The Impact of Natural Urban Terrain on Urban Wind Environment in High-Density Neighborhoods

Tanya Talwar[1], Chao Yuan[1,2]
[1] National University of Singapore
[2] NUS Cities, National University of Singapore, Singapore

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KEYWORDS: Urban Wind Environment, Urban Terrain, LES Model, Non-isothermal Simulation, High Density Neighborhood

BACKGROUND

Understanding the urban wind environment through CFD is necessary to develop measures to reduce heat risks and increase resilience. Due to complexity of microclimatic interactions and limitations of computational resources, simplifications in geometry are adopted like the topography of the local area (Type III) is modelled as flat ground.

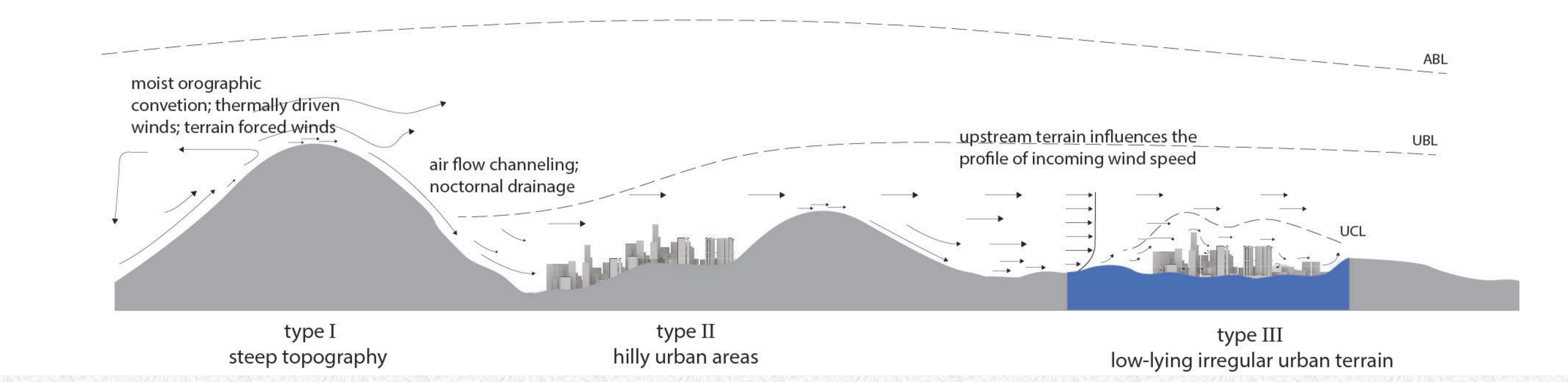


Figure 1 Different types of complex terrains found in the literature studies and their varying influence on the environment at different spatial scales and resolution. This study focuses on the significance of the low-lying natural urban terrain i.e. type (III). ABL: Atmospheric Boundary Layer; UBL: Urban Boundary layer; UCL: Urban Canopy Layer.

Research gap

Multi-physics modelling of dense urban areas with terrain geometry have received limited attention and research is needed to find a balance between modelling accuracy and computation cost.

AIM

- Investigate the influence of local topography (i.e., low-lying natural urban terrain (Type III)) on local wind and temperature conditions.
- Provide better understanding of the conditions under which the low-lying natural urban terrain should be considered and accounted for in the numerical simulation of urban wind environment.

METHODS

- Impact of terrain assessed by cross comparing simulation models with simplified flat ground and natural topography.
- Case A: a non-isothermal weak wind and high-temp condition that induces buoyancy-driven flow
- Case B: an isothermal wind-driven scenario, i.e., neutral conditions, yearly-averaged wind conditions, frequently used for wind permeability and thermal comfort study.
- High resolution transient Large Eddy Simulation (LES) with standard Smagorinsky-Lilly sub-grid scale model was used to resolve near ground air flow.

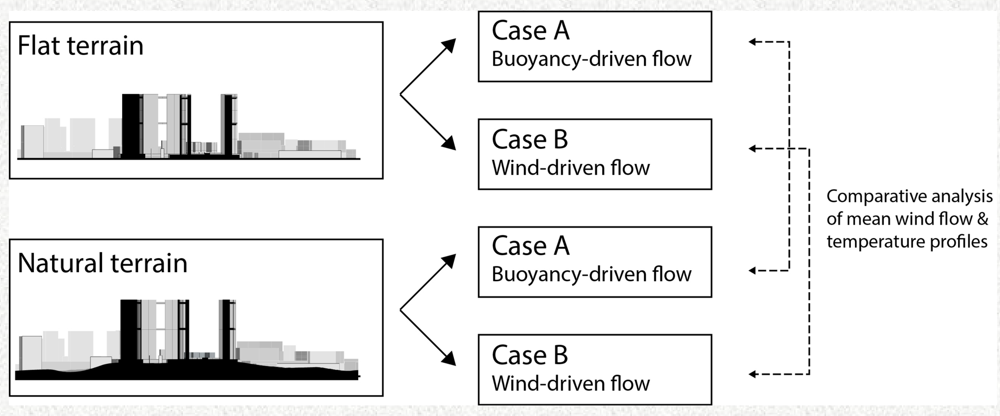
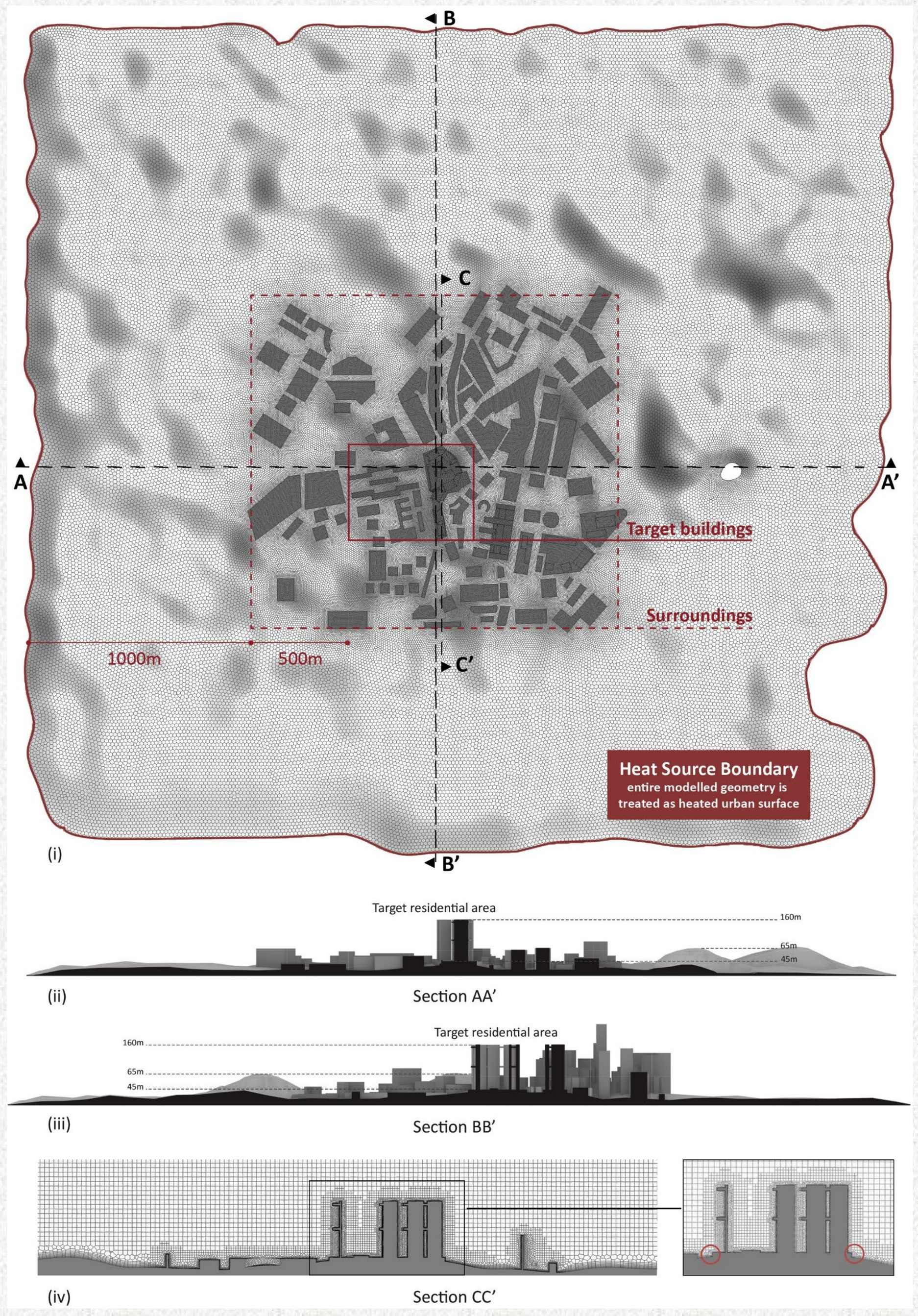


Figure 2 For both Case A and Case B, models with simplified flat ground and real natural topography are simulated. They feature identical building geometries.



*3D model with mesh for the CFD simulation (i) Top view of the study area (2km*2km) in Tanjong Pagar neighborhood. (ii)(iii) Cross section of the study area along line AA' and BB'(iv) Domain mesh along the section line CC'. Cells are further refined at the corners to avoid intersection errors during the meshing.*

FINDINGS

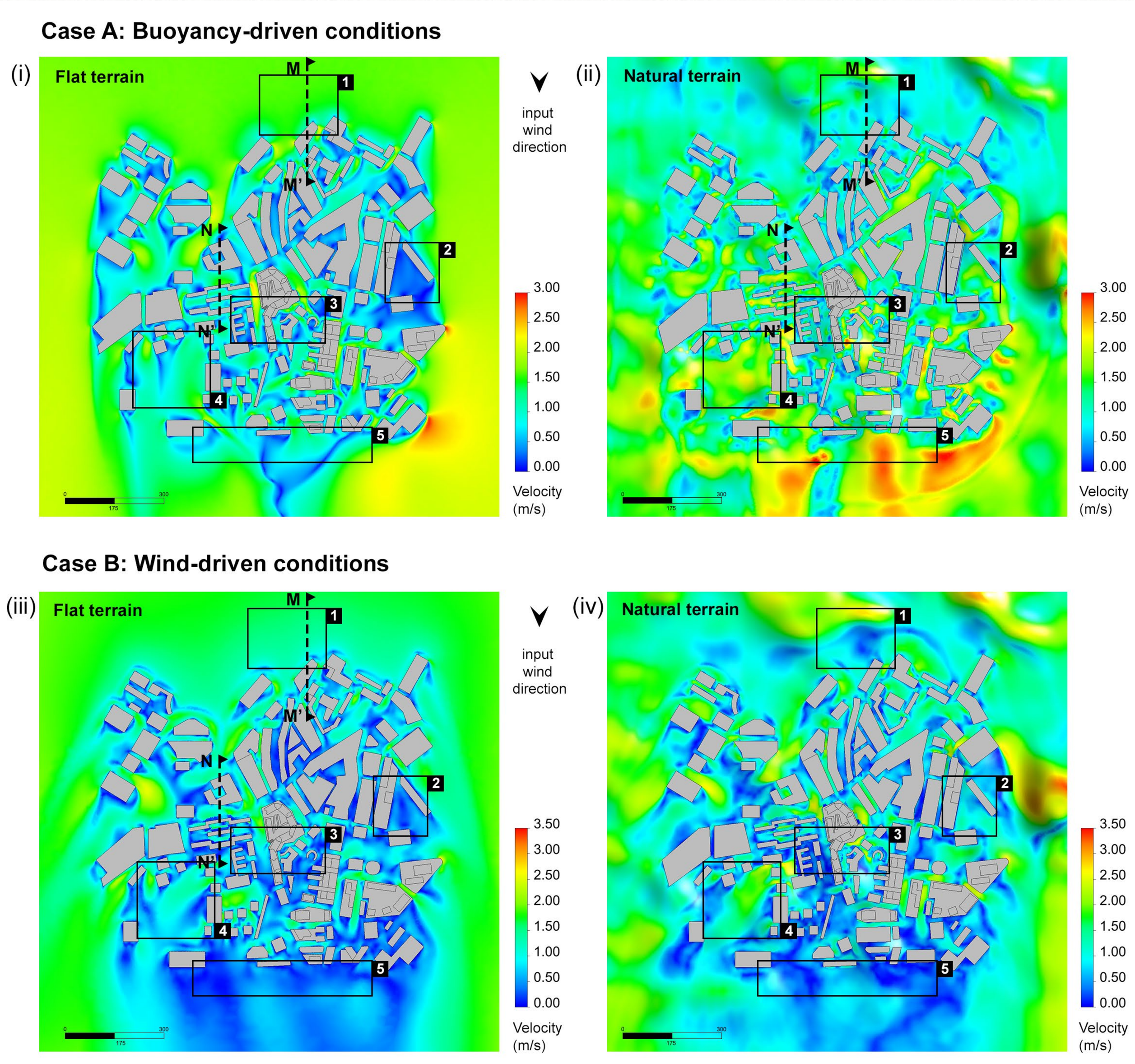


Fig 2. Spatial distribution of time averaged wind velocity at 2m heigh from the ground for (a) Case A flat terrain model (b) Case A terrain type III model (c) Case B flat terrain model (d) Case B terrain type III model

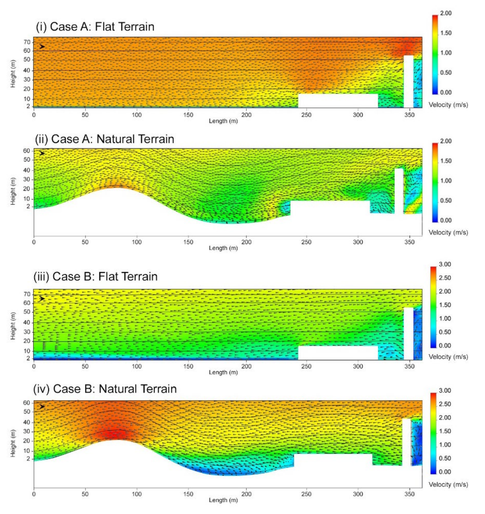


Fig. 3 Contour and vector plot of time averaged wind speed at section line MM'. There is an amplification at the crest and separation immediately downwind at the wake region causing a reduction in wind speed compared to the scenario with flat topography.

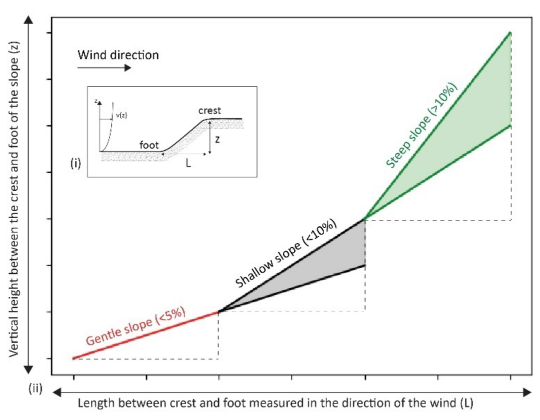
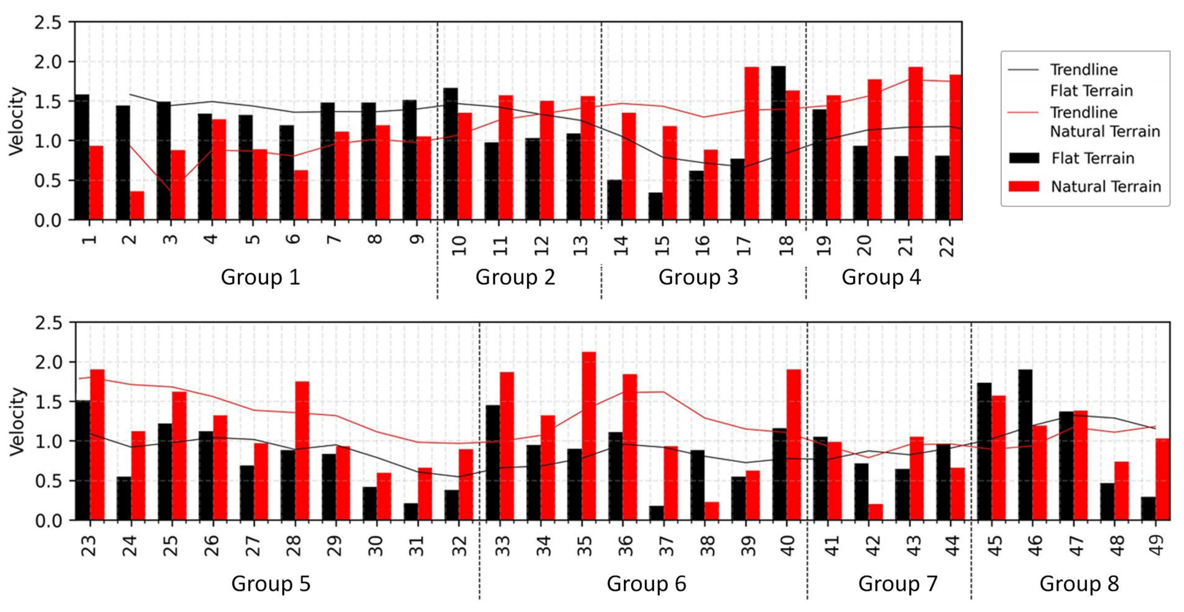


Fig. 4 Topography within the study area is classified in three categories based on a standard slope descriptor. It is defined by ratio between the vertical height between the crest and foot of the slope (z) and length between crest and foot measured in the direction of the wind (L) i.e psi = z/L.

Location of test probes and their groups marked on the model with natural terrain and buildings. The probe locations and number are the same for both Case A and Case B. 49 representative locations, divided into seven groups, were selected within the built area for test probes located 2m above ground.



Bar charts of time-averaged wind speed at pedestrian level for Case A at various test point locations.

KEY DISCUSSION POINTS

- Wind speeds lower with flat ground in both isothermal and non-isothermal cases.
- Impact on pedestrian wind speed (0.4m/s – 0.8m/s) is statistically significant under buoyancy driven flows

Density	Slope	Case A	Case B
Low	Gentle	Optional	Optional
Low	Shallow	Recommended	Recommended
Low	Steep	Recommended	Recommended
Medium	Shallow	Recommended	Optional
Medium	Steep	Recommended	Optional
High	Shallow	Optional	Optional
High	Steep	Optional	Optional

- In low-density areas with either steep (psi > 0.1) or shallow slopes (0.05<psi<0.1), deviations in average wind speed can be as high as 40-45% in both cases.

CONCLUSIONS

- A localised impact on the urban environment due to coupled influence of building densities and slope in both Cases A and B.
- Recommendation to include natural topography for Low-density areas, like neighbourhood parks and historical developments.
- Shallow and steep slopes notably impact buoyancy-driven flows in in medium density and should be modelled.
- High-density areas exhibit little or no difference in wind speed between flat and natural terrain scenarios, because building clusters dominate microclimate.
- Flat topography is unable to capture the disturbances in the incoming flow caused by an immediate upstream terrain.

Future applications

- Results of this study will be applied while conducting simulations of residential neighbourhoods modelled with natural urban terrain under high-temperature scenarios. This will help develop mitigation and adaptation measures during extreme heatwave conditions.
- Parametric study with varying density, slope and buoyancy ratios to provide general guidelines.
- A more realistic urban environment could be represented by combining natural urban terrain geometry with vegetation in future studies of urban microclimate.

Contact
Tanya Talwar (tanyatalwar@nus.edu.sg
PhD researcher/Research associate

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