On some characteristics of the spatial distribution of turbulence components over the Bolund hill determined in wind tunnel compared to full-scale measurements

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Abstract

A comparison is presented between wind tunnel (WT) and full scale (FS) measurements of spatial distributions of turbulence intensities, $I_{u_i} = \sigma_{u_i} S^{-1}$, and their ratios; u_i being the fluctuations of velocity components and S the mean velocity magnitude, over the Bolund hill. The Bolund experiment, conducted by Risø-DTU during a 3-month period in the winter of 2007-2008, is probably the most relevant test case of flow models oriented to wind energy analysis, in this case, over highly complex terrains, in neutral conditions and non affected by Coriolis forces. The Bolund hill is a small peninsula, with an almost vertical 11 m height escarpment facing westerly winds, and a nearly flat plateau extending towards East. This geometry produces complex flow structures which are a challenge for numerical and wind tunnel simulations. The available results, since the end of the Bolund experiment, have mainly focused on the spatial distribution of the mean velocity magnitude and turbulent kinetic energy. Our interest is now in how the turbulent kinetic energy is distributed among the velocity components (what is relevant for wind turbine response), and to which extend our wind tunnel experiment (1:115 scale, 3CHotWire, 3CHW, and Particle Image Velocimetry, PIV) can reproduce these distributions.

Additionally, some flow spatial structures visualized and identified in the wind tunnel are presented. A quantification of the bias of WT results with respect to FS ones are calculated, being, in the case of turbulence intensities:

$$\epsilon_{I_{u_i}} = 100 \frac{I_{u_i} I_{u_i 05}^{-1}\big|_{WT} - I_{u_i} I_{u_i 05}^{-1}\big|_{FS}}{\left|I_{u_i} I_{u_i 05}^{-1}\right|_{FS}},$$

where $I_{u_i 05}$ is the value in an undisturbed upstream position at a reference height. The bias at different locations, for 3CHW and PIV techniques and two Reynolds numbers in the WT test, was obtained and is presented in the analysis. Averaged absolute bias values (for all evaluated positions over the island, both measurement techniques and both Reynolds numbers) are $[\epsilon_{I_u}, \epsilon_{I_v}, \epsilon_{I_w}] = [-46.5\%, -50.6\%, -53.6\%]$ at $z = 2\,\mathrm{m}$ height a.g.l, and $[\epsilon_{I_u}, \epsilon_{I_v}, \epsilon_{I_w}] = [-20.7\%, -33.0\%, -26.9\%]$ at $z = 5\,\mathrm{m}$ height a.g.l.

Wind tunnel setup

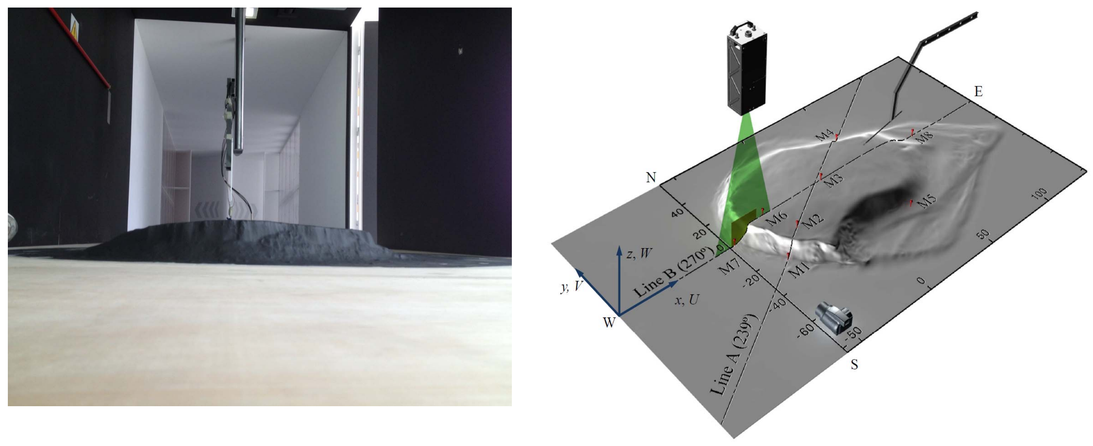

Figure 1. Left: The 1:115 scale Bolund mock-up in the ACLA16 wind tunnel during the 3D hotwire test. Right: Scheme of the Particle image velocimetry and hotwire tests setup. Metmast locations and reference systems.

Turbulence intensity profiles

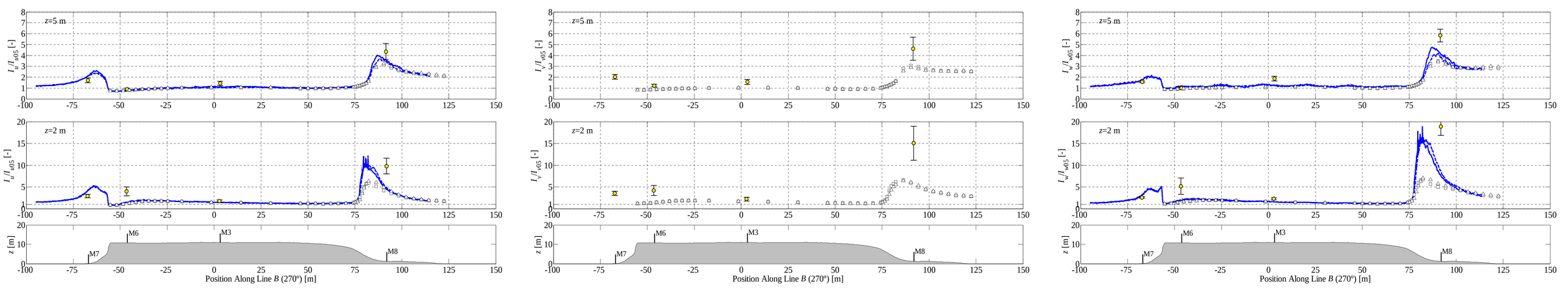

Figure 2. Normalised turbulence intensity I_{ui}/I_{ui05} at z=2 m a.g.l. and z=5 m. a.g.l.: Continuous lines, PIV for $Re_{h1} = 4.15\times10^4$, dashed lines, PIV for $Re_{h2} = 8.21\times10^4$, squares, 3CHW for $Re_{h1} = 4.15\times10^4$; triangles, 3CHW for $Re_{h2} = 8.21\times10^4$. Full-scale results (yellow dots with uncertainty bars). Velocity components expressed in the wind reference system. Line B (See figure 1). Wind direction 270º. Left: Longitudinal component, center: lateral component, right: vertical component.

Flow structures

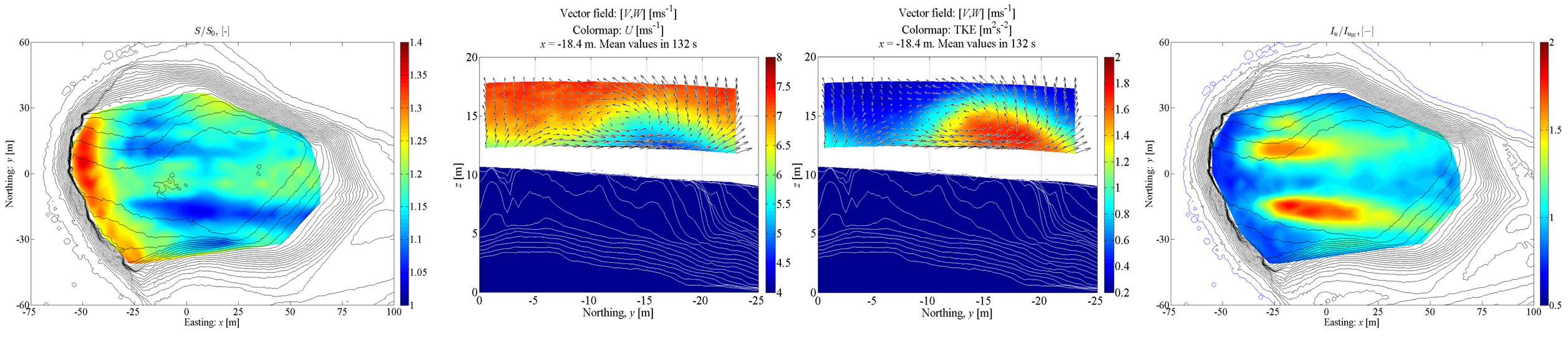

Figure 3. Left: Speed-up, S/S_0 at z=5 m a.g.l. Center: Vector field: [V,W] [m s^{-1}] and U and TKE colormaps at x=-18.4 m. Velocity components expressed in Bolund reference system. Right: Normalized turbulence intensity I_{ui}/I_{ui05} on a isoheight surface at z=5 m a.g.l.. 3CHW measurements for $Re_{h1} = 4.15\times10^4$. Velocity components expressed in wind reference system. All results for wind direction 270º.

Bias metrics

%	M7	M6	M3	M8	MAE	MAE*
ε_{Iu}	23.3	–13.2 (B)	–25.1 (W)	–23.8	21.4	20.7
ε_{Iv}		–28.6 (B)	–34.2	–36.1 (W)		33.0
ε_{Iw}	12.9	6.8 (B)	–37.4 (W)	–36.5	23.4	26.9
$\varepsilon_{\Delta S}$	1.7 (B)	–6.1	11.3	16.0 (W)	8.8	11.1

Table 1. Bias in the determination of Normalised turbulence intensity I_{ui}/I_{ui05} and speed-up S/S_0 at z=5 m. The bias in the determination of the speed up, $\varepsilon_{\Delta S}$, is indicated as a reference.. The results are mean values for two Reynolds numbers $Re_{h1} = 4.15\times10^4$ and $Re_{h2} = 8.21\times10^4$ and PIV and 3CHW. All results for wind direction 270º. MAE is the mean of absolute values of bias for met masts M7, M6, M3 and M8 and MAE* for M6, M3 and M8.

Conclusions

Acknowledgements

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