Atmos. Meas. Tech. Discuss.,
doi:10.5194/amt-2017-86-RC2, 2017

Atmospheric Measurement Techniques Discussions
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Interactive comment on "Three-Dimensional Structure of Wind Turbine Wakes as Measured by Scanning Lidar" *by* Nicola Bodini et al.

N. Gayle Nygaard (Referee)

nicny@dongenergy.dk

Received and published: 8 May 2017

Summary: this paper presents single lidar measurements of multiple wind turbine wakes. A wind field reconstruction model is used to derive wake characteristics from the line of sight wind speeds. The presented model is an extension to multiple wakes of a previous model developed by the same research group to characterize a single wake. Results are presented for the decay of the velocity deficit and the increase of the wake width with downstream distance. The wake centerline is found to shift orientation with height, indicating stretching of the wake profile in veered flow. The results are interesting and add to the developing picture of wakes in wind farms.

The method is sound, but could have been better explained, especially with regards to the vertical dimension and the influence of multiple elevation tilts (see specific comments below). The authors find some differences between the outer and the inner turbines in a row, but no explanation for these differences is offered.

The paper is definitely worthy of publication, but I suggest the authors consider the questions and suggestions below to improve the presentation of the methodology and the results.

Questions and suggestions:

In the model of Eq. (4) there is no reference to the vertical dimension or the elevation angle. Is it supposed to be applied at a fixed elevation angle? It is unclear how the vertical structure of the wakes is considered. At a fixed elevation angle the laser beam will probe at increasing height with increasing range. Were multiple elevation tilts combined in figures 7 and 8 to account for this?

Consider adding a reference to Wang and Barthelmie - Journal of Physics: Conference Series 625 (2015) 012017 - Wind turbine wake detection with a single Doppler wind lidar. This has a similar wake wind field reconstruction method.

P1, L23: The reduction in power for turbines in wake can exceed the 40% mentioned as the upper limit. As is well known, it is very sensitive to wind direction, being largest when the wind is aligned with rows of turbines. Also the observed maximum reduction depends on the size of the wind direction sector over which the data are averaged. But even for a 30 degree sector Nygaard 2014 found reductions of up to 60% for certain conditions. The total wake loss considering all wind directions and wind speeds is typically less than 20%. My point is that the 40% mentioned in the text is a meaningless number without further context. It only applies for certain wind directions and for averaging over a sector of a certain size. I invite you to make the context of this number clearer or to consider, if a specific value is needed.

P2, L11: the appropriate reference for the Jensen model is N. O. Jensen, A note on wind generator interaction, Risø-M-2411 (1983). The reference you have to Jensen

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1984 was new to me, so thank you for pointing it out. However, on a quick browse through that paper I did not see any mentioning of the Jensen wake model. The Jensen 1983 report is often cited together with the 1986 paper by Katic, Højstrup and Jensen, which introduces the method of wake superposition employed in the Park model in WAsP.

P2, L28: it is important to include more references on capturing multiple wakes in wind farms. At present only two are listed. But since this is the main focus of the paper it is crucial to establish the existing state of this area of study. “Among others” is insufficient. Here are some suggestions: âĂć Hirth et al., Wind Energy 18, 529 (2015) - Coupling Doppler radar-derived wind maps with operational turbine data to document wind farm complex flows âĂć Hirth et al., Wind Energy (2015) - Dual-Doppler measurements of a wind ramp event at an Oklahoma wind plant âĂć Kumer et al., Energy Procedia 80 245 (2015) - Characterisation of single wind turbine wakes with static and scanning WINTWEX-W LiDAR data (already cited elsewhere in the paper) âĂć Wang and Barthelmie paper mentioned above âĂć Van Dooren et al., Remote Sens. 2016, 8, 809 - A Methodology for the Reconstruction of 2D Horizontal Wind Fields of Wind Turbine Wakes Based on Dual-Doppler Lidar Measurements

P3, L12: a photo or photo collage would greatly assist the understanding of the setup of the field campaign, the description of the surroundings and possibly the interpretation of the results.

P3, Fig.1: the figure is good, but should only include the relevant information. Were all the surface flux stations used in determining the atmospheric stability? Were all profiling lidars used in the analysis? Leave out the details not connected with this paper.

Sec 2.1: the text should specify clearly how the profiling lidars were used in the analysis. Section 2.1 has a brief mention of a comparison between the scanning lidar and WC-3. How was this done? What did the results show? WC-3 was used to deter-

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mine veer on page 14, but please introduce this in the description of the observational dataset. Was WC-2 used for anything in the present study?

P4, L15: the period at the beginning of the line belongs at the end of the previous line Sec.2.1.1: I miss a detailed description of the scan patterns. What was the sector size for the PPI scnas? What was the time per scan? This is hinted at on P14, but it belongs in this section. What was the order of the RHI and PPI scans? Am I right that the RHI scans are not used in the present analysis? If that is correct, then please state that. Was the pointing accuracy of the scanning lidar checked using hard target returns (eg from the wind turbines)? This information is important to interpret the results and should be included. Alternatively, if the authors have made this informaiton available elsewhere, a reference could suffice.

P5, Fig. 2: how large was the change in elevation between the lidar location and the turbines? State what is was, then argue why it can be neglected. Otherwise, make an assessment of the uncertainty or bias it introduces into the results.

P6, L3: the Monin-Obukhov length has dimensions of Length. I assume the listed limits should be in meter.

P6, L6: insert a “The” at the beginning of the line. Same on line 23 after Figure 3.

P6, L12: define carrier-to-noise ratio. Explain the filter on CNR (<-27dB) and why this is necessary. Why was this threshold chosen? How sensitive are the results to this value?

P6, L13: do data refer to the line of sight wind speeds?

P6, L13: define \mu and define MAD in an equation. Is the standard deviation equal to MAD (it is cryptically stated to be evaluated according to MAD)? How sure are you that the outliers removed are not physical? Do you know the source of the outliers you exclude?

P6, L23: I suggest inserting “the assumed” in front of uniform ambient wind speed.

P7, L1: there is a “the” missing in front of ambient flow speed.

P7: it would be very useful to have an overview image or map showing the turbine locations and the scanned sector.

P7, Fig.3: to define the wind direction there should be an indication of the north (or south) direction in the figure. Is south upwards in the figure?

P9, L19: MAD acronym was already defined. When the method was applied again, did you use the same bounds as on page 6?

P9, L20: “mean characteristic” – is this for the entire database or for a single scan?

P9 L21: define the Pearson correlation coefficient and the mean squared error.

P10, Fig. 5: what do the corresponding plots of data availability look like? These could be important to include to understand if the some of the decrease in Figure 5 is driven by the measurements and not by wake characteristics. I would also like to know the number of scans included in the stable and unstable curve. Were there no neutral conditions?

P11, Fig. 6: are these plots along the wake centerlines? What was the wind direction and how was it oriented with respect to the turbine row? This can be deduced from figures 8 and 9, but you might as well make it clear here.

P11, Fig. 7: the authors should attempt to explain the differences they see. While the two outer turbines both have smaller deficits than the inner turbines, the difference in deficit between the two outer turbines is larger than the difference between the inner turbine and the outer turbine with the highest deficit. It would be useful to label the curves with the turbines they belong to. Could there be a relation with the vertical structure of the wakes and sampling the wakes at different heights. As stated above it is important to know how the different elevation tilts were combined (or not) in making this figure. Is the width of the shaded bands one or two standard deviations? I suggest making the same plot for the 23 August data.

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P 11, L 4: replace low with small

P12, L 12: the passive voice makes it hard to understand the sentence. Consider rephrasing it. I think you mean widest, when you write largest.

P16, Fig. 11: I am not sure I agree with the conclusion of a larger angular difference for the outer turbines based on the linear fits. The linear fits are very poor. Indeed, the data could be seen as describing an oscillation, where the inner and outer turbines follow each other.

P20, L16: &amp should be &.

P21, L14: Spera, D should be Neustadter, H. E. and Spera, D. and the page number is 240 not 241.

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