SCIENTIFIC REPORT

ACTION: ES1303 TOPROF
STSM: COST-STSM-ES1303-TOPROF
TOPIC: Measurement of wind gusts using Doppler lidar – part 2
VENUE: Technical University of Denmark, Risø, Roskilde, Denmark
PERIOD: 25 – 29 January, 2016

Host: Sven-Erik Gryning, (Technical University of Denmark, Denmark)
Applicant: Irene Suomi (Finnish Meteorological Institute, Finland)
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Introduction

Wind gust measurements have traditionally been limited to about the lowest two hundred meters of the atmosphere which can be reached by weather masts. Doppler lidars could potentially provide information from higher levels and thereby fill this gap in our knowledge. To measure the 3D wind vector, we need information from at least three different lines of sight pointing towards different directions, (e.g. Lane et al., 2013). The instrument sensitivity depends on the amount of aerosol present and the velocity measurement uncertainty is directly related to the amount of signal (Pearson et al., 2009). It typically takes several seconds to measure each line of sight with sufficient sensitivity and therefore the temporal resolution of the wind measurement is of the order of tens of seconds, which is not sufficient for gusts (e.g. Suomi et al., 2015). However, the Doppler lidar can provide high resolution turbulent measurements, both in the vertical direction (O'Connor et al., 2010), and potentially in the horizontal direction (Vakkari et al., 2015). Recently Rottner and Baehr (2014) have developed a method to measure turbulence by reconstruction of the wind on the basis of Dopper lidar observations and a particle filter. In this work, we will go one step further and apply this method to estimate wind gusts using lidar, and compare the results with mast measurements.

The main objectives of the work are to

- derive gusts from the available lidar parameters
- test the turbulence reconstruction method by Rottner and Baehr (2014) to estimate the gusts
- compare the results of the above methods and validate them against mast observations
- determine the minimum lidar requirements to estimate gusts and provide uncertainties for these estimates. This requires understanding of the relationship between wind gusts and turbulent intensity. By relating wind gusts to turbulence measurements, it would then be possible to extend the surface gust measurements with a vertical profile throughout the boundary layer.

The purpose of this STSM was to learn about the turbulence reconstruction method from Lucie Rottner who had a parallel STSM to DTU premises and to discuss the possibilities on how to apply the method to derive the gusts.

Objectives

The main objectives of the STSM were

- Introduction to wind gusts measurements (Irene)
- Introduction to the turbulence estimation method, and presentation of the results previously obtained (Lucie)
- Definition of the frame work: real time parameters required, number of cases to study
- Performing the first test experiments
- Using the experiences previously obtained to begin the work on the relationship between wind gusts and turbulent parameters
- discuss the status of the grantee's PhD work with Sven-Erik Gryning, who is one of the supervisors of the PhD thesis

Data and methods

Measurements

The measurements used in this study were collected at the Danish National Test Station for Large Wind Turbines operated by DTU. It is located at Høvsøre at the western coast of Denmark, about 1.7 km distance from the shoreline (Figure 1). The site includes a 116.5 m high meteorological mast equiped with sonic anemometers at six levels (10m, 20m, 40m, 60m, 80m and 100m). They are deployed on booms pointing towards north, which means that during southerly winds the instruments are in the shadow of the structure of the mast. The mast is also affected by the wind turbine wakes in the northerly sector, and by the coastline in the west (Floors et al., 2011). Hence, easterly sector represents the most homogeneous undisturbed conditions and therefore will be the focus of this study. A detailed description of the mast, its instrumentation and the site are provided by Peña et al. (2015).

The period chosen for testing the turbulence reconstruction method is October 2015, because there were predominant easterly winds during that period (Figure 2).

Lidar measurements were taken close to the mast and the instrument was oriented such that the structure of the mast and the wind turbines did not interfere the measurements. The lidar was a Leosphere WindCube V2 lidar. It had 5 beams, one vertical and four conical, each having a 28º zenith angle.

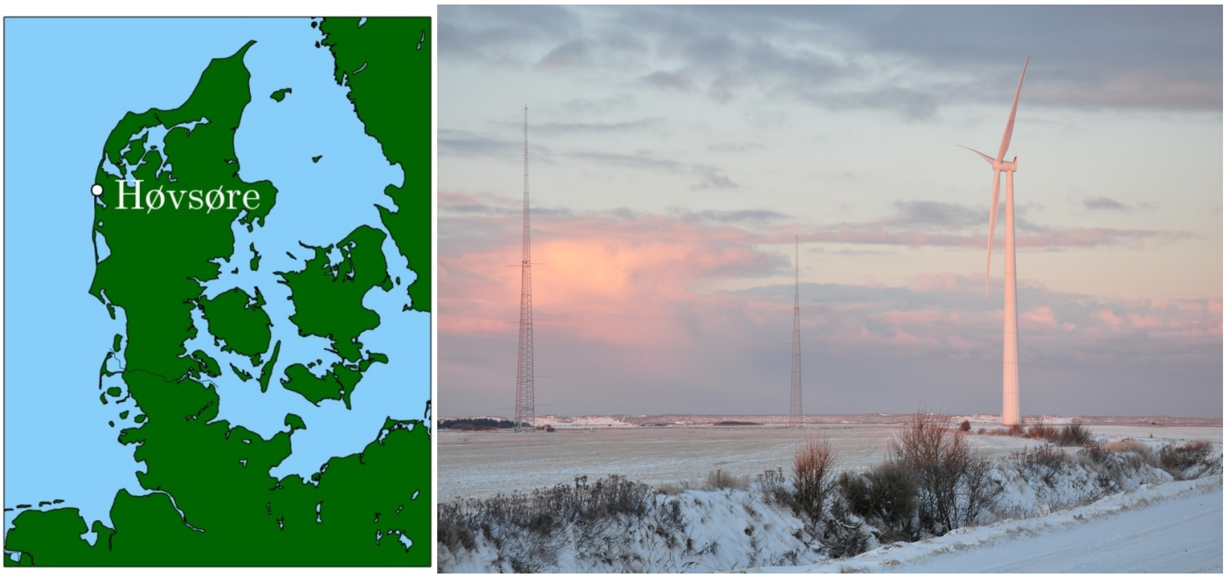

Figure 1: The Danish National Test Station for Large Wind Turbines is located at Høvsøre, at the western coast of Denmark (left). The 116.5 m tall meteorological mast is situated at left on the right hand side picture.

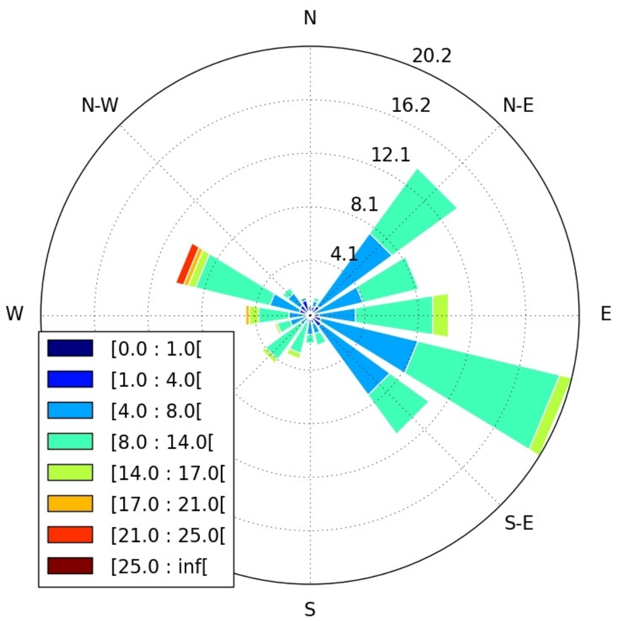

Figure 2: Windrose from the observations at 100m level at Høvsøre meteorological mast during October 2015.

Turbulence reconstruction method

During the STSM, Lucie Rottner gave an introduction to the turbulence reconstruction method. The method is based on a stochastic Lagrangian Model and non-linear particle filtering. It uses Doppler lidar radial wind measurements as input, and provides turbulence statistics in the scales up to about 100m and/or 1 min as output. Figure 3 shows the lidar set-up, an illustration of the particles within the model and an example of the time series of turbulent kinetic energy (TKE) as an output from the particle model (the red curve). For comparison, also the reference measurements of TKE calculated in 10 min time blocks are shown in Figure 3 (black stairs).

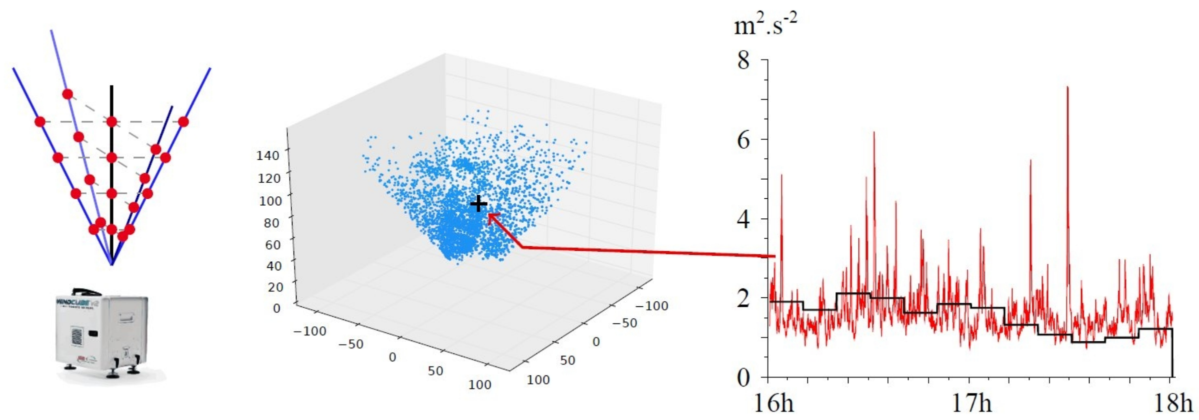

Figure 3: WindCube lidar with an illustration of the five lines of sight (left), an example of particles within the volume of the particle filter (middle) and an example of the TKE calculated from the particle velocities (red curve) and from the reference measurements (black stairs) (right).

First results

The turbulence reconstruction model provides a time series of the reconstructed wind velocity components as output. Figure 4 shows an example of such a time series. The results of the turbulence model not only reproduce the wind speed time series but the model is also cabable of removing unrealistical peaks from it.

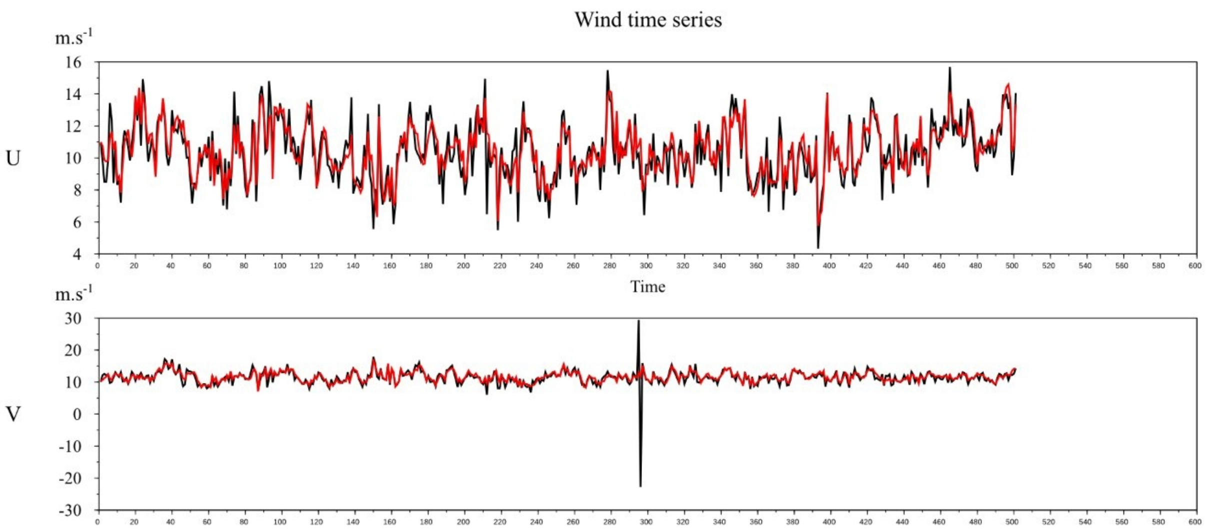

Figure 4: An example of the time series of the horizontal wind velocity components as observed directly by the lidar (black curve) and from the turbulence reconstruction method (red curve).

In addition to the reconstructed wind signal, the turbulence model can provide additional information derived from the particle velocities within the model volume. An example of such information is the TKE time series shown in Figure 3. In this study, we will investigate how such information about the particle velocities could be used in the derivation of a gust estimate. Figure 5 shows the first results of such analysis. At first, the data was divided into 10 min bins. The mean horizontal wind speeds calculated from the reference sonic anemometer, directly from the original lidar measurements and from the reconstructed wind speed agree well (the dashed lines in Figure 5). The wind speed maxima, i.e. the gusts, were calculated from sonic anemometers by applying a 3.8 s moving average to the measured 20Hz wind speed signal and the gust was determined as the maximum of each 10 min period of the signal. The length of the moving average window, 3.8 s, was chosen to be the same as the time taken for a lidar to measure a full set of five beams, i.e. it is the reslution of the lidar measurements (as well as of the reconstructed velocity).

In Figure 5, the wind gust speed of the reconstructed wind agrees well with the sonic anemometer gusts of 3.8 s duration, but the original lidar wind speed maxima are slightly higher than the sonic ones. Figure 5 also shows that the unrealistically high maximum in the lidar wind gust speed centered at 85 min is efficiently removed by the reconstruction method.

In Figure 5, the maxima of the sonic anemometer data ($U_{max,sonic}$, the raw 20Hz measurements) are clearly higher than the ones derived from the original or reconstructed lidar measurements. One possibility to estimate the wind gust is to take the maximum of the particle velocities as the gust estimate. However, in this case it leads to unrealistically large wind speed maxima. However, potentially the information about the particle velocity distributions within the turbulence model could be used to fill the gap between the lidar maxima and the maxima of the raw sonic anemometer signals.

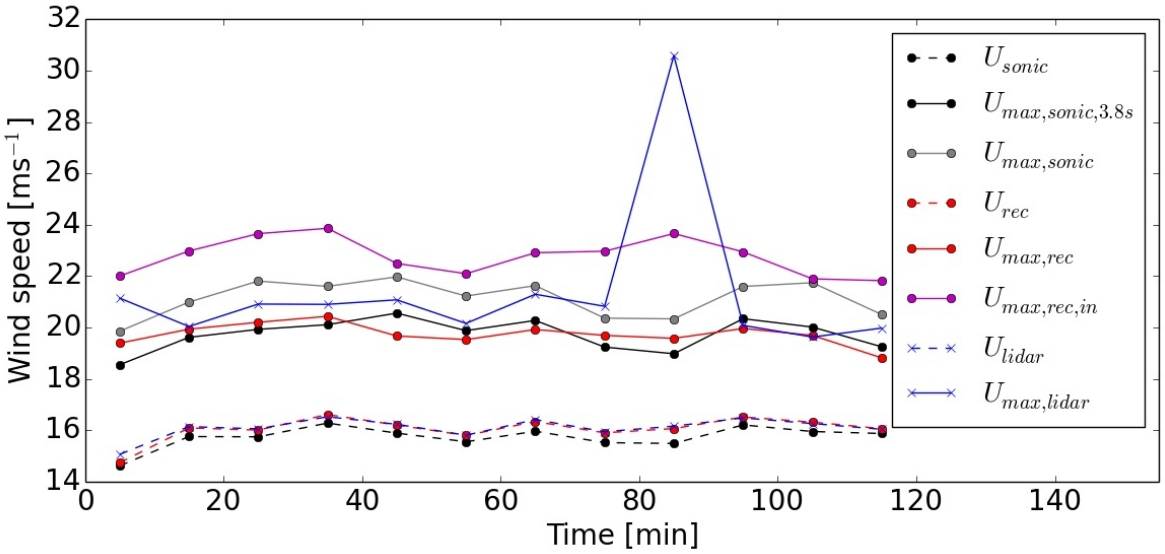

Figure 5: Mean wind (U) and wind gust (U_{max}) speed calculated from the original lidar, reconstructed lidar (rec) and sonic anemometer measurements. For the latter, U_{max} is calculated as the maximum of the 3.8 s moving averages and as the maximum of the original raw (20 Hz) signal.

Summary

All goals of this STSM were successfully achieved. The parallel STSM by Lucie Rottner provided a unique opportunity to learn about the novel stochastic turbulence reconstruction model that can be applied to lidar measurements to realistically estimate turbulent fluctuations in the atmospheric boundary layer. The discussions with Lucie Rottner during the STSM were fruitful and yielded in a common understanding of the experimental framework for testing the turbulence reconstruction method to estimate wind gusts. Also the results of the first experiments were promising and serve as a good basis for future collaboration. DTU provided excellent facilities for this successful STSM, by providing the data and the expertise related to working with it. Moreover, during the STSM and to support it, DTU started another lidar measurement campaign at the National Test Centre for Large Wind Turbines at Østerild (57° 3' 0.27" N, 8° 52' 55.70" E) which is located north of Høvsøre. The advantage of this site is that there is available a 250 m high, extensively instrumented meteorological mast, which will provide good quality reference measurements from sonic anemometers at heights 8, 40, 103, 175 and 241 m.

The host Sven-Erik Gryning supported the goals of this STSM to be achieved by assisting in organizing appointments with the other experts at DTU. Moreover, this STSM provided an opportunity to discuss the status of the grantee's PhD work as Sven-Erik Gryning is one of the supervisors of the thesis.

Deliverables

As an outcome of this STSM an abstract was submitted to the 22nd Symposium on Boundary Layers and Turbulence, which will be held in Salt Lake City, Utah, USA during 20–24 June 2016 (Suomi et al., 2016).

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