Detailed near-road dispersion modelling for exposure assessments

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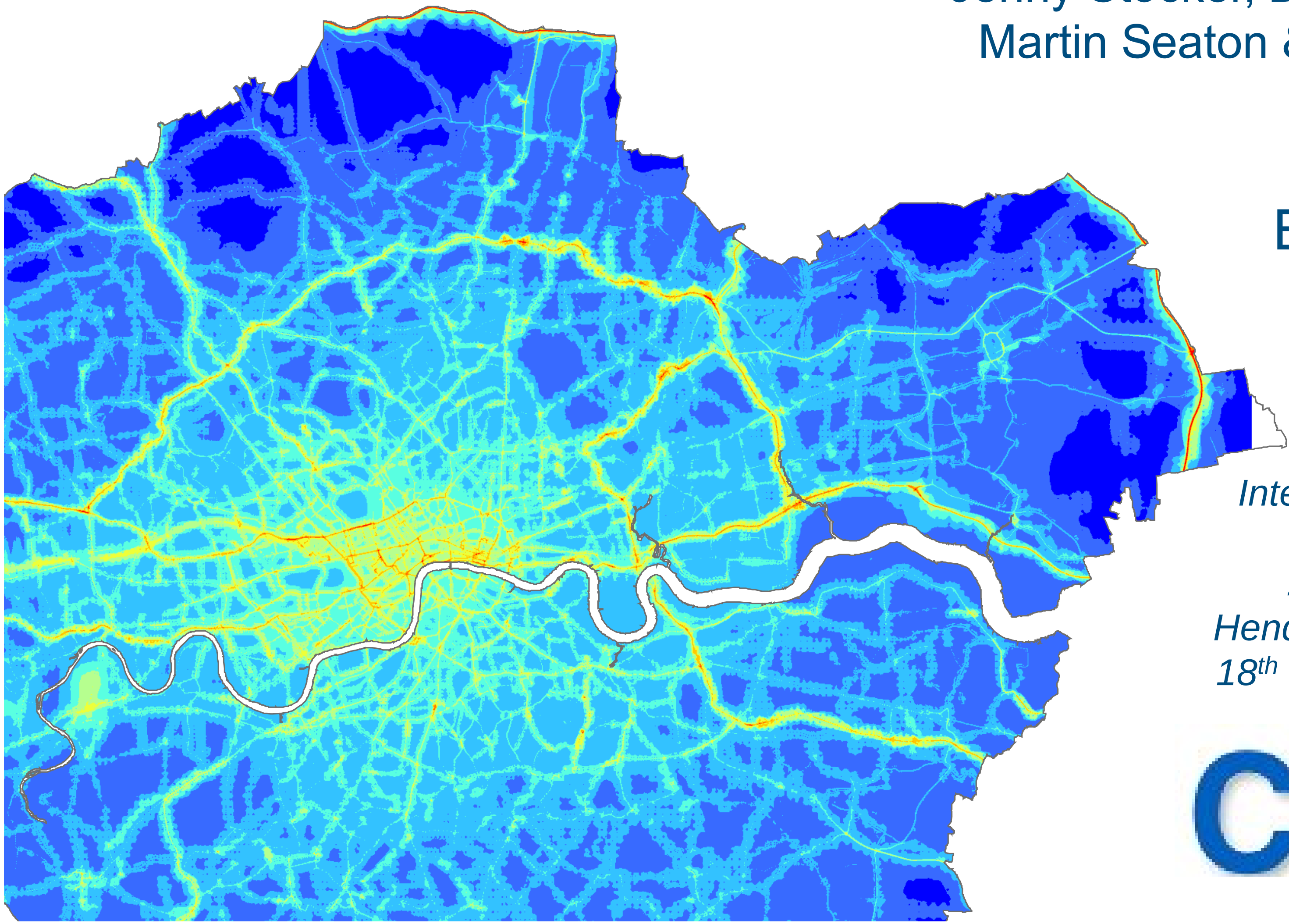

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CERC

Outline of talk

- Complexities of modelling air quality in urban areas:
  - Emissions
  - Meteorology
  - 'Background' pollution levels
  - Non-linearities (chemistry, vehicle-induced turbulence)
  - Effects of structures on dispersion
- Inputs to pollution-exposure calculations
- Modelling mitigation scenarios
- Evaluation of near-road source dispersion models
  - ADMS-Urban, AERMOD, CALINE & RLINE
  - Field campaigns & wind tunnel experiments
  - US-UK collaboration exercise

Complexities of modelling air quality in urban areas
Emissions

TRAFFIC MODELLING → **EMISSIONS MODELLING** → **DISPERSION MODELLING**

Inputs:

Vehicle types	Traffic model outputs	Emissions model outputs
Traffic volumes (ATC, manual)	Emission factors	Meteorological data
Road network	Fleet data (fuel, engine sizes)	Road geometries (incl. canyons)
Transport demand	Vehicle ages	Background concentrations
	Road gradients	Building density

Time scales:

24-hour average	Average speed (drive cycle)	Annual averages
AM & PM peaks, Inter-peak (IP)	Micro simulation (per second)	Hourly (and related statistics)
Hourly		
Micro simulation (per second)		

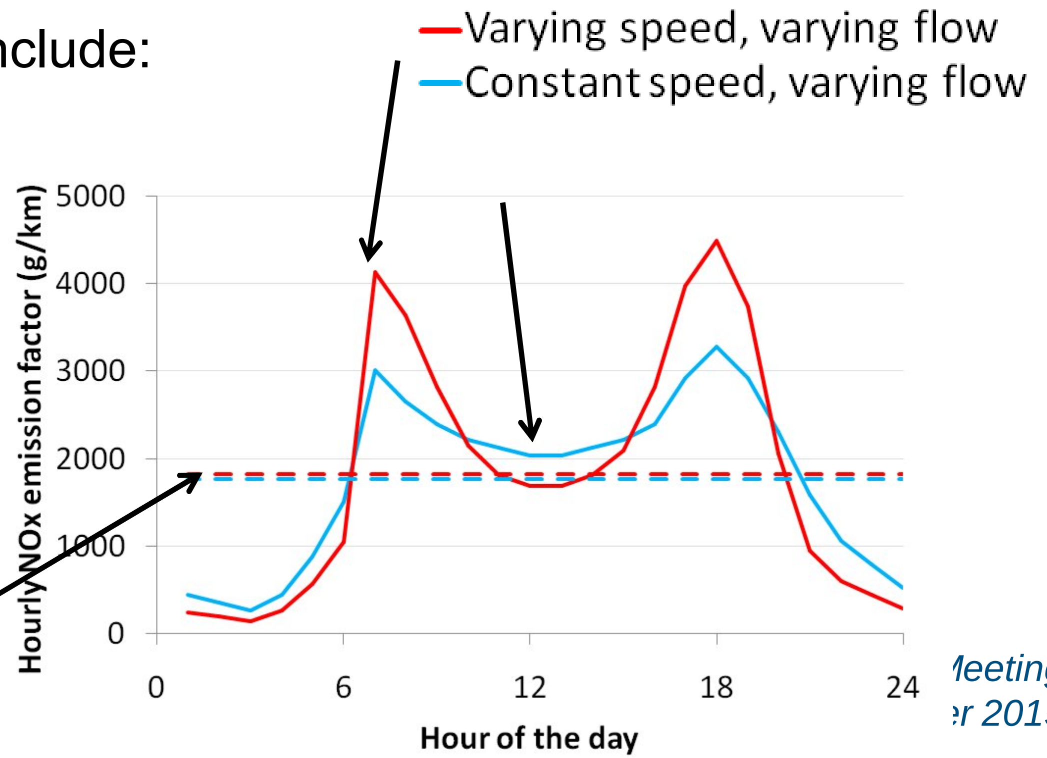
Spatial resolution:

Large scale	n/a	Large scale
Small scale		Small scale

Complexities of modelling air quality in urban areas
Emissions

- Annual average daily emission rates are not sufficient for dispersion modelling
  - Dispersion calculations are performed hourly
  - The same emission rates result in different ground level concentrations at different times of the day (eg variations in wind speed, chemistry effects)
  - Even annual average calculations will be wrong if no temporal variation in emissions are included
- Emissions inventories may include:
  - Traffic flows
  - Traffic speeds
  - Fleet compositions
- The temporal variation in speed and flow must be included in the modelling

Adjustment for speed may not change the average emission, but does change the peaks, so will affect concentrations



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Complexities of modelling air quality in urban areas

Emissions

- Some published emission factors are not robust
- The recent VW vehicle scandal highlights the issue with NO_x emissions from diesel vehicles, already known in Europe:
  - 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				
London taxi	FX	2				
London taxi	Met	2				
London taxi	TX1	2				
London taxi	Met	3				
London taxi	TXII	3				
London taxi	MV111	4	594	64.1 ± 1.3	11.9 ± 0.9	18.6 ± 1.5

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

Emissions

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Vehicle Type	Emission Standard	Remote sensing / Standard factors (NO_x) %	Remote sensing primary NO_2
Diesel Car	Euro0	144	15
	Euro1	167	14
	Euro2	172	9
	Euro3	138	16
	Euro4	129	28
	Euro5	101	25
Diesel trucks < 12 tonnes	Euro2	136	21
	Euro3	147	18
	Euro4	213	8
	Euro5	216	8
Diesel trucks > 12 tonnes	Euro2	143	12
	Euro3	153	24
	Euro4	206	3
	Euro5	241	4
Petrol Car	Euro0	91	5
	Euro1	131	1

Complexities of modelling air quality in urban areas

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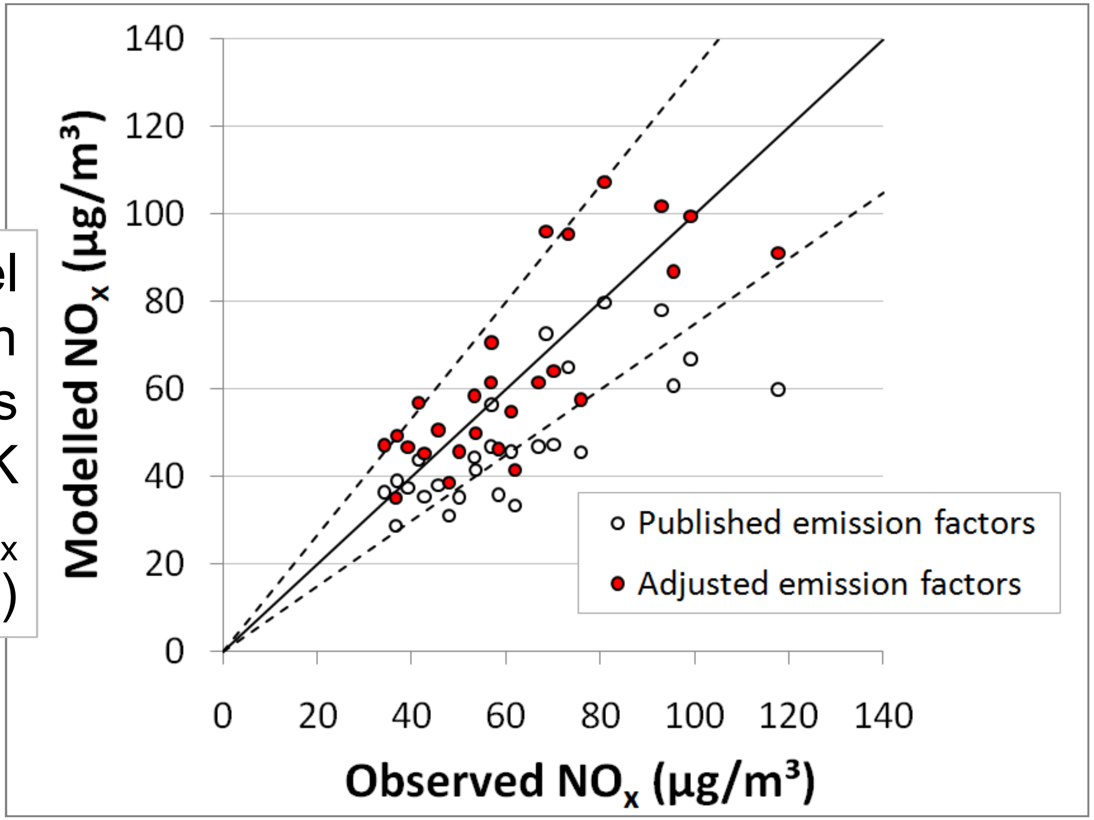
Example ADMS-Urban model validation at 26 urban background continuous monitoring sites in London, UK (Annual average 2012 NO_x concentrations)



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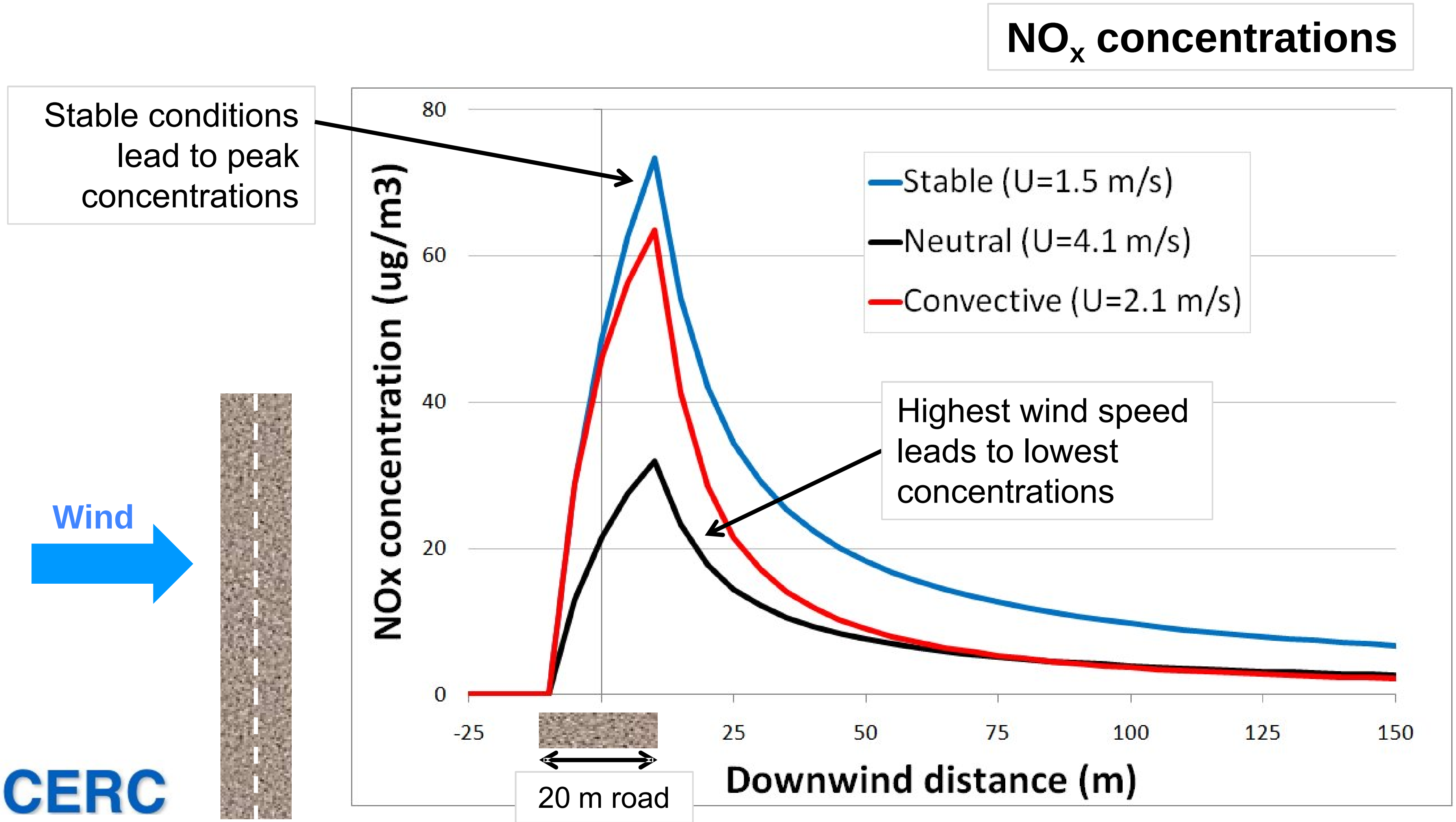
Complexities of modelling air quality in urban areas
Meteorology

- Different meteorological conditions lead to very different concentrations
- Consider the concentration decay downwind of a road



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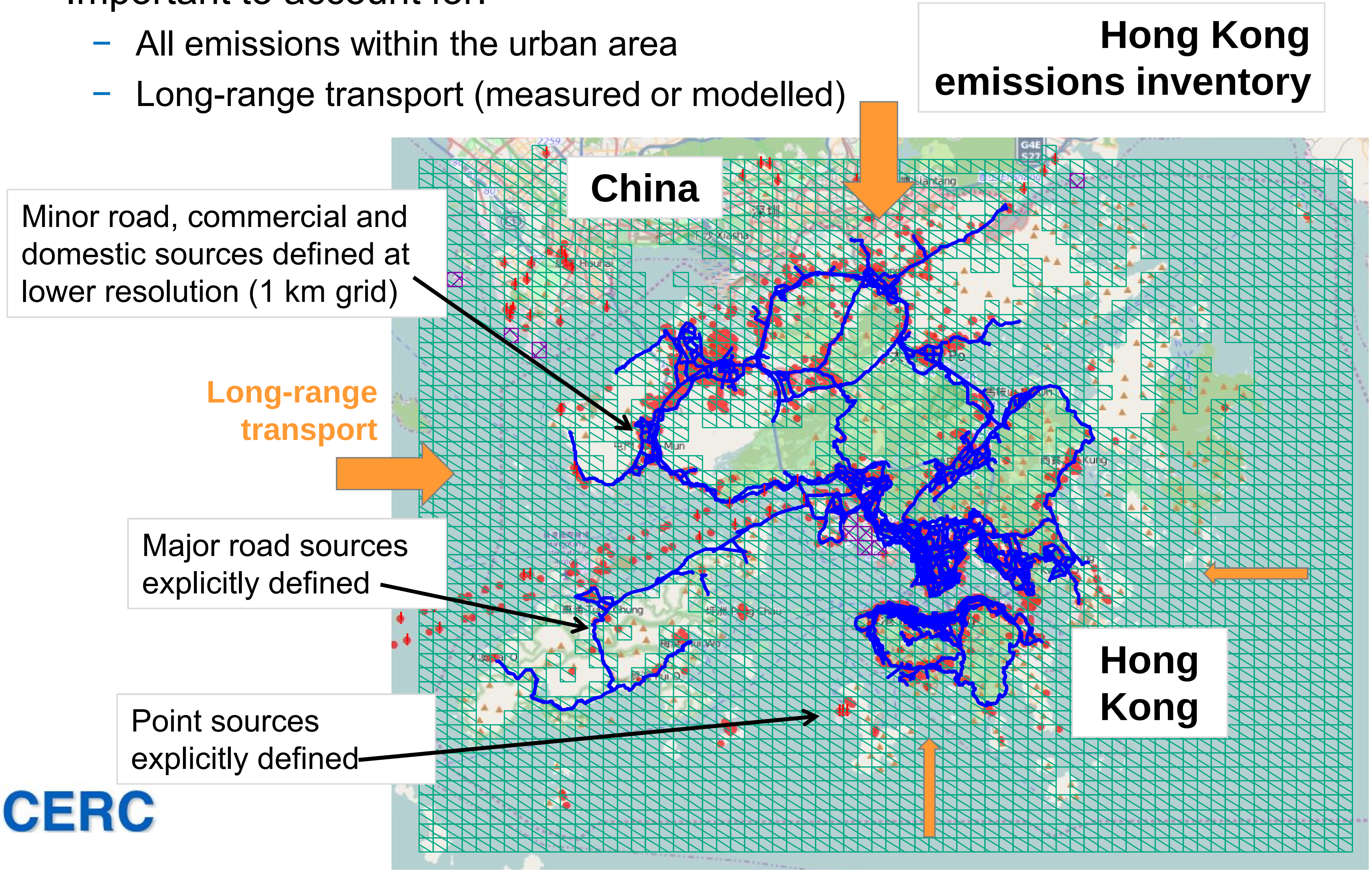
Complexities of modelling air quality in urban areas

'Background' pollution levels

- Important to account for:
  - All emissions within the urban area
  - Long-range transport (measured or modelled)



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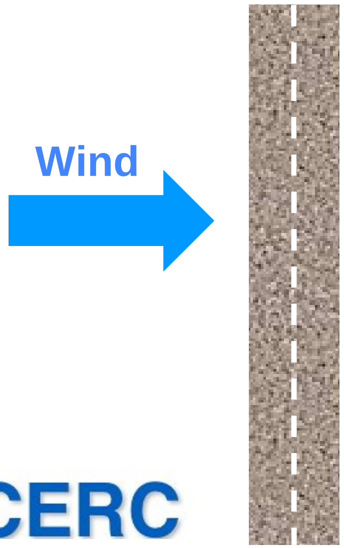
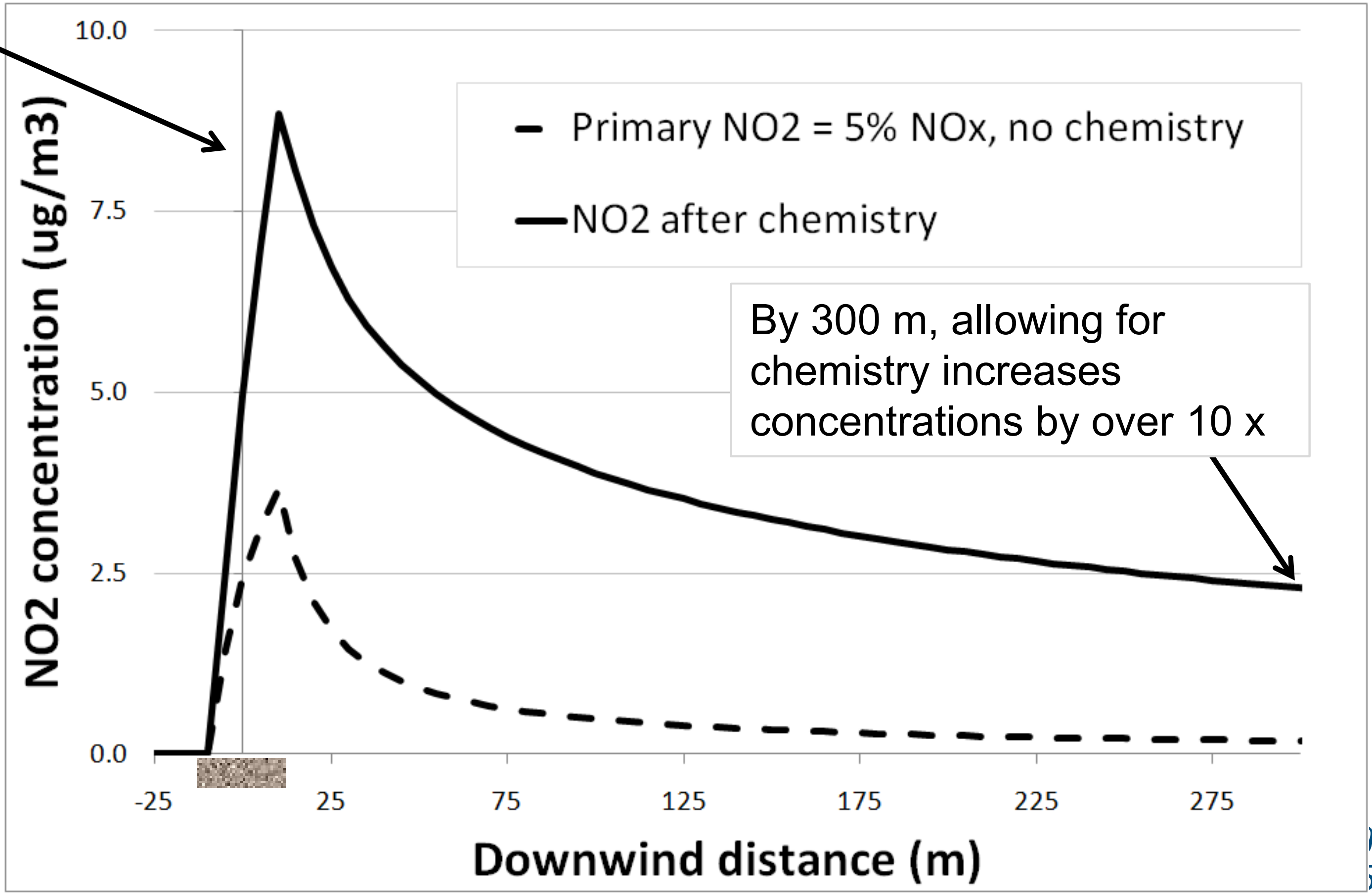
Non-linearities: Chemistry

- Allowing for chemistry significantly increases concentrations relative to the dispersion of primary NO_2

Adjacent to the road, allowing for chemistry increases concentrations by over 2 x

NO_2 concentrations in stable conditions





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Complexities of modelling air quality in urban areas

Non-linearities: Chemistry

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Generic Reaction Set (GRS) in ADMS-Urban (Venkatram et al., 1994)

hν	= Ultra-violet radiation
ROC	= Reactive Organic Compounds
RP	= Radical Pool
SGN	= Stable Gaseous Nitrogen products
SNGN	= Stable Non-Gaseous Nitrogen products

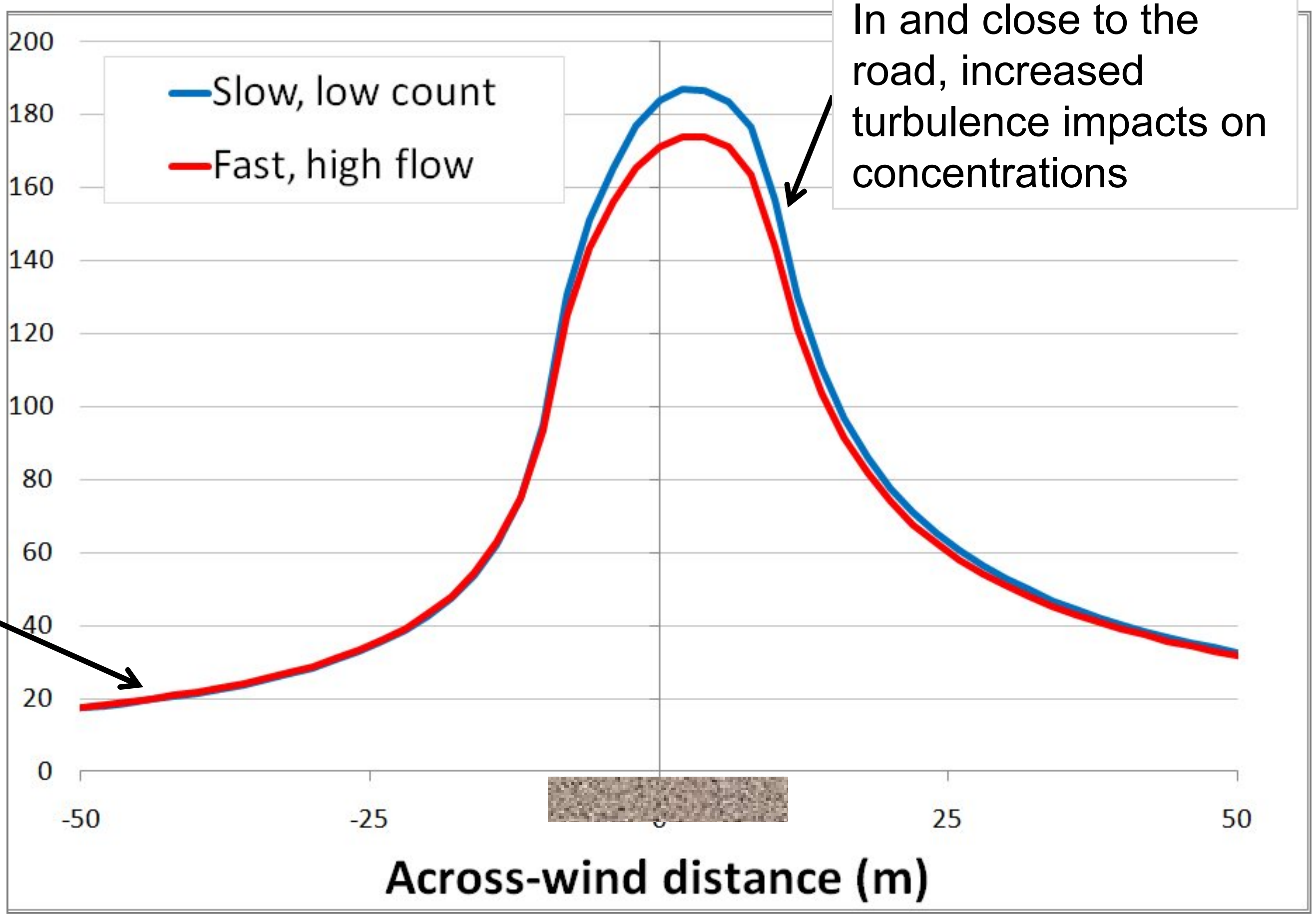
1.	ROC + hν	→	RP + ROC
2.	RP + NO	→	NO_2
3.	NO_2 + hν	→	NO + O_3
4.	NO + O_3	→	NO_2
5.	RP + RP	→	RP
6.	RP + NO_2	→	SGN
7.	RP + NO_2	→	SNGN

Complexities of modelling air quality in urban areas

Non-linearities: Vehicle-induced turbulence

- More vehicles on a road reduces ‘per vehicle’ concentrations due to increased turbulence
- Large, fast vehicles create greatest turbulence

Normalised period-average concentrations



In and close to the road, increased turbulence impacts on concentrations

By 50 m, minimal influence of the increased turbulence

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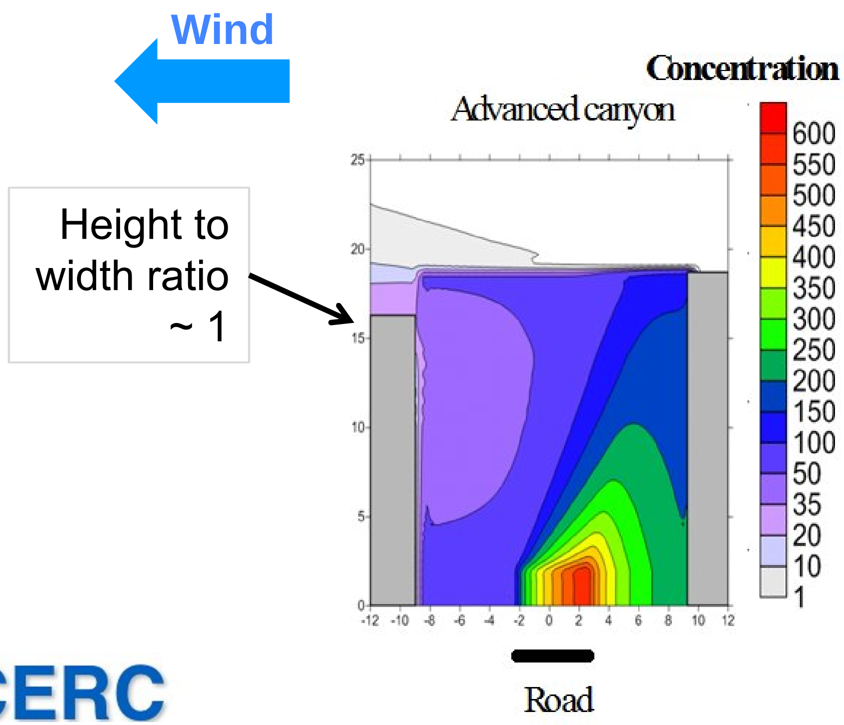
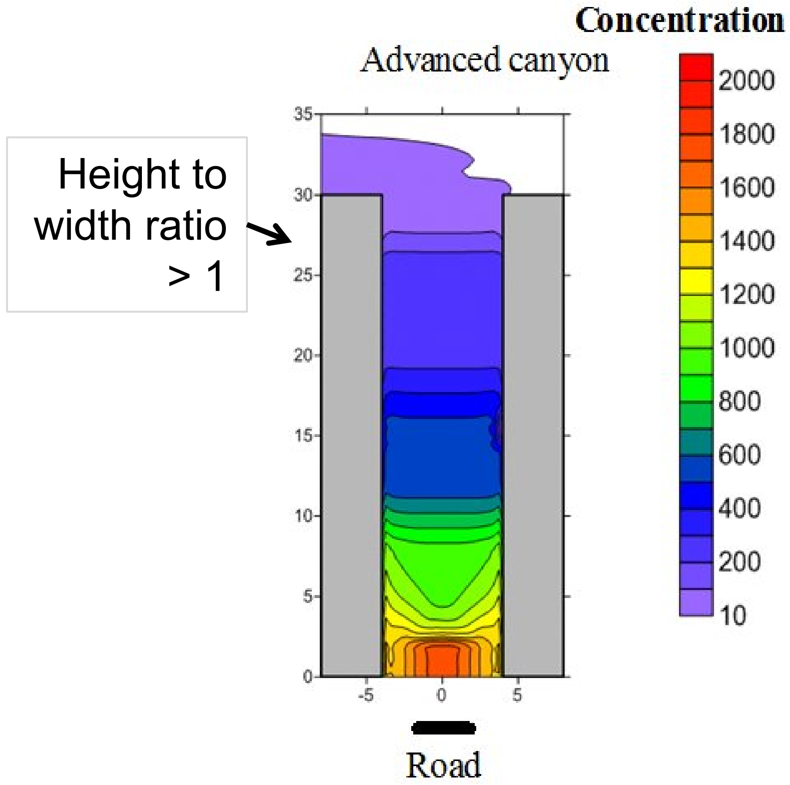
Complexities of modelling air quality in urban areas

Effects of structures on dispersion

- Buildings in an urban area reduce wind speed and increase turbulence
- Upwind boundary layer profiles are displaced above the building canopy
- Locally, the wind flow and dispersion within ‘street canyons’ is complex; wind flows at street level may be in the opposite direction to the prevailing wind
- Road features such as tunnels require special consideration





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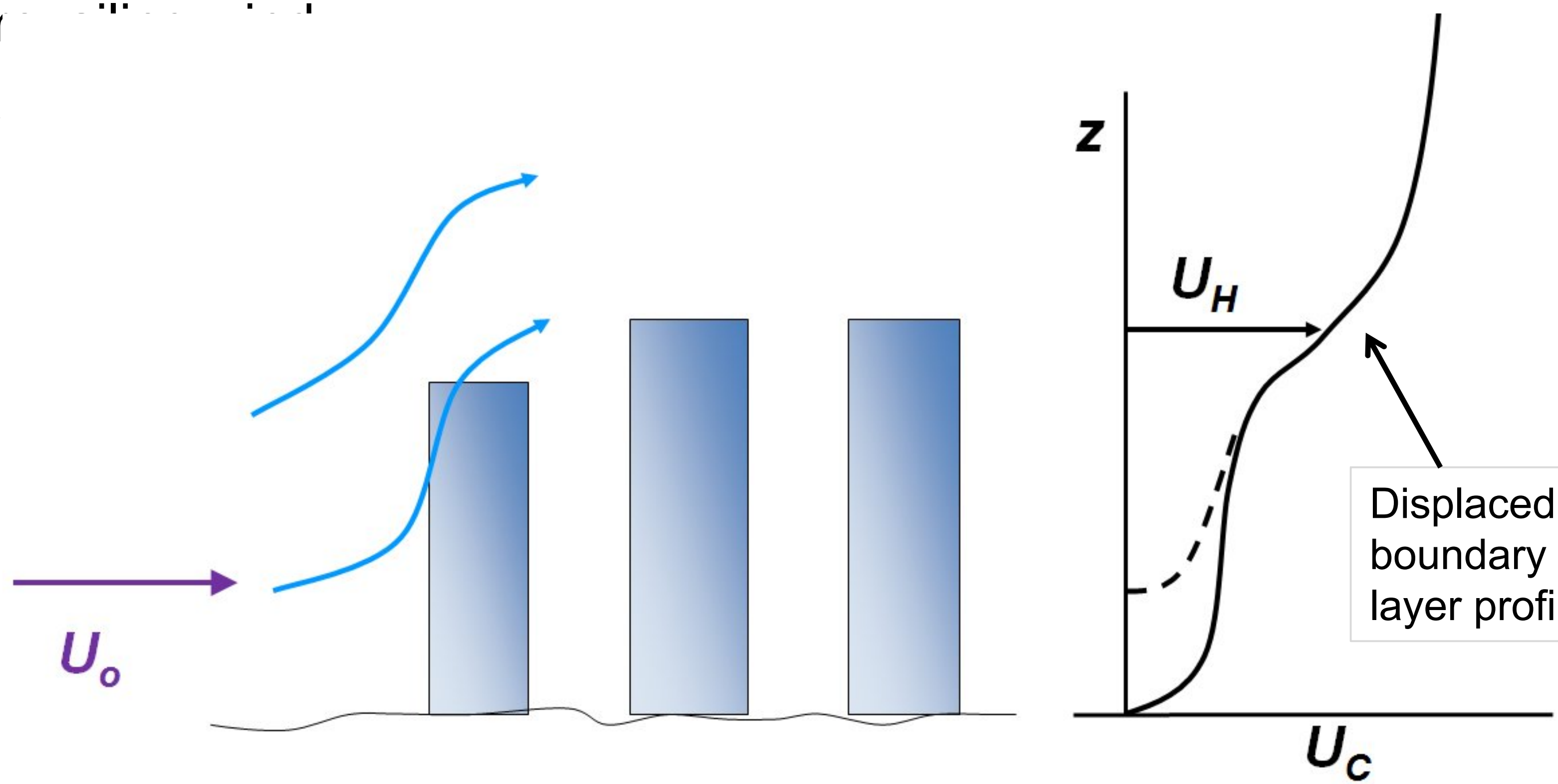
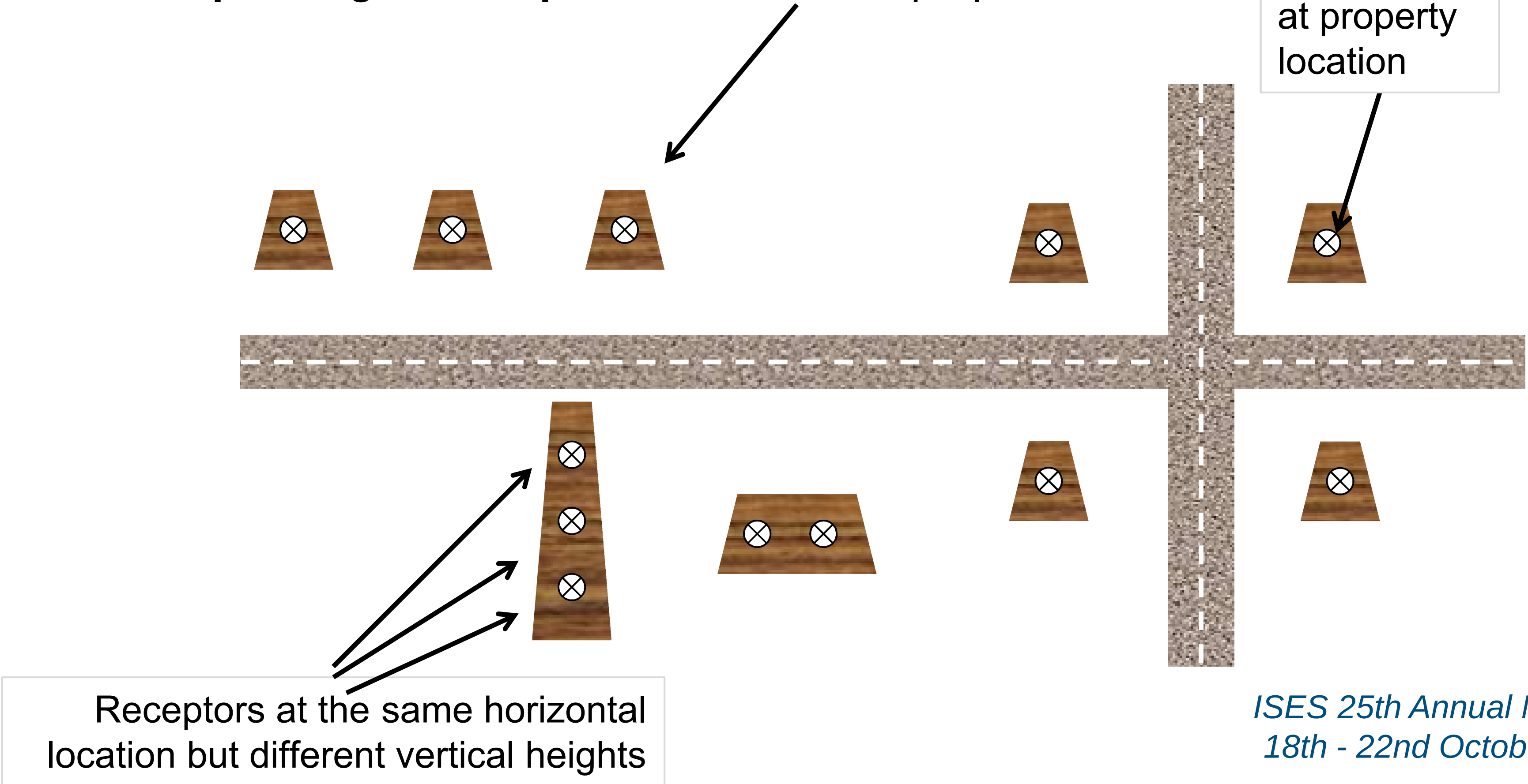


Inputs to pollution-exposure calculations

- **Temporal resolution** of dispersion model output:
  - Usually hourly averages
- **Spatial resolution** of dispersion model output:
  - Receptors anywhere in the 3D pollutant concentration field
- **Example long-term exposure:** residential properties



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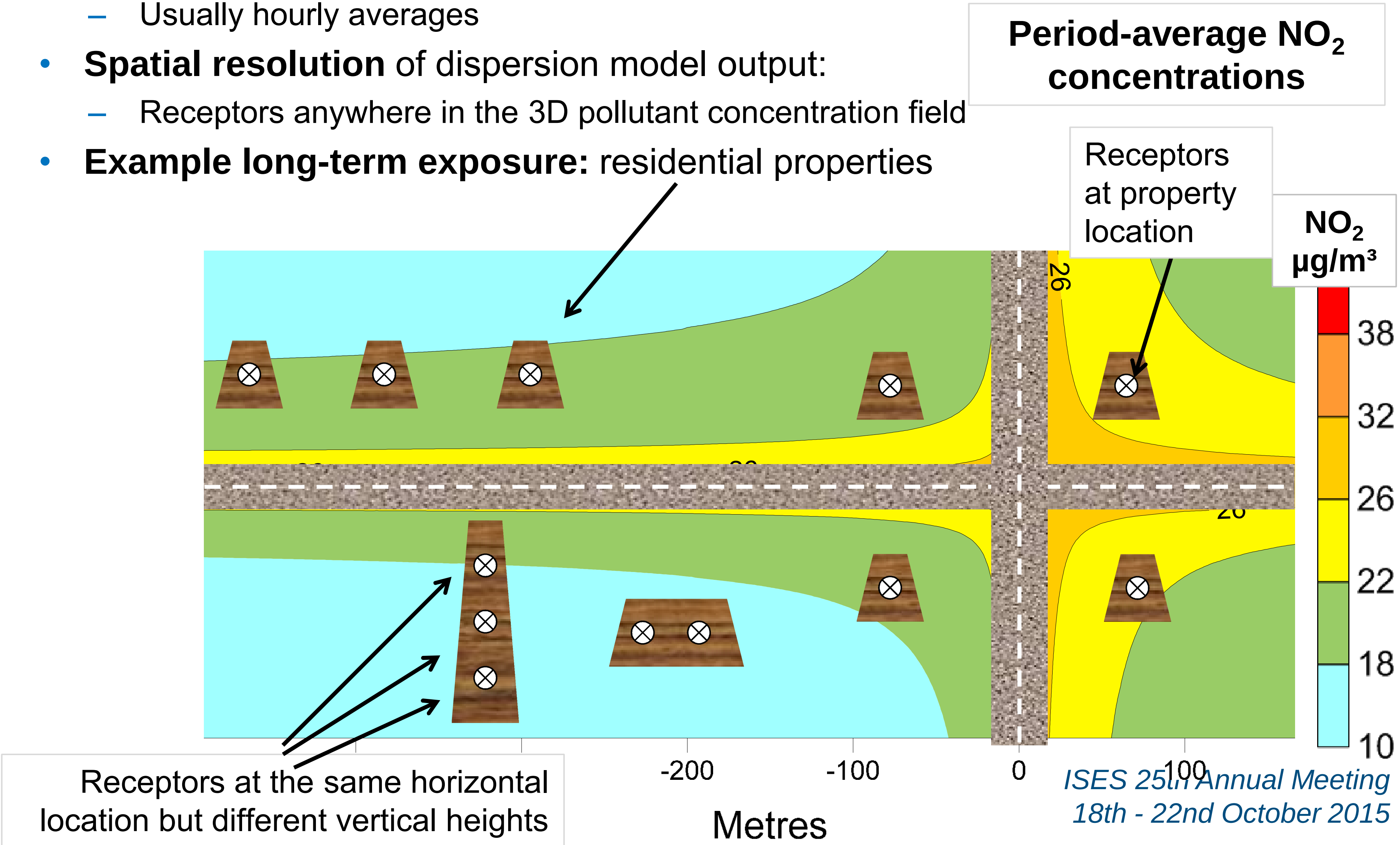

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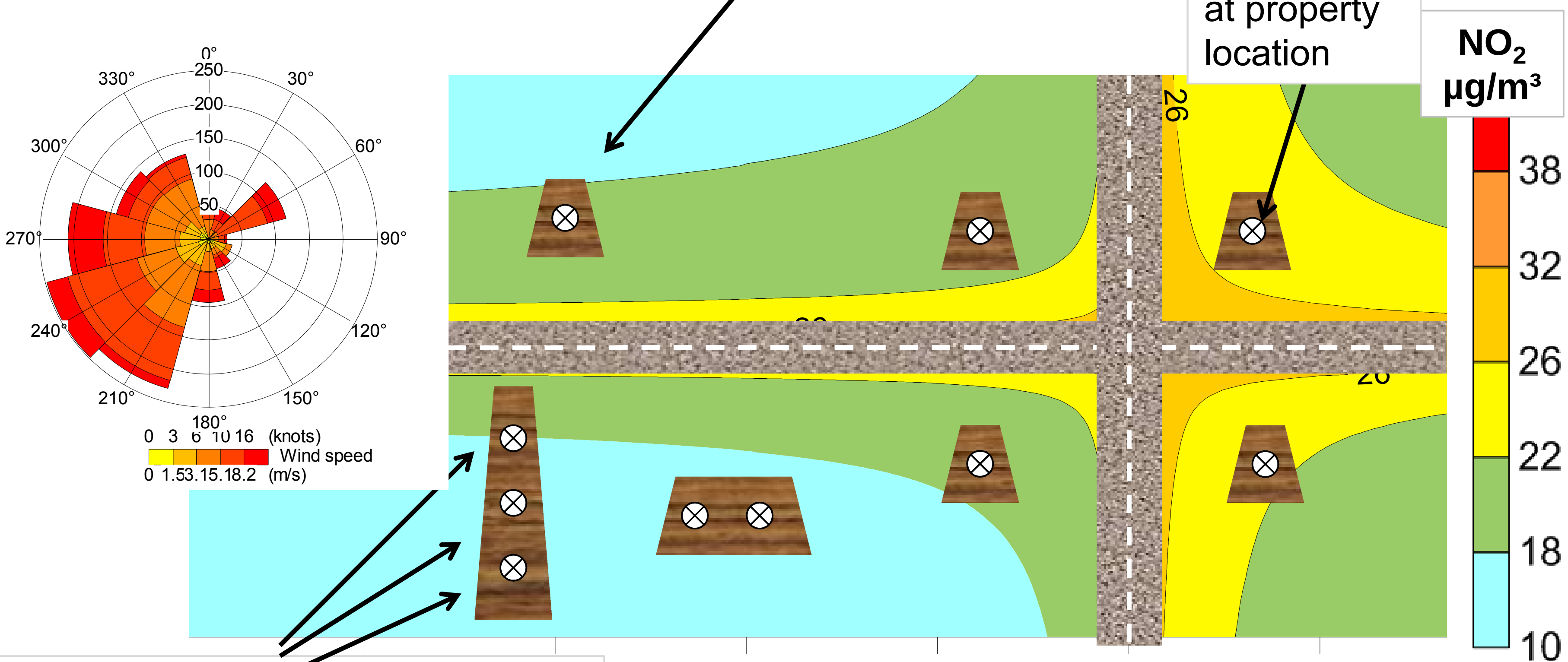
Period-average NO_2 concentrations

Receptors at property location



Receptors at the same horizontal location but different vertical heights

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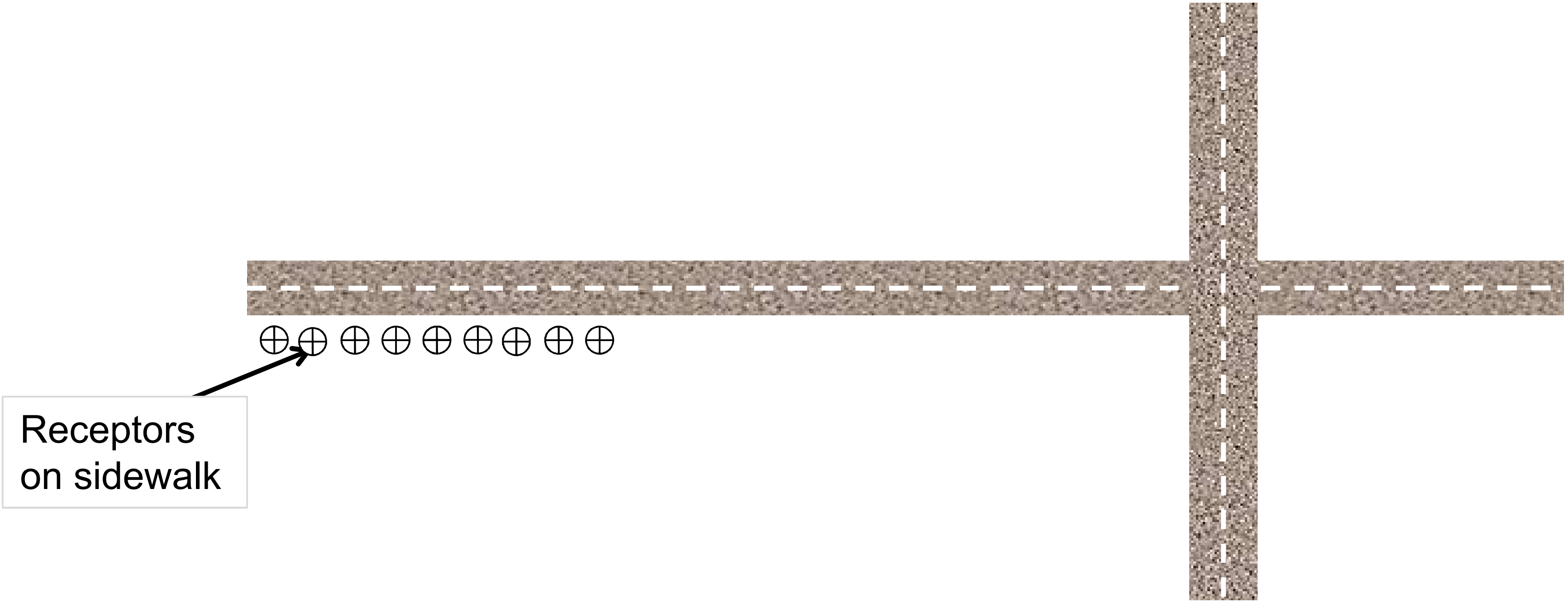

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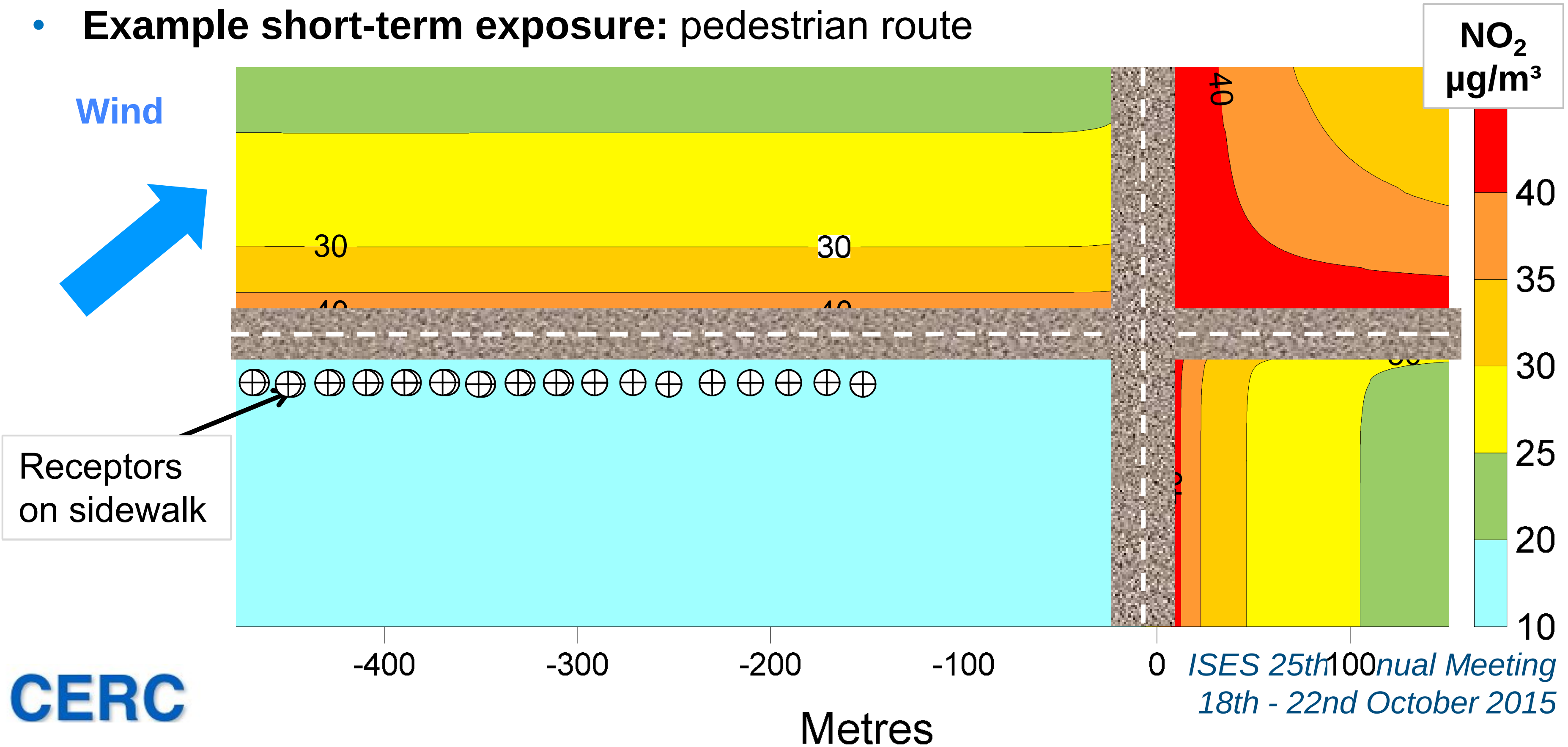

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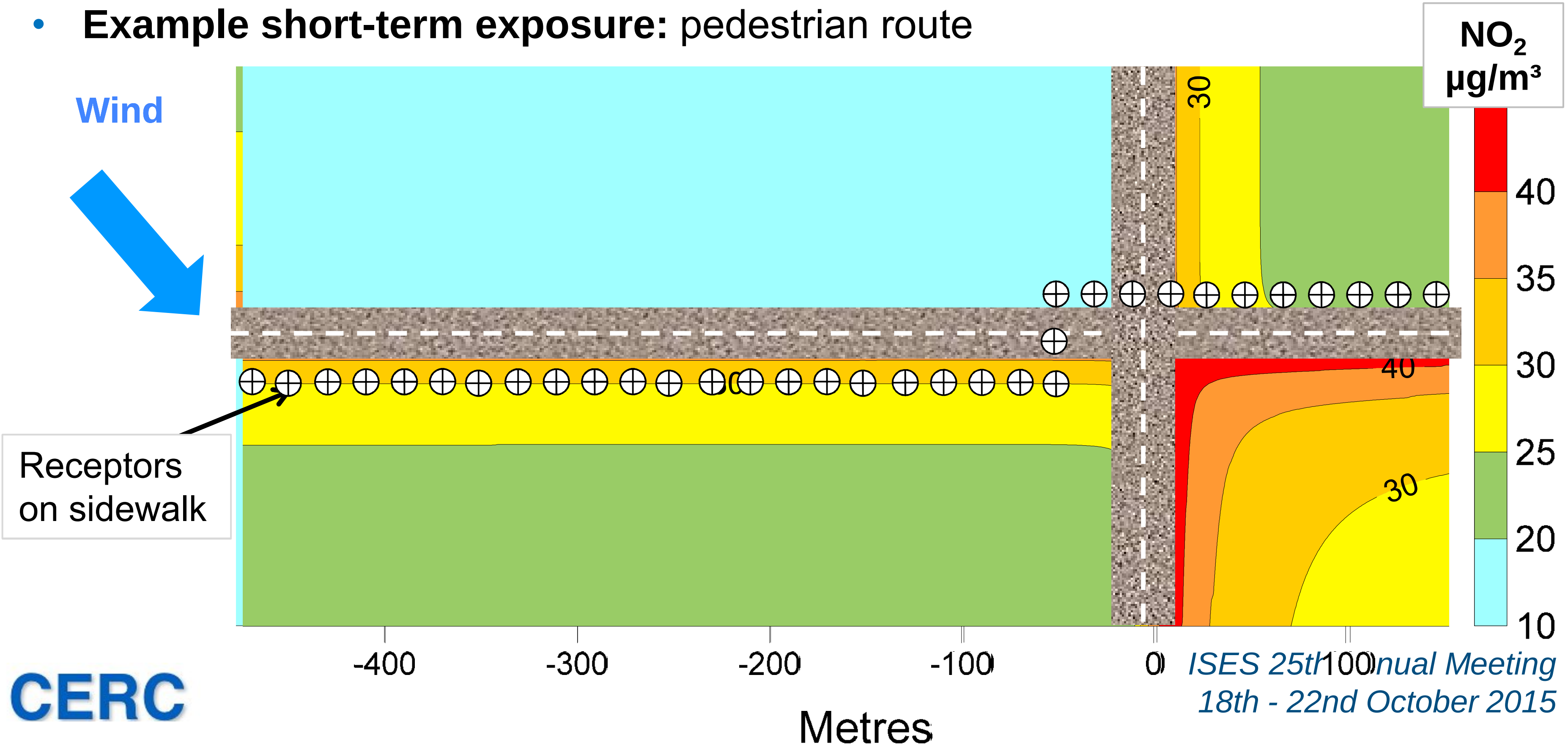

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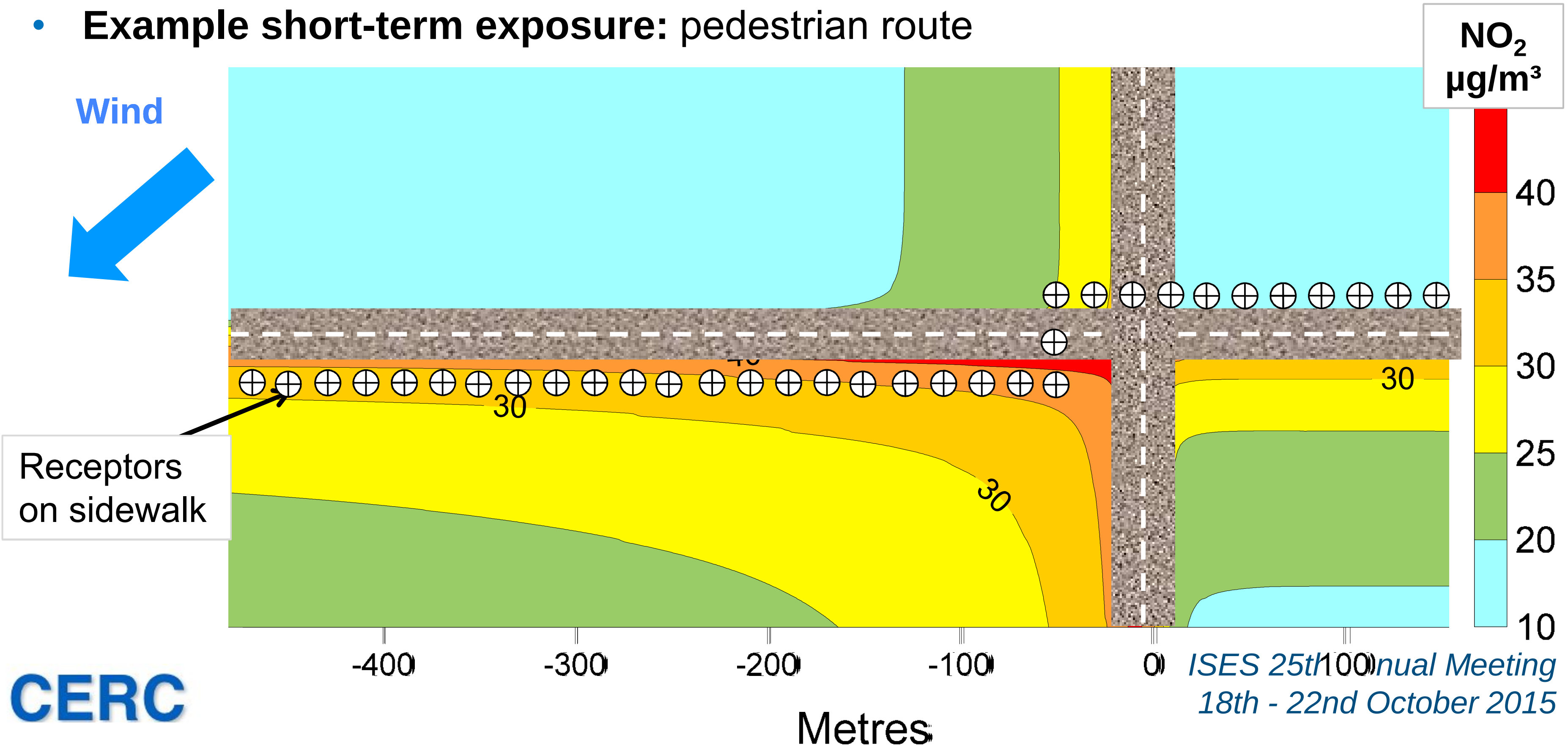

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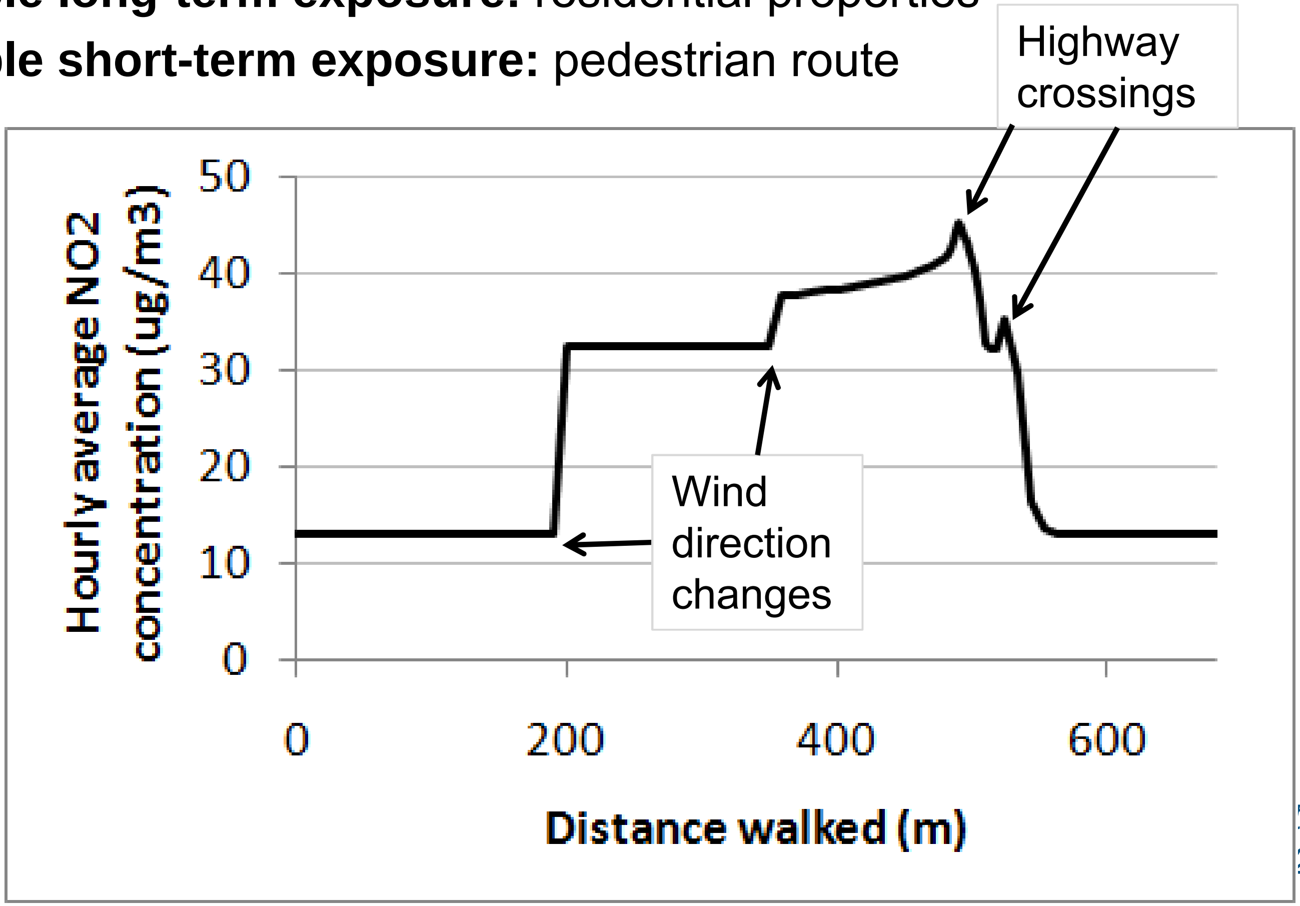
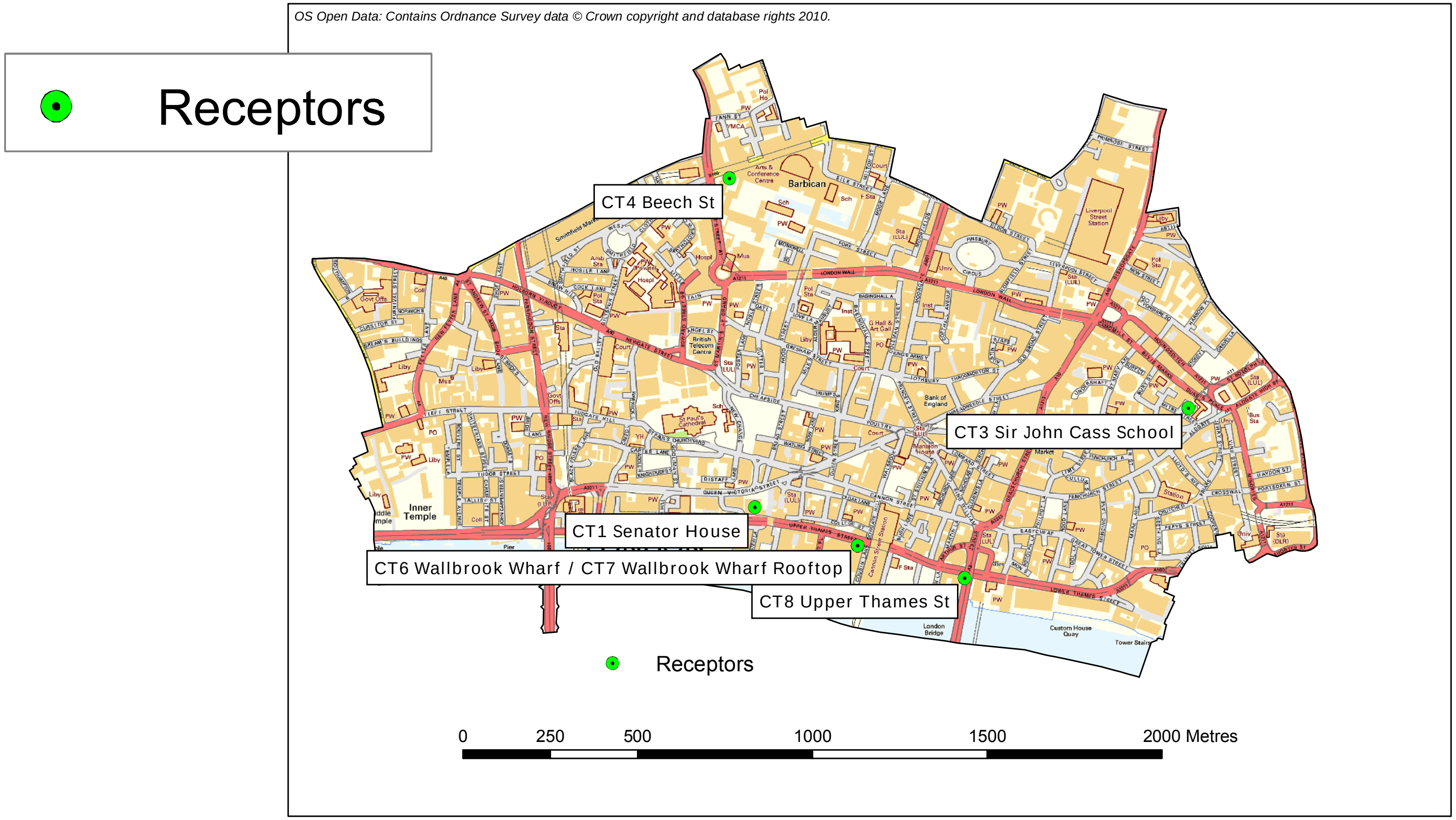


Modelling mitigation scenarios

- Pollution mitigation scenarios include:
  - Emission-reduction scenarios:
    - Low-emission zones (excluding vehicles)
    - Congestion charging (reducing vehicle numbers)
  - Physical barriers
    - ‘Noise’ barriers
    - Foliage barriers

Modelling mitigation scenarios

- How do you know which emissions sources to target?
  - ➢ Perform source apportionment analyses
- Method:
  - – Validate model configuration at receptor locations for base case year



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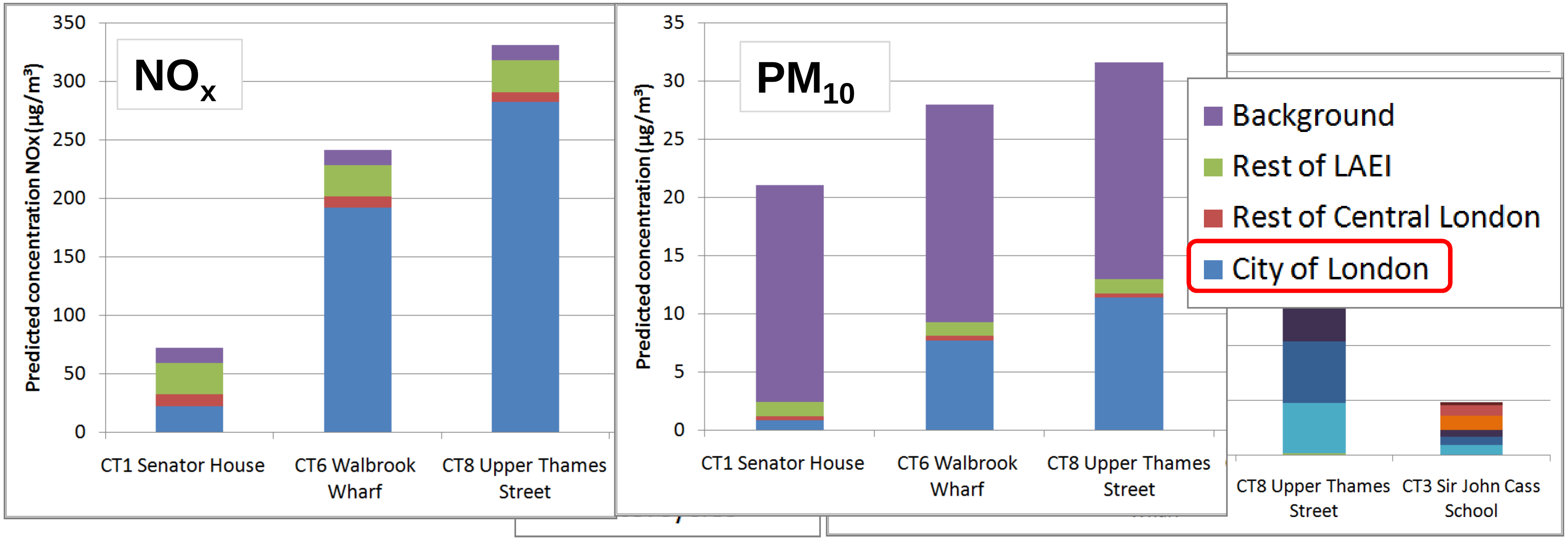
    - o Often of interest to consider what proportion of concentration is from outside of area



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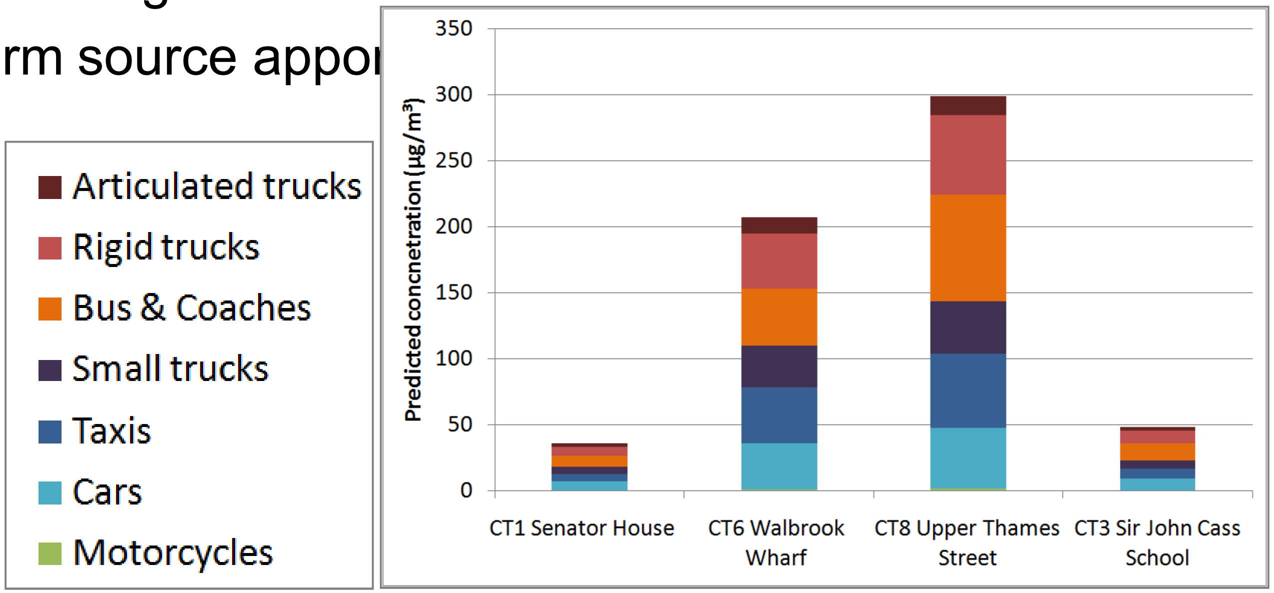
    - o Apportion remaining concentration within domain
    - o Cannot perform source appor chemistry



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Modelling mitigation scenarios

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- Method:
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  - Calculate contribution from each source / group of sources to each receptor
    - Often of interest to consider what proportion of concentration is from outside of area
    - Apportion remaining concentration within domain
    - Cannot perform source apportionment for NO_2 because of chemistry

Modelling mitigation scenarios

- Perform emission reduction modelling:
  - Assess reduction in concentration at various receptors within the domain for base case year, and future years

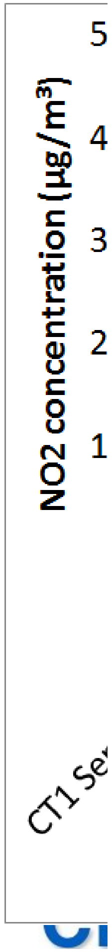

Table 2.1: Summary of CCZ & North/South Circular scenarios

Short name	Year	Area	Description	Pollutants assessed
Euro 4 CCZ 11	2011	CCZ	Minimum standard of Euro 4 for all diesel vehicles	PM_{10} & $PM_{2.5}$
Euro 4 NS 11	2011	North/ South Circular	Minimum standard of Euro 4 for all diesel vehicles	PM_{10} & $PM_{2.5}$
Euro 4 plus electric 11	2011	CCZ	Minimum standard of Euro 4 for all diesel vehicles & electric taxis	PM_{10} & $PM_{2.5}$
Biomethane	2011	CCZ	Biomethane used by 50% of lorries, large vans & taxis	PM_{10}, $PM_{2.5}$ & NO_x
25% electric	2011	CCZ	25% of taxis, vans & cars are electric	PM_{10}, $PM_{2.5}$ & NO_x
Euro 5 CCZ	2011	CCZ	Minimum standard of Euro 5 for all diesel vehicles	PM_{10} & $PM_{2.5}$
		North/		

Modelling mitigation scenarios

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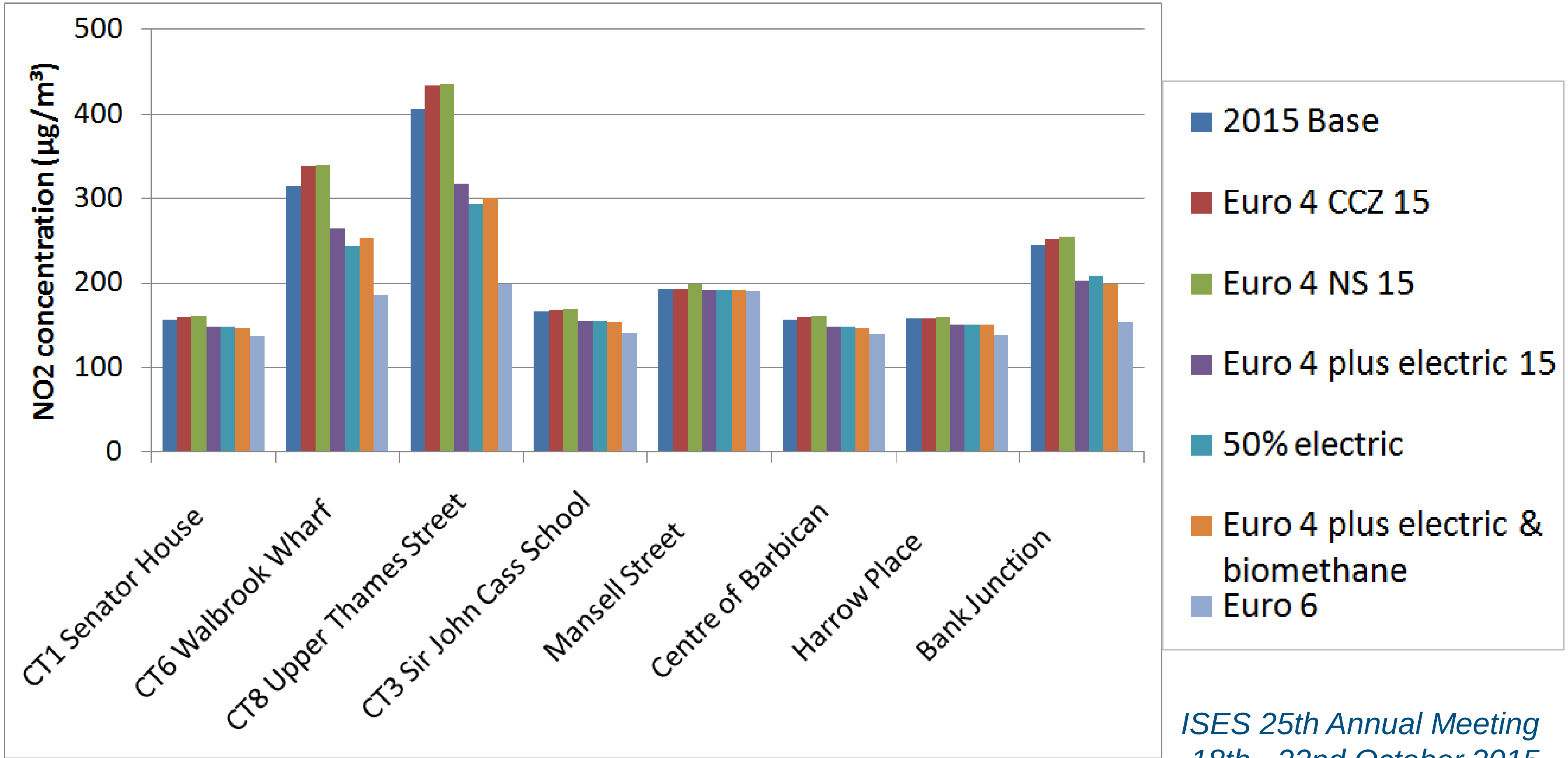

Evaluation of near-road source dispersion models

- Various near-road source dispersion models available

Model	Meteorology	'Road' source definition	Traffic turbulence	Reference	Status
ADMS-Roads	Monin-Obukhov	Line or road	Initial σ_{z0} plus allowed for in dispersion	McHugh et al., 1997	UK model for dispersion from road sources
AERMOD	Monin-Obukhov	Area, line & volume	Initial user-defined σ_{z0}	Cimorelli et al., 2005	US EPA regulatory model for short range dispersion
CALINE4	Pasquill Gifford	Line	Initial σ_{z0}	Benson, 1989	California's model for detailed project-level CO analyses
RLINE	Monin-Obukhov	Line	Initial user-defined σ_{z0}	Snyder et al., 2013	US EPA research tool

Evaluation of near-road source dispersion models

- Various near-road source dispersion models available
- CERC is involved in the cooperation agreement between the UK Environment Agency and the US Environmental Protection Agency (EPA):

  "Evaluation of roadway models"
  - Comparisons of modelling results with physical experiments (field campaigns, wind tunnel experiments)
  - Comparisons of modelling results from different models
  - Focus on near-road concentration distributions

Recent publication:

Heist, D., Isakov, V., Perry, S., Snyder, M., Venkatram, A., Hood, C., Stocker, J., Carruthers, D. and Arunachalam, S., 2013: Estimating near-road pollutant dispersion: a model inter-comparison.

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  - Comparisons of modelling results from different models
  - Focus on near-road concentration distributions
- Current work involves model evaluation when 'noise' barriers are in place

Summary

- Dispersion modelling of emissions in urban areas is a **complex task**
- Models are available that accurately represent urban meteorology, chemistry and flow fields
- Emissions remain uncertain, but when real-world estimates are used, **models perform well**
- Receptors can be placed at any location, allowing the calculation of detailed concentration fields, which can be used as inputs to **long- and short-term pollution-exposure calculations**
- Dispersion models are useful tools for source apportionment and to assess the usefulness of **mitigation scenarios**
- Confidence in model output is derived from **extensive model evaluation**

Thank-you

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