August 27-31, 2023
FLORENCE - ITALY
16th International Conference on Wind Engineering
ICWE 16

Impact of future change in sea surface temperature due to global warming on typhoon intensity ― Numerical simulation of Typhoon Hagibis (2019) considering sea surface temperature warming ―

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SUMMARY:
Typhoon intensity has been projected to increase owing to global warming. Therefore, the influence of global warming on the wind-resistant design of buildings should be considered. Typhoon Hagibis (2019) is one of the strongest typhoons to have made landfall in Japan. In this study, numerical simulations of Typhoon Hagibis (2019) considering sea surface temperature (SST) warming were conducted to investigate the impact of future changes in SST on typhoon intensity. The SST for future climate conditions was created by adding the difference between October monthly mean SST in the 2090s and 2010s (dSST), which were predicted by MRI-CGCM3, to that for current climate conditions. Under future climate conditions, the typhoon continued to develop up to a higher latitude, and the typhoon intensity at landfall increased significantly compared to that under current climate conditions. This was because under future climate conditions, the SST at higher latitudes were much higher than that under current climate conditions.

Keywords: Global warming, Sea surface temperature, Typhoon intensity

1. INTRODUCTION

Typhoon intensity has been projected to increase owing to global warming (IPCC, 2014). Therefore, the influence of global warming on the wind-resistant design of buildings should be considered. Azegami et al. (2021) conducted numerical simulations under current and future climate conditions for Typhoon Hagibis (2019), which is one of the strongest typhoons to have made landfall in Japan, and showed that Typhoon Hagibis (2019) intensified under future climate conditions. However, the development and attenuation processes of typhoons, which affect typhoon intensity during landfall, have not been sufficiently investigated, and further studies are necessary to clarify the impact of global warming on typhoon characteristics.

In this study, we conducted numerical simulations of Typhoon Hagibis (2019) under current and future sea surface temperature (SST) conditions and investigated the impact of SST warming on the development and attenuation processes of typhoons.

2. COMPUTATIONAL CONDITIONS

A Weather Research and Forecasting model (WRF) (Skamarock et al., 2008) was used as the meteorological model. Figure 1 and Table 1 present the computational domain and conditions, respectively. The size of the computational domain was 2700 km × 3600 km. The horizontal grid resolution was 5 km, and the number of vertical layers was 75 (minimum layer thickness: 60 m). The physical models used in this study are presented in Table 1.

Table 2 presents the simulation cases. The target of the simulation was Typhoon Hagibis (2019). The simulation periods were from 00:00 UTC, 06:00 UTC, 12:00 UTC, and 18:00 UTC on October 7th, 2019 to 12:00 UTC on October 13th, 2019. The influence of the initial conditions on the simulation results was examined by varying the starting time. The typhoon bogus scheme and data assimilation were not used in this study. The CTL (control run) and PGW (pseudo global warming run) in Table 2 represent the simulation cases under current and future SST conditions, respectively. In the CTL, the final analysis data (FNL) of the National Centers for Environmental Prediction (NCEP) were used for the initial and boundary conditions of the atmosphere, land surface, and SST. In the PGW, although the FNL were used for the initial and boundary conditions of the atmosphere and land surface, those of SST were set by adding the difference in SST between the current and future climate (dSST) to the FNL with reference to the pseudo global warming method (Kimura and Kitoh, 2007). The dSST was calculated from the October monthly mean SST in the 2010s (2010–2019) and 2090s (2090–2099), which were predicted by MRI-CGCM3 (Yukimoto et al., 2012) under the RCP8.5 scenario (IPCC, 2014).

Figure 2 shows the spatial distributions of dSST and SST in the CTL and PGW. In the PGW, the SST was much higher than that in the CTL at higher latitudes because the dSST was greater at higher latitudes.

3. SIMULATION RESULTS

3.1. Track of the typhoon

Figure 3 shows the simulated typhoon track. The plot in Figure 3 shows the location of the typhoon center every 3 h in the WRF, every 6 h south of 30°N and every 3 h north of 30°N in the best track. Although the track of the typhoon south of 20°N in the CTL agreed well with that in the best track, the track of the typhoon north of 20°N in the CTL tended to deviate westward from that in the best track. The track of the typhoon north of 20°N in the PGW tended to deviate eastward from that in the CTL. However, because the variations in meteorological elements are relatively small in the east-west direction, the development and attenuation processes of the typhoon were investigated based on the simulation results in the next section.

3.2. Central pressure of the typhoon

Figure 4 shows the results for the central pressure of the typhoon. In the CTL, although the typhoon developed from 15°N, the central pressure from 15°N to 22.5°N tended to be higher than that in the best track. This may be because the typhoon intensity in the initial condition tended to be weak owing to the coarse grid resolution of the FNL. However, the minimum central pressure of 915–920 hPa at 22.5°N in the CTL agreed well with the minimum central pressure of 915 hPa in the best track. In the CTL, the central pressure rose from 25°N, and the typhoon began to attenuate. Although the central pressure during the attenuation process in the CTL was slightly lower than that in the best track, the trend of the central pressure was captured, and the central pressure at the landfall latitude of 34.5°N was 946–955 hPa in the CTL. This value agreed well with the central pressure of 955 hPa at a landfall latitude of 34.5°N in the best track. In the PGW, the typhoon reached a minimum central pressure of 877–880 hPa at 26.5°N.

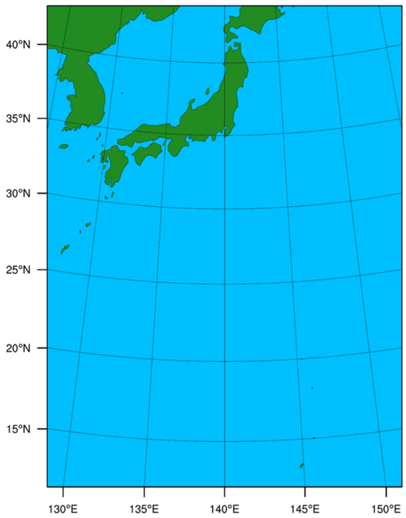


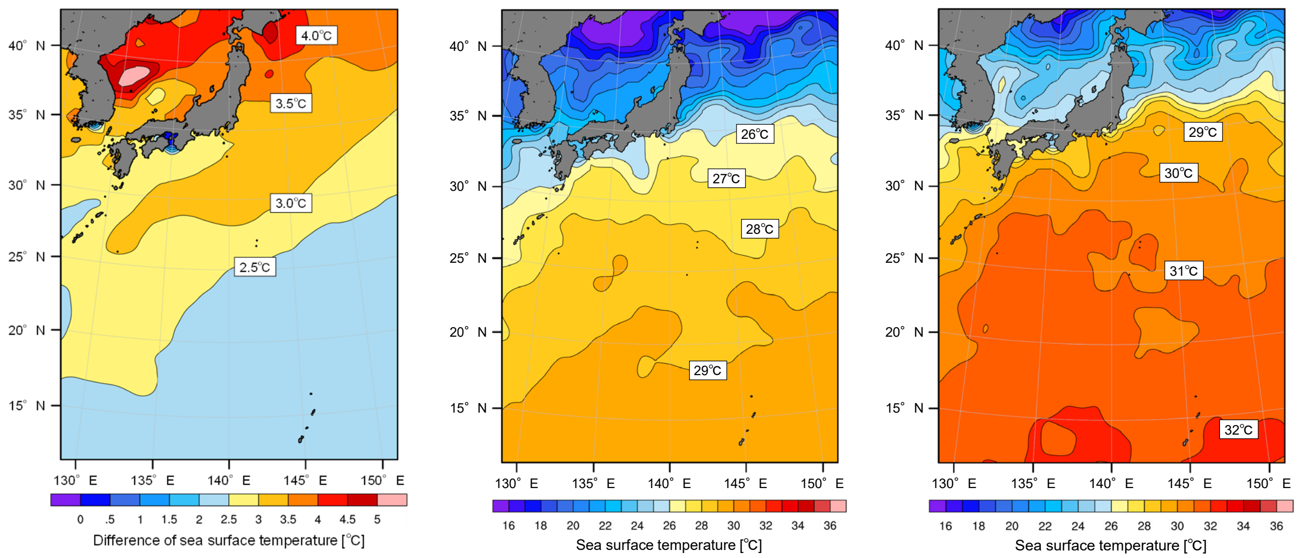
Figure 1. Computational domain.

Table 1. Computational conditions.

Domain size	2700 km × 3600 km
Horizontal grid resolution	5 km
Number of vertical layers	75 layers (minimum layer thickness: 60 m)
Time resolution	10 s
Planetary boundary layer scheme	YSU scheme
Land-surface model	Unified Noah land-surface model
Surface layer scheme	Revised MM5 Monin-Obukhov scheme
Microphysics scheme	WSM 6-class graupel scheme
Cumulus convective parameterization	Kain-Fritsch scheme
Long wave radiation scheme	RRTMG scheme
Short wave radiation scheme	

Table 2. Simulation cases.

Case	Start time		End time	Initial and boundary conditions
CTL_0000	2019/10/07	00:00 UTC	2019/10/13 12:00 UTC	Atmosphere: FNL Land surface: FNL SST: FNL (SST in the current climate)
CTL_0600		06:00 UTC		
CTL_1200		12:00 UTC		
CTL_1800		18:00 UTC		
PGW_0000	2019/10/07	00:00 UTC	2019/10/13 12:00 UTC	Atmosphere: FNL Land surface: FNL SST: FNL+dSST (SST in the future climate)
PGW_0600		06:00 UTC		
PGW_1200		12:00 UTC		
PGW_1800		18:00 UTC		



a) dSST b) SST in the CTL c) SST in the PGW

Figure 2. Spatial distributions of dSST and SST in the CTL and PGW.

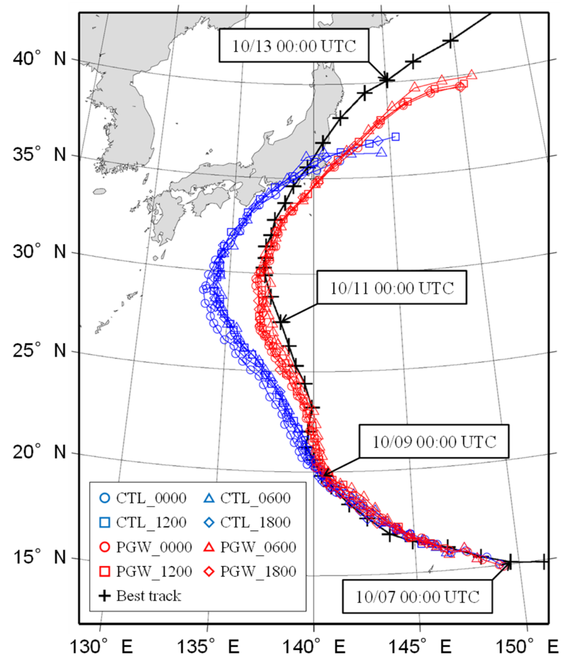


Figure 3. Track of the typhoon.

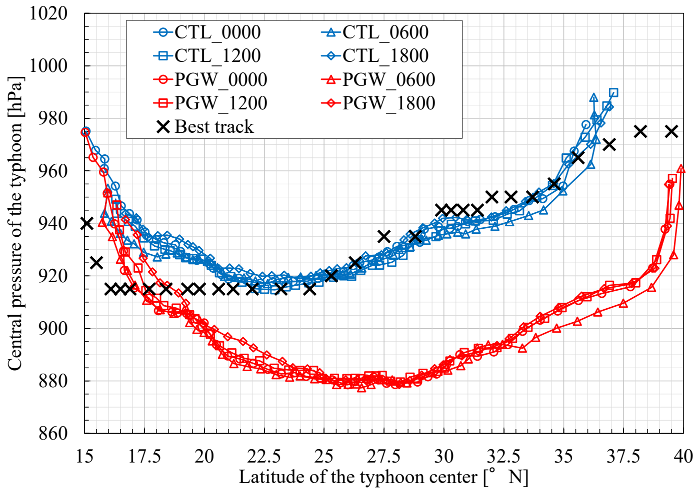


Figure 4. Central pressure of the typhoon.

This value was 35–43 hPa lower than the minimum central pressure in the CTL. In the PGW, the central pressure increased from 29°N, and the typhoon began to attenuate. The central pressure at the landfall latitude of 34.5°N was 900–907 hPa, which was 39–55 hPa lower than that in the CTL.

In the PGW, the typhoon continued to develop up to higher latitudes than in the CTL, and the typhoon intensity at the landfall latitude increased significantly. This is likely because SST warming is greater at higher latitudes than at lower latitudes.

4. CONCLUSIONS

We conducted numerical simulations of Typhoon Hagibis (2019) considering SST warming. Typhoons are indicated to develop up to higher latitudes under future SST conditions than under current SST conditions. These characteristics of the typhoon under future SST conditions significantly increased the typhoon intensity at the landfall latitude.

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