The impact of ocean coupling on the genesis of Typhoon Songda (2022) simulated by two atmosphere-ocean coupled models

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1. Introduction

A tropical depression was formed around the edge of subtropical high northwest of the Mariana islands on 26 July in 2022. The tropical depression moved north northwestward along the edge of subtropical high and developed to a tropical storm Songda on 28 July. The Philippine Sea was covered with high sea-level pressure prior to the onset of a tropical depression with the sea surface temperature higher than 30°C. The area of high sea surface temperature expanded from the onset to the genesis of Songda. To investigate the impact of ocean coupling and high sea surface temperature extending east of Philippines on the genesis of Songda, we conducted numerical simulations using a nonhydrostatic atmosphere model, the non-hydrostatic numerical weather prediction model ASUCA (Ishida et al. 2022) coupled with an ocean model and the coupled atmosphere-wave-ocean model (Wada et al., 2018).

2. Experimental design

The atmosphere model ASUCA is an atmosphere model and this study uses the ASUCA coupled with a 1-dimensional ocean model (OASUCA). The coupled atmosphere-wave-ocean model (CPL) consists of a nonhydrostatic atmosphere model previously used as a numerical weather prediction model in the Japan Meteorological Agency (JMANHM), a mixed-layer ocean model and the third-generation ocean surface wave model. JMANHM is also used for the numerical simulation on the genesis of Songda.

Table 1 shows a list of numerical simulations. The computational domain is the same among the three simulations, NHM, CPL and OASUCA. The domain is 4500 km (zonal) x 2700 km (meridional) of which center location is 22.5°N, 130°E. The horizontal resolution is 3 km. The number of vertical layers is 96 for ASUCA (the top height is about 37 km) and 55 for NHM (the top heigh is about 27 km).

Table1 List of numerical simulations

Name	***Model***	***Cumulus Parameterization (CP) & cloud physics***
NHM	JMANHM	No CP & ice phase predicted
CPL	JMANHM coupled with a mixed layer ocean model and the third-generation ocean surface wave model (Wada et al. 2018)	No CP & ice phase predicted
OASUCA	ASUCA coupled with a 1-dimensional ocean model (Ishida et al. 2022)	No CP & ice phase predicted but the formation process of graupel is simplified.

All the simulations are started from 00UTC on 21 July in 2022. The integration period is 9 days (216 hours). An initial condition and 6-hourly boundary conditions for the atmosphere are created from the global objective atmospheric analysis data of the Japan Meteorological Agency (~20 km horizontal resolution). In addition, an initial condition for the ocean is created from the North Pacific version of the oceanic analysis data (~0. 1° horizontal resolution) merged with the Optimally Interpolated SST (OISST) daily product (0.25° horizontal resolution) obtained from the Remote Sensing Systems (http://www.remss.com) as of 20 July. In the OASUCA experiment, the World Ocean Atlas (WOA) 2018 (https://www.ncei.noaa.gov/products/world-ocean-atlas) and Merged satellite and in-situ data Global Daily Sea Surface Temperature (MGDSST) are used for creating oceanic initial conditions. Physical processes used in this study are standard as referred in Ishida et al. (2022) for OASUCA except without the usage of cumulus parameterization and Wada et al. (2018) for NHM. The Regional Specialized Meteorological Center (RSMC) Tokyo best track data (https://www.jma.go.jp/jma/jma-eng/jma-center/rsmc-hp-pub-eg/besttrack.html) is used to validate the results of numerical simulations.

3. Results

3.1 SST

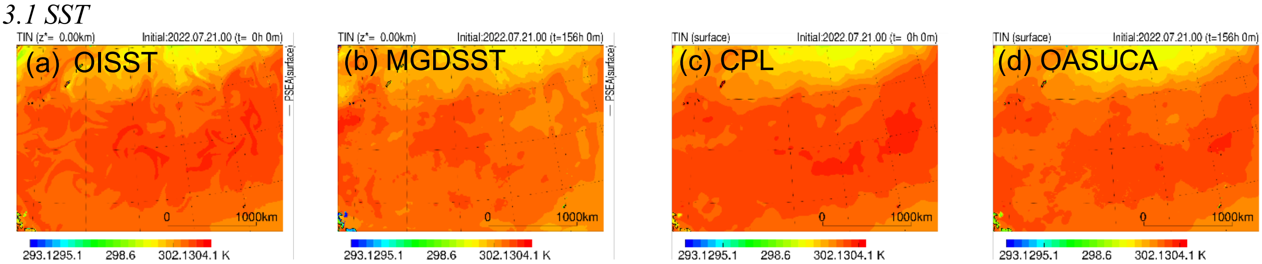

Figure 1 Horizontal distributions of sea surface temperature at 0 h obtained from (a) OISST and (b) MGDSST and at 156 h in the (c) CPL and (d) OASUCA experiments. The unit of sea surface temperature is K and the color range is from 293.15 K (20˚C) to 304.15 K (31˚C).

Figure 1 shows the horizontal distribution of sea surface temperature at 0 h used in the CPL (Fig. 1a) and OASUCA (Fig. 1b) experiments and at 156 h in the CPL (Fig. 1c) and OASUCA (Fig. 1d) experiments . All the numerical experiments successfully simulate an onset of tropical depression at the edge of subtropical high at 12 UTC on 27 July (Fig.2) although the OASUCA model simulates a tropical cyclone, which develops more rapidly than the RSMC-Tokyo best track data . In this study, the simulated tropical depression is regared as a precursor of Songda (2022). However, the area of high sea surface temperature east of the Philippines and east-west asymmetric pattern obtained from OISST at 12 UTC on 27 July (not shown) could not be reasonably simulated in the CPL (Fig. 1c) and OASUCA (Fig. 1d) experiments. Simulated sea surface temperature in the CPL experiment (Fig. 1c) becomes realistically low east of the computational domain compared to that in the OASUCA experiment (Fig. 1d).

3.2 Wind speeds at the lowermost level

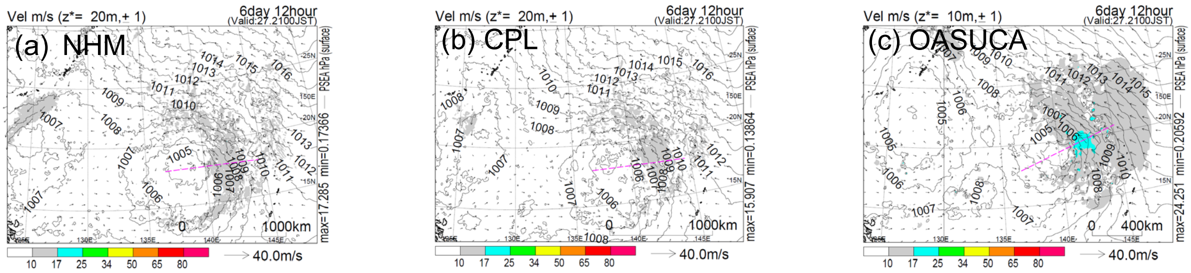

Figure 2 Horizontal distributions of wind speeds at an altitude of 20 meters at 156 h in the (a) NHM and (b) CPL experiments, and those at an altitude of 10 meters at 156 h in the (c) OASUCA experiment. A dashed magenda line in each panel shows a cross-section line in Fig.3.

Figure 2 shows the horizontal distributions of wind speeds near the surface. All the simulations show relatively high wind speed exceeding 10 m s^{-1} northeast to east of a tropical depression. The OASUCA (Fig. 2c) simulates wind speeds exceeding 10 m s^{-1} at a higher altitude than the NHM (Fig. 2a) and CPL (Fig. 2b) around the edge of subtropical high. This indicates that the impact of ocean coupling on wind speeds near the surface is relatively small compared with that of the difference of the atmosphere model between OASUCA and NHM.

3.3 Vertical wind structure across the center of tropical depression

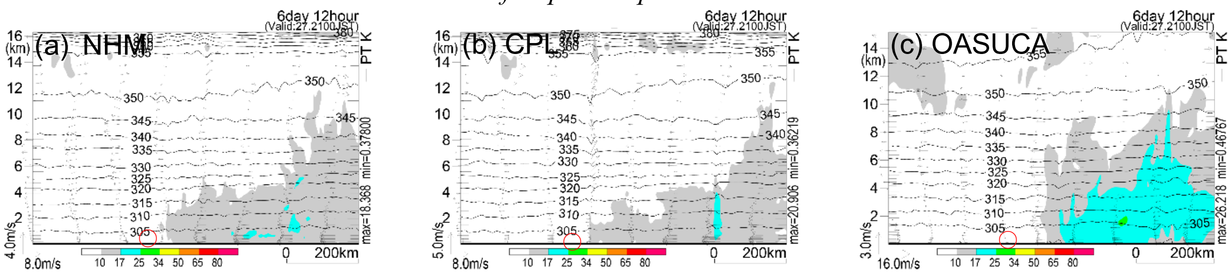

Figure 3 Vertical sections of simulated wind speeds with simulated potential temperatures at 156 h in the (a) NHM, (b) CPL, and (c) OASUCA experiments. The location of cross section is shown in each panel of Figure 2. Red circles correspond to the location of convergence near the surface.

Figure 3 shows the cross section of simulated wind speeds with simulated potential temperature across the center of a simulated tropical depression in the NHM (Fig. 3a) and CPL (Fig. 3b) experiments and across the center of a tropical cyclone in the OASUCA experiment (Fig. 3c). The magnitude of simulated wind speeds around the edge of subtropical high is greater in the OASUCA experiment (Fig. 3c) that in the NHM (Fig. 3a) and CPL (Fig. 3b) experiments. The locations of the tropical depressions and the tropical cyclone correspond to the area of relatively weak convergence. Those are not affected by the impact of ocean coupling and the difference in the models used in this study.

4. Concluding remarks

We conducted numerical simulations on an onset of Songda in 2022 using JMANHM, CPL and OASUCA models. From the results of numerical simulations, we obtain the following results.

1. The impact of sea surface temperature on an onset of a tropical depression is relatively small.
2. Wind speeds at an altitude of 10 meters simulated by the OASUCA model are higher than those at an altitude of 20 meters simulated by the NHM and CPL models.
3. The locations of the convergence of surface winds are not affected by the impact of ocean coupling as well as the difference between the models, which may be regarded as characteristics of the formation of a tropical depression or a tropical cyclone.

It should be noted that the OASUCA model tends to overdevelop the tropical depression to a tropical cyclone compared to the RSMC-Tokyo best track analysis although the simulated track is more reasonable to the best track than the CPL model. The relation of high winds around the edge of subtropical high and simulated track will be one of the subjects in the future.

References

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