The impact of ocean coupling on the rainfall distribution of Typhoon Nanmadol (2022) at the landfall

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1. Introduction

Typhoon Nanmadol (2022) made landfall on Southern Kyushu at 08 UTC on 18 September. The Japan Meteorological Agency (JMA) issued a heavy rain emergency warning for Miyazaki prefecture at around 04 UTC on 14 September before the typhoon made landfall and passed over the region. In fact, the typhoon caused the maximum value on precipitation observations since the start of statistics at several stations in Miyazaki Prefecture (https://www.data.jma.go.jp/miyazaki/shosai/pdf/r4/20220921_saigaiji_houkoku.pdf). To investigate the effect of ocean coupling on the heavy rainfall, we conducted numerical simulations on Nanmadol from the early developing phase to the decaying phase using the JMA nonhydrostatic atmosphere model (NHM), the atmosphere-wave-ocean coupled model (CPL: Wada et al., 2018), the current JMA operational atmosphere model ASUCA, and the ASUCA coupled with a one-dimensional ocean model (OASUCA). The simulation results were used to assess the effect of ocean coupling on the rainfall distribution when the typhoon made landfall on Southern Kyusyu.

2. Experimental design

The computational domain is common among the simulations conducted by the NHM and CPL. The domain is 4900 km (zonal) x 4800 km (meridional) of which center location is 30.0°N, 140°E. The horizontal resolution is 2.5 km. The number of vertical layers is 55 for NHM and CPL (the top height is about 27 km). The time step for the atmosphere model is 10 s, that for the ocean model is 60 s and that for the ocean surface wave model is 360 s. The initial time for the simulations by the ASUCA and OASUCA are 00UTC on 15 September in 2022, while that by the NHM and CPL are 18UTC on 14 September in 2022 because the numerical simulations at which initial time is 00 UTC on 15 September has not been complete yet. The integration period is 105 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). The width of lateral boundary relaxation sponge layers is set to be 140 due to the control of track simulations. In addition, an initial condition for the ocean in the NHM and CPL experiments 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. No boundary condition is used in the CPL experiment, while the simulated sea surface temperature in the OASUCA experiment is restored to the initial condition at a constant time. In the NHM and ASUCA experiments, sea surface temperature is fixed during the integration. 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 Simulated tracks and central pressures

Figure 1a shows the comparison of the RSMC-Tokyo best track with the simulation results. Although the results of track simulations in the NHM and CPL experiments show eastward biases compared with the best track, those in the ASUCA and OASUCA experiments are reasonable to the best track.

Figure 1b shows the timeseries of the RSMC-Tokyo best track central pressures along with the simulated ones. Unlike the result of track simulations in the ASUCA and OASUCA experiments, both models could not simulate the best-track decreasing rate of central pressure and the minimum central pressure.

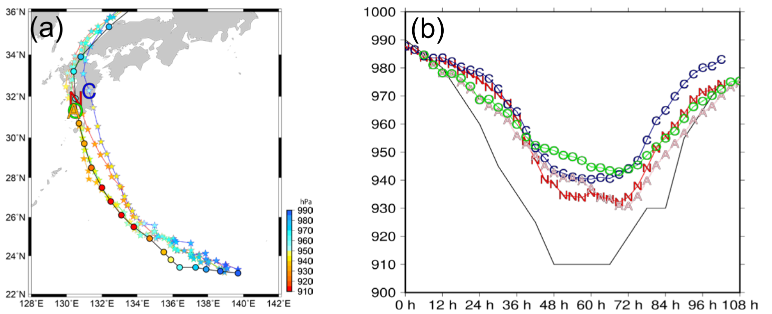
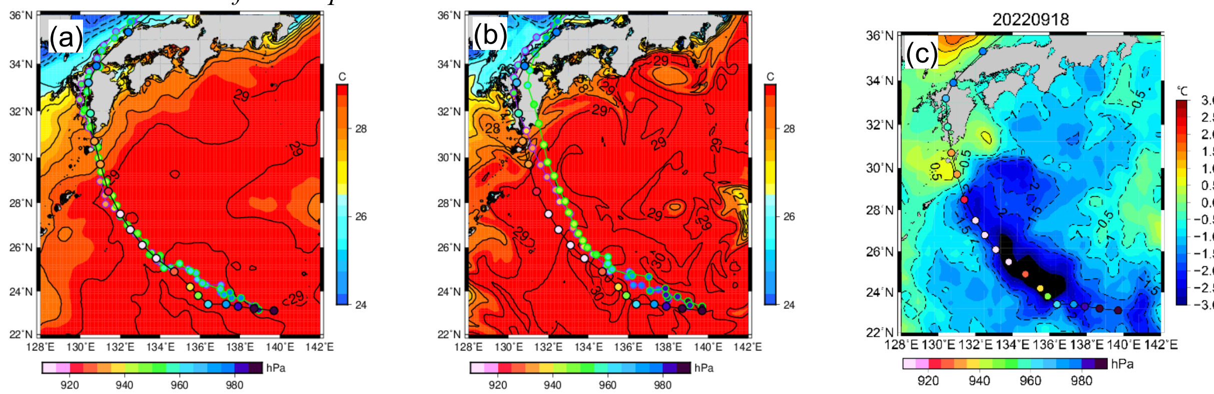


Figure 1 (a) RSMC-Tokyo best track positions (circles) every 6 hours with colors indicating the value of best-track central pressures with the positions (stars) simulated by the NHM (red), CPL (blue), ASUCA (orange) and OASUCA (green). The alphabets indicate the location of simulated typhoon at 00 UTC on 18 September in the NHM(N), CPL(C), ASUCA(A) and OASUCA(O) experiment. (b) Time series of RSMC-Tokyo best-track central pressures (black solid line) with the simulated ones. The abscissa in (b) is a relative time from 18UTC on 14 September.

The effect of ocean coupling on the simulated central pressure is represented by the difference of simulated central pressure between NHM and CPL and between ASUCA and OASUCA. The differences are relatively small in the early intensification phase and increase in the late intensification phase. The maxima of the differences were achieved in the mature phase. At 00UTC on 18 September, the difference in the simulated central pressures is still large in spite of the difference of the landfalling location between NHM and ASUCA (CPL and OASUCA).

3.2 Simulated sea surface temperatures



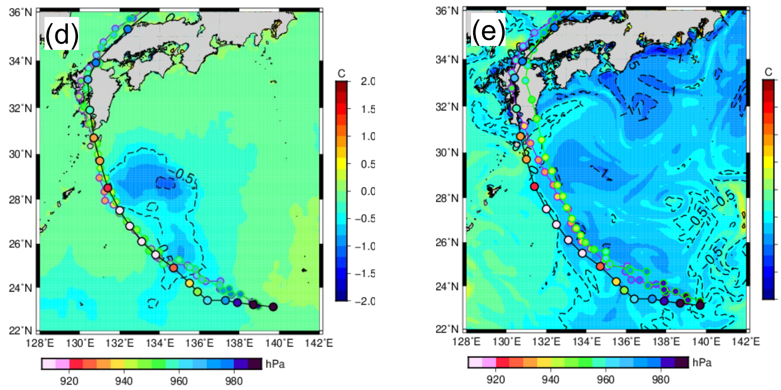


Figure 2 (a)&(b) Horizontal distribution of sea surface temperature at the initial time (a) in the ASUCA and OASUCA experiments and (b) in the NHM and CPL experiments. (c) Horizontal distribution of the variation in microwave optically interpolated sea surface temperature on 18 September from the sea surface temperature on 13 September. (d)&(e) Horizontal distribution of the difference in sea surface temperature at 00UTC on 18 September (d) between ASUCA and OASUCA and (e) between NHM and CPL. In all panels, colors within the circles indicate the value of central pressure.

At the initial time, the horizontal distribution of sea surface temperature used in the ASUCA and OASUCA experiments (Fig. 2a) is similar to that used in the NHM and CPL experiments (Fig. 2b) although a finer distribution is found in Fig. 2b. Microwave optically interpolated sea surface temperature data indicate that sea surface cooling was induced along the track after the passage of Nanmadol (Fig. 2c). The magnitude of the sea surface cooling exceeds 3 °C. Sea surface cooling simulated in the OASUCA experiment is confined around the right-hand side of the track (Fig. 2d), while sea surface cooling in the CPL experiment (Fig. 2e) becomes similar to that analyzed by using the microwave optically interpolated sea surface temperature data (Fig. 2c). These differences in SST simulations between CPL and OASUCA do not, however, lead to the improvement of simulated track and central pressure. Rather, relatively small magnitude of simulated sea surface cooling may be attributed to relatively high minimum simulated central pressures.

3.3 Simulated rainfall at 00 UTC on 18 September

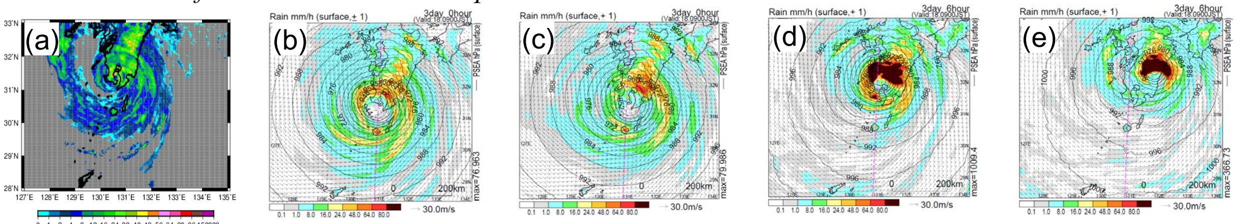


Figure 3 The 1-hour rainfall distribution (mm / hour) (a) analyzed every 10 minutes, simulated in the (b) ASUCA, (c) OASUCA, (d) NHM, and (e) CPL experiments at 00 UTC on 18 September.

Figure 3a shows the 1-hour rainfall distribution analyzed every 10 minutes. Shield-like heavy rainfall distribution is observed in Miyazaki Prefecture. All the simulation results show the occurrence of heavy rainfall in Miyazaki Prefecture, but the almost all the precipitation is simulated around the eyewall of simulated Nanmadol where the effect of ocean coupling on the precipitation amount is clearly found (Fig. 2b-2e). In other words, heavy precipitation in Miyazaki Prefecture induced by topography is not well improved by ocean coupling, which may be attributed to track errors particularly in the NHM and CPL experiments, and insufficient intensity simulations attributed to the structural change of the typhoon.

4. Future works

Numerical simulation experiments will be continued under the policy that improvements in the physical processes in the atmosphere model, rather than the effects of ocean coupling, are more important to more realistically reproduce both typhoon intensity and heavy precipitation associated with the typhoon.

References

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