Technical Meteorology

Wind tunnel investigation of the spatial variability of turbulence characteristics in the urban area of Basel City, Switzerland

PHYSMOD2003

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Agenda

- Motivation and overview BUBBLE project
- Remarks on general modelling approach
- Approach flow
- Urban flow
- Summary and Outlook

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- **Motivation and overview BUBBLE project**
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The BUBBLE project investigates turbulence and dispersion phenomena in the Urban Boundary Layer (UBL) of Basel, CH.

Major activities

- Operation of an extensive net of field measurement stations
- Simulation of dispersion scenarios with numerical models
- **Realization of a wind tunnel study to model turbulence and dispersion scenarios**

Timeline

- 2001/02: Yearlong operation of measurement stations in Basel
- **2003: Wind tunnel study on turbulence in the UBL of Basel**
- 2004: Wind tunnel study on pollutant dispersion in Basel

Participating institutions (e.g.)

- ETH Zürich, University of Basel, University of Hamburg (MI)
- Many, many more (see project website)

Further information

http://www.unibas.ch/geo/mcr/Projects/BUBBLE/

The wind tunnel study contributes systematic and extensive turbulence and dispersion measurements over the urban roughness of Basel, CH.

	Motivation
Provide detailed and well-documented turbulence and dispersion data	• Complement the field measurements • Support the interpretation of the field measurements in Basel (e.g. temporal and spatial representativeness) • Provide reference and validation data for numerical modelling
Study dispersion phenomena under systematically varying boundary conditions	• Provide reference and validation data for numerical modelling

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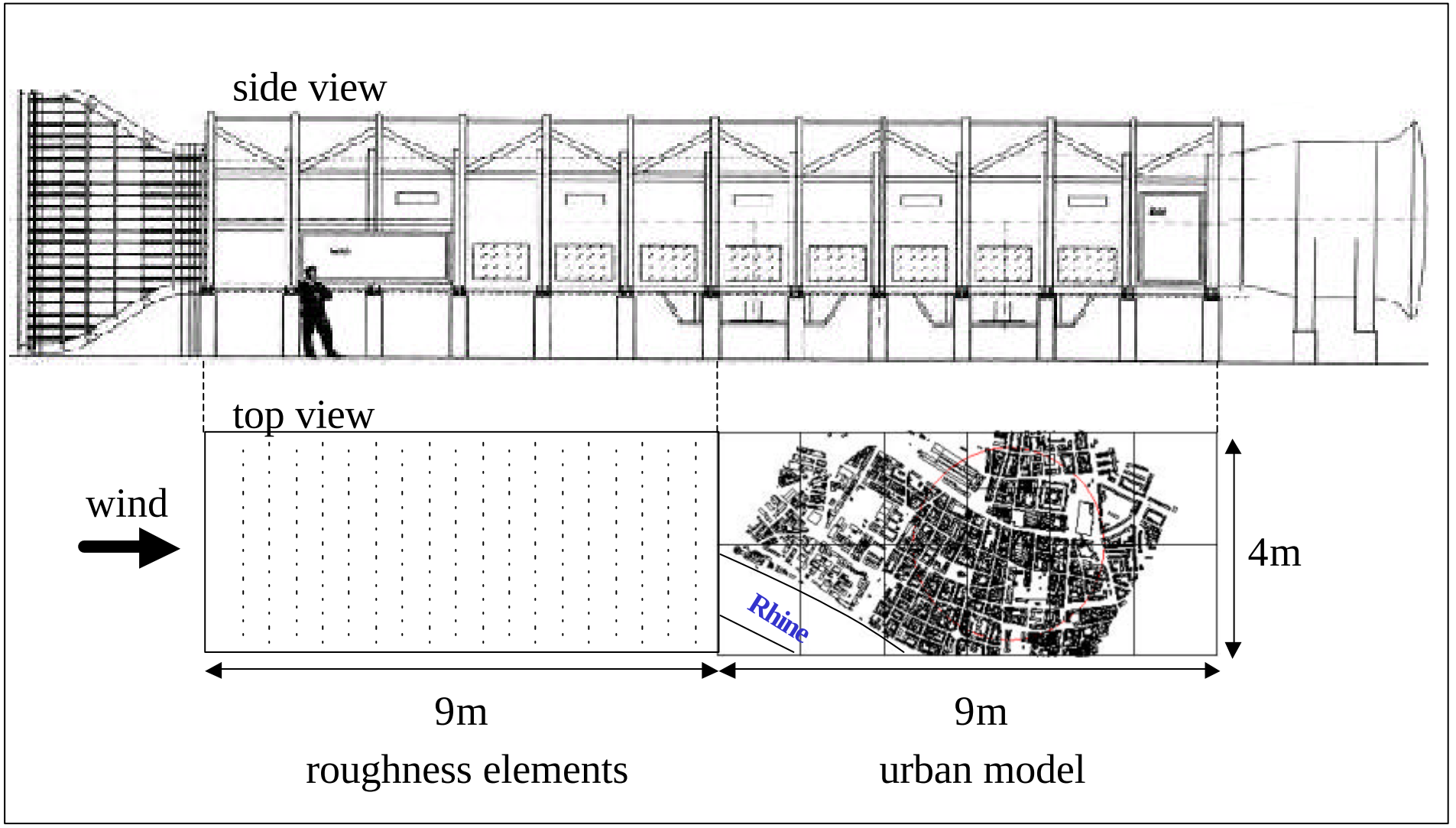
The wind tunnel study is conducted in the Large Boundary Layer Wind Tunnel ‚WOTAN' at the Meteorological Institute of the University of Hamburg.

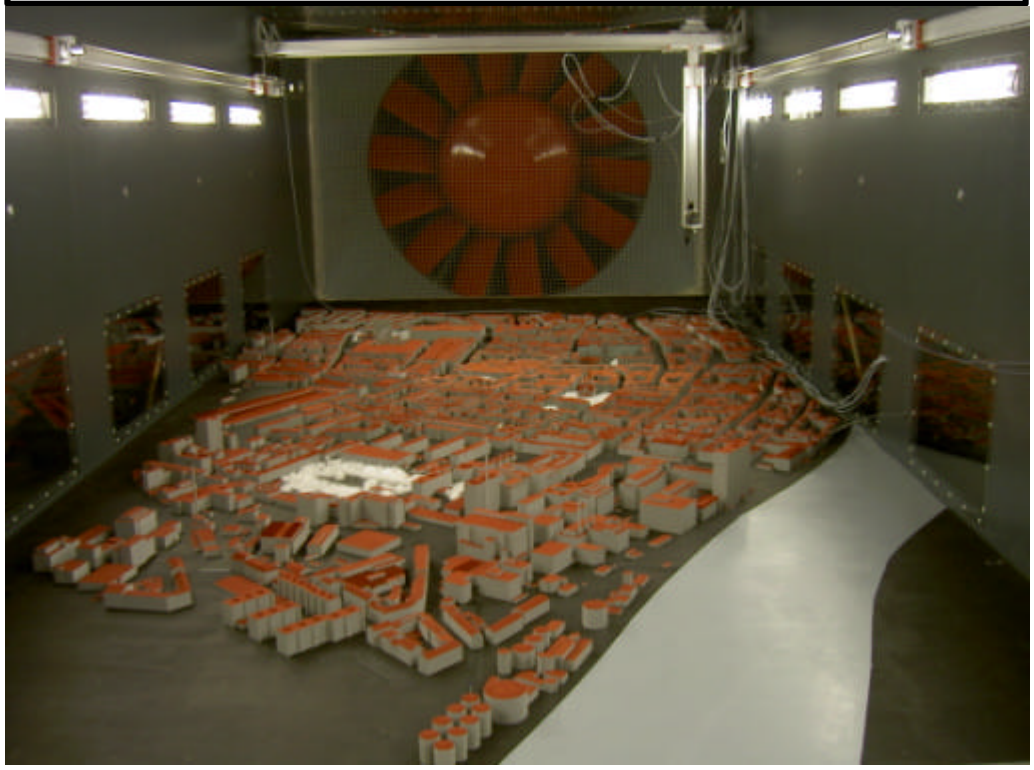


The specification of the urban area is given by an extensive CAD model provided by the authorities of Basel, CH.

Model scale: 1:300

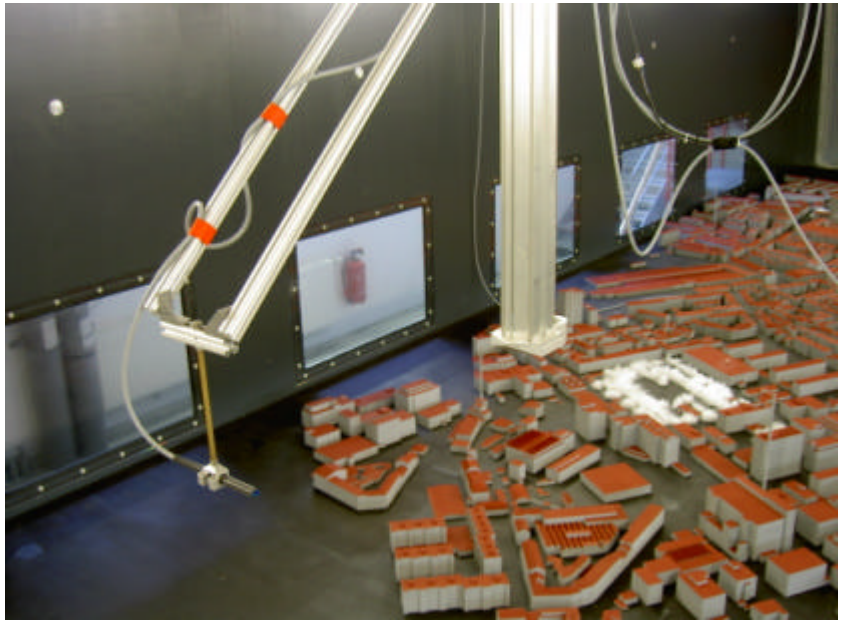
Model area: ~ 2.4km x 1.2km

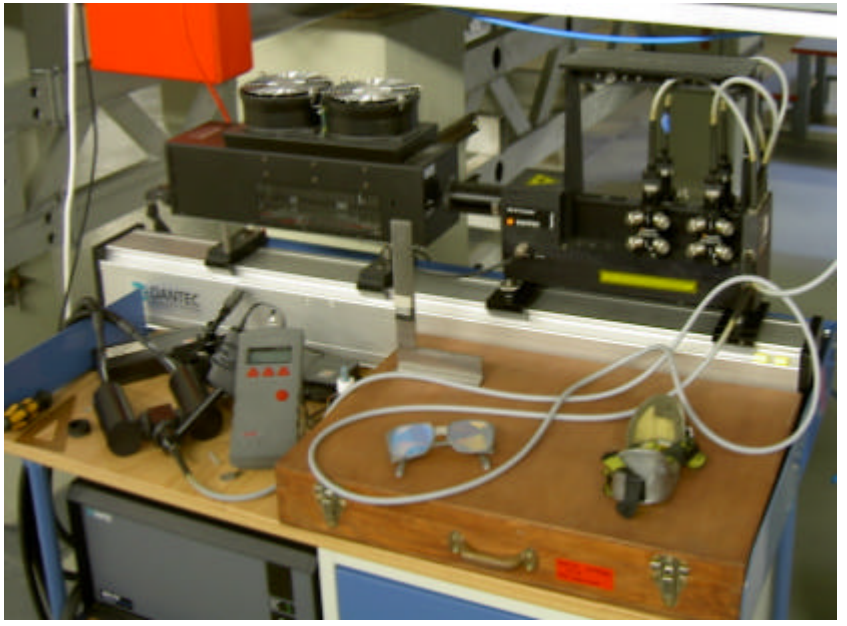
No. of houses: ~ 3.200



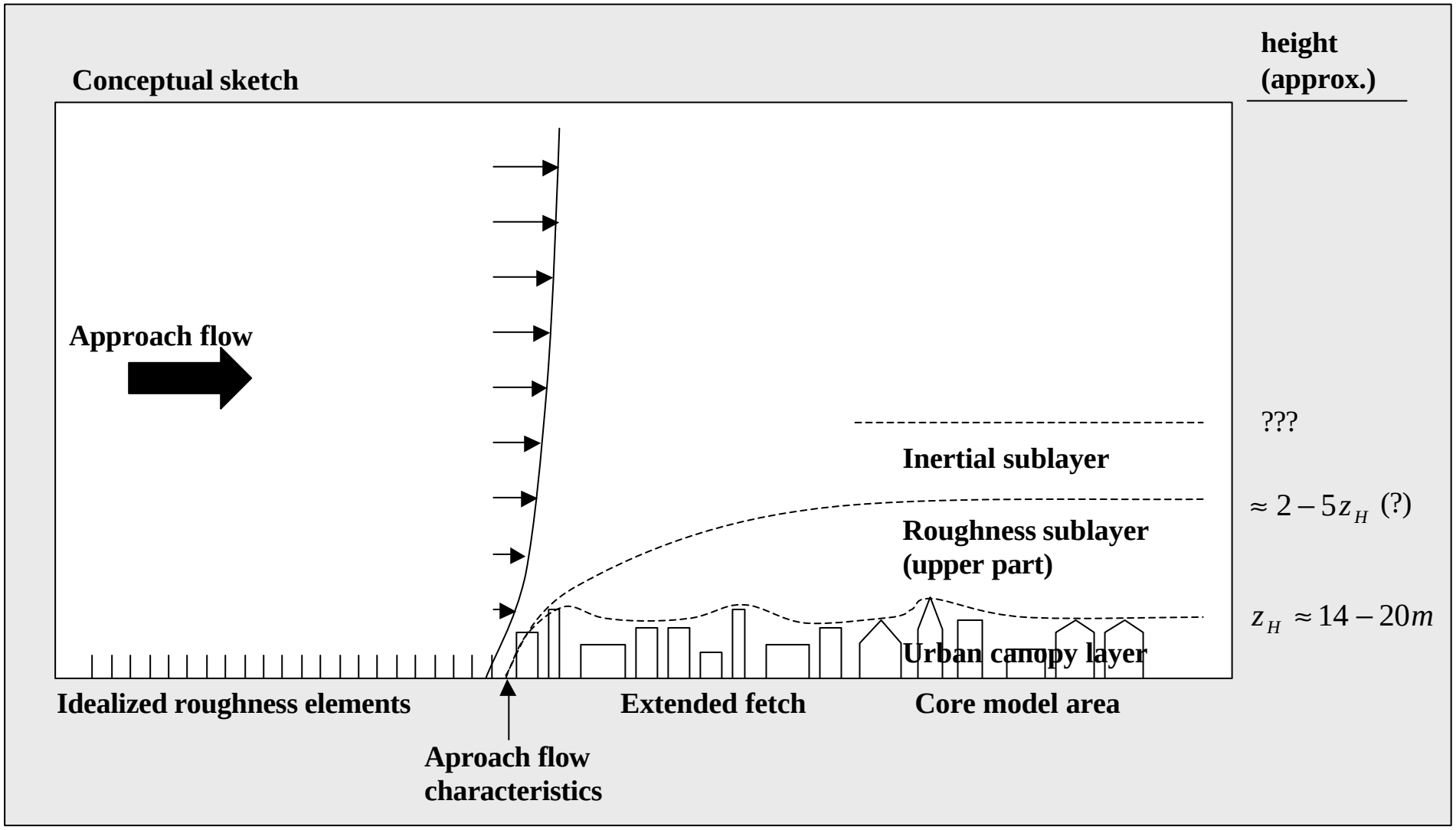
Instantaneous velocity measurements are conducted with two dimensional laser Doppler anemometry (LDA).

Characteristic	Detail
Simultaneously measured velocity components	2 velocity components
Measurement accuracy	~0.05m/s
Measurement volume (ellipsoid)	~1.5mm x 0.12mm x 0.12mm
Measurement frequency	up to 10^3 Hz
Automatic probe positioning accuracy	~1mm





Focus of the modelling approach is on the flow within the urban surface layer (~150m above ground) under neutral stratification.



Basic similarity laws and transfer functions are applied to ensure applicability of wind tunnel results to the full scale scenario.

Similarity number	Criterion	Realization
Reynolds number 1 Re independency above Re_{crit} (VDI*)	$\mathrm{Re}_{\mathrm{mod}} = \frac{\bar{u}_{ref} \cdot L_{ref}}{n} > \mathrm{Re}_{crit} \approx 10\,000$	$\mathrm{Re}_{\mathrm{mod}} \approx \frac{10^{1} \cdot 10^{-1}}{1{,}5 \cdot 10^{-5}} \approx 60\,000$
Roughness Reynolds number 1 Ensuring insignificance of viscous effects (VDI*)	$\mathrm{Re}_{*} = \frac{u_{*} \cdot z_0}{n} > 5$	$\mathrm{Re}_{*approach\ \ flow} \geq 15$

Parameter	Transfer function	Application (e.g.)
Length scales	$L_{\mathrm{mod}} = \frac{L_{full\ scale}}{300}$	z_0, d_0, L_{ux}, L_{uy}, L_{uz}
Time scales	$T_{\mathrm{mod}} = \frac{T_{full\ scale}}{300}$	Spectra S_{ii} in frequency space

*VDI guideline 3783 from December 2000

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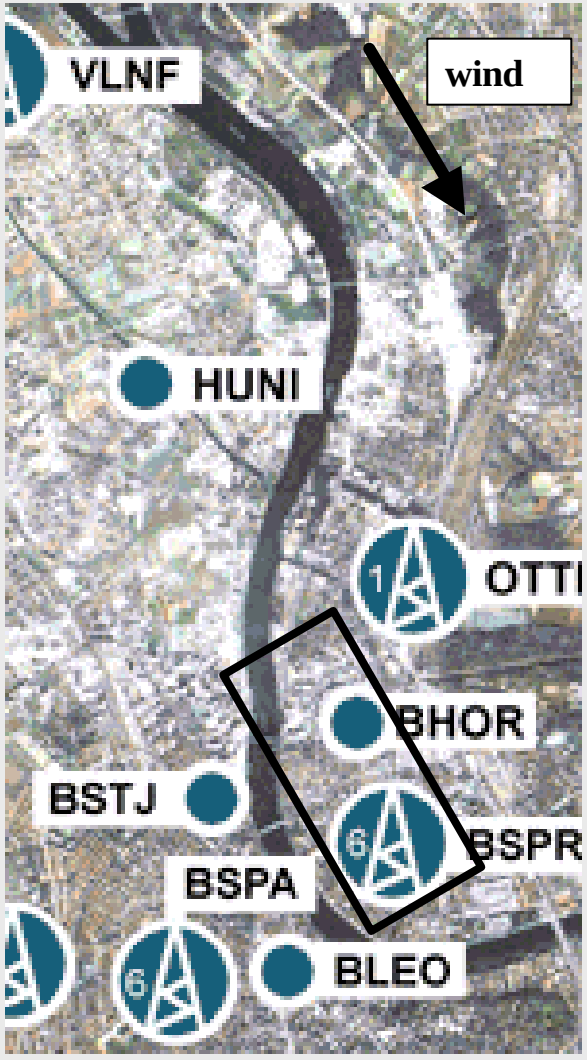
The approach flow is modelled according to measured profiles and references appropriate for Basel, CH.

Basel area



Roughness classification of approach flow:

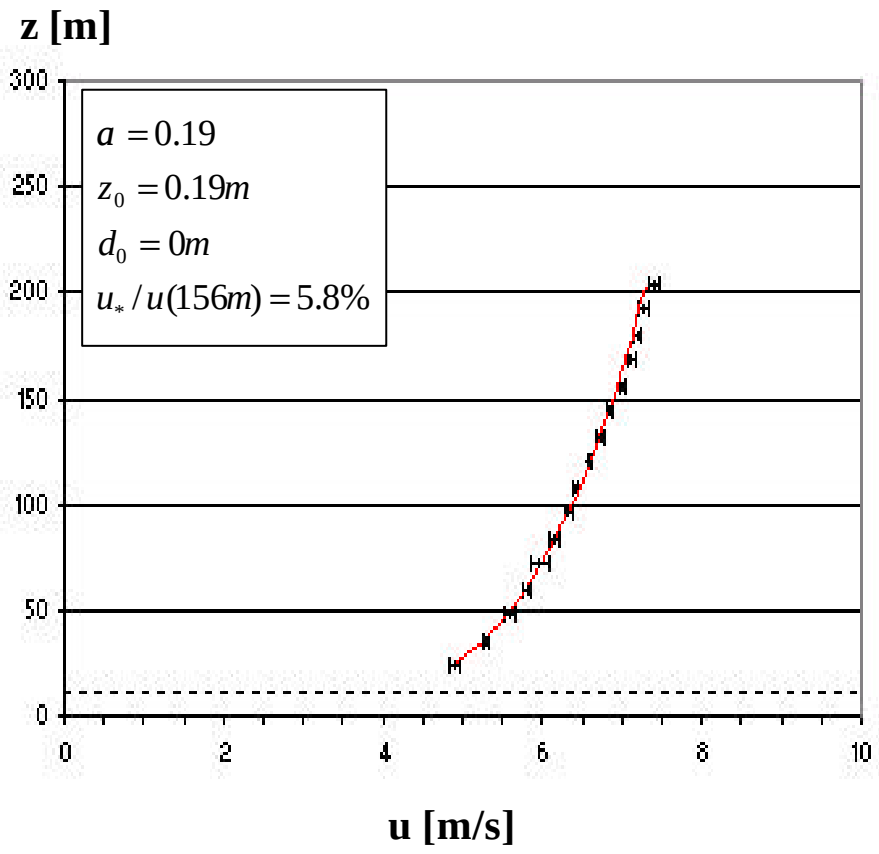
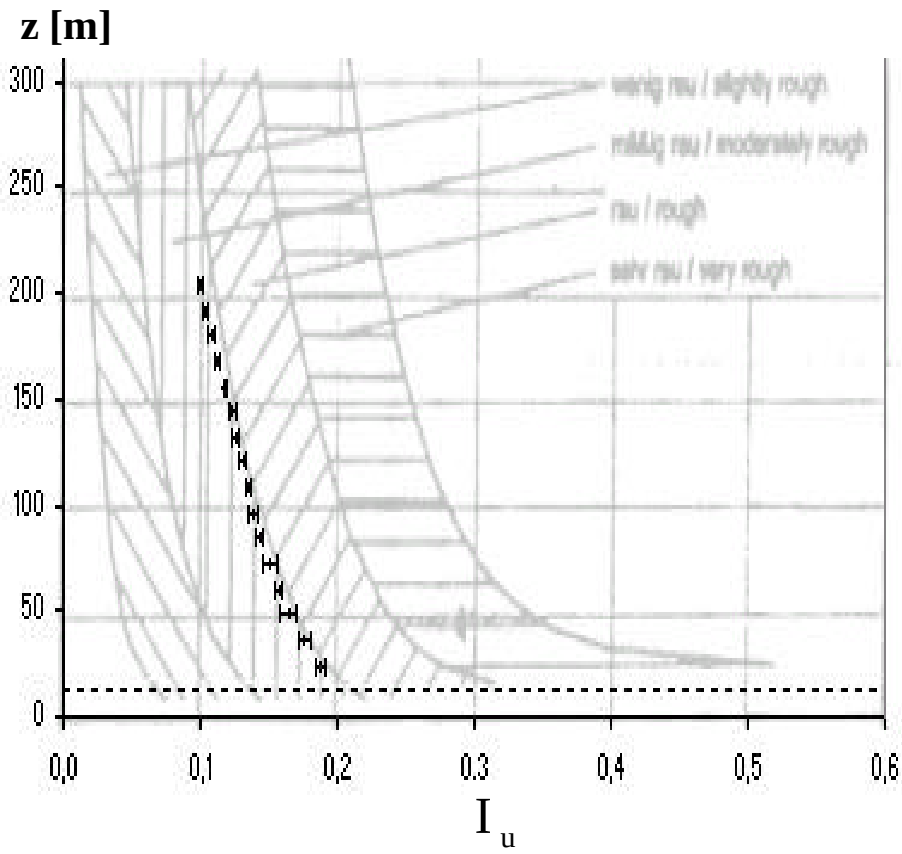
- „moderately rough“ / „rough“ (VDI)
- Roughness class 5 (Davenport)

Target values for modelling (mean wind profile):

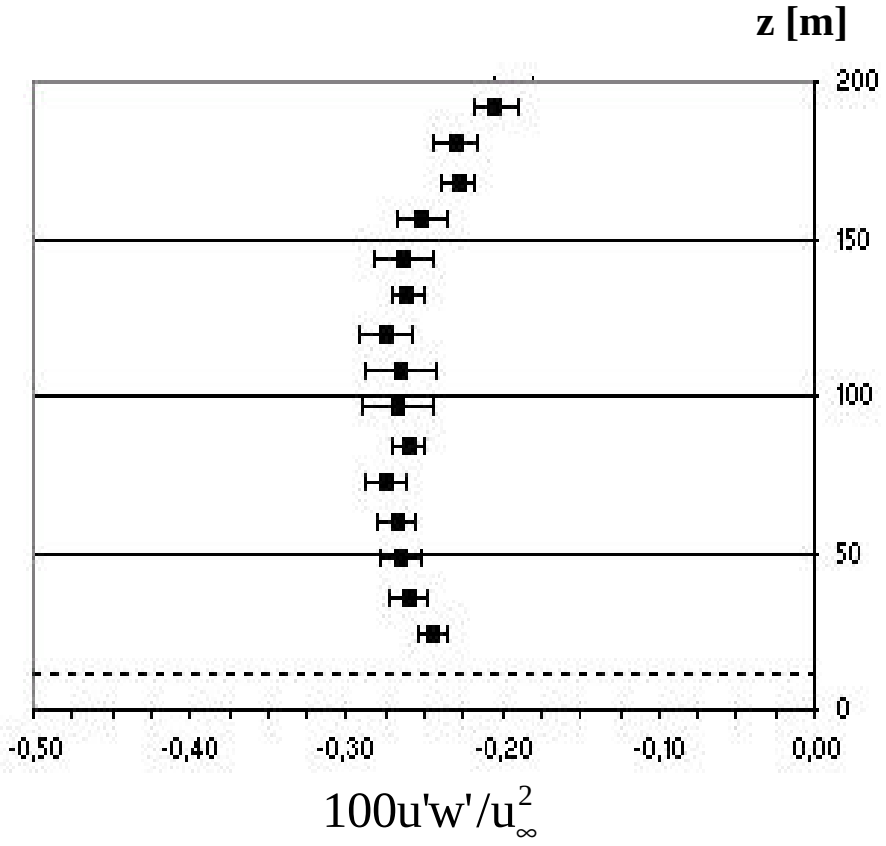
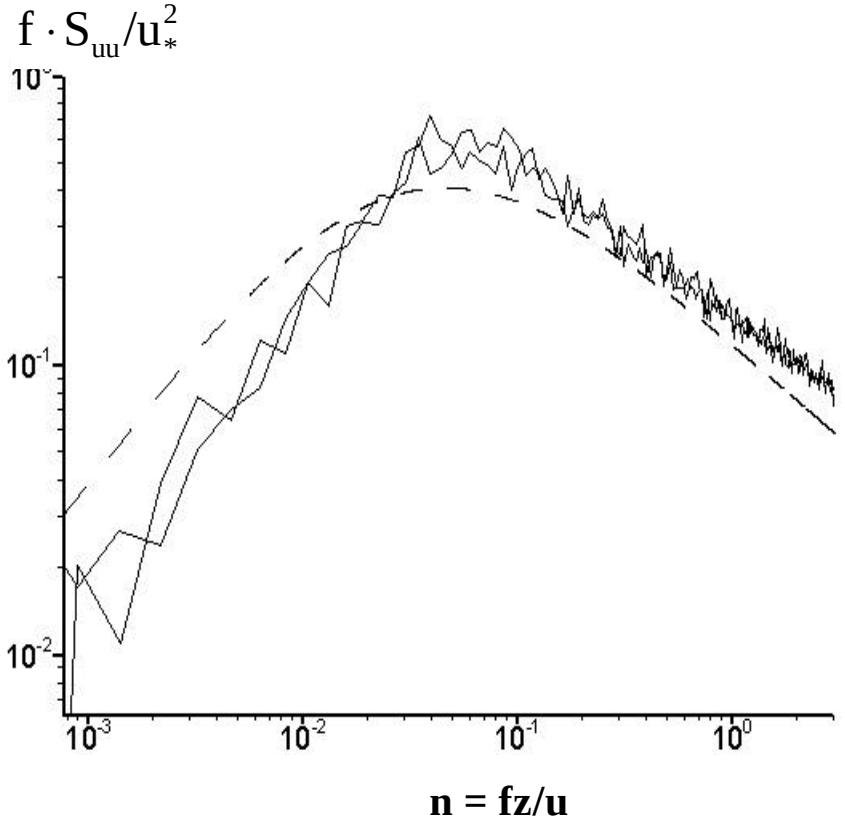
Profile exponent: $a \approx 0.18$

Roughness length: $z_0 \approx 0.2m$

The modelled mean wind and turbulence intensity profiles of the approach flow correspond well to references.

Mean wind profile (dotted line: height of roughness elements)	**Turbulence intensities (e.g.)** (references from VDI guidelines)
	

A „constant flux“ layer is well-established and the turbulence spectra coincide with references.

Reynolds stress u´w´	**Spectral densities (e.g.)** (reference: Kaimal (1972))
	

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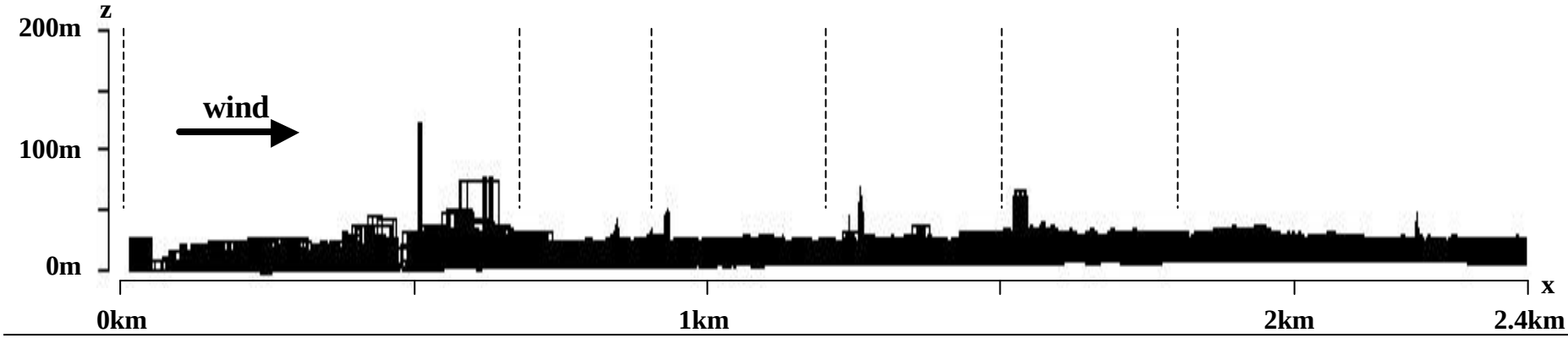
The urban flow study focuses on three aspects.

Study objective	Study approach
Flow development	Analysis of vertical profiles along the model axis
Horizontal inhomogeneity	Analysis of horizontal mesh profiles at 5 height levels in and above the RS
Variability of vertical profiles	Analysis of 9 vertical profiles in the vicinity of BSPR (above roof level)

The flow over the core model area is still developing.

Turbulence intensity I_u	
Reynolds stress u´w´	



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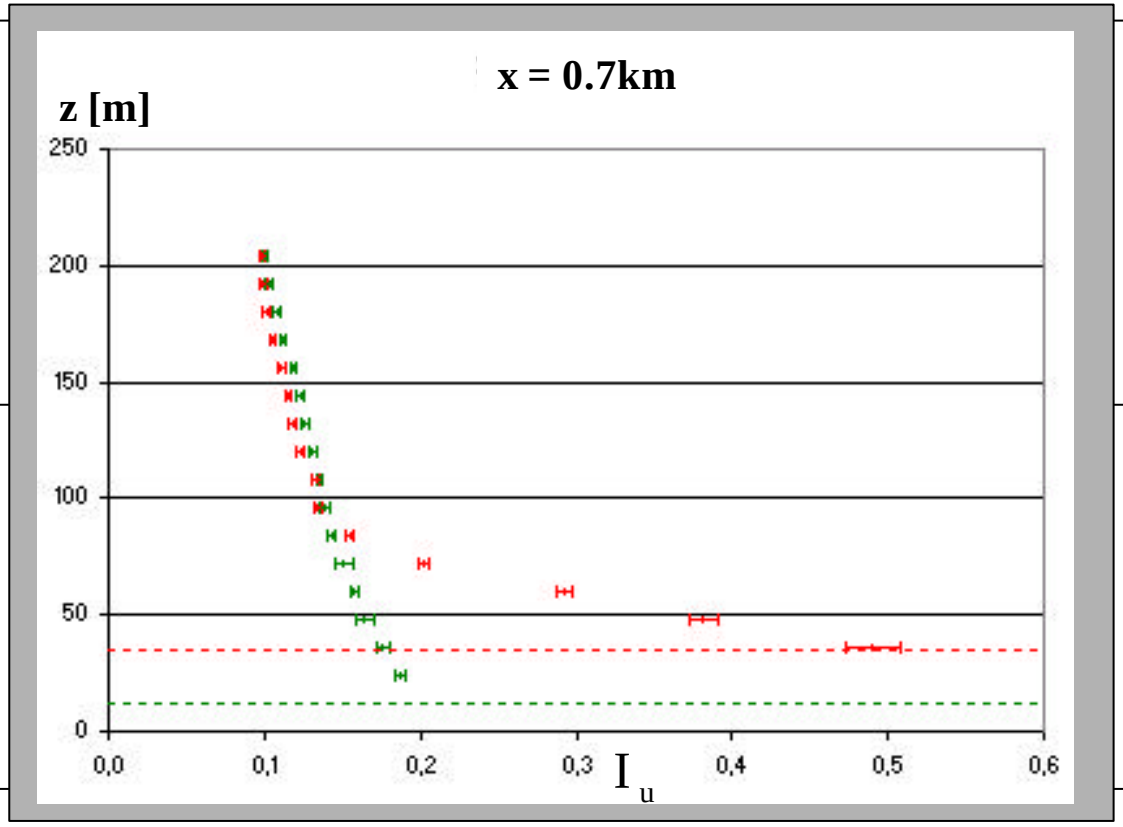

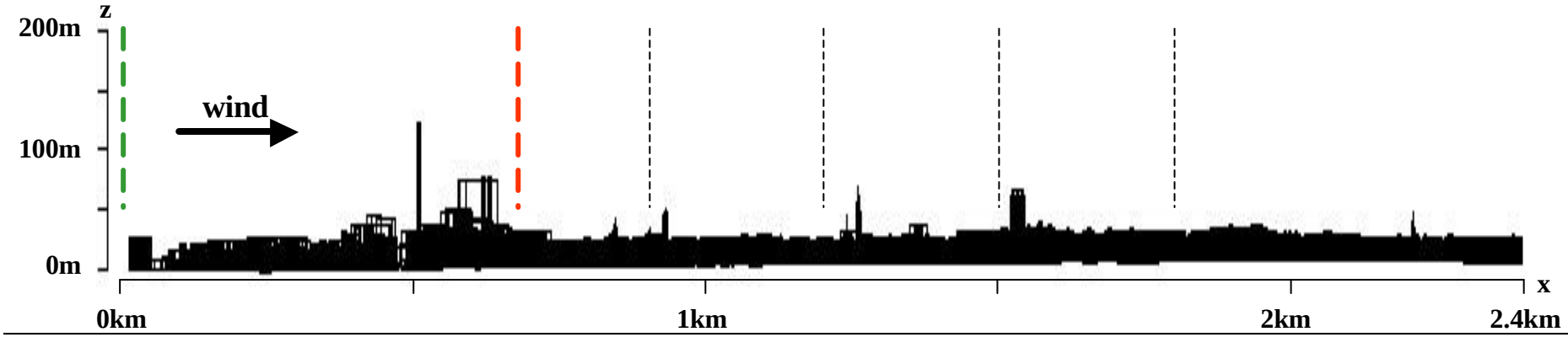

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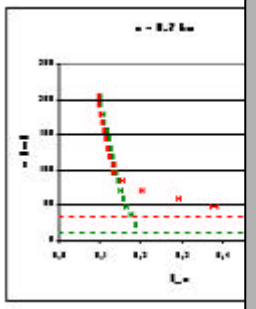
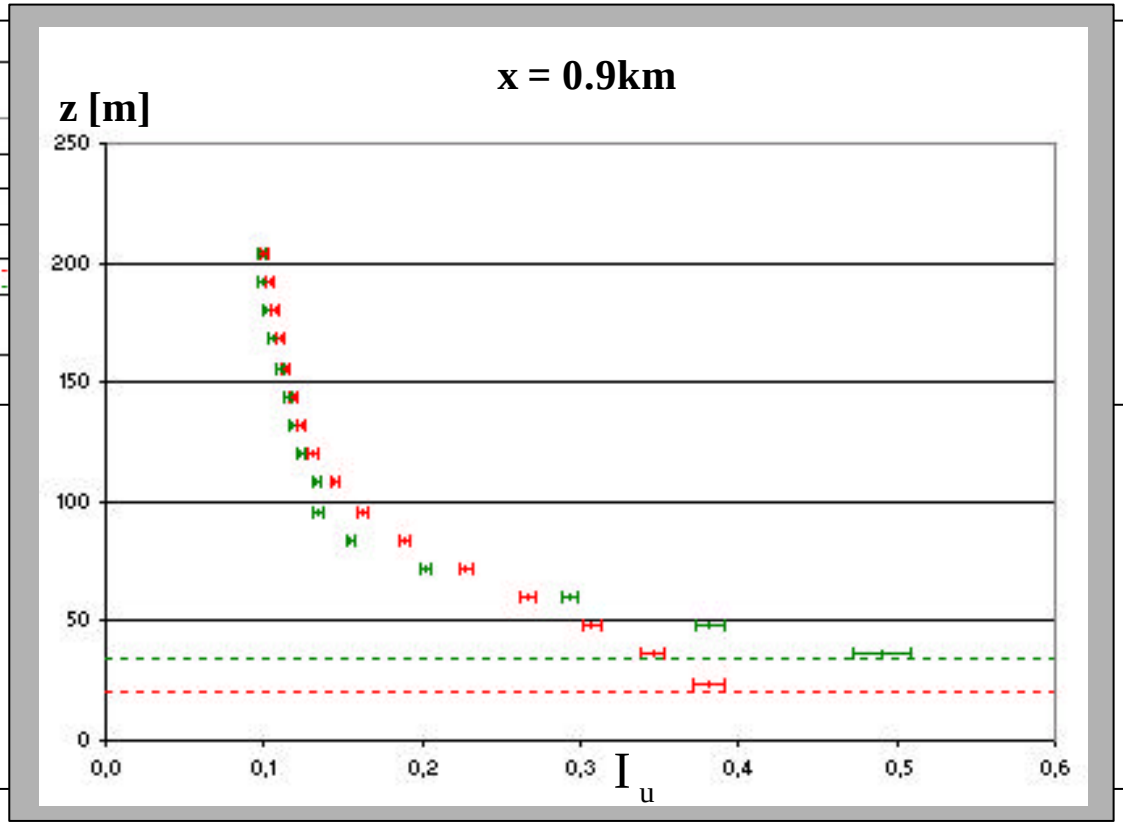
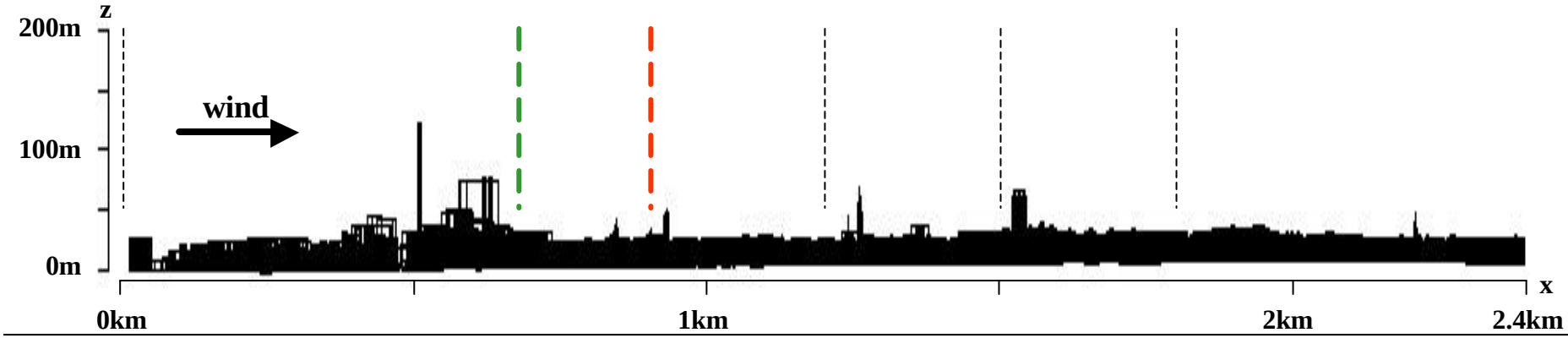
Turbulence intensity I_u	
Reynolds stress u´w´	





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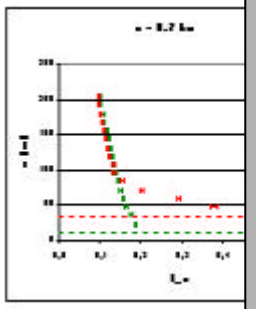
Turbulence intensity I_u	
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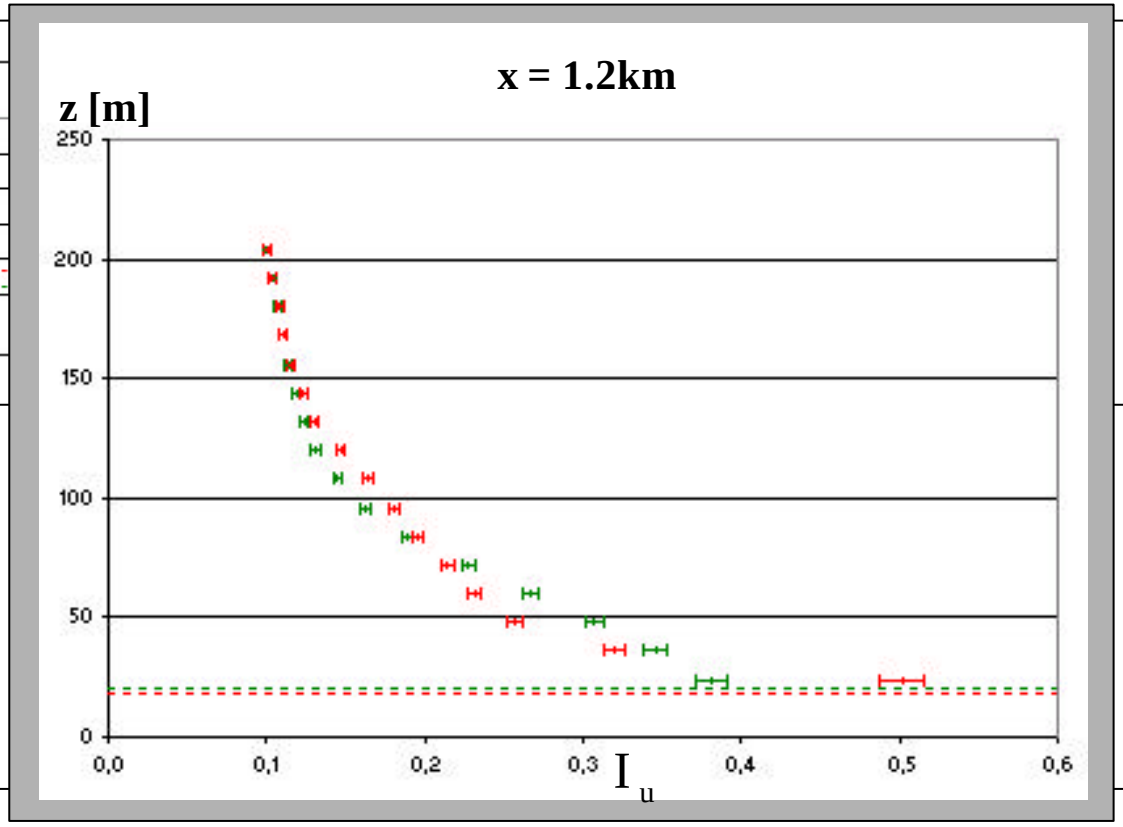

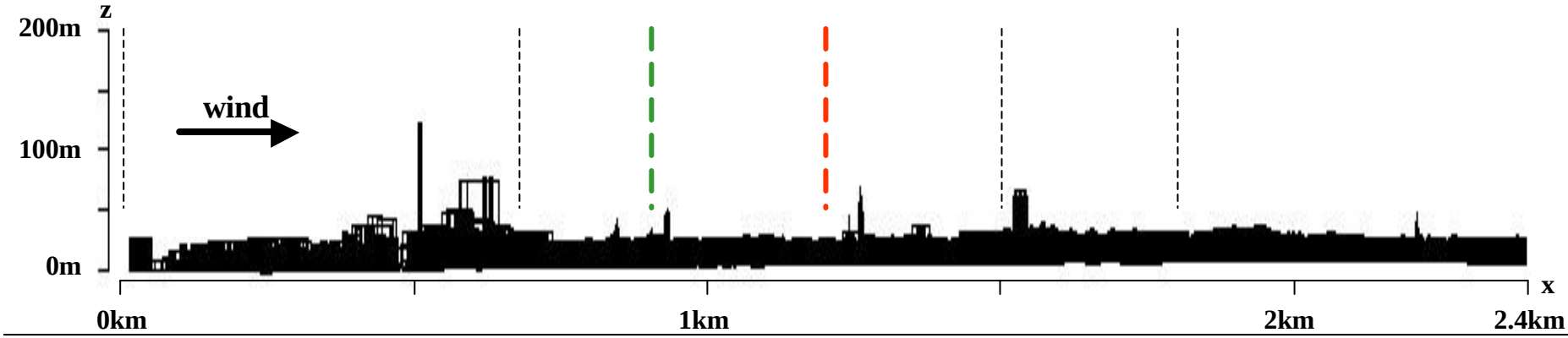

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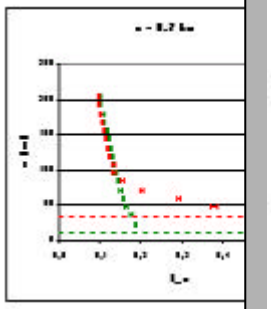
Turbulence intensity I_u	
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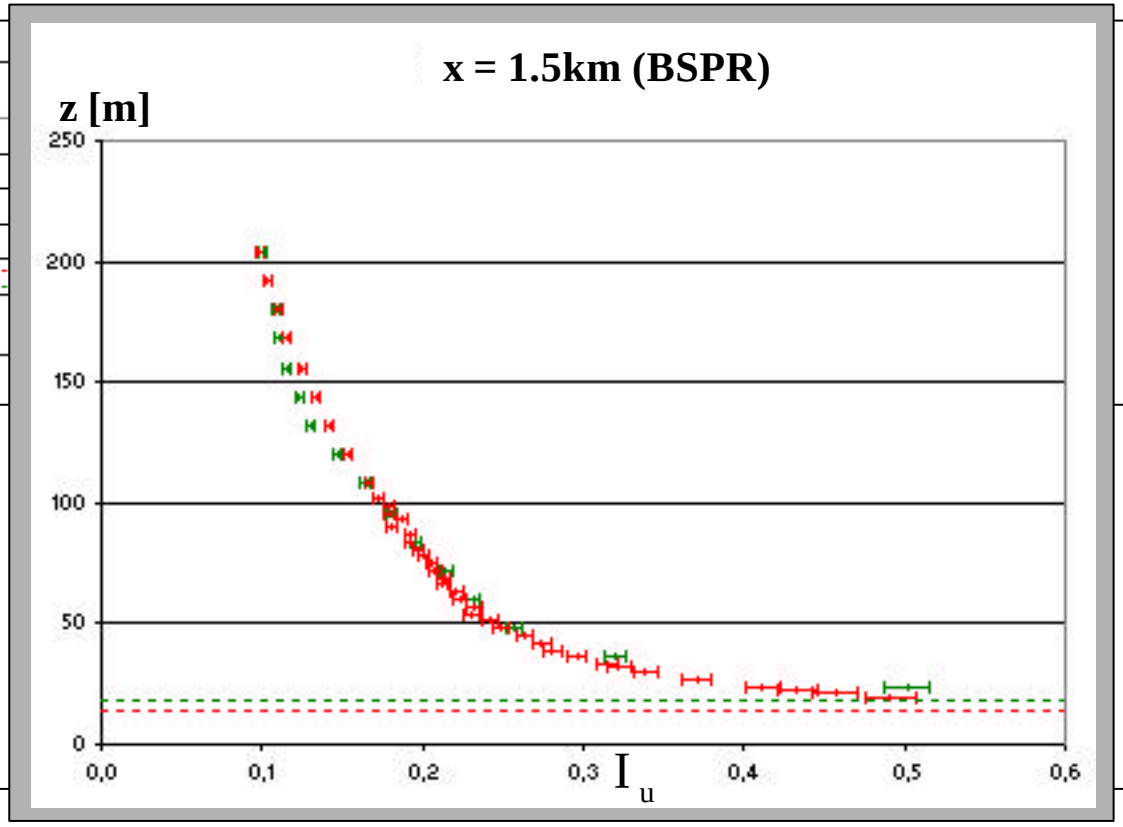

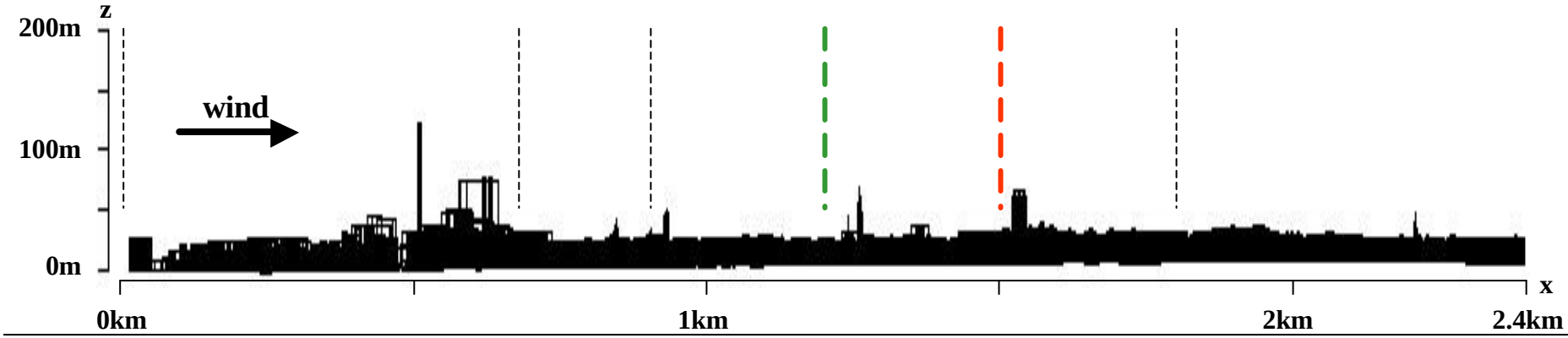

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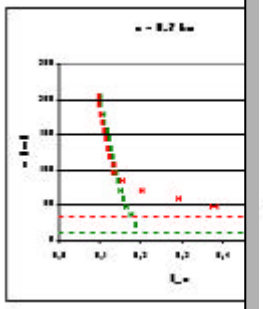
Turbulence intensity I_u	
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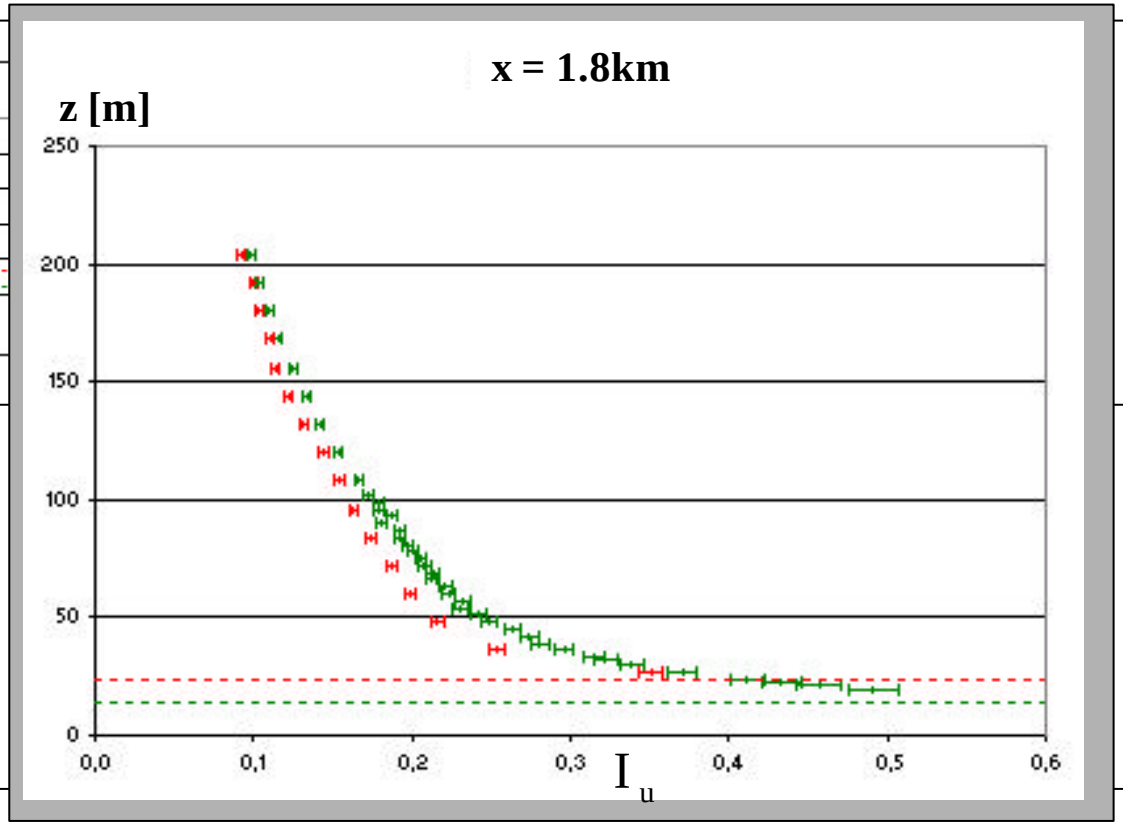

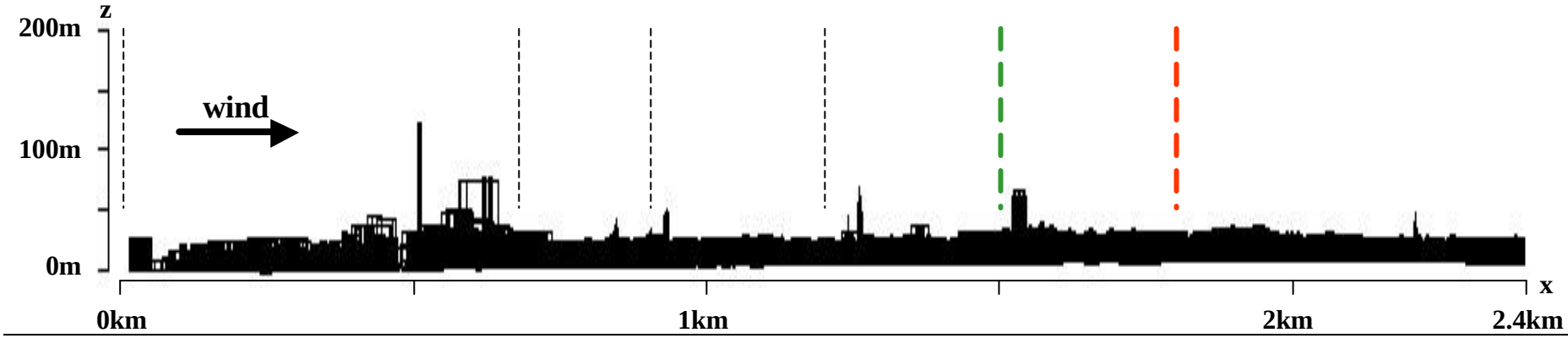

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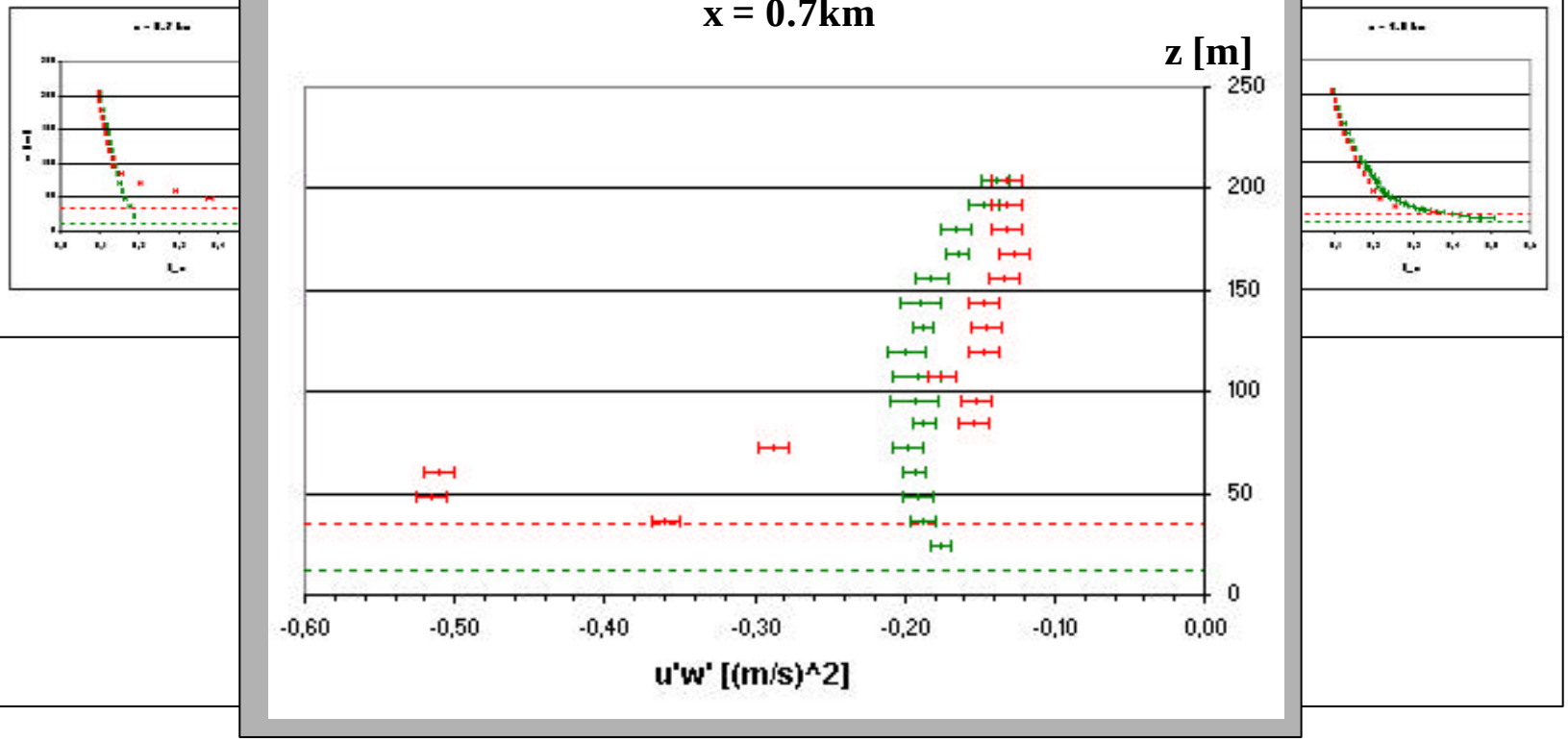
Turbulence intensity I_u	
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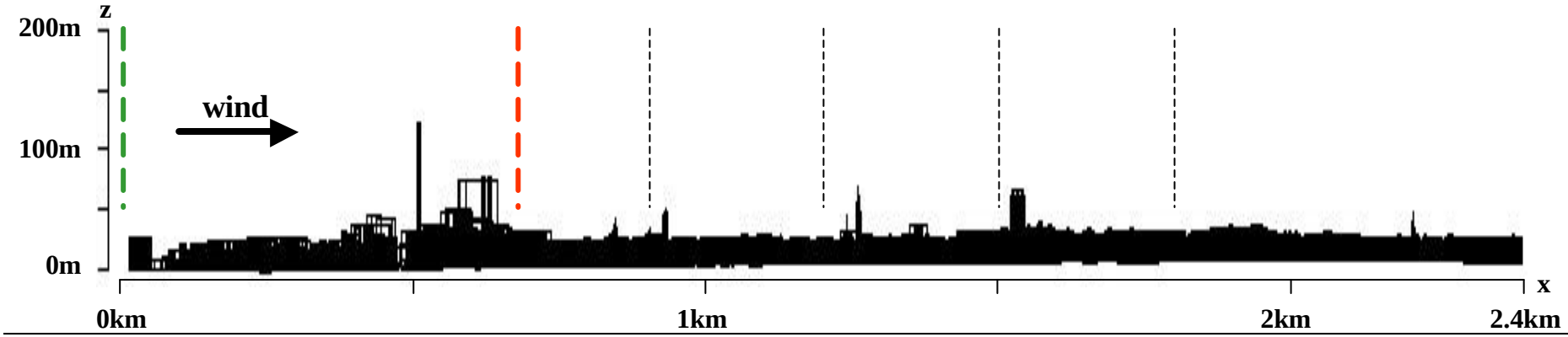

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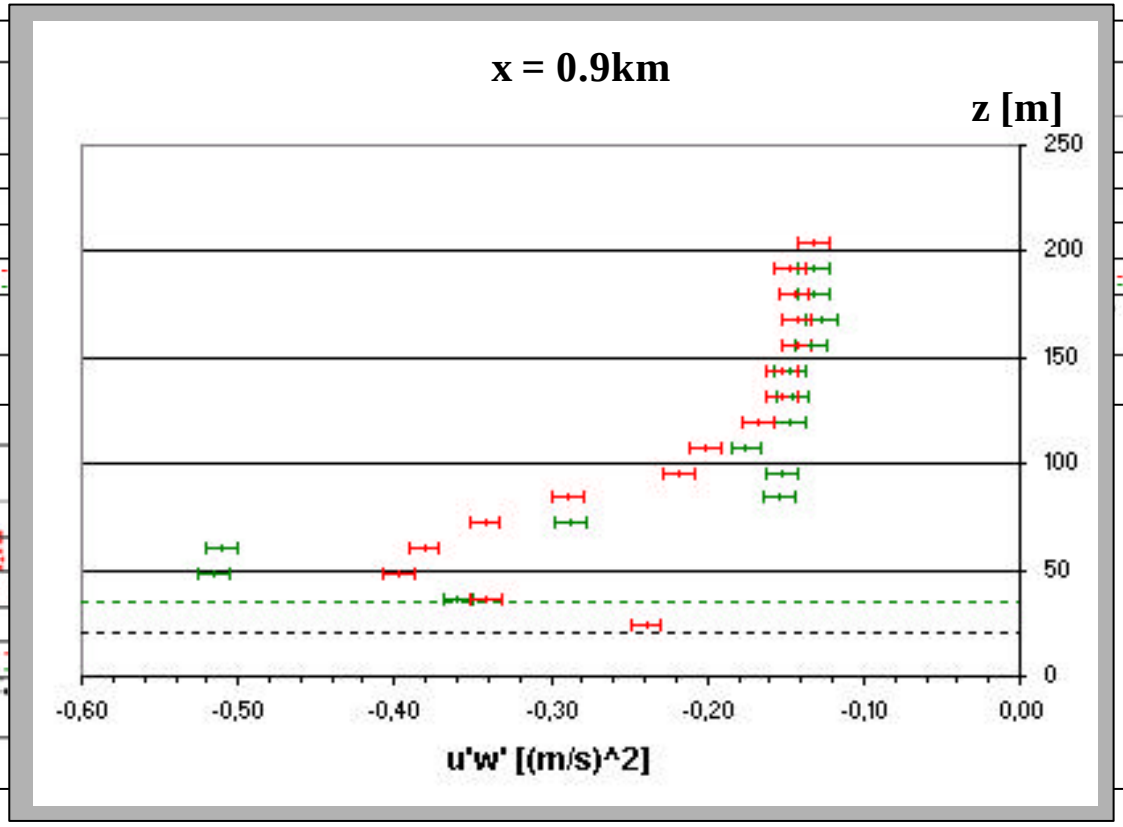

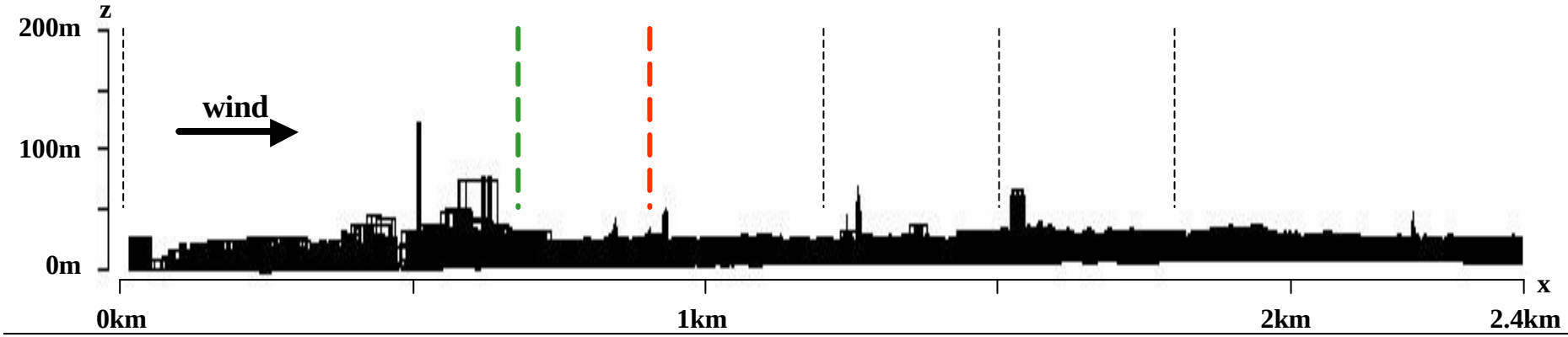

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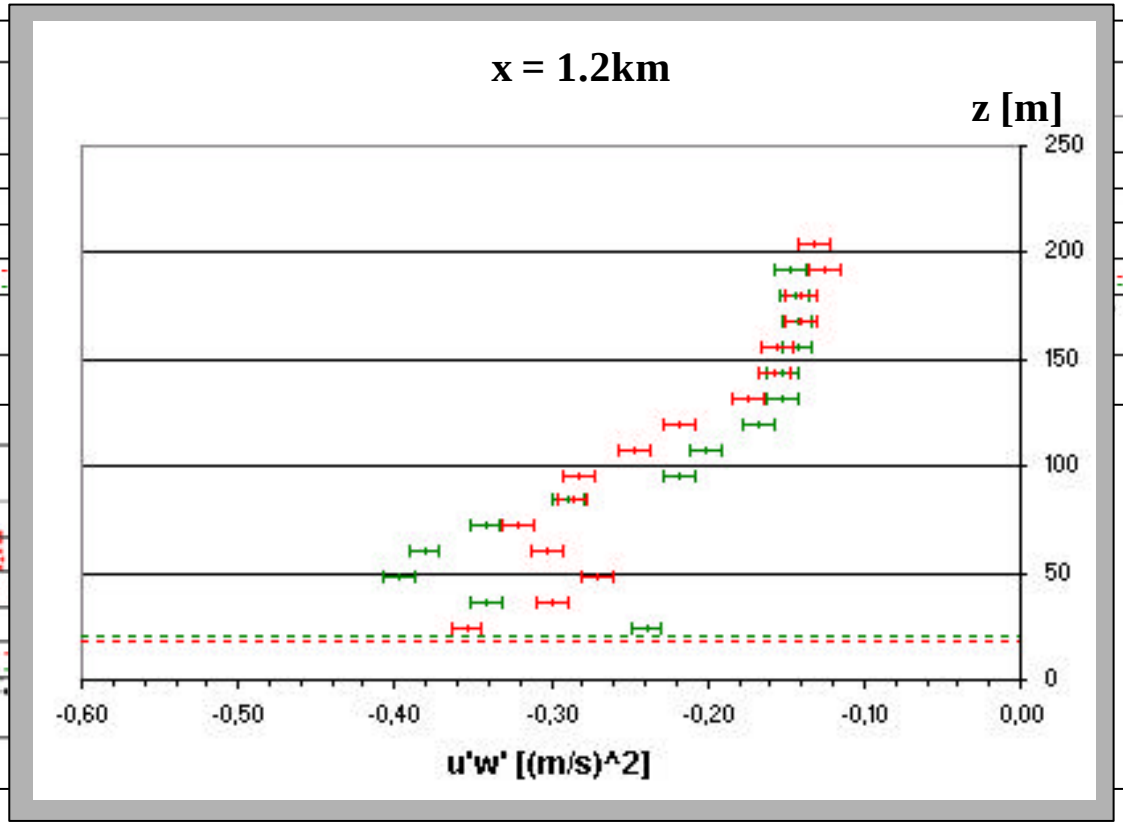

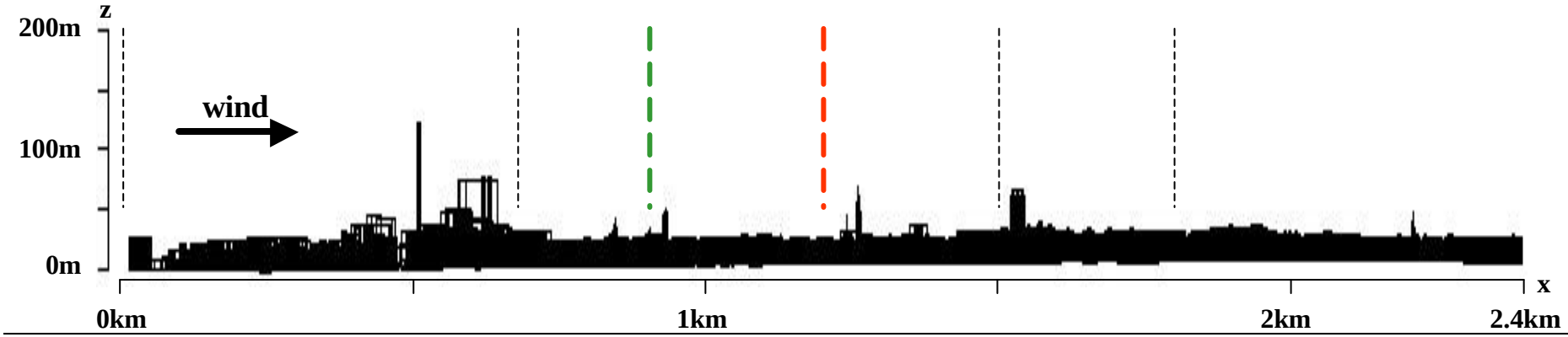

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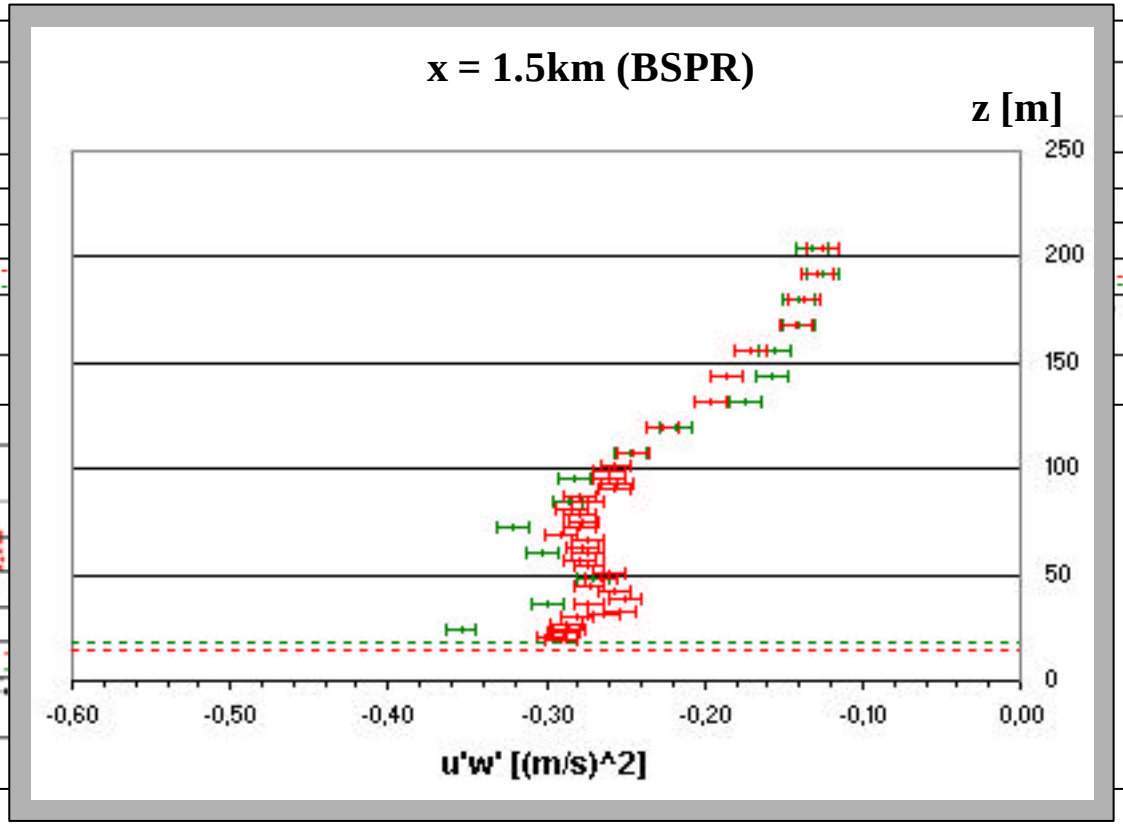

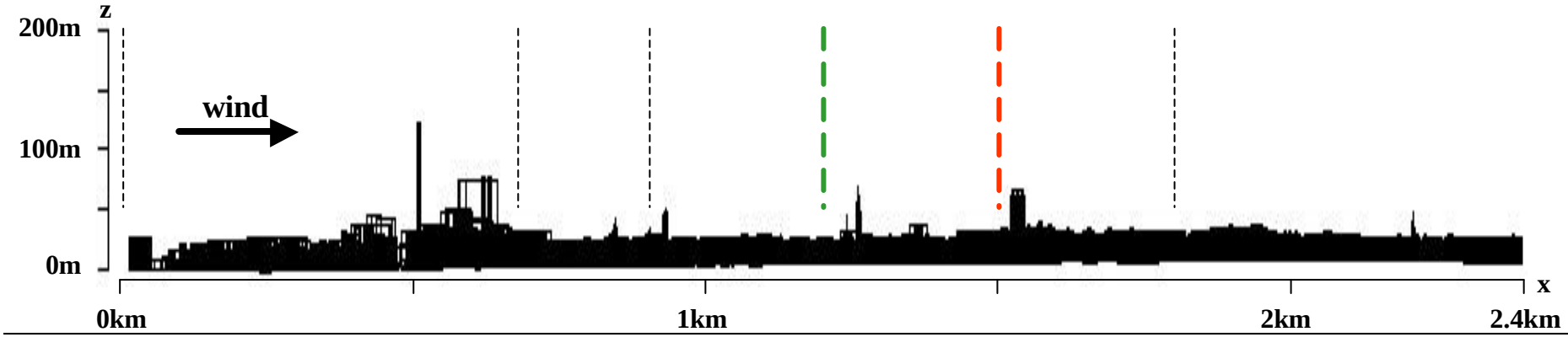

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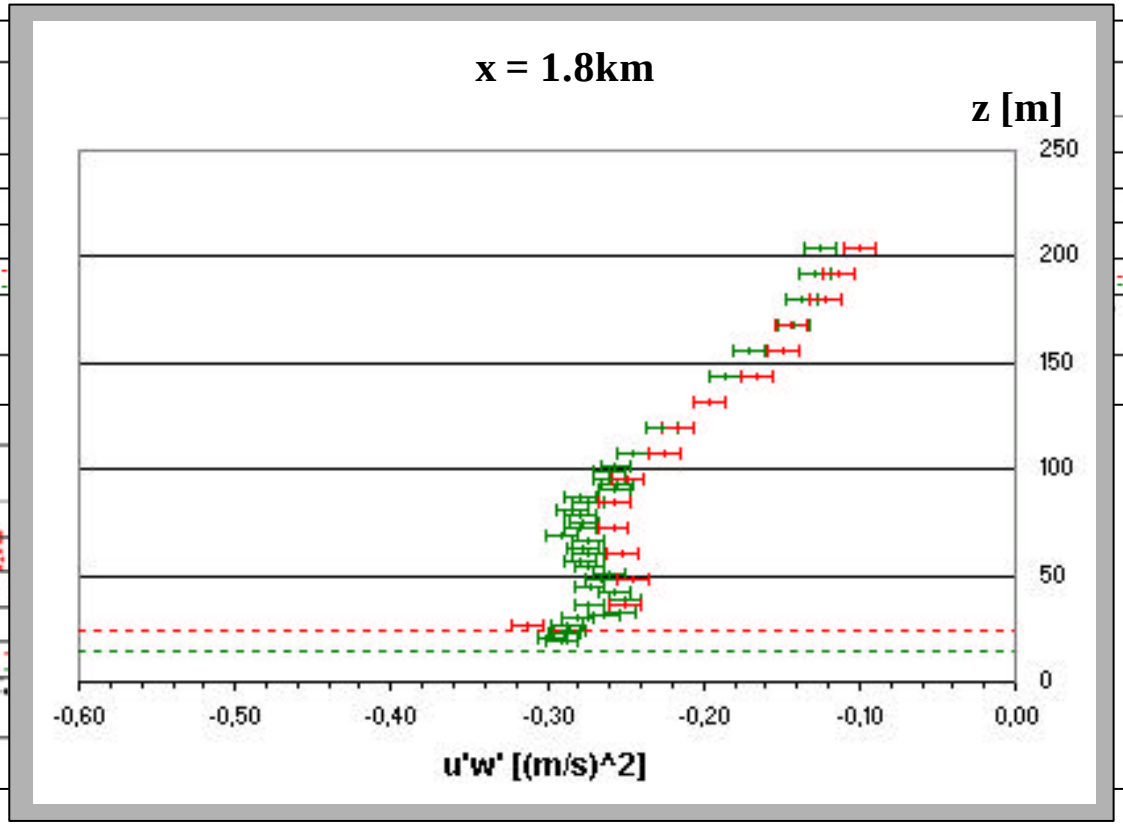

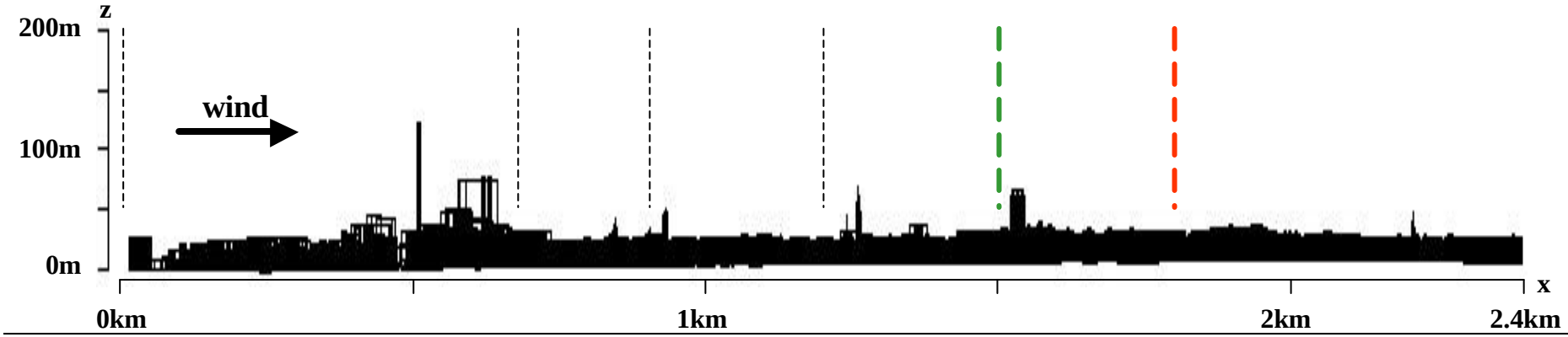

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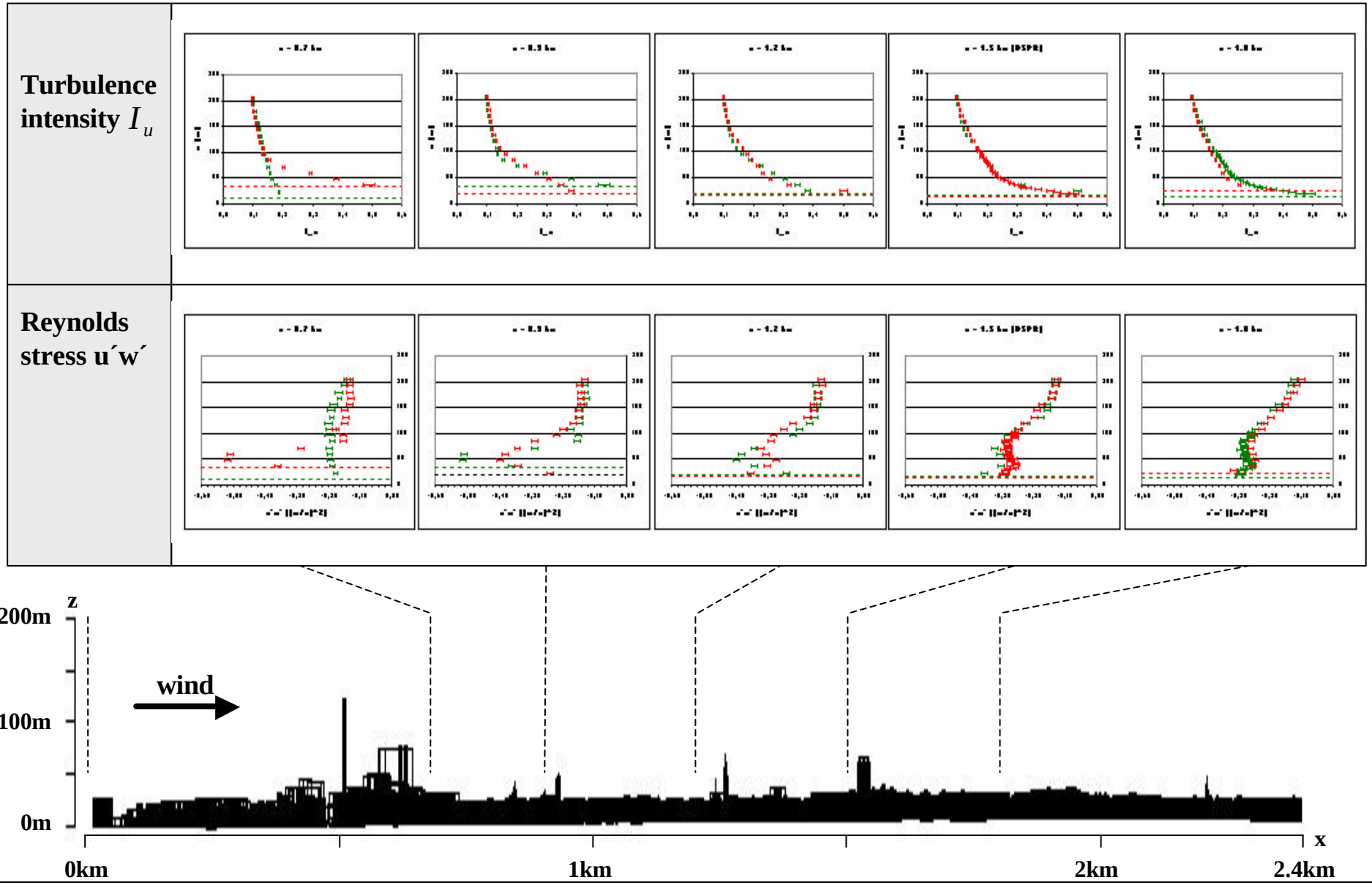
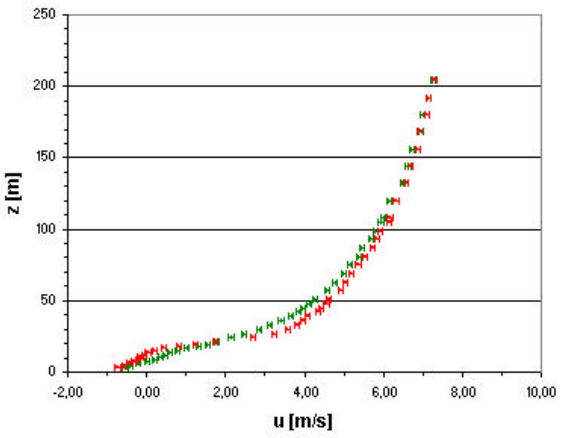
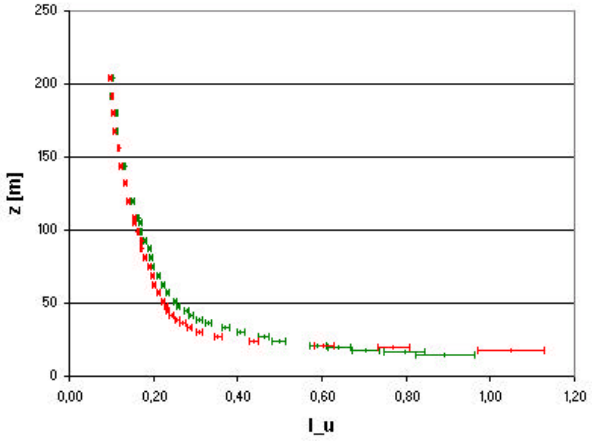
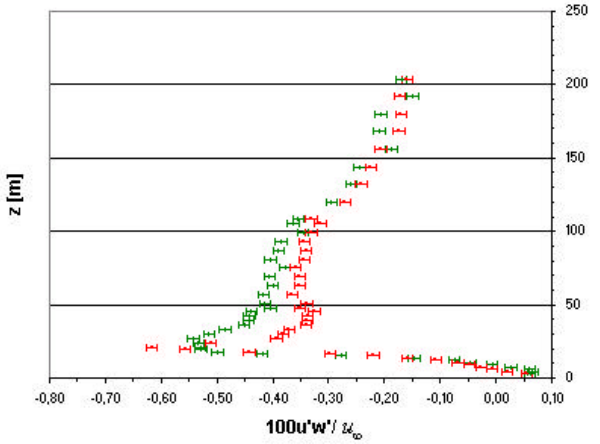
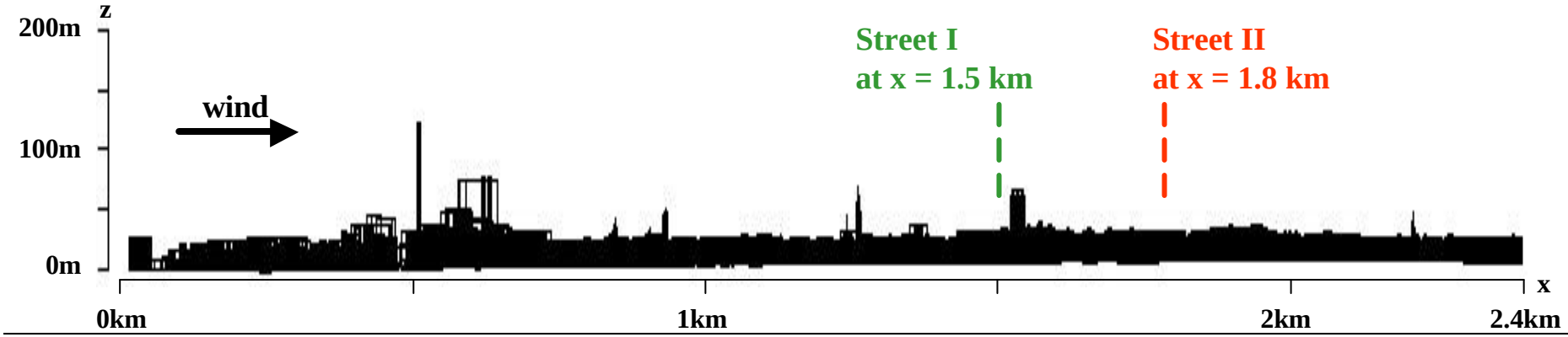
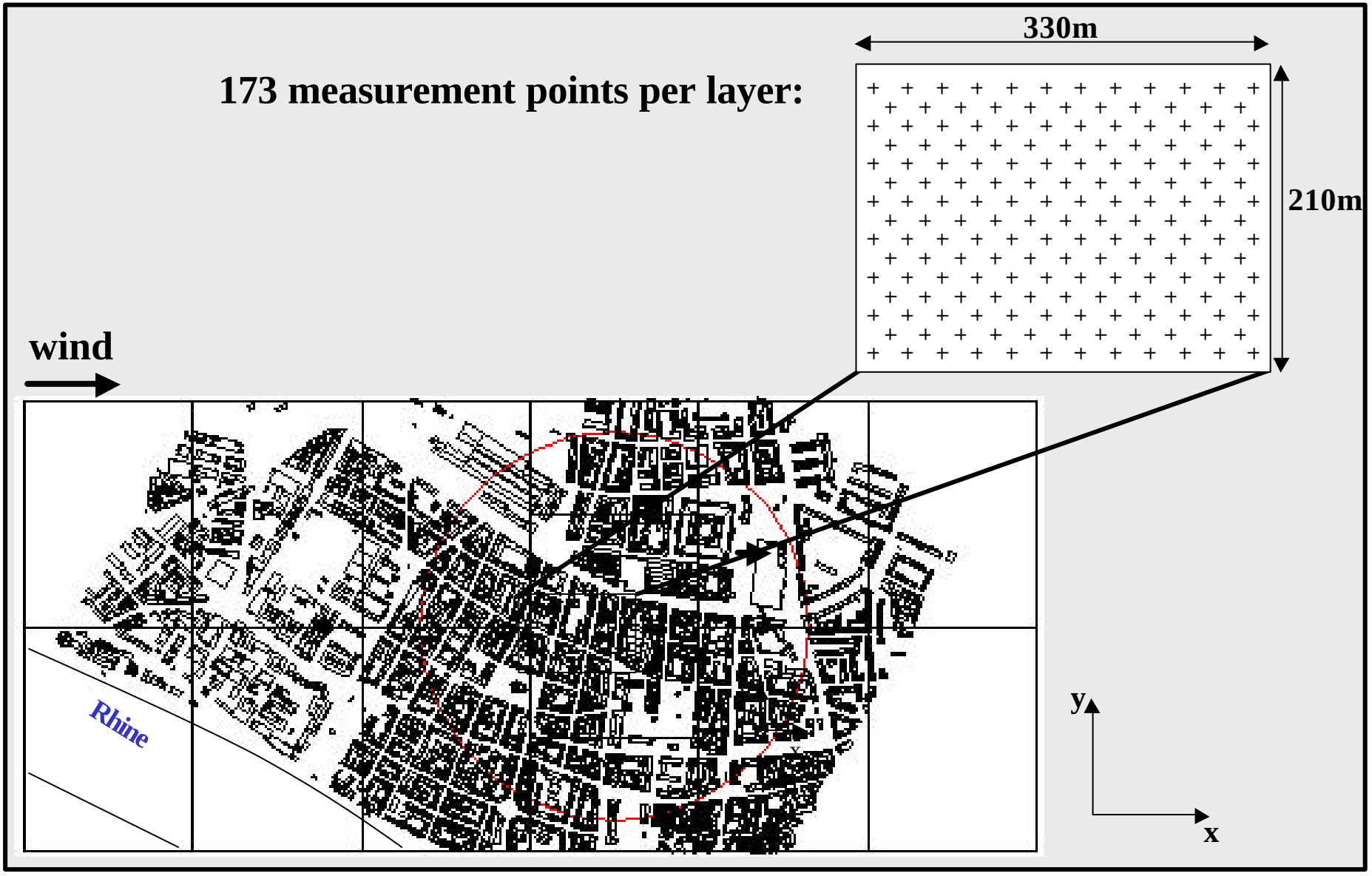


Two vertical profiles from street level upward give further indication of a still developing flow over the core model area.

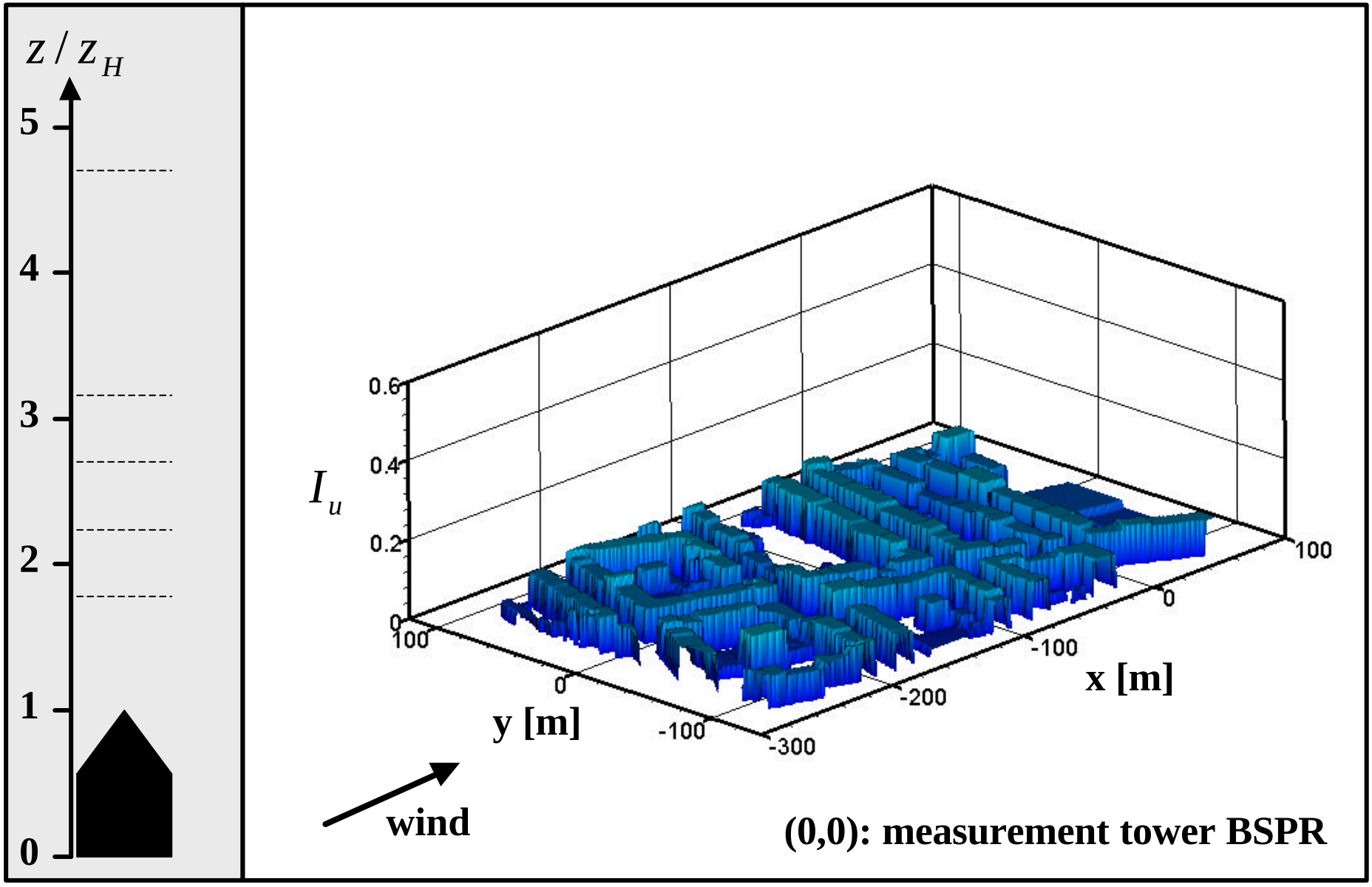
Mean wind speed u	Turbulence intensity I_u	Reynolds stress u‘w‘
		



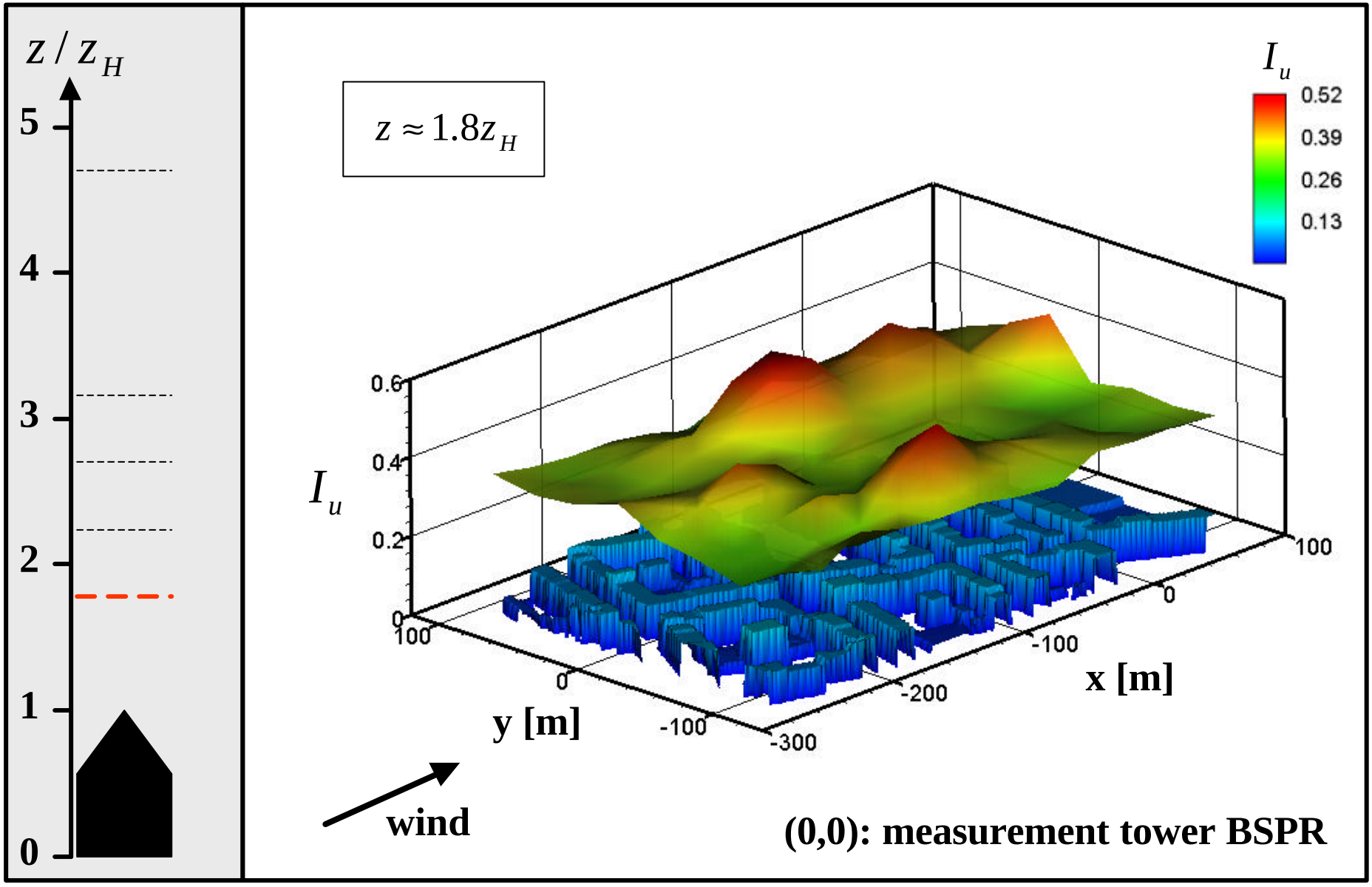
Horizontal turbulence measurements allow an assessment of the horizontal flow inhomogeneity within the RS.



The turbulence intensity I_u (e.g.) was measured at five height levels.



The turbulence is horizontally inhomogeneous up approximately $3z_H$.



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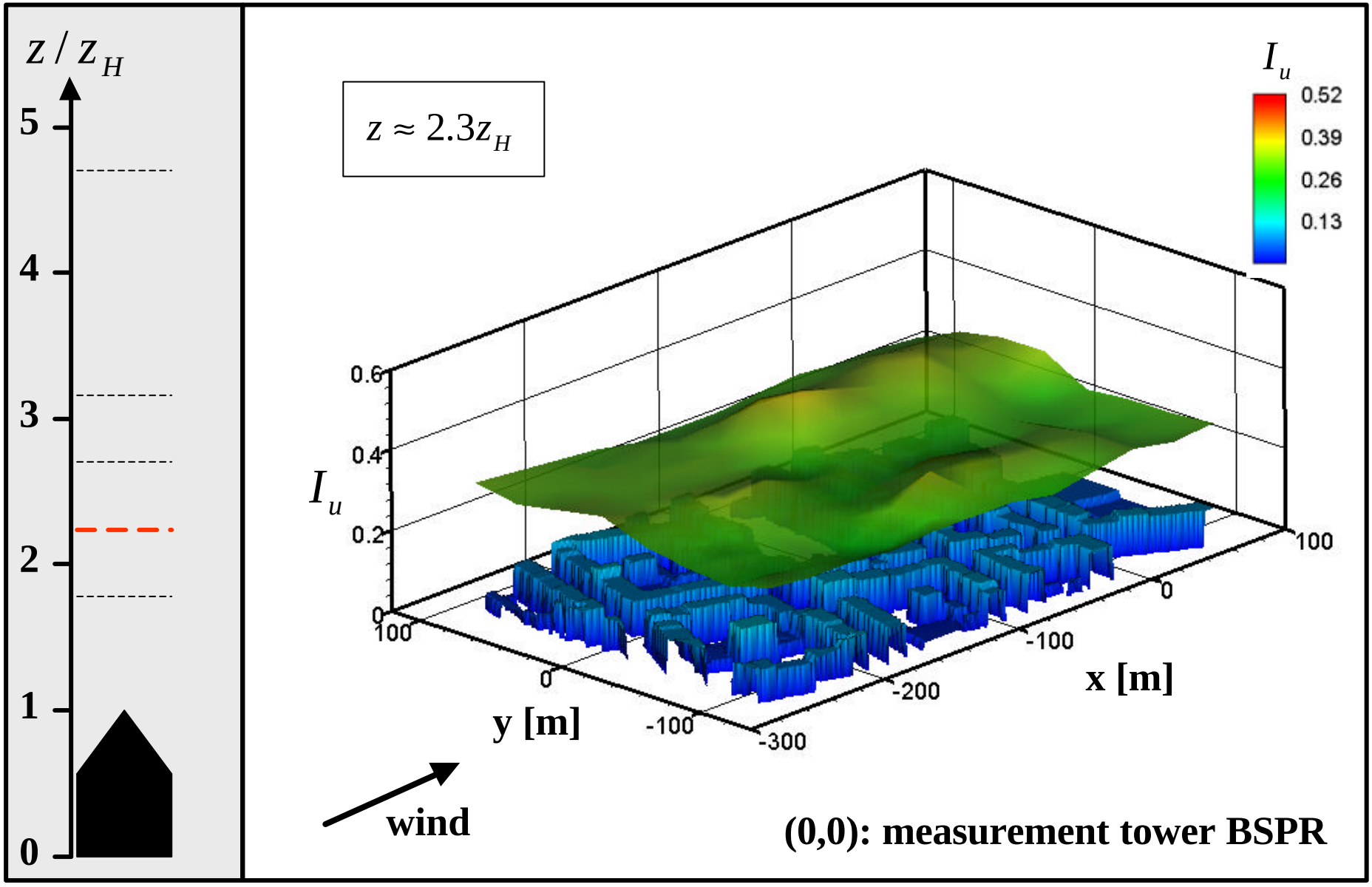

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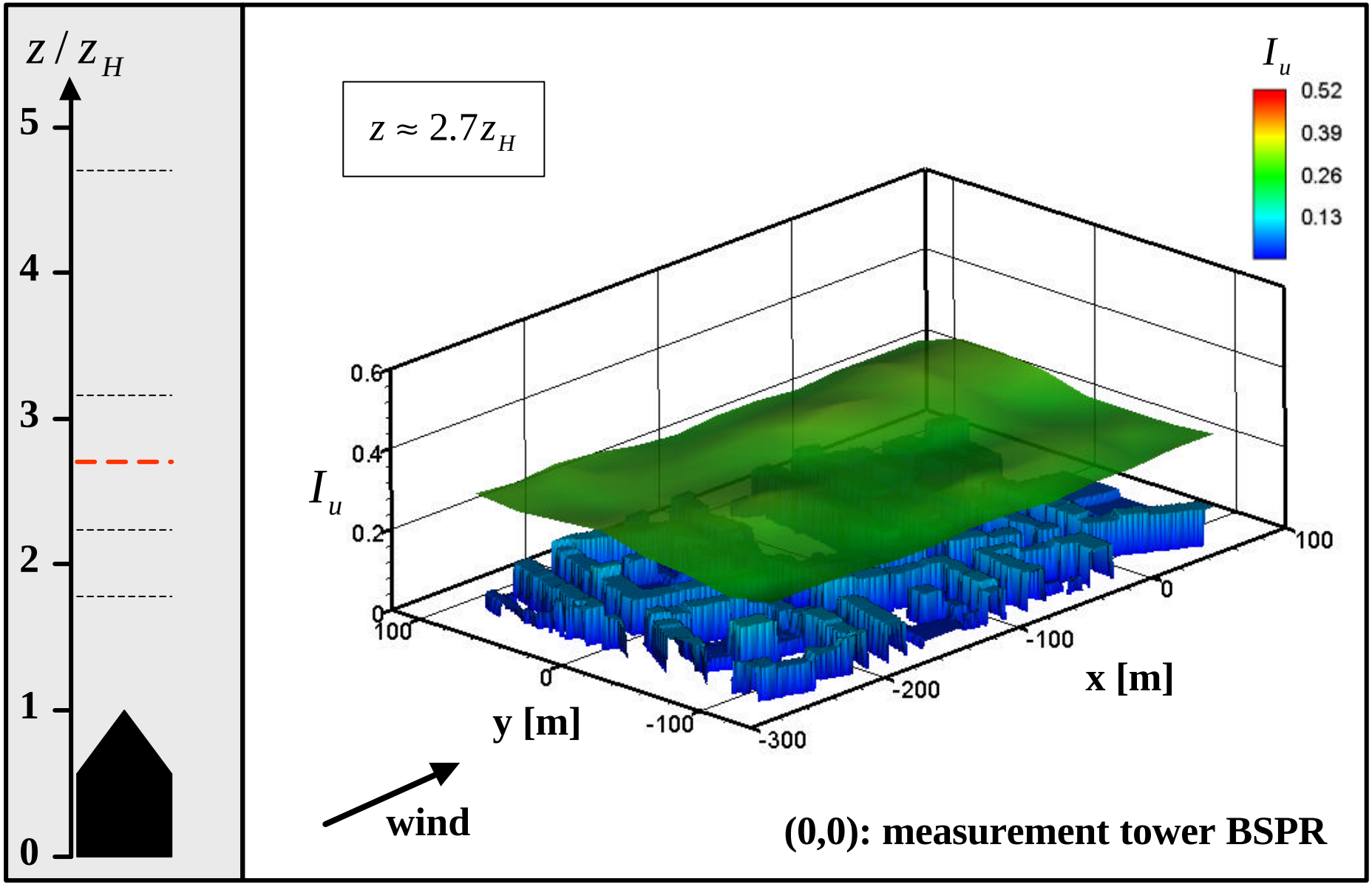

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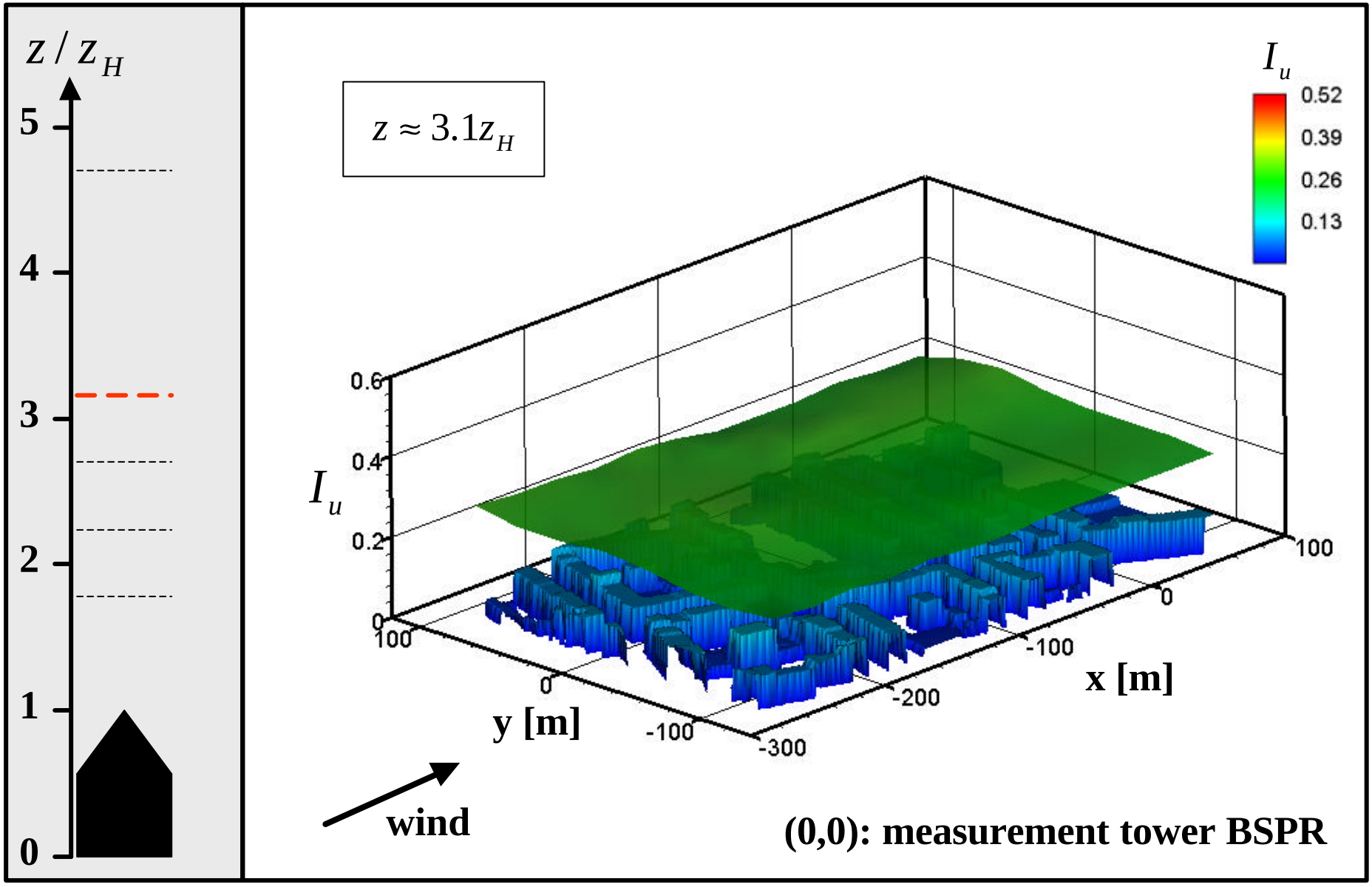

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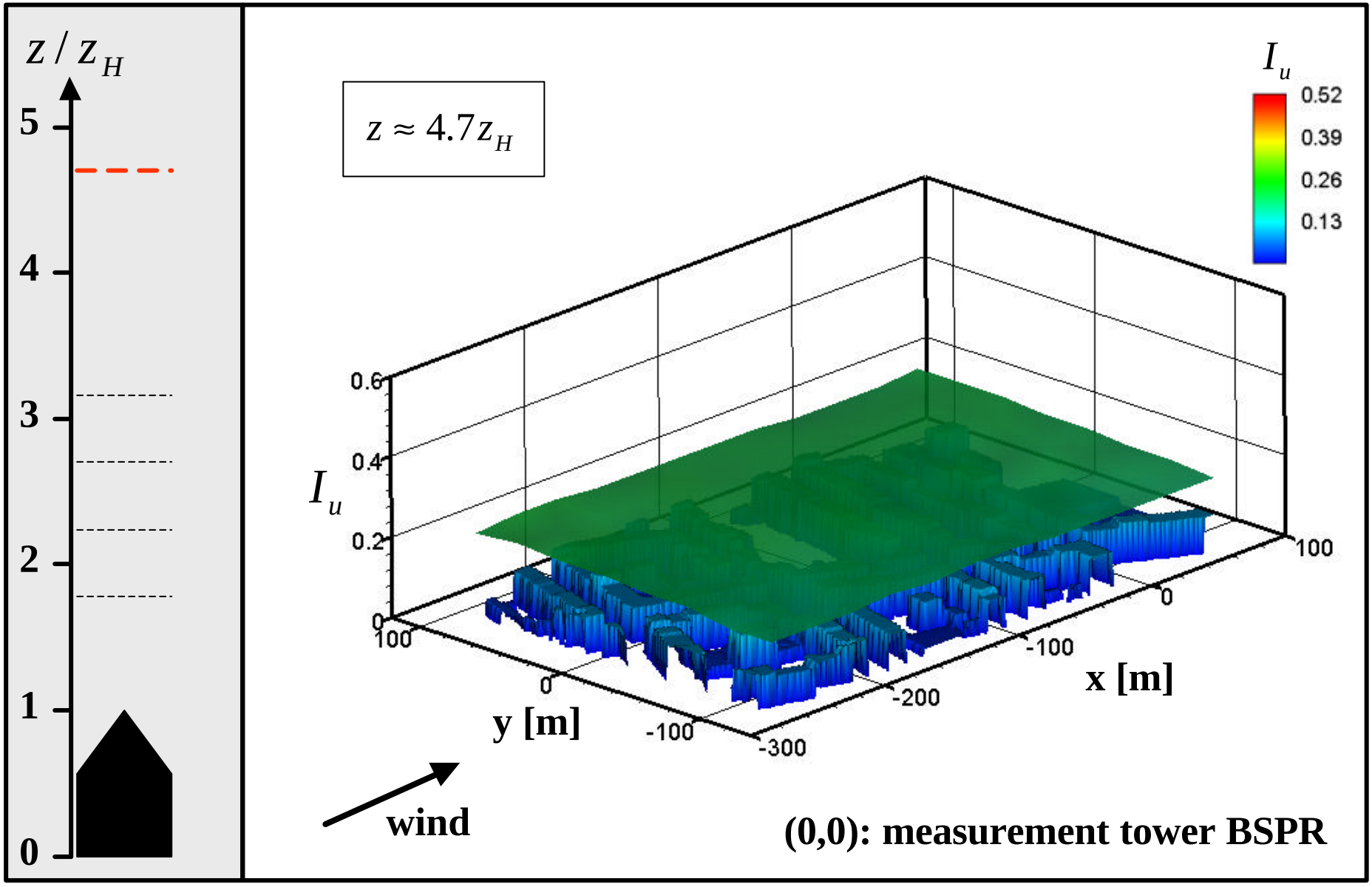
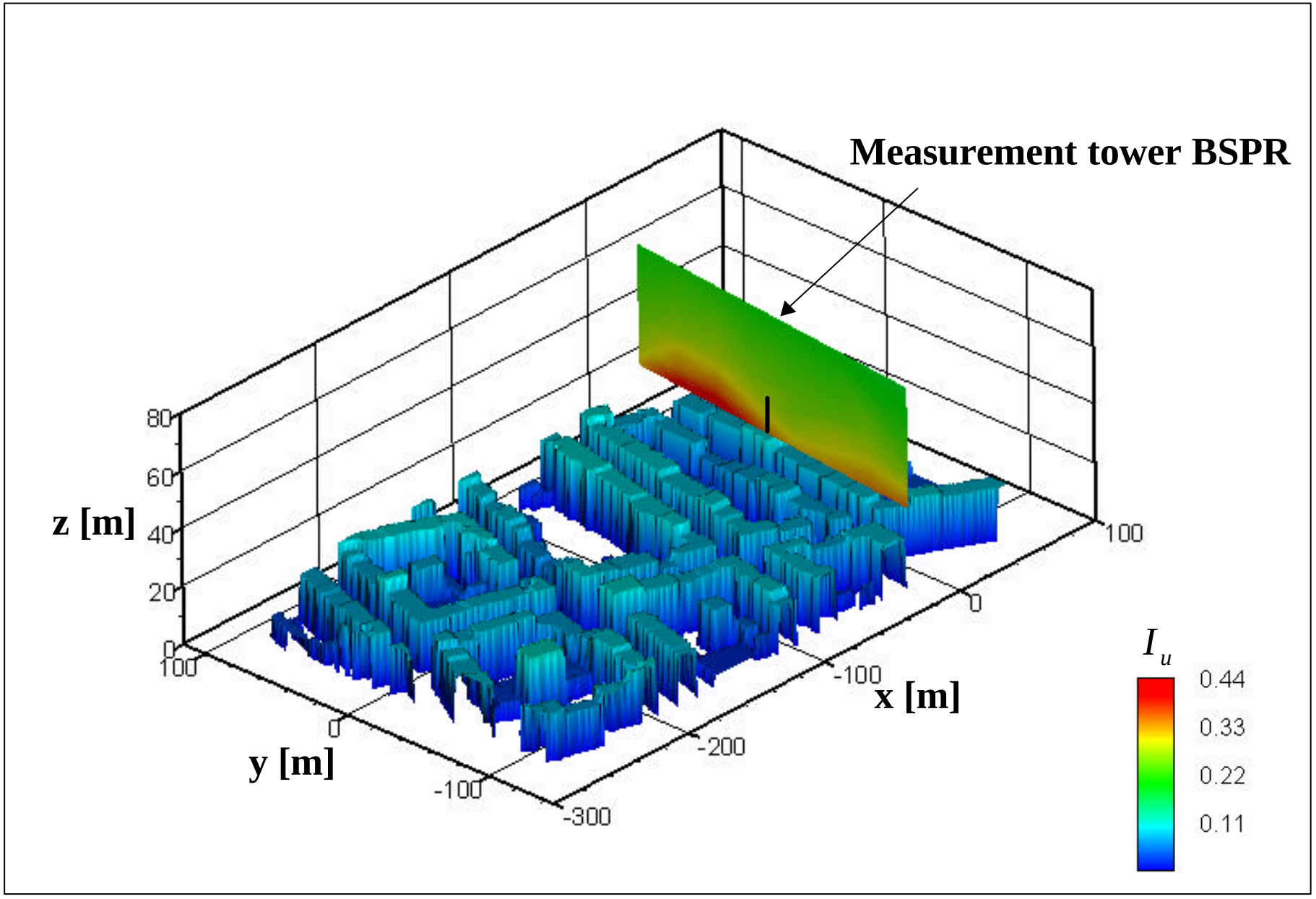


Vertical profiles in the RS depend significantly on the measurement location.



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- Motivation and overview BUBBLE project
- Remarks on general modelling approach
- Approach flow
- Urban flow
- **Summary and Outlook**

The preliminary data analysis already allows first conclusions.

Observation	Conclusion
At x = 1.2km to 1.6 km: Horizontal flow homogeneity increases significantly above $z \approx 3z_H$.	$z \approx 3z_H$ appears to be a reasonable height estimation for the urban roughness sublayer in Basel, CH.
At x = 1.5km and x = 1.8km: A „constant shear“ layer is well-established between z≈50m and z≈100m with decreasing „constant shear“ from x = 1.5km to x = 1.8km.	An inertial sublayer up to z≈100m with approx. constant shear stress and logarithmic wind profile* can exist even over urban roughness.

*not shown in this presentation

Outlook

	Planned activities (e.g.)
Quantitative analysis of turbulence data	• Application of appropriate scalings to the profiles • Computation of horizontally averaged mean profiles in the RS with corresponding scatter widths • Comparison to full scale data from Basel
Dispersion experiment (2004)	• Modelling the tracer release experiment in Basel • Systematic measurement of concentration data for numerical model evaluation