Numerical simulations of Typhoon Haishen by a coupled atmosphere-wave ocean model with two different oceanic initial conditions

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1. Introduction

A tropical depression was upgraded to a tropical storm around 22.6°N, 145.9°E at 12 UTC on 31 August in 2020, which was named Haishen. Haishen moved southwestward in the early intensification phase and then changed the direction to northwestward from 2 September. During the northwestward movement in the intensification phase, Haishen reached the minimum central pressure of 910 hPa at 12 UTC on 4 September. On 5 September, Haishen changed the direction to north northwestward and entered the East China Sea on 6 September. The Japan Meteorological Agency (JMA) forecasted that Haishen would be extremely strong (below 930 hPa) in the East China and possibly make landfalling in Japan while sustaining the strong intensity. However, Haishen weakened rapidly before entering the East China Sea. In the East China Sea, sea surface cooling was caused by the passage of preceding typhoon, Maysak. However, the cold wake was not sufficiently analyzed in the oceanic initial condition used in the forecast. To investigate the effect of the sea surface temperature (SST) distribution at the initial time and ocean coupling processes on the rapid weakening of Haishen, numerical simulations were conducted by using a nonhydrostatic atmosphere model (NHM) and the coupled atmosphere-wave-ocean model (CPL) (Wada et al., 2018).

2. Experimental design

Table 1 shows a list of numerical simulations. Each initial time was 0000 UTC on 2 September in 2020. The computational domain was 3080 x 3480 km with a grid spacing of 2 km. The number of the vertical layer was 55. The top height was approximately 27 km. The integration time was 132 hours. The time step was 5 seconds for NHM, 30 seconds for the ocean model, and 6 minutes for the ocean surface wave model. The cumulus parameterization of Kain and Fritsch (1990) (KF in Table 1) was used for comparison.

Table1 List of numerical simulations

Name	*Model*	*SST at the initial time*	*Cumulus Parameterization*
NHM	NHM	OISST	-
CPL	CPL	OISST	-
NHM_MGD	NHM	MGDSST	-
CPL_MGD	CPL	MGDSST	-
NHMKF	NHM	OISST	Kain and Fritsch (1990)
CPLKF	CPL	OISST	Kain and Fritsch (1990)
NHMKF_MGD	NHM	MGDSST	Kain and Fritsch (1990)
CPLKF_MGD	CPL	MGDSST	Kain and Fritsch (1990)

The 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. As for the initial condition of SST, the Optimally Interpolated SST (OISST) daily product with horizontal resolution of 0.25°, obtained from the Remote Sensing Systems (http://www.remss.com) was used. In addition, the Merged satellite and in situ data Global Daily Sea Surface Temperatures in the global ocean (MGDSST) data set (Kurihara et al., 2006) (MGD in Table 1) was used for comparison.

3. Results

3.1 Track simulations

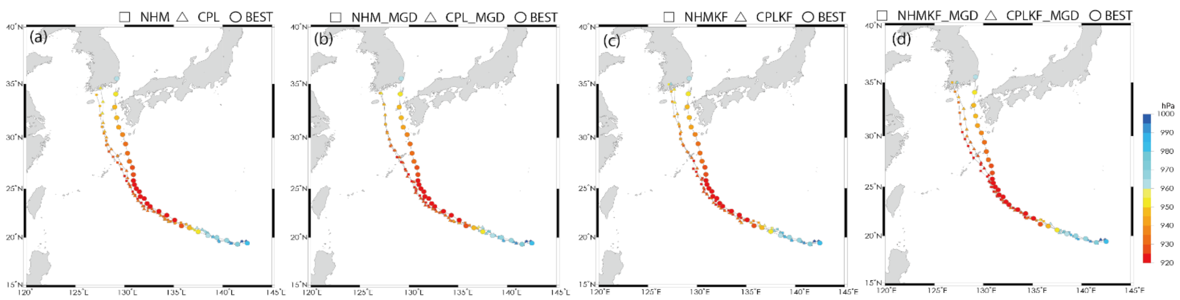

Figure 1 Simulated tracks in the experiments (a) NHM and CPL, (b) NHM_MGD and CPL_MGD, (c) NHMKF and CPLKF, and (d) NHMKF_MGD and CPLKF_MGD together with the RSMC best track. The interval is 3 hours for simulation results, while that is 3 or 6 hours depending on the location of Haishen relative to the Japanese archipelago. Colors in marks indicate the value of central pressure.

Figure 1 shows the results of simulated tracks and central pressures in all simulations together with the Regional Specialized Meteorological Center (RSMC) Tokyo best track (https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html) data. All simulated tracks clearly show a westward deflection compared to the best track after the best track Haishen changes the moving direction north-northwestward. The result indicates that there is less impact of ocean coupling and cumulus parameterization on the simulated tracks.

3.2 Intensity changes

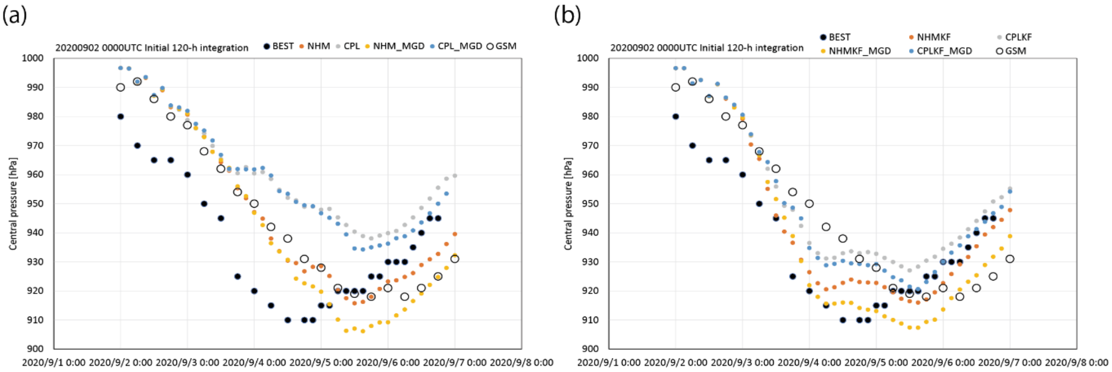

Figure 2 The evolution of RSMC best track central pressure, central pressures predicted by JMAGSM, and simulated central pressures in the experiments (a) NHM, CPL, NHM_MGD, and CPL_MGD and (b) NHMKF, CPLKF, NHMKF_MGD, and CPLKF_MGD.

Figure 2 shows the simulation results of central pressures, the prediction result of central pressures calculated by JMA global spectral model (GSM) and the RSMC best track central pressure. Since the initial value of central pressure differs between the RSMC best track central pressure and the central pressure at the initial time of integration used in all simulations and the prediction by GSM, the values of simulated central pressure and central pressure predicted by GSM tend to be higher than the best track central pressure in the intensification phase from the initial time to 00 UTC on 5 September. In addition, the time to reach the lowest central pressure, including the GSM results, is later than that of the RSMC best track. This may be one of the reasons that overdevelopment was forecasted in the East China Sea.

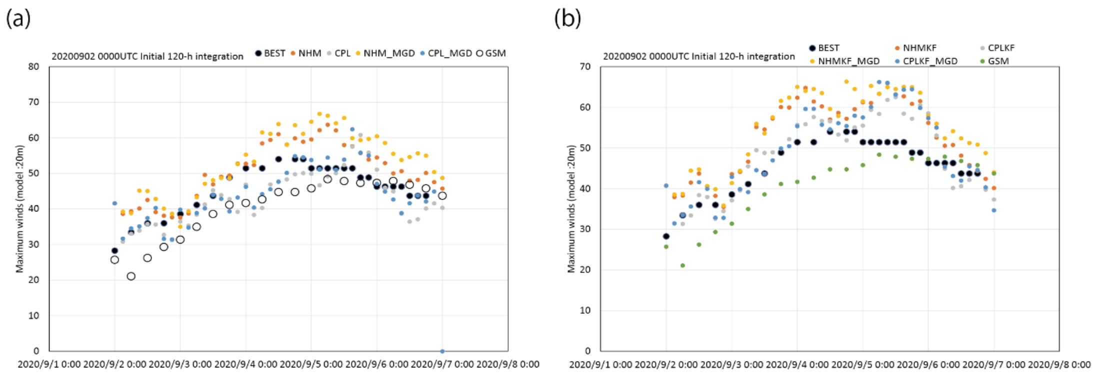

Figure 3 The evolution of RSMC best track 10-m maximum wind speed, 10-m maximum wind speeds predicted by JMA global spectral model and simulated 20-m maximum wind speeds in the experiments (a) NHM, CPL, NHM_MGD, and CPL_MGD and (b) NHMKF, CPLKF, NHMKF_MGD, and CPLKF_MGD.

Figure 3 shows the simulation results of 20-m maximum winds, the prediction result of 10-m maximum winds calculated by JMA global spectral model (GSM) and the RSMC best track 10-m maximum sustained wind speed. The height of 20 m corresponds to the model level near the surface. The effect of ocean coupling on 20-m maximum wind speed is more obvious in the experiments without the KF cumulus parameterization (NHM, CPL, NHM_MGD, and CPL_MGD) than that in the experiment with the cumulus parameterization (NHMKF, CPLKF, NHMKF_MGD, and CPLKF_MGD). Although the simulated tracks are shifted to the west, the simulation result by the coupled model with the cumulus parameterization seems to be better for the intensity change in the weakening phase, which is consistent with the result shown in Fig. 2.

4. Future study

Haishen was a relatively compact typhoon with a concentric eyewall. One of the ideas is the investigation of the effects of ocean coupling and cumulus convection on the inner-core structural change. The other idea, which will be reported in a companion report (Wada, 2021), is to investigate the effect of higher resolution (less than 1 km) on the simulation of Haishen.

References

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