COUPLING OF NUMERICAL WEATHER PREDICTION MODELS AND PHYSICAL SIMULATIONS FOR URBAN WIND ENVIRONMENT

Djordje ROMANIC
Horia HANGAN
Why urban studies matter?

- >50% of global population lives in cities (United Nations, 2014)
- 79.3% of the French population lives in cites (United Nations, 2014)

Toulouse. Source: http://www.ambafrance-be.org/IMG/jpg/P008356.jpg
Numerical Weather Prediction (NWP) models

• Parametrization of the urban environments in the NWP models:
  1. Simple variation of the surface parameters – slab models
  2. Coupling of urban canopy layer model with NWP model
     - Single Layer Models: -> 1st layer of the NWP model
     - Multi Layer Models: -> several layers of the NWP model
  3. Coupling of microscale CFD model with NWP model

• First option is still utilized in most operational NWP models used by national meteorological services
• Other two options are used for research and in industry (e.g. urban wind energy, dispersion of pollutants)
Wind tunnels vs. CFD

- Both techniques are valid, but both have positives and negatives
- Advantages of wind tunnels over CFD:
  1. More reliable estimates of peak values
  2. Long computational time of CFD models
  3. CFD simulations highly sensitive to numerous parameters in the model
- Disadvantages of wind tunnels over CFD:
  1. Less flexibility of inflow conditions
  2. Scaling
  3. Convective vs. Buoyancy flows
WRF-ARW model: Results

- Testbed: City of Cacak (central Serbia); July 21, 2014
Wind atlas + CFD

- PanAm Village site in Toronto

Source: Toronto’s Condo Blog
1. \( z = 80 \text{ m} \) from Canadian Wind Energy Atlas and \( V_{gr} \) based on \( \alpha_1 = 0.1 \)

2. IBL growth

3. ABL at site: \( \alpha_1 = 0.1 \) above IBL and \( \alpha_2 = 0.34 \) below
Mean power density (upper panels) and wind speed (lower panels) 8 m above the buildings and ground for 90° direction (left panels) and 240° direction (right panels). Flow direction is along the x-axis.
Wind atlas + CFD results: wind energy

Wind potential

Delivered energy
Nominal Power = 30 kW
Nominal Speed = 11.8 m/s
Cut-in Speed = 4 m/s
Cut-out Speed = 20 m/s

Rotor Diameter = 10 m
Rotor Height = 8 m
The Wind Engineering Energy and Environment (WindEEE) Dome

- WindEEE Dome: new three dimensional and time-dependent wind chamber
- can simulate various wind systems from sheared winds and gust fronts to tornadoes and downbursts
- a multi-scale, multi-purpose facility for wind research

www.windeee.ca
WindEEE: Preliminary Design

- straight/sheared flow
- tornado flow
- downburst flow
WindEEE: Engineering Design

- 106 individually controlled fans
- 2 MW maximum power
- 5 m lift and turntable
- 1600 floor roughness elements
Six Initial Design Specifications:

- Straight Mode Uniform
- Straight Mode Boundary Layer
- Straight Mode Shear
- Tornado
- Downburst
- Reversed Flow Mode

+ HH 7 😊
WindEEE: Tornadoes and Downbursts
A new approach

• Coupling NWP models with WindEEE physical simulator

• Wind profiles from NWP models are inflow conditions for WindEEE

• Placing model of a city block and running simulation with realistic inflow conditions

• Benchmarking micro-scale models by controlled parametrization
Thank you!

www.windeee.ca
Numerical Modeling: Trend Data Analysis

Mean Annual Wind Speed per Direction

Mann-Kendall non-parametric test for trend (Mann, 1945; Kendall, 1970)

Sen’s slope estimator (Sen, 1968)

\[ S = \sum_{y_1=1}^{n-1} \sum_{y_2=y_1+1}^{n} sgn(x_{y_2} - x_{y_1}). \]

\[ Y = Q(y - 1948) + B, \]