Responses to Reviewers' Comments

on the manuscript entitled ' Inclusion of the subgrid wake effect between turbines in the wind farm parameterization of WRF ' submitted to Geoscientific Model Development .

We sincerely thank the editor and two reviewers for their very constructive comments and suggestions, which helped us to improve our manuscript significantly. We made necessary modifications to address all of concerns raised by two reviewers in the revised manuscript where the changes are highlighted. Major modifications of our manuscript include:

1. The CFD experimental part has been expanded to include validation of single turbine wake simulation results against measured results and introduction of double turbine wake experiments (Section 3).
2. We have updated the version of the WRF to 4.3 and repeated the previous experiments (Section 4).
3. We have updated the organization of the manuscript and rewrite some sections.

Responses to Reviewer 2:

Here the authors try to include subgrid wake effects in the Fitch scheme, which is the WRF's default wind farm parametrization. The manuscript is at this state and stage very weak both in its conceptualization, its presentation, and its results, and therefore, I cannot suggest its publication. I became very worried about this work, so I stopped reading it after I saw the authors even carried out sensitivity experiments as well! So, my review goes until Section 4.1. I apologize but my opinion is that this manuscript needs major surgery before it can be submitted again to a proper journal as GMD. Unfortunately, I have to recommend its rejection, but I encourage the authors to revise it thoroughly. Also, I strongly recommend sending this paper to a English grammar office since the language can be also largely improved; it is not much about misspellings but about the way to write science per se.

Thank you for your comments and we have revised the article based on your request. We have identified issues with the previously presented effects based on the feedback you provided and we have now obtained more accurate and reliable results.

1. CFD: already in the abstract you mentioned that the coefficients will be derived from CFD results, but you do not say anything about what do you mean by CFD here. Moreover, you do not mention what CFD tool you used later in the manuscript. CFD can be anything; it can even be WRF itself! Since it is an important part of your study, the "CFD" should be properly described, is it LES, RANS, uRANS? What is the turbine model in it? How is turbulence model? Etc.

Thank you very much for your comments. The details of the CFD experimental section have been added (L. 283-330). We use the RANS method with a solid model for the turbine and a realizable k-ε model for the turbulence model.

2. Section 3.1: As mentioned in point 1 there is no description of the so-called CFD model. But also important is that from the text, it sounds as if the subgrid model you

end up using is based on Eq. (4), which is determined by the coefficients you estimate based on your specific CFD precomputations. This reads as if the layout of the wind farm or the turbine itself is different from that you used in your CFD precomputations, then these coefficients in Eq. (4) will also differ (or are they generic?). Then, this ends up not being a generic wind farm parameterization anymore because (I guess) you did not simulate all possible layouts within a grid cell or all types of turbines.

As far as we know, a significant number of offshore wind farms (in the South China Sea area) are constructed according to a regular layout. This paper focuses on the construction of future mega wind farms, which also tend to have a regular pattern within the majority of their occupied grids. Although certain variations may exist at the wind farm edges, their impact on the entire facility is small. More importantly, the angular correction coefficient and the expansion correction coefficient have been calculated in this paper using CFD experiments. This ensures that the incoming wind speed of each turbine can be accurately calculated, even when the wind farms are not arranged in an east-west or north-south direction. The calculations are based on the wake of the front turbine combined with superposition effect of the wake, rather than on the layout of the wind farm. Therefore, we believe that the new parameterization scheme can still work relatively well in other possible wind farm layout schemes as well as other types of turbines.

3. In order to understand the results shown in Fig. 11, information about the wind direction within the 3 days of simulation is needed. From Fig. 10 we only have a snapshot and it hints as the northeasterly sector is the one dominant but direction can change quickly during these three days.

Thank you so much for your suggestion. Version 4.3 of the WRF software is utilized to re-run the experiment, and the new outcomes are assessed. The analysis now uses the time-averaged outcomes for the last six hours of the simulation, rather than the snapshot results.

4. Also related to point 3 above: It is difficult to understand what do you mean by wind energy in Figure 11 and the text around it in page 16? Do you mean the amount of energy that you could extract from the wind? If so, then it should not depend on the wind farm parameterization but only on the wind climatology without the wind farm (basically you should have run a simulation without then wind farm). However, you have two different results for the two types of parameterization so I guess this is the energy extracted within the 3 days but then the units should be in MW h/day or similar. The numbers you provide in Page 16 are all very strange. What does $1.44\text{x}10^{13}$ mean? Or $8.54\text{x}10^{12}$? There is no "absorption of wind energy in the wind farm region" How can you know that the error is reduced (line 353), how could you know it was being overestimated? The text in lines 348-357 is just way too weird.

Thank you for your comments. The kinetic energy of the wind in the wind farm area is the remaining energy in the environment after the conversion of electrical energy by the wind turbines. It is calculated based on the wind speed of the wind farm area obtained from simulation. In the original wind farm parameterization scheme, the incoming wind speeds of the turbines in the grid are equal to the incoming wind speeds of the turbines in the "first row" owing to the lack of consideration of the sub-grid wake, leading to an overestimation of the wind kinetic energy extracted from the wind farm. The simulation findings reveal heightened wind kinetic energy within the wind farm, implying a rectification of the wind energy over-absorption in the previous parameterization method.

From our latest results, the wind energy inside the wind farm region using the new scheme, which is 5.80737×10^{13} kg·m^2/s^2 in total, is higher than that of the original scheme (5.29162×10^{13} kg·m^2/s^2), increasing by 9.75%. More details can be seen from line 403-412.

5. Figure 12 and text around: Also a very strange plot and description. I guess you do not mean 70 MW in the colorbar but GW? But most importantly, is this power output at a particular time? I mean is this the instantaneous power output or some kind of average power output within the 3 days. Further, the number is strange as your maximum power output should be 76800 MW but you have numbers of 11639 and 5703 MW, so about 10% of the rater power of this mega hyper wind farm.

Thank you for your points. The color-bar denotes the power output of a specific electrical grid, providing a maximum of 75MW per grid (25*3). The unit of measurement for the color-bar in this case is MW with no doubt. Version 4.3 of the WRF software was utilized to re-run the experiment, and the new outcomes were assessed. The analysis now uses the time-averaged outcomes for the last six hours of the simulation, rather than the instantaneous results at a specific moment in time. Regarding the issue of low power, it is possible that this is due to WRF version issues. In the latest results, the total power of the wind farms reaches 22.37GW, which is about 40% of the maximum power output.

6. And perhaps more importantly: if I understood correctly the new parametrization (Fitch and subgrid model) results in larger energy yield than the original one (Fitch only). If the Fitch scheme is basically the same, the effect of the subgrid model should be to lower the energy yield as you are accounting for the effect of wakes within the grid cell. So I do not really understand why is your new scheme yielding more energy.

Thank you for your comments. Version 4.3 of the WRF software has been utilized to re-run the experiment, and the new outcomes were assessed as mentioned before.

The analysis now uses the time-averaged outcomes for the last six hours of the simulation. From our current time-averaged results, the total power of the wind farm is now closer under the original and new parameterization schemes, but the spatial distribution of the power is quite different. In the back row grid of the wind farm, the total power in the new scheme is lower than in the original scheme due to the added wake effect, which is physically intuitive that the wake will lead to a reduction in power. However, at the right edge of the wind farm, the power at the edge of the grid is slightly higher than in the original scheme due to the higher incoming wind speed calculated in the new scheme, even though the wake effect is taken into account.

Specific comments:

1. Line 20: “These coefficients are added in the WRF”; I guess you mean that they were added in a new implementation of the Fitch scheme, which is coupled within the WRF modelling system.

You are correct, and we have made a more accurate statement in the paper. (Line 23)

2. Line 21: “Sensitivity experiments”; here you need to say of what? Spatial resolution, PBL schemes? What kind of sensitivity?

The sensitivity tests presented involve varying distances between turbines. The purpose is to demonstrate an approximation to the original layout when the spacing is sufficiently large. (Line 24)

3. Line 25: “shows more advantages” compared to what?

The benefit lies in the reduction of the overall power of the turbine in the wake region in new scheme compared to the original. We have also explained this in the paper. (Line 28)

4. Line 35: replace “achieving a rapid development period

Accepted and revised. (Line 36)

5. Line 59: full stop after meters and then start a new sentence with “Numerical”

Accepted and revised. (Line 55)

6. Line 76: delete “technology” after “LES”

Accepted and revised. (Line 73)

7. Line 78: replace “LES simulation of wind farm is processed by the” by “LES is combined with”

Accepted and revised. (Line 75)

8. Lines 80-83: these two sentences referring to the work of Elshafei et al. (2021) has nothing to do with your work

Many thanks for your suggestion. We have removed the citation to their paper. (L. 77)

9. At the end of the introduction, you introduce the different sections of your work but not all of them.

Thank you for your suggestion. We have revised this part. (L. 82)

10. (1)—(3) are wrong as these are not those implemented in the original Fitch scheme

Equations (1) to (3) have been replaced with:

To obtain the vertical distribution of TKE and velocity, the basic principle is that each vertical level k that intersects the rotor contributes proportionally to the fractional rotor area contained in that level A_k and to the horizontal wind speed at that level U_k:

$$\frac{\partial \mathrm{TKE}_k}{\partial t} = \frac{1}{2}\frac{A_k C_{\mathrm{TKE}} U_k^3}{(z_{k+1} - z_k)}, \quad (3)$$

$$\frac{\partial u_k}{\partial t} = -\frac{1}{2}\frac{A_k C_T U_k u_k}{(z_{k+1} - z_k)}, \quad \text{and} \quad (4)$$

$$\frac{\partial v_k}{\partial t} = -\frac{1}{2}\frac{A_k C_T U_k v_k}{(z_{k+1} - z_k)}, \quad (5)$$

where u_k and v_k are the horizontal wind components and z_k is the height of vertical level k. Equations (3)–(5) are multiplied by a correction factor if energy conservation is not met across the rotor. If multiple turbines are present in the same grid cell, each will add the exact same contribution to the TKE and momentum tendencies as in Eq. (3)–(5).

11. (4) and some others: you use the dot product to represent multiplication sometimes. You should not. This is the dot product between two vectors and a coefficient is not a vector

Accepted and revised. (Line 122 Eq. 4)

12. Line 148: Replace “which is related to the roughness” by “which can be related to the roughness”

Accepted and revised. (Line 140)

13. Line 160: “Eq. (2.5)” there is no such an equation, so do you mean Eq. (5)?

We're sorry we made such a cheap mistake, and we've revised it. (Line 154)

14. Line 286: “two-turbine wake experiment” which one? Did you introduce it before?

We regret that we could not include this part of the work initially due to space restrictions. We have now added this section to the paper. (Line 298-316)

15. Lines 311 and 312: Do you mean “Implementation”?

Accepted and revised. (Line 365-366)

16. Line 339: what is “the kind of speed”?

I am sorry to have caused a deviation in your understanding of a wind speed condition we expressed, and we have made a more accurate statement in the paper. (Line 392)

17. Lines 339-341: please rephrased. What do you mean by conducive?

I am sorry to have caused a deviation in your understanding. Our aim is to convey the evident experimental phenomena that can be observed in numerical simulations under such a high wind speed conditions. (Line 394-395)

18. Fig 11: Is this for the innermost domain? If so please state this in the caption

This is for the innermost domain (wind farm area) and we have state this in the caption.

19. Fig 12: what are the units of the turbulent kinetic energy?

The unit of the turbulent kinetic energy is the same as the wind kinetic energy.