Second reply to the reviewers of "An analytical formulation for turbulence kinetic energy added by wind turbines based on large-eddy simulation"

18 February 2025

Please note that the reviewers' comments are in *italic*, our responses in regular font, and the changes to the manuscript in blue color.

Reviewer #1

- *In the author's response to reviewers, the relationship between ΔTI and ΔTKE has been added. However, I believe there is a typo in it, i.e. $\sqrt{\Delta TKE}$ instead of ΔTKE?*

  Thank you so much for catching the typo, which is now corrected.

Reviewer #2

- *Regarding my comments on the curve-fitting nature of this work, I did not mean to suggest that the developed model is not useful. My intention was to provide a suggestion for enhancing the scientific quality of the study. However, I understand that this is ongoing research and indeed an important step toward more accurate TKE prediction.*

  Thank you for the clarification.

- *Regarding my comment on using "empirical" instead of "analytical": I still do not fully agree with your response. While the example you provided (i.e., the Gaussian wake velocity model) incorporates empirical assumptions (e.g., wake shape), it simplifies governing flow equations to predict the maximum velocity deficit, so there is a difference here. That said, I appreciate that the terminology is somewhat subjective, and I respect your choice to use "analytical" instead of "empirical."*

  Thank you for accepting our use of "analytical".

- *Regarding my comment on line 141 (based on the original manuscript), I understand your point that turbulence in the ABL is not isotropic, and the streamwise component is typically larger than the other two. However, while the streamwise direction aligns with the wind, it is not necessarily west-east. The current wording suggests that x is aligned with the west-east direction, regardless of wind direction. This is why I suggested discussing the values of σ_u, ... in the next paragraph, where you later clarify that in your work x coincides with the streamwise direction.*

  There is often a confusion about the coordinates to use in the wind energy community. The IEC uses the convention of aligning the x axis with the streamwise direction, thus with the average wind direction. With such a convention, the variance of wind speed σ_U^2 basically coincides with that of the u component σ_u^2. But in meteorology, the x axis is not the streamwise direction, it is always the west-east direction. In such a case, the variance of wind speed is not well approximated by that of the u component only. I (Archer) have a paper in review in WES that talks exactly about these issues (Archer, 2024). In this manuscript, the story we are telling is:

1. If turbulence was isotropic, the three variances would be identical;
2. The "real" atmosphere, which is studied in meteorology and atmospheric science, is not isotropic because the west-east direction, which is conventionally the x direction, is more turbulent than the other two;
3. In wind energy science and engineering, the x axis is conventionally aligned with the mean wind, or, in other words, the streamline direction. Even with this convention, the turbulence is not isotropic because the standard deviation along x is largest.

We added a small clarification to the manuscript and a more accurate citation:

"the IEC standard recognizes that the three standard deviations in Eq. 7, even with the convention of aligning the x-axis streamwise, should be different from one another and recommends that any wind velocity field for turbulence models used for standard turbine classes satisfy the following conditions: $\sigma_v \geq 0.7\sigma_u$ and $\sigma_w \geq 0.5\sigma_u$ (International Electrotechnical Commission, 2019, Table C.1, Eq. C.10)

- *Regarding my comment on line 271, I did not see a response. This may have been due to an error in document generation. While it is not a major issue, I wanted to mention it in case you intended to provide clarification that did not appear in the final version.*

  We apologize for missing your comment in our previous reply. Here is our reply:

  "This finding is consistent with several published studies. Crespo and Hernández (1996) proposed that the maximum added TI depends only on C_T in the near wake and has a very weak dependency on TI_∞ in the far wake (i.e., the power exponent is -0.0325, see Eq. 2); the equations for maximum added TI proposed by both Larsen et al. (1996) and Frandsen (2007) depend only on C_T; and the formulations for maximum added TI by IQ2018, shown in Eq. 3, and by TIAN2022, shown in Eq. 5, have a much weaker dependency on TI_∞ than on C_T. However, other studies have proposed that TI_∞ has a non-minor role (Ainslie, 1988; Xie and Archer, 2015)."

References

Archer, C. L.: Brief communication: A note on the variance of wind speed and turbulence intensity, Wind Energy Science Discussions, 2024, 1–8, https://doi.org/10.5194/wes-2024-159, 2024.