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Interactive comment on "A control-oriented dynamic wind farm model: WFSim" *by* Sjoerd Boersma et al.

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Dear Referee #2,

We thank you for your feedback. Please find our responses to your questions below.

(1) Page 2: The first paragraph of the abstracts reads like part of an introduction. Please reformulate the abstract in a more functional manner. Specify what you mean by "validated with high fidelity data" and give a rough summary of the findings. Also, preferably use present or past tense instead of "will be" formulations.

Answer: Thank you for this valuable comment. The abstract will be rewritten and we will specify more precisely what we did in the paper.

(2) Pages 3/4: In the model summary, please fill the gap between LES models and engineering models with 3D RANS references.

Answer: The following:

Crespo, A., Hernandez, J., Fraga, E., and Andreu, C.: Experimental validation of the UPM computer code to calculate wind turbine wakes and comparison with other models, Journal of Wind Engineering and Industrial Aerodynamics, 1988.

and

Özdemir, H., Versteeg, M. C., and Brand, A. J.: Improvements in ECN wake model, ICOWES conference, 2013.

are both referring to a 3D RANS wind farm model. We will mention this more specific.

In addition, the following references will be included:

M. Avila, A. Folch, G. Houzeaux, B. Eguzkitza, L. Prieto, D. Cabezón, A Parallel CFD Model for Wind Farms, In Procedia Computer Science, Volume 18, 2013, Pages 2157-2166.

van der Laan, M. Paul & Sørensen, Niels & Réthoré, Pierre-Elouan & Mann, Jakob & Kelly, Mark & Troldborg, Niels. (2014). The k-ε-fP model applied to double wind turbine wakes using different actuator disk force methods. Wind Energy.

We would like to hear if then still a reference is missing.

(3) Page 5: Indicate what you mean by "high fidelity simulation data" and the corresponding site/wind farm characteristics (number of turbines, turbine types, ...)

Answer: With high-fidelity simulation data we mean flow velocities in the x- and y-direction at hub-height and turbine power signals computed with a LES based wind farm model. In the revised version of the paper we will specify this in the introduction and also the number of turbines and their specifications.

(4) Page 7, first paragraph: Please clarify if the axial symmetry is assumed or not, in other words elaborate on the function tilde_v3(x,y,z). How to imagine the 2D model embedded into 3D space?

Answer: We do not assume axial symmetry, and in particular we do not define a symmetry axis (which would be necessary to start with when introducing axial symmetry). Nevertheless, our choice (w$\sim$0 and dw/dz $\sim$ dv/dy) is inspired by conditions required for axial symmetry. If a single turbine is considered, and we look at a streamline along the turbine axis, axial symmetry implies indeed w$\sim$0 and dw/dz $\sim$ dv/dy, but requires further conditions on dv/dz and dw/dy (which we do not impose in our model). Away from the turbine axis, these conditions are not consistent anymore with axial symmetry, nor are they for a full wind farm case with multiple turbines. They rather imply equal divergence/convergence of streamlines in y and z direction. We do not expect this assumption to be accurate everywhere, but we presume it to be good enough to resolve the lack of relaxation of purely 2D models. If necessary, a more general form (w$\sim$0 and dw/dz $\sim$ c dv/dy), with c a tuning parameter (e.g. obtained through state estimation) could be considered, but results in the current work indicate that this may not be necessary. We will incorporate these issues better in the revision, using above discussion.

(5) Page 8: Please elaborate on the physics behind or the purpose of the function G.

Answer: The function G is a smoothing function that ensures a mixing length parameter that is differentiable. Also, from a physical point of view, it is more realistic to smoothly change the turbulence characteristics instead of abruptly.

(6) Page 9: The mixing length is for example unequal zero within the shaded area of turbine n in the central region of Fig. 3 (beginning of the curved arrow), i.e., at the region of the ramp (to which that arrow is pointing). Why should the ramp have that jump to zero at x_n' = d? In other words, why is d smaller infinity? What does that mean physically? What is the physical meaning of the beginning of the ramp at x_n' =

d'? Please make the model a little more plausible to the reader. What is the physical implication of zero mixing length everywhere else?

Answer: The jump at zero is smoothened out by the function G.

At this point we would like to stress that we developed an engineering model and some of the parameter are introduced for tuning purposes. In general we could say that the turbulence model is parameterized by l_s,d,and d'. It allows us to regulate in which area in the wind farm model we would like to have more or less wake recovery. Increasing values of l_uˆn results in more wake recovery. Thus, if we allow d to be infinite, the wake recovery would also increase when the wake passes a downwind turbine. This is from a physical point of view not realistic since much more physics is happening when wind passes a turbine.

By setting the mixing length parameter to zero downwind of a turbine (before a downwind turbine) we could say that we reset the wake recovery again. This parametrization is also not based on pure physical reasoning, but captures a change in wake recovery after flowing through a rotor. We are using a linearly increasing mixing length l_uˆn behind the rotor following the results presented in:

Iungo, G. V., Viola, F., Ciri,U., Rotea,M. A., and Leo: Data-driven RANS for simulations of large wind farms, Journal of Physics: Conference Series, 2015.

Overall we think that it is good to mention that the included turbulence model is a simplified mixing length model found heuristically using and adapting information from the reference above. We will state this more clearly in Section 2.1.

(7) Page 9: The vector s is undefined.

Answer: s = [x,y], i.e., it indicates a position in the farm in the x,y coordinate frame. We will also indicate this in the text.

(8) Page 14: What is meant by "a regular notebook"? Which programming language was used for the implementation?

Answer: The programming language is MATLAB and the notebook contains an Intel Core i7 2.7 GHz processor. We will explicitly mention this in the revised version, also that the simulations are done using a single core.

(9) Page 14: What is the meaning of “relatively small”?

Answer: Order of magnitude three smaller. Basically, elements in the off-diagonal matrices are of order O(1) while the elements in the diagonal matrices are of the order O(10ˆ3). We will mention this more explicitly in the paper.

(10) Did you check mesh convergence for the presented results? Please add a comment or a graph.

Answer: We did not study mesh convergence in detail, but rather looked into whether LES data could be approximated with the presented simplified wind farm model. We will include a note regarding this subject in the paper, but are not planning to do such a study in this work.

(11) Please quantify explicitly the calculation times for all results. How does it relate to the response time of the controller and the chosen time step of the simulation? Answer: The two-turbine case presented in Section 3.2.1 takes 0.02 sec per time step and the nine-turbine case presented in Section 3.2.2 takes 0.1 sec per time step. We will explicitly write these CPU times in the corresponding paragraphs.

Assuming that the controller contains the presented model, it is difficult to say what the controller response time will be. This depends on how the presented model is used in the controller. When applying the model in a model predictive controller, the controller response time depends, e.g., on the prediction horizon. Also, the employed optimization procedure could demand for line search techniques or a backward simulation. In such a case, additional trajectories need to be simulated.

However, the objective of this work is to keep the CPU time of the model as low as possible, while still capturing the dominant wind farm dynamics relevant for control

purposes. The objective of the controller design should also be to keep the CPU times sufficiently low such that online control can be achieved.

The time step of the simulations could be chosen larger or smaller while not changing the CPU time per time step and not affecting stability (we employ an implicit discretisation method). However, we did not validate the WFSim simulation results in such cases. This could be an interesting study.

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