Atmosphere-wave-ocean coupled-model simulation on rapid intensification of Typhoon Hagibis (2019)

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1. Introduction

Typhoon Hagibis (2019) enlarged rapidly its size from its genesis at 18UTC on October 5 to its rapid intensification. After reaching a central pressure of 915 hPa at 12 UTC on October 6, the central pressure lasted 66 hours. The typhoon made landfall in the Izu Peninsula after it was travelling over the ocean where the sea surface temperature exceeded 27 ° C, while maintaining its large size and strong intensity. Extraordinary large amounts of water vapor were transported to the Japanese archipelago while the typhoon was moving north, causing record-breaking heavy rains in eastern Japan and increasing flood damage from river floods. In order to understand the dynamic and thermodynamics of rapid intensification and large size, numerical simulations were performed on Hagibis in the early and rapid intensification phase using the 1-km mesh coupled atmosphere-wave-ocean model (Wada et al., 2018).

2. Experimental design

The list of numerical simulations is shown in Table 1. Each initial time was 0000 UTC on October 6. The computational domain was 1620 x 990 km. The number of the vertical layer was 55. The top height was approximately 27 km. The integration time was 42 hours. The time step was 3 seconds for NHM, 18 seconds for the ocean model, and 6 minutes for the ocean surface wave model.

Table1 List of numerical simulations

Name	*Model*	*Ocean*
NHM	NHM	2019
CPL	Coupled NHM-wave-ocean model	2019
NHMAVE	NHM	Climatology
CPLAVE	Coupled NHM-wave-ocean model	Climatology

The physical components were exchanged between NHM, the ocean model, and the ocean surface wave model every time step of a 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. In addition, climatological oceanic averaged data are calculated by using the oceanic reanalysis data from 1982 to 2018 (Usui et al., 2017). When the climatological data are used in the simulation, 'AVE' is added to the end of the experiment name shown in Table 1. It should be noted that to simulate a strong typhoon, the coverage of sea spray was assumed to be 100% instead of 4% (Wada et al. 2018).

3. Results

3.1 Track and central pressure

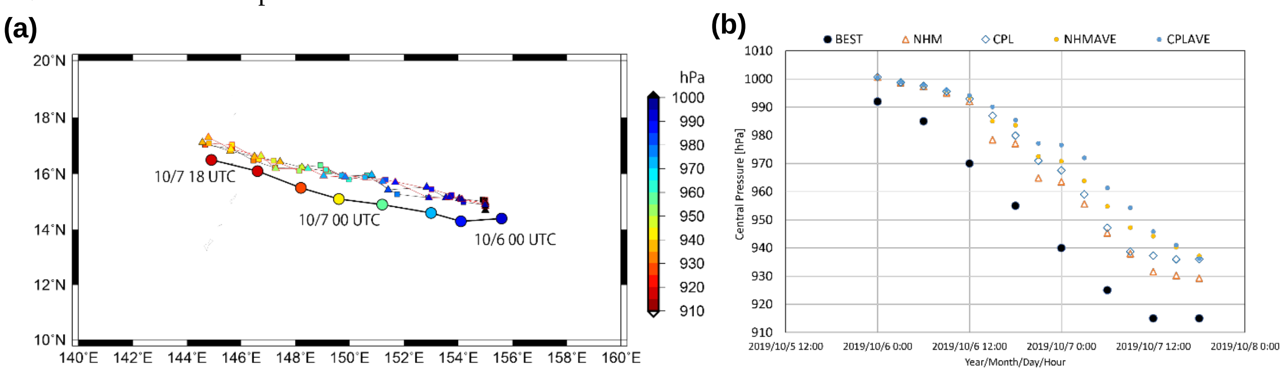

Figure 1 (a) Regional Specialized Meteorological Center (RSMC) Tokyo best track and simulated tracks listed in Table 1 from 00 UTC on October 6 to 18 UTC on October 7 in 2019. (b) Time series of RSMC Tokyo best track central pressure and simulated central pressures listed in Table 1.

Figure 1 shows the simulated tracks and Regional Specialized Meteorological Conter (RSMC) Tokyo best track for comparison. Although the simulated tracks were deflected north, the moving direction west-northwest was well simulated. Although the initial value of the center pressure was higher than that of RSMC best track central pressure, the change in simulated central pressure was reasonable compared with that in RSMC Tokyo best track central pressure. Regarding the impact of difference in the oceanic initial conditions between real-time analysis and climatological mean on the central pressure simulation, the simulated central pressures in the NHM and CPL experiments tended to be lower than those in the NHMAVE and CPLAVE experiments. In addition, the effect of ocean coupling became clearer as the simulated central pressure decreased. The sea surface temperature underneath the typhoon was hardly cooled over the ocean where the oceanic mixed layer was relatively deep. Therefore, the simulated central pressure could deepen more rapidly and was able to maintain the lowest value since the upper-ocean heat content on October in 2019 was higher than climatological mean (not shown).

3.2 Structural change during rapid intensification

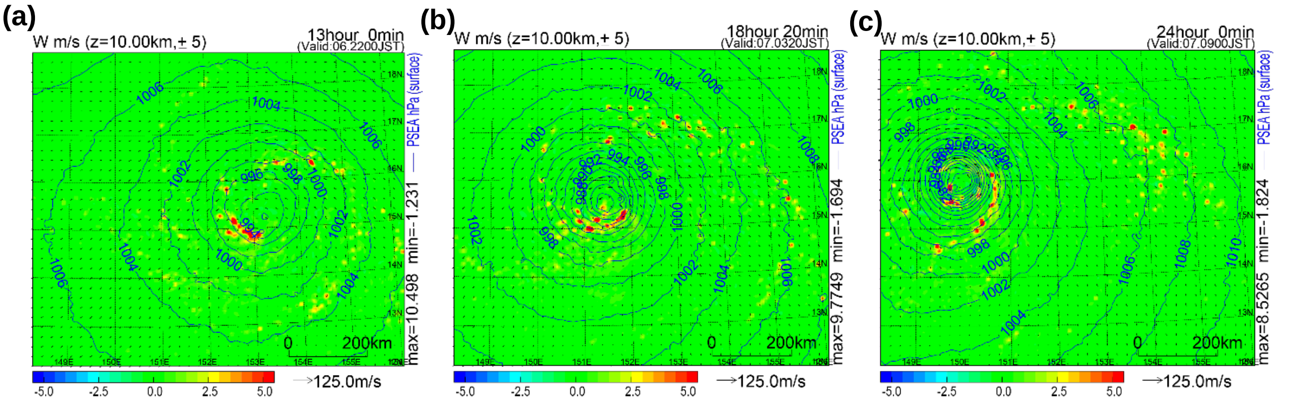

Figure 2 Horizontal distributions of vertical wind velocity (m s^{-1}: colors), horizontal winds at a 10-km height (m s^{-1}: vectors) and sea-level pressure (hPa: contours) at (a) 13-h, (b) 18-h 20-min, and 24-h integration times.

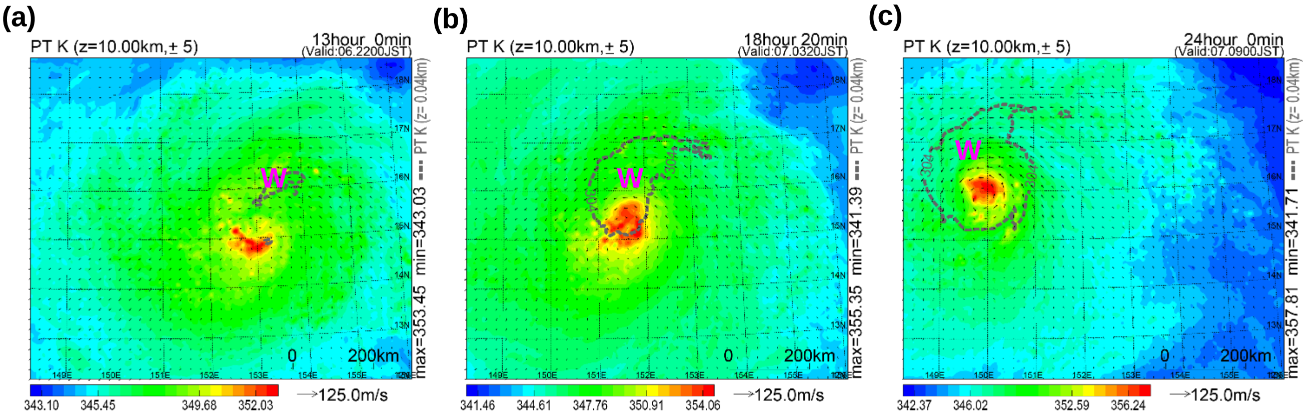

Figure 3 Horizontal distributions of potential temperature (K: colors), horizontal winds at a 10-km height (m s^{-1}: vectors) and surface potential temperature (K: contours) at (a) 13-h, (b) 18-h 20-min, and 24-h integration times.

Figures 2 and 3 show the horizontal distributions of vertical velocity and potential temperature at a 10-km height at 13h, 18h20m and 24h. At the 13-h integration time, the area of upward motion was spirally distributed southwest of the typhoon center where the potential temperature was higher than its surroundings. Apart from the upper warm area, there was a high potential temperature area near the surface northeast of the typhoon center. The near-surface warm area began to overlap with the upper warm area at the 18h20m integration time when the area of upward motion moved spirally south of the typhoon center, and finally the upper warm area was included in the near surface warm area at the 24h integration time. At the time, the central pressure had been rapidly lowering. In addition, another upward-motion area, corresponding to a spiral rainband outside the eyewall was generated.

4. Summary and future subject

The rapid intensification of Typhoon Hagibis (2019) was reasonably simulated in the NHM and CPL experiments. The rapid intensification and the sustenance of the lowest central pressure occurred when Hagibis passed over the ocean where the upper-ocean heat content was higher than the climatological mean. The upward vertical velocity in the upper troposphere contributed to the formation of high potential-temperature area southwest of the typhoon center, whereas high potential temperature area was formed near the surface northeast of the typhoon center. The central pressure lowered rapidly when the high potential temperature area in the upper troposphere was included in the potential-temperature area near the surface. The relationship between the formation of potential-temperature area near the surface and the enlargement of typhoon size is a subject in the future.

References

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