Estimating urban wind characteristics via neural networks

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Scientific-proffesional conference with international participation: Challenges in meteorology 3
21.11.2013.

Introduction

- Atmospheric boundary layer (ABL)
- Wind tunnel experiments
  - major tool in studying wind loading of structures, air pollutant dispersion, efficiency of wind energy farms, urban micrometeorology
  - The Counihan (1969) and Irwin (1981) methods with barrier, spires, and surface roughness – the most common approaches
  - required to precisely simulate ABL flow, Kozmar (2010, 2012)
  - expensive
- Artificial neural networks (ANN)
  - interesting possibility
  - previous research indicates capabilities of ANN to solve wind engineering problems (Khanduri et al. (1997) , Fu et al. (2006, 2007) , Varshney and Poddar (2012), etc)
- Scope:
  - To develop ANN which will yield a design of experimental hardware that leads to an appropriate simulation of ABL flows

Hardware setup

Wind tunnel dimensions: h,w,l = 1.8m, 2.7m, 21m

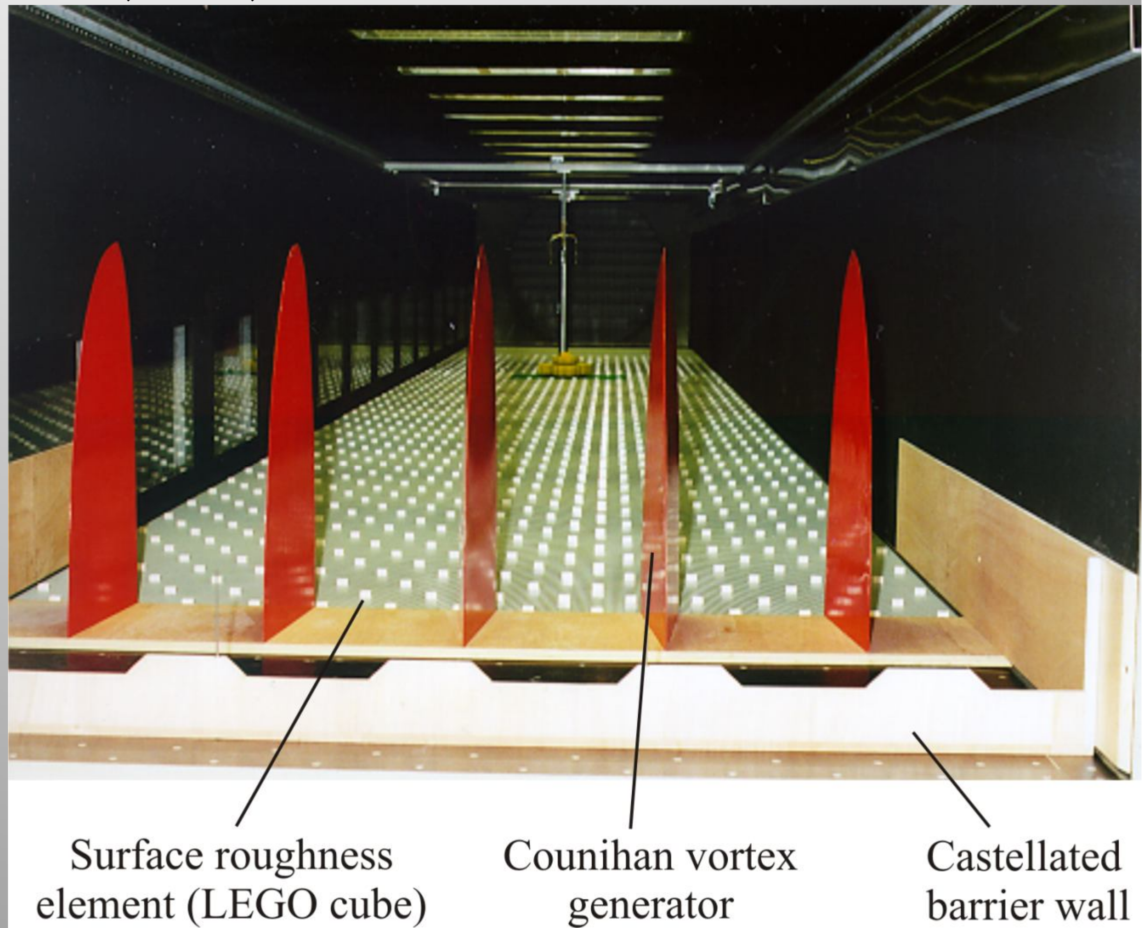
Blower: 210kW

Measurements: 18 points

Triple hot wire probe

DANTEC 55P91

Period of measurements: 150s



ANN

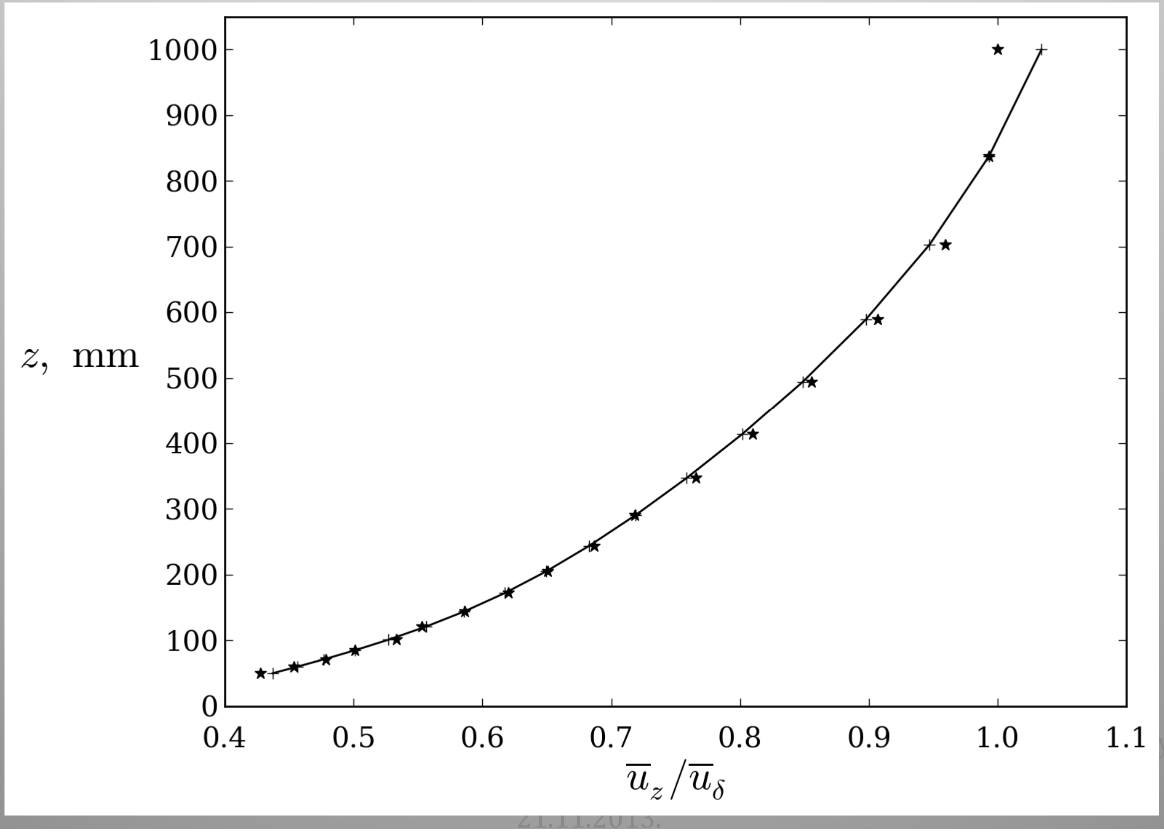
- Numerical method that simualtes biological brain for learning and recognizing patterns in data sets (Bishop, 1995)
- Regression problems (Antonić et al, 2001) - *feed forward* ANN
- **Input parameters**: basic barrier height, barrier castellation height, surface roughness spacing density, surface roughness elements height and measurement point heights.
- **Output parameters:**
  - mean wind speed $\overline{u} = \frac{1}{T}\int_0^T u(t)\,\mathrm{d}t$
  - turbulence intensity $I_u(z) = \frac{\sqrt{\overline{u'^2(z)}}}{\overline{u}_z}$ $I_v(z) = \frac{\sqrt{\overline{v'^2(z)}}}{\overline{u}_z}$ $I_w(z) = \frac{\sqrt{\overline{w'^2(z)}}}{\overline{u}_z}$
  - Roughness Reynolds number $\mathrm{Re}_\mathrm{R} = \frac{u_\tau \cdot z_0}{\nu}$
  - turbulence length scale $L_{u,x} = \int_0^\infty R_{u,x}(\Delta t)\,\mathrm{d}\Delta t$ $L_{v,x} = \int_0^\infty R_{v,x}(\Delta t)\,\mathrm{d}\Delta t$ $L_{w,x} = \int_0^\infty R_{w,x}(\Delta t)\,\mathrm{d}\Delta t$
  - power spectar density

$$u(t) = \overline{u} + u'(t)$$
$$v(t) = \overline{v} + v'(t)$$
$$w(t) = \overline{w} + w'(t)$$

Results

MEAN WIND VELOCITY

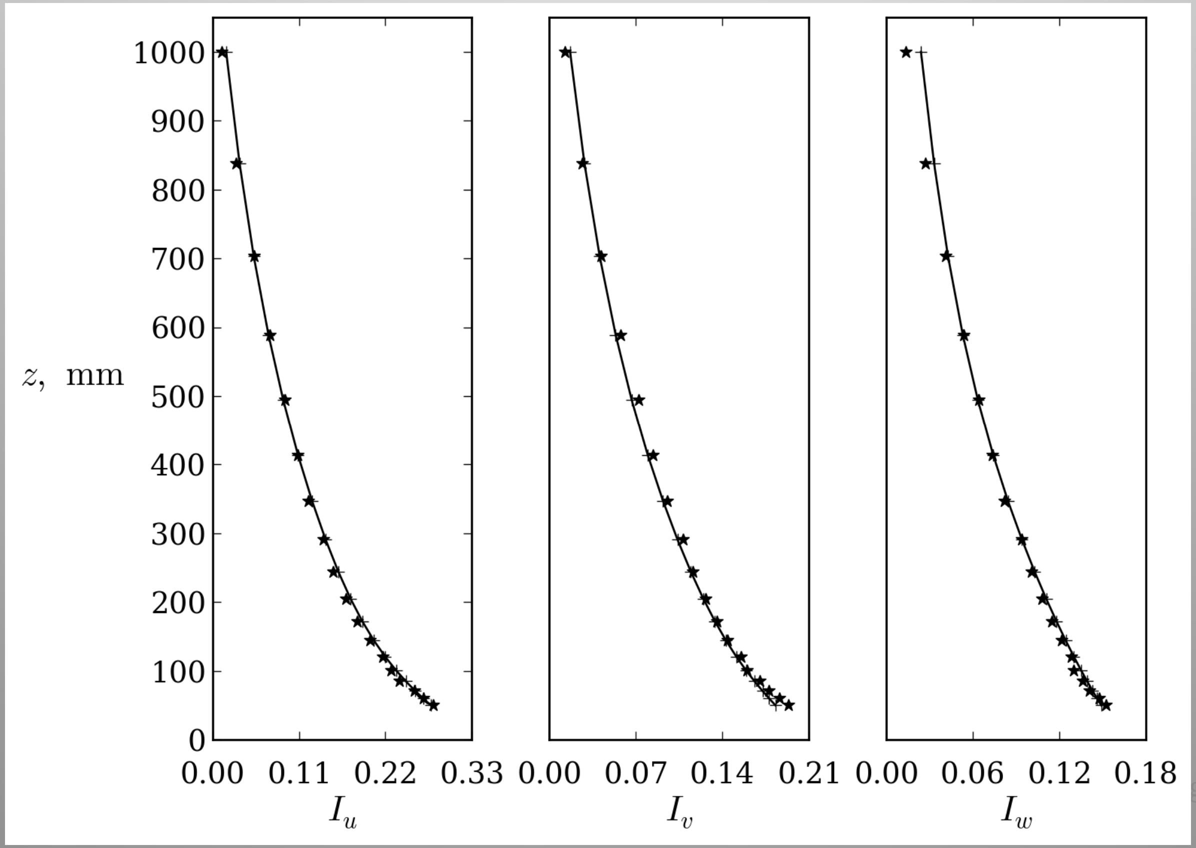
- Important **basic** feature in wind engineering environmental aerodynamics studies, meteorology, etc.
- Gives information on **wind shear with height**
- Neccessary for tall buildings, wind farms, other complex structures



Results

TURBULENCE INTENSITY

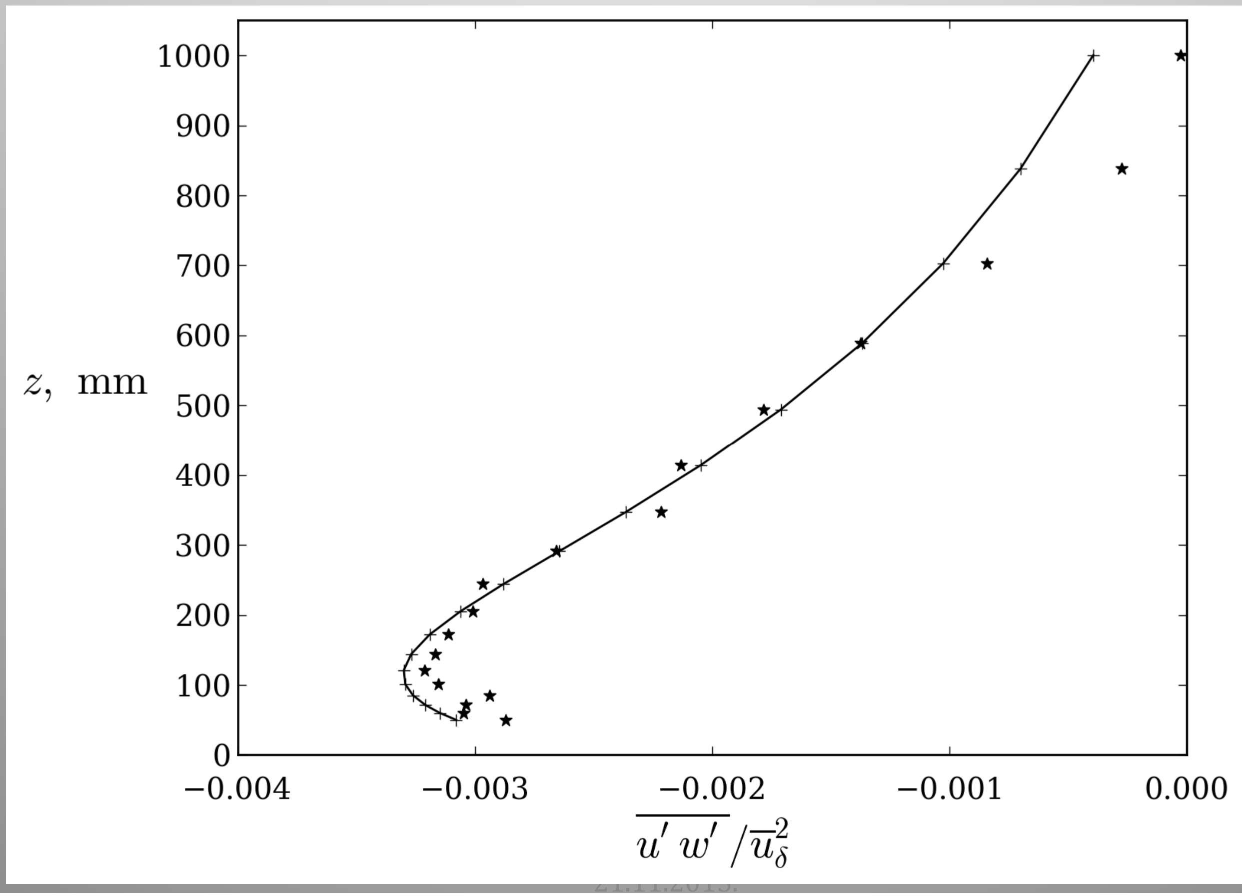
- Important when considering **dynamic loading** of engineering structures
- Longitudinal and lateral component – tall buildings
- Vertical component - bridges



Results

TURBULENT REYNOLDS STRESS

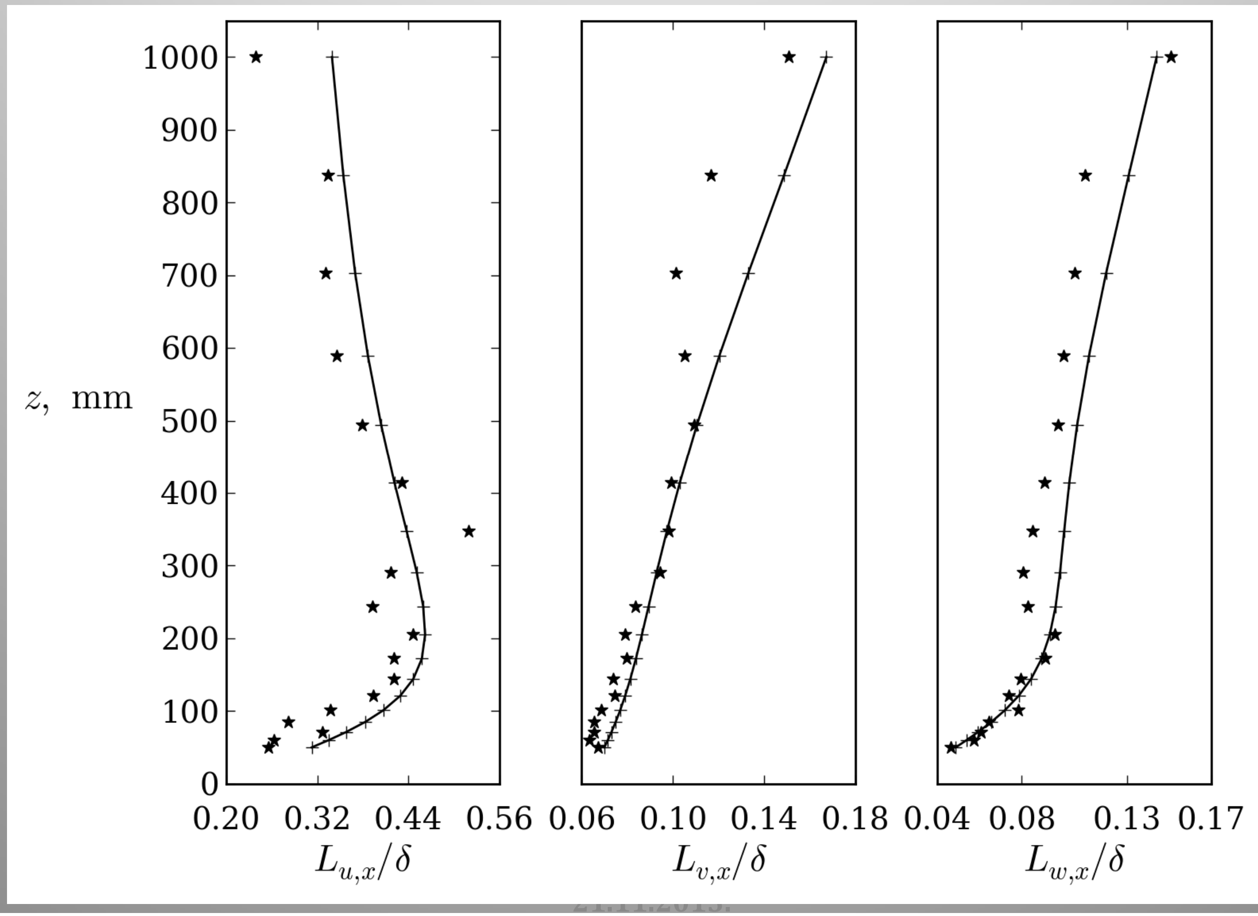
- Major physical mechanism for **vertical heat and mass transfer** within ABL
- Pollutant dispersion and dilution, health problems



Results

TURUBLENT LENGTH SCALE

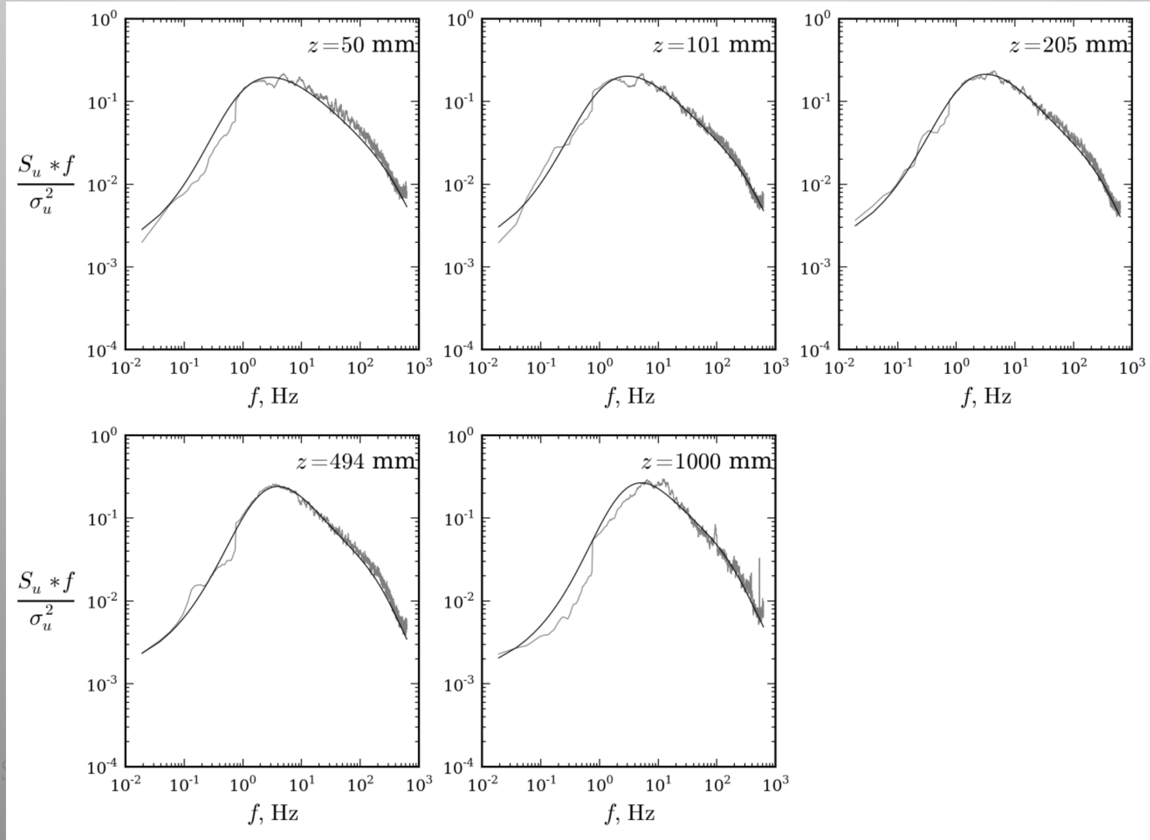
- Represent **average size of turbulent eddies** within ABL
- Important for designing engineering structures, depend on eddie size – different structure loads



Results

POWER SPECTRAL DENSITY OF VELOCITY FLUCTUATIONS

- When dealing with **complex fluid-structure interactions** – distribution of TKE highly important (wide range of frequencies)
- Longitudinal and lateral power spectar – tall and slender structures



longitudinal component

Results

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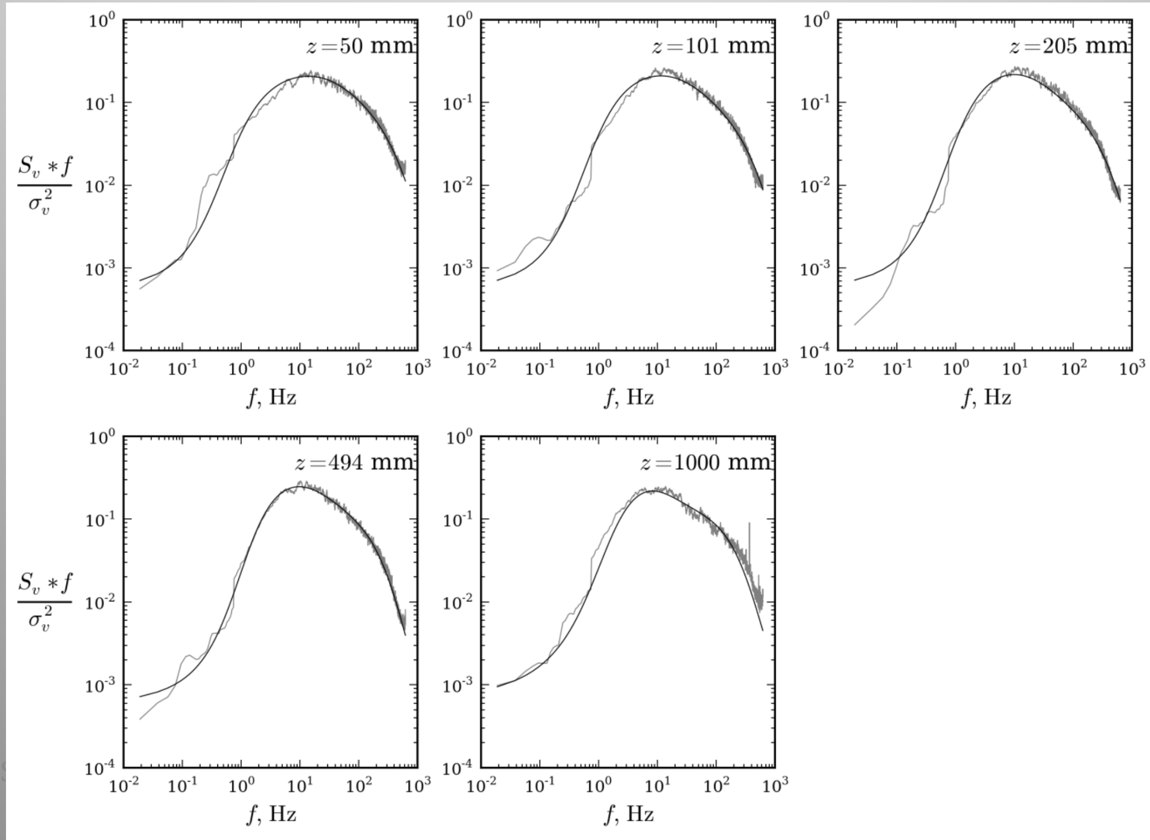
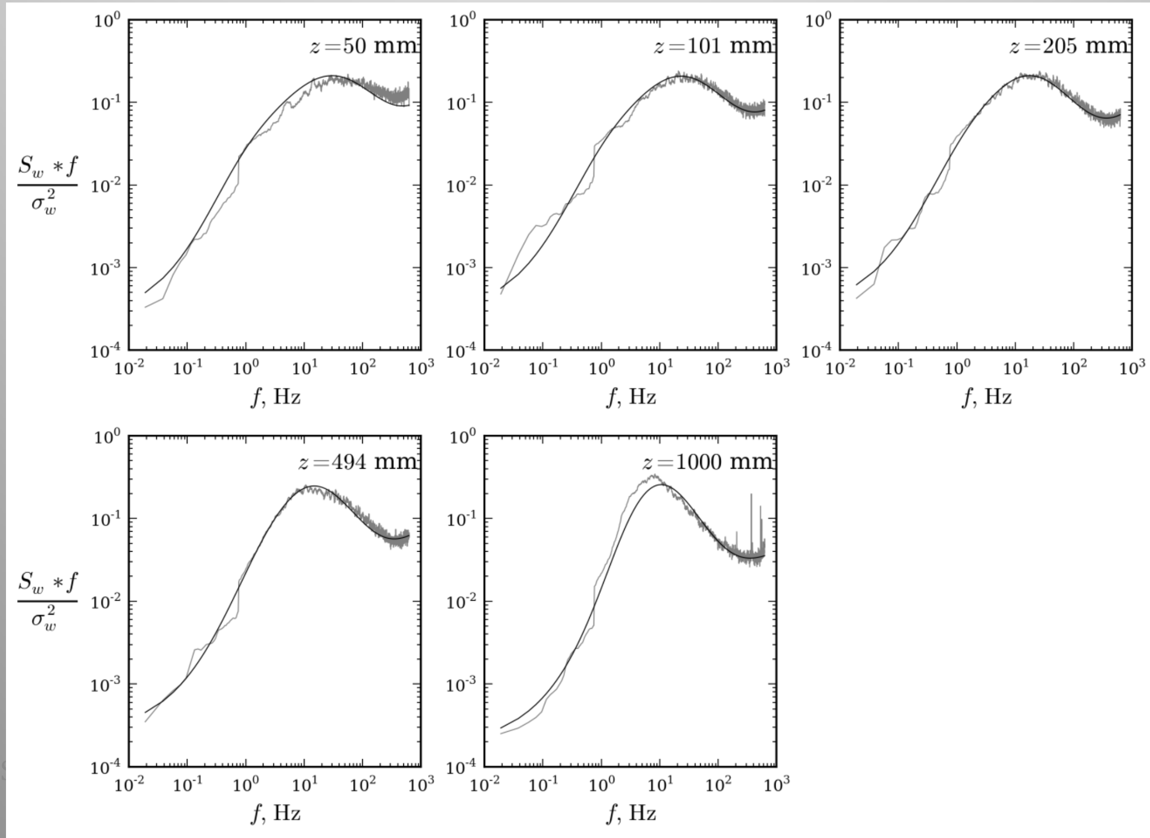


lateral component

Results

POWER SPECTRAL DENSITY OF VELOCITY FLUCTUATIONS

- When dealing with **complex fluid-structure interactions** – distribution of TKE highly important.
- Vertical component - bridges



vertical component

Conclusions

- ANN - developed in order to enable time efficient and **less expensive designing of experimental hardware** for ABL simulations in wind tunnel
- Estimating **optimal design** of wind tunnel setup in order to simulate the ABL
- In general, the modelling results show **very good agreement** with the experimental results – lower ABL

- Proposed approach proves to be a **valuable tool** in wind tunnel studies as it offers possibility for a “quick” and economic designing of the neccessary experimental hardware

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