Relative importance of regional and local pollutant sources in deep street canyon

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Introduction

- Hong Kong is one of the World's highest city population densities of some 60,000 persons/km^2.
- Population: 7.3 mil
- Total land: 1106km^2
- Hong Kong is called as a "vertical city" – urbanized areas have tall buildings and narrow streets.

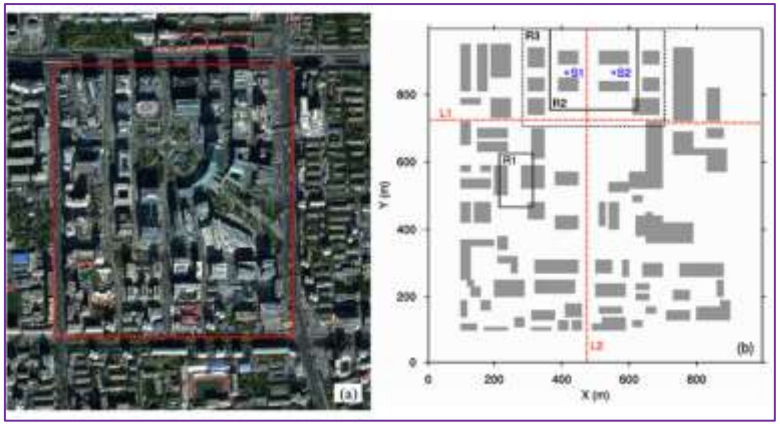
- Air quality in Hong Kong is an important problem because of the local and regional pollutant sources.
- Urban air pollution can be complicated by urban form, topography and weather conditions.
- Weather pattern largely affects the air quality in Hong Kong. There are number of studies focusing on the weather pattern and air quality in Hong Kong.
- Dense environments affect the pollutant dispersion. Studies ignored vertical pollutant variations and the effects of buildings.

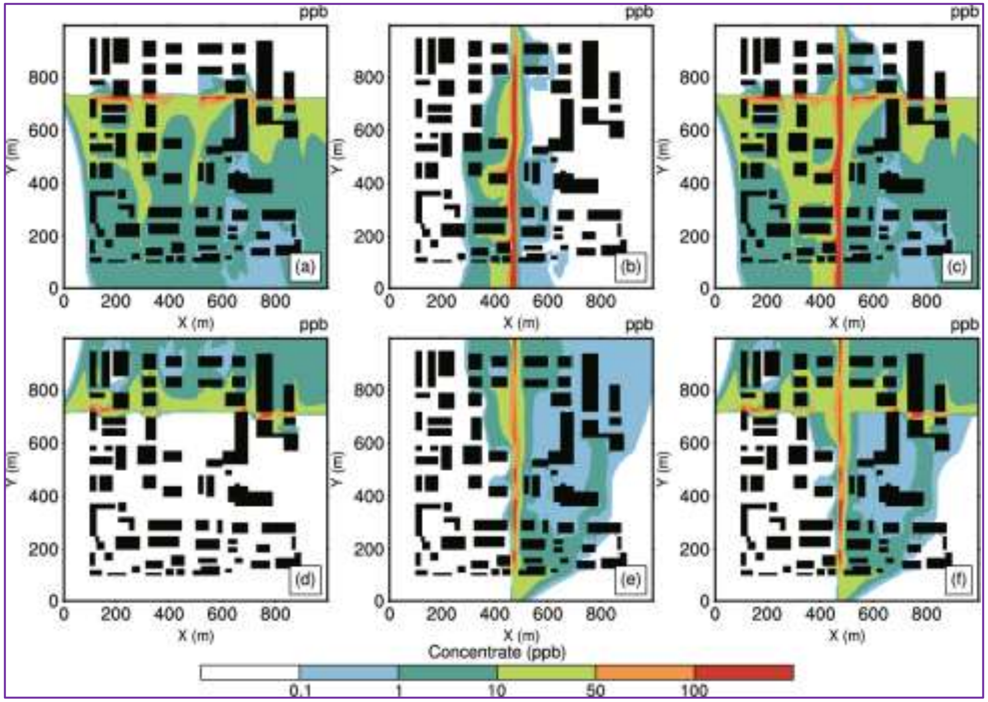
Previous studies

Flows and pollutant dispersion in street canyon

- Idealized simulations: relatively simple urban morphologies
- Quasi-realistic: mesoscale+CFD

Miao et al. (2013) – Beijing; WRF-OpenFOAM



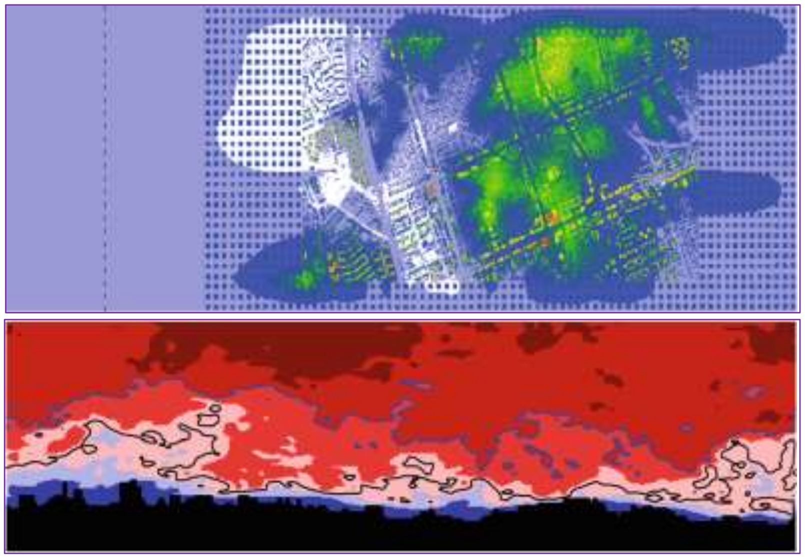


Pollutant dispersion pattern of line sources is complicated due to buildings, wind direction and source location.

Previous studies

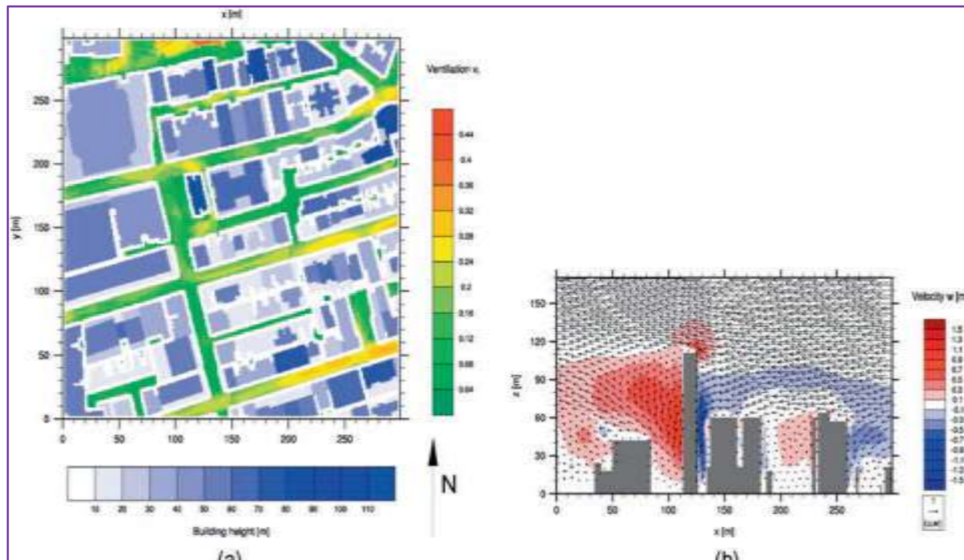
- Quasi-realistic: mesoscale+CFD

Park et al. (2015) – PALM
Seoul, South Korea



Specific areas (apartments, behind high-rise buildings and park) are selected to analyse the turbulent flow structure.

Letzel et al. (2012) –PALM
Hong Kong



Single tall building locally enhances ventilation due to vertical advection.

Objectives

To answer key questions related to the influence of local and regional effects on Hong Kong air quality inside deep street canyons:

- How does the relative importance of regional and local sources vary with height?

- How is the balance between them affected by the building geometry?

- What are the key physical processes?

Issues will be assessed by coupling a mesoscale model to an urban-scale computational fluid dynamics model.

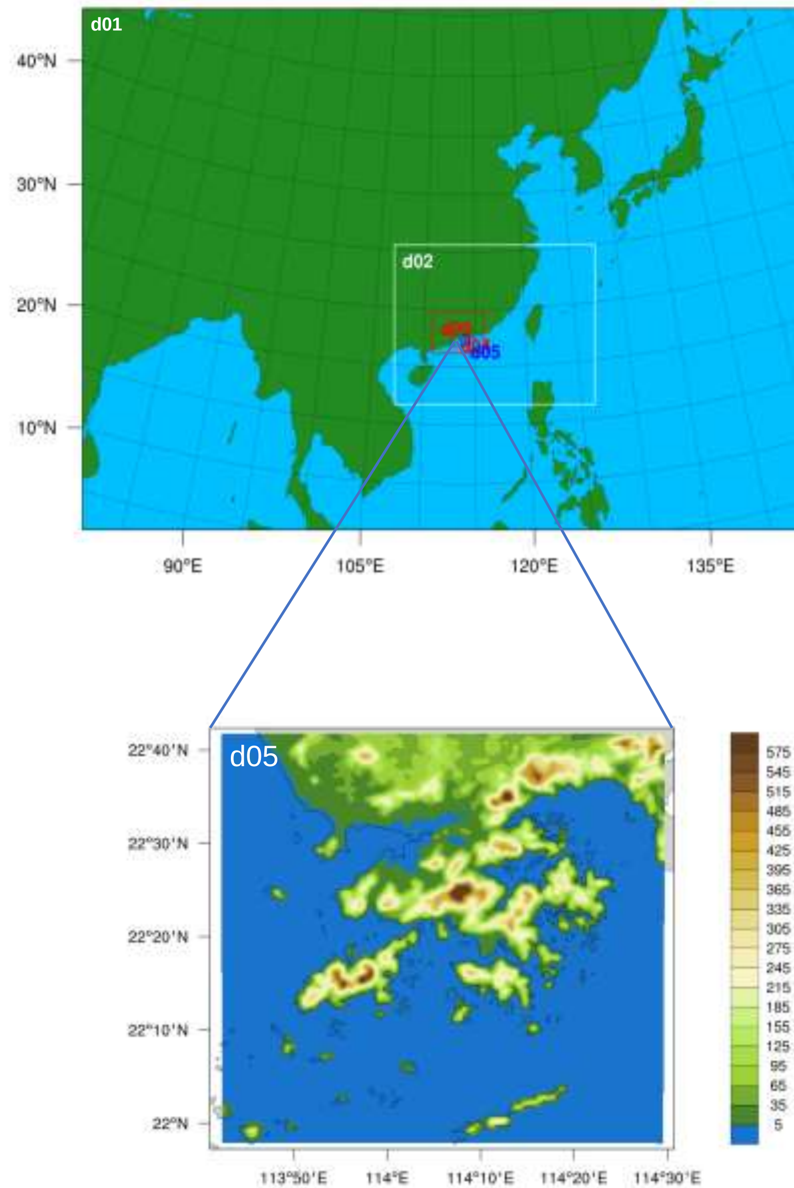
Coupled simulations

WRF → **PALM**

Mesoscale model: WRF v3.7

	D1	D2	D3	D4	D5
Horizontal grid dimension	283×184	223×169	172×130	214×163	241×241
Vertical layers	30				
Horizontal grid size (km)	27	9	3	1	1/3
Time integration (h)	54h starting from 0600 UTC 9 Jan 2017				
Time step (s)	162	54	18	6	2
Microphysics scheme	WRF Single-Moment 6-class				
Cumulus parameterization	Kain-Fritsch		none		
LW Radiation	RRTM (Rapid Radiative Transfer Model)				
SW Radiation	Dudhia shortwave radiation				
PBL	YSU PBL				
UCM	Single-layer UCM				
Initial/boundary conditions	NCEP final analysis data (6-h intervals, 1°×1° resolution)				

Model domains



Experimental design

CFD model: PALM

Elevation data with 2-m resolution

Domain size: 960m × 576m × 384m

Analysis area: 576m × 576m

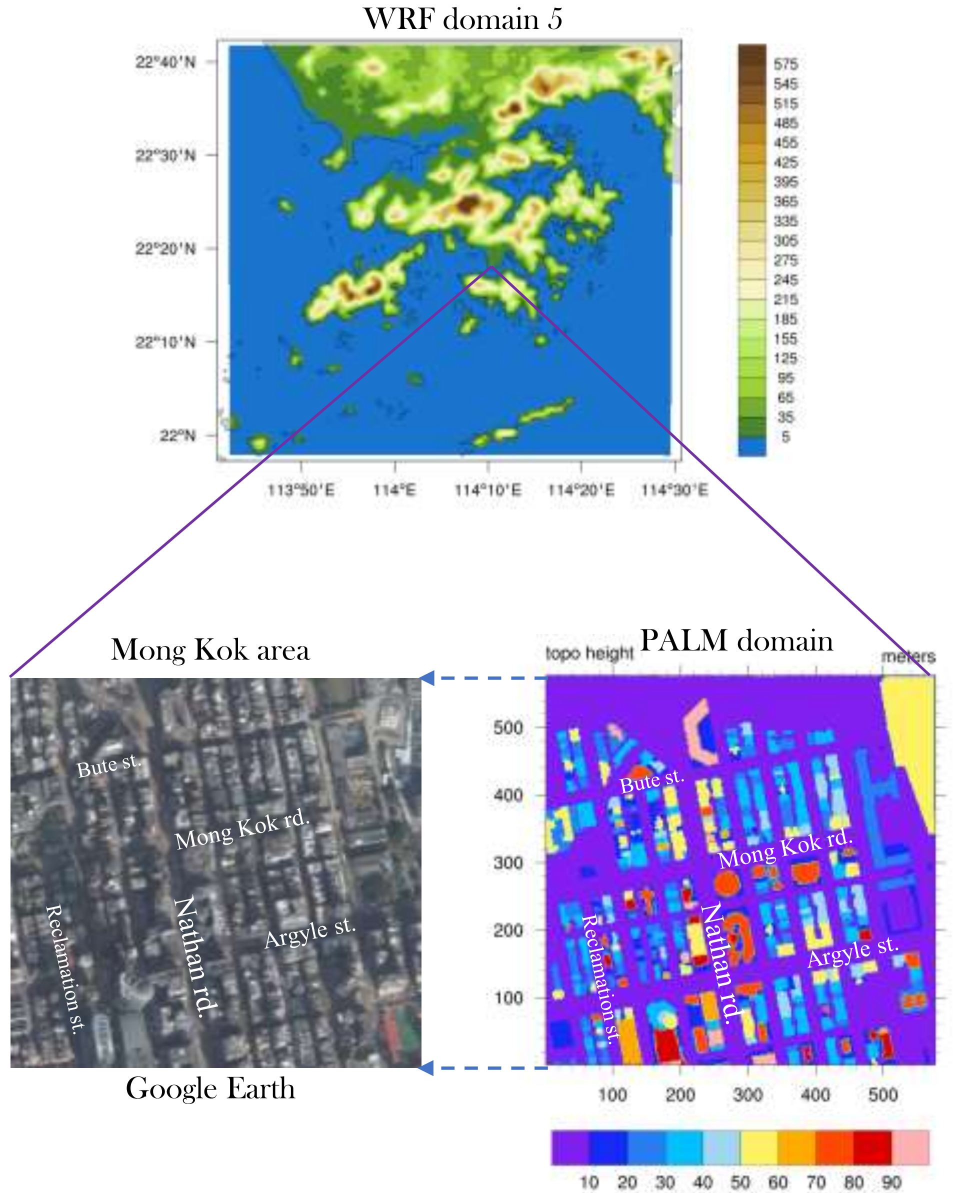
Grid size: Δx=2m, Δy=2m, Δz=4m

Simulation time: 3600 s after 7200 s precursor run

Boundary condition:

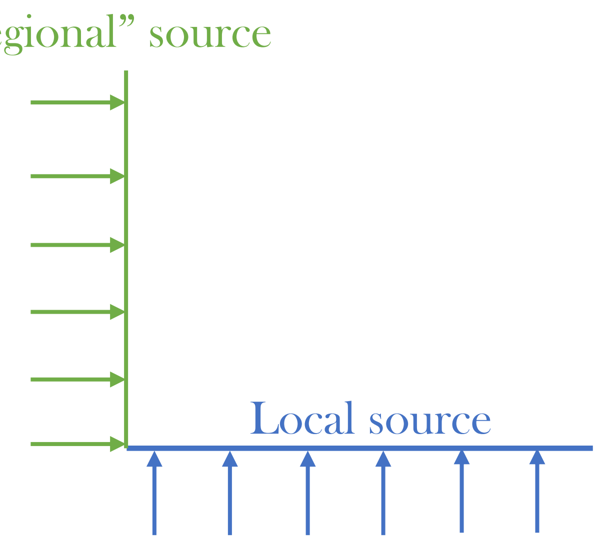
Dirichlet/radiation in the *x*-direction

Cyclic in the *y*-direction



Experimental design – PALM

3 cases:
1) Local source – LS
2) "Regional" source – RS
3) 1+2 - CTRL



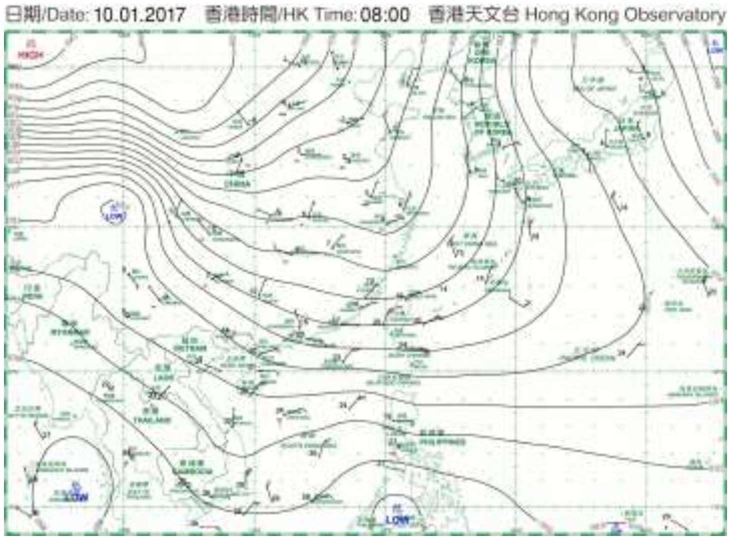
Time-dependent mesoscale inflow perturbation are incorporated using Newtonian relaxation i.e. nudging method.

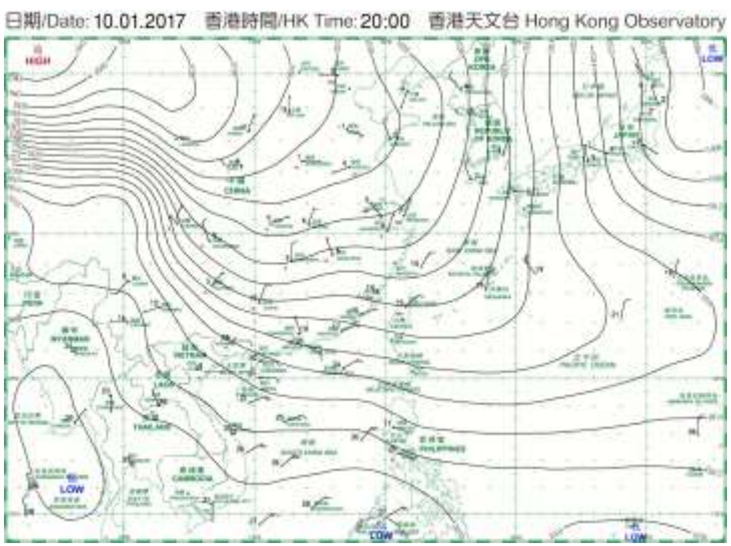
$$\frac{\partial \bar{u}_i}{\partial t} + \frac{\partial \bar{u}_i \bar{u}_j}{\partial xj} = -\frac{1}{\rho_0}\frac{\partial \bar{\pi}^*}{\partial x_i} - \frac{\partial \tau_{ij}}{\partial x_j} + g_i + F_N$$

$$F_N = C_0 e^{-x/l}\left(\vec{u} - \vec{u}_{meso}\right)$$

Weather condition

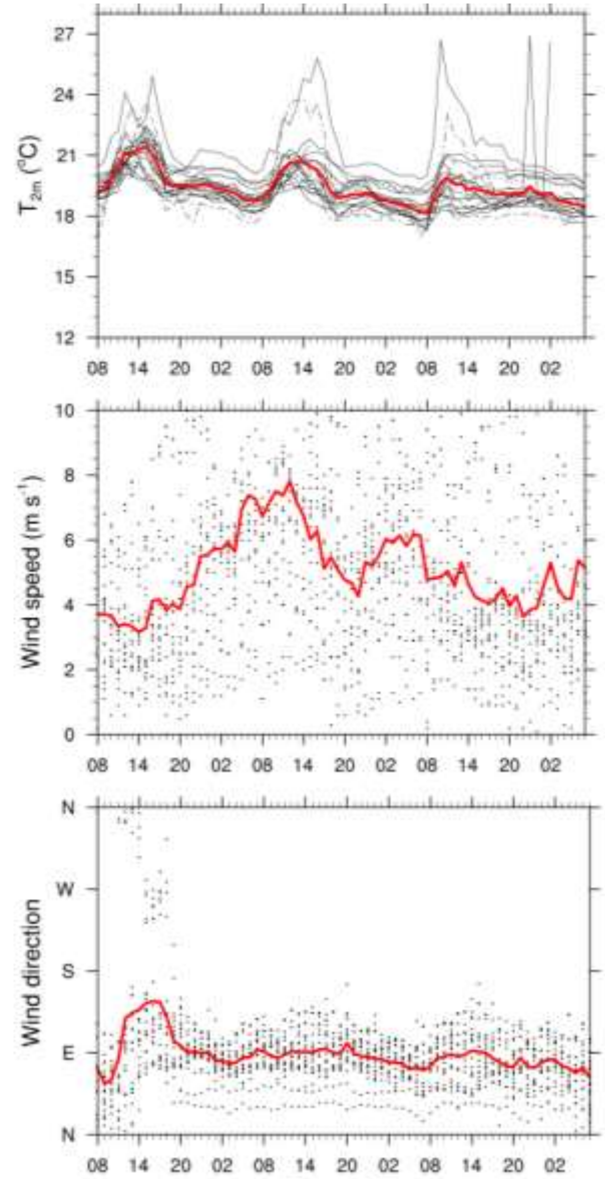
Weather maps





During the study period, easterly wind was dominant in HK.

Diurnal variations

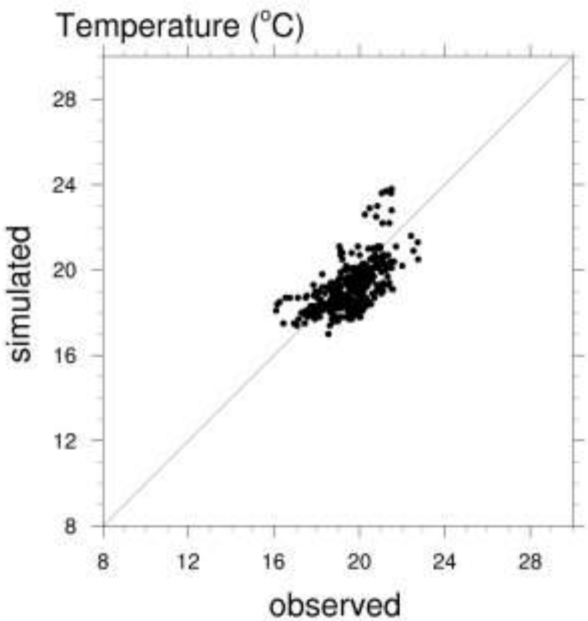


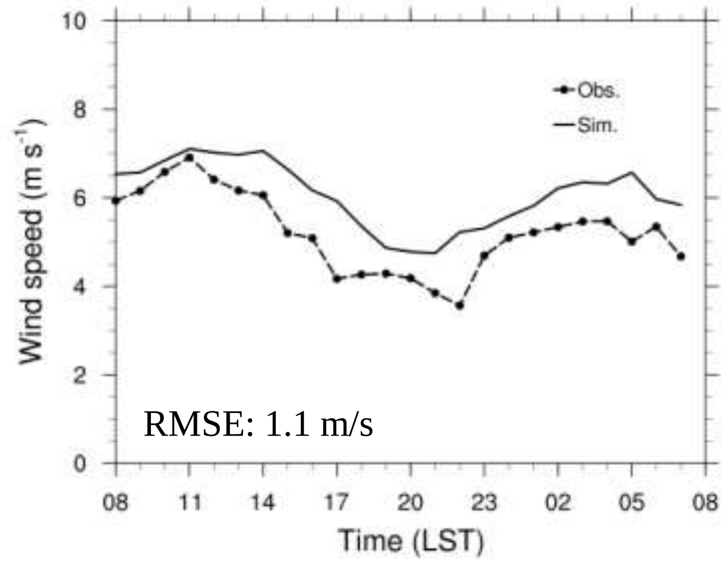
Red – average over the stations in HK

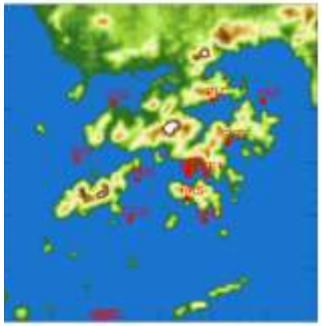
Model validation (1)

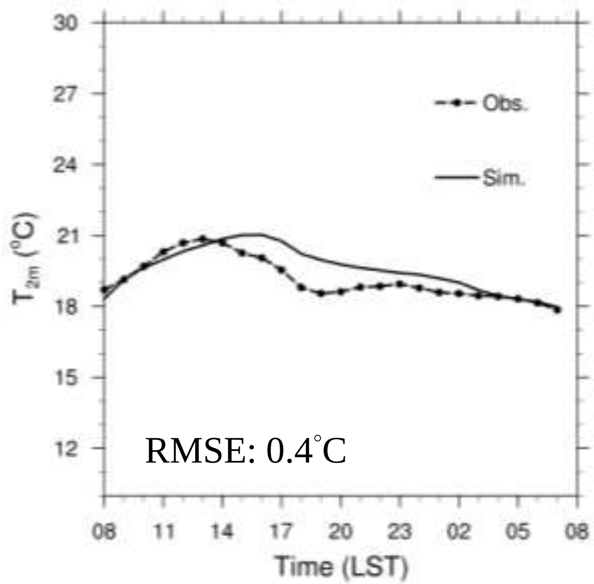
Stations: B10, BHD, CCH, HKO, KP, HKS, HM2, HMZC, KP, KPC, LFS, PEN, PLC, SE1, SKG, TAP, TKL

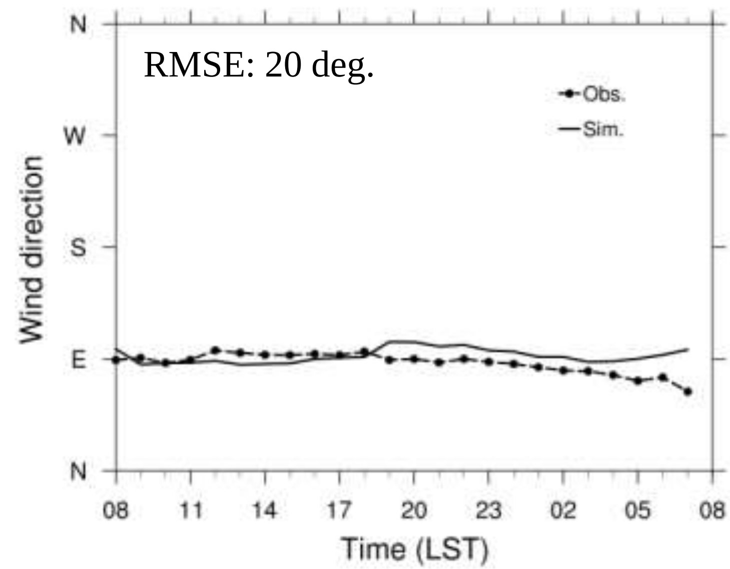
Validated for 10 Jan 2017.





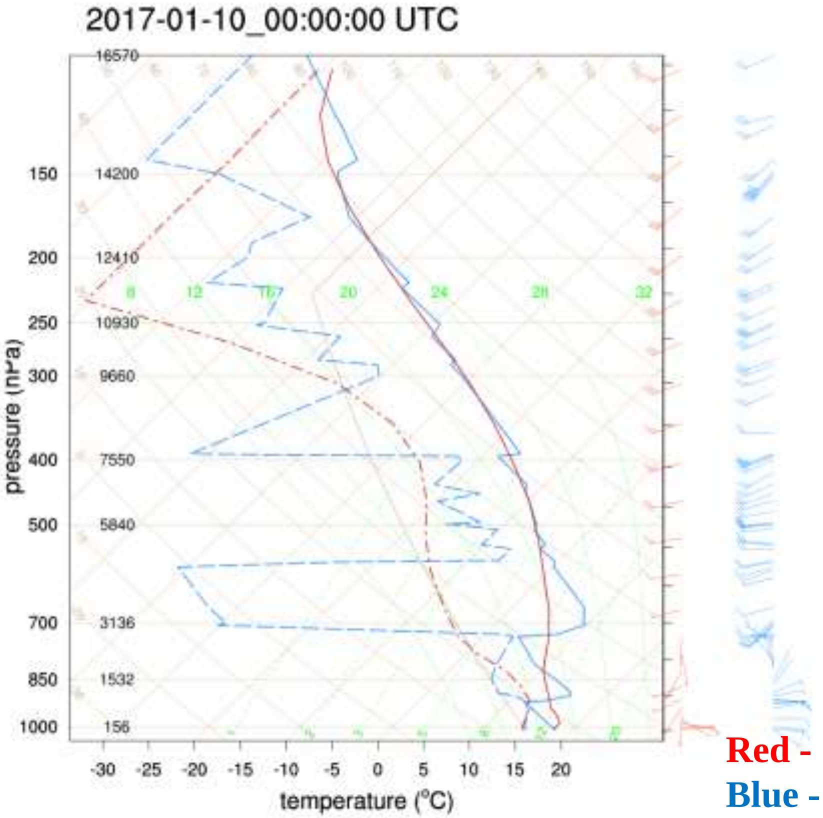


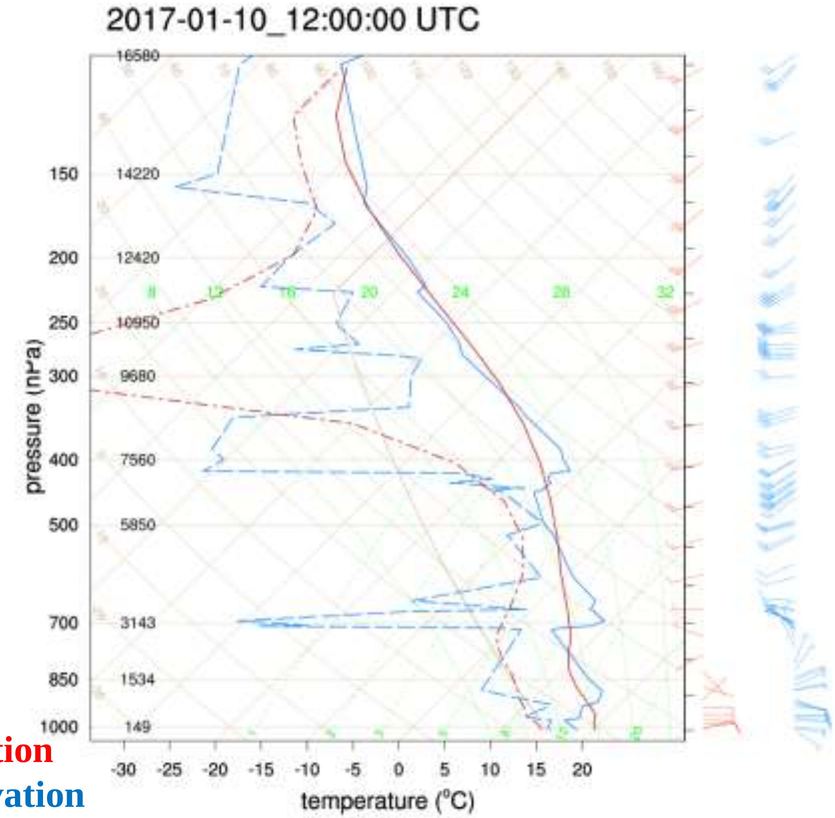




Model validation (2)

King's Park 45004



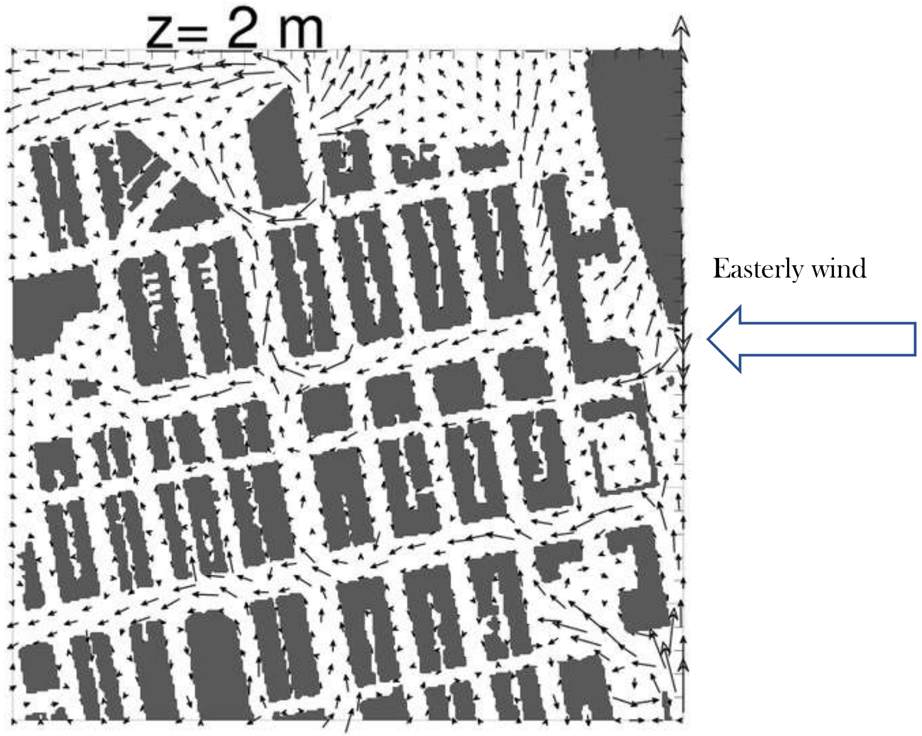


Red - Simulation

Blue - Observation

Results

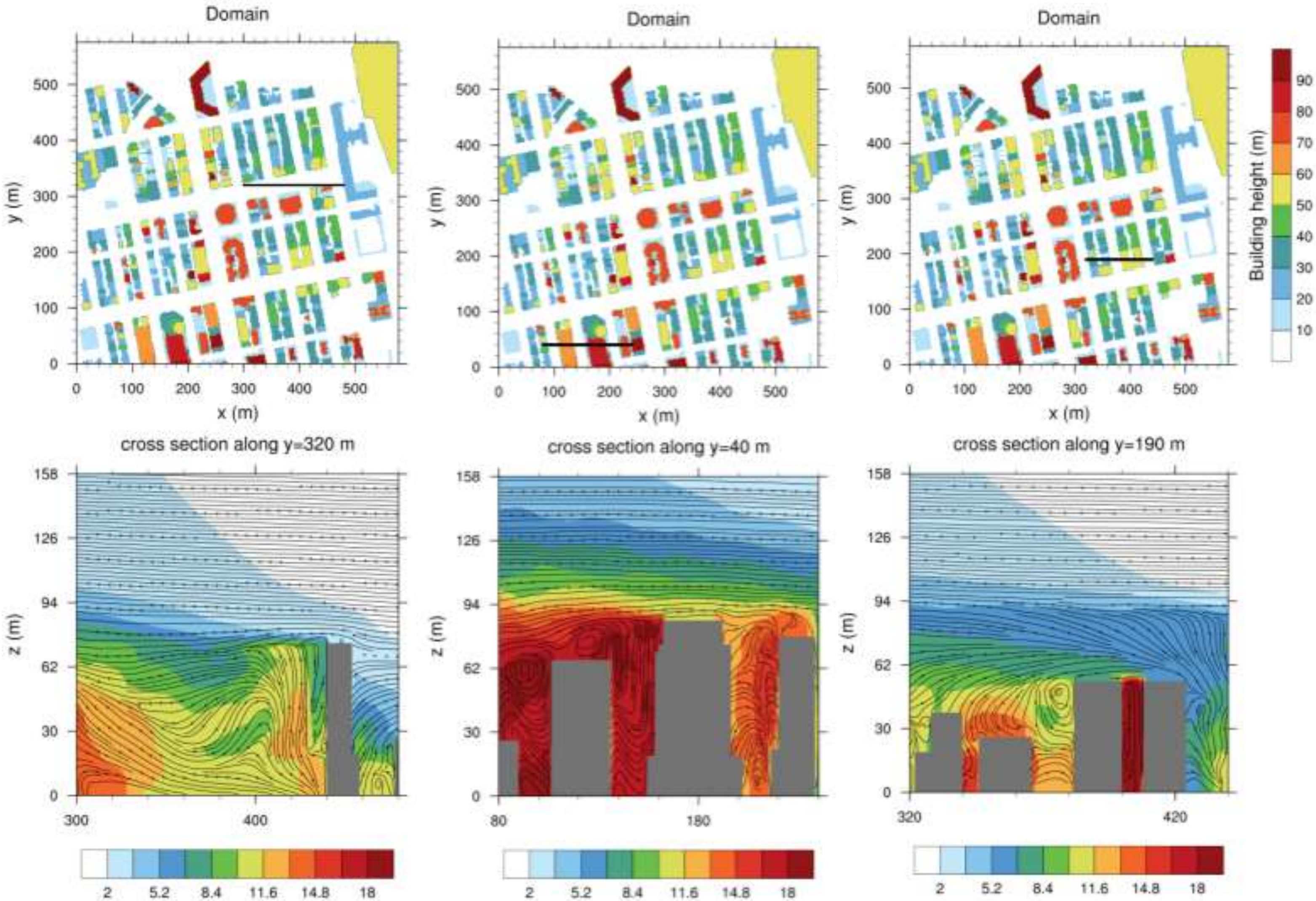
Wind vectors in the complex morphological streets



Time-averaged horizontal wind at heights

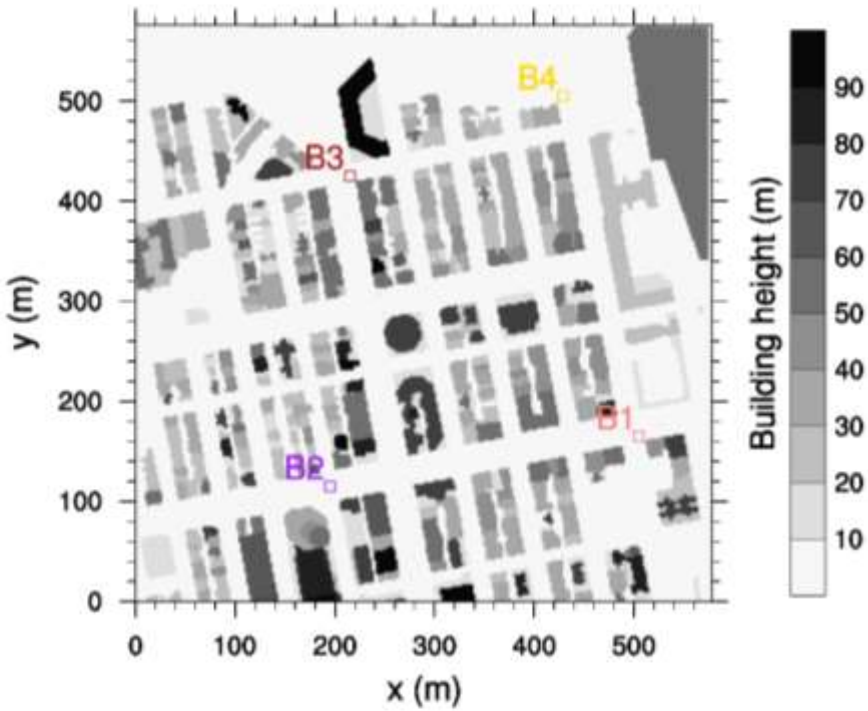
Results

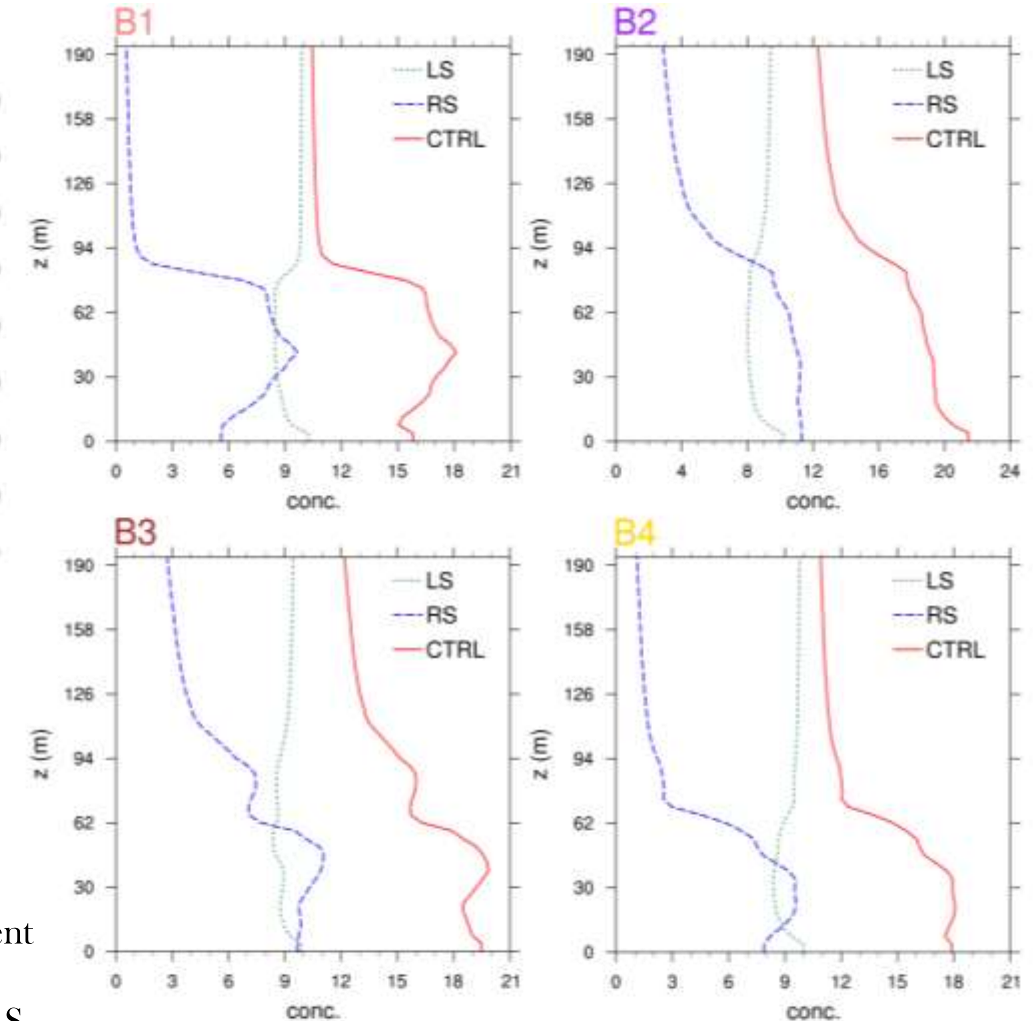
Vertical cross sections



Results

Vertical profiles of the scalar concentration **at the intersection streets**





B2 – 34-50-62-72 m. closer to 72 m.

B1 – 10-42-54-86 m; closer to 42 m.

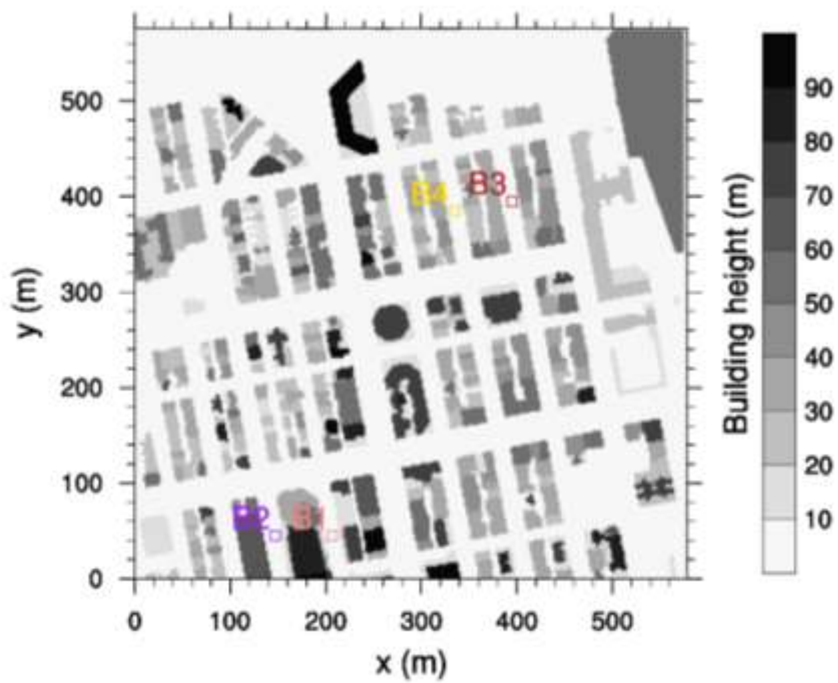
B3 – 18-58-58-90 m; closer to 58 m.

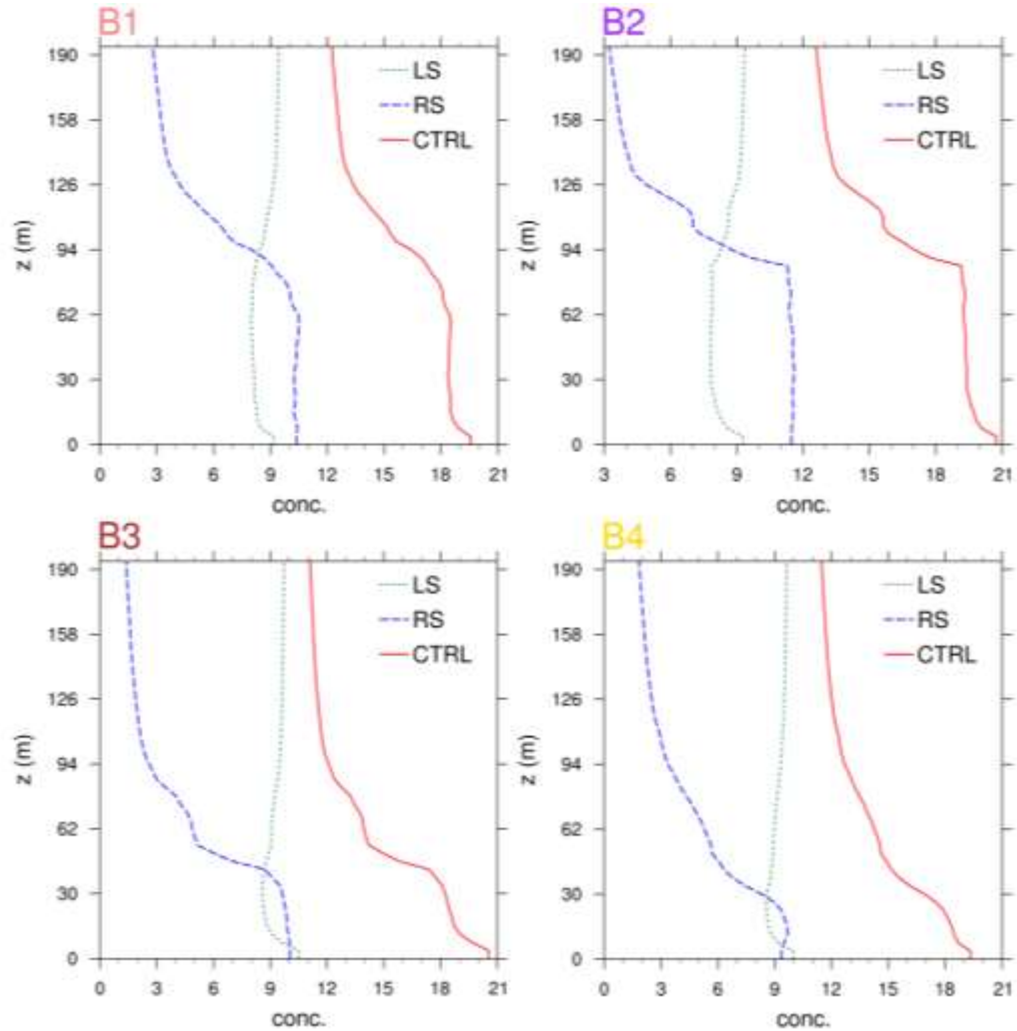
B4 – 22-36-42-50 m; closer to 38 m.

- Vertical structure of pollutant largely dependent on the heights of nearby buildings.
- Larger concentrations near surface in LS, consequently CTRL. General shape of CTRL in the upper level is defined by the RS.

Results

Vertical profiles of the scalar concentration **in deeper and shallower street canyons**



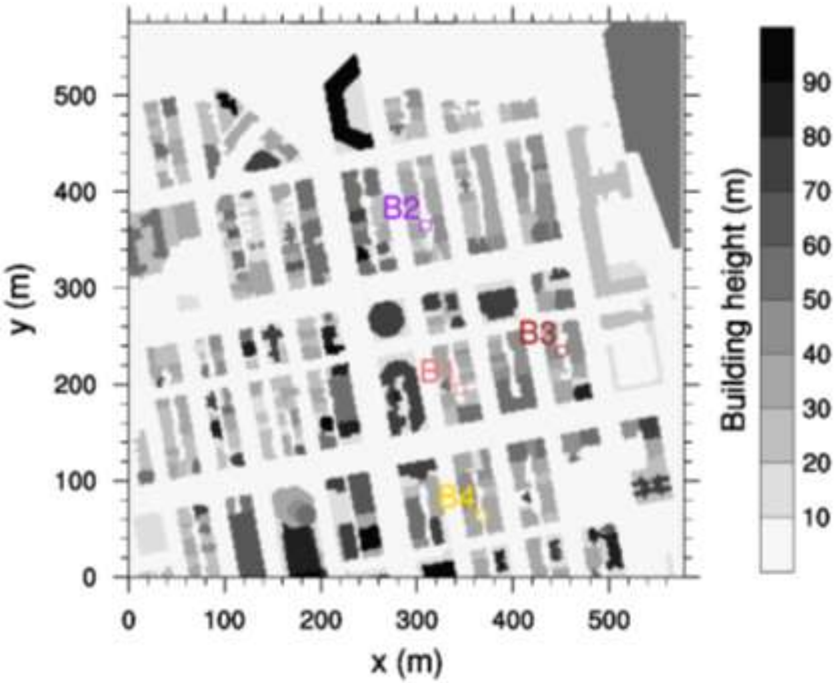


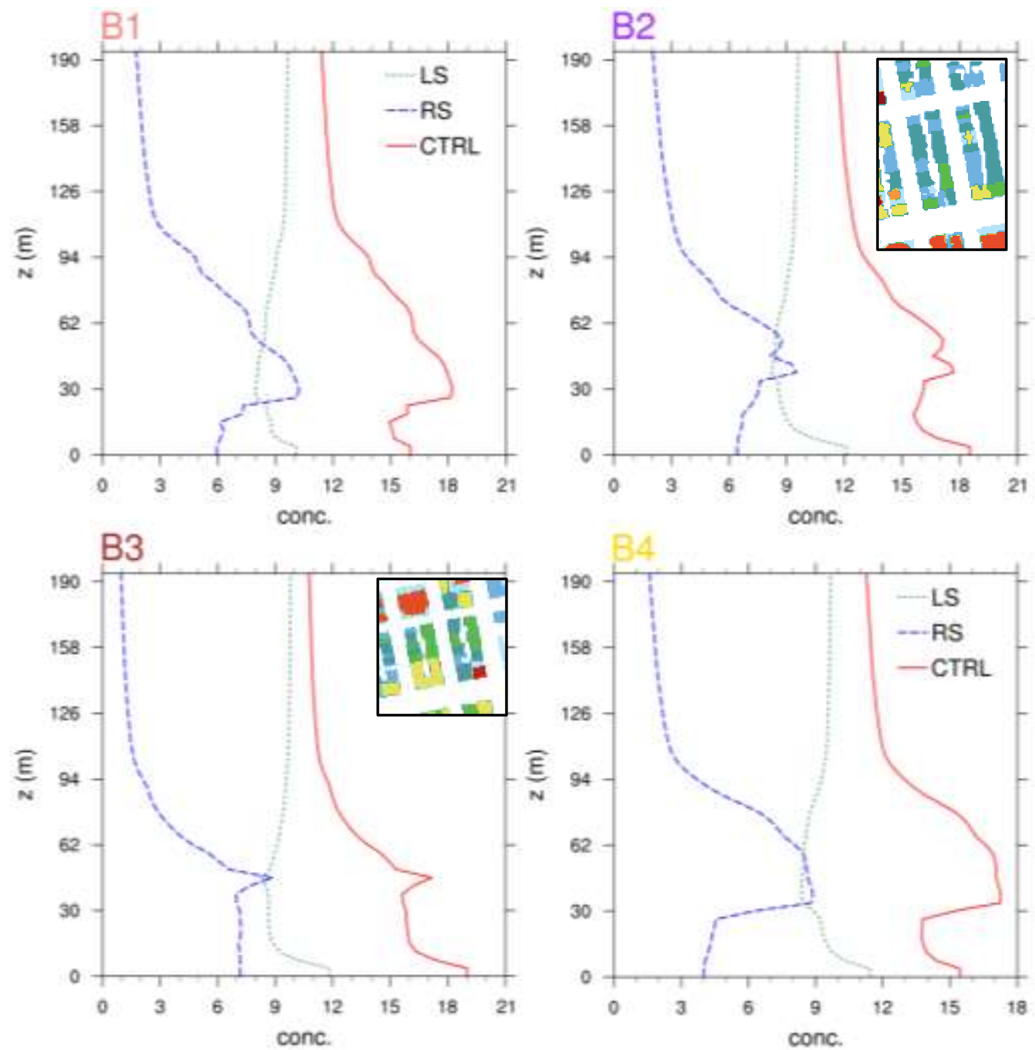
B1, B2 – deeper street canyons (18-86 m.)
Shallower B3 – 38-42 m.
Shallower B4 – 22-26 m.

- Vertical structure of pollutant largely dependent on the heights of nearby buildings.
- Larger concentrations near surface in LS, consequently CTRL. General shape of CTRL in the upper level is defined by the RS.

Results

Vertical profiles of the scalar concentration **in the narrow open spaces between buildings**





B1 – 26-58 m; entrance at 26 m.

B2 – 34-42-46 m.

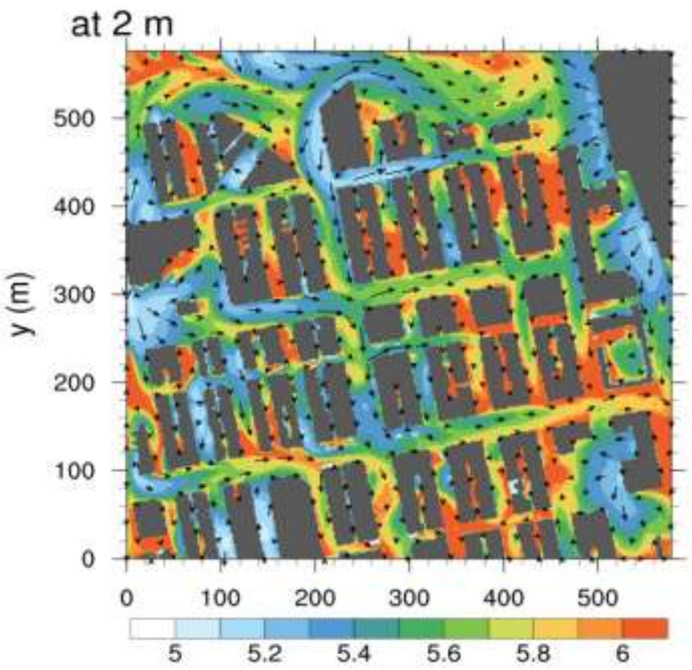
B3 – 26-46 m.

B4 – 34-38 m.

- Building heights and spaces between buildings largely affect the particle entrainment in the narrow spaces between buildings.
- Lower level: CTRL follows by LS
- Upper level: CTRL follows by RS

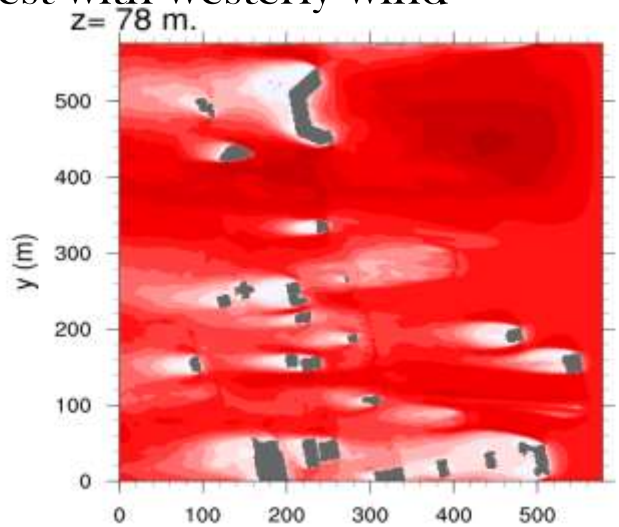
Results

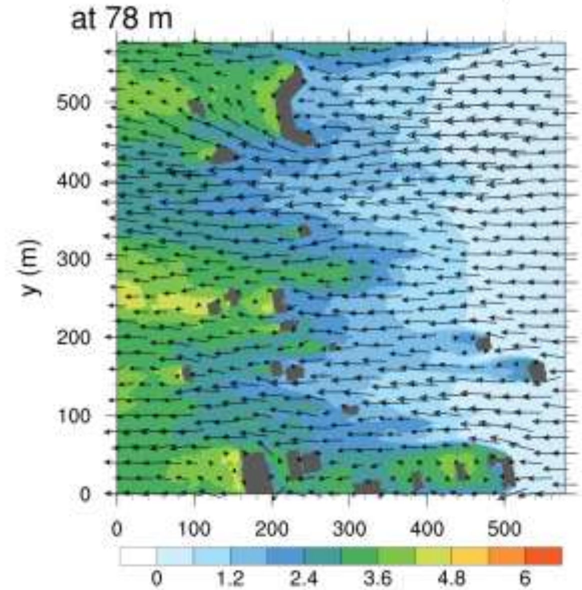
Idealised test with westerly wind



Results

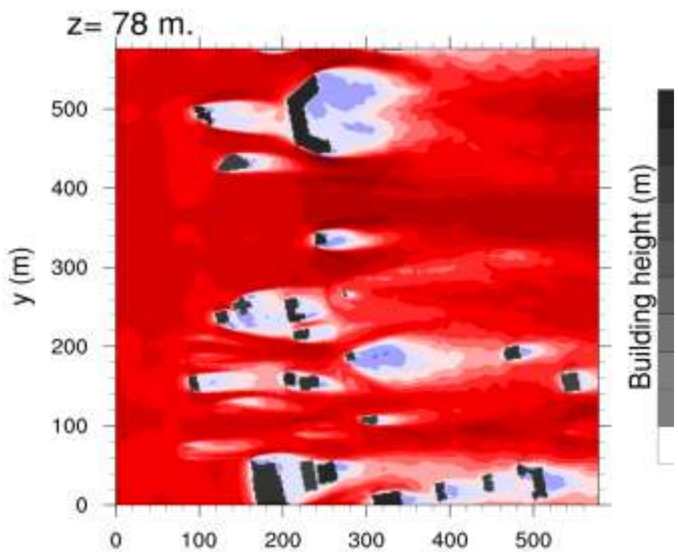
Idealised test with westerly wind

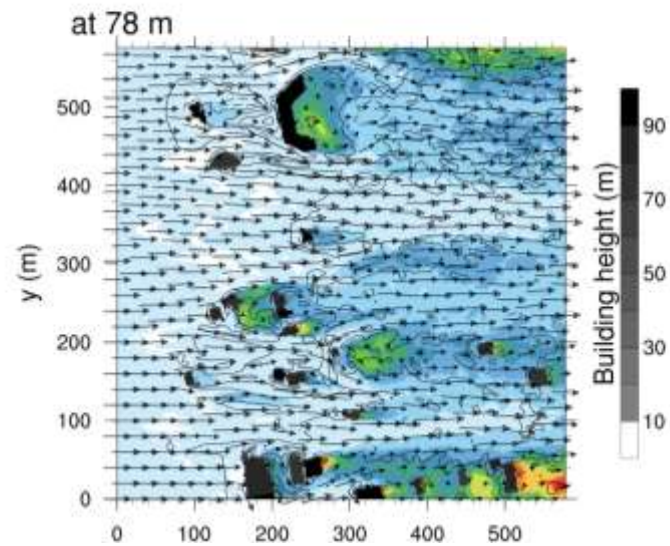




Easterly wind

Westerly wind





Next steps

- Examine the pattern under different weather conditions
- Conduct experiments with real regional emission data
- Comparison with measurements to calibrate the initial local sources

Summary

- Coupling of mesoscale model (WRF) with a CFD model (PALM) is done to provide realistic boundary conditions.
- Vertical structure of the sources is largely dependent on building geometry, locations.
- Wind direction has significant effect on the particle dispersion.

Thank you for your attention!

Q&A