Roles of ocean coupling and cumulus parameterization in predicting rainfall amounts caused by landfalling typhoons in the Philippines

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1. Introduction

In the Philippines, 4-5 typhoons make landfall in a year on average. Climatologically, typhoons tend to pass through the central and southern parts of the Philippines in December. Since the heavy rainfall associated with the typhoons sometimes cause floods and thereby natural disasters in these areas, it is urgent to establish numerical forecasting particularly for heavy rainfall associated with the typhoons and to improve the accuracy of the rainfall forecast.

The purpose of this study is to evaluate the applicability of a nonhydrostatic atmosphere model (NHM) for rainfall forecasts associated with landfalling typhoons in the Philippines. This study addressed typhoons Kai-Tak, Tembin in 2017 and Sanba in 2018. Numerical simulations on these typhoons were performed by NHM and the atmosphere- wave-ocean coupled model (Wada et al., 2010, 2018) with a horizontal resolution of 3 km. We compared rainfall simulations by the model without any cumulus parameterizations with those with the Kain-Fritsch cumulus parameterization (KF) (Kain and Fritsch, 1990).

2. Experimental design

The list of numerical simulations is shown in Table 1. The initial time was 0000 UTC on 14 December in 2017 for Kai-Tak, 0000 UTC on 21 December in 2017 for Tembin, and 0000 UTC on 11 February in 2018 for Sanba. The computational domain was the same for three typhoon cases (Figure 1): The domain was 2520 x 2520 km. The number of vertical layers was 55. The top height was approximately 27 km.

Table1 List of numerical simulations

Name	*Model*	*Cumulus Parameterization*	*Typhoon cases*
A	NHM	No	Kai-Tak (2017/12/14/0000) Tembin (2017/12/21/0000) Sanba (2018/02/11/0000)
AWO	Coupled NHM-wave-ocean model	No	
AKF	NHM	KF	
AWOKF	Coupled NHM-wave-ocean model	KF	

The integration time was 72 hours. The time step was 6 seconds for NHM, 36 seconds for the ocean model, and 6 minutes for the ocean surface wave model. The physical components were exchanged between NHM, the ocean model, and the ocean surface wave model every time step of the model with a longer time step. The Japan Meteorological Agency (JMA) global objective analysis with horizontal resolution of 20 km and the JMA North Pacific Ocean analysis with horizontal resolution of 0.5° were used for creating atmospheric and oceanic initial conditions and atmospheric lateral boundary conditions.

The daily accumulated rainfall amount obtained by numerical simulations was verified against in-situ (raingauge) observations. Standard deviation, simulation bias to observation, correlation coefficient, bias score and equitable thread score were calculated. Climatological relative frequency was calculated based on all in-situ raingauge observations of three typhoon cases used in this study.

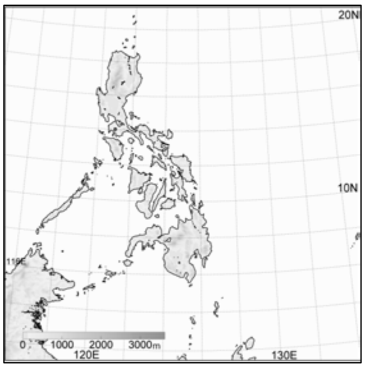

Figure 1. Computational domain.

3. Results

Figure 2 shows the standard deviation, simulation bias to observation, and correlation coefficient of daily accumulated rainfall for 24 h, 48 h, and 72 h forecasts. Simulated daily accumulated rainfall was calculated as a difference between the precipitation accumulated by the moment in view and 24 hours before. The simulation bias to observation is equal to the slope of the linear regression. In conducting statistical analysis, daily accumulated precipitation data for the three typhoon cases are combined into one sample. Without the KF cumulus parametrization in the daily accumulated rainfall simulation, both the simulation bias and the correlation coefficient clearly decreased for 72 h forecasts in the A and AWO experiments although some improvement was found in the daily accumulated rainfall simulation connected with reducing the standard deviation. With the KF cumulus parameterization, the accuracy of the daily accumulated rainfall simulation was sustained even for 72 h, while the accuracy for 24 h and 48 h forecasts was not better than that in the A and AWO experiments.

Figures 3 and 4 show the bias and equitable threat scores at 24 h, 48 h, and 72 h. The atmosphere-wave-ocean coupled model can contribute to improving the bias and equitable threat scores by quantitatively changing the simulated daily accumulated precipitation, particularly when the threshold of daily accumulated precipitation was small (Figure 4b). However, it is the cumulus convection parameterization that fundamentally changes the characteristics of the score.

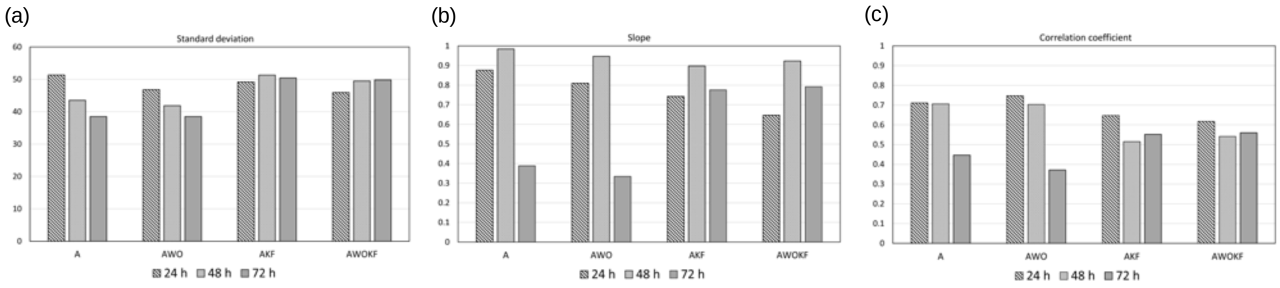

Figure 2 Standard deviation (a), simulation bias to observation (slope of the regression model) (b), and correlation coefficient (c) of daily accumulated rainfall at 24 h, 48 h, and 72 h.

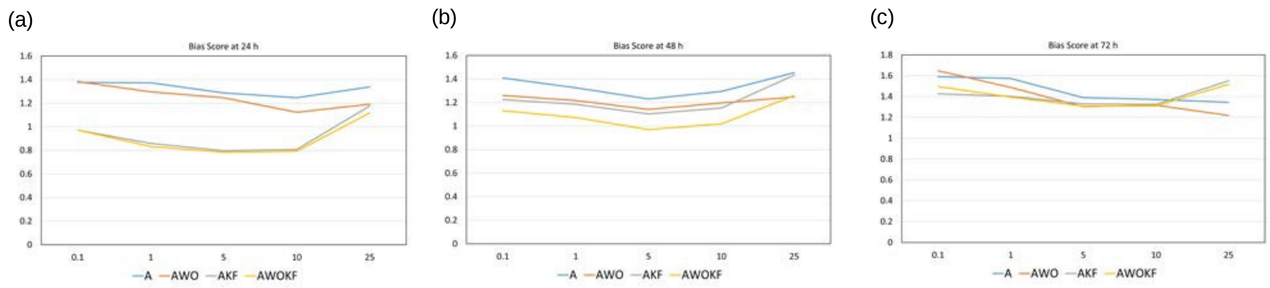

Figure 3 Bias score in each daily accumulated rainfall threshold of daily accumulated rainfall at 24 h (a), 48 h (b), and 72 h(c).

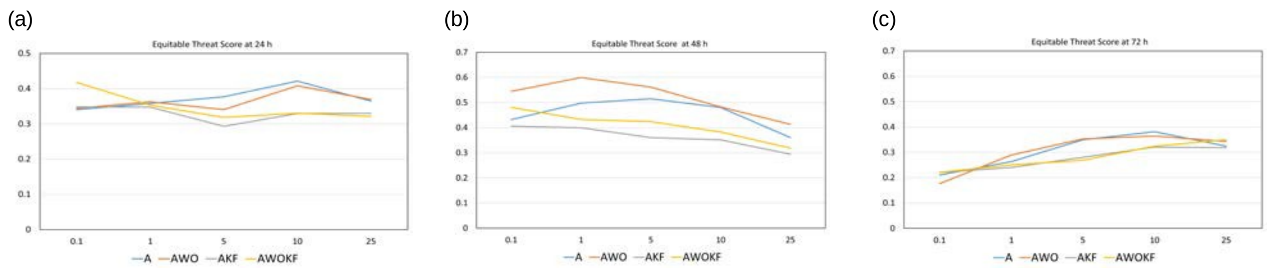

Figure 4 Equitable threat score in each daily accumulated rainfall threshold of daily accumulated rainfall at 24 h(a), 48 h (b), and 72 h (c).

4. Concluding remarks

In numerical forecasting of heavy rains associated with typhoons making landfall in the Philippines, the forecast accuracy can be sustained at best only 48 hours when using the NHM without the KF cumulus parameterization. Even using the atmosphere-wave-ocean coupled model, the forecast accuracy cannot be fundamentally improved. As for the introduction of the KF cumulus parameterization in this study, it should be noted that it has been tuned to be optimized for heavy rainfalls around Japan. It is necessary to carry out suitable tuning for forecasting heavy rainfall associated with landfalling typhoons around the Philippines.

This verification result is only the result of numerical simulations with only one initial condition for each of three typhoon cases. From now on, it is necessary to increase the number of cases to verify. At that time, it may be sufficient to carry out numerical simulations with the NHM, not with the atmosphere-wave-ocean coupled model.

References

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