Enhanced “urban breathability” leads to deterioration in ground-level air-quality

M. J. Barnes[1]
T. K. Brade[1] A. R. MacKenzie[2] J. D. Whyatt[1]
D. J. Carruthers[3] J. Stocker[3] C. N. Hewitt[1]

[1]Lancaster Environment Centre
Lancaster University

[2]School of Geography, Earth and Environmental Sciences
University of Birmingham

[3]Cambridge Environmental Research Consultants Ltd

8th May, 2013

m.barnes1@lancaster.ac.uk

Introduction

- Background to study
- Model verification
  - Fixed surface roughness
  - Variable surface roughness
- Localized reductions in surface roughness
  - Ground level results
  - Above ground level results

Background

- Air quality in a city can be improved by:
  (a) Reducing emissions
  (b) Moving people
  (c) Enhancing breathability
- Focus on the latter using a commercially-available dispersion model (ADMS-Urban)
- Acheived using varying surface roughness values

Aims and objectives

Aim

To explore extent to which air-quality can be improved by localized reductions in surface roughness

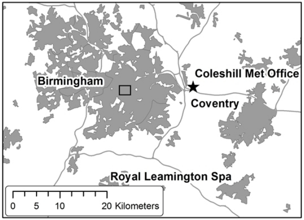
1st objective

To compare model performance of ADMS-Urban using fixed or variable roughness

2nd objective

To use the best model representation to assess impacts of improved ventilation

Birmingham



© Crown Copyright OS 1:25,000
Raster 2013. An Ordnance
Survey/Edina supplied service

Surface roughness

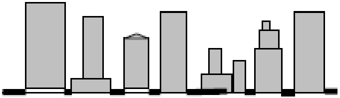
ADMS-Urban

- Variable roughness introduced in version 3.1

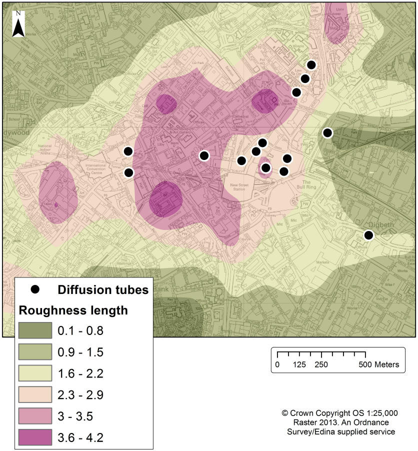
Roughness length (Z_0)

- Height where mean wind speed becomes zero
- $\sim 1/30$th of the height of the roughness elements

City centre, 2 – 4 m



Parkland, 0.1 m



Summary of annual mean NO_2 concentration ($\mu g\ m^{-3}$)

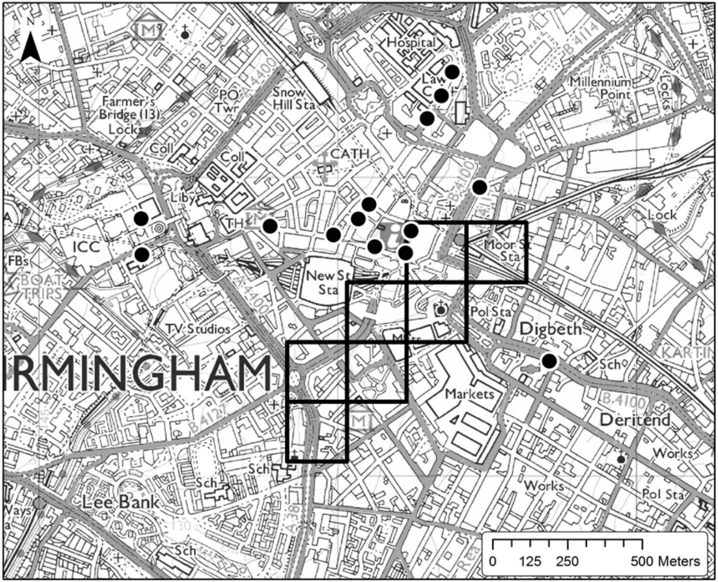
	Observed	Fixed	Variable
Min	33	42	40
Mean	44	54	50
Max	59	80	70

Pearson correlation

Fixed 0.67

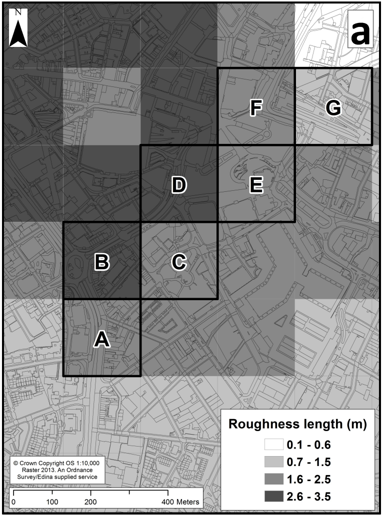
Variable 0.72

Urban breathability

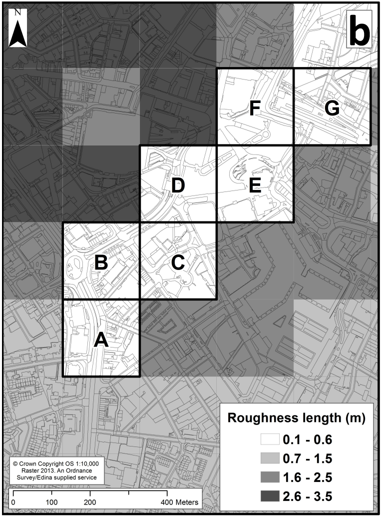


Area of reduced roughness

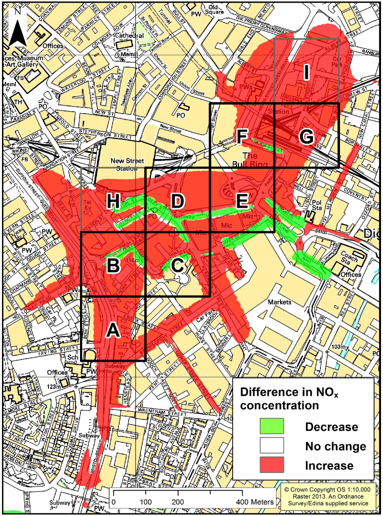
Built up city centre



Urban parkland



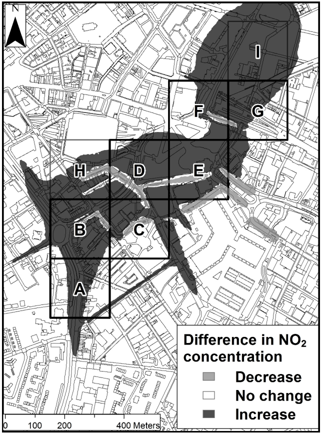
Results, ground-level

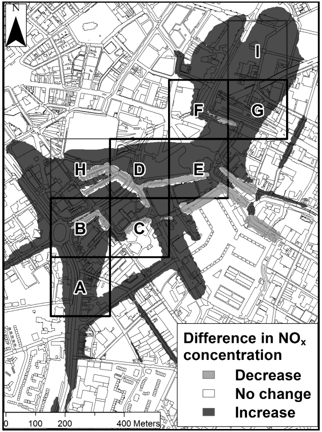


Results initially appear counter-intuitive

- Localized reduction in roughness length has resulted in a localized increase in ground-level concentrations for NO_x and NO_2
- Street canyons have been removed
- Effects not uniform
- Downwind areas also affected (squares H and I)

Results, ground-level





$\mu g\ m^{-3}$	A	B	C	D	E	F	G
Mean NO_2 increase	2.4	4.8	1.8	1.6	2.3	2.2	3.2
Mean NO_x increase	11.4	14.7	7.8	–0.2	7.3	7.8	7.9

GPE

Mean wind speed at height Z is a function of surface roughness ...

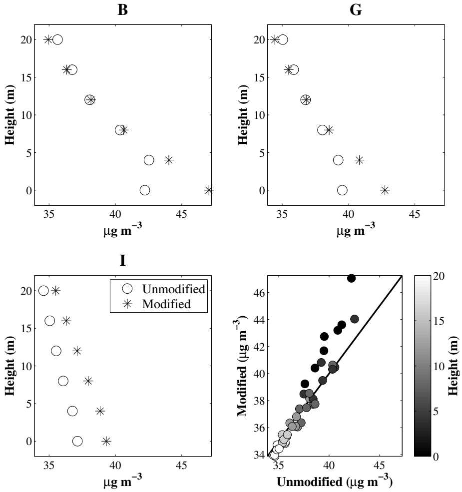
(Simplified) Gaussian Plume Equation

$$C(x, y, z) = \frac{q}{2\pi\sigma_y\sigma_z\langle u\rangle} exp(\ldots$$

- Pollutant concentrations near a ground-level source depend on the sensitivities to the surface roughness of σ_z and σ_y, and of $\langle u\rangle$, which tend to have opposing effects

- Reducing $\langle u\rangle$, the vertically averaged wind speed, increases the concentration
- Turbulent mixing dominates over horizontal ventilation

Results, above ground-level



o — unmodified surface roughness (built up city)
* — modified surface roughness (parkland)

Conclusions

- Improved model performance using variable roughness
- Reduced roughness increases ground-level pollutant concentrations
  - Turbulent mixing dominates
- View results with caution, or do not use air dispersion models for air quality impacts of such interventions

Thank you, any questions

Acknowledgements

We thank Birmingham City Council for provision of diffusion tube data. This work was carried out as part of the UK EPSRC Sustainable Urban Environment programme, grant no. EP/F007426/1.

m.barnes1@lancaster.ac.uk