Training event on Atmospheric Composition Data Exploitation

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
Italiadomani

Atmospheric models:

The case of Copernicus Atmosphere Monitoring Service (CAMS)

Training event on Atmospheric composition data exploitation, 29 January 2025

Mark Parrington (mark.parrington@ecmwf.int)

Atmosphere Monitoring

@mparrington.bsky.social
@copernicusecmwf.bsky.social

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COPERNICUS ATMOSPHERE MONITORING SERVICE

CAMS is one of six thematic information services provided by the Copernicus Earth Observation Programme of the European Union.

Implemented (and C3S) by ECMWF on behalf of the European Commission

Fire danger and flood forecasts provided to CEMS

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WHAT IS THE SCOPE OF CAMS?

CAMS provides **consistent and quality-controlled** information related to air pollution and health, solar energy, greenhouse gases and climate forcing, everywhere in the world.

Air quality

Policy tools

Solar energy

Ozone layer and UV radiation

Emissions and surface Fluxes

Climate forcing

http://atmosphere.copernicus.eu

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CAMS PORTFOLIO

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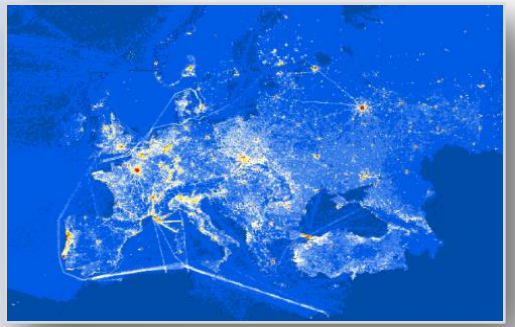

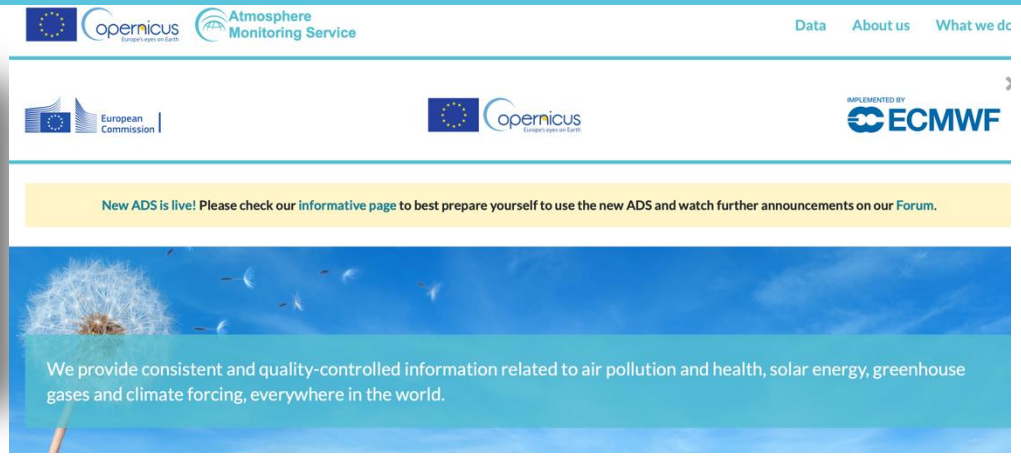

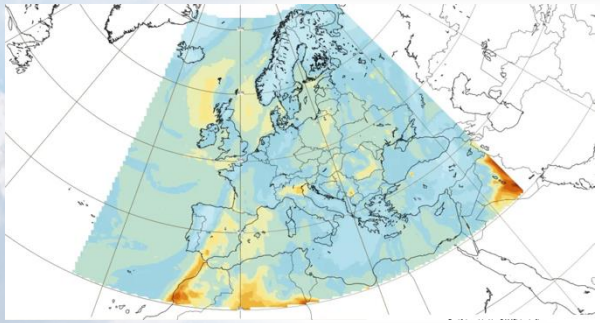

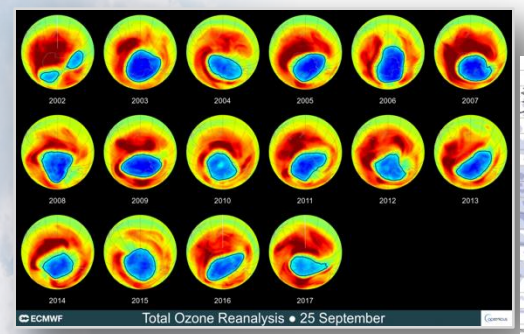

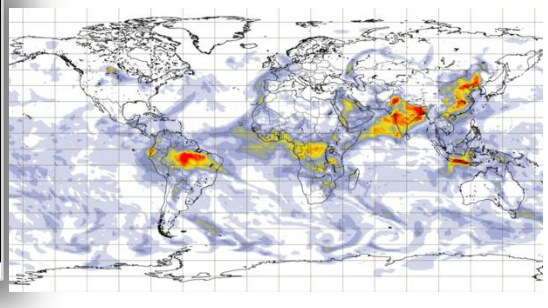

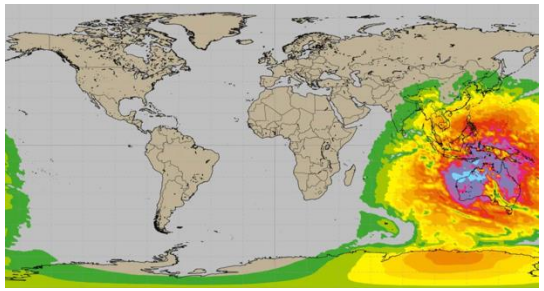

- CAMS provides open & free information products based on Earth Observations about:
  - past, current and near-future (forecasts) global and regional atmospheric composition;
  - European air quality;
  - Ozone layer monitoring;
  - emissions and surface fluxes of key pollutants and greenhouse gases;
  - solar radiation;
  - climate radiative forcing.

http://atmosphere.copernicus.eu
http://ads.atmosphere.copernicus.eu

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Global and Regional CAMS systems

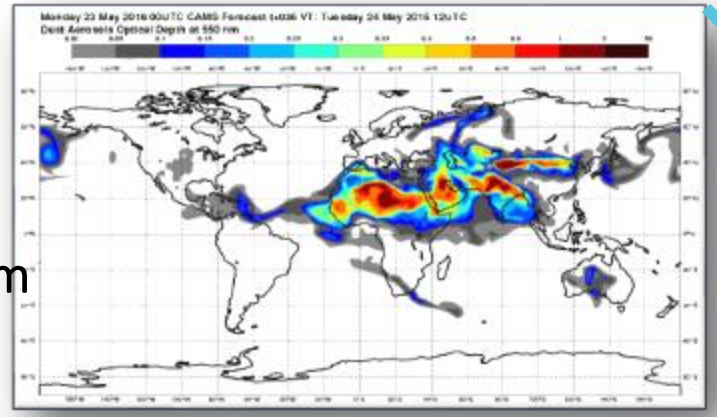
Atmosphere Monitoring

Global CAMS Emissions

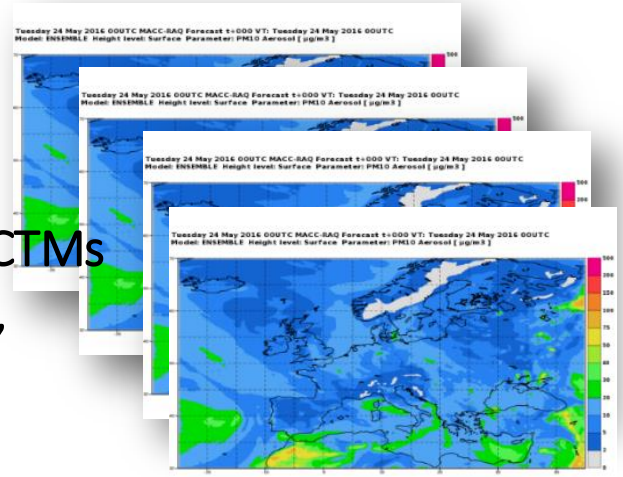
GFAS wildfire emissions

European CAMS Emissions

ECMWF IFS global, 40x40 km

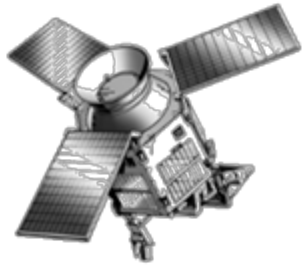


Boundary Conditions



11 regional CTMs over Europe, 10x10 km

Data assimilation



Satellite Observations (AOD, O_3, CO, NO_2, SO_2)

Surface AQ observations

Data assimilation

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CAMS EUROPEAN AIR QUALITY PORTFOLIO

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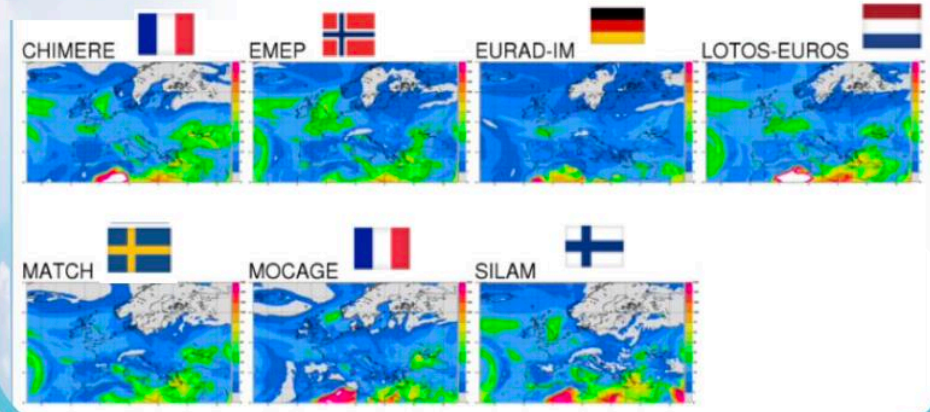
Based on a multi-model approach (same boundary conditions, same emissions, same meteo, assimilation of 1000+ surface observations for key species)

Individual operational AQ models



DEHM (AARHUS University)

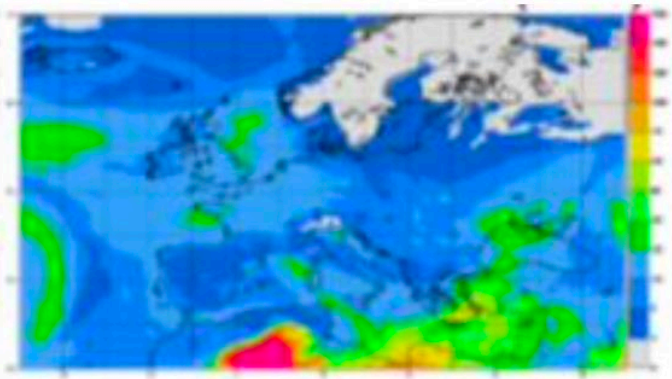
GEM-AQ (IEP)

MINNI (ENEA)

MONARCH (BSC)

Operational AQ ensemble

(incl. spread/uncertainty)



- Once daily D+4 forecasts
- Regulatory pollutants and pollens
- Annual reanalyses
- ~ 10km resolution

http://regional.atmosphere.copernicus.eu

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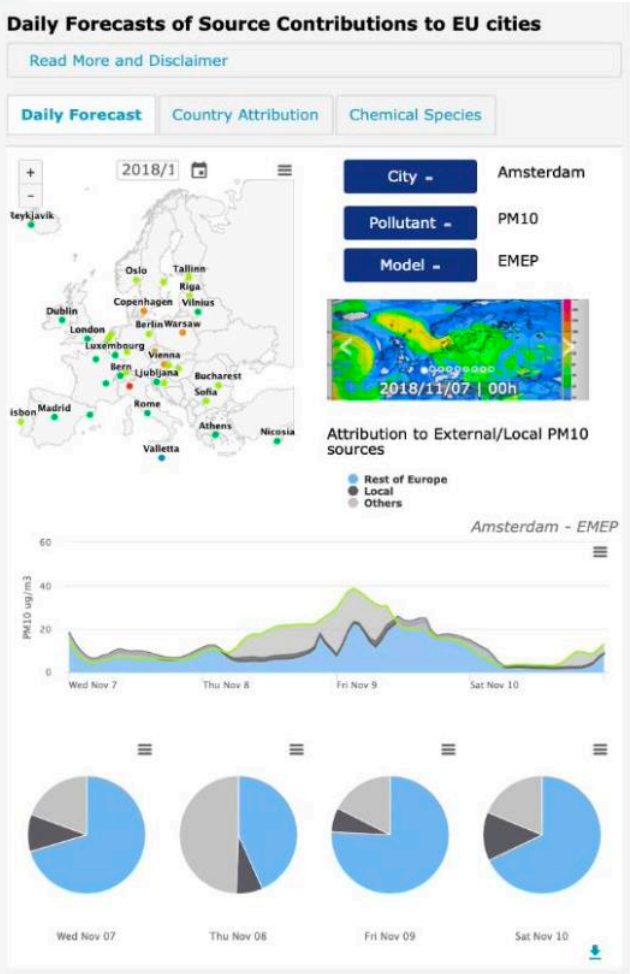
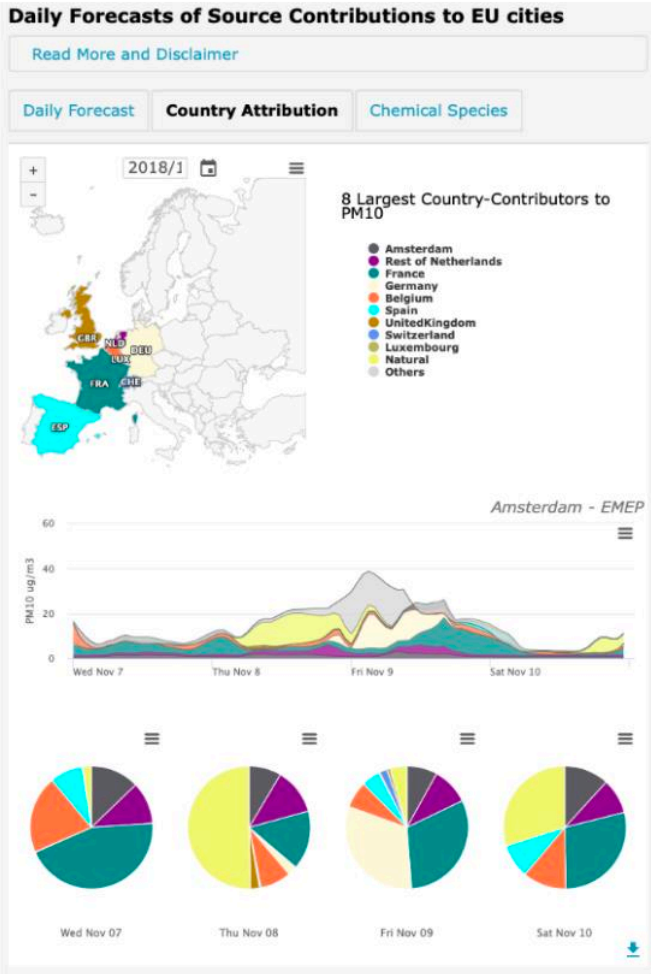
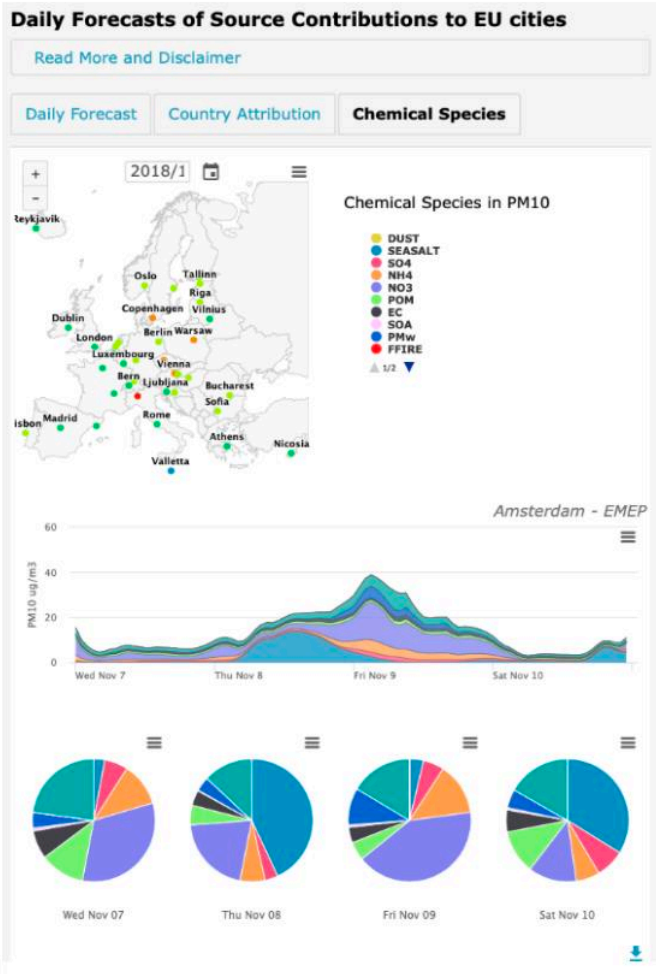
PRODUCTS IN SUPPORT OF POLICY USERS

Experimental: local vs imported, geographical origin, chemical speciation







http://policy.atmosphere.copernicus.eu/DailySourceAllocation.html

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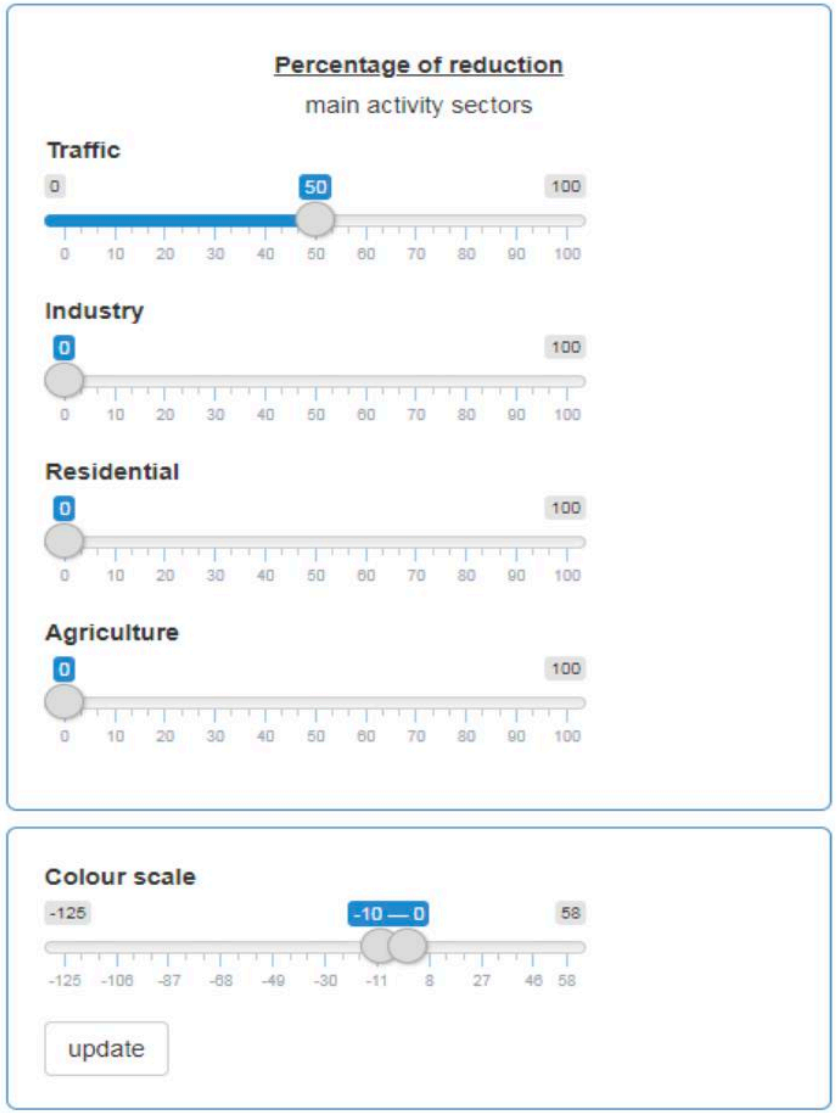
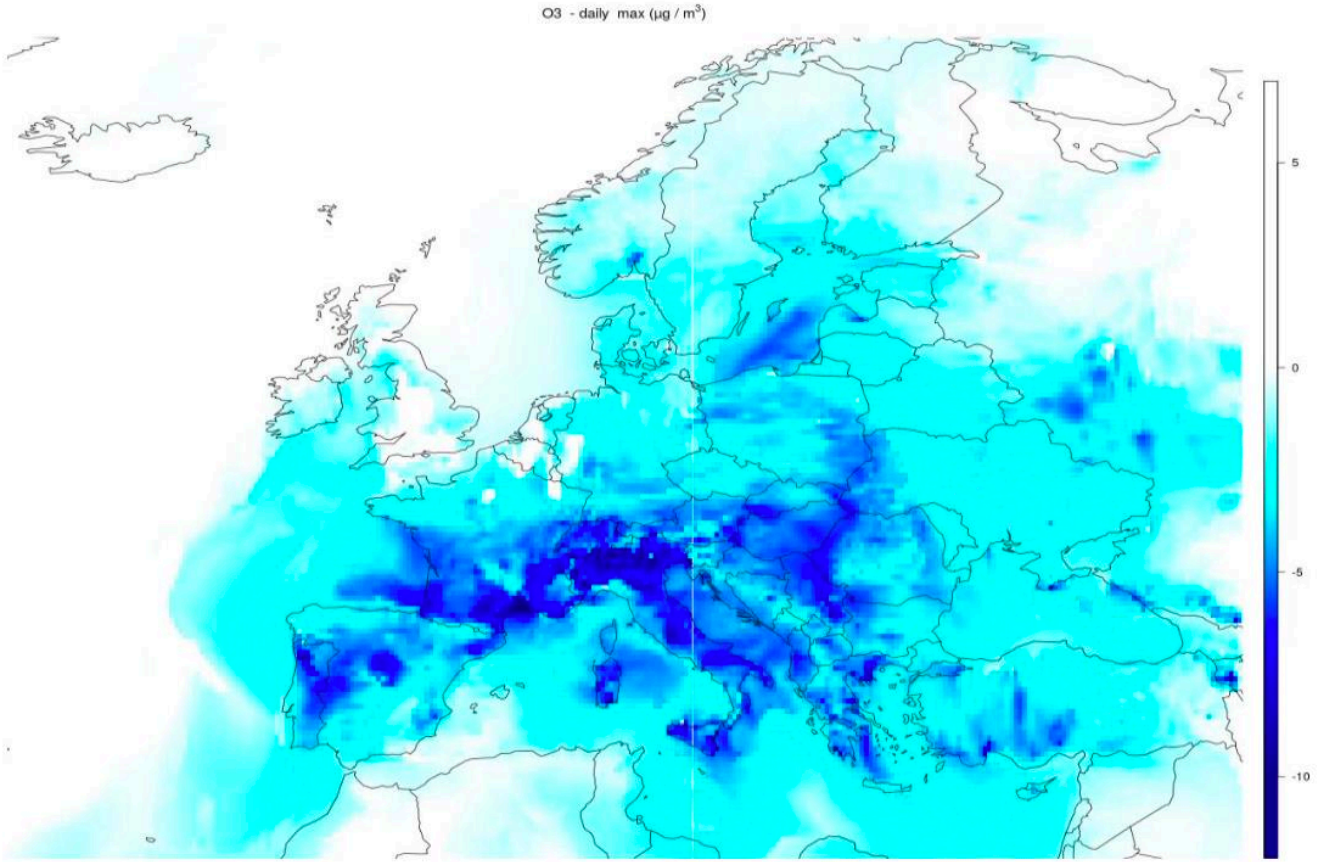
PRODUCTS IN SUPPORT OF POLICY USERS

Atmosphere Monitoring

Assess the effect of emission reductions on daily forecasts



CAMS_ACT : O3, PM10 (PM2.5 coming)



http://policy.atmosphere.copernicus.eu/CAMS_ACT.html

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Earth Observation in CAMS

Atmosphere Monitoring

Species	Instruments
CAMS NRT	
O_3	S5P, GOME-2, OMI, OMPS-NP, MLS, OMPS-LP, GEMS
CO	S5P, IASI, MOPITT
NO_2	S5P, GOME-2, GEMS
Aerosol	MODIS, VIIRS, PMAp, S3
CO_2	GOSAT, IASI, OCO-2
CH_4	GOSAT, IASI, S5P
SO_2 (volcanic)	S5P, GOME-2, IASI
SO2 (anthropogenic)	S5P
HCHO	S5P
GFAS fire emissions	MODIS, VIIRS, GOES, Himawari, S3

CAMS uses Earth Observation data from many satellites for atmospheric composition and weather.

---- Used

---- Undergoing testing

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Exciting times ahead

Atmosphere Monitoring

MetOp-SG-A

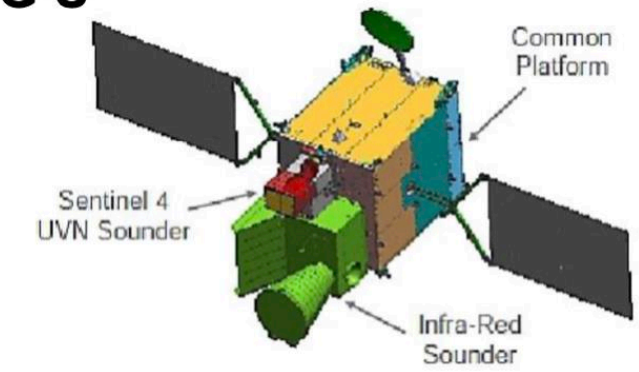
- IASI-NG
- 3MI
- Sentinel-5

Preparation activities using S5p data, gradually introduced in operational global forecasting system. Feedback from CAMS testing has led to significant improvements in data quality.

EUMETSAT

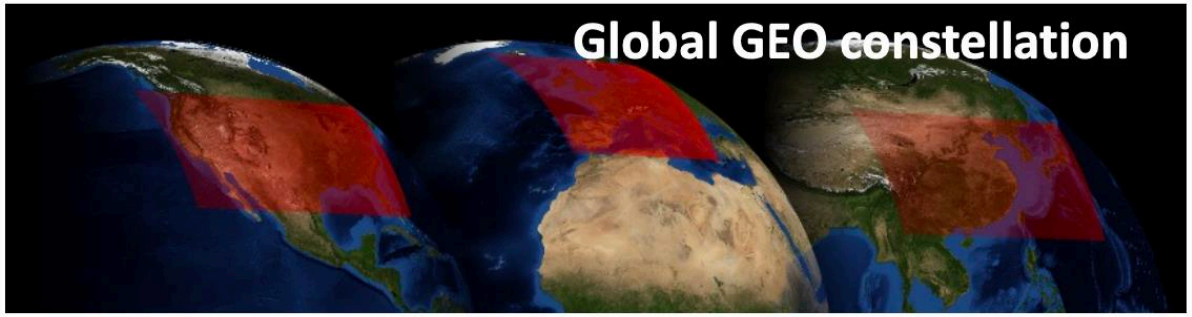
esa

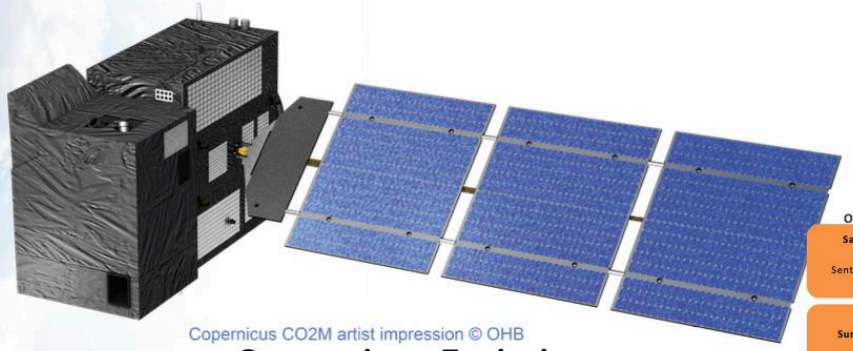
MTG-S



- IRS
- Sentinel-4

Initial studies for the use of Sentinel-4 observations in the regional forecasting models

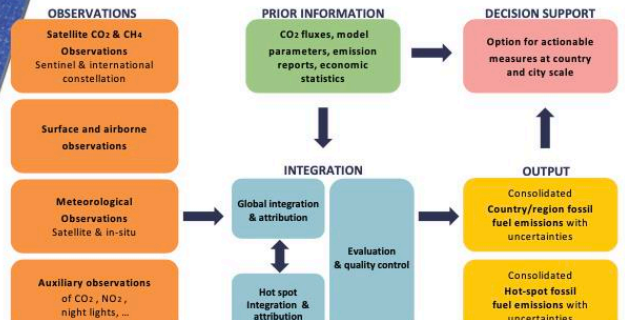




Copernicus CO2M artist impression © OHB

CO2M

Copernicus Emission Monitoring & Verification Support Service



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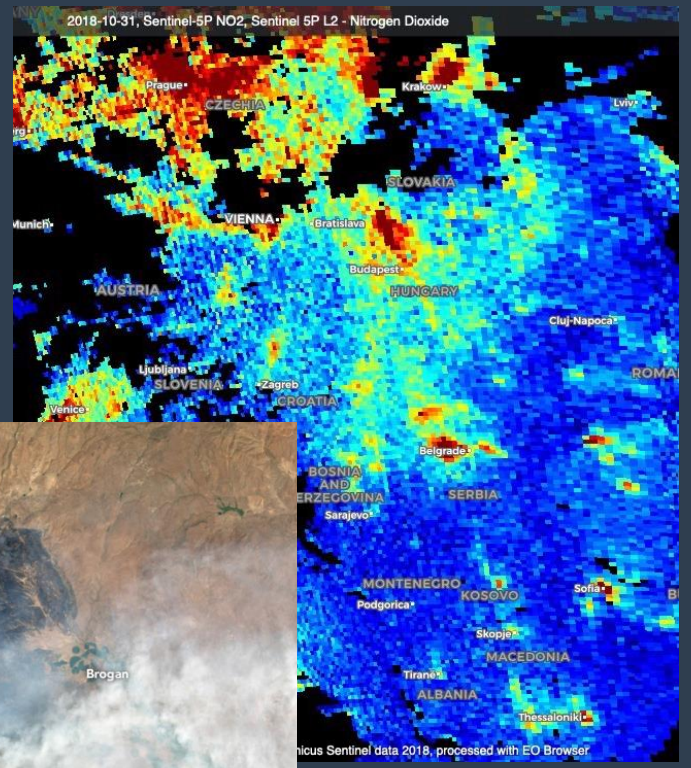
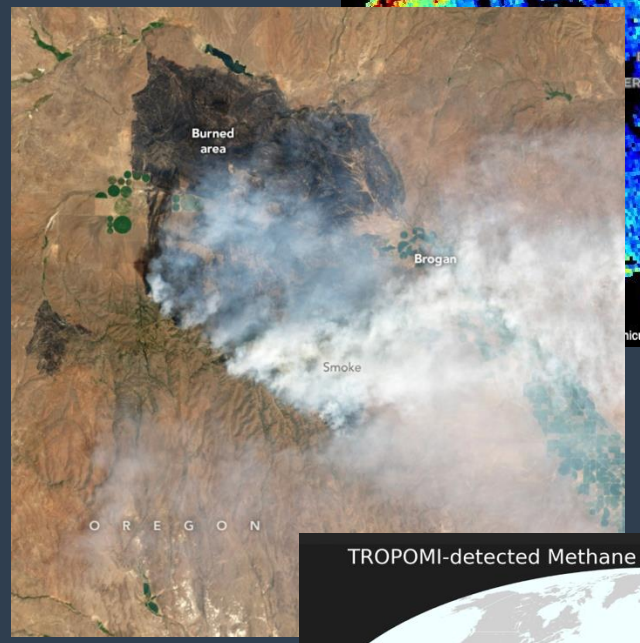
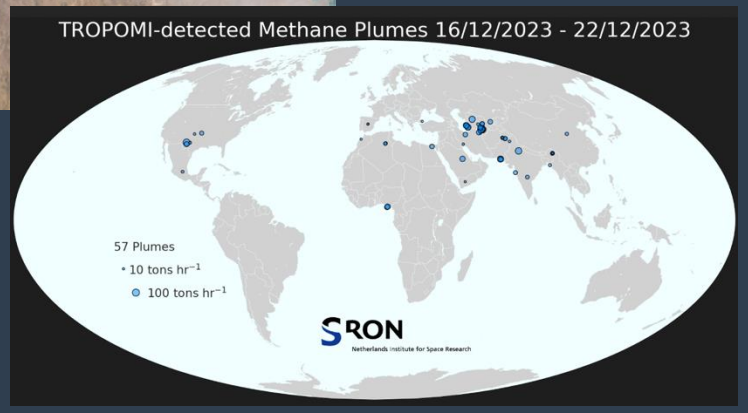
Sattelite observations : a game changer ?

- To monitor areas that are not well covered by in-situ networks
- To monitor exceptional emission events and long-range patterns : dust plumes, wildfires, volcanoes eruptions
- To support emission reporting checking or detection of emissions sources (inverse modelling approaches)
- BUT :
  - Sattelites monitor columns or half-columns,
  - Need calibration processes to retrieve data
  - Revisit the same area “only” periodically,
  - Do not see anything in cloudly conditions
- Availability of geostationnary sattelites monitoring atmospheric composition likely to be the most promising development to complement in-situ networks : TEMPO (US), GEMS(Korea), Sentinel 4 (Europe - 2025)





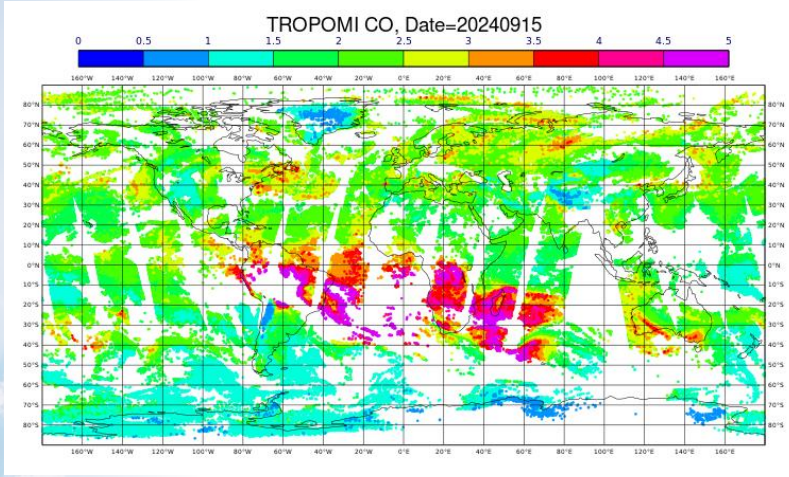


ECMWF

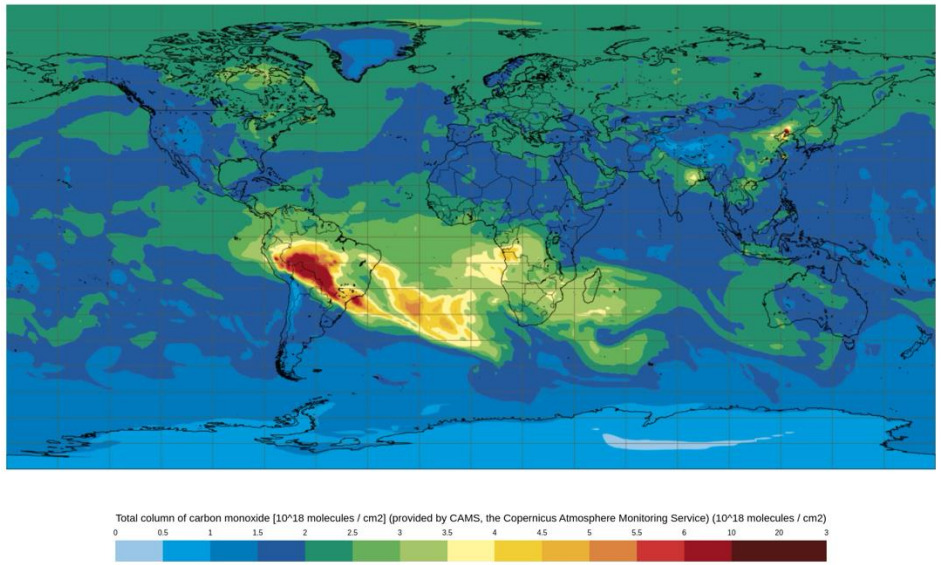
CAMS Global Forecasts – CO as example

Atmosphere Monitoring

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



Carbon Monoxide forecasts



Medium-range forecast

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

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

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Assimilation of O3 data in global model

Atmosphere Monitoring

Antje Inness 2024 lecture

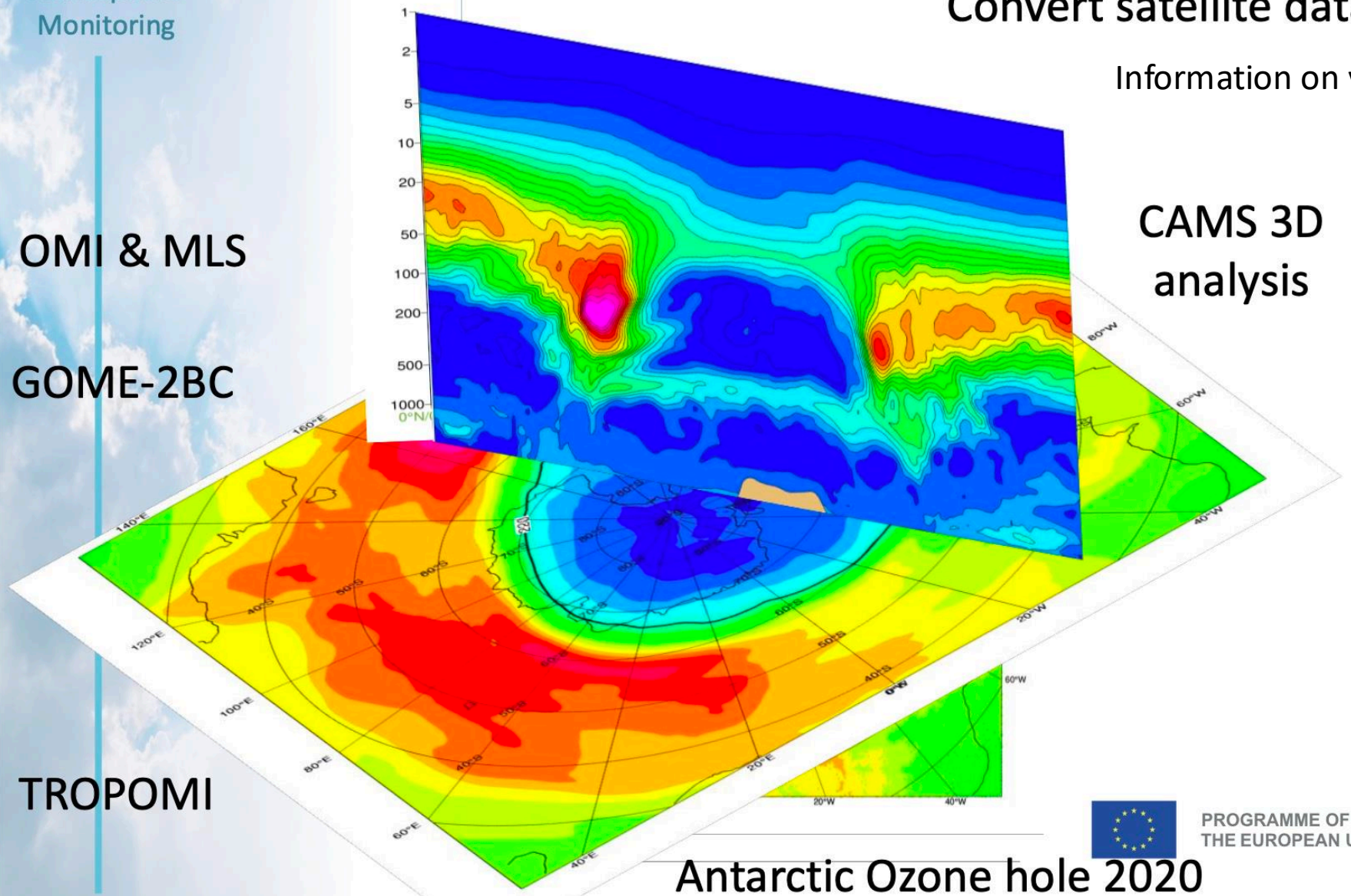
Convert satellite data into maps without gaps

Information on vertical distribution

OMI & MLS

GOME-2BC

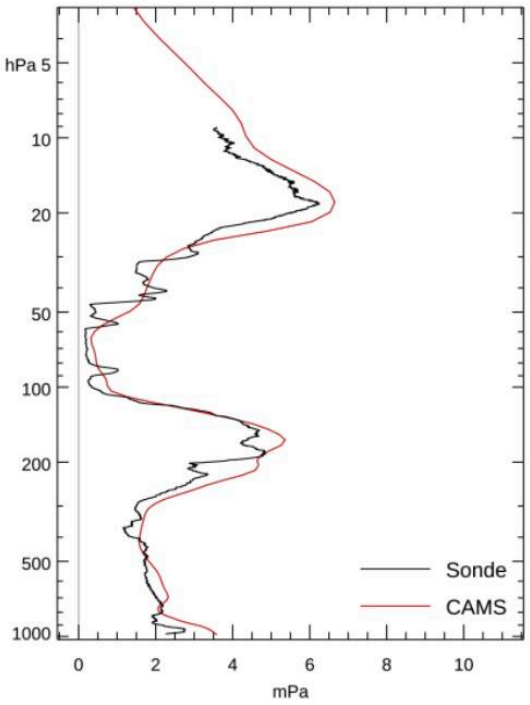
TROPOMI



CAMS 3D analysis

Antarctic Ozone hole 2020

Comparison with independent data



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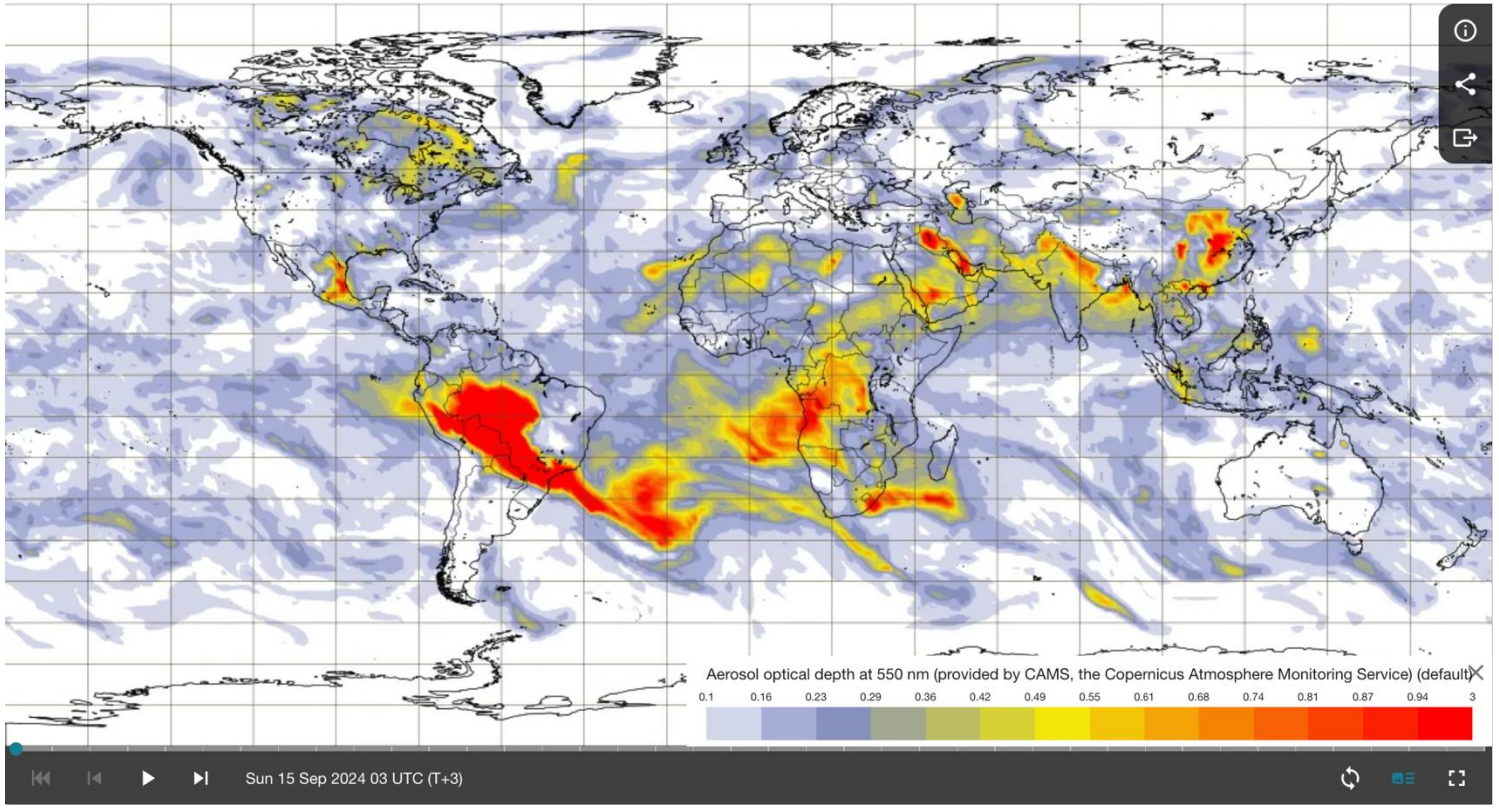
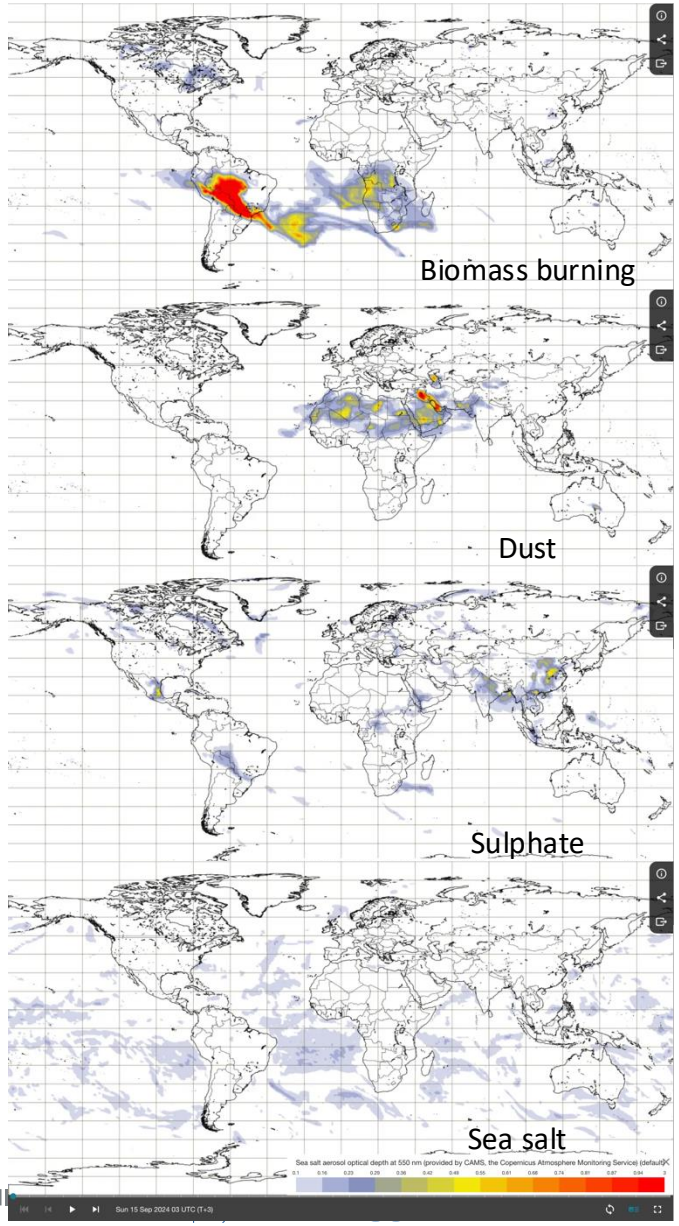
What do atmospheric data tell us? Aerosols

Atmosphere Monitoring

Total Aerosol Optical Depth at 550nm forecast initialized 15 Sept 00 UTC





What does the map tell us? Where is this aerosol coming from?

- Biomass burning (historic fires in the Amazon region, seasonal fires in tropical Africa)
- Mineral dust (dust belt extends from Sahara to east Asia)
- Sulphate aerosols (wildfires, volcanic activity, anthropogenic emissions)
- Sea salt (wind driven over the oceans)

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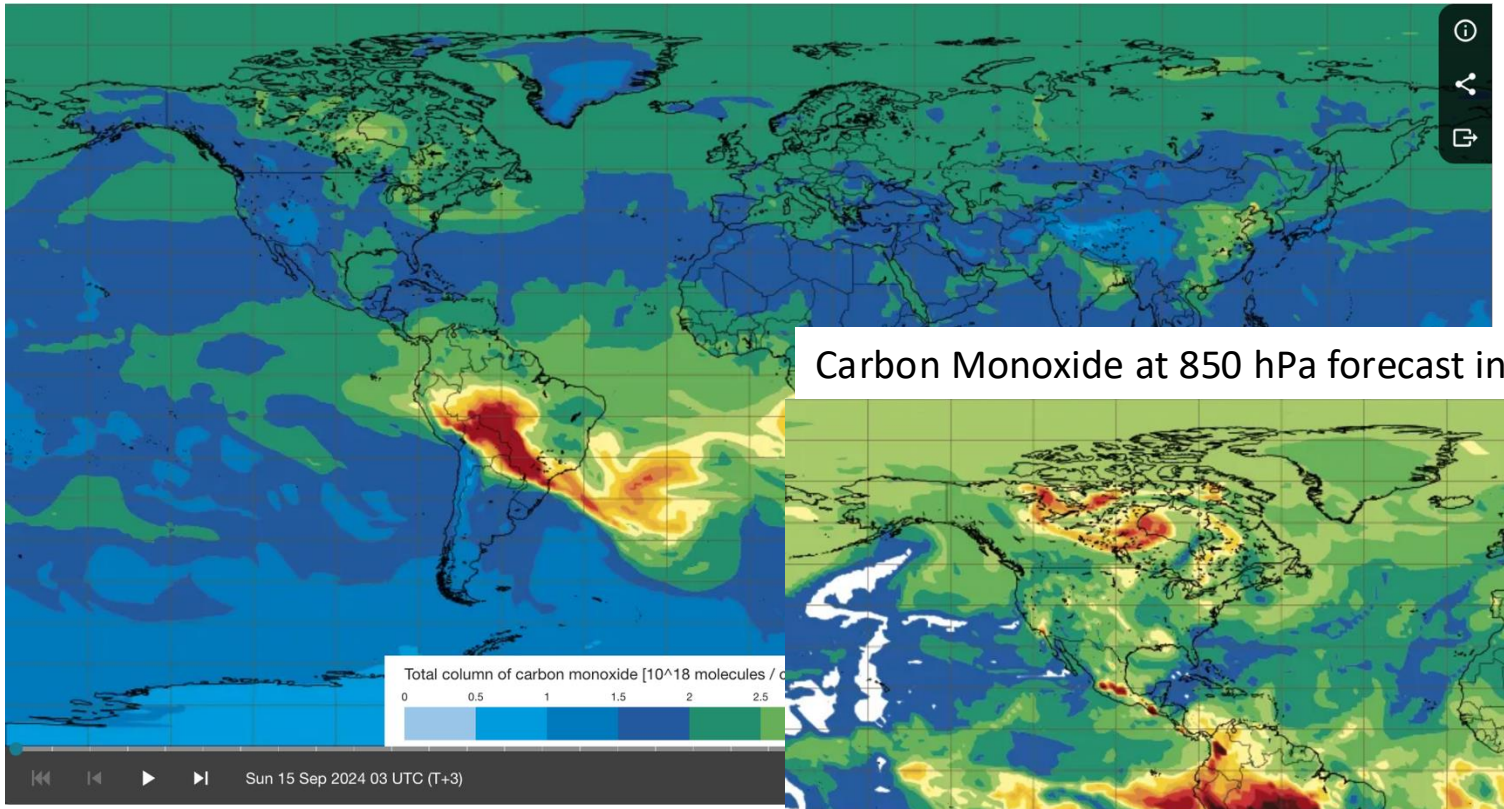
What do atmospheric composition data tell us? Carbon monoxide

Atmosphere Monitoring

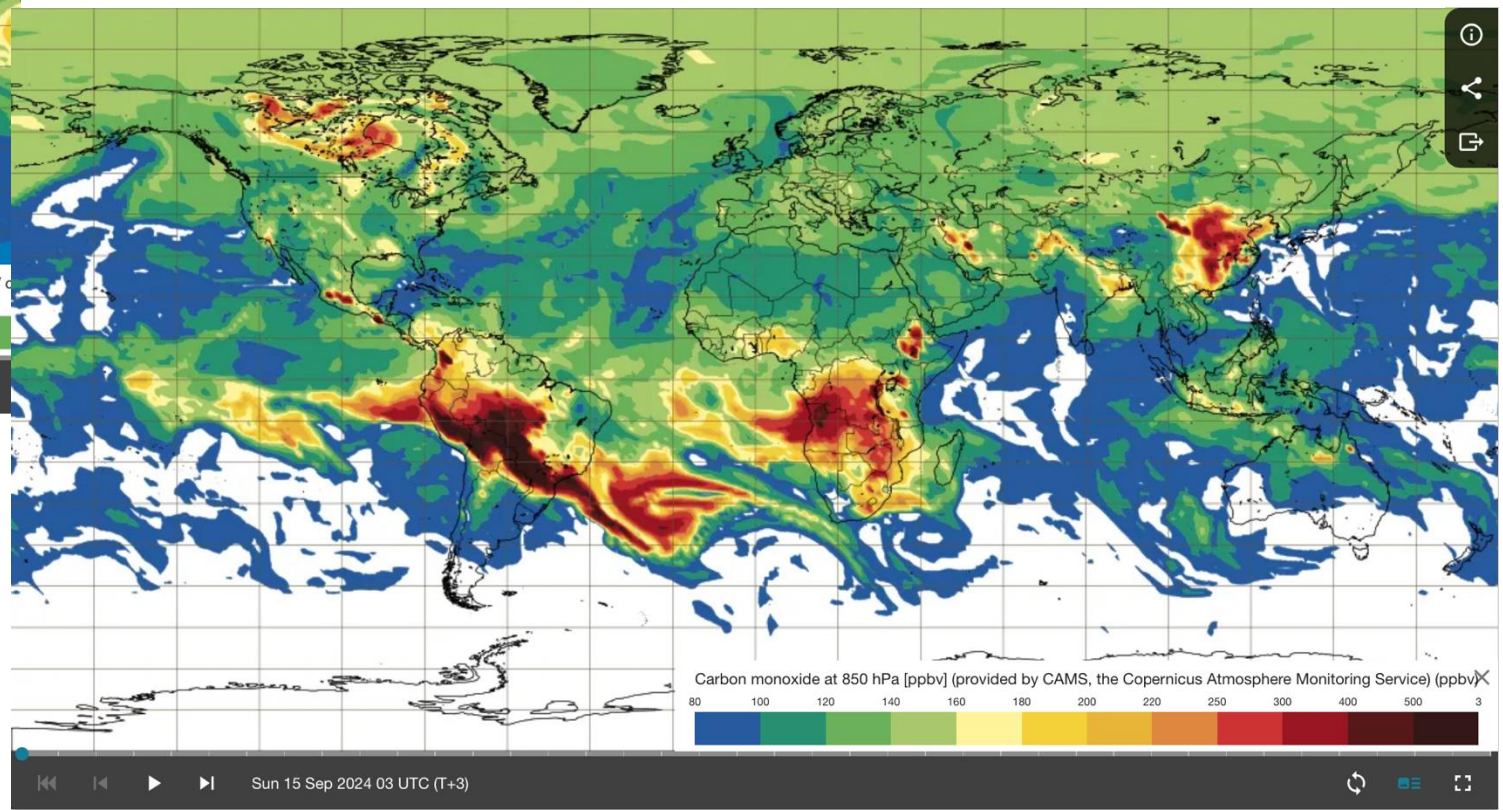
Total Column Carbon Monoxide forecast initialized 15 Sept 00 UTC



Carbon monoxide (CO) is a product of incomplete combustion and a good pollution tracer.

- Total column CO indicates most significant pollution sources (e.g., smoke from South America & tropical Africa).

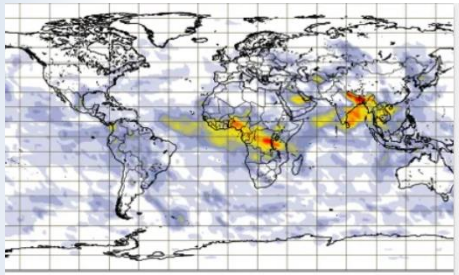
Carbon Monoxide at 850 hPa forecast initialized 15 Sept 00 UTC



However, CO concentration at different levels of the atmosphere highlights additional regions:

- North America (wildfires)
- E Asia (anthropogenic pollution)

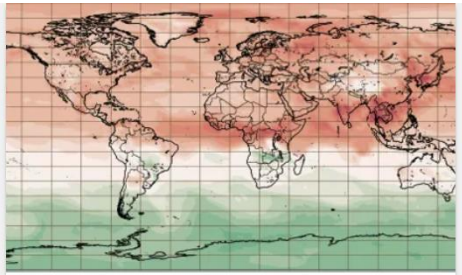
Atmosphere Monitoring



Latest CAMS forecast

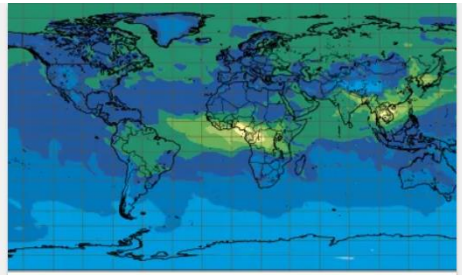
Aerosol forecasts

CAMS aerosol forecasts



Carbon Dioxide forecasts

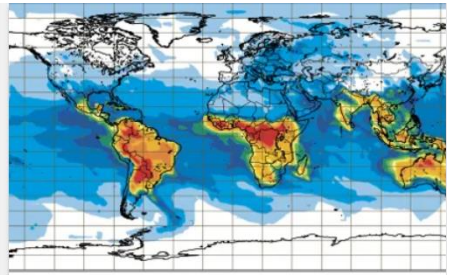
CAMS carbon dioxide forecasts



Latest CAMS forecast

Carbon Monoxide forecasts

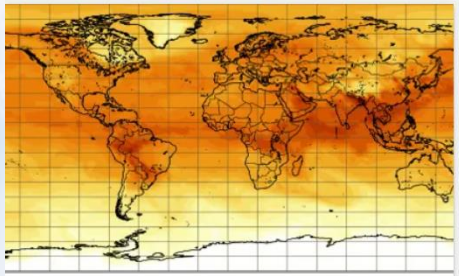
CAMS carbon monoxide forecasts



Latest CAMS forecast

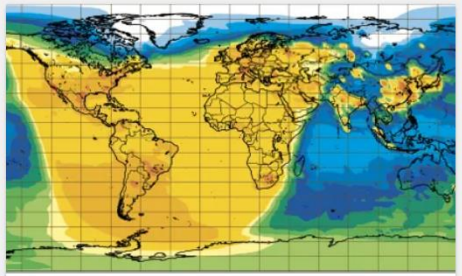
Formaldehyde forecasts

CAMS formaldehyde forecasts



Methane forecasts

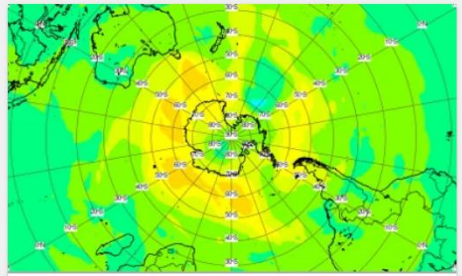
CAMS methane forecasts



Latest CAMS forecast

Nitrogen Dioxide forecasts

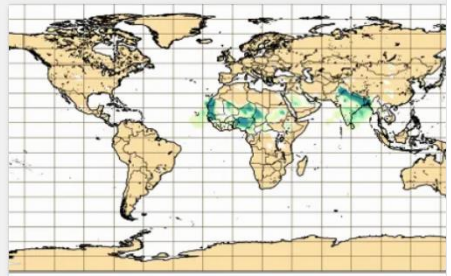
CAMS nitrogen dioxide forecasts



Latest CAMS forecast

Ozone forecasts

CAMS ozone forecasts



Latest CAMS forecast

Particulate matter forecasts

CAMS particulate matter forecasts

https://atmosphere.copernicus.eu/charts/packages/cams/

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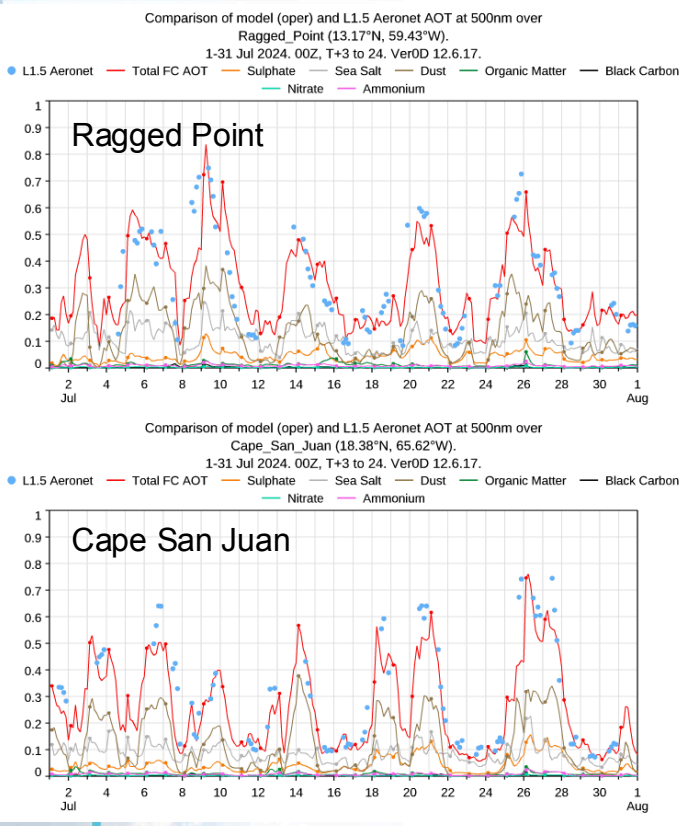
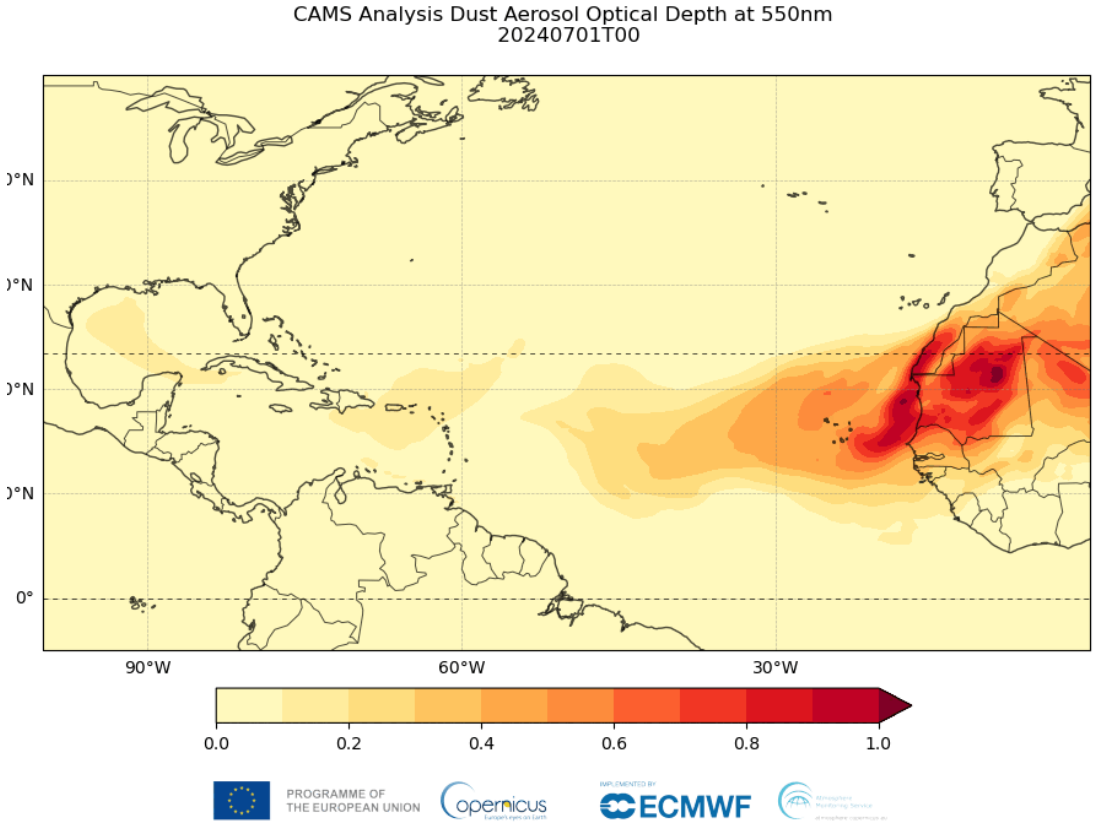
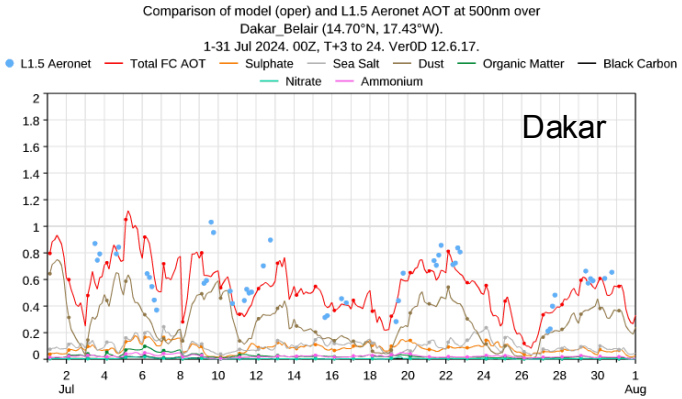
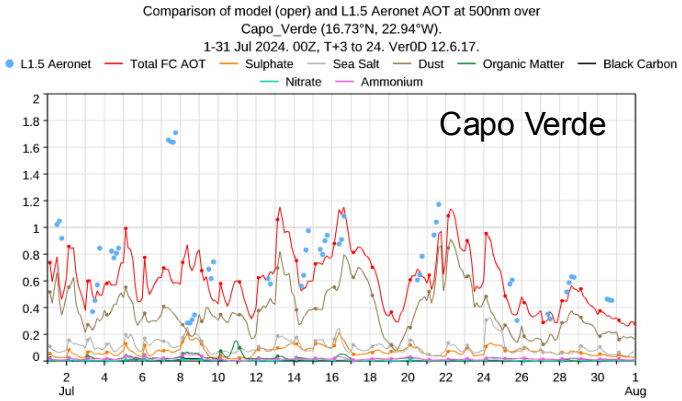
Dust events : JULY 2024

Atmosphere Monitoring









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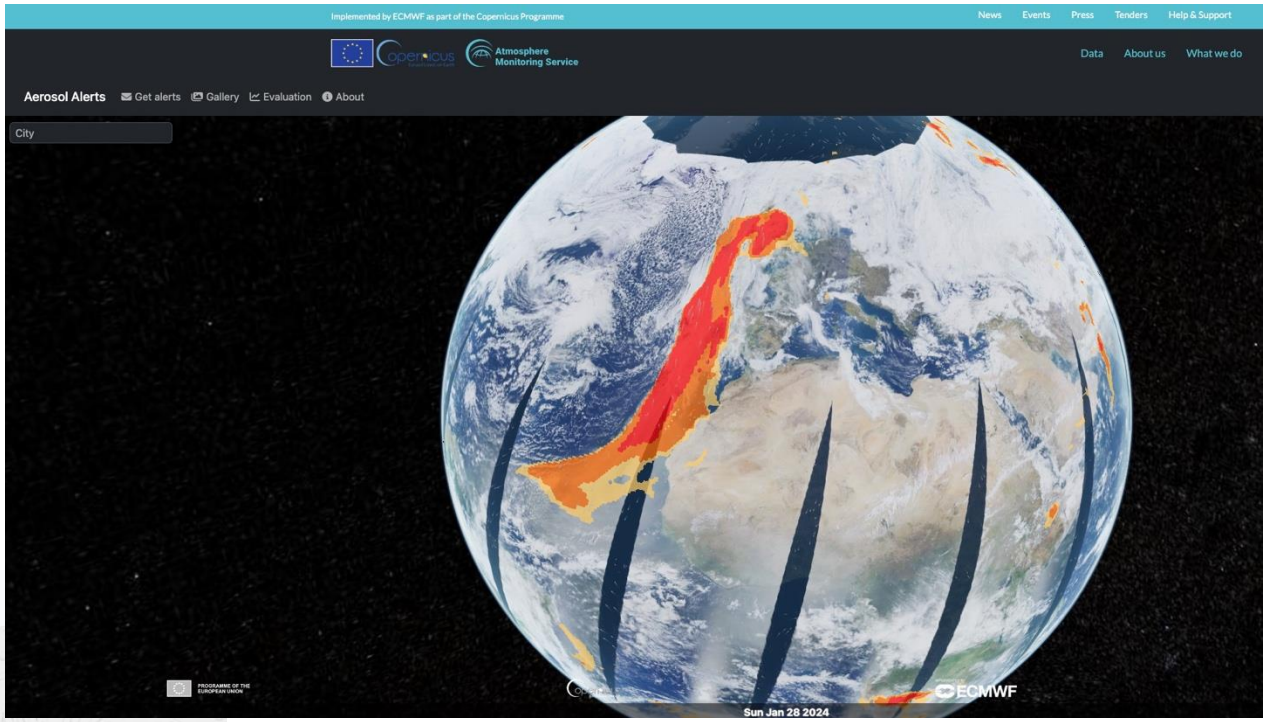
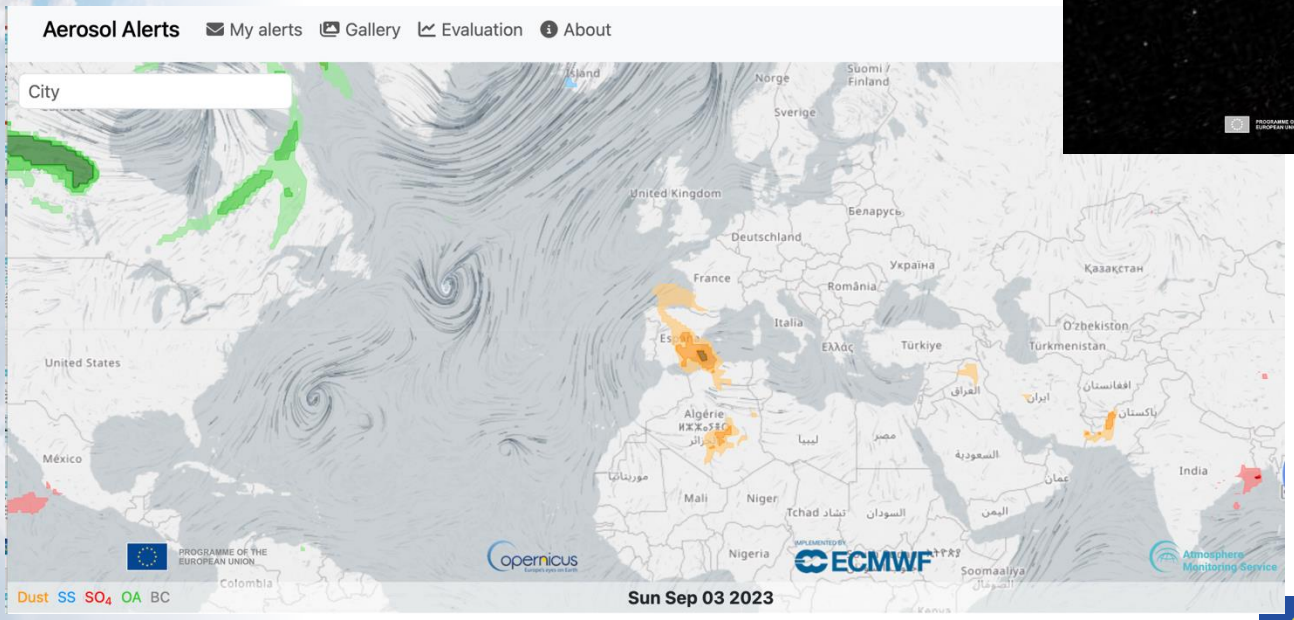
CAMS Aerosol Alert system

Atmosphere Monitoring

The CAMS aerosol alert system allows users to see (or even receive or declare) alerts for anomalous aerosol events.





https://aerosol-alerts.atmosphere.copernicus.eu

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Europe's eyes on Earth

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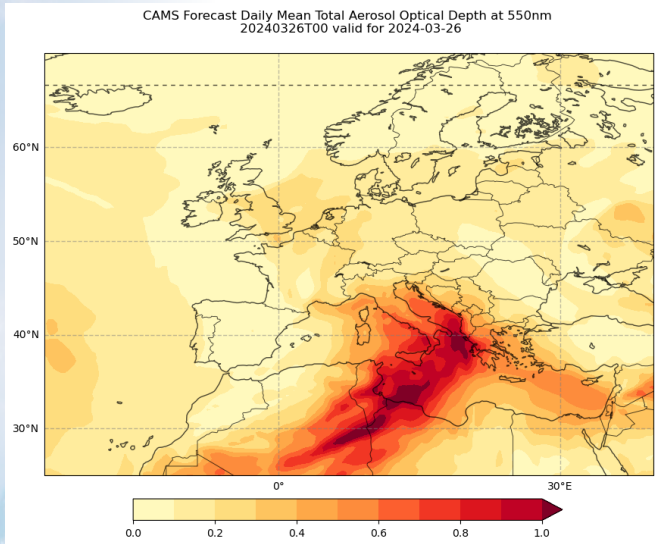
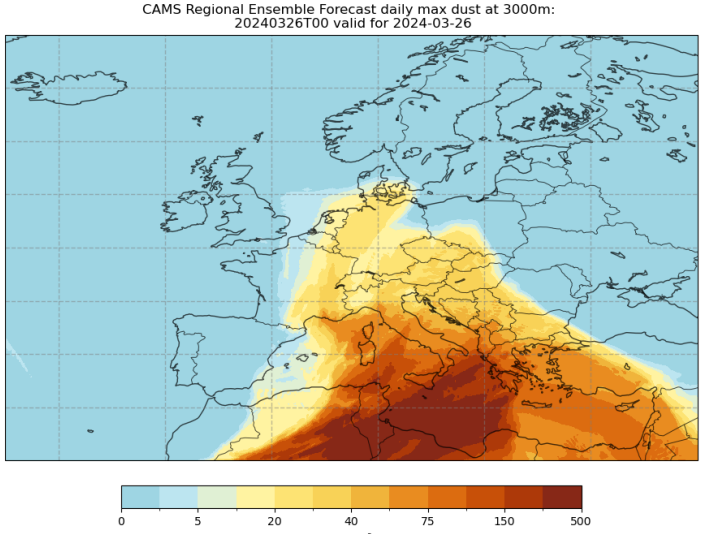
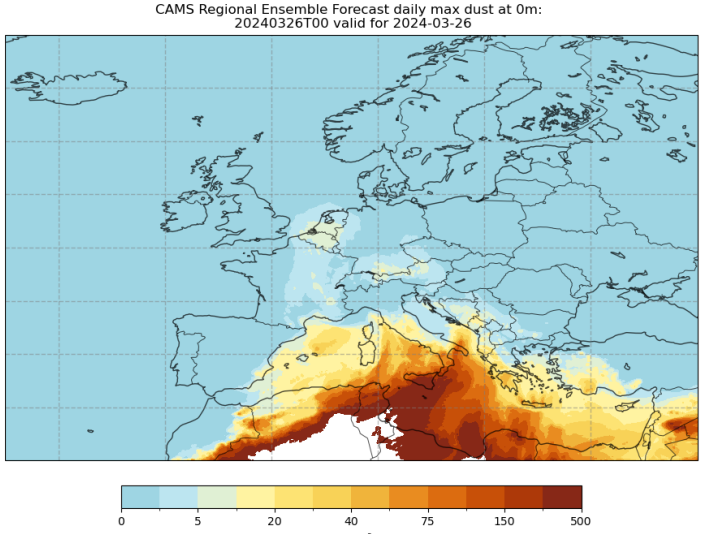
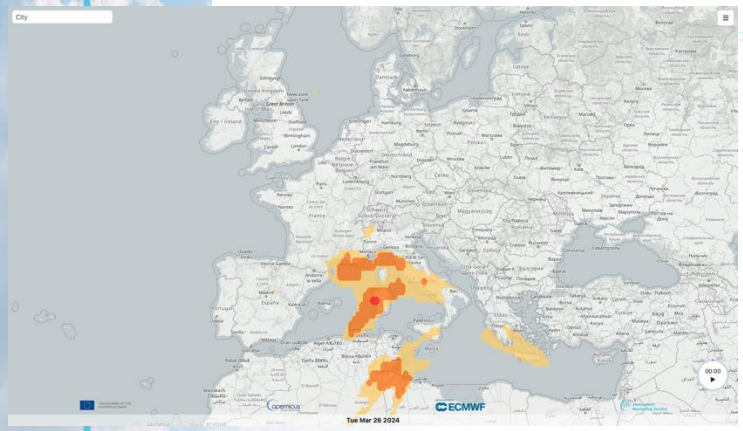
Saharan dust transport: 26 March

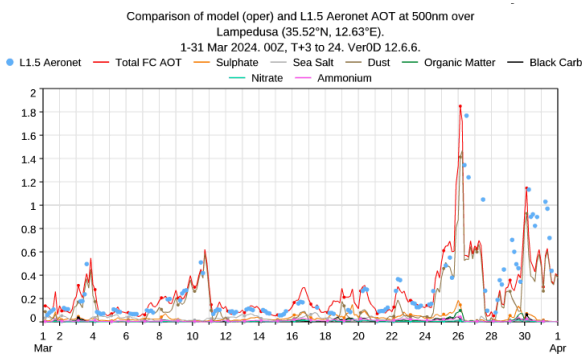
Atmosphere Monitoring

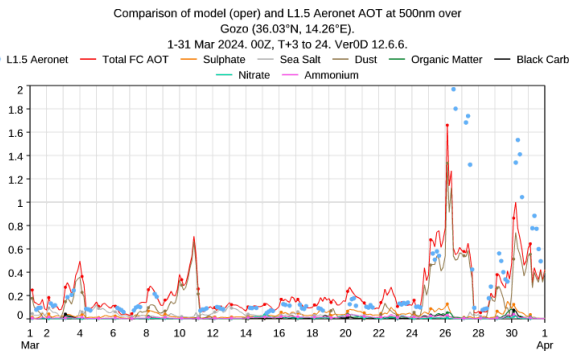


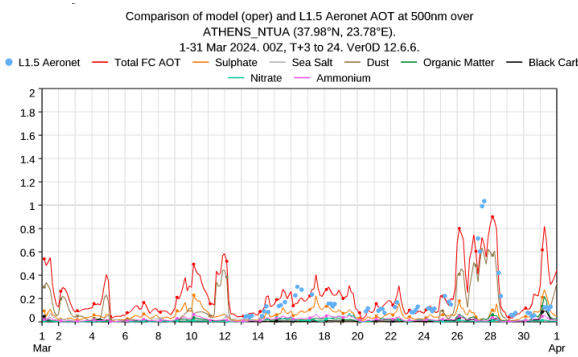












- Transport across S Europe/central Mediterranean with large AOD enhancements well represented in CAMS 24-h forecasts vs. Aeronet.

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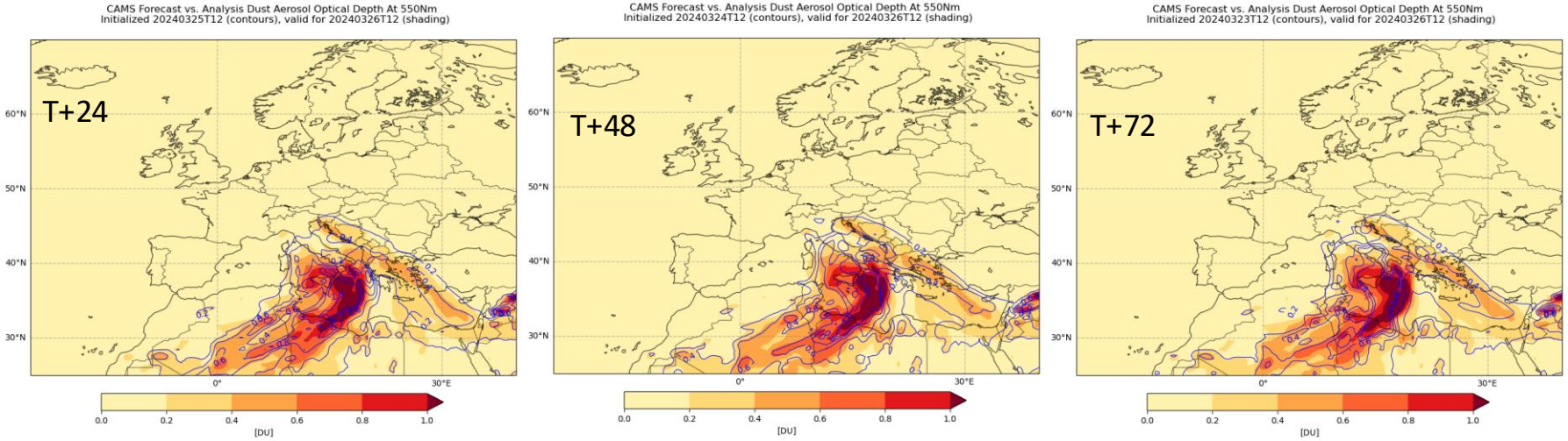
Saharan dust transport: 20 March

Atmosphere Monitoring



- Evaluation of CAMS o-suite forecasts vs. analysis over central Mediterranean.
- Shading shows analysis, blue contours show forecasts valid for 26 March 12 UTC.
- Distribution longer-range dust transport occurs up to T+120 but magnitude increases (and improves) as forecasts get closer to analysis time.

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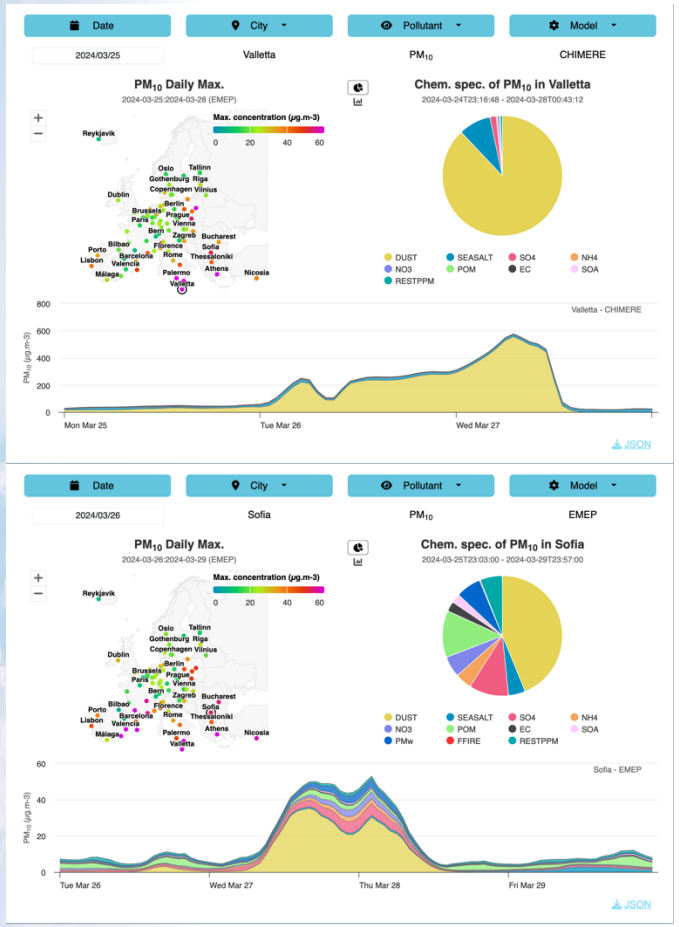
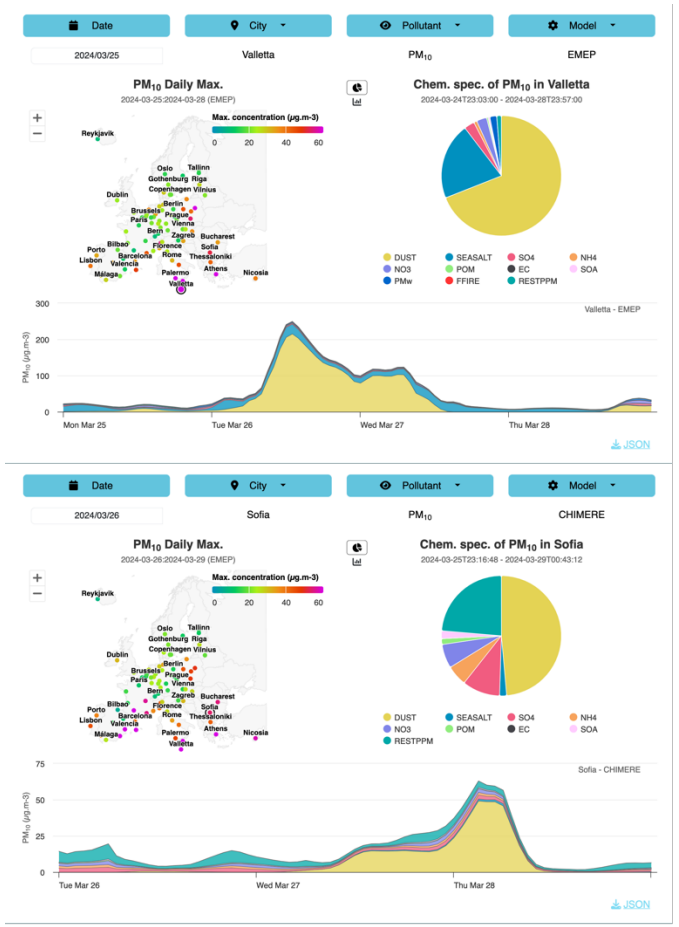
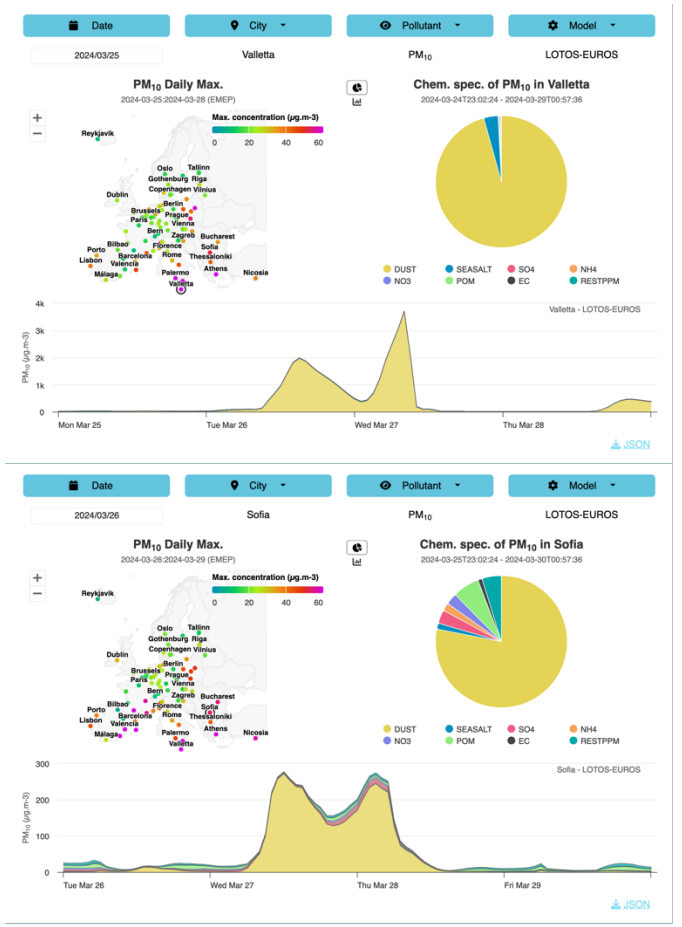
Saharan dust transport: 26 March

Atmosphere Monitoring







- Challenge in using CAMS policy support tools for evaluating PM10 speciation with three CTMs.
- Some differences in relative contibutions of dust vs. other sectors, and in timing of episodes.

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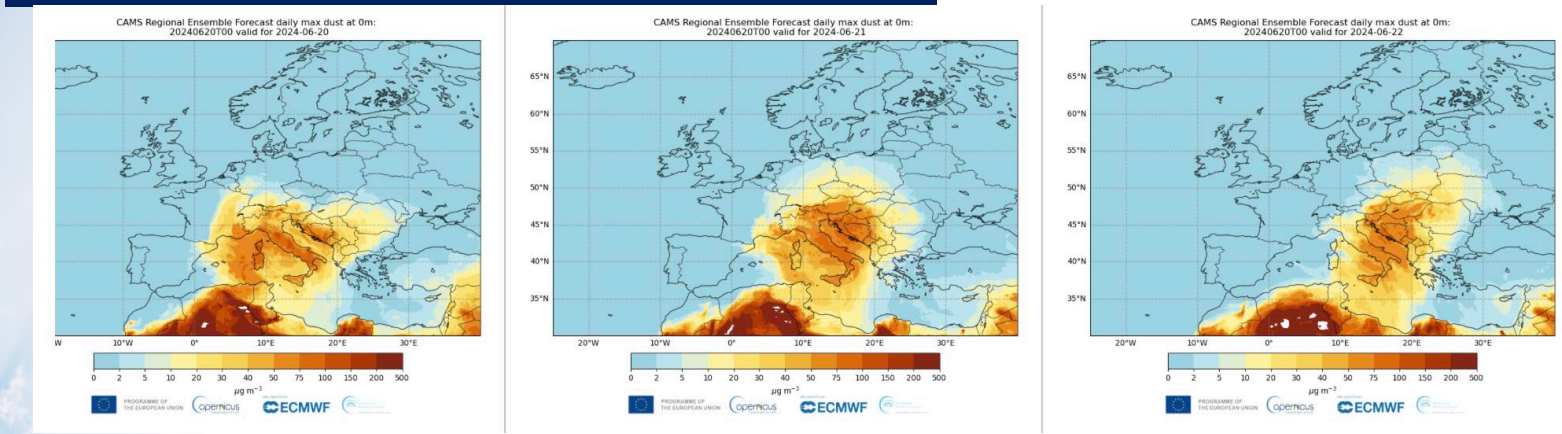
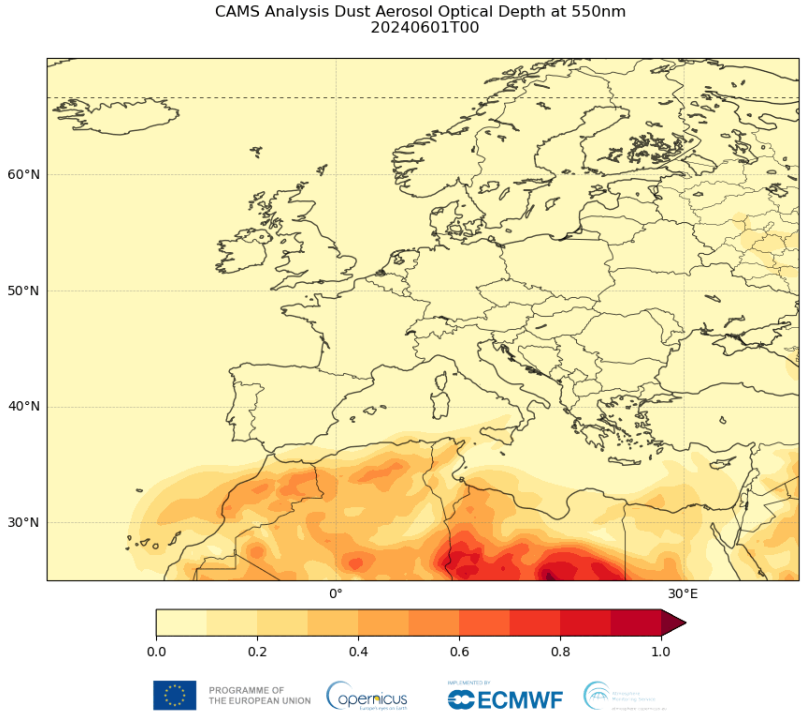
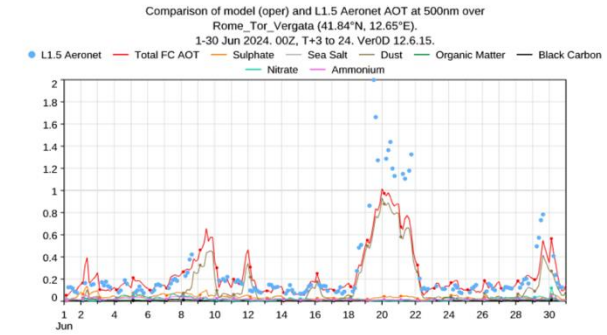
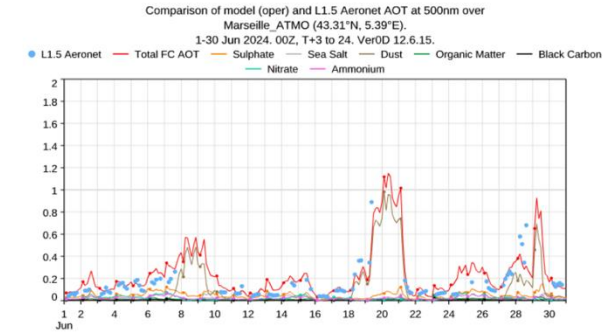
Monitoring transboundary air pollution events

Saharan dust plumes (June 2024)









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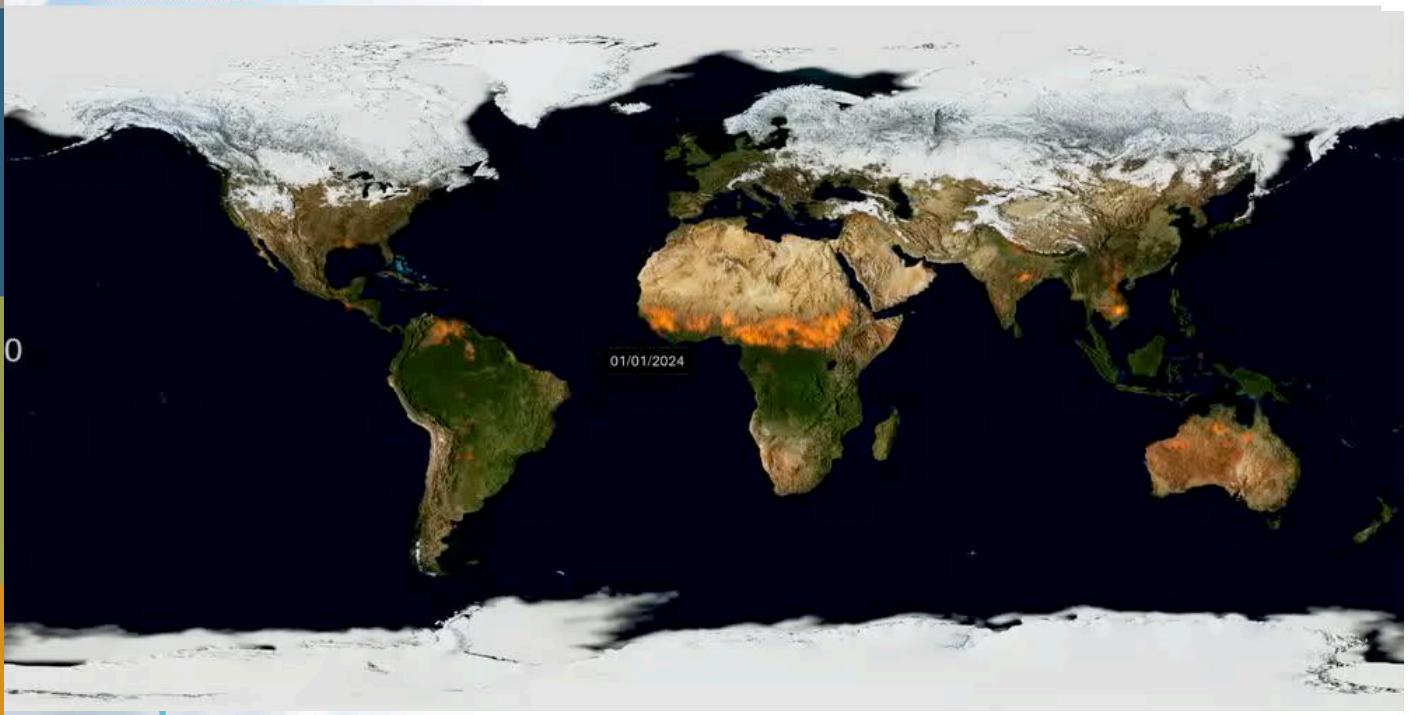
Europe's eyes on Earth

Estimating Global Wildfire Emissions

Atmosphere Monitoring

Daily wildfires 1 January – 31 December 2024



CAMS emissions products:

- Global anthropogenic emissions
  - 10 km x 10 km resolution; 2000-most recent year; based on nationally reported activity data
- Shipping emissions
  - 10 km x 10 km resolution; 2000-most recent year; based on AIS data
- Biogenic emissions inventory
  - 10 km x 10 km resolution; 2000-most recent year; based on MEGAN driven by ERA5 meteorology

- Global Fire Assimilation System (**GFAS**); see https://ads.atmosphere.copernicus.eu/cdsapp#!/dataset/cams-global-fire-emissions-gfas?tab=overview
- Uses satellite observations of Fire Radiative Power (FRP)
  - Currently Aqua and Terra MODIS FRP observations
  - FRP from VIIRS, Sentinel-3, and geostationary satellites are being tested for future implementation
- Global Coverage at ~10km Resolution
  - *Daily Output: 1-day behind NRT*
  - Hourly Output (+24-h means): 7-hours behind NRT
- Emissions of aerosols and gases are estimated using factors dependent on vegetation type.
- Injection heights calculated with Plume Rise Model and IS4FIRES

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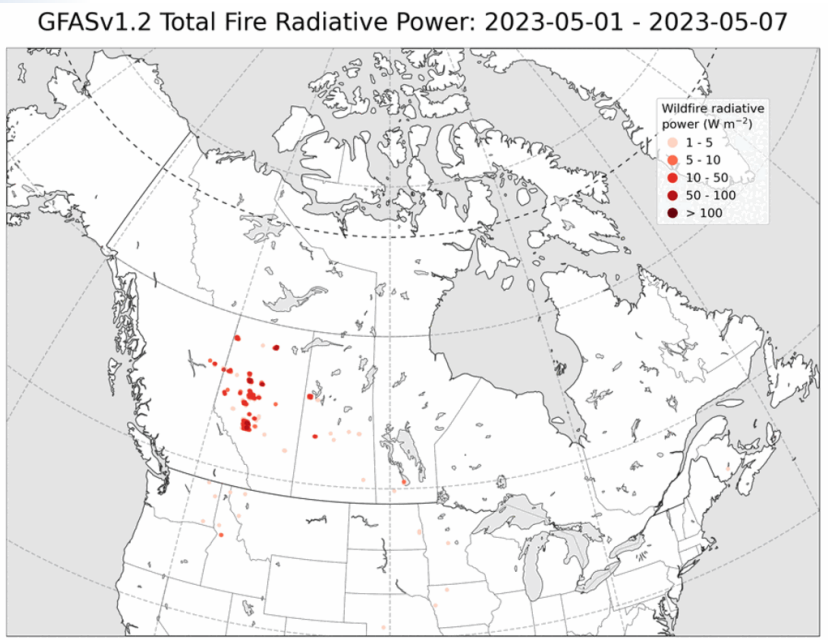
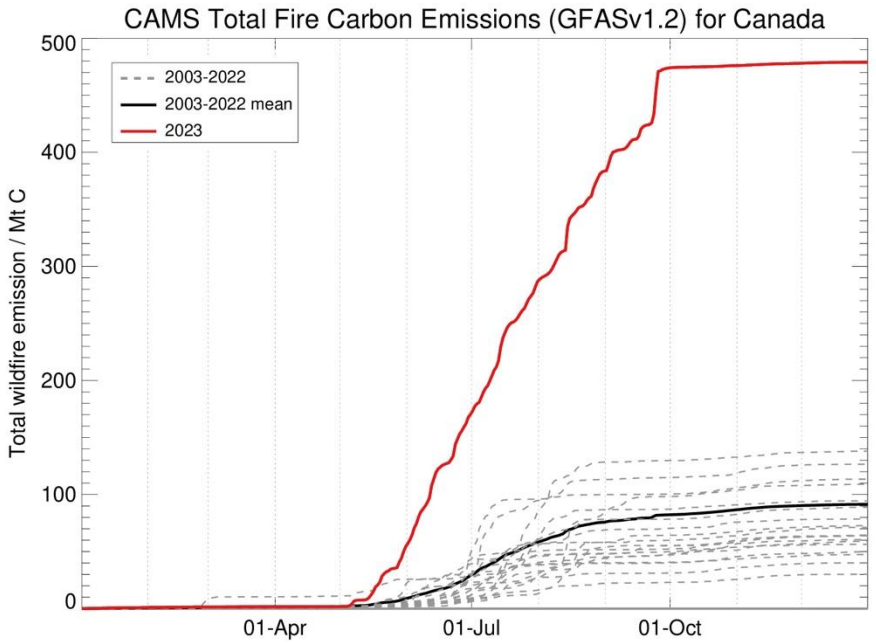
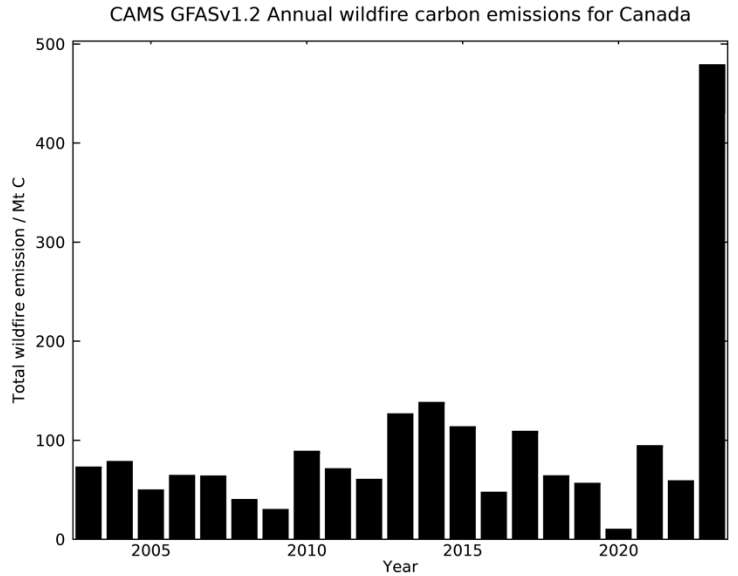
Canada wildfires 2023

Atmosphere Monitoring





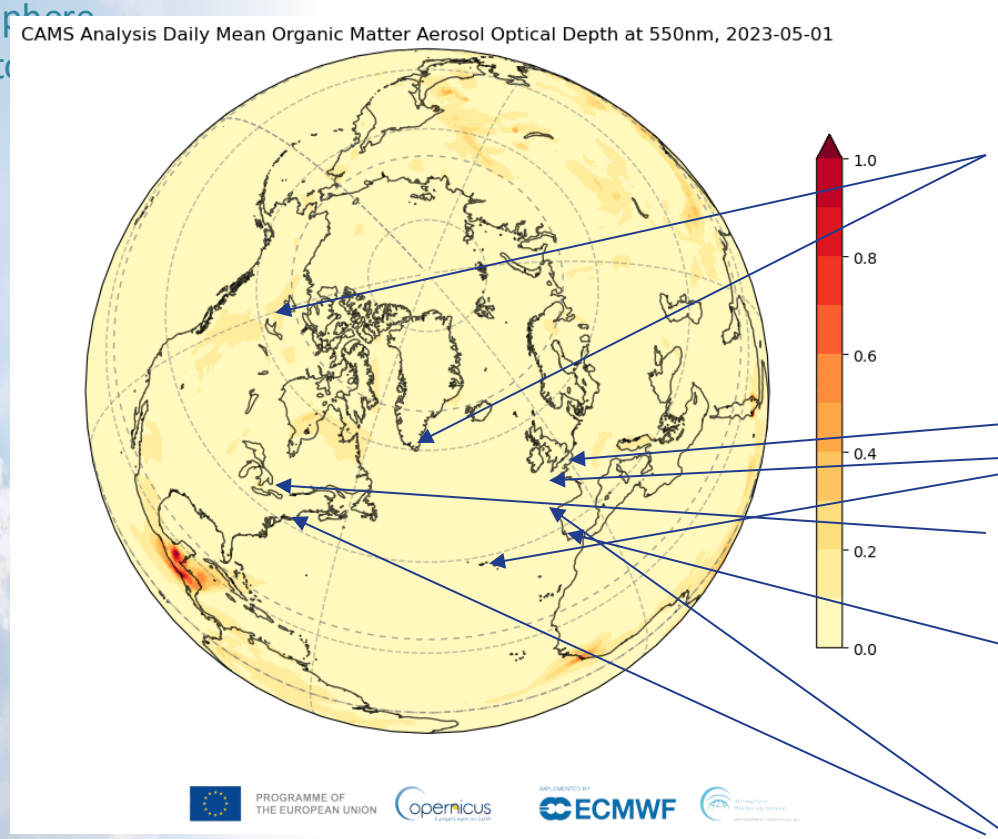


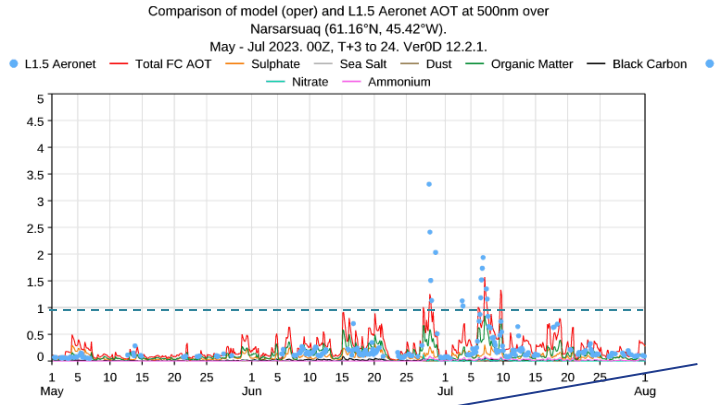
- Canada experienced the highest number of fires, burnt area and emissions on record during 2023 with fires continuing from the beginning of May to the end of September.
- The majority of Canada's provinces experienced large-scale wildfires throughout the summer with Northwest Territories, Quebec, British Columbia and Alberta.
- Several reports and studies published in 2024.

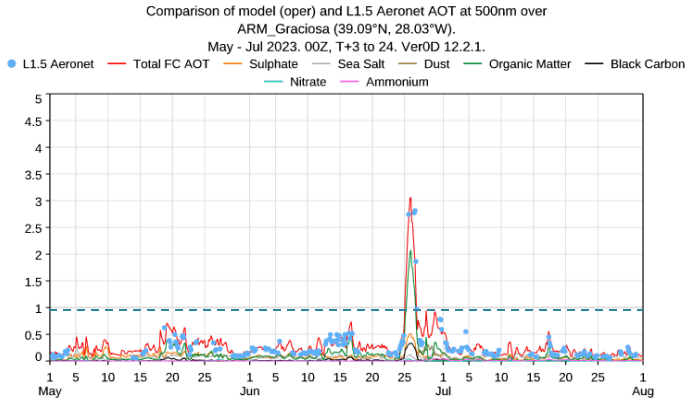
https://atmosphere.copernicus.eu/northern-hemisphere-wildfires-summer-extremes

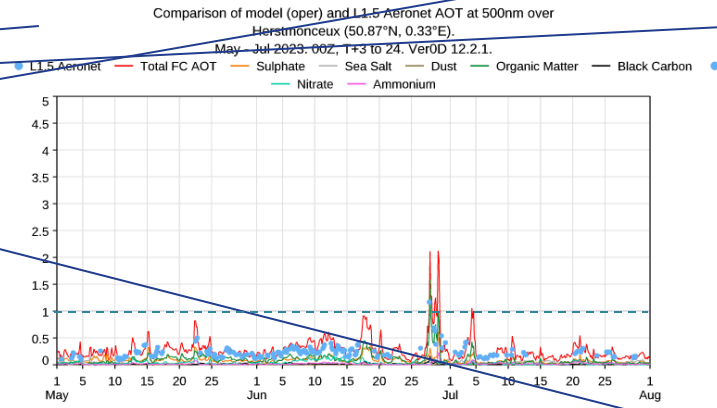
ECMWF

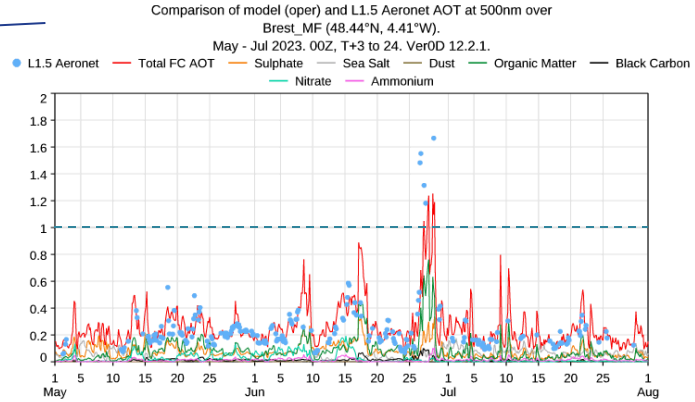
Wildfire smoke transport between May and October

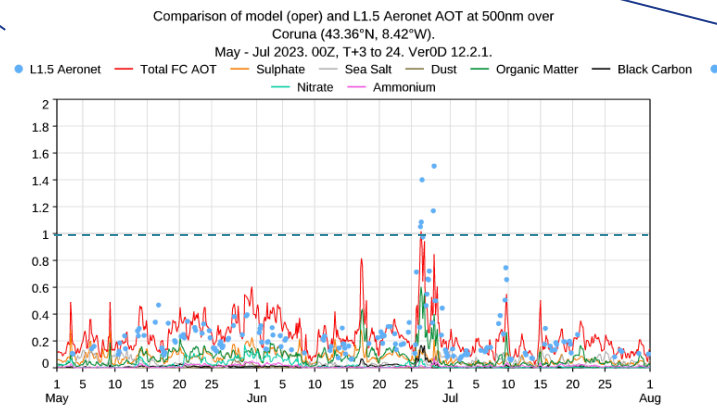


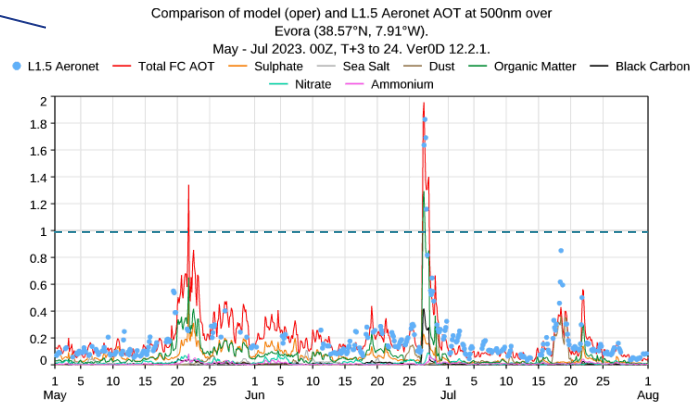








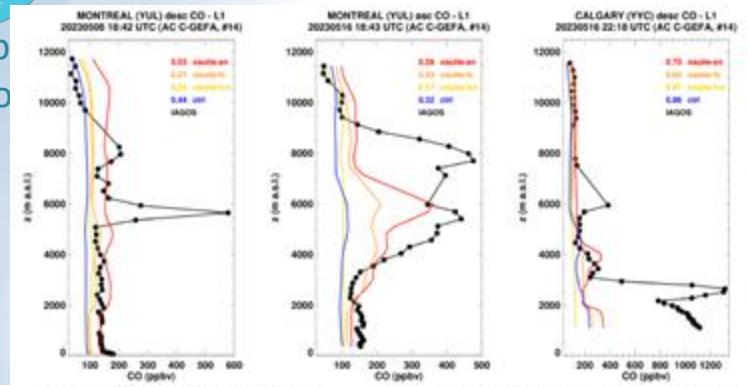


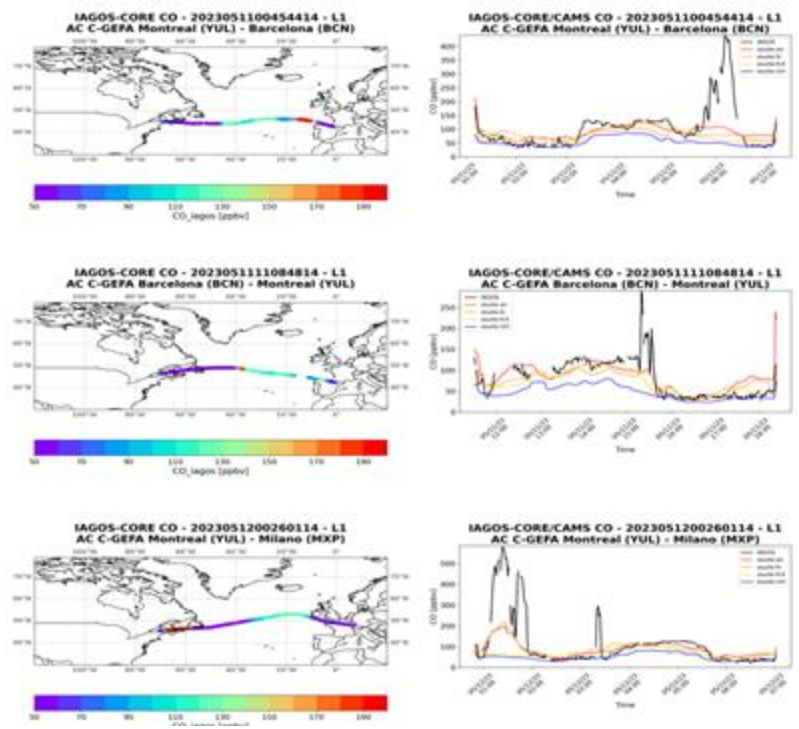


- Long-range transport of smoke from fires across Canada across North America and the North Atlantic throughout the summer.
- Good evaluation of CAMS Aerosol Optical Depth (AOD) against Aeronet under much of the smoke transport.
  - See example time series between May-October for Yellowknife, Toronto and Brookhaven.
  - Plus examples across the North Atlantic/W Europe at the end of June.

CAMS forecast vs IAGOS measurements: North America

Atmosp
Monito





nadian and U.S. airports
aring spring 2023 across

https://www.iagos.org/products/
https://www.iagos.org/products/daily_profiles/
https://www.iagos.org/products/cruise_nrt/

May CO profiles over several airports in North America

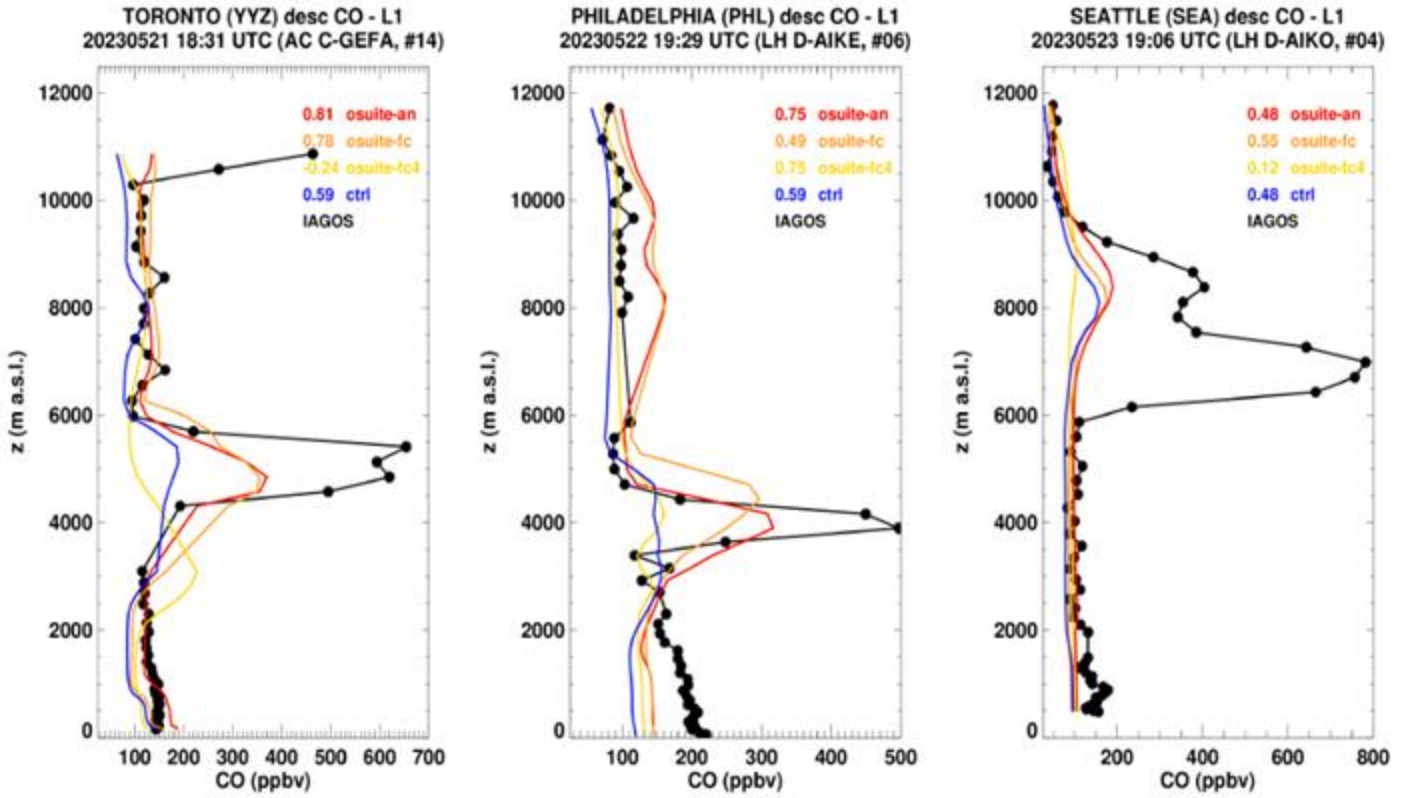


Figure 13.2.1: Examples of CO profiles sampled by IAGOS with the CAMS model at different Canadian and U.S. airports showing the long-range transport of pollution from the forest wildfires in Alberta during spring 2023 across North America.

https://atmosphere.copernicus.eu/eqa-reports-global-services

CAMS forecast vs IAGOS measurements: Europe

Atmosphere Monitoring

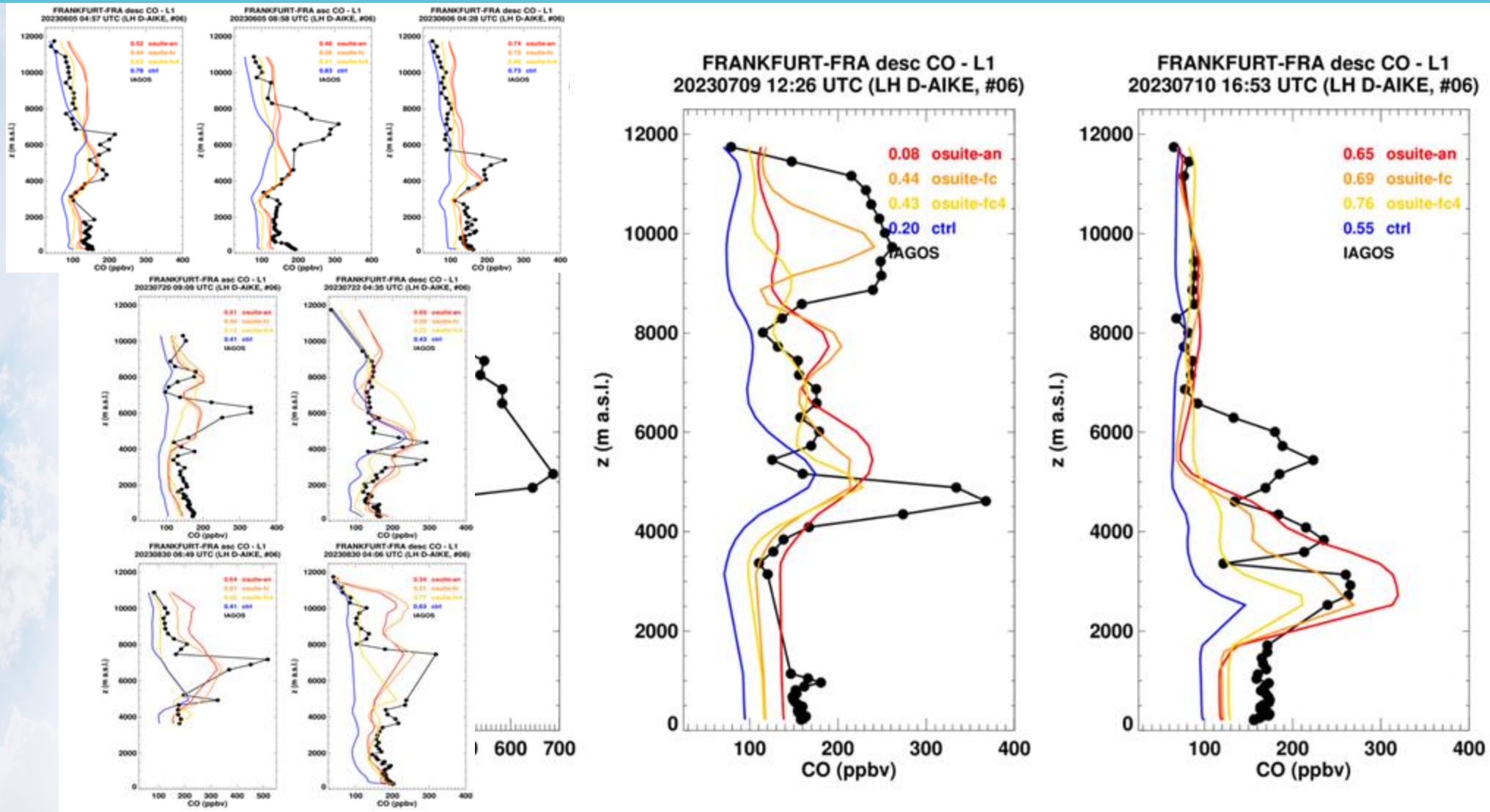


Figure 13.2.1: CO profiles from IAGOS (black) and the o-suite over Frankfurt during JJA 2023 showing plumes from wildfires in North America. The desc and asc stands for ascending and descending flights. Units: ppbv.

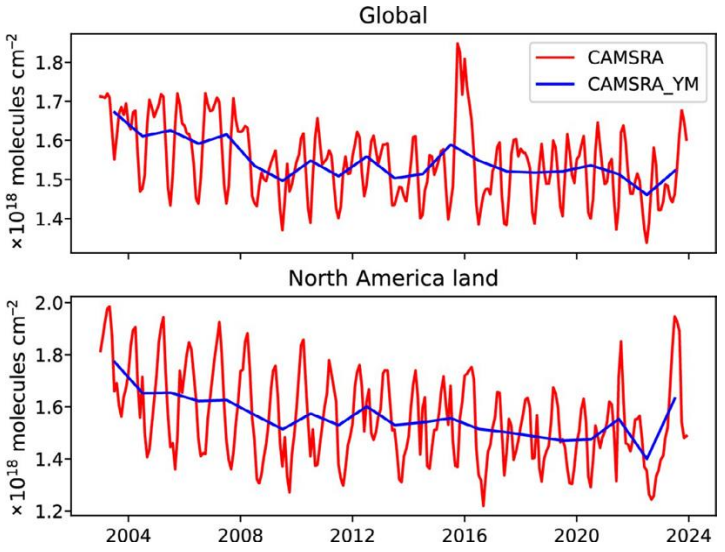
Global reanalysis of atmospheric composition (EAC4)

Atmosphere Monitoring

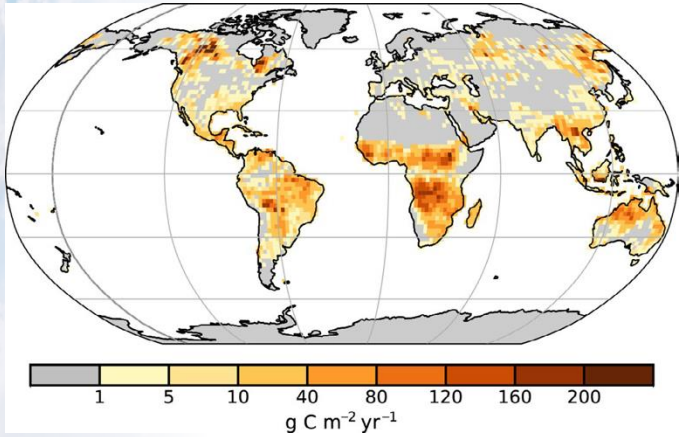
The atmosphere datastore now contains a full 21-year global re-analysis dataset for reactive gases and aerosol (EAC4).

https://ads.atmosphere.copernicus.eu/datasets/cams-global-reanalysis-eac4?tab=overview

The re-analysis takes stock of all available observation datasets using a fixed version of the CAMS forecast model. It is the BEST ESTIMATE of atmospheric composition patterns and evolution over the last two decades.



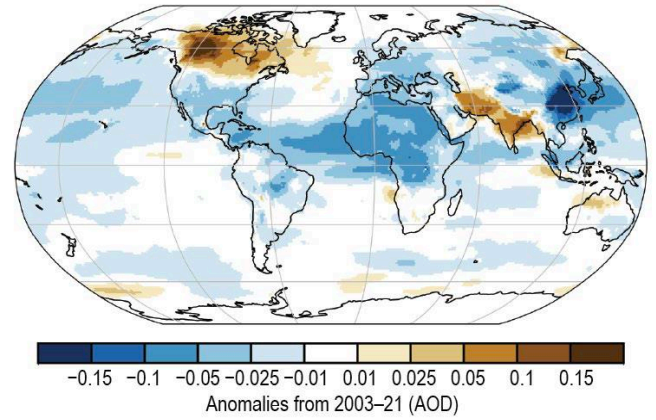
Carbon monoxide



Fire emissions

(x) Total Aerosol

Total aerosol



CAMS contributed to the BAMS State of the Climate with detailed information.

Inness et al. 2019, https://doi.org/10.5194/acp-19-3515-2019

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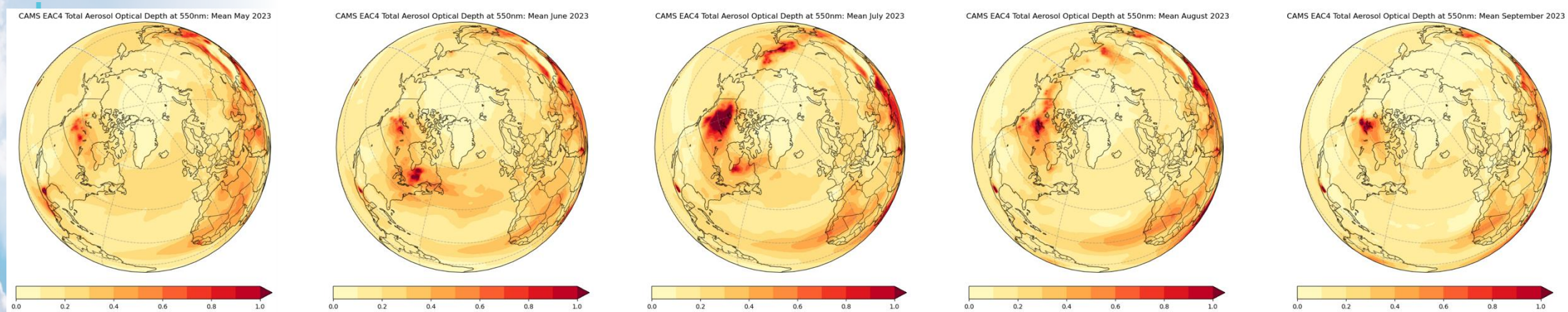
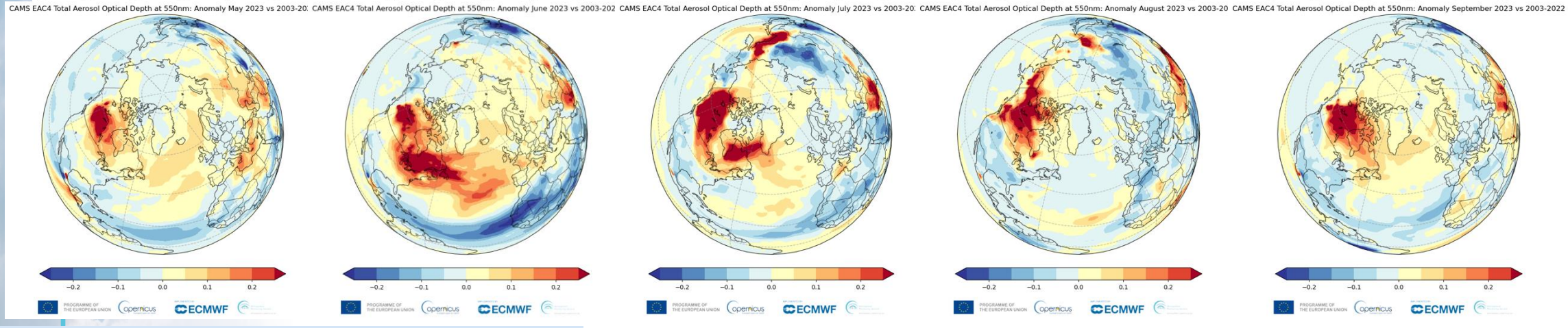
2023 monthly mean AOD anomalies

Atmosphere Monitoring

May | June | July | August | September



Monthly mean AOD



Monthly mean AOD anomaly

Reanalysis

Using a combination of observations and computer models to recreate historical climate conditions.

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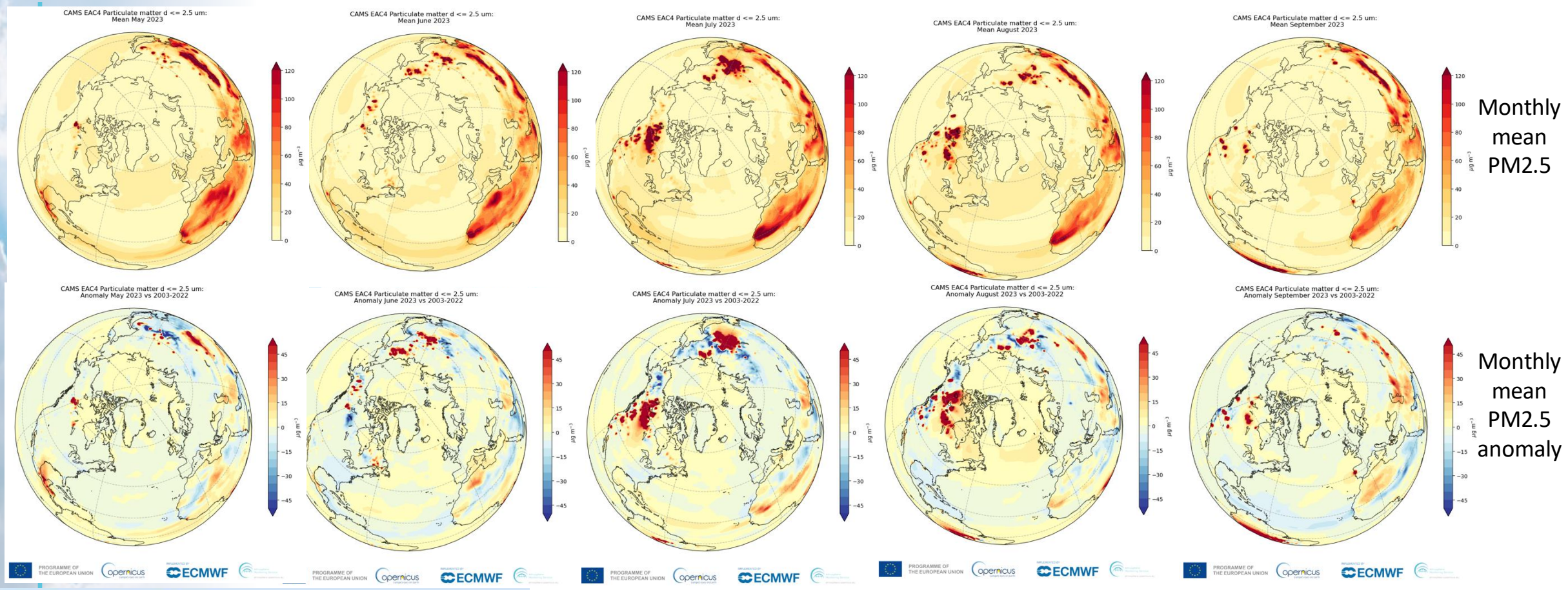
Inness et al. 2019, https://doi.org/10.5194/acp-19-3515-2019

2023 monthly mean PM2.5 anomalies

Atmosphere Monitoring

May | June | July | August | September



Monthly mean PM2.5

Monthly mean PM2.5 anomaly

Reanalysis

Using a combination of observations and computer models to recreate historical climate conditions.

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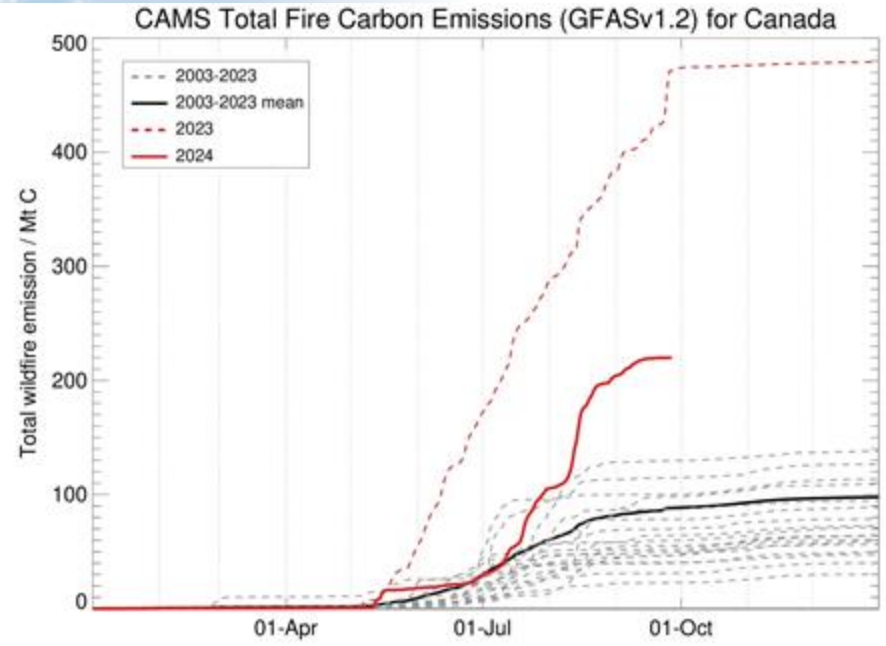
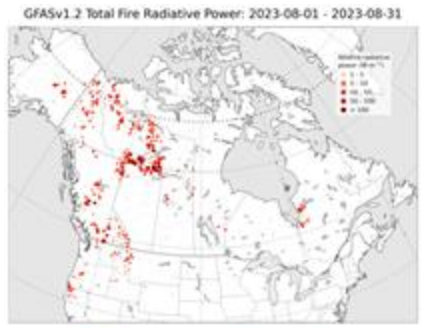
Inness et al. 2019, https://doi.org/10.5194/acp-19-3515-2019

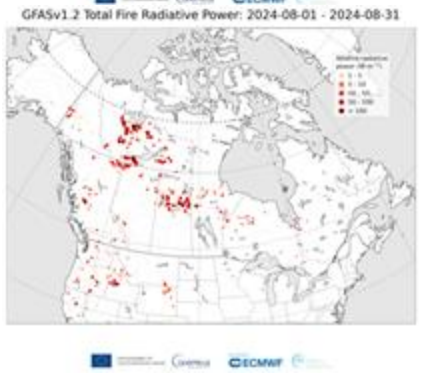
NRT Monitoring: Canada wildfires 2024

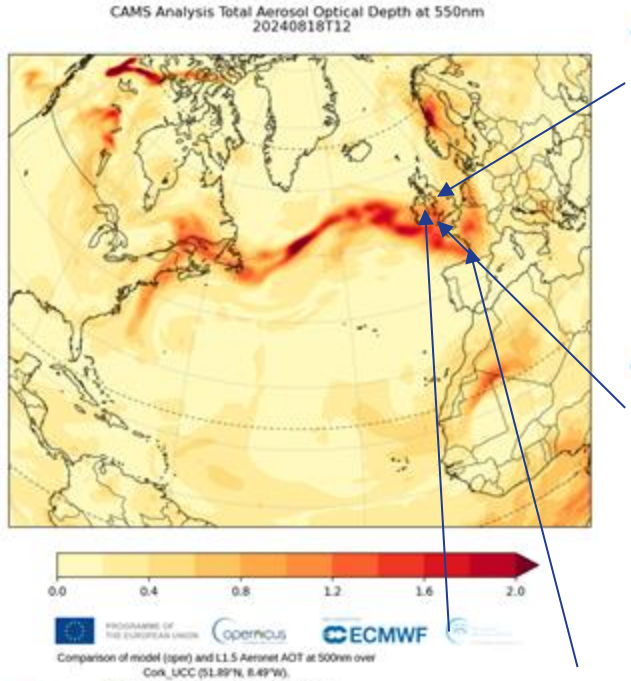
Atmosphere Monitoring

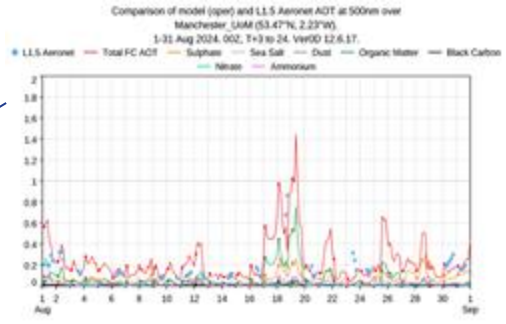
https://www.ecmwf.int/en/newsletter/181/news/monitoring-2024-canada-wildfires-cams

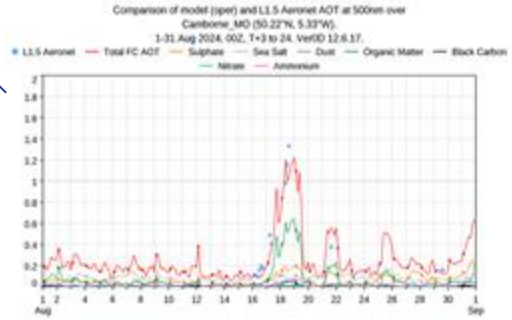


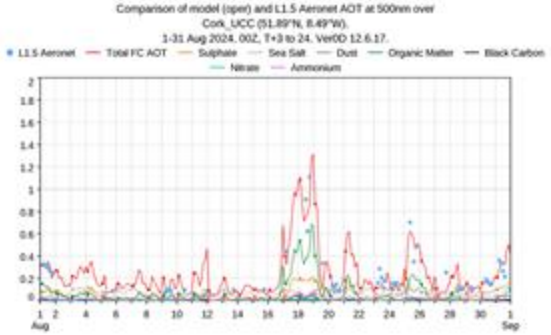












- 2024 is the second most extreme wildfire year for Canada after 2023 in terms of emissions.
- Western provinces/territories have all experience at least one month with highest emissions for that month in the summer.
- Significant long-range transport episode reached Europe resulting in measured surface PM2.5 and AOD enhancements.

https://atmosphere.copernicus.eu/smoke-canadian-wildfires-reaches-europe

PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

IMPLEMENTED BY ECMWF

CAMS Quality Assurance

Atmosp
Monitc

Home / Help & support / Quality assurance

Quality Assurance

https://atmosphere.copernicus.eu/quality-assurance

An important element of the CAMS services is the Evaluation and Quality Assurance (EQA) of the products. Not only does CAMS produce many data sets for its users, it also provides information about how accurate these products are. Users can therefore make better use of the data sets by taking the uncertainty into account.

Global Services

The global analyses and forecasts are evaluated every three months. CAMS uses a multitude of independent observational data sets to verify these products. In addition, the global reanalysis and test runs for all system upgrades are carefully assessed in a similar way to provide clear indications of the quality of these products.

Supplementary services

The solar radiation products (irradiance and UV) are evaluated every three months and the annual greenhouse gas flux estimates are being evaluated with each release of a new data set. CAMS uses a multitude of independent observational data sets to verify these products.

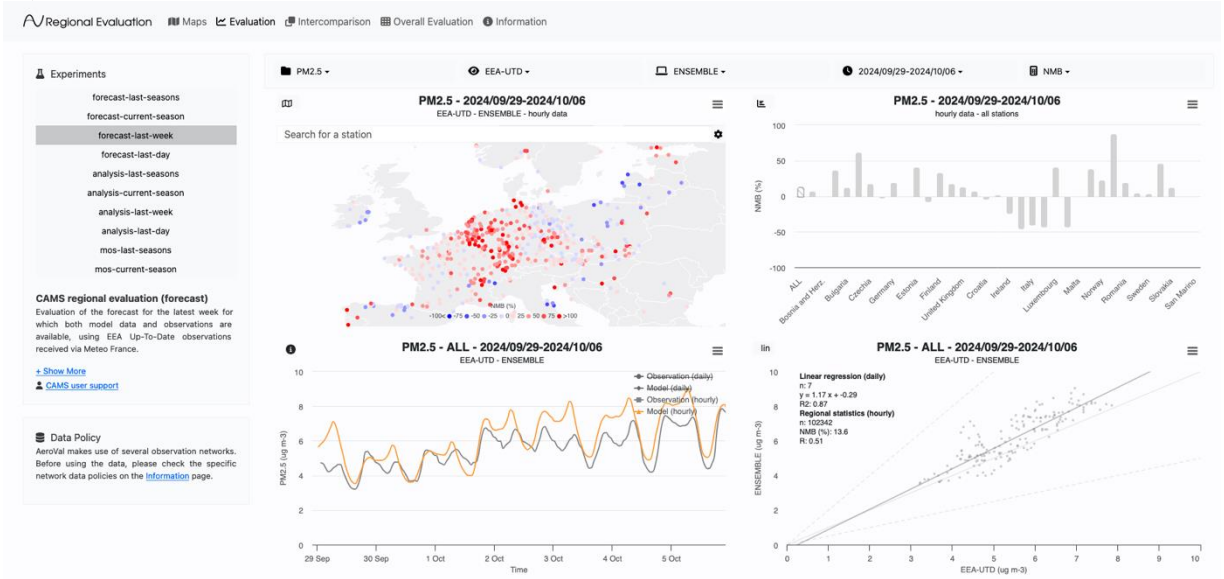
Regional services

The regional analyses and forecasts are evaluated on a 3-monthly basis. CAMS uses a multitude of independent observational data sets to verify these products. The reports include a report for each modelling system as well as for the ensemble of the models. Validation is focused on surface concentrations but a separate report is generated to assess above-surface values as well as the interface between the global and regional systems.

- Validation is central to CAMS operations.
- Quarterly validation reports.
- Global and regional evaluation servers.

https://global-eqc-server.atmosphere.copernicus.eu/pages/evaluation/?project=cams2-82&experiment=IFS

https://regional-evaluation.atmosphere.copernicus.eu/pages/evaluation/?project=cams2-83



Atmosphere Monitoring

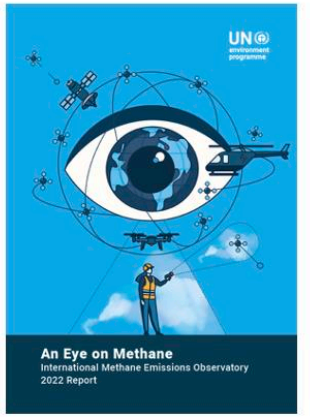
and at the international level

UNITED NATIONS PARIS CLIMATE AGREEMENT

LRTAP Long-range Transboundary Air Pollution

WORLD METEOROLOGICAL ORGANIZATION

WMO GLOBAL GREENHOUSE GAS WATCH



SUSTAINABLE DEVELOPMENT GOALS

ICLEI Local Governments for Sustainability

PROGRAMME OF THE EUROPEAN UNION

Copernicus Europe's eyes on Earth

IMPLEMENTED BY ECMWF

Supporting the implementation of environmental policies

In Europe

Atmosphere Monitoring

ZERO POLLUTION AMBITION

Reactive gas, aerosols

GHG

Solar radiation

Ambient Air Quality (AAQ) Directives

Maximum concentrations of air polluting substances (PM_{10}, $PM_{2.5}$, SO_2, NO_2, O_3 + 8 more)

SETTING OBJECTIVES FOR GOOD AIR QUALITY

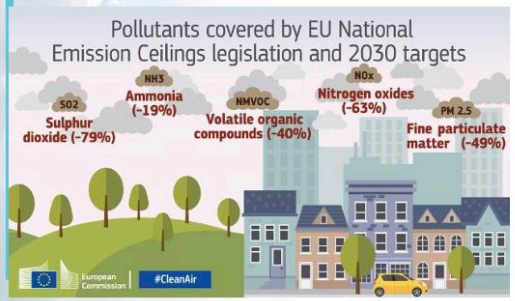
REDUCING EMISSIONS OF POLLUTANTS

National Emission reduction Commitments Directive

National emission totals (SO_2, NO_x, NMVOC, $PM_{2.5}$, NH_3)

Source-specific emission standards

- IED Directive
- MCP Directive
- Eco-design Directive
- Energy efficiency
- Euro and fuel standards



EU Methane Strategy

Covenant of Mayors for Climate & Energy EUROPE

SUSTAINABLE DEVELOPMENT GOALS

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And informing the public

LE SOIR

Published on 02/21/2023 at 15:50 | Reading time: 1 min

U A cloud of dust from the Sahara is heading towards
according to forecasts by the Copernicus Atmosphe
Service (CAMS). The large cloud is currently travel
Atlantic Ocean. It will hit Western Europe in the next few d

The New York Times

SUBSCRIBER-ONLY NEWSLETTER

Climate Forward

Understanding the New Era of Fire

Wildfires, driven by climate change, have become more intens
and frequent, but scientists are still trying to understand larger
patterns.

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The Copernicus Atmosphere Monitoring Service, a research organization funded by the European Union, reported this month that fires in Canada were above average in some regions, and about 25,000 people had to be evacuated from their homes when Jasper National Park in Alberta was burned by the biggest blazes it's experienced in a century.

Large-scale and intense wildfires carrying smoke across northern hemisphere

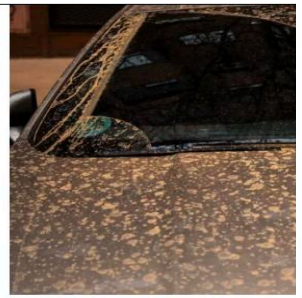
Late spring and early summer blazes in Canada, Alaska eastern Russia add to carbon emissions

The Guard
News provide

A wildfire near Ashcroft, British Columbia, on 20 July. The province had tota of 11.1 megatonnes across June and July, which were increased by fires. Photog Winter/Reuters

The northern hemisphere has had a large number of intense wildfires in the first half of summer, carrying vast amounts of smoke across Eurasia and

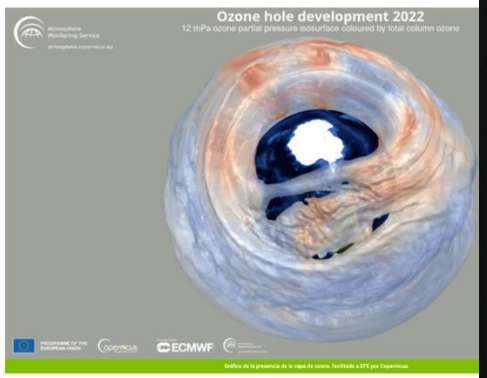
Copernicus: in arrivo sabbia del Sahara sul Mediterraneo orientale, attenti alle polveri sottili



di redazione Green&Blue

Secondo le previsioni del Copernicus Atmosphere Monitoring Ser sahariane investirà soprattutto Grecia, Cipro e Turchia occidentale, con implicazioni per la qualità dell'aria. La Società Italiana di Medicina Ambientale: "Rischi per chi soffre di asma e malattie respiratorie"

EFE:Verde



CAPA OZONO

Aprobada la quinta enmienda del Protocolo de Montreal, s después

Publicado por: Pedro Pablo G. May 9 de marzo, 2023

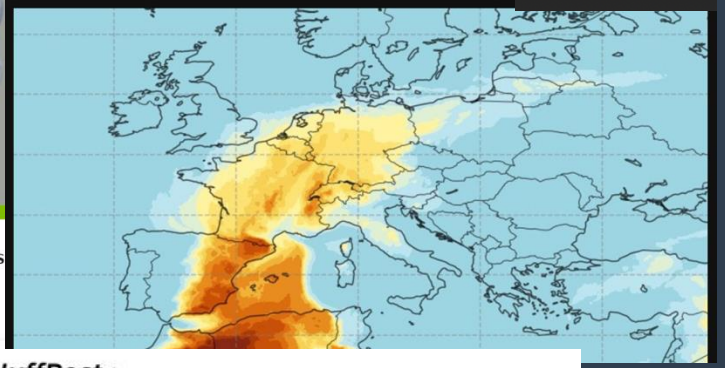
'Exceptionally intense' Saharan dust cloud hits Europe, bringing hazy skies and blanketing cars

The current dust cloud is the third of its kind from the Sahara to reach Europe in recent weeks, but has been branded particularly "intense" by the European Union's Copernicus Atmosphere Monitoring Service (CAMS).

Victoria Seabrook
Climate reporter @SeabrookClimate

Monday 8 April 2024 11:26, UK

sky news



À voir également sur *Le HuffPost* :

ITINERIS

THANKS!

IR0000032 – ITINERIS, Italian Integrated Environmental Research Infrastructures System
(D.D. n. 130/2022 - CUP B53C22002150006) Funded by EU - Next Generation EU PNRR-Mission 4 “Education and Research” - Component 2: “From research to business” - Investment 3.1: “Fund for the realisation of an integrated system of research and innovation infrastructures”

Finanziato dall'Unione europea NextGenerationEU
Ministero dell'Università e della Ricerca
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