Response to reviewers

21st of June 2021

1 General comment to reviewer # 3

We would like to express our gratitude to referee #3 for his/hers time and effort revising the manuscript with the working title of "Norwegian hindcast archive (NORA3) - A validation of offshore wind resources in the North Sea and Norwegian Sea". With the comments from referee 3 we strongly believe that the manuscript now is better and more precise. Please see our response to the comments below (new text added to the paper is in italic font).

1.1 Respons to major comments from reviewer #3

RC1: It is not clear that why the authors use NORA3 for their study. They gave Table1 which shows the related datasets and also,they emphasized that the NEWA dataalso prepared similar to NORA3. But they did not make neither qualitive nor quantitive comparison between these two datasets and explained whythey used or what is the superiority of NORA3. So, it is not clear why the authors prefer NORA3 instead of NEWA.

AC1: We had hoped that it was clear from the paper that we use NORA3 because it is a newly produced wind dataset, that has not been validated for wind power resource estimations. Thus the objective of the paper is an evaluation of this new simulation. This is a prerequisite to ensure a sound and critical use of the simulations by stakeholders and fellow researchers.

NORA3 compares to f.ex NEWA in terms of model configuration like spatial and temporal resolution, initial- and boundary information. We would like to emphasize that we do not "prefer NORA3 instead of NEWA". As several new wind resource data set are becoming available a model comparison is indeed of great interest and something we will pursue in future work. However, given the page limitations and the fact that this is the first paper to evaluate the wind resource estimates from NORA3 we have prioritized to put the focus on a detailed comparison against observations instead of introducing a second objective to the paper.

However, we have added a validation of NORA3 towards the host data set (ERA-5). A figure illustrating a quantile-quantile plot between the model and the observations will be added to the paper, in addition to two tables including validation of mean and standard deviation of seasonal wind speed. The following section will be added to the paper:

Comparison of NORA3 and ERA-5

The NORA3 wind estimates in 10 masl are extensively validated against observations and compared against the ERA-5 reanalysis in Haakenstad2021NORA3:Sea. Nevertheless, we compare the performance of NORA3 and ERA5 towards the observed wind speed climatology in the six wind sensor heights (68-140 masl).

The observed seasonal average and standard deviation of the wind speed are shown in Table 3 and Table 4, respectively. In addition, the relative difference between the observations and NORA3 (n3 (%)) and the observations and ERA5 (e5 (%)) are also shown. Table 3 shows that the modeled average seasonal wind speed from NORA3 are consistently closer to the observed values for all the seasons. The standard deviation (std) is here a measure of the variability in the wind speed. The seasonal variability is shown in Table 4. Compared to ERA5, NORA3 is consistently closer to the observed seasonal std for all the six sites.

Figure 3 shows the quantile-quantile plot (qq-plot) between the observed wind speed and modeled wind speed by NORA3 and ERA5. The qq-plot determines if the two data sets are drawn from the same sample distribution. If the circles lie on the reference line the data sets comes from the same data distribution. For all the six sites the models perform best for the lowest wind speeds ($u \leq 10ms^{-1}$). For both models the deviation from the reference line ("ref line") increases with increasing wind speed percentile. Nevertheless, NORA3 is consistently closer to the reference line compared to ERA5, and especially for wind speed exceeding a typical cut-off wind speed. A technical feature called "high wind ride through" enables the turbine to exploit more of the very strong wind speeds ($u \geq u_{co}$). In offshore areas higher winds is happening more frequently. Therefor, the importance for a NWP model to estimate these strong wind events correctly increases. NORA3 outperforms ERA5 for these high wind speeds ($u \geq u_{co}$).

As illustrated in Fig 3, the largest difference between the observations, NORA3 and ERA-5 is found for wind speeds exceeding a typical cut-out limit of 25 ms^{-1} ($u \geq u_{co}$). Since the power production is terminated or at least reduced when $u \geq u_{co}$ we calculate the wind power capacity factors (CF) for the three data sets. This is done to see how the the models perform in terms of power production where the strongest wind speeds not influence the result due the production cut-out limit. Table 4 contains the CF for the observed data, NORA3, and ERA-5 for the six sites. NORA3 performs consistently better than ERA5 for all the six sites. For the six sites used in this study, NORA3 is 1.8 percentage point closer to the observed average CF-value compared to ERA-5.

The validation of wind climatology in NORA3 and ERA5 show that the downscaling of ERA5 in the process of creating NORA3 has resulted in an improved wind resource data set. The remainder of this study will focus on the validation of NORA3 towards observed wind climatology.

RC2: I believe that the length of the simulation does not provide enough information about the climatology of the region to select the best offshore wind farm areas. In my opinion, if the authors want to define the best offshore wind production areas, they should keep the simulation period as long as possible to include extreme atmospheric conditions and inter annual variability. Moreover, If I would have preferred NORA3 instead of longer simulation and finer temporal resolution NEWA, I would rather simulate the model for fine horizontal simulation such as 1km. Thus, it might help to solve the mesoscale circulations such as sea-land breezes at near-coastal wind farm that can affect the power productions.

AC2: Thank you for pointing out the length of the model time series. I agree - using the data set for mapping the area most suited for wind power production the times series should be as long as possible. The NORA3 data set is continuously being generated and will when finalized cover the time period from 1979 and onward. Hence, the possibility to download and analyze a much longer NORA3 time series will be possible in the near future.

RC3: It is not clear to me that how the model downscaled 31km ERA5 data to 3km HARMONIE-AROME domain. According to the authors explanations, I think ERA5 is directly downscaled to 3km that I have concern about this sharp interpolation affects the performance of the model

AC3: There is no clear recommendation from the literature on the best strategy for downscaling, regarding nesting down gradually or direct leap to a finer resolution. Recent papers indicate that there is little quality difference between the two approaches, but a tendency for better results using no nesting [4, 1].

RC4: Wind speed interpolation should be conducted by using log-profile wind calculation. The authors did not give information about model general tendency to atmospheric stability or any characteristic of the domain stability. Therefore, logarithmic wind profile can be used for the interpolation

AC4: Thanks for your comment. Both logarithmic wind profile (log law) and power law wind profile (power law) assumes neutral atmospheric stability of the atmosphere and will have deficiencies in stable and unstable conditions where either the wind shear or the buoyant turbulent fluxes dominates. [3] reviewed different extrapolation methods (logarithmic models, Deaves and Harris, and power law) for 96 different locations worldwide. He concluded that the power law was the most reliable and widly most used extrapolation method. In addition, according [5] the usage of log-law is most suited near the surface. Despite the aforementioned results from Gualitieri and Sill we have compared the performance of the log law and the power law (with time varying power exponent) for the six offshore sites used in this study. For the majority of the sites, interpolating NORA3 wind speed to the sensor height using the two different methods (log-law and power law) we see that the model bias using log law is larger than using the power law method for the majority of the sites. Therefor, we stick to the power law method with a time dependent power exponent when wind speed interpolating is conducted.

The following text is added to section 2.2 (new text in italic):

Wind speed interpolation

To avoid introducing additional uncertainties into the observational data set, we verify the wind variables from NORA3 at the wind sensor heights, ranging from 68-140 m.a.s.l., for each site (see "WSH" in Table 1 for the sensor heights). By contrast, the wind power verification is performed at a typical hub-height, at 100 m.a.s.l., to ensure the production estimate are comparable between sites.

The interpolation of wind speed data to another height is usually done by either logarithmic law, Heaves and Davis, or power law. [3] reviewed the three aforementioned methods for 96 different locations worldwide. He concluded that the power law was the most reliable and also the method most frequently used extrapolation method. In addition, according [5] the usage of log-law is most suited near the surface. Despite the aforementioned results from Gualitieri and Sill we have compared the performance of the log law and the power law (with time varying power exponent) for the six offshore sites. For the majority of the sites the model bias using log law is larger than using the power law method. Therefor, the interpolation of wind speed data to sensor height or hub-height is done using the power law relation ([2]). The interpolated wind speed is sensitive to the choice of the power law exponent α. Usually, α is assigned based on assumptions about atmospheric stability and surface roughness, both of which can introduce erroneous results. However, the data from NORA3 allows us to calculate α for each time step (i). Rearranging the power law relation, we get the following expression for the power law exponent α: ...

2 Response to minor comments from reviewer # 3

RC1: Line 52: WRF model running 10 separate model runs for 10 independent regions" should be ...running independently for 10 domains.

AC1:: The paragraph will be removed in the revised version of the manuscript.

RC2: Line 80 "model runs with a horizontal resolution of 31 x 31km" should be 3x3km

AC2: Done.

RC3: line 83 "by many European countries" instead of the countries Weather Services should be proper.

AC3: Done. The sentence it rewritten in the following way: "... and it is used in short-range operational forecasting and research by many European weather *services and research institutes"*

RC4: Line 95-96 "from the National Centers for Environmental Protection (NCEP) (1oresolution)" there are different horizontal resolution NCEP data be specific for that. I think it should be NCEP-FNL data.

AC4: The section will be removed in the revised version of the manuscript.

RC5: Line 190 "Hence, the observed wind speed is somewhat more intermittent and variable than the modeled wind speed, indicating that HARMONIEAROME is missing some of the high-frequency variability embedded in the wind field". I think this sentence conflict with the previous sentence, the authors stated that the observation wind speed is between 4.7-6.5 m/s. I understand that the modeled wind speed is more variable but wind speed between 4.7-6.5 m/s is less seen from the model outputs

AC5: Thanks for commenting on this badly explained phrase. During the generation process of the paper we performed a spatial filtering of the observational and modeled data using a Butterworth filter. This result was not implemented as a part of the paper. Performing this filtering illustrated that NORA3 was missing out some high frequency variability. I will add some clarifying text....

RC6: Line 191 "HARMONIEAROME" should be HARMONIE-AROME.

AC6: Done.

RC7: Line 193-196 Weibull distribution notation I recommend to use common parameters terminology for Weibull distribution which the readers are familiar instead of a and b notations.

AC7: Thank you for this comment. I have now changed a and b to λ and k.

RC8: It is interesting to see the dominant direction missed by the model especially at Sleipner where the flow is channeled. I would expect the almost bidirectional wind as we can see on the observation in Figure A0 for Sleipner (NW-SSE direction). How does the authors explain this? Do they believe the model capture the common flow patterns?

AC8: Thank you for bringing attention to the wind rose at Sleipner and for this interesting comment. Looking at Figures A1, B1 and B2 we can conclude that the model is somehow struggling with winds in the whole sector SSE-NWW, underestimating the wind speed and also the occurrence of these wind events in this sector. Since a oil- and gas platform is a large structure some flow distortion is expected to happen. It is difficult to state whether the difference between the observations and NORA3 values at Sleiper is due to the model or due to flow distortion caused by interaction between the flow and the platforms. However, Sleipner is the site with largest deficiencies between the observational and modeled data. For that reason a flow distortion of unknown magnitude and importance is probably present at Sleipner.

RC9: I recommend the authors use meteorological wind direction notation instead of given the direction in a degree unit. For example, 0:29 NW, 30:59 NNW in the text and also in Figure B2.

AC9: Thanks for your suggestion for changing the xlabels in Fig B. I have now changed the xlabels in Fig B2 to abbreviations of the corresponding wind direction interval (SE, NNW osv). I will also change the text in sections related to wind directions accordingly.

RC10: Also I saw "wind park" many places in the manuscript. I recommended to use "wind farm" (line 146,228,230).

AC10: Done.

References

[1] A. Beck. Impact of nesting strategies in dynamical downscaling of reanalysis data. *Geophysical Research Letters*, 31(19):L19101, 2004.

[2] S. Emeis. *Wind Energy Meteorology*. Springer, 2 edition, 2018.

[3] G. Gualtieri. A comprehensive review on wind resource extrapolation models applied in wind energy. *Renewable and Sustainable Energy Reviews*, 102:215–233, 2019.

[4] M. Raffa, A. Reder, M. Adinolfi, and P. Mercogliano. A Comparison between One-Step and Two-Step Nesting Strategy in the Dynamical Downscaling of Regional Climate Model COSMO-CLM at 2.2 km Driven by ERA5 Reanalysis. *Atmosphere*, 12(2):260, 2 2021.

[5] B. L. Sill. Turbulent boundary layer profiles over uniform rough surfaces. *Journal of wind engineering and industrial aerodynamics*, 31:147–163, 1988.