Effects of Sea Breeze on City Ventilation - Important for Air Ventilation Assessments?

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Why we did it

- As urban population increases, preserving an acceptable city climate becomes a major challenge of future city planning
- Air Ventilation Assessments (AVAs) help city planners to predict city ventilation of planned construction sites
- To sufficiently predict ventilation, an AVA must cover the real atmospheric situation
- Current AVA focus only on neutral conditions

→ **Is this sufficient for summery weak-wind conditions in a coastal city area?**

How we did it

- LES simulation of Kowloon peninsula (Hong Kong), using the model PALM
- Summer weak-wind condition: easterly background wind: 1.5 ms^{-1}, fixed surface heat flux: 200 Wm^{-2}
- Two cases:
  - homogeneous heating throughout domain
  - sea-breeze case where only land is heated
- Divide city into 3 regions (according to [2]): C1: SW ventilated; C2: weakly ventilated; C3: SE ventilated
- Passive scalar released at surface within city area

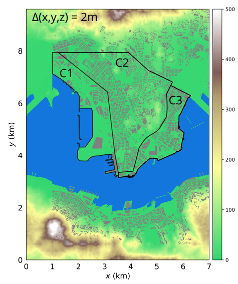

Figure 1: Model domain with terrain height in m and region definition.

How is the ventilation?

- Sea breeze penetrates city area along the entire coastline, forming a convergence zone above the city
- Higher V_r at west coast due to lower building density and flat terrain
- Comparison shows higher V_r in sea-breeze case especially in western part of Kowloon

Definitions:

$$V_r = \frac{v_{2m}}{v_{ref}}$$

$v_{ref} = v_{2m}$ (outside of city area) [1]

$$V_{r,\,norm} = \frac{V_r\ \text{(sea-breeze case)}}{V_r\ \text{(homog. heating case)}}$$

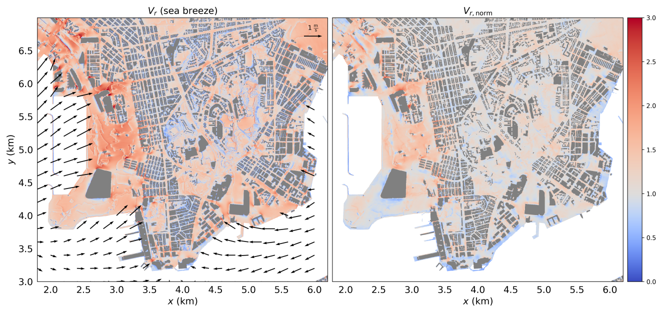

Figure 2: Velocity ratio V_r and wind vectors of the sea-breeze case (left), and normalized velocity ratio $V_{r,\,norm}$ (right).

Is the pollution dispersion influenced by sea-breeze?

- Scalar concentration differs significantly between cases
- Strong west-east gradient in sea-breeze case, north-south gradient in homog. heating case
- Different wind fields yield large differences in s* between cases
- Depending on case, high s* values are observed in different city areas

Definitions:

$$s^* = \frac{s}{Q_s\ t_e}$$

t_e: emission time

Q_s: emission rate

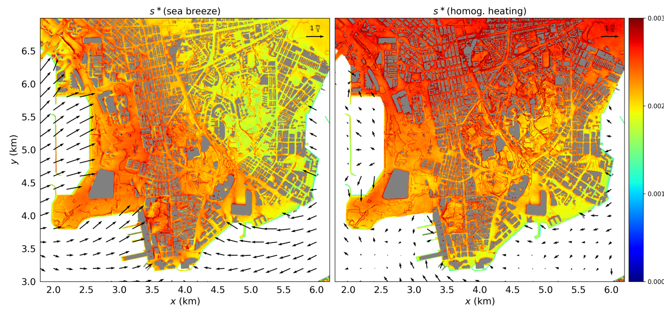

Figure 3: Normalized scalar concentration s* and wind vectors for the (left) sea-breeze case and (right) homogeneous-heating case.

Looking at different city regions

- C1, C2, C3 correspond to different city regions according to [2]
- Mean wind direction (dir, Tab.1) agrees with classification made by [2] for sea-breeze case but not for homog. heating case
- Although C1 has highest ventilation, pollution is also highest

→ Between Kowloon and Hong Kong Island, complex wind circulation transports pollution over sea where it re-enters the city area

- Vanishingly low correlation between V_r and mean building height H_{avg} confirm that H_{avg} plays a minor role for city ventilation (Fig.4, see also [1])
- V_r and plan-area index (PAI) are to some degree correlated, with C2 (city center) showing strongest correlation

	V_r		s*		dir	
C1	1.74	1.46	0.0023	0.0023	224° (SW)	149° (SE)
C2	1.29	1.21	0.0022	0.0022	165° (S)	168° (S)
C3	1.38	1.34	0.0020	0.0020	137° (SE)	145° (SE)

Table 1: Mean values within regions C1-C3; left: sea-breeze case, right: homog. heating case.

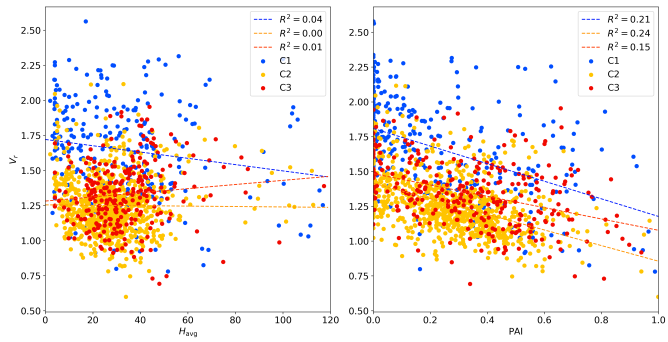

Figure 4: Correlation between velocity ratio V_r and (left) mean building height H_{avg} and (right) plan-area index PAI; each data point represents a 100m x 100m area within the specified region; sea-breeze case.

Let's summarize

- Ventilation changes significantly between sea-breeze case and homogeneously heated case in strength and direction
- More complex wind circulation lead to differences in pollution concentration (W-E gradient instead of N-S)
- Main wind direction from measurements can only be reproduced if sea-breeze is considered

→ **It is essential to cover sea-breeze effects if a sufficient analysis of the city ventilation is focused during summery weak-wind conditions!**

What's next

- Further detailed analysis of wind system between Kowloon and Hong Kong Island should reveal more details of sea-breeze effects on ventilation
- Compare results with real-world measurements in Hong Kong
- Using PALM's new nesting methods, a larger area can be simulated to study effects of large-scale wind systems (see also poster 1D-51)

References & Acknowledgments

[1] Gronemeier, T., S. Raasch, E. Ng (2017). Effects of unstable stratification on ventilation in Hong Kong. Atmosphere, 8, 1-15, doi:10.3390/atmos8090168

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