Modelling the neighbourhood-scale dispersion of traffic-induced ultrafine particles

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UK-US Collaboration on Air-Quality Modelling & Exposure Science: Workshop 16-17 November 2020

Introduction

Multicomponent microphysics
(Condensation/Evaporation)

Ultrafine particles (UFPs)
(Traffic emissions)

Dispersion
(Turbulence)

Neighbourhood-scale dispersion of UFPs
(< 1 km, transport times of few minutes)

Large-eddy simulation model for UFPs
Weather Research and Forecasting LES mode (WRF-LES-UFP)

To simulate the dispersion and evolution of size-resolved ultrafine particles (UFPs diameter < 0.1 μm) at the neighbourhood-scale

Methodology

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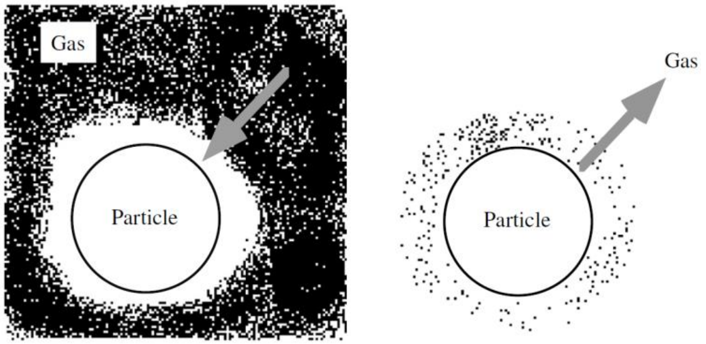
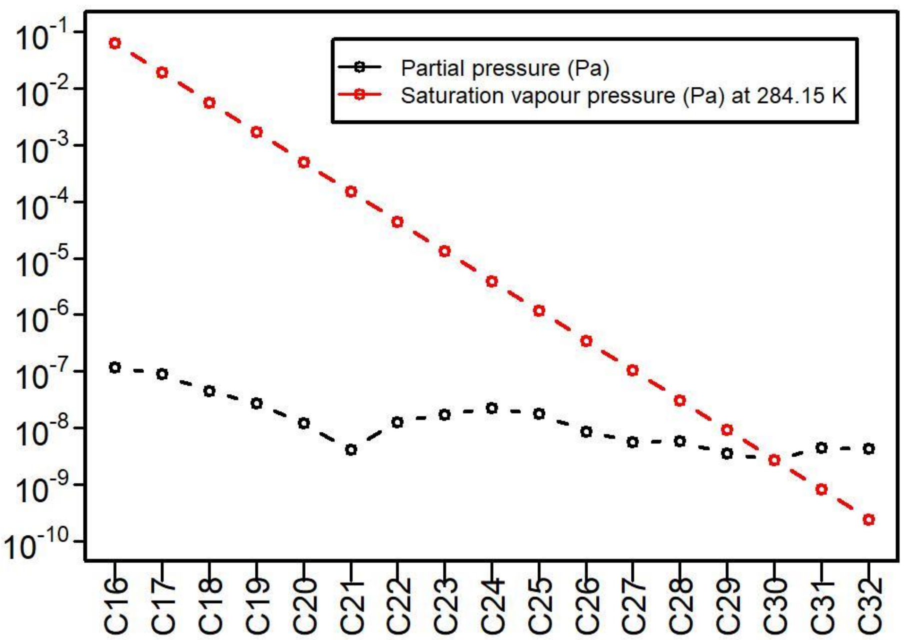
Multicomponent microphysics: Condensation/evaporation

- Partial pressure of a gas vs its saturation vapour pressure over particle surface
- Stiff system, various time scales for SVOC components (N-Alkanes from C16 to C32).



17 representative SVOCs (C16-C32)
+1 non-volatile core.
15 sectional log-scale size bin
(6 nm - 500 nm)

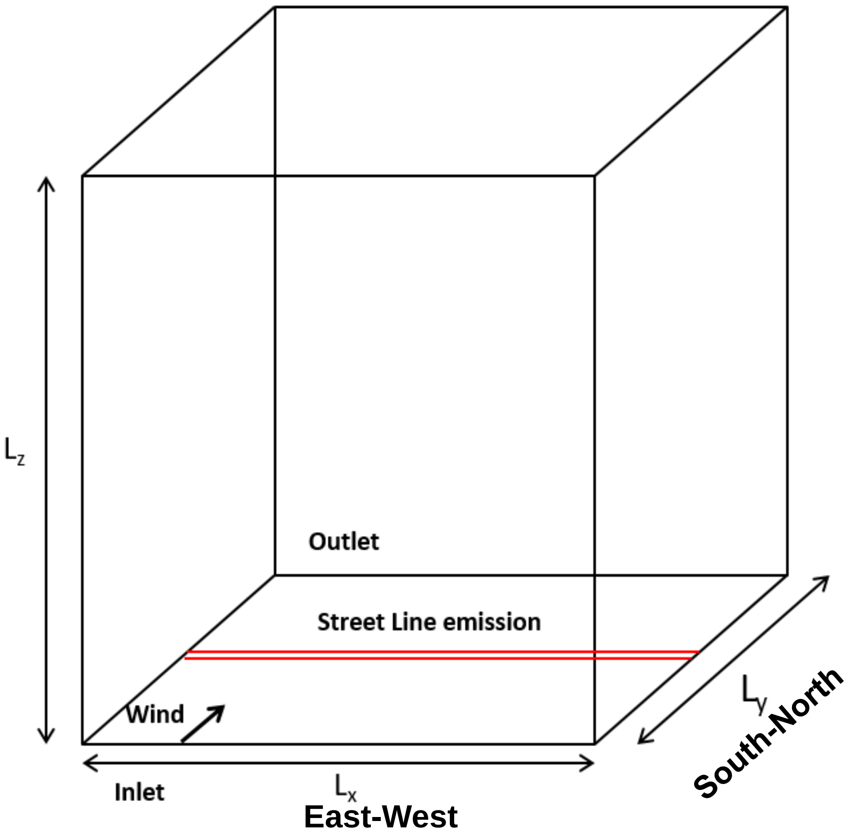


Methodology

WRF-LES-UFP domain settings

- ❑ $\Delta x \times \Delta y$ = 20 m × 20 m, stretched Δz

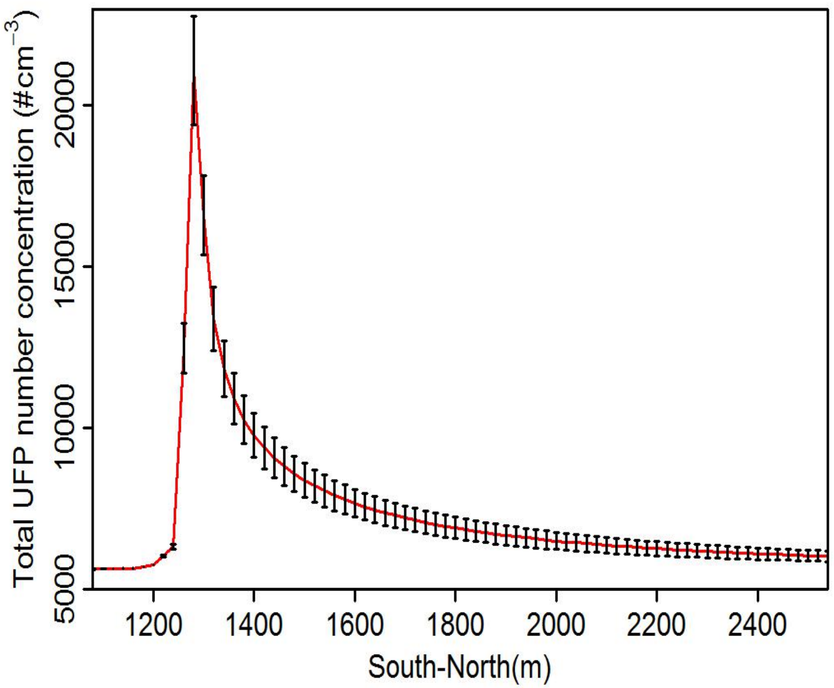
  2.54 km × 2.54 km × 1 km
- ❑ BLH = 500 m, T = 284.15 K
- ❑ Surface southerly wind
- ❑ Flow: periodic
- ❑ Tracers: fixed inlet, open outlet
- ❑ Above canyon dispersion



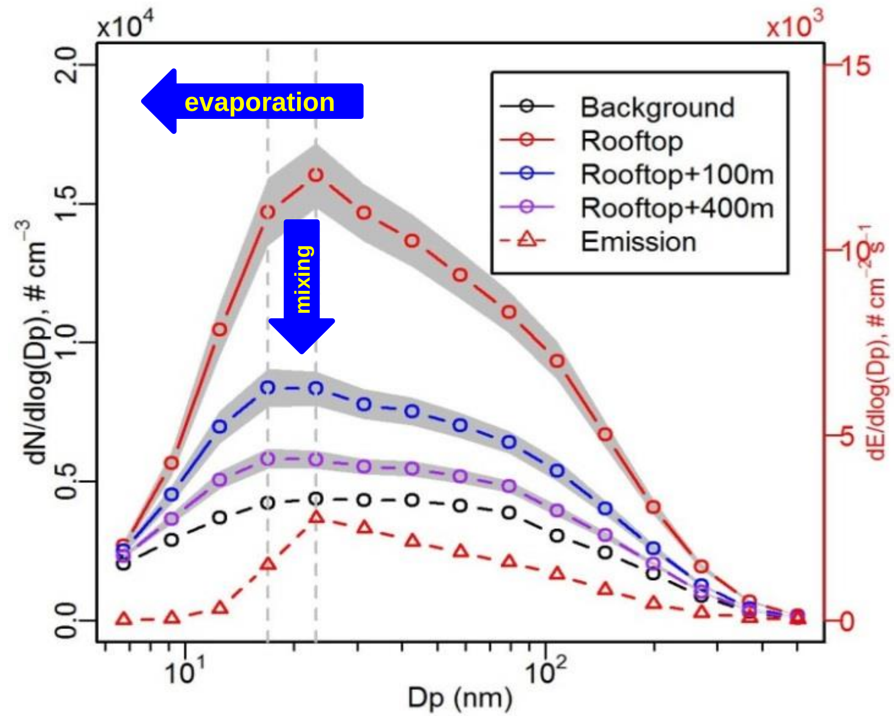
Results

Idealised one-line emission scenario

(a) $C_m \pm C'$ along the South-North line



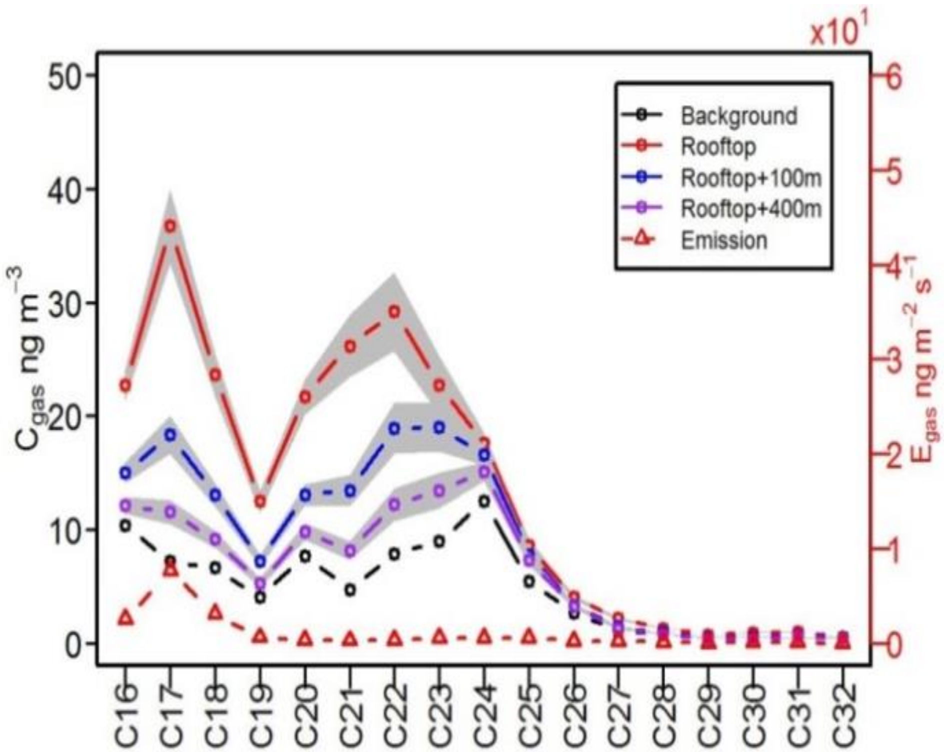
(b) UFP number-size distribution



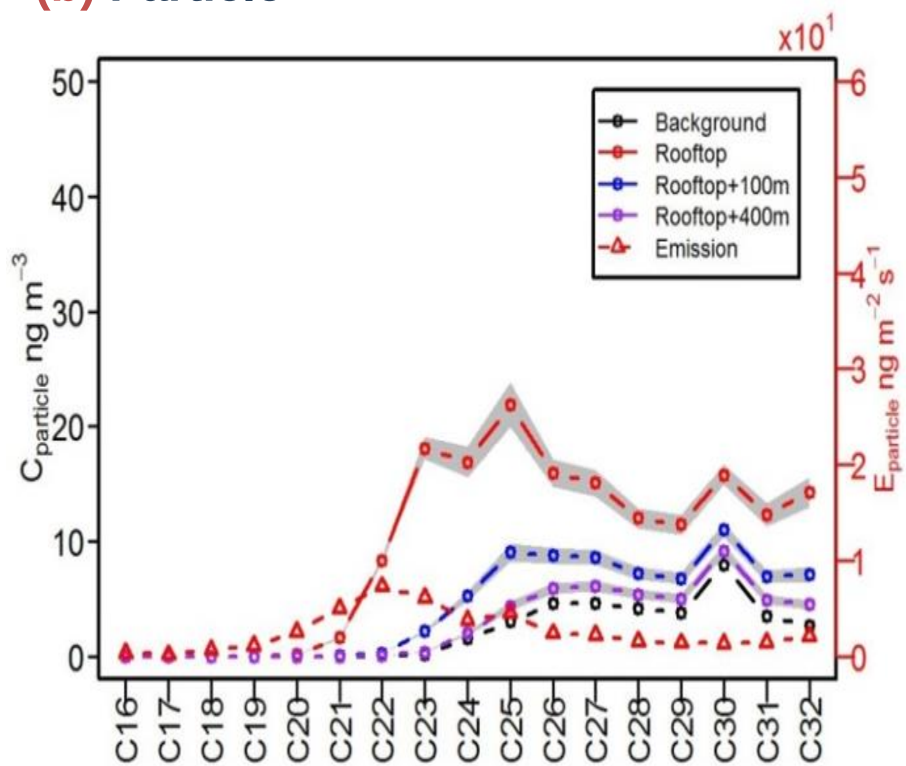
Results

Idealised one-line emission scenario

(a) Gas



(b) Particle

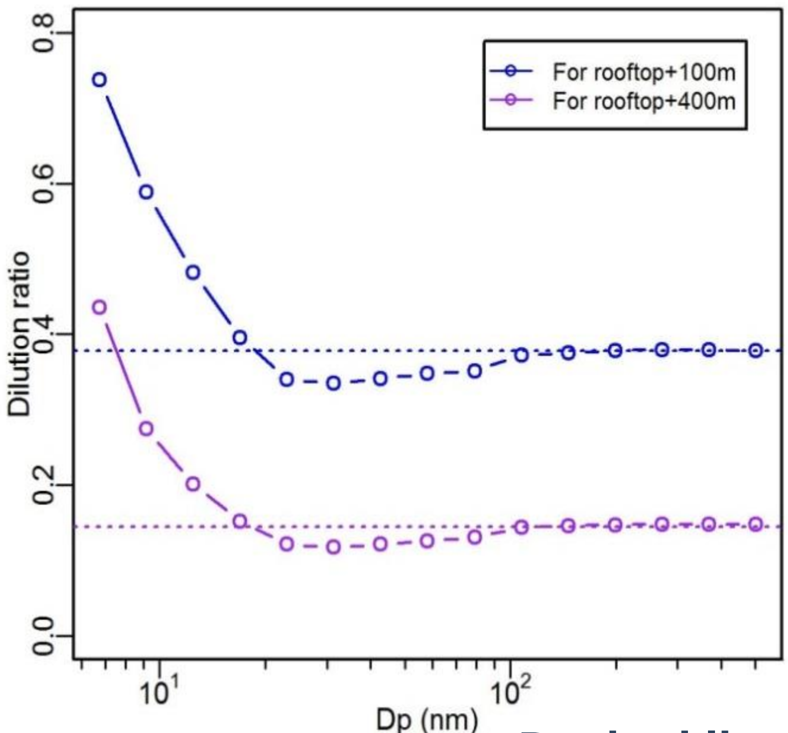


Results

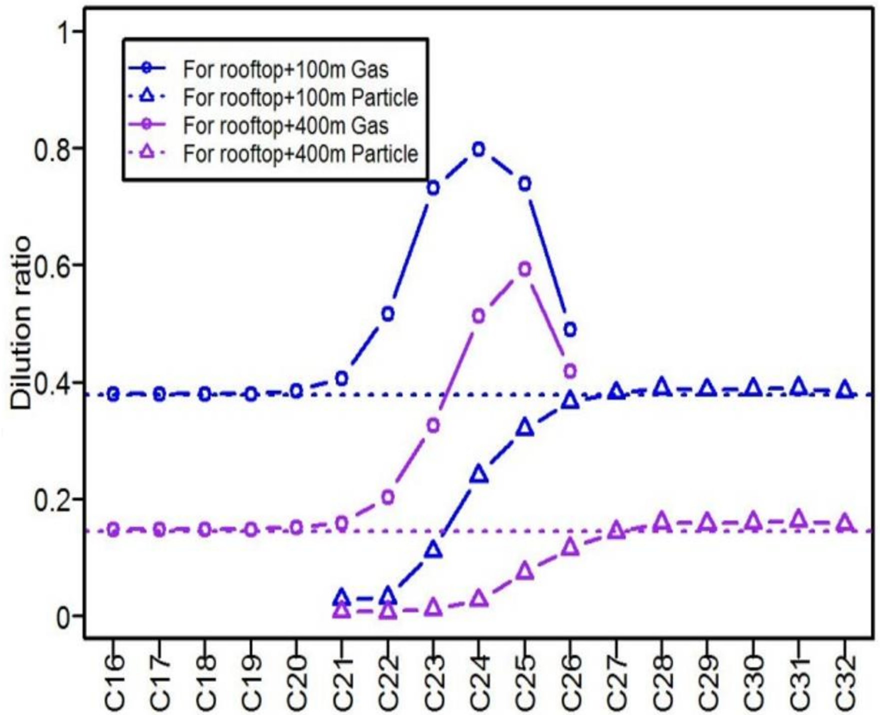
Idealised one-line emission scenario

Dilution ratio: defined as $(C_{downwind} - C_{bg})/(C_{rooftop} - C_{bg})$

(a) For UFP sizes



(b) For SVOCs

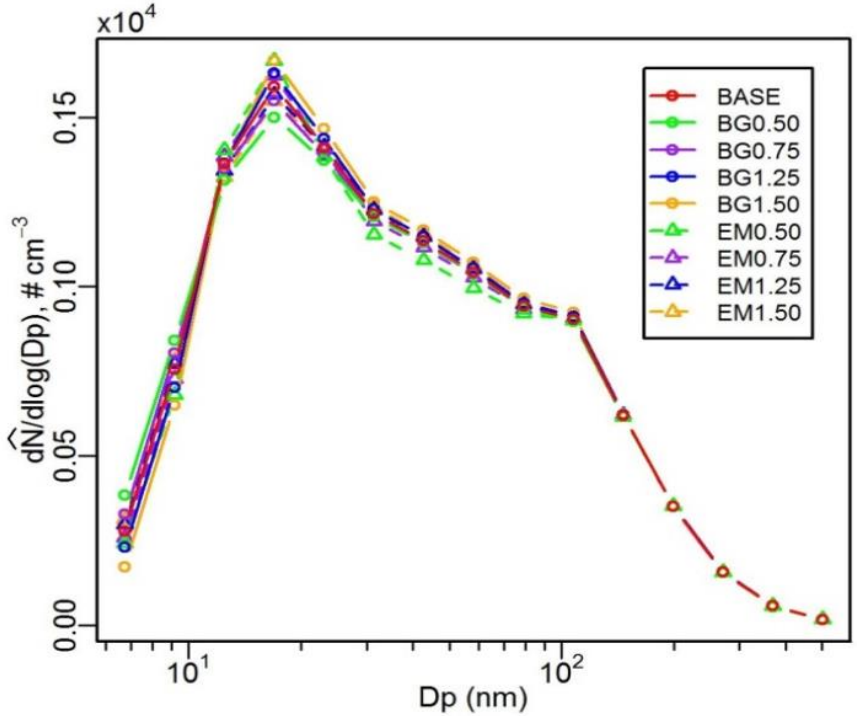


Dashed lines: Passive scalar

Smaller particles (UFPs < 100 nm) and medium range carbon SVOCs behave non-linearly

Idealised one-line emission scenario

$d\widehat{N}/dlog(Dp)$ at rooftop + 400m



A scaled concentration for the *ic*th case:

$$\hat{C}^{ic} = (C^{ic} - \alpha C_{bg}^{BASE})/\beta$$

C^{ic}: Concentration of any quantity in the *ic*th case,
C_{bg}^{BASE}: Background concentration in Case BASE

α and β are the multiplied coefficients for the background and emission, respectively.

α=[1.0] and β=[1.0], i.e. Case BASE

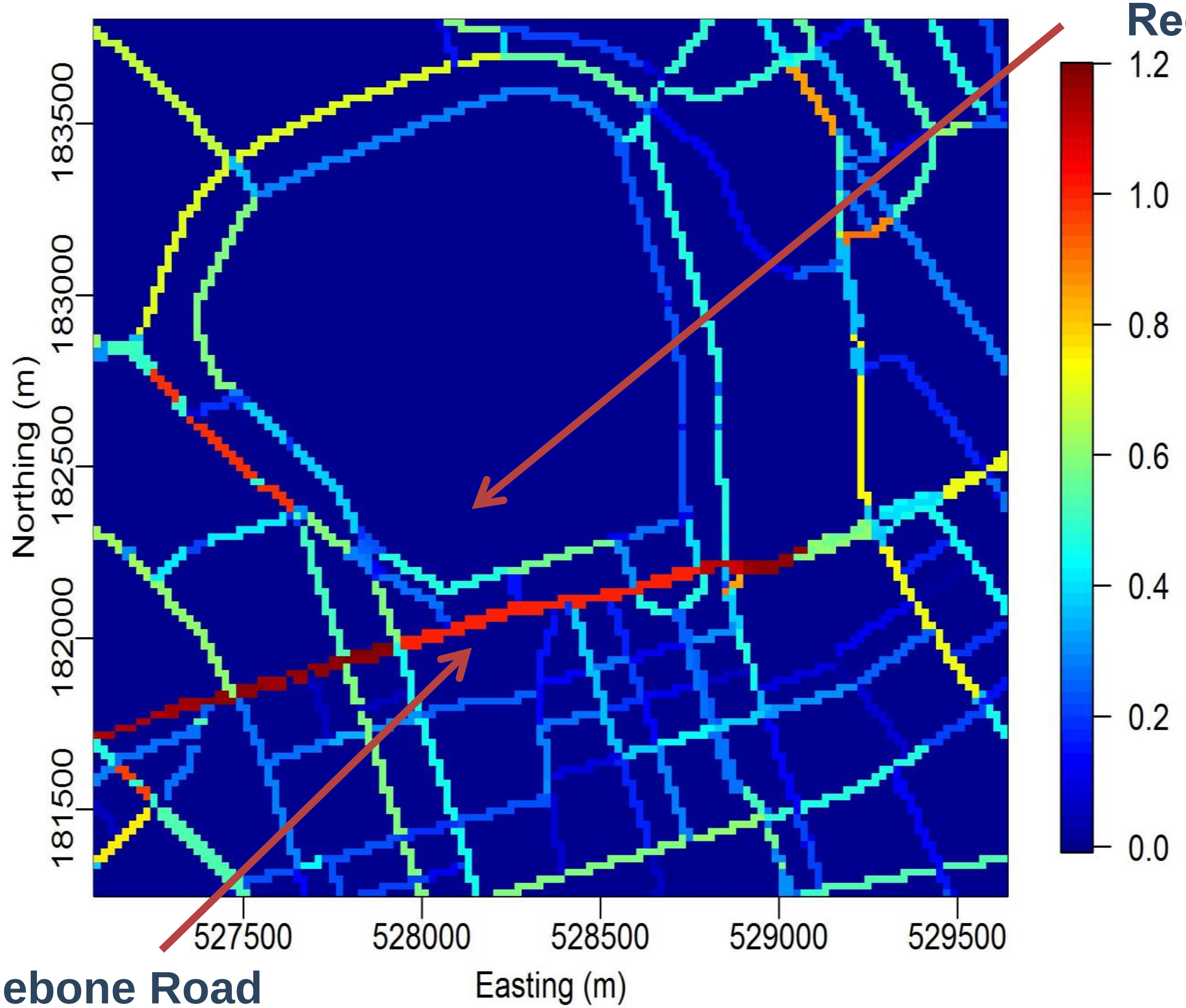
α=[0.5, 0.75, 1.25, 1.5] and β=[1.0], i.e. Cases BG0.5, BG0.75, BG1.25, and BG1.5.

α=[1.0] and β =[0.5, 0.75, 1.25, 1.5], i.e. Cases EM0.5, EM0.75, EM1.25, and EM1.5.

Results

Street network scenario: relative traffic

Regent's University



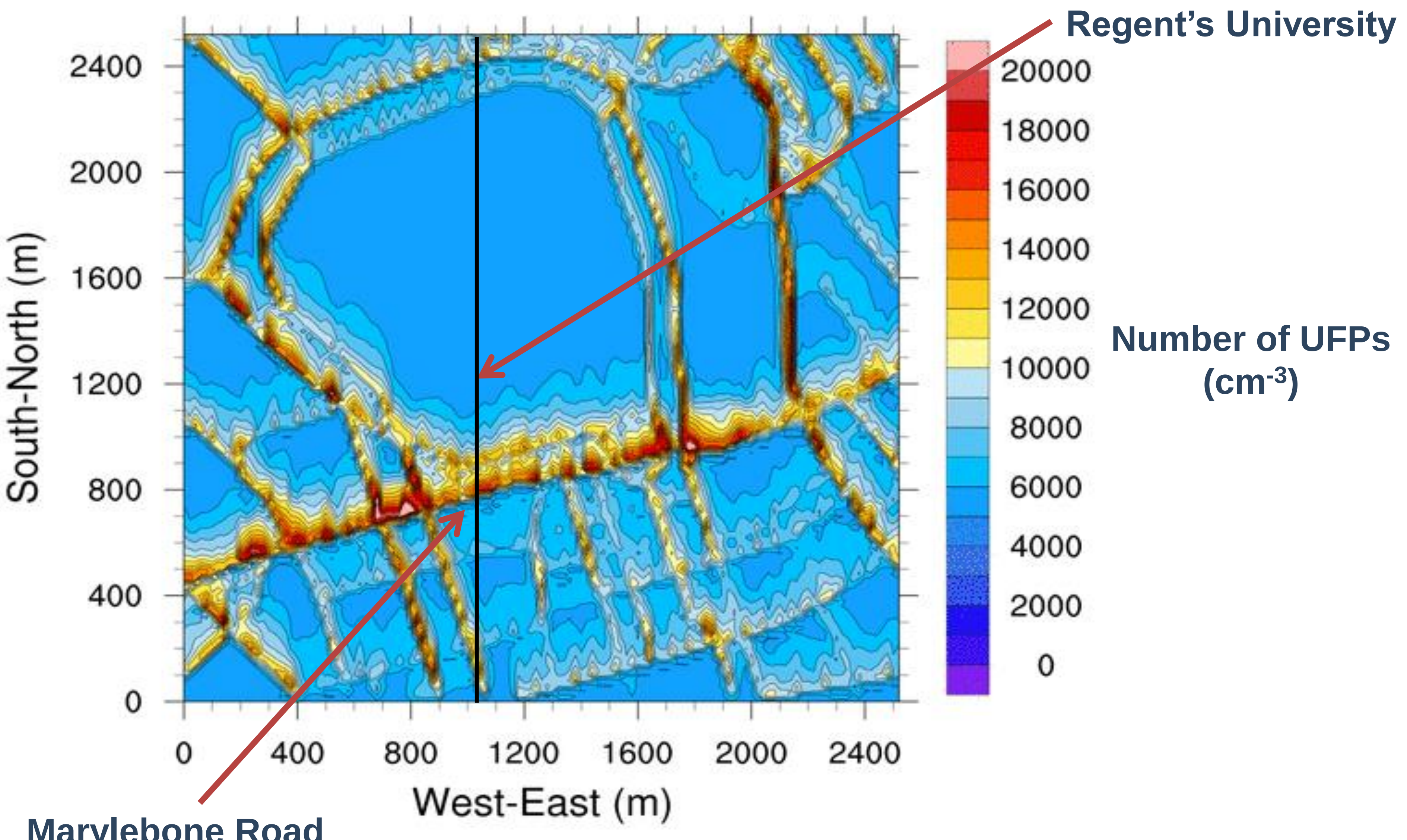
Relative traffic activity (vs. Marylebone Road)

Marylebone Road (Reference)

London Atmospheric Emissions Inventory (LAEI) 2013

Results

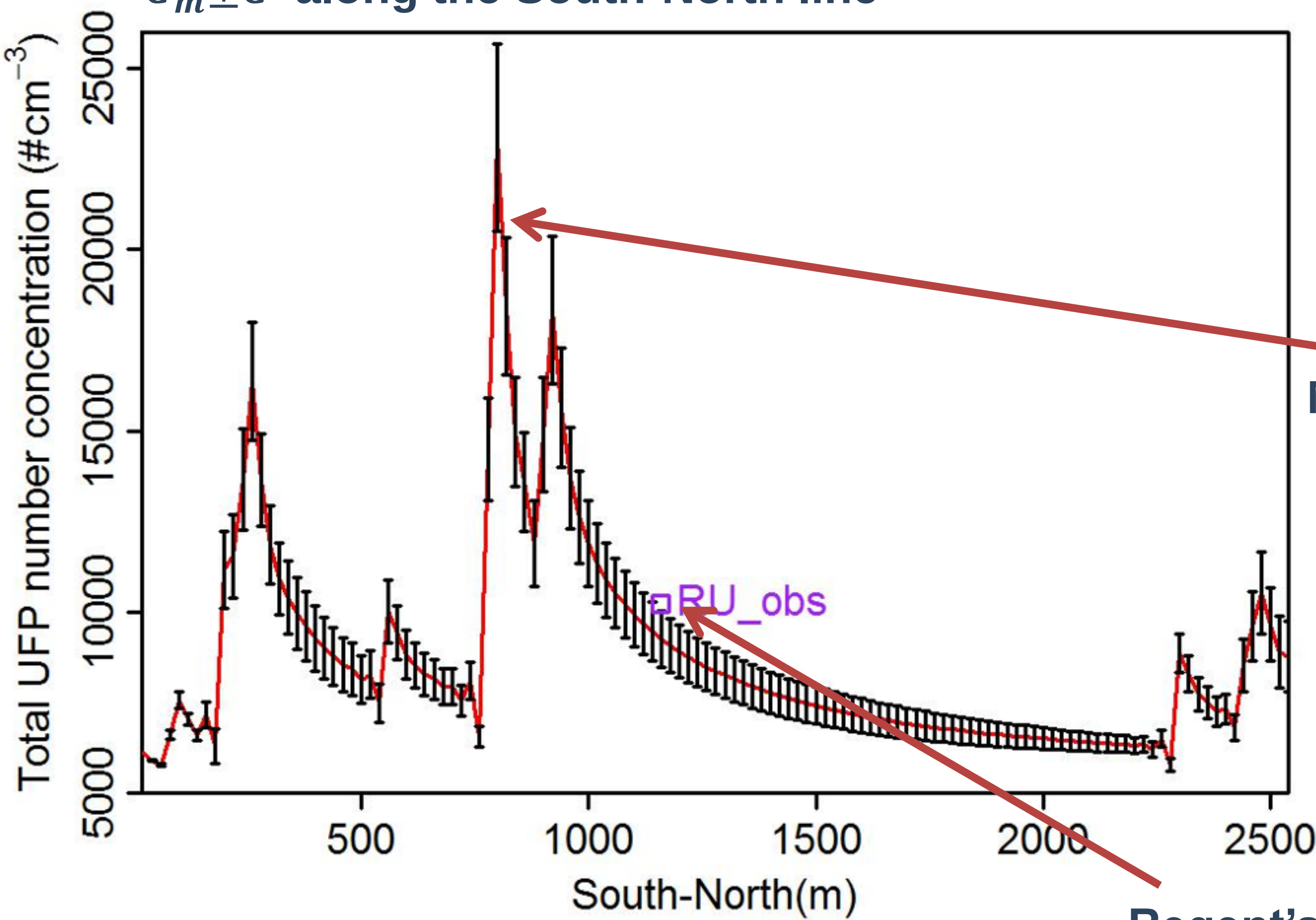
Street network scenario: total UFP concentration



Results

Street network scenario: total UFP concentration

$C_m \pm C'$ along the South-North line



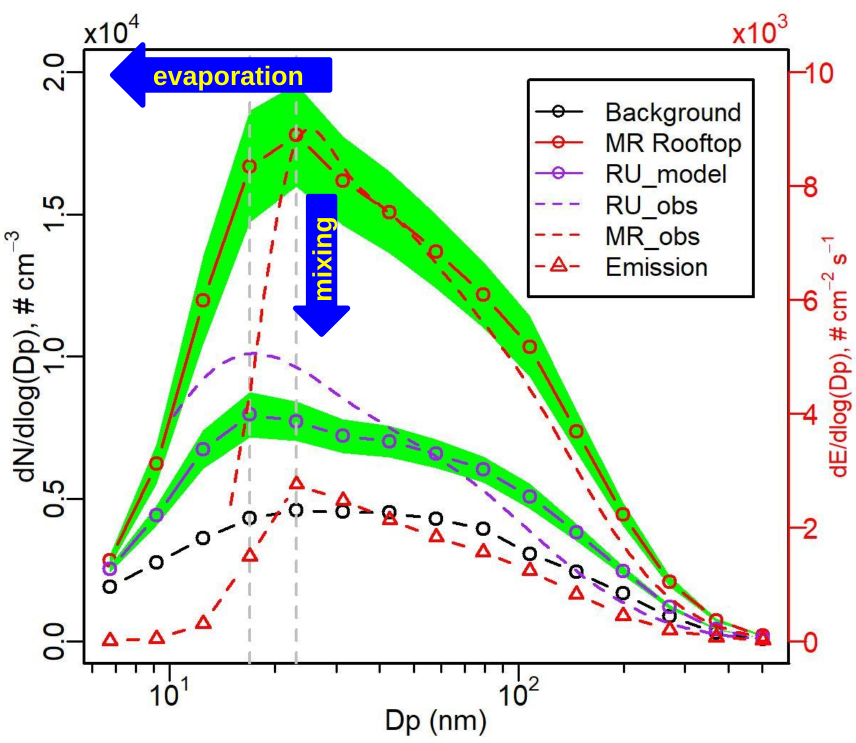
Rooftop Marylebone Road

Regent's University

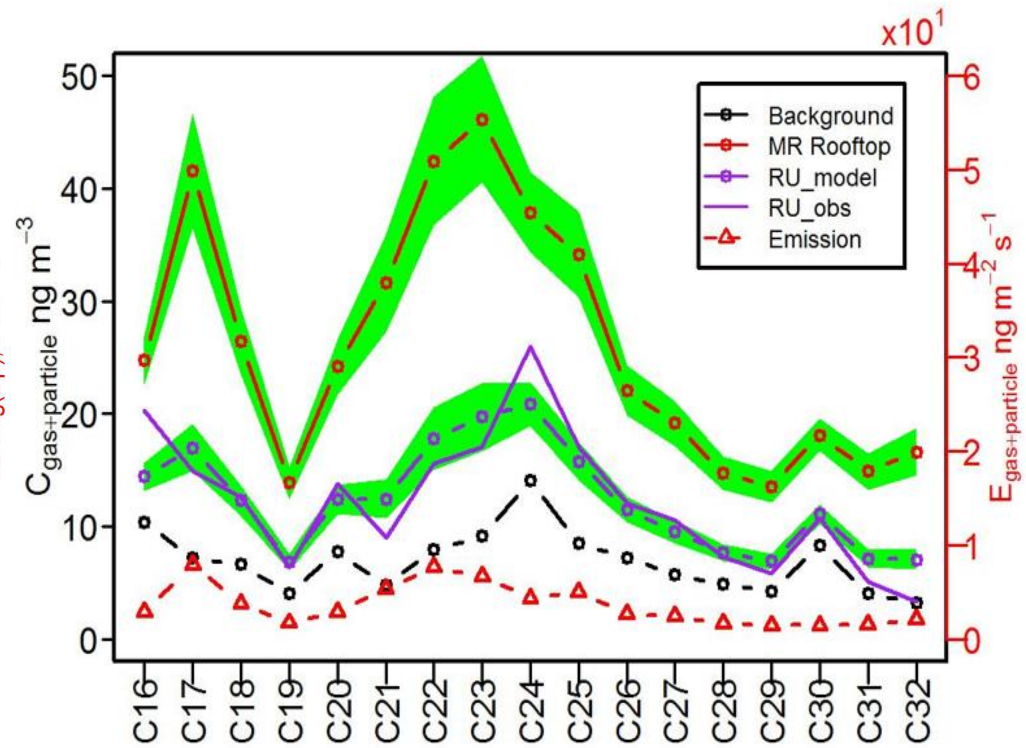
Results

Street network emission scenario

(a) UFP number-size distribution



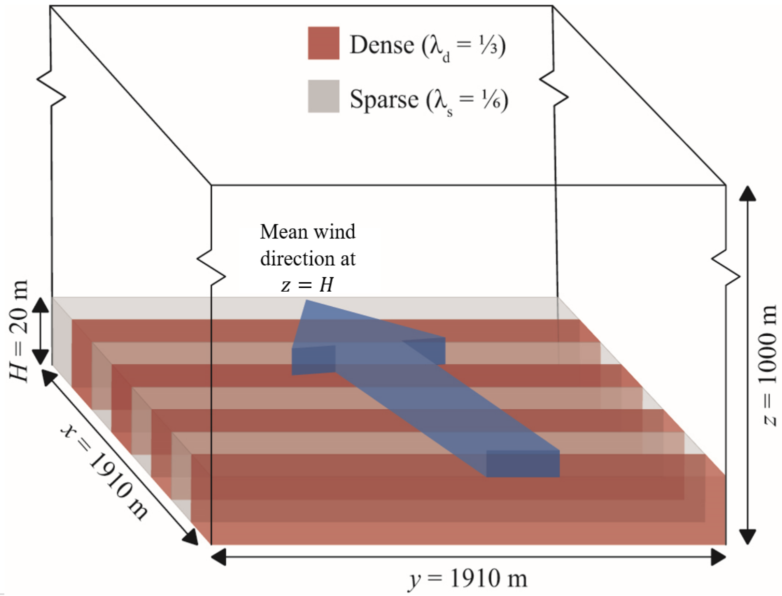
(b) SVOCs (Gas + Particle)



Results

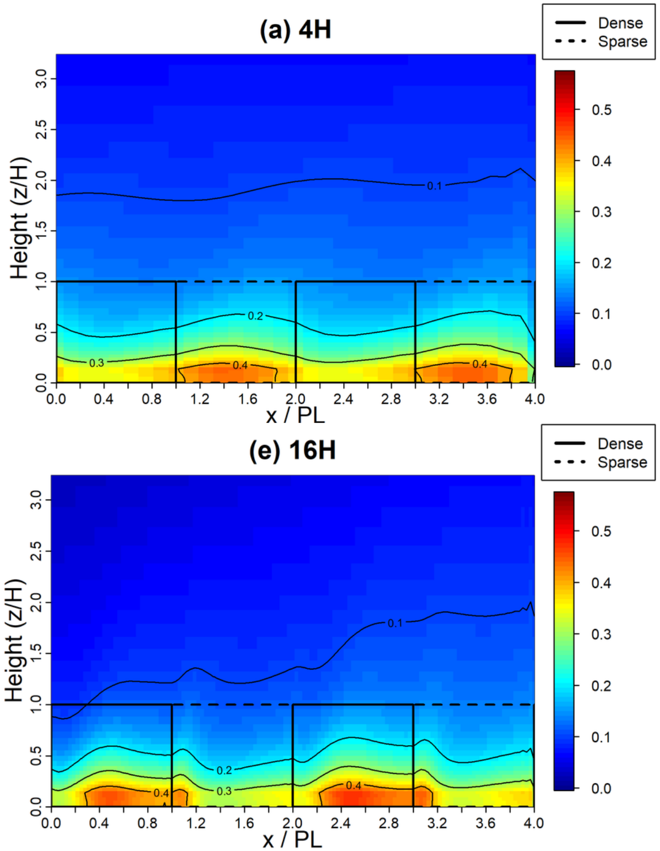
In-canyon dispersion in patchy neighbourhoods

Domain Setup



Density varied in patches of 4*H*, 6*H*, 8*H*, 12*H* and 16*H*

Normalized pollutant concentration

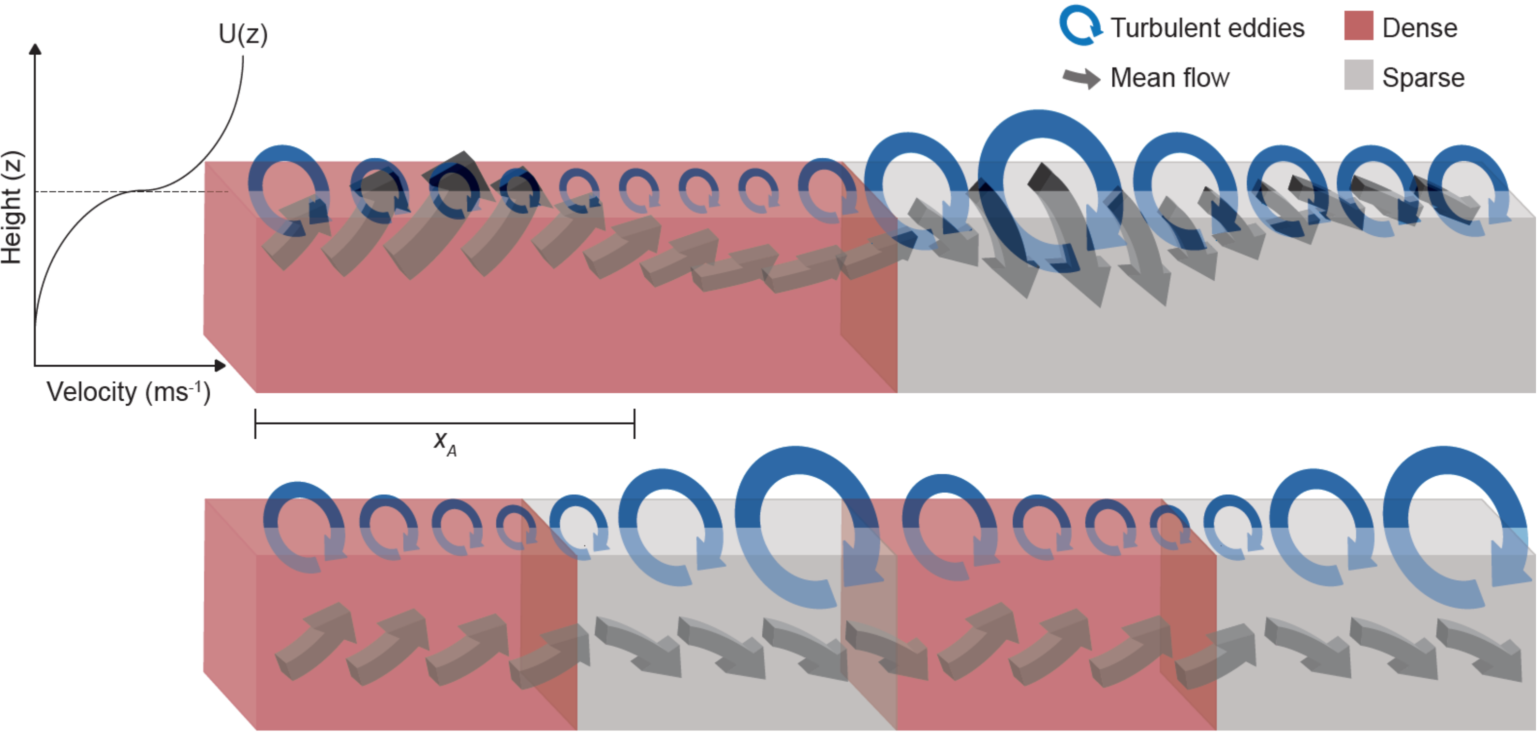


PL: patch length

Bannister, E. J., Cai, X., **Zhong, J.**, MacKenzie, A. R. 2020. Neighbourhood-scale flow regimes and pollution transport in cities. *Boundary-Layer Meteorology (Forthcoming).*

Results: in-canyon dispersion

Conceptual regimes of neighbourhood-scale flow



Ventilation regime
$(PL \gg x_A)$

Percolation regime
$(PL < x_A)$

x_A: adjustment distance of the flow PL: patch length

Bannister, E. J., Cai, X., **Zhong, J.**, MacKenzie, A. R. 2020. Neighbourhood-scale flow regimes and pollution transport in cities. *Boundary-Layer Meteorology (Forthcoming).*

Discussion and conclusions

1) Neighbourhood-scale (< 1 km, transport times of few minutes) evolution of size-resolved UFPs comprises:

- the effects of emissions
- mixing with background
- multicomponent microphysics

2) Passive-like scalars scale linearly with emission rate or background concentration. An appreciable level of non-linearity occurs for smaller particles (UFPs < 100nm) and medium-range carbon SVOCs

3) This WRF-LES-UFP model of gridded UFP emissions at the neighbourhood-scale can simulate a real-world street network

4) We propose two conceptual regimes of neighbourhood-scale flow —*ventilation regime* and *percolation regime*—based on the dense/sparse patch length and the adjustment distance

THANK YOU

11/2020