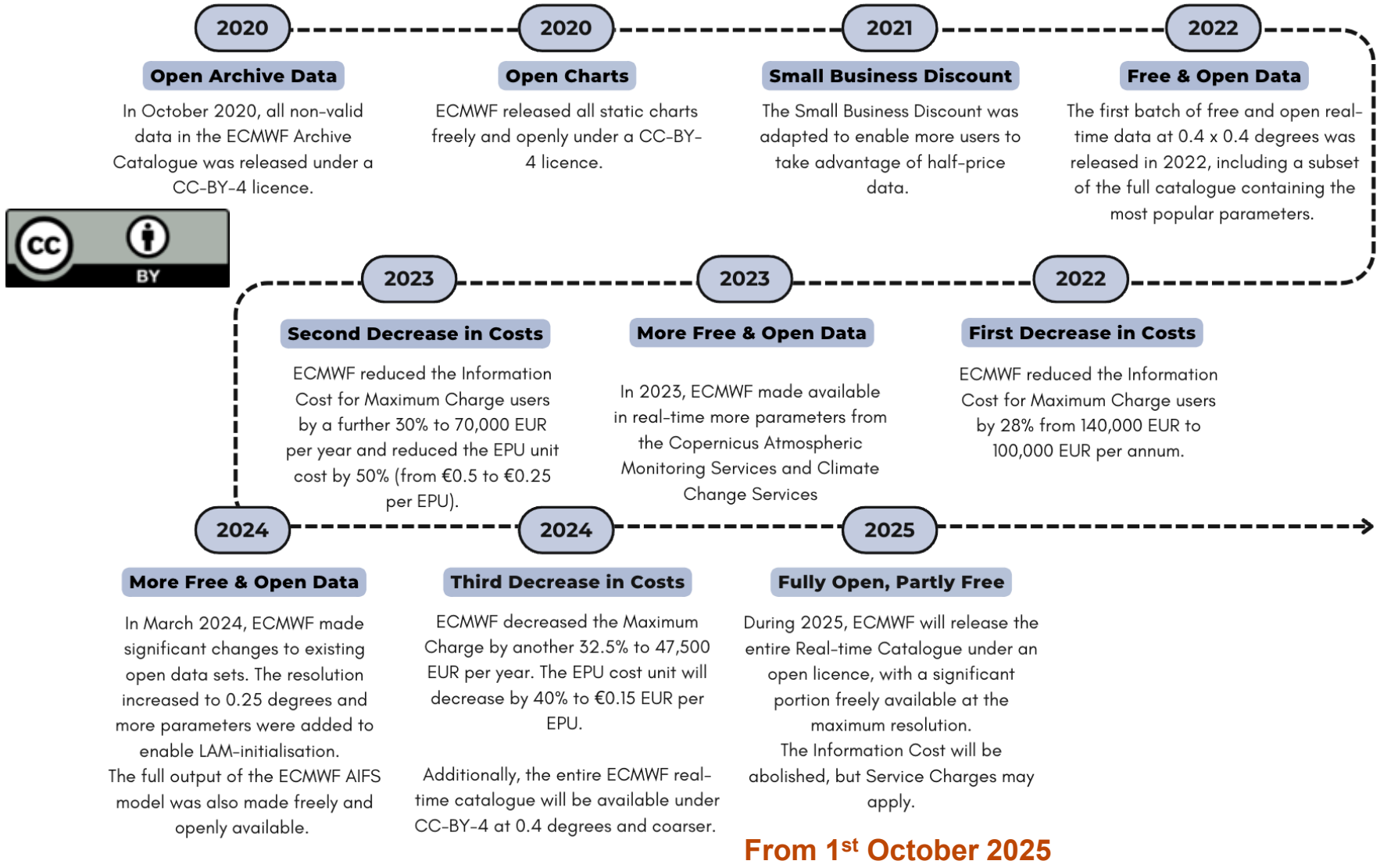


CAMS is developing a CO2MVS (Monitoring and Verification Support Capacity) for the European Commission. It is built around the CAMS global data assimilation and forecasting system.

CO_2 emission estimation capabilities are being tested with Sentinel-5p NO_2 observations through the use of emission ratios. The system is particularly designed to work with CO2M satellites, which will be launched in 2027 (2) and 2028 (1).

Access to ECMWF open NWP and Copernicus data

The road to open data



Open Data portal – free and open dataset

- Data from IFS and AIFS models in GRIB format
- **0.25 degrees** resolution (higher resolution coming soon)
- **Subset** of most popular parameters

Copernicus data generated by ECMWF available

- On the Climate Data store (CDS)
- On the Atmosphere Data Store (ADS)

A few take-away messages

- Space-based observations are absolutely critical to allow accurate forecasts and provide advanced weather, air pollution and extreme events warnings systems:
  - Global overview to develop reliable and accurate NWP and atmospheric composition forecasting systems
  - Less exposed to extreme conditions than in-situ networks

- European satellite constellations are unparalleled, with different space-based sensors providing complementary multi-spectral real-time observations of the atmosphere.

- Investment in observing systems, but also in advanced (AI) utilisation systems is critical for further improving forecasting capacities, but also air pollutants and GHG emissions retrievals.

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Thank you