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# Prediction of typhoon-induced gust wind speed using mesoscale model and best track data

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**SUMMARY**

A new method for identifying typhoon parameters and combining wind fields is proposed. Annual maximum mean wind speeds are predicted using the proposed wind field model and validated using 30 years of observed data. The slope of linear regression line for the annual maximum mean wind is improved from 0.78 for the mesoscale model to 1.02 for the proposed model. Next, a peak factor of 3.5 is evaluated as the 90% quantile of the 3-second gust wind speed based on the analysis of observed data. Annual maximum 3-second gust wind speeds are evaluated by the mesoscale model and the proposed method, and validated using 12 years of observed data. The slope of linear regression line for 3-second gust wind speeds is improved from 0.84 for the mesoscale model to 0.98 for the proposed model. The predicted 50-year recurrence gust wind speed matches well with that obtained from the observed data.

***Keywords:*** *mesoscale model, best track data, typhoon parameter, peak factor, 3-second gust wind speed*

## 1. INTRODUCTION

Typhoon Maemi, which struck Miyako island of Japan in 2003, damaged more than 1,000 electric poles. To improve the safety of structures, it is necessary to accurately estimate maximum wind speeds. Mesoscale models tend to underestimate sea level pressure depth and wind speed near the typhoon center. Tanemoto and Ishihara (2013) proposed a new wind field model that combined a mesoscale model and a typhoon model using a weighting function. However, this model cannot express very large typhoons, and the accuracy of typhoon parameters needs to be improved.

In gust wind prediction, IEC61400-1 (2019) requires 3-second gust wind speed for 50-year occurrence wind speed with a peak factor of 3.5. Ishizaki (1983) proposed an empirical formula for the peak factor, which is a function of averaging time, however, the evaluated peak factor for 3-second gust wind speed is 2.65, which does not cover the majority of the observed peak factor. Peak factors must be investigated by using observed data.

In this study, a new typhoon parameter identification method and a new synthetic wind field model are proposed. The 10-min mean wind speed is evaluated using the identified typhoon parameters, and validated using long-term observation data in Miyako island. Furthermore, the peak factor for 3-second gust wind speed is investigated based on the observation data. The 3-second gust wind speeds are predicted by the proposed model, and validated using long-term observation data in Miyako island.

## 2. METHODOLOGY

### 2.1. Identification of typhoon parameters for mean wind speed prediction

The sea level pressure of a typhoon is expressed by Holland (1980) as shown in Eq. (1).

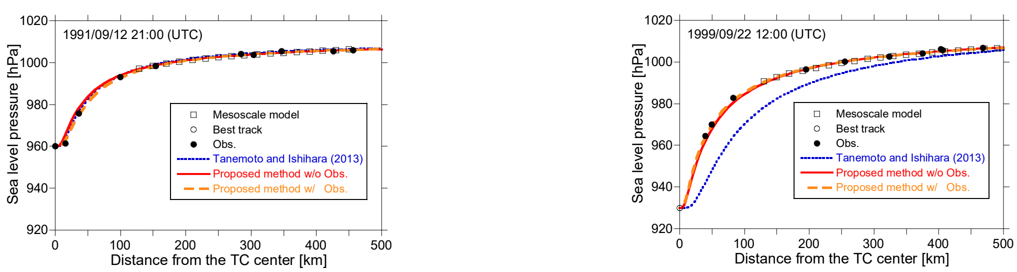
$$p^T(r) = p_c + (p_\infty - p_c)exp\left[-\left(\frac{R_{max}}{r}\right)^B\right] \quad (1)$$

where $p_c$ is the central pressure, $p_\infty$ is the ambient pressure, $R_{max}$ is the radius at maximum wind speed, $r$ is the radial distance from the typhoon center, and $B$ is the shape parameter. To accurately determine typhoon parameters using the Holland model, a new method is proposed to identify typhoon parameters in a two-step procedure using pressures from a mesoscale model and best track data. Table 1 shows the input dataset and the parameters identified in each step. $r$ is the distance from the typhoon center obtained from the best track, and $\hat{r}$ is the distance from the typhoon center obtained from the mesoscale model. In Step 1, $\hat{p}_\infty$ and $\hat{R}_{max}$ are identified using only the pressure field from the mesoscale model. The location of the typhoon center and central pressure are identified from the pressure field of the mesoscale model. Based on the identified central location, the pressure distribution is calculated. Assuming $\hat{B} = 1$, $\hat{p}_\infty$ and $\hat{R}_{max}$ are identified by fitting pressure distribution using the least squares method. In Step 2, assuming $p_\infty = \hat{p}_\infty$, $R_{max}$ and $B$ are updated using the best track data and the observed pressure from the meteorological station.

Table 1: List of input data and identified parameters.

| | Input data | Identified parameters | | | | |
|---|---|---|---|---|---|---|
| Step 1 | $p^M(\hat{r}_i)$ $(\hat{r} < R_{TC})$ | $\hat{\boldsymbol{r}}_{\boldsymbol{c}}$ | $\hat{p}_c$ | $\hat{p}_\infty$ | $\hat{R}_{max}$ | $\hat{B} = 1$ |
| Step 2 | $p^{O_j}(r_j)$ $(r \leq r_0)$<br>$p^M(\hat{r}_i)$ $(r_0 < \hat{r} < R_{TC})$ | $\boldsymbol{r}_{\boldsymbol{c}}$ | $p_c$ | $p_\infty = \hat{p}_\infty$ | $R_{max}$ | $B$ |

Figure 1 shows the pressure distributions predicted using the mesoscale model and the proposed model. The conventional model overestimates the amount of pressure drop near the typhoon center of the very large typhoon Typhoon 9918, while the proposed model shows good agreement with the observed values. It also shows that the proposed method can predict the typhoon's pressure field with high accuracy even when no observed pressure data is available.




(a) Typhoon 9117 (1991/09/12 21:00 UTC) (b) Typhoon 9918 (1999/09/22 12:00 UTC)

Figure 1: Pressure distribution predicted by mesoscale model and proposed model

A synthetic wind field model is proposed to account for the pressure difference between the mesoscale model and typhoon model. The synthetic wind speed $u^C(r)$ is calculated by adding the wind speed difference to the wind speed $u^M(\hat{r})$ predicted by the mesoscale model. The wind speed difference $u^T(r) - u^T(\hat{r})$ is derived from the pressure distributions based on the identified typhoon parameters. The wind speed ratios $C^{SM}$ and $C^{ST}$ are obtained from CFD.

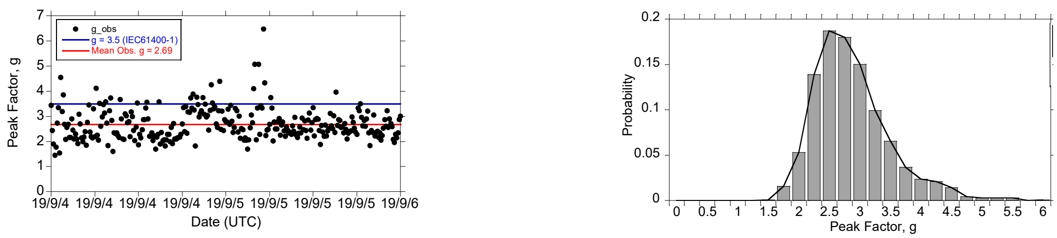
$$u^C(r) = u^M(\hat{r},\theta)\cdot C^{SM} + \left(u^T(r,\theta) - u^T(\hat{r},\theta)\right)\cdot C^{ST} \tag{2}$$

### 2.2. Evaluation of peak factor for gust wind speed prediction

Gust wind speed $U_{max}(t)$ is predicted by multiplying the mean wind speed $\bar{u}(t)$ by the sum of 1 and the product of the peak factor $g$ and the turbulence intensity $I_u(\theta(t)$.

$$U_{max}(t) = \bar{u}(t)(1 + gI_u(\theta(t))) \tag{3}$$

where $\bar{u}(t)$ is the 10-minute wind speed predicted by Eq. (2). $I_u(\theta(t))$ is the turbulence intensity. In this study, the values predicted by Ishihara et al. (2020) using a numerical urban model and large eddy simulation for Miyako island are applied. $g$ is the peak factor, analyzed from the observations of 3-second gust wind speeds and 10-minute average wind speeds from 2008 to 2019 during typhoon at Miyakojima Observatory as shown in Figure 2. The average and standard deviation of the analyzed peak factor are 2.75 and 0.62, respectively. This result indicates that a peak factor of 3.5 as used in IEC 61400-1 corresponds to the 90 % quantile. In this study, the peak factor of 3.5 is used to evaluate 3-second maximum gust wind speed.



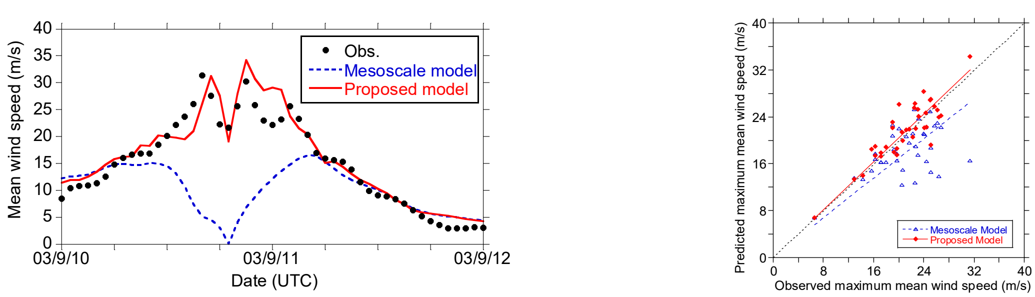

(a) Time series in Typhoon 1913 (b) Distribution

Figure 2: Analysis of peak factor using observations

## 3. RESULTS AND DISCUSSIONS

### 3.1. Prediction of mean wind speed

The predicted annual maximum mean wind speeds over the past 30 years are validated by observations from 1990 to 2019 in Miyako island. As shown in Figure 3 (a), the time series predicted by the proposed model agrees well with the observed data in Typhoon 0314. The slope of the linear regression line without considering offsets is improved from 0.78 for the mesoscale model to 1.02 for the proposed model, as shown in Figure 3 (b).

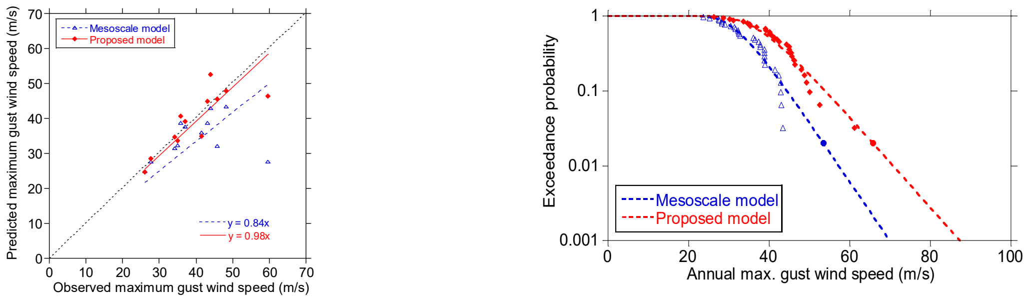



(a) Time series in Typhoon 0314 (b) Mean wind speeds for 37 events

Figure 3: Annual maximum mean wind speed predicted by the mesoscale model and the proposed model

### 3.2. Prediction of gust wind speed

The annual maximum 3-second gust wind speed over 12 years is predicted by the mesoscale model and the proposed method. The extreme wind speed of 50-year recurrence gust wind speed is then estimated. The slope of the linear regression line is improved from 0.84 for the mesoscale model to 0.98 for the proposed model, as shown in Figure 4 (a). The results in Figure 4 (b) show that the extreme wind speed evaluated by the mesoscale model is predicted to be 53 m/s, 20 % lower than 66 m/s evaluated by the proposed model. The accident investigation showed that most of the electrical poles collapsed at a wind speed of 69 m/s. The wind load using the predicted extreme wind speed is roughly consistent with the strength of electrical pole on Miyako island.




(a) Predicted and observed maximum gust wind speed

(b) Extreme gust wind speeds predicted by mesoscale and proposed model

Figure 4: Prediction of gust wind speed and extreme wind speed

## 4. CONCLUSIONS

In this study, extreme wind speeds are predicted using the mesoscale model and JMA best track data. The conclusions are obtained as follows.

1) A new method for identifying typhoon parameters and combining wind fields is proposed. Annual maximum mean wind speeds are predicted by the proposed combined wind field model and validated using 30 years of observed data The slope of the linear regression line is improved from 0.78 for the mesoscale model to 1.02 for the proposed model.

2) The peak factor of 3.5 is evaluated as the 90% quantile of 3-second gust wind speeds based on the analysis of observed data. Annual maximum 3-second gust wind speeds are evaluated by the mesoscale model and the proposed method and validated using 12 years of observed data. The slope of the linear regression line is improved from 0.84 for the mesoscale model to 0.98 for the proposed model. The predicted 50-year recurrence wind speed matches well with that obtained from the observed data.

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