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A Large Eddy Simulation to determine the effect of trees on wind and turbulence over a suburban surface

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1 Introduction

Motivation

Robust modeling of flow and turbulence over urban canopies is required to properly predict air pollution and dispersion in cities. In many suburban neighbourhoods, tree cover is 10 to 30% and trees are often taller than buildings. Effects of trees on drag, mean wind and turbulence in cities are not accounted for in current weather, air pollution and dispersion models.

Goals

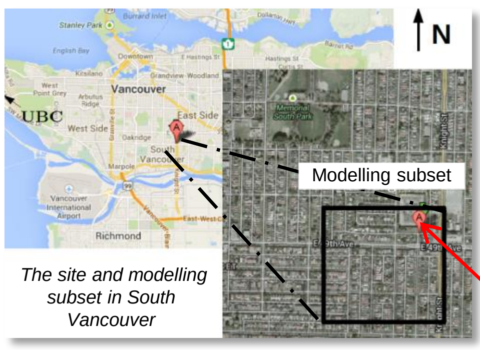
Study numerically the effect of trees on mean wind flow and turbulence within and over a realistic urban canopy.

1. **Validate LES (Large Eddy Simulation) results against tower measurements**
2. **Study the effects on mean flow and momentum fluxes**
3. **Determine the variations of aerodynamic roughness length z_0, displacement height d and blending height h_b**

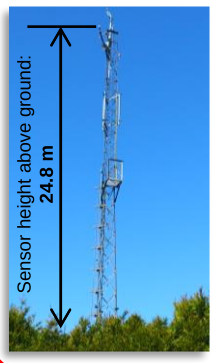
2 Site and data

Study site

- **512 x 512 m subset** of the residential neighbourhood 'Sunset' in Vancouver, Canada
- Flat topography without high buildings (avoid wake shedding)
- Mean building height **h = 5 m**
- Areal fraction of trees: 0.12



The site and modelling subset in South Vancouver



Location of UBC research tower in South Vancouver, Canada

Wind and temperature data

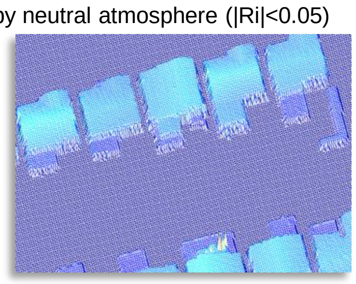
We use data measured at the **UBC urban climate measurement tower** inside our modelling domain. 4 years of wind velocity and temperature measurements at 20 Hz were analyzed.

Conditional sampling:

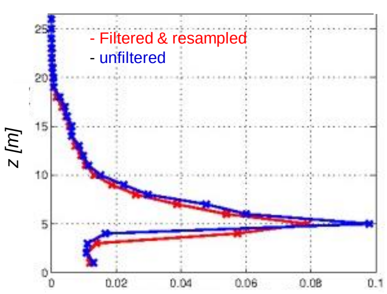
- Based on wind direction (+/- 10°) and its standard deviation
- Selection of periods characterized by neutral atmosphere (|Ri|<0.05)

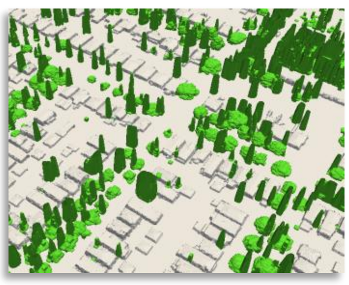
LiDAR data / Surface boundary

- Point cloud with 20 points/m²
- Triangulation of building points
- Representation of **Leaf Area Density**, LAD(z), as vertical Weibull
- Computation of **drag force** exerted by the leaves as a function of height



Triangulated buildings





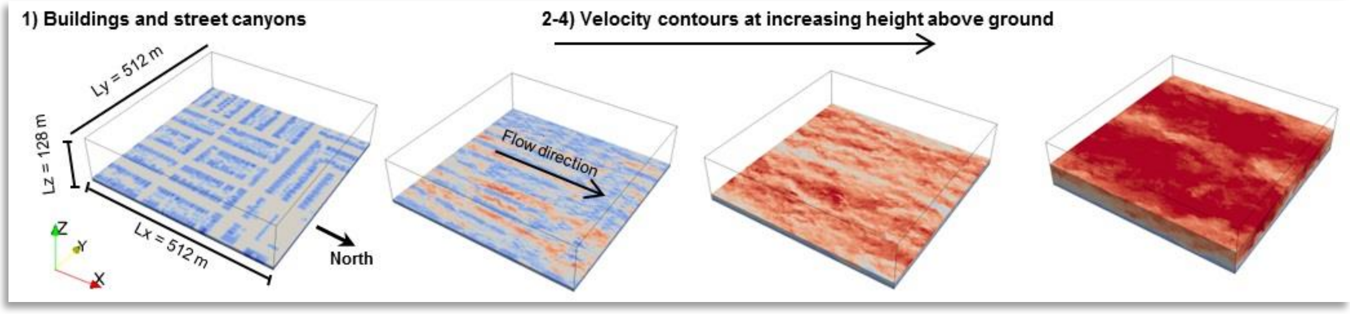
Buildings and isosurface of Leaf Area Density = 0.002 m²/m³

3 LES model

An **Immersed Boundary algorithm** (IBM) was coupled with a **Large Eddy Simulation** (LES) code, in order to resolve the 3D-airflow over and within the urban canopy. The filtered Navier-Stokes equations are solved in a regular domain. Flow is driven by a constant pressure gradient. Spatial resolution is 2 m.

Boundary conditions

- Periodic in the horizontal
- No slip at the surface, Free slip at the top of the domain
- Stress boundary condition at the interface, based on the logarithmic equilibrium profile

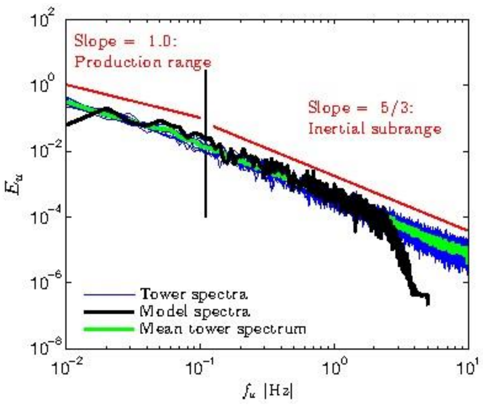


Color contours of the instantaneous streamwise velocity field on horizontal planes at varying height above ground (qualitative): Notice the presence of alternating high/low speed streaks, which are meandering and affecting the flow in the Roughness Sublayer below.

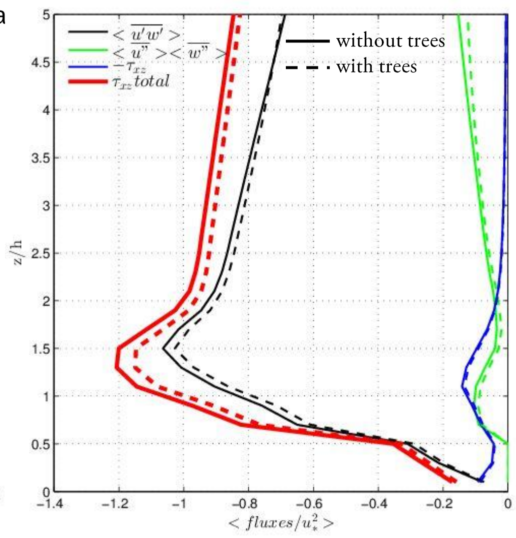
4 Results

1. Validation of power spectra

- Comparison of streamwise velocity spectra
- Typical slopes of inertial subrange and production range with slope change at similar location for both model and data

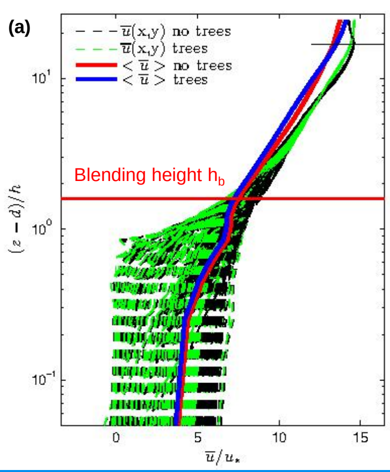


2. Dispersive fluxes



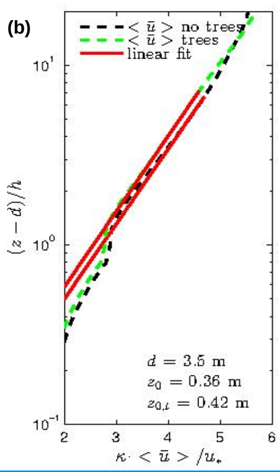
- **Reynolds flux** $< \overline{u'w'} >$ below z = 5h is smaller if trees are present
- **Dispersive flux** $< \overline{u''} >< \overline{w''} >$ is smaller with trees → Trees reduce vertical exchange of horizontal momentum
- **Subgrid stress** τ_{xz} is small, as expected. Peak at house roof level (z = h), produced by immersed SGS model (reproducing shear on walls).

3. Canopy properties



***(a)** Vertical profiles of streamwise velocities at different locations along x for a given location y*

***(b)** Example of two linear fits (with / without trees) to normalized streamwise velocity profiles for d = 3.5 m*



Displacement height d

- Determined using five different methods
- **Mean value found: d = 3.25 m**

Aerodynamic roughness length z_0

- Linear fits to normalized streamwise velocity profiles for different displacement heights d
- Criterion for acceptable fit: Linear fits for both cases with and without trees have to be parallel
- **$z_{0,\text{no trees}}$ = 0.36 - 0.40 m, $z_{0,\text{trees}}$ = 0.42 - 0.46 m**

Blending height h_b

- Determined from collapse of vertical profiles of streamwise velocity
- **h_b = 11.24 m +/- 1.56 m (with trees)**

5 Conclusions

- **Modelling results have been validated with measurements. Limitation: only single-point measurements available**
- **The presence of trees results in a reduction of dispersive fluxes below z = 5h**
- **Trees slow down the flow, but also reduce the heterogeneity of the flow field**
- **Values for z_0 and d are realistic and comparable to findings of earlier studies**
- **Blending heights h_b are meaningful and they should be investigated more in depth**

6 Selected references

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