An evaluation of ADMS-Urban model performance using real-world emissions estimates

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ADMS-Urban & ADMS-Roads User Group Meeting
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Project background

- **NERC-funded** project 'CureAir':

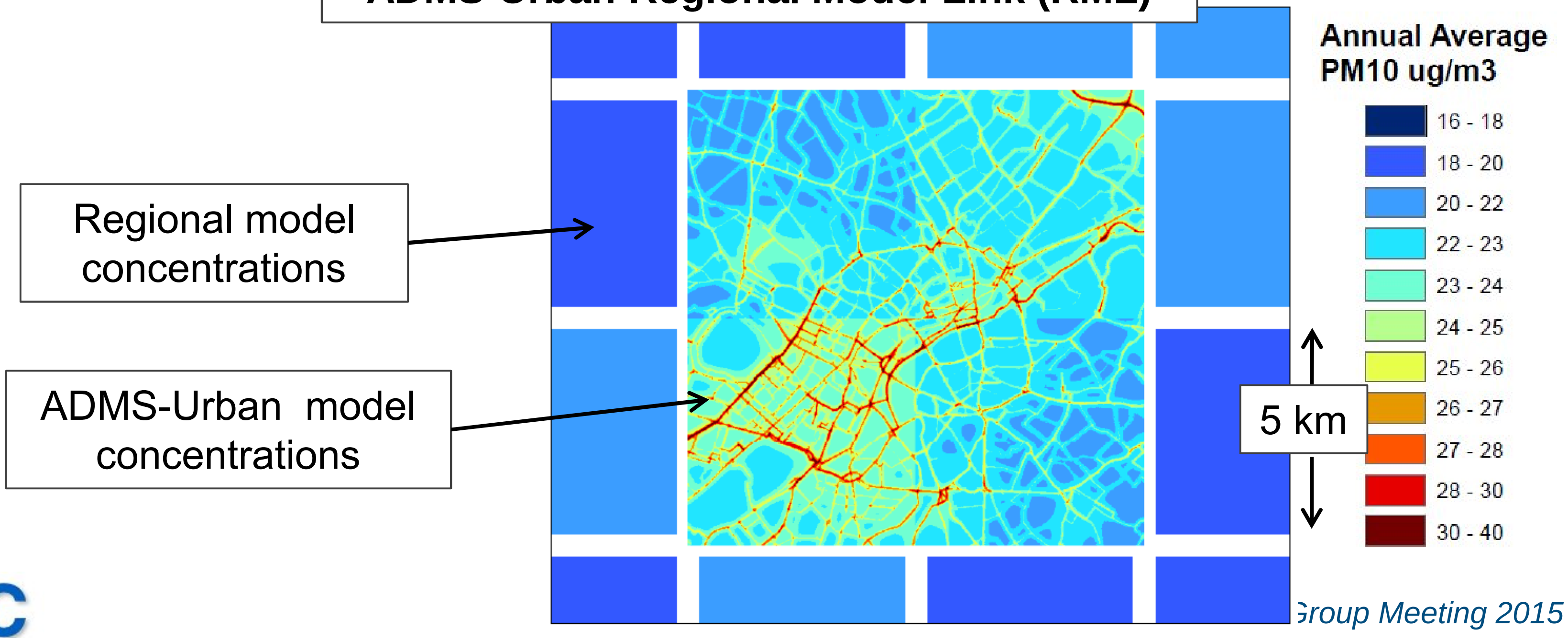
  C*oupled* ***U****rban and* ***R****egional processes:* ***E****ffects on* ***AIR*** *quality*

  (project reference NE/M003906/1)
- Partners
  - School of GeoSciences, University of Edinburgh
  - School of Chemistry, University of Leeds
  - CERC
  - Centre for Ecology & Hydrology (CEH), Edinburgh
- Work Packages:
  - WP1: Create a modelling framework for simulating regional to local air quality
  - WP2: Detailed evaluation from field measurements and 0-D MCM for London
  - WP3: Evaluation of UK-wide decadal coupled model simulations of air quality
  - WP4: Quantifying weather-sensitive chemistry processes during recent heatwaves
  - WP5: Assessing the impact of climate change on future O_3 and PM events

Project background

- CERC involvement:
  - Develop and validate a regional to local scale modelling system for 2002 - 2013
  - Focus on state-of-the-art chemistry at all scales
  - Assess the influence of the Urban Heat Island on pollutant concentrations:
    - Dispersion
    - Chemistry
  - Predict regional and local climate and pollution at the end of the century 2091 – 2100

ADMS-Urban Regional Model Link (RML)



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- Year 1:
  - Modify CERC's ADMS-Urban RML to run on the UK's national supercomputer used by academic institutions: ARCHER ✓
  - Compare the results of CERC's simplified GRS chemistry scheme (7 reactions) with those from the Master Chemical Mechanism (>10 000 reactions) **ongoing**
  - Validate ADMS-Urban for London 2012 ✓
  - Validate ADMS-Urban RML for London 2012 & then 2002 – 2011, 2013 **ongoing**

ADMS-Urban model configuration
Emissions

- Some published road traffic emission factors are not robust
- The recent VW vehicle scandal highlights the issue with NO_x emissions from diesel vehicles:
  - Monitored NO_x & NO_2 not decreasing in line with emissions estimates
  - Real-world tailpipe measurements do not agree with vehicle manufacturer data

Vehicle type	Fuel / type	Euro class	Sample size	NO_x/CO_2	NO_2/CO_2	NO_2/NO_x %
Passenger car	Petrol	0	204	85.1 ± 10.7	0.5 ± 0.4	0.6 ± 0.4
Passenger car	Petrol	1	392	54.1 ± 6.5	0.7 ± 0.3	1.3 ± 0.6
Passenger car	Petrol	2	2848	39.3 ± 2.4	0.5 ± 0.1	1.4 ± 0.4
Passenger car	Petrol	3	5593	15.3 ± 1	0.3 ± 0.1	2.1 ± 0.5
Passenger car	Petrol	4	8843	10.3 ± 0.7	0.4 ± 0.1	4.1 ± 0.7
Passenger car	Petrol	5	1998	4.8 ± 0.7	0.4 ± 0.1	8.4 ± 3
Passenger car	Petrol hybrid	4	154	1.6 ± 1	0.2 ± 0.4	12.9 ± 27.8
Passenger car	Petrol hybrid	5	605	7 ± 3.2	1.1 ± 0.4	15 ± 8.9
Passenger car	Diesel	0	15	47 ± 8.7	7.2 ± 2	15.3 ± 5
Passenger car	Diesel	1	62	55.7 ± 7.4	7.6 ± 1.5	13.7 ± 3.3
Passenger car	Diesel	2	363	65.5 ± 4.1	5.7 ± 0.5	8.7 ± 0.9
Passenger car	Diesel	3	2610	62.9 ± 1.5	10.3 ± 0.4	16.3 ± 0.8
Passenger car	Diesel	4	5836	47.7 ± 0.9	13.5 ± 0.4	28.4 ± 0.9
Passenger car	Diesel	5	[illegible]	[illegible]	[illegible]	[illegible]
London taxi	FX	2	[illegible]	[illegible]	[illegible]	[illegible]
London taxi	Met	2	[illegible]	[illegible]	[illegible]	[illegible]
London taxi	TX1	2	[illegible]	[illegible]	[illegible]	[illegible]
London taxi	Met	3	[illegible]	[illegible]	[illegible]	[illegible]
London taxi	TXII	3	[illegible]	[illegible]	[illegible]	[illegible]
London taxi	MV111	4	594	64.1 ± 1.3	11.9 ± 0.9	18.6 ± 1.5
London taxi	TX4	4	4719	49.2 ± 0.7	6 ± 0.3	12.3 ± 0.5
London taxi	TX4	5	185	79.7 ± 7.4	15.8 ± 2	19.9 ± 3.2
London taxi	MV113	5	329	62.9 ± 3.1	23.6 ± 1.2	37.6 ± 2.7
Van (N1)		1	26	74.8 ± 14.6	9.3 ± 2.8	12.5 ± 4.5

New insights from comprehensive on-road measurements of NO_x, NO_2 and NH_3 from vehicle emission remote sensing in London, UK, David C. Carslaw, Glyn Rhys-Tyler, Atmospheric Environment, Volume 81, December 2013

ADMS-Urban model configuration

Emissions

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- The recent VW vehicle scandal highlights the issue with NO_x emissions from diesel vehicles:
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  - Real-world tailpipe measurements do not agree with vehicle manufacturer data
- By calculating the corresponding CO_2 emission factors, for each vehicle category, it is possible to estimate an adjustment factor

Vehicle Type	Emission standard	Remote sensing / Standard factors (NO_x) %	Remote sensing primary NO_2 (%)
Diesel Car	Euro1	170	14
	Euro2	175	9
	Euro3	139	16
	Euro4	134	28
	Euro5	172	25
HGV trucks < 12 tonnes	Euro2	136	21
	Euro3	147	18
	Euro4	214	8
	Euro5	217	8
HGV trucks > 12 tonnes	Euro2	144	12
	Euro3	153	24
	Euro4	206	3
	Euro5	239	4
Petrol Car	Euro1	376	1
	Euro2	471	1
	Euro3	343	2
	Euro4	302	4

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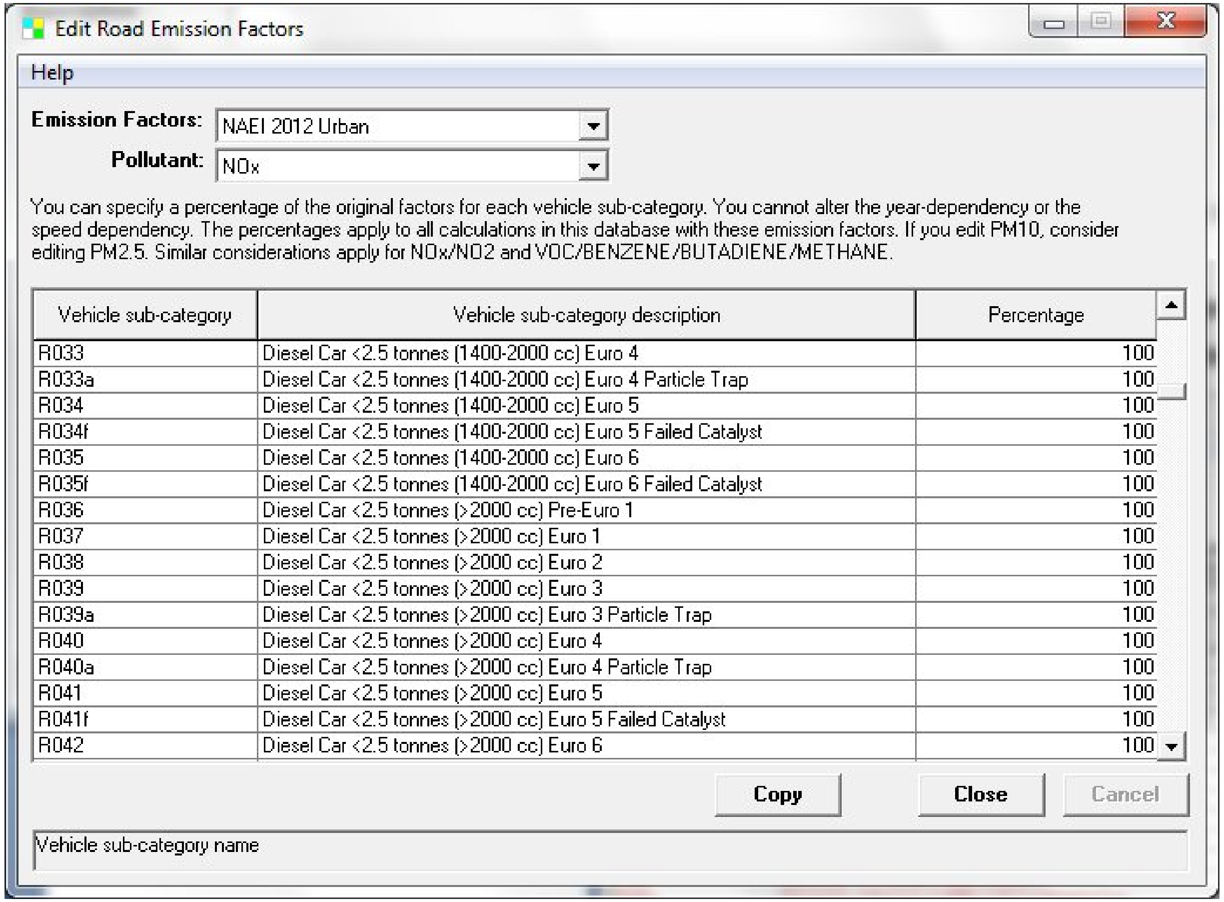
- These factors can be entered directly into EMIT



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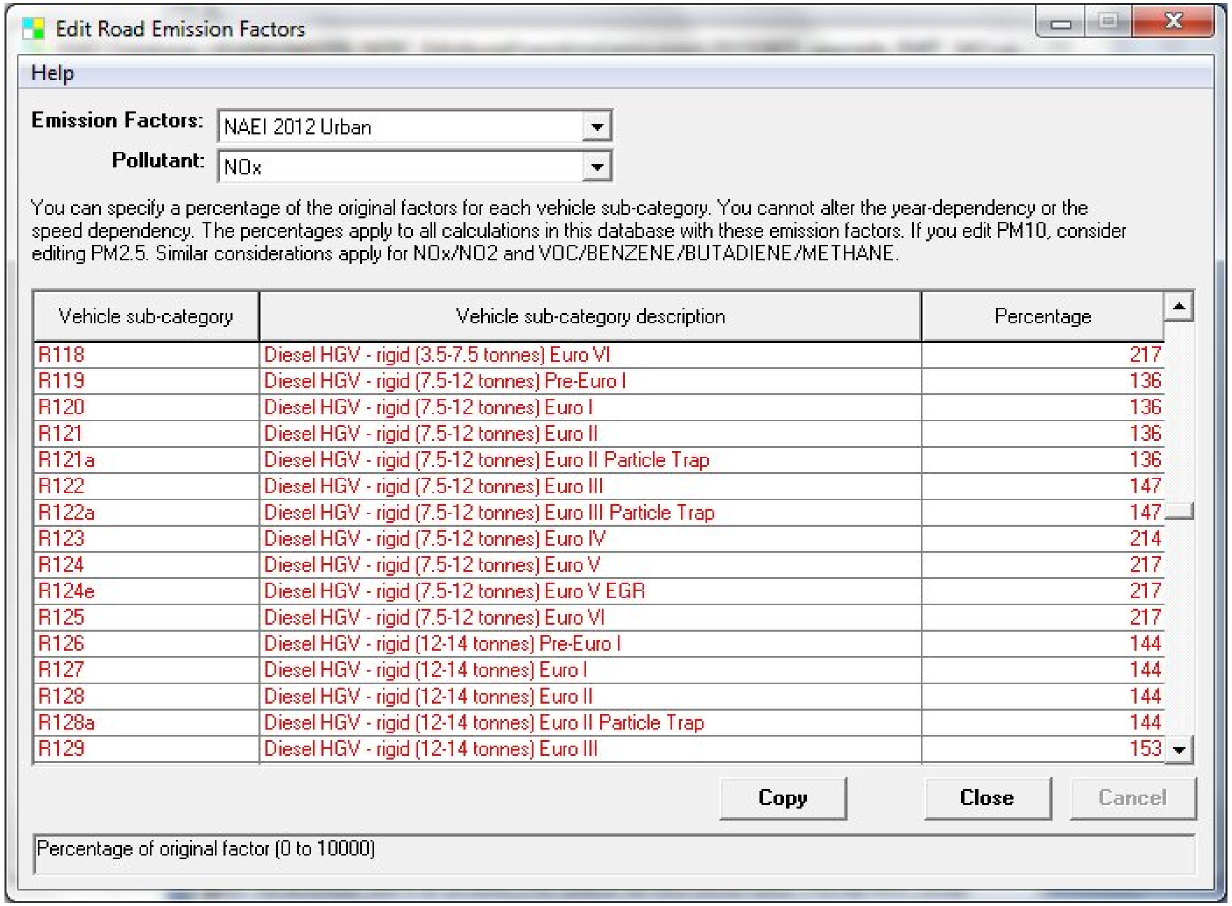

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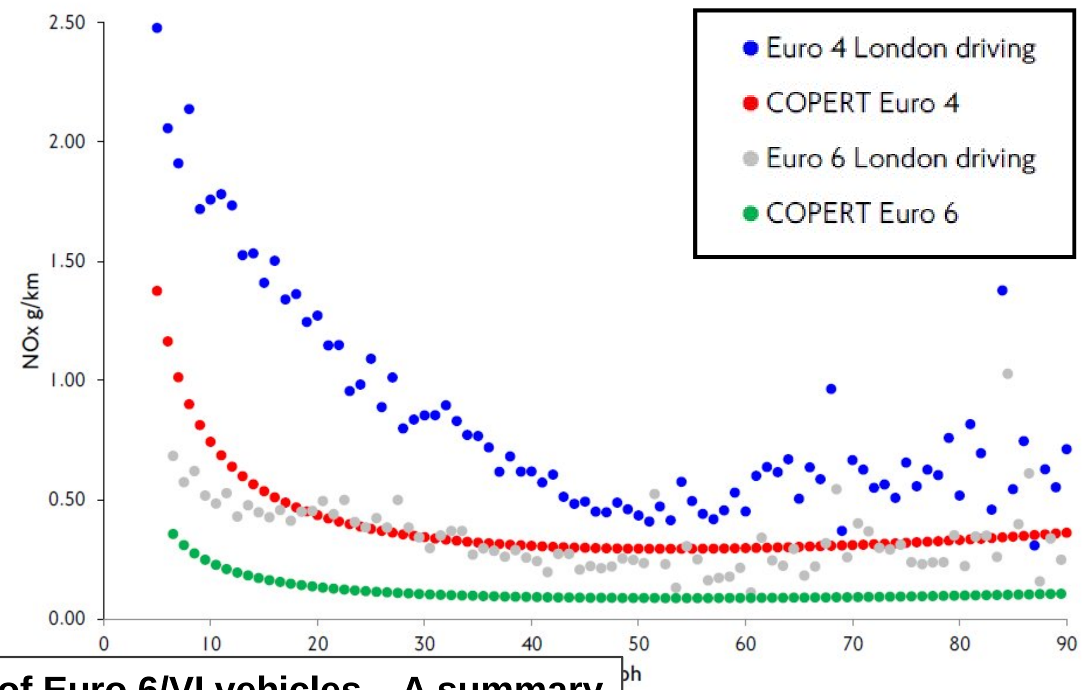
- Is it valid to use speed-independent adjustments?

Figure 4 Comparison of London emissions functions with COPERT 4 functions (diesel cars).

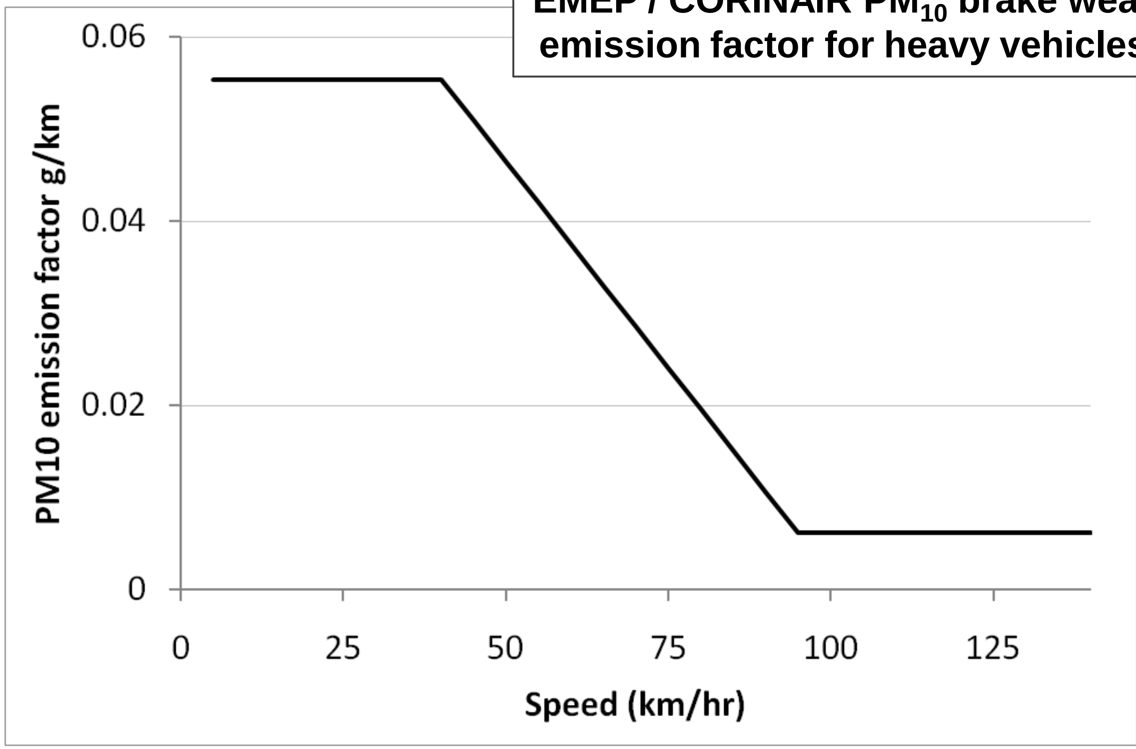


In-service performance of Euro 6/VI vehicles – A summary of testing using London drive cycles, TfL, September 2015

ADMS-Urban model configuration
Emissions

- Some published road traffic emission factors are not robust
- PM_{10} and $PM_{2.5}$ road traffic emissions have a high non-exhaust component:
  - Traffic PM_{10} emissions are ~ 75% non-exhaust
  - Traffic $PM_{2.5}$ emissions are ~ 50% non-exhaust
  - Non exhaust emissions comprise **brake, tyre** and **road wear**, and **resuspension** of particulates on the road surface
- Some published factors have coarse categorisation but have qualitatively correct behaviour eg EMEP / CORINAIR factors

EMEP / CORINAIR PM_{10} brake wear emission factor for heavy vehicles



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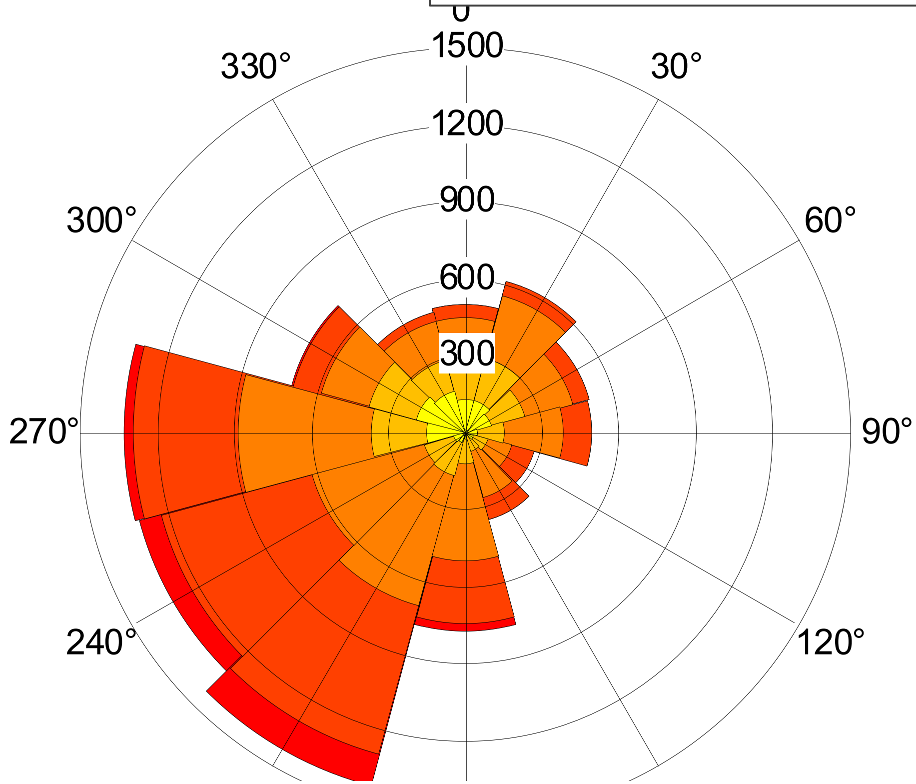
- Some published factors have coarse categorisation but have qualitatively correct behaviour eg EMEP / CORINAIR factors
- But measurement component analyses at hotspots indicate non-exhaust component may be much higher, particularly for brake wear
- LAEI uses adjustment factors, calculated from measurements at Marylebone Road:
- These approximate factors can be included as adjustments to the base case

	Base method emissions g/km/s	Base method proportion	New method emissions g/km/s	New method proportion	Scaling factor (or emission change)
Exhaust	0.0227	0.54	0.0227	0.22	1.00
Tyre wear	0.0077	0.18	0.0084	0.08	1.09
Brake wear	0.0119	0.28	0.0431	0.42	3.63
Resuspension	-	-	0.0290	0.28	-

ADMS-Urban model configuration
Meteorology

- Use Heathrow measured meteorology data, as prevailing wind from South West
- Wind speeds decrease in urban areas compared to rural / airport locations due to the presence of buildings
- ADMS-Urban allows for this decrease in wind speed, using 2 methods:
  - Basic adjustment: Setting a different roughness length at the met site and the dispersion site
  - Using the Urban Canopy flow field option

ADMS-Urban wind rose for Heathrow



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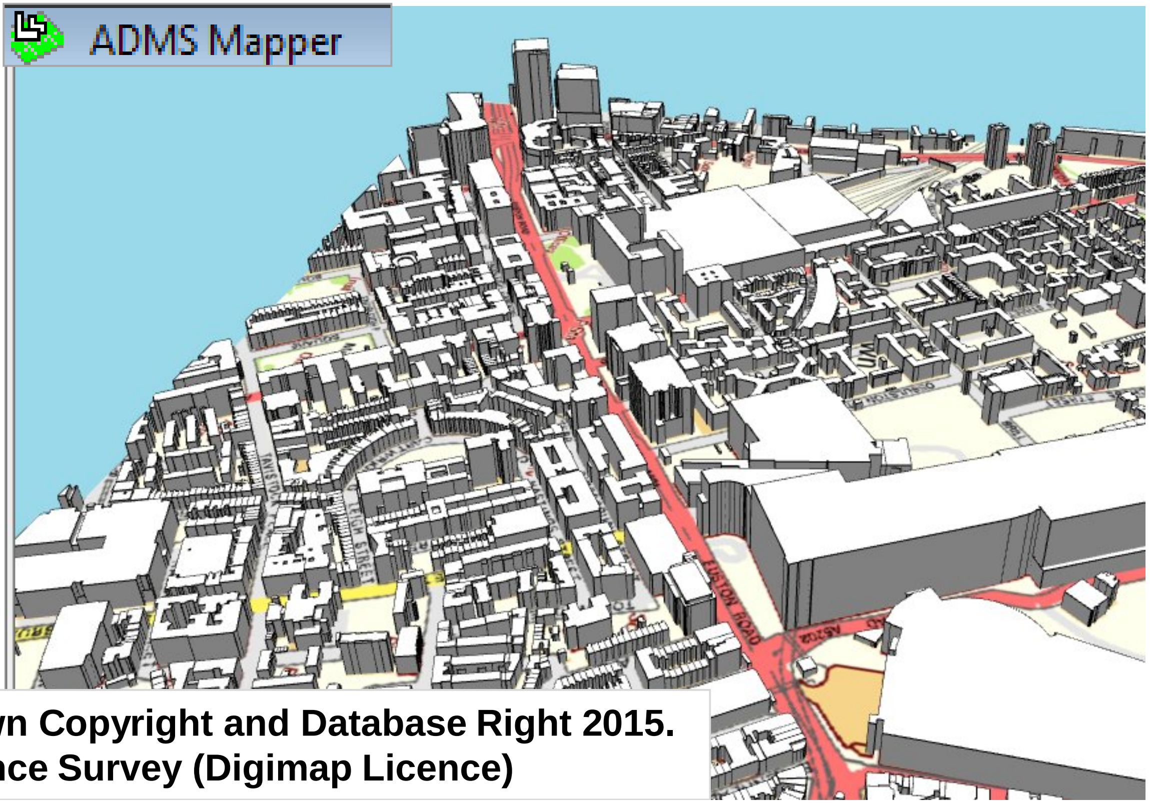
Urban Canopy flow field

- Requires 3D buildings data as input
- ArcGIS Tools available to pre-process buildings data
- Model calculates the spatial variation of roughness length, giving a spatial variation of wind speed related to building density



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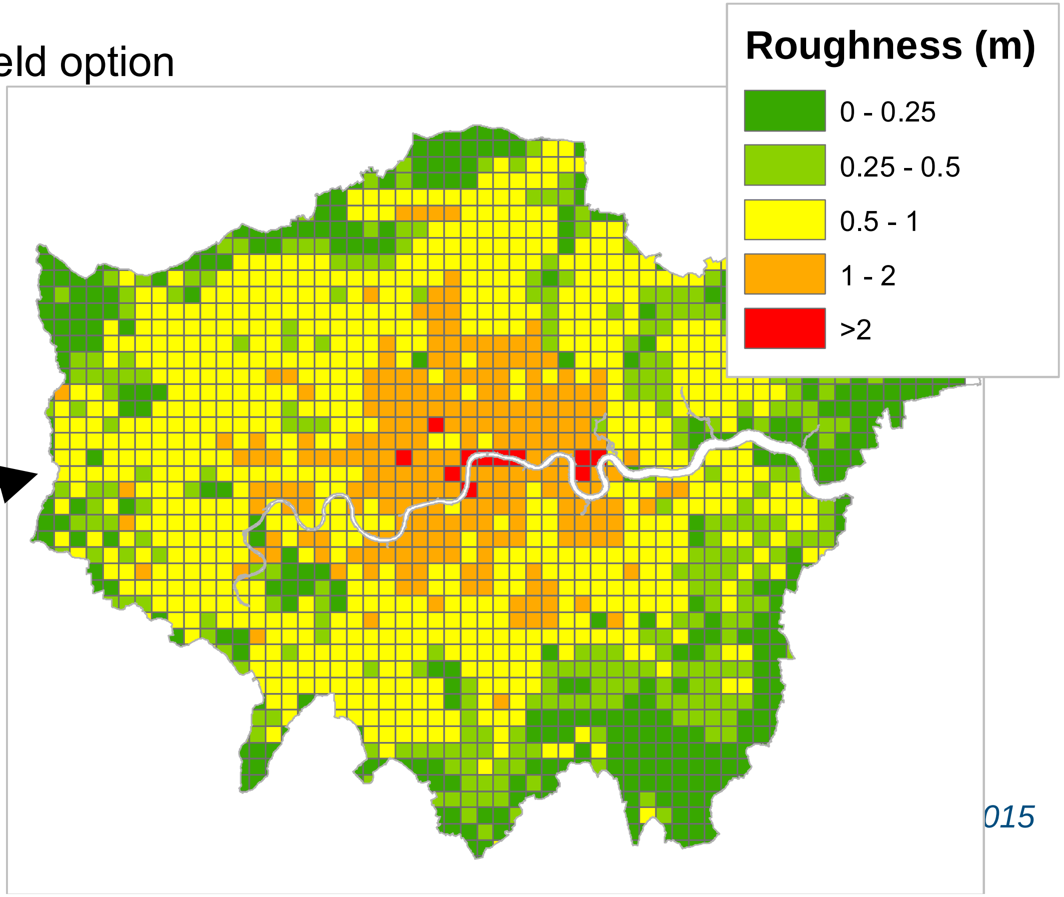
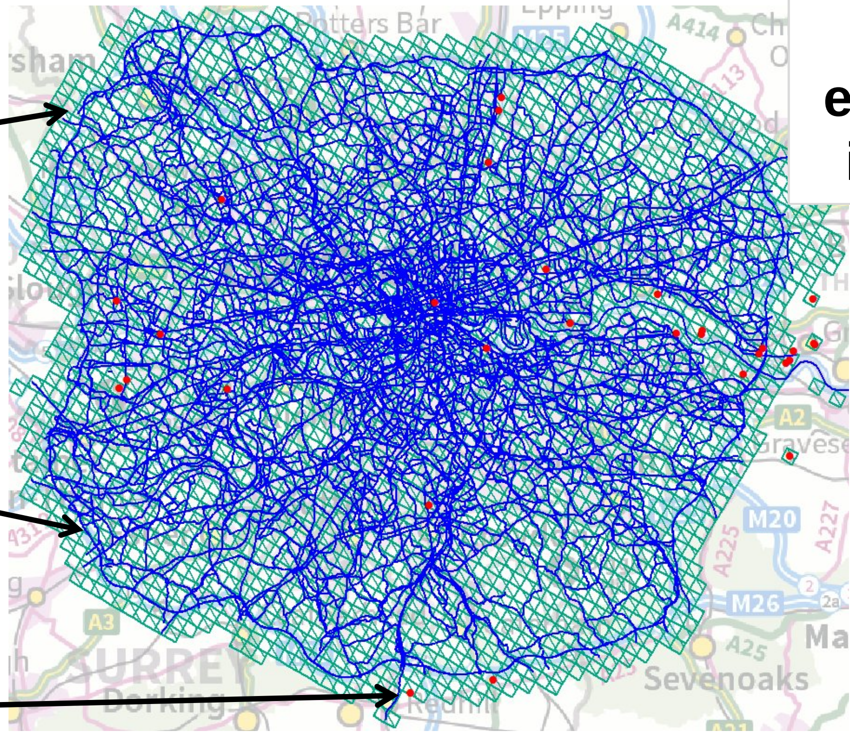


ADMS-Urban model configuration
Background

- Base case run: use measured data
- ADMS-Urban RML: upwind background taken from regional model
- Alternative approach to calculating background:
  - Minimum value over the domain
  - Ensure that the NO_x, NO_2 and O_3 are from the same location for any particular hour



London emissions inventory

Minor road, commercial and domestic sources defined at lower resolution (1 km grid)

Major road sources explicitly defined

Point sources explicitly defined

Background PM_{10}

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ADMS-Urban model configuration
In-road parameters

- Many road and kerbside receptors are located within street canyons
- Wind flow and dispersion within ‘street canyons’ differs considerably from open road locations
- ADMS-Urban allows for street canyons, using 2 methods:
  - Basic canyons: add canyon height and width information in the model interface
  - Using the Advanced Canyon option

Advanced Canyon parameters

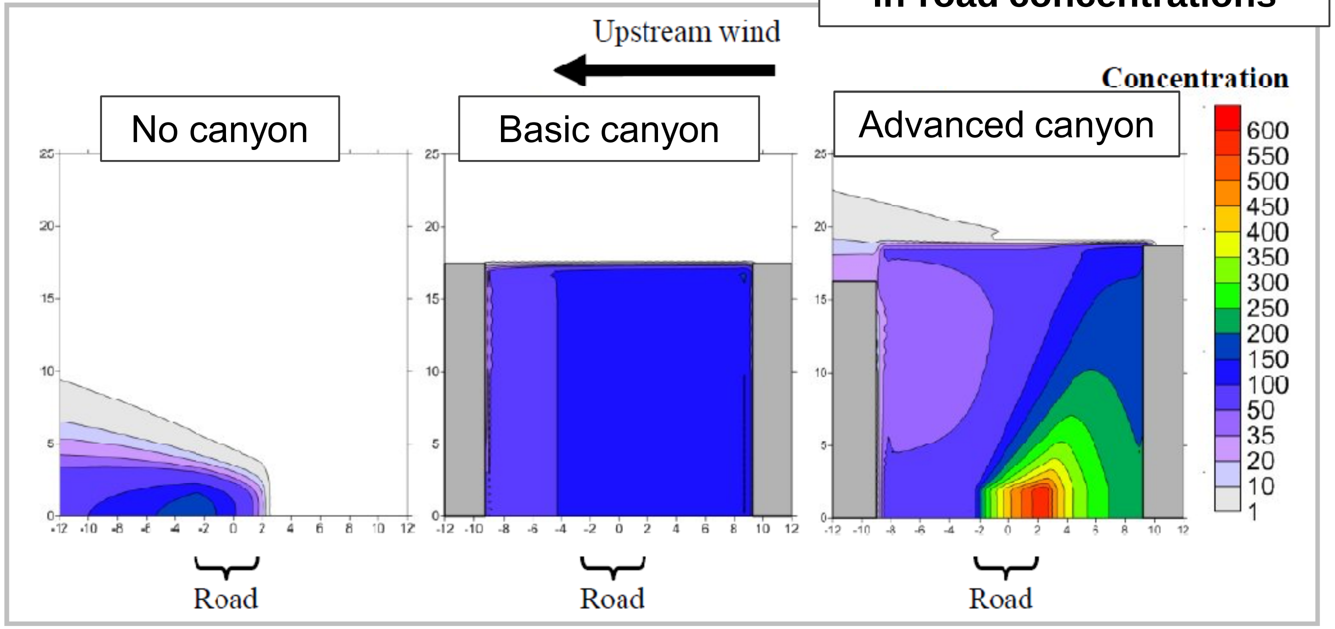
- Requires 3D buildings & road network data as input
- ArcGIS Tools available to pre-process data

Note:

An estimate of the road width is required, eg:

- Default based on road classification
- 0.7 x canyon width

Example comparison of in-road concentrations



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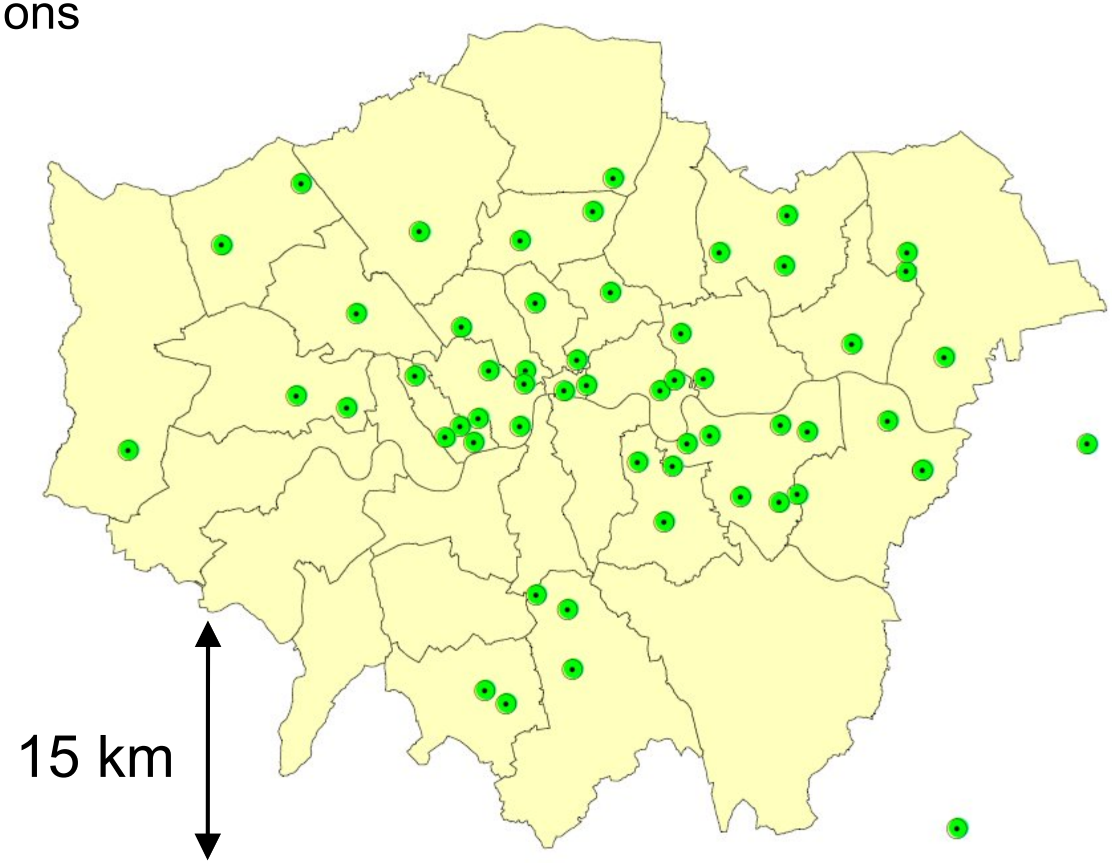
ADMS-Urban model configuration
Receptor network

- 56 receptors
- Full range of receptor types modelled
- Validation for 2002 – 2013 for all pollutants except $PM_{2.5}$ (from 2009)
- 2012 as 'pivot' year for emissions

	Roadside	Kerbside	Urban Background	Suburban	Total
NO_x	24	6	16	6	52
NO_2	24	6	16	6	52
O_3	8	1	13	4	26
PM_{10}	21	5	13	5	44
$PM_{2.5}$	7	1	4	2	14



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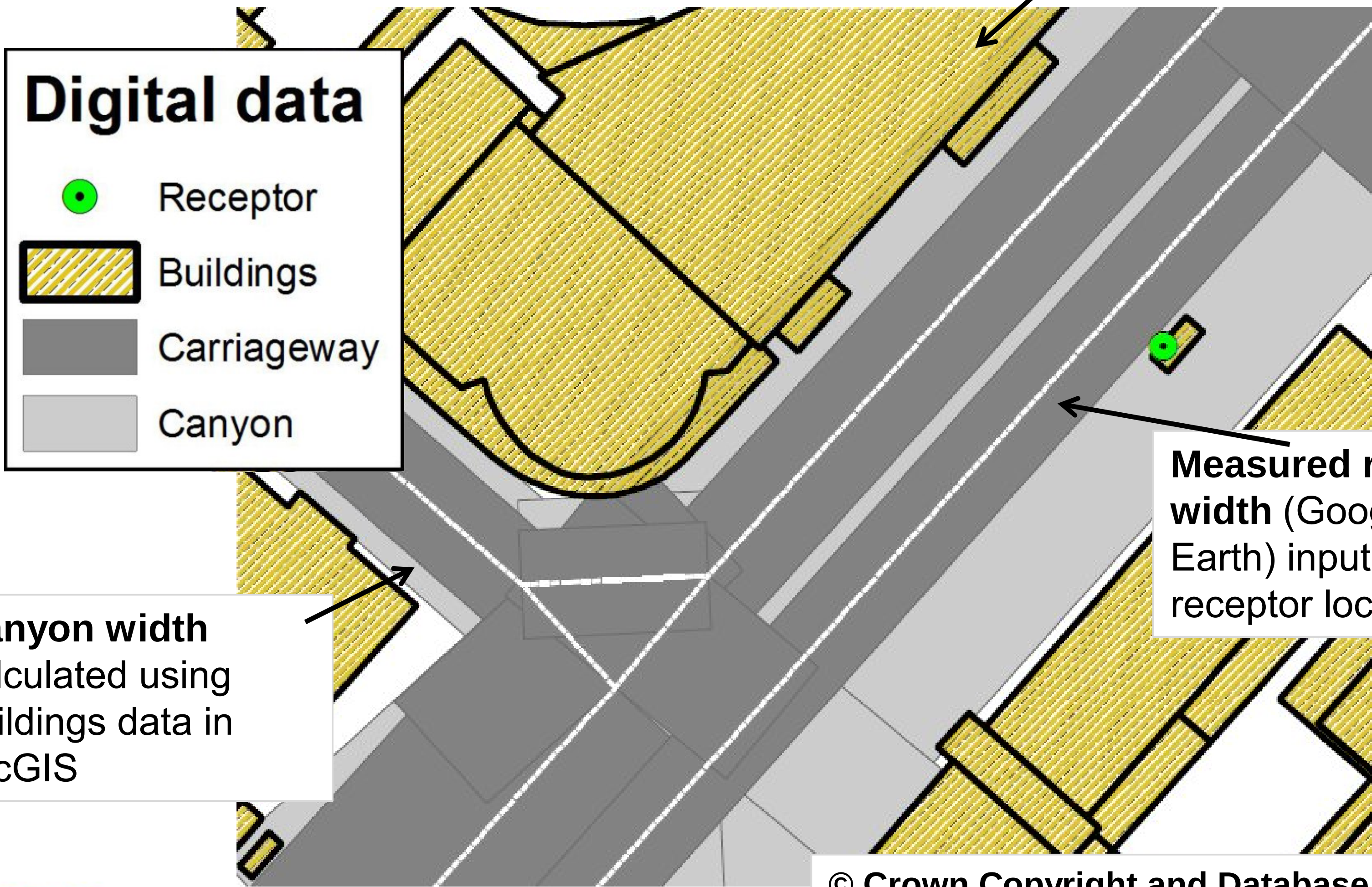
ADMS-Urban model configuration
Receptor network

- Check location for each receptor



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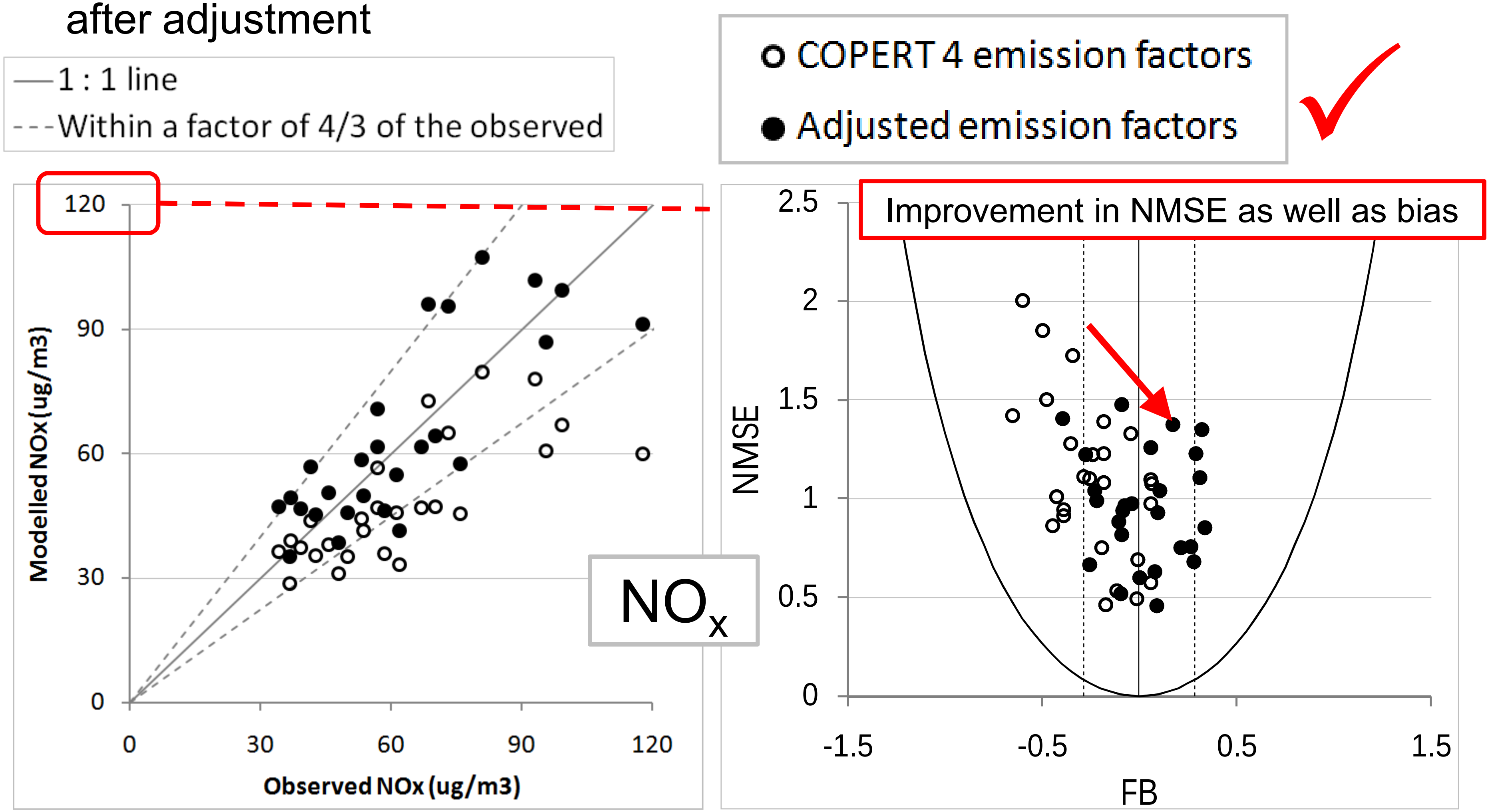
ADMS-Urban model results
NO_x, NO_2 and O_3

- NO_x **urban background** annual average concentrations before and after adjustment



Chang & Hanna, Air quality model performance evaluation. *Meteorol. Atmos. Phys.* **87**, 167–196 (2004)

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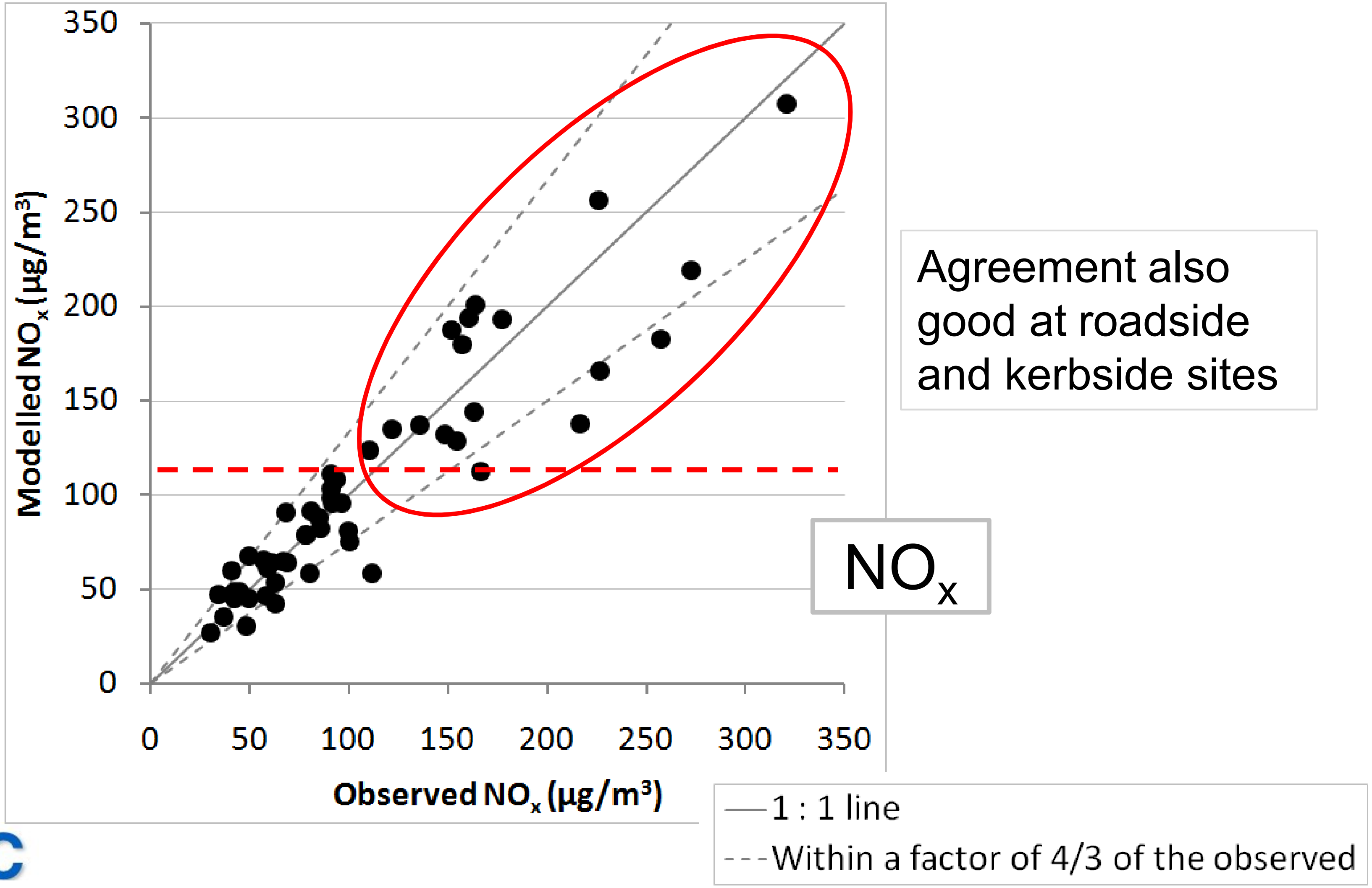
ADMS-Urban model results
NO_x, NO_2 and O_3

- NO_x annual average concentrations: **all receptors** for 2012 after adjustment



Agreement also good at roadside and kerbside sites

NO_x

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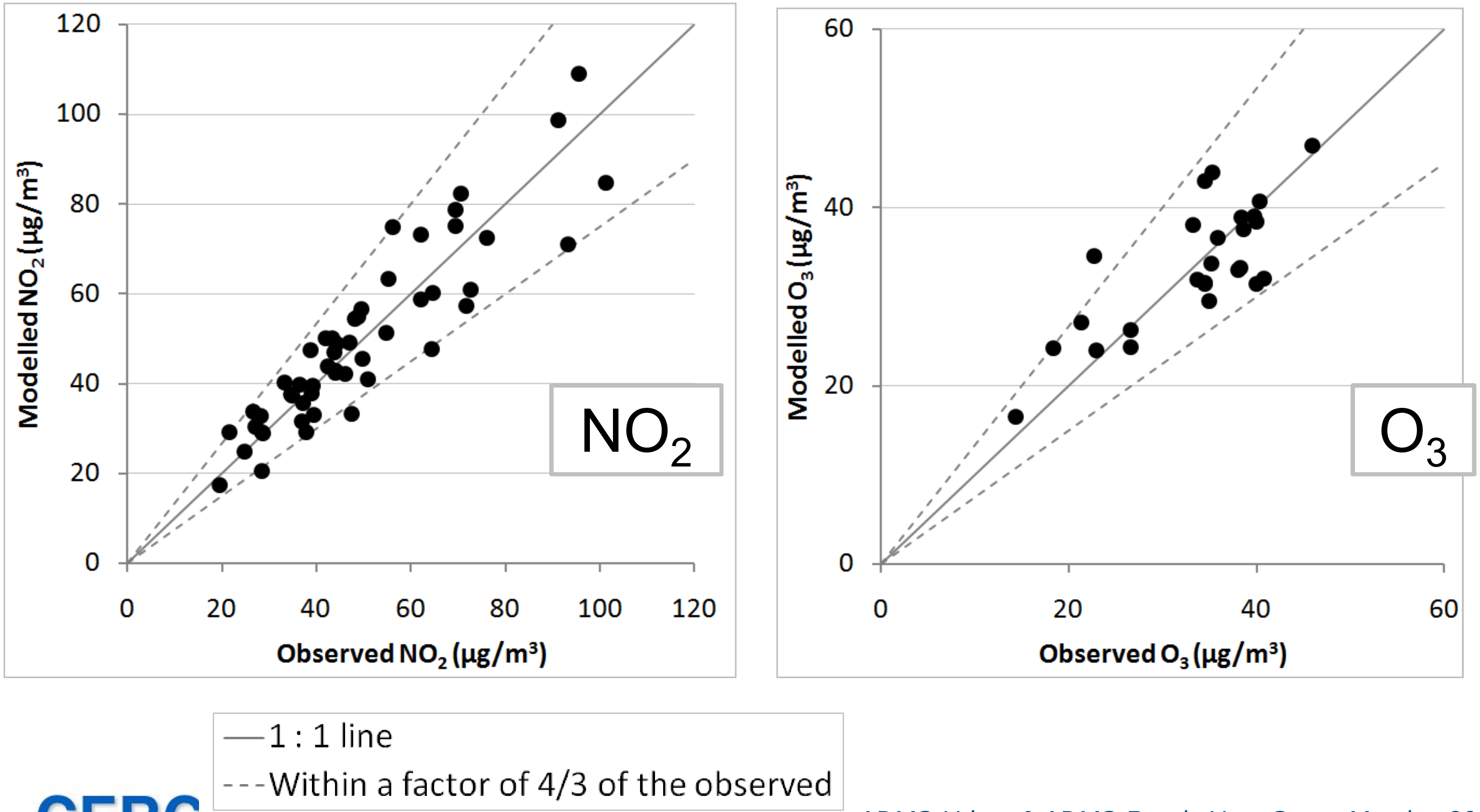
ADMS-Urban model results

NO_x, NO_2 and O_3

- NO_2 and O_3 annual average concentrations: all receptors for 2012 after adjustment



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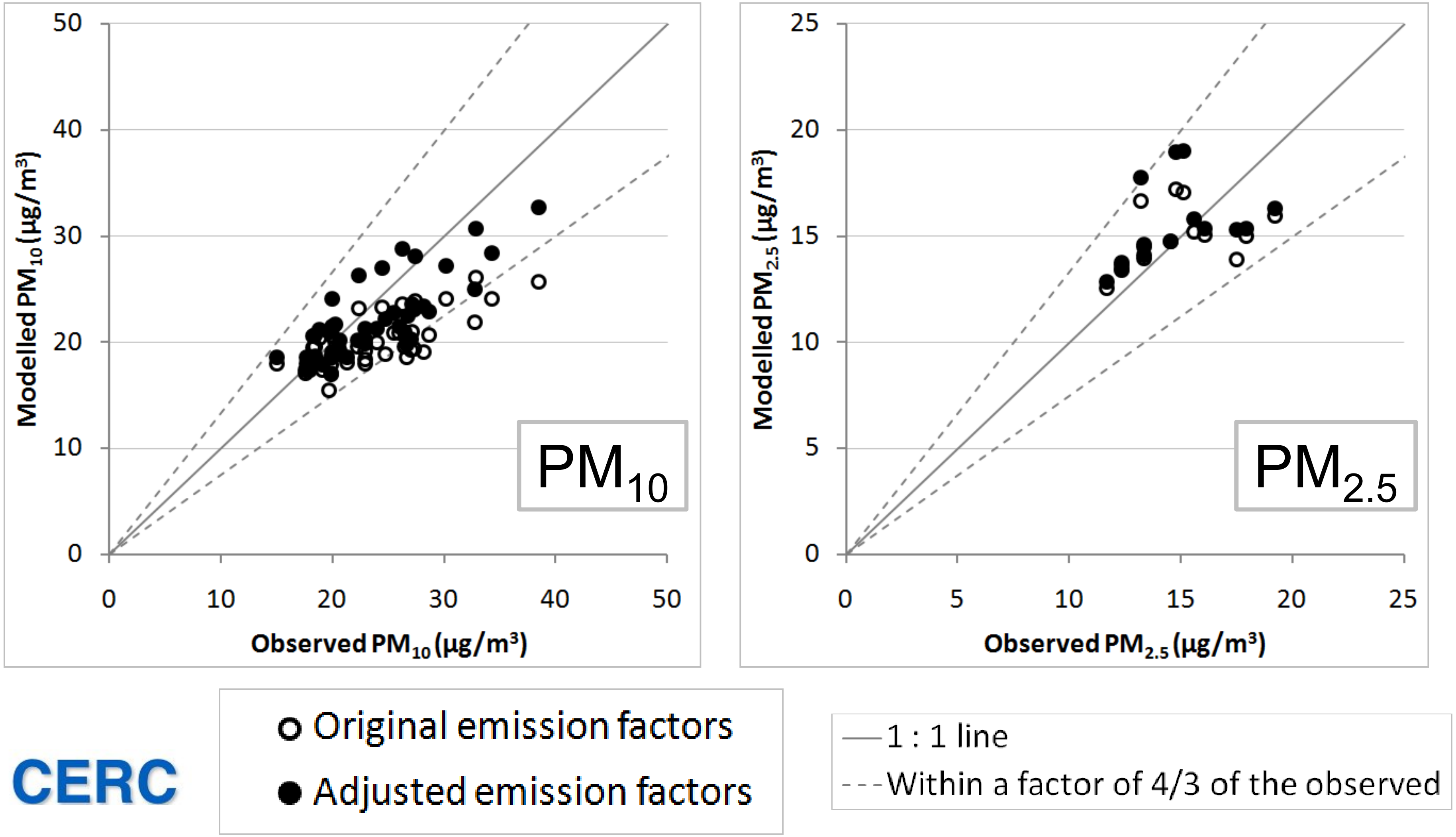
ADMS-Urban model results
PM_{10} and $PM_{2.5}$

- PM_{10} and $PM_{2.5}$ annual average concentrations before and after adjustment



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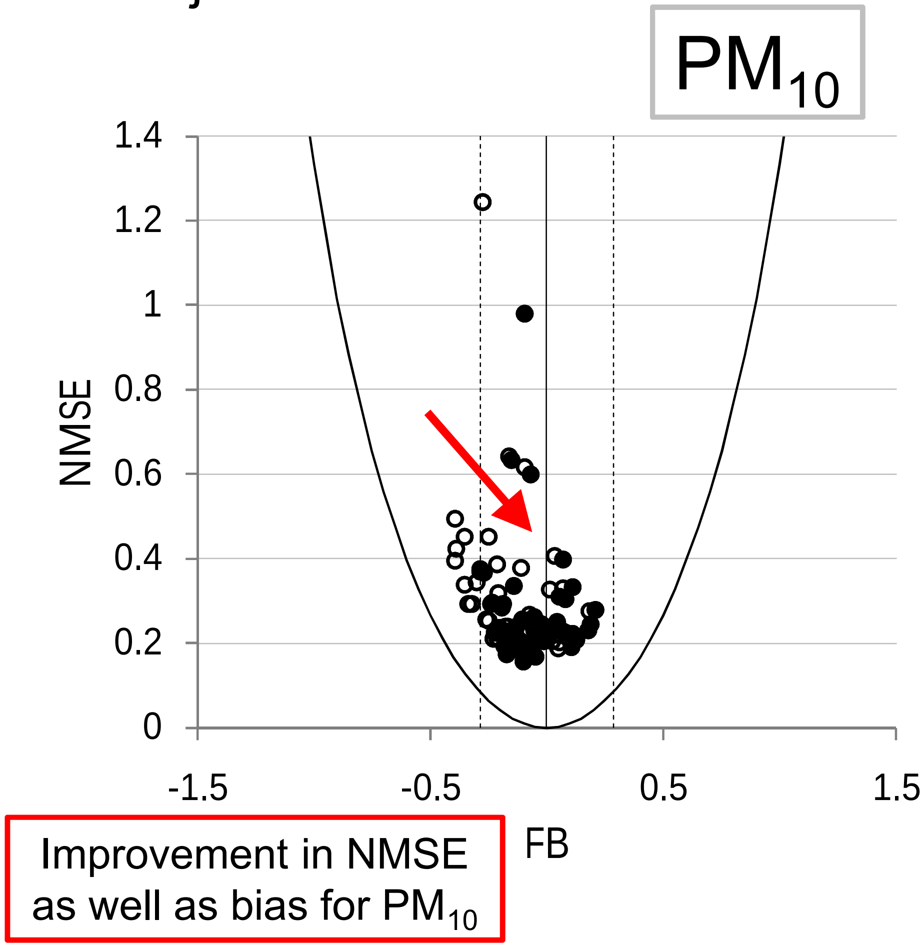

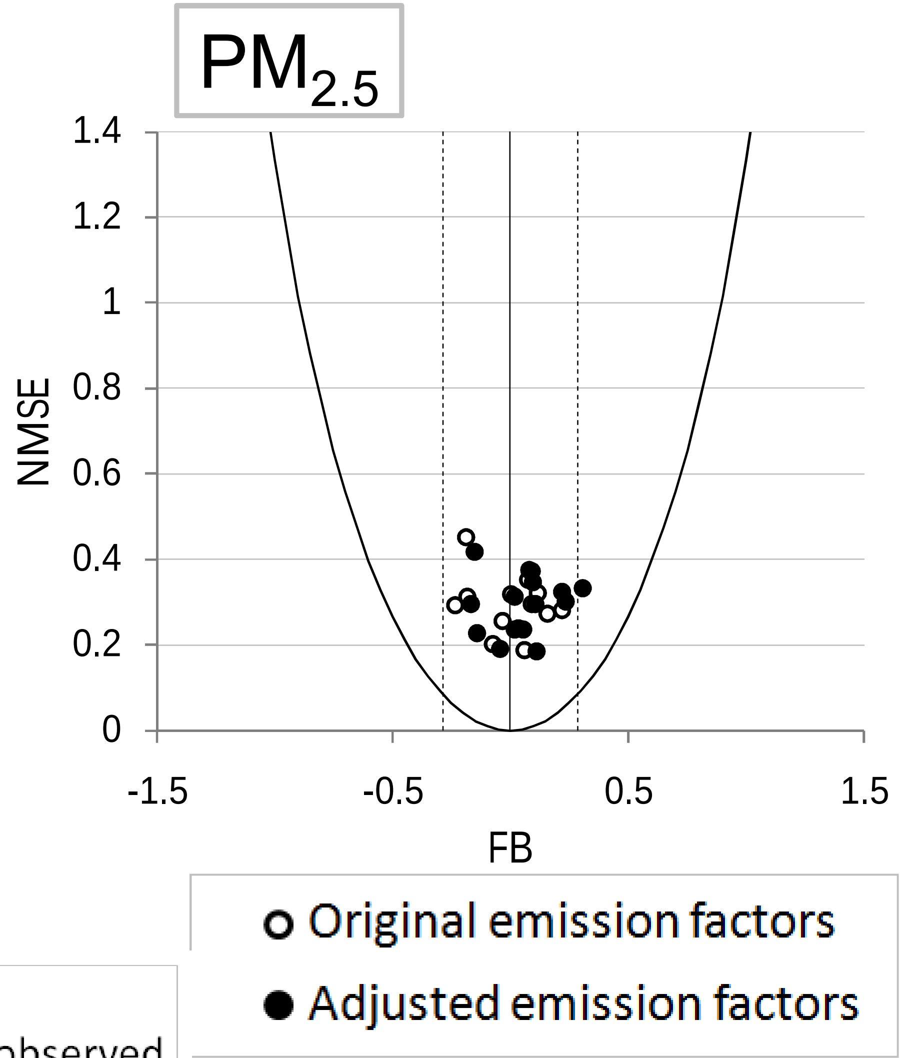

1 : 1 line
Within a factor of 4/3 of the observed

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ADMS-Urban model results

Final statistics for all pollutants, over all sites

Statistics relate to modelling for 2012 (ADMS-Urban 3.4.3)

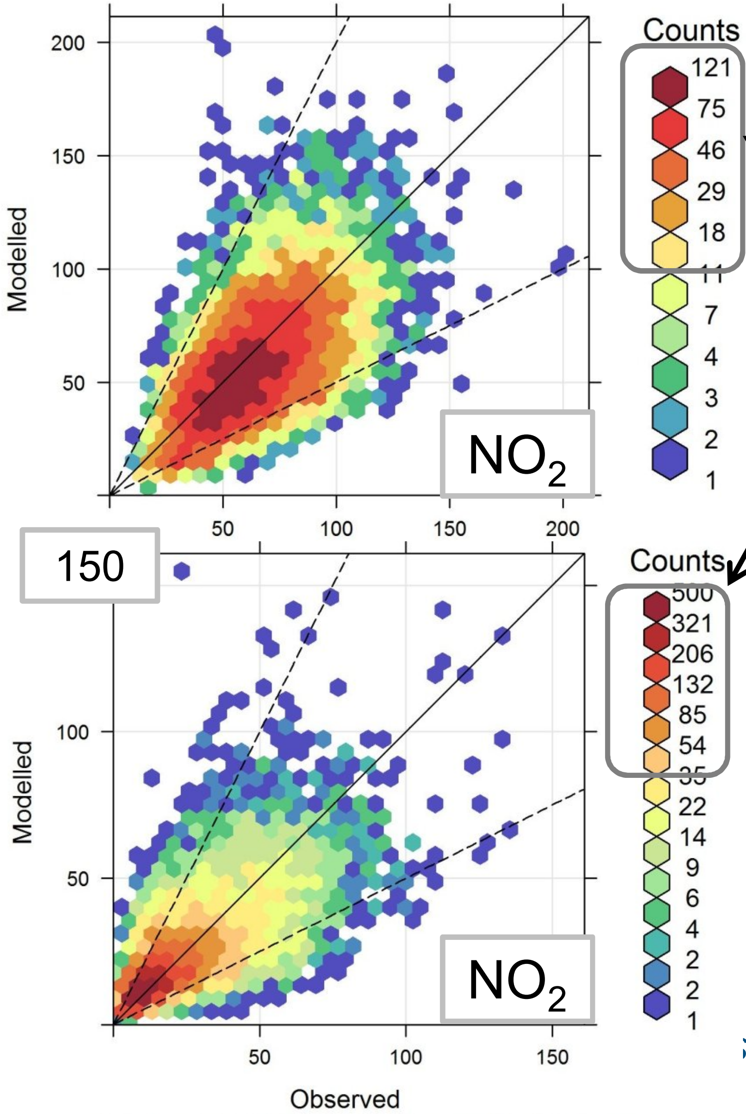
Pollutant	*Obs. mean*	Mod. mean	NMSE	FB	R	FAC2
NO_x	110.7	105.7	0.72	- 0.05	0.70	0.72
NO_2	49.8	49.9	0.28	0.002	0.71	0.83
O_3	33.1	33.0	0.24	- 0.001	0.77	0.67
PM_{10}	23.8	22.1	0.36	- 0.08	0.63	0.88
$PM_{2.5}$	14.8	15.6	0.29	0.06	0.75	0.83
Perfect model	***n/a***	**n/a**	**0.0**	**0.0**	**1.0**	**1.0**

ADMS-Urban model results
“Focus on state-of-the-art chemistry at all scales”

- Assess model predictions on an hour-by-hour basis

Example roadside site

Example urban background site



Much greater concentration variation at roadside site

Data capture for both sites > 93%

ADMS-Urban model results
“Focus on state-of-the-art chemistry at all scales”

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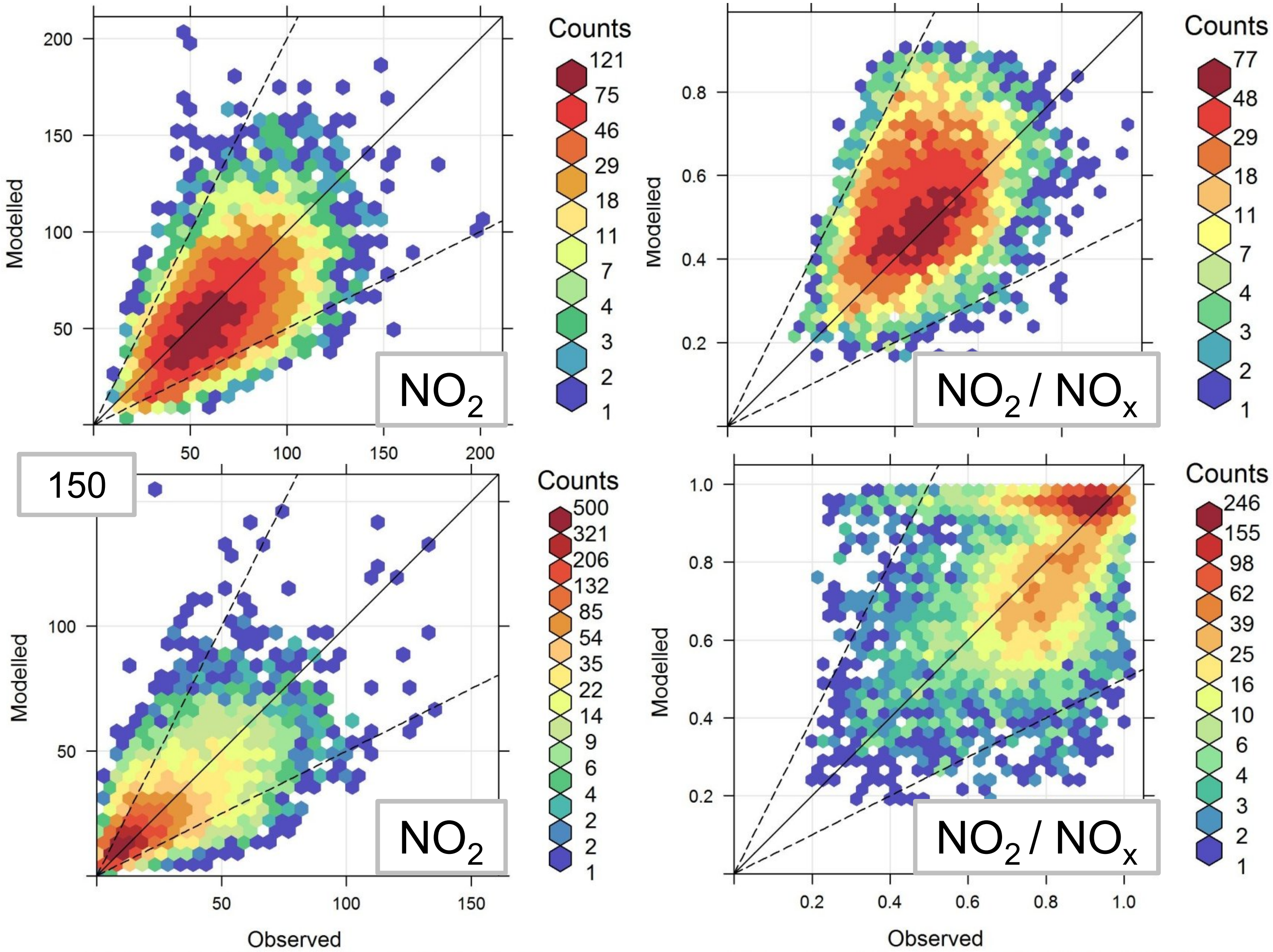
Example roadside site

Example urban background site



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Lessons learnt

- **Using adjustment factors based measurement data improves model performance...**
- **...and may remove the need for post-modelling adjustment factors!**

Modelling tips:

- When modelling chemistry, use upwind direction-dependent background concentrations
- To allow for flow field variations over the domain, use the **urban canopy module**
- To allow for complexities of dispersion in the urban areas, use the **advanced canyon** and **tunnel** model options
- Locate road / kerbside receptors on the pavement, within the canyon, at the correct distance from the kerb