Variations of the wake height over the Bolund escarpment

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1 Introduction

To obtain high quality results in numerical and physical modeling for wind energy purposes, is it important to verify these models with reliable real world measurements (Jackson and Hunt, 1975; Hunt et al, 1988; Chow and Street, 2009; Castro et al, 2003; Silva Lopes et al, 2007; Conan, 2012). Bolund, an isolated flat-topped hill with steep sides in the Roskilde Fjord, Denmark, (Fig. 1) serves as such a baseline reference for various studies with respect to numerical and physical modeling since a mast based atmospheric experiment was conducted by DTU Wind Energy during winter 2007-2008 (Bechmann et al, 2009; Berg et al, 2011). To obtain a more comprehensive understanding of the flow pattern over the Bolund peninsula, especially close to the surface, a complementary field experiment on the Bolund peninsula was conducted. In October 2011 a laser anemometer, in the following called WindScanner (Sjöholm et al, 2014; Angelou et al, 2012), was placed on the peninsula 20 m inland from the westward facing escarpment.

2 Approach

The WindScanner, aligned on the 270° axis, was operated during westerly wind conditions to scan the area downstream of the Bolund edge. The atmospheric flow was measured in seven, 7-m high vertical profiles with distances between 8 m and 31 m from the scanning lidar (Fig. 2). In addition to the seven vertical profiles a horizontal arc extending ± 60° was scanned 90 m away from the instrument. The line-of-sight wind speeds of the eighth profile were used to determine the undisturbed inflow wind speed and wind direction.

While westerly wind directions prevailed, lidar measurements were recorded continuously during an almost 24 hour long measurement period.

Figure 1: Photo of Bolund, taken south of the peninsula.

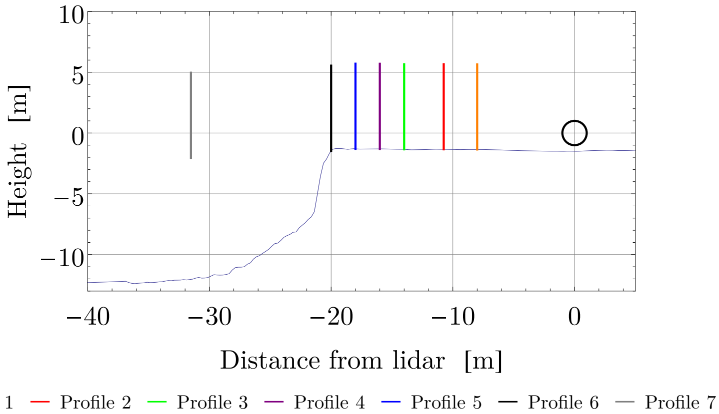

Figure 2: The position and height of the 7 vertical profiles scanned by the lidar relative to the Bolund escarpment. The position of the WindScanner itself is indicated by the circle.

3 Main body of abstract

The characteristic of the escarpment induced wake is investigated by identifying the boundary between the turbulent flow layer and the less turbulent layer above. Due to the high measurement-sampling rate a precise determination of the interface between the two distinctly different layers is possible. We determine the wake height using three different methods. One of the used methods is the calculation of the displacement thickness (Hinze, 1975). The results of the wake-height identifications with this method is exemplary presented in Fig. 3.

All three methods manage to identify a wake height, although the height differs between the methods. The calculated wake height for each profile location can be put in relation to the undisturbed wind direction and speed (Fig. 4). With increasing distance from the escarpment, the wake heights show a stronger dependence on the wind direction. The lowest wake heights of every profile is located at a wind direction of 270°. Depending on the distance from the escarpment the wake height increases between 10% and 80% when the wind direction deviates from west, either to the north or the south ± 15°. At larger direction deviations the height seems constant.

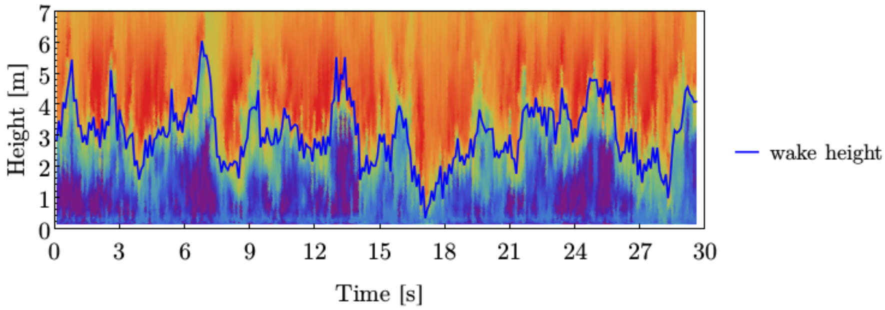

Figure 3: The line-of-sight projected wind-speed scan at profile 2, 10.75 m from the WindScanner during 30 seconds. 300 consecutive vertical profiles are plotted and the determined wake height is shown as the solid blue line.

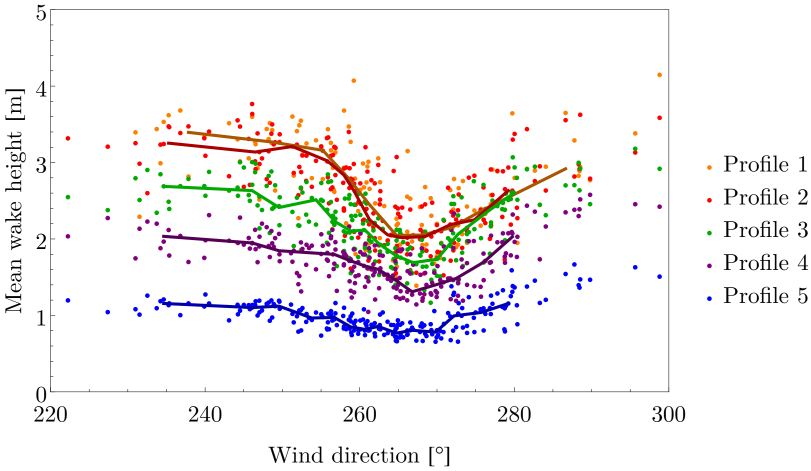

Figure 4: Dependence of the determined wake height and the wind direction. The solid lines depict the average wake height. The profile number increases with increasing distance from the WindScanner. The wake height is calculated through the definition of the displacement thickness.

4 Conclusion

The new remote sensing based wind profile measurements provide a unique data set for validation of unsteady flow modeling over complex terrain for wind energy. Based on the analysis of the high frequency atmospheric measurements with a rapidly scanning continuous-wave Doppler lidar a relationship between the escarpment induced wake height and the wind direction could be shown.

5 Learning objectives

- The audience will observe the new remote sensing based wind profile measurements.
- The audience will learn about a new reference data set for numerical modeling.
- The audience will learn about the development of an escarpment induced wake and the relationship between wake height and wind direction.

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