

Reply to Referee 1 by Borowski et al..

We thank the referee for the very helpful comments that have significantly contributed to improving the manuscript and have addressed each comment below. Our answers are given in “italics”. The line numbers given refer to the initial version of the manuscript.

General comments:

This paper makes a good contribution to the literature on evaluating long-term variability in the wind resource, an ongoing challenge for wind energy science. The authors make good use of a set of long-term (by wind energy standards) tall-tower data sets to compare several methods to estimate multidecadal wind speed variability from much-less-than-multidecadal in-situ observations. They apply several MCP methods and three widely used ML methods to data from sites in different geographical and climatological settings. The ideal outcome would be to determine the best method(s) to use given a particular geographic or climatological setting, but given the complexity of the wind resource, the results are a little more nuanced than that, and understandably so. Nonetheless, the authors describe how the methods compare to each other across these settings and are able to offer some tentative conclusions and recommendations for estimating long-term variability from short-term records.

⇒ Thanks for your comment and your positive view on our manuscript. We agree that we would have been happy to determine more generalized recommendations, which is difficult - as you noted - due to the complexity of the wind resource at the various sites.

Specific comments:

(1) Lines 100-105: The ERA5 data set begins in 1940 but your analysis begins in 1950. Given your goal of characterizing long-term variability, why exclude this additional 10 years of reanalysis data?

⇒ Thank you for the comment. The backward extension of ERA5 has been publicly available since 2023 (Soci et al., 2024). The original design of the study began before that. Thus, we started with including data from 1950 onwards. The quality of reanalyses has steadily improved over time as more and more observational data has been integrated over the decades. Studies indicated that especially data for the decade prior to 1950 are much poorer - in particular in Europe - resulting in lower quality reanalyses (Soci et al., 2024). Thus, we decided to not extend our analysis backwards when the data became available.

(2) Table 2: Are all the sites freestanding met towers or are they towers in the vicinity of a wind turbine, which might possibly be affected by wakes from some wind directions?

⇒ Thanks for this comment, we checked every location carefully. Indeed, there are some sites with wind farms in the immediate surrounding, e.g. Goodnoe Hills and Butler Grade. However, turbines are not in dominating wind direction sectors and should thus not have a relevant impact on our analyses. A respective sentence has been added to the Section 2.1.1 (line 88): “Some masts, e.g. Butler Grade and Goodnoe Hills have wind turbines in the surrounding but not from relevant wind direction sectors. So, the majority of sites are not impacted by wakes.”

(3) Line 210: The headings in Table 4 list 2010-2016 and 2012-2016, but the text says the MER is for 1950-2020. I suggest adding that bit of info to the table heading, just as a reminder to readers.

*⇒ Thank you for this comment, we revised the caption of Table 4 and changed it to:
“Overview of the mean max. hindcast ensemble range (MER [m s^{-1}]) for the time period from 1950 to 2020 and its normalization (MNER [%]) by the mean measured wind speed. The ensemble is based on the individual years within the time intervals 2010 to 2016 and 2012 to 2016.”*

(4) **Lines 220-227:** I was confused at this point about why you would want to reduce the influence of interannual variability when creating a long-term reference data set. You talk about this a bit later in the paper, but maybe add a note here that you'll come back to this in section 3.4.1? In general, I think it might be useful to say a little more in the paper about the importance of long-term "data" such as reanalyses, which in theory can include ENSO and other climate patterns that influence long-term variability at a site.

⇒ *Thanks for the comment. To give the reader a better orientation, we have included a note (line 224) directing readers to the detailed discussion in the respective section: "The impact of the years 2010 and 2011 is further analyzed and discussed in greater detail in Section 3.3.1 using various MCP approaches."*

Further, we added some more information about the importance of long-term data to the manuscript in the introduction, data and discussion section:

"Introduction (line 49): Long-term datasets, such as reanalysis data that integrate model outputs with actual measurements, can capture and reflect these effects. Consequently, long-term data are crucial for analyzing historical trends, variability, and anomalies in climate patterns, making them essential for assessing long-term wind conditions."

"Section 2.1.2 (line 94): Current generation of reanalysis datasets provide data over periods of more than 50 years and therefore multi-decadal records of atmospheric conditions, enabling the study of large-scale climate patterns and their impact on (regional) wind variability."

"Discussion (line 364): Long-term data from reanalyses enable the analysis of historical climate parameters and patterns, particularly their variations and temporal developments, and are therefore essential for estimating wind resources. Although reanalyses largely depict fluctuations and patterns in a uniform manner, differences in model physics and resolutions lead to discrepancies. Expanding the study to include various reanalyses could help quantifying the sensitivity to long-term data and reducing related uncertainties."

(5) **Line 240:** You note here, and in several other places in the paper, that the MNER doesn't seem to depend much on terrain complexity. Do you have any hypotheses as to why? I encourage you to include a bit more discussion of this - even if only possible hypotheses - in the Discussion and Conclusions section (e.g., lines 380-383). Perhaps that discussion can also touch on your comments about sensitivity to sample size and data gaps (lines 259-263).

⇒ *Thank you for the comment. We have revised the manuscript and included additional sentences in the discussion section (line 354): "A generalizable dependency of these values on terrain complexity could not be identified. This could be an indication that the variability is more dependent on other characteristics of the local wind climate such as the homogeneity of the wind direction distribution, the land-use in the surroundings or the quality of the measurement data (see "Database" below)."*

Technical comments:

(6) **Figure 9:** The figure caption should say 2012-2016, not 2010-2016.

⇒ *Thanks for the comment. Changed accordingly.*

(7) **Figure 10:** The figure caption shows 2010-2016 (MNER2010-2016 %) twice; the second one should be 2012-2016.

⇒ *Thanks for the comment. Changed accordingly.*

References

Soci, C., Hersbach, H., Simmons, A., Poli, P., Bell, B., Berrisford, P., et al.: The ERA5 global reanalysis from 1940 to 2022, Quarterly Journal of the Royal Meteorological Society, <https://doi.org/10.1002/qj.4803>, 2024.