**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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## ***RC1***

## General comments:

The authors of this manuscript develop a fractal-based technique for simulating multivariate nonstationary wind speed fields by the stochastic Weierstrass Mandelbrot function. Based on the comparative analysis of the four methods, it was found that the structure function is more suitable and reliable. For case study, the authors also analysed the significant non-stationary properties and fractal dimensions of Typhoon wind speed data at various heights and demonstrate the effectiveness of the proposed multivariate typhoon wind speed simulation method. The paper is well-structure and detailed, with a lot of pages that are mathematical and technical but it still easy to follow. I truly congratulate the authors on this manuscript, which I believe should be considered for publication after major changes.

***Response***: Thanks for reviewing our paper. Listed below please find our written responses to your specific comments.

## Specific Comments:

1. Line 113, a reference of the box counting method should be added

   ***Response***: Thanks for your question. The reference has been added in line 113 of new manuscript, as follows:

   "The box counting method (Sarkar and Chaudhuri, 1994) mainly consists of placing the wind speed time series with grids,"

2. Line 169-179, The explanation of the results in Figures 1-4 is too concise, especially lacking the comparison of some quantitative results. For example, in Figure 4, quantitative value is needed to show the accuracy improvement of the structure function method compared to other methods.

   ***Response***: Thanks a lot. The more detail explanation has been added in lines 171-185 of the new manuscript, as follows:

"For this comparison study, a fractal dimension of 1.7, which is the common value for wind speed series reported in the literature (Li et al., 2001; Cui et al., 2022), was applied in Eq. (11) to generate the time series, as shown in Fig. 1. Four estimation methods were then used to estimate the fractal dimension of the generated time series of Fig. 1, and the log-scale fitting plots corresponding to four estimation methods were presented in Fig. 2. Fig. 2 shows that the R/S analysis method get the lowest estimate, *D*=1.0836, significantly deviating from the true value of 1.7. On the other hand, the structure function method provides the most accurate result of 1.6941 with the smallest relative error of 0.35% in terms of the sample used in this exercise. By repeatedly sampling the phase random number $\emptyset$ in Eq. (11), 50 different time series have been generated with the same set of parameters (i.e., *A*=1, *D*=1.7 and $\gamma$=1.08). Fig. 3 presents the estimated results of fractal dimensions for 50 generated time series samples, showing that the random parameter $\emptyset_n$ have little effect on the recognition accuracy of the dimension $D$. Besides, the structure function method consistently obtained the best estimates around actual value 1.7 compared to other three methods, i.e., box counting method, variation method and R/S analysis method. For a range of fractal dimensions from 1.4 to 1.8, different time series were also generated by Eq. (11), and the fractal dimensions were estimated respectively by four methods and reported in Fig. 4 against the given values (i.e., the black dashed line $\mathrm{y = x}$). As shown in Fig. 4, while the structure function method may slightly overestimate the fractal dimension for dimensions below 1.7 and provide a minuscule underestimate for dimensions above 1.7, it remains the most accurate method to estimate the fractal dimension of a given time series among the four methods in comparison. "

3. Line 242, multivariate synchronous simulation of wind speeds, such as?

***Response***: Thanks for your comments. The univariate fluctuating wind speed can be simulated by Eq. (15) in section 2.3 (i.e., the simulation of wind speed at the single point). Whereas, the synchronous simulation at different location points should represent the corresponding spatial correlation. This is the research point of section 2.4 (namely, the Multivariate synchronous simulation of wind speeds). We introduce a Gaussian random sequence $\varphi$ with zero mean and standard deviation of $\sigma_\varphi$ (i.e., $\varphi \sim N(0, {\sigma_\varphi}^2)$) in Eq. (15) to get Eq. (27) and Eq. (29). We can select a suitable $\sigma_\varphi$ to make the cross-correlation coefficient of multivariate synchronous wind speeds simulated by Eq. (15) and Eq. (27) very close to the actual value from the measured synchronous wind speeds at different location points. This is the main point of section 2.4.

4. Line 303, whether 526 is a sufficient sample?

***Response***: Thanks for your reviewing. Generally speaking, due to the unpredictability of the typhoon track and huge cost for the construction of meteorological gradient tower, it is very difficult to obtain complete observational data of Typhoons at different heights using the three-dimensional (3D) sonic anemometers fixed at the meteorological tower. Fortunately, the super typhoon Mangkhut was well recorded when it passed Shenzhen, china. From Fig. 8, the mean wind speed increase from a very low wind speed to high value, and then gradually decrease to a low level, which completely record the process of the super typhoon Mangkhut passing Shenzhen. These data are very rare and valuable. All measured wind speeds (526 samples) at different heights were applied to conduct the study of this paper, and also employed for the comparison of Typhoon wind characteristics based on different wind speed models reported by Cai et al (2022). Besides, only 1800 second measured wind speed time histories of the thunderstorm downburst were also employed by wang et al (2013) and Huang et al (2020) for the simulation of multivariate nonstationary winds. Thus, all measured wind speed data recorded during the super Typhoon Mangkhut passing Shenzhen, china (i.e., 526 wind speed samples) is sufficient for demonstrating the validness of proposed approaches in this paper for the simulation of multivariate synchronous wind speeds.

Cai, K., Huang, M.F., Xu, H.W., Kareem, A. (2022). Analysis of Nonstationary Typhoon Winds Based on Optimal Time-Varying Mean Wind Speed. *Journal of Structural Engineering*, 148(12):04022199.

Huang, G.Q., Peng, L.L., Kareem, A., Song, C.C. (2020). Data-driven simulation of multivariate nonstationary winds: a hybrid multivariate empirical mode decomposition and spectral representation method. *Journal of Wind Engineering and Industrial Aerodynamics*, 197: 104073.

Wang L, Mccullough M, Kareem A. (2013). A data-driven approach for simulation of full-scale downburst wind speeds. *Journal of Wind Engineering & Industrial Aerodynamics*, 2013, 123: 171-190.

5. Line 307, why the author chose Typhoon Mangkhut as an example? It is better to give brief reason to show its representativeness.

***Response:*** Thanks for your comments. The research point focus on the simulation and fractal dimension estimation of nonstationary wind field, and Mangkhut is the super typhoons, which present the extremely strong nonstationary characteristic. That is why we chose Typhoon Mangkhut as an example to conduct a detail study in this paper. Some improvement has been added in the line 319-322 of the revised manuscript, as follows:

"It is evident from Fig. 8 that mean wind speeds increase first and then decrease gradually over time, which present the strong nonstationary characteristic of the Typhoon Mangkhut. That is the reason why these measured records were chosen in this paper as the case study for the simulation of multivariate nonstationary wind speeds."

6. Line 433. The discussion section can be enriched, highlighting the main contributions of this research, as well as possible future applications. As such a highly technical paper, this will make it clearer to the general reader what problem the article is trying to solve.

***Response:*** Thanks for your comments. The conclusion section has been enriched as you suggest. Some improvements have been added in lines 448-453 and 470-475 of 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.”