Ozone sensitivity to VOCs emissions and lessons learned for the design of the Spanish National abatement plan

Alba Badia, Oriol Jorba, Hervé Petetin, Marc Guevara, Roger Garatachea, Kevin Oliveira and Carlos Pérez García-Pando

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Outline

1. Some insights from the Spanish national ozone plan
2. MONARCH contribution to TFMM and beyond
3. Improving the Characterisation of Anthropogenic NMVOC in Europe
4. Future steps

Some insights from the Spanish national ozone plan

A comprehensive set of emission scenarios in key sectors

EB: base case (2019)

EP: planned scenario (2030 with national plans) →

-12% of VOC emissions
-42% of NOx emissions
(highest changes in road transport, some industries and electricity generation)

EEs: specific scenarios based on EP, but with

- Lower reduction from traffic
- Higher reductions from industries
- Higher reductions from solvent use
- Higher reductions from aviation, national and international shipping

EXs: extreme scenarios over Spain such as:

- No anthropogenic NOx emissions
- No anthropogenic VOC emissions
- No anthropogenic emissions
- No biogenic emissions (in and outside Spain)

Anthropogenic emissions: HERMES bottom-up
Biogenic emissions: online MEGAN

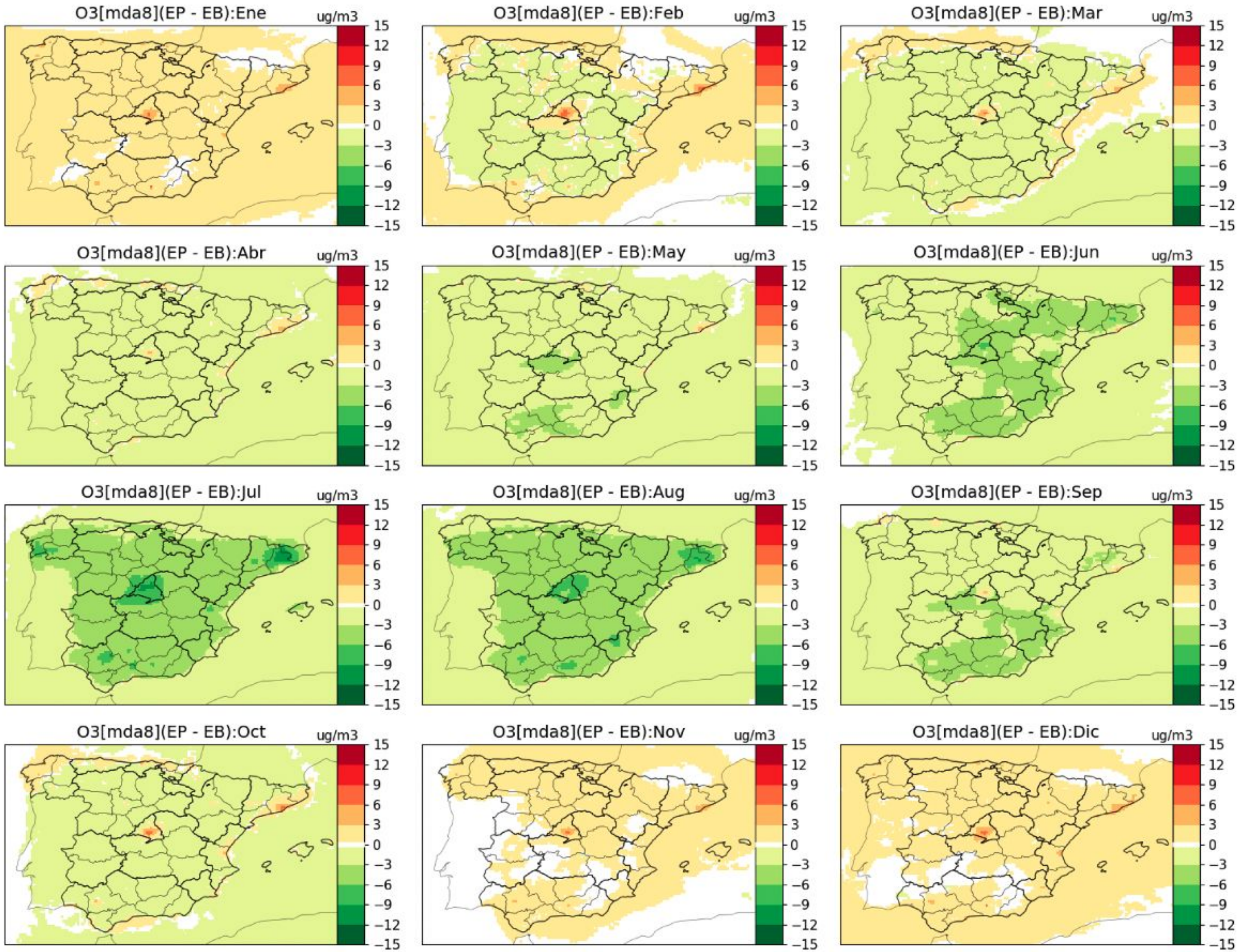
→ **MONARCH air quality model**

The planned scenario strongly reduce O3$^{(mda8)}$ levels, especially during the ozone season and key polluted regions

Differences of O3$^{(mda8)}$ between planned scenario and base case (EP-EB):

Strong reduction of O3$^{(mda8)}$, especially during Apr-Sep, over most of the country, except in some coastal cities like Barcelona
-3 µg/m3 on average in Apr-Sep

Key contribution of road transport (not shown)



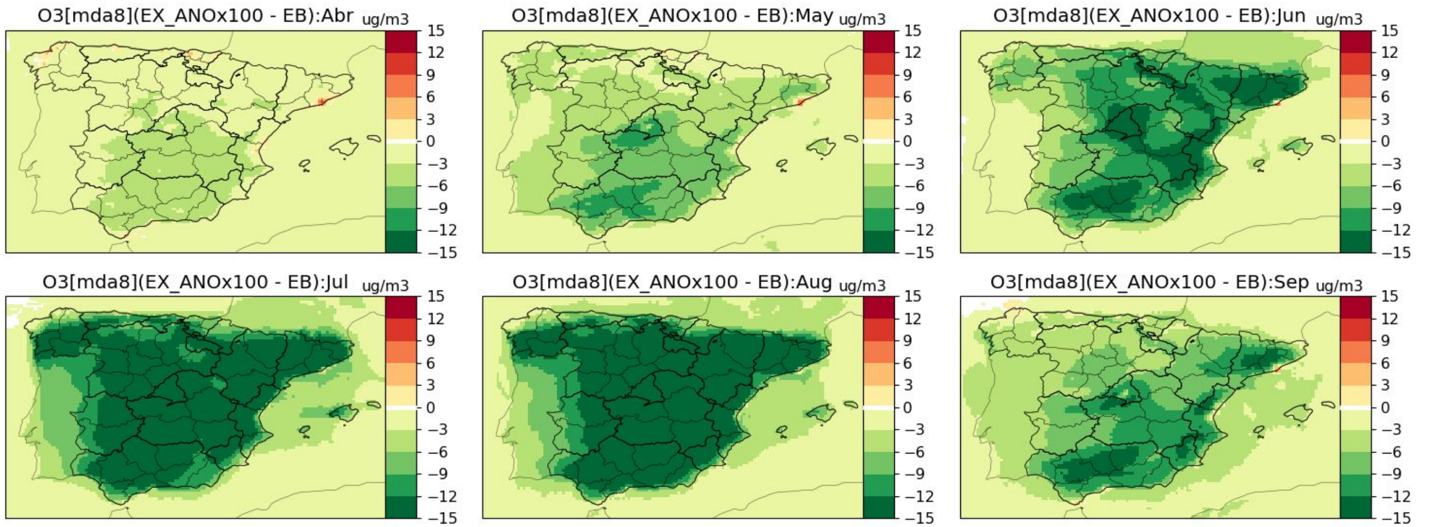
Anthropogenic NOx emissions play a key role in O3 production and VOCs

April…

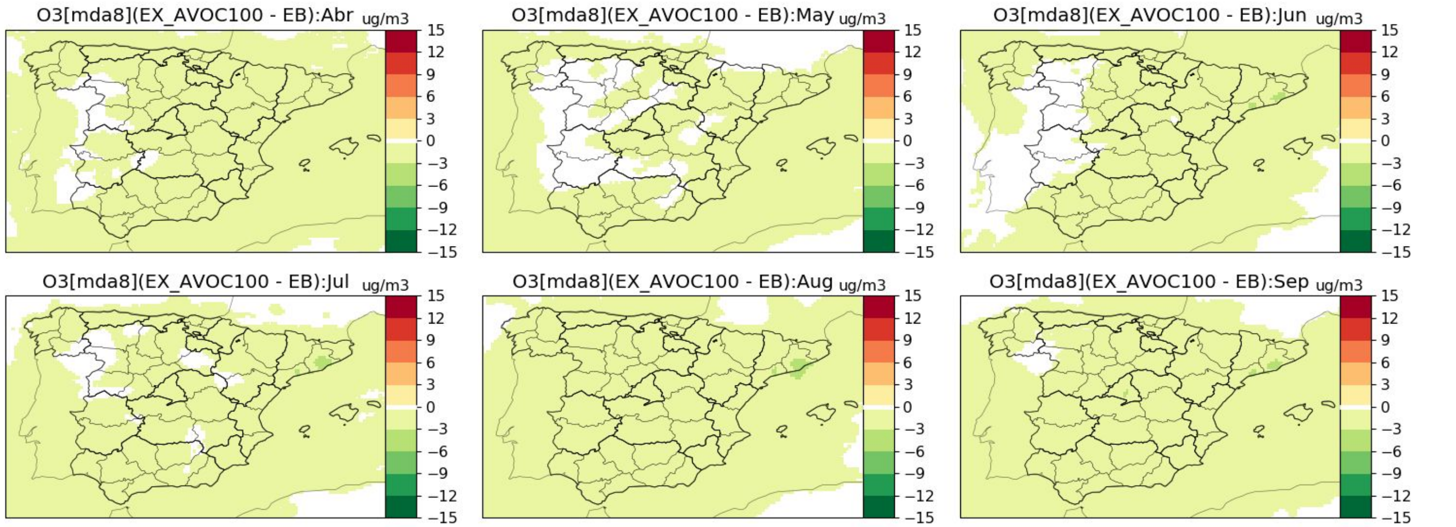
…September

Impact of removing anthropogenic NOx (above) and VOC (below) emissions on $O3^{(mda8)}$:

Spanish anthropogenic NOx emissions strongly contributes to ambient O3 levels across Spain
-14 µg/m3 on average in July



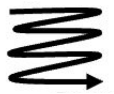
Spanish anthropogenic VOC emissions play a much lower role
up to -5 µg/m3 in July over specific locations



BSC 20 YEARS

Biogenic VOC emissions play a key role (combined with anthropogenic NOx)

April…



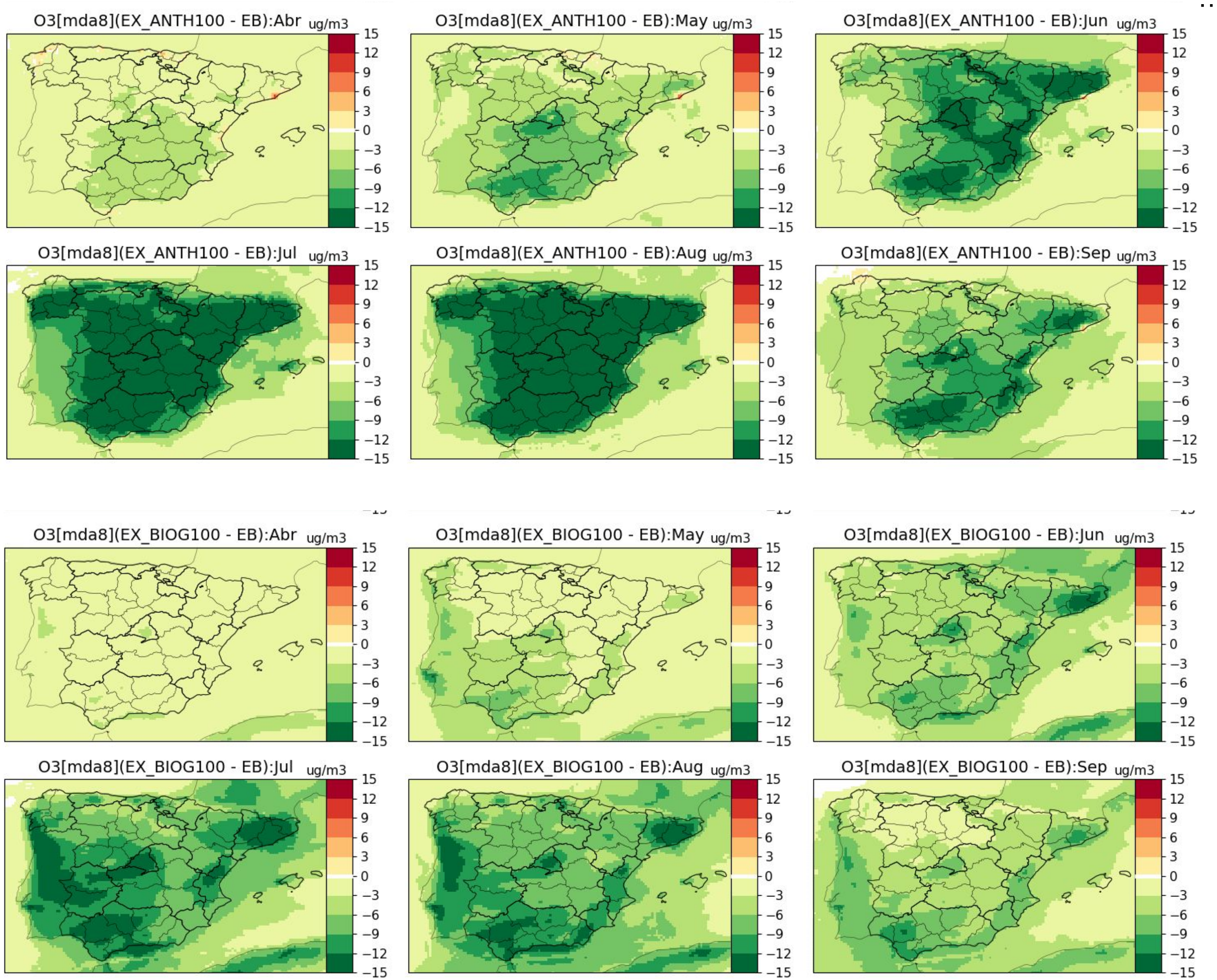
…September

Impact of removing all anthropogenic (above) and all biogenic emissions (below) on O3^(mda8):

Both anthropogenic and biogenic emissions contribute strongly to O3^(mda8) levels in Spain during April-September, but anthropogenic emissions contribute more

-9 and -5 µg/m3 on average in Apr-Sep.

Biogenic VOC emissions combined with anthropogenic NOx emissions thus appear as the dominant contributors to O3 production in Spain



Ozone episode frequency in Spain mainly driven by anthropogenic NOx and biogenic VOC emissions

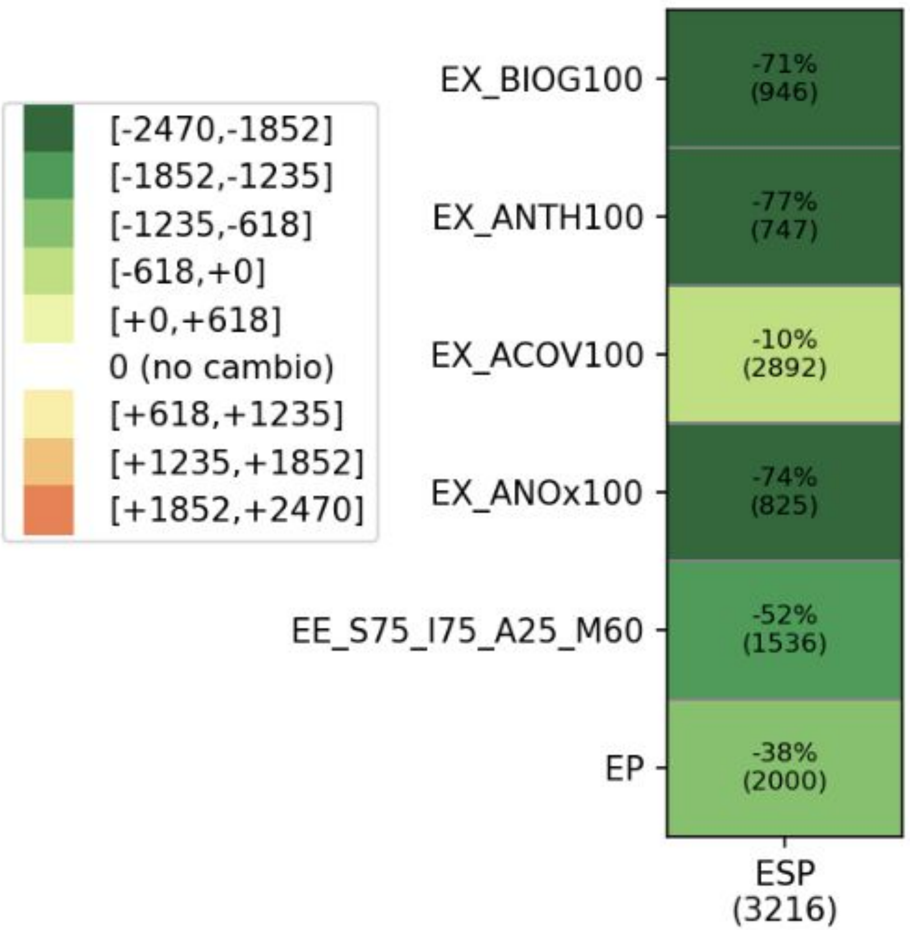
Relative change of # exceedances (and #exceedances):

Key role of anthropogenic NOx emissions

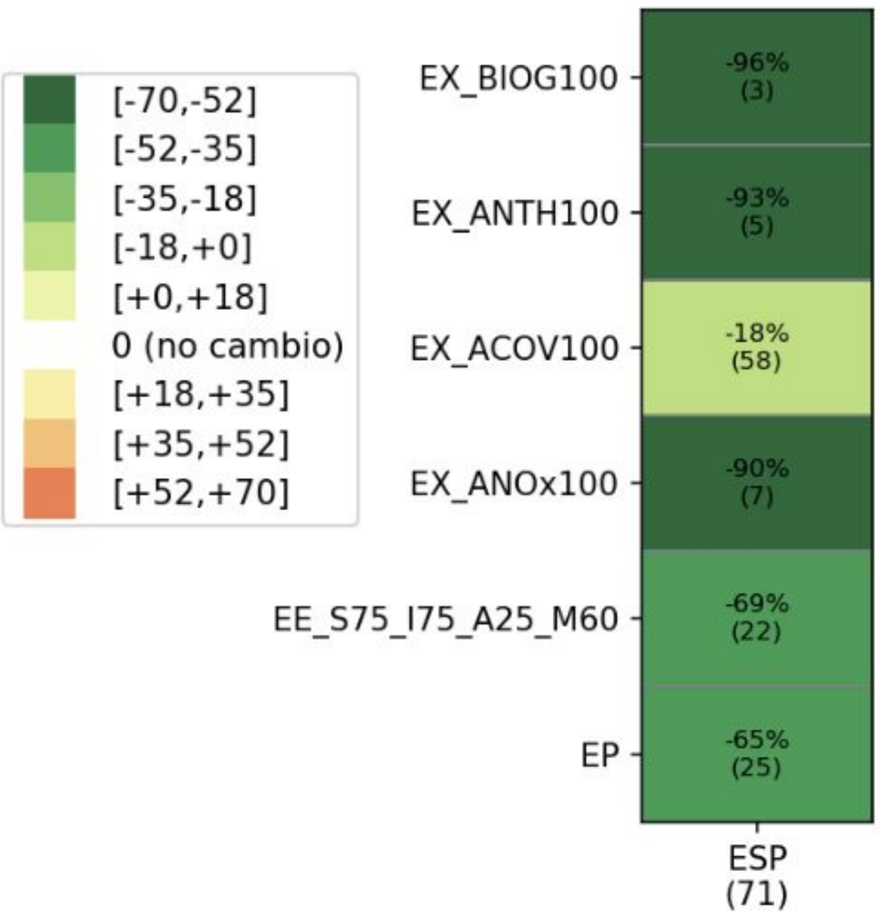
Key role of biogenic VOC emissions, limited contribution of anthropogenic VOCs

Strong improvement with EP scenario, still margin of improvement on with more ambitious scenario

O3(mda8) > 120 ug/m3

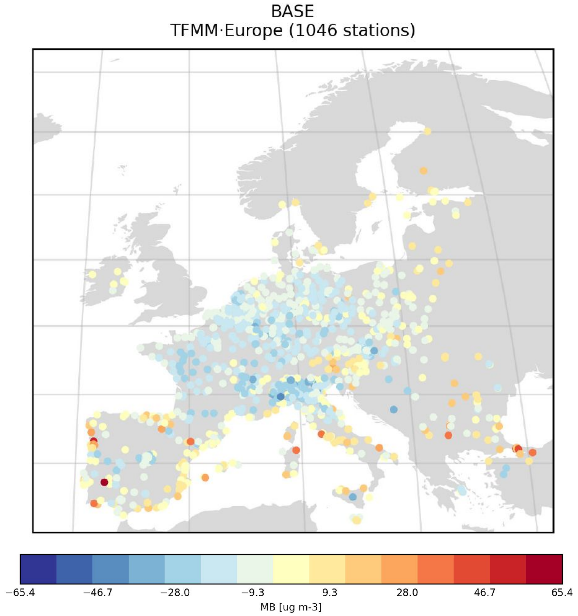


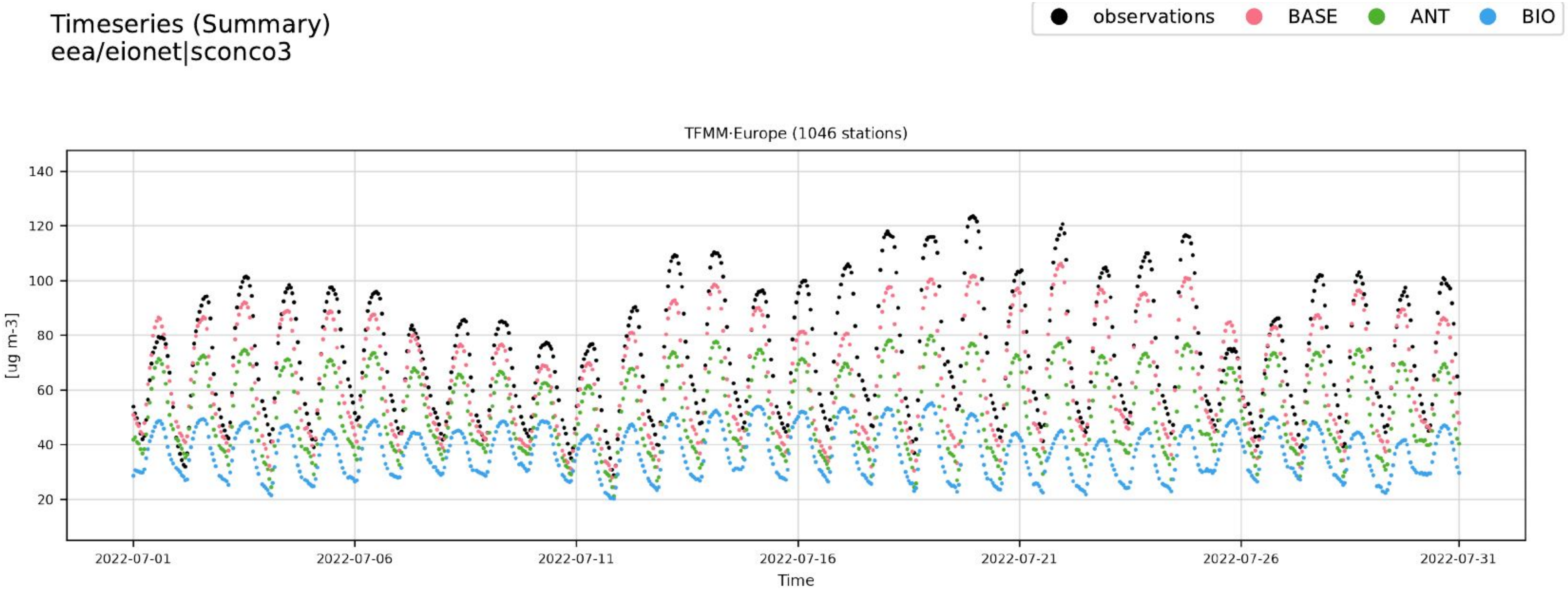
O3(max) > 180 ug/m3



MONARCH contribution to TFMM and beyond

TFMM July 2022 - O3 validation (BASE scenario)





MONARCH has a tendency to underestimate surface ozone in summer.

Analysing chemical processes:

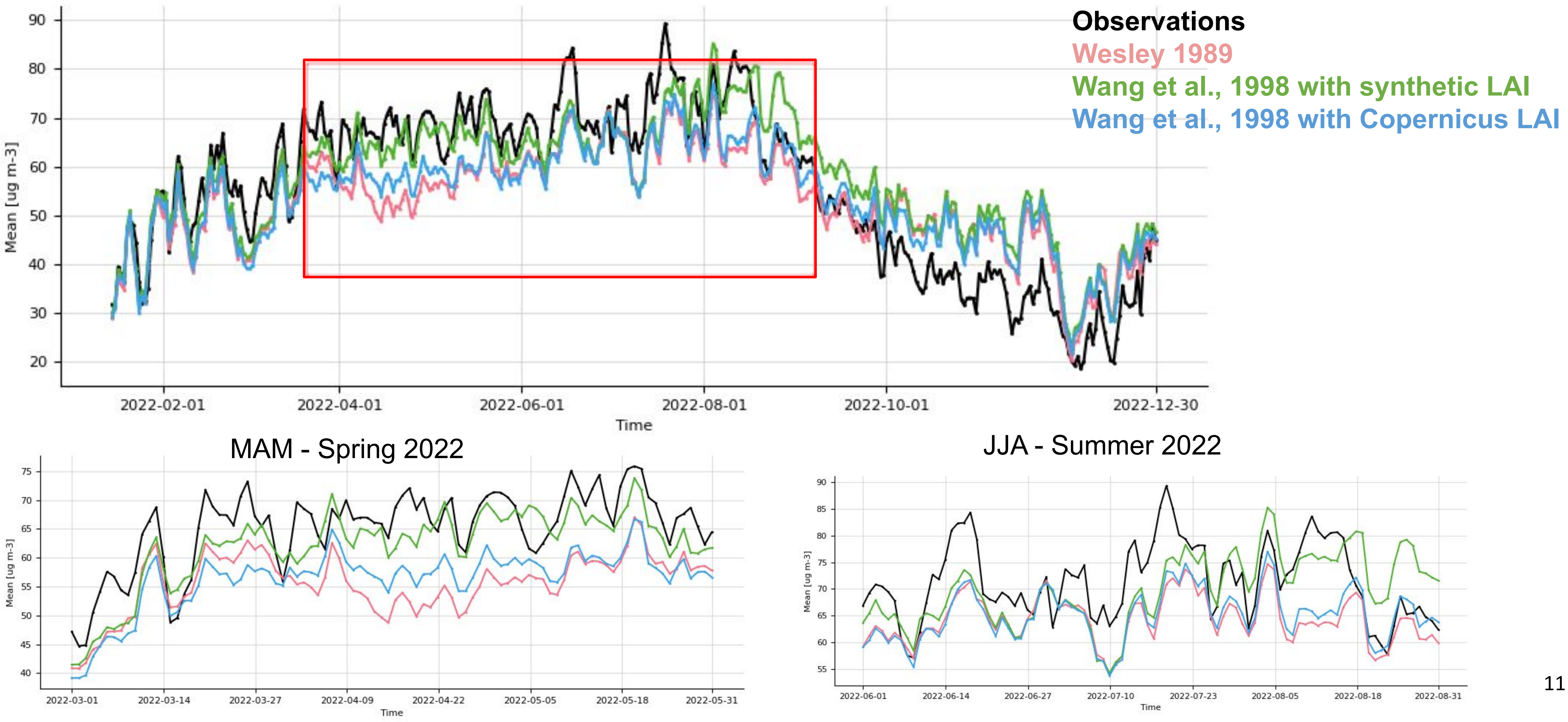
- test new dry deposition scheme
- biogenic emissions (not yet)

		Mean	StdDev	NMB	NME	RMSE	r
Europe	BASE	-10.70	-5.34	-14.43	25.81	23.84	0.77
NorthEurope	BASE	-11.16	-5.34	-16.97	25.70	21.85	0.79
SouthEurope	BASE	-1.32	-2.39	-1.72	21.17	21.68	0.75
CentralEurope	BASE	-15.92	-7.67	-20.23	27.10	26.26	0.78

20 BSC YEARS

TFMM July 2022 - O3 validation (dry deposition treatment)

Wang, et al., 1998: light correction (using LAI) in canopy stomatal resistance + dependence of LAI on external resistance

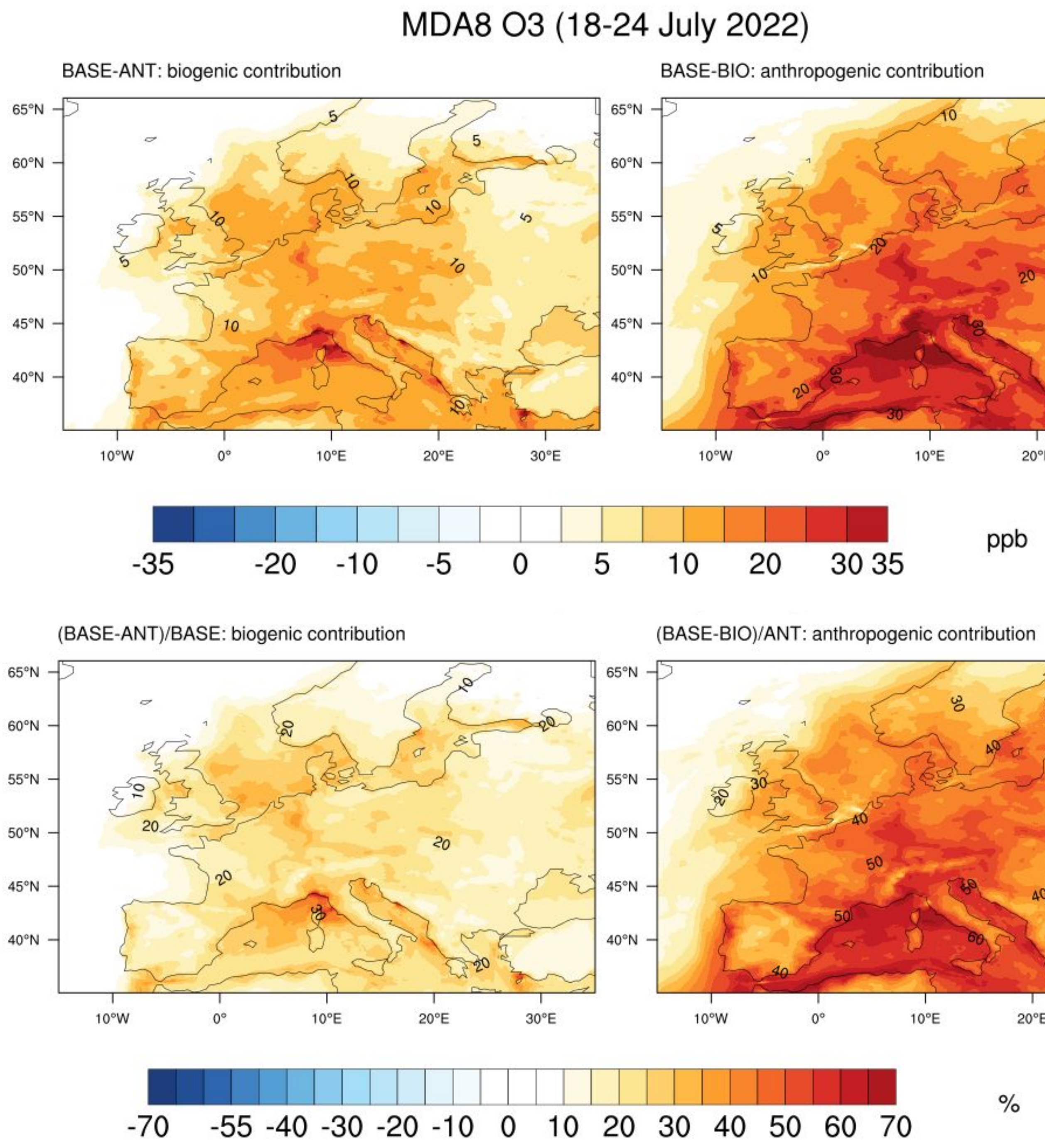


TFMM July 2022: O3

Differences of $O3^{(mda8)}$ between base case scenario and ANT & BIO scenarios:

- Over land, biogenic sources (VOCs and soil NO_x) contribute between 5–10 ppb (10-20%) to MDA8 ozone.
- Anthropogenic sources contribute between 10–20 ppb (20-50%).
- Shipping emissions make a significant contribution.

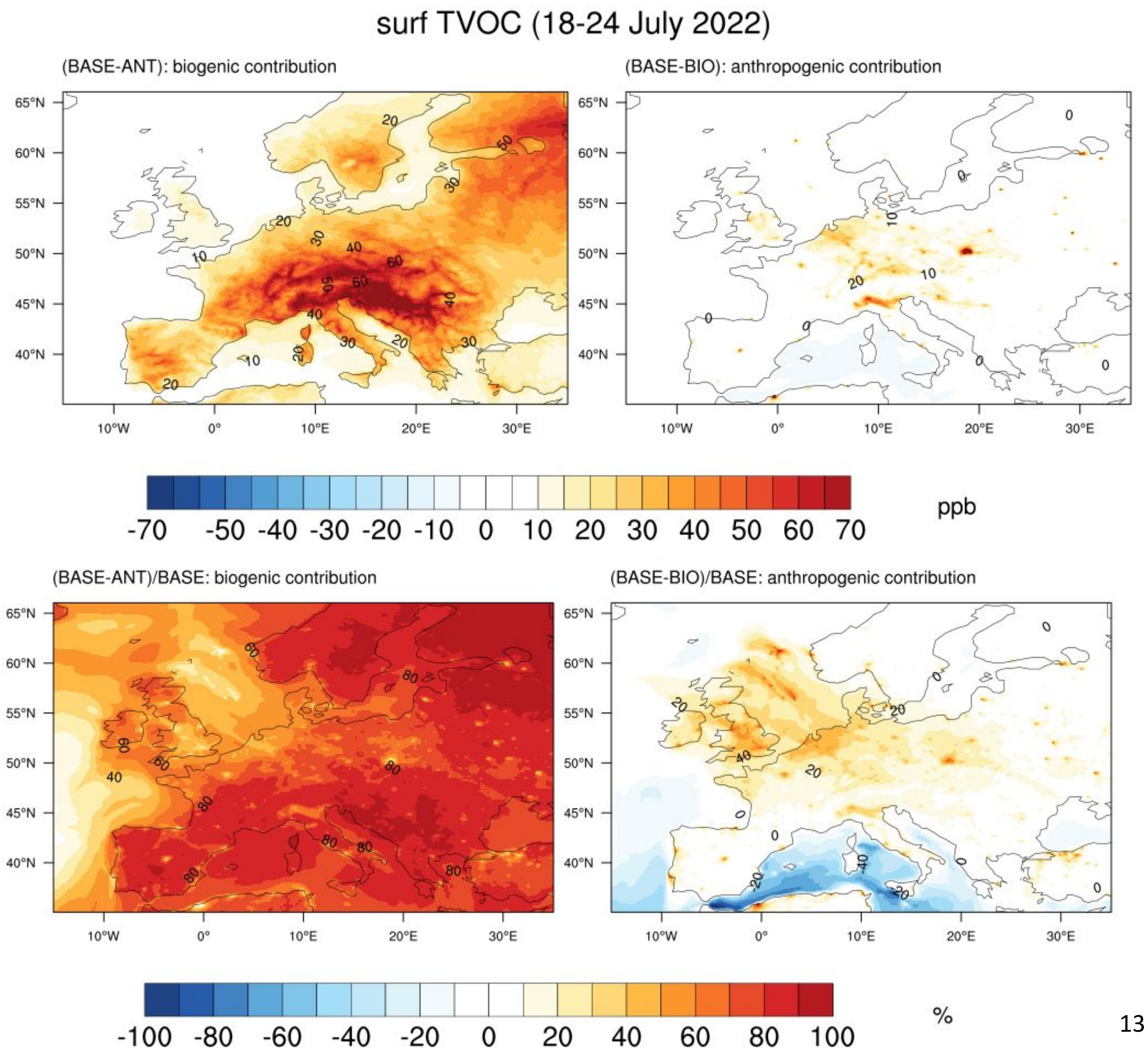
Anthropogenic sources contribute more than twice compared to biogenic sources to MDA8 ozone.



TFMM July 2022: VOC

Differences of total VOC between base case scenario and ANT & BIO scenarios:

- The main source of VOCs over large forested areas in central Europe is biogenic, contributing up to 60 ppb (80%).
- Anthropogenic contributions are concentrated in hotspots such as industrial areas and solvent use.

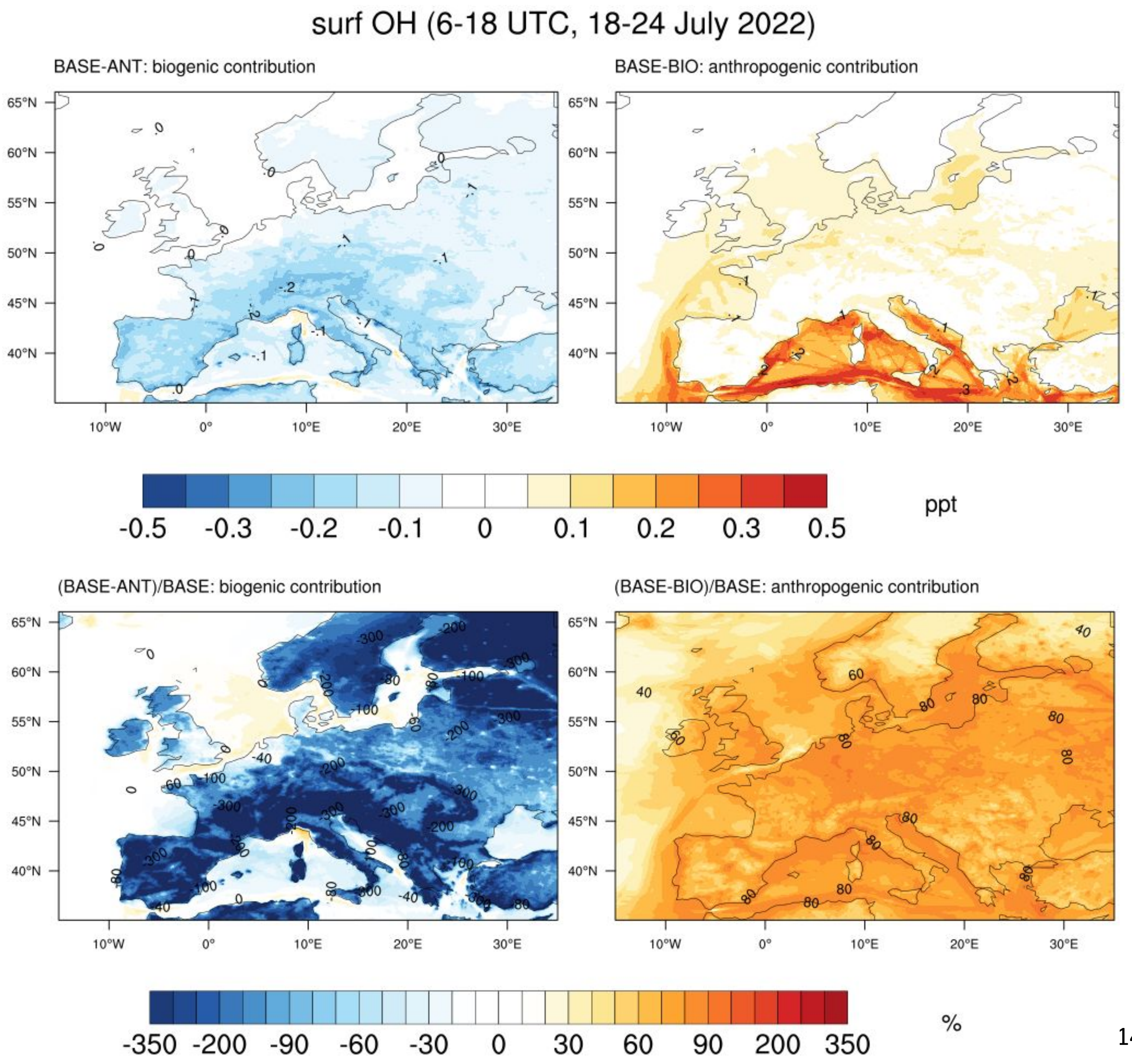


TFMM July 2022: OH

Differences of OH between base case scenario and ANT & BIO scenarios:

- A lower atmospheric oxidation capacity (reduced OH) is associated with the biogenic contribution.
- Anthropogenic emissions contribution lead to enhanced oxidation efficiency (increased OH).

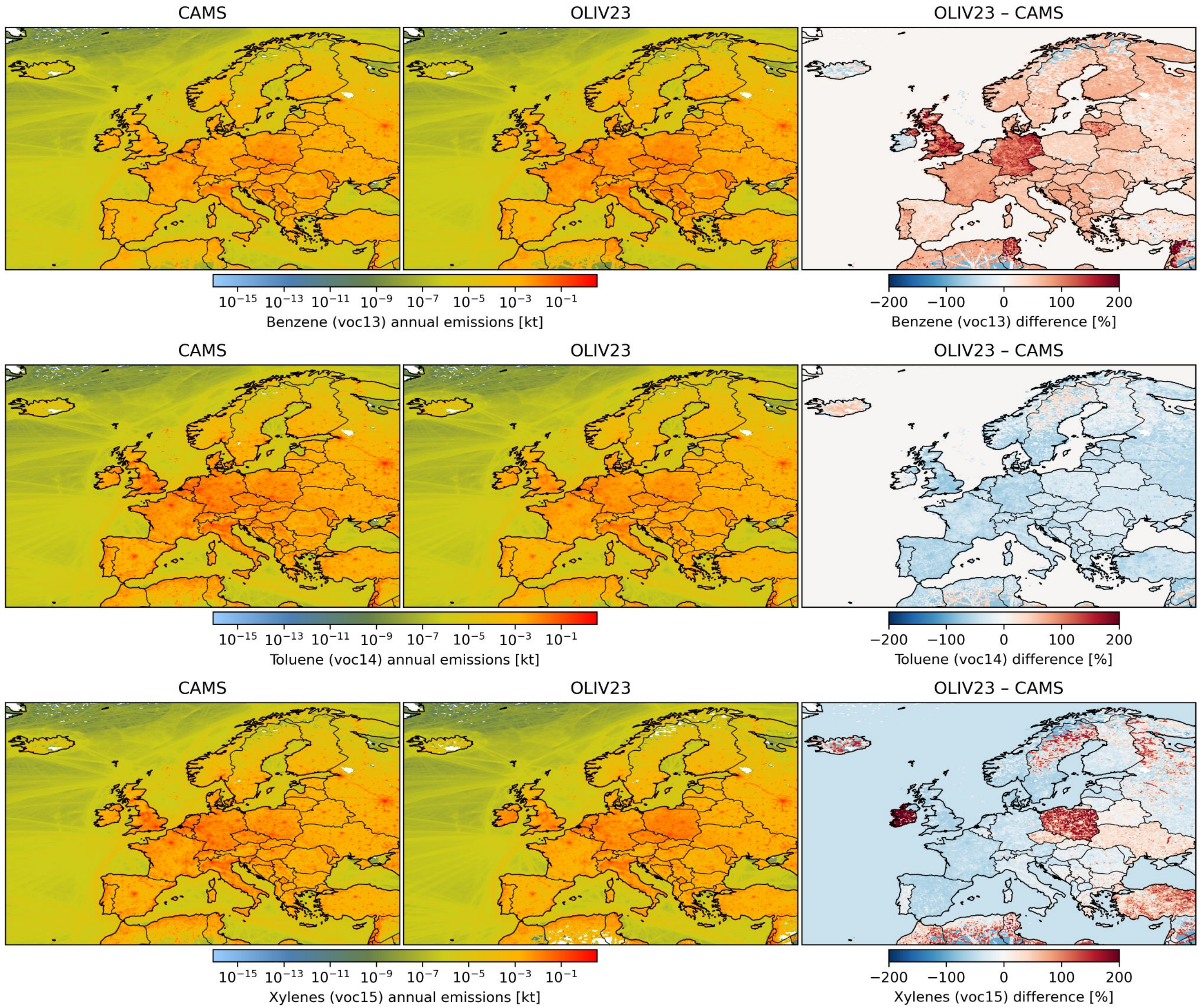
Compare the OH field across models. Do the other groups agree to provide their OH fields?



Improving the Characterisation of Anthropogenic NMVOC in Europe

CAMS-REG NMVOC in Europe

Fig.: Gridded (0.1° x 0.1°) annual emissions of benzene, toluene and xylenes (kt), using CAMS OLIV23 default speciation (col. 1) and (col. 2), along with the relative differences (col. 3).



- Developed an updated NMVOC speciation profile database for Europe (2005–2020), based on Oliveira et al. (2023, 2025a), fully compatible with CAMS-REG; published on Zenodo (Oliveira et al., 2025b)
- Speciation changes impact individual NMVOC emissions (> ±15%) and shift spatial distribution due to shifts in sectoral contributions.

Oliveira, K., Guevara, M., Jorba, O., Querol, X., Pérez García-Pando, C. (2023). **A new NMVOC speciated inventory for a reactivity-based approach to support ozone control strategies in Spain**. *Science of The Total Environment*, Volume 867, 1 April 2023, Article 161449, pp. 1–16, ISSN 0048-9697.

Oliveira, K., Guevara, M., Kuenen, J., Jorba, O., Pérez García-Pando, C., Denier van der Gon, H. (2025a - under revision). **Enhancing Anthropogenic NMVOC Emission Representation for European Air Quality Modelling. *Environmental Pollution*.** Available at SSRN: http://dx.doi.org/10.2139/ssrn.5197276

Oliveira, K., Guevara, M., Kuenen, J., Jorba, O., Pérez García-Pando, C., & Denier van der Gon, H. (2025b). **Oliveiraetal NMVOC split for CAMS-REGv7.1 [Data set].** Zenodo. https://doi.org/10.5281/zenodo.15019284

CAMS-REG NMVOC in Europe

- Improved benzene model performance, especially in winter, due to better characterisation of residential wood combustion

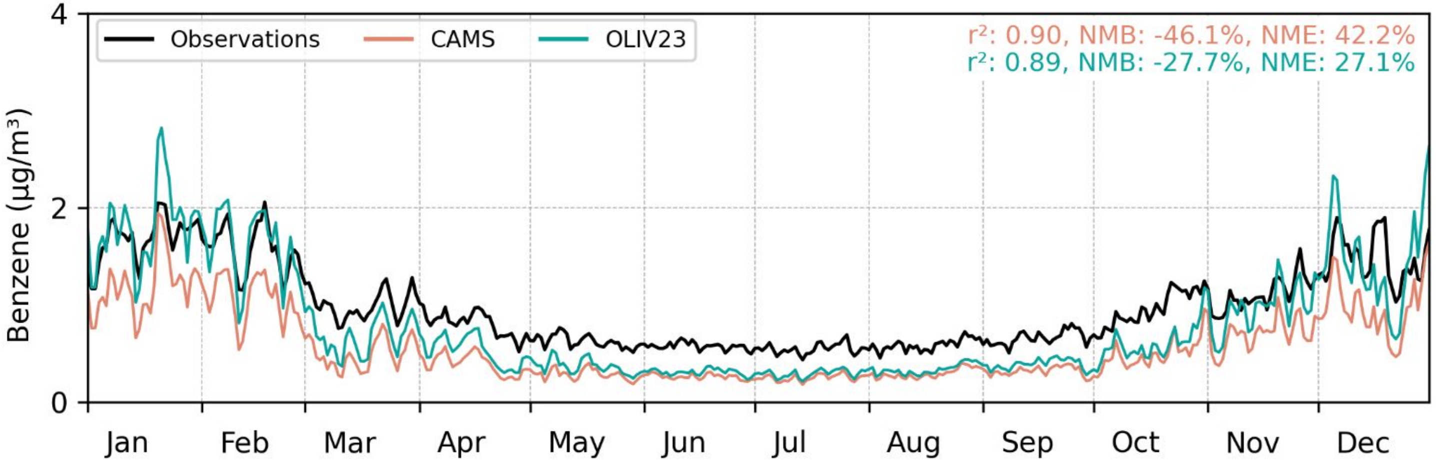
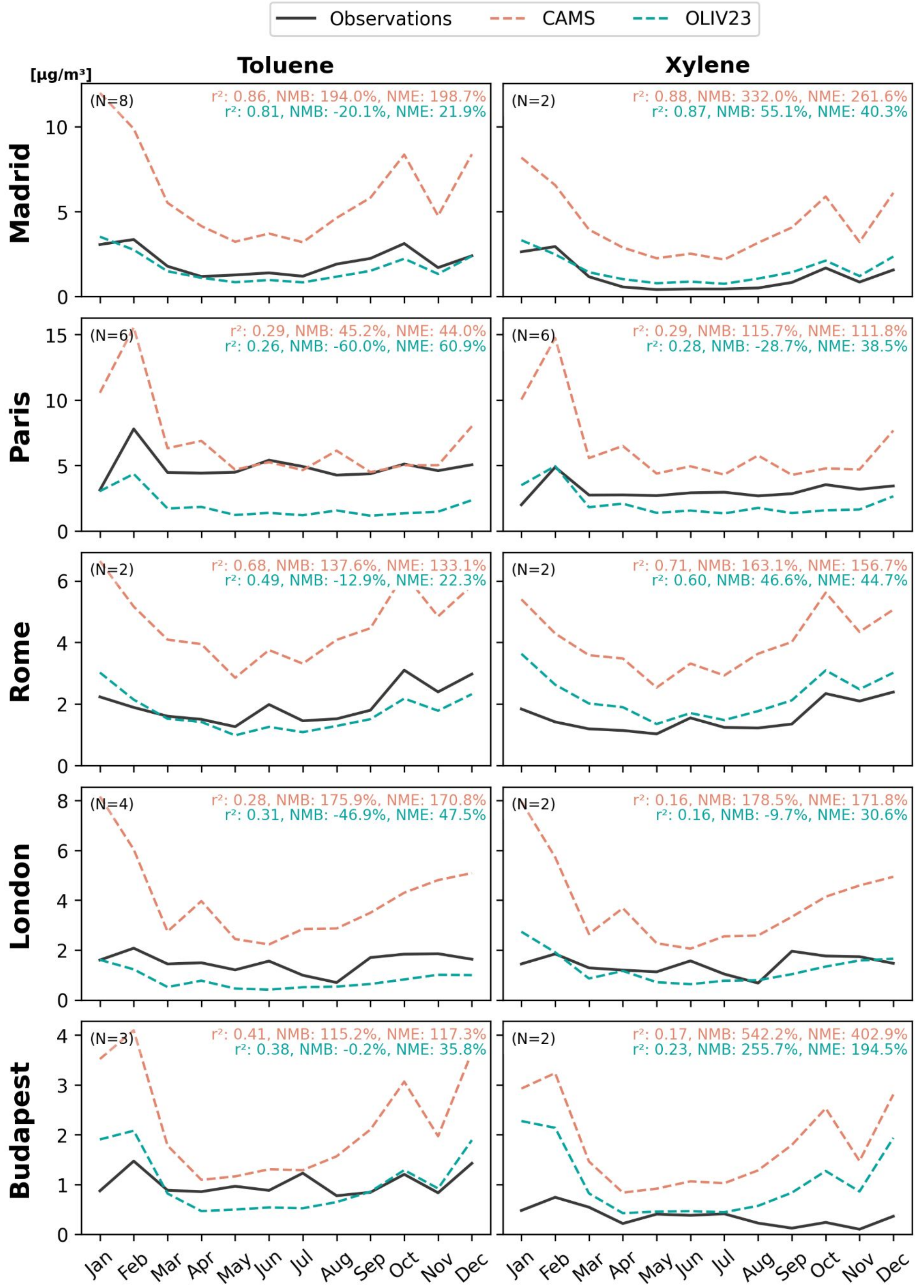


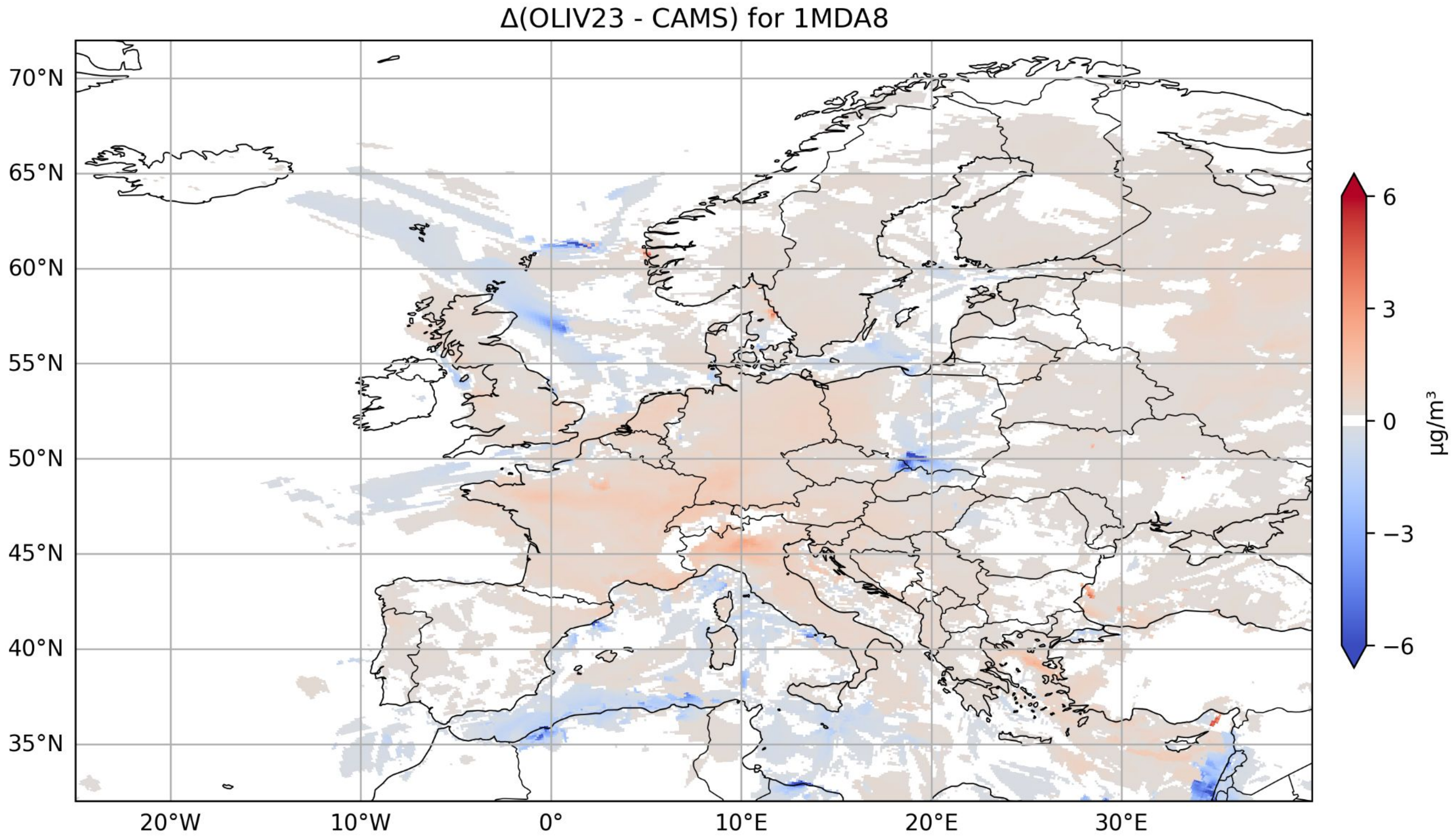
Fig.1: Averaged daily benzene concentrations (µg/m³) modelled and measured for all stations in 2019.

- Improved toluene/xylene performance in cities by reducing overestimations through better characterisation of the solvent sector

Fig.2: Modelled and measured monthly average concentrations of toluene and xylenes (µg/m³) across six EU capital cities



Difference in the MDA8 between CAMS and OLIV23



- NMVOC speciation updates have a limited impact on modelled O_3.
- Moderate decrease of around 6 μg/m³ in the southern region of Poland
- We plan to study the impact of NMVOC speciation on aerorols.

Future steps

Future steps

TFMM exercise:

- Further analysis, specific VOC.
- Changes in ozone chemical regimes
- Analyse the modelled HCHO:NO_2 ratio with TROPOMI (tropospheric column)

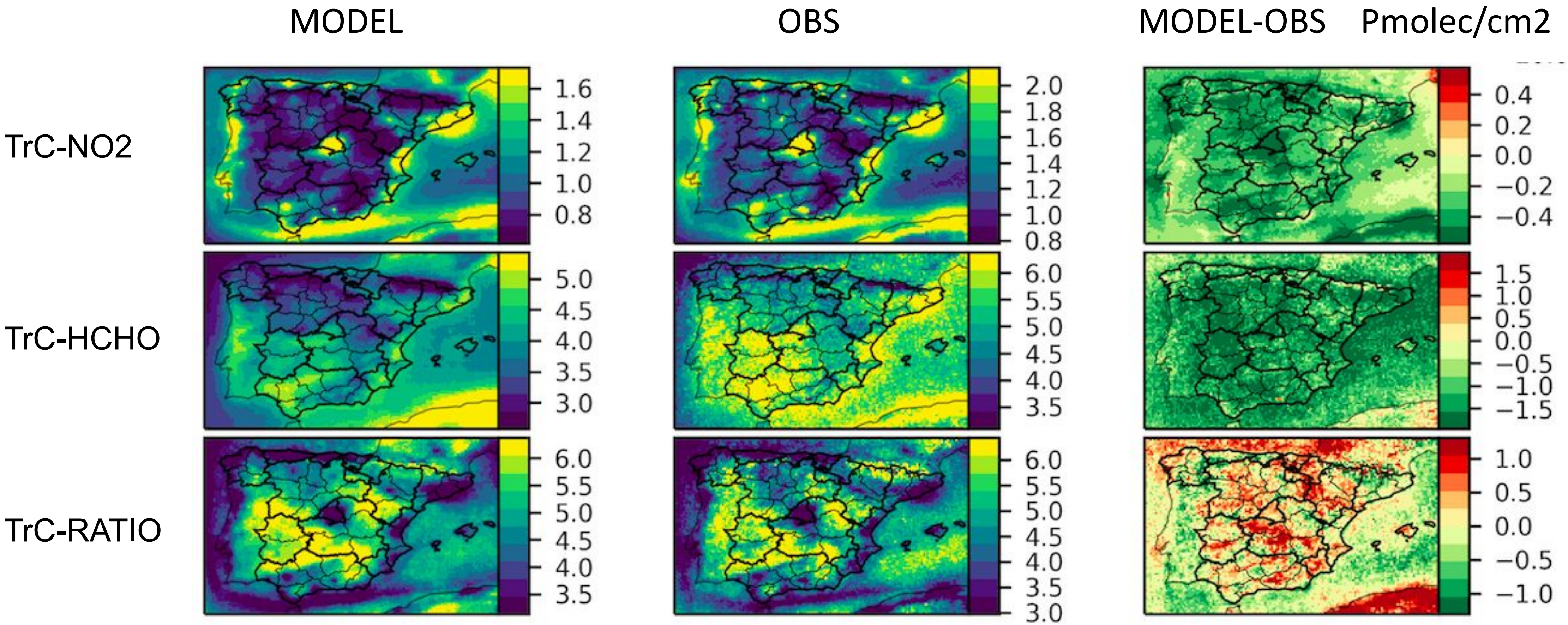
O3/VOCs chemistry:

- Sensitivity of O_3 to different dry deposition treatments
- Sensitivity of biogenic emissions (MEGANv3…, soil NO)
- Sensitivity to other chemical schemes (e.g. CB06, CRACM)

Other activities:

- Extending O_3 analysis to particulate matter formation in Spain (new activity after Plan O_3 studies)

Future steps: NO2 and HCHO tropospheric columns (TROPOMI) against models



Do the other groups agree to provide NO_2 and HCHO fields?

Thank you!

We acknowledge support from the Ministerio para la Transición Ecológica y el Reto Demográfico and the RESPIRE project, which is part of the Recovery, Transformation and Resilience Plan (Plan de Recuperación, Transformación y Resiliencia, PRTyR) funded by the European Commission to repair the harm caused by the Covid-19 crisis

alba.badia@bsc.es

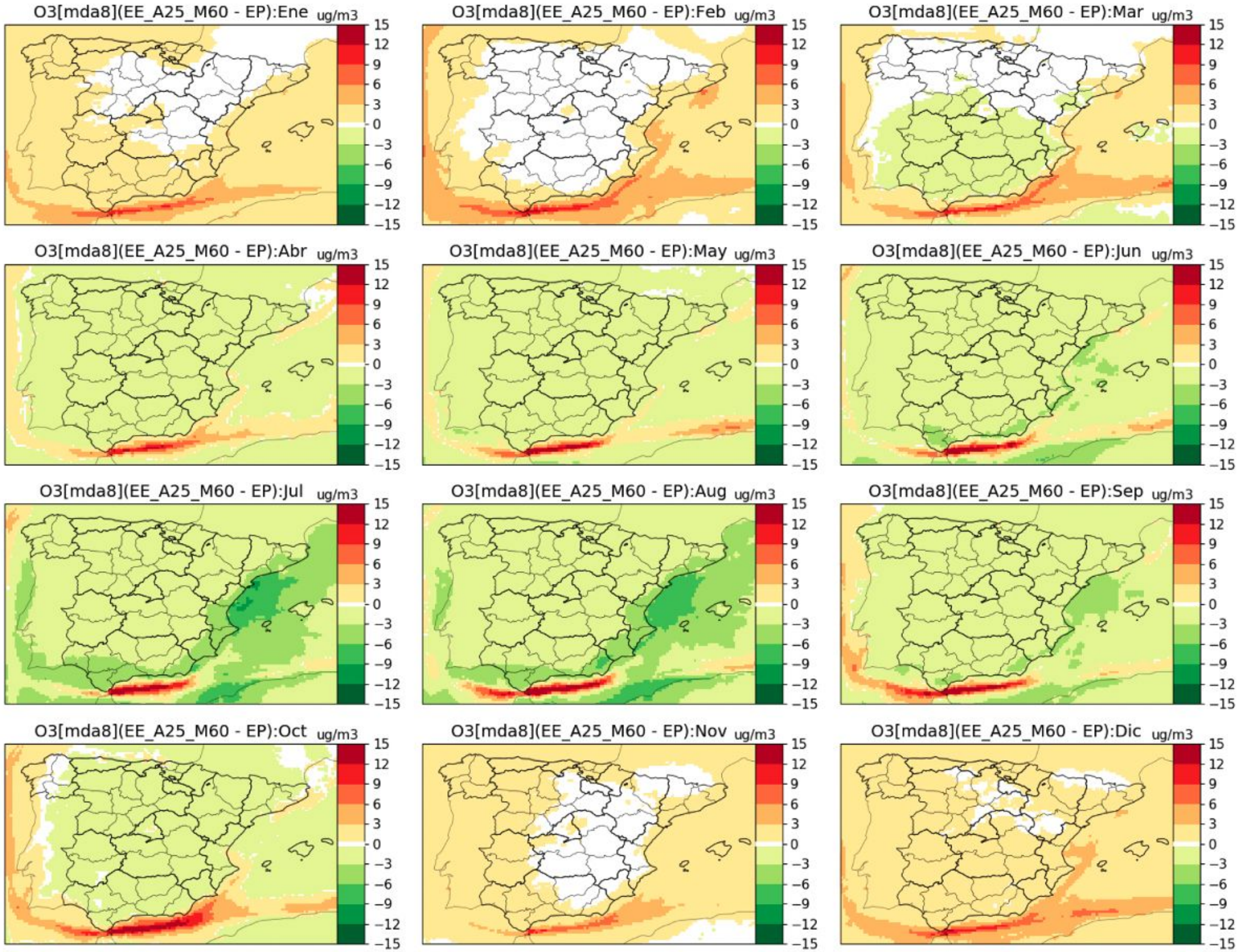
Additional slides

Key additional improvement expected with reduced shipping emissions

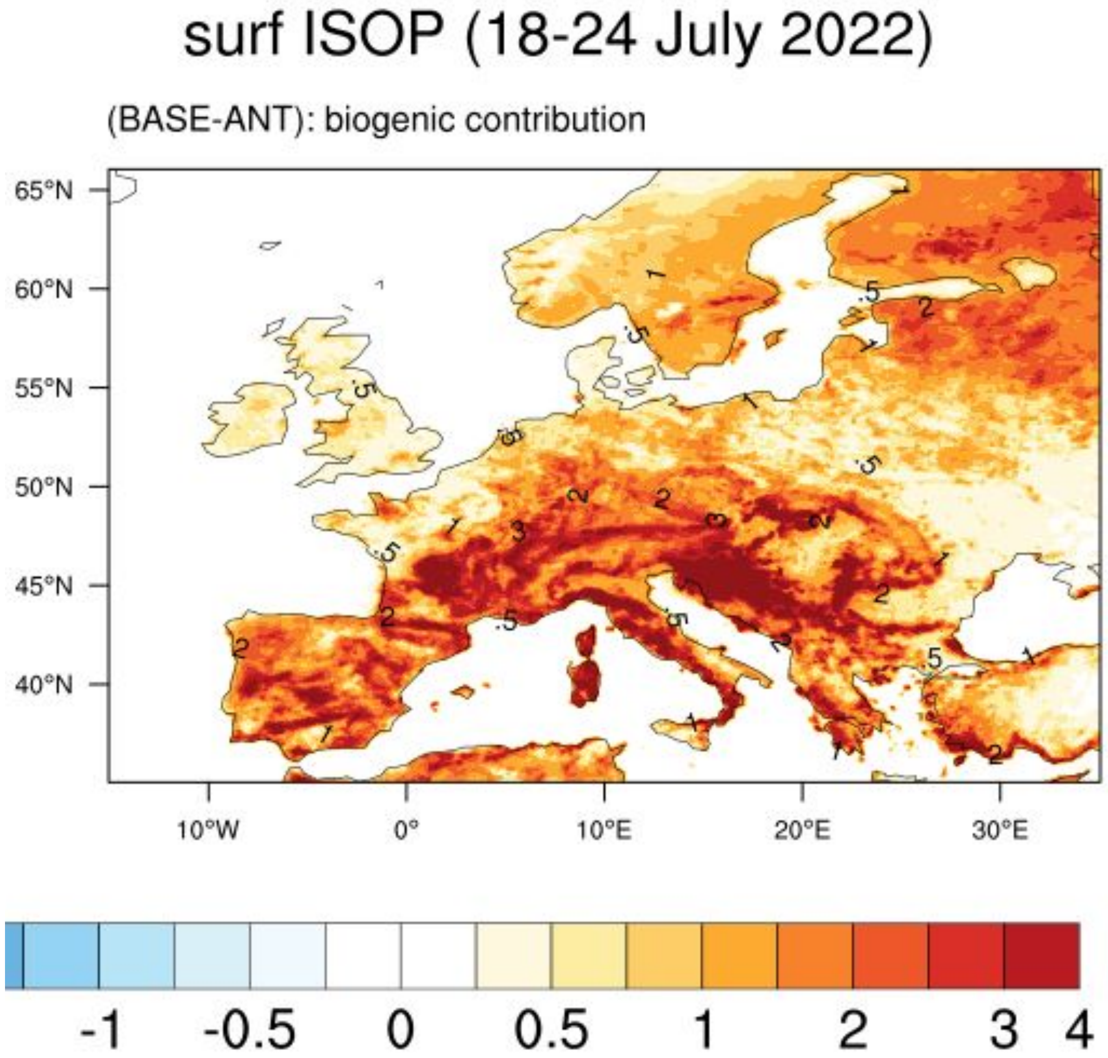
Strong improvement of O3$^{(mda8)}$, especially along the coast but also over the entire península

-2 µg/m3 on average in Jun-Aug and Spain, up to -8 µg/m3 in specific coastal locations

Up to -29 µg/m3 in specific days and in specific cells



TFMM July 2022: isoprene, all biogenic



TFMM July 2022 other analysis: OH concentration