Bridging Wind Tunnel Experiments and Large-Eddy Simulation for Pollutant Dispersion in Tree-Lined Canyons

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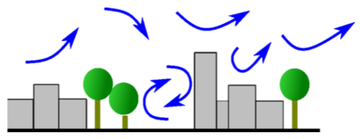
Motivation

Urban greenery improves urban **microclimate**, but its impact on pollutant dispersion remains debated.

This study combines **Wind Tunnel (WT) experiments** and **Large-Eddy Simulations (LES)** to investigate how tree drag modulates flow and scalar transport in street canyons.

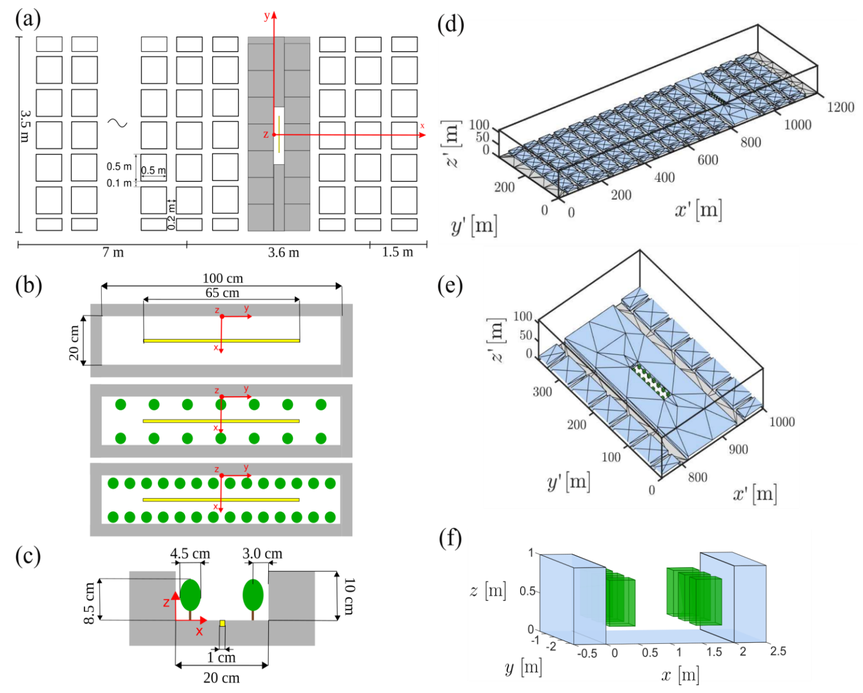


Key Findings

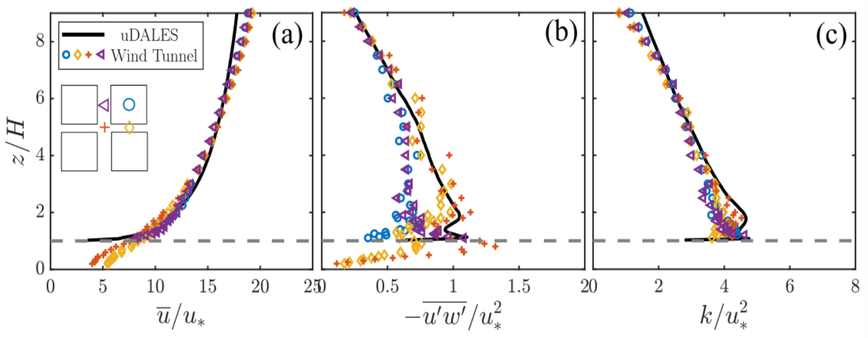
- **uDALES** simulations accurately reproduce flow and dispersion fields in tree-lined street canyons.
- The **drag length** (ℓ_d) is confirmed as an effective metric to describe tree drag.
- Canyon flow results from the **interplay** between the geometric scale (H) and tree spacing.
- **Tree drag** significantly alters both flow patterns and pollutant dispersion within the canyon.
- The average concentration and **ventilation efficiency** remain unchanged across different tree densities and drag levels.

Ensuring consistency between LES and experimental setup

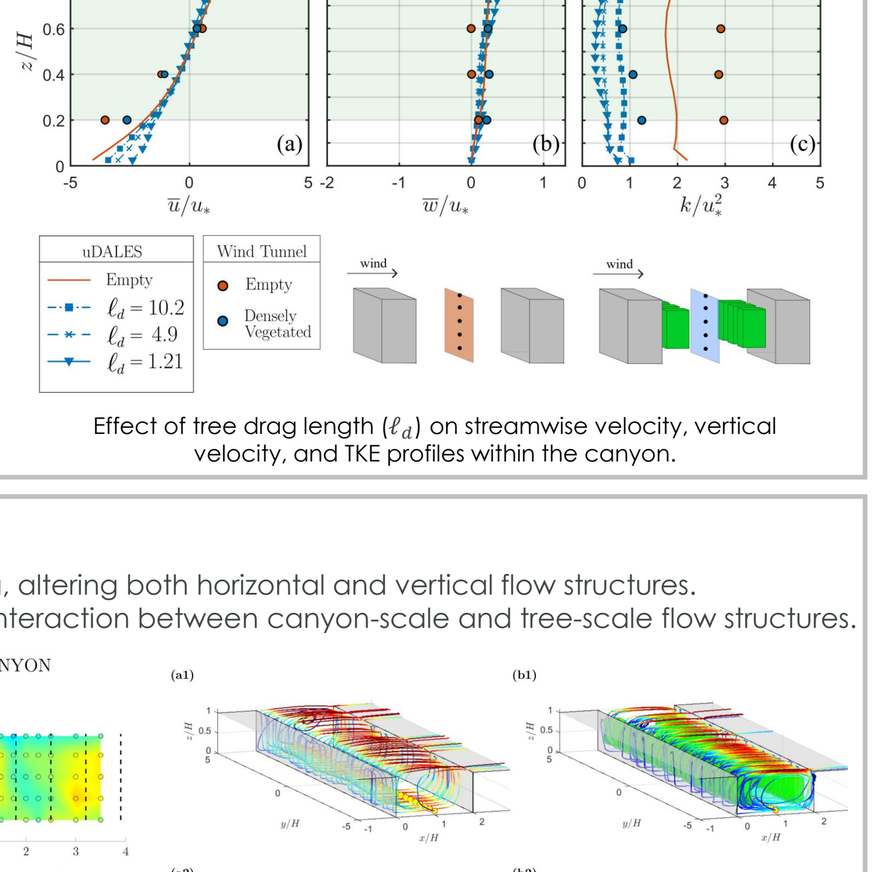
- WT conducted at École Centrale de Lyon replicates urban canyons with varying tree densities.
- LES performed with uDALES, using volumetric drag models parameterized by drag length (ℓ_d).
- Alignment of boundary layers, scaling, and tree aerodynamic properties (C_d, ℓ_d)ensures consistency between WT and LES.



Experimental and numerical configurations for tree-lined urban canyons.



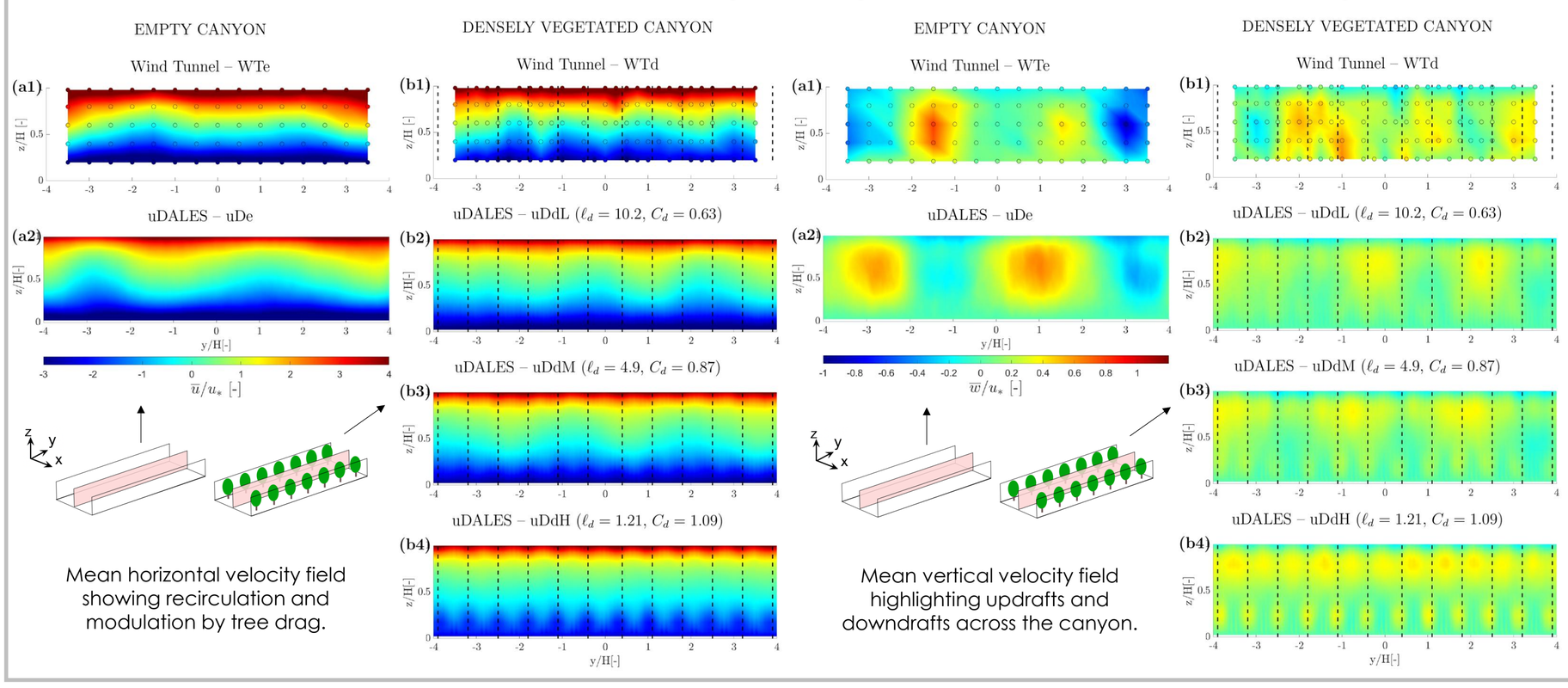
Vertical profiles of velocity and turbulence statistics for WT and LES boundary layers.



Effect of tree drag length (ℓ_d) on streamwise velocity, vertical velocity, and TKE profiles within the canyon.

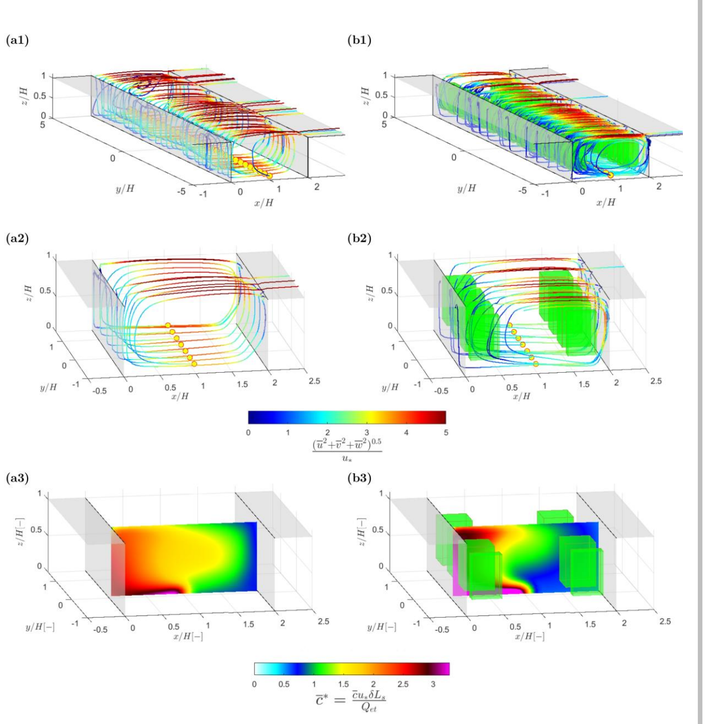
The velocity field within the canyon

- LES captures large-scale recirculating patterns observed in WT.
- Vegetation introduces a secondary scale related to tree spacing, altering both horizontal and vertical flow structures.
- High tree drag confines flow between trunks. Lower drag allows interaction between canyon-scale and tree-scale flow structures.



Mean horizontal velocity field showing recirculation and modulation by tree drag.

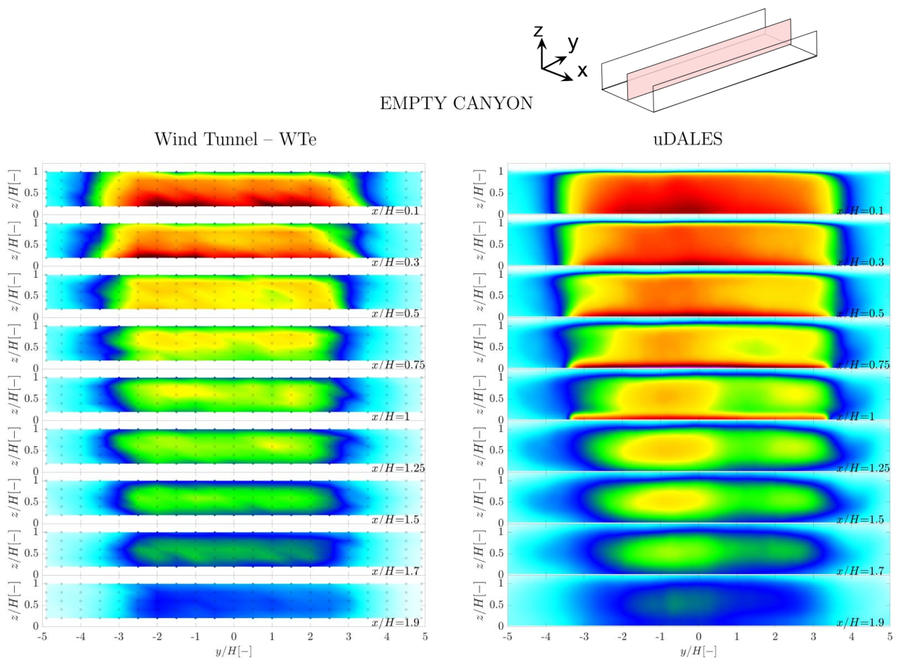
Mean vertical velocity field highlighting updrafts and downdrafts across the canyon.



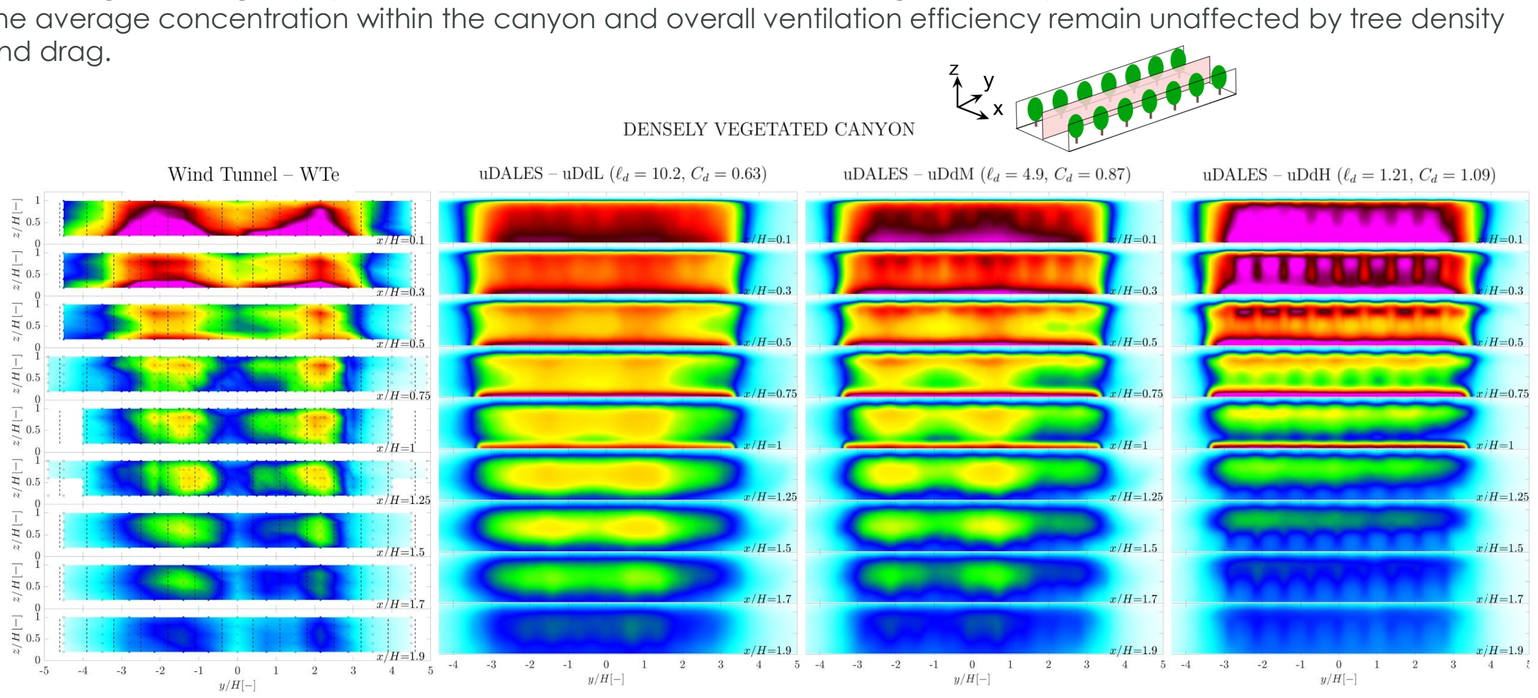
Streamlines visualize the interaction between canyon-scale flow and tree-induced patterns.

The concentration field within the canyon

- Pollutant dispersion is modulated by tree density and drag.
- Vegetation alters concentration patterns, breaking the canyon symmetry.
- Increasing tree drag reshapes the concentration distribution, creating localized pollutant zones near the tree crowns.
- The average concentration within the canyon and overall ventilation efficiency remain unaffected by tree density and drag.



Pollutant dispersion in the empty canyon, dominated by recirculation.



Pollutant dispersion in the vegetated canyon, modulated by tree drag and spacing.

References:

[1] Grylls, and van Reeuwijk, 2021. *Tree model with drag, transpiration, shading and deposition: Identification of cooling regimes and large-eddy simulation. Agricultural and Forest Meteorology.*

[2] Fellini, Marro, Del Ponte, et al., 2022. *High resolution wind-tunnel investigation about the effect of street trees on pollutant concentration and street canyon ventilation. Building and Environment.*

[3] Del Ponte, Fellini, Marro, et al., 2024. *Influence of street trees on turbulent fluctuations and transport processes in an urban canyon: a wind tunnel study. Boundary-Layer Meteorology.*

[4] Majumdar, Vita, Ramponi, et al., 2025. *The drag length is key to quantifying tree canopy drag. Journal of Wind Engineering and Industrial Aerodynamics.*