

Review on “Assessing Future Wind Speed Variations: Methodology for Climate Model Integration in Wind Resource Assessment”

The manuscript presents a methodological framework for assessing future wind speed changes under climate change by combining a measure–correlate–predict (MCP) approach with onshore mast stations, reanalysis, and climate model simulations. The topic is relevant to the wind energy community because climate change signals are not often incorporated into wind resource assessment and site selection practices. I particularly appreciate the evaluation chain extending from mast observations to reanalysis data and climate model simulations.

However, in its current form, the manuscript does not clearly establish whether its principal contribution is (i) a methodological framework for integrating MCP techniques with climate projections or (ii) an assessment of future wind resource changes at the selected sites. Although the manuscript is generally understandable, its central argument, methodological description, presentation of results, and discussion require substantial clarification. Several figures also contain repetitive information and could be consolidated. My main comments are presented below.

Major Comments

1. The central objective and contribution of the manuscript must be clarified.

The authors should decide whether the manuscript is primarily methodological or application oriented and revise the title, objectives, structure, and conclusions accordingly. If the main contribution is methodological, the manuscript should provide a more detailed description and evaluation of more MCP or bias-correction methods, while the number of study sites could potentially be reduced. For example, a small set of sites representing different levels of terrain complexity might allow a more focused methodological assessment and substantially simplify the figures.

Conversely, if the main purpose is to describe future wind resource changes across the selected locations, the title and framing should reflect this objective. A title along the lines of “Assessment of Future Wind Speed Variations at Tall Mast Sites in Northern Europe” might then be more appropriate. In that case, the rationale for selecting the sites and the regional representativeness of the results should be explained explicitly.

2. The rationale for using a single MCP method requires stronger justification.

It is unclear why the analysis relies on only one MCP method, particularly because the projected changes are primarily presented as differences in the mean and as the minimum–maximum range across ensemble members. Comparable climate change statistics can be obtained using other statistical post processing or bias adjustment methods, such as quantile delta mapping, which is designed to preserve the modelled climate change signal.

MCP methods are constructed to align the statistical characteristics of a target series with those of a reference series. Consequently, demonstrating that an MCP-corrected series agrees better with the reference than an uncorrected series is not, by itself, sufficient to establish

the robustness or suitability of the selected method. The manuscript should:

- evaluate whether the current MCP method preserves, attenuates, or amplifies the climate change signal;
- compare it with at least one alternative MCP, bias adjustment, or statistical downscaling method; and
- discuss the uncertainty introduced by the choice of correction method.

Including additional methods would provide at least a partial assessment of methodological uncertainty and would make the conclusions regarding future wind resource changes more robust.

3. The effect of the MCP transformation on the climate change signal should be quantified.

Following the previous point, the manuscript should show the raw wind speed changes projected by the climate models before applying the MCP procedure. Without this comparison, it is difficult to determine whether the reported site level changes originate from the climate models or are attenuated or amplified by the MCP transformation.

For transparency, I recommend adding a figure or table comparing the raw and MCP adjusted changes for each site and model. The regression's slope coefficients used in the MCP procedure could also help diagnose the modification of the climate signal. For example, the authors could report the slope for each directional sector and model, or an appropriately weighted mean across sectors.

4. The number and content of the figures should be reconsidered.

Several figures contain overlapping information, and some are discussed only briefly in the text. This raises the question of whether all figures are necessary in the main manuscript. Figures 4 and 11, for example, appear to receive less than one paragraph of discussion. This does not necessarily mean that they require more description; rather, the authors should evaluate whether they contribute sufficiently to the central argument.

Suggestions on modifying the figure's content:

- Figures 7 and 8 appear to contain overlapping information. If Figure 8 already conveys the relevant seasonal behaviour, Figure 7 could be moved to an appendix and cited as evidence that the climate models reproduce the seasonal cycle reasonably well.
- Figures 5 and 6 could potentially be consolidated. For example, panels (a) and (b) of Figure 6 might replace or be incorporated into panels (b) and (d) of Figure 5.
- The future wind resource results could be presented seasonally rather than monthly if the monthly changes are broadly consistent within each season.
- If the study is primarily methodological, using a smaller number of representative stations would substantially reduce the number of panels and improve readability.

These are examples rather than prescriptive solutions. The broader objective should be to remove repetition and ensure that every figure contributes directly to the main research question.

5. The introduction should provide a broader methodological context.

The introduction does not adequately position the selected MCP approach relative to other methods used to address systematic differences between climate model output and reference

data. The authors briefly mention dynamical downscaling, but the manuscript should also discuss statistical downscaling and bias adjustment methods commonly used in climate studies.

The revised introduction should address the following questions:

- What dynamical and statistical downscaling methods are available?
- what other bias correction methods can be used or have been used for wind-related variables?
- Have these approaches been applied in the regions represented by the selected sites or in comparable wind energy studies?
- Have previous studies demonstrated improvements in relevant quantities such as wind speed distributions or annual energy production (AEP)?
- Why is the selected MCP method particularly suitable for the present application?

This context is needed to establish the novelty of the study and justify the methodological choices.

6. The discussion and conclusions require substantial development.

The discussion currently reads primarily as a summary of the results. In my view, only the paragraph in lines 429–436 provides substantial interpretation. The manuscript should include a more critical discussion of the method, its uncertainty, and the broader implications of the findings.

In particular, the authors should discuss (not limited to):

- alternative bias adjustment and downscaling approaches;
- uncertainty associated with the choice of MCP method;
- whether an ensemble of MCP methods could be used to quantify methodological uncertainty;
- the dependence of method performance on terrain complexity;
- the reasons why uncorrected climate models perform poorly at some sites;
- whether similar model behaviour has been reported in previous studies;
- possible influence of the models' climate sensitivity on the projected changes; and
- the implications of the results for wind resource assessment and energy production.

The conclusions should then identify the study's main methodological or regional contribution rather than simply stating that an MCP method was applied at seven stations.

Minor Comments

1. Provide a complete and reproducible description of the MCP method.

The method should be described in sufficient detail for the analysis to be reproduced. In particular, the authors should specify whether the wind data are divided into directional sectors, how many sectors are used, how sector boundaries are defined, and whether a minimum number of observations is required within each sector.

The manuscript should also clarify how temporal resolution differences are treated. If regression coefficients derived from sorted hourly ERA5 wind speeds are subsequently applied to the sorted six-hourly climate model output, this procedure and its implications should be stated explicitly.

2. Assess the consistency of wind direction distributions.

For the SpeedSort method, the mapping of wind speeds to reference wind direction sectors may be affected if the climate models and the reference dataset have substantially different wind direction frequency distributions. The manuscript should document whether these distributions are sufficiently consistent or evaluate the sensitivity of the results to any differences.

Even if the study focuses on future wind speed (as it is currently stated in the title), the authors should acknowledge that changes in wind direction are relevant to wind energy applications, particularly because of the relation of the inflow wind direction and the wind farm layout. If possible, projected wind direction changes should be included in an appendix.

3. Define terminology and acronyms consistently.

Several terms and acronyms are used before they are defined, including MCP, corrected ERA5, and “corr. ERA5”. The abstract and main text should be treated as separate components, with acronyms defined at first use in each. If MCP is used only once in the abstract, spelling out the term may be preferable. Terminology for corrected datasets should also be standardised throughout the manuscript and figures.

4. Figures in the introduction.

Figure 1 does not appear necessary in the introduction unless it illustrates an essential concept required to understand the method or results. The accompanying text states that the effects of anthropogenic climate change are less pronounced for wind, but the figure appears to show only one specific site. At this point, the reader may not know where the site is located or whether it supports such a general statement. The authors should either justify the site’s representativeness, revise the statement, move the figure to a more appropriate section, or remove it (preferred option).

5. Include a map of the study locations.

If the selected locations are central to the analysis, the manuscript should include a map showing the stations. Referring readers to a separate publication for their geographical context makes the site-specific results difficult to follow. A map would also help readers interpret regional patterns and assess the representativeness of the selected locations.

6. Shorten and reorganise Section 2.1.2.

Section 2.1.2 could be substantially reduced. Much of its content appears more appropriate for the introduction. The methodological section could instead contain a concise description supported by the table listing the ten climate models. The repeated statements in lines 132–135 should also be removed.

7. Report relative changes and discuss their practical significance.

In the future wind resource analysis, the authors should consider reporting relative changes instead to absolute changes. Readers may find it difficult to evaluate the significance of changes of 0.2 or 0.5 ms^{-1} across regions with different baseline wind climates. Relative changes, and potentially estimated implications for wind power or AEP, would provide more meaningful context. Absolute changes may still be retained where they are useful.

8. The temporal implementation of the MCP method should be evaluated.

In addition to fitting separate relationships for each wind-direction sector, the MCP procedure could be calibrated separately by season or month rather than using a single relationship. The authors identify this possibility in the conclusions but defer its evaluation to future work. Given its direct relevance to the proposed methodology, this comparison should be included in the present manuscript. An evaluation of annual (the current one), seasonal, and, where the sample size permits, monthly calibrations would establish whether temporal stratification improves performance and would strengthen the scientific significance of the study.

9. Revise the figure captions for clarity and consistency.

Captions should explain the content needed to interpret each figure but should not contain extended discussion or speculation. For example, the explanation in the caption of Figure 4 that model differences may arise from differences in model height belongs in the main text. By contrast, essential plotting information, such as the use of different colour bar ranges, should remain in the caption.

The caption of Figure 12 is particularly difficult to follow and requires substantial clarification. Panel letters or another consistent labelling system should be used to help readers identify each component. More generally, panel labels and references to panels should follow a consistent format across all figures and captions.

Specific Comments

- **Lines 24–25:** Please specify the geographical region or locations to which this statement refers.
- **Line 107:** Please correct the typographical error in the reference.
- **Lines 151–152:** The meaning of this sentence is unclear. Please rewrite it and state explicitly what process, dataset, or comparison is being described.
- **Lines 170–180:** This paragraph should be rewritten. Its main message and the logical relationship among its statements are currently difficult to identify.