Review of "A wind-farm wake-turbulence parameterization for the WRF model (EWP v2.0)" by Garcia-Santiago, Badger, Hahmann, Volker, Ott, van der Lann, and Kelly, submitted to Geoscientific Model Development

The authors describe a novel method to account for the added TKE by wind turbines in a mesoscale model (WRF) via the introduction of a variable called latent kinetic energy (LKE), such that its evolution resembles that of the wake production term in the TKE equation. The formulation is derived via the double-averaging approach of Raupach and Shaw (1982). The LKE formulation is then inserted in the WRF model and the results are compared with those obtained with LES. Favorable comparisons emerge and the sensitivity to a few tuning parameters are presented. Overall, the study is very interesting, relevant, and original. It has been the most exciting paper that I have reviewed in a long time! It should definitely be published eventually.

The methods are, however, rather cumbersome to explain and at times not convincing. There are so many steps and additional assumptions/simplifications between the original equations, which were rigorously derived, and the final product that is inserted in the WRF (the equation for C) that I am not convinced that the C variable is what we think it is anymore. This is possibly not a concern when the results look good, as they do for the simple neutral case presented here; but when things get complicated (non-neutral stability, wind direction and speed variability, diabatic effects, irregular layouts, etc.) and the results no longer look good, I am afraid that interpreting the results will be impossible because the connection with the real physical meaning of LKE and TKE may be lost. I feel that the paper might not be ready for "show time" yet and that a general simplification of the approach is needed (see comment 6).

Major Remarks

1. The authors use the notation $\bar{(.)}$ for ensemble averages, but in mesoscale models the variables in the Reynolds-averaged Navier-Stokes equations are intended to be time averages, not ensemble averages. Ensemble averages are used in laboratory settings where the same experiment is repeated n times and then ensemble averages are calculated over all experiments; in real world applications for which mesoscale models are employed, this is obviously not possible and that is why the variables are intended to be time averages. The paper by Raupach and Shaw (1982), which pioneered the double averaging approach, in fact uses time averages, not ensemble averages. Last but not least, in the weather forecasting community the term "ensemble average" is reserved for averaging over several instances of the same simulation but with small changes from one another, in either the initial conditions, the parameterization choices, or the resolution. For the sake of clarity and to avoid confusion, I suggest that all instances of "ensemble averag*" be replaced with "time averag*". This would also make the two separate concepts of time versus space averages even clearer.

2. The double-averaging concept for LKE needs further clarifications. As far as I can tell, the idea of splitting the time-average component $\bar{k}$ into a spatial mean $\langle\bar{k}\rangle$ and

a fluctuation $\bar{k}''$ comes from the presence of sub-grid features, like wakes in Fig. 1.

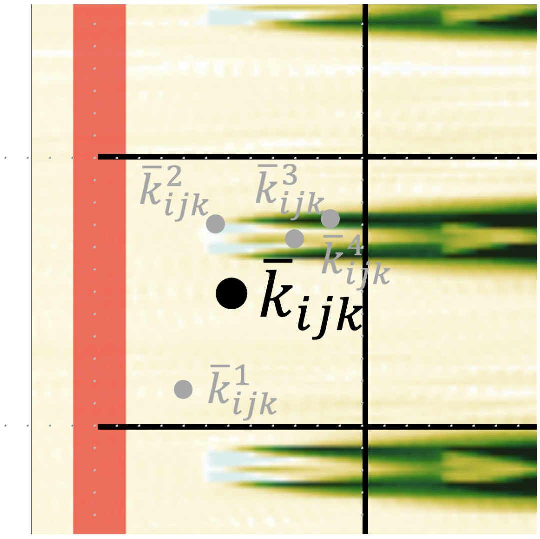

Figure 1: The grid-value $\bar{k}_{ijk}$ is the output of a mesoscale model, which is a value representative of the entire grid cell ijk, but there are actually several different sub-grid values $\bar{k}^1_{ijk}$, $\bar{k}^2_{ijk}$, etc.

It makes sense that, if we want to represent the effects of sub-grid wakes, at grid cell ijk we should look at the spatial average $\langle\bar{k}\rangle$. However, practically speaking, it is not clear how this spatial average should be performed. In the case of Fig. 1, there are 4 values of average TKE. Is $\langle\bar{k}\rangle$ equal to the sum of the 4 values divided by 4? Or, is the grid cell ijk further subdivided into smaller (regular or not) grid cells and then $\langle\bar{k}\rangle$ should be the area-weighted average? Should the value $bark_{ijk}$ be used at all in this average? Or perhaps it does not really matter how exactly the spatial average is calculated? Regardless, it appears that:

$$\langle\bar{k}\rangle \neq \bar{k}. \qquad (1)$$

We will get back to this inequality shortly.

3. L. 230 : "λC represents the sink of LKE and corresponding source of TKE". This is very important and yet not justified (or not explained clearly). The fundamental assumption here is that the sink of LKE goes entirely into TKE. How valid is this assumption? You suggest a link between the two (LKE and TKE) via the $\bar{\mathcal{P}_w}$ term but, as I discuss at issue 12 below, this is not entirely correct, or at least not well explained.

4. Fig. 3 and 4: clearly the added TKE is too much (about 50% too high after 2L) and reaches too far downstream.

5. Fig. 5: It is not clear how the wind speed deficit is treated in these runs. Please add a quick reminder of how the EWP and Fitch treat it. Regardless, from Fig. 5b, the effect on the wind speed deficit is significantly worse for lower values of c_λ. Basically, to get better TKE than with Fitch, the price to pay seems to be an excessive wind speed deficit. This is a big problem and it should be investigated because of its implications on wind power predictions.

6. The proposed method is convoluted and the logics behind it is hard to understand and possibly even harder to explain. Here is my best attempt at explaining this approach:

   1) The traditional TKE budget (Eq. 1 and A6) in the presence of wind turbines can be modified to account for their added TKE via an extra term $\mathcal{S}_{wt}$ (Eq. 3).

   2) To obtain this term, the spatial averaging concept is applied to derive an equation for LKE (Eq. A10).

   3) We can also derive an equation for the spatial average of TKE (Eq. A7). Note that this is NOT TKE.

   4) By comparing A10 and A7, there is a term that appears in both equations with opposite signs, called $\langle\bar{\mathcal{P}_w}\rangle$ (but it's not really there in the TKE equation). This is a good candidate for $\mathcal{S}_{wt}$. This term does not depend on any turbine characteristic.

   5) The term $\langle\bar{\mathcal{P}_w}\rangle$ behaves very similar to LKE itself in the far wake (Fig. 1b), suggesting that we can parameterize $\langle\bar{\mathcal{P}_w}\rangle$ as LKE itself (with proper scaling).

   6) To parameterize $\langle\bar{\mathcal{P}_w}\rangle$, the LKE equation A10 is replaced with a much simpler formulation (Eq. 7), that allows LKE to be treated as a scalar variable in WRF (this is a big leap). The loss term is proportional to LKE itself (-λC). There is also a source term Q.

   7) Now we need to parameterize λ as a function of c_λ (Section 2.2.1) and the source term Q as a function of the turbine drag force (Section 2.2.2).

   8) The results depend on the value of c_λ and the choice of the PBL scheme, among other tuning parameters (like σ_0).

   9) The $\mathcal{S}_{wt}$ term in the TKE equation is then equal to $+\lambda C$.

   Needless to say, this is complicated and at times not entirely convincing. The steps from 1) to 5) are not necessary, really. Eq. 7 does not really need to be justified and, to be honest, the previous 5 steps do not justify the form of Eq. 7 when compared to Eq. A10 anyway. The manuscript would benefit from a simplification of the approach: start with Eq. 7 and then focus on the parameterizations required for it. You do not need to spend pages of derivations to study the term $\langle\bar{\mathcal{P}_w}\rangle$.

   I stopped reviewing after Section 5.2.

Minor Remarks

7. Eq. 2: The term $\langle\bar{\mathcal{T}_w}\rangle$ is not in Eq. A7.

8. Eq. 2: Why is there only $\langle\bar{\mathcal{T}_t}\rangle$, and not also $\langle\bar{\mathcal{T}_d}\rangle$ and $\langle\bar{\mathcal{T}_p}\rangle$?

9. Eq. 2 and Eq. A7: Why is the term $\langle\bar{\mathcal{P}_w}\rangle = \langle\overline{u_i'u_j'}''\frac{\partial\bar{u}_i''}{\partial x_j}\rangle$ a "wake production" term? It looks like the shear production term but for the dispersive components. Why is this term "the primary missing source of turbine-induced TKE"?

10. L. 110: the term $\langle\bar{\mathcal{P}_f}\rangle$ is obviously the only term directly associated to the turbine via the drag force f_i and its perturbations f_i'. How can it possibly be "negligible"?

11. Eq. 3 and text above it: please confirm that you are **not** assuming that $\langle \bar{\mathcal{P}}_s \rangle = \bar{\mathcal{P}}_s$ etc. It would invalidate Eq. 1.

12. L. 135: It is not possible that the term $\langle \bar{\mathcal{P}}_w \rangle$ be in both the TKE and the LKE budgets because there is no space averaging in the TKE budget (Eq. A6). This appears to be a foundational step to explain the exchange of energy between TKE and LKE, but it is not true. See also comment 3 above. If we take the space average of Eq. A6 to obtain Eq. A7, then the term $\langle \bar{\mathcal{P}}_w \rangle$ appears with a minus sign. But this is not TKE (inequality in Eq. 1). Thus no term appears in both the TKE and LKE budgets with opposite signs.

13. Eq. A6: I suggest that you name each term of the time-average budget explicitly, like you did in Eqs. A7 and A10 for the spatial-average budgets. There seems to be no $\bar{\mathcal{P}}_w$ term.

14. L. 148 and footnote and L. 593: the term $\langle \bar{\mathcal{F}}_d \rangle$ is not in RS1982 and cannot be in it because they did not have turbines. Do you mean $\langle \bar{\mathcal{C}}_d \rangle$?

15. L. 163: The sentence "suggesting that the depletion of LKE by $\langle \bar{\mathcal{P}}_w \rangle$ is inveresely proportional to a characteristic time scale" needs to be expanded and explained. This is a crucial link between LKE and TKE.

16. L. 197: the entire rotor diameter is included for each turbine, or just the fraction of it that belongs to the grid cell? Also, it should be a function of wind direction.

Edits and typos

17. L. 132: replace "deals" with "deal".

18. L. 209: replace "neglected" with "neglect" and "leading" with "leaving".

19. L. 216: explain better starting at "We neglect a fixed ..", what are you referring to?

20. L. 219: remove the ")" after r_0.

21. L. 221: replace "lef-" with "left-".

22. L. 233: replace "tracer" with "tracers".

23. Fig. 5b: typo on the y-axis? What parameter is used to normalize the wind speed deficit?

24. Fig. 6: typos on the x-axes? Perhaps the units are partially missing? What is the first legend item (missing subscript)?

25. L. 576: subtracting "from", not "to".

26. L. 588: subtracting "from", not "to".

27. L. 580: a bar is missing over k: $\bar{k} = \frac{\overline{u_i' u_i'}}{2}$.