

REPRODUCING TROPICAL CYCLONES: A NOVEL COMBINED APPROACH OF VORTEX-FOLLOWING WITH BOGUSSING USING WRF

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INTRODUCTION

Storm surges are well-known as abnormal sea level rises, primarily resulting from the combined influence of atmospheric pressure and wind field systems generated by tropical cyclones (TCs). Therefore, accurate estimation of meteorological fields of atmospheric pressure and wind during cyclonic events is significant in estimating storm surges. However, meteorological data downscaling sometimes deviates atmospheric pressure and wind fields from observations. Consequently, the pursuit of a robust method to modify the atmospheric pressure and wind fields within meteorological data has taken significant research interest (Kawabata et al., (2012) and Iwamoto et al., (2023)). This study attempts to introduce a globally applicable novel approach for reproducing TCs by modifying atmospheric pressure and wind fields through Weather Research and Forecasting (WRF) downscaling.

DATA AND METHODS

Figure 1 shows the framework used in this study. Japanese Reanalysis for Three Quarters of a Century (JRA-3Q) and ECMWF Reanalysis v5 (ERA5) were used as grid point value (GPV) data. The best-track data for cyclones were downloaded from the Japanese Meteorological Agency (JMA) and the International Best Track Archive for Climate Stewardships (IBTrACS). Separate computational domains, each having three sets of domains, were used for Moving-Nest and Fixed-Nest in WRF. Three domains were designed with d01(36.45 km),

d02(12.15 km), and d03(4.05 km) spatial resolutions from outermost to innermost. WRF Version 4.1.2 with Advanced Research WRF (ARW) configuration was applied. During the WRF downscaling process, a combined approach of Vortex-Following with Bogussing was implemented. WRF's TC Bogus scheme was used to create the initial conditions of d01 for the Vortex-Following Moving-Nest simulation. The reproducibility of TC was further improved by using the WRF's Fixed-Nest simulation. During the Fixed-Nest simulation, boundary conditions of the three domains were set through Bogussing based on Moving-Nest simulation results of d02 and d03. Finally, the wind speed and position of TC were corrected to obtain better results. These data were used to force a storm surge model to confirm the reproducibility of TCs. Storm surge was estimated by coupling ROMS and SWAN models in the COAWST modeling system. Three domains were designed for ROMS and SWAN models with 0.25°, 0.05°, and 0.01° spatial resolutions from outermost to innermost.

REPRODUCING TROPICAL CYCLONES

The three most destructive TCs: Typhoon Vera (1959) with a focus on Ise Bay in Japan, Hurricane Irma (2017) with a focus on the Lesser Antilles Islands in the Caribbean Sea, and Cyclone Kevin (2023) with a focus on Mele Bay in Vanuatu Island were selected for this study. All three TCs were well reproduced using this Moving Bogus approach, and TC's position error and the central pressure deviation with respect to the best-track data confirmed sufficient reproducibility. The model results of Typhoon Vera are discussed here. Figure 2 shows the modeled track with the best-track data.

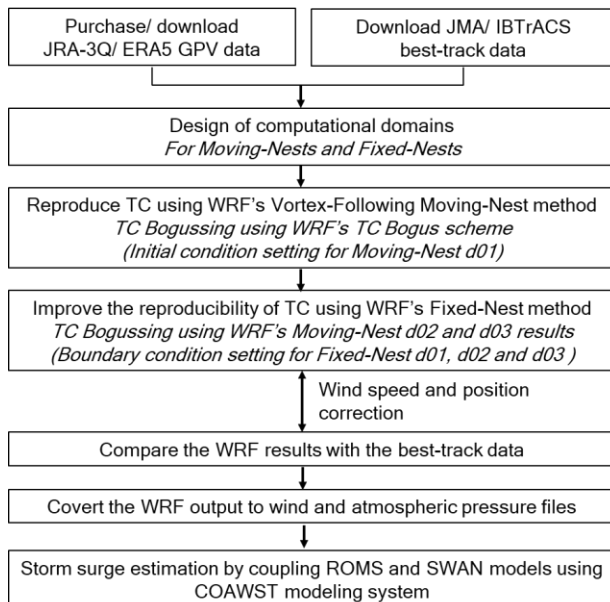


Figure 1 - Framework of this study

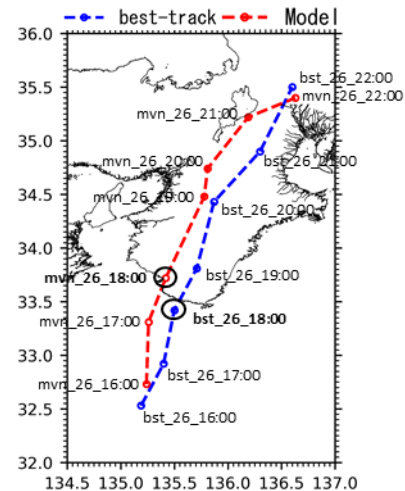


Figure 2 - Comparison of the modeled track for Typhoon Vera with the best-track data for the period of 1959/09/26 16:00 to 22:00 JST

The modeled track followed the best-track data though they were deviated to the west. When Typhoon Vera made landfall just after 1959/09/26 18:00 JST near Shionomisaki, Japan, the modeled track advanced about 1 hour by the best-track (see large open circles in Figure 2). Figure 3 shows the central pressure deviation from the best-track, which was less than 10 hPa when the typhoon was strong. When Typhoon Vera was in the ocean, at 1959/09/26 09:00 JST, the modeled maximum wind speed was 55.7 m/s (Figure 3). A snapshot of the offshore wind field before Typhoon Vera passed the Ise Bay area is shown in Figure 4.

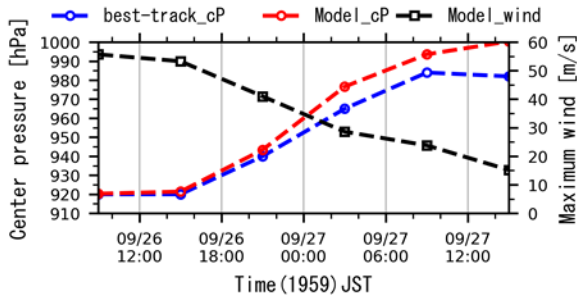


Figure 3 - Comparison of the central pressure (cP) with best-track data, and modeled maximum wind speed for Typhoon Vera

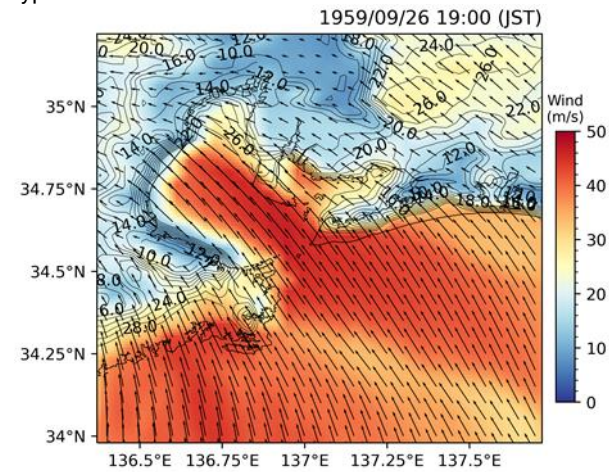


Figure 4 - A snapshot of wind distribution around Nagoya at 1959/09/26 19:00 JST

ESTIMATING STORM SURGE

Storm surge was estimated for Typhoon Vera to further confirm the reproducibility of TCs using the method proposed in this study. Figure 5 shows a snapshot of the modeled tide level deviation (ζ) using COAWST when it reached its peak at Nagoya Port (35.1° N, 136.9° E). Modeled ζ is compared with the JMA's tidal observations at Nagoya Port (Figure 6). The maximum tide level at Nagoya Port has been recorded as 3.89 m with a 3.45 m tide level deviation at 1959/09/26 21:35 JST (Kawabata et al., (2012)). The modeled tide level deviation was obtained as 3.50 m with a 5-minute delay compared to the observed data. This validates the effectiveness of the proposed

method in accurately reproducing atmospheric pressure and wind fields during the cyclonic event of Typhoon Vera. It was observed that the strong offshore wind field significantly influences ζ in the inner bay area.

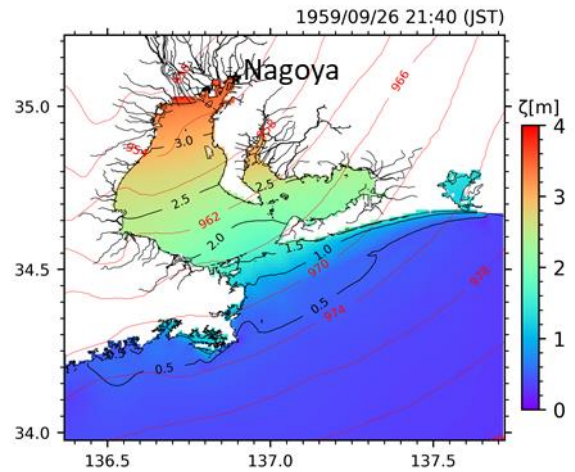


Figure 5 - Spatial distribution of tide level deviation (ζ) (shaded) and sea level pressure (red contours) when it reached its peak at Nagoya tidal observational location

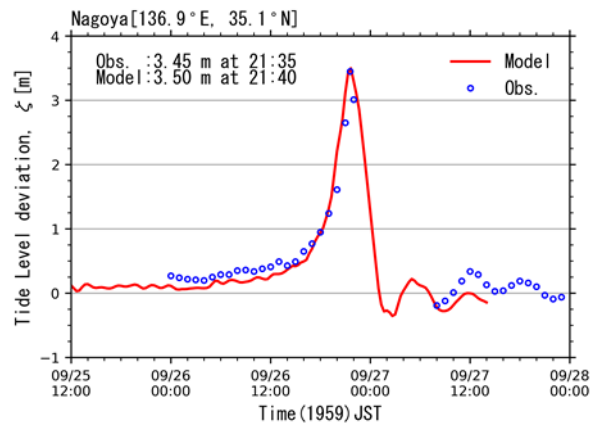


Figure 6 - Temporal distribution of tide level deviation (ζ) at Nagoya observational location

CONCLUSION

The proposed combined method of Vortex-Following with Bogussing using WRF could reproduce TCs with reasonable accuracy. The method was consistent for reproducing typhoons, hurricanes, and cyclones. Hence, this novel approach is robust enough to reproduce TCs globally.

REFERENCES

Iwamoto et al. (2023): A proposal of a semi-empirical method for modifying the atmospheric pressure and wind fields of tropical cyclones, Coastal Engineering Journal, vol. 65, No. 3, pp. 418-432.
 Kawabata et al. (2012): Reanalysis and Reforecast of Typhoon Vera (1959) Using a Mesoscale Four-Dimensional Variational Assimilation System, Journal of the Meteorological Society of Japan, vol. 90, No. 4, pp. 467-491.