The importance of meteorology for air quality modelling and analysis
- *are suitable data available in complex environments*?

David Carruthers, CERC

R Met Soc Conference, Exeter 13-14 July 2017

Contents

- Key meteorological inputs to local air quality models
    - sensitivity to different met data
- Variability in met variables across urban areas
- Variation with height in flow and pollutant concentrations

Key meteorological inputs for dispersion modelling

- Wind speed and direction
- Turbulence
- Boundary layer height

  - typically estimated from surface observations using surface layer and mixed layer scaling

- Many complexities arise in heterogeneous topography:

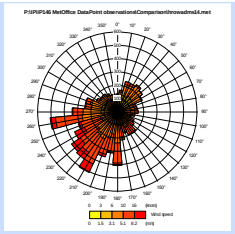
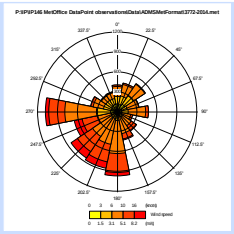
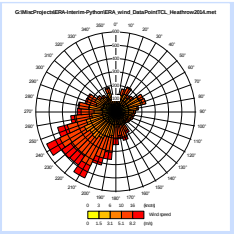
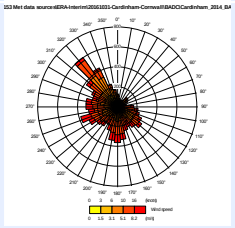
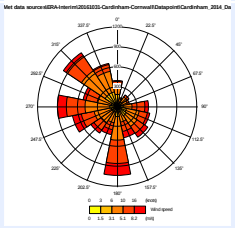
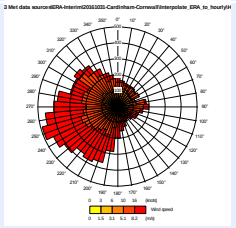
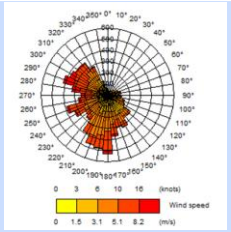
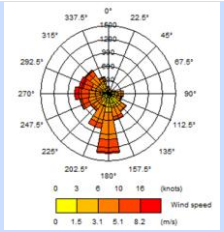
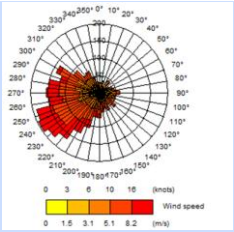
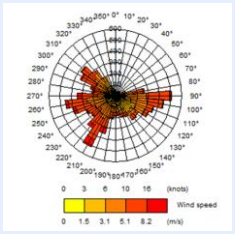
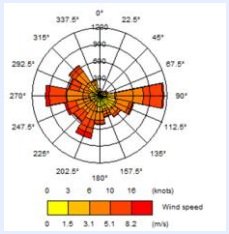
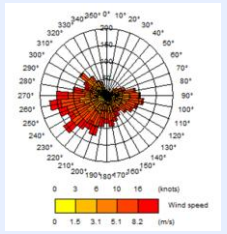
  - e.g. complex terrain, urban areas etc.

Sources of meteorological data

Provider	Product	Type	Sector size	Availability
Met Office	'ADMS' data	Observations	10°	Licensed
Met Office / BADC	UK Hourly Weather	Observations	10°	Research only
Met Office	Datapoint	Observations	22.5°	Free
ECMWF + ……	ERA-Interim	Reanalysis	-	Free

- Met Office Datapoint provides hourly observations for about 200 UK sites. The data are not quality assured.
- ERA-Interim is a global reanalysis using the Integrated Forecast System (IFS). Resolution ~0.7° or about 80km for UK. 3-hourly data from 1979.

Wind roses from different data sources

	MetO BADC	MetO Datapoint	ERA-Interim
Heathrow			
Cardinham			
Rostherne No 2			
Glasgow/ Bishopton			

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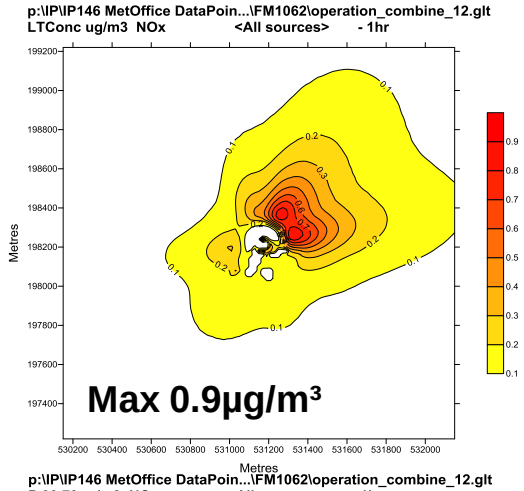
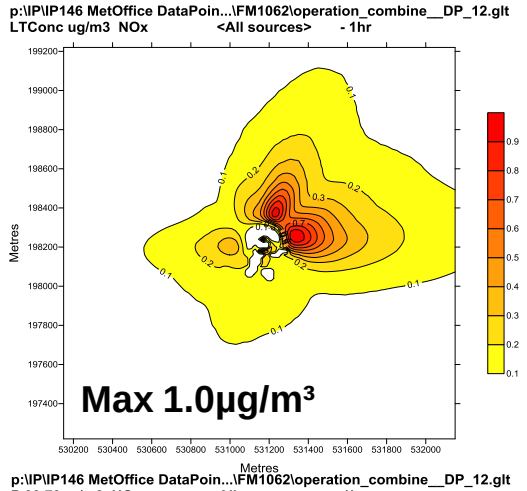
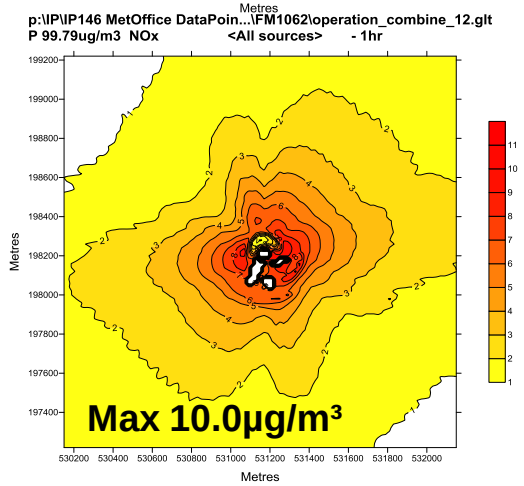
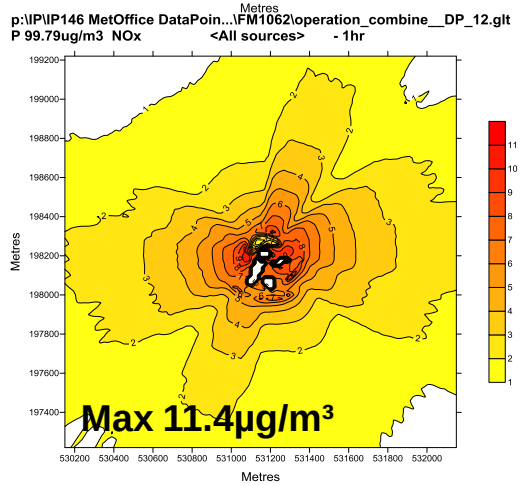
Mean wind speed from different data sources

	MetO BADC	MetO Datapoint	ERA-Interim
Heathrow	**4.17**	**4.14**	**4.67**
Cardinham	**4.99**	**4.97**	**7.08**
Rostherne No 2	**3.65**	**3.57**	**5.34**
Glasgow/ Bishopton	**3.90**	**3.84**	**4.91**

Annual average wind speed (m/s) for four sites from different sources of meteorological data

Effect on dispersion modelling for an industrial site

	Met Office 'ADMS'	Met Office Datapoint
Annual average NOx		
99.79th percentile of hourly NOx		

Met data for Heathrow 2012

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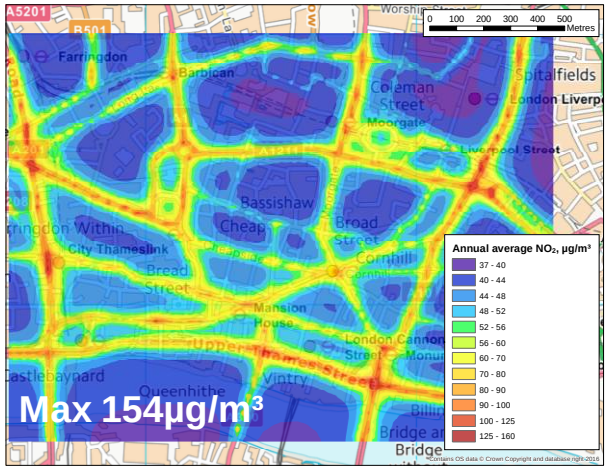
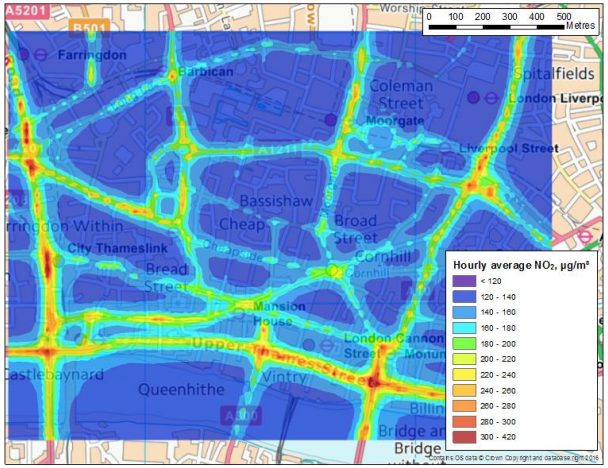
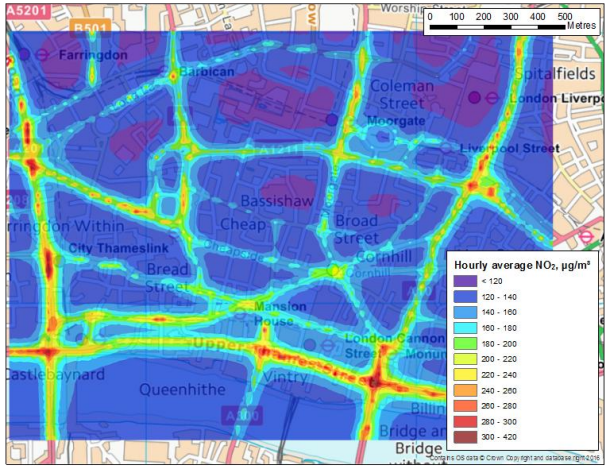
Effect on dispersion modelling for an urban site

Met data for Heathrow 2012

	Met Office 'ADMS'	Met Office Datapoint
Annual average NO_2		
99.79th percentile of hourly NO_2	 Max 441µg/m³	 Max 437µg/m³

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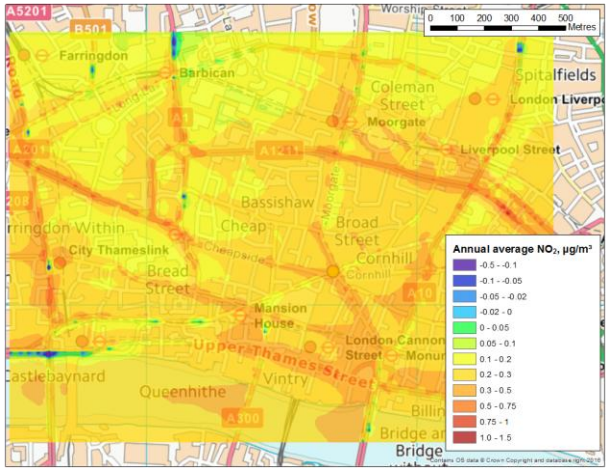
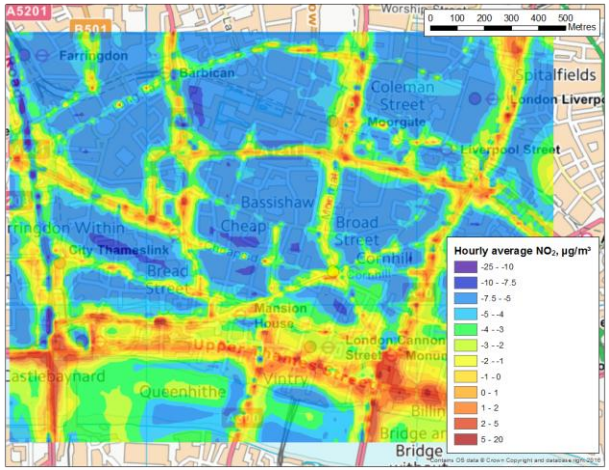
Effect on dispersion modelling for an urban site



Difference
Annual average NO_2



Difference - 99.79th percentile of hourly NO2

- Difference in concentrations with Met Office Datapoint and 'ADMS' data
  – positive values (yellow and red):higher values using Datapoint
- Annual average NO_2 greater for Datapoint by ~ 1µg/m³ at roadsides, apart from a small number of busy roads where a slight decrease. ~ 0.1µg/m³ increase at background locations.
- 99.79th percentile NO_2 greater for Datapoint by 2-5µg/m³ at roadsides. Concentrations at background locations decrease by 5-10µg/m³.

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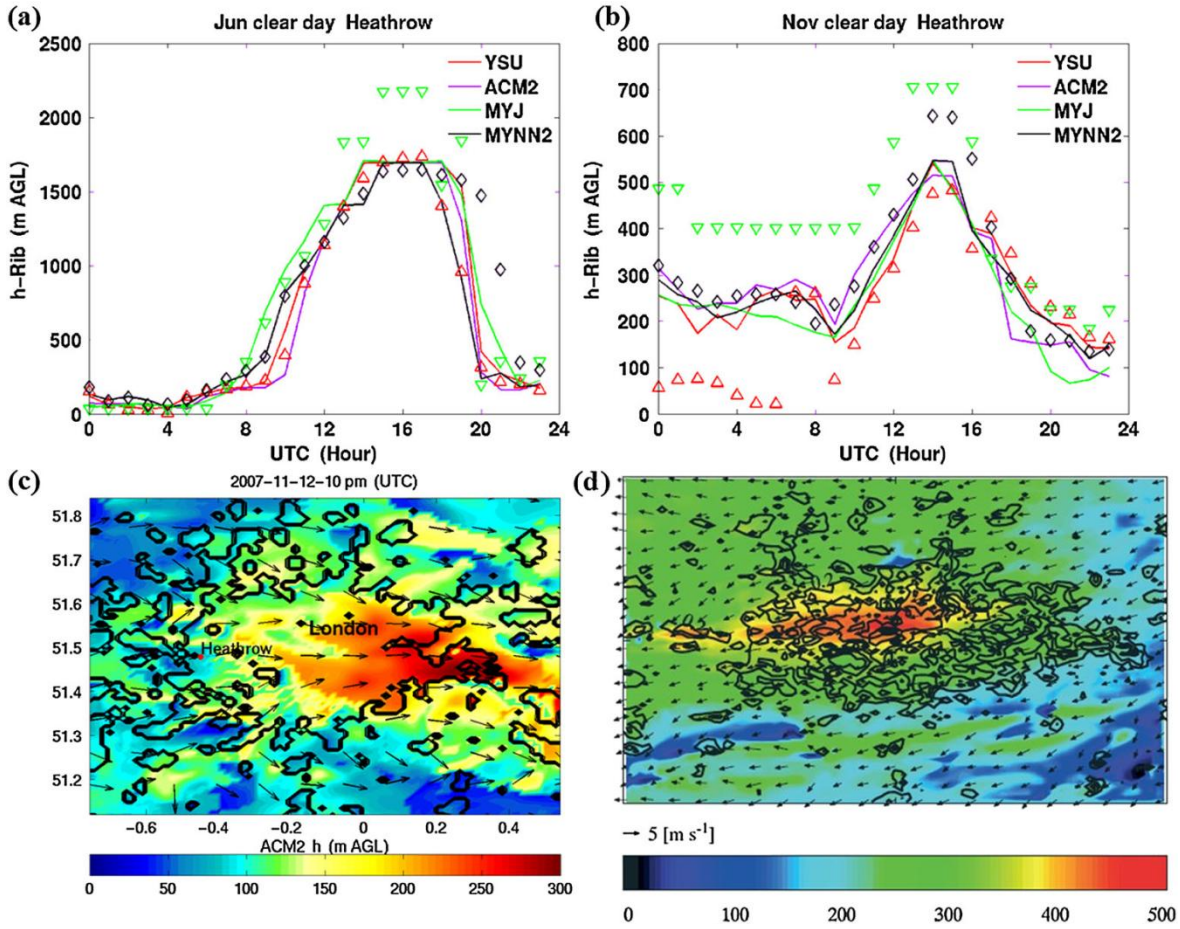
Variability in met variables across urban areas

- Boundary layer height

Variability in met variables across urban areas - Urban effect on Boundary Layer Height



PBL height on clear days of
(a) 2 June
(b) 12 November (symbols: predictions by each PBL scheme; solid lines: diagnoses by the bulk Richardson number method); PBL height over Greater London
(c) at 10 P.M. on 12 November 2007 from ACM2 predictions in WRF
(d) at 10 P.M. on 7 May 2008 from simulations of Bohnenstengel et al. [2011] (black contours circumscribe the urban grids area, and black vectors indicate the 10m wind vectors)

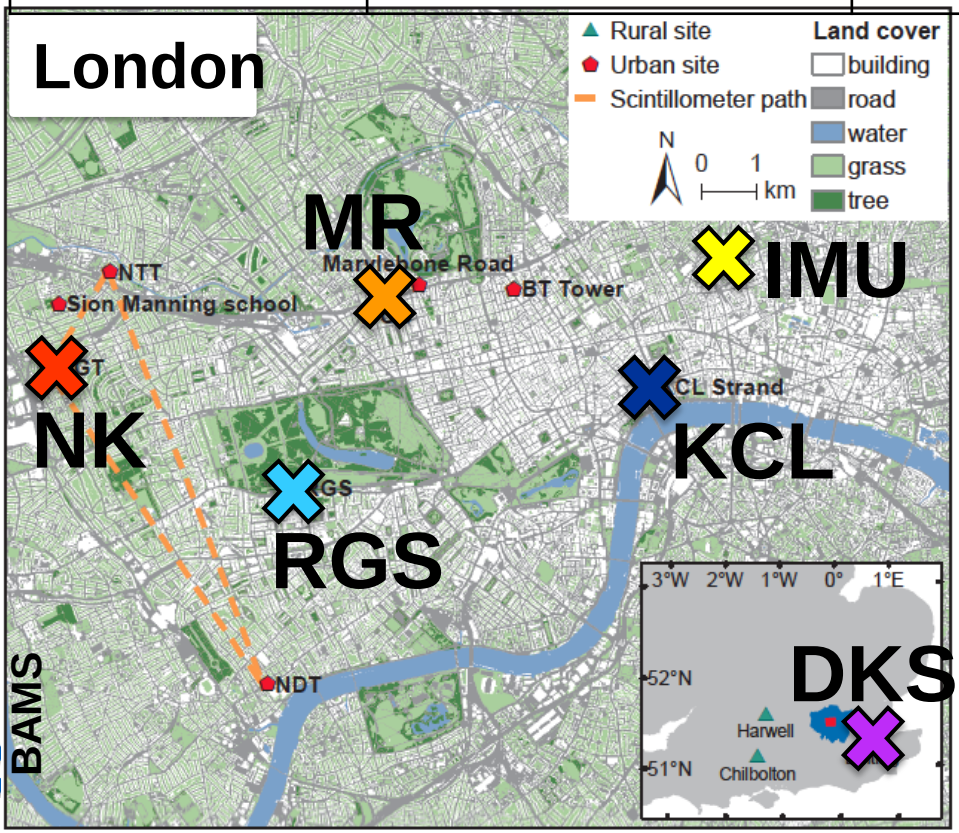
Xie Bo et al 2013, JGR:*Structure of the planetary boundary layer over Southeast England: Modeling and measurements.*

LUMO (London Urban Met Observatory) Ceilometer network

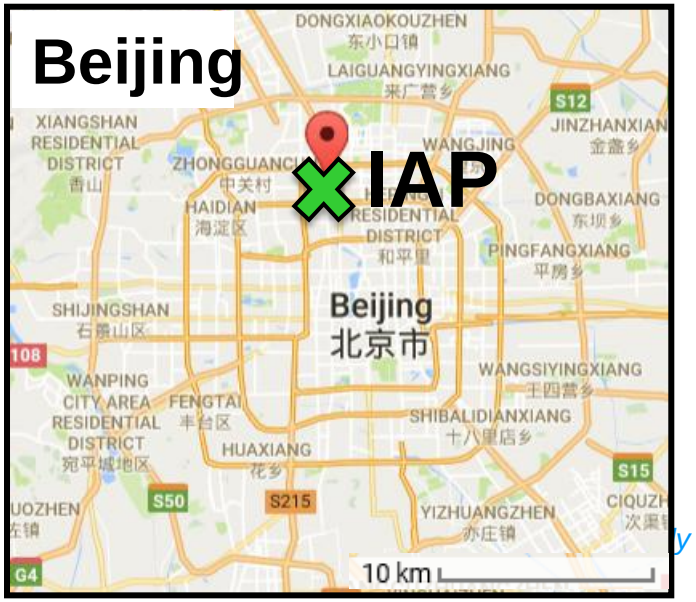
Sue Grimmond, Simone Kotthaus, Elliott Warren @University of Reading

www.met.reading.ac.uk/micromet

Central London	Since 2006	KCL, RGS, NK, MR, IMU	FP7 Bridge, NERC ClearfLo, EU H2020 URBANFLUXES
Central Beijing	Nov 2016 – June 2017	IAP	NERC APHH Airpro
Detling	Oct 2010 – Sep 2012	DKS	ClearfLo (Janet Barlow)



- **Vaisala CL31**
- **Resolution: 15 s, 10 m**



Bohnenstengel et al. 2014, BAMS

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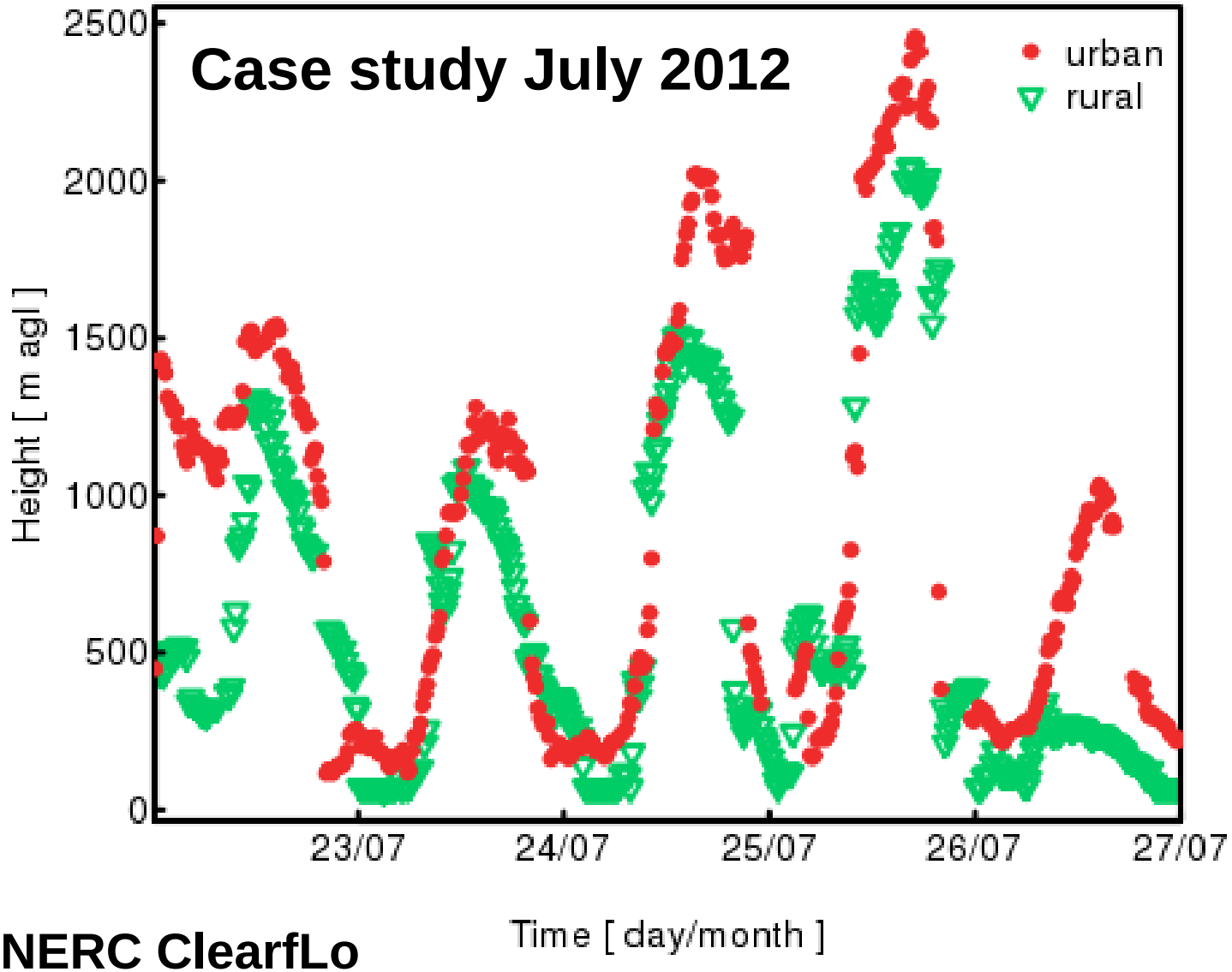
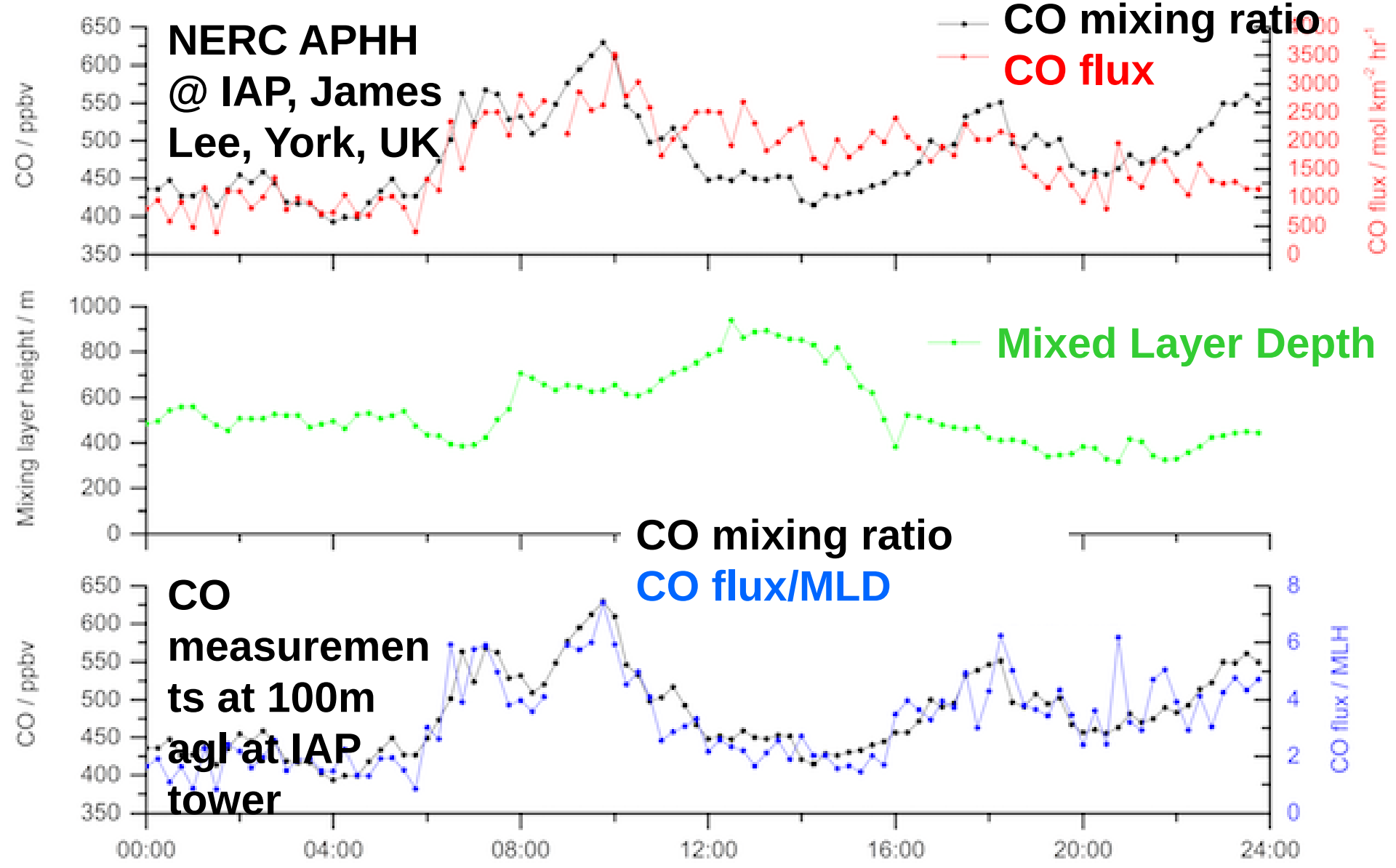
Variability in meteorology across urban areas - Urban effect on Boundary Layer Height

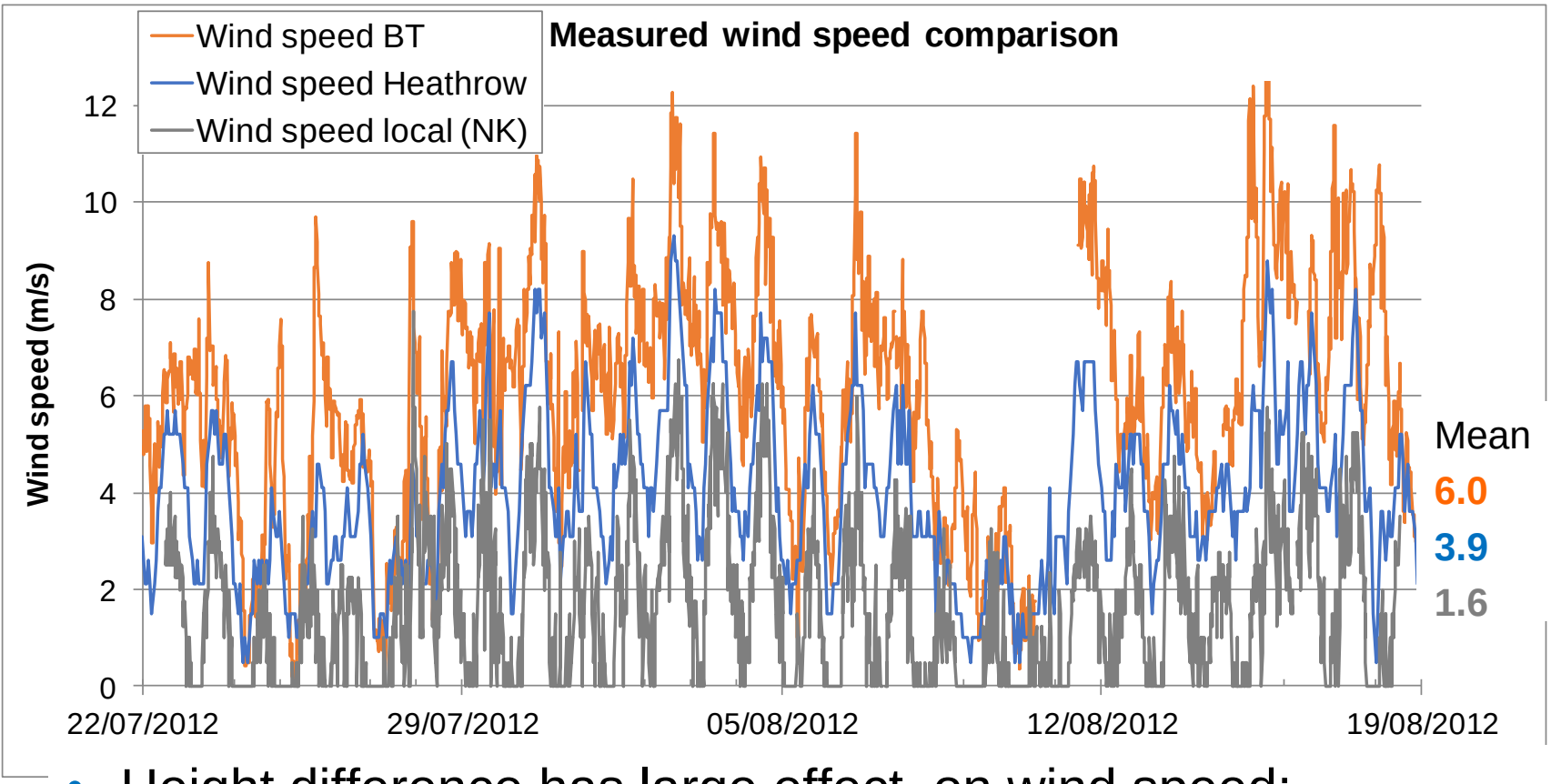


NERC ClearfLo

CO – budget (3 day average)

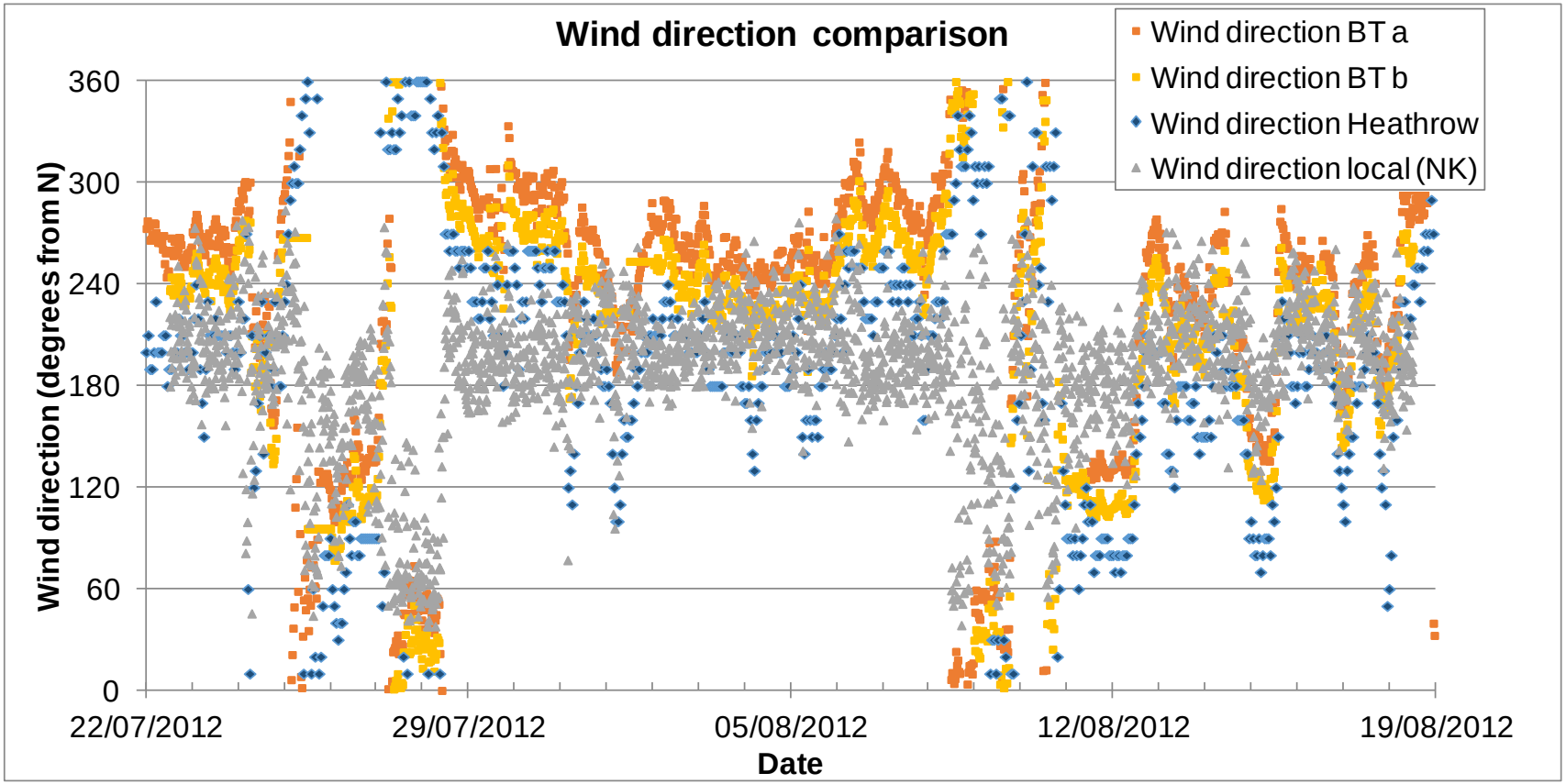


Variability across urban areas – measured wind speed



- Height difference has large effect on wind speed:
  - BT (180 m) > Heathrow (10 m) > NK (5 m)
  - But bigger measured reduction at NK (~40%) than expected from height (16%)
- Averaging time difference affects variability
  - BT 30 minute, Heathrow 1 hour, NK 15 minute
- NK measurements include many zero wind speeds

Variability across urban areas – measured wind direction



- NK measurements do not show wind directions > 280, < 40
  - Local channeling effect? Or measurement equipment failure?
- BT directions are veered by ~35°(b) or ~56°(a) compared to Heathrow
  - bigger than expected from height difference

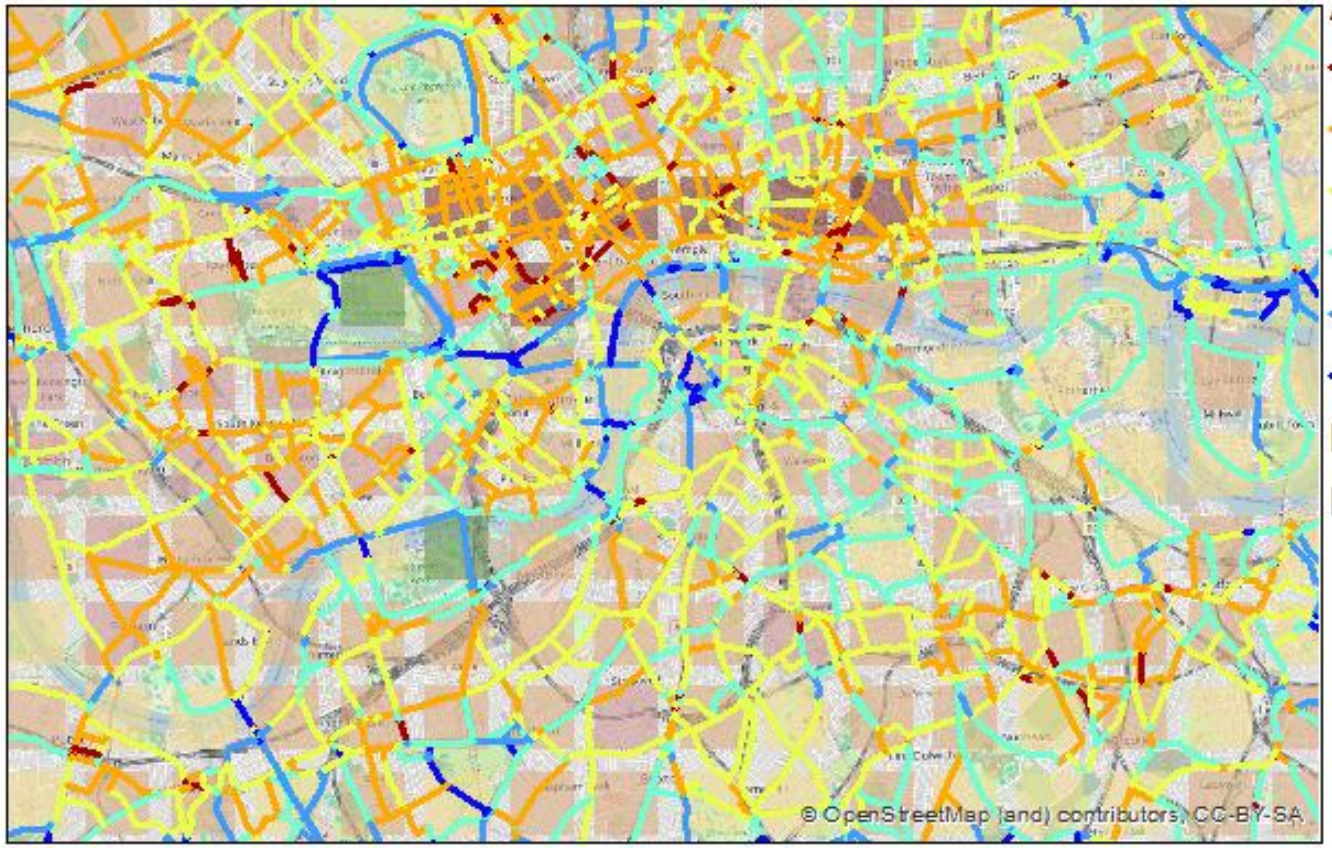
Variability across urban areas – Modelling approaches

- Regional models with urban features: WRF, Met Office …
- LES
- CFD
- Semi – analytic

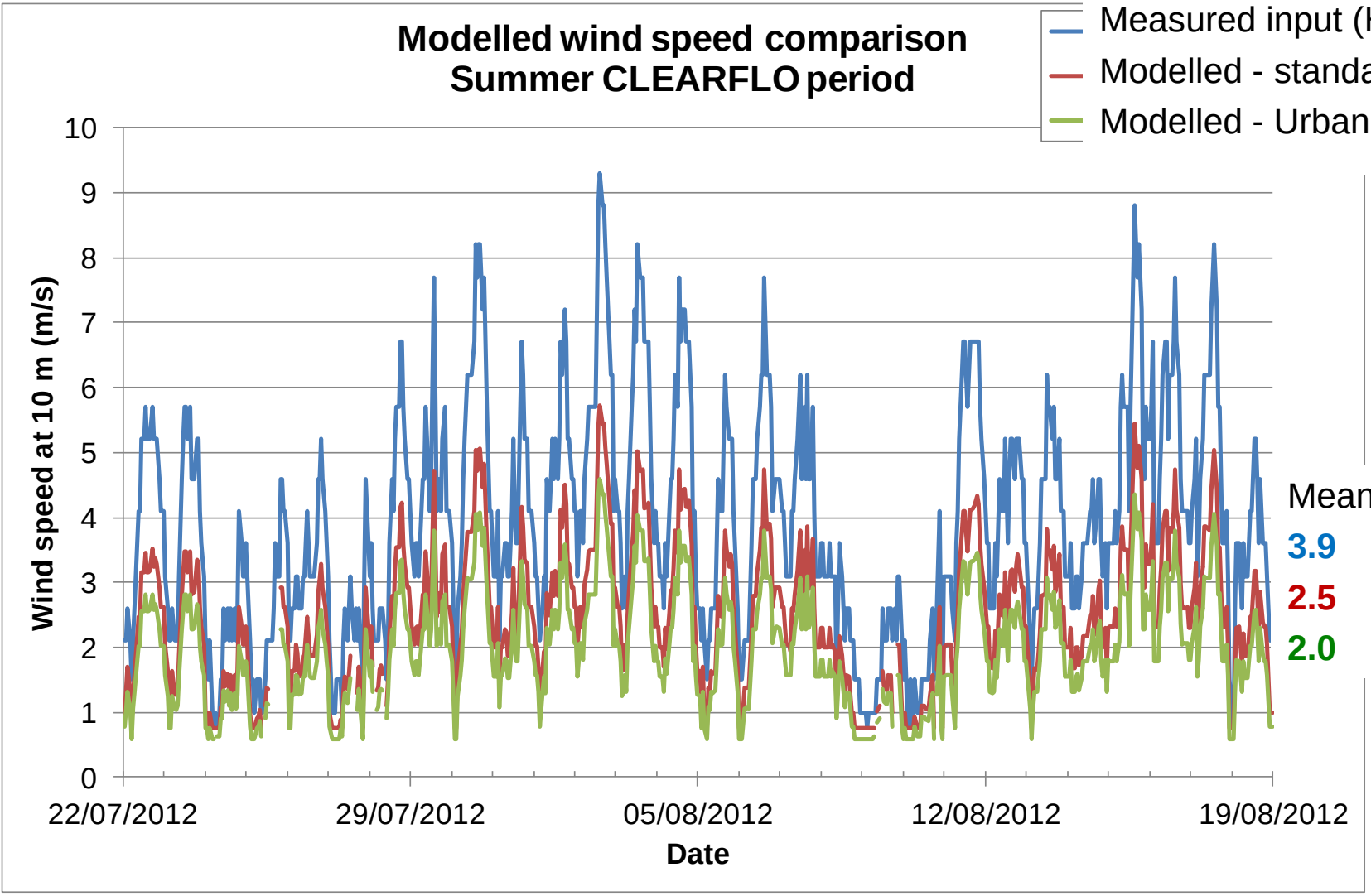
  - e.g. ADMS-Urban which includes explicit representation of sources, urban canopy model, street canyon model

Variability across urban areas: Building density/'Porosity

Central London road porosity and 1 km building density values



Variability across urban areas – modelled wind speed



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Standard: roughness at Heathrow 0.1 m, urban 1.0 m

Urban canopy: height 9.3, horizontal and vertical building density ~0.25

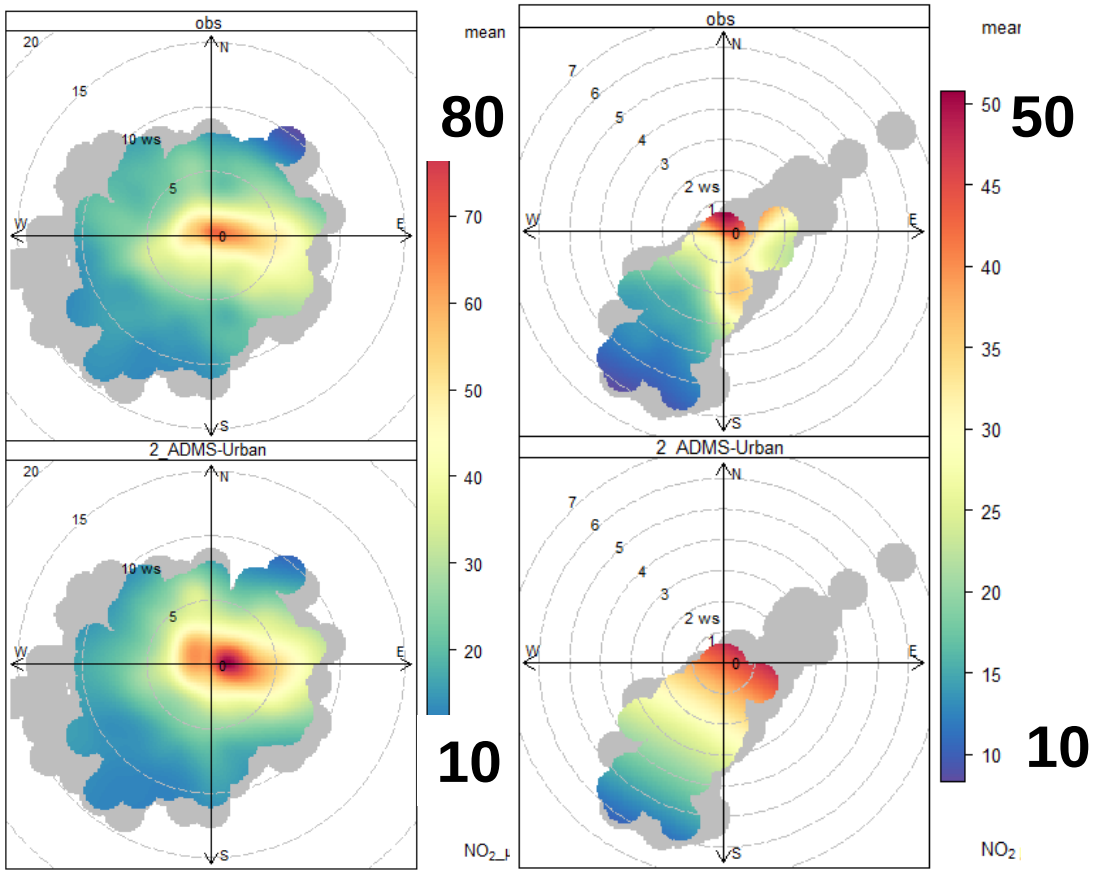
North Kensington site (KC1)

- Core measurement site (urban background) during CLEARFLO campaigns
- Routine concentration measurements at 3m.
- Wind speed and direction measurements were made at 5 m

Observed

NO_2 $\mu g/m^3$

Modelled



LHS: Heathrow met data - 2012

RHS: Local met data – summer 2012

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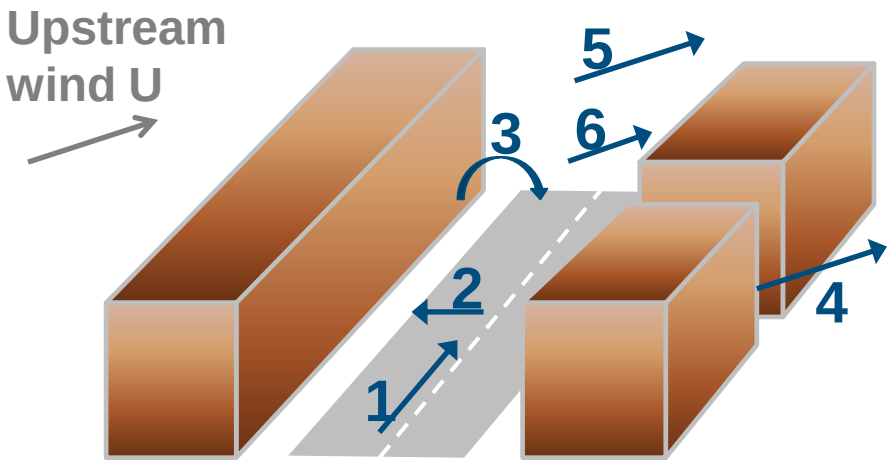
Pollutant concentrations

- Variations of concentration with height

Pollutant concentrations
Street canyon dispersion effects

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**
6. Pollutants enter/leave the canyon from the **canyon end**



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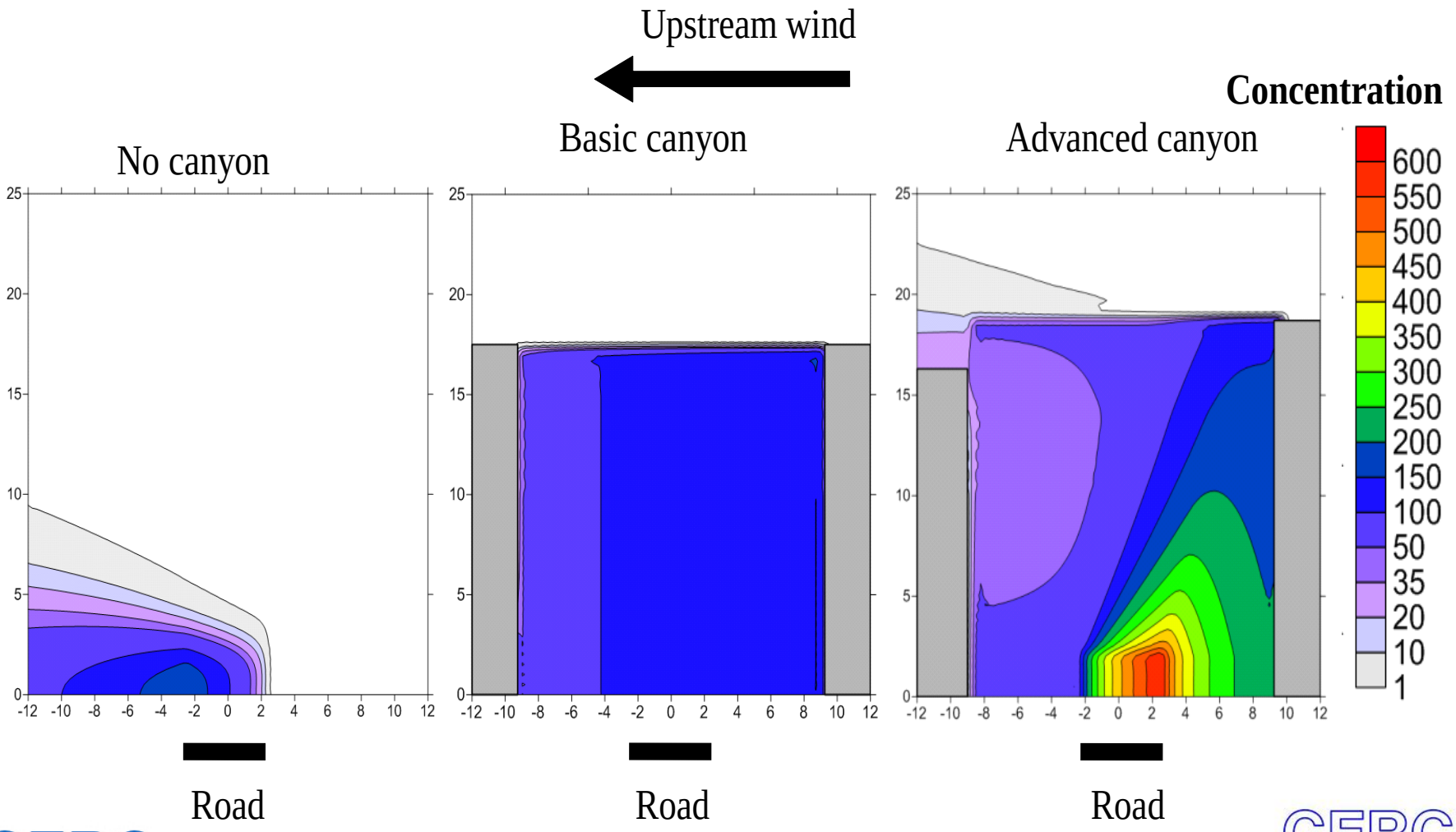
Pollutant concnetrations
ADMS-Advanced street canyon model simulations



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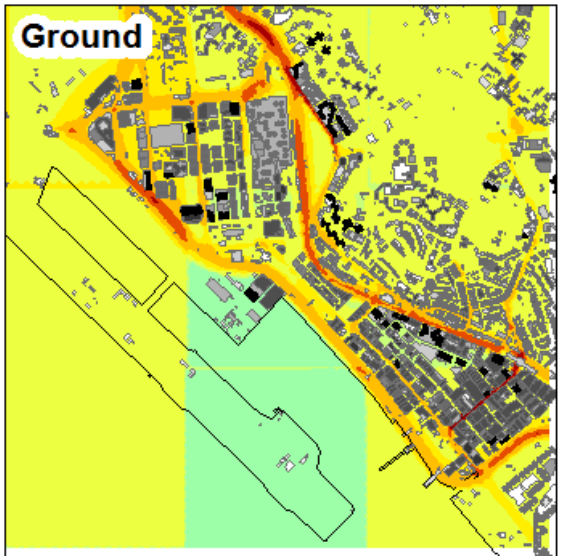
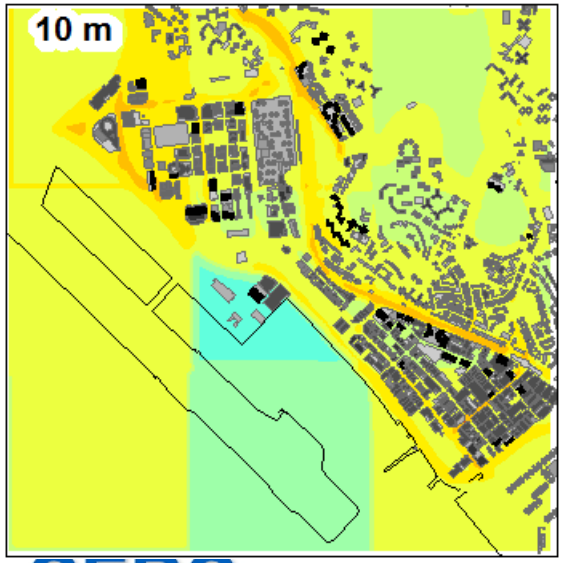
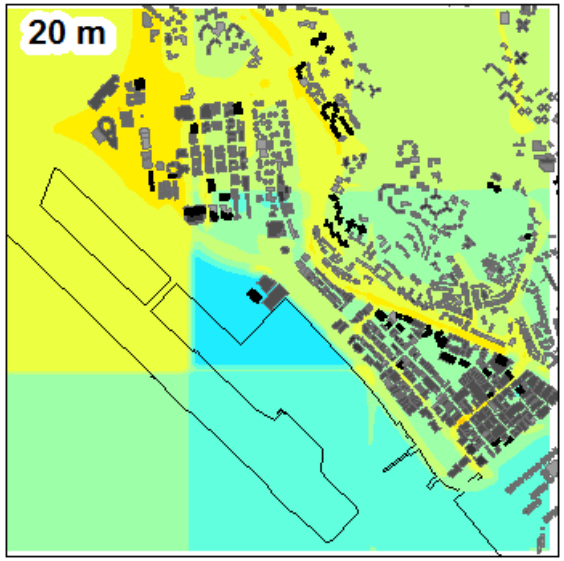
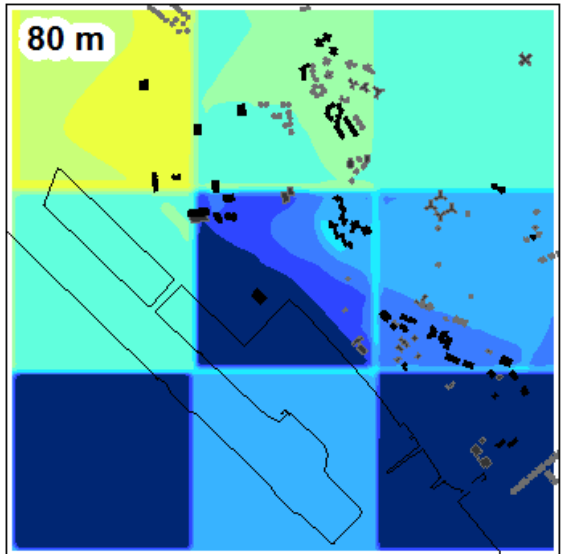
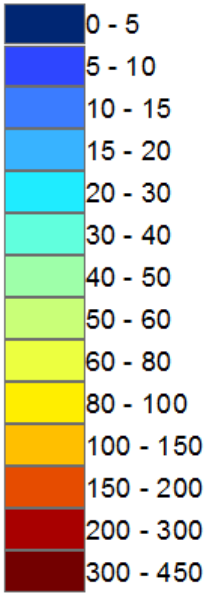
Concentration Contour output at different heights











NO_2 concentration ($\mu g/m^3$)

Plots show a single hour of data

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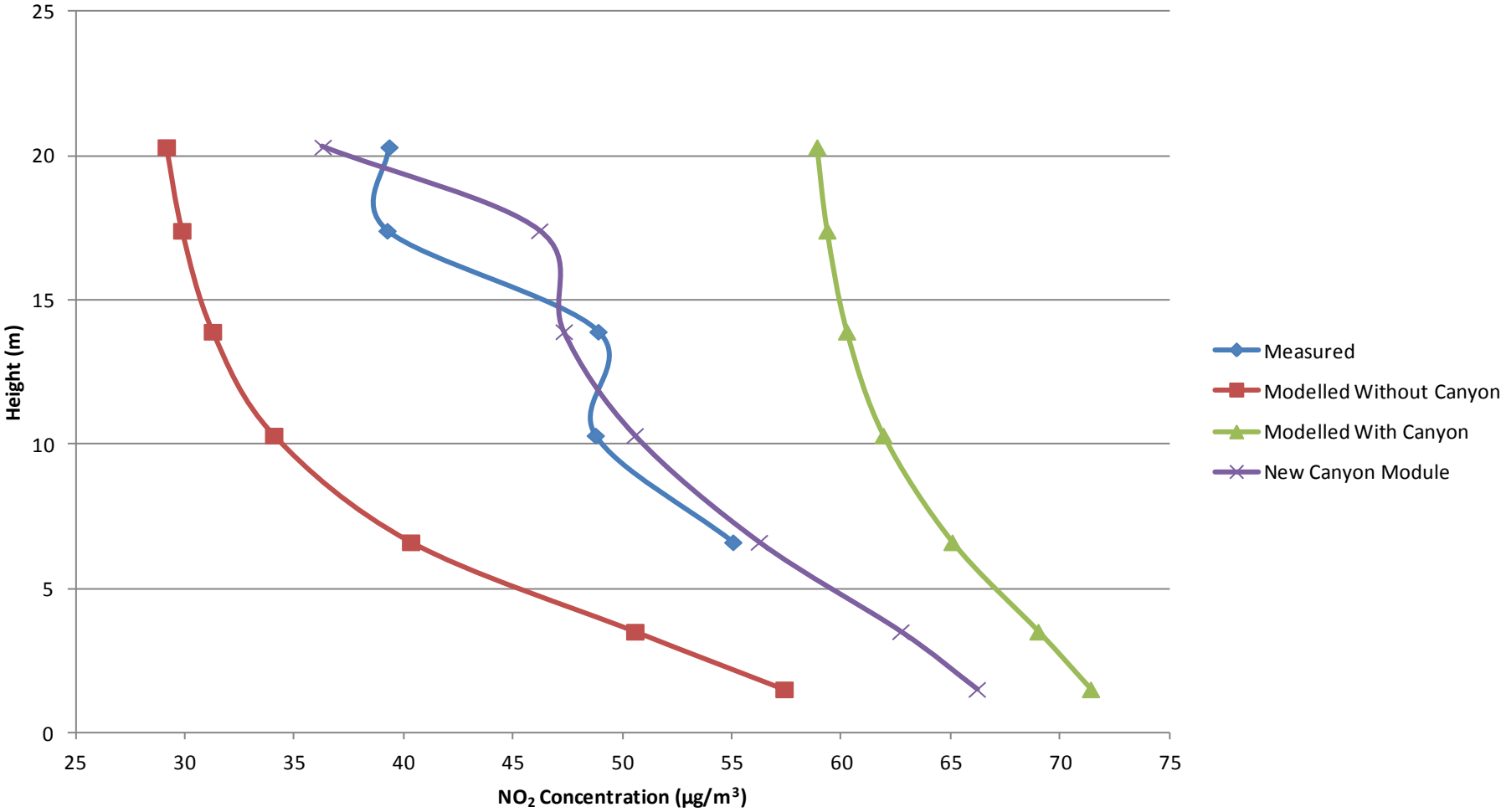
New Canyon Module – "True" Canyon



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Air Quality CONSULTANTS

Issues to consider

- Airflow and pollutant concentrations are highly variable in urban areas
- Despite field experiments (e.g. Clearflo) still lack of knowledge of spatial variation of airflow and turbulence data and also of the boundary layer height and its evolution.
- High spatial resolution models either use simplifying parameterisations or are constrained by computer resources or by large data volumes.
- Local models typically require background field as input (e.g. upwind or above canopy). However model verification or improvements in parameterisations requires more local data.
- ***How do we fill these gaps? Field expts can't do it all. What should be the role of sensors , remote sensing? What other technologies should be utilized?***

- **Thank you!**

- **Acknowledgements:**
  - **North Kensington measured wind speed and direction from NERC-funded CLEARFLO project http://www.clearflo.ac.uk/**
  - **Reading University (Simone Kotthaus, Sue Grimmond, Elliott Warren) for slides 12,13 &14**
  - **AQC (Ricky Gellatly) for slide 25**