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Extreme typhoon wind speeds in Hong Kong integrating the effects of climate change using the Shared Socioeconomic Pathway 5-85 (SSP5-85)

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SUMMARY:
The statistically predicted wind fields and the extreme wind speeds in Hong Kong are estimated by using an integrated typhoon wind field model that combines the effect of climate change on future typhoon wind fields and probabilistic models of typhoon key parameters (i.e., translation velocity, approaching angle, central pressure deficit, radius to the maximum wind, the minimum of closest distance and the occurrence rate). In comparison with the previous climate condition (SSP historical), the most extreme climate scenario — the Shared Socioeconomic Pathway 5-85 (SSP5-85), is used to forecast the typhoon wind fields in Hong Kong for the next 60 years. The SSP5-85 predicts that the mean Sea Surface Temperature (SST) around Hong Kong will rise by 2.24°C from 1961-2020 to 2021-2080, resulting in a 12.97% increment in the predicted typhoon mean wind speed. Additionally, the extreme winds in Hong Kong for the next 60 years are generated and compared with the design wind speeds recommended by the Hong Kong Wind Code 2019, and the safety of the design wind speed is proven under the severe climate change.

Keywords: typhoon wind field, climate change, extreme wind speeds

1. INTRODUCTION

The typhoon is one of the most potentially destructive extreme weather events affecting human societies in the coastal regions in the Northwest Pacific Ocean, especially in areas that are heavily inhabited and developed, such as Hong Kong. The increase in Sea Surface Temperature (SST) is strongly associated with more intense typhoons because the warm sea may enable typhoons to gather more energy and develop faster and stronger than ever before. Typhoon wind predictions require long-term observations maintained by meteorological weather stations. However, due to the vulnerability of remote anemometers, there may not be enough data recorded, which could result in inaccurate wind field estimates. As a result, the research community generally accepts the Monte-Carlo Simulation (MCS) as a viable method for analyzing the risks associated with typhoons. Since the MCS employs a specific wind field model, the accuracy of the typhoon boundary layer wind field model is crucial for wind field predictions, potential damage due to the consequences of global warming, and adapting the mitigation actions against typhoons. In the current study, the refined wind field model that considers that the pressure varies with height, is employed to predict the statistical wind fields and extreme wind speeds in Hong Kong. This study intends to show how climate change can be taken into account when estimating the wind fields of typhoons and to determine the expected wind fields and extreme winds for upcoming typhoons. A severe climate scenario is employed to determine the predicted SST, and its implications on key parameters for probabilistic typhoon models are investigated. Improvements are made in this study based on the models and techniques proposed by Wang et al. (2022): 1) more completed SST models are provided (28 in total); 2) increasing the typhoon influencing circle from 250km to 500km in order to include additional best-track data; 3) investigating the extreme wind speed and comparing it with the suggested value given by the wind code. Future typhoon wind fields are forecast using the MCS, and the Peak-over threshold (POT) approach is utilized to determine the extreme wind speeds in Hong Kong. Comparisons between the design wind speeds recommended by the Hong Kong Wind Code 2019 and the expected extreme winds under climate change impacts are described.

2. METHODOLOGY

2.1. Typhoon wind field model

The three-dimensional Navier-Stokes equations can be used to describe the wind field inside the typhoon boundary layer. The refined typhoon wind field model is employed in this study since it includes variations of the pressure with height based on simplified 3-D Navier-Stokes equations. The basic equations are shown in Eqs. (1) to (3) (Huang and Xu 2012).

$$\frac{d\vec{v}_h}{dt} = -\frac{1}{\rho}\vec{\nabla}_h p - f\vec{k}_h \times \vec{v}_h + \vec{F}_h \quad (1)$$

$$p = p_0\left(1 - \frac{gz}{\theta c_p}\right)^{\frac{c_p}{R}} \quad (2)$$

$$p_0 = p_{c0} + \Delta p_0 exp\left[-\left(\frac{RMW}{r}\right)\right]^B \quad (3)$$

where $\overrightarrow{v_h}$ is the horizontal wind velocity vector; ρ is the air density; $\overrightarrow{\nabla_h}$ is the the 3-D del operator; p denotes the atmospheric pressure; f is the Coriolis parameter; $\overrightarrow{k_h}$ is the unit vector in the horizontal direction; $\overrightarrow{F_h}$ is the horizontal frictional force; p_0 is the surface pressure; g is the gravitational acceleration; z is the height above the sea surface; θ is the potential temperature and is assumed to be constant in the present study; c_p is the specific heat capacity of air; R is the ideal gas constant; p_{c0} is the central pressure of a typhoon at the sea surface; Δp_0 is the central pressure deficit; RMW is the maximum radial distance from the typhoon centre to the maximum wind speed; r is the radial distance from typhoon center, and B is Holland's radial profile parameter.

2.2. Climate scenario

The Intergovernmental Panel on Climate Change (IPCC) predicts long-lasting global warming in its Sixth Assessment Report (AR6) which was published in 2022, and projects global socioeconomic changes with a set of climate policies (IPCC 2022). Five comparable scenarios for climate change, the Shared Socioeconomic Pathways (SSPs), are designed to capture the varying levels of mitigation and adaptation of global warming by society. SSP 5-85 is recognized as the severe warming state in which society undertakes insufficient measures to moderate or slow the pace of global warming. The SSP historical is adopted in this study to describe the previous climate condition, and the annual SSTs during 1961-2020 (previous climate) and 2021-2080 (future climate) obtained from the climate models, are compared and illustrated in Figure 1. In particular, 28 SST models (e.g., ACCESS-CM2, ACCESS-ESM1-5, BCC-CSM2-MR, BCC-ESM1, CAMS-CSM1-0, CanESM5, etc.) are taken into account in both for the past and the future climates, which is more sophisticated than in Wang et al. (2022). Following the SSP 5-85, it is found that the mean annual SSTs near Hong Kong would be increased by 2.24°C in the next 60 years (2021-2080).

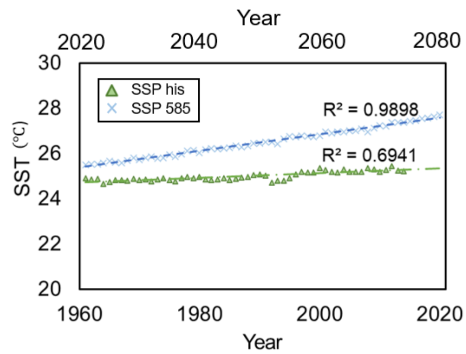

Figure 1. Mean SSTs during 1961-2020 and 2021-2080 in Hong Kong.

2.3. Probabilistic model and Peak-over threshold method

A five-step process which is described by Wang et al. (2022), is used to determine the probabilistic model of six key typhoon wind field parameters. The observed SSTs obtained from the European Centre for Medium-Range Weather Forecasts (ECMWF) ERA5, and recording key parameters from the best-track data kept by meteorological stations are utilized to create the probabilistic models of typhoon parameters. 500 km is chosen as the typhoon influencing circle. In this study, the Peak-over threshold (POT) method is adopted to predict the extreme wind speed in Hong Kong with 50 years return period, and the processes of the POT method are provided by Holmes et al. (2001).

3. RESULTS

3.1. Predicted wind field

The detailed validation processes of the SST model and refined typhoon wind field model are given by Wang et al. (2022). Figure 2 shows the statistical comparison of typhoon wind speeds between the historical and the future climate, as determined by Eqs.(1)-(3) while accounting for global warming. It is discovered that the mean annual SSTs close to Hong Kong would rise by 2.24°C for the following 60 years (2021-2080) following the SSP 5-85. Such a change in the SSTs considerably affects the typhoon wind field, as seen in Figure 2, where the distribution of wind speed from a future typhoon notably differs from that of a current typhoon. The mean value of the statistically typhoon wind speed increased by 12.97%, which reaching up to 12.93 m/s in the next 60 years, from 2021 to 2080.

3.2. Extreme winds compared with design wind speeds

The design wind speed at gradient height (500m), according to the Hong Kong Wind Code 2019

(Buildings Department 2019), is 56.6 m/s. The power law variation is adopted to transform the wind speed to that at 90 m (v_{90} =46.87 m/s), which is the same height as the results from the revised typhoon model. The predicted extreme wind speed with a 50-year return period considering the effects of climate change is 44.13 m/s, which is slightly less than the design wind speed recommended by the Hong Kong wind code. Therefore, to guarantee the safety of structures during severe global warming, the design wind speed does not need to amplify or multiply by a climate factor.

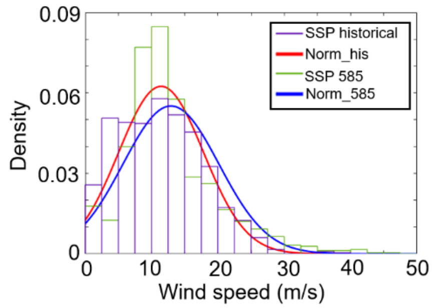

Figure 2. Comparison of the Normal distributions for typhoon wind speeds in 1961-2020 and 2021-2080, where 'his' presents 'SSP historical', and '585' means 'SSP 5-85'.

4. CONCLUSIONS

The influence of global climate change on future typhoon wind fields in Hong Kong is evaluated by combining the SSP 5-85 climate change scenario, Monte Carlo Simulation, a typhoon wind field model and the typhoon key parameters probabilistic model. It is noted that the SST close to Hong Kong will rise by around 2.24℃ in the next 60 years (2021-2080), increasing the mean wind speed of future typhoons by 12.97%. Such an increase in the SST will also have a positive impact on the extreme winds in Hong Kong. The predicted extreme wind speed is 44.13 m/s under the SSP 5-85, which is somewhat lower than the design wind speed recommended by the Hong Kong Wind Code 2019 (46.87 m/s). The wind code is still functional even in severe climate change conditions without using an amplifier or a climate factor.

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