Responses to Reviewers' Comments for Manuscript
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Tall Wind Profile Validation Using Lidar Observations and Hindcast Data

Addressed Comments for Publication to

Wind Energy Science (ISSN 2045-2322)

by

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1 Authors' Response to Reviewer 2

1.1 General comment

General Comments. This paper addresses an important and timely topic by validating three widely used wind reanalysis and hindcast models—NORA3, NEWA, and ERA5—against lidar measurements at five strategic locations in the North Sea and along the Norwegian coast. The validation focuses on wind speed profiles at heights relevant to modern wind turbines and emerging airborne wind energy systems (100-500 m), making this study directly applicable to the future of wind energy technology. The study effectively uses appropriate error metrics, including the Earth Mover's Distance (EMD), to evaluate model performance across offshore, coastal, and complex terrain sites. The findings emphasize the critical need to select appropriate wind atlases based on site-specific geography and altitude, particularly in complex terrain where regional models like NORA3 tend to outperform global datasets like ERA5. The study also underscores the need for more tailored lidar wind profilers to accommodate the growing size of modern wind turbines and the emerging technology of airborne wind energy systems. While the paper provides valuable insights, it acknowledges limitations in the temporal scope, as the datasets do not cover a full climatology period. The authors suggest expanding measurement sites and improving temporal resolution in future studies to strengthen conclusions. Overall, this study makes a significant contribution to the ongoing effort of properly validating reanalysis models for the evolving wind energy sector.

Response:

We thank the reviewer and appreciate the positive feedback and constructive comments on our article. We address the comments below and updated the manuscript adequately.

1.2 Specific comment

Comment 1

Why is the FINO1 platform used for model validation when it is located near several wind farms? As noted in the manuscript, this proximity likely affects the measurements, making FINO1 unsuitable for validation unless the models explicitly account for the wind farms or the data are filtered to exclude disturbed wind directions. Since the measurements at FINO3 do not have nearby wind farms, wouldn't they already provide a more representative view of undisturbed offshore conditions?

Response:

For a complementary answer, we refer to our response to Reviewer 1. We consider it important to include the FINO1 data to illustrate how the presence of a wind farm may affect the agreement between modelled wind data and lidar measurements. Rather than dismissing the data, we believe it is valuable to highlight and discuss this interaction, as it documents how wind speed can be affected by man-made offshore structures. We believe that including both the FINO1 and FINO3 datasets enhances the value of our study, particularly as few previous studies, to our knowledge, incorporate data from both platforms. This dual perspective adds depth to our analysis and offers useful contributions to future research, particularly in the context of wind resource assessments in areas with sea-covered wind farms.

we have added the following lines in the manuscript

The measurement data were collected by reference DWL instruments within the area covered by ERA5, NORA3, and NEWA. Two lidar campaigns were conducted in the marine ABL at the FINO1 and FINO3 locations, two others at coastal sites (Sola and Lista airports in Norway), and one in complex terrain (Bjerkreim, Norway). This diverse set of locations—comprising offshore, coastal, and complex terrain sites—provides a robust basis for assessing the performance of wind atlases for tall wind profiling. The FINO1 and FINO3 platforms offer complementary datasets for analyzing wind conditions near offshore energy installations (Podein et al., 2022). FINO1's proximity to wind farms enables an examination of discrepancies between lidar measurements and wind atlases. Combining data from both platforms highlights the challenges of wind resource assessment in such *areas and underscores the need for cautious application of wind atlases near offshore energy projects.*

Comment 2

In line 300, it is mentioned that the EMD values are comparable across all models at coastal locations. However, this is not the case for the Sola site, where there are noticeable differences between the models.

Response:

We agree with the reviewer. This sentence seems to be an artefact of an older version of the manuscript. This sentence has been removed for the sake of brevity and the next sentence has been adjusted as

At the coastal sites and complex terrain Bjerkeim, NORA3 achieves the lowest EMD, underlining its potential in heterogeneous topographies. As expected, ERA5 shows significantly higher EMD values than the other two models onshore, which is attributable to its lower horizontal spatial resolution.

Comment 3

The paper emphasizes the validation of hindcast data at higher altitudes, beyond what has been extensively studied. Given this, why focus on results at 150 m, a height already typical for current wind turbines, when higher-altitude data are available? The higher- altitude comparisons would seem more aligned with the study's stated objectives.

Response:

We have added a new figure showing the bar plot at the altitude closest to 300 m and added the following lines in the manuscript to clarify the comment of the reviewer

Figure 8 compares four error metrics describing the discrepancies between measurements and modelled mean wind speed data across five sites: FINO1, FINO3, Sola, Bjerkreim and Lista at a single height, corresponding to the range gate of the lidar nearest to 150 m. Figure 9 shows similar error metrics at a height of ca. 300 m, which is more relevant for airborne wind energy ssytems. The results presented in Figs. 8-9 highlight key differences in error metrics among the wind datasets, complementing the error metric profiles shown in Fig. 10. Notably, the variability in error metrics observed at 150 m and 300 m aligns with the one seen at other altitudes, reinforcing the consistency of our findings.

The results at 150 m are representative of wind characteristics relevant to modern wind turbines, making them practical for wind energy applications and directly linked to the capacity factor analysis presented later. Additionally, the error metrics at 150 m complement the full-profile analysis and highlight key differences among the wind datasets at a reference height commonly used for model validation. While higher-altitude data are included in the profile analysis, focusing on 150 m also facilitates the discussion of turbine capacity factors later in the paper.

1.3 Technical correction

Comment 4

In the introduction, it might be appropriate to add the reference, where they use ERA5 to compute AEP of airborne wind energy systems: Schelbergen, M., Kalverla, P. C., Schmehl, R., and Watson, S. J.: Clustering wind profile shapes to estimate airborne wind energy production, Wind Energy Science, 5, 1097–1120, https://doi.org/10.5194/wes-5-1097- 2020, 2020

Response:

We agree with the reviewer; we have added this reference to the introduction when refering to the use of tall wind speed profile for wind resource assessment.

Comment 5

In line 54, the acronym "AWE" is repeated unnecessarily. Please use the acronym directly after the first mention.

Response:

We have adjusted the use of the acronym as suggested by the reviewer.

Comment 6

In line 111, it is generally not proper styling to add directly an url to the text. Please include it in the references and refer to that.

Response:

We follow the recommendation of the reviewer and we have now added the url link in the data availability section.

References

Podein, P., Tinz, B., Blender, R., & Detels, T. (2022). Reconstruction of annual mean wind speed statistics at 100 m height of FINO1 and FINO2 masts with reanalyses and the geostrophic wind. *Meteorologische Zeitschrift*, *31*, 89–100.