Wavelet analyses of turbulent flow above surface with 5 different classes of roughness

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Experimental set-up

Boundary layer above five types of rough surfaces is simulated in a wind channel. Series of roughness elements generate a highly turbulent flow. Intensity of turbulence reaches up to 40%. **Particle image velocimetry** of a high repetition rate (2000 Hz) provided a number of 2-D snapshots of instantaneous velocity vectors. The flow dynamics in the vertical plane X-Z are investigated. **The Wavelet analysis** is used to reveal the **direction of coherent structures** in the flow and their **frequency of occurence**.

Channel facility and model

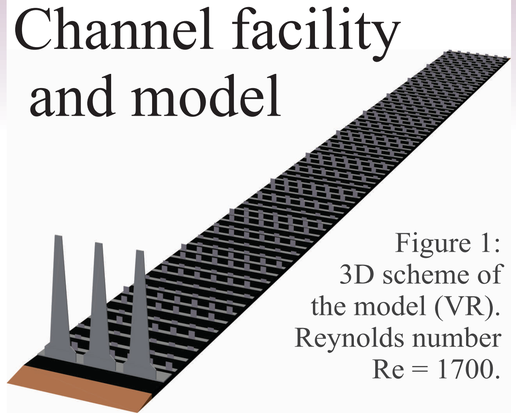


Figure 1: 3D scheme of the model (VR). Reynolds number Re = 1700.

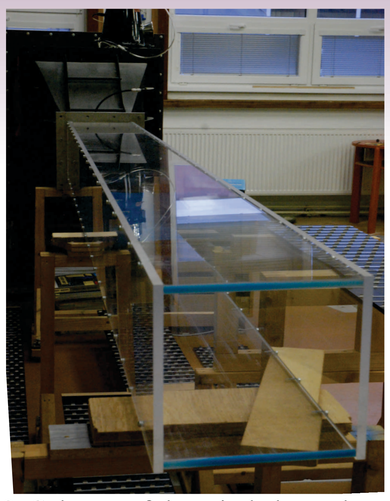
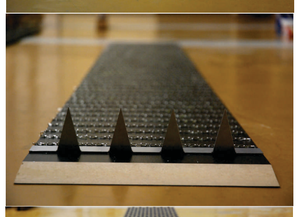


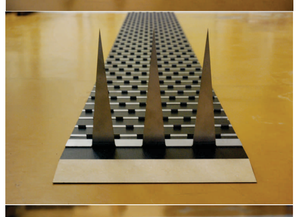
Figure 2: Scheme of the wind channel: Cross-section 0.25 m x 0.25 m. Reference wind speed 5 m/s.

Models

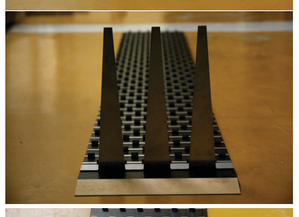
Slightly rough (SR)
z_0=0 m, d_0=3 m, α=0.09
Scale: 1:1000



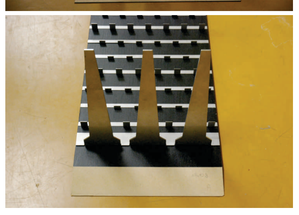
Moderately rough (MR)
z_0=0.06 m, d_0=7 m, α=0.15
Scale:1:750



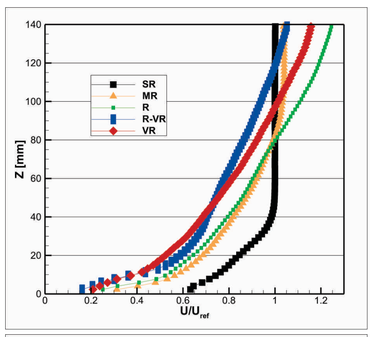
Rough (R)
z_0=0.37 m, d_0=3 m, α=0.19
Scale 1:400

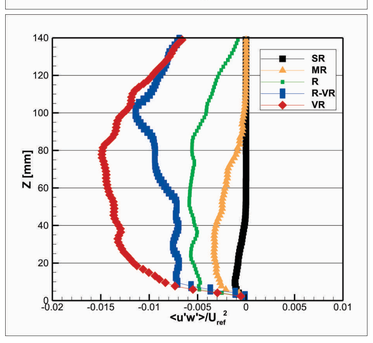


Rough-very rough (R-VR)
z_0=0.54 m, d_0=5 m, α=0.21
Scale 1:400



Very rough (VR)
z_0=0.60 m, d_0=8 m, α=0.24
Scale 1:250





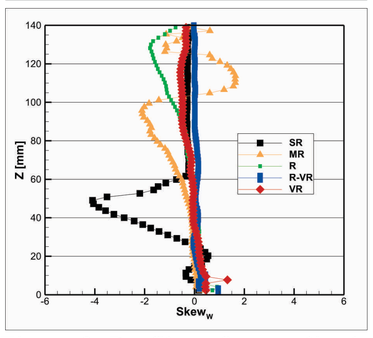
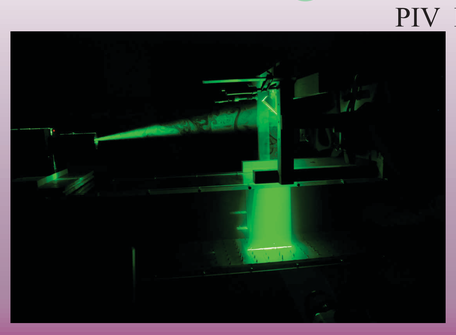


Figure 3: Profiles of normalised velocity, momentum flux and skewness of the vertical velocity.

Particle Image Velocimetry

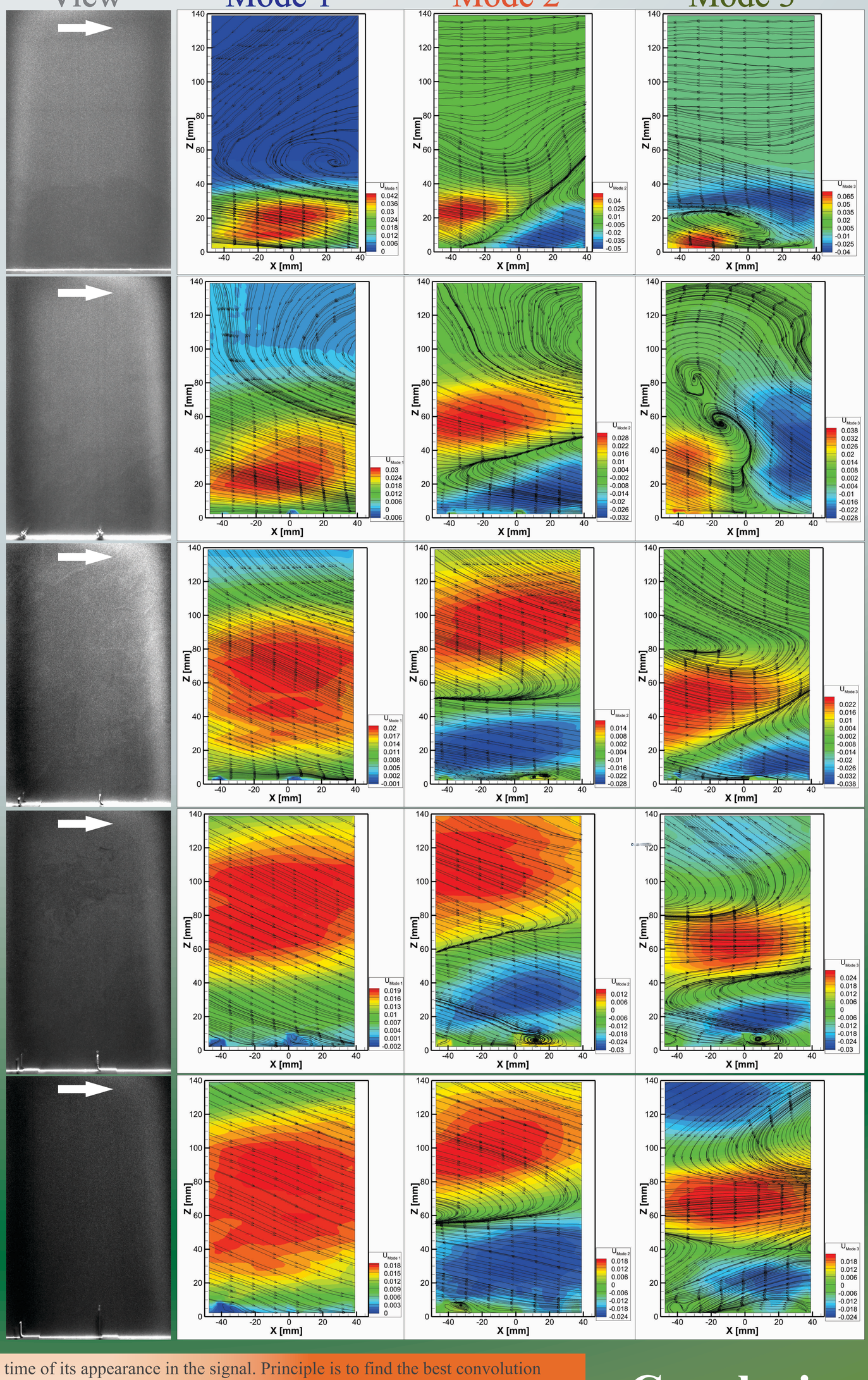


PIV Diode pumped Nd:YLF
Repetition rate 2000 Hz
Camera resolution 1280 x 800 pxs
Interrogation area 32 x 32 pxs
Overlapping 50% (77 x 49 vectors)
Energy 10 mJ
Area 140 x 90 mm
Acquisition time 2 s

POD decomposition

Figure 4:
POD decomposes a complex flow into individual modes on the basis of TKE. The spatial shape of the modes assumably represents **coherent structures** with the majority of the TKE in the flow. The modes exhibit a **consistent pattern** in the vertical plane for various roughness classes. The dimension of the patterns increases **with the increasing roughness**.

The first modes reveal almost no vortical structures but **sweep** and **ejection** events (a fast downward and a slow upward motion). Each mode has its own POD expansion coefficient which evolves in time and acts as a weight factor.



Wavelet Analysis

Wavelet analysis reveals the frequency and time of its appearance in the signal. Principle is to find the best convolution between the signal and a mother wavelet. We adopted Matlab code developed by Torrence&Compo (1998), modified after Ge (2007) and properly normalised. Local power spectra of the analysis provides temporal locations of energetic harmonic events.

Mexican hat Mother function applied to the first POD expansion coefficient reveals the direction of the flow dynamics - the sweep or the ejection, their frequency and time of occurence.

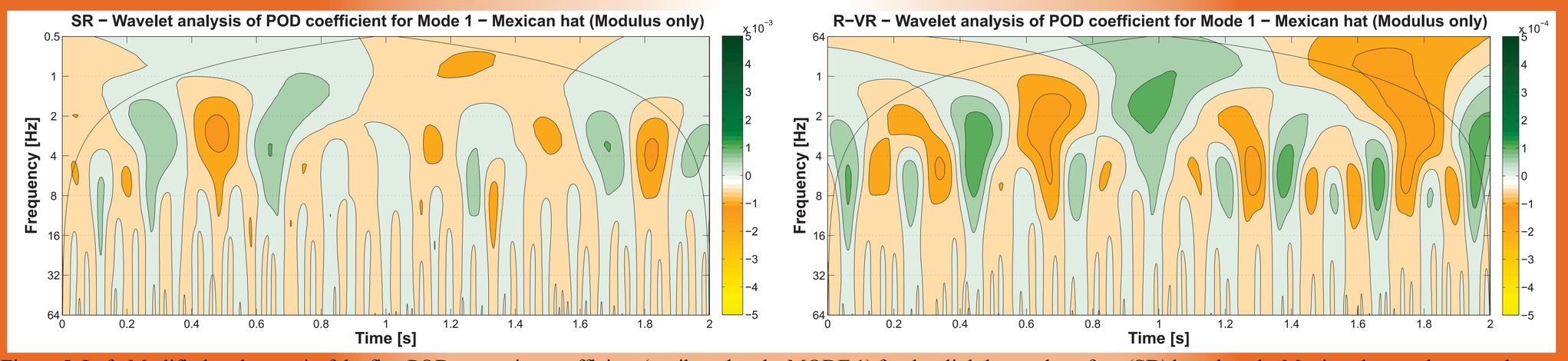


Figure 5: Left: Modified scalogram* of the first POD expansion coefficient (attributed to the MODE 1) for the slightly rough surface (**SR**) based on the Mexican hat used as a mother wavelet. Right: Modified scalogram* of the first POD expansion coefficient (MODE 1) for the rough-very rough surface (**R-VR**). The orange colour corresponds to the sweep event, the green colour denotes the ejection event. The black line denotes cone of influence. Note the low number of the significant events for the SR surface.

*Wavelet power spectrum usualy depicts the energy spectrum (density of energy - square of the Wavelet modulus - for particular frequency) divided by period of signal. The modified scalogram shows only the Wavelet modulus divided by period of the signal.

Conclusion

POD provides reliable results of the modes from the very turbulent flow. The most dominant mode contains 20% of TKE (**Slightly rough - SR**) and 41% of TKE (**Very rough - VR**). The shape of the modes is **consistent**, only the scale of the structures increases with the increasing roughness.

Wavelet analysis is able to detect different type of energetic structure and manifest them in a **transparent way.**

The Mexican hat function is chosen as a better for evaluation of the direction of the sweep and ejection events. The rougher terrains exhibit the **higher number of events** centered at **higher frequencies**.

Torrence C. and Compo G. P. (1998): A practical guide to wavelet analysis. *Bull. Am. Meteorol. Soc.*, vol. 79, p. 61-78.
Ge Z. (2007): Significance Tests for the Wavelet Power and the Wavelet Power Spectrum. *Annales Geophysicae*, vol. 25, p. 2259-2269.