Review WES-2022-84: Validation of Turbulence Intensity as Simulated by the Weather Research and Forecasting model off the U.S. Northeast Coast, by Tai et al.

This paper makes use of WRF model outputs and calculates turbulence intensity (TI) in terms of a standard WRF output Turbulence Kinetic Energy (TKE) (Eq. 3). This study also made efforts to improve the simulation by using alternative Sea Surface Temperature (SST). The comparison of TI with measurements from one site suggests there is agreement between measured and modeled values, particularly for TKE, wind speed and temperature parameters. However, even though there is slight improvement in TI using new SST in the modeling, the results of TI are not as good as the other parameters which are direct outputs from the model.

The reviewer believes that it is not a coincidence, as the reviewer is not convinced the applied algorithm for calculating TI using TKE is correct. This is seen as a major point, even though there are several merits in the current study, including the clear paper structure, sensitivity tests of SST and corresponding analysis. The reviewer therefore recommends 'Major revision' (or even 'rejection', depending on the editor's judge how serious the following point 1 is).

- The authors simplified Eq. (1) and Eq. (2) to Eq. (3) by stating: "Here we assume sigma_w^2 is negligible as the sigma_w^2 is often much smaller than sigma_u^2 and sigma_v^2 offshore due to relatively low surface flux".

Firstly, surface flux of what? Is it always small? Probably not when you later address "unstable" conditions.

Response: We thank the reviewer for his/her insights regarding uncertainties in TI modeling. Here, we meant to say surface "sensible heat" flux. The sea surface sensible heat is extracted from the ocean in association with an air-sea temperature difference. In this case, it is apparent the value of latent heat flux would vary with the magnitude of air-sea temperature difference and is used in this study as the proxy of stability. We have revised the paragraph to avoid confusion. Please refer to discussions in Section 3.2.

To verify dependency of wind variances on corresponding stability, we have conducted observational analysis and please find more detailed discussions in the third response below. We note the algorithm for sub-grid TI calculation used in our study does include the vertical wind variance (σ_w^2) as the formula used in this study (Eq. 4 in the manuscript) employs TKE in the numerator:

$$TI \cong \frac{\sqrt{2 * TKE}}{\bar{U}}$$

In this case, the three-dimensional wind components of variances are considered in our algorithm. To clarify this, we revised the relevant paragraph in Section 3.2 from Line 196 to 261 and hope it addresses the comment.

Moreover, as described in Section 4.3, the model-resolved (mesoscale) TI is also considered in our study. Our analysis shows it may also contribute to a large fraction of uncertainty in modeled TI when mesoscale systems occur.

Finally, potential uncertainty in lidar-measured turbulence is also raised by one of the reviewers. The reviewer suggests including the conclusion proposed by the report: Sathe, A., Banta, R., Pauscher, L., Vogstad, K., Schlipf, D., Wylie, S., 2015. Estimating Turbulence Statistics and Parameters from Ground- and Nacelle-Based Lidar Measurements. IEA Wind Task 32 Expert Report. ISBN 978-87-93278-35-6. Their results indicated that pulsed lidars can measure a value of turbulence which is significantly larger than a sonic anemometer at 80 m above the ground under unstable conditions. We have included relevant discussion in Section 4.2 from Line 421 to 424.

Secondly, here the authors also "followed" "Eq. 1 in Bodini et al 2020" - which only has the first part of Eq. (3) and which was used for lidar measured 2-min averaged wind, which is very different from the WRF output here.

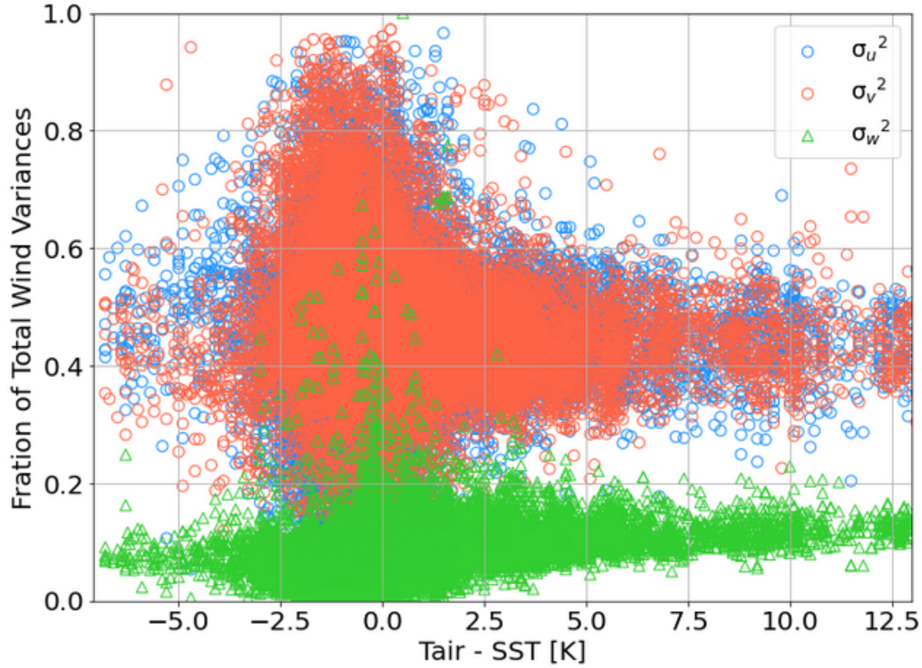
Response: We discussed the limitation in obtaining three-dimensional winds on turbulent scales from the model parameterization scheme in Section 3.2. This prevents us from using original form of TI formula (Eq. (1) in the manuscript). And since the simulated hub-height TI are validated by using lidar measurements, the current derivation should be reasonable. To address the reviewer's comment, we have revised the paragraph from Line 196 to 261 and included two additional references (Shaw et al. (1974) and Wharton and Lunquist (2011)) that used the same equation as Eq. 3 in the manuscript for TI calculation from lidar measurements.

Thirdly, one has to prove if sigma_w^2 is negligible – one cannot simply assume. As sigma_u, sigma_v and sigma_w are boundary turbulence parameters and there are numerous literatures addressing the relationship between the three variables in the surface layer when being normalized with friction velocity. A recent report from DTU (Larsén, X. G. (2022). Calculating Turbulence Intensity from mesoscale modeled Turbulence Kinetic Energy. DTU Wind Energy. DTU Wind Energy E No. E-0233) derived the relation between TI and TKE using boundary-layer turbulence model, the Kaimal model. From this approach, sigma_w is not negligible. It is recommended to refer to this report.

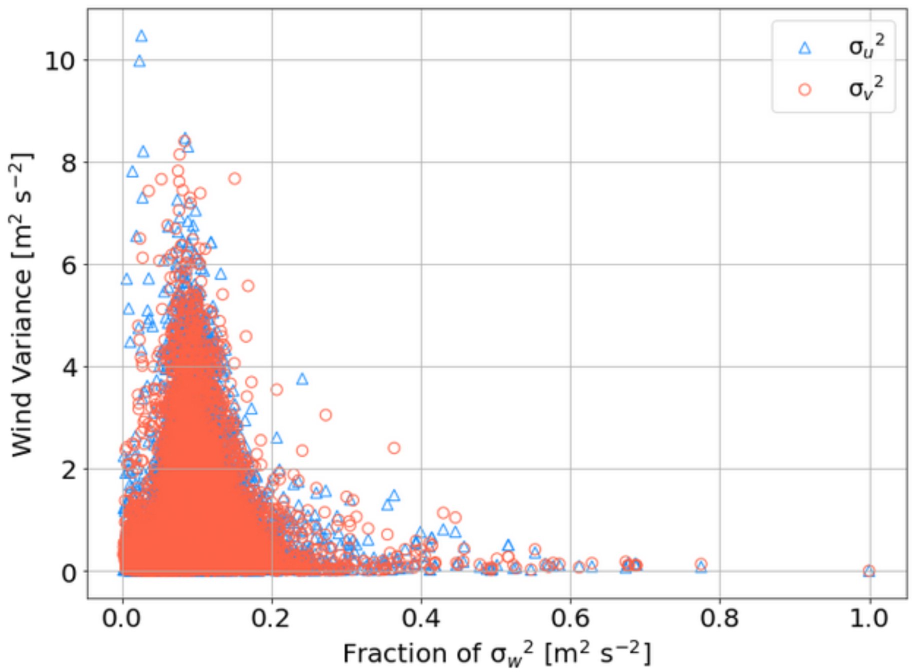
Response: We thank the reviewer for suggesting an alternate approach in deriving TI from TKE. The derivation in Larsen (2022) is based on a coordinate system with the perspective of a wind turbine, meaning that the u-component considered in its TI equation (Eq. 1) is streamwise (along) wind component, while we consider the full three-dimensional wind here. The differences in the definitions makes it difficult to compare the two approaches. In addition, it is known that the Kaimal model used in the Larsen (2022) study is more suitable for application in neutral conditions. This may potentially limit the applicable scenarios for our modeling. Therefore, we have included the suggested reference with a brief description in Section 3.2 from Line 196 to 201, but didn't apply the approach to our study.

To address the comment in relative importance of wind variances, we conducted additional analysis of observational datasets collected at the MVCO ASIT and we used them to characterize the distribution of observed wind variances and summarized results as following:

Figure below shows the fraction of three components of wind variances ($\frac{\sigma_u^2}{\sigma_u^2+\sigma_v^2+\sigma_w^2}$, $\frac{\sigma_v^2}{\sigma_u^2+\sigma_v^2+\sigma_w^2}$, $\frac{\sigma_w^2}{\sigma_u^2+\sigma_v^2+\sigma_w^2}$) normalized by the total variance as a function of stability (using buoy-measured air temperature minus SST as its proxy). The results suggest overall, the fractions of horizontal wind variances (σ_u^2 and σ_v^2) are larger than the vertical wind variance (σ_w^2). In addition, there is no evident correlation between the fraction of σ_w^2 and stability. In most of the conditions, the fraction of σ_w^2 is no greater than 0.2. Only a few data points exceed 0.2 but they mostly occur during neutral conditions (Tair – SST is close to zero).



We further analyze what may cause those data having relatively large fraction of σ_w^2. By looking at the corresponding horizontal wind variances (σ_u^2 and σ_v^2) in function of fraction of σ_w^2 as in the figure below, we find that the relatively large fraction of σ_w^2 (larger than 0.4) is most likely due to concurrently small values in σ_u^2 and σ_v^2 (smaller than 1 $m^2 s^{-2}$).



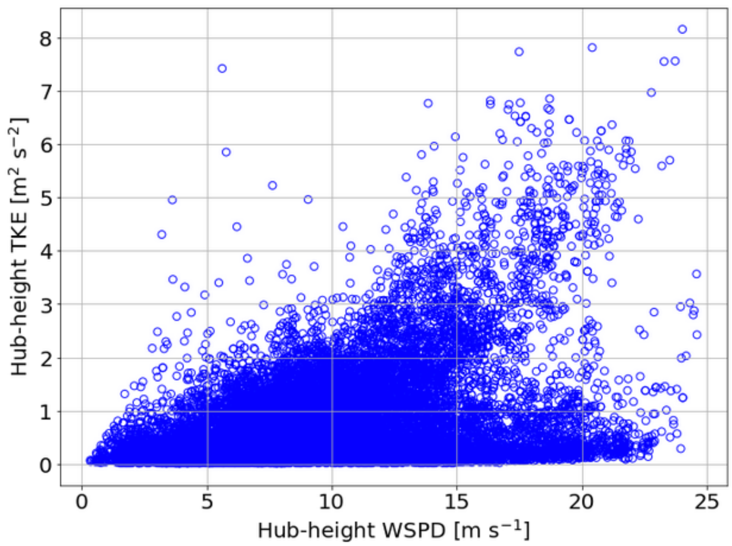
A figure (Figure 2 in the revised manuscript) is added to illustrate the observed PDFs of three wind components of variances and their dependency on stability. Corresponding descriptions can be found in Section 3.2 from Line 202 to 206.

- The authors suggest "for any given value of total horizontal wind variances, TI would be larger when the wind speed is relatively smaller or vice versa".

This is not true. The authors suggest TKE, and U are not correlated, which is not correct, particularly over water. Stronger winds over water generally lead to rougher surface (if the water surface is not covered by foam), which corresponds to larger TKE.

Response: We thank the reviewer for pointing out this. We want to note that the description mentioned in the comment was not meant to imply TKE and wind speed are not correlated but just an explanation of the equation itself.

To verify the correlation between TKE and wind speed, we plotted the hub-height wind speed and TKE as collected by the MVCO ASIT lidar from January to mid-June of 2020. While it suggests larger TKE values can be observed as wind speed increases, the spread of TKE values is large and there is a cluster of points with relatively small hub-height TKE even when the wind speed is relatively large.



Moreover, in the manuscript, we also discussed how the TI model errors can be correlated with wind speed and TKE as given in Figure 5. The results indicate large TI errors are associated with large TKE errors and have less dependency on wind speed.

Despite the relationship between TKE and TI is not fully linear, we do agree that the original interpretation may be somewhat misleading. Hence, we eliminated and revised the corresponding paragraph. Hope this helps answer the reviewer's comment.

- Would the authors please explain how much value is added when downscaling HRRR (3 km) to WRF (2 km)?

Response: We thank the reviewer for the question, and we are happy to provide additional clarification. We need to perform model downscaling (or initialization) by using any one of the valid atmospheric analysis products. Compared to other available reanalysis products (e.g., ERA5, MERRA2, and FNL), HRRR analysis has several advantages including 1) the model core of HRRR, the WRF model, is identical with what we use in this study; 2) it has a grid spacing of 3 km, which is very close to what we use (2 km); 3) it is constrained hourly by assimilating radar observations including Doppler velocity and reflectivity. The constrain in simulated hydrometeors is unique among all the analysis products which reduces some of the uncertainties in the prediction of precipitating clouds. Therefore, we decided to use HRRR analysis as the initial and boundary conditions for our simulations. A few sentences are added in Section 3.1 from Line 163 to 169 to supplement.

- In some of the analysis, the authors mixed "shear" with "TI".

Response: We went through the manuscript and fixed it as much as we can find.

Reference:

Sathe, A., Banta, R., Pauscher, L., Vogstad, K., Schlipf, D., Wylie, S., 2015. Estimating Turbulence Statistics and Parameters from Ground- and Nacelle-Based Lidar Measurements. IEA Wind Task 32 Expert Report. ISBN 978-87-93278-35-6.