Reply to Dr. Andrea Hahmann, Editor Reviewer

Since the second referee was unavailable to review your answers to the revised manuscript, I have read and evaluated your answers and revised the manuscript myself.

I want to congratulate you on completing most of the revisions to the referee and my satisfaction. However, one of the points raised by referee Patrick Volker deserves some attention. I return to the point below.

> *We are actually very thankful that you were willing to step in for Patrick. Please find our replies below.*

Q1. You made a nice explanatory figure in response to the reviews. Why not add it to the manuscript? It will be helpful to explain the various overlap options graphically.

> *We added the figure to the manuscript as Figure 1 and discussed it as follows:*
>
> *"Looking at Figure 1 as an example, Turbine 4 is affected by three wakes, each of which causes its own wind speed (e.g., $V_{4,1}$ is caused by Turbine 1 and is a partial wake case, with some of the rotor affected by the wake and the rest unaffected, thus experiencing $V_{4,0}$). The resulting wind speed at Turbine 4 is the result of the mixing of the three individual wind speeds. With M4 (Eq. 12), the resulting wind speed is basically the average of the (partially recovered and therefore relatively high) wind speed from the farthest turbine and that (fresh and relatively low) of the nearest turbine, plus all the others in between. In a sense, M4 can be thought of as a way to indirectly account for partial wake recovery due to the added turbulence from multiple wakes and entrainment.*
>
> *On the other hand, method M4 may underestimate the deficit in the case of perfectly aligned turbines because it tends to dilute the wakes of the nearest turbines with the partially-recovered wakes of those further upstream. Even in the aligned case, however, M4 is effective because it avoids the unrealistic continuous drop in wind speed as more and more turbines are aligned that other wake superposition methods suffer from. While every wake superposition strategy introduces some level of under- or over-estimation, comparison with observational data, discussed in the next sections, indicates that M4 is generally the most accurate."*

Q2. I am missing a discussion section in the manuscript. L566-569 does not belong in the conclusions and could be included in this new discussion section.

> *We note that Section 4 is titled "Results <u>and discussion</u>" because we did not want to just describe the results, but rather discuss them while we presented them. This is an intentional choice that we made because we believe that simply presenting results without a proper discussion is not only boring, but also less effective. It would be very*

difficult at this point to separate the result presentation from the result discussion. Unless absolutely critical, we kindly ask to keep the current structure of the paper.

In an effort to ameliorate this issue, we renamed the Conclusions to "Conclusions, limitations, and future work".

In addition, in my opinion, two critical points deserve attention.
(1) Wind farm parameterizations have been extensively used to study the possible farm-to-farm wakes (you cite a few in L46). [Many of the old studies are wrong because of the TKE advection bug in the WRF model that you helped to solve] These effects are much harder to evaluate in the parameterization because one needs data from two or more wind farms and/or many strategically located tall masts. But the important point is that improving the wind farm parameterization power production, as you have done in your manuscript, does not automatically improve the characterization of the wind farm wake, which is important for farm-to-farm studies. This point deserves to be mentioned in a discussion section.

We added the following to the "Conclusions, limitations, and future work" section, L. 575:

"Another limitation is that we focused only on wind power production for validation. Wind farm parameterizations have been extensively used to study in-farm as well as farm-to-farm wakes. These wake effects on variables like temperature, humidity, turbulence, or heat fluxes are much harder to evaluate in a parameterization because multiple data sources are needed at and downstream of multiple wind farms, including strategically located tall masts and lidar measurements. Improving the power production alone, as we did in this study, does not automatically improve the characterization of the wind farm wakes."

(2) The double counting of the wake effects is, in my option, real and should also be mentioned. Parameterizations, by definition, make many assumptions, and in your case, the wake of turbines in the upstream grid point could be accounted for twice. First, by the turbine wake overlap method and later when the WRF model advects the TKE and wind deficit downstream. By the way, the issue is not only in space but also in time. The wake from one turbine takes some time to travel to the next grid box. I don't mean that you should reformulate your scheme, but the point should be added to a discussion section.

We added the following to Section 4.2, L. 437:

"when the Jensen parameterization is used, this effect is still present but it is added on to that of the sub-grid wakes. This causes a potential double-counting issue of the wake effects, which will be explored next by comparing results at various grid resolutions."

and the "Conclusions, limitations, and future work" at L. 580:

"Lastly, when the wind farm is partitioned over multiple grid cells (i.e., in the multi-cell cases) and the Jensen parametrization is used, there is the possibility of both resolved and sub-grid wakes being present simultaneously in the same grid cell, thus potentially double-counting some of the wake effects. By contrast, when WRF-Fitch is used, the resolved wake is the only wake effect that is accounted for, but it is generally too weak. When the Jensen parameterization is used, however, the resolved wake is still present, but it is in addition to the sub-grid wakes, which are generally stronger. Overall, we find that accounting for the (strong) sub-grid wakes with the Jensen parameterization, even in the presence of the inevitable (but small) resolved wake, gives more accurate results than relying on just the resolved wake. However, this issue needs to be investigated further, as discussed by Ma et al. (2022)."

Q3. Adding your scheme to the WRF repository is a valuable goal. However, this could take time. I would strongly encourage you to make the source code for your scheme available to the community. Maybe the code could be available by request?

We have submitted the request to add our scheme to the WRF repository to the WRF Physics Review Panel. Currently, this request is under review. While we wait, the code is also available by request. We added the following:

"While this request is under review, the code is available by request."

In addition, I have a few minor points that should be corrected (lines refer to the ATC manuscript line numbers):

1. Please ensure that all units follow the WES guidelines of units formatted with negative exponents. Some of the units in the figure axis in the manuscript do not; also, in L518.

The units in Figure 11 and in L518 are now written exponentially.

2. I am old fashion, and I think the model WRF should be referred to as "the WRF model" not just "WRF."

We agree that the acronym WRF does not contain the word "model" in it and therefore in many cases it is better to add it. However, we started adding it and it became a messy task very quickly. For example, many sentences were like this: "in WRF and MPAS" and they would have been replaced with "in the WRF model and in MPAS," because MPAS already contains "model" in the "M." This caused three additional words for one occurrence of WRF and did not add any clarity. If anything, it made the sentence awkward. There are some 64 instances of "WRF" in the paper, if we added "model" to each, we would add basically an entire paragraph with no real advantage.

We decided to state that we will use "WRF" instead of "WRF model" as follows at L. 74:

"… to two mesoscale models: the WRF model (referred to as just "WRF" or "the WRF" hereafter) and the Model for Prediction Across Scales (MPAS; Skamarock et al. 2012)."

3. L17. It should be "..., and as wind turbine ROTORS expand in diameter..."

Done.

4. L18. "Wind turbine ... decrease wind farm power production." Concerning what? I suggest you revise the sentence.

We clarified the sentence as follows:

"When a wind turbine wake hits a downstream turbine, it can cause a significant reduction in its power production; these wake losses negatively impact wind farm power production."

5. L42. I think it will be better to cite a peer-reviewed paper than an unavailable conference abstract. I propose Volker et al (2017), https://doi.org/10.1088/1748-9326/aa5d86, since you are already citing one of P. Volker's manuscripts.

Done.

6. L44. The WRF abbreviation refers to Weather, Research and ForecastING.

Revised.

7. Figure 1. The wind turbines' locations are shown by black circles... BTW, what are the red arrows? It is not explained in the caption.

The caption was updated as follows:

"The black arrows are the wind vectors at the grid cells; the red arrow is the wind vector at the grid cell of interest, replicated at the relevant upstream grid cells; and the green arrows are the average of the wind direction at the grid cells and that at the grid cell of interest."

8. L264. "The Lillgrund wind farm is located in Sweden." -> "The Lillgrund wind farm is located in a narrow straight between Denmark and Sweden."

Done.

9. L354. Figure 3 shows THE relative...

Revised here and similar expressions in the manuscript.

10. L534. Maybe "Fig. 8a in Pan and Archer (2018)..."

Done.