Authors’ Response to Reviewer 1

***Reviewer’s Comment #1*:** I am not completely sure of your distinction between good and fair in the grading. I have indicated the level "fair" in the meaning the paper meets the expected requirements for a scientific paper.

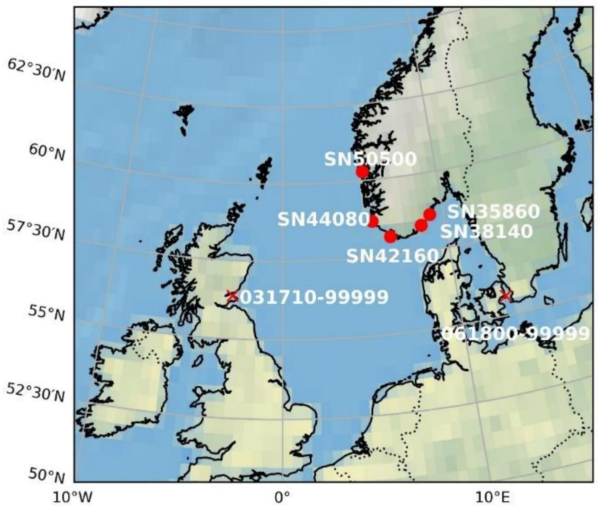
***Response to Comment #1*:** Thank you very much for the clarification. We appreciate your constructive feedback and have carefully revised the manuscript based on your comments to improve both the clarity and relevance of the work. We hope the revised version will better reflect the strengths of the study.

***Reviewer’s Comment #2*:** My comments regarding the revisions: The authors have quantified the levels of accuracy of using wind speed series of different lengths regarding estimates of various statistical parameters related to wind energy. The results are however - as they also state - limited to Southern Norway using coastal weather stations only. The authors invite more studies for other areas. Although not a request, it would have added extra value if it somehow had been included in this paper.

***Response to Comment #2*:** Thank you for your thoughtful and constructive suggestion. We have extended our analysis by incorporating two additional coastal stations located outside Norway—one in Denmark and one in Scotland. These sites are situated in or near operational wind farms in the North Sea and thus serve as relevant and practical complements to our original Norwegian stations.

Both stations provide 46 years of hourly wind speed observations, allowing us to test the robustness of our findings in different geographical and climatological settings. Specifically, we used these longer and uninterrupted datasets to explore the differences between random and continuous sampling approaches, which also responds to related concerns in Comment #3. This additional analysis enhances the generalizability of our guidance on data length requirements for wind resource assessments.

To maintain the coherence of the manuscript structure, we have incorporated this complementary analysis into Section 4.1 of the Discussion. We also present the added contents as follows:



"**Figure 1: Distribution of the weather stations used in this study.** (*Line 205 in the clean version of the revised manuscript*)"

"*4.1 Sensitivity to sampling strategy and climatic non-stationarity*

In wind energy assessments, continuous sampling is more commonly used than random sampling because it preserves temporal structure and seasonal variability in wind speed time series, and most importantly, only long-term data are not available. However, continuous sampling may also introduce systematic bias, particularly over short durations, due to temporal autocorrelation and underlying climatic non-stationarity. To investigate the extent of this effect and assess the generalizability of random sampling, we conducted a sensitivity analysis using 46 years (1979–2024) of hourly wind speed data from two coastal meteorological stations: Copenhagen Airport (061800-99999, Denmark) and Leuchars (031710-99999, Scotland). These sites were chosen for their long-term records and meteorological similarity to the five Norwegian locations analyzed earlier. Copenhagen station exhibits a long-term decreasing wind speed trend (Fig. S1), consistent with broader global observations (Zeng et al., 2019).

Our results show that continuous sampling generally requires significantly longer periods to achieve the same level of uncertainty in estimated distribution parameters compared to random sampling (Fig. 7). This discrepancy arises because random sampling draws from multiple years, thereby capturing a wider range of interannual variability and reducing exposure to temporal clustering. Consequently, the 90% confidence intervals (CIs) under random sampling are symmetric for all parameters, while under continuous sampling, only the CIs for mean wind speed, Weibull scale parameter, and power density are symmetric. Shape-sensitive parameters, including standard deviation, skewness, kurtosis, and especially the Weibull shape parameter, exhibit pronounced asymmetries under continuous sampling, particularly at short durations (<2 years). This suggests that the presence of systematic climatic anomalies in continuous subsets may bias shape estimation.

These findings support earlier recommendations by Murthy et al. (2017), who advocate using at least four to ten years of data for reliable wind energy assessments. Our results suggest that when using continuous sampling, at least five years of data may be required to achieve ±10% relative uncertainty in power density *estimates, although this threshold is site-specific (e.g., Copenhagen station requires more than 10 years). We further recommend that random sampling be considered as a complementary tool to identify potential biases in short-term continuous assessments.*" (*Lines 355-379 in the clean version of the revised manuscript*)

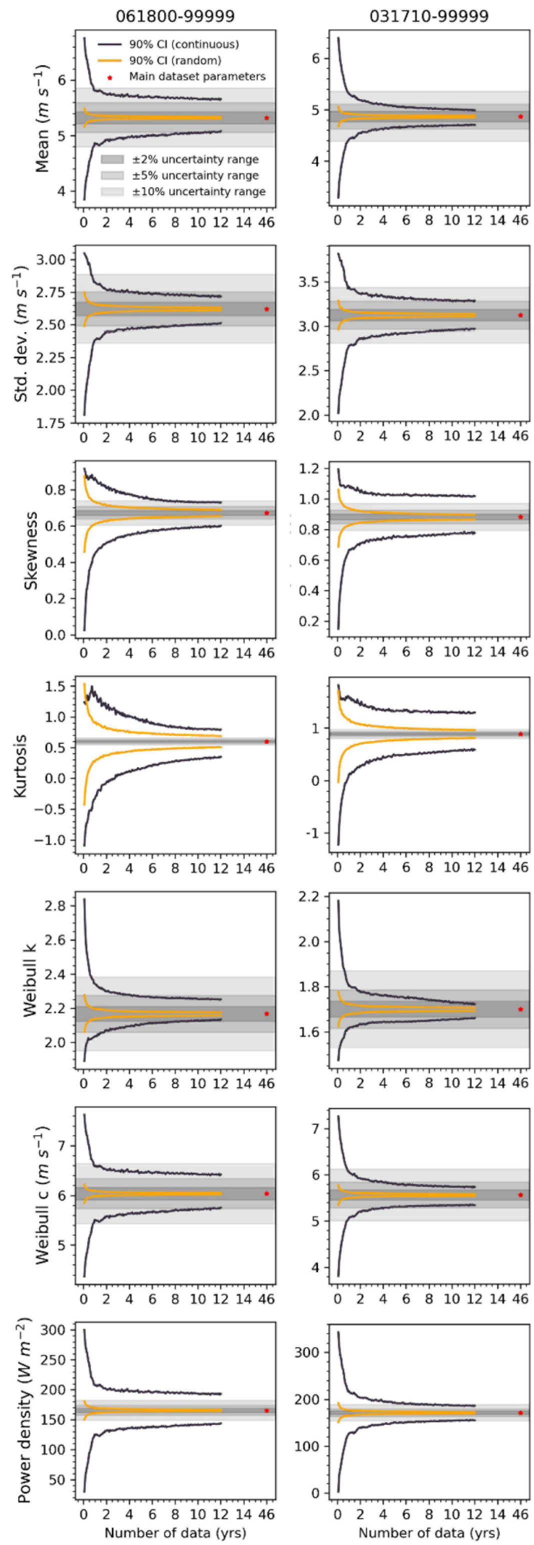


Figure 7: distribution parameters and Weibull power density derived from random sampling (orange lines) and continuous sampling (black lines), based on in-situ measurements from weather stations. Asterisks indicate values computed from the full 46-year dataset. Values for sample lengths between 14 and 46 years are omitted for

visual clarity. Details of the experimental setup and sampling procedures are provided in the Methods section. (*Lines 380-385 in the clean version of the revised manuscript*)

***Reviewer's Comment #3*:** Given that the paper is focusing on wind energy it is a bit surprising that the Wind Atlas approach is not discussed in the paper. Not even mentioned. I would like to see a discussion of wind atlas and the wind energy intensity estimates.

***Response to Comment #3*:** Thank you for highlighting this important point. In response, we have added a dedicated subsection (Section 4.2) in the Discussion, which introduces the Wind Atlas methodology and discusses its relevance to wind energy resource assessments. This section also presents a comparison between Global Wind Atlas estimates and our station-based observations in terms of key wind energy metrics. We believe this addition enhances the energy-focused perspective of the paper and addresses your suggestion effectively.

"*4.2 Evaluation of global wind atlas estimates against observations*

Since the publication of the first European Wind Atlas in 1989 (Dörenkämper et al., 2020), the wind atlas methodology has been widely adopted for regional wind resource assessments, including in countries such as Finland (Tammelin et al., 2013) and Greece (Kotroni et al., 2014). The Global Wind Atlas (GWA), developed by the Technical University of Denmark, applies the well-established numerical wind atlas method to downscale coarse-resolution reanalysis data to microscale levels. This is achieved using linearized flow models and topographic corrections based on the WAsP model. GWA provides publicly accessible estimates of mean wind speed and power density, which have been used in applications such as bias correction of reanalysis data for wind power simulations (Gruber et al., 2022).

Given the energy-focused perspective of this study, it is relevant to compare our results with GWA estimates. We extracted GWA values at the nearest grid points for selected stations and compared them with observational estimates based on the full time series. Table S7 presents this comparison, focusing on two key metrics in wind energy assessments: mean wind speed and power density. The results show that GWA consistently overestimates both wind speed and power density relative to our station-based observations.

One likely explanation for this discrepancy lies in the different ways topographic effects are incorporated. As described by Davis et al. (2023), the GWA estimates the predicted wind climate (PWC) by applying high-resolution topographic perturbations to the generalized wind climate which is based on coarse reanalysis fields. The PWC is represented by a set of Weibull distributions and directional frequencies for each of 12 directional sectors, and these are used to calculate derived variables such as mean wind speed and power density." (*Lines 412-433 in the clean version of the revised manuscript*).

Reviewer's Comment #4**:** They compare their analysis of observed wind speed with an equivalent analysis of reanalysis data using ECMWF data, ERA5.

They don't discuss the topography issue. This is important, as one must expect the height of the surface in the nearest gridpoint to be crucial to the interpretation of reanalyzed wind fields very near the surface or close to the surface.

Response to Comment #4**:** Thank you for highlighting this important point. In response, we added a new paragraph to the revised manuscript to discuss the surface elevation differences between the ERA5 grid cells and the actual station locations. The elevation values are now also included in Table 1.

"*Moreover, we compared the surface elevation of the ERA5 grid cells with the actual heights of the five Norwegian weather stations (Table 1). While all stations are situated near sea level (ranging from 4 m to 48 m above mean sea level), ERA5 grid elevations differ substantially, with four out of five stations showing discrepancies exceeding 40 m, and one exceeding 110 m. Specifically, ERA5 overestimates elevation at three stations and underestimates it at two. Interestingly, despite the mix of elevation biases, ERA5 wind speeds are overestimated at four stations and underestimated at only one. A station where ERA5 overestimated elevation is also the one where wind speed is underestimated. This suggests that elevation mismatch alone cannot fully explain the direction or magnitude of wind speed biases. Other factors, such as surface roughness and land use type, may also contribute to the discrepancies.*" (*Lines 462-469 in the clean version of the revised manuscript*).

Table 1: Details of weather stations used in this study. (*Lines 201-203 in the clean version of the revised manuscript*).

Station ID	Location	Data source	WMO number	Latitude	Latitude of ERA5 grid	Longitude	Longitude of ERA5 grid	Height above mean sea level	Elevation of ERA5 grid
SN50500	Flesland	MET Norway	1311	60.2892º N	60.25º	5.2265º E	5.25º	48 m	0.3 m
SN44080	Obrestad Fyr		1412	58.6592º N	58.75º	5.5553º E	5.50º	24 m	5.6 m
SN42160	Lista Fyr		1427	58.1090º N	58.00º	6.5675º E	6.50º	14 m	127.1 m
SN38140	Landvik		1464	58.3400º N	58.25º	8.5225º E	8.50º	6 m	55.4 m
SN35860	Lyngør Fyr		1467	58.6362º N	58.75º	9.1478º E	9.25º	4 m	43.9 m
061800-99999	Kastrup	HadISD	/	55.618º N	/	12.656º E	/	5.2 m	/
031710-99999	Leuchars		/	56.373º N	/	-2.868º E	/	11.6 m	/

Note: As the last two stations (Kastrup and Leuchars) were added specifically for the sensitivity analysis discussed in Section 4.1, they were excluded from the comparison with ERA5.

***Reviewer's Comment #5*:** One of the objectives in the paper is addressing the possibility that one can use randomly (in the time series) selected data to obtain the necessary distribution parameters. They state that this method is working for both near the surface and at elevated levels. And they then use this method for their following analyses.

***Response to Comment #5*:** Yes, addressing the feasibility of using randomly selected time samples to estimate wind speed distribution parameters is one of the main objectives of our study. This approach is motivated by the fact that many meteorological stations have long-term wind speed records that are incomplete or discontinuous in time. Traditionally, such datasets are excluded from wind resource assessments due to their temporal gaps. However, our results show that by applying random sampling to these fragmented but long-term records, it is still possible to capture key distribution characteristics.

In our analysis, we demonstrated the feasibility of this approach by comparing the 90% confidence intervals of distribution parameters obtained through different sampling methods. Furthermore, the revised manuscript now includes a comparison with continuous sampling. The results indicate that continuous sampling generally requires significantly longer data periods to achieve comparable uncertainty levels. A more detailed comparison between random and continuous sampling methods is also provided in our response to Comment #1.

We acknowledge, as stated in the manuscript (Lines 442–445), that these findings are based on analyses using a 90% confidence interval. This level implies that while minor discrepancies may exist, they are negligible under certain statistical assumptions. Therefore, we conclude that random sampling provides a practical and statistically robust alternative, particularly in situations where preserving diurnal or seasonal structures is not feasible.

"*It was noted that this finding is drawn from analyses utilizing a 90% confidence interval. This confidence level indicates that while minor discrepancies may exist in the data, they are considered negligible under specific statistical assumptions. Therefore, we conclude that random sampling provides a practical and statistically robust alternative, particularly in scenarios where it is not feasible to retain the characteristics of diurnal cycles or seasonality.*" (*Lines 442-445 in the clean version of the revised manuscript*).

***Reviewer's Comment #6*:** Page 8 and page 10 contain very detailed graphical illustrations of this point. They are however not easily grasped: 5 stations and 7 parameters giving 35 small plots. Even in a A4 print it is not a simple exercise to see every point discussed. Especially in figure 3 the blue colors are not easily identified.

Page 10, figure 3, contain an extra column with a1) - a6) superimposed on the middle column of small plots. Should be removed.

***Response to Comment #6*:** Thank you for your valuable feedback regarding the visual clarity of the figures. In response, we have revised the figures to improve readability. Specifically, we retained only three key variables, mean wind speed, Weibull scale parameter (c), and power density, for the five Norwegian stations in the main manuscript, and moved the remaining variables to the supplementary materials. In addition, we have adjusted the color scheme to enhance visual distinction, particularly addressing the issue raised about the blue tones in Figure 3. The superimposed column labels (a1)–a6)) previously shown in the middle column of Figure 3 have also been removed, as suggested. An example of the revised figure is shown below:

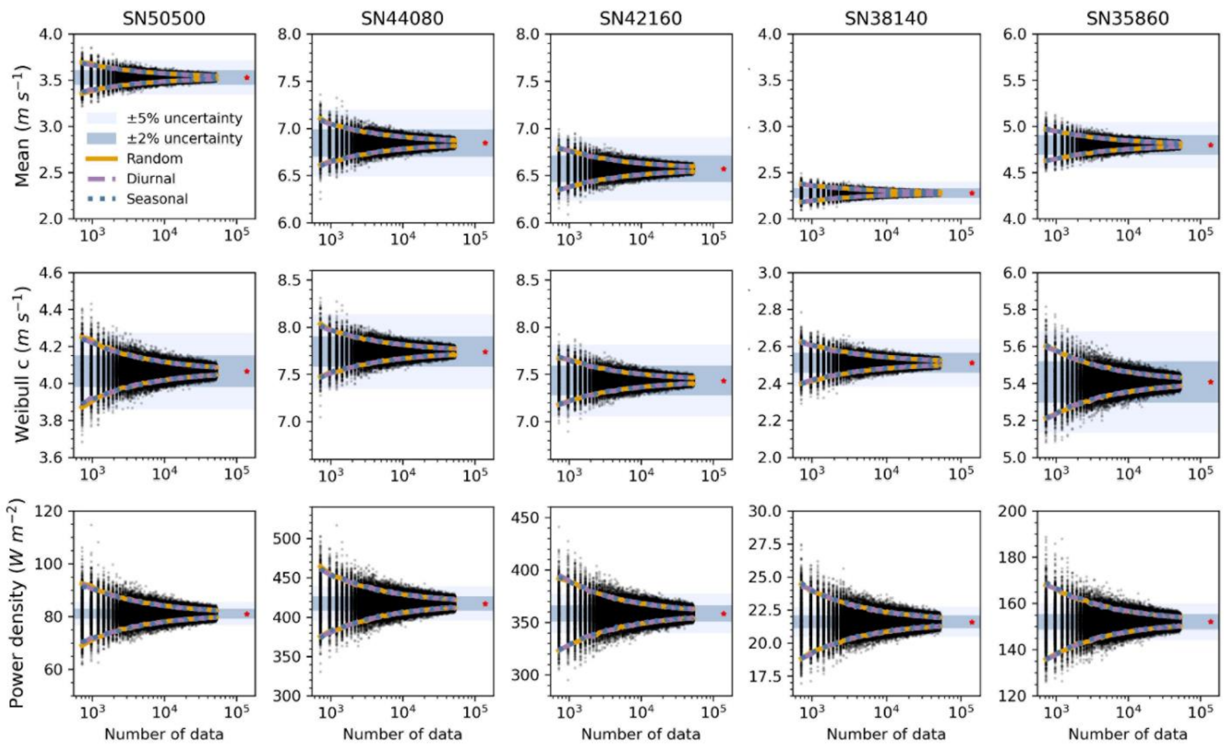


Figure 2: Estimates of mean wind speed, Weibull scale parameter, and power density from three sampling strategies, based on in-situ observations from five Norwegian stations. The 90% confidence intervals (CIs) are shown for each sampling method: random (orange), diurnal-cycle-retained (purple dashed), and seasonality-retained (blue dotted). Each black dot represents a parameter estimate from a single sampling realization of random sampling; corresponding realizations for the other two methods are not shown. Sample sizes range from 720 to 52,560 (30 days to 6 years), increasing in 240-hour (10-day) increments, with 1,000 realizations per size. Red asterisks indicate the reference values from the full 16-year hourly dataset (see Table 2). Shaded areas represent ±2% (dark blue) and ±5% (light blue) deviation ranges from full-series values. (*Lines 220-228 in the clean version of the manuscript*)

***Reviewer's Comment #7*:** The authors distinguish between statistical parameters that are quickly obtained, like the mean, st.dev. and Weibull parameters, and other parameters like skewness and kurtosis requiring much longer time, respectively 1,6 years and 88 years of data.

I cannot easily see where these numbers are coming from.

***Response to Comment #7*:** Thank you for pointing this out. The values of 1.6 years for skewness and 88 years for kurtosis refer to the estimated amount of hourly wind observations required to achieve a given level of accuracy in estimating these shape-related parameters. These estimates correspond to the least demanding stations in our study: for skewness, 14,084 hourly observations are required at station SN35860, which is equivalent to approximately 1.6 years of data. For kurtosis, 777,573 hourly observations are required at station SN38140, corresponding to about 88 years. These values are reported in Table 4 of the revised manuscript. We have clarified the process of how these values were obtained and revised the corresponding explanation in the manuscript to improve transparency. The updated text is shown below:

"*3.3 Determine an effective sample size for capturing overall wind characteristics*

To determine the optimal sample size for capturing wind characteristics, we analysed the relationship between percent errors and sample sizes (Fig. 4-5). Percent error measures discrepancies between parameters from the full dataset and smaller subsets. Based on the 90% CIs derived from 1,000 realizations of random sampling of in-situ observations (orange lines in Fig. 2 & Fig. S4), we computed percent errors of CI bounds and fitted power-law equations to describe their dependence on sample size. These fitted equations are summarized in Table 3 and allow extrapolation of error margins for any given sample size." (Lines 272-277 in the clean version of revised manuscript)

"*To facilitate practical use, we calculated the minimum sample sizes required to achieve ±10%, ±5%, ±2%, and ±1% error margins for each parameter at each station (Table 4).*" (Lines 286-287 in the clean version of revised manuscript)

***Reviewer's Comment #8*:** A statement about a 88 year time scale based on a time series not longer than 16 years is a bit strange. How is this calculation done? It must be based on some assumptions, but which ones? And what about non-stationarity features of the time series like effects of climate changes?

***Response to Comment #8*:** The 88-year time scale mentioned in the manuscript is not derived from actual observational data of such duration but rather estimated using the fitted equations that describe the relationship between percent error and sample size, as shown in Table 3 of the manuscript. These equations were obtained through curve fitting based on the random sampling results, as described in detail in the response to Comment #7.

Once the equations are established, they allow us to estimate the sample size (in hours or years) required to achieve a given level of percent error. For instance, if one sets a percent error threshold, the model may suggest that up to 88 years of continuous data would be required to meet it. This is a theoretical extrapolation

Regarding the reviewer's concern about non-stationarity due to climate change, we fully agree this is an important issue. However, for the purposes of this study, we assume stationarity. Our aim is to assess how the length of the dataset affects the estimation of wind distribution parameters, not to assess trends in the wind climate. The reference long-term datasets are used to characterize the current wind climate baseline, not to make future projections. We acknowledge that climate-driven changes in wind characteristics could influence the applicability of these estimates in future conditions, and we agree this is a valuable direction for future work.