Evaluation and development of regional air quality modelling and data assimilation aspects - *Highlights from CAMS-61 project*

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FINNISH METEOROLOGICAL INSTITUTE
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TFMM, 3-5th May 2022

BACKGROUND

COPERNICUS ATMOSPHERE MONITORING SERVICE (CAMS)

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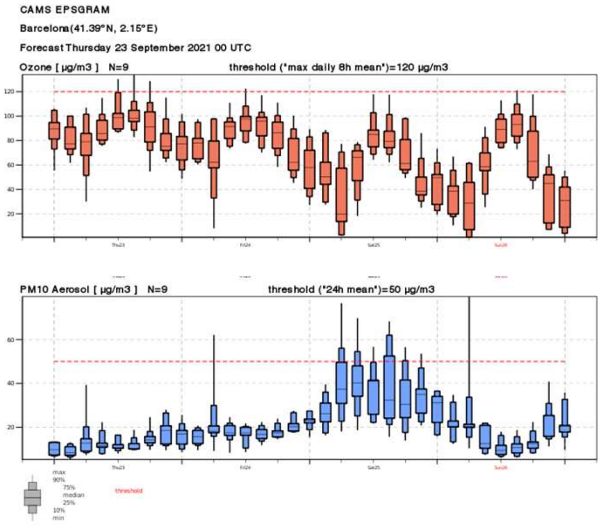
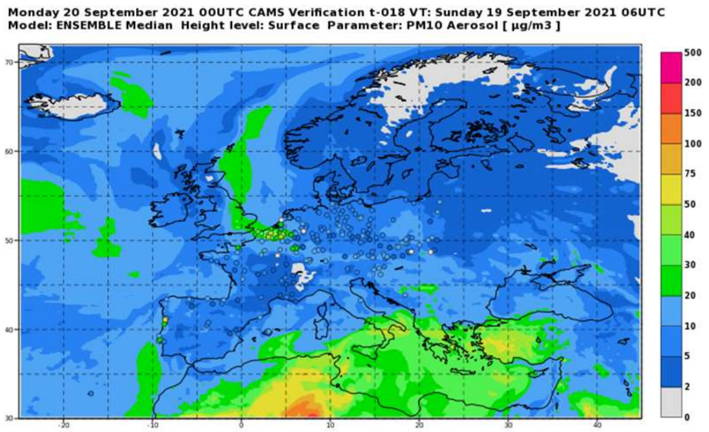
REGIONAL AIR QUALITY SERVICE

Within CAMS an ensemble of 9 (soon to be extended to 11) chemistry transport models provides daily analyses and forecasts over Europe. https://atmosphere.copernicus.eu/

CHIMERE | DEHM | EMEP | EURAD-IM | GEM-AQ | LOTOS-EUROS | MATCH | MOCAGE | SILAM | ENSEMBLE





Model setup similar:
0.1°x0.1°
CAMS-REG-AP emissions,
CAMS forest fire emissions
Boundary conditions from CAMS reanalysis

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CAMS_61 project (January 2020 – June 2021)

Improve the quality of CAMS regional air quality service

Through: provision of development plans, guidelines, working examples and tools for the continuous upgrade of the service. It includes

(i) a in depth assessment of the CAMS regional forecasts

(ii) best practices for coupling forecasts to analyses → Potential of using data assimilation adjusted emissions into the forecasts

(iii) model-agnostic tools for the data assimilation of Sentinel-4 and 5p observations → **CSO tool** - Generic observation operator for satellite data

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+ efforts from regional air quality modeling teams

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In-depth assessment of the CAMS Regional Systems

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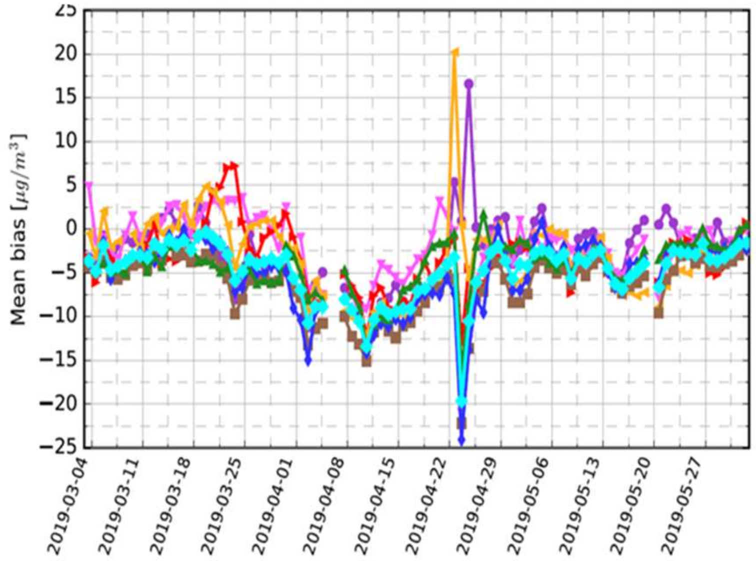
- Phase 1: Evaluation of the operational CAMS regional forecast data (2018-2019)
  - PM10, PM2.5, NO2, O3
  - Where do all models go wrong? Where do we see large spread or outliers?
  - Using screened EEA AQ e-Reporting/EBAS/WMO-GAW NRT observational data (GHOST tool by BSC- **G**lobally **H**armonised **O**bservational **S**urface **T**reatment)



- Phase 2: Diagnostic evaluation based on dedicated model runs (model re-runs 2018)
  - Speciated PM, Deposition, PBL, meteorology
  - Observational data from EIONET, EBAS/EMEP and AERONET networks

- Phase 3: Sensitivity studies
  - Role of boundary conditions versus inner domain production of dust and sea salt
  - Sensitivity to BVOC emissions
  - Sensitivity to BLH
  - REF 2 emissions

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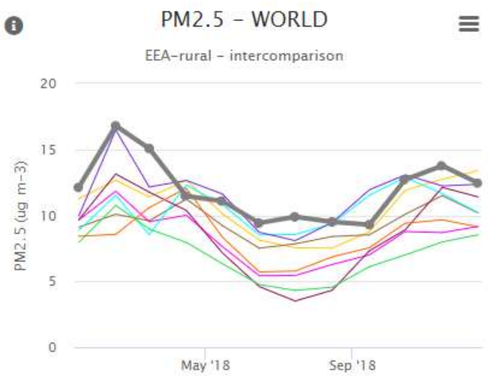
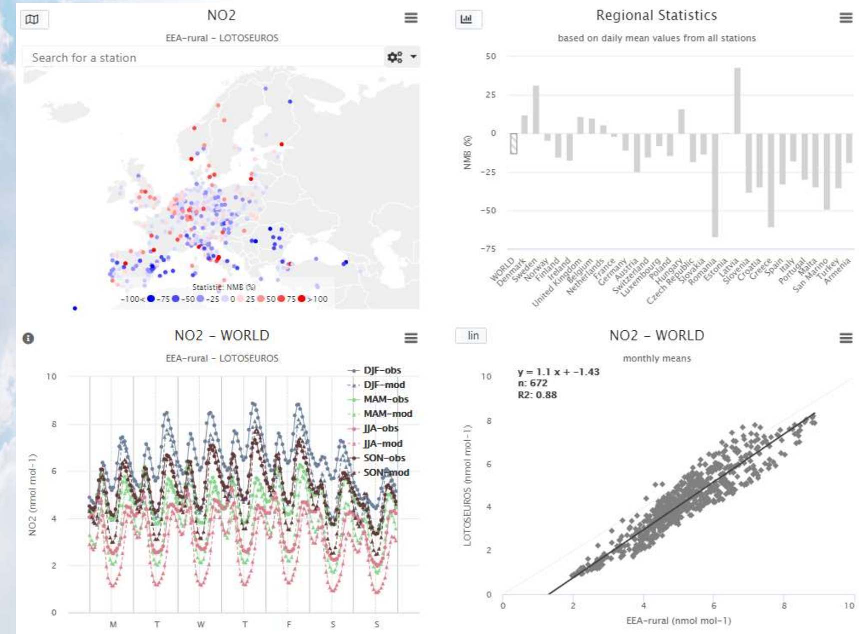
AEROCOM interface for evaluation in all three phases





NO2	EEA-rural	-40.6	-28.6	-23.8	-29.1	-2.3	2.6	-19.0
	G-EBAS	-36.6	-16.2	-15.2	-13.0	11.9	18.1	2.1
O3max	EEA-rural	5.5	2.5	-7.9	-3.5	6.9	-4.3	-8.2
	G-EBAS	5.0	1.2	-8.2	-4.6	4.1	-6.8	-9.2
OX	EEA-rural	13.7	14.6	-2.1	0.6	4.2	-0.2	-3.3
SO2	EEA-rural	-79.6	-49.3	-31.4	-7.2	-22.9	-6.9	-58.7
	G-EBAS	-67.5	19.1	2.3	92.6	43.0	76.8	-11.9
CO	EEA-rural	-41.9	-41.2	-32.9	-40.0	-37.2	-42.2	-27.4
	G-EBAS	-18.9	-24.4	-9.2	-23.5	-3.5	-22.3	-11.0
PM2.5	EEA-rural	-2.7	-11.4	-12.9	-2.0	-11.2	-10.6	-9.8
	G-EBAS	6.1	2.2	-4.2	15.7	-1.2	4.0	3.7
PM10	EEA-rural	-29.1	-13.9	-26.2	-29.1	-13.2	-31.1	-23.7
	G-EBAS	-27.1	3.6	-20.4	-23.0	-3.2	-21.6	-17.1
SO4	EBAS-d	-11.4	-28.7	-35.1	-25.1	-32.7	-56.2	-57.1
	EBAS-m	-14.6	-32.4	-37.8	-29.0	-35.8	-58.2	-58.6
tNO3	EBAS-d	-9.7	314.6	-13.6	46.4	18.2	-20.9	-50.7
	EBAS-m	-8.3	315.3	-12.8	50.1	20.1	-19.7	-49.0
tNH	EBAS-d	-4.8	-37.3	-13.4	17.9	-2.2	-12.5	-1.5
	EBAS-m	-3.8	-36.4	-12.5	20.5	-0.6	-10.7	-0.1
NH3	EBAS-d	-54.1	-68.6	-42.4	-18.1	-42.3	-36.6	-9.1
	EBAS-m	-24.4	-60.6	-18.1	6.1	-13.3	-7.1	14.9
NH4	EBAS-d	35.4	-12.5	-7.7	50.2	16.2	-17.6	-33.0
	EBAS-m	37.2	-13.3	-7.0	49.7	17.4	-17.4	-33.4
HNO3	EBAS-d	-42.1	917.2	-50.6	11.9	-29.5	-25.4	-27.3
	EBAS-m	-45.1	865.8	-53.7	8.4	-34.2	-29.5	-31.3
NO3_PM25	EBAS-d	10.8	-26.9	-37.0	34.1	-8.6	-30.6	-52.5
	EBAS-m	-7.4	-37.7	-47.0	19.0	-19.5	-38.4	-57.9
NO3_PM10	EBAS-d	17.2	19.5	-1.9	54.2	37.1	-24.1	-51.9
	EBAS-m	23.5	20.6	0.3	53.5	37.0	-22.6	-52.1
SS_PM25	EBAS-d	86.2	260.4	-66.8	-60.4	99.4	33.3	51.1
	EBAS-m	64.6	217.3	-72.0	-64.0	72.3	23.5	28.7
SS_PM10	EBAS-d	4.5	91.7	-17.8	-76.5	62.0	-13.9	-13.8
	EBAS-m	4.2	94.2	-17.7	-76.3	63.7	-13.8	-13.8
EC_PM25	EBAS-d	19.4	-13.8	15.9	53.7	81.3	70.9	14.2
	EBAS-m	17.3	-12.0	15.2	52.5	83.2	71.6	14.6
OC_PM25	EBAS-d	-82.9	-9.1	-33.8	-37.1	0.8	-1.8	58.0
	EBAS-m	-82.5	-8.5	-32.4	-37.2	1.5	2.0	61.4
WetOXS	EBAS-d	-24.5	-41.6	-23.0	-25.9	-59.2	-53.3	-72.8
	EBAS-m	-12.2	-35.3	-16.3	-17.3	-53.8	-46.9	-69.4
WetRDN	EBAS-d	-14.3	-45.4	-2.5	-19.6	-24.5	-56.1	-30.2
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WetOXN	EBAS-d	-13.8	-40.8	-19.0	-37.9	-47.4	-67.3	-81.9
	EBAS-m	-6.3	-36.3	-13.6	-29.4	-41.4	-63.3	-79.3
Precip	EBAS-d							-95.9
	EBAS-m							-99.2
AOD	AERONET	-83.0		19.4	-64.2	-4.1	-8.3	-24.9

NMB (%): 100, 50, 0, -50, -100

- https://aerocom-evaluation.met.no/

$PM_{2.5}$ and PM_{10} bias 2018

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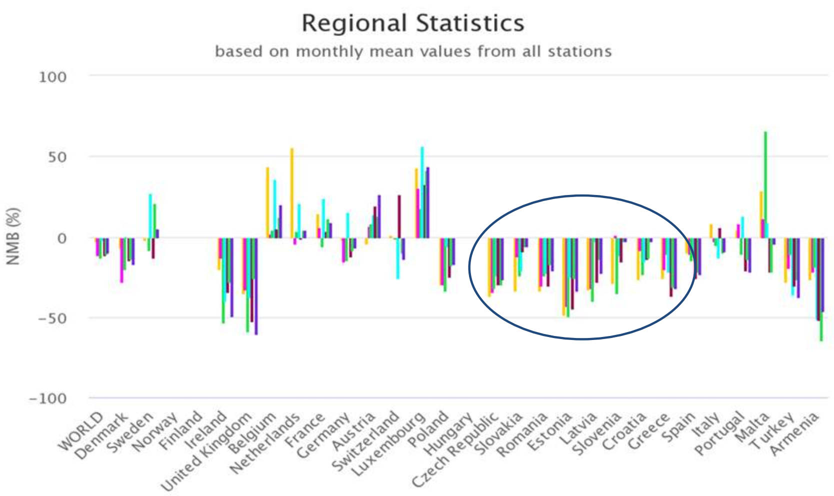
		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
PM2.5	EEA-rural	-2.7	-11.4	-12.9	-2.0	-11.2	-10.6	-9.8
	G-EBAS	6.1	2.2	-4.2	15.7	-1.2	4.0	3.7
PM10	EEA-rural	-29.1	-13.9	-26.2	-29.1	-13.2	-31.1	-23.7
	G-EBAS	-27.1	3.6	-20.4	-23.0	-3.2	-21.6	-17.1

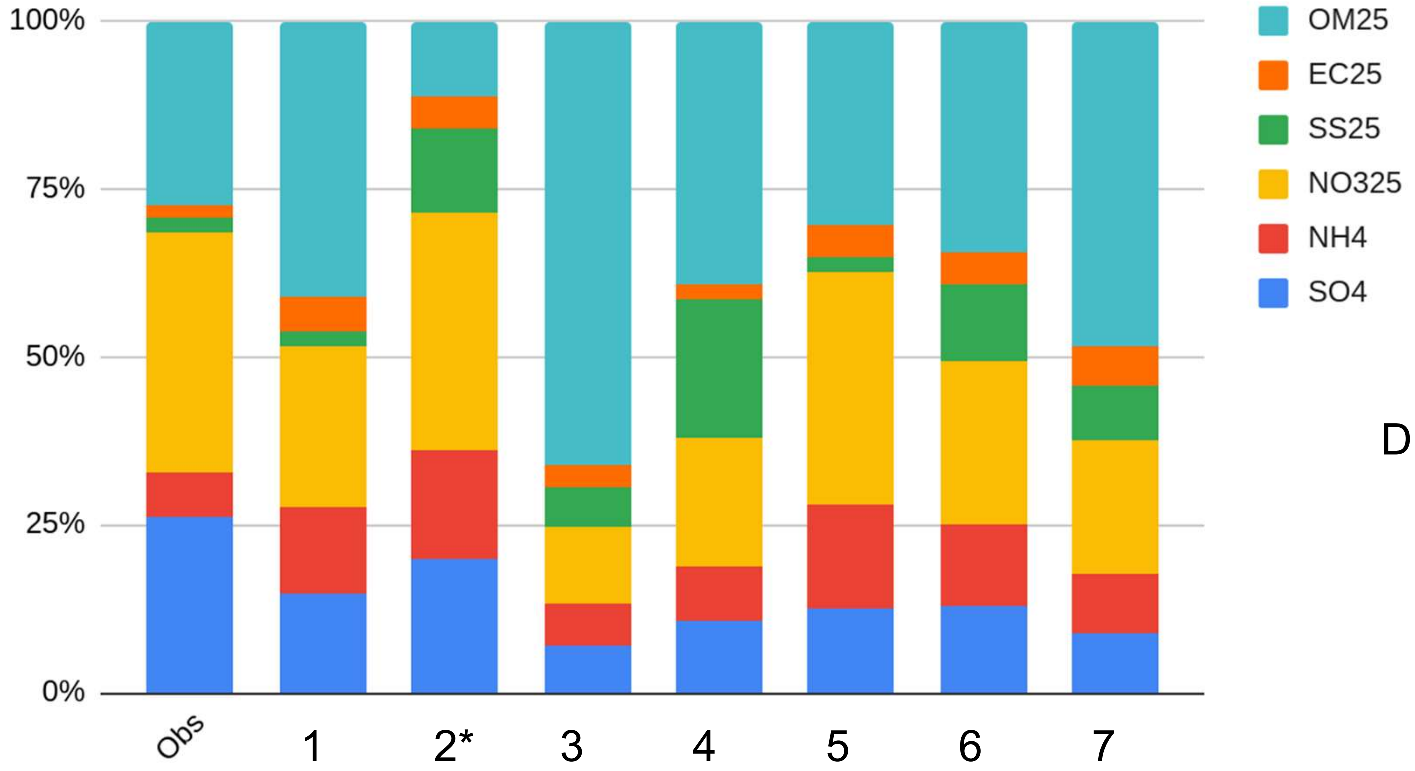
NMB (%) colour scale: 100, 50, 0, -50, -100

EEA-rural = rural background EIONET measurements
G-EBAS = **EMEP**, ACTRIS, AMAP, GAW and HELCOM



- Rather consistent biases across model
- Relatively small bias for $PM_{2.5}$, +- 10%
- More negatively biased PM_{10} (except 2 and 5)
- Some regions consistently underestimated
- Some areas are consistently underestimated by all models (emissions?)

Percentage contribution of chemical components (average of 6 French sites) 2018



Different composition:

- OM (30-70%)
- Sea salt (2-20%)
- SIA (25-75%)

- Note: Composition is different in different parts of Europe

Not included: dust, water

*Only SOA included, no primary OC

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Evaluation of SIA at background sites (mostly EMEP observations)

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
SO2	G-EBAS	-67.5	19.1	2.3	92.6	43.0	76.8	-11.9
SO4	EBAS-m	-14.6	-32.4	-37.8	-29.0	-35.8	-58.2	-58.6

Sulfate consistently underestimated (despite SO_2 very different)

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
NH4	EBAS-m	37.2	-13.3	-7.0	49.7	17.4	-17.4	-33.4
NO3_PM25	EBAS-m	-7.4	-37.7	-47.0	19.0	-19.5	-38.4	-57.9
NO3_PM10	EBAS-m	23.5	20.6	0.3	53.5	37.0	-22.6	-52.1

NMB (%): 100, 50, 0, -50, -100

Ammonium and nitrate varies (over- and under-estimated 50%), e.g. 4 and 7 very different

Seasonal variation (Median R (monthly))

		Model 1	Model 2	Model 3	Model 4	Model 5	Model 6	Model 7
SO2	G-EBAS	0.30	0.31	0.37	0.35	0.36	0.28	0.42
SO4	EBAS-m	0.59	0.67	0.73	0.43	0.66	0.22	0.77
NH4	EBAS-m	0.73	0.79	0.77	0.70	0.77	0.69	0.73
NO3_PM25	EBAS-m	0.85	0.89	0.81	0.74	0.87	0.88	0.85
NO3_PM10	EBAS-m	0.70	0.74	0.68	0.69	0.74	0.69	0.54

R-Time: 1, 0.75, 0.5, 0.25, 0

Sulfate: consistently low bias, but variation in temporal correlation

Nitrate/ammonium: mostly high r, with one exception (some models do not have coarse nitrate formation)

Low correlation in NH_3/tNH_4 related to temporal variation of NH_3

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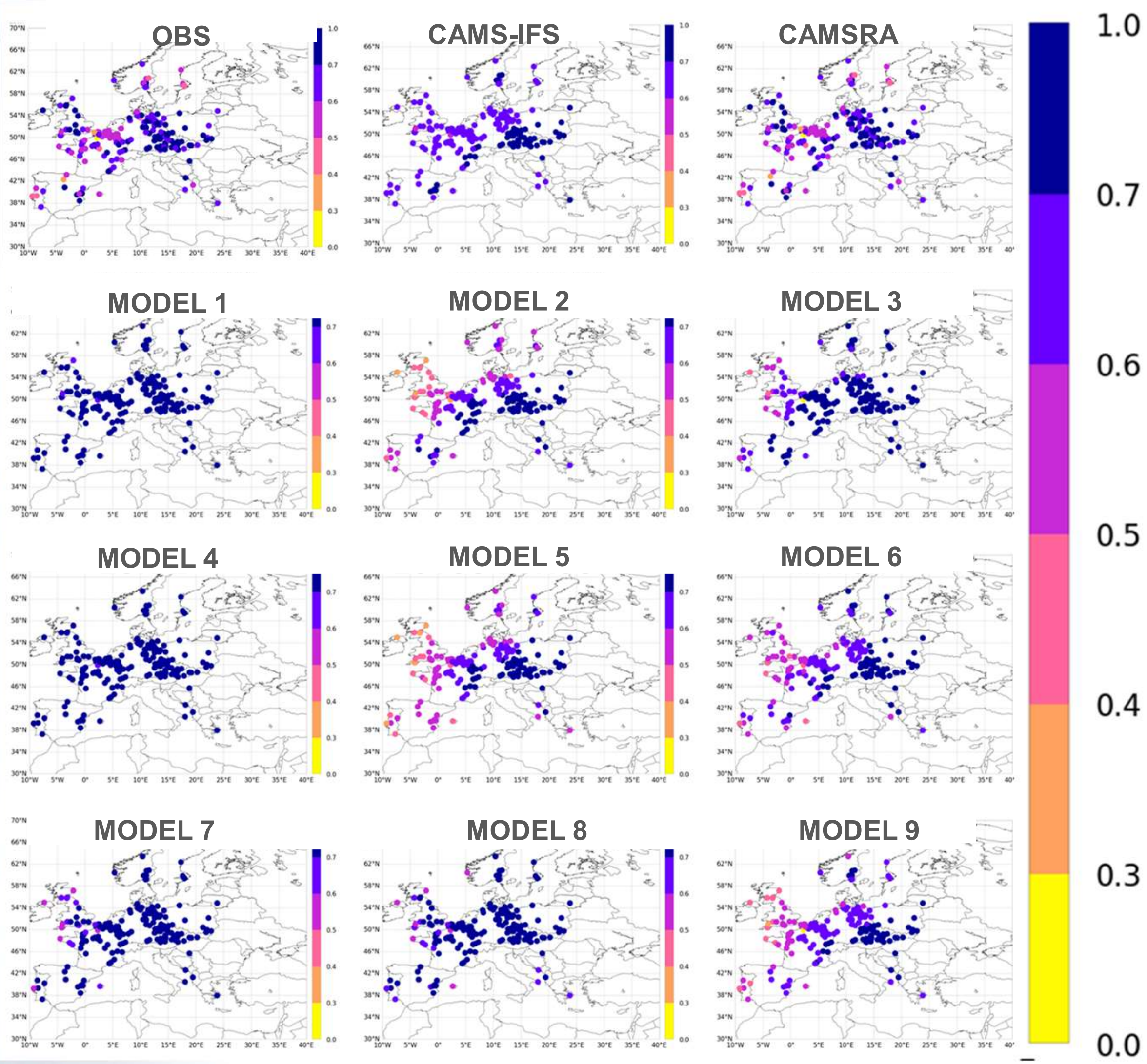
Focusing on dust: $PM_{2.5}/PM_{10}$ ratio - **All days**



PM2.5/PM10 ratios results:
Expect the highest ratios in central Europe (less dust, sea salt in PM10)

- Some models have little variance in $PM_{2.5}/PM_{10}$ ratios
- Some models capture the lower ratios at Atlantic sites and the Mediterranean (more affected by dust and sea salt)

Only two of the models decrease their PM ratios in the Mediterranean during "dusty" days

Results depending on implementation of dust boundary conditions and within domain production

Some models do not have 'within domain production' of dust

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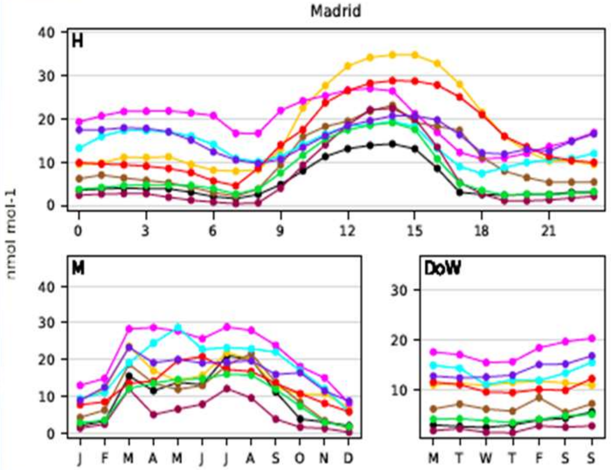
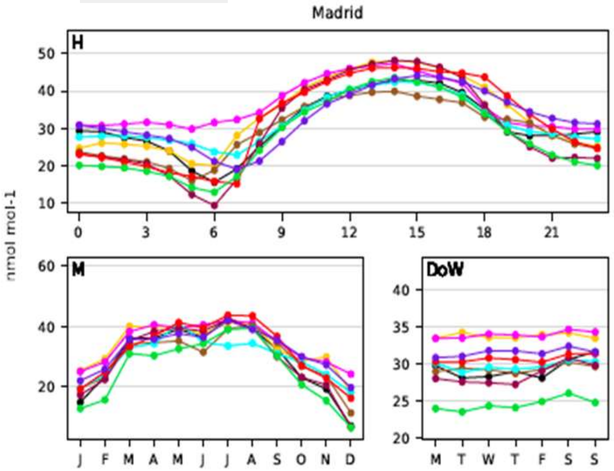
Dedicated ozone evaluation around the Mediterranean

p5

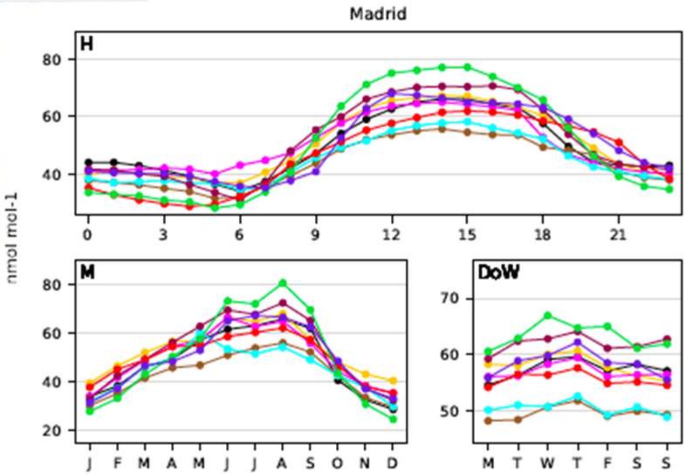


p50



Madrid - Ozone
Periodic Cycles

p95



P5: General overestimation, but very large variability between the models diurnally and seasonally.

P50: General very good performance diurnally and seasonally (with exception of early morning ~06:00h).

P95: Diurnal and seasonal phase is well captured, but large variability in the daytime and summer months (i.e. strong production times).

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Temporal Ozone Bias Correlation investigation

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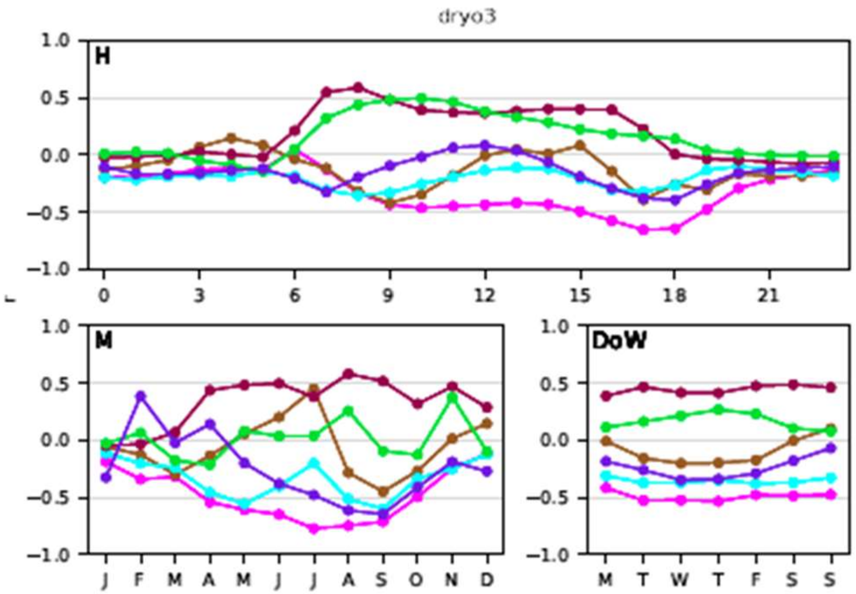
Correlation of bias in ozone with several parameters investigated

From the analysis performed, it was clear there is no silver bullet across the regional models to correct surface ozone.

Detailed in depth analysis, such as this is needed to find specific issues per model. This work could easily be extended to the entire European domain.



Issue: LOTOS-EUROS was found to have an overestimation of ozone in summer, especially in the Mediterranean
Possible reason: The vegetation dependent deposition parameters in this climate zone may differ from the default western European settings
Experiment: update of the stomatal conductance parameters for Mediterranean vegetation for ozone only
Impact: less stomatal closure in summer and thus more effective deposition during warm and dry conditions leading to a slight decrease of modelled ozone values.

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In-depth assessment CAMS Regional air quality forecasting Systems

Issues related to **forcings** of the model (emissions, boundary conditions):

Phase II
REF1 emissions

e.g. models overestimate EC and underestimate OC

Phase III
REF2 emissions

Performance improved through the use of an emission inventory including condensables for residential wood burning (Denier vander Gon (2015))

→ Since March models use newest REF 2 in CAMS regional

- OM contribution still varies a lot between models
- Large difference in temporal correlation
- Including SOA formation is important for summer OC

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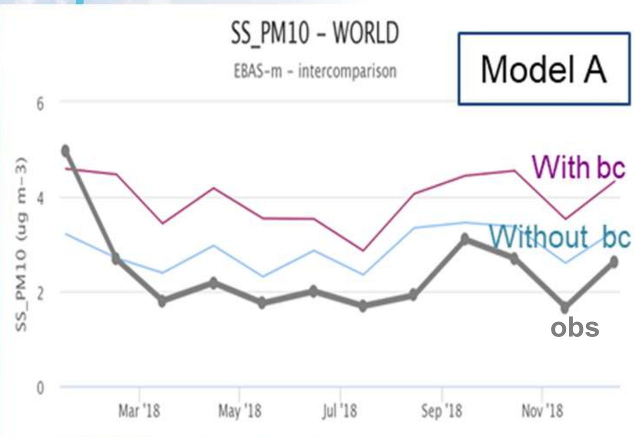
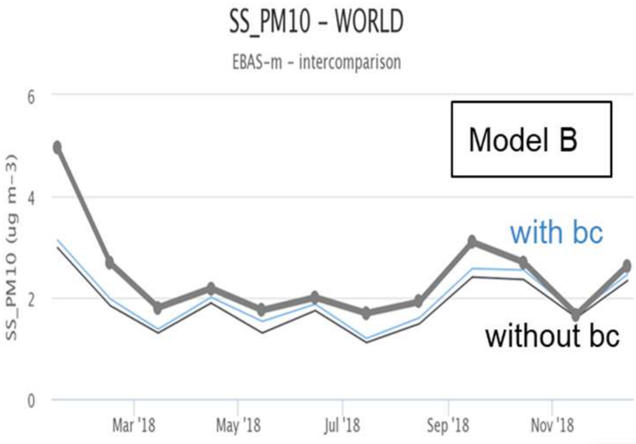
In-depth assessment CAMS Regional air quality forecasting Systems

Issues related to **forcings** of the model (emissions, boundary conditions):

e.g. large differences in impact of sea salt and dust coming from the boundary conditions





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	EBAS-d	10.8	-26.9	-37.0	34.1	-8.6	-30.6	-52.5
	EBAS-m	-7.4	-37.7	-47.0	19.0	-19.5	-38.4	-57.9
	EBAS-d	17.2	19.5	-1.9	54.2	37.1	-24.1	-51.9
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	EBAS-m	-6.3	-36.3	-13.6	-29.4	-41.4	-63.3	-79.3
Precip	EBAS-d							-95.9
	EBAS-m							
AOD	AERONET							

NMB (%) 100 50 0 -50 -100

Large differences in sea salt resulting from within-domain production (most important, but some models do not include it)

Results of the global model improve continuously, which might require revisions in regional models

Can also be due to transport/deposition

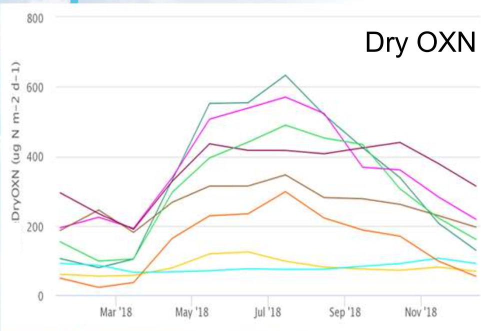
EEA-rural = rural background EIONET measurements
G-EBAS = **EMEP**, ACTRIS, AMAP, GAW and HELCOM

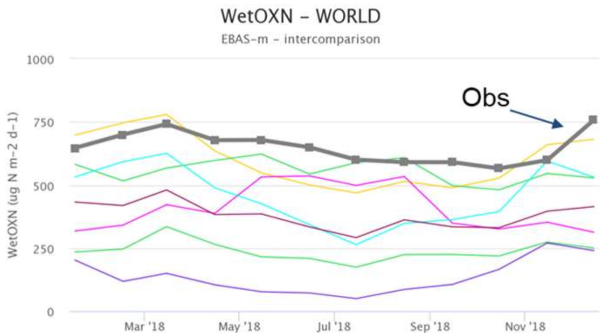
Atmosphere Monitoring

In-depth assessment CAMS Regional air quality forecasting Systems

Issues related to **processes** in the model (e.g. transport, deposition, chemistry, production of sea salt and dust):

e.g. very large variability in deposition





NO2	EEA-rural	-40.6	-28.6	-23.8	-29.1	-2.3	2.6	-19.0
	G-EBAS	-36.6	-16.2	-15.2	-13.0	11.9	18.1	2.1
O3max	EEA-rural	5.5	2.5	-7.9	-3.5	6.9	-4.3	-8.2
	G-EBAS	5.0	1.2	-8.2	-4.6	4.1	-6.8	-9.2
OX	EEA-rural	13.7	14.6	-2.1	0.6	4.2	-0.2	-3.3
SO2	EEA-rural	-79.6	-49.3	-31.4	-7.2	-22.9	-6.9	-58.7
	G-EBAS	-67.5	19.1	2.3	92.6	43.0	76.8	-11.9
CO	EEA-rural	-41.9	-41.2	-32.9	-40.0	-37.2	-42.2	-27.4
	G-EBAS	-18.9	-24.4	-9.2	-23.5	-3.5	-22.3	-11.0
PM2.5	EEA-rural	-2.7	-11.4	-12.9	-2.0	-11.2	-10.6	-9.8
	G-EBAS	6.1	2.2	-4.2	15.7	-1.2	4.0	3.7
PM10	EEA-rural	-29.1	-13.9	-26.2	-29.1	-13.2	-31.1	-23.7
	G-EBAS	-27.1	3.6	-20.4	-23.0	-3.2	-21.6	-17.1
SO4	EBAS-d	-11.4	-28.7	-35.1	-25.1	-32.7	-56.2	-57.1
	EBAS-m	-14.6	-32.4	-37.8	-29.0	-35.8	-58.2	-58.6
tNO3	EBAS-d	-9.7	314.6	-13.6	46.4	18.2	-20.9	-50.7
	EBAS-m	-8.3	315.3	-12.8	50.1	20.1	-19.7	-49.0
tNH	EBAS-d	-4.8	-37.3	-13.4	17.9	-2.2	-12.5	-1.5
	EBAS-m	-3.8	-36.4	-12.5	20.5	-0.6	-10.7	-0.1
NH3	EBAS-d	-54.1	-68.6	-42.4	-18.1	-42.3	-36.6	-9.1
	EBAS-m	-24.4	-60.6	-18.1	6.1	-13.3	-7.1	14.9
NH4	EBAS-d	35.4	-12.5	-7.7	50.2	16.2	-17.6	-33.0
	EBAS-m	37.2	-13.3	-7.0	49.7	17.4	-17.4	-33.4
HNO3	EBAS-d	-42.1	917.2	-50.6	11.9	-29.5	-25.4	-27.3
	EBAS-m	-45.1	865.8	-53.7	8.4	-34.2	-29.5	-31.3
NO3_PM25	EBAS-d	10.8	-26.9	-37.0	34.1	-8.6	-30.6	-52.5
	EBAS-m	-7.4	-37.7	-47.0	19.0	-19.5	-38.4	-57.9
NO3_PM10	EBAS-d	17.2	19.5	-1.9	54.2	37.1	-24.1	-51.9
	EBAS-m	23.5	20.6	0.3	53.5	37.0	-22.6	-52.1
SS_PM25	EBAS-d	86.2	260.4	-66.8	-60.4	99.4	33.3	51.1
	EBAS-m	64.6	217.3	-72.0	-64.0	72.3	23.5	28.7
SS_PM10	EBAS-d	4.5	91.7	-17.8	-76.5	62.0	-13.9	-13.8
	EBAS-m	4.2	94.2	-17.7	-76.3	63.7	-13.8	-13.8
EC_PM25	EBAS-d	19.4	-13.8	15.9	53.7	81.3	70.9	14.2
	EBAS-m	17.3	-12.0	15.2	52.5	83.2	71.6	14.6
OC_PM25	EBAS-d	-82.9	-9.1	-33.8	-37.1	0.8	-1.8	58.0
	EBAS-m	-82.5	-8.5	-32.4	-37.2	1.5	2.0	61.4
WetOXS	EBAS-d	-24.5	-41.6	-23.0	-25.9	-59.2	-53.3	-72.8
	EBAS-m	-12.2	-35.3	-16.3	-17.3	-53.8	-46.9	-69.4
WetRDN	EBAS-d	-14.3	-45.4	-2.5	-19.6	-24.5	-56.1	-30.2
	EBAS-m	-9.4	-43.1	2.6	-13.4	-17.9	-53.0	-25.8
WetOXN	EBAS-d	-13.8	-40.8	-19.0	-37.9	-47.4	-67.3	-81.9
	EBAS-m	-6.3	-36.3	-13.6	-29.4	-41.4	-63.3	-79.3
Precip	EBAS-d							-95.9
	EBAS-m							-99.2
AOD	AERONET	-83.0		19.4	-64.2	-4.1	-8.3	-24.9

NMB (%): 100, 50, 0, -50, -100

- Representation of dry and wet deposition should be improved and detailed.
- Implement budget checks as a part of the benchmarking (where the total deposition for e.g. Sulphur should equal total emissions plus inflow minus outflow of the domain).
- Deposition will be a focus area in CAMSII regional air quality service project (also in AQMEII)

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Conclusion

- The evaluation proved very useful to identify general issues but also model specific issues, potential for model-specific improvements for different processes identified
- Identified issues have been connected to issues with
  - Forcing of the models (e.g. emissions and its distribution/timing, boundary conditions)
  - Internal model processes (e.g. deposition, transport, chemistry)
- Some of the general recommendations:
  - Integrate a benchmark test in the operations of the CAMS regional service (operational evaluation)
  - Specific focus on natural components (e.g. revision of dust scheme, inclusion within domain production of dust, work on BVOC emissions (now very different), CAMS natural emission module?)
  - Move into the direction of dynamic emission modelling for anthropogenic emissions (e.g. temp. dependent ammonia and traffic emissions)
  - Improve and detail representation of dry and wet deposition, and include budget checks

Special thanks to all the modelling teams and the CAMS 61 partners for this work

Thank you for your attention

Questions? comments?

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