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

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1. Introduction

Wada (2020) reported from the results simulated by a 1-km mesh nonhydrostatic atmosphere model and the coupled atmosphere-wave-ocean model (Wada et al., 2018) that the rapid intensification and the sustenance of the lowest central pressure of Hagibis (2019) occurred when it passed over the ocean where the upper-ocean heat content was higher than the climatological mean. Regarding the impact of a difference in the oceanic initial conditions between real-time daily analysis and climatological daily mean on the simulated central pressure of Hagibis in the intensification phase, the central pressures simulated with the oceanic initial condition obtained from the real time oceanic daily analysis dataset tended to be lower than those obtained from the climatological daily mean. This result, however, is obtained from a single deterministic simulation result at one specific atmospheric initial condition and thus it is not always robust for various atmospheric initial conditions. To perform an ensemble simulation for Hagibis, multiple atmospheric initial conditions are needed. This report conducts two sets of ensemble simulation by using the results of ensemble simulations conducted by the coupled atmosphere-wave-ocean model with two different oceanic initial conditions and focuses on the difference in the impact of a difference in the oceanic initial conditions on simulated Hagibis in the intensification phase.

2. Experimental design

The experimental design is the same as Wada (2020). The atmospheric initial condition in Wada (2020) is regarded as that in the control run. The Japan Meteorological Agency (JMA) global atmospheric ensemble prediction data with a horizontal grid spacing of 1.25° were used to add perturbations to the atmospheric initial condition used in Wada (2020). Although up to 50 perturbations were available, 25 of them were used in this study due to the limitation of computational resources. Two sets of ensemble simulation were carried out using these 26 atmospheric initial conditions for the real time and climatological mean oceanic initial conditions, respectively. The integration time in all simulations was 48 hours. However, the simulation of one atmospheric initial condition (No.19) with the climatological mean oceanic initial condition became unstable during the integration and terminated abnormally. This is the reason that the analysis period is from the initial time up to 36 hours. The Regional Specialized Meteorological Center (RSMC) Tokyo best track data is used for validation of the simulation results.

3. Results

3.*1 Simulated track and central pressure*

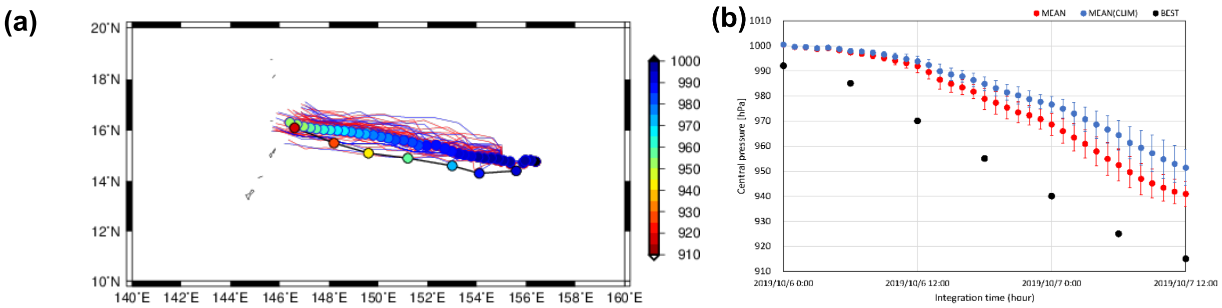

Figure 1 Results of (a) ensemble mean track simulations (a line with circles every hour) and (b) ensemble mean central pressures with the standard deviation every hour. Red colors in Figs. 1a, b show the results of numerical simulations with the real time oceanic initial condition, while blue colors in Figs. 1a, b show those with the climatological mean oceanic initial condition. Black colors in Figs. 1a, b show the RSMC best track (data is depicted every 6 hours). Colors within the circle in Fig. 1a shows the value of central pressure (The unit of the color bar is hPa).

Figure 1a shows a simulated track in each member, the ensemble mean simulated with the real time oceanic initial condition and the ensemble mean with the climatological mean oceanic initial condition, and the RSMC best track for validation. Each simulated track and the ensemble mean were deflected north irrespective of the oceanic initial condition, which is the same as the result of Wada (2020). The width of the ensemble spread normal to the track of ensemble mean (Fig. 1a) shows that the northward bias cannot be improved by simply replacing the atmospheric initial condition. This suggests that it is necessary to set a larger number of ensemble members to statistically improve the track simulation. Nevertheless, it should be noted that a few simulated tracks are close to the RSMC best track or shows the southward deflection compared to the RSMC best track.

Figure 1b shows the time series of the ensemble mean central pressures simulated with the real time oceanic initial condition, those simulated with the climatological mean oceanic initial condition and the RSMC best track central pressure. The standard deviation is calculated for simulated central pressures every hour. The initial value of center pressure used in the ensemble simulations is higher than that of RSMC best track central pressure irrespective of the addition of the perturbation to the atmospheric initial condition. Regarding the impact of difference in the oceanic initial conditions between real-time analysis and climatological mean on the central pressure simulation, the central pressures simulated with the real time oceanic initial condition tend to be lower than those simulated with the climatological mean oceanic initial condition. The difference of simulated central pressures between the real time and the climatological mean oceanic initial conditions is significant after 07 UTC on 6 September (after the 7-hour integration time) at the 99% confidence level based on t-test. The result supports the findings of Wada and Chan (2021) that Hagibis became stronger because the amount of the upper ocean heat content (tropical cyclone heat potential) increased recently around 15-20˚N, 140-150˚E.

3.2 Sea surface temperature distribution

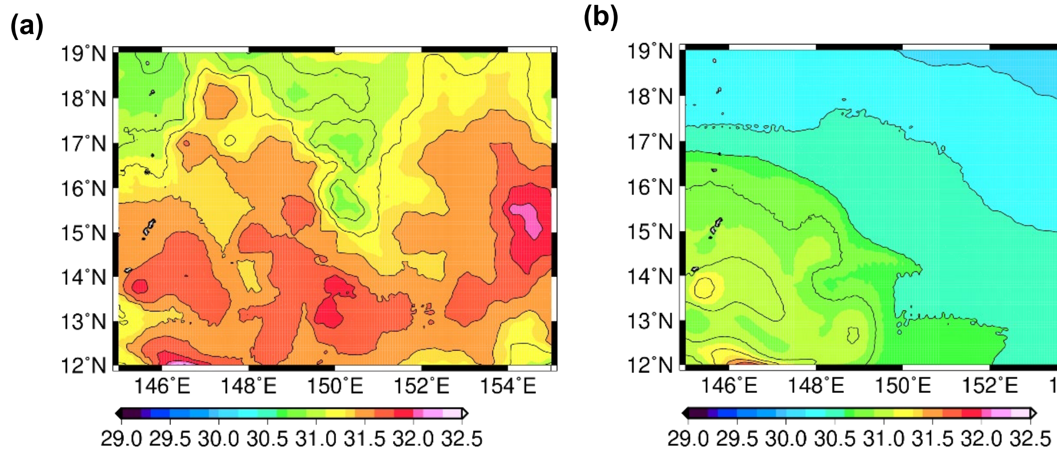

Figure 2 Horizontal distributions of the ensemble mean SST (˚C) simulated with (a) the real time oceanic initial condition and that simulated with (b) the climatological mean oceanic initial condition. The contour interval is 0.1˚C. Colors also indicate the value of SST.

Figure 2 shows the horizontal distributions of ensemble mean sea surface temperature (SST) at the 36-h integration time simulated with the real time oceanic initial condition (Fig. 2a) and with the climatological mean oceanic initial condition (Fig. 2b), respectively. The ensemble mean SST simulated with the real oceanic initial condition is higher in the whole computational domain than that simulated with the climatological mean. It is considered that the difference in the ensemble mean of simulated SST is related to that in simulated central pressure of approximately 10 hPa shown in Fig. 1b, which corresponds to the result of Wada and Chan (2021). Despite the clear difference in the ensemble mean of simulated SST distribution shown in Fig. 2, however, the impact on the ensemble mean of simulated Hagibis's track is small. It should be noted that the atmospheric initial condition used in this study is the same in the two sets of ensemble experiments, which does not reflect the difference in the atmosphere resulted from the difference in the oceanic initial condition or the difference due to the recent upper-ocean warming (Wada and Chan, 2021).

4. Summary and future subject

This study focused on the effect of the difference in the oceanic initial conditions between real-time analysis and climatological mean on the simulation of Typhoon Hagibis (2019) in the intensification phase. Two sets of ensemble simulations are performed separately with a 1-km mesh regional atmosphere-wave-ocean coupled model and 26 atmospheric initial conditions created by adding the perturbation based on JMA global atmospheric ensemble prediction data. The result shows that the difference of simulated central pressures between real-time analysis and climatological mean oceanic initial conditions is significant after the 7-hour integration time at the 99% confidence level based on t-test although there is little impact on the ensemble mean of simulated tracks. The difference in the ensemble mean of simulated SST is related to that in simulated central pressure of approximately 10 hPa at the 36-h integration time, which is consistent with the result of Wada and Chan (2021). It is one of the subjects in the future that the effect of ocean coupling on the ensemble simulation with 26 atmospheric initial conditions will be statistically investigated by conducting another ensemble simulation with a noncoupled atmosphere model.

References

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