AC 2

"Applying a Random Time Mapping to Mann modelled turbulence for the generation of intermittent wind fields"

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We would like to thank the reviewer for the valuable comments, questions, and suggestions. They helped us significantly. We agree that the manuscript needs improvement and revised it as described below. All your comments have been addressed below in blue. Line numbers refer to the marked version of the manuscript "marked.pdf"

General comments:

The intermittency of atmospheric wind fields has already been examined in many studies in the past. The working group in Oldenburg has been working for a long time on the investigation of the influences of intermittent wind fields on the aerodynamic properties of airfoils and wind turbines and the development of methods for the synthetic generation of wind fields taking intermittency into account. The present manuscript represents a further contribution to this topic. It proposes the combination of the CTRW-based approach suggested by Kleinhans with the established Mann model for turbulence generation, in order to utilize the spatial correlations considered in the latter model. The differences to the original Mann model are exemplified by a generated wind field and the load statistics for a 1.5 MW turbine calculated with BEM by means of FAST. It could be shown that mean values and variances of the wind fields and loads agree well. However, the extended approach, denoted time-mapped Mann model, shows intermittencies, both, in the generated wind field and in the calculated loads except for the flapwise blade root bending moment. The consideration of shear, as foreseen in the Mann model, obviously requires further, considerable development effort in the CTRW approach and is still pending. The present results are therefore limited to a wind field without shear.

The manuscript is concisely written and contains a good and broad overview of the specific state of research. However, unconventional nomenclature, partial lack of introduction of variables in the text, and inconsistent use of variables complicate readability. The results show some peculiarities in the predicted loads that may be attributed to the turbine BEM model rather than to the wind field model.

You are right, there were some undefined nomenclature and other issues. We have modified the manuscript to make it as clear and readable as possible.

The turbine model should be checked prior to the interpretation of the results.

We have based our turbine simulations on a validate model.

In the results section, the authors largely limit themselves to describing the results visible in the pictures without analyzing and explaining peculiarities in the results. In this respect, the manuscript should be improved.

You are right, the explanation of some results was not clear. Therefore, we have elaborated the results to be clear as possible.

Moreover, I do not see why an Appendix is necessary and suggest incorporating the content directly in the paper.

We have added this appendix since the cubic case is only used to show some concepts related to the number of grid points. Therefore, we thought that writing this part as an appendix would make it easier for the reader to follow the mainstream of ideas.

In conclusion the study is relevant and I in principle support publication of the manuscript if the following comments are taken into account and the interpretation of the results is elaborated.

Thank you for your positive feedback. All comments are addressed in this document.

Specific comments and remarks:

- Please introduce new properties throughout the document (like e.g. r in L. 104, Δx 2 and Δx 3 in L. 115, ...) and use the variables consistently.

Noted and modified in both cases. Also, it is checked over the whole paper to be used consistently and can be seen in the marked version of the manuscript.

- L. 112: „where the double index does not indicate a summation here" is more confusing than helpful.

This sentence is now replaced in line124 of the marked version of the manuscript with "where the ii-index refers to the respective diagonal element of the tensor".

- L.132: Are u 1 and u 2 velocity fluctuations or absolute velocities? Compare eq. (1) small vs. capital letter.

You are right, u1 and u2 are the velocity fluctuations as indicated in Eq.1. However, in this line, we intend to show the absolute velocity of U_1 and U_2. The symbols are now corrected in line 152 of the marked version of the paper.

- L. 138f.: An increasing deviation for reduced τ is hardly visible in Fig. 1 due to the vertical shift. Perhaps this can be made visible by a more appropriate choice of the ranges shown.

You are right, the differences are hardly visible in Fig 1 (a). However, the differences are made visible through plotting the kurtosis in Fig 1 (b). In Fig 1 (b), a wider range of τ is studied to show the change of the kurtosis with τ. However, strong deviations from Gaussianity are observable even for large τ values due to the superposition of large-scale structures as explained by Böttcher et al. (2007). The work by Böttcher et al. has been accordingly mentioned and referenced in the paper in line 172. An additional explanation on this reason for the curves looking similar in Fig 1 (a) is given in lines 173-176.

- L172: “different” ” multiple”/”several”

Noted and modified.

- Figure 2: To use x2 as vertical component and x3 as lateral is unusual (cf e.g., Mann,1998). Please ensure consistency throughout the paper. N as well as the Δ values likely refer to the Mann box parameters. These are not introduced yet, please do so. Using Δx 2 and Δx 3 with a different meaning than in equation (6) confuses. I suggest to use e.g., $\Delta x_{1,M}$ and $\Delta x_{2,M}$ here.

Thank you for this hint. This work has followed the same numbering as Mann (1988). However, in the previous version of the paper, the numbering was not correct in Fig.2. This mistake is now fixed, and the figures are updated.

For Δx_1, Δx_2, and Δx_3 describing the Mann box, they are now called $\Delta x_{1,m}$, $\Delta x_{2,m}$ and $\Delta x_{3,m}$ as suggested. This has been modified in Tab. 1 and appendix A1

- L. 255ff: Is there a specific reason why you prefer Eq. (21) instead the derivation according to IEC 61400-01 if no shear is considered? L=0.8*Λ with Λ = 42m due to z hub > 60m →L=33.6m

Yes, you are right that the IEC61400-1 gives another method to calculate the length scale. However, according to *Hannesdóttir et al. (2019)*, the turbulence length scale was calculated using Eq. 21 (now Eq. 20 in the updated version of the manuscript) because the turbine is large, and the turbulence length scale should be of the same order of magnitude as the hub height. We have used this equation to also use it for even larger wind turbines. An additional statement has been added to the manuscript to clarify this issue in lines 293-295 in the marked version of the manuscript.

- Table 1: Please justify the choice of the Mann box parameter. How is length n x1 chosen? n*Δx in lateral direction is not even twice the integral length scale L; is this sufficient to resolve the statistics?

In general, the parameters of the Mann box were selected to be a compromise between the reasonable representation of the wind field and the computational resources needed for the simulations. In Fig. 6 we have provided a comparison between spectra of the Mann field, the time-mapped Mann field, and the theoretical spectra calculated from Eq. 14, where the plots showed good agreement. Hence, we assume that the correlation can be displayed sufficiently using this length scale value and that the current statistics are sufficient. At the same time, the computational effort is still reasonable.

n_{x1} was chosen to achieve a simulation time long enough to perform the appropriate field analysis and to be within the limits of the number of points in the Mann box generation tool. So, $\Delta x_{1,m}$ was calculated according to U_1 and n_{x1}.

Also, the values of $\Delta x_{2,m}$ and $\Delta x_{3,m}$ are set to be close to $\Delta x_{1,m}$ to avoid any problems that could happen due to high aspect ratios of the grid cells. Accordingly, n_{x2} and n_{x3} are selected to cover the whole turbine without exceeding the numerical limits of the tool and to keep the field big enough to perform different statistical analyses in x_2 and x_3 directions. We use $n_{x2}=n_{x3}$ and $\Delta x_{2,m}= \Delta x_{3,m}$ because of the symmetric shape of the turbine and because there are no expected differences in the field in x_2 and x_3 directions. Accordingly, it is reasonable to make the parameters of the Mann box in x_2- and x_3- directions the same. The value for the Mann box parameter $c_K\varepsilon^{2/3}$ was introduced in the ESDU spectral model.

- L. 269ff: As Kleinhans pointed out, one disadvantage of the CTRW approach is the definition of the various parameters (α, c, Δs_t) that control the intermittency. The general validity of the approach is limited in particular by the fact that α depends on the time lag and must be calibrated in order to correctly represent real intermittent wind fields. The values chosen in the present study do not contain a $\alpha(\tau)$ dependency and differ significantly for c, Δs t but also for α from the values chosen by Kleinhans. Are there any recommendations for selecting these parameters for practical cases and can the authors reason their choice?

The selection of the parameters was based on the calculated kurtosis (from Eq. 11) of v_1 for the generated time-mapped signals. An iterative process was performed for achieving the target values of Kurt(v_1). These target values are in a comparable range to the Nordex data in Fig. 1 and to those presented in *Schwarz et al.* (2020) for different atmospheric measurement data sets. The main objective of the iteration was to achieve intermittent behavior without compromising the other statistical features such as the standard deviation and the spectrum. In general, as already mentioned in Sec. 2.3, lower values of α and higher values of c and Δs_t will lead to more intermittent time series. An additional statement has been added to the manuscript to clarify this issue in lines 308-309 in the marked version of the manuscript.

- L. 279: Repetition of the statement from L. 276f.

The sentence in line 276 is now deleted.

- L. 283: Please include your definition of (κ =2*π*f/U) and specify U to make sure whether it’s an angular wavenumber.

The definition has been added to the manuscript to clarify this issue in line 319 in the marked version of the manuscript.

Since in this section we apply Fourier transform in space and this results in the wavenumber in space, we do not want to confuse it with the frequency space. If the comment is referring to the Ref. Mann (1998), where f is either the frequency or the Coriolis parameter in Equ. 18 of this reference, then we do not have the second term of Equ. 18 i.e. f is the frequency as described in Ref. Mann (1998).

- Fig. 6: Fig. (a) obviously shows a narrowband spectrum whereas (b) and (c) seem to be smoothed or have large frequency bins. Please justify this inconsistency or align.

Fig. 6(a) represents the spectrum in x_1-direction with nx_1 = 131072 while Figures 6(b) and (c) represent the spectra in x_2- and x_3-directions with $nx_2 = nx_3$ = 32. The lower number of grid points in x_2- and x_3-directions caused these smooth curves in Figures 6(b) and (c) after using the Fourier transform to generate the spectra. An explanation statement has been added to the manuscript to clarify this issue in lines 366-368 in the marked version of the manuscript.

- L 291ff: Please rework interpretation of Fig 6 and explain what spectra characteristic was to be expected for the new wind field model (e.g. L. 293: Does the difference between Time-mapped and original Mann in 6(a) for low wavenumber represent intermittency?

That is a good remark. It is important to note that the difference between the Time-mapped and original Mann field in Fig. 6 does not represent the intermittency. As indicated in Sec. 2.1, the velocity spectrum is not sufficient to show the intermittency. Therefore, increment statistics should be used in this case to show the effects of intermittency. Here, an explanation statement has been added to the manuscript to clarify this issue in lines 358-359 in the marked version of the manuscript.

- L. 294f: The statement cannot be followed because the small wavenumber range is not shown in plots 6(b) and (c).

You are right, we cannot plot the spectra for low wavenumbers because of the small number of grid points in x_2- and x_3-directions. However, the deviation happens for high wavenumbers. We have rephrased this in lines 356-358 in the marked version of the manuscript.

- L296: The number of grid points in vertical and lateral direction is the same for the Mann model and the time-mapped Mann model, Therefore I cannot follow your explanation that the differences result from the grid. Please clarify.

The Time-mapped Mann field is generated from time mapping of the different slices of the original Mann field. To get the required time step in the time-mapping process, the slices of the time-mapped field must be regenerated using linear interpolation. This linear interpolation between the time-mapped slices and the regenerated slices leads to interpolation errors and hence the deviations, as shown in Fig.3. and lines 351-353

- L. 297ff: The conclusion from comparison to A1 is not obvious. Ranges are different and therefore deviations are hardly comparable. Moreover, changes in grid size and resolution are mixed and hence effects cannot be attributed to a finer discretization for sure. It is still unclear why the size or resolution should explain differences between time-mapped and original Mann model.

For each box, there are three different parameters used to generate the box: the overall box size, the grid cell size, and the number of cells. It is not possible to change the value of one of these parameters alone without changing at least one of the other two parameters to generate a grid with comparable results. Therefore, we have generated a new grid with cubic cells to have independence of the direction since all directions have the same grid points and cell sizes. This explanation has been added to the appendix of the manuscript in lines 479-483.

- L. 308ff: Please mention the "settings" (Δx_2 , Δx_3) also in the text and ensure that this distance values are not confused with Mann box parameters and elaborate the interpretation.

Noted and modified in the manuscript to clarify this issue in lines 291-292 in the marked version of the manuscript. We have also renamed these parameters to $\Delta x_{1,m}$ $\Delta x_{2,m}$, and $\Delta x_{3,m}$ not to be confused with the spatial steps in the statistical calculations.

In the comparison between Mann and Time-mapped Mann fields, the velocity spectra are expected to be the same since the one-point spectra are not able to show the effects of the time mapping. Therefore, two-points statistics, like coherence, are used to show these effects. In Fig. 7, we can notice the differences between Mann and Time-mapped Mann fields in the x_1-direction while x_2- and x_3-directions are almost similar. The same can be noticed in Fig. A2. This explanation has been added in lines 356-357 in the marked version of the manuscript.

- L. 311ff: Can the authors please interpret this characteristic in more detail and explain the difference to the behavior for the cubic case in Appendix? The plots in A2 are somehow smoothed, please get it consistent with Fig. 7.

Both, Fig. A2 and Fig. 7 were plotted in the same way. The noise that can be seen in Fig. 7 comes from a larger number of points in the x_1-direction in the original field. However, the lower number of points of the cubic case compared to the original case makes plot A2 smoother. An additional statement has been added to the manuscript to clarify this issue in lines 366-368 in the marked version of the manuscript.

- Fig 7: Please do not mix (x,y,z) and (x_1 ,x_2 ,x_3) and get it consistent with Fig. 2.

Noted and applied over the whole text.

- P. 19, Tab. 3: I assume that the Dynamic Stall and the Dynamic Inflow models were activated in the FAST calculations. To be on the safe side, this should be mentioned. Moreover, does the turbine have tilt?

Noted and modified in Tab. 3. Also, the turbine has a 5° tilt.

- Fig. 10: For better differentiation of the figures, the specific moment (RootFlap, …) depicted in (a) to (d) could be added to the axis labels or the respective figures.

Noted and the plots were modified as requested.

- L. 357ff: Fig. 10 shows interesting results. Fig. 10 (b) - (d) clearly shows the influence of intermittency. However, Fig. 10 (a) does not show any impact of intermittency in the results with the new model. This is strange since I cannot see how the blade bending loads and the thrust (as the sum of the three blade loads in the same direction) differ in their intermittent behavior that strongly. Please conduct further investigations to explain this unusual behavior. Further, in (b) - (d) the intermittent effect decreases considerably faster for larger time lags τ than in the wind field in Fig. 8. The analysis of the causes for these relevant and interesting differences would be an important outcome of the investigations. Here the authors merely refer to future studies. I would, however, expect the authors to make investigations into potential reasons and provide explanations in the present paper.

The RootFflap in Fig 10 shows a significant difference to the other loads. In fact, the RootFlap increment PDF seems to be non-intermittent at all. However, that is not entirely correct, it just turns out that it exhibits oscillations like Fig 11 but with much lower amplitude and on a different frequency which is not captured by the specific selected time step sizes in Fig 10 a.

Conclusions about the faster decrease of the intermittency for loads compared to wind need further investigation. The investigation of how different spatial correlations of the wind (e.g non-correlated, fully correlated) affect the intermittency of the loads might explain this difference. However, in *Mücke et al.* (2011), the authors have shown that the kurtosis of the measured wind is higher than the kurtosis of the resulting turbine torque (the torque was calculated from numerical simulations by using atmospheric wind measurements as input). These ideas were elaborated in lines 428-430.

- Fig. 11: Also, in the case of the unusual characteristics of the Kurtosis shown in Fig. 11 (strong drop for smaller time lags, strong peaks at τ =1s, 2s,...), no analysis of the results and indication of possible causes was made. The statement "This might be directly related to the wind turbine and is subject to future research." is not sufficient here. Please check the BEM model and settings and ensure that no tower impact, tilt, gravity etc. is considered and elaborate the interpretation.

We have double-checked the settings of our BEM model and we can confirm that the predicted response of the turbine is due to the characteristics of the wind field, and not due to the turbine model. Further analysis of the results has shown that the effect of the intermittency is related to the rotational frequency of the turbine (see line 433 in the marked version of the manuscript).

- P. 23: It would be interesting to compare the fatigue loads resulting from the original Mann model and the extended model and I suggest including the corresponding results in the paper to show the intermittency has a relevant impact on the loads.

You are right, it would be interesting to compare the resulting fatigue loads. However, it is important to first investigate whereas the proposed guidelines for calculating fatigue loads can properly detect the intermittent structures. The proposed rainflow counting method focuses on the amplitude of the oscillations rather than their temporal scales, that correspond to a key aspect of the intermittency. Given the discrepancies between the current definition of fatigue loads and the nature of the intermittency, it is questionable how accurate they can be correlated. In *Mücke et al* (2011), the authors concluded that the resulting larger fluctuations on the torque from an intermittent wind field were not detected by the rainflow cycle counting algorithm.

- Conclusion: It would be nice if findings on the conversion of the intermittent wind field to the turbine loads and the fatigue loads could be added, see comment above.

Noted and added to the conclusion.

- Figs. A1/A2: The thin grid lines and axis ticks are barely visible (in the printout). The lines in Fig. A2 should be thicker.

Plots are modified as requested.

Typos:

- L- 152: Pope (2001) →(Pope (2001))

Noted and corrected in line 183 of the marked version of the manuscript.

- L. 190: (s) / (t) →no brackets

Noted and corrected in line 221 of the marked version of the manuscript.

- L. 250: space after „area.“

Noted and corrected in line 282 of the marked version of the manuscript.

- L. 270: „c=20“ →„c=20s.“ + math mode in latex

The parameter c is dimensionless, refer to Equ. 19 and line (0< τ_α<c) where τ_α is dimensionless. Math mode is now used and corrected in line 305 of the marked version of the manuscript.

- L. 321: “τ Fig. 9” →“τ. Fig. 9”

Noted and corrected in line 305 of the marked version of the manuscript.

- Tab. 4, caption: for consistency “Rel.Diff.” →Rel.Diff”

Noted and corrected in Tab. 4 of the marked version of the manuscript.

- L. 369: “sec” →“seconds”

Noted and corrected in line 417 of the marked version of the manuscript.

- L. 406: „...= 1“ →„...= 1m“

Noted and corrected in line 459 of the marked version of the manuscript.