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Prediction of sea level pressure and ocean surface wind speed using mesoscale and typhoon models

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SUMMARY: (10 pt)
This paper proposes a new method of combining mesoscale and typhoon models for the prediction of sea level pressure and ocean surface wind speed during tropical cyclones. The identification methods for the parameters in Holland model and the influence radius of tropical cyclones are proposed. The sea level pressures and significant wave heights during tropical cyclones are well captured by the proposed model using combined ocean surface wind speed, while those at the central region of tropical cyclones are underestimated by the mesoscale model. As a result, the prediction error of the maximum sea level pressure depth and maximum wave height during a tropical cyclone decreases from +16.9% and -14.4% for the mesoscale model to +1.6% and -0.2% for the proposed model.

Keywords: tropical cyclone, mesoscale model, sea level pressure

1. INTRODUCTION

For the prediction of extreme wave heights during tropical cyclones (hereafter TC), at least 30 years of hindcasting is needed due to the lack of offshore observations (IEC 61400-3-1, 2019). The wind speed at 10 m height above sea water level, which is named as ocean surface wind speed, is used as the input data of wave hindcasting. Since the ocean surface wind speeds predicted by the mesoscale model are underestimated during TCs, the combined wind field model of mesoscale and typhoon models was proposed by Tanemoto and Ishihara (2013). However, Schloemer’s model used in the combined wind field model may underestimate the sea level pressure distribution in TCs. Also, the influence radius of TC used in this model may be overestimated.

In this study, Holland’s model (Holland G. J., 1980) is adopted, and the identification methods of its parameters and the influence radius of TC are proposed. The predicted sea level pressure, ocean surface wind speed and significant wave height by the mesoscale and proposed models are investigated and compared with the observations during TCs.

2. METHODOLOGY

2.1. Numerical Models

The mesoscale model of WRF ARW ver. 3.4.1 is used to predict sea level pressure and ocean surface wind speeds, and the third-generation wave prediction model WAVE WATCH III ver.

4.18 to predict significant wave heights. Fig. 1 shows the domain setup. Fig. 2 presents Typhoon 9512 (hereafter T9512) passed over Kanto coastal area with the central pressure of 930hPa, which is the lowest value over past 30 years in this area.

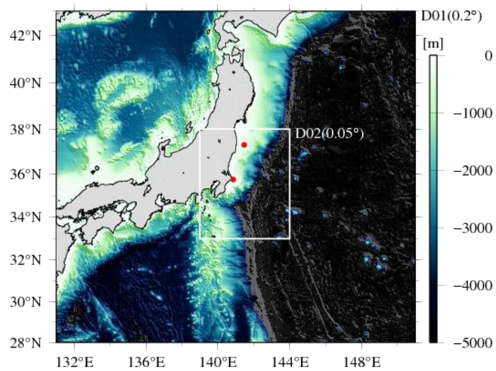

Figure 1. Domain setup and grid resolutions

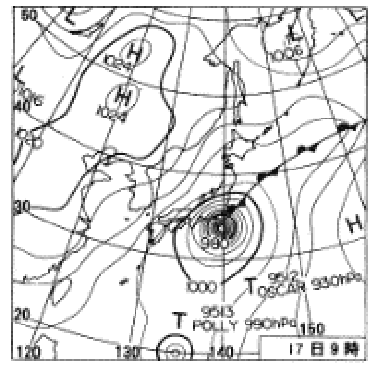

Figure 2. Weather map (1995/9/17 0:00UTC)

2.2. New Combined Method of Sea level Pressure and Ocean Surface Wind Speed

The sea level pressure of a TC can be expressed by the Holland's model as shown in Eq. (1).

$$\frac{p(r)-p_c}{p_\infty - p_c} = exp\left(-\frac{R_m}{r}\right)^B \quad (1)$$

where p_c is the central pressure, p_∞ is the ambient pressure, R_m is the radius at the maximum wind speed, r is the distance from the centre of TC, and B is the shape parameter. In case of B =1, this equation is known as the Schloemer's model.

The influence radius of TC R_{TC} is determined from an empirical relation as shown in Eq. (2).

$$V_{15}R_{15} + \frac{1}{2} f R_{15}^2 = \frac{1}{2} f R_{TC}^2 \quad (2)$$

where R_{15} is the radius of V_{15} (wind speed of 15m/s), and Coriolis parameter f. Since p_c and R_{15} are obtained from the Japan Meteorological Agency (hereafter JMA) best track, three unknown parameters R_m, p_∞, and B (hereafter TC parameter) need to be identified. In Tanemoto and Ishihara (2013), R_m and p_∞ were identified using sea level pressure at R_{TC} from the reanalysis and gradient wind balance equation at R_{15} based on the Schloemer's model. In this study, after determining p_∞ by the above method, R_m and B are identified by the least-squares method using sea level pressure of the reanalysis ERA5 (Hersbach et al, 2020) more than 150km from the center of TC and the observed those at the JMA meteorological stations within 150km.

The combined sea level pressure and ocean surface wind speed u_C can be obtained from u_T and u_M by typhoon and mesoscale models using a weight function W, as shown in Eq. (3).

$$u_C = Wu_T + (1-W)u_M, \; W = \left(\frac{R_{TC}^2 - r^2}{R_{TC}^2 + r^2}\right)^n \quad (3)$$

where r is the distance from the centre of TC, the weight factors of $n = 0.25$ and $n = 0.5$ are used for the sea level pressure and ocean surface wind speed. In this study, the influence radius of TC R_{TC} is defined as the distance from the centre of the TC to the point where the sea level pressure from the typhoon model is equal to that from the mesoscale model.

3. RESULTS

3.1. Prediction of Sea Level Pressure and Ocean Surface Wind Speed during a Tropical Cyclone

A one-year simulation from February 2013 to January 2014 is performed by mesoscale model and validated by the observations at Choshi. The predicted wind speeds show good agreement with the observations, and the relative error of the annual average wind speed at 80m is 2.2%. However, during Typhoon 1326 on Oct. 16^{th}, the sea level pressure is overestimated by 19.2hPa, resulting in an underestimation of predicted wind speed by 9.4m/s.

The predicted sea level pressures by the mesoscale and proposed models are compared with the observed those as shown in Fig. 3. The sea level pressures obtained from ERA5 agree with the observations at the distances larger than 150 km, but overestimate those near the centre of T9512. The predicted sea level pressures by the Schloemer's model significantly underestimate the observations, while those by the Holland’s model show good agreement with the observations even though the observations within 150km are not used for the TC parameter identification. It is obvious that the sea level pressures can be accurately determined by the proposed method even though at the offshore site where no observed data are available.

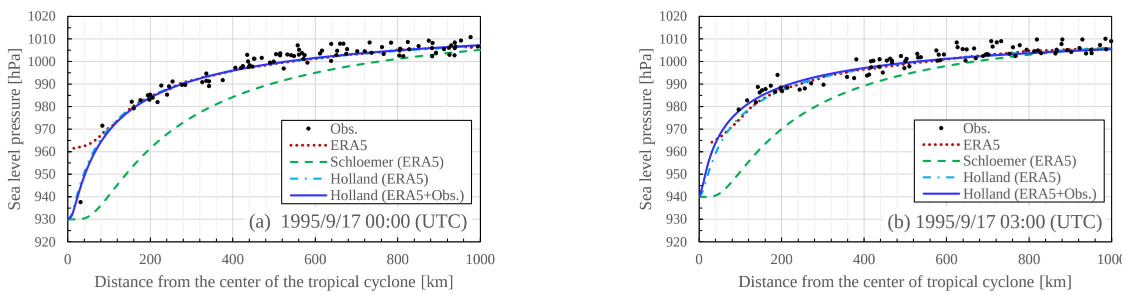

Figure 3. Comparison of sea level pressures obtained from the mesoscale and proposed models

As mentioned above, the mesoscale model can reproduce the sea level pressure distribution as shown in Figs. 4 and 5 away from the centre of TC but underestimates the maximum sea level pressure depth during T9512 at Choshi, while the proposed model well captures the rapid pressure drop near the centre of tropical cyclone. The prediction errors of the maximum sea level pressure depth decrease from +16.9% for the mesoscale model to +1.6% for the proposed model.

The ocean surface wind speeds and its time series predicted by the mesoscale and proposed models are shown in Figs. 6 and 7. It is found that the mesoscale model underestimates the ocean surface wind speed during tropical cyclone, while the proposed model well captures its increase.

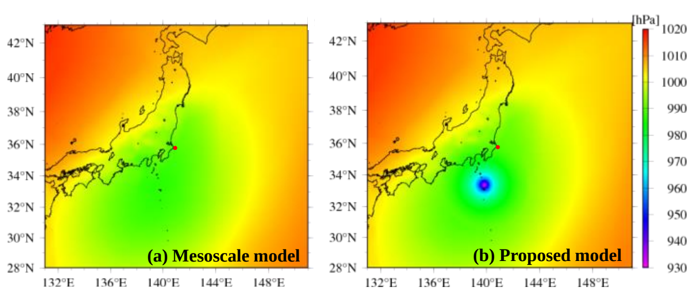

Figure 4. Comparison of sea level pressures (1995/9/17 0:00 UTC)

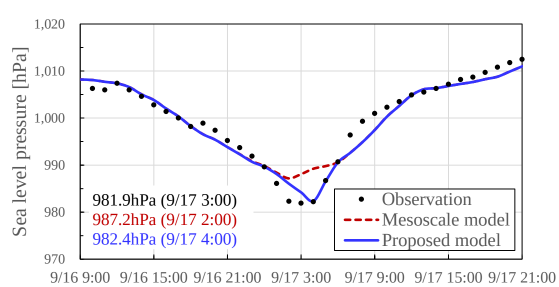

Figure 5. Time series of sea level pressure

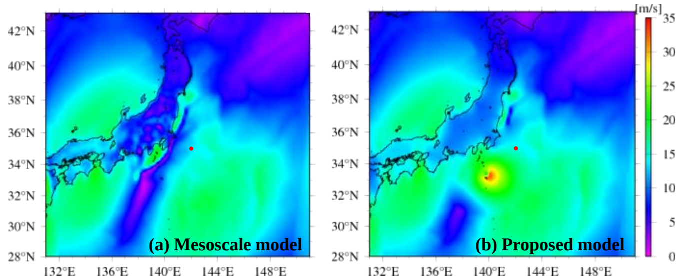

Figure 6 Comparison of ocean surface wind speeds (1995/9/17 0:00 UTC)

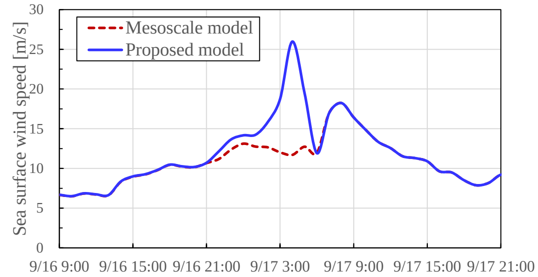

Figure 7. Time series of ocean surface wind speed

3.2. Prediction of Significant Wave Heights during a Tropical Cyclone

The significant wave heights during T9512 predicted from the combined wind speed by the mesoscale model and proposed model are shown in Figs. 8 and 9. The peak of significant wave height predicted by the mesoscale model is underestimated by 14.4% because the storm area near the centre of the TC is not well reproduced. On the other hand, the proposed model simulates the storm area well and reduces the prediction error to -0.2% as well as improves swell and the onset time of the peak of significant wave height.

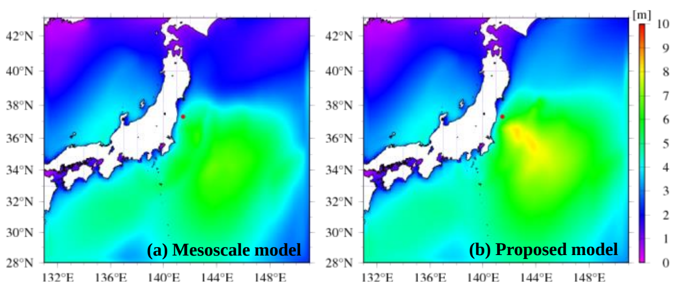

Figure 8. Comparison of significant wave heights (1995/9/17 9:00 UTC)

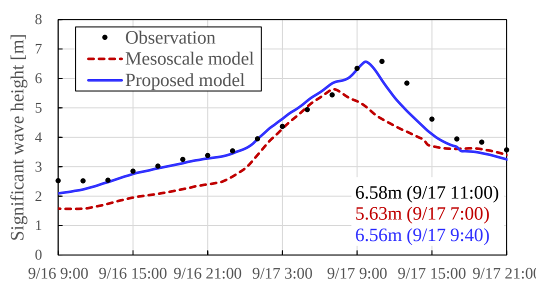

Figure 9. Time series of significant wave heights

4. CONCLUSITONS

A new combined model for the prediction of the sea level pressure and ocean surface wind speed based on the mesoscale and typhoon models are proposed. The predicted sea level pressure and significant wave height by the proposed model show good agreement with the observations. The prediction errors of the maximum sea level pressure depth and maximum of significant wave height during Typhoon 9512 decrease from +16.9% and -14.4% for the mesoscale model to +1.6% and -0.2% for the proposed model.

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