Review: An LES Model for Wind Farm-Induced Atmospheric Gravity Wave Effects Inside Conventionally Neutral Boundary Layers

Summary

The authors propose a new computational approach to include the impact of wind far-generated gravity wave-effects in LES of conventionally neutral boundary layers that is more computationally efficient than other approaches used in the literature. The authors use results from a multi-layer model of the atmosphere to deform the inversion layer in the LES and account for the effect of wind far-triggered gravity waves on the flow. The authors show proof of concept for two flow cases, a subcritical and supercritical flow. Their new modeling approach provides a realistic representation of gravity wave effects within the boundary layer when compared to simulations that follow common practices. In general, the manuscript is well written, and the results are sound. However, I have some comments that should be addressed before publication. Mainly, the authors make strong statements about the causes of blockage that should be revisited. Based on the results presented in this paper, it seems gravity waves play a secondary role in velocity reductions upstream of the wind farm. However, there is a lot of emphasis throughout the paper on gravity waves causing most of the global blockage effect.

Major Comments:

1. Global blockage effects: The authors are drawing strong conclusions on the mechanisms that cause the global blockage effect. They attribute the velocity deceleration upstream of the wind farm either to a gravity wave-induced pressure gradient or to flow confinement (e.g., Lines 41-43, Lines 185-187, Lines 289-291, Lines 344-345, Lines 388-389). I agree that flow confinement and gravity waves may play a role in these cases; however, the deceleration of the wind upstream of the wind farm can also be due to other mechanisms that are likely present in these simulations but that are not discussed here (Bleeg and Montavon, 2022; Sanchez Gomez et al., 2023). In fact, the authors clearly show that other mechanisms (i.e., not gravity wave-induced velocity decelerations) are responsible for more than 50% of the velocity deceleration upstream of the wind farm and gravity-wave-induced blockage is secondary (Figure 6).
2. Rigid-lid approximation: The authors use the rigid-lid approximation throughout the manuscript; however, it is not clear what is the purpose of using such a simplified and unrealistic modeling approach. In Lines 83-85, the authors suggest the rigid-lid approximation may be useful for use in engineering parameterizations. What do the authors mean by engineering parameterizations? Also, the rigid-lid approximation is tested here neutral boundary layer flow, which is unrealistic compared to the atmospheric boundary layer. For example, Bleeg and Montavon (2022) show that neglecting the temperature stratification in the capping inversion and troposphere misrepresents the blockage effect.

Minor Comments:

1. Line 153-154: Why are the wind farm and upper layer characterized by the same background velocity? This assumption virtually discards the effect from shear and the large gradients associated with the atmospheric surface layer.
2. Figure 2: The divergent color map is not centered at 0, making it very difficult to distinguish between positive and negative inversion displacements.
3. Lines 299-300: I would argue that the AGW-modeled and AGW-resolved approaches do not predict almost the same pressure perturbation for the subcritical case (Figure 3a). Differences in the pressure perturbation field between the AGW resolved and modeled approaches are at least on the order of 10% upstream of the wind farm.
4. Lines 307-312: The differences upstream of the wind farm are just as large (or larger) than the differences at the domain outflow. However, the hypothesis presented by the authors does not address these differences. The flow upstream of the wind farm is outside and downstream of the fringe region and these differences are still large.
5. Lines 344-345: The authors conclude that flow confinement is responsible for blockage to a lesser extent than gravity waves. However, Figure 6 clearly shows that the velocity deceleration with gravity waves is less than twice as large as the deceleration in the rigid-lid simulations. Thus, it seems flow deceleration from gravity wave-induced pressure gradients is not the main cause for blockage in these simulations. Also, I would argue that flow confinement is not the only cause for blockage in the rigid-lid case.
6. The authors mention that the LES domain should extend to one or more wavelengths in each direction (Line 113). However, extending the LES above ~10-12 km in the atmosphere means you are performing simulations above the tropopause, where the temperature stratification is very different from the constant lapse rate assumed within the troposphere. Is gravity wave propagation sensitive to having multiple thermally stratified layers like in the atmosphere compared to a single constant lapse rate? This might be out of the scope of the paper but is something to consider.

References

Bleeg, J. and Montavon, C.: Blockage effects in a single row of wind turbines, J. Phys.: Conf. Ser., 2265, 022001, https://doi.org/10.1088/1742-6596/2265/2/022001, 2022.

Sanchez Gomez, M., Lundquist, J. K., Mirocha, J. D., and Arthur, R. S.: Investigating the physical mechanisms that modify wind plant blockage in stable boundary layers, Wind Energ. Sci., 8, 1049–1069, https://doi.org/10.5194/wes-8-1049-2023, 2023.