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Atmospheric Measurement Techniques Discussions

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

Anonymous Referee #1

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SUMMARY: This paper discusses the analyses of wind turbine wake structure considering varying atmospheric stability regimes using measurements from a single scanning lidar; representing an extension of the work of Aiken and Lundquist (JTECH, 2014). Frequency in wake detection, wake velocity deficits, wake width, and wake centerline results are presented. I found the discussion related to the wake stretching as a result of vertically veering wind direction to particularly interesting. The impact of atmospheric stability on wake behavior is a very important aspect to understanding wind plant performance as a whole, and as this paper shows there are significant and consistent (e.g. diurnal) changes in wake behavior as a result of the background stability. I believe the results of this paper are a meaningful contribution and worthy of publication, but I do have a few comments/questions requesting clarity for how the measurements are used to construct the analyses and what the downstream implica-

tions are for the presented results.

MAJOR COMMENTS/QUESTIONS: While the title infers a 3D construction of the wakes for analysis, in reality, all of the presented wake statistics are only assessed from individual 2D planes. Since multiple elevation tilts are used, I would have liked to see the author construct fully integrated 3D volumes of data by interpolating the polar data from a given elevation series (by elevation series I mean a single collection of the six elevation tilts between 1.5-2.8 degrees) into a 3D Cartesian grid. Otherwise, when assessing wake deficit and width, how can we be certain that any given 2D plane is a complete representation of the absolute downwind wake deficit or wake width since that plane only represents a horizontal 2D "slice" somewhere through the wake? Since deficits and widths were computed separately from the individual PPI elevation planes within the same elevation series, this would mean multiple wake deficit/width calculations for the same downwind distance exist within the same elevation series, but inherently represent different vertical locations within the wake. Or maybe the generated wake statistics for one elevation series are binned by range regardless of their height? Additional discussion on how the statistics from individual tilts within a single elevation series are merged (or not) would provide for a better understanding of the bulk wake statistics (e.g. deficit and width) and how representative the statistics are of the character of the full wake at any given downwind distance. I apologize if I have misinterpreted the analysis, but I believe there needs to be further clarification of how the 2D planes of PPI data are used to generate the wake statistics, and what inherent assumptions/limitations are associated with the methods. I would also encourage the author, though not required, to consider analyzing the data in a true 3D framework when constructing the presented wake statistics.

MINOR COMMENTS/QUESTIONS: 1. P4, L8: What is the range from the WINDCUBE to the four turbines of interest? The distances can be inferred from Figure 2, but the numbers would be useful in the text.

2. P 4, L 14: What is the scan speed of the lidar? What range of azimuths are scanned?

3. P4, L 19: How long does it take the lidar to scan the series of six elevation tilts?

4. P9, L 11: This comment relates to the Major Comments/Questions section above. How is the ambient flow wind speed defined on the 2D PPI plane? Since the PPI plane is slanted, if the ambient flow wind speed is determined upstream of a given turbine, can you comment on the impact of using this value for constructing wake deficits downstream of the turbine, but at lower heights due to the slanted PPI plane? Is the comparison being made at different heights because the PPI plane is sloped? If so, what are the implications on the wake deficit calculations?

5. P9, L30: How many scans are used to generate the statistics in Figure 5? Are all of the 438/576 scans performed on 23 Aug/26 Aug considered? Are all elevation tilts considered?

6. P10, L13: Does this statement imply that a single elevation series of six scans takes 11 minutes to complete? If so, that may answer Question 3 above.

7. P10, L18: While the difference in wake deficit between the inner and outer wakes is shown, can the author comment on the difference in wake deficit between the outer turbines, as that difference is actually more substantial? Which line is for which turbine? Assuming the wind direction is relatively consistent throughout (maybe a bad assumption), can a composite PPI image be provided corresponding with this period to highlight if there are any features in the flow (e.g. a turbine row edge effect) that could be contributing?

8. P12, L2: While the author states comparable results occur between the 23-August and 26-August cases, do the red lines, for example, flip with the different wind direction, again inferring some type of turbine row edge effect?

9. P12, L18: Could an example PPI image or composite be included to visually highlight the wind direction dependence on wake width detection being discussed here?

10. P12, Section 4.4: This comment relates to the Major Comments/Questions sec-

tion above. Perhaps consider constructing a 3D volume of interpolated information, as opposed to compositing two horizontal planes for comparison. The change in wake centerline with height, supported by the presented measurements, is a really neat result of this study. The actual shape of the ellipsoid could potentially be better described (and compared to previous measurements) if the data were constructed in a 3D framework.

11. P12, L28: Why were the data separated between 55-75 m and >75 m, especially given hub height is at 80 m and data exist below 55 m within the rotor sweep. Why was the lower region bound vertically by 20 m but the upper region allowed to be larger? A quick comment on why this method was chosen could be beneficial.

MINOR EDITS: 1. P2, L16: “four” instead of 4.

2. P4, L15: The period at the start of this line should be at the end of the previous line.

3. P4, L23: “six” instead of 6.

4. P6, L14: Insert a period after (MAD).

5. P7, L11: Insert the word “the” between “as independent”.

6. P9, L19: MAD is already defined on P6.

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