Review of "Measuring dynamic wake characteristics with nacelle mounted LiDAR systems" by Inga Reinwardt et al., manuscript number: wes-2019-89

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1. General comments

This study presents the results of a measurement campaign, using nacelle mounted lidar pulsed lidars, focusing on the wake of a small, closely-spaced wind farm in a mostly flat terrain. The lidar measurements aim to capture the behavior of the wake in terms of deficit and meandering and compare with numerical predictions of different variations of the dynamic wake meandering (DWM) model. The measurement results are used to calibrate the parameters of one of the variations of the DWM in order to better fit the numerical results to the measurements. The analysis is mostly qualitative.

- In terms of language the text is well written and clear. Some improvements are needed on the structure and phrasing used. See specific comments.
- Good literature review especially regarding previous campaigns.
- The analysis is mainly qualitative. Quantitative analysis should also be used to back up the arguments. More explanation on why we see what we see not only explaining what we see is needed.
- The data don't seem to be enough especially in higher TIs to generalize the conclusions.
- Clearer explanation of the tools/methods used especially for the numerical part. How were the virtual lidar measurements done, what software was used, what are the assumptions…? This will improve reproducibility and make the work more transparent.
- More discussion is needed on the uncertainties like yaw direction, sampling rate, low sample size, distance of met mast (especially to WTG2), other wake interactions, LOS reconstruction, etc. How much do all these affect the results? More thorough discussion is needed on these points.
- Some more tangible results would be good in order for this work to be more useful for the research community. Can the data sets and the codes used to post process and fit the DWM model be made publicly available? Under which condition are the recalibrated parameters valid (terrain, ambient conditions, turbine types etc.)?
- Language and argumentation need to be more concise. Avoid qualitative terms like "quite", "relatively", "probably", "becomes apparent", "almost" etc. A lot of argumentation is based on oral and visual argumentation instead of quantitative and causal analysis.

The data sets from the measurement campaign and the findings of a recalibrated variation of a specific DWM model can be useful for the wind energy community and is relevant in the context of the journal. Showing the shortcomings of current engineering models as well as issues associated with measurement campaigns has a value for the wind energy research community. I suggest the manuscript for publication after addressing the comments suggested here.

2. Specific comments

Title

Is the title reflecting the content? Maybe use a more descriptive one, like for instance: "Calibrating a DWM model with measurements of dynamic wake characteristics using nacelle mounted lidar systems"?

Abstract

Specify the objectives of the paper clearly, not only the campaign. What do we learn by reading the paper?

I would suggest removing lines 4-5 as no discussion on the optimization procedure is done in the paper itself.

Introduction

L 13: Engineering models like the Frandsen model are intended to calculate mainly the wake deficit and shape and not the wake induced turbulence. It should be clearly stated.

L 24: What is meant by 2D wind field here? The lidar can measure 1D (LOS direction only) and 3D in terms of space (have the pulsed technology with range gates). Please clarify.

At the end of the introduction a paragraph should be added stating clearly the objectives of the paper. A small reference on the content and structure of the following sections could also make the work easier to follow.

Wind farm

L 67-68: As I understand load measurements are not used in the study, what is the relevance of mentioning the load sensors here?

L 69: LiDAR system of WTG 1 is installed inside the nacelle and measures through a hole in the rear wall: This is an interesting and uncommon setup. Are there any limitations or benefits using this set up? It could be useful information for future campaigns.

L 70: A nacelle mounted GPS is mentioned for the nacelle yaw position tracking. What is the uncertainty of such a system? Did you correlate it with the high frequency SCADA data for nacelle direction? Is there any data filtering based on SCADA or gps nacelle position in order to make sure that the turbines were not yawing often during the accepted time intervals?

L 78-80: The Richardson number is mentioned here. It is not mentioned how it was used to filter the data or how it is used in general in the study. Stability is only mentioned again in L 216 where it is stated that it is not considered. Am I missing something?

L 79: State the heights of measurements used for the calculation of the Richardson number.

How many rays are used in each pulse for the campaign?

Are the SCADA data used 10min averages or high frequency?

How is the met-mast equipped (heights of measurements, measurement devices…)?

L 73-88: A lot of information in this paragraph. Would be clearer to add a table with all the filtering as well as the amount of total data and data kept after filtering. This way it will be easier to identify sources of bad measurements and provide a condensed overview.

L 85-88: Give more details on the final setup of the lidar campaign. What was the sampling rate per scan/ray? Which range gates were used (as 750m exceeds the distance of the downwind turbines and usually this type of devices cannot measure below 50-100m)? Exact information on the campaign can be very useful for future research.

L89-94: Is there any uncertainty in that? According to the misalignment of the nacelle to the main direction, the tilt or yaw flows and the lidar angle, the uncertainty can be significant. Is there a way to quantify that? What are the angles used and how small are they?

The previous comments are correlated to the general comments on discussion of uncertainty and reproducibility of the study.

Wind speed deficit in MFR calculation

L 107-108: "However… campaign" This is a good example of more concise language and argumentation needed in the paper. What does highly improbable mean (especially when only 1 10min data set is used for some TI bins later on)? What does very robust mean? Please be more specific in the arguments used to validate assumptions.

L 118-120: Maybe I am missing something, but it is not clear to me how this plausibility check works. Can you explain it more?

Lidar simulation

This section needs a lot of work, with a lot of missing information. More information is needed in order to ensure reproducibility. How is the lidar simulator working? How are the wind fields created and how is the DWM model incorporated? Are you using Turbsim or Mannbox generator or some other turbulence generator? How is the LOS speed reconstruction done? Do you consider perfect lidar measurements? How are the range gates and probe volume averaging considered?

L 129-131: This is the only reference through the paper to the optimization study to find an optimal pattern. It results to a simple horizontal scan of 11 equispaced points. It is very general and does not explain the procedure. I think it should either omitted from the paper and only state the used trajectory or add a dedicated section with more details and figures.

L 136: What does very well mean in this context? Can it be quantified e.g. with error metrics or R^2?

L 144-146: What does optimal operating conditions mean? Does it mean it operated on max CP, CT which in turn produce the highest deficit? Please be more specific. Maybe a dimensionless CP-CT vs wind speed curve would be useful here but also for the argumentation in L 299 about thrust being constant.

Some references on studies using virtual lidar measurements:

Dimitrov, N., and Natarajan, A., "Application of simulated lidar scanning patterns to constrained Gaussian turbulence fields for load validation," Wind Energy, Vol. 20, No. 1, 2017, pp. 79–95. doi:10.1002/we.1992.

Pettas, V., Costa García, F., Kretschmer, M., Rinker, J. M., Clifton, A., and Cheng, P. W., “A numerical framework for constraining synthetic wind fields with lidar measurements for improved load simulations,” AIAA Scitech 2020 Forum, American Institute of Aeronautics and Astronautics, Reston, Virginia, 2020, pp. 1–6. doi:10.2514/6.2020-0993

Dynamic wake meandering model

Sections 6.1 and 6.2: Nice, thorough description of the models. Can you explain how you generated the wind fields (tools, models, parameters, discretization) and how you implemented the variations of the DWM models? Is this an in-house tool or a commercial/open source tool? Can the codes be shared with others so that such validations can be repeated with other data sets?

Section 6.3: As stated, the wake induced turbulence in the DWM model is not used in this study. I suggest to remove this section as it does not add something to the purpose of the paper.

L 258-259: What does relatively good agreement mean in this context? Please be more precise and avoid using such expressions.

Measurement results

Discussion in this section needs to be more quantitative and not only qualitative and the language needs to be more concise (look at previous comments). It feels more like describing the plots instead of explaining and quantifying what we see (e.g.: “The degradation of the wind speed deficit in downstream direction is clearly identifiable”, “The reason is probably the wake of other turbines in the wind farm.”, “it becomes apparent that the wind speed deficit in the FFR is less pronounced.”, “The most obvious explanation is the reduced number of measurement results in these bins and the higher uncertainty that comes along with it”). I suggest revising this section in terms of phrasing and adding some quantitative results.

The results with high shear and low TI (and vice versa) suggest some kind of stability based filtering in the results. Is this done somehow? Would this be an important parameter on how well the DWM models and the parameter fitting perform?

L 270-271: Can't this (along with the observation that the center of the wake in the MFR is not exactly at the 0 point) correlated to the rotational direction of the rotor too?

L 277-280: This discussion is interesting and would be more relevant if it could quantify the trade-offs. As mentioned in a previous comment this could fit in the numerical study of the optimization.

L 293-298: and L 305 and L 311-314: The data for bins of TI higher than 12 seem very sparse with 1 or 2 data sets each. Are these sufficient to extract conclusions about the models and fit parameters? I would suggest a more thorough argumentation for using them or removing values higher than 12 from the anlysis.

Table 2: Could it include also shear values? Or maybe a plot can be added showing the joint probabilities of shear and TI. This will help to give a better overview of the conditions to the reader.

Figure 2 is hard to read. I recommend plotting it again with thicker lines and playing with line style, markers and size

L298-301: As mentioned earlier, a CP-CT curve vs wind speed would be more clear for this argument.

L 314-318: The argumentation here is weak. More quantitative results are needed and more concise language in order to validate the assumptions.

Comparison between measurements and DWM model simulation

L 323: Which are the distances used in the simulations?

L 325-326: "However, the wind speed gradient in axial direction is relatively low and almost linear in the observed downstream distances, so that a fair comparison between simulation and measurements is carried out". The phrasing relatively low and almost linear are not making an argument for the assumptions. Please explain why you consider this valid. Moreover, it is not clear what is meant by fair comparison in this context.

L329 Avoid the phrase 'it is obvious',

L320-336 In general the analysis here is only descriptive and qualitative. Can the convergence be quantified and the discrepancies of the model to the measurements explained based on their assumptions and detail level?

L 342 How were the simulations performed? What code was used, what type of spatial and temporal discretization? Give more details.

L345 It is not clear to me what does this weighting mean. Can you explain it a bit more along with the reasoning?

L 346 It is stated that the calibrated model "coincides very well with the measurements". Can you quantify this improvement by comparing with the level of agreements of the previous models?

L 350-362 In this paragraph the differences between the models described based on figure 10. Can you add some explanation on why the models behave differently? What is the driver of this behavior?

Conclusions

L 366 As commented earlier the part about deriving an optimal scan pattern is not discussed at all through the paper. I would suggest you either add a section on this optimization procedure or remove it from the text.

L374 comparably good agreement: This is not clear as a conclusion. As stated earlier I think more concise language and quantitative results are needed.

3. Minor comments

L 64 with small turbine distance→five closely spaced Nordex turbines

L 65 in main wind direction → in the main wind direction

L 117 instant in time→ instance of time

L326 donstream→downstream