Developments of ADMS-Urban for complex urban environments: application to London and Hong Kong

Presented by

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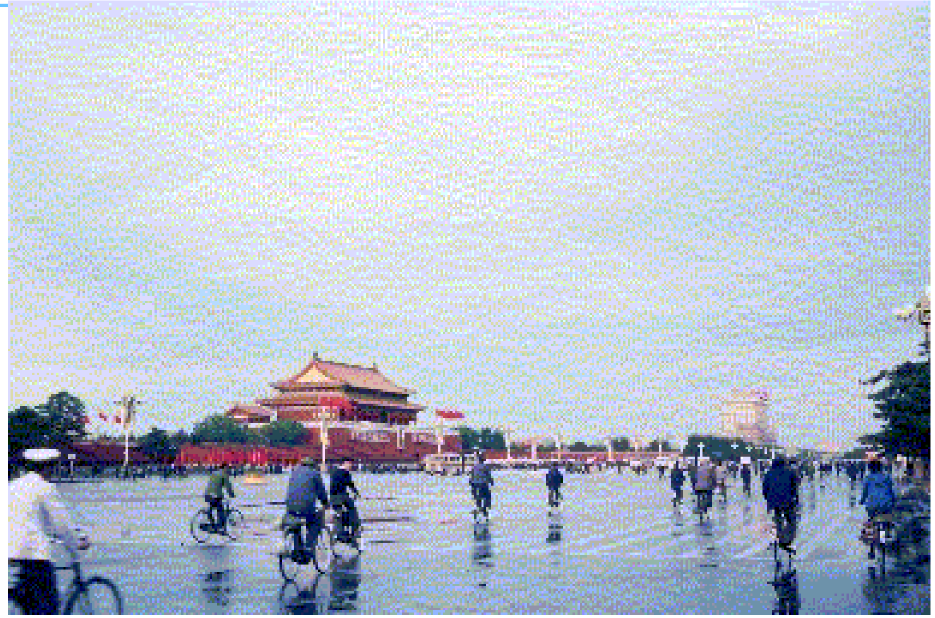
Chang An Avenue, Beijing, in 1979 长安街



Contents

- Introduction to ADMS-Urban
- Urban Canopy and advanced street canyon model
- Nesting ADMS-Urban in regional models
- Conclusions

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ADMS-Urban Model Capabilities

- ADMS-Urban is designed to model dispersion from a wide range of urban sources – first release 1996
- Gaussian type model with point, line area, road and grid sources; non-Gaussian vertical profile of concentration in convective conditions
- Concentration calculated at high resolution (<10m)
- Fully integrated street canyon model
- Includes meteorological pre-processor
- Options for different chemical mechanism; considers effects of complex terrain
- Integration with Geographical Information Systems (GIS) and an Emissions Inventory Database (EMIT)
- Used in many major cities for air quality management, forecasting etc: e.g. London,Manchester,Glasgow,Dublin, Budapest, Rome, Barcelona, Beijing, Hong Kong, Shanghai, Singapore, Cape Town etc.

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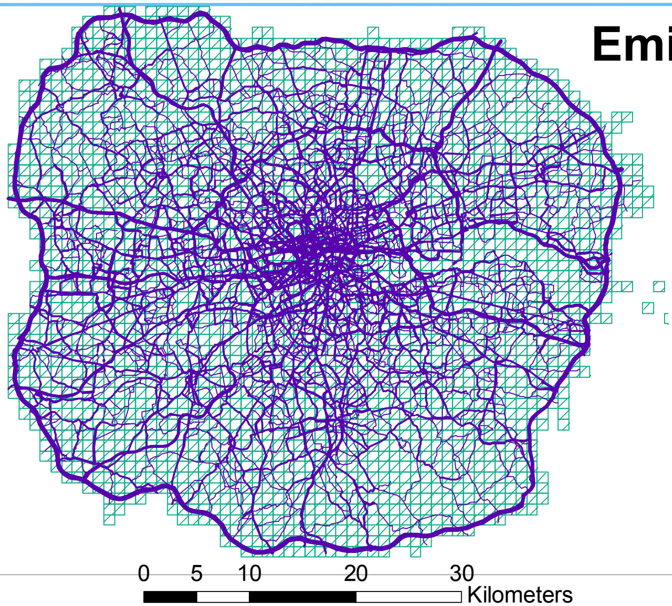
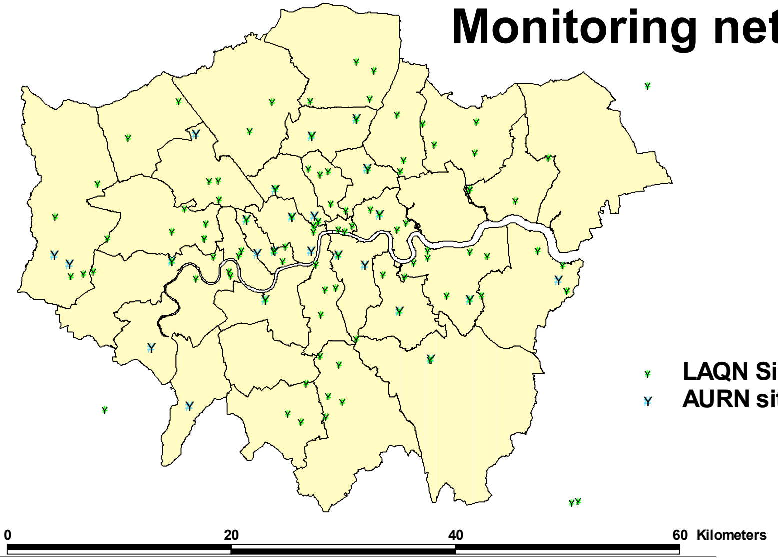
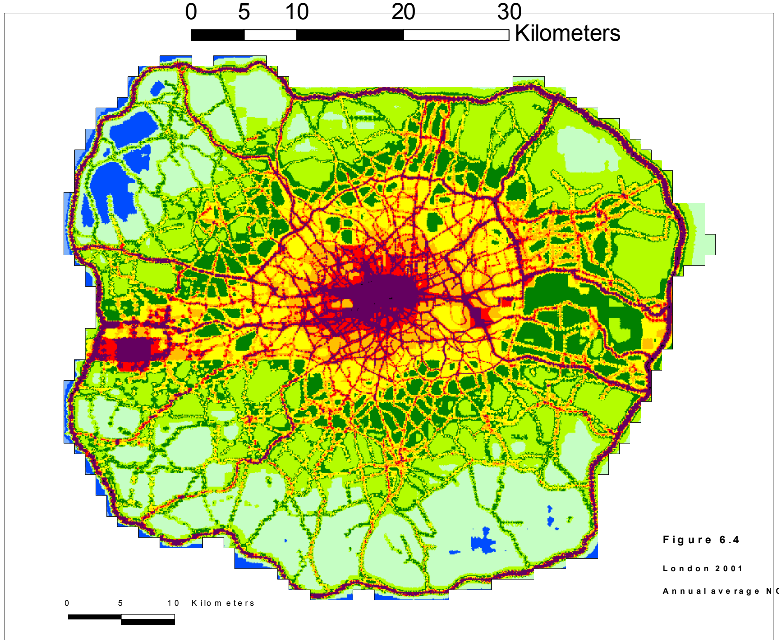
Example use of ADMS-Urban

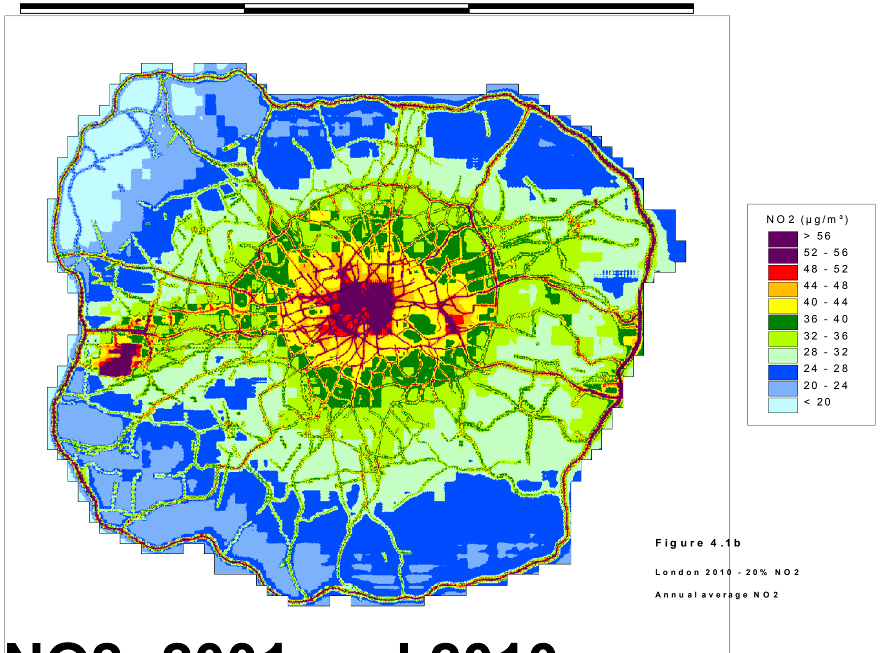
Emissions



Monitoring network

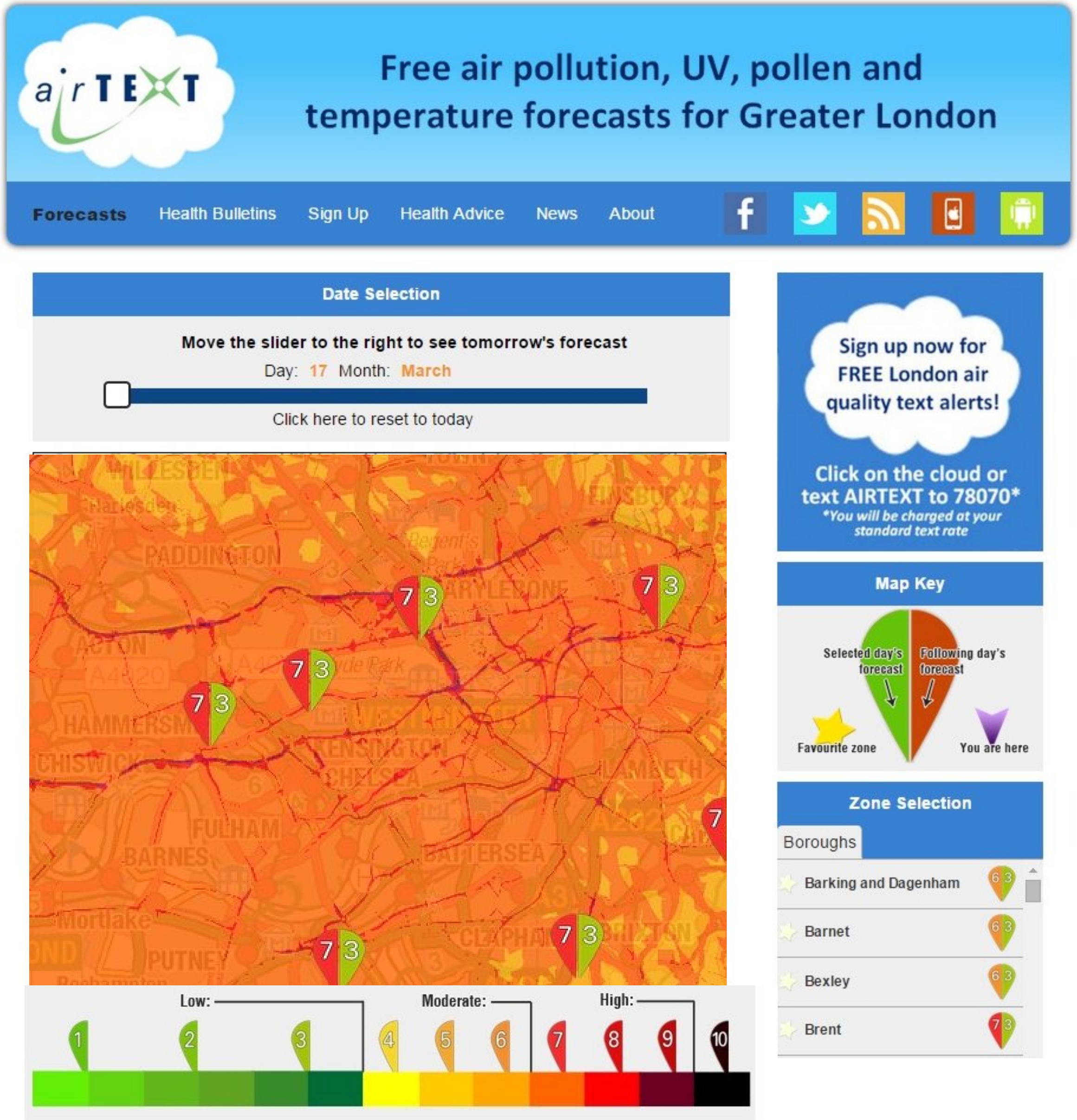






Modelled annual average NO2: 2001 and 2010

High Pollution Episodes



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ADMS approach to NOx chemistry

Background

- For near-road modelling, reactions over short temporal and spatial scales are of interest
- ADMS uses the Generic Reaction Set (Venkatram et al., 1994), which is a simplified semi-empirical photochemical model:
  - Reactions 3. and 4. are specific and occur quickly
  - All other reactions are generic
- More complex chemistry schemes can be included in ADMS

Generic Reaction Set (GRS) in ADMS

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

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

ADMS-Urban User Guide
http://www.cerc.co.uk/environmental-software/user-guides.html

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ADMS approach to NOx chemistry

Practical implementation

- ***Dispersion and chemistry are modelled as an uncoupled system***
- During dispersion, at each output point, the following are recorded:
- Total concentration from all N sources, $\sum_{i=1}^{N} C_i$, where Ci is the concentration from a particular source
- Sum of the product of concentration and pollutant age, Ai, $\sum_{i=1}^{N} C_i A_i$
- After dispersion, the average pollutant age can be approximated as

$$Age = \frac{\sum_{i=1}^{N} C_i A_i}{\sum_{i=1}^{N} C_i}$$

- ***Different average ages are calculated for 'near sources' and 'far sources' and the chemistry scheme applied for these average ages***
- Rural background ozone is assumed to be fully entrained
- Background VOCs may be included

Generic Reaction Set (GRS) in ADMS

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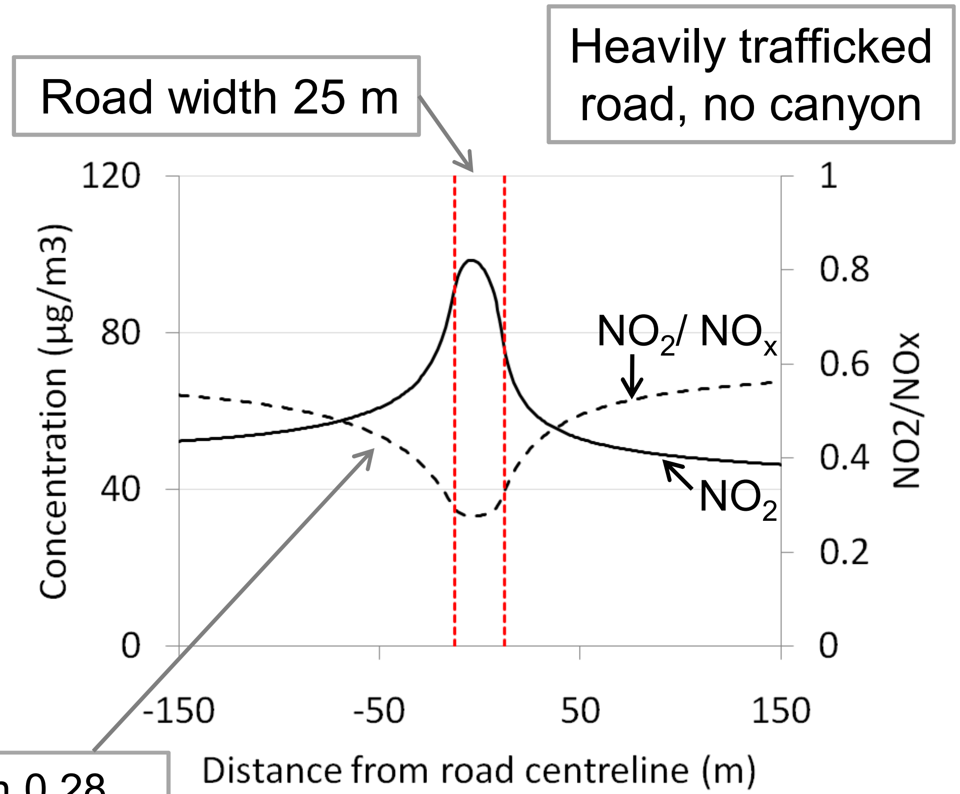
ADMS approach to NOx chemistry

Model results and validation

- Look at how annual average NO_2 decays away from the road, relative to NO_x

	Road source	Annual average rural background
NO_2	0.35 g/km/s	13.2 µg/m³
NO_x	2.36 g/km/s	16.8 µg/m³
NO_2/NO_x	**0.15**	**0.79**



NO_2/NO_x increases from 0.28 in-road to 0.55 at 150 m

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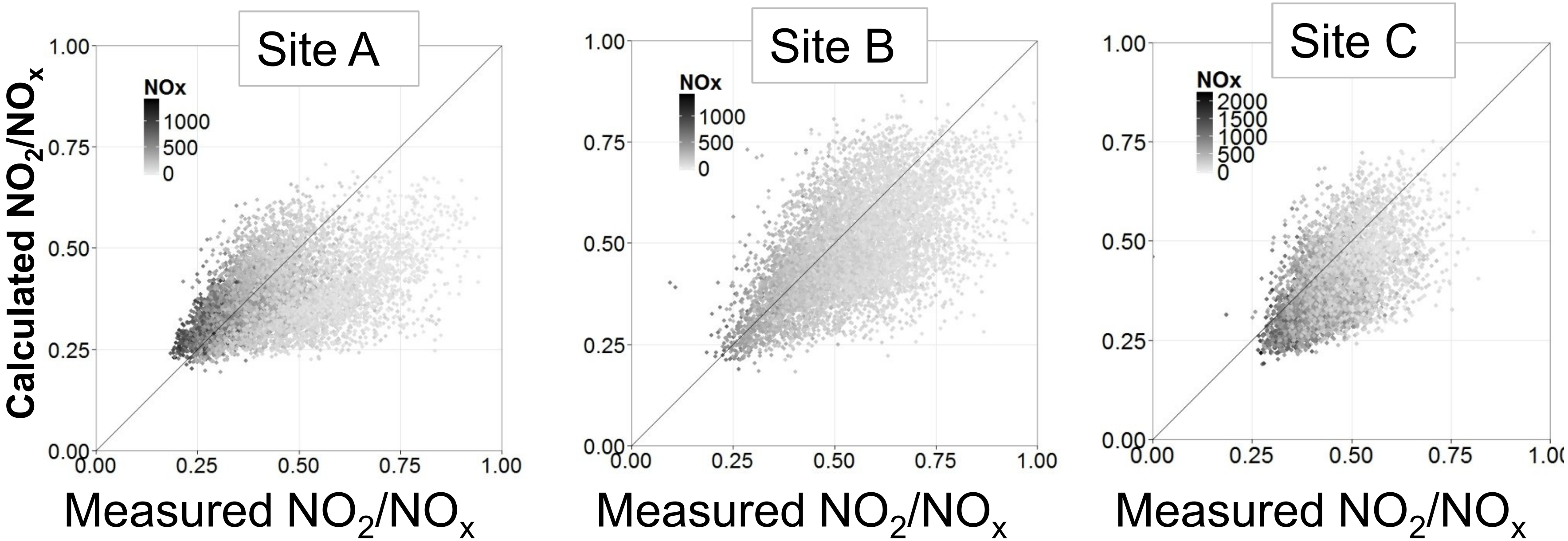
ADMS approach to NOx chemistry

Model results and validation

- Look at how NO_2 decays away from the road, relative to NO_x
- How does the model compare to measurements?



	Site A	Site B	Site C
Monitor distance from road (m)	1.5	3.0	1.0
Monitor height	2.5	4.0	2.0
Total AADT	**70,000**	**10,625**	**43,500**

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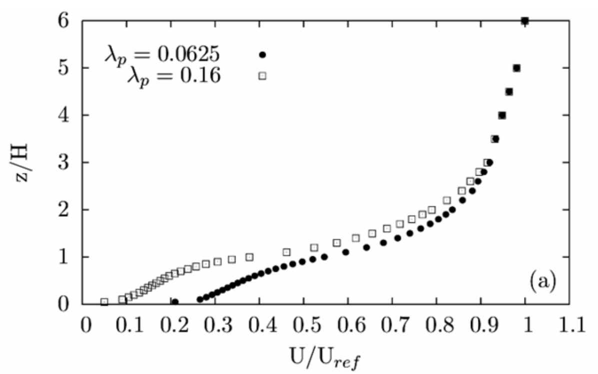
Limitations of ADMS-Urban

- Street canyon model (OSPM) is idealized – limited variation of concentration with height
- Idealized mean flow and turbulence model
- Does not consider regional scale impacts on urban air quality (except through background monitoring data)
- Simplified chemical reaction scheme only applicable in near field

Background: Urban Canopy Flow

- Urban architecture affects local air flow
- Important to use urban flow characteristics for accurate calculation of pollutant dispersion
- Earliest historic studies (CFD, wind tunnel and field experiments) used regular arrays of cubic obstacles to represent urban buildings
- Some later extensions to real urban areas with irregular arrays and non-cubic buildings
- Parameterisation based on published experimental and wind tunnel data, CFD and theoretical considerations

a)



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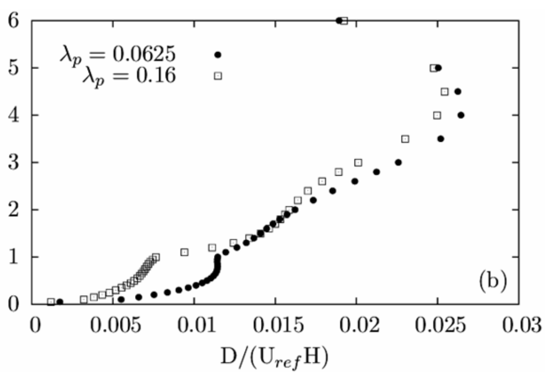
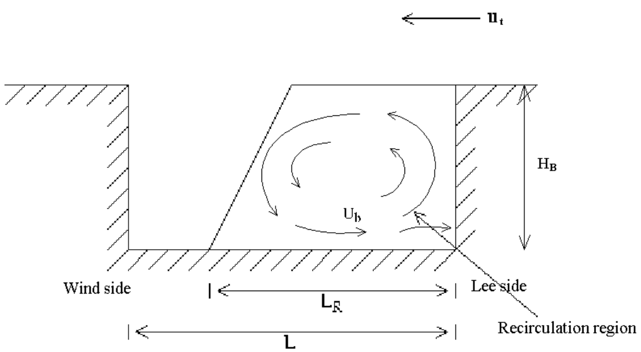


Background: Canyon Flow and dispersion

- Many modern urban areas feature closely-packed tall buildings which form street canyons
- Existing dispersion models for street canyons, eg. OSPM, were developed based on 'European' urban geometries
  - Canyon heights and widths of similar magnitude
  - Symmetric properties on each side of a canyon
- Choice required between canyon and non-canyon modelling



- Improved modelling of street canyons should include:
  - Tall canyons (height/width > 1)
  - Asymmetric canyons: height, width, building density
  - Smoother transition between non-canyon and canyon modelling

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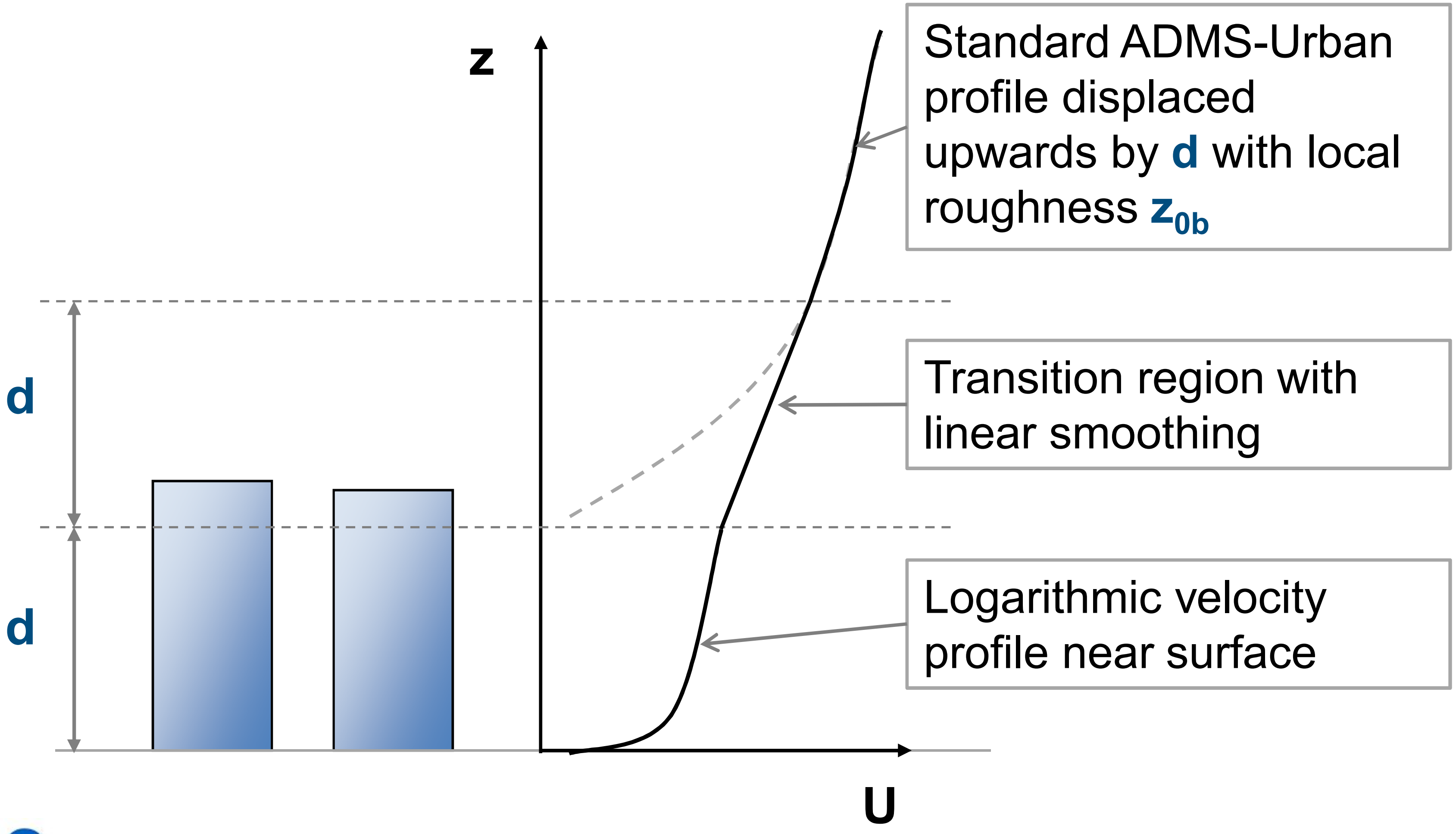
Urban Canopy Flow
Implementation in ADMS-Urban: Wind speed

Three-part velocity profile: above 2x displacement height, below displacement height and transition region.



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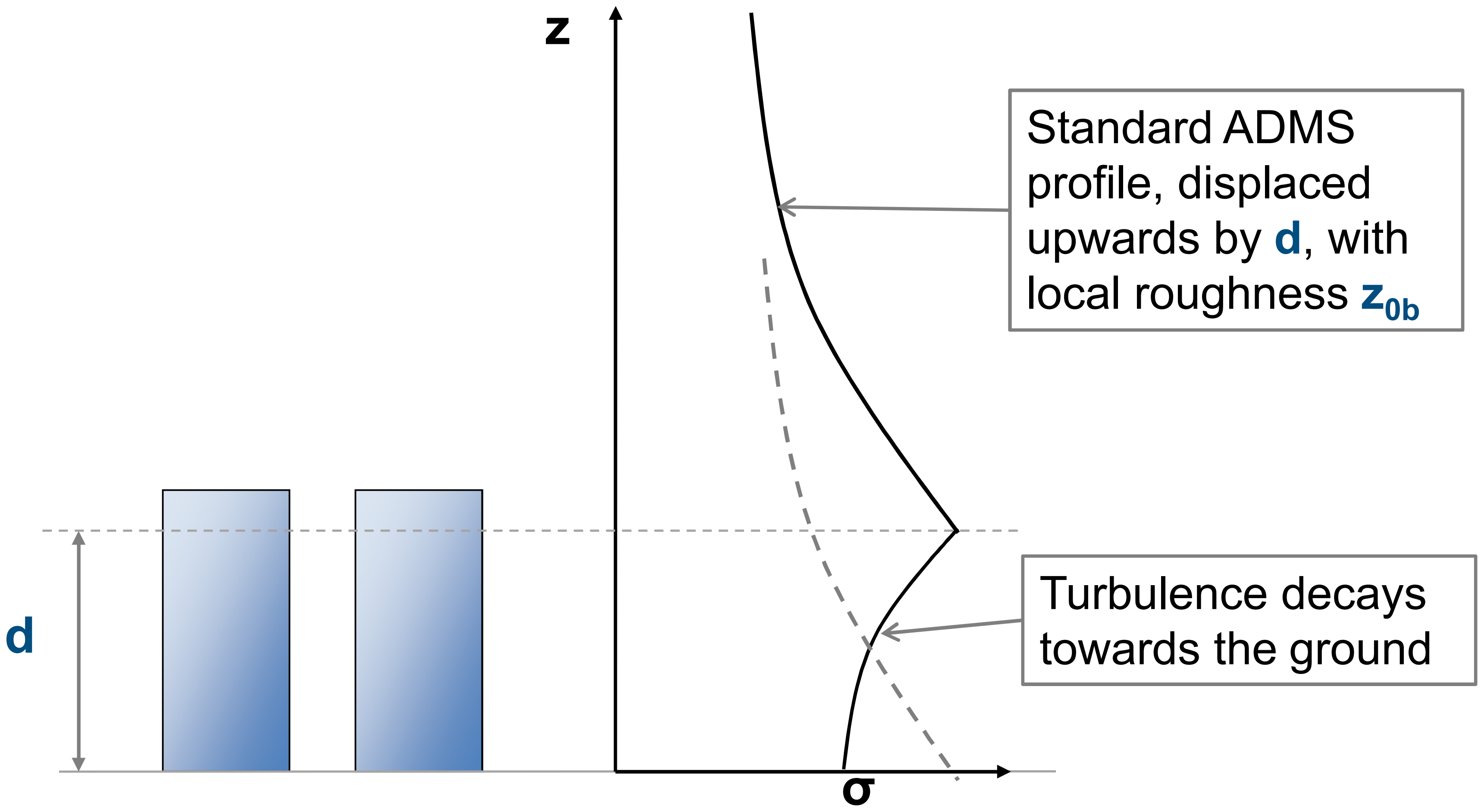
Details of standard ADMS velocity profiles can be found at http://www.cerc.co.uk/environmental-software/technical-specifications.html

Urban Canopy Flow
Implementation in ADMS-Urban: Turbulence

Two part profile: above and below displacement height



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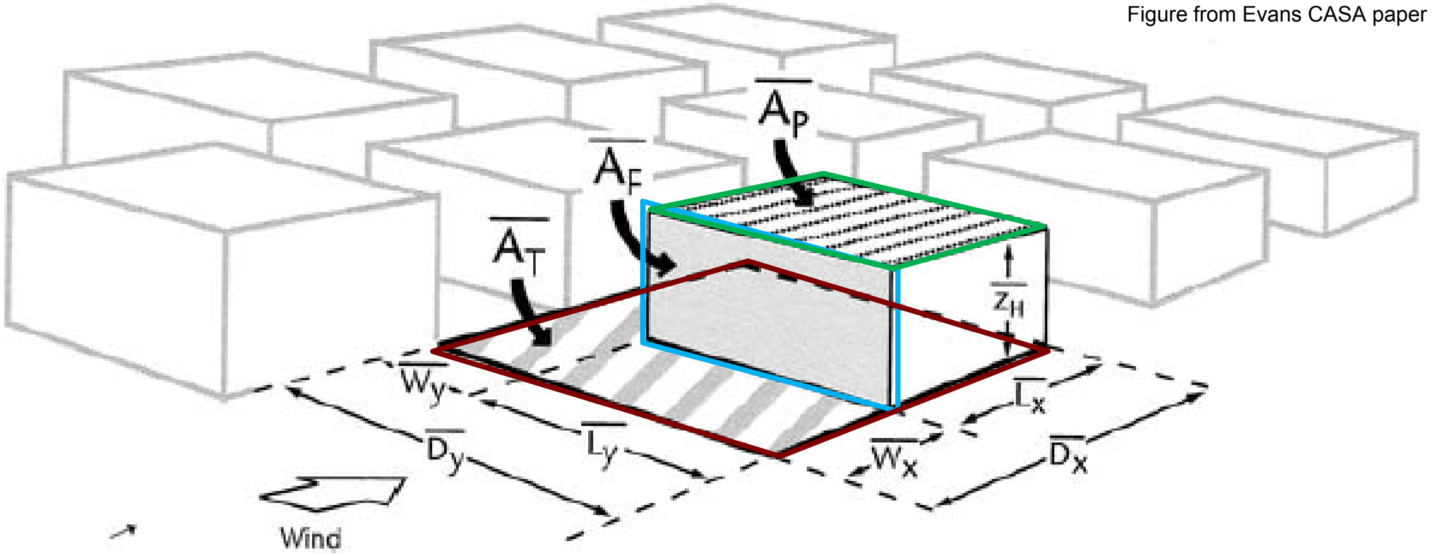
Details of standard ADMS turbulent velocity profiles can be found at
http://www.cerc.co.uk/environmental-software/technical-specifications.html

Urban Canopy Flow: Characterisation of urban area

Figure from Evans CASA paper



- Effective roughness z_{0b} and displacement height **d** calculated relative to average building height **H** using plan and frontal area fractions λ_P and λ_F
- $\lambda_P = A_P/A_T$
- $\lambda_F = A_F/A_T$
- $d/H = 1 + (\lambda_P - 1)\alpha^{-\lambda P}$
- $z_{0b}/H = (1-d/H)\exp\{-(0.5\beta C_D\lambda_F(1-d/H)/\kappa^2)^{-0.5}\}$

Macdonald *et al.* 1998 *Atmos. Environ.* **32**:1857-1864

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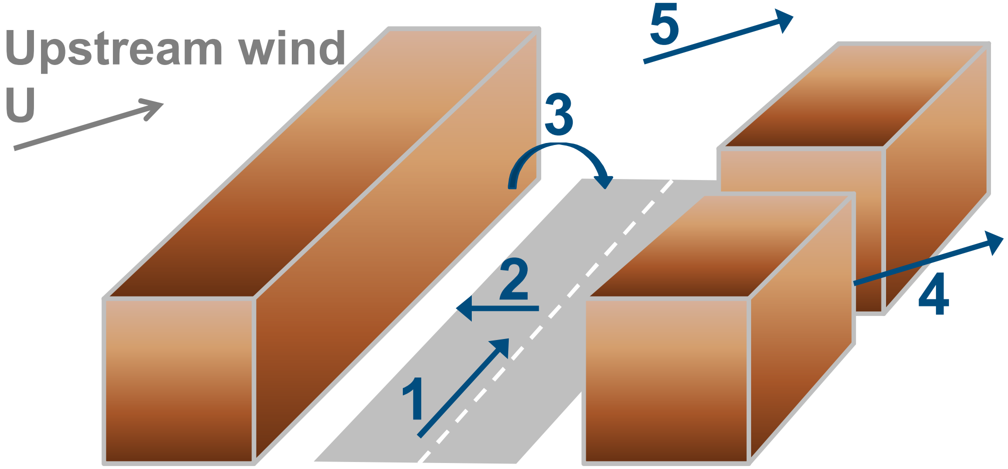
Canyon Flow and Dispersion

Theory: Canyon effects

5 principal effects of street canyons on dispersion

1. Pollutants are channelled **along** street canyons
2. Pollutants are dispersed **across** street canyons by circulating flow at road height
3. Pollutants are trapped in **recirculation** regions
4. Pollutants leave the canyon through gaps between buildings as if there was **no canyon**
5. Pollutants leave the canyon from the **canyon top**



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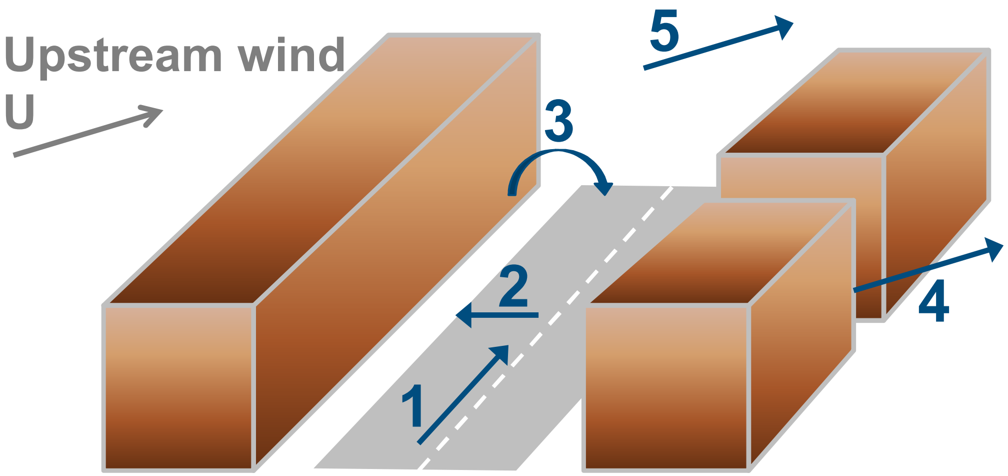
Canyon Flow and Dispersion
Theory: Component sources

Each effect is modelled using a component source, with differing

- Source **geometry**
- Source **dispersion** type
- **Wind direction**
- **Region of influence**
- Source strength

The final concentration is the weighted sum of contributions from the component sources with weights depending on canyon geometry, porosity and wind direction



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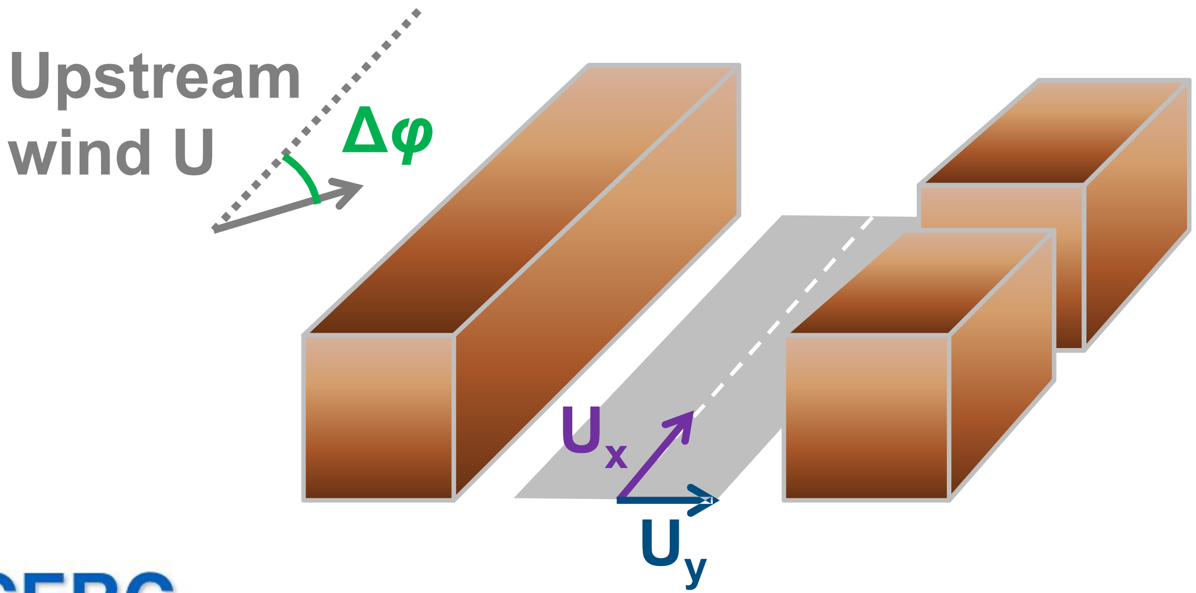
Canyon Flow and Dispersion

ADMS-Urban Implementation: Canyon flow

- Upstream wind is split into components parallel and perpendicular to the canyon axis
- Perpendicular component takes account of recirculation $\hat{h}(z)$ and is further reduced by obstacles (user-defined factor η)

$U_x(z) = U(z) \cos \Delta\varphi$

$U_y(z) = U(z)\, \eta\, \hat{h}(z) \sin \Delta\varphi$



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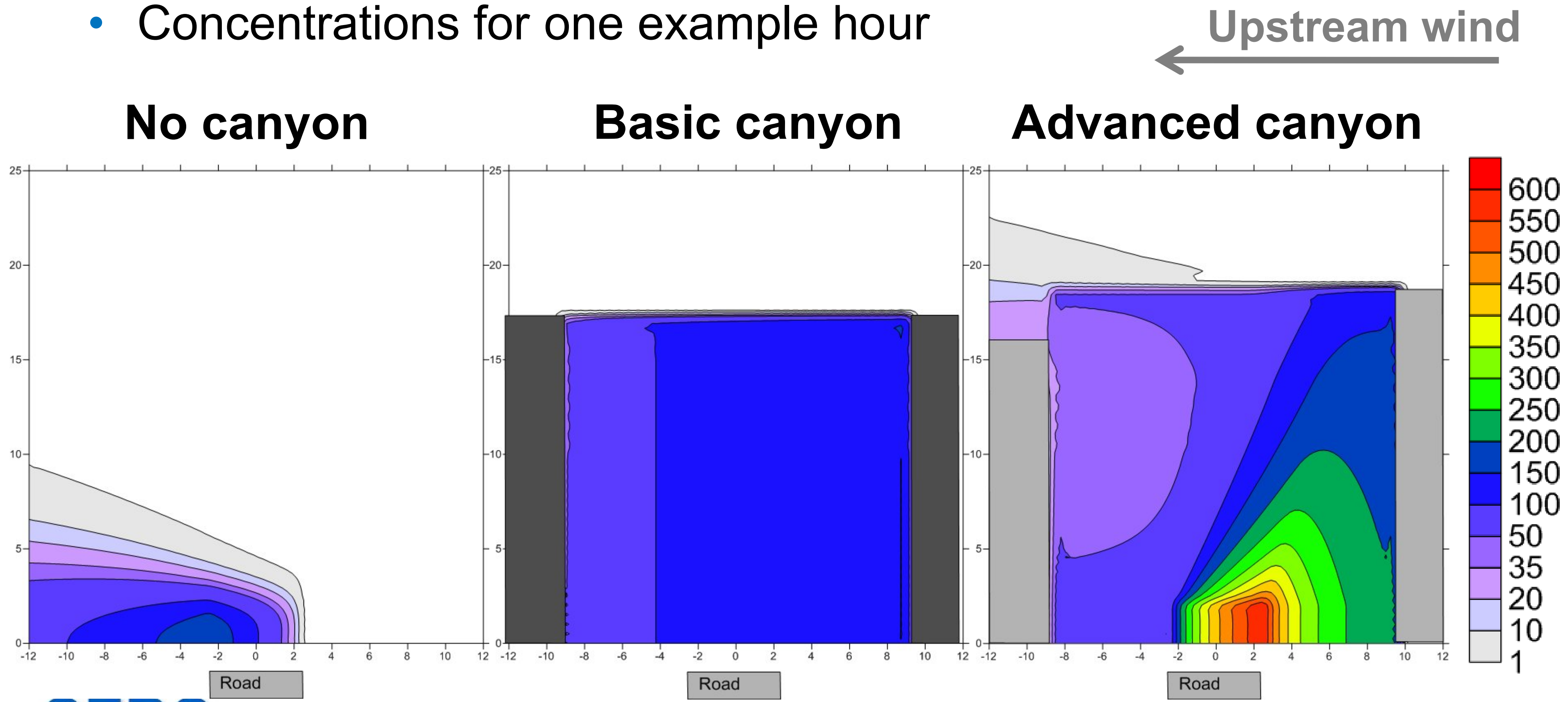
Canyon cross-section contours

- Canyon with properties set to those for KC5 monitoring site – Earls Court Road
- Slight asymmetries in height, width and porosity
- Concentrations for one example hour



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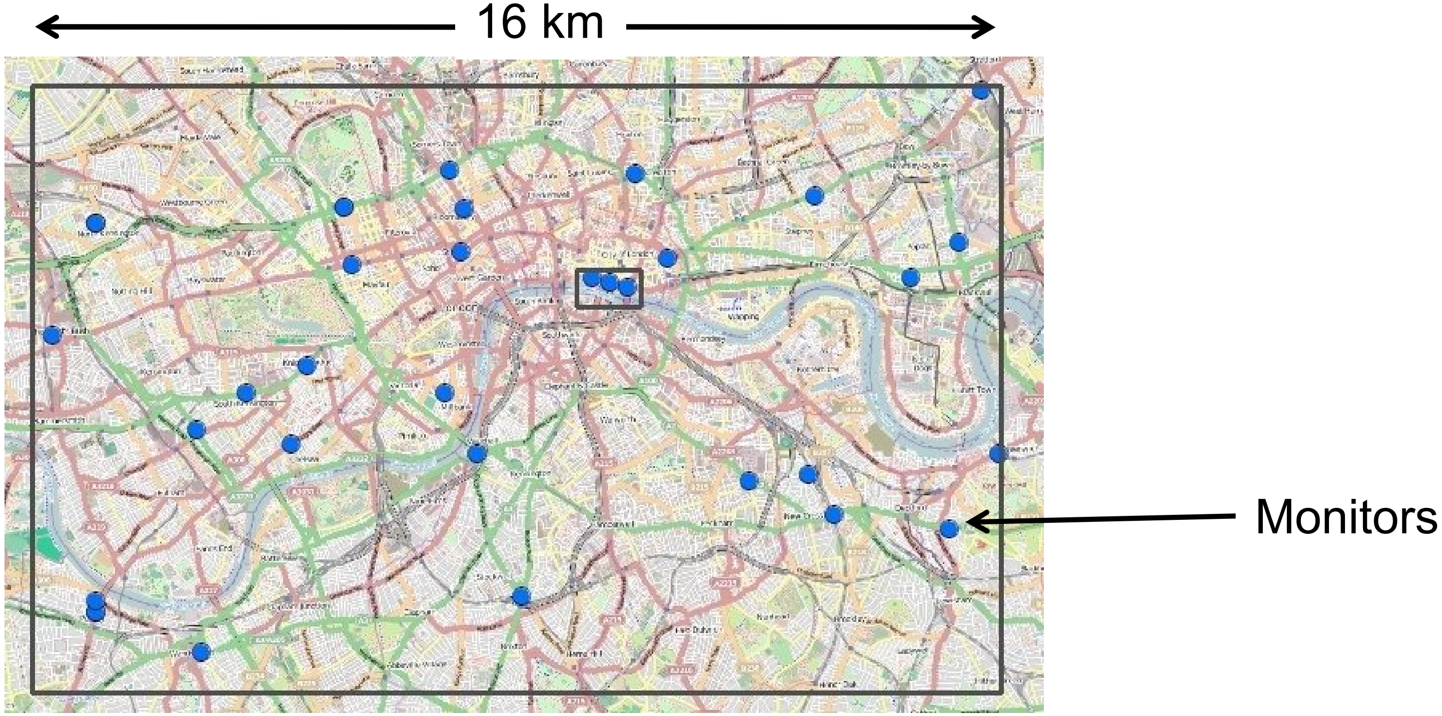
ADMS-Urban model set-up for London
Input data

- Standard ADMS-Urban modelling approach for London
  - Measured meteorological data from Heathrow airport
  - Measured upwind rural background concentrations
  - London Atmospheric Emissions Inventory (LAEI) emissions data
  - Modelling year 2012
  - Modelling domain 10x15 km central London

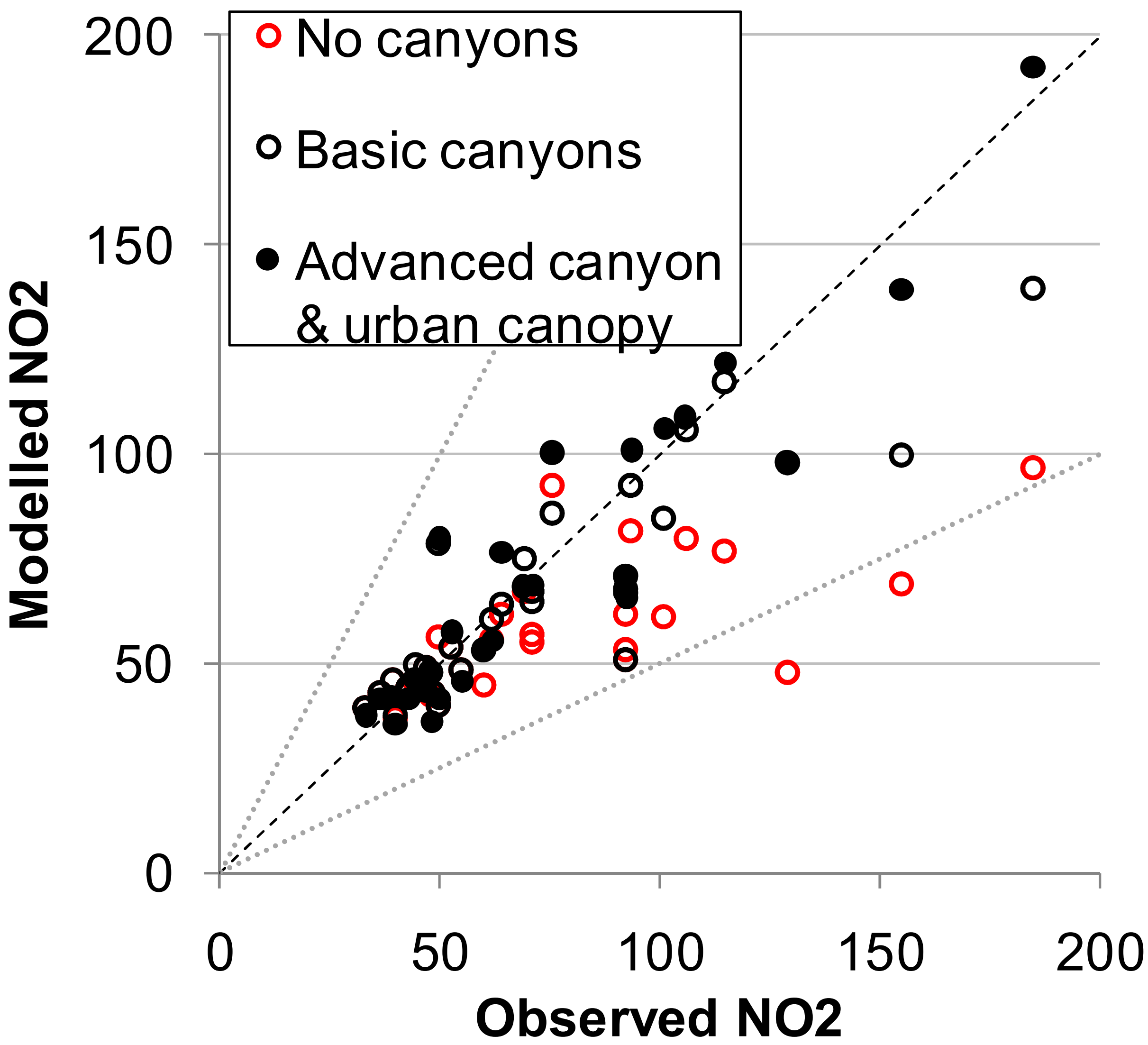
- Model configurations tested
  - **No canyon**: no street canyon modelling
  - **Basic canyon**: existing ADMS-Urban street canyon model
  - **Advanced canyon & Urban Canopy**: Urban Canopy flow field with new street canyon modelling

ADMS-Urban model set-up for London
Monitoring network

- 29 monitors located within the ‘buildings data’ area
- Monitor information (values, locations, heights) available from web
- Data for NO_x, NO_2, PM_{10}, $PM_{2.5}$, O_3
- 21 kerbside/roadside, 8 urban background
  - Some of the urban background sites are within canyons
- Monitor heights generally less than or equal to 3 m



Validation Results
Mean NO_2 concentrations scatter plot



- All sites shown
- When canyons are modelled, means usually increase, giving a better estimate
- Modelling canyons does not affect the lower concentration sites

Validation Results

NO_2 concentration statistics

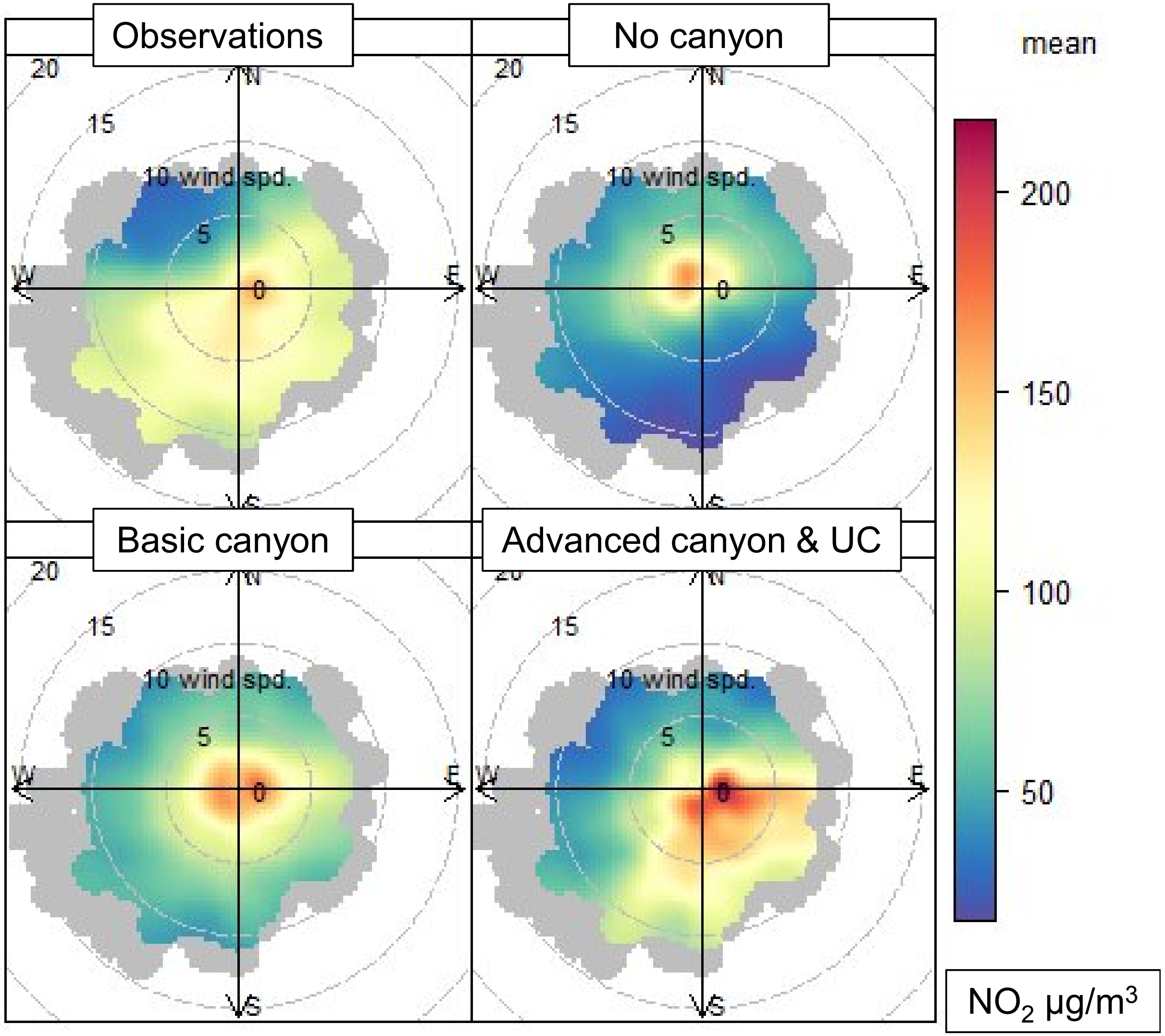
- Data for all sites for whole year
- Best statistics highlighted

Data	Mean	NMSE	R	Fac2	Fb
Observed	70.8	0.00	1.00	1.00	0.00
No Canyon	54.8	0.73	0.38	0.74	-0.26
Basic Canyon	65.0	0.40	0.61	0.82	-0.09
Advanced Canyon & Urban Canopy	**67.9**	**0.32**	**0.70**	**0.83**	**-0.04**

Validation Results

Polar plots: Full canyon

- Consider a receptor 'CD9' within a standard canyon (H/g = 0.96, porosity = 0.26)



- Wind from North West gives low concentrations and from the South East gives high concentrations due to presence of canyon
- 'No canyon' and 'Basic canyon' runs predict similar concentrations in all directions

NO_2 concentrations

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Nesting local model (e.g. ADMS-Urban) in regional model (e.g. CMAQ, CAMx)

- Advantages of a **nested model system**

Model feature	**Model**	
	Regional (eg grid based)	**Local (eg Gaussian plume)**
Domain extent	**Country (few 1000 km)**	City (50km)
Meteorology	**Spatially and temporally varying from meso scale models**	Usually spatially homogeneous
Dispersion in low wind speed conditions	**Models stagnated flows correctly**	Limited modelling of stagnated flows
Chemical processes	**Reactions over large spatial and temporal scales**	Simplified reactions over short-time scales
Source resolution	Low	**High**
Validity	Background receptors	**Background, roadside and kerbside receptors**

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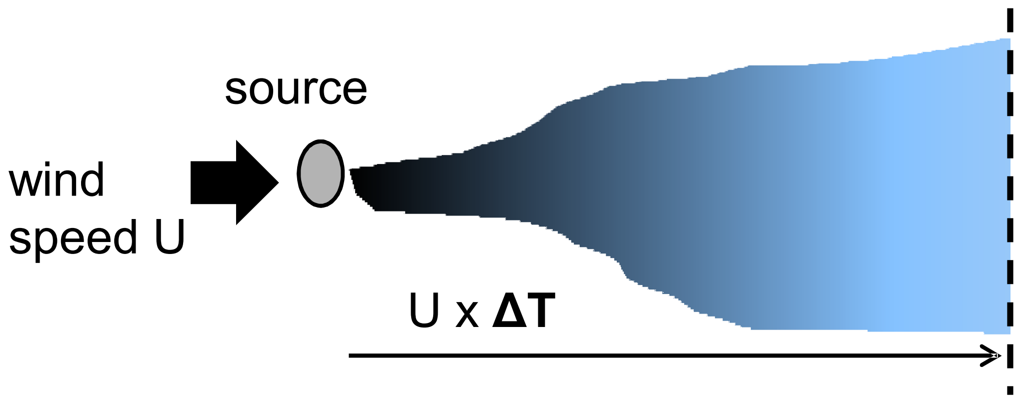
Nesting system concept

- **Aim:** to nest local model in regional model without double counting emissions i.e.:

Concentration within nested domain	=	Regional modelling of emissions	-	Gridded locally modelled emissions (ΔT)	+	Explicit locally modelled emissions (ΔT)



ΔT is the time taken to mix the explicitly defined emissions to produce a concentration field that varies spatially on the same scale as the regional model

ΔT varies with meteorology

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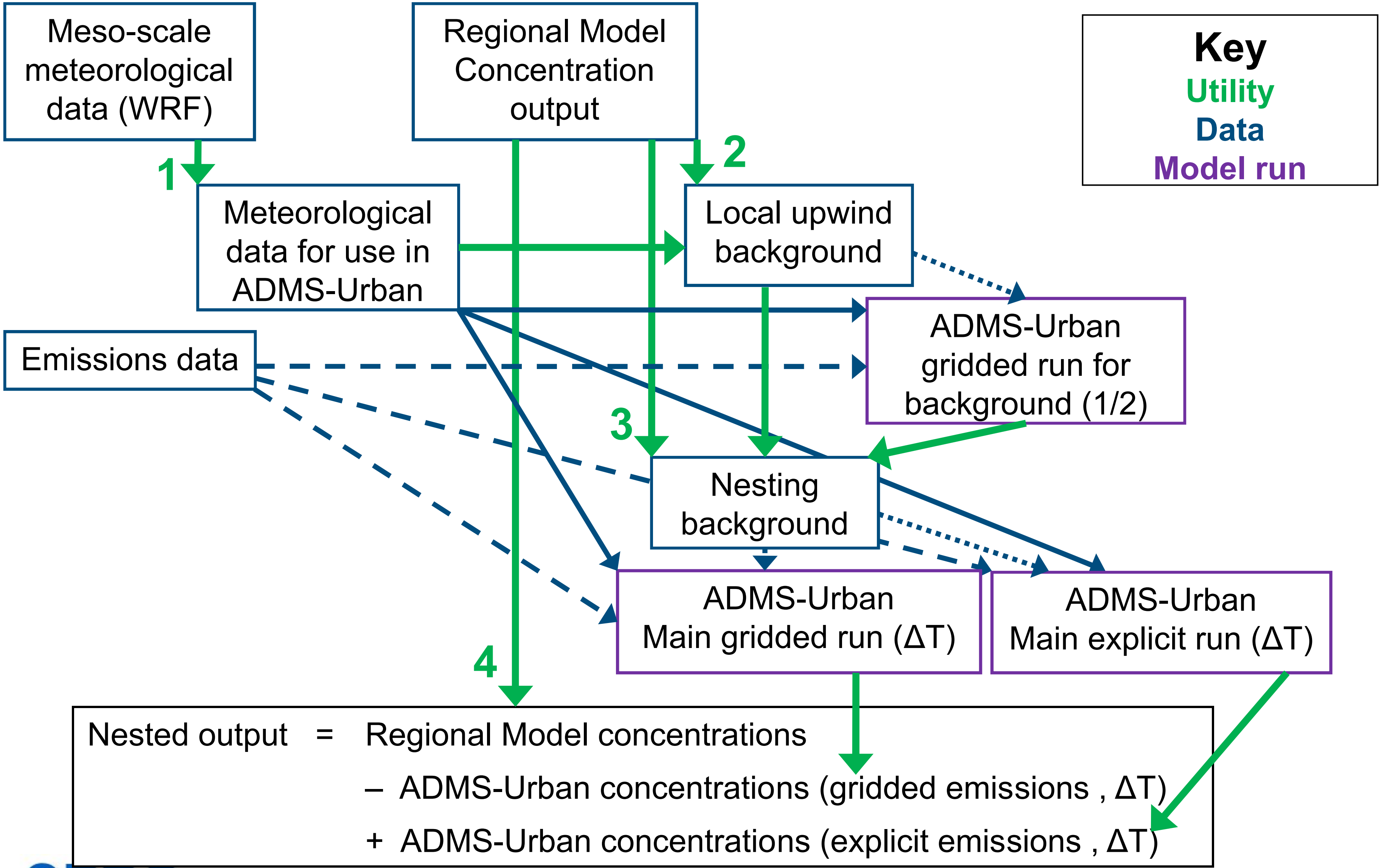
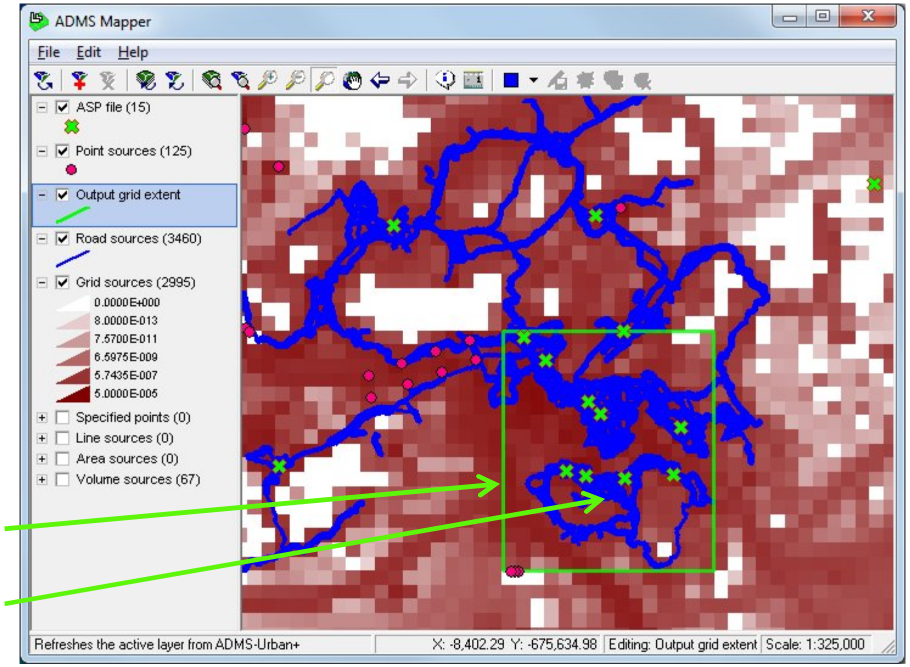
Nesting system components



Example use of system

- **Domain:** Hong Kong Special Administrative Region (HK SAR)
- **Period:** 2010
- **Regional models:** WRF (v 3.2) and CAMx (v 5.4)
- **Input data:**
  - 1 km regional model data (Yao *et al.*, 2014)
  - Gridded emissions data as used in CAMx
  - For major roads, traffic flow, speed and location data
  - Point source information

Emission sources & output locations



Contouring domain

Monitors

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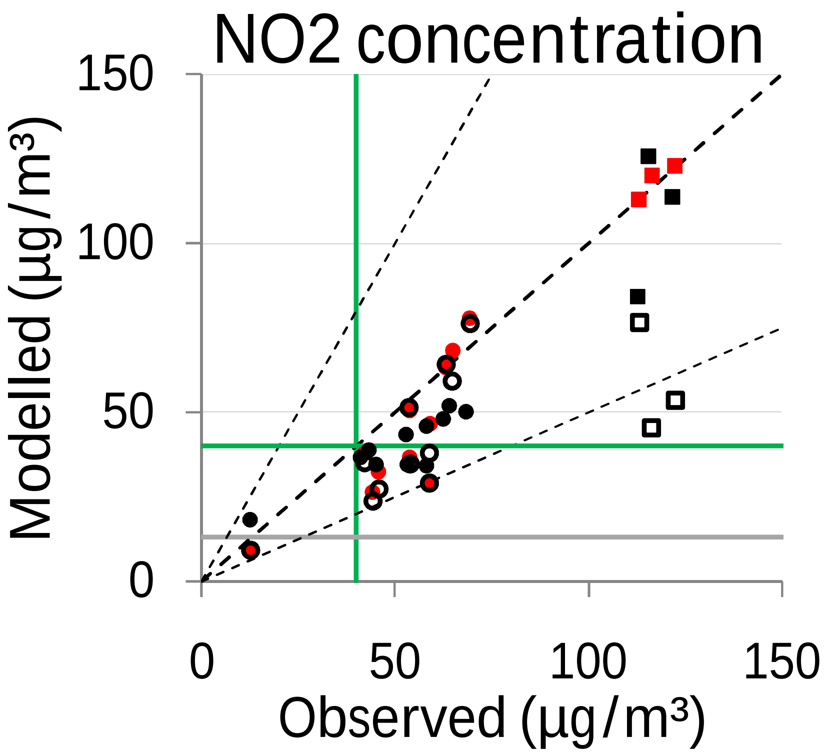
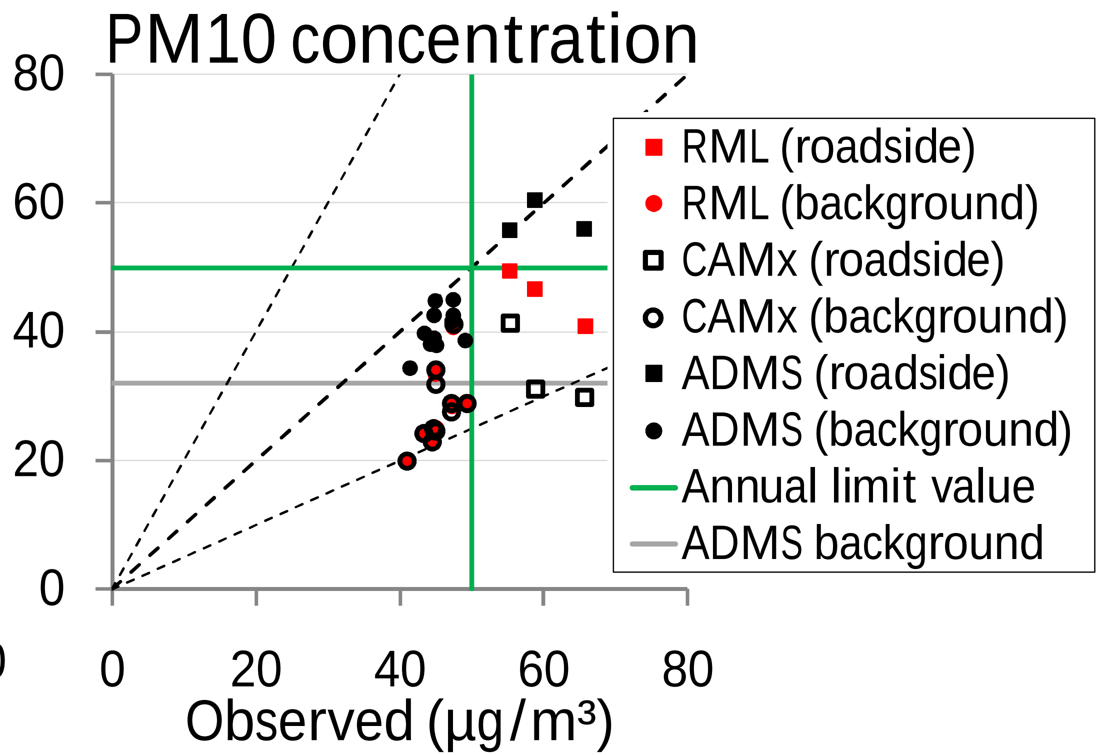
Example use of system

- **Results: validation at monitors**
  - ■ ADMS-Urban (uses measured background concentrations & meteorology)
  - ■ ADMS-Urban RML
  - □ CAMx





Example use of system

- **Results: validation at monitors**

ADMS-Urban (uses measured background)

ADMS-Urban RML

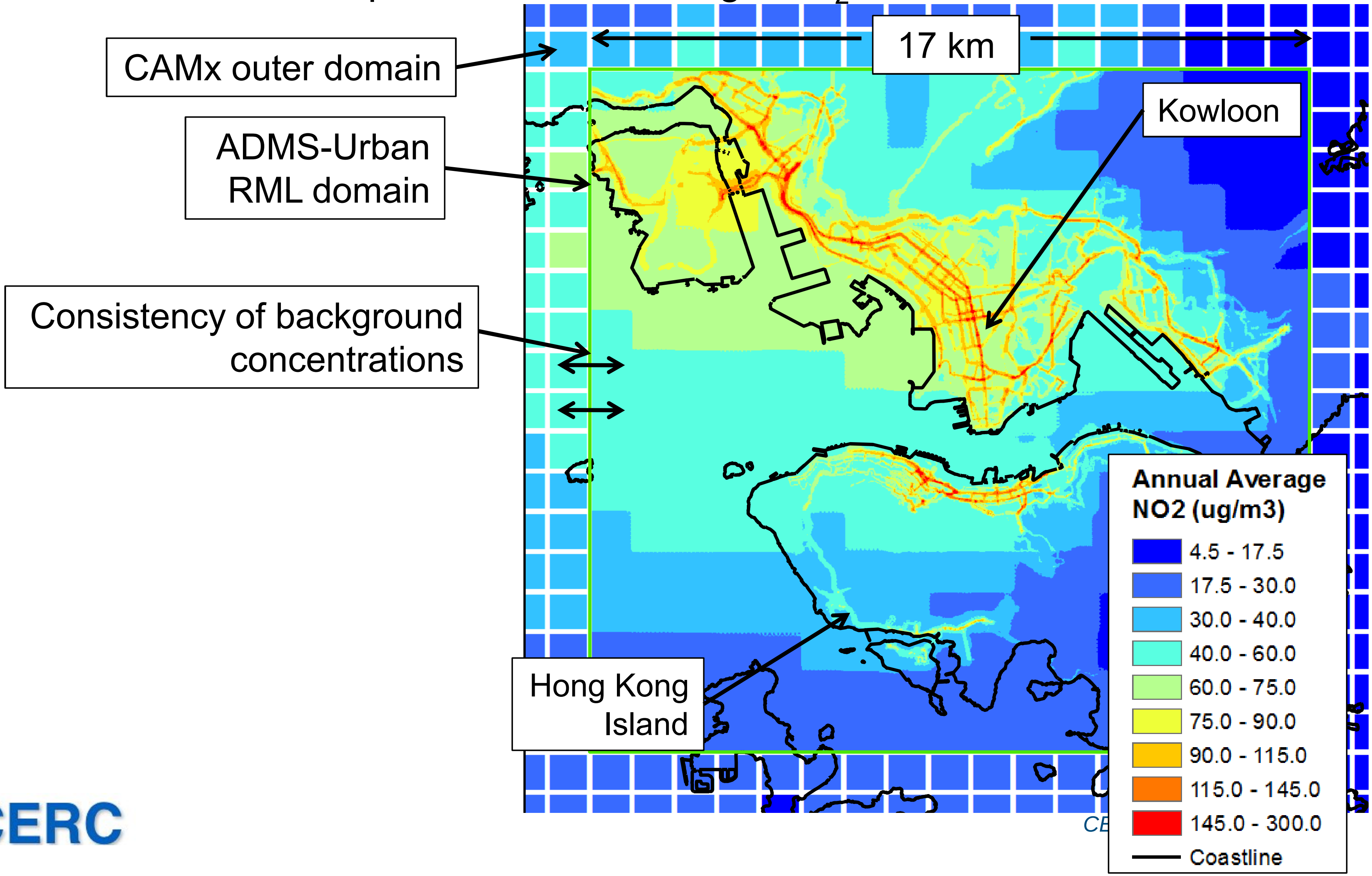
CAMx

NO_2 statistics

Site type	Sites	Model	Observed (µg/m^3)	Modelled (µg/m^3)	R	Fac2
Roadside	3	ADMS-Urban	116.6	104.4	0.66	0.88
		ADMS-Urban RML	117.2	115.2	0.63	0.95
		CAMx	117.2	58.5	0.49	0.45
Background	10	ADMS-Urban	54.7	41.3	0.57	0.70
		ADMS-Urban RML	55.6	47.0	0.57	0.72
		CAMx	55.6	44.1	0.54	0.68
Rural	1	ADMS-Urban	12.5	18.4	0.52	0.87
		RML (nested)	12.7	9.0	0.30	0.52
		CAMx	12.7	9.0	0.30	0.52

Example use of system

- **Results:** contour plot of annual average NO_2



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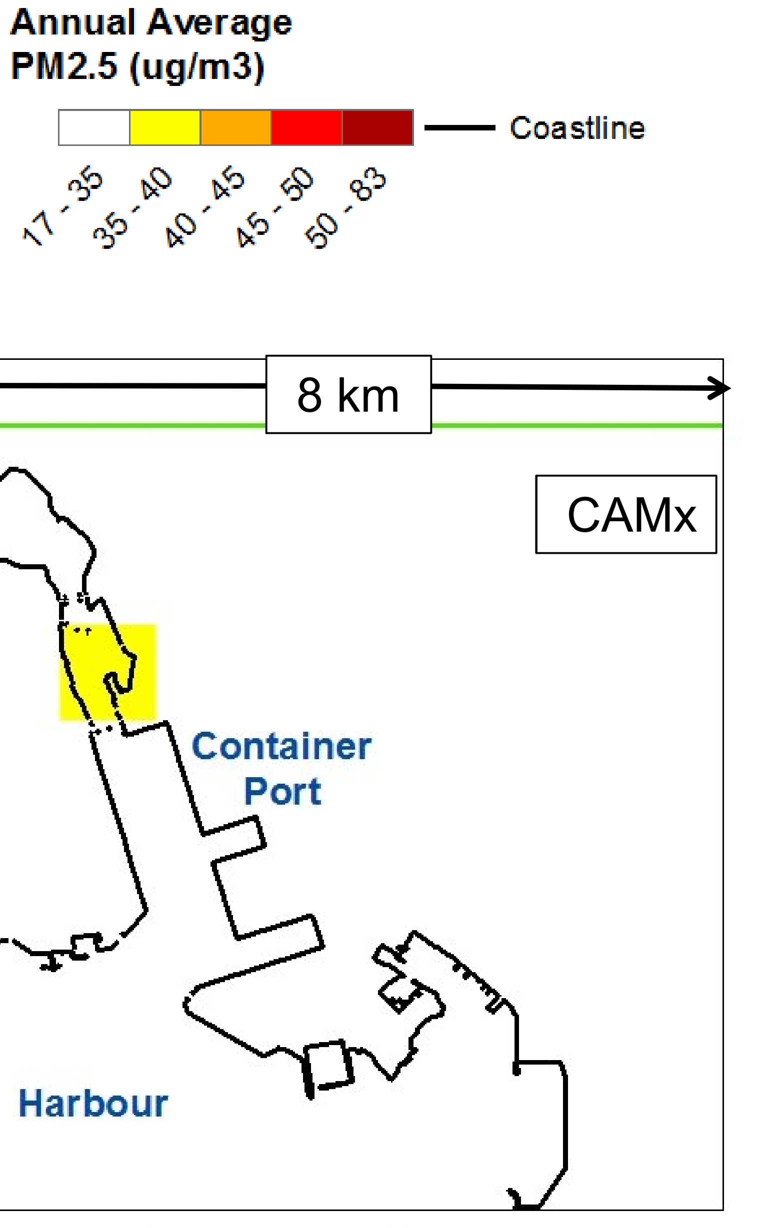
Example use of system

- **Results:**
  - Contour plot for $PM_{2.5}$
  - Exceedences of the annual average air quality objective, 35 µg/m³



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Conclusions

- New practical parameterisations for modelling urban canopy flow field and complex street canyon effects have been developed

- System for integrating local (urban) and regional models (CMAQ, CAMx,EMEP4UK) has been developed.

- Further system development taking place as part of NERC Cure-Air project (Universities and Edinburgh and Leeds, and CEH)

Acknowledgements

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Environmental Protection Department
The Government of the Hong Kong Special Administrative Region