Review: ***The wind farm as a sensor: learning and explaining orographic and plant-induced flow heterogeneities from operational data***

Summary

The authors describe a method for identifying and reconstructing flow heterogeneity within a wind farm caused by orography and the interaction of turbine wakes with the atmospheric boundary layer. The proposed model combines measurements and an engineering wake model to recreate flow heterogeneity within a wind farm. Their model incorporates parametric corrections to a simplified, physics-based engineering wake model to represent unmodeled physics. Parametric corrections are based on atmospheric variables (e.g., wind speed, wind direction, turbulence intensity, surface stability) and the engineering wake model. They test their model in two very different wind farms: one onshore and one offshore. For the onshore wind farm, they find terrain is likely the dominant factor influencing flow heterogeneity. For the offshore wind farm, their model captured coastline effects, local speedups around the wind farm, and deep array effects. For both wind farms, the proposed model reduces the error in the power production estimate compared to the stand-alone engineering wake model. In general, the manuscript is well written, and the results support their conclusions. I recommend the paper is accepted after minor revisions.

Specific comments

Lines 73-74: Soften the language regarding gravity waves. Only a specific set of LES studies and some simplified linearized simulations show gravity wave initiation in very large wind farms and under a very specific set of atmospheric conditions. There is still a lot of uncertainties around this issue.

Lines 162-171: Please comment on the importance of including $\Delta U_{amb \rightarrow wake}$. For instance, it has been shown that the wake follows the terrain in stable conditions but tends to deflect upwards in unstable conditions (e.g., Wise et al. (2022)), influencing power production of downstream turbines.

Line 326: Please explain how you define the observability threshold.

Lines 441-442: Please explain how you decided on the observability threshold. Did the choice of threshold modify the results?

Line 382 and 640: You mention rotor equivalent wind speed, which requires having the wind speed profile throughout the turbine rotor layer. Yet you are using point-measurement wind speed from a nacelle-mounted anemometer. Please make correction.

Lines 392-394: Please include distribution of TI and shear for daytime and nighttime conditions. Are TI and shear dependent on wind direction? I would expect the land/sea fetch varies by wind direction sector, modifying TI and shear.

Figure 4: Please specify in the caption what the dashed black line is.

Lines 514-515: How are you comparing the eigenshapes with terrain? Are you estimating a correlation between both? Or is it just by visual inspection?

Line 538: Although visual inspection can provide a first approximation to the agreement between both fields, a quantitative assessment is necessary given that it validates whether the proposed model captures the spatial variability. A quantitative estimate can be easily obtained by interpolating the simulation field to the learnt field from Figure 7.

Lines 539-540: Like my previous comment, you can find the correlation between terrain and speedups/slowdowns.

Figure 10: Please show the entire range of the standard deviation for panel b.

Figure 11: Given that this is a very extensive paper, consider moving this figure to the Appendix.

Lines 733-735: Gravity waves in the free atmosphere can presumably modify wind speed and pressure at hub height. Please make correction.