Validation metrics for time dependent obstacle resolving simulations

Jörg Franke, Pham Ha Thanh | Faculty of Engineering | Vietnamese-German University | Thu Dau Mot | Vietnam

18th International Conference on Harmonisation within Atmospheric Dispersion Modelling for Regulatory Purposes, 9-12 October 2017, Bologna, Italy

Vietnamese-German University

Introduction
Validation of turbulence resolving time-dependent simulations

- Increasing usage of turbulence resolving time-dependent simulations
  micro-scale, built environment

- Validation mainly for low order statistics
  mean, variance, turbulent fluxes

- Availability of spatial and temporal high resolution data from experiments
  wind tunnel, time series, coincident measurements of flow and concentration

- Validation to be extended to statistics of flow and dispersion dynamics
  quadrant analysis, time and length scales, spectra, wavelet, …

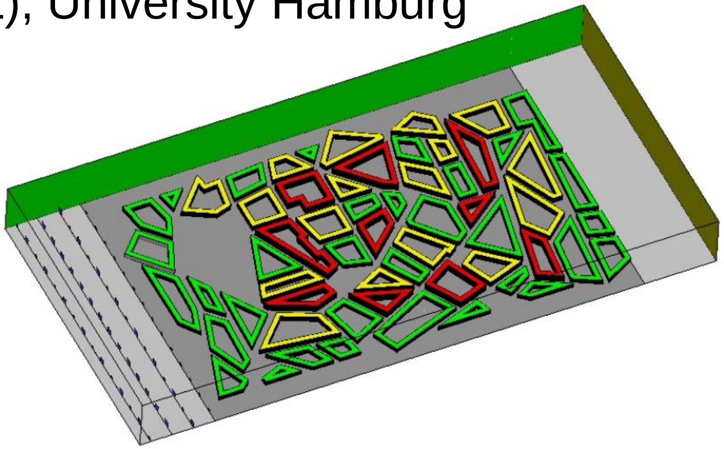
- **Metrics are needed for quantitative comparison**

- Suggestion of a metric for comparing distributions (Cumulative Distribution Function)

Introduction

Ultimate target: thorough validation of LES against the „Michelstadt“ case

- Michelstadt – Generic European city center model (1:225 scale)
- Environmental Wind Tunnel Laboratory (EWTL), University Hamburg
- Measurement data
  - 2D velocities
  - Concentrations from continuous releases
  - Concentrations from puff releases
- Time-series of measurement data available
- Used for RANS and (initial) LES validation



© EWTL

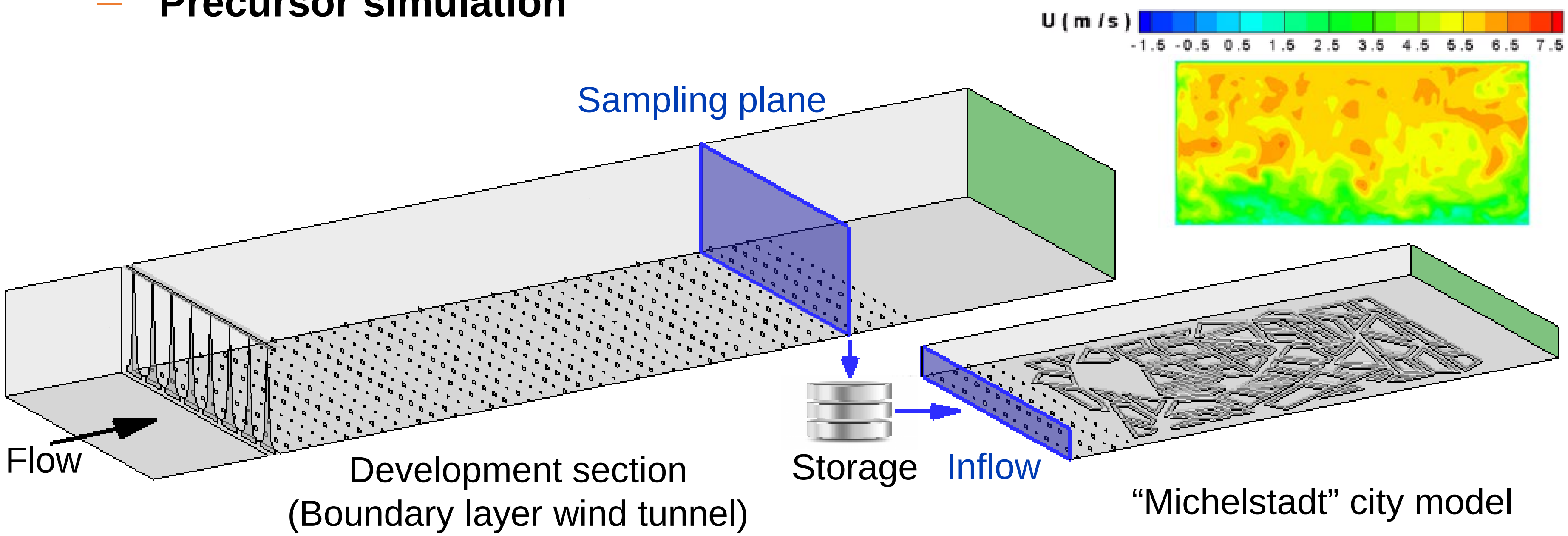
© EWTL

Vietnamese-German University

Introduction

Current state: precursor simulation for inflow generation

- Time-dependent simulations require time-dependent inflow boundary conditions
  - Synthetic turbulence
  - **Precursor simulation**



- **Validation metrics discussed for velocity data of precursor simulation**
- Experimental data available for setup without Michelstadt model, **but full roughness**

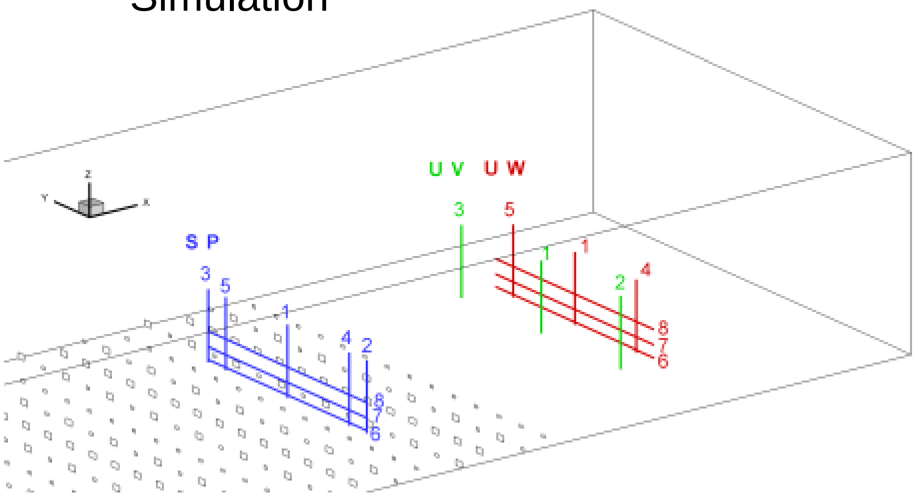
Vietnamese-German University

Numerical parameters

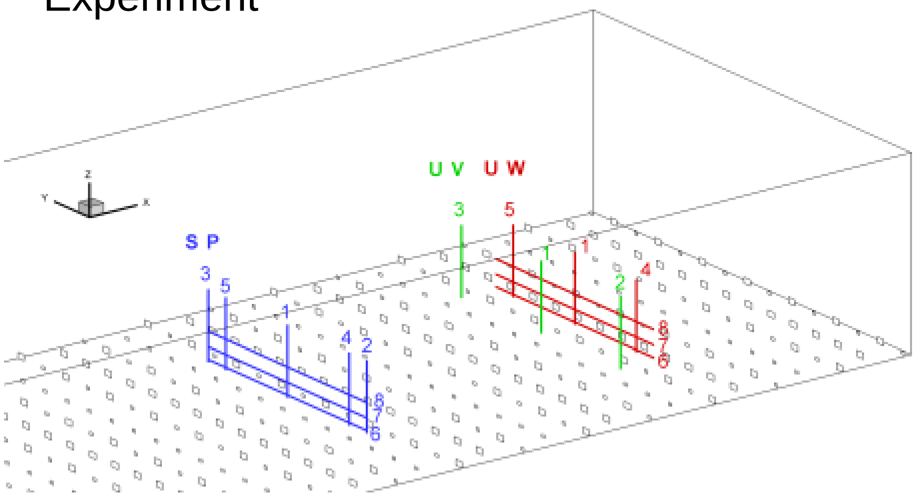
Computational domain and sampling locations

- Simulation with roughness elements like in Michelstadt experiment
- Experiments without Michelstadt model, but roughness on entire bottom

Simulation



Experiment

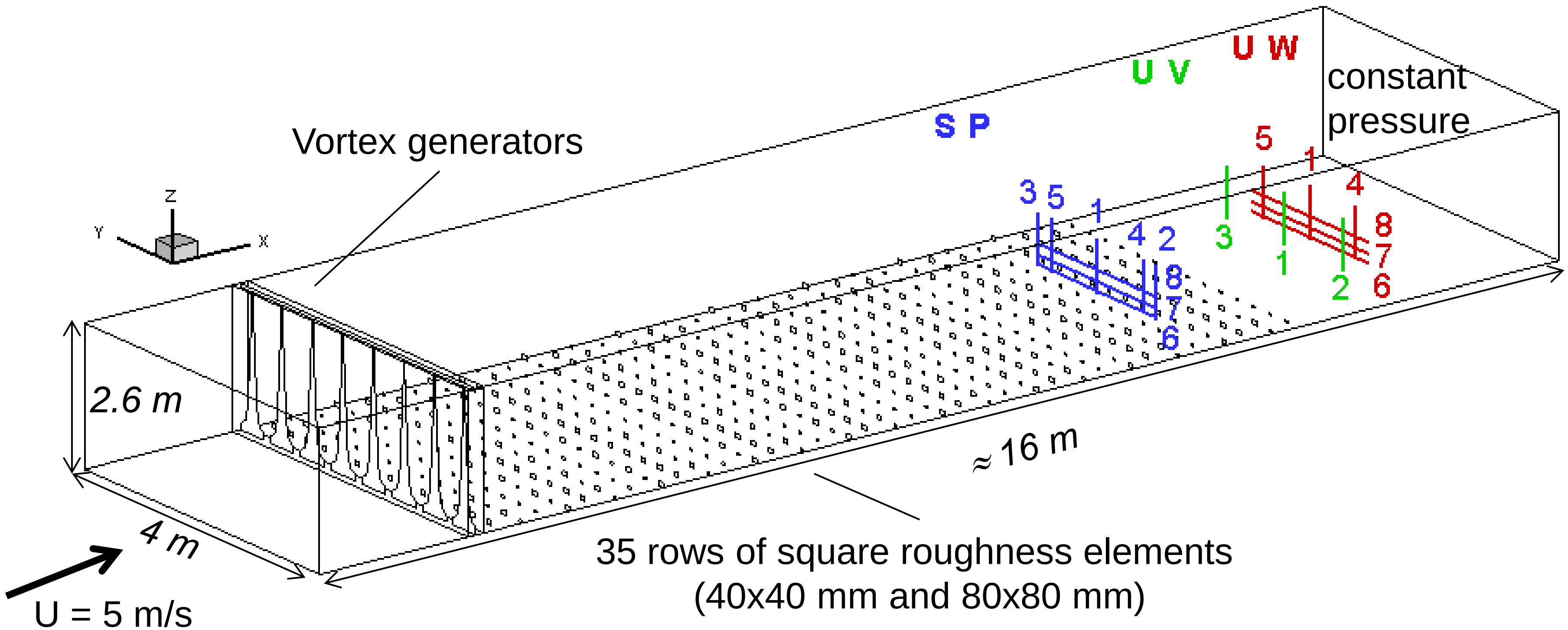


- **Simulation**: sampling of velocities at lines in sampling plane (**SP**)
- **Simulation and experiment**: sampling of velocities at lines (**UV** & **UW**), indicative of measured velocity components
- **SP** and **UV** have same relative position in roughness array

Vietnamese-German University

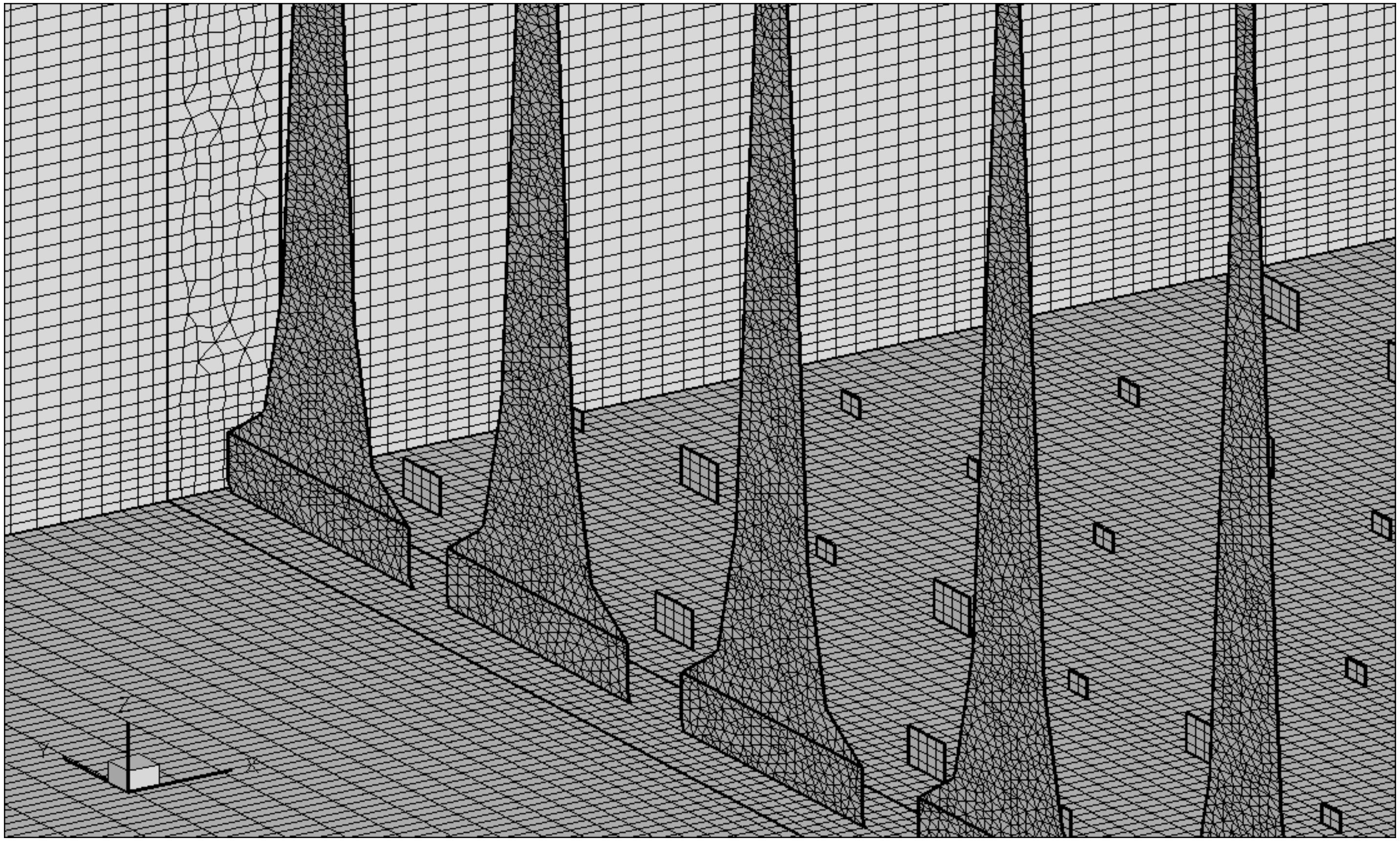
Numerical parameters

Computational domain and boundary conditions



Numerical parameters
Computational grid

- Hybrid: tetra-pyramid mix around vortex generators, Cartesian hexa elsewhere
- Coarse mesh resolution close to walls, about 10 million cells (70 % are hexa)



Numerical parameters

Simulation setup and experimental data post processing

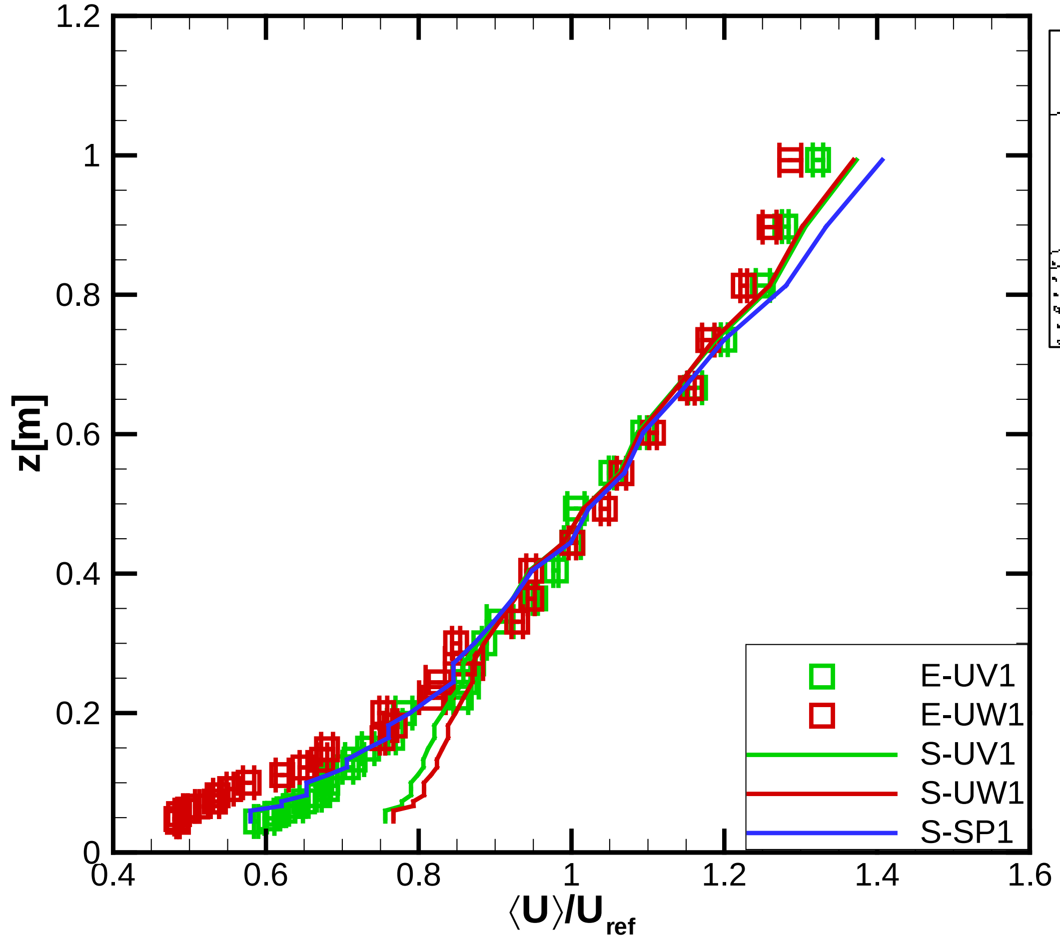
- Implicitly filtered Navier-Stokes equations with constant density and viscosity
- pisoFoam solver OpenFOAM 2.4.0
- Dynamic one equation subgrid scale model ($\Delta_i = \sqrt[3]{V_i}$)
- Spalding wall functions on no-slip walls
- Time step $0.001\ s$, sampling interval $0.004\ s$ $(250\ Hz)$
- Simulation data sampled for $120\ s$, about 38 flow through times
- Experimental data sampled between about $200\ s$ and $300\ s$
- **For low-order statistics**
  - Experimental data segmented in $120\ s$ intervals with 90% overlap
  - Mean values and 95% confidence intervals determined from segments

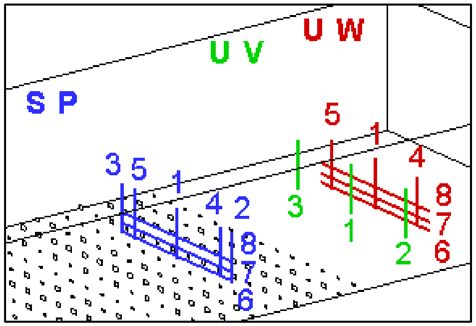
Vietnamese-German University

Results

Low order statistics – $y = 0\ m$

- Non-dimensional mean velocity component in flow direction

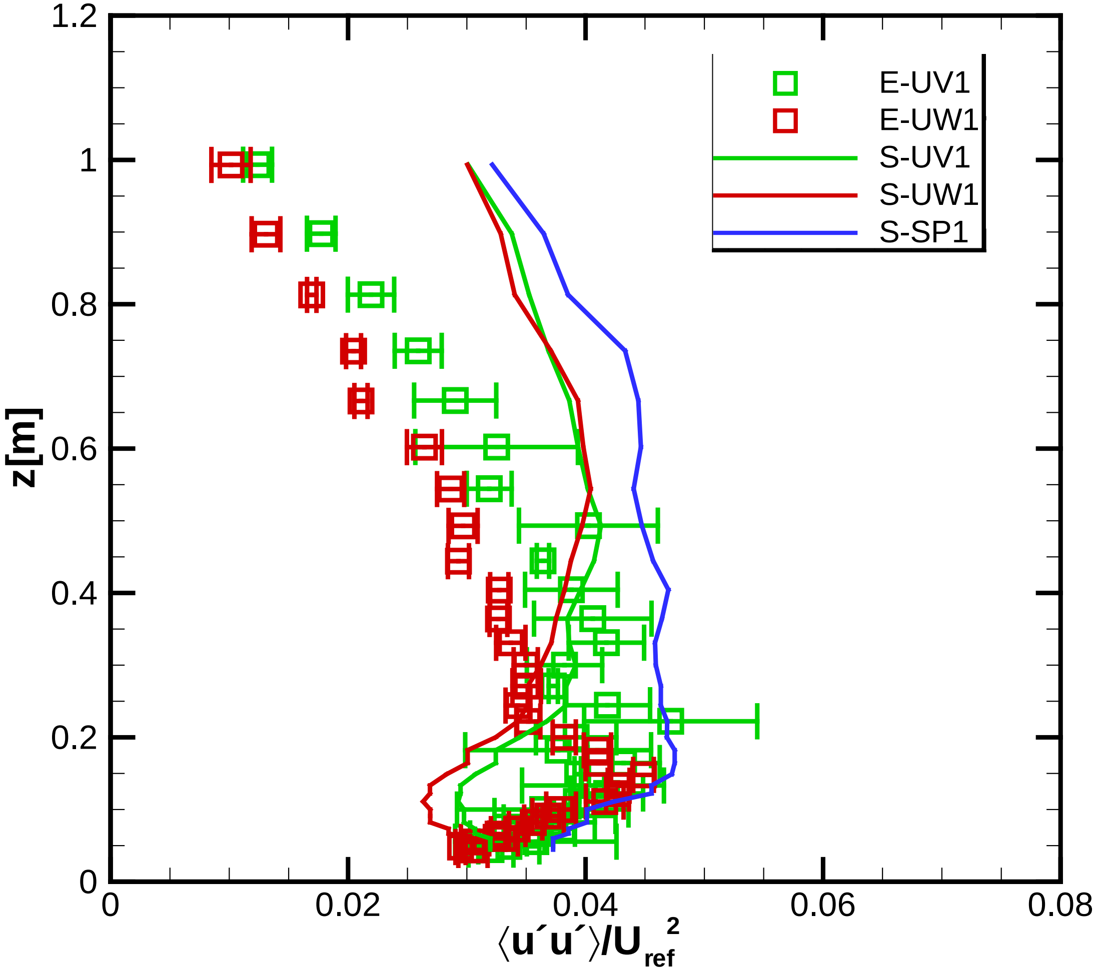


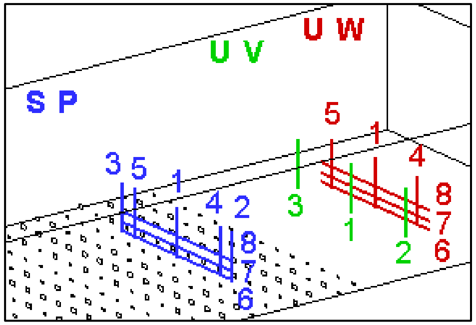


Results

Low order statistics – $y = 0\ m$

- Non-dimensional variance of velocity component in flow direction



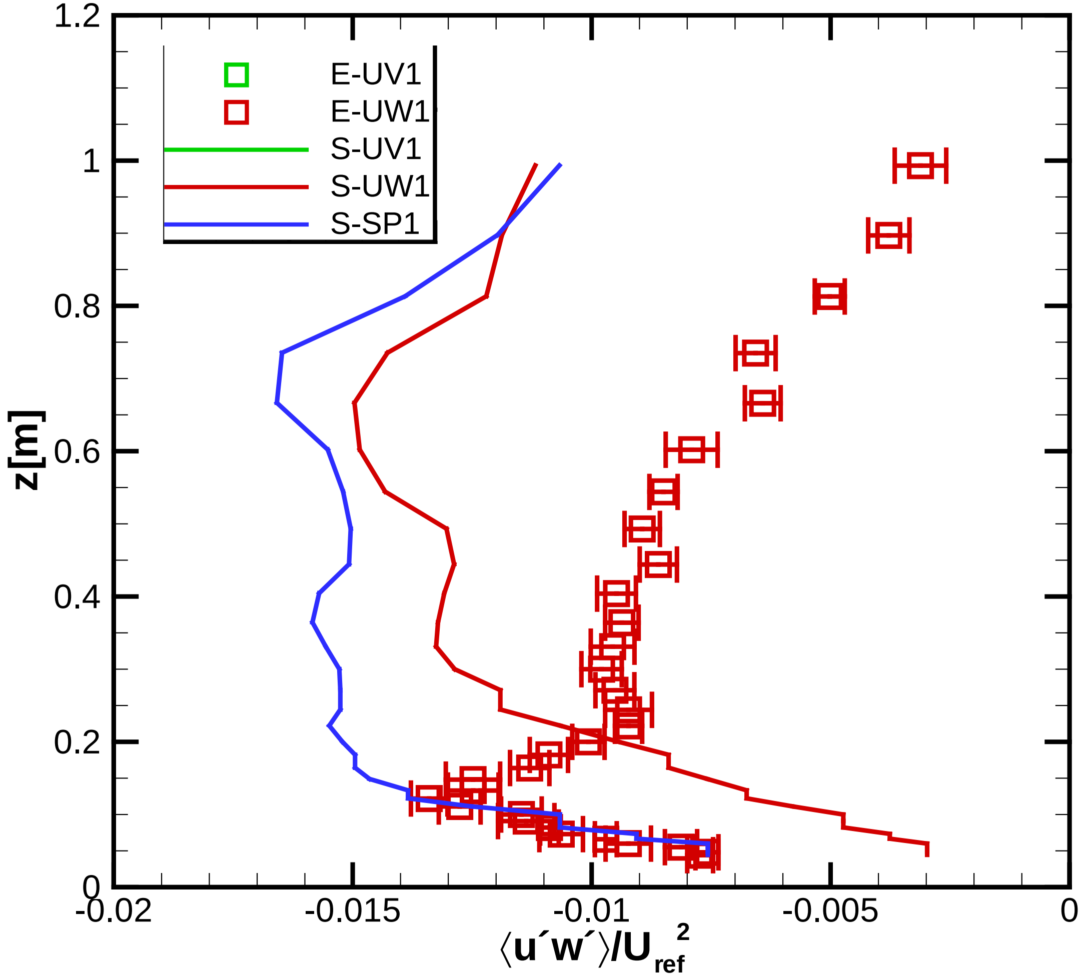


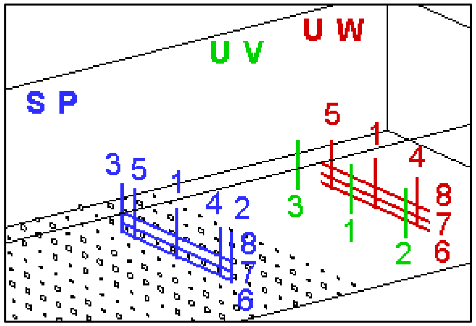
Vietnamese-German University

Results

Low order statistics – $y = 0\ m$

- Non-dimensional mean turbulent vertical momentum flux





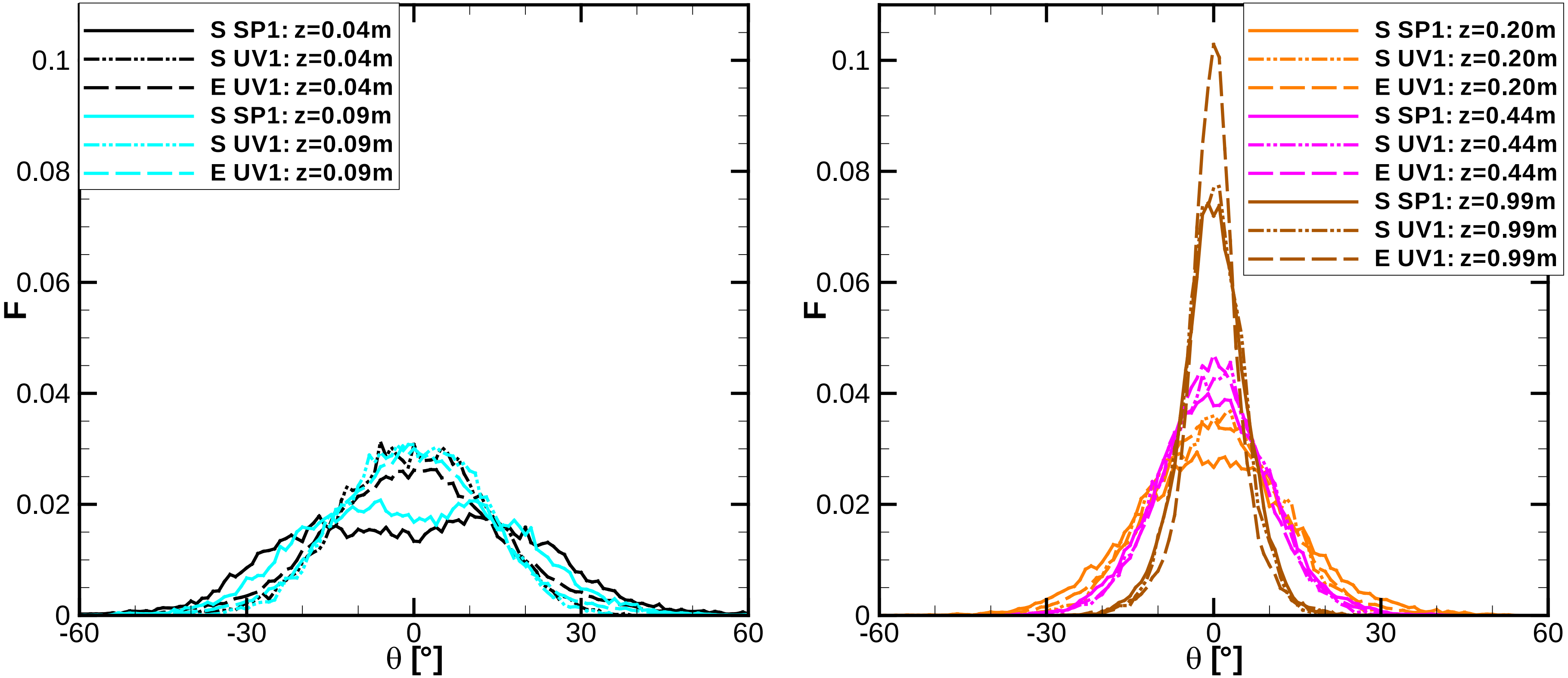
Results

Horizontal wind direction fluctuations at UV1 and SP1

- Instantaneous wind direction fluctuations around mean wind direction

$$\theta = tan^{-1}(V/U) - \langle tan^{-1}(V/U) \rangle$$

- Frequency distribution F at 5 points



Vietnamese-German University

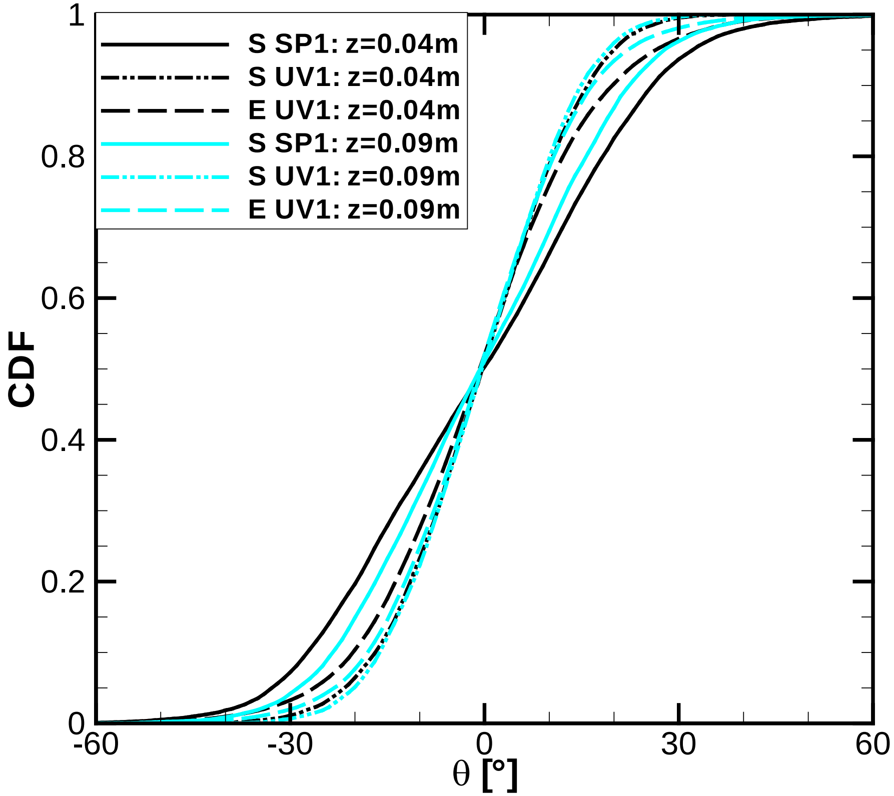
Results

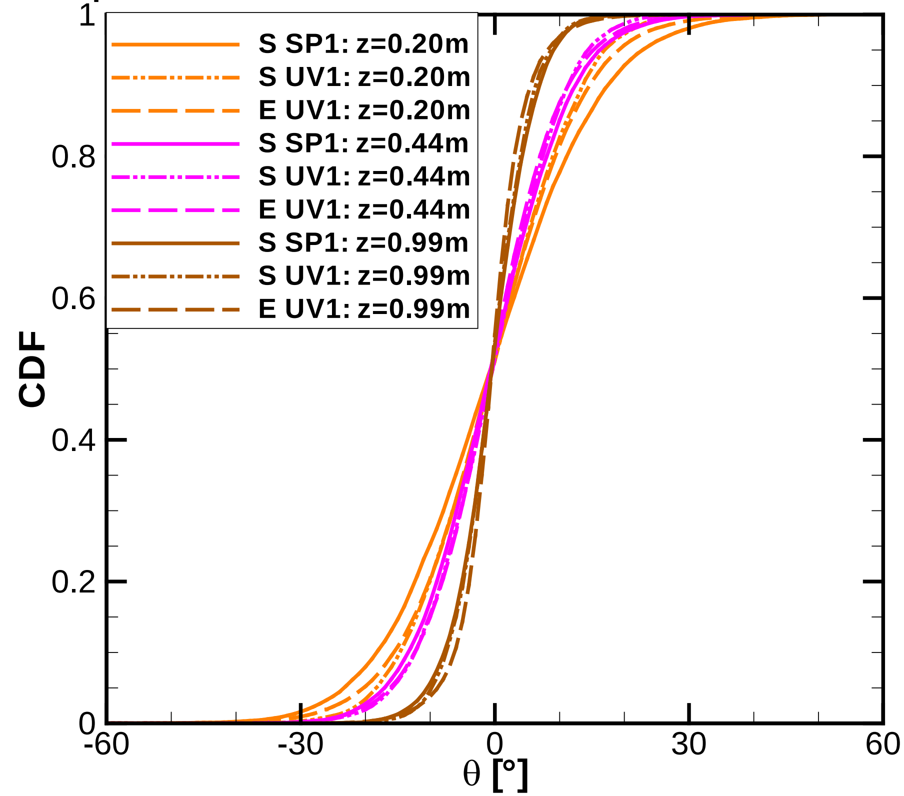
Horizontal wind direction fluctuations at UV1 and SP1

- Instantaneous wind direction fluctuations around mean wind direction

$$\theta = tan^{-1}(V/U) - \langle tan^{-1}(V/U) \rangle$$

- Cumulative Distribution Function CDF at 5 points





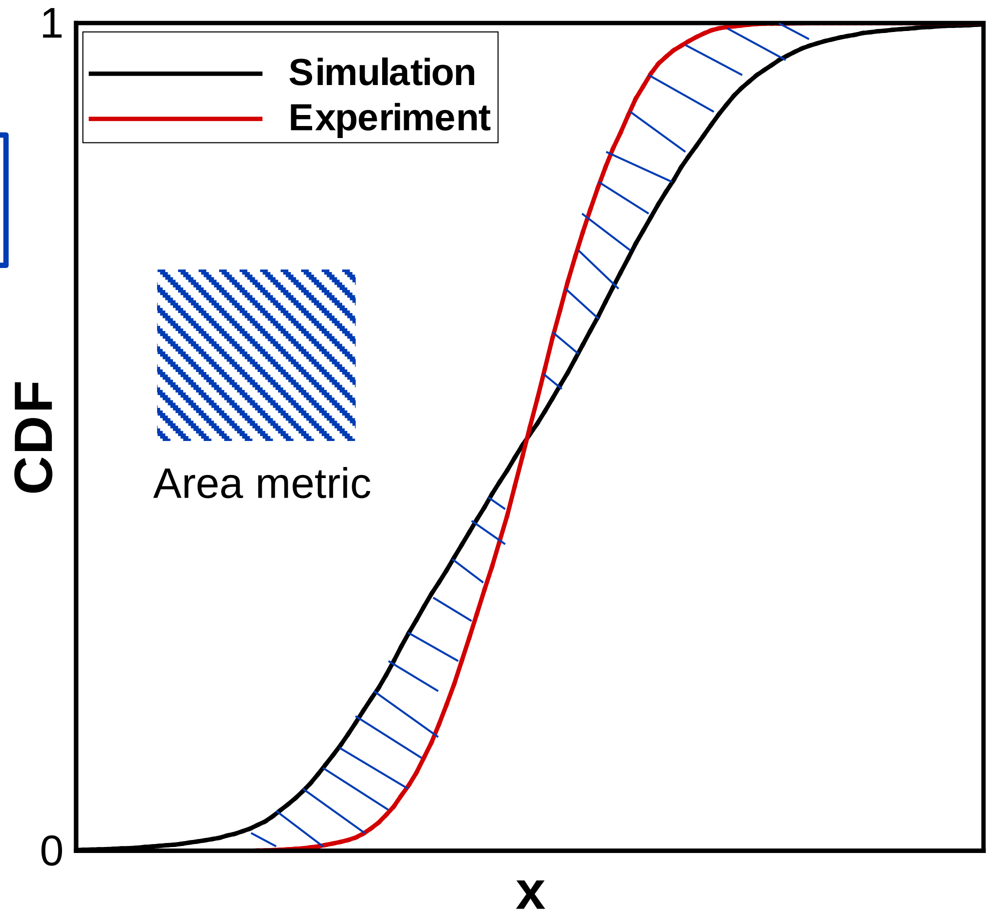
Vietnamese-German University

Results

Horizontal wind direction fluctuations at UV1 and SP1

- „Area metric“ of Ferson et al. (2008) for comparing probabilistic results
- **Area between CDFs**

$$\boxed{AM_x = \int_{-\infty}^{\infty} \left| CDF_S(x) - CDF_E(x) \right| dx}$$

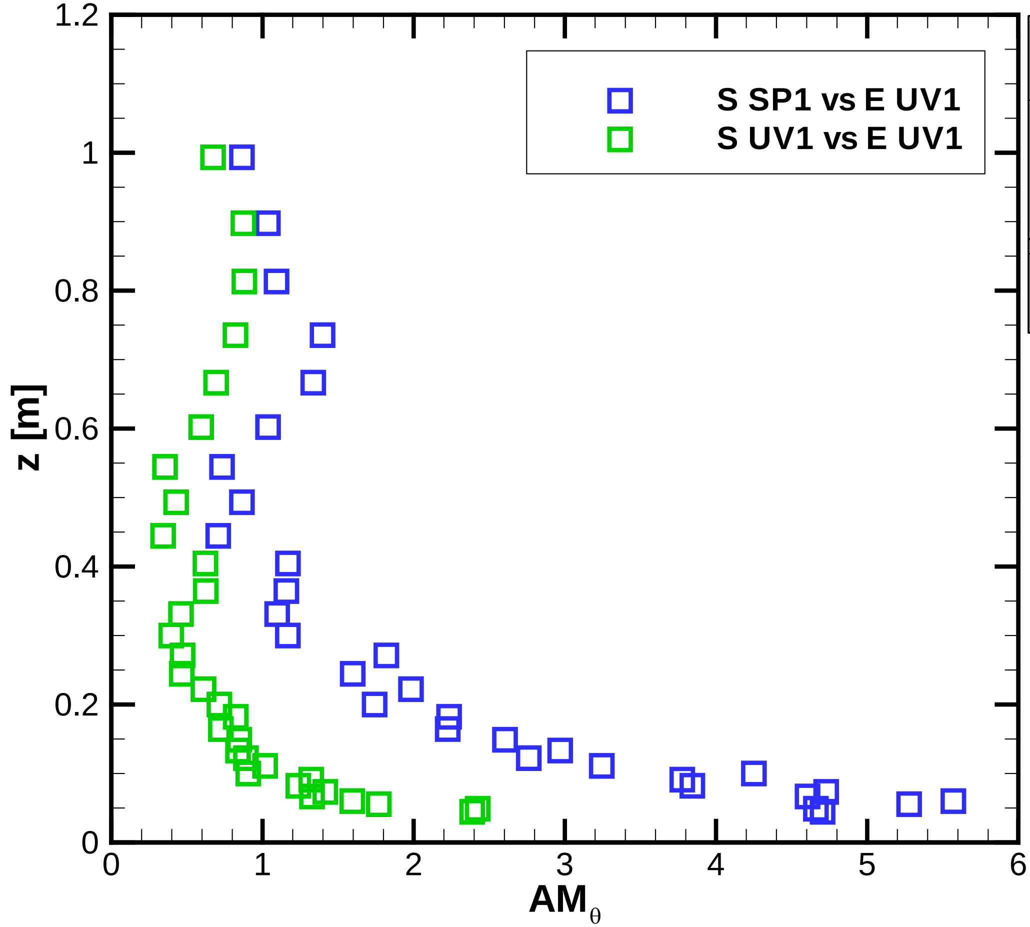


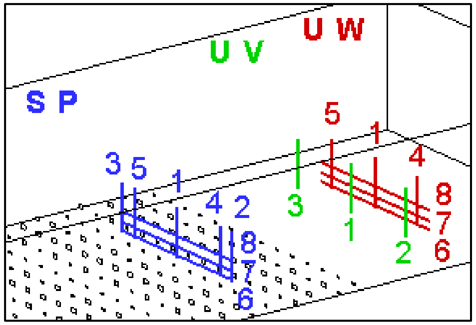
Ferson, S., W.L. Oberkampf and L. Ginzburg, 2008: Model validation and predictive capability for the thermal challenge problem. *Computer Methods in Applied Mechanics and Engineering*, **197**, 2408–2430

Results

Horizontal wind direction fluctuations at UV1 and SP1

- Area metric AM_θ (in degree)





Summary

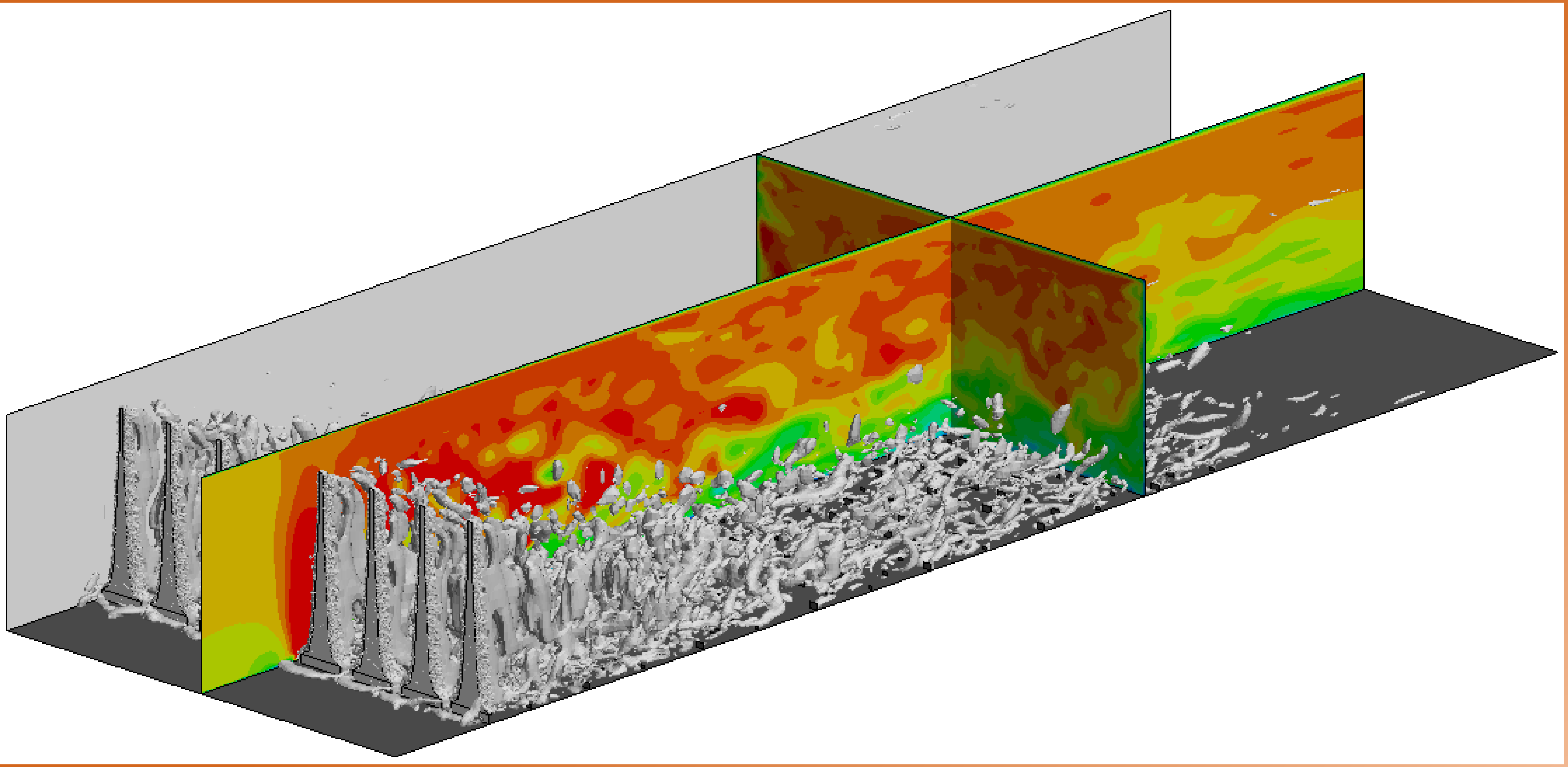
- Precursor simulation performed for subsequent LES of Michelstadt case
- Low-order statistics at sampling locations within roughness array agree better with experiments close to the ground
- Distributions of horizontal wind direction fluctuations close to the ground agree better at simulation locations without roughness
- Better low order statistics despite different dynamics

- Area metric of Ferson et al. (2008) suitable to compare distributions
- Application to validation of LES needs further investigation and discussion
- More metrics needed for quantitative comparison of statistics of scales and dynamics

Acknowledgement

Computing time for the simulation was provided on the High Performance Computing cluster of the Faculty of Computer Science & Engineering, Ho Chi Minh University of Technology, Ho Chi Minh City, Vietnam

Thank you for your kind attention



Vietnamese-German University

VGU
VIETNAMESE-GERMAN UNIVERSITY

Jörg Franke

Le Lai Street, Hoa Phu Ward,
Binh Duong New City,
Binh Duong Province,
VIETNAM
Tel. (0274) 222 0990, Ext. 115
Mobil. 0127 487 3675
joerg.franke@vgu.edu.vn
visit www.vgu.edu.vn