Sensitivity of air quality to emissions changes

Contribution to FAIRMODE Cross-cutting Task 9 on
Air Quality Model Projections

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FORMAT

- **Introduction to FAIRMODE CT- 9 Activity**
- **WRF-CMAQ analysis as a contribution to CT-9 for March 2015 PM episode – London**
  - Sensitivity to emissions inventory
  - Sensitivity to model grid resolution
  - Changes due to reductions in over emissions
- **Conclusions**

Acknowledgements

Cross-cutting Task 9 Team especially Bertrand Bessagnet, Alexandra Monteiro and Philippe Thunis
DEFRA, UK for Air Quality data
UK Met Office for met data

FAIRMODE CT9

FAIRMODE chair: **Ph. Thunis (JRC)**

FAIRMODE CT9:

Chair: **A. Monteiro (Univ. of Aveiro)**

Co-chair: **B. Bessagnet / formerly E. Pisoni (JRC)**

FAIRMODE CT9 OBJECTIVES

- For a given mitigation scenario, models provide different absolute results C^M_{scen}

- **BUT, HOW DO THEY BEHAVE ON DELTAS?**

$$\Delta = C^M_{scen} - C^M_{bc}$$

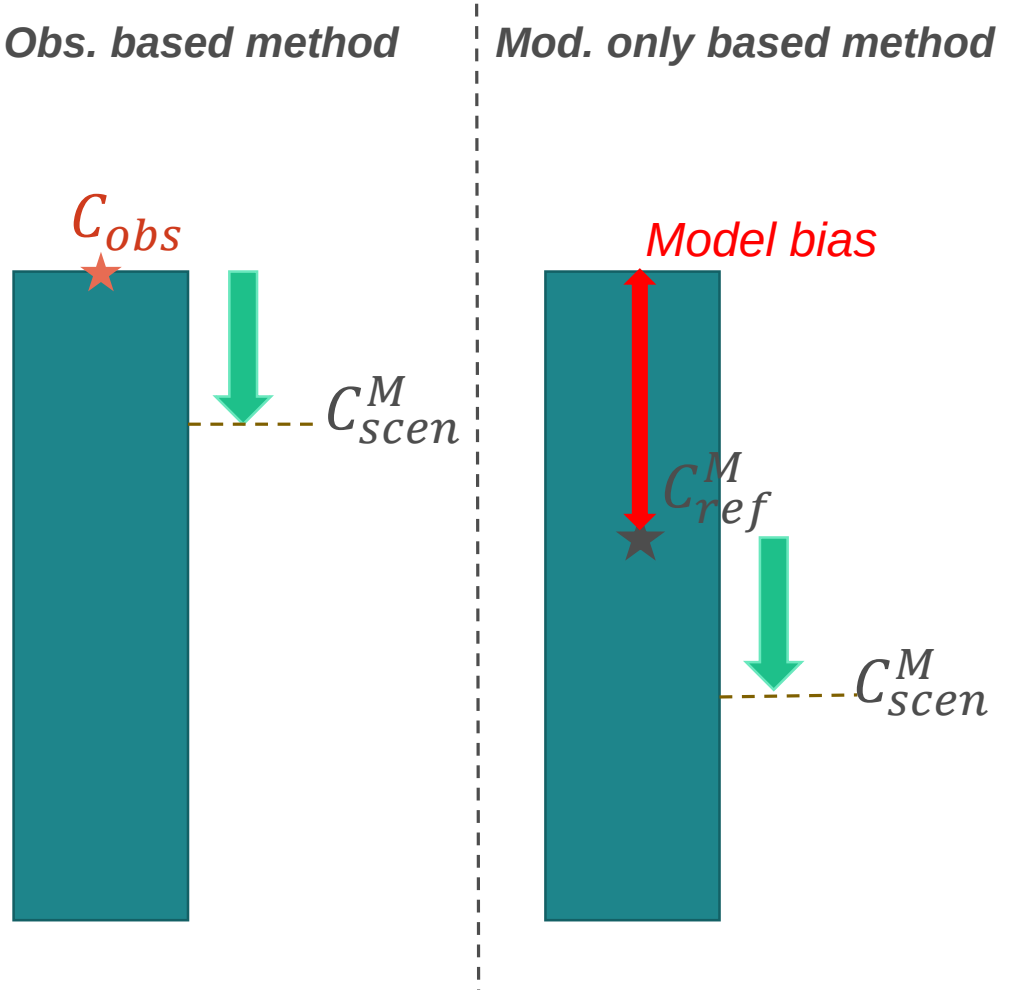
- What is the order of magnitude of differences? How to evaluate these differences? Which indicators?
- Can we explain the differences, what are the main drivers?

It is important to assess the robustness of deltas for urban policies!

FAIRMODE CT9 CONTEXT

- Many inter-comparison exercises of air quality models
- No recent exercises to assess the capacity of models to simulate “delta” (Formerly CityDelta, EURODELTA) particularly at more local sacle
- **Need to have a long term inter-comparison <u>platform</u> to continually assess model responses**

- A Model Concentration Delta can be applied to an observation C_{obs} to evaluate a scenarios based on ‘*bc*’ reference and ‘*scen*’ simulations:
  - Absolute (for O3?): $C_{scen} = C_{obs} + \left(\boldsymbol{C^M_{scen} - C^M_{bc}}\right)$
  - Relative (for NO2 or PM?): $C_{scen} = C_{obs} \times \left(\boldsymbol{C^M_{scen} - C^M_{bc}}\right)/\boldsymbol{C^M_{bc}}$
  - ***Techniques often used but rarely assessed***



European Commission

The overall framework

Set-up

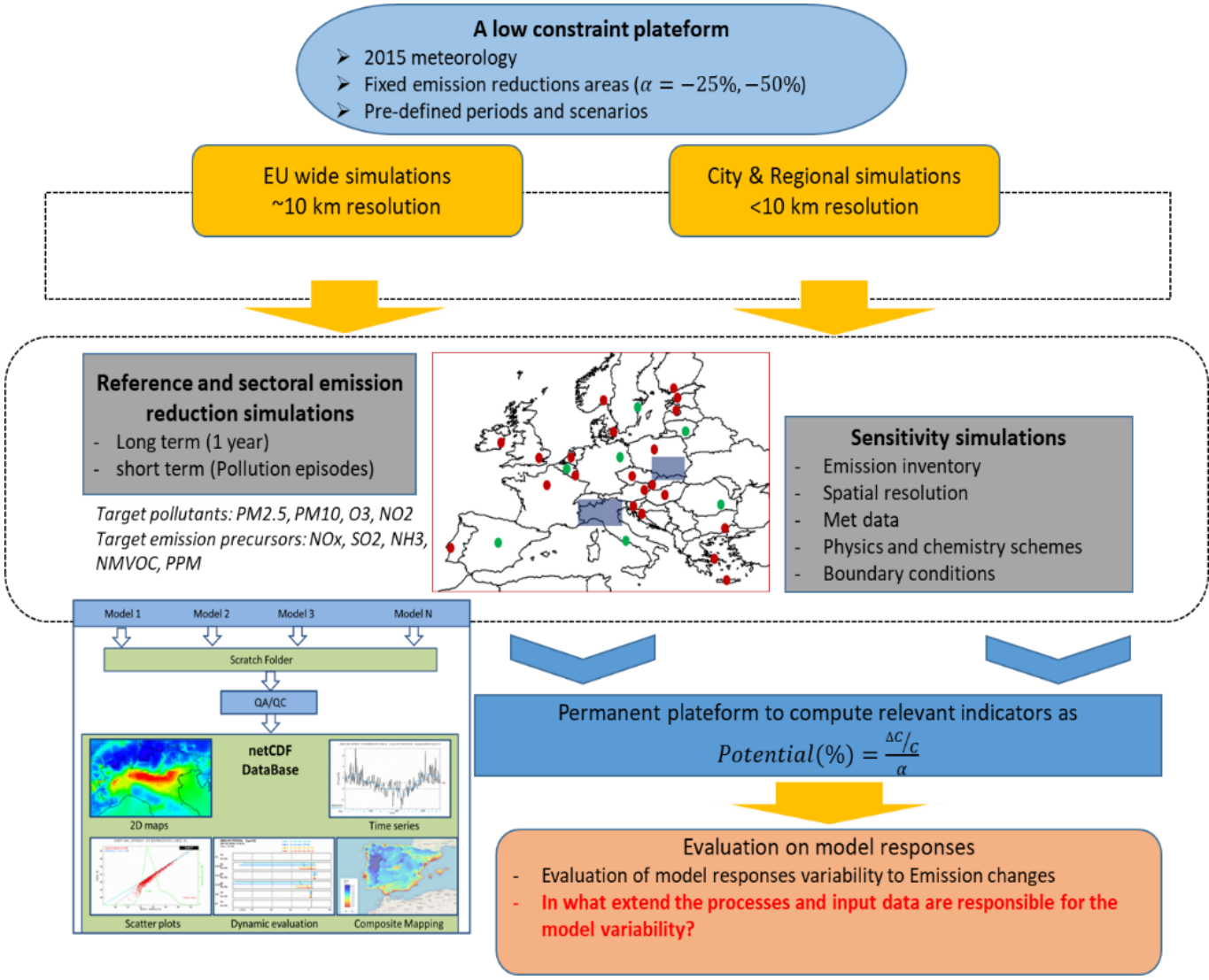
- Short term (ST) on episodes (PM10, NO2, O3)
  - Emissions reduced only during 2015 episodes from 00:00 to 23:00
- Long term (LT) simulations (PM10, NO2, O3)
  - Emissions reduced the whole year 2015
- Two reductions so far:
  - 25% and 50% from a base case (BC)
- Reduced species depends on target pollutants
  - **PM10**: PPM, NOx, VOC, NH3, SO2, ALL
  - **Ozone**: NOx, VOC, ALL
  - All together or separately

Indicators

- The **Absolute Potential** is defined as the reduction in µg/m^3 scaled by the reduction $\boldsymbol{\alpha}$ of the scenario (25 or 50%) of a precursor from base case BC
  - $\boldsymbol{APl} = \left(C \quad - C^{BC}\right)/(\alpha \quad)$ ($\boldsymbol{APl} \times \boldsymbol{\alpha}$ is the delta of concentrations)
- The **Relative Potential** is defined as the reduction in % scaled by the reduction $\boldsymbol{\alpha}$ of the scenario (25 or 50%) of precursor ***n*** from base case BC and by the BC concentrations.
  - $\boldsymbol{RPl} = \left(C \quad - C^{BC}\right)/(\alpha \quad \times C^{BC})$
- The **Absolute Potency** in µg/m^3/(ton/day) is defined as the derivative of the concentration with respect to the emissions density E of a precursor or in other words the rate with which the concentrations (***C***) will change as a result of an emission density E)
  - $\boldsymbol{APy} = \left(C \quad - C^{BC}\right)/(\alpha \quad \times E^{BC})$

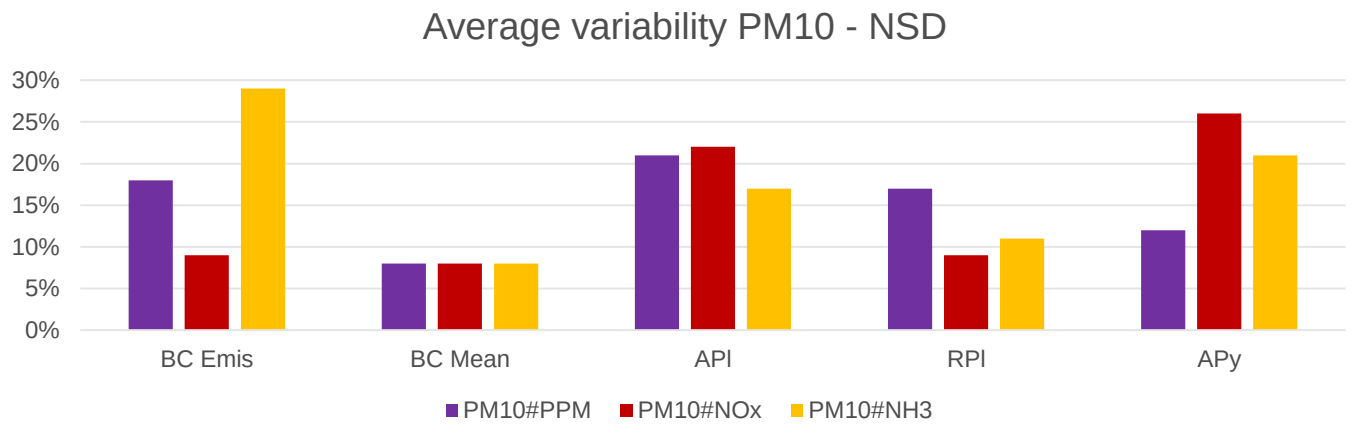
Models and teams involved - Overview

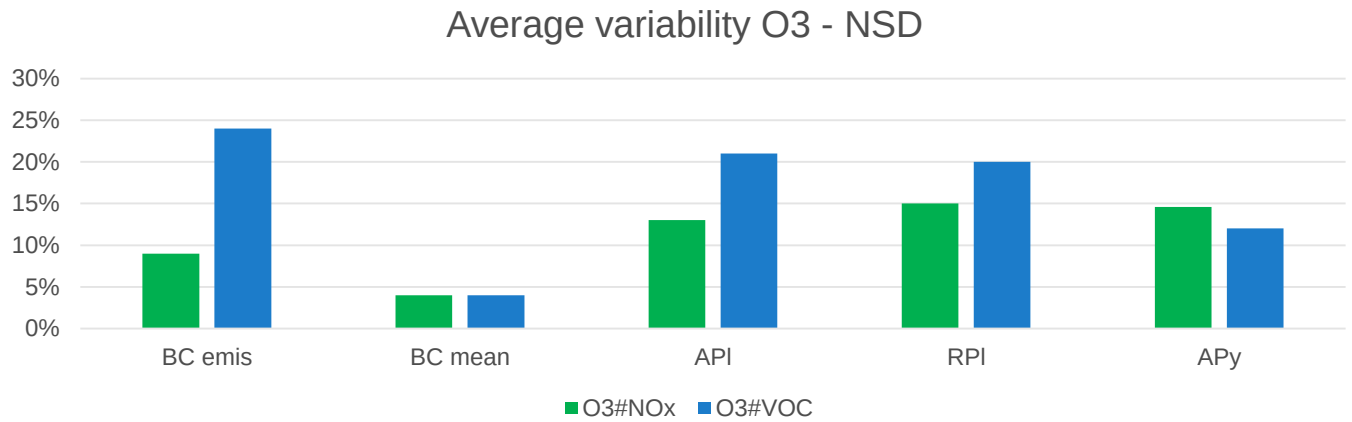
Team name - Country		Model Name
JRC	(EU)	EMEP
JRC	(EU)	WRF-Chem
ZAMG	(AT)	WRF-Chem
Met Norway	(NO)	EMEP
Met Norway	(NO)	EMEP + uEMEP
Cyl	(CY)	WRF-Chem
NKUA	(GR)	WRF-Chem
DHMZ	(HR)	ADMS-Urban
DHMZ	(HR)	LOTOS-EUROS
LMD/IPSL	(FR)	WRF-CHIMEREv2020r1
UH-CACP	(UK)	WRF-CMAQ
CIEMAT	(ES)	IFS-CHIMEREv2017r4
ENEA	(IT)	WRF-MINNI
UNIBS	(IT)	WRF-CAMx
IRCELINE	(BE)	CHIMERE + RIO + ATMOSTREET



Preliminary results on variability

- Less variability on O3 BC Mean than PM10 BC Mean
  - 4 versus 8 %
- Variability of RPI << API (less clear for O3)
  - 10 to 25% depending on the indicator





Variability from models M assessed by Norm. Std. Dev.

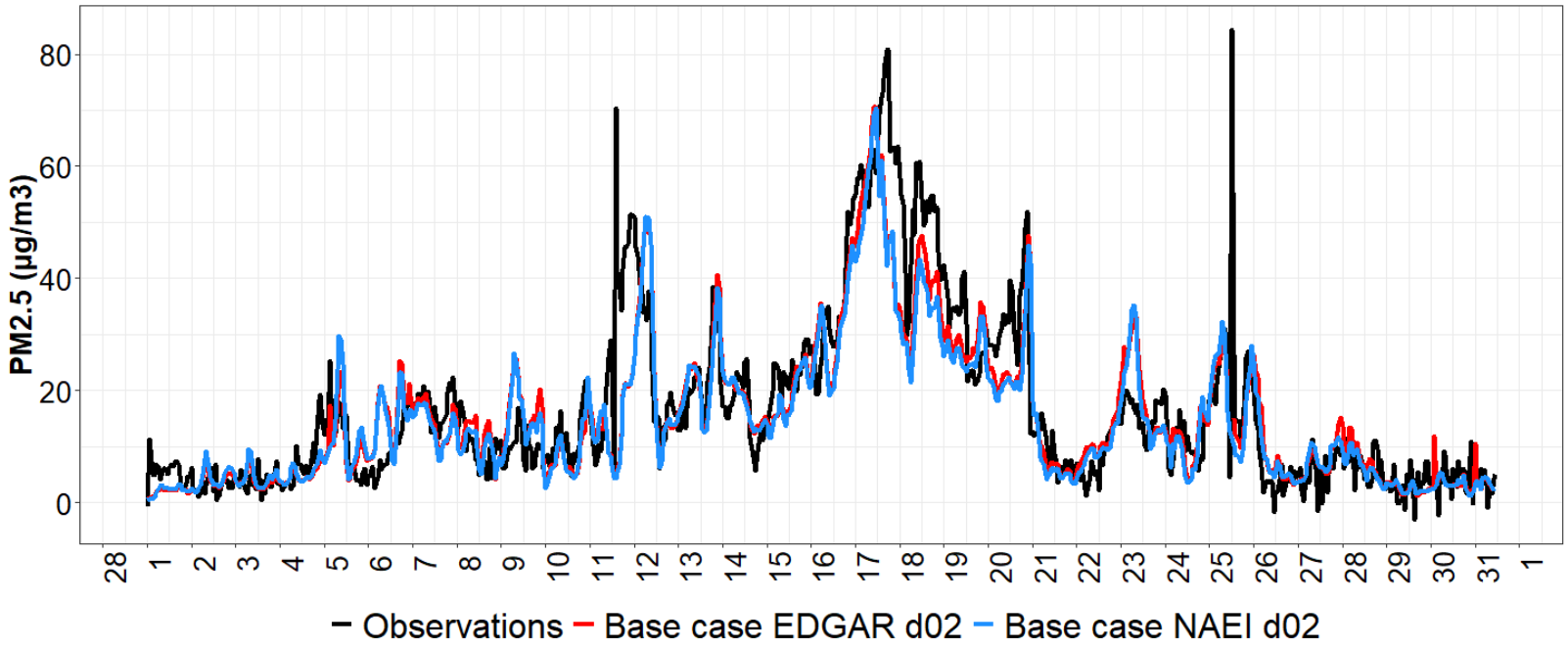
$$NSD_{IND} = \sqrt{\frac{\sum_{m=1}^{M}(IND_m - \overline{IND})^2}{(\overline{IND})^2}}$$

European Commission

WRF-CMAQ Analysis

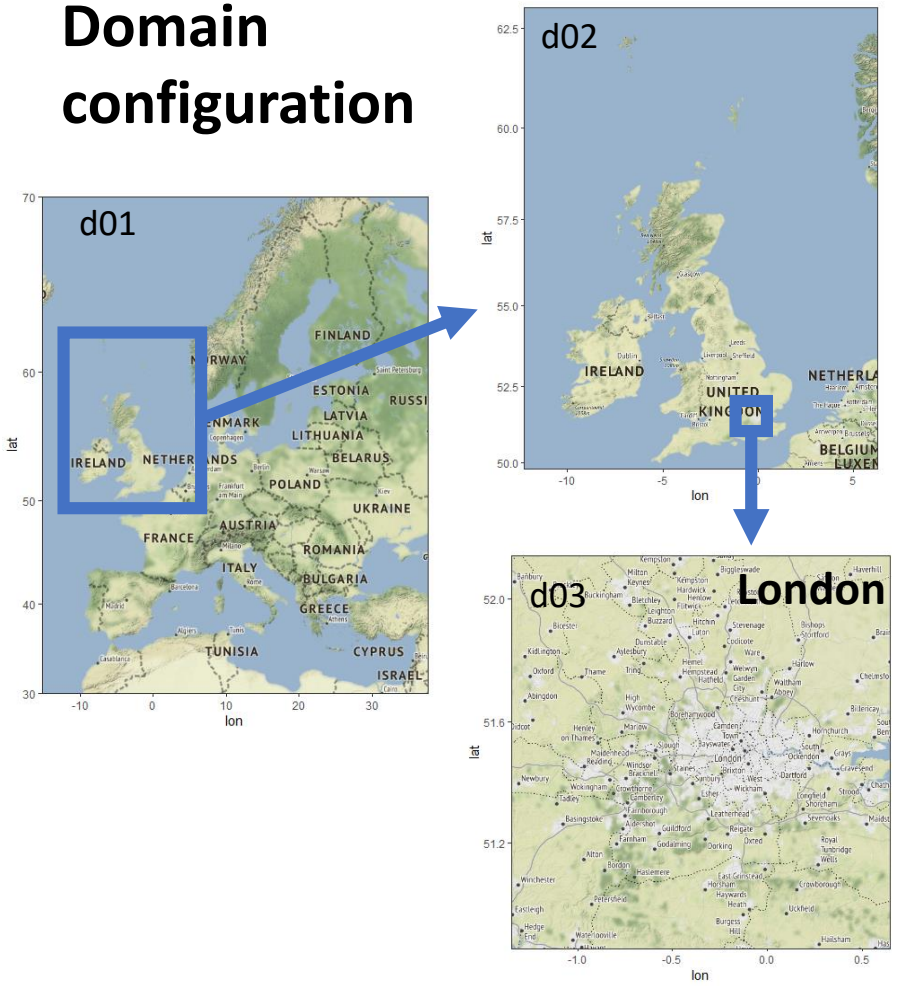
UH-CACP Team

March 2015



Model setup

Domain configuration



	Europe	UK	London
Domain ID	d01	d02	d03
Resolution	25 km	5 km	1 km

Episode period for PM

- March 2015

Meteorology model

- WRF v4.2
- NCEP GFS initial-boundary condition data

Air quality model

- CMAQ v5.3.2

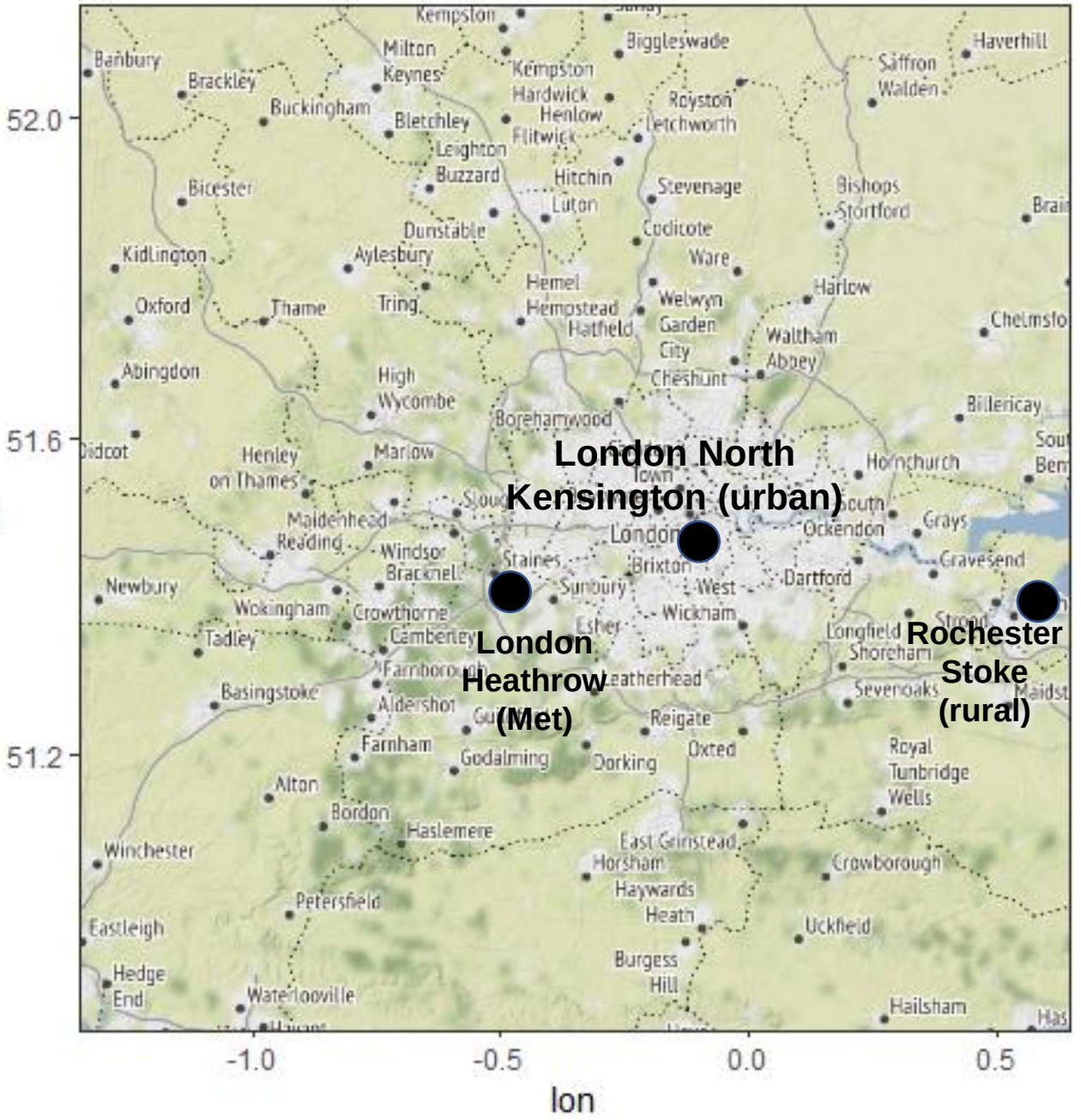
Emissions

- EDGAR v5 emission inventory at 0.1º (2015)
- NAEI 1x1km UK emission inventory (2015)
- Biogenic emissions via MEGAN version 2.1
- Anthropogenic emissions via SMOKE v4.6

Background stations for model evaluations

Station Name	Long.	Lat.	Type	Alt.
London North Kensington	51.521	-0.213	Urban	5
Rochester Stoke	51.456	0.635	Rural	14

Observations from :
UK Air Department for Environment Food & Rural Affairs (DEFRA)
https://uk-air.defra.gov.uk/

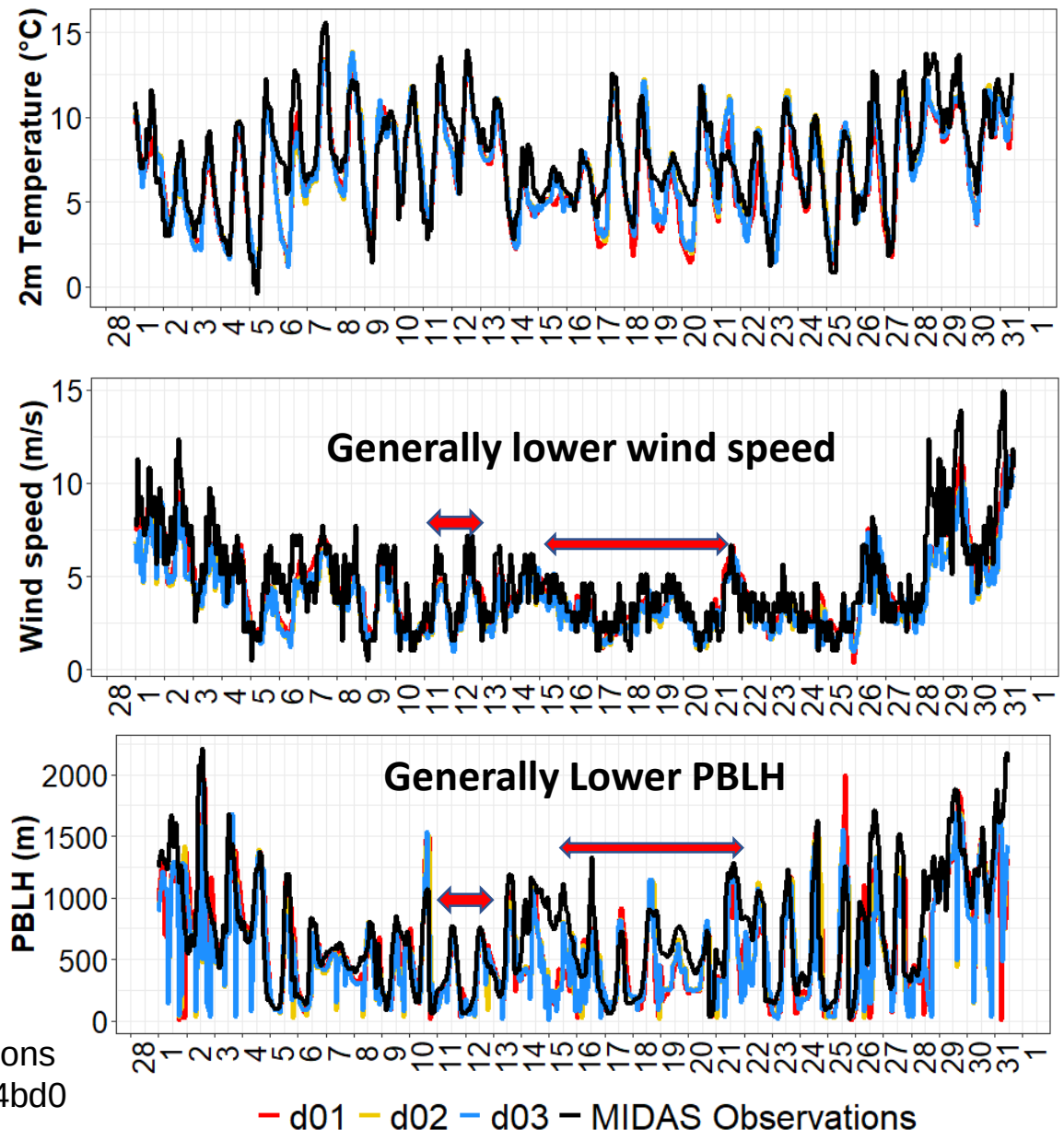


WRF model performance evaluation for London Heathrow station for d01, d02 and d03

Performance metrics

		n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	IOA	r2
T2	d01	768	0.95	- 0.84	1.23	- 0.11	0.161	1.56	0.892	0.736	0.80
	d02	768	0.95	- 0.57	1.13	- 0.08	0.148	1.47	0.889	0.758	0.79
	d03	768	0.96	- 0.63	1.14	- 0.08	0.150	1.46	0.893	0.755	0.80
RH	d01	768	0.96	6.57	15.26	0.09	0.213	19.25	0.613	0.413	0.38
	d02	768	1.00	2.73	8.05	0.04	0.112	10.47	0.801	0.690	0.64
	d03	768	1.00	2.89	8.15	0.04	0.114	10.51	0.799	0.686	0.64
WS	d01	766	0.96	- 0.35	1.04	- 0.07	0.215	1.38	0.849	0.737	0.72
	d02	766	0.95	- 0.87	1.21	- 0.18	0.251	1.61	0.849	0.693	0.72
	d03	766	0.95	- 0.87	1.26	- 0.18	0.260	1.64	0.837	0.682	0.70
WD	d01	766	0.93	1.24	22.37	0.01	0.122	52.76	0.871	0.875	0.76
	d02	766	0.93	1.03	21.81	0.01	0.119	50.79	0.880	0.878	0.77
	d03	766	0.94	0.75	21.61	0.00	0.118	49.62	0.884	0.879	0.78
PBCH	d01	768	0.75	-149	254	- 0.20	0.345	369	0.714	0.657	0.51
	d02	768	0.76	-172	256	- 0.23	0.348	373	0.720	0.655	0.52
	d03	768	0.75	-190	257	- 0.26	0.351	373	0.730	0.652	0.53

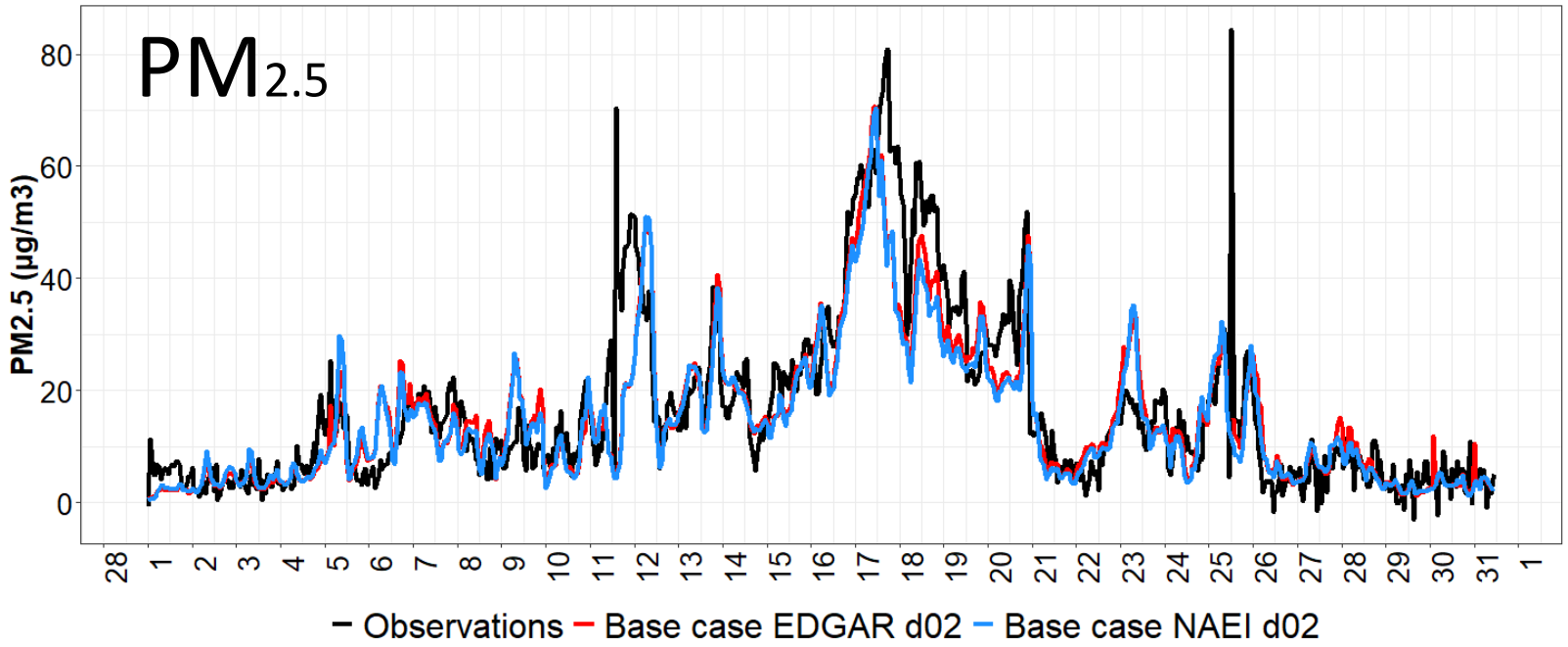
PBLH is compared to ERA5 where others compared to MIDAS observations.
MIDAS : Met Office Integrated Data Archive System Land and Marine Surface Stations
Available from http://catalogue.ceda.ac.uk/uuid/220a65615218d5c9cc9e4785a3234bd0

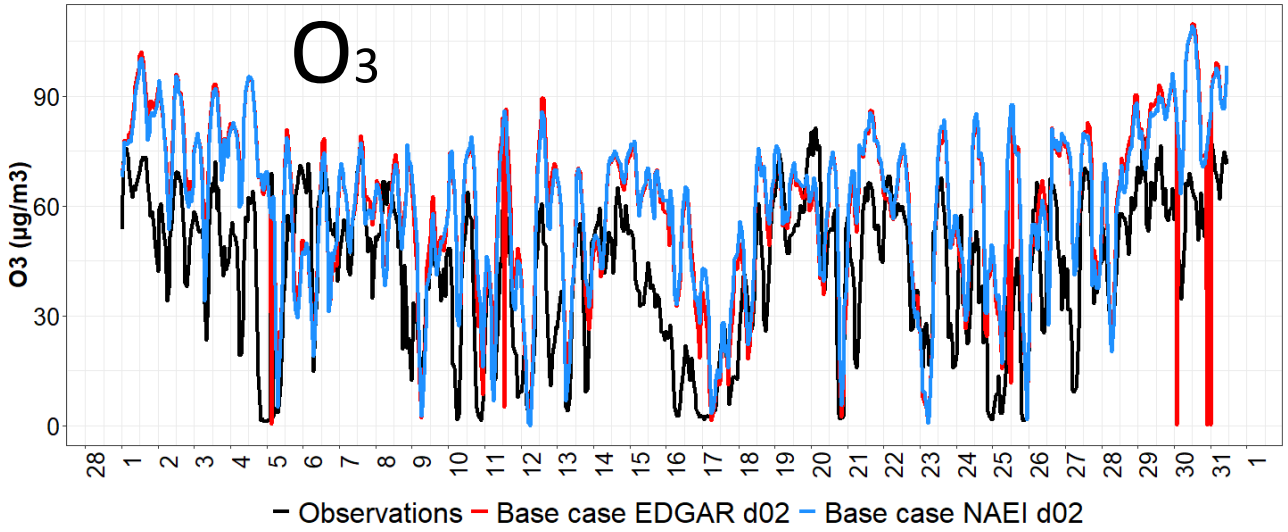


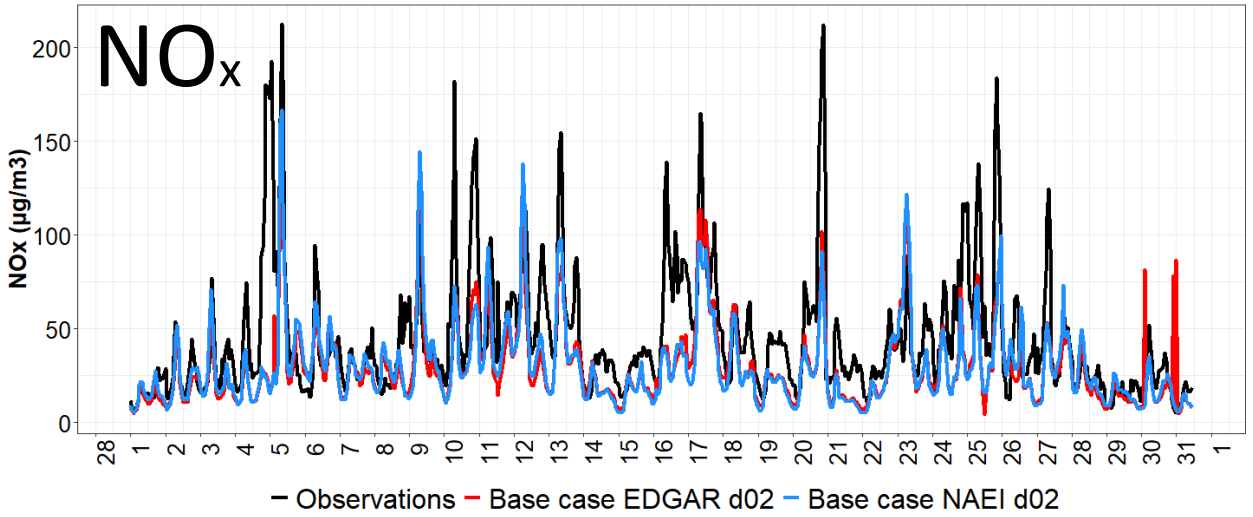
Sensitivity to emission inventory

London North Kensington (urban BG) station

Comparison of hourly CMAQ output (d02) with both EDGAR and NAEI emission inventories for March 2015



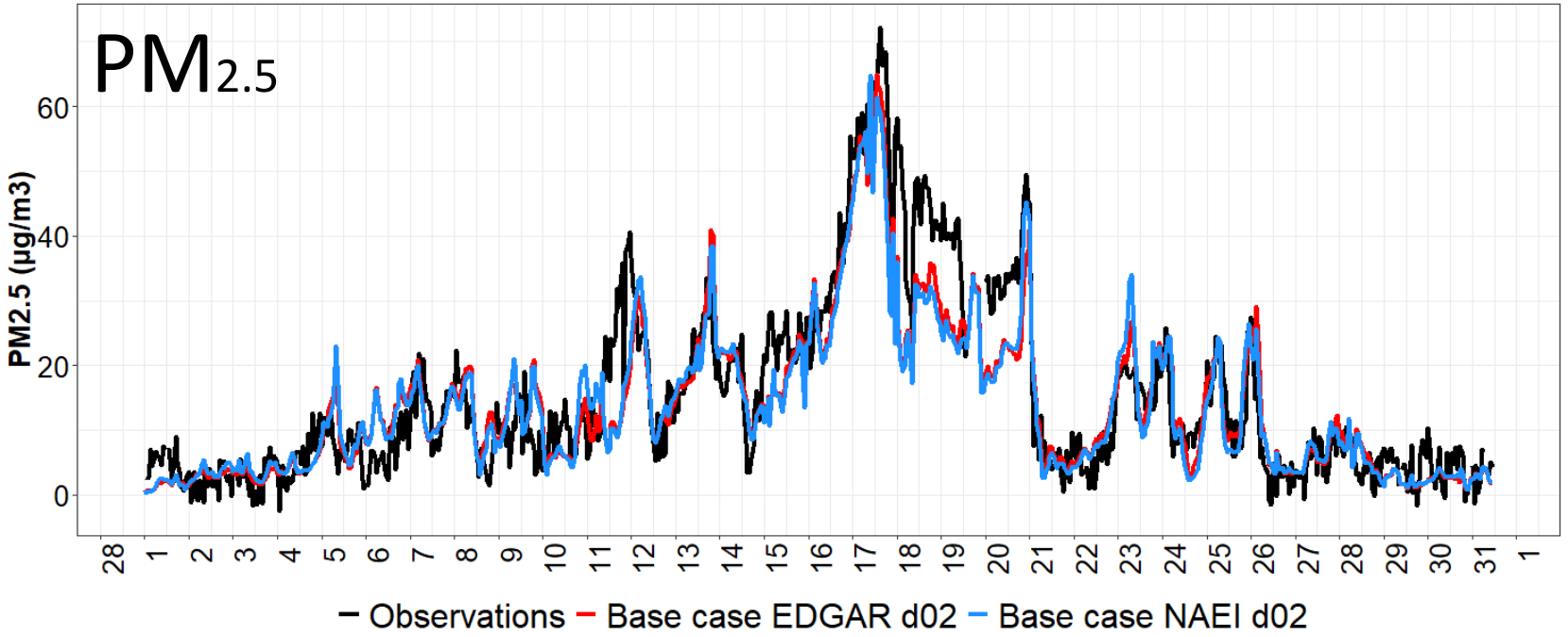


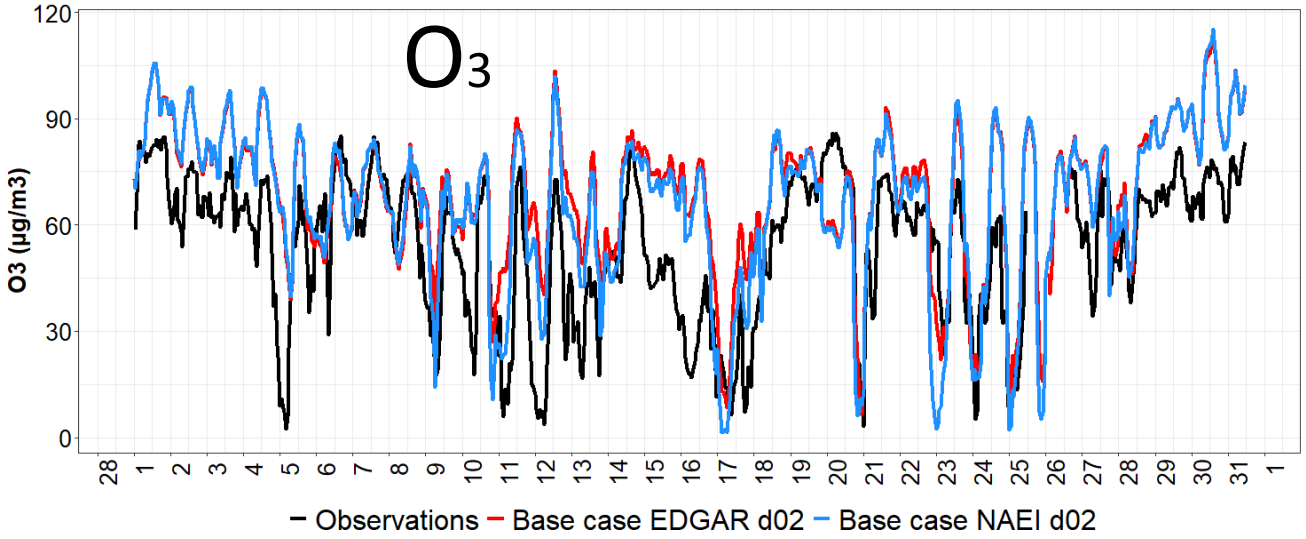


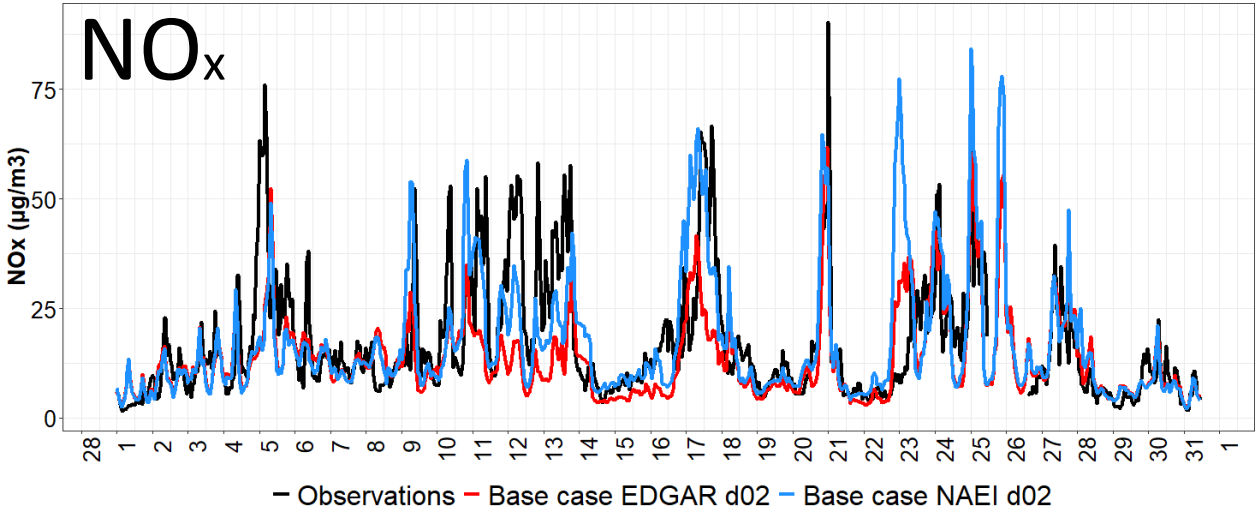
Sensitivity to emission inventory

Rochester Stoke (rural BG) station

Comparison of hourly CMAQ output (d02) with both EDGAR and NAEI emission inventories for March 2015
Linear interpolation for EDGAR







Emission inventory comparison for London NK (Urban BG)

		n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA	r2
NO	BC EDGAR d01	719	0.61	-2.07	4.89	-0.28	0.66	10.69	0.53	0.34	0.67	0.28
	BC EDGAR d02	742	0.56	-2.51	4.70	-0.35	0.65	10.31	0.57	0.35	0.68	0.32
	BC NAEI d02	742	0.53	-2.02	4.89	-0.28	0.67	10.74	0.54	0.33	0.66	0.29
NO2	BC EDGAR d01	717	0.72	-10.34	13.41	-0.30	0.39	17.60	0.67	0.10	0.55	0.45
	BC EDGAR d02	740	0.80	-9.32	12.04	-0.27	0.36	16.20	0.72	0.19	0.60	0.52
	BC NAEI d02	742	0.76	-9.10	12.50	-0.27	0.37	16.89	0.67	0.16	0.58	0.46
NOx	BC EDGAR d01	719	0.66	-16.25	20.96	-0.35	0.46	31.38	0.62	0.14	0.57	0.39
	BC EDGAR d02	742	0.72	-15.46	19.40	-0.34	0.43	30.00	0.66	0.20	0.60	0.44
	BC NAEI d02	742	0.70	-14.95	19.61	-0.33	0.44	30.36	0.63	0.19	0.60	0.40
O3	BC EDGAR d01	719	0.74	17.58	21.70	0.42	0.51	25.70	0.63	-0.24	0.38	0.40
	BC EDGAR d02	742	0.77	16.63	20.75	0.39	0.48	24.86	0.65	-0.18	0.41	0.43
	BC NAEI d02	742	0.77	17.24	20.52	0.40	0.48	24.65	0.67	-0.16	0.42	0.44
PM10	BC EDGAR d01	713	0.89	-5.85	8.40	-0.21	0.30	12.08	0.75	0.32	0.66	0.56
	BC EDGAR d02	735	0.91	-4.61	7.57	-0.17	0.28	10.16	0.82	0.38	0.69	0.67
	BC NAEI d02	742	0.89	-5.45	8.17	-0.20	0.30	11.33	0.79	0.34	0.67	0.62
PM2.5	BC EDGAR d01	716	0.80	-2.01	5.95	-0.12	0.35	9.48	0.80	0.49	0.74	0.64
	BC EDGAR d02	738	0.81	-1.18	5.24	-0.07	0.32	7.84	0.86	0.55	0.77	0.75
	BC NAEI d02	741	0.80	-1.90	5.59	-0.12	0.34	8.67	0.84	0.52	0.76	0.71

BC : Base Case

NAEI : National Atmospheric Emission Inventory of UK

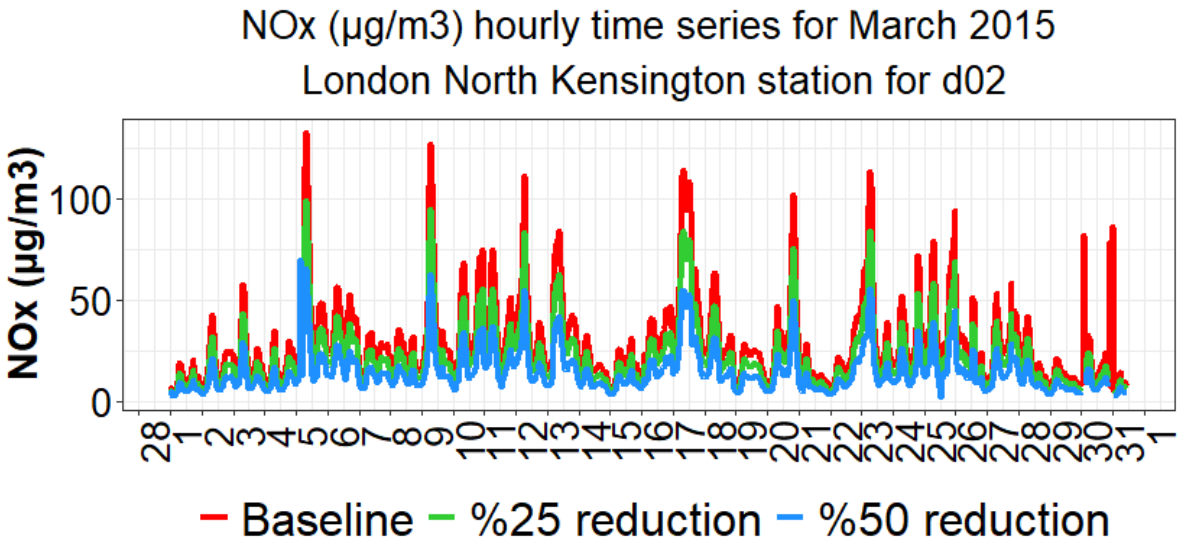
Emission inventory comparison for Rochester Stoke (Rural)

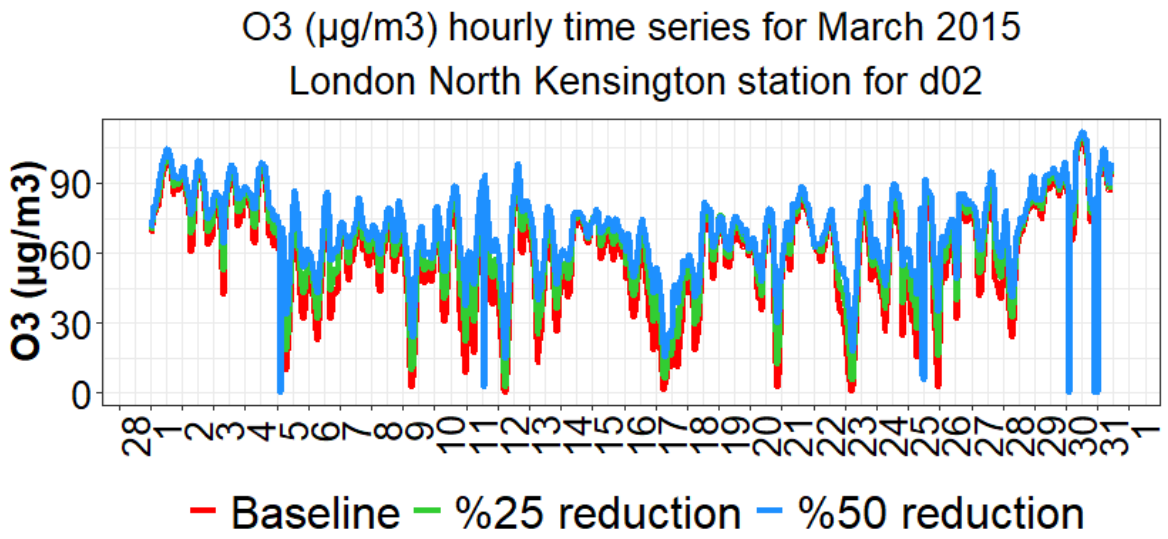
		n	FAC2	MB	MGE	NMB	NMGE	RMSE	r	COE	IOA	r2
NO	BC EDGAR d01	714	0.25	-0.69	1.34	-0.40	0.78	2.58	0.43	0.10	0.55	0.19
	BC EDGAR d02	714	0.30	-0.80	1.18	-0.47	0.69	2.35	0.55	0.20	0.60	0.30
	BC NAEI d02	714	0.50	0.31	1.30	0.18	0.76	2.66	0.65	0.12	0.56	0.42
NO2	BC EDGAR d01	714	0.61	-3.32	7.26	-0.23	0.50	10.57	0.54	0.16	0.58	0.30
	BC EDGAR d02	714	0.75	-2.46	6.37	-0.17	0.44	9.65	0.61	0.26	0.63	0.37
	BC NAEI d02	714	0.79	0.23	6.33	0.02	0.44	10.40	0.61	0.27	0.63	0.37
NOx	BC EDGAR d01	714	0.58	-4.90	8.80	-0.29	0.52	13.20	0.50	0.15	0.58	0.25
	BC EDGAR d02	714	0.75	-3.68	7.68	-0.22	0.45	12.07	0.57	0.26	0.63	0.33
	BC NAEI d02	714	0.81	-0.35	7.51	-0.02	0.44	12.49	0.59	0.28	0.64	0.35
O3	BC EDGAR d01	714	0.89	12.18	16.80	0.22	0.31	20.27	0.71	0.03	0.51	0.51
	BC EDGAR d02	714	0.87	15.25	18.14	0.28	0.33	21.72	0.71	-0.05	0.47	0.50
	BC NAEI d02	714	0.87	12.90	17.13	0.24	0.32	20.57	0.73	0.01	0.50	0.53
PM10	BC EDGAR d01	733	0.84	-0.47	6.95	-0.02	0.32	9.88	0.75	0.39	0.69	0.56
	BC EDGAR d02	733	0.88	-0.71	6.17	-0.03	0.28	8.23	0.82	0.46	0.73	0.68
	BC NAEI d02	733	0.88	-0.99	6.41	-0.05	0.29	8.50	0.81	0.44	0.72	0.66
PM2.5	BC EDGAR d01	727	0.72	-1.07	5.41	-0.07	0.36	8.04	0.83	0.51	0.75	0.69
	BC EDGAR d02	727	0.76	-1.31	4.71	-0.09	0.32	6.66	0.89	0.57	0.79	0.80
	BC NAEI d02	727	0.76	-1.43	4.97	-0.10	0.33	6.99	0.88	0.55	0.77	0.78

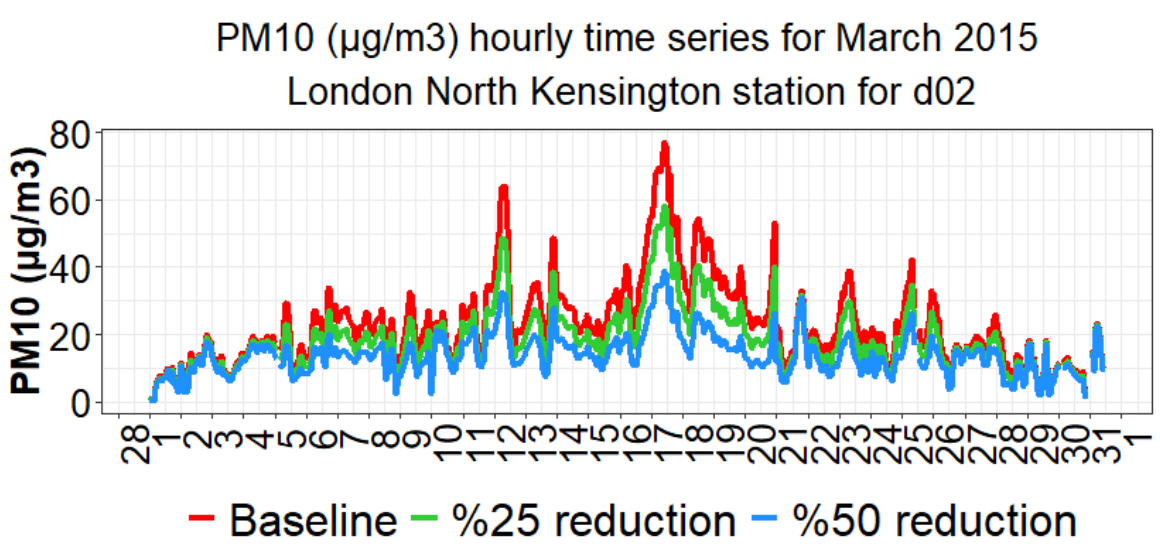
BC : Base Case

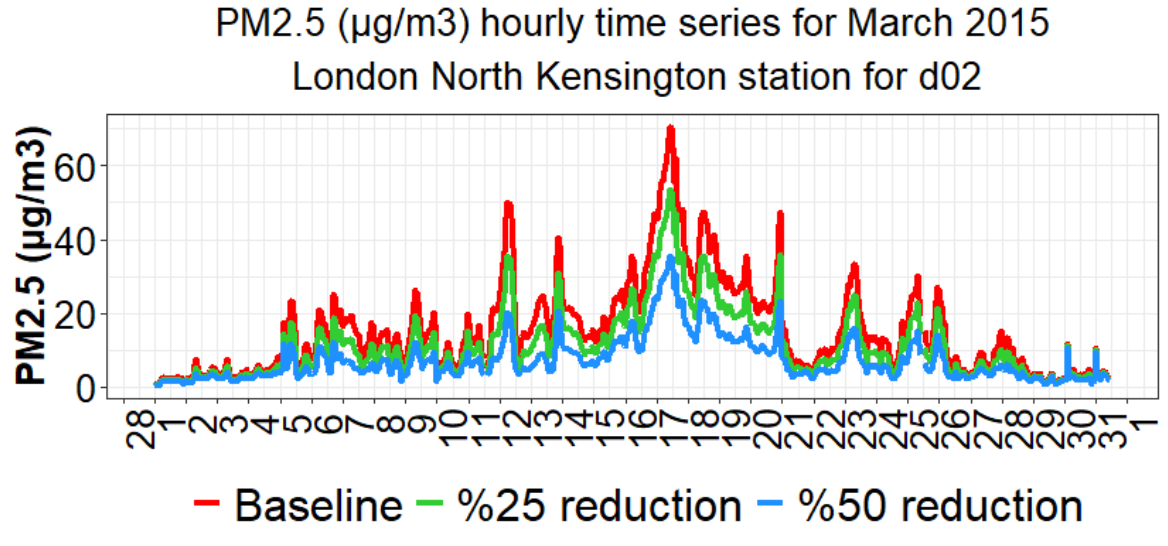
NAEI : National Atmospheric Emission Inventory of UK

Baseline and Reduction Scenarios for London North Kensington station

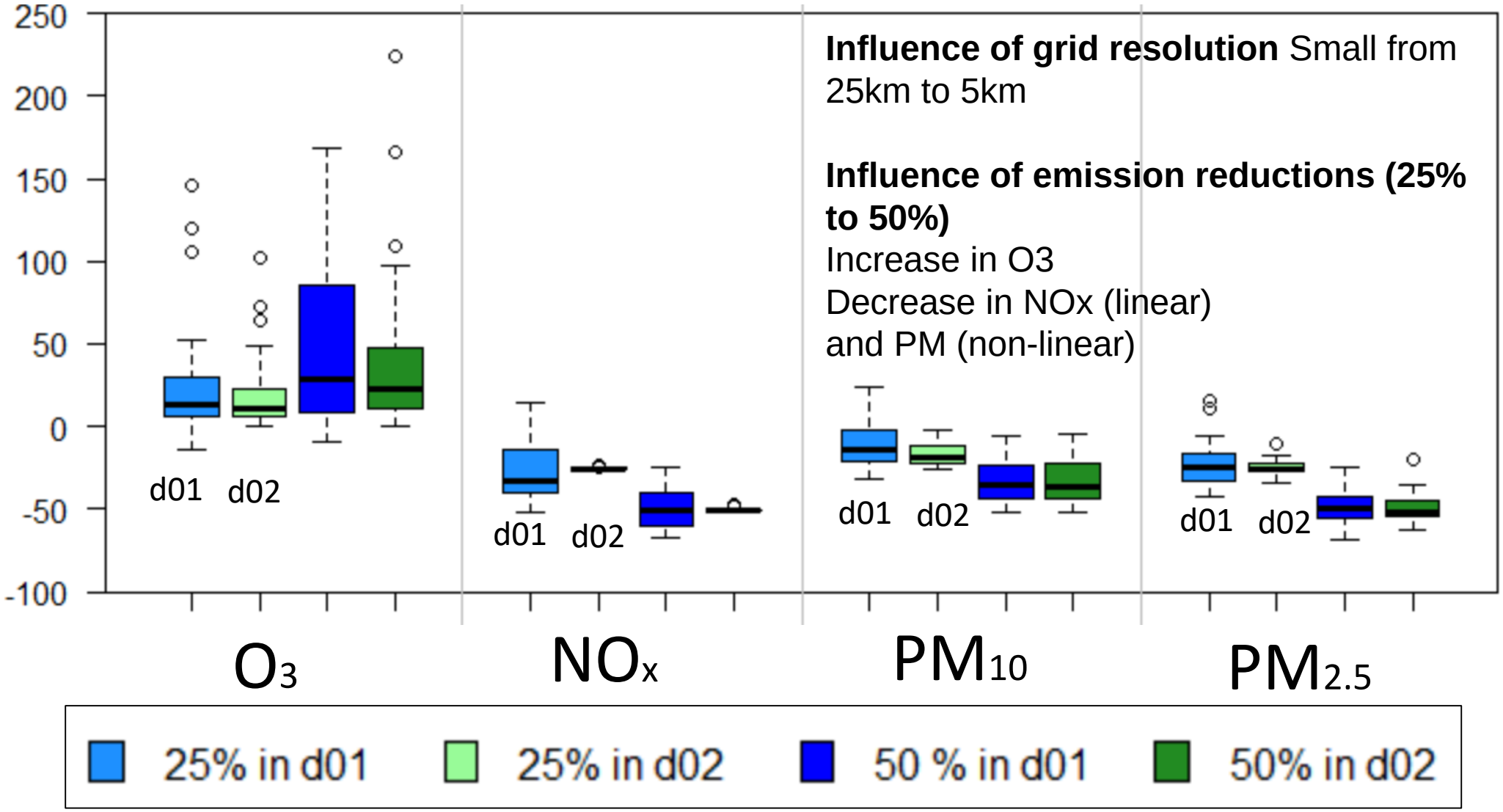






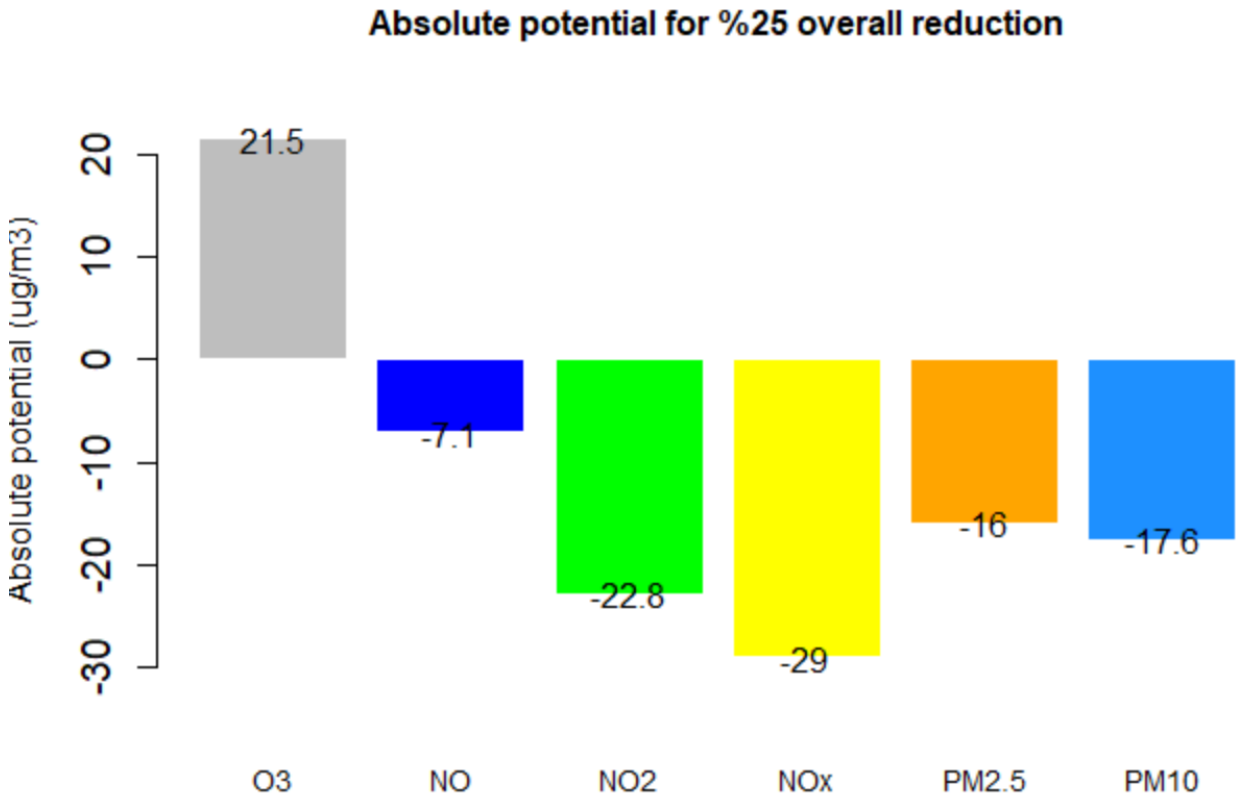


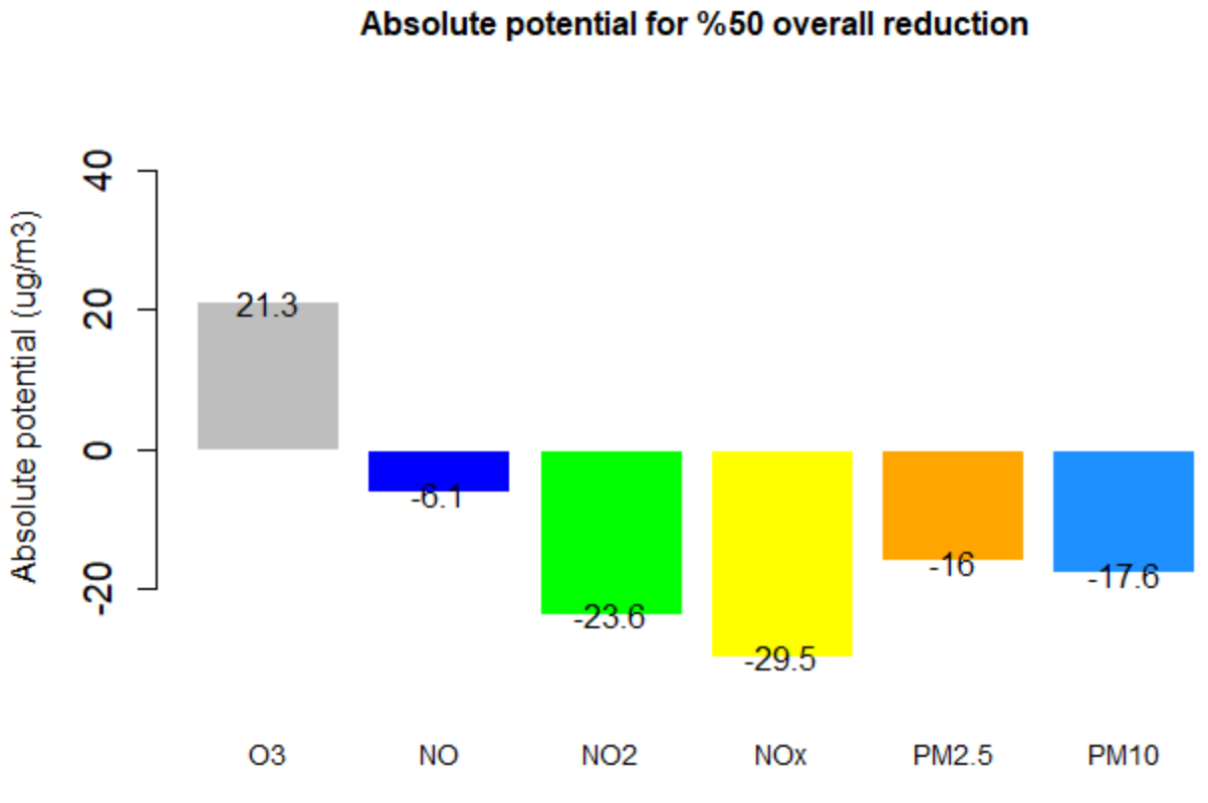
% Reduction in daily averaged model predictions with EDGAR inventory for London North Kensington station (March 2015)



% reduction = (Cscenario – Cbc) x 100/Cbc

Absolute potential for 25% and 50% emissions reductions for London North Kensington Station





The **Absolute Potential** is defined as the reduction in **µg/m³** scaled by the reduction α of the scenario (25 or 50%) of a precursor from base case

$$APl = \left(C \quad - C^{BC}\right)/(\alpha \quad)$$

Conclusions

- A framework for evaluating modelled changes in air pollutant concentrations (deltas) due to changes in emissions has been developed by FAIRMODE CT-9
- Model analysis based on WRF/CMAQ has been conducted for March 2015 PM episode (largely LRT driven with stable local conditions)
- Use of local higher resolution emission inventories is recommended where available
- Grid resolution of about 5km may provide optimal model performance for secondary air pollutants (O3 and PM2.5) at background locations
- Linear reductions in NOx concentrations are predicted for 25% and 50% reductions in overall emissions
- Non-linear reductions are predicted for PM and increases in O3 for the same emissions scenarios
- Domain 3 (1km x 1km grid resolution) and sensitivity to reductions in emissions of individual primary species are underway