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A simplified statistical method for preliminary regional typhoon risk assessment based on best track data

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SUMMARY:
An accurate typhoon wind risk assessment method is of great significance for the offshore or coastline region. It is the mainstream method to perform the Monte-Carlo (MC) typhoon modelling for simulating at least 10,000 years storms for estimating the extreme wind speed. However, there will be a technical threshold for engineering applications of this technique and the repetitive computation will be quite computational expensive for the assessment on a regional level. For the purpose of preliminary typhoon risk assessment of a region, a simplified statistical method is proposed. In the proposed method, the extreme wind speed is estimated with the extended "Improved Method of Independent Storms" (XIMIS) method, based on simulated wind field results using best track typhoon data. The results of the simplified statistical method are validated by comparison with the local code and used to present the wind map for typhoon risk assessment in offshore area with high efficiency and acceptable accuracy.

Keywords: simplified regional typhoon risk assessment method, XIMIS, wind field model

1. INSTRUCTION

A large percentage of population and high developed cities are located along the coastline, which are likely to suffer from typhoon threat. Thus, the assessment of the typhoon risk with extreme wind speed is of great significance to safety of infrastructure in those area.

Xiao et al.(2011) used the typhoon sub-regional track model to assess the typhoon risk in southeast coastal region in China. The accuracy of sub-regional track model is dependent on the sample richness, and it is a mainstream method to calculate the extreme wind speed using full track model for typhoon hazard estimation. The full track model aims to simulate the whole evolution process of the typhoon, from generation to extinction. Vickery(2000) firstly conducted full track model with 5×5° grid resolution in north Atlantic Ocean and then the idea was developed by other researchers (Huang et al., 2021). With the simulated typhoon samples, the extreme wind speed could be presented with the parametric wind field model(Huang et al., 2021).

However, there will be a technical threshold for engineering application of MC simulation and the repetitive computation of extreme wind speed for each grid will be computationally expensive when assessing a large area for preliminary purposes. In this paper, a simplified statistical method is proposed with wind field model and extreme analysis method XIMIS for regional typhoon risk assessment. The comparison of the simplified statistical method and local code design wind speed will be presented to show the validity and efficiency of proposed method.

2. A SIMPLIFIED STATISTICAL METHOD FOR TYPHOON RISK ASSESSMENT

Yan Meng model (Yan et al., 1995) is adopted here to interpret the wind field evolution along the historical typhoon track from database of Joint Typhoon Warning Center (JTWC) with typhoon center position, and the maximum wind speed $V_{\max}$. The typhoon intensity parameter ($V_{\max}$) was used from 1970 to 2014 as the data prior to the satellite era was felt to be less reliable. With the generated wind velocity field, wind speed time history at any location and height of interest can be obtained. Then, the extreme value analysis is conducted based on the XIMIS.

2.1. Wind Field Model

The Yan Meng model gives gradient height of wind field as following:

$$v_g(r,\beta) = \frac{V_T \sin\beta - rf}{2} + \sqrt{\left(\frac{V_T \sin\beta - rf}{2}\right)^2 + \frac{r}{\rho_a}\frac{\partial p(r)}{\partial r}} \tag{1}$$

$$p(r) = p_c + (p_n - p_c)\cdot exp[-(R_{mw}/r)^B] \tag{2}$$

where v_g is the wind speed at free atmosphere, β is the typhoon angle, V_T is the translation speed, f is the Coriolis parameter, ρ_a is the air density. $p(r)$ is the pressure at the distance r from the typhoon centre, and p_n represents surrounding ambient air pressure, p_c is the air pressure at typhoon center, R_{mw} is the maximum wind speed radius and B is the Holland B parameter.

The validation of the wind field model is demonstrated by typhoon in 2018/08/22 in Fig.1. The results of wind field model is in good agreement with the field measurement data.

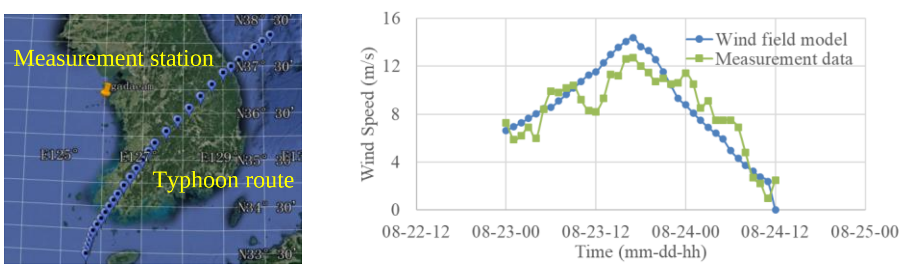

Figure 1. Comparison of simulated wind speed and measured wind speed: typhoon route (left); typhoon speed(right)

2.2. Extreme Value Analysis Method: XIMIS

At first, the sample data are squared, i.e., $q=v^2$, to transform the parent distribution closer to an exponential for accelerating the convergence(Harris, 2009). The average annual rate of occurrence of storms will be denoted by $a = N/R$ with total storm number N and observation period R. From extreme value theory, the appropriate asymptotic form is the Fisher-Tippet distribution when the parent distribution is of the exponential class.

$$\emptyset(q) = \exp[-\exp(-y)] = \exp[-\exp\{-\alpha\,(q-\gamma)\}] \tag{3}$$

where y is the standard reduced variate and α, γ are the dispersion and location parameters.

In XIMIS, the unbiased mean reduced variate for the largest peak could be expressed as $\bar{y}_1$ with value of ln(R)+0.5772. And then the Poisson process model assumption for independent event is applied for other ranks with $\bar{y}_{m+1} = \bar{y}_m - 1/m$. Given the set of ranked values of q_m, together with the $\bar{y}_m$, a weighted least-squares method is used to fit the line on the Gumbel plot and derive the value for the parameters α and $\alpha\gamma$,

$$\alpha = \frac{\sum_{m=1}^{N} w_m \bar{y}_m q_m - (\sum_{m=1}^{N} w_m \bar{y}_m)(\sum_{m=1}^{N} w_m q_m)}{\sum_{m=1}^{N} w_m q_m^2 - (\sum_{m=1}^{N} w_m q_m)^2}, \quad \alpha\gamma = \alpha \sum_{m=1}^{N} w_m q_m - \sum_{m=1}^{N} w_m \bar{y}_m \tag{4}$$

where w_m are the m-th storm weight (Harris, 2009).

2.3. Validation and Application of Simplified Statistical Method

Six cities are selected for the validation of simplified statistical method, which represent the different sample richness. The comparison of extreme wind speed at 100-year return period is shown in Table 1 (with Manila compared in 50y). It could be seen that the results of the simplified statistical method in Shenzhen, Manila, Shanghai and Xiamen are in good agreement with the local code value. For Busan and Seoul, the results deviate slightly from the local code but still comparable. It indicated that richness of samples may affect the accuracy of simplified statistical method, the results for the location with less samples may have lower accuracy. But for the typhoon risk assessment relative to the adjacent area, the results could still be used for reference.

Table 1. Comparison of simplified statistical method with local code in 10m height with hourly mean speed(m/s)

Location	Shenzhen	Manila	Shanghai	Xiamen	Busan	Seoul
Proposed Method	35.9	34.8	28.6	36.9	32.4	26.4
Local code	35.6	36.3	29.0	36.5	35.6	24.4

For Manila, the full track Monte Carlo simulation is also conducted for 10000 years. The extreme wind speed results from full track Monte Carlo simulation are also presented and compared in Fig.2, which further verify the accuracy of proposed method. The proposed method is further used to generate the wind map for the Philippines area and compared with the local code zone division. The wind map is following the local code and illustrated with 3s wind speed in 10m height and 50-year return period. It could be seen from Fig.3 that the wind map is quite comparable with the local code zone division: the north-east region shows largest typhoon risk because of direct typhoon attack, and the south region is exposed with less typhoon risk as the low latitude is not conducive to the typhoon development. However, the east-south corner indicates a particular risk. This characteristic is also presented in the wind map of Association of Structural Engineers of the Philippines with longer return period. The comparison results demonstrate the applicability of proposed method for preliminary typhoon risk assessment. The proposed method is also used for presenting the wind map in offshore 50km area of the South Korea with hourly mean wind speed in 10m height and 100-year return period. The results indicate that the east and south region tend to show the higher typhoon risk compared with west and north region respectively. Fig.4 also shows that the results are consistent with the trend of Korea Building Code wind map, with the marked wind speed being converted to the mean hourly wind speed in marine terrain.

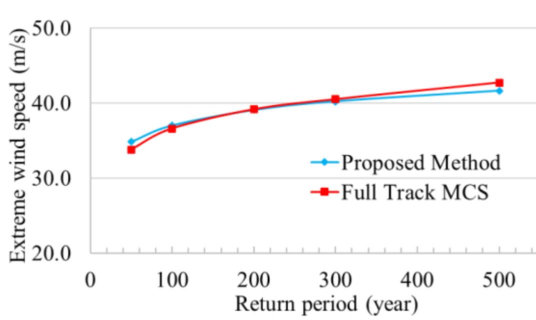

Figure 2. Extreme wind speed of Manila

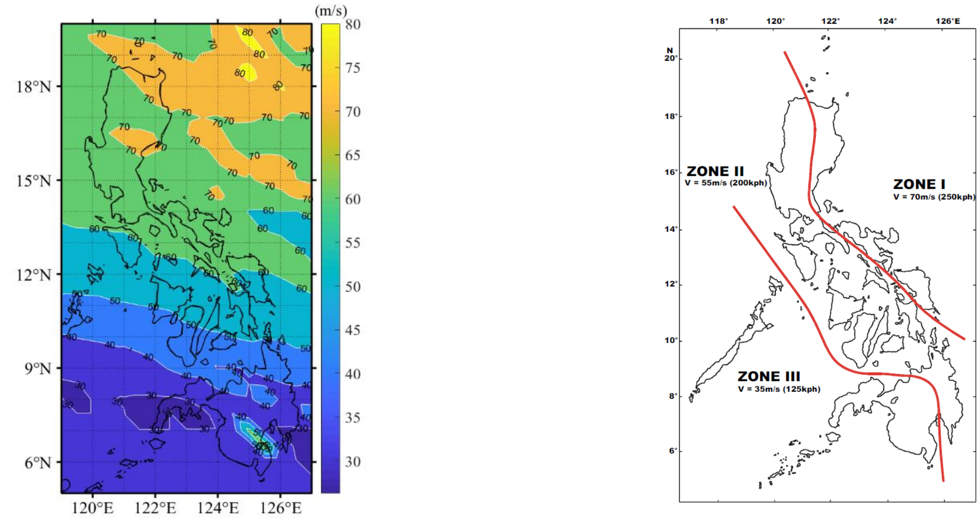

Figure 3. Wind map of the Philippines area: proposed method(left) and local code(right)

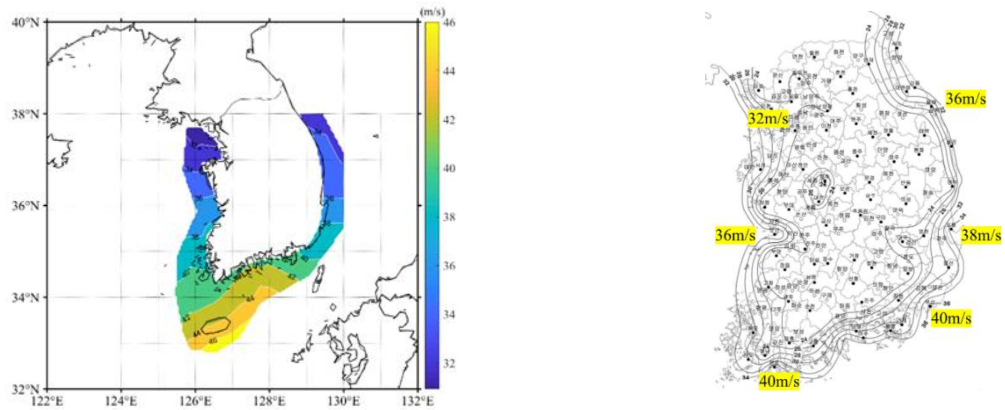

Figure 4. Wind map of the South Korea offshore areas: proposed method(left) and local code(right)

3. CONCLUSIONS:

1. The proposed simplified statistical method gives quite accurate prediction for locations with rich historical typhoon samples. The prediction accuracy may drop for locations with limited typhoon samples, but could still provide reference for preliminarily relative comparison purpose.
2. The wind map based on the simplified method efficiently show the typhoon risk, which is consistent with the local code and the Monte Carlo simulation results in selected locations.

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