Review: Contreras et al.: Identification of optimal ERA5 model level for wind 2 resource assessments in mountainous terrain

Summary:

The paper examines whether ERA5 wind speeds from higher model levels can better represent wind conditions in mountainous terrain than surface level wind-speeds. The main finding is that wind speeds from ERA5 at higher model levels are better suited to characterise wind conditions at exposed location in mountainous terrain, as they show significantly higher correlation to wind speed measurements (10 m and 100 m). The results provide interesting new insights, which are of high relevance for the application of reanalysis data for wind energy. They significantly contribute to the discussion on how to best apply reanalysis data in mountainous terrain. The paper is well written and generally well structured and provides novelty. The experimental data and the model data choices seem sound. However, major revisions especially in the methodology are needed before it can be published.

Main concern:

The strongest scientific point of the paper is the identification of the higher model levels as being more representative for the wind climate on ridges and exposed locations. However, the current methodology weakens this finding by combining the analysis of the higher levels with a machine learning model for long term correlation(LTC)/as a measure correlate predict (MCP) method. The use of a Random Forest (RF) model makes the analysis less transparent and introduces disadvantages. While using a RF model is not inherently a bad choice for LTC/MCP it has several disadvantages for the study:

1. A RF seems overly complex for a model with only one input feature. It essentially is a "step-wise" function fitted to the data. A linear model would be a lot more transparent here. Even if low wind speeds might be mapped below 0, low wind speeds are in general not relevant for wind energy applications. Alternatively, higher order polynomials could be used.

2. RF models are not distribution-conserving. In general, the variance will be reduced by using a RF. As most machine learning models, RF will miss

extremes and tend to bias predictions towards the mean. The reduced dispersion in the distribution is therefore likely to be at least in part due to the application of the RF model to the ERA5 data.

3. Except for the correlation the results are only shown for the combination of ERA5 data with a machine learning approach. This makes it difficult to judge, what the contribution of the ML-model to the quality of the results was.

4. The discussion compares the results with several other studies using machine learning. However, some of these are different applications and in some cases the direct comparison of performance indicators does not make sense. E.g. [1] developed a model to estimate wind speeds at locations with no prior measurement. This is a significantly different use case from the LTC/MCP investigated here, for which a measurement on site is needed. Also the last paragraph of the discussion does not seem to be well rooted in the presented results, as it discusses a completely new topic (climate change).

Recommendation:

1. Include a direct comparison of the distributions found in the ERA5 data at different model levels with the measurement data. This way wind speed distributions of ERA5 can be better evaluated without the possibly distorting effect of the RF.

2. The application of a simple linear model (in addition to the RF) would increase the transparency of the analysis and remove some of the black box effect the RF has.

3. The application of widely used MCP methods like linear regression (with residuals) or variance ratio [2] would improve the comparability to other studies evaluating MCP approaches. This would also help to judge, if the the performance of the MCP in high mountain ranges reaches similar levels as in flat terrain if the appropriate height level is used.

4. Revise the discussion and focus more on studies looking at LTC/MCP. It would be interesting to know how good estimates in mountainous terrain can get in comparison to simpler terrain given the appropriate height level is chosen. Remove the last paragraph from the discussion.

Specific comments:

- L16: Insert "the": "the ERA5 model level data set"
- L19: Write "to" instead of "for".
- L51: There are also regional reanalysis. Please rephrase.

- L53: ... (ERA5) is the 54 preferred reanalysis in the wind power meteorology community (Olauson, 2018)." This is somewhat misleading. The study evaluates the dataset but does not investigate its acceptance in the wind energy community. Please rephrase.

- Section 2.3: I think it is not justified to dedicate a section to the fact that Pearson's coefficient of correlation was used to identify the height of the best correction. Recommendation: merge with Section 2.4.

- A RF with just one input feature is an unconventional choice (see comments above). please clearly state and justify this here. Also the application of more transparent approaches is recommended here (see comment above).

- Section 2.1: It would be great to have wind roses of the sites here. The main ridge of the mountain range of the Andes has a clear orientation. Therefore this would help to understand the influencing topography better.

- 97: Typo: "...has been stablished..."

- 157: Grammar needs to be corrected, e.g. "This was done following MEASNET".

- 188: Can you provide a justification why no interpolation was performed?

- "For each site, both models were trained using observed hourly wind speed data from the first three years of the monitoring campaign (i.e., January 2021 to December 2023)." Usually one year of data is used for LTC. This would also make results more comparable to other studies. Why did you deviate from this? Please change or justify.

- 247:Grammar: "to quantify"

- L207: "In this study, the RF model was preferred over a conventional regression model because it provides more 207 consistent predictions (e.g., non-negative values), particularly at low wind speeds." Usually low wind speeds (so low that the linear regression would provide negative values) are not of interest for wind energy applications. I think it would still be good to include a widely used regression method like linear regression with residuals or variance ratio in the analysis as a reference or to make a better argument against their usage.

- 290: Check grammar.

  L300: "This pronounced difference, compared to the other sites, may be attributed to the larger discrepancy between the actual site elevation and the ERA5 model elevation.“ Please state differences here.

- 331: It is stated that M4 is located on a hilltop and should be suitable for wind energy purposes. Can these very low wind speeds for such a site be explained in more detail from the specific terrain characteristics. This is mentioned in line 305, but could be discussed more.
- L386: "The results presented above confirm that ERA5 consistently underestimates wind speed variability in the tropical Andes in line with other studies in complex terrain." The paper does not analyse the distribution of ERA5 directly but rather the output of the RF model. From the current analysis this conclusion cannot be drawn. Also, it would be nice to differenciate stronger between the characteristics of the different height levels.
- 386: Check grammar: "confirms" - "confirm"
- 398: Spelling: "intricated" - indicated
- L408: "The lower performance in M4 is caused by the lower performance of the RF models in estimating particularly lower wind speeds (i.e., 0-2 m s-1) where high frequency values within this range are common in this site." I don't understand this sentence.
- 425: Typo "transformers"
- 436: Typo, correct to "not commonly assessed"

References

[1] Wenxuan Hu, Yvonne Scholz, Madhura Yeligeti, Lueder Von Bremen, and Ying Deng. Downscaling ERA5 wind speed data: a machine learning approach considering topographic influences. *Environmental Research Letters*, 18(9):094007, September 2023.

[2] Anthony L. Rogers, John W. Rogers, and James F. Manwell. Comparison of the performance of four measure–correlate–predict algorithms. *Journal of Wind Engineering and Industrial Aerodynamics*, 93(3):243–264, 2005.