Journal: Wind Energy Science

Manuscript: Fractal-based numerical simulation of multivariate typhoon wind speeds utilizing Weierstrass Mandelbrot function

Dear Editor:

We have carefully considered all the review comments and believe that we have revised the manuscript to the best of our ability. Listed below please find our written responses to the reviews' comments and the corresponding revisions which have been highlighted in yellow. We will look forward to hearing from you.

Yours Sincerely,

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Specific Comments:

1. This paper proposes a "fractal-based" technique for the analysis and simulation of typhoon wind velocities. At first sight, this could be seen as a potential contribution to the advancement of state of-the-art wind energy analysis and simulation techniques, which too often rely on quasi-normal assumptions. However, the typhoon wind velocities could be easily out of the range of the exploitable wind velocities by turbines. Surprisingly, the authors do not discuss this possible limitation at all and more generally how their results could be used in the wind energy framework.

Response: Thanks for your attention. We appreciate your thoughtful consideration of the potential limitations regarding the applicability of typhoon wind velocities to wind energy systems. You raise a valid point that typhoon winds can be outside the typical range of exploitable wind velocities by turbines. In our paper, our primary focus is on the analysis and simulation of typhoon wind velocities from a fractal perspective, which can have broader applications beyond wind energy.

While we acknowledge that typhoon wind velocities may not align with the optimal operating range of wind turbines, it's essential to highlight that our research contributes to the understanding of wind behavior under extreme conditions. This knowledge can be valuable for various applications, including structural wind load calculations, disaster prevention and mitigation analyses, and the assessment of structural wind-induced vibrations.

Regarding the specific issue of wind energy applications, you rightly point out that the operation of wind turbines during typhoons is a complex engineering challenge. We believe that our simulation methodology can serve as a valuable tool in the broader context of wind energy research. However, we also recognize that the integration of typhoon wind data into wind energy systems involves additional considerations, such as turbine, and grid management. While these aspects are beyond the scope of our current study, they represent a crucial avenue for future research and development in the field of wind energy.

In summary, while our paper primarily focuses on the fractal analysis and simulation of typhoon wind velocities, we appreciate your input regarding its potential applications in the wind energy framework. We believe that our work lays the foundation for further exploration of how typhoon wind data can be effectively integrated into wind energy systems and look forward to future research in this direction.

Additionally, several necessary explanations have also been added in lines 448-475 of the new manuscript, as follows:

"Wind is the natural movement of air relative to a planet's surface, and the time history of wind speed exhibits self-similar fractal characteristics. However, accurately determining the fractal dimension, which quantify the degree of this self-similarity in the wind speed time history, presents a significant challenge. Furthermore, current fractal-based method for simulating wind speeds lack the ability to capture the nonstationary feature of wind speed and reflect the actual spatial correlations within the wind velocity field. To address these issues, this paper focuses on determining an appropriate method for the fractal dimension estimation of wind speeds, and then propose the stochastic WM function-based numerical simulation method (SWM method) for the multivariate nonstationary wind speed simulation. The study demonstrates that the structure function method is a more suitable technique for estimating the fractal dimension than the box counting method, variation method, and R/S analysis method. Field-measured wind data recorded during Typhoon Mangkhut (2018) were used to present the performance of the proposed method. The specific findings are as follows

(1) Various methods to determine the fractal dimension of winds affect the accuracy of the estimated fractal dimension estimation. The mean fractal dimension of 1.75 obtained by the structure function method is closest to the representative value of 1.7 than other three methods. Furthermore, the estimated fractal dimension by the structure function method is quite robust and insensitive to stationary or nonstationary wind models used.

(2) The multivariate wind speed components simulated by the proposed fractal-based SWM method are in good agreement with the measured records in terms of fractal dimension, standard deviation, probability density function, wind spectrum and cross-correlation coefficients. The proposed SWM method combined with the TVM components is capable of generating nonstationary multivariate typhoon wind speeds.

This paper enhances our understanding of typhoon wind from a fractal perspective, and provides a novel approach for simulating typhoon wind speed time histories. We believe that our work lays the foundation for further exploration of how typhoon wind data can be effectively integrated into structural wind load calculations, disaster prevention and mitigation analyses, the assessment of structural wind-induced vibrations, and the wind energy framework and look forward to future researches in these directions."

2. Unfortunately, a more radical limitation is the use of the stochastic Weierstrass-Mandelbrot function as the stochastic model of wind velocities that is extremely outdated.

   Response: Thanks for your review. Although the stochastic Weierstrass-Manderlbrot function was proposed at 1980, it has been also extensively used recently to construct the 3D fractal tooth surface (Xia et al., 2023), study the effect of the disturbance in economic and financial system (Zhang, 2023) and so on due to its unique performance for the fractal feature. Thus, it is not out of date to adopte this function to simulate the fractal wind speeds.

   Xia, Heng et al. "Nonlinear dynamics analysis of gear system considering time-varying meshing stiffness and backlash with fractal characteristics." Nonlinear Dynamics 111 (2023): 14851 - 14877.

   Zhang, Li. "Generalized Weierstrass-Mandelbrot with Disturbance for Big Data Applications in Economic and Financial Systems." *2023 IEEE 8th International Conference on Big Data Analytics (ICBDA)* (2023): 53-56.

3. It is ironic that Richardson (1926) used the Weierstrass function (as presented by Klein, 1902) as a pedagogic example of the non-differentiability of wind and was cautious enough to state he was not suggesting that it has anything to do with real wind.

   Response: While Richardson (1926) did not establish a direct connection between the Weierstrass function and real wind, it is important to note that subsequent research has explored potential links. References in this paper to works by Humphrey et al. (1992), Barszcz et al. (2012), Liu et al. (2013), Wu et al. (2015), and Lyu et al. (2018) highlight attempts to bridge this gap and apply the Weierstrass function to real wind characteristics. These efforts underscore the meaningfulness of using the Weierstrass function as a tool for studying and simulating real wind phenomena.

4. On the contrary, the present authors rely on Mandelbrot's assertion that one parameter of the function is "the" fractal dimension to limit their investigations to how best to estimate this single dimension, whereas, since the early 1980s, wind intermittency has been considered to result from an infinite hierarchy of embedded fractal supports, and, hence a similar hierarchy of fractal dimensions. See, for instance, Calif and Schmitt (2014) and Fitton et al. (2014) for applications to wind energy, Lazarev et al. (1994) and Lee et al. (2020) for typhoons, as well as references herein. This hierarchy corresponds to the physical fact that increasing wind fluctuations are concentrated on smaller and smaller fraction of space-time. It is hard to understand how the authors missed this fundamental methodological point in their state of the art. Fractal analyses, as carried out by the authors, have therefore been abandoned in favour of multifractal analyses. In the present case, the authors estimate the fractal dimension using only the second order structure function, whereas it has become quite common to estimate the dimension hierarchy using the structure functions of all positive orders. It is worth noting that the underlying stochastic model is quite different from the Weierstrass-Mandelbrot function and gives a different meaning to the scaling exponents and associated dimensions, including for the second order.

Response: Thank you for highlighting the importance of multifractal analyses in wind speed studies. While the multifractal phenomenon has indeed been demonstrated using the structure function, the estimation of multifractal dimensions with clear physical significance remains a challenge. I acknowledge the value of exploring the relationship between the multifractal Weierstrass-Mandelbrot function and multifractal wind speeds in future research. It's important to note that our current paper focuses on multivariate wind speed simulation with a single fractal dimension, which addresses a specific aspect of wind behavior. We appreciate your input, and your suggestions will be taken into consideration in future investigations. At the same time, this shortcoming has been added in the line 438-444 of the new manuscript, and relative papers have been cited as follows:

By combining the TVM components, the proposed SWM with a single fractal dimension is able to reproduce nonstationary typhoon wind speed series effectively. It is worth noting that, while there have been studies on the multifractal description of atmospheric wind speed (Calif and Schmitt, 2014; Laib et al., 2017), a comprehensive explanation and calculation of multifractal dimensions with clear physical significance have not yet been adequately established. The simulation of multifractal wind speeds based on the WM function is thus a research area that requires further investigation in the future.

Calif, R., Schmitt, F.G. (2014). Multiscaling and joint multiscaling description of the atmospheric wind speed and the aggregate power output from a wind farm. *Nonlinear Processes in Geophysics*, 21: 379–392.

Laib, M., Golay, J., Telesca, L., Kanevski, M. (2017). Multifractal analysis of the time series of daily means of wind speed in complex regions. *Chaos, Solitons and Fractals*, 109, 118-127.

5. Overall, the current manuscript is not so well suited to the scope of Wind Energy Science, but, among Copernicus Press journals, better to that of Nonlinear Processes in Geophysics. However, to be successful, a fundament methodological update should be carried out before transferring this paper.

Response: Thank you for your detailed comments and suggestions. We appreciate that you think our paper might be more suitable for "Nonlinear Processes in Geophysics". However, we believe that our paper aligns with the scope of Wind Energy Science. With the increasing demand for electricity in society, there were more and more wind turbined installed at the offshore area, which was sensitive to gradually increasing Typhoons, especial at the south-eastern coastal part of China. Thus, developing an accurate method to represent and simulate typhoon wind speed is vital for the dynamic analysis and wind energy framework of the wind turbine under typhoon event. To compensate the development of these fields, this paper conducted a multivariate typhoon wind speed simulation, which consider the actual fractal characteristic. This paper can promote the understanding of typhoon wind speeds with a view of the fractal, and provide us with a new way to simulate typhoon wind speeds and then conduct the dynamic analysis, safety assessment and wind energy framework of wind turbines. We have done our best to improve the new manuscript to meet the requirements of Wind Energy Science. We hope to contribute valuable insights to the field of wind energy through this research. Some improvements have been added in the line 470-475, as follows:

"This paper enhances our understanding of typhoon wind from a fractal perspective, and provides a novel approach for simulating typhoon wind speed time histories. We believe that our work lays the foundation for further exploration of how typhoon wind data can be effectively integrated into structural wind load calculations, disaster prevention and mitigation analyses, the assessment of structural wind-induced vibrations, and the wind energy framework and look forward to future researches in these directions."