Modelling the impact of wood burning, road transport and agricultural emission reduction on total and secondary inorganic $PM_{2.5}$ in the West Midlands, UK using WRF-CMAQ.

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The West Midlands Air Quality Program – WM-Air

Air pollution in the West Midlands:

- Affects 2.8 million people
- reduces average life expectancy by up to 6 months
- direct and indirect economic costs

The West Midland Combined Authority (WMCA):

- Defined an integrated approach to policy development with a focus the environment.
- Air quality has been declared a first order priority by Birmingham & Solihull NHS Sustainability and Transportation partnership (STP).

The Modelling Strand:

- established model approaches to enable rapid horizon scanning of future scenarios.
- Simulations performed from regional scale to urban scale

The Models used:

- **WRF v3.9.1** - meteorology
- **CMAQ v5.2.1** – chemistry transport processes
- **ADMS-urban** – pollutants dispersion

The WMAir Project areas:

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WM-Air – Regional Modelling

Landuse

Plant Species

Leaf Area Indexes

Emission factors

Biogenic emissions (MEGAN)

Meteorological conditions (WRF)

Anthropogenic Emissions for UK

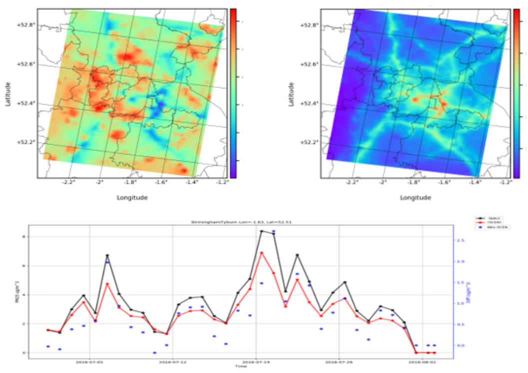
(HERMES tool)

(EMIT tool)

CAMSv3.1 Europe (10x10km)

NAEI UK (1x1km)

Chemistry-transport processes (CMAQ)



Applications

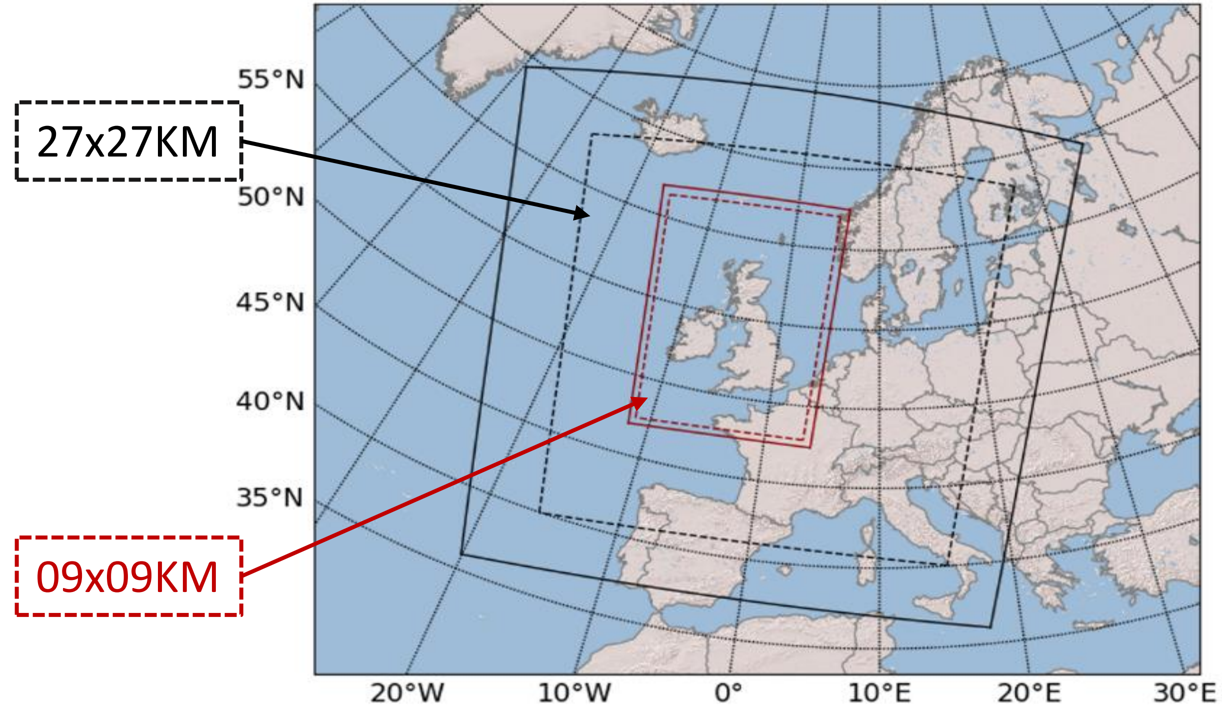
Ant. Emissions:
- CAMSv3.1(Europe 10x10km)
- NAEI (UK 1x1km)

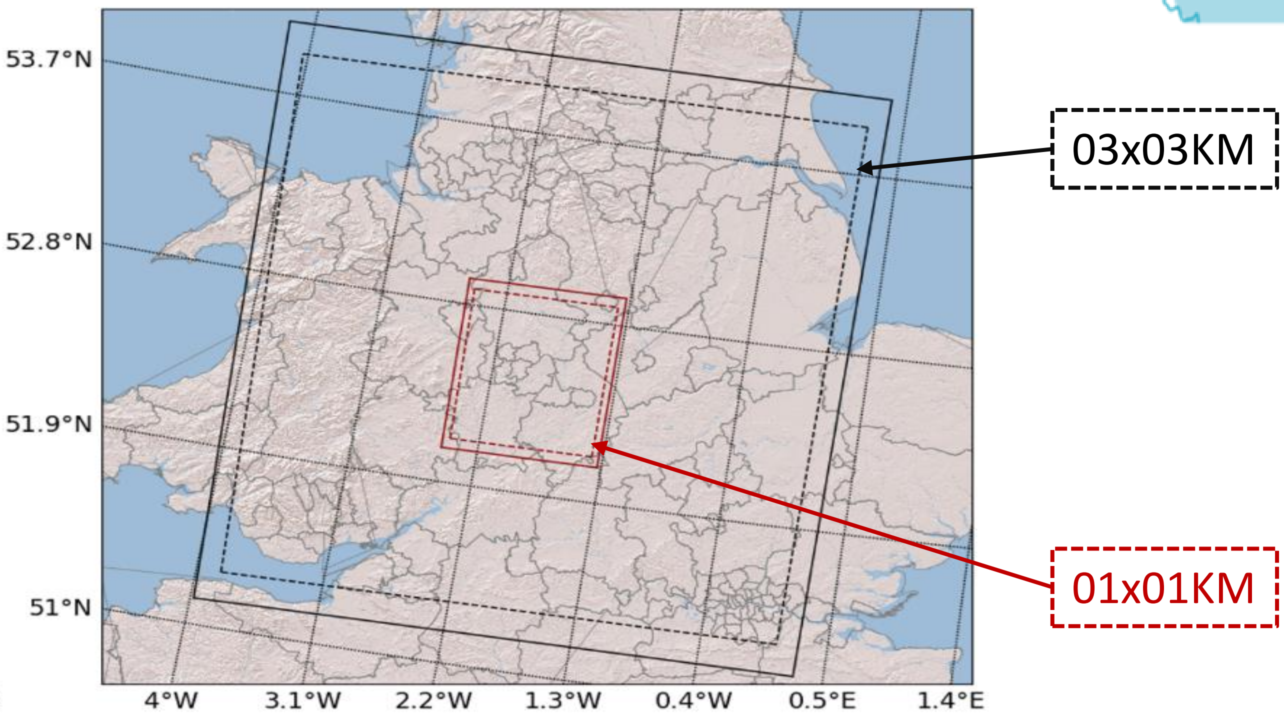
Bio. Emissions:
- MEGAN v3.1
- LAIv from Copernicus database 2016

WRF Validation:
- 126 stations
- Vertical and Surface validation of meteorology

CMAQ Validation:
- up to 81 stations
- Roadside, urban and rural background sites

WM-Air – Regional Modelling





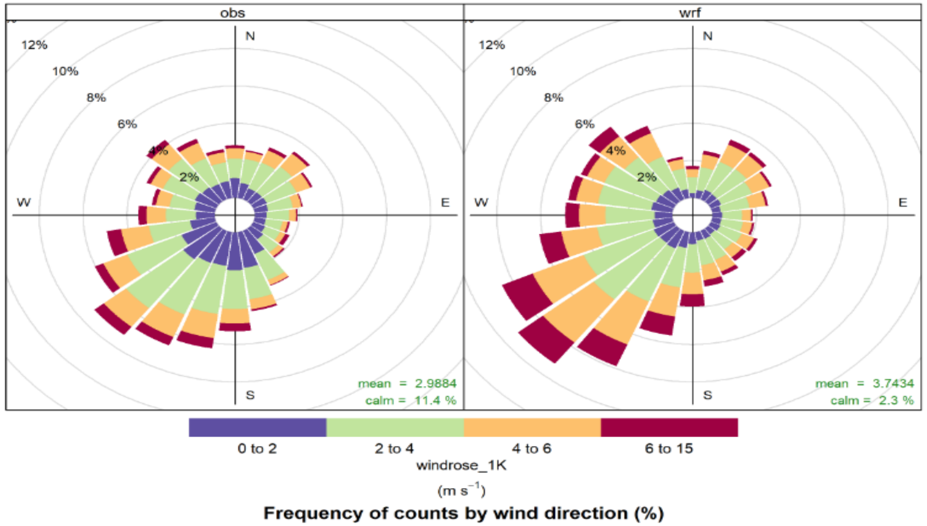
WRF Configuration		CMAQ Configuration	
WRF version	3.9.1	**CMAQ version**	5.2.1
Grid resolution	27km, 9km, 3km, 1km	**Grid Resolution**	27km, 9km, 3km, 1km
Vertical levels	30	**Sp. Projection**	Lambert Conformal Conic - LCC
IC/BC	ECMWF ERA5 reanalysis	**IC/BC**	CMAQ Hemispheric Outputs
Land use	USGS	**Chemical Scheme**	CB05e51_ae6_aq
Urban Physics	BEP	**Emission Process.**	HERMES and EMIT pre-processor
Boundary Layer	BouLac	**Anthropogenic Emissions**	CAMS3.1/NAEI
Surface Layer	Monin	**Temporal Em. Profiles**	Simpson et al.,2011 (EMEP)
Land surface	NOAH	**Natural Emissions**	MEGAN3.1

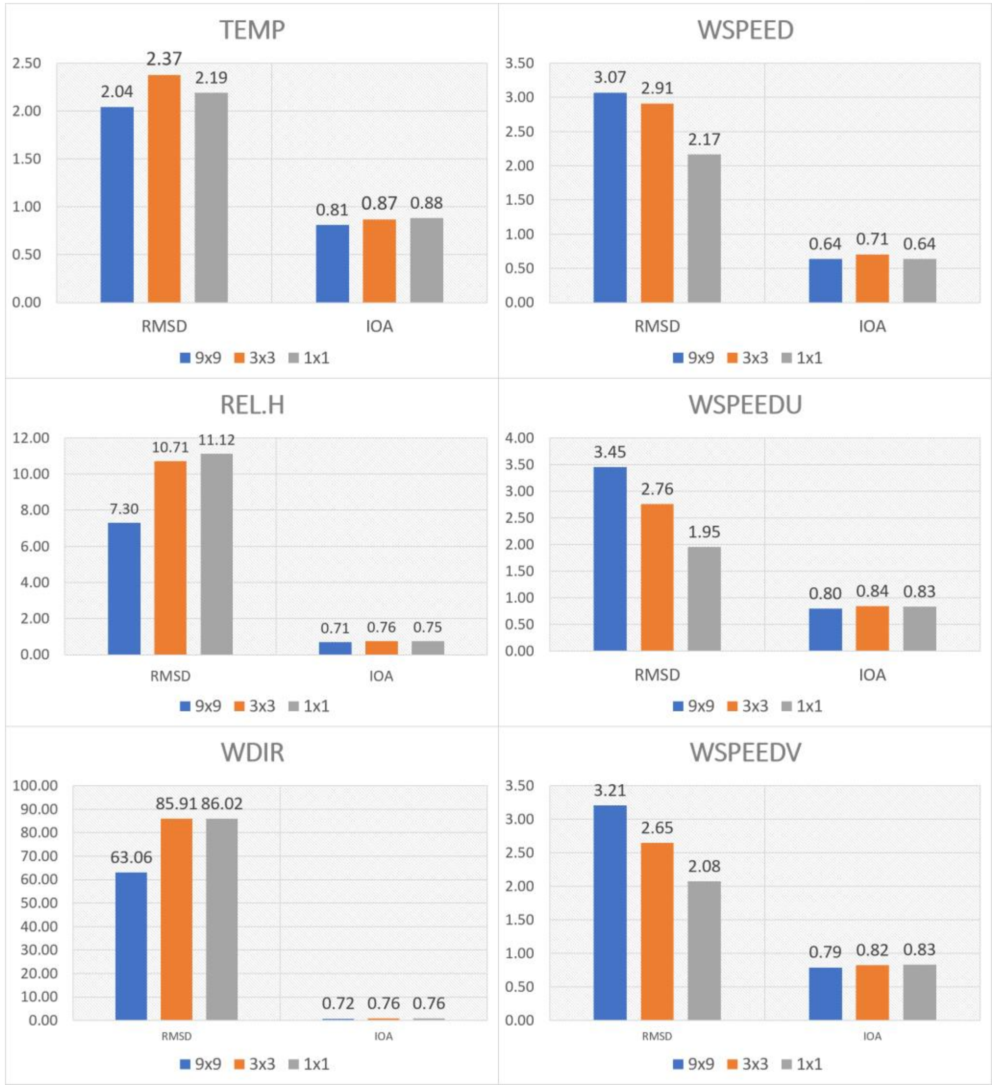
WRF Validation for base case 2016:

Statistical evaluation of the model performance against observations from:

- **UK Met Office** : surface variables on 126 stations in UK
- **Wyoming University** [1] : vertical observations from 8 stations in the UK

✓ **Statistical parameters:** MNB, RMSD, R, IOA
✓ **Variables:** SFC Temp, RH[2], W Speed, W Dir, W Speed U and V





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WRF Validation for base case 2016:

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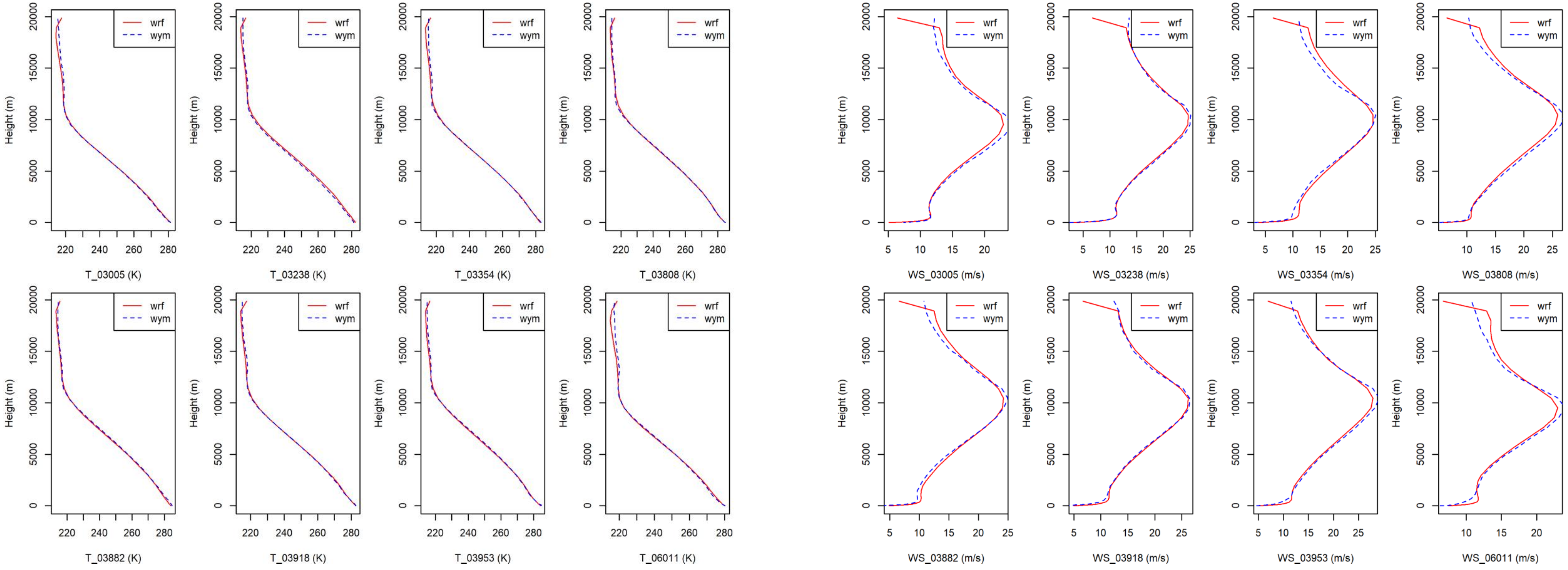
Vertical profiles for the domain 9x9km for temperature and wind speed from 0 to 20000 m a.g.l.



Observations obtained from the database of the Wyoming University (blue dashed lines) with the outputs from the WRF model (red line).

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CMAQ Validation for base case 2016:

AURN-DEFRA

Weather observations :
- R. Humidity
- Temperature
- Wind Speed
- Wind Direction

Validation Pollutants :
- C_6H_6 (benzene)
- C_5H_8 (isoprene)
- O_3
- NO, NO_2, NO_X
- $PM_{2.5}$

Additional Variables:
- $OX = NO_2 + O_3$
- $PM_{2.5}/PM_{10}$
- NO_2/NO_X

Model validation has been done using the traditional **statistical parameters**:
- mean normalised bias (MNB)
- root mean square error (RMSD)
- parson coefficient (R)
- index of agreement (IOA)

The evaluation of the model performances has been done on **a total of 95 stations** divided by:
- Urban Background: 66 (UK)
- Rural Background: 15 (UK)
- Road side 14 (WM)

MFB and MFE [3] normalise the bias and the error for each model-observed pair by the average of the model and observation before taking the final average.

$$MFB = \frac{1}{N} \sum_{i=1}^{N} (C_m - C_o)/(C_o + C_m/2)$$

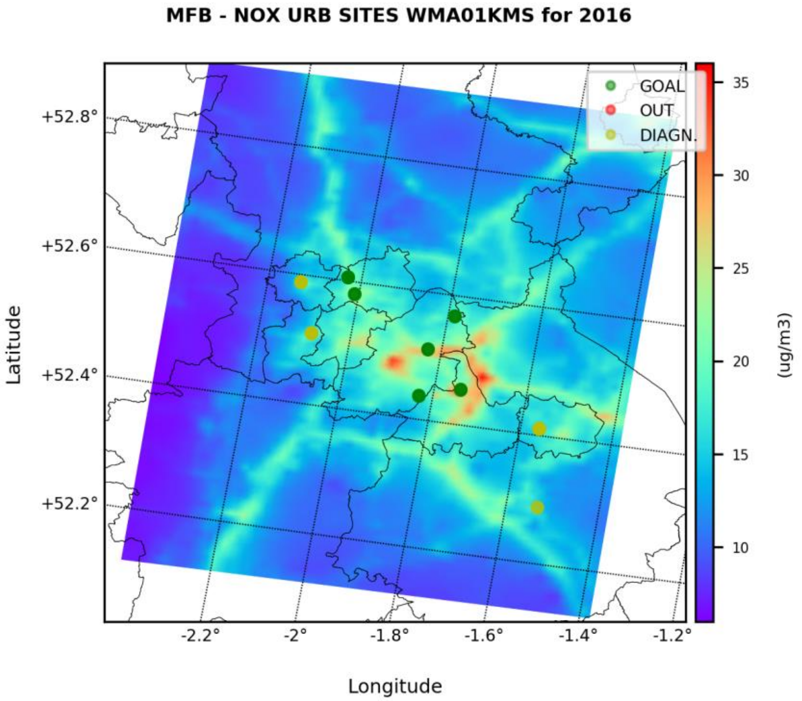
$$MFE = \frac{1}{N} \sum_{i=1}^{N} |C_m - C_o|/(C_o + C_m/2)$$

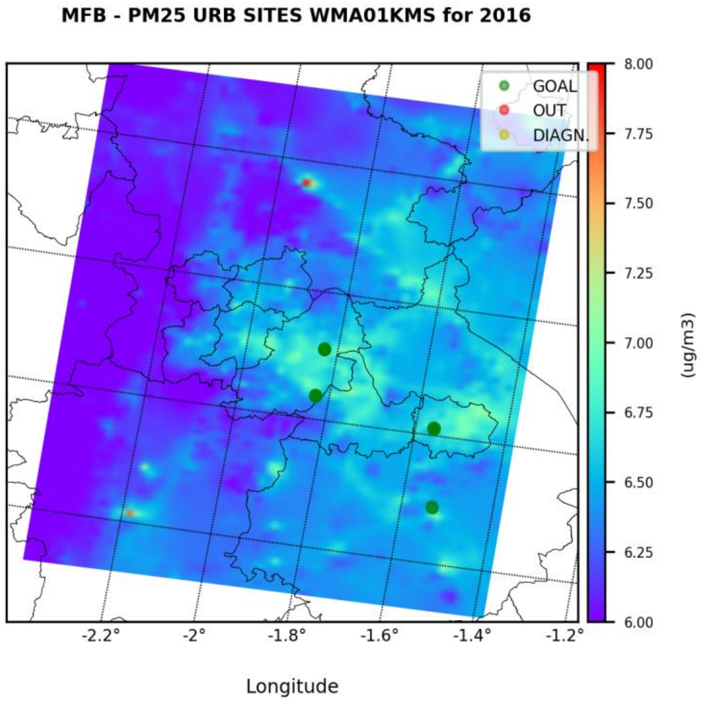
The performance goal for the modelling system is attested for MFE ≤ 50% and MFB ≤ ± 30% (GOAL)

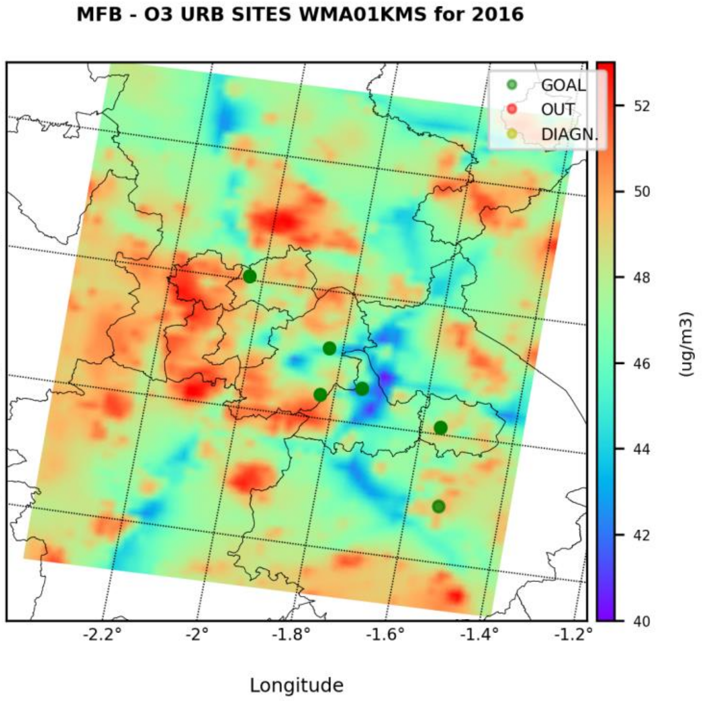
An average performance by the model is attested for MFE ≤ 75% and MFB ≤ ± 60%. (DIAGN.)

Values with MFE > 75% and -60% > MFB > +60% represent a poor representation by the model. (OUT)

CMAQ Validation for base case 2016:







NO_x	GOAL	DIAGN	OUT
MFB	6	4	0
MFE	9	1	0

NO_2	GOAL	DIAGN	OUT
MFB	7	3	0
MFE	9	1	0

$PM_{2.5}$	GOAL	DIAGN	OUT
MFB	4	0	0
MFE	4	0	0

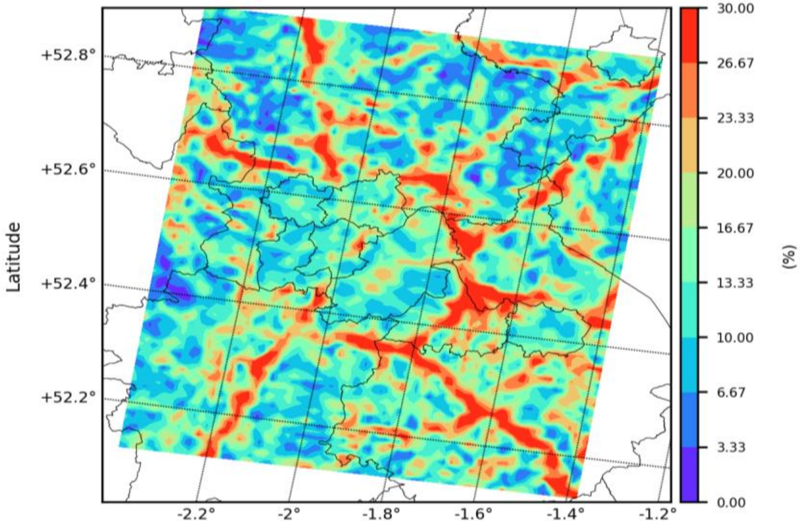
PM_{10}	GOAL	DIAGN	OUT
MFB	0	5	0
MFE	5	0	0

OX	GOAL	DIAGN	OUT
MFB	5	0	0
MFE	5	0	0

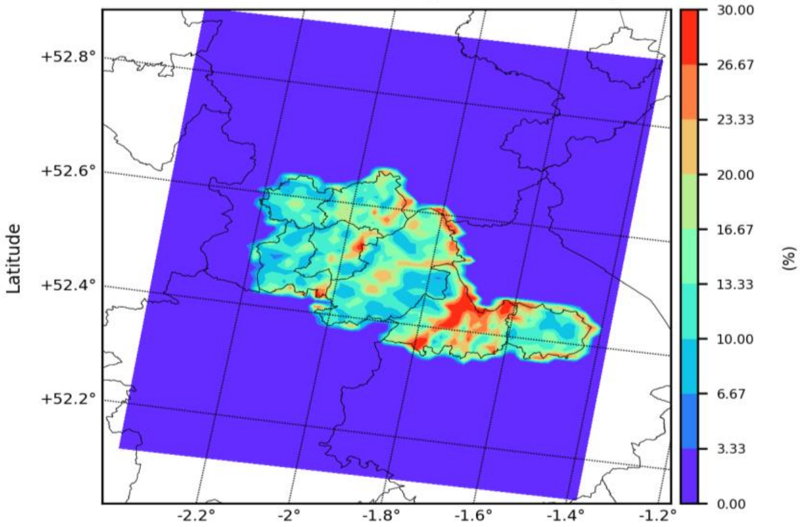
O_3	GOAL	DIAGN	OUT
MFB	6	0	0
MFE	6	0	0

Scenarios with Reduced emissions:

Full Domain reduction (FD)



Masked Scenario reduction (MS)



Scenarios Design:

- **Full Domain Scenarios (FD):** anthropogenic emissions reduced in the domain at 27x27, 9x9, 3x3 and 1x1 km of resolution.
- **Masked Domain Scenarios (MS):** anthropogenic emissions reduced only inside the West Midlands area corresponding to the 3x3, 1x1km domains.
- **SNAP2** and **SNAP7** scenarios have reduced primary emissions of: CO, VOC, PM_{10}, $PM_{2.5}$, NO, NO_2, NH_3 and SO_2.
- **SNAP10** scenario has primary NH_3 emissions reduced only.
- **SNAP7+10** combine the characteristics of the two individual scenarios.

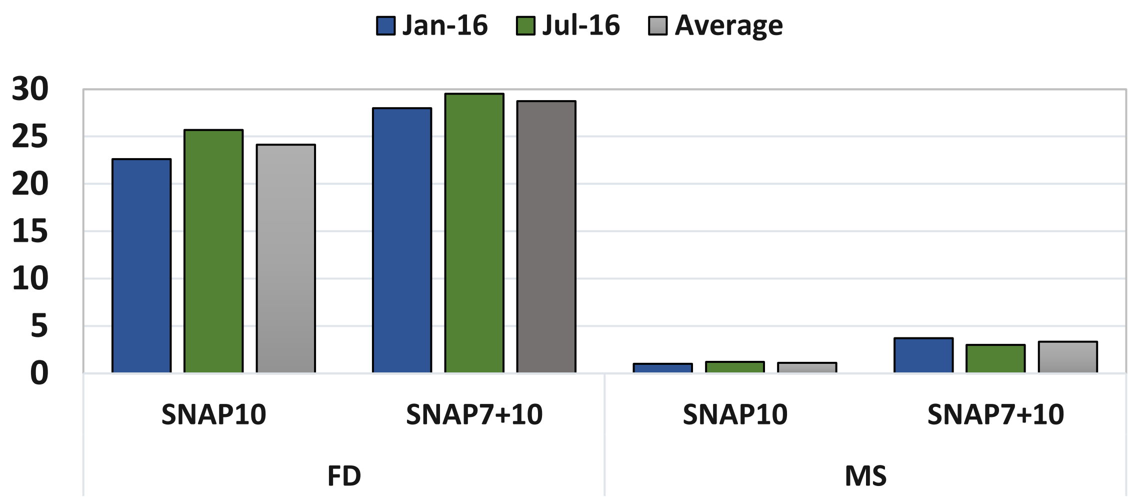
Scenarios	Sector	[%] Reduction
Wood Burning	**SNAP2**	**85**
Agriculture	**SNAP10**	**30**
Road Transport	**SNAP7**	**30**
Agriculture + Road Transport	SNAP10 + SNAP7	30 + 30

Scenarios with Reduced emissions:

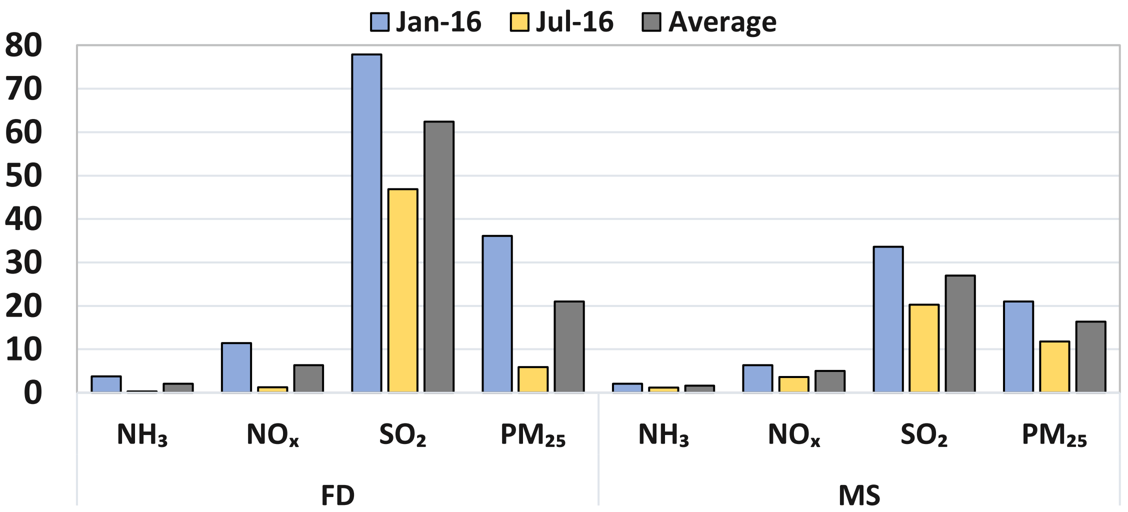
Percentage of reduction of total monthly emissions:

- **SNAP2 and 7 :** reduction applied to all the primary emissions of the sector
- **SNAP10:** reduction applied to the NH_3 only
- **SNAP7+10:** reduction of 30% on all road transport emissions. Additional reduction of 30% on NH_3 from agriculture.

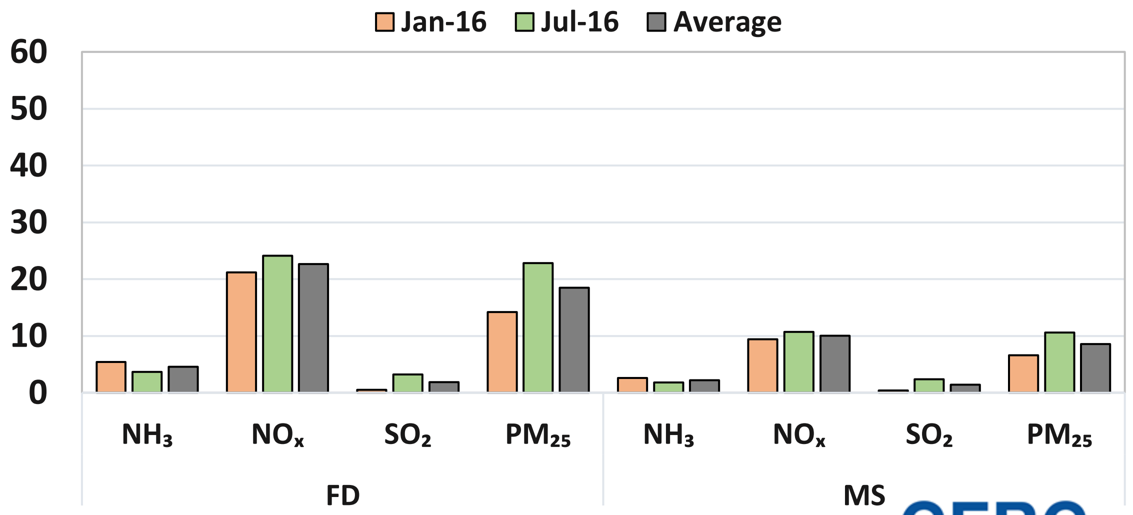
NH_3 - REDUCTION (%)



SNAP2 – EMIS REDUCTION (%)



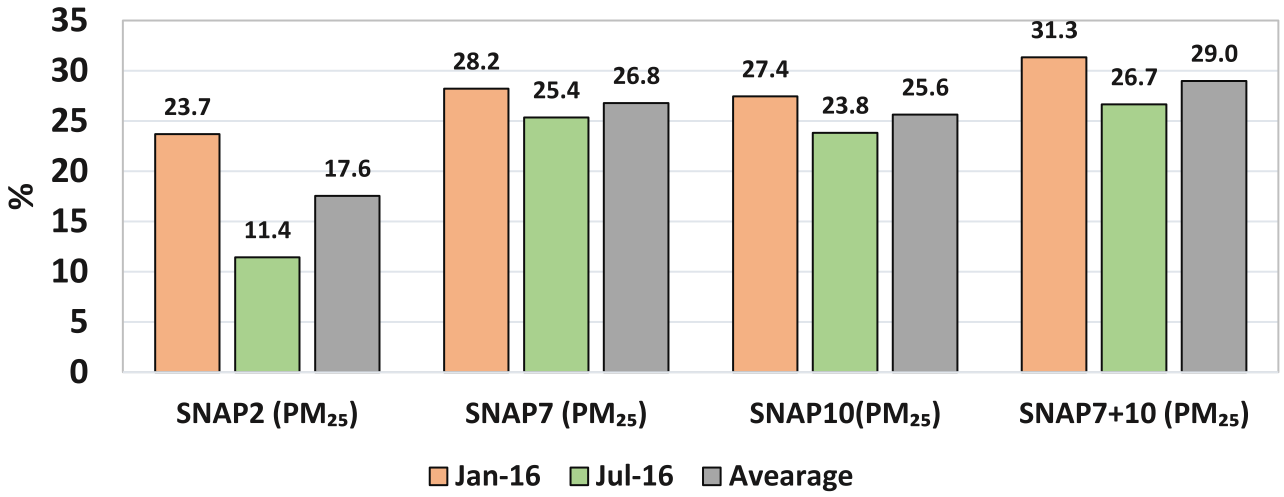
SNAP7 – EMIS REDUCTION (%)



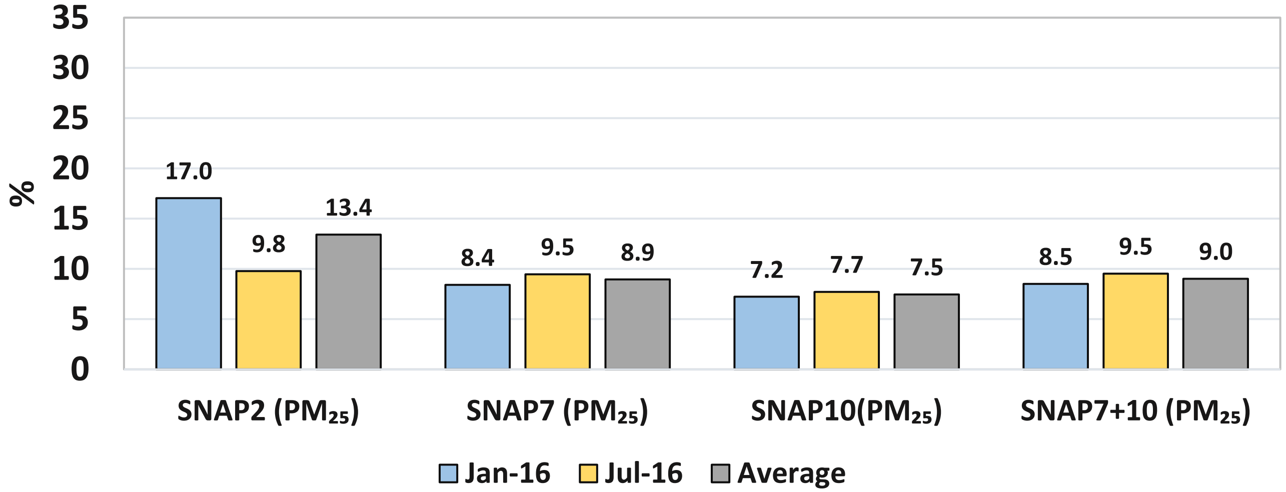
Scenarios with Reduced emissions:

FD Scenarios:
- The highest reduction is seen in the **SNAP7+10** Scenarios
- The **SNAP2** scenario has the highest seasonal variability in the reduction
- The **SNAP10** emissions are located outside the WM border and influence the concentrations also inside the mask.

<u>FD Concentrations</u> **percentage reduction**

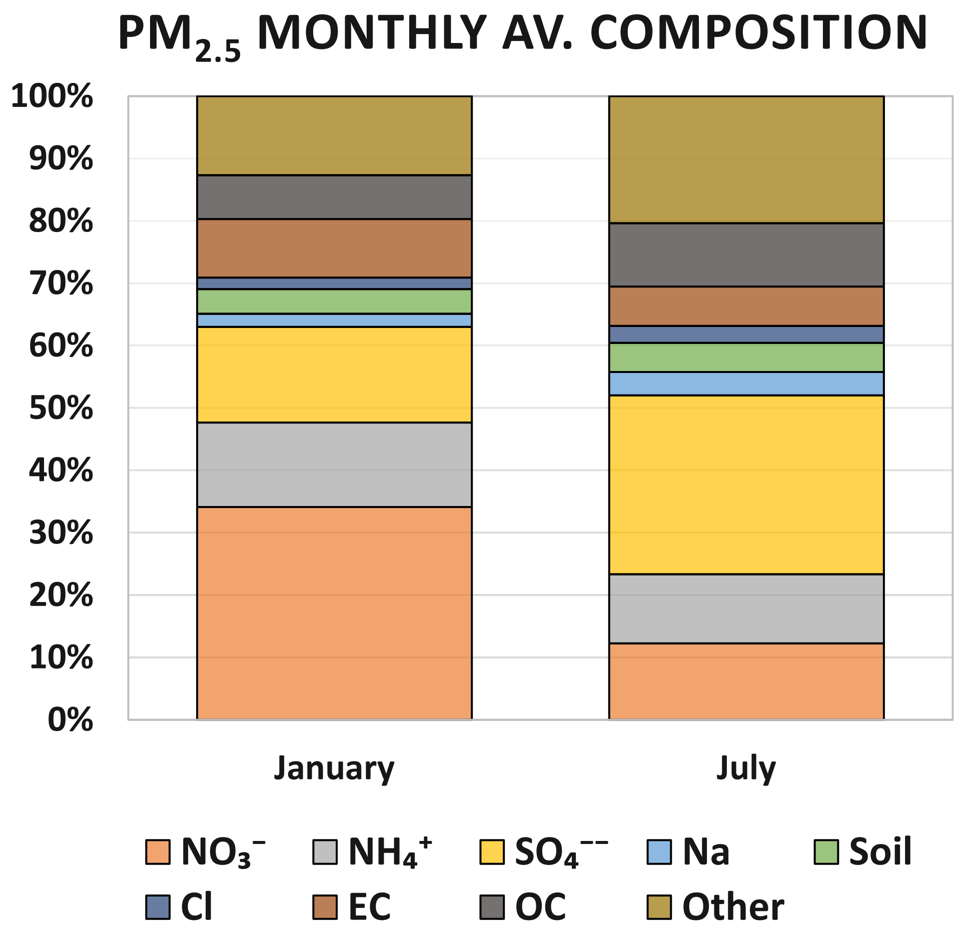


<u>MS Concentrations</u> **percentage reduction**



MS Scenarios:
- The highest reduction is seen in the **SNAP2** Scenarios
- The **SNAP2** scenario has also the highest seasonal variability in the reduction
- The reduction of **SNAP2** has higher influence the concentrations inside the mask.

Secondary Inorganic Fractions of $PM_{2.5}$:



The concentrations of $PM_{2.5}$ fractions for the masked area of the West Midlands:

- $PM_{2.5}$. composition in january is highly influenced by dominated by NO_3^-
- $PM_{2.5}$. composition in July is highly influenced by dominated by SO_4^{2-}

- The percentage of SIA in $PM_{2.5}$ can vary according to meteorological seasonal conditions and transport phenomena from EU. [4]
- Sulphates and Nitrates are dominant in the experimental source apportionment of $PM_{2.5}$ in the West Midlands urban conurbation areas.[5]

Secondary Inorganic Fractions of $PM_{2.5}$:

- The response of $PM_{2.5}$ and the SIA SO_4^{2-}, NO_3^- and NH_4^+ to precursors emissions change has been calculated in terms of fraction concentration change (FC) [6]:

		MS SCENARIOS				FD SCENARIOS			
		SNAP2	SNAP10	SNAP7	SNAP7+10	SNAP2	SNAP10	SNAP7	SNAP7+10
Jan-16	PM_{25}	0.17	0.07	0.08	0.09	0.28	0.30	0.32	0.34
	NO_3^-	0.09	0.08	0.08	0.09	0.16	0.44	0.45	0.50
	NH_4^+	0.15	0.13	0.13	0.13	0.23	0.54	0.53	0.58
	SO_4^{--}	0.24	0.15	0.16	0.16	0.34	0.49	0.47	0.50
Jul-16	PM_{25}	0.10	0.08	0.09	0.10	0.11	0.21	0.23	0.24
	NO_3^-	0.40	0.40	0.42	0.42	0.41	0.83	0.84	0.86
	NH_4^+	0.16	0.15	0.15	0.15	0.15	0.43	0.41	0.44
	SO_4^{--}	0.03	0.02	0.02	0.02	0.03	0.16	0.16	0.17

$$FC = \frac{1}{N}\sum_{i=1}^{N}\frac{B_i - C_i}{B_i}$$

N is the total number of the ground level computational cells within the domain
i is the ground computational cell
B_i is the base case predicted value of the pollutant concentration in the i cell
C_i is the predicted value of the pollutant concentration in the i cell for each of the scenario applied.

- **MS Scenarios:** highest FC from **SNAP2** and SO_4^{2-} with an almost linear reduction in comparison with the emissions (33%) in January. Highest FC from NO_3^- in July in all scenarios (~40%)

- **FD Scenarios:** highest FC from **SNAP7+10**. The reduction of SO_4^{-2}, NO_3^- and NH_4^+ is similar in January. The reduction in **SNAP7+10** is highly influenced by the reduced transport emissions in the masked area and agricultural emission from outside the borders.

Conclusions:

a. The modelling System WRF-CMAQ have been validated for Air quality simulations at high resolution focused on the West Midlands, UK.

b. WRF-CMAQ has been validated to conduce simulations of air quality over the WM area using observational data from surface and on vertical for meteorology and from different type of background.

c. Scenarios with reduced emissions of Ammonia from agriculture, wood burning and road transport have been simulated for the WM.

d. Results have shown that local or national policies can have different impact on the resulting levels of $PM_{2.5}$.

e. Local policies for the WM should be oriented to reduce the wood burning emissions being these the most effective in reduce the concentrations or $PM_{2.5}$ inside the masked area.

f. National policies could focus on the implementation of policies combining the reduction of primary emissions from transport and agriculture and optimizing the effect of reduction both in rural and in urban areas.

g. Finally, the combined reduction of transport and agricultural emissions has the higher effect in reducing the concentrations of the main secondary aerosols forming $PM_{2.5}$. The most affected SIAs by the emission reduction in the scenarios have been NO_3^- and SO_4^{-2} for the combined scenario and for wood burning respectively.

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Thanks for the attention!

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References:

[1] http://weather.uwyo.edu/upperair/sounding.html

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[6] Tsimpidi, A. P., Karydis, V. A., & Pandis, S. N. (2007). Response of inorganic fine particulate matter to emission changes of sulphur dioxide and ammonia: The eastern United States as a case study. Journal of the Air & Waste Management Association, 57(12), 1489-1498. https://doi.org/10.3155/1047-3289.57.12.1489

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