

We thank the reviewer for reviewing our manuscript and providing comments to improve our work. Below are the point-by-point comments, replies and changes.

A) Figure 1 has been updated and Figure 2 has been included. This is appreciated. However, there are various points in the text that refer to aspects of the simulated flow, and accuracy of the method, that are difficult to establish from the contour plots of figure 1 and the time-series of Figure 2. This includes observation that there is a low level jet with nose similar to hub height (line 236), that the mean wind speed (in AGW and non-AGW cases is 5 m/s) whereas the mean of AGW cases looks < 5 m/s from Figure 2, that there is greater turbulence in the simulated flow than measured flow and to confirm statements such as those on line 85 and line 107. A quantitative comparison is needed of the measured and simulated conditions. Comparison of profiles - of velocity, turbulence, potential temperature - at specific time-steps during the AGW event would provide greater clarity. Such quantitative comparison - on average and at specific points - would also be of value to the future use of this paper for reproduction of the conditions modelled, which would be very difficult to establish from the contour plots provided.

Reply

We follow the reviewer's suggestions and add a figure to show quantitative comparisons of wind speed and turbulent kinetic energy between simulation and measurement for the AGW case, and between AGW and non-AGW simulations. Temperature results are not included because (i) temperature data are not available for measurement and (ii) temperature profile is a conventionally neutral boundary layer for simulation (as has been demonstrated in lines 79-80 in the revised draft).

Rivision

We have added Fig. 3 and modified lines 94-107 in the revised draft.

The left panel of Fig. 2 shows time-height histories from simulation (bottom) and measurement (top) for the AGW case. The simulation not only captures the low-frequency wind speed oscillations, but also resolves turbulence structures with higher spatio-temporal resolution. To further quantify this comparison, we show wind profiles in Fig. 3 and wind-speed time series in Fig. 4. In Fig. 3, the profiles of AGW crest (a), AGW trough (b) and mean (c) wind speed from the simulation follows those from the measurement. The turbulent kinetic energy (d) from the simulation increases at lower heights, similar to the trend in the measurement but with higher magnitudes. Such difference is expected because the simulation resolves more turbulence motions. This explanation is supported by the wind speed time series in Fig. 4, which indicates that the simulation captures smaller-scale turbulent fluctuations, in addition to large-scale AGW oscillations observed

from the measurement.

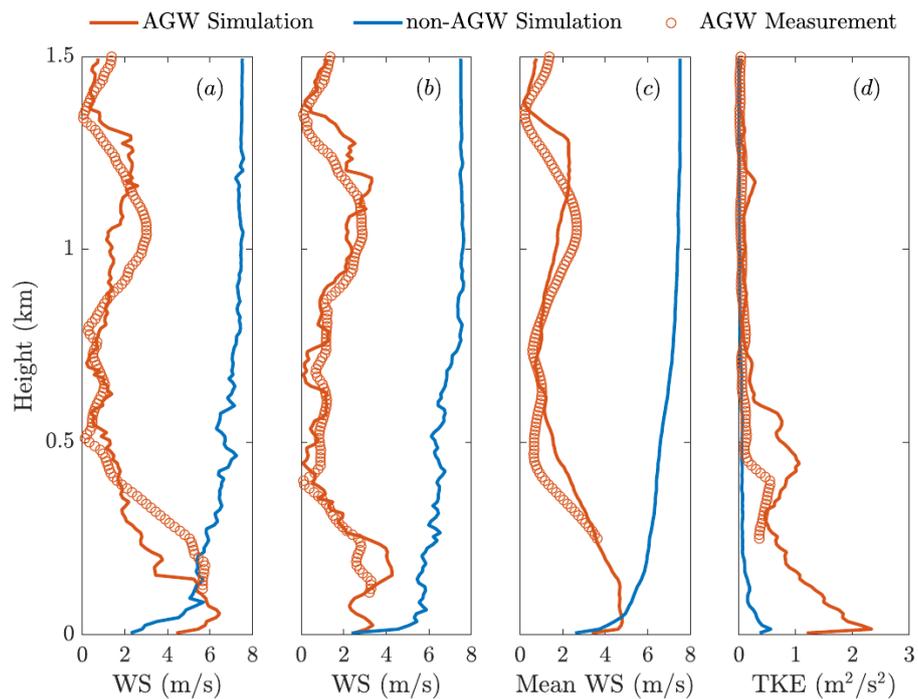


Figure 3: Vertical profiles of (a) instantaneous wind speed at AGW crest, (b) instantaneous wind speed at AGW trough, (c) mean wind speed and (d) turbulent kinetic energy. Data are compared between AGW simulation (red lines), non-AGW simulation (blue lines) and AGW measurement (red circles). The mean wind speed and turbulent kinetic energy at lower heights are not shown for AGW measurement due to the lack of wind-speed data over several time steps, as shown in the top-left contour in Fig. 2.

Figures 3 and 4 also show comparisons between the AGW (red lines) and non-AGW (blue lines) simulations. For the AGW case, both the instantaneous (see Fig. 3a and b) and mean (see Fig. 3c) wind speed profiles exhibit a high-speed zone at lower heights, indicating the presence of low-level jets. Such vertical profiling differs significantly from the non-AGW one, where mean wind speed typically increases monotonically with height above the ground (see Fig. 3c). Besides, the AGW case shows higher turbulence kinetic energy at lower heights (see Fig. 3d), which is also evident by the larger wind-speed fluctuation magnitudes shown in Fig. 4.”

B) The clarifications regarding the TKE spectra (now Figure 8) are appreciated. However, it is stated (line 221 and line 14) that “the TKE from these inflow peaks shifts to higher frequencies”. It is not clear that a shift has been demonstrated. Fig.8 indicates that the peak in the onset spectra at St_{AGW} is not evident in the wake cases. This is not necessarily shifted. It could be that this is suppressed by the wake. At 4D the peak in inflow observed at St_{ABL} is not evident but this seems to be re-established (re-energised) by 8D, and presumably increases with greater distance downstream as the ABL flow re-establishes. There is also a secondary peak between St_{ABL} and St_{wake} . Please could rephrasing (lines 221 and 14) be considered or the mechanism of frequency shifting be expanded

upon.

Reply

We thank the reviewer for these insightful comments on wake dynamics. We agree that the low-frequency TKE can be suppressed by the wake and be re-energized at further downstream. For example, the frequency peak St_{ABL} , which corresponds to capping inversion layer height, tends to be re-established at 8D downstream. We also agree that the notable peak between St_{AGW} and St_{ABL} should be mentioned, although we currently do not ascertain its origin. To clarify those points, we rephrase the sentences regarding wake spectral characteristics in Abstract and Section 3.2.

Rivision

We have corrected line 13 in Abstract in the revised draft.

... as low-frequency velocity fluctuations are suppressed in the far-wake region.

We have corrected lines 200-205 in Section 3.2 in the revised draft.

While the mechanism of turbulence generation remains consistent, the AGW and non-AGW cases exhibit differences in their spectral characteristics. For the AGW case, the inflow low-frequency peaks are suppressed by the wake flow and re-energized further downstream. For example, St_{ABL} is re-established in the wake spectra for the 8D case. Additionally, there is a notable peak between St_{ABL} and St_{Wake} in the wake spectra. The origin of this peak is currently unclear.”

C) Turbine power attenuation. The further analysis shown in Figure 8 with turbine spacing of 8D is appreciated as is the further detail provided in the response to reviewers. However, the points made in the reviewer response regarding negative power generation should be included in the manuscript to clarify this to readers. It is not clear why T1 differs for 4D spacing to 8D spacing and this difference makes it unclear how much of the attenuation observed from T1 to T2 (and subsequently) is due to the different event modelled. This should be clarified. Finally, it remains unclear that the simulation of T3 adds value since the power levels are so low. It seems that the main findings regarding attenuation and time-lag due to the AGW could be made more clearly by focusing on T1 and T2 only and this is recommended.

Reply

We agree that the explanation on negative power generation should be included in the manuscript. Also, we revise the power analysis part to be focused on T1 and T2 for clarity. We thank the reviewer for pointing out the different T1 power for 4D spacing to 8D spacing. By checking the code and data, we think this difference is because the use of inconsistent datasets. To clarify these points, we correct the code and replot the figure.

Revision

In the revised draft: (i) We have added lines 244-247.

At low wind speeds, the aerodynamic torque is not enough to overcome generator and drivetrain losses. As a result, the reported power output can be negative, meaning the turbine is consuming electrical power to keep the generator running.

(ii) We have replotted Fig. 11 and 12, and modified lines 236-237.

For the 4D spacing case, the presence of AGWs induces large-scale power oscillations at the first turbine (T1), which are strongly attenuated at the downstream turbines (T2).

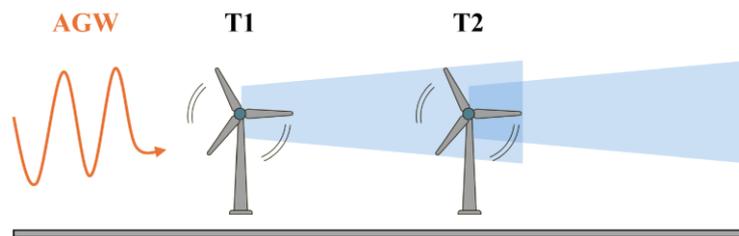


Figure 11: Schematic of the simulation of two turbines under the AGW inflow condition. From upstream to the downstream is subsequently T1 and T2..

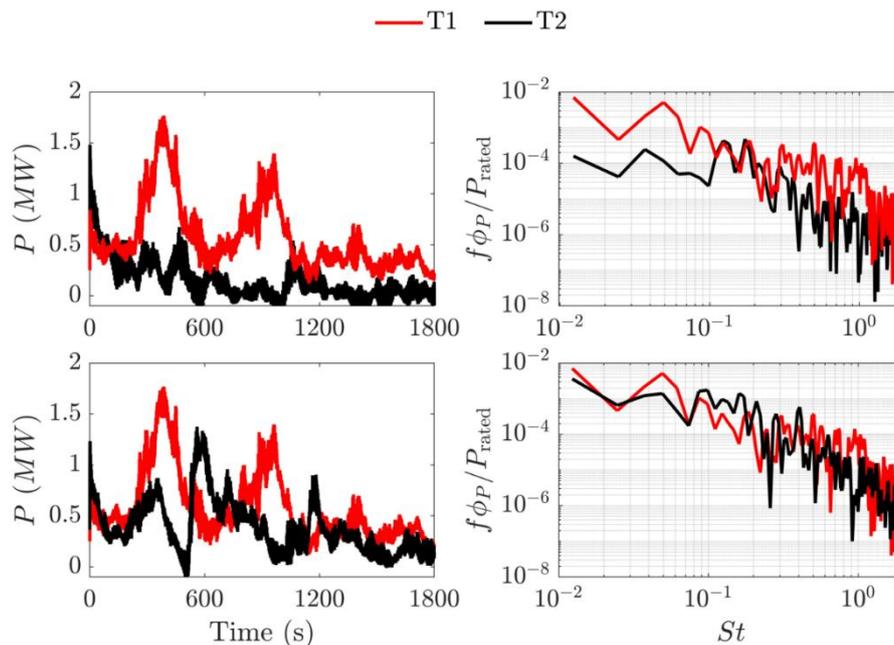


Figure 12: Time series (left) and spectra (right) of turbine power for the three-turbine simulations with 4D (top) and 8D (bottom) spacings during the AGW event.

Specific points

- Line 26 - the simulations presented indicate that frequencies associated with the AGW do not occur in the wake so would be useful to provide a reference for this statement on line 26/27 and later comment on whether the conditions studied here differ.

Reply

The results that shows that measured wind farm power oscillates with AGWs is from the work by Draxl et al. (2021). The measurement data are from WFIP2 project, in which turbines are sparsely distributed with a spacing of around 10D. With such a wind farm layout, the onset AGW oscillations can directly affect most turbines and the wake effects become less prominent.

Rivision

We have modified lines 27-28 in the revised draft.

The influence of AGWs on wind farm performance has recently attracted considerable attention (Wilczak et al., 2019; Xia et al., 2021). Through time series analysis on WFIP2 measurement data, Draxl et al. (2021) observed that low-frequency oscillations in turbine power production correlate with wind speed fluctuations associated with AGWs. The turbines in WFIP2 are sparsely distributed and the wake effects are insignificant.

- Line 116 - considering the low wind speeds modelled it would be helpful to add a comment on the cut-in speed of the turbines, or a comment regarding the minimum torque and hence possibility of negative power based on the response to reviewers.

Reply

We add a comment on the cut-in speed of the turbines to indicate possibility of negative power.

Rivision

We have added line 113 in the revised draft.

The turbine cut-in wind speed is 3 m/s.

- Line 241 - the figure (and the response to reviewers) indicate Gaussian from 3 D not 2 or 3D.

Reply

We correct the text to indicate Gaussian from 3D.

Rivision

We have corrected lines 222-223 in the revised draft.

The velocity then begins to recover from approximately $x/D=3$, where the wake deficit becomes Gaussian-shaped.

- Line 247 - check consistency of text re Fig 6 with caption of Fig 6.

Reply

We will correct the text regarding the definition of TKE.

Revision

We have modified lines 166-167 in the revised draft.

... where the overlines indicate time averaging.

Figure 7 shows the TKE