NWTF

Urban Tall Building Clusters: Influence on Flow and Pollutant Dispersion

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URBAN TALL BUILDING CLUSTERS: INFLUENCE ON FLOW AND POLLUTANT DISPERSION

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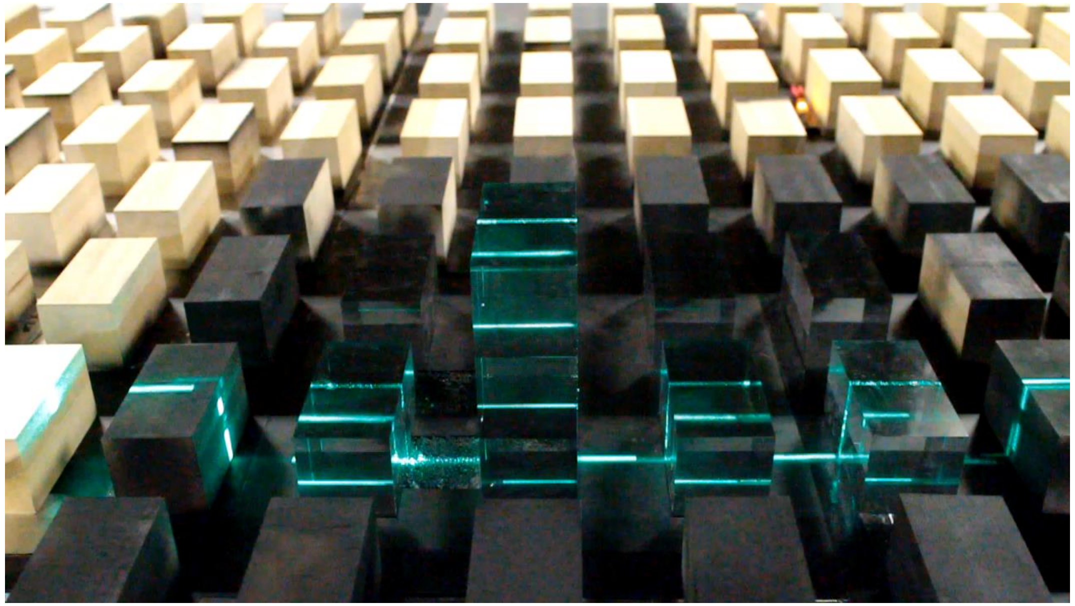
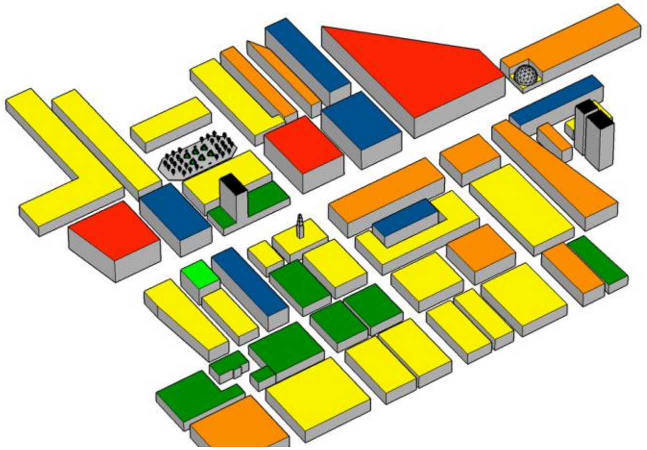
INTRODUCTION

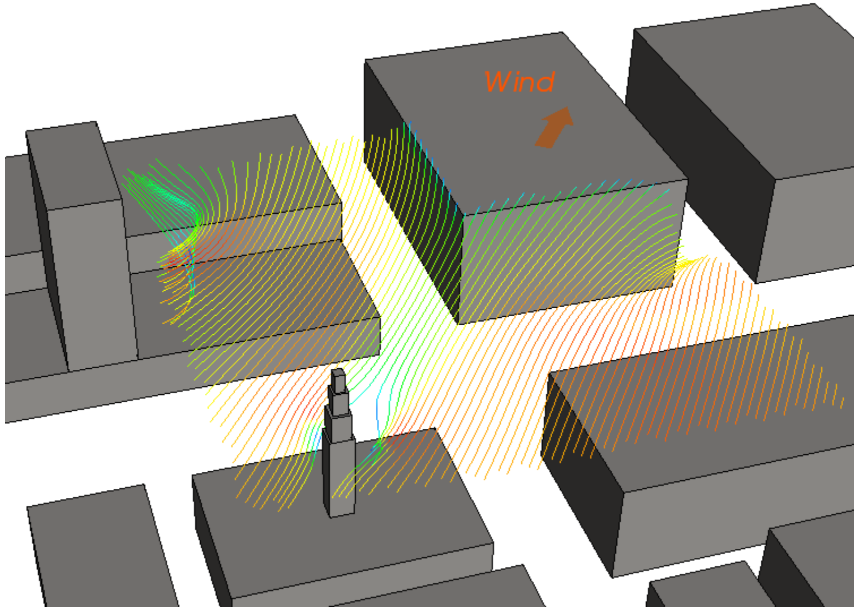
Carpentieri et al., Boundary-Layer Meteorology, 2009

High-rise buildings produce significant changes in

- Pedestrian comfort
- Surface temperature
- Pollutant Dispersion
- Street Ventilation



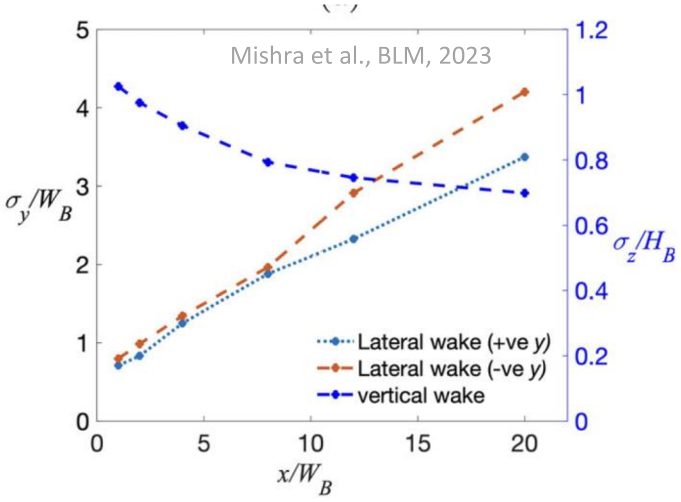




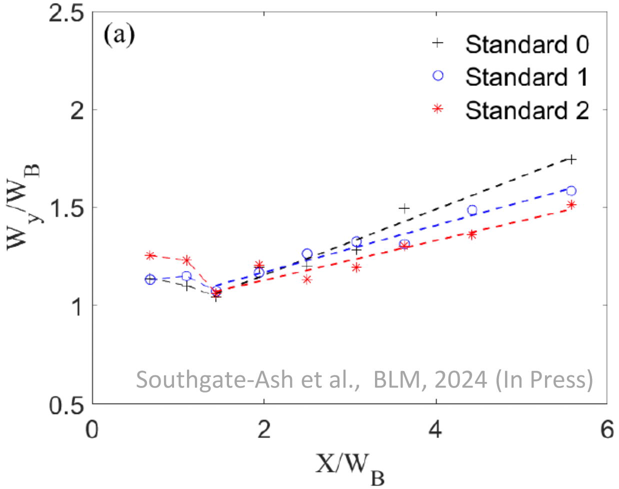
MODELLING BUILDING WAKES

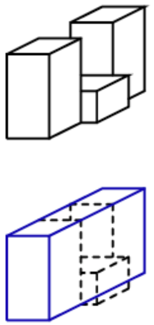
- Current wake modules in dispersion models, such as ADMS-BUILD and PRIME are built on the classical wake theory on a simplified building geometry

Tall building (AR=6)



Short (AR=1), multi-scale features

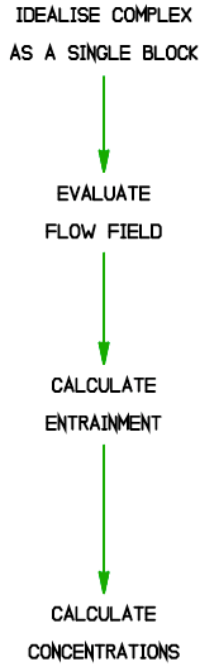


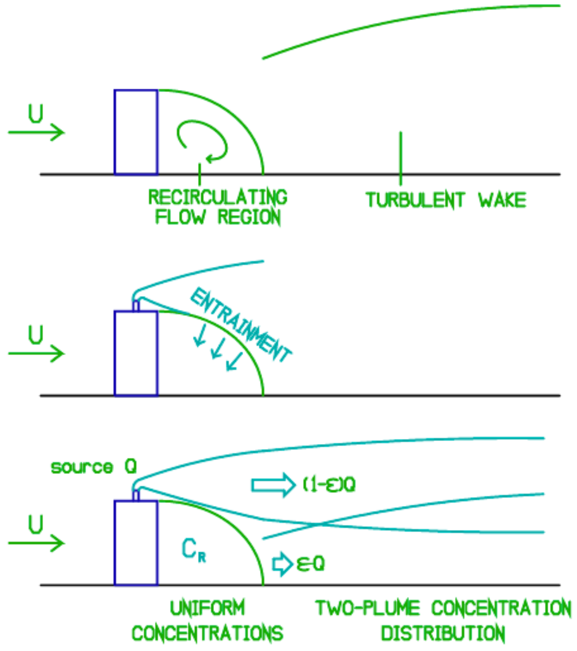


Wake growth prediction:

PRIME: $\sim x^{\frac{1}{3}}$

ADMS: $\sim x^{\frac{1}{2}}$

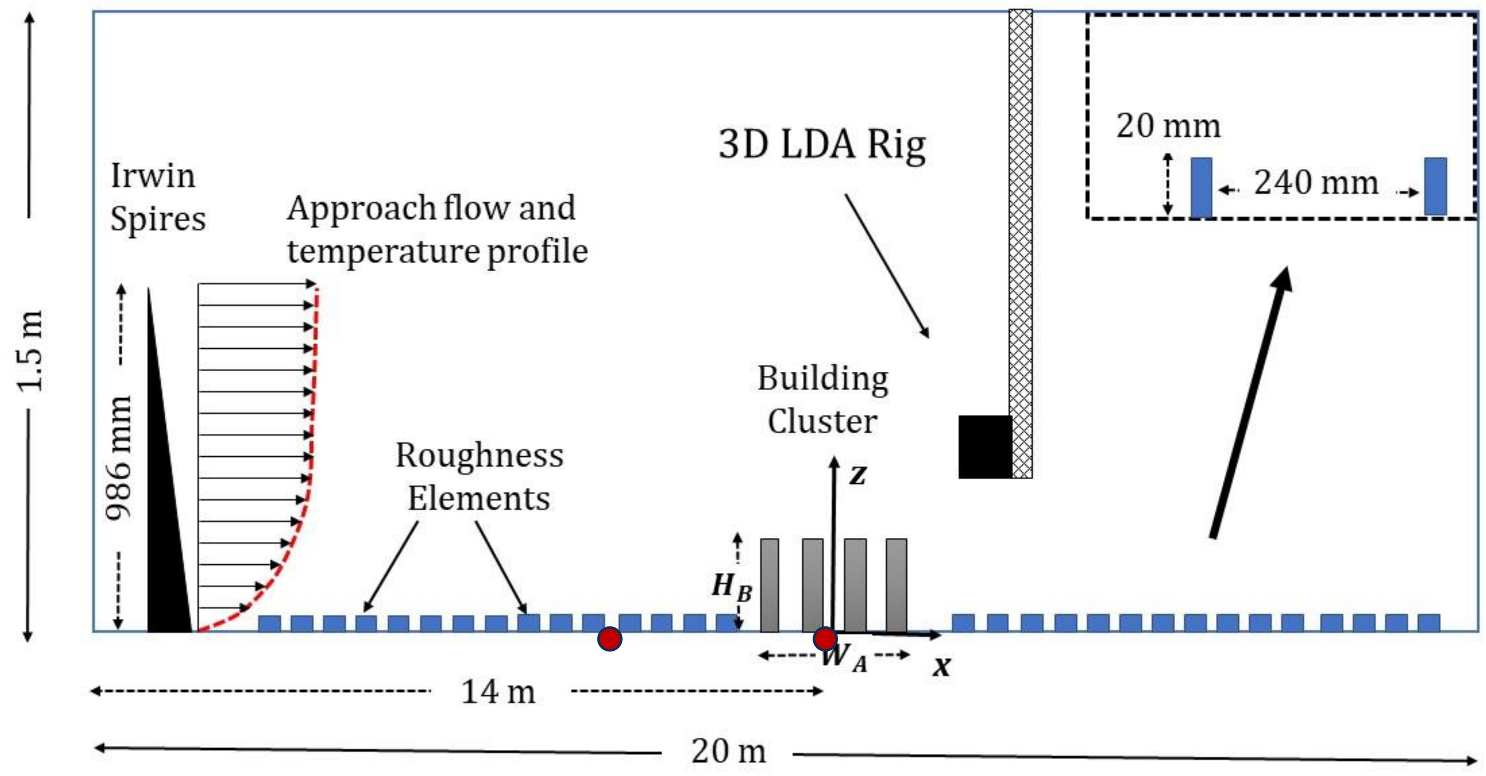




Current modelling systems need to incorporate the effects of:

- Tall buildings
- Tall building clusters
- Non-neutral stratification
- Realistic building features

EnFlo wind tunnel, University of Surrey



Working section: 20 m x 3.5 m x 1.5 m

$U_{ref} = 2$ m/s

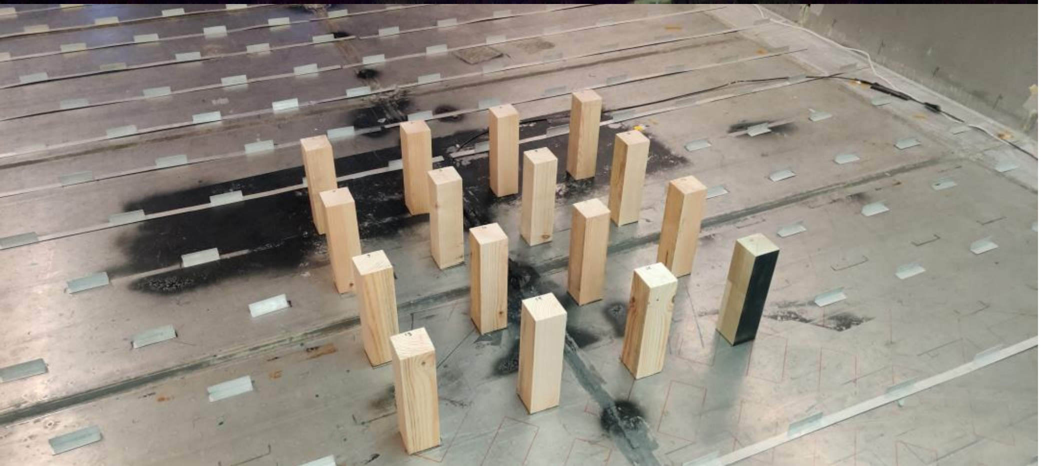
$\delta = 1$ m

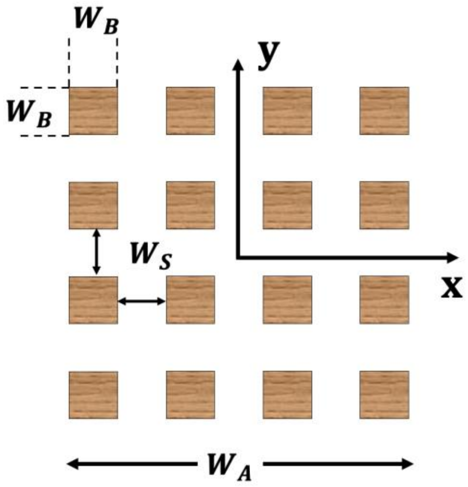
$Re_\delta = 1.32 \times 10^5$

SBL: $Ri_B = 0.22$

Instruments

- 3D laser Doppler anemometer (u, v, w)
- Cold Wire Anemometer (θ)
- Fast flame ionization detector (C)





Measurement Plane

- Lateral: $z = 0.5H_B$
- Vertical: $y = 0$

Geometrical Parameters

Array size: N=1, 2, 3, 4, 5, 8

Spacing between buildings:

W_S/W_B = 0.5, 1, 2, 3, 4

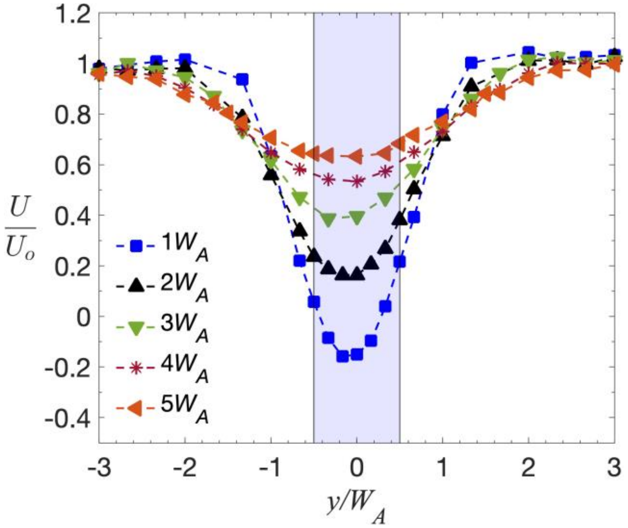
Building aspect ratio: AR=4, 6, 8

($W_B = 60$ mm, $H_B = 240, 360, 480$ mm)

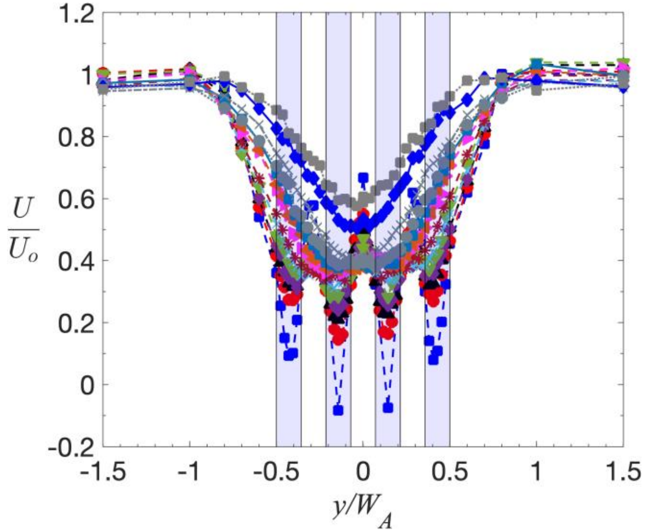
Wind direction: 0º, 22.5º, 45º

Surrounding roughness: lower, higher

SB



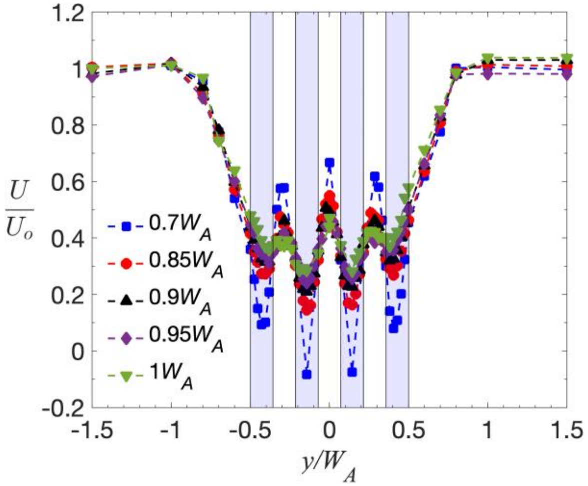
N = 4, $W_S = W_B$



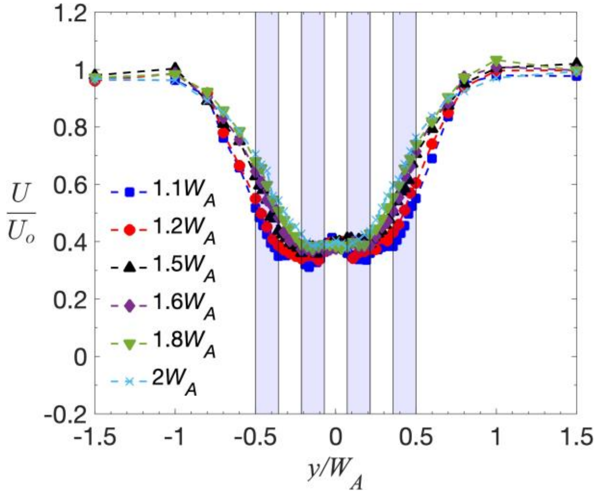
Mishra et al., BLM, 2023

- (1) Near-wake regime: Distinct wake behind individual buildings
- (2) Transition-wake regime: Wakes adjust to form a single wake
- (3) Global-wake regime: Single wake similar to behind a single building

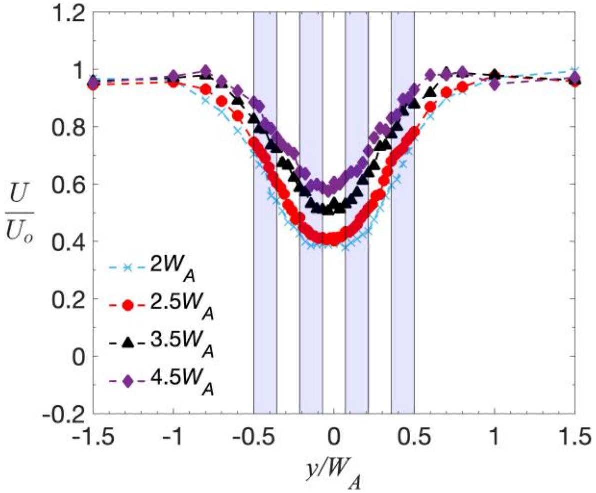
(1) Near-wake



(2) Transition-wake



(3) Far-wake

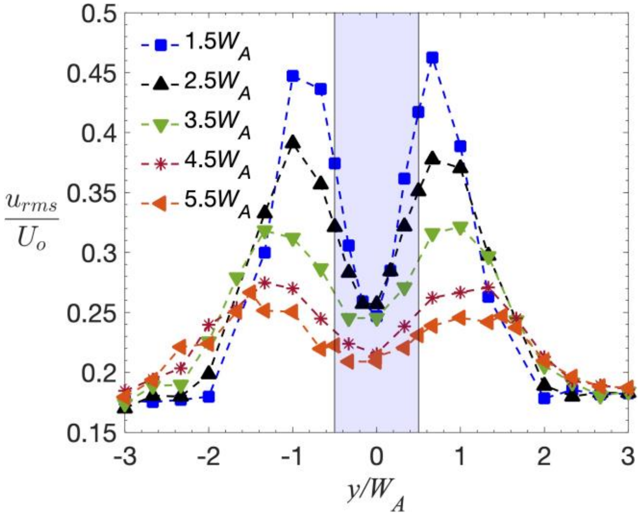


$$\left.\begin{array}{c} (1).\;\; 0.5W_A \leq x \leq 1W_A \\ (2).\;\; 1W_A \leq x \leq 2W_A \\ (3).\;\; x \geq 2W_A \end{array}\right\}$$ for all *N*, *AR*, W_S

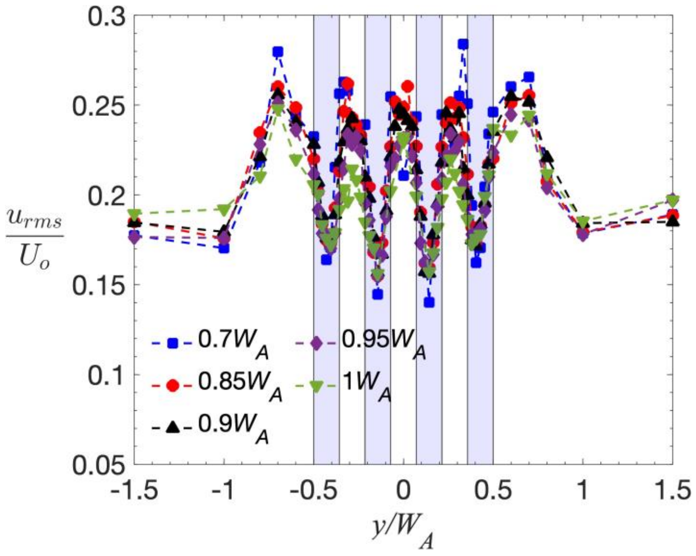
TURBULENT CHARACTERISTICS

Mishra et al., Flow, 2024

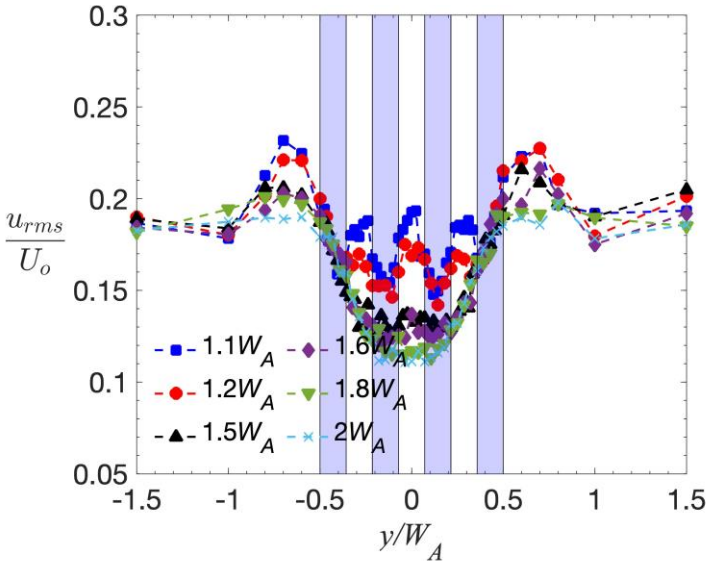
Single Building



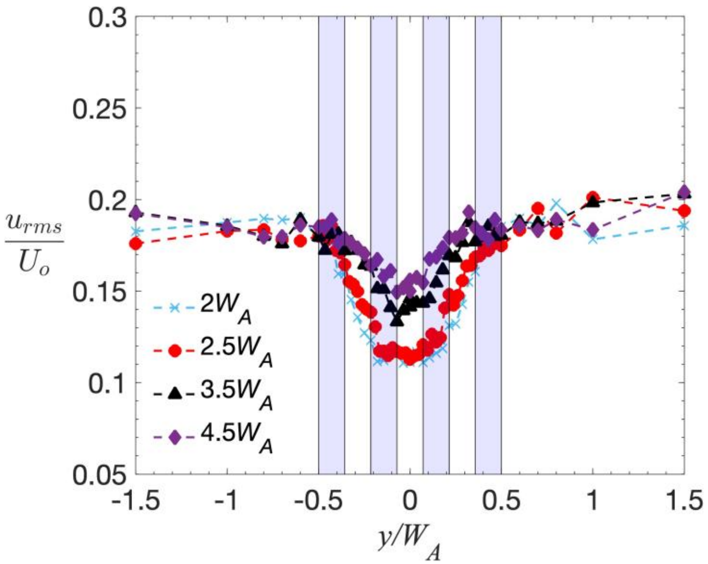
Near-wake



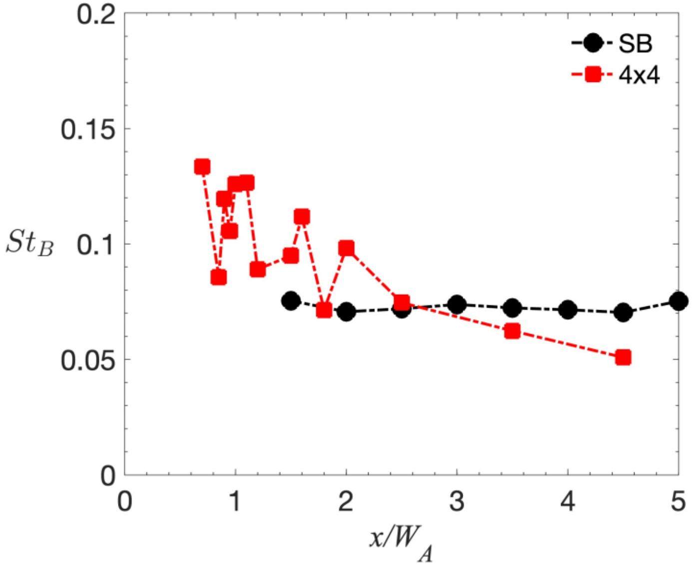
Transition-wake



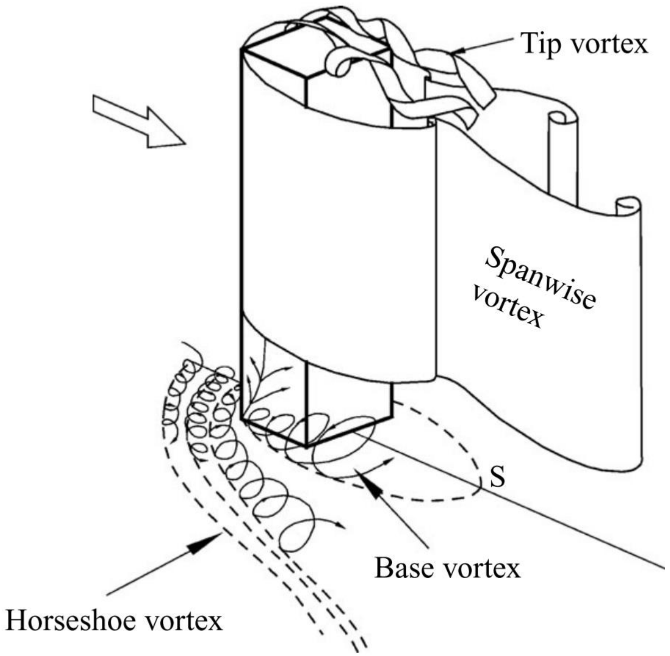
Global-wake



Mishra et al., Flow, 2024

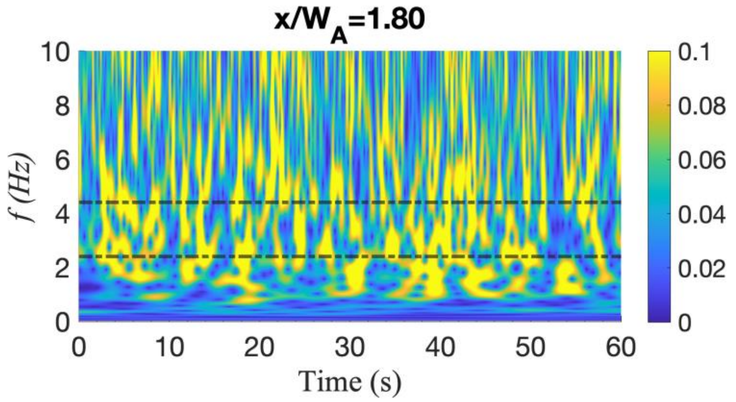


- Infinite square cylinder (from literature): $St_B = 0.14$
- Isolated Building: $St_B = 0.075$
- Building Cluster:
  - $St_B = 0.14$ in the near wake
  - $St_B = 0.06$ in the far wake
- Interaction of Base vortex, Tip vortex, and Spanwise Vortex

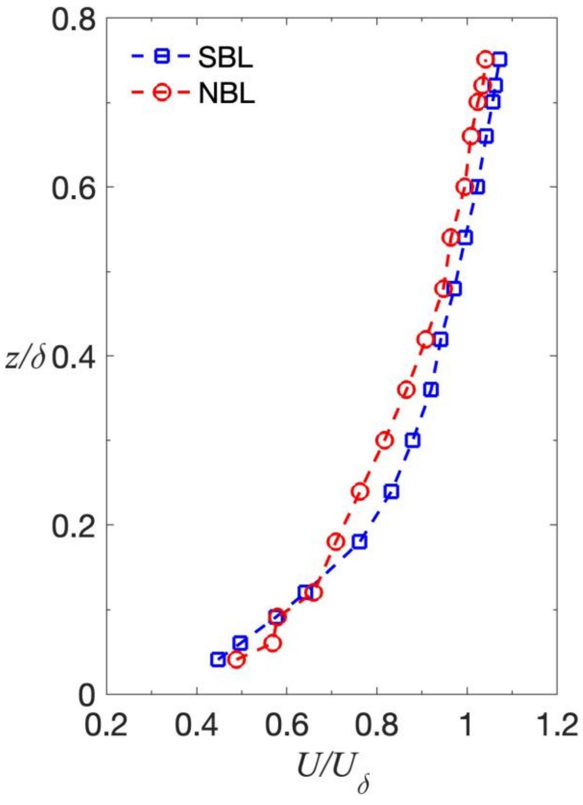


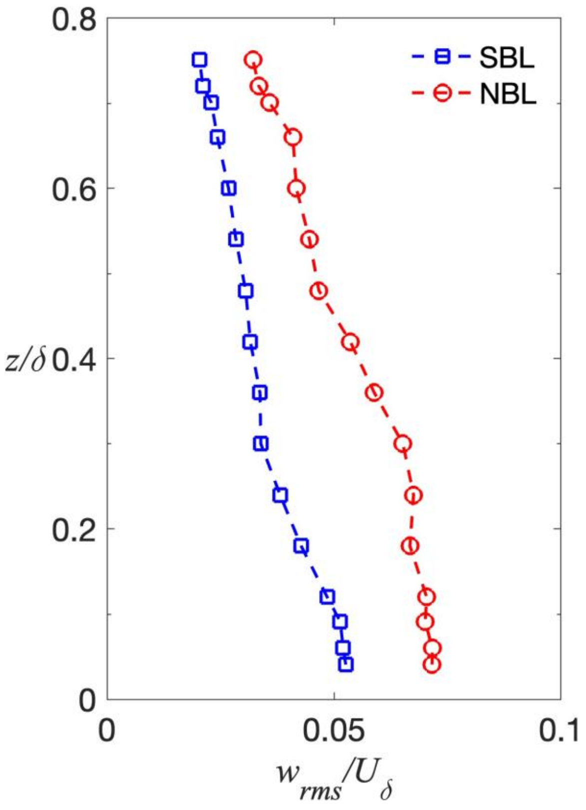
Cluster vs. single tall building:

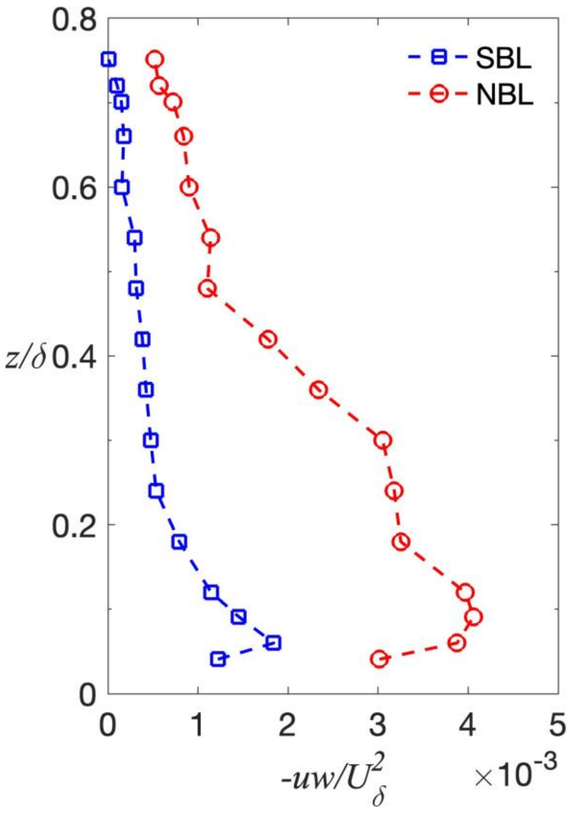
- Multiple dominant vortex-shedding frequencies characterise the transition wake regime
- Non-harmonic



Approach Flow







Mishra et al., *In Prep*

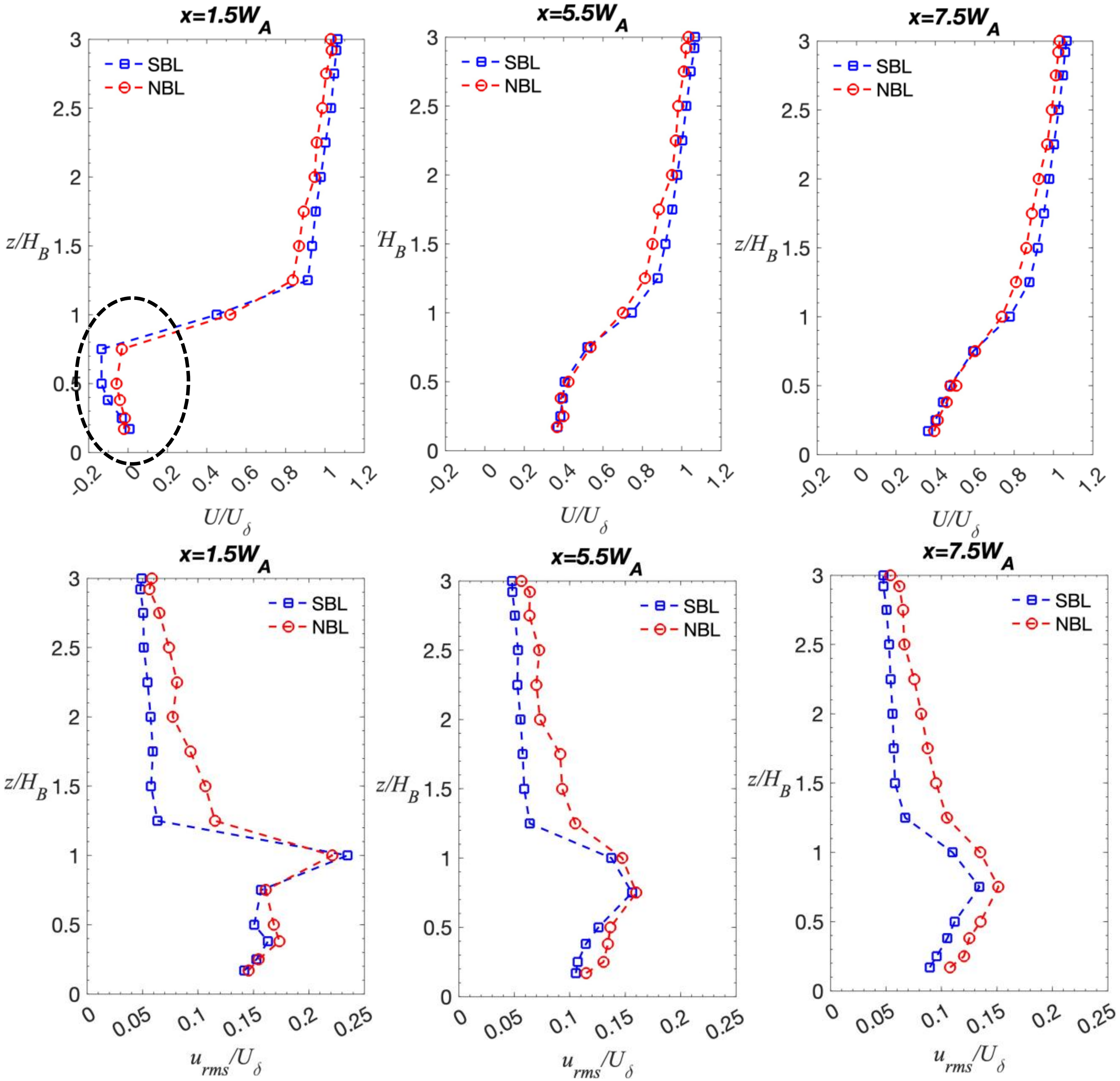
W A K E I N S T A B L E S T R A T I F I C A T I O N

Single tall building

Stably Stratified Wake shows:

- Stronger recirculation
- Accelerated flow on the building roof

Shear-generated turbulence dominates the flow

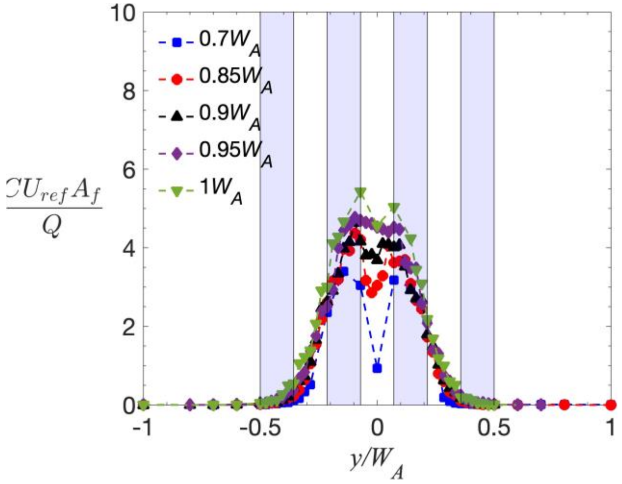


Mishra et al., *In Prep*

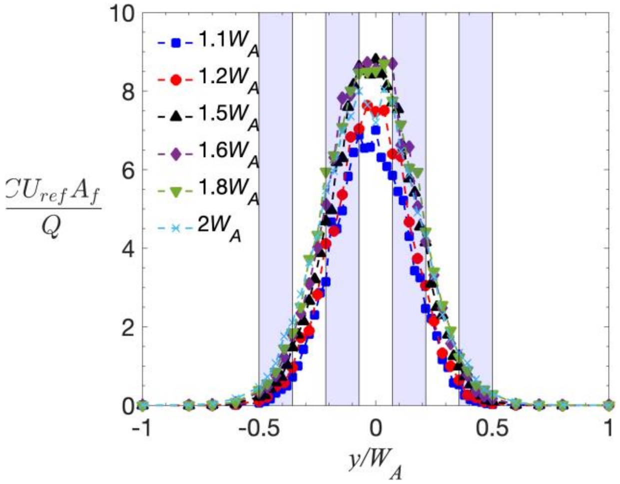
POLLUTANT DISPERSION CHARACTERISTICS

Bi et al., *under review*

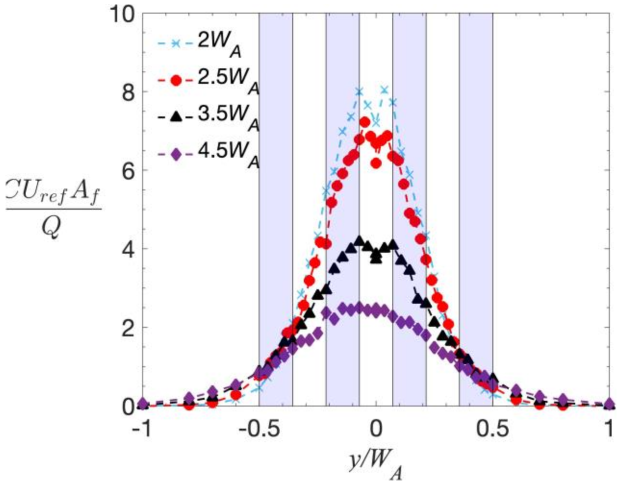
Source Location: Centre



Vertical recirculation aids vertical dispersion of pollutant

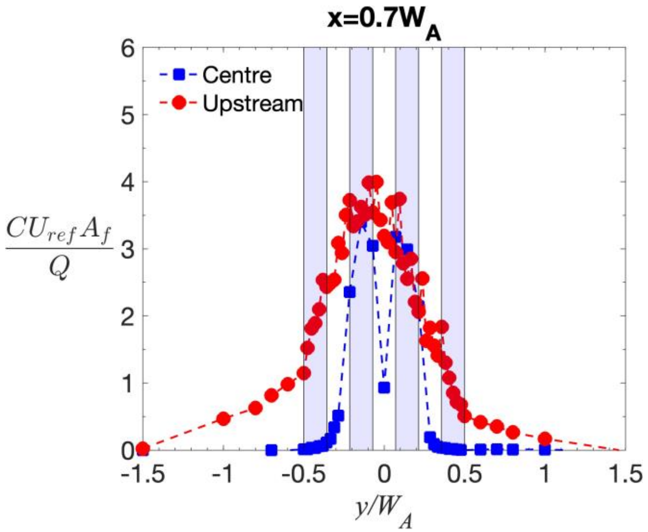


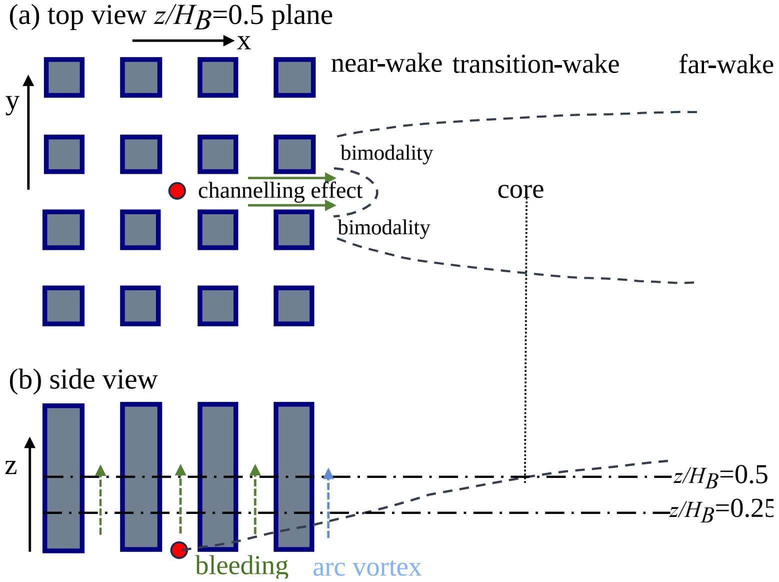
Accumulation of pollutant



Concentration reduces as the plume spreads

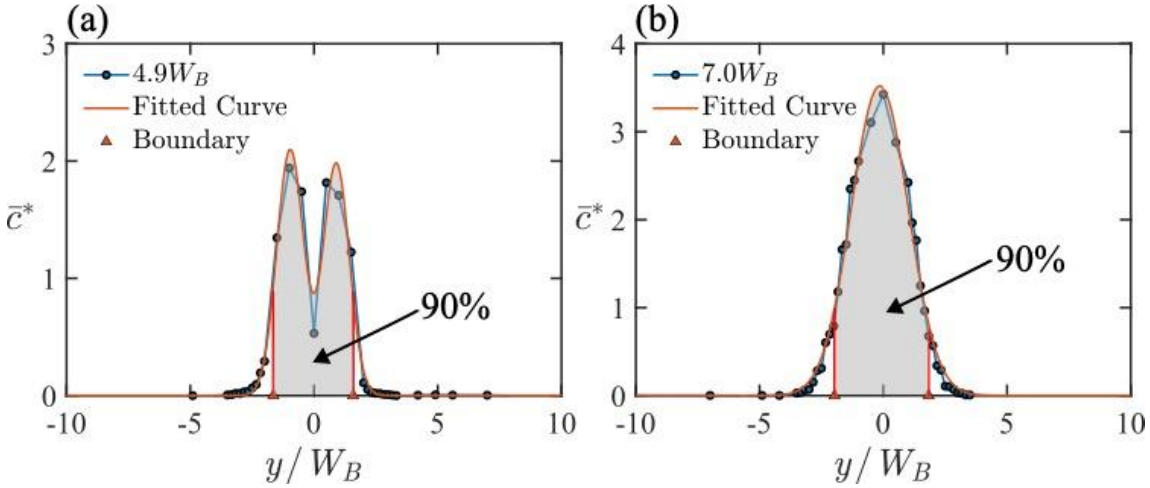
Bimodal Distribution





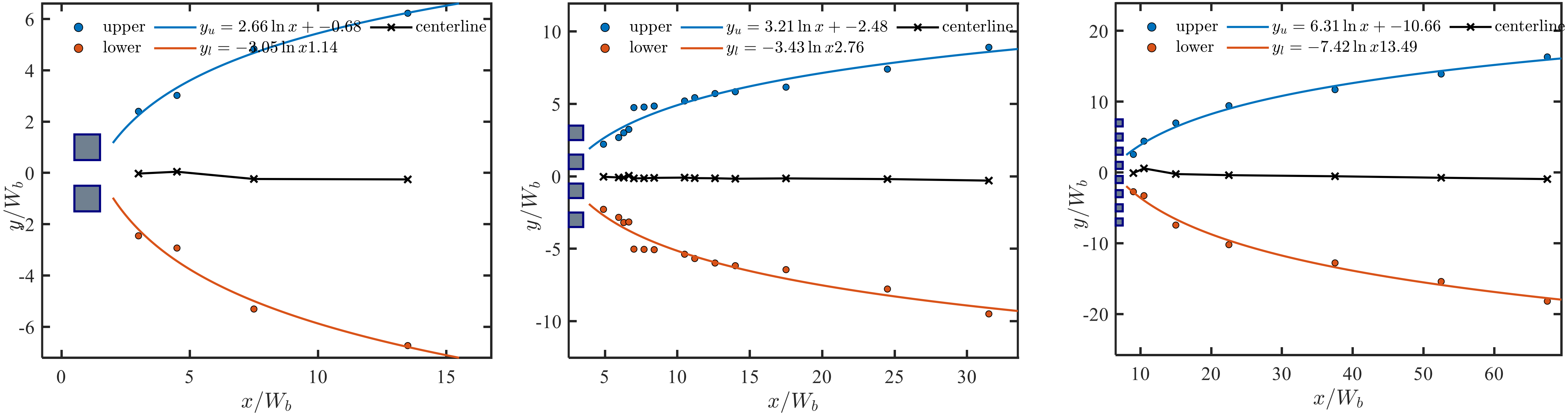
POLLUTANT DISPERSION CHARACTERISTICS

Bi et al., *under review*



- ✓ The lateral growth of the plume is logarithmic in the intermediate/far-wake

$$y^* = A \ln x^* + C$$



SUMMARY

- 3 different wake regimes can be identified behind tall building clusters:
  - Near Wake
  - Transition Wake
  - Far Wake
- The individual building effect is dominant in the near-wake region
- Uniform wake advection in the transition wake region
- Far Wake region is governed by the cluster width
- Mechanical turbulence generated by the buildings dominates the buoyant suppression in weakly stratified flows
- The building’s wakes significantly influence the temperature distribution of the atmosphere at the neighbourhood scale
- Cluster wake causes complex pollutant plume development, with vertical spread (causing bimodality in some cases) and logarithmic lateral growth

Mishra et al.,
BLM, 2023

Southgate-Ash et al.,
BLM, 2025 (in press)

Mishra et al.,
Flow, 2024

Bi et al.,
WES Conference, 2024

Mishra et al.,
WES Conference, 2024

Bi et al.,
BBAA IX, 2024

Questions?