# What can regional air quality models can bring us (in general and in the COVID-19 lockdown situation)?

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### Why do we need chemistry-transport models ?

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- To investigate the chemical/physical processes involved
- To predict air pollution in the near future
- To simulate alternative realities

To evaluate and improve our current scientific understanding

To warn in advance people at risk so that they adapt their outdoor activities

> To allow public authorities to take short-term emission reduction measures

To plan observational campaigns

To conduct impact studies and design most efficient mitigation measures



### What value regional models bring compared to global models ?

Policy-relevant spatial scale (national/european)

• Finer spatial resolution

Atmosphere Monitoring

- Higher quality input data
- More detailed representation of chemical/physical processes

To estimate more precisely to which pollution levels people are exposed

To reduce the representativeness issues in model-observation comparisons

To include explicit rather parameterized representations of some processes

To take into account more chemical species and reactions

To refine the meteorological and emission inputs

Europear

### **Regional model applications**

Atmosphere Monitoring Different types of products from regional models, allowing different types of applications :

### AQ forecasts

Predictions of AQ a few days in advance

### • AQ re-analaysis

Long-term (typically multi-year) combination of model-based simulations and AQ observations (data fusion, data assimilation)

### AQ source apportionment

Model-based approaches for estimating the contribution of specific regions, countries, emission sectors...

### AQ emission scenario

Regional simulation with alternative emission forcing







# CAMS INFORMATION FLOW

Atmosphere Monitoring



Earth Observation from satellite (>75 instruments) and insitu (regulatory and research)





40km Globe (twice daily, d+5)

CAMS main operational data assimilation and modelling systems







### CAMS European AQ Forecasts

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#### AIR QUALITY in Europe: Ensemble modelling

 PM10 - Daily mean concentration - Forecast computed with Ensemble model. Valid for: 2018-10-10



#### DOWNLOAD AND APIs

News!

Catalogue of services

#### EUROPEAN AIR QUALITY SERVICES

- OTHER AIR QUALITY MAPS
- ENSEMBLE MODI
- HOURLY FORECASTS & ANALYSES EPSGRAMS
- PARTNER MODELS
- HOURLY FORECASTS
- HOURLY ANALYSES
- ENSEMBLE VS PARTNER MODE
- DAILY MEAN AND MAXIMUM
- REANALYSES
- ENSEMBLE REANALYSIS
- SIGNIFICANT EVENTS
- NRT OBSERVATIONS

### DATA DOWNLOAD

- ONLINE DATA
- ARCHIVES
- REANALYSIS DATA
- OGC WEB SERVICES
- DATA SERVER FACILITIES

#### O VERIFICATION RESULTS

**CECMWF** 

OPERPICUS Europe's eyes on Earth

European Commission

- FORECAST VS OBS
- ANALYSIS VS OBS
- ANALYSIS VS FORECAST
- MEAN SCORES
- TIME SERIES
- TAYLOR DIAGRAMS

Scale for concentration (Unit : µg/m<sup>3</sup>)

## CAMS Regional production- overview

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# **Operational Europe-wide Air Quality Service based on**:



## CAMS Regional Production – Near Real Time (NRT) products

### Atmosphere Monitoring

# Individual & Ensemble 4-Day Forecasts:

- 03, NO2, CO, SO2, PM10, PM2.5, PM10, NO, NH3, PANs & NMVOC, SIA Dust Surface, 50m, 250m, 500m, 1000m, 2000m, 3000m, 5000m
- Birch, Grass and Olive & Ragweed Pollens (surface)
- Resolution 0.1°

# Individual & Ensemble Analyses (DD-1):

- 03, NO2, CO, SO2, PM10, PM2.5, PM10, NO, NH3, PANs & NMVOC , SIA
   Dust
- Surface, 50m, 250m, 500m, 1000m, 2000m, 3000m, 5000m
- Assimilation/data-fusion of in-situ surface observations and some models column satellite data

# Validation & Statistics products:

- Forecasts & Analyses versus Observations, Various Scores, Daily Mean & Max plots
- EPSgrams + scores per station dataset (csv format file)





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Emissions are both an input to CAMS global (10x10km) and regional systems and a popular product. Entirely new datasets have been released covering 2003 to 2019 (extrapolation).

Example: CO<sub>2</sub> emissions from shipping activities (provider: FMI, Finland).



Carbon dioxide emissions (10^3 kg)							
				· · · · · · · · · >			
10.0	100.0	1000.0	10000.0	100000.0			



Carbon dioxide emissions (10 <sup>3</sup> kg)							
				· · · · · · · · · >			
Ó.O	100.0	1000.0	10000.0	100000.0			



# CAMS Regional Production: progress as a group

Atmosphere Monitoring

- Same weather forecasts,
  same emissions, same
  chemical boundary
  conditions: enough spread
  is generated though and it
  makes model-dependent/
  independent comparisons
  meaningful
- Model median really hard to beat (on average)









Ozon







### CAMS Regional production: coupling with machine learning

Atmosphere Monitoring

## **Statistical correction**

- Regional models often coupled with MOS (model output statistics) approaches for correcting biases at monitoring stations
- Many types of MOS : simple linear models, Kalman filter, analogs, sophisticated machine learning models



### Spatial downscaling: Copernicus 2.0 National Uptake Scheme

Atmosphere Monitoring

Monday 21 March 2016 00UTC MACC-RAQ Forecast t+000 VT: Monday 21 March 2016 00UTC Model: ENSEMBLE Height level: Surface Parameter: PM10 Aerosol [ µg/m3 ]



**Objective:** generalise operational integrated modelling chains to monitor and forecast air quality in a fully consistent way from the global scale to the city scale.



Please note colour scales are different.

CAMS regional + local observations





### Support to Intensive Measurement Campaings

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- Characterize some sporadic pollution events
  - Example of CARA French program : temporary filter measurements of chemical composition of PM pollution when pollution episodes are forecasted
- Support the planning of field experiments involving mobile measurements (on-board cars or research aircraft for instance)
  - Locate spatially and temporally events of scientific interest : dust storms, transport of anthropogenic plumes from megacities, biomass burning events
  - Help identifying sources of interest

Flight planning of the ARCTAS summer campaign. <u>Objective</u>: to sample the northern branch of the Siberian biomass plume that was forecasted to reach 87N







Europea

# The Regional Production – Reanalysis products

- Atmosphere Monitoring
  - Hourly concentrations for O3, NO2, CO, SO2, PM10 and PM2.5 + NO,  $NH_3$ , NMVOC, PANs
  - Surface + 7 levels (50, 250, 500, 1000, 2000, 3000, 5000)
  - Assimilation/data-fusion of in-situ surface observations and some models column satellite data
  - Various air quality indicators:
    - Seasonal and annual mean surface concentrations
    - Number of threshold exceedances over Europe for
      - PM10: daily 50µg/m<sup>3</sup>
      - O3: hourly 180µg/m<sup>3</sup> & 240 µg/m<sup>3</sup> and daily max 8-h 120µg/m<sup>3</sup>
    - Additional air quality indicators
    - Identification of the major pollution events: http:// policy.atmosphere.copernicus.eu
  - Data sets (Surface level & Ensemble only so far) available for:
    - Validated reanalyses: 2014 2015 2016 2017 2018
    - Interim reanalyses: 2015 2016 2017 2018 2019



REANALYSIS DATA Home > Services > RegionalAirQuality > Data access > Resnatysis data								
Data access	Ensemble and Fo	e Analysis recast	Indi	vidual Analyses	Indiv	vidual Forecasts	Analy	/erification of /ses & Forecast
Archived data	Online data	Reanalysis	data	Data server ser	rvices	WMS & WCS se	rvices	
	AMS Reg	ional Air	Qu	uality - Rea	naly	sis data		
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### **Regional reanalyses: Impact studies**

#### Atmosphere Monitoring



Ozone (number of days with 8-hour daily maximum over 120 mg.m<sup>-3</sup>)

Regional reanalyses are required to bridge the gap with exposure scales and assess impacts.

Multi-year reanalyses are useful because:

- interannual variability is very large especially in Europe so one particular year may not be representative
- some impacts (health) result from long term or even childhood exposures

### Integration in EEA AQ maps







### CAMS regional production : some downstream users



CAMS European air quality forecasts are used to provide the up-to-date information on air pollution, pollen, UV and dust.

#### Air quality: an exclusive and daily air quality forecast programme



Every day, Euronews offers to its European viewers air quality forecasts of major European cities. Each city is featured with an air quality index, from 1 to 5 (very good to very poor).

### aqicn.org (International)



#### SafeAdviser (Latvia)



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### CAMS regional policy service

Atmosphere Monitoring

- A number of products and services dedicated to policy support
  - Assessment of the air pollution status in Europe based on the combination of a multi-models ensemble approach, in-situ observation data and satellite retrievals
  - Improving our understanding of air pollution patterns and episodes in Europe
    - role of local sources versus long range transport,
    - chemical composition,
    - activity sectors,
    - trends...

### policy.atmosphere.copernicus.eu

-	Implemented by BCMWF as part of The Copernicus Programme			News Events Press Tenders Help&support		
Ø	Atmosphere Monitoring Service	DATA	ABOUT US	WHAT WE DO	QSEARCH	

#### **Overview on Policy Support**

The CAMS policy web pages provide a number of products and results that aim at supporting decision and policy making in the management of air pollution episodes. Policy services are based on the air quality regional services capacities to elaborate added- value products describing the evolution of air quality in Europe and the influence of main anthropogenic sources, helping in designing appropriate and efficient policy responses to episode situations.

Moreover, it is expected that the policy products may be useful tools to support communication action of policy makers towards the general public, and regulatory reporting according to the European air quality Directives (2008/50/EC) and their implementation decisions (201/869/EU).

Policy services take stock of the high modelling capacities and expertise of CAMS teams to provide relevant information on the causes of pollution episodes and their development in the future, and insights about the main drivers that lead to such situations. They vary with the country and the period of the year. CAMS products are well-suited and validated to characterize air pollution background levels in the European countries. It means average air pollution to which citizens are exposed every day. But the accuracy of the tools and models implemented to runs CAMS services is not sufficient to describe in detail air pollution patterns and sources inside the citize, especially hot spot situations and buy roads or industrial sources. For all questions and suggestions interested users are invited to contact the user support.

Overv	iew on Policy Support
Contro	ol Scenarios
Po	licy Scenarios
Air	Control Toolbox
Source	Contribution to EU Cities
Da	ily Forecasts
Pri	evious Episodes Analysis
Ye	arly SR overview
CAMS	Air Quality Reports
Policy	workshops



### Source apportionment

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# Assess the contribution of the different emission sources to pollutant concentrations

- More or less sophisticated methods proposed in the literature :
  - "Brute force" : run multiple simulations zeroing out some emission sources (but limitations due to non-linearity of atmospheric chemistry)
  - Tagging pollutant by source (region and/or sector)





### **CAMS Policy Service Source apportionment**

Atmosphere Monitoring

- Geographical origin and chemical speciation of PM and O3 forecasts in 40 major European cities
- Source contribution split into :
  - local
  - national
  - EU

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- other countries
- natural
- (based on EMEP model)

# **Daily Forecasts** Pollutant . Inbution to External/Local PM10 source LUD liked Jun 20 Tue Jun 21 Wed Jun 28 The Jun 29

### Previous Episodes Analysis



### https://policy.atmosphere.copernicus.eu/SourceContribution.php





## **CAMS Policy Service Source apportionment**

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- (based on EMEP model)



https://policy.atmosphere.copernicus.eu/SourceContribution.php





### CAMS Policy Service: Chemical speciation

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Chemical speciation gives an information about the sectors potentially involved



https://policy.atmosphere.copernicus.eu/SourceContribution.php





## CAMS Policy Service: Air Control Toolbox

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# Web-based fast response episode scenario forecasting

- Accounting for the complexity of atmospheric chemistry & long range transport for the current forecasting situation
- Based on regional chemistrytransport + daily machine learning





# How can regional models be useful at the time of COVID-19 ? (and which benefits can the COVID-19 situation provide to regional models)



## COVID-19 situation : opportunities & challenges

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• COVID-19 mobility restrictions strongly (but heterogeneously) modified the anthropogenic emission forcing

## • **Opportunities** :

To validate current modeling systems under strongly unusual conditions
 To assess the potential benefits of future pollution mitigation strategies

### • Challenges :

To estimate which change it induced on pollutant concentrations (independently of the meteorology)

To understand the physical/chemical mechanisms behind these changes



### Impacts of COVID-19 lockdown on AQ

- Atmosphere Monitoring
- COVID-19 impact can first be assessed using AQ (surface, satellite) observations, using simple approaches like comparisons with previous years
- Here over Spain with TROPOMI NO2 tropospheric columns :



### Impacts of COVID-19 lockdown on AQ

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### Limitation : confounding effect of the meteorological variability ignored!



### Impacts of COVID-19 lockdown on AQ – Weather normalization techniques

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- Taking into account the confounding effect of the meteorological variability on AQ can be done using more sophisticated weather normalization approaches
- For instance based on machine learning models fed with meteorological data:



Petetin et al., 2020, ACP





Relative changes of  $PM_{25}$  (%)

**C**ECMWF

-10

-30

European

opernicus

2. Relate these changes to changes in emissions and production/destruction processes

### COVID-19-related emission changes

Atmosphere Monitoring Requirement for CTMs : to estimate the anthropogenic emission reduction factors in source sectors most impacted by COVID-19 (using activity data obtained from multiple data sources)



Daily emission reduction factors in the 4 emission sectors most impacted (Guevara et al., 2020, ACP)



### COVID-19-related emission changes

Atmosphere Monitoring

#### NOx AVERAGE WEEKLY EMISSIONS (EU-28)

Emissions during the COVID-19 pandemic







Dataset available soon through the CAMS <u>Atmosphere Data Store</u>

CAMS European daily emissions for the lockdown :

Development of daily-, country- and sector-dependent COVID-19 emission reduction factors (Guevara et al., 2020), to be combined with the CAMS-REG European inventory (Kuenen et al., 2020) for AQ modelling





# CAMS multi-regional-model Lockdown hindcast

Monitoring

11 Contributing Models	
CHIMERE (INERIS)	
DEHM (Aarhus Univ.)	+-
EMEP/MSC-W (Met Norway)	╬
EURAD-IM (RIUUK)	
GEM-AQ (WUT/IEP)	
Lotos-Euros (KNMI+TNO)	
MATCH (SMHI)	+
MOCAGE (Météo-France)	
SILAM (FMI)	+-
MINNI (ENEA)	
MONARCH (BSC)	2篇6

- Leveraging on several CAMS elements: ۰
  - Air Pollutant Emissions (CAMS\_81 & BSC)
  - Regional production (CAMS\_50)
    - Multi-model approach
    - 11 participating models
  - Policy Service (CAMS\_71)
    - Coordination





### CAMS multi-regional-model Lockdown hindcast

**Atmosphere** Monitoring

### Up to 60% reduction in NO2 surface concentrations

NO2 concentration mean difference, ENSEMBLE (absolute diff. in ug/m3) Lockdown scenario minus Reference (2020-03-01 to 2020-04-30)







### Up to 20% reduction in PM10 surface concentrations

PM10 concentration mean difference. ENSEMBLE (absolute diff. in ug/m3) Lockdown scenario minus Reference (2020-03-01 to 2020-04-30)



PM10 concentration mean difference, ENSEMBLE (relative diff. in %) Lockdown scenario minus Reference (2020-03-01 to 2020-04-30)



Next steps : to evaluate the consistency of these reductions with observations, to assess the impacts of COVID on precursors (VOC) and production of secondary pollutants (secondary PM, O3)...

-20

-40

-60



### Conclusion

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- Regional AQ models : essential for both scientists and policy-makers
- Different types of products (*forecast, reanalysis, source apportionment, emission scenario*) for different types of applications
- CAMS provides a large panel of products available to a wide users community
- COVID-19 offers opportunities (e.g. better understanding of AQ, more efficient near-future mitigation measures)
- Observations alone or combined with statistical methods : useful but limited interpretability
- Need for regional models fed with high-quality emission data to understand the impacts of COVID-19 on AQ
- On the other side, discrepancies between expected and observed changes can allow identifying deficiencies in current modeling systems



# Regional production: Conclusion... Hervé PETETIN (<u>herve.petetin@bsc.es</u>) Augustin COLETTE (<u>augustin.colette@ineris.fr</u>)





#### Among others:



Atmosphere Monitoring

Meteo-France, France: N. Assar,, G. Collin, J.M. Damas, M. Joly, L. Martin, V. Petiot, M. Pithon, M. Plu, B. Saclier, S. Rouzeau, H.Pech, M.Hulin, A. Royer INERIS, France: A. Colette F. Meleux, L. Rouil, A. Ung

Aarhus University, Denmark (DEHM): C.Geels, J.H. Christensen, K. Hansen, Z. Ye
BSC, Spain (MONARCH): O. Jorba, M.T Pay, M. Guevara, D. Bowdalo, J. Benavides
ENEA, Italy (MINNI): M. Adani, L. Ciancarella, L. Vitali
FMI, Finland (SILAM): R. Kousnetsov, M. Sofiev
IEP-NRI, Poland (GEM-AQ): J.W. Kaminski, J. Struzewska
INERIS, France (CHIMERE): A. Colette F. Meleux, A. Ung
KNMI, the Netherlands (LOTOS-EUROS): H. Eskes, J. Ntouros, R. Versendaal
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