Response to Referee Comments for "Design and analysis of a wake model for spatially heterogeneous flow"

Corresponding author: Alayna Farrell

February 2, 2021

Abstract

The authors would like to thank the referees once again for their comments. The authors believe that this paper is further improved by addressing the referees' concerns.

Referee Report 1:

General comments:

This paper presents an interesting improvement of the FLORIS wind farm model with the implementation of a method to take into account an heterogeneous atmospheric inflow. The original wind farm model is well described and a considerable effort has been made on the description of the new implementation during the reviewing process. In general, the comments of the last reviewing process were well addressed: the procedure is now more detailed with figures helping to the understanding. The authors propose some elements to discuss the limitations of the model. The test case is well described and the analyse is exhaustive with interesting comments for each metric.

Here are some specific comments and technical corrections:

- In general in the introduction, the authors should be more specific while mentioning "variant conditions". "Spatially variant conditions" is more adapted in order to avoid confusion with unsteady conditions.

    - L37: consider replacing "during these conditions" with "under these conditions".

      This edit has been made.

- L48: consider adding "spatially" variant weather conditions.

  This edit has been made.

- In Section 3.1

  - Consider adding x/y coordinate axes (or Easting/Northing) in Figures 2 and 3.

    Axis labels have been added to Figures 2 and 3.

  - L236: consider adding a reference to L245 since, at this point of the article, the reader could wonder about how the model deals with different hub heights, especially for wind farms in complex terrain.

    A reference has been added.

- In Section 3.3

  - L256: maybe changing "center of the flow field" into "center of the simulation domain" would make the location of the rotation center more clear ?

    This change has been made.

  - L286: The sentence is not clear "is that which causes".

    This paragraph has been reworded to improve clarity.

- In Section 4

  - There is only one subsection (4.1).

    An additional subsection has been added to this section.

  - L397: Consider adding "with respect to the"

    This edit has been made.

  - L398: Consider changing the end of the sentence "the addition[...] contributes to improvements or improving ?"

    This edit has been made.

- L441: "is observed"

  This edit has been made.

- In Section 5

  - L476: "indicate"

    This edit has been made.

Referee Report 2:

Overall Comment:

Thanks to the authors for thoroughly addressing my points and performing a major revision. I appreciate the time the authors spent to consider each point in both of the reviews. The discussion of the model, its motivation, and derivation is much clearer to this referee with the revisions made. However, I still have uncertainty about the wind farm data comparison and I recommend another revision to address these questions.

General comments:

1. Overall, given the lack of detail (due to understandable IP constraints), the field SCADA data comparison is not ideal for proving that the new model has addressed the issue of flow field heterogeneity. In fact, the most convincing use case of the heterogeneous wake model proposed is presented in a separate paper [1]. This referee recommends including the LES test case in this manuscript.

   An additional Subsection 4.1 has been added to the validation analysis to discuss the accuracy of FLORIS simulations compared to LES, similar to the work of Fleming et al. (2020).

2. Related to Point 1, there still appear to be unexpected results in the comparison with SCADA data that require more investigation and/or explanation. The proposed method does seem to have good merit, and in some cases comes with substantial improvement compared to the homogeneous model (by getting localized estimate u_∞ improvements),but less attention is given to situations where performance is not affected or worse than homogeneous FLORIS. It would be hard for a FLORIS or other wake model user in the community to understand when to use the heterogeneous model versus the homogeneous in a general model setting based on this paper, especially given the poor performance at low wind speeds.

   More discussion of uncertainties regarding the model's performance has been added to the conclusion.

Specific Comments:

1. Abstract: The addition of quantitative results in the abstract is helpful, but the discussion has been made selectively. The heterogeneous model does reduce MAE but in fact it increases MAPE and this should be mentioned in the abstract to not appear to be selective by the authors. Based

on the discussion, whether the method improves MAE or MAPE compared to homogeneous methods will likely be site-specific (e.g. based on the wind rose) due to poor performance for low wind speeds.

A statement regarding the variability of the proposed model's performance in different site-specific operational conditions is now included in the abstract.

2. Line 28: The reference to Schreiber seems out of place. Data-driven wake model parameter corrections have also been proposed by [e.g. 2,3,4], among others.

   Discussion of these modeling techniques has been revised and relocated to the next paragraph.

3. Brogna et al. (2020) should be discussed in the introduction as prior work in the domain.

   A reference to Brogna et al. (2020) has been added to the discussion of prior work in the introduction.

4. Equation 3: Missing parenthesis.

   Parentheses have been added.

5. Line 294: What does it mean for "the flow-field grid points to conflict in the rotated grid?" I don't quite understand this sentence or the stated rotation limiting case. Would this be a case where the rotated grid folds back on itself and has different original points in the same rotated x-y space?

   Your explanation of this concept is correct. This refers to a case where the rotated grid points (shown in Fig. 7a) fold back onto themselves, causing the overlapping points to be erroneously assigned velocity deficit if they overlap a region that is in the wake downstream of a turbine. The referenced paragraph in the text has been reworded for clarity.

6. The added discussion of the TI model is helpful!

7. Figure 13: Can the FLORIS predictions without wake losses be added to this figure for visual comparison?

   An additional Subsection 4.1 has been added, comparing FLORIS simulations to LES. This added discussion provides several plots visually comparing differences in accuracy due to wake calculations.

8. Some of the newly added sentences have typographical errors (e.g. Line 295), I suggest the authors check over them in detail.

   The newly added sections have been proofread in detail, and typos have been fixed.

9. Thank you to the authors for including the results of FLORIS without wake losses included. I want to be sure I understand the results you're presenting.

   (a) Comparing Tables 3 and B2:

      i. The wake losses make no difference to turbine specific MAE for velocity of < 5 m/s (expected)

      ii. Including wake losses reduces FLORIS MAE only slightly for 5-11 m/s for the heterogeneous model and has no impact on the homogeneous model (unexpected)

      iii. Including wake losses significantly reduces MAE for >11 m/s where we would not expect significant wake interactions (as the rated wind speed is reached), this is also unexpected. There is no impact for the homogeneous model and more impact for the heterogeneous model.

      Since the turbines in the observed wind farm are relatively spaced out, it is expected that the wind farm will not show significant wake losses during certain flow conditions. The substantial improvements seen when including wake loss calculations at high wind speeds may be due to the greater influence of turbulence intensity at higher wind speeds, which is factored into the wake model. The LES study presented in subsection 4.1 presents an analysis of a wind farm that has a more densely packed turbine layout and more prominent wake effects for further analysis.

   (b) Comparing Tables 2 and B1, including wake loss modeling degrades FLORIS's performance in the heterogeneous model.

      Since the average power predictions of individual turbines within the wind farm do show improvements when including the FLORIS wake *calculations, this apparent decrease in total power output accuracy may be a reflection of the self-compensating effect that occurs when taking an overall sum of a wind farm. Some details in wake modeling performance may be misrepresented when the overpredictions and underpredictions between turbines are merged in to one lump sum of error.*

(c) Comparing Tables B1 and B2, why does the heterogeneous model have lower MAE for the farm than homogeneous but higher MAE than homogeneous when MAE is turbine specific?

These variations in relative model performances may again be due to the effects of turbulence at high wind speeds, which are not calculated when excluding wake losses, and consequently, the turbulence not updating at each turbine based on the wake model as discussed in Annoni et al. (2018); Niayifar and Porté-Agel (2015) A comparison of these two tables shows that the most prominent differences are observed in the higher wind speed ranges, which may be subject to greater uncertainty without wake calculations included.

(d) Given that including or excluding wake effects in FLORIS seems to have a very small impact on the MAE (there is virtually no impact on homogeneous FLORIS MAE), that seems to indicate to this referee that this is not an ideal test case for a wake model.

Although the relatively low wake effects in the observed wind farm may be less than optimal, their influence is still prominent enough to be observed in the analysis of wind turbine power predictions, particularly on an individual-turbine basis. Since producing accurate power predictions at individual turbines within a wind farm is so crucial for the development of wind farm controls, wind resource assessment, and many other applications, these results seem to be noteworthy and worth reporting. In further validations of the heterogeneous model, presented in Subsection 4.1, a wind farm with closer turbine inter-distances is used to obtain a more thorough indication of the proposed model's capability of modeling wake influence.

References

Annoni, J., Fleming, P., Scholbrock, A., Roadman, J., Dana, S., Adcock, C., Porte-Agel, F., Raach, S., Haizmann, F., and Schlipf, D.: Analysis of control-oriented wake modeling tools using lidar field results, Wind Energy Science, 3, 819–831, 2018.

Brogna, R., Feng, J., Sørensen, J. N., Shen, W. Z., and Porté-Agel, F.: A new wake model and comparison of eight algorithms for layout optimization of wind farms in complex terrain, Applied Energy, 259, 114 189, https://doi.org/10.1016/j.apenergy.2019.114189, 2020.

Fleming, P., King, J., Bay, C. J., Simley, E., Mudafort, R., Hamilton, N., Farrell, A., and Martinez-Tossas, L.: Overview of FLORIS updates, Journal of Physics: Conference Series, 1618, 022 028, https://doi.org/10.1088/1742-6596/1618/2/022028, 2020.

Niayifar, A. and Porté-Agel, F.: A new analytical model for wind farm power prediction, Journal of Physics: Conference Series, 625, 012 039, https://doi.org/10.1088/1742-6596/625/1/012039, 2015.