Reply to reviews – WES-2026-84

Paul Boumendil, Pierre-Antoine Joulin, Quentin Rodier, and Valéry Masson

Reviewer #1 :

We sincerely appreciate your positive feedback on our manuscript and thank you for your valuable comments and suggestions. As several of your general comments overlapped with those raised by reviewer 2, we addressed them simultaneously and try to carefully balance both sets of recommendations where necessary.

The details of these revisions are described below. The comments from the reviewers are in black, while our responses are in blue. Excerpts from the manuscript are enclosed in quotation marks (“”). Additions made to the manuscript following the review are highlighted in **bold**.

Summary:

This manuscript uses multiscale atmospheric modeling to investigate how a wind farm acts near surface temperatures in Southern France. Specifically, the authors investigate a case study from 7-8 April 2021 when nearly two-thirds of France experienced freezing temperatures. The authors do a really nice job of motivating this case study by discussing the financial impacts of the freeze. The authors use a coupled Meso NH/SURFAEX/EOL framework going from mesoscales down to 5 m resolution where they have an actuator disk to represent individual wind turbines. They validate their coarser domain results using limited observations from a nearby airport. They do see a warm bias in the near-surface air temperature that is a result of the AROME forecast used as forcing and is not necessarily impactful for the science questions they are answering. The authors have simulations with and without the wind turbines which help isolate the e ect of the wind farm. They see some interesting interactions between the wind turbine wake dynamics and a local katabatic flow. Ultimately, they arrive at similar trends as other studies showing warming below wind turbine wakes but the interaction with a terrain-induced flow is quite fascinating. There are some really nice figures in this manuscript and I think the authors generally do a good job at explaining what their model predicts. I believe that the manuscript is publishable with some minor revisions.

General Comments:

1- I’m not sure Fig. 4 is providing useful information. Did the airport launch any radiosondes during the analysis period? If they did, it would make sense to look at vertical profiles, but otherwise, the time-series in Fig. 3 provides a more useful comparison. The vertical structure is not relevant to a validation section since there are

no vertical observations to compare with. The profiles shown in Fig. A1 are enough to understand the vertical structure of the atmosphere during the time of interest.

Unfortunately, no radiosonde launches are performed at Perpignan airport or in its vicinity. The closest operational radiosonde station is located in Nîmes, approximately 200 km away. The vertical profiles of Figure 4 have been moved to the Appendix. The Figure A1 has been moved to section 4.3.

2- What is the power ratio metric used for Fig. 8? Regardless, I also don't think this figure is necessary. It's not adding to the story as the focus is not on power but wake dynamics and meteorological effects.

What we refer to as the power ratio is the ratio between the power produced by the wind turbine and its maximum theoretical power output.

New sentence added before line 315 : « **Figure 9 shows the ratio between the mean power produced by the ADR and the maximum theoretical power output of the wind turbine. Power ratio** is maximal for turbines located along the outer edges of the farm, unaffected by upstream wakes, whereas turbines within the interior produce around half of the power."

We agree that power output is not the focus of this study. However, we believe that this figure provides useful context for the subsequent analysis. It illustrates the wake effects within the wind farm through the decrease in power output for downstream turbines. It also highlights the heterogeneity between the wind direction and the turbine orientation across the wind farm. For these reasons, we have chosen for now to keep the figure in the main text.

3- I would find many of the plan/terrain-following figures to be easier to interpret if they had more contour lines given how important terrain is for the flow described in this paper. Figure 10 is where I first realized this, but I feel this way for Fig. 5, as well. Even though the terrain is not very steep, it obviously drives the flow characteristics. Figures 11, 12, and 13 would all benefit from more contour lines.

Thank you for this suggestion, contour lines have been added to Figure 9b and Figure 5. The contour interval has also been reduced from 20 m to 10 m in Figures 9, 11, 12, and 13.

4- Figures 12 and 13 show slight cooling upwind of the wind farm. Could you hypothesize why? Is this due to modeling uncertainty or is there a physical reason? This is relevant since it could increase frost risk.

Thank you for this question. This slight upwind cooling is a physical effect rather than a modeling artifact. It is driven by the upstream blockage effect: as the flow approaches the wind farm, local wind speed deceleration reduces near-surface turbulent exchanges. In a stable nighttime boundary layer, this attenuation of downward turbulent

heat transport towards the surface allows local radiative cooling to prevail, leading to a slight drop in temperature.

We address this mechanism in detail in our responses to the major comments 4 and 5 of reviewer 2 as well as in the revised text of Section 5.2 and 5.3 and new figures.

5- Section 6.1: This subsection largely restates what has already been said previously in the manuscript. I suggest removing this subsection and putting any sentences that you think are important in the earlier relevant parts of the manuscript. For example, the paragraph about the 3D temperature iso-surfaces states that the warming region progressively rises in altitude. This figure and discussion would be a nice complement to Figs. 12 and 13 but feels insubstantial where it currently is.

Thank you for this comment and suggestion. Rather than removing Section 6.1 and merging its content into the Results section (which is already dense and has been further enriched with new figures in this revision) we opted to the alternative approach suggested by the reviewer n°2: expanding section 6.1 into a true scientific discussion by adding reference to literature results (see major comment 5 of reviewer 2). Furthermore, to improve the critical depth of the all discussion, a new subsection (Section 6.4: Limitations and uncertainties) has been added at the end of Section 6.

Specific comments:

- Line 1: The first sentence of the abstract is a run-on sentence. I'd suggest changing the comma to a period to split into two sentences.

Changed as suggested

- Line 46: Remove "can".

Removed as suggested

- Line 51: Large Eddy Simulation should not be capitalized.

Changed as suggested

- Line 70: I think it's appropriate to include the citation for the actuator disk with rotation. To my knowledge, the first paper with this implementation is Wu and Porte Agel 2011. You could also add the citation on line 198.

Added as suggested

Line 72: coupling and not couplings.

Corrected as suggested

Line 90: The sentence beginning with "The idea…" needs to be slightly rewritten. It's unclear as written.

Replaced by *"The objective is to"*

Figure 1: The capitalization in the legend entries is not consistent and there is a typo for the COVER573 entry.

Capital letters added where missing, and the legend entry for COVER573 has been corrected.

Section 2.2 heading: remove "the".

Removed as suggested

Line 120: I think situation needs an s at the end à situations.

Corrected as suggested

Line 130: during few days à be more specific, i.e., for two days.

Additionally, **two** intrusions of cold and dry polar air affected France **during the first half of April**, as reported by Météo-France in its April 2021 climate bulletin (Lemoine.2021).

Line 164: Shouldn't Deardor be cited explicitly here? This sentence might need to be rewritten.

Added as suggested

Line 164: at the exception should be with the exception.

Corrected as suggested

Figure 3: 3€ needs more legend entries. What do the dashed lines correspond to?

We have simplified the titles and added a legend for the solid and dashed line in the subplots.

Line 246: solide should be solid.

Corrected as suggested

Figure 5: I find this color bar diicult to look at. The slower wind speeds are too dark to interpret the map. Also, the figure caption says they are vertical cross-sections, but they are horizontal or terrain-following plan views.

Figure 5: The colormap has been inverted and extended up to 12 m/s. The arrows have also been changed to black and white to improve overall visibility.

Figure 6: For 6(j), the colorbar should be RH not HR. The left column needs a bottom x axis label and y axis labels.

Corrected as suggested, same correction apply to Fig. B1

- Line 325: The mechanism of the farm acting as an obstacle is wind farm blockage. Blockage is explicitly mentioned later in the text, but I would include a reference/citation here.

The wind farm blockage effect has now been explicitly introduced, and a relevant reference on this topic has been added.

"These wind speed anomalies arise from the same mechanism as the sub-rotor acceleration but acting at the scale of the farm. ***This phenomenon, commonly referred to as wind farm blockage (Bleeg.2018)****, occurs because the wind farm behaves as an obstacle that locally modifies the atmospheric circulation,* ***forcing the flow to decelerate in front of the wind farm*** *and accelerate around and above the farm in order to satisfy mass conservation."*

Line 346: Replace "As for the wind speed deficit," to "Following the analysis done for the wind speed deficit…" or something like that.

Corrected as suggested

Line 349: Terrain at higher elevations?

Corrected as suggested

Line 362: Is this supposed to be the start of another paragraph?

Jump to line removed

Line 368: flown à flow

Corrected as suggested

Figures 12 and 13: profil à profile for the (b) subplots

Changed as suggested

Line 441: Some recent work from the AWAKEN field campaign (Lundquist et al. 2026) similarly found how terrain-related flows can introduce meteorological variations even very mild terrain.

Thank you for sharing this highly relevant article in the context of this manuscript. The reference has been added to the list in this line.

Line 469: The word flow should be added after katabatic.

Corrected as suggested

Figure A1: Is the solid vertical line in (a) the cut-in speed? If yes, add that in the legend or caption.

Corrected in caption

Line 511: I would rewrite this sentence to just say that there is large wind direction shear or wind veer. Vertically stratified wind direction is not a common way to describe what you're seeing.

"The wind direction is also strongly vertically stratified (see Fig. A1b), leading to vertically sheared flow conditions." replaced by *"The wind direction also exhibits strong* ***vertical shear*** *(see Fig. A1b), resulting in pronounced* ***wind veer****."*

Appendix B1: I don't think this needs to be a separate subsection in the appendix. It makes it odd that Fig. C2 is referenced in the previous subsection on line 525 before the figure has been introduced.

Section B1 has been removed merged into Appendix B. The numbering of Figures C1, C2, and C3 has been updated accordingly.

Line 525: I would use an adjective other than Ying-Yang to describe the shape of the vertical motion.

"the typical Ying-Yang shape with upward vertical motion" replaced by "**forming a counter-rotating pattern characterized by** upward motion"

Line 535: I believe "aloft" should be after warmer air.

Corrected as suggested