

# CAMS

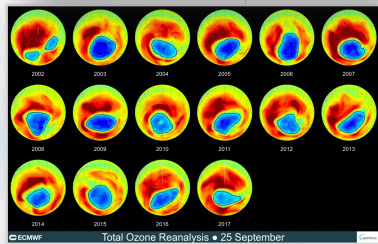
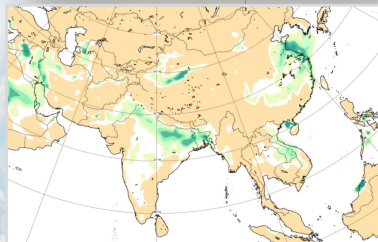
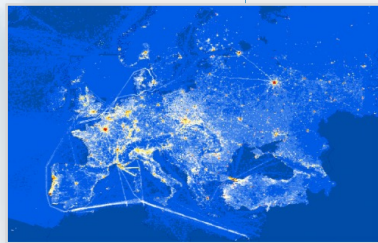
COPERNICUS ATMOSPHERE  
MONITORING SERVICE

PROGRESS AND CHALLENGES  
WITH AIR QUALITY  
FORECASTING IN EUROPE

Vincent-Henri Peuch (ECMWF)

...and many European colleagues





CAMS provides **open & free** information products based on Earth Observation about:

- past, current and near-future (forecasts) global atmospheric composition;
- the ozone layer;
- European air quality;
- emissions and surface fluxes of key pollutants and greenhouse gases;
- solar radiation;
- climate radiative forcing.



Atmosphere  
Monitoring

# CAMS DISTRIBUTED IMPLEMENTATION

CAMS 4<sup>th</sup> General Assembly, Budapest, September 2019

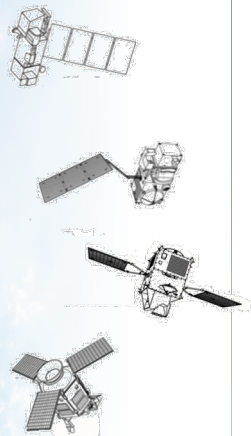


196 different entities from 31 European countries, IOs and 3<sup>rd</sup> countries.

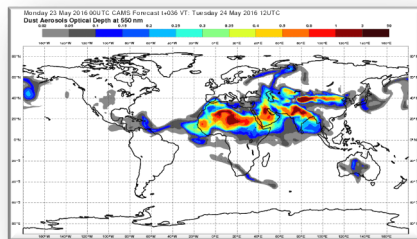
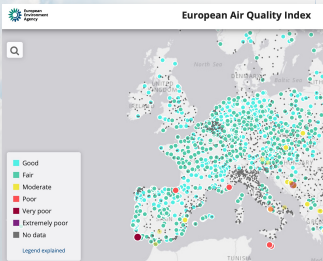


# CAMS INFORMATION FLOW

Atmosphere  
Monitoring

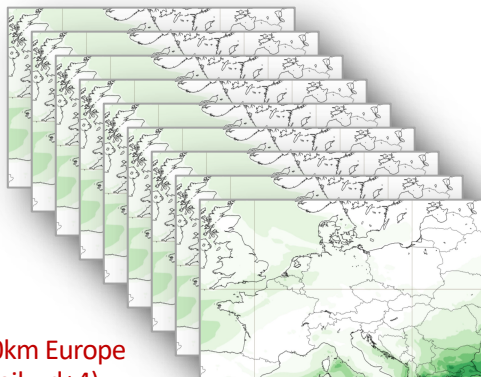


Earth Observation  
from satellite (>80  
instruments) and in-  
situ (regulatory and  
research)



40km Globe  
(twice daily, d+5)

CAMS main operational data  
assimilation and modelling systems



10km Europe  
(daily, d+4)

CAMS users

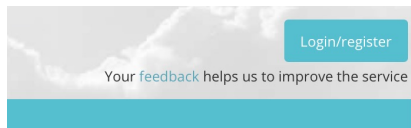




Atmosphere  
Monitoring

# THE CAMS ATMOSPHERE DATA STORE (ADS)

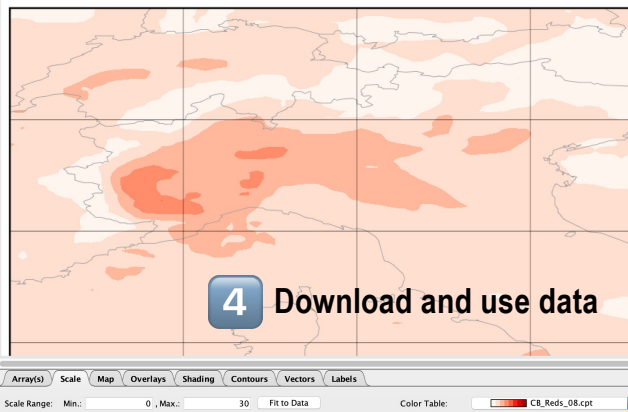
## 1 Register (once)



## 2 Search catalogue

- CAMS global reanalysis (EAC4)**  
EAC4 (ECMWF Atmospheric Composition Reanalysis 4) is the fourth generation ECMWF global reanalysis of atmospheric composition. Reanalysis combines model c with observations from across the world in...
- CAMS global reanalysis (EAC4) monthly averaged fields**  
EAC4 (ECMWF Atmospheric Composition Reanalysis 4) is the fourth generation ECMWF global reanalysis of atmospheric composition. Reanalysis combines model c with observations from across the world in...
- CAMS global inversion-optimised greenhouse gas fluxes and concentrations**  
This data set contains net fluxes at the surface, atmospheric mixing ratios at model levels, and column-mean atmospheric mixing ratios for carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>) and nitrous oxide (N<sub>2</sub>O)...
- CAMS solar radiation time-series**  
The CAMS solar radiation services provide historical values (2004 to present) of Global, Direct and Diffuse Solar Irradiance, as well as of Direct Normal Irradiance. TI of this is 0
- CAMS E**  
This dataset significantly includes:
  - Ammonia
  - Dust
  - Nitrogen monoxide
  - Ozone
  - Birch pollen
  - Grass pollen
  - Non-methane VOCs
  - Particulate matter < 2.5 µm (PM2.5)
  - PM10, wildfires only
  - Secondary inorganic aerosol
  - Carbon monoxide
  - Nitrogen dioxide
  - Olive pollen
  - Particulate matter < 10 µm (PM10)
  - PM10, wildfires only
  - Secondary inorganic aerosol

mass concentration of pm2p5 ambient aerosol in air



## 4 Download and use data

## 3 Fill-in form

Home Search Datasets FAQ

Welcome to the Atmosphere Data Store

Dive into this wealth of information about the Earth's past, present and future Atmosphere data. Register for free to obtain ADS and its Toolbox.

We are constantly improving the services and adding new datasets. For more information, please consult our FAQ or the CAMS forum.

Enter search term(s)  All

ENS\_ANALYSIS.nc

- latitude
- level
- longitude
- pm2p5\_conc
- time

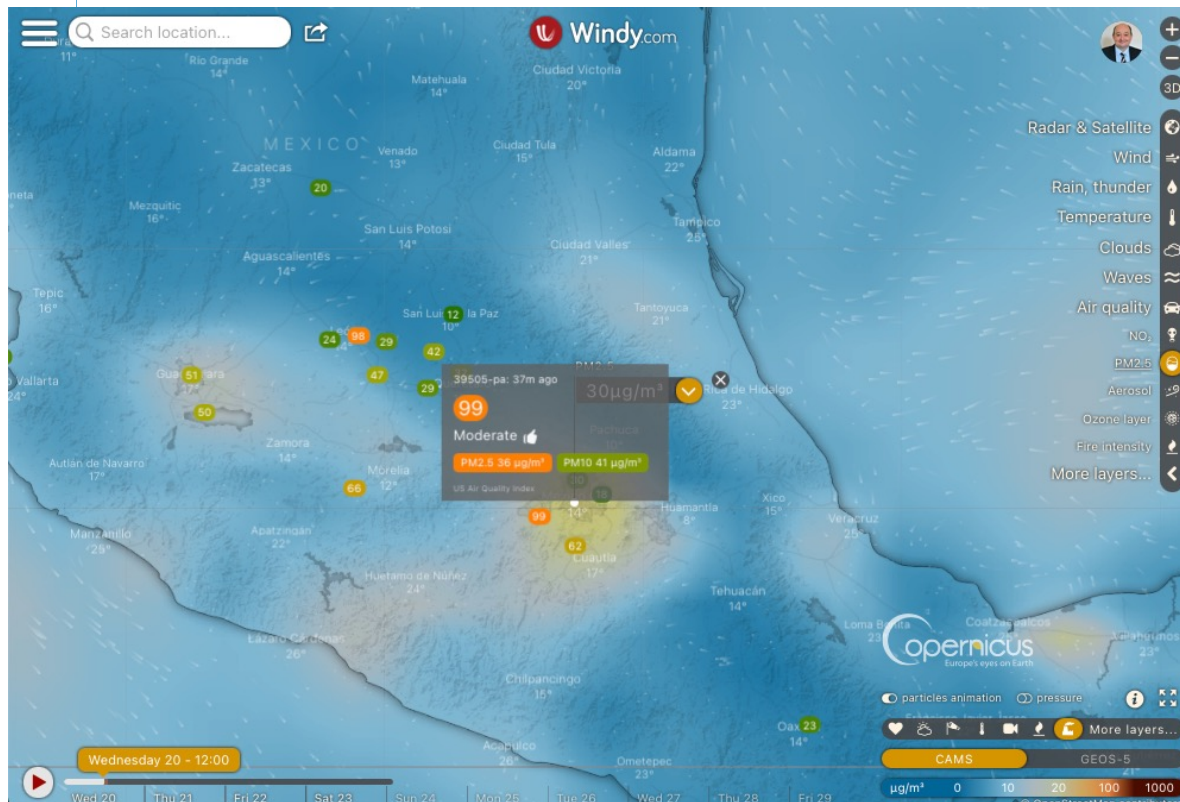
<http://ads.atmosphere.copernicus.eu>





# WHAT'S GOING ON NOW?

Atmosphere  
Monitoring



You can also see CAMS outputs through several of our own users (here: [windy.com](https://www.windy.com)). Overlay of current air pollution (PM2.5) and local observations.



# IFS: COMPOSITION CONFIGURATIONS

A. Inness et al., The CAMS reanalysis of atmospheric composition, ACP, <https://doi.org/10.5194/acp-19-3515-2019>, 2019.

A. Agusti-Panareda et al., Modelling CO<sub>2</sub> weather – why horizontal resolution matters?, ACP, <https://doi.org/10.5194/acp-2019-177>, 2019.

S. Rémy et al., Description and evaluation of the tropospheric aerosol scheme in the Integrated Forecasting System (IFS-AER, cycle 45R1) of ECMWF, GMD, 12, 4627–4659, 2019, <https://doi.org/10.5194/gmd-12-4627-2019>.

V. Huijnen et al., Quantifying uncertainties due to chemistry modelling – evaluation of tropospheric composition simulations in the CAMS model (cycle 43R1), GMD, <https://doi.org/10.5194/gmd-12-1725-2019>.

## Current oper version

- Based on IFS Cy47r3 (12/10/21)
- T511 (~40km)
- L137

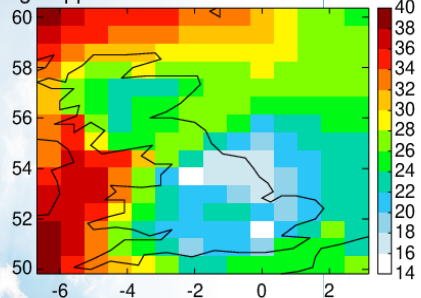




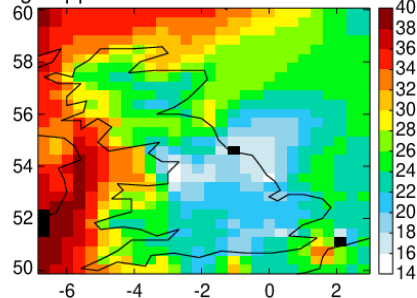
## Ozone

## NO<sub>2</sub>

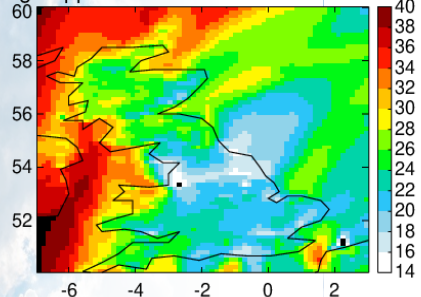
go3 ppb sfc UK 80km 2019021515



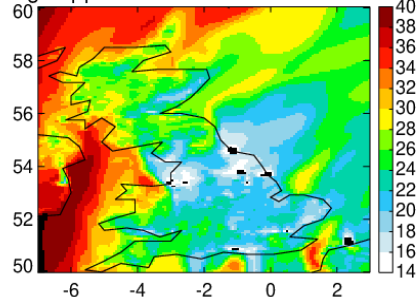
go3 ppb sfc UK 40km 2019021515



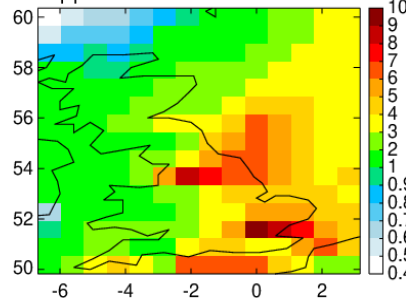
go3 ppb sfc UK 18km 2019021515



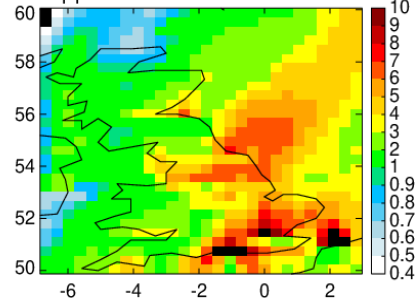
go3 ppb sfc UK 9km 2019021515



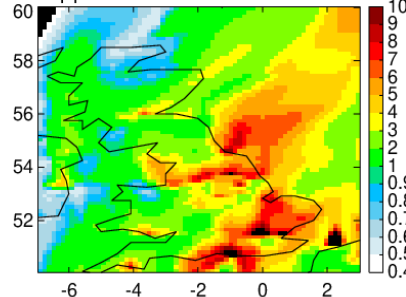
no2 ppb sfc UK 80km 2019021515



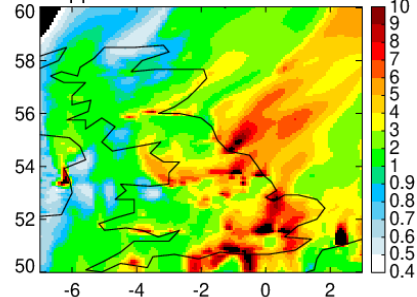
no2 ppb sfc UK 40km 2019021515



no2 ppb sfc UK 18km 2019021515



no2 ppb sfc UK 9km 2019021515



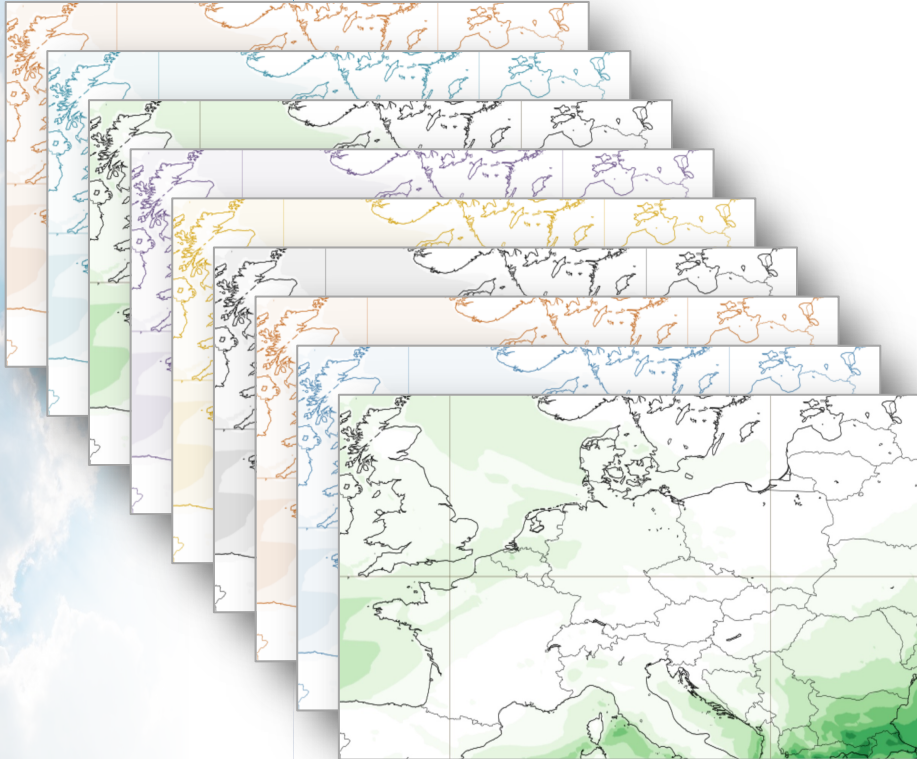
Higher spatial resolution allows to make use of high-res information of emission data





Atmosphere  
Monitoring

# CAMS REGIONAL AIR QUALITY ENSEMBLE

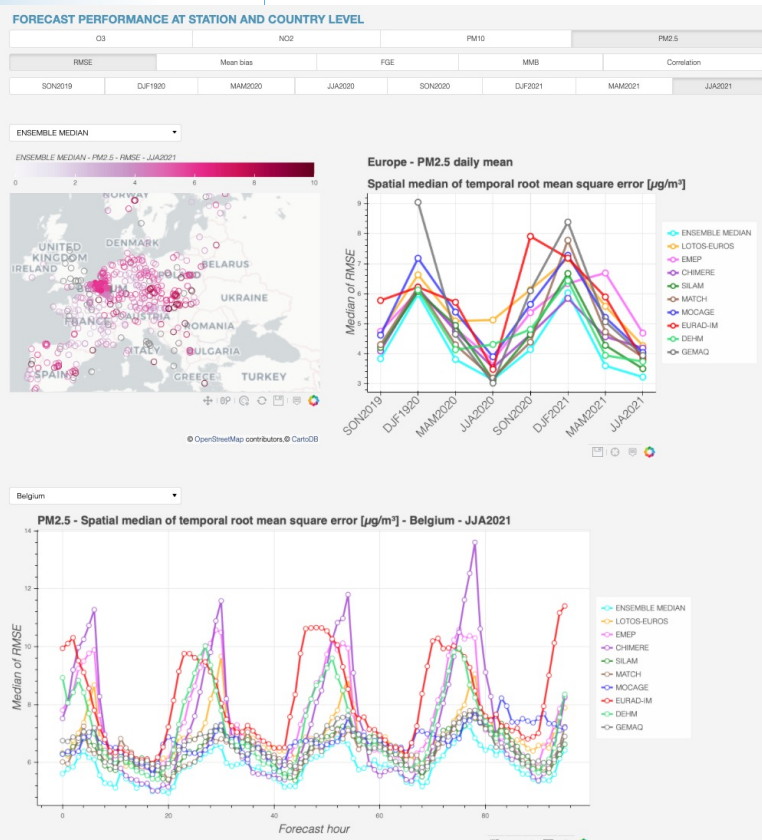


- Over Europe, a multi-model ensemble is used to deliver forecasts (with uncertainty).
- It has now 9 operational members (CHIMERE, DEHM, EMEP, EURAD, GEM-AQ, LOTOS-EUROS, MATCH, MOCAGE, SILAM) and 2 more are ramping up (MONARCH, MINNI).
- Effectively, a “premier league” for original air quality models in Europe, leveraging on national efforts and expertise.

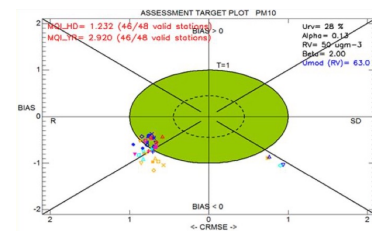


# ROUTINE PERFORMANCE EVALUATION

<https://regional.atmosphere.copernicus.eu/evaluation.php?interactive=cdf>



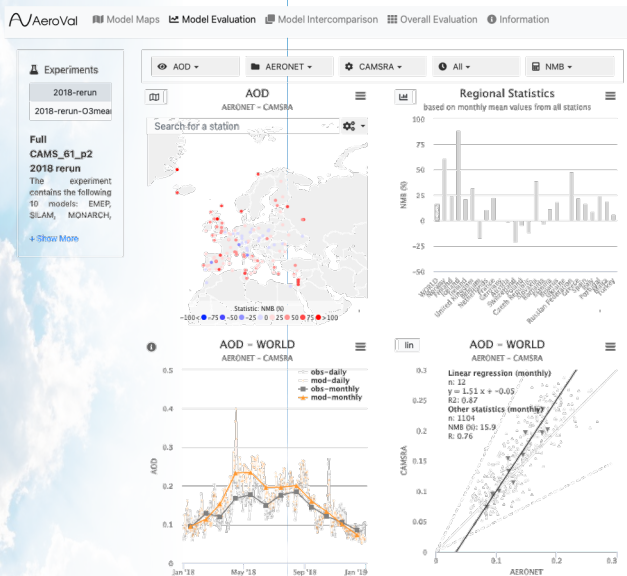
- Careful selection of sites for verification (representativeness)
- 9 models + ensemble median
- 8 last quarters
- O<sub>3</sub>, NO<sub>2</sub>, PM<sub>10</sub>, PM<sub>2.5</sub>
- RMSE, Mean bias, FGE, MMB
- Expanding to incorporate JRC-led FAIRMODE Modelling Quality Objectives and Benchmarking





# IN-DEPTH MODEL EVALUATION

3 phases, including re-runs with additional outputs in order to get deeper understanding on the strengths and weaknesses of each modelling system. Focus on 2018.



[https://aerocom-evaluation.met.no/main.php?project=cams61\\_p2&exp=2018-rerun](https://aerocom-evaluation.met.no/main.php?project=cams61_p2&exp=2018-rerun)

Work led by TNO (R. Timmermans, M. Schaap et al.)



## SELECTED FINDINGS

### Ozone

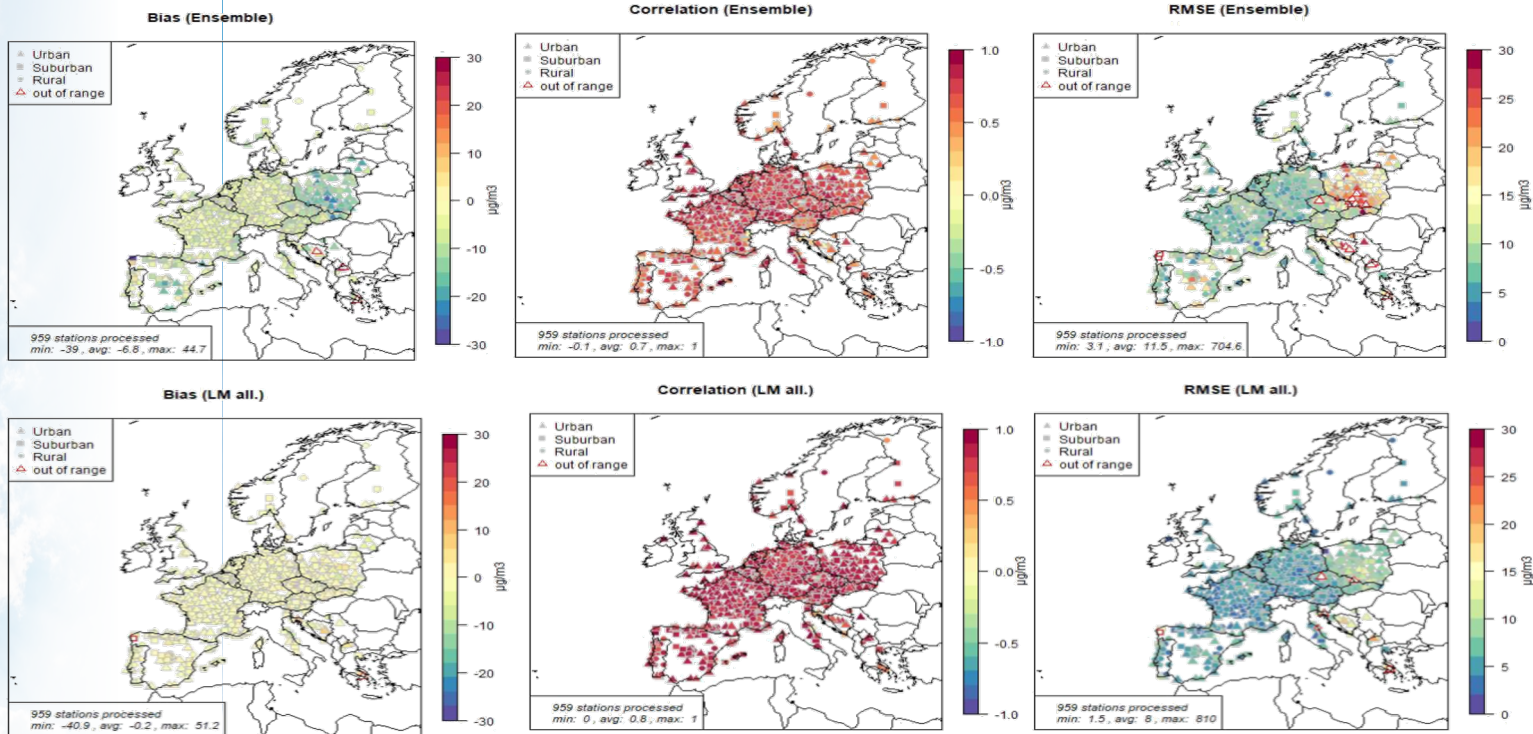
- positive bias in the Mediterranean area, worse where where mesoscale phenomena could control the ozone dynamics
- generally, the models do a poorer job at capturing the ozone diurnal cycle than the seasonal cycle, and across the percentiles

### PM

- there is a large spread in the results for sea salt, with approximately a factor 5 between the model with the lowest and highest sea salt concentrations, both in PM10 and PM2.5.
- most models underestimate OC in summer. Recommend to perform a sensitivity analysis with much increased BVOC emissions in summer.
- most models underestimate SO<sub>4</sub> by 35% and more. Sulphur wet deposition is substantially underestimated.
- comparison to observations of ammonia plus ammonium and ammonia indicates that the temporal emission profiles for NH<sub>3</sub> overestimates NH<sub>3</sub> emissions in late winter.
- ammonium aerosol concentrations and nitrate varies from being substantially overestimated to substantially underestimated.
- most model significantly underestimate wet deposition of oxidized nitrogen.



# MODEL OUTPUT STATISTICS (PM<sub>10</sub>, 2019)



Mean Biases: -6.8 to -0.2  $\mu\text{g}/\text{m}^3$   
Correlation: 0.7 to 0.8  
RMSE: 11.5 to 8  $\mu\text{g}/\text{m}^3$

Recommended solutions compatible with model upgrades  
use ML (ridge and LASSO)

Work led by INERIS (A. Colette et al.)



## Five fusion methods tested:

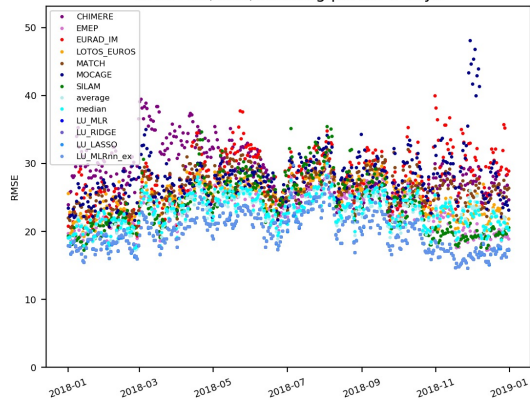
- multi-linear regression (MLR);
- regularized MLR with the LASSO regularization term (Least Absolute Shrinkage and Selection Operator); regularized MLR with Ridge regularization term (RIDGE);
- conditional MLR with non-negative model weights MLRnn;
- Krishnamuti et al. version of classical multilinear regression (KRISH).

The tests covered analysis and forecast for  $\text{NO}_2$ ,  $\text{O}_3$ ,  $\text{CO}$ ,  $\text{SO}_2$ ,  $\text{PM}_{2.5}$ ,  $\text{PM}_{10}$ . Considered learning periods ranged from 1 to 350 days. The hourly weighting coefficients were handled with a Gaussian smoother with width ranging from 0.01 h up to 5 h. **The simulations confirmed the added value of the fusion post-processing of the ensemble.**

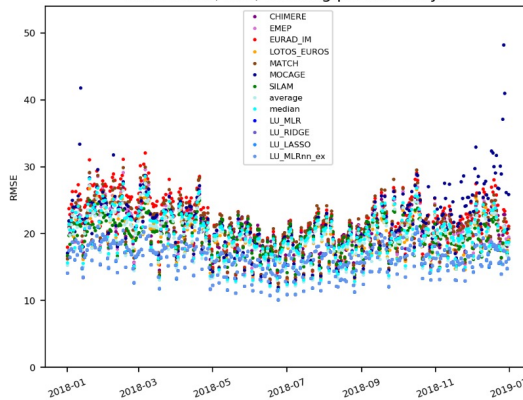


# WORKING ON ENSEMBLE METHODS

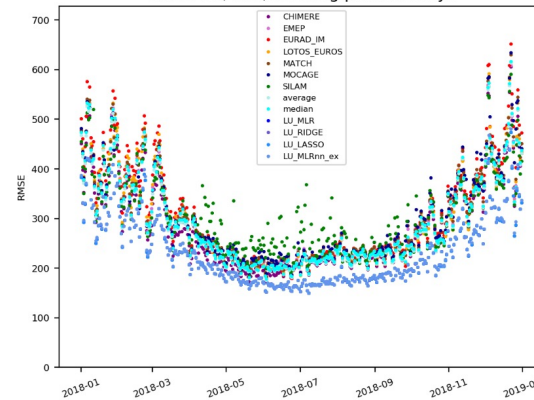
RMSE O3, fcst, learning period 1 days



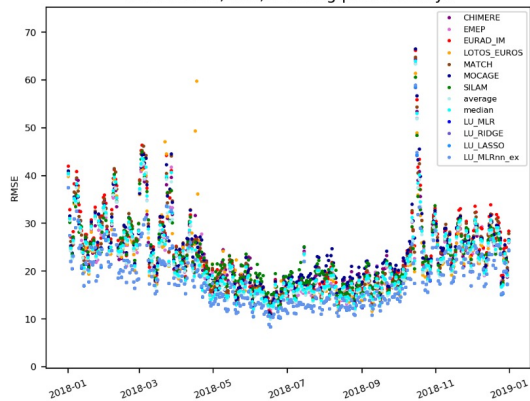
RMSE NO2, fcst, learning period 1 days



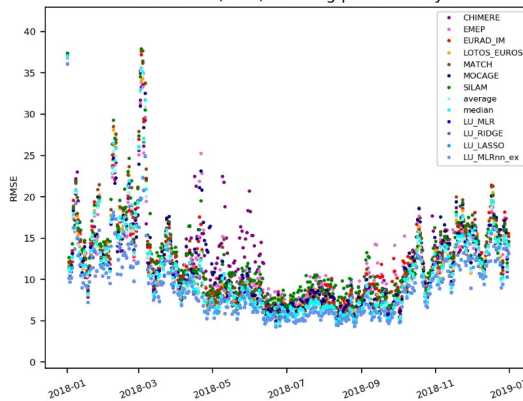
RMSE CO, fcst, learning period 1 days



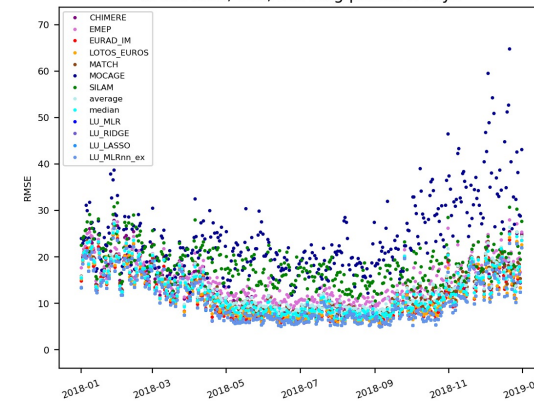
RMSE PM10, fcst, learning period 1 days



RMSE PM25, fcst, learning period 1 days



RMSE SO2, fcst, learning period 1 days





The following setups were identified for operational usage of the system:

- For analysis / reanalysis, a 1-day learning with hourly coefficients with  $\sigma = 0.01$  hr. For such setup, space-resolving RIDGE showed sufficiently stable results but non-negative MLR can also be considered for its reasonable performance.
- For forecasting, the situation is completely different. A reasonable compromise between the strongest skill of the day 0 of the forecast and day 4 is achieved for: 10 days of learning, hourly resolution of weights and  $\sigma = 2$  hours. In this case, space-resolving RIDGE demonstrates the best skills followed by non-negative space-resolving MLR.

All fusion models show lower RMSE and higher correlation coefficient than individual and ensemble-mean models. Behaviour of the standard deviation ratio is essentially not constrained by the current fusion approaches.

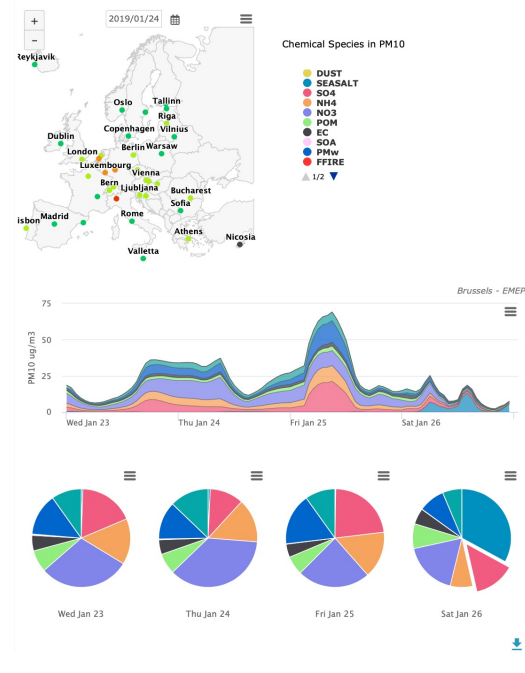
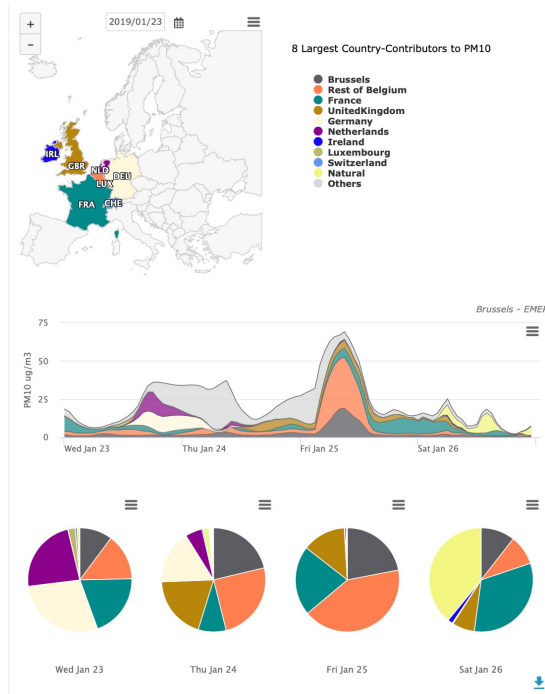
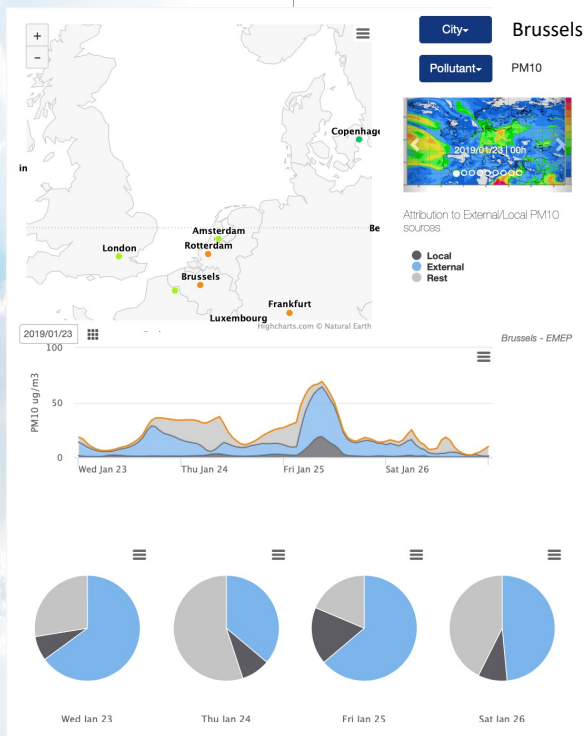




Atmosphere  
Monitoring

# PRODUCTS FOR AIR QUALITY MANAGERS

For the European capitals, daily analysis of local versus large scale contribution to air pollutant concentrations. Where does pollution come from? What is the chemical composition of PM?



<https://policy.atmosphere.copernicus.eu>



Atmosphere  
Monitoring

# THE CAMS AIR CONTROL TOOLBOX (EUROPE)

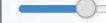
Field: Daily Concentrations  
 Pollutants: PM10  
 Forecast Base Time: 2020-06-09  
 Valid Time: 2020-06-09

### Emissions of the main activity sectors

#### From Europe

Traffic

reduction: 60%



Industry

reduction: 20%



Residential

reduction: -15%



Agriculture

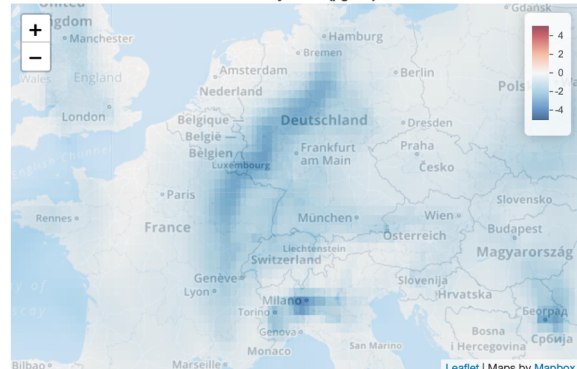
reduction: 0%



#### Color scale upper limit



Concentration map | Difference map | Country scenario  
 PM10 daily mean ( $\mu\text{g}/\text{m}^3$ )



Difference between the reference PM10 map including only the main anthropogenic sources and the user scenario assuming a Europe-wide uniform reduction of: Agriculture: 0 % ; Traffic: 60 % ; Residential: -15 % ; Industry: 20 %

Get map

The CAMS ACT has been recently adjusted to support European Member States with the management of air quality during the COVID-19 crisis.

Field: Daily Concentrations  
 Pollutants: PM10  
 Forecast Base Time: 2020-06-09  
 Valid Time: 2020-06-09

Target city: Paris

### Emissions of the main activity sectors

From Europe

Traffic: reduction: 60%

Industry: reduction: 20%

Residential: reduction: -15%

Agriculture: reduction: 0%

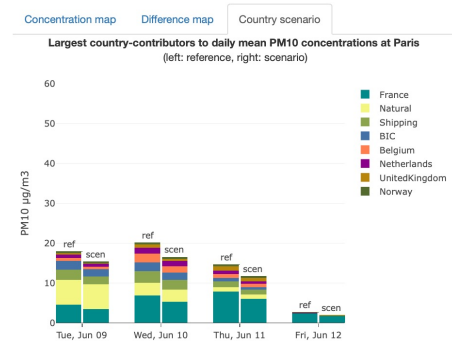
From France

Traffic: reduction: 70%

Industry: reduction: 15%

Residential: reduction: 5%

Agriculture: reduction: 0%

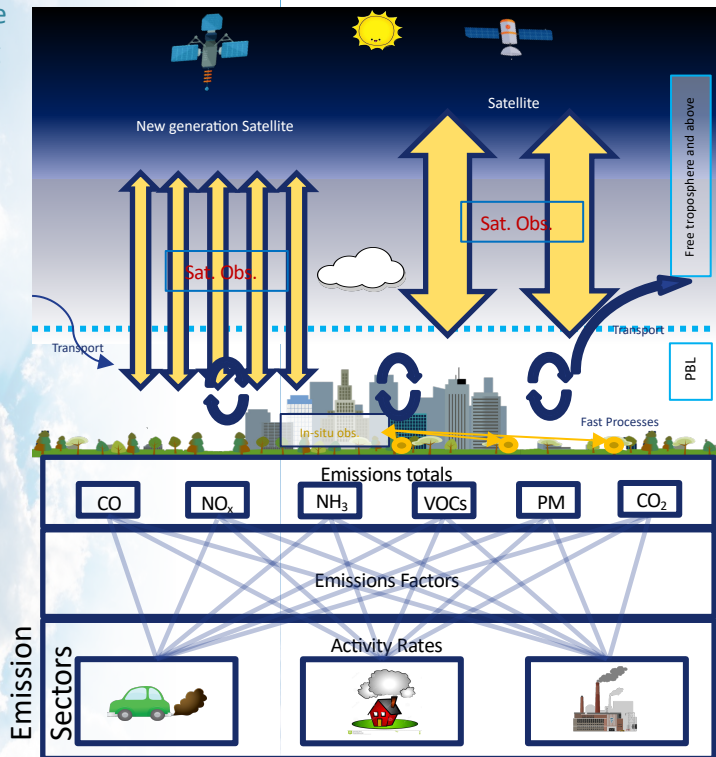


Co-designed with EU Member States and operated using one of the ensemble members (CHIMERE, Ineris, FR).

<https://policy.atmosphere.copernicus.eu>



# TARGET: OBSERVATIONS-BASED EMISSIONS



- Target species (direct): NO<sub>2</sub>, CO, NH<sub>3</sub>, CH<sub>4</sub>, SO<sub>2</sub> (large sources only)
- Target species (indirect): PM<sub>2.5</sub>/PM<sub>10</sub> (AOD and aerosol size information) and NMVOCs (HCHO, glyoxal, vegetation parameters...).
- global, ~10km, hourly.
- Sectorial inversion.
- Requirements on emissions prior information (link to activities on uncertainty).
- Links and support to policies on AQ and GHG emissions, working with the Member States and national efforts.



Atmosphere Monitoring



Copernicus EU



Copernicus ECMWF



@CopernicusEU  
@CopernicusECMWF  
@VHPeuch



@copernicusecmwf



Copernicus EU  
Copernicus ECMWF



[www.copernicus.eu](http://www.copernicus.eu)  
[atmosphere.copernicus.eu](http://atmosphere.copernicus.eu)

