Peer review of: How do convective cold pools influence the boundary-layer atmosphere near two wind turbines in northern Germany?
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Comments

Line 85 – maybe say "Northern Germany" instead of Hamburg, since the two Kirsch studies (2021 and 2024) were conducted in Hamburg and Lindenberg (near Berlin) respectively.

This is a good suggestion. We have changed this in the revised manuscript to "northern Germany".

Line 94 – I'm not entirely sure but is there a typo here? Section 2 outlines are observational datasets → Section 2 outlines observational datasets

Thank you for catching this typo. We meant to say "Section 2 outlines **our** observational datasets." This has been changed accordingly in the revised manuscript.

Line 96 — I would mention that Section 5 also contains estimates of wind power increase.

This is a good suggestion that will provide additional clarity for the reader. We have included it as follows in the revised manuscript: "Section 5 highlights changes throughout the turbine rotor layer and estimates of wind power increase during cold pool passages."

Line 142 – Would it be possible to make a table with the different instruments, the measurement resolutions, and what they were used for? Just to have a complete picture of the measurement set-up.

We had originally decided against doing this due to the complexity of listing the different measurement systems in a single table, but have now endeavored to combine the data into a table as efficiently as possible. This instrument table now appears as Table 1 in the revised manuscript. We gladly would like any feedback on the understandability of this table.

We use 5 different types of data: Lidar, MWR, Inflow Mast, Ground Weather Station and Turbine. In the 1st paragraph of Section 2.1, we state both the starting date of measurements and what the instrument is used for. The measurement time periods for each instrument are given within Section 2.1 and in the new Instrument Table, and we explain the Lidar and MWR output frequencies being dependent on their respective scanning patterns.

In regards to the Inflow Mast data, we now include in the Instrument Table a list of each sensor *that we use in the manuscript* with their respective height, measuring time period, and output frequency. The use of these sensors to measure a certain variable is quite straightforward we feel, so we opted to not put the "use" in the table as well. Especially when calculating the virtual potential temperature, we require the combined use of the temperature, humidity, and pressure sensors, which would have complicated the table even more if we specifically listed their "use".

In reality, the inflow mast contains even more sensors beyond what are used in the manuscript that measure the atmospheric state variables (temperature, humidity, pressure, wind) at various heights from 2-149m. Specifically, we have 10 ultrasonic anemometers, 10 cup anemometers, 7 temperature sensors, 7 humidity sensors, 2 barometers, and 1 rain gauge. We do not have a sensor of each type at each height, but in general, we have these sensors at 10m, 34m, 62m, 85m, 120m, and 143m.

Line 160 – What exactly is a positive daily wind anomaly?

This phrasing could be misleading, we agree. This phrase means a positive wind speed anomaly relative to the daily mean wind speed. In other words, this means that the wind speed around the time period of a cold pool gust front is larger than the average for that calendar day. We applied this criterion so that we detect gust fronts that stand out from the background wind conditions on a given day. We have re-phrased this in the revised manuscript as follows:

"*Continuous-θ_v-decrease time periods include at least one time step of measurable rainfall exceeding 1 mm hr^{-1} and a positive wind speed anomaly relative to the daily mean wind speed within +/- 10 minutes* *of T_0. This rainfall threshold is used to remove instances of very weak convection or possible rainfall measurement error, while the wind speed anomaly is inspired by Kruse et al. (2022) and verifies a more significant cold pool gust front strength compared with the background flow conditions (given our interest in quantifying cold pool impacts on wind turbines)."*

Line 170 – Should this say "A theta_v drop of at least 1.5 K occurs within 30 minutes of T_0" ?

Yes, you are correct. 'At least' has been added into the revised manuscript:
"A θ_v drop of **at least** 1.5 K occurs within 30 minutes of T_0."

Line 175 – What does it mean that you prescribe that theta_v must recover at least somewhat? In case a person wanted to recreate your detection algorithm, what quantitative criterion would they have to include?

We could have explained this better, and we agree that we should describe this more quantitatively for reproducibility purposes. We have re-worded this sentence as follows:
"*Finally, we prescribe that θ_v must increase after reaching its minimum value and that this increase occurs within 60 minutes of T_0.*"

Line 180 – What exactly is t_0 - 30 minutes? The 1-min minute averaged value of a variable at t_0–30 minutes, or the instantaneous value at t_0 - 30 minutes? Or the 30-min averaged value calculated between t_0-30 minutes and t_0?

We agree that this could have been stated more clearly. We use the 1-min averaged values at T_0-30 minutes to represent the pre-event environmental conditions. The text has been amended to provide additional clarification:
"*We conservatively define the 'pre-cold pool environment' as the environmental conditions present at T_0-30 minutes, with findings by Kirsch et al. (2021) and Kruse et al. (2022) indicating that near-surface environmental conditions do not significantly change until at least T_0-15 minutes. The 1-minute averaged environmental conditions at T_0-30 minutes from the MWR, lidar, and mast data provide a proxy for the background environment prior to each of the detected cold pool passages*."

Line 186 – I would mention/quote here that Kruse et al (2022) linked convective cells to ground-based cold pools.

Yes we should have done this before, since Kruse did use radar data as well. We have now cited Kruse et al. (2022) after point 1 in this sentence:
"*While weather station and meteorological mast observations can and have been used to identify convective cold pools (e.g., Kirsch et al., 2021; Hoeller et al., 2024), additional radar measurements can be useful to (1) confirm the presence of a parent convective cell linked to the ground-based cold pool (Kruse et al., 2022) and (2) provide comparison between radar-derived convection characteristics and near-surface cold pool characteristics*."

Table 1 – Maybe highlight "pre-event environment" in the table and specify in the caption. At a first glance, I thought these were the CP temperature drops and was very surprised.

Thank you for this insight. We have now italicized the "pre-event environment" header within Table 1, and have included additional wording in the Table 1 caption to emphasize that these columns represent the conditions *before* the cold pool passages (and are not due to the cold pools themselves).

Figure 2 – I do not see the magenta dot indicating WIVALDI in the plots.

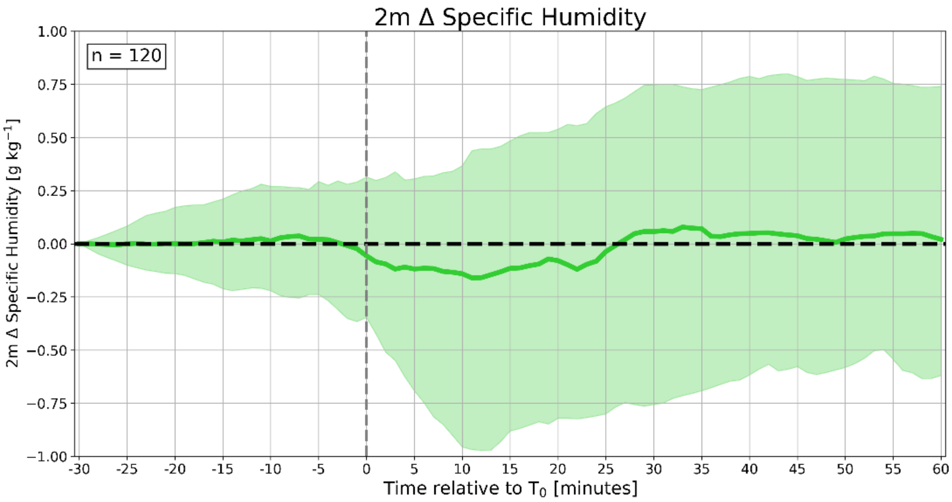
Thank for you catching this mistake. We had forgotten to remove this phrase which corresponded to a previous version of Figure 2. We have removed this phrase in the updated Figure 2 caption, and highlighted that the figure panels are centered on WiValdi. We hope that with this information, in addition to noting the location of WiValdi in Figure 1, will be sufficient for the reader to understand where the location of WiValdi is in Figure 2.

Figure 3 – More a comment than a question: did you also look at specific humidity? This is the one feature of a CP that was not in agreement between the Kirsch 2021 and Kruse 2022 studies, with the Kirsch 2021 study showing an increase in moisture, and the Kruse 2022 study showing a decrease in moisture within the CP with respect to the pre-event environment. It

would be interesting to see how moist/dry your CPs are since they are located towards a more coastal area like the Netherlands.

Yes, we agree that the specific humidity variations are an interesting point of discussion for cold pools. Kirsch et al. (2021) and Kruse et al. (2022) both seem to show decreases in relative specific humidity immediately after T_0. But then as you stated, they differ thereafter.

As shown below from our ground station attached to the MWR, we somewhat align with both Kirsch and Kruse. We have a longer-term decrease in relative moisture after T_0, in agreement with Kruse. However, we also show an increase in relative moisture from the pre-event environment after T_0+25 minutes or so, in agreement with Kirsch. Notably also, we show a little more than half of cases have a decrease immediately after T_0, but a sizable proportion also show an increase. Therefore, we would have to say that our observations do not wholly agree or disagree with either paper. As the near-surface moisture variations are not a crucial point related to the focus of our paper on the wind and stability changes within the turbine rotor layer, we decided to not highlight these observations in our paper. Nonetheless, it would be good for future research to delve deeper into this aspect of cold pools.



Line 245-246 – I'm a little confused. Do you apply your detection algorithm to the temperature time series measured at 100 m and 85 m? Shouldn't you apply it to 2 m with the thresholds you used and check the corresponding temperature data at 100 m and 85 m? If you use the same thresholds at higher altitudes as for T2m, I would also expect that you find a decreased sample size at higher altitudes.

We do not use the detection algorithm at higher altitudes. The timestamps at which we detect cold pools are from the MWR ground station. Your 2nd question is exactly what we do. We use the timestamps from 2m, and then see at those times what different variables look like at other heights. For additional clarity, the 'decreased sample size of detected cold pool events' later in the same sentence is due to the Mast data availability since the Mast only started recording data in November 2022 (whereas the MWR started measuring in November 2020).

Line 252 – Have you defined "sonic"?

This was overlooked. Thank you for catching this. "Sonic" refers to an ultrasonic anemometer for brevity, especially so that the legend labels in Figures 4 and 5 can fit the instrument names. This has been defined in Section 2.1 and changed afterwards to just "sonic" for consistency.

Line 272 – Then the Eddy dissipation rate "epsilon" rises again, right? Is this worth

This is definitely an interesting feature. We believe that it is likely indicating an end to the near-surface stabilization (e.g., backside of the cold pool), where the near-surface environment is shifting towards the background atmosphere again. We think this is likely since we know that turbulence strength tends to be elevated under more convective conditions, and thus the near-surface environment is probably changing stability regimes by the time period where the eddy dissipation rate is increasing again.

However, as we sometimes had multiple cold pool events detected on a given day within a couple hours of each other that could influence conditions by T_0+60 mins (e.g., case study), and given our focus on the primary gust front passage which precedes the subsequent stabilization, and since we don't believe we have sufficient supporting evidence to identify the backside of the cold pool passage over WiValdi at this time, we chose to not describe this feature in the paper so as to not be too unduly speculative.

Line 310 – "averaged vertical profiles up to 1km height": What exactly does this mean? Could you add some words to clarify?

We agree that the wording of this phrase could be better. This is referring to vertical profiles of wind speed and wind direction from our Lidar that extend up to 1 km height, and these 1-min vertical profiles are averaged from T_0 to T_0+5 minutes to better isolate the time period of the gust front passage. We have re-phrased this sentence as follows:

"*As the wind speeds induced by cold pools often maximize above the surface within the height range of wind turbines, we isolate the vertical structure associated with the peak gust front strength as shown in Figures 3 and 4 using vertical profiles up to 1 km height averaged from T_0 to T_0+5 minutes*."

Line 312 – Wouldn't you say that the median wind speed shows a relative increase from the pre CP environment up to about 700–800 m, from the plot?

Yes, you are correct. We were trying to be too conservative with our description. The median relative wind speed increase has a zero-crossing point close to 800m, and the median relative wind direction change first crosses the zero point at roughly 700m. Therefore, we have edited the manuscript to reflect an estimated cold pool depth from these 2 metrics of 700-800m.

Line 319 – more-detailed → more detailed?

This is perhaps a grammar preference, but we have changed it according to your suggestion in the revised manuscript.

Line 320 – more-limited → more limited?

This is perhaps a grammar preference, but we have changed it according to your suggestion in the revised manuscript.

Line 320 – when → in which?

This is a good catch. We are referring to the mast sample sizes in Figure 7. This has been added into the revised manuscript.

Line 323 – "dashed black lines": In what plot?

This becomes more obvious later in the sentence, but we agree that the Figure reference could be placed earlier in the sentence to provide better clarity. This has been done in the revised manuscript: "*A typical gust front peaks in strength around the turbine hub-height at +3 m s^{-1} (Fig. 7a), exhibiting a nose shape within the turbine rotor layer (34-150 m; dashed black lines) as has been observed by past work (Lombardo et al., 2014; Gunter and Schroeder, 2015; Canepa et al., 2020), with the vast majority of cases showing increased wind speeds from the background flow.*"

Line 373 – cut-outhub-height → cut-out hub-height?

Thank you for catching this. This has been changed in the revised manuscript.

Figure 8 – I might have missed this, but why is the sample size always different? Is it due to when the given sensors were active?

Yes exactly. We explain at the beginning of the Figure 7 discussion that "There is a more-limited sample size when all mast instrumentation heights are available...". On the inflow meteorological mast, we have 10 sonics alongside 6 temperature and humidity sensors, which do not all have the same data availability unfortunately. The same mast instrumentation is used in Figures 7 and 8, where the sample size when all sonics are available is "n=25" [for wind shear and wind veer; Figs. 8a-b] and the sample size when all temperature and humidity sensors are available is "n=35" [for static stability; Fig. 8c]. As we explained this sample size difference earlier for the same instrumentation, we did not think that it required additional discussion again for Figure 8.

Lines 400-end (Conclusions) – The conclusions are written very clearly. I would however, like to see a paragraph that puts your WiValdi CPs into the context of the other CP composites measured in similar locations (Kirsch 2021 Hamburg, Kruse 2022 Netherlands, Kirsch 2024 Lindenburg); not only contextualising the detection method. One of course has to take into account that the detection methods are slightly different, since the detection algorithm you used is a bit tweaked with respect to the other Northen European studies, and that the locations are different (more coastal vs more in-land), which are details worth mentioning. Both the Kirsch 2021 and Kruse 2022 studies had measurements at "hub-height" (even if the focus was not on wind power) so there could be interesting comparisons there. This kind of contextualizing could also give an indication on whether the effects of CPs on wind power are expected to be the same everywhere, or completely different based on the location.

This is a good suggestion. We have now included a few sentences to place our study in the context of Kirsch and Kruse's respective studies.

'*In terms of the bulk cold pool characteristics (strength, temporal evolution, vertical structure) related to kinematic and thermodynamic variations, we are in broad agreement with other European cold pool studies (Kirsch et al., 2021; Kruse et al., 2022). However, the 'nose' in θ_v near hub height is one cold pool feature also found by Kirsch et al. (2021) that is not observed by Kruse et al. (2022). As such, additional observational work is needed to determine if this aspect of the cold pool vertical structure is commonly found, since its impact on wind turbine wakes in terms of static stability is crucial for assessing the net impact of convective cold pools on wind power production in whole wind farms*.'