Development of a new 1D urban canopy model: coherences between surface parameterizations

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Canopy Interface Model (CIM) – A need for theoretical coherence

A 1-D Canopy Interface Model (CIM) was developed in order to simulate the effect of urban obstacles on the atmosphere in the boundary layer (Mauree, 2014). The model solves the Navier-Stokes equations on a high-resolved gridded vertical column. Past theories were implemented one by one with the objective to test their relative coherences. The final proposition guarantees the coherence in any atmospheric stability and terrain configuration with a modification of the scaling parameters.

Mixing turbulent coefficients and mixing length

Several parametrizations were proposed to simulate the turbulent mixing coefficients over plane surfaces and complex surfaces. The most famous and used turbulence closure are:

- First-order turbulence closure: $\mu_t = k u' w' / \varepsilon$
- 1.5-order turbulence closure: $\mu_t = c_k \varepsilon / l$

\( l \) is the mixing length, that is understood as the maximum distance that an air parcel may travel before to be in contact with a surface.

Without obstacles in neutral case

- $\mu_t = 1$ and $l = z$
- Kinetic energy is constant with height: $e = c s e$
- Energy production equaled to energy dissipation: $P = \mu_t \left( \frac{\partial u}{\partial z} \right)^2 = \varepsilon = c_k \frac{\varepsilon}{l}$

Figure 1. Comparison of the wind $U$ (m/s) and $e$ (m$^2$/s$^2$) profiles computed using the analytical solution from the Prandtl surface-layer theory and CIM.

Without obstacles in a stratified atmosphere

- $\mu_t \neq 1$ and $l = z$
- Kinetic energy not constant with height anymore: $e \neq c s e$
- Energy production equaled to energy dissipation (Brouwers, 2007; Chatuchiphan and Wilson, 2009):
  \[ P(1 - R_i) = \mu_t \left( \frac{\partial u}{\partial z} \right)^2 = \varepsilon \]
- Consequence: a direct relation between $\mu_{tu}$ and $R_i$ that is $\mu_{tu} = (1 - R_i)^{-2}$
- Close to the MOST theory!
- Coherence with the MOST: $\mu_{tu} = (1 - C_s R_i)^{-1}$ with $C_s = 4 \beta_m (1 + \beta_m) \frac{z}{\lambda}$ in stable atmosphere and $C_s = \beta_m (1 + \beta_m) \frac{z}{\lambda}$ in stable atmosphere with $\beta_m$ and $\lambda_m$ constants used in the universal stability functions as proposed by Businger et al (1971)

Open question: Why do we need $C_s$?

Figure 2. Comparison of wind $U$ (m/s), potential temperature (in K) and $e$ (m$^2$/s$^2$) vertical profiles obtained with the MOST over a plane surface and with CIM under stable conditions (with and without the $C_s$ correction).

Implementation of urban obstacles

CIM is based on a porosity formulation of the buildings. The mixing length is taken from Santiago and Martilli (2010):

\[ l(f) = \max(h - d; z(f) - d) \]

with $d$ the displacement height taken as a function of $h$ and the porosity $d = h(1 - \varphi)$.

Figure 3. Comparison of the wind $U$ (m/s) and $e$ (m$^2$/s$^2$) profiles computed with a CPI (Thanks to J.L. Santiago and A. Martilli) and CIM. Cubic obstacles of 25 m. Porosity of 0.75.

Applications: CIM in WRF

CIM was introduced in WRF so that the coupled system could provide high resolution meteorological profiles.

Figure 4. Comparison of the hourly wind speed (in m/s) simulated by several WRF configuration at 50m

- Ref. WRF with 5m vertical resolution
- C1: WRF with a first vertical level at 9km high
- meso C3. WRF+CIM
- C3. CIM results in WRF

You are also invited to listen:

- Mauree et al., Evaluation of building energy use: from the urban to the building scale (NOMT11 - 24/Jul/2015: 2:15pm-4:00pm)
- Kohler et al., Could urban climate modelling systems provide urban planning guidelines in the context of building energy performance issues? (UDC6 - 24/Jul/2015: 11:00am-12:30pm)

REFERENCES

- Mauree, D. 2014 - Development of a multi-scale meteorological system to improve urban climate modeling, PhD Université de Strasbourg

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