Sensitivity of horizontal resolution and sea spray to the simulations of Typhoon Roke in 2011

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1. Introduction

A previous report of Wada (2012) indicated that the horizontal resolution of 2 km was not enough to simulate the maximum intensity and structural change of Typhoon Roke in 2011 although the nonhydrostatic atmosphere model without ocean coupling well reproduced a rapid decrease in central pressure, 30 hPa in a day. In reality, a rapid intensification of Roke occurred when sea surface cooling was induced by the typhoon. This study addresses the sensitivity of horizontal resolution to the simulations of the typhoon. In addition, the sensitivity of an increase in turbulent heat fluxes due to the effect of sea spray induced by strong winds to the simulations was investigated in order to investigate the impact on the maximum intensity and intensification of simulated Roke.

2. Experimental design

Summary of numerical simulations performed by the atmosphere-wave-ocean coupled model (Wada et al., 2010) is listed in Table1. The coupled model covered nearly a 1600 km x 1600 km computational domain with a horizontal grid spacing of 2 km in experiments A2km and C2km, and that of 1.5km in experiments C1.5km and CSP1.5km. The coupled model had 40 vertical levels with variable intervals from 40 m for the near-surface layer to 1180 m for the uppermost layer.

Table 1 Summary of ocean coupling/noncoupling, horizontal resolution and sea spray parameterization

Experiment	Ocean coupling	Horizontal resolution	Sea spray
A2km	NO	2 km	-
C2km	YES	2 km	-
C1.5km	YES	1.5km	-
CSP1.5km	YES	1.5km	Bao et al.(2000)

The coupled model had maximum height approaching nearly 23 km. The integration time was 84 hours (84 h) with a time step of 6 seconds in the atmospheric part of the coupled model. The time step of the ocean model was six times that of the coupled model. That of the ocean wave model was 10 minutes. Oceanic initial conditions were obtained from the oceanic reanalysis datasets with a horizontal resolution of 0.1° (Table 1) calculated by the Meteorological Research Institute multivariate ocean variational estimation (MOVE) system (Usui, et al., 2006). The sea spray parameterization described in Bao et al. (2000) was used in experiment CSP1.5km.

3. Results

Figure 1 displays time series of the Regional Specialized Meteorological Center Tokyo (RSMC-Tokyo) best track central pressure every six hours and simulated central pressure of Roke every three hours in experiments A2km, C2km, C1.5km and CSP1.5km from 0000 UTC on 18 September to 1200 UTC on 21 September in 2011. The result of sensitivity numerical experiments indicated that the intensification rate simulated in experiment C1.5km, defined as a decrease in central pressures for six hours, was more reasonable to that of the RSMC-Tokyo best track than that simulated in experiment C2km, particularly from 1200 UTC on 19 to 1200 UTC on 20 September. However, simulated central pressures could not reach 940 hPa, the lowest central pressure reported in the RSMC-Tokyo best track data. The lowest simulated central pressure in experiment C1.5km was 949 hPa at 1200 UTC on 20 September, 9 hPa higher than the best track central pressure.

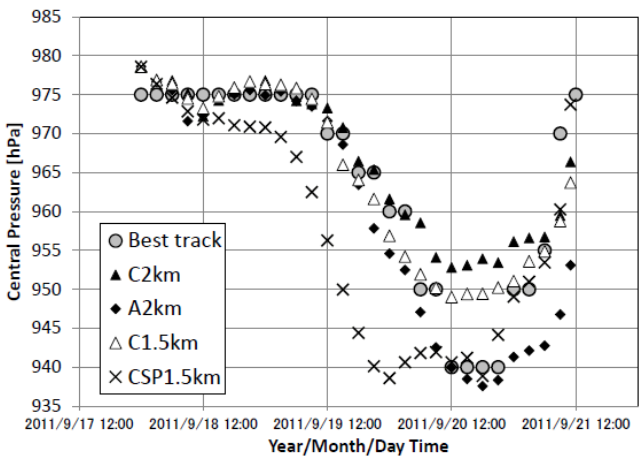

Figure 1 Time series of the best track central pressure and simulated central pressure of Roke in experiments A2km (close diamonds), C2km (close triangles), C1.5km (open triangles) and CSP1.5km (cross marks) from 0000 UTC on 18 September to 1200 UTC on 21 September in 2011.

The experiment CSP1.5km performed by the coupled model incorporating the sea spray parameterization (Bao et al., 2000) indicated more rapid intensification during an earlier integration time in experiment CSP1.5km than in experiments A2km, C2km and C1.5km, which was not consistent with the best track data. The lowest simulated central pressure in experiment CSP1.5km was 938.6 hPa at 0000 UTC on 20 September, which was reasonable to the lowest best track central pressure (940 hPa) although the simulated one appeared 18 hours earlier than the best track one. During the decaying phase of Roke, simulated central pressures tended to be low in experiment A2km and high in experiment C2km, while those were reasonable in experiments C1.5km and CSP1.5km from 0000 UTC to 1200 UTC on 21 September. The results of sensitivity numerical experiments with/without the sea spray parameterization suggest that excessive sea-air turbulent heat fluxes are not necessary for Roke's intensification during an early integration time.

Figure 2 depicted the RSMC-Tokyo best track and simulated positions of Roke every six hours in experiments A2km, C2km, C1.5km and CSP1.5km from 0000 UTC on 18 September to 1200 UTC on 21 September in 2011. No significant differences of simulated positions appeared among experiments A2km, C2km and C1.5km, which had the eastward bias when approaching the Japanese Honshu islands (north of 30°N). The simulated track in experiment CSP1.5km showed more eastward deflections than in experiments A2km, C2km and C1.5km. This indicates that the introduction of sea spray parameterization into the coupled model is not appropriate for the simulation of Roke although the lowest central pressure was well reproduced. In other words, the increase in turbulent heat fluxes beneath Roke due to the effect of sea spray induced by strong winds could not contribute to the improvement of Roke's simulation.

Figure 3a displays the horizontal wind speeds at 20 m height in experiment C1.5km at 36 h, when the simulated typhoon began to intensify in experiment C1.5km. The maximum wind speed was ~50 m s^{-1}. The vertical profile of wind speeds (Fig. 3b) indicates that wind speeds were relatively high in the western side where the maximum latent heat flux was relatively high (~488 W m^{-2}: not shown).

Figure 3c displays the horizontal wind speeds at 20 m height in experiment CSP1.5km at 36 h, when the simulated typhoon was intensifying. Interestingly, the maximum wind speed at 20 m height was almost the same as that in experiment C1.5km. The vertical profile of wind speeds (Fig. 3d) indicates a symmetric structure compared with that shown in Fig. 3b. The maximum latent heat flux was ~508 W m^{-2}, which was almost the same as that in experiment C1.5km. Therefore, the effect of sea spray on intensification of simulated Roke appeared in structural change of simulated typhoon, that is, a shrinking process during the intensification.

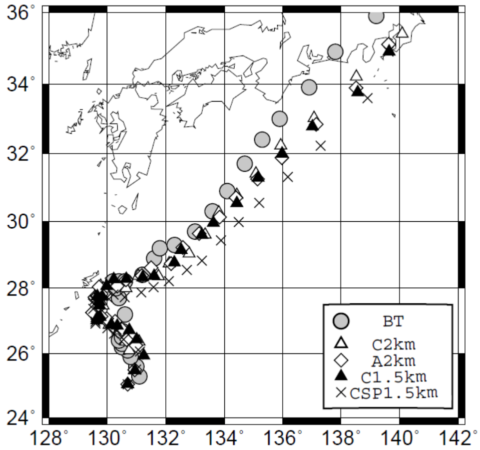

Figure 2 Best track and simulated tracks of Roke in experiments A2km (open diamonds), C2km (open triangles), C1.5km (closed triangles) and CSP1.5km (cross marks) from 0000 UTC on 18 September to 1200 UTC on 21 September in 2011.

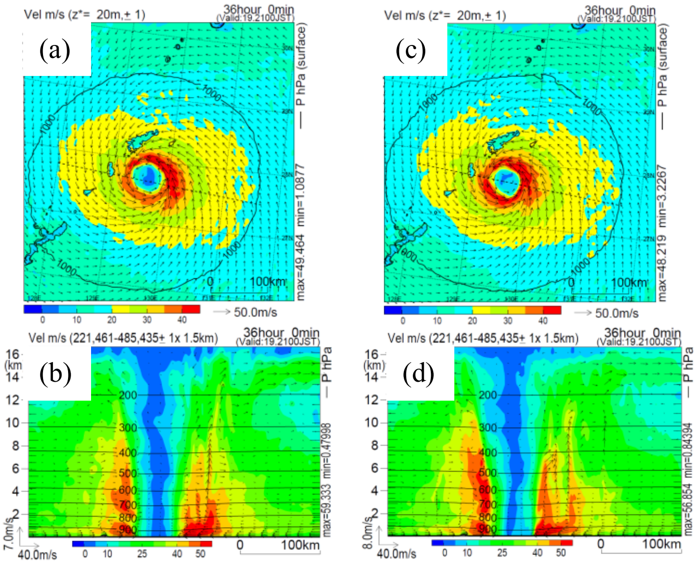

Figure 3 (a) Horizontal distribution of wind speeds at 20 m height in experiments C1.5km and (b) vertical profile of wind speed across the line depicted in Fig. 3a. (c) The horizontal distribution in experiment CSP1.5km. (d) The vertical profile in experiment CSP1.5km. Contours indicate the pressure every 100 Pa.

4. Discussion and conclusion

Even though the sea spray parameterization was incorporated into the coupled atmosphere-ocean model, the present numerical study suggests that the intensity prediction performed by the coupled model could not be improved in all typhoon cases. This result implies that less intensification calculated by the coupled model is not responsible for relatively small turbulent heat fluxes but due to lack of inner-core process of the typhoon. Even though the horizontal resolution is set to 1.5 km, this study shows that the inner-core structure is not always simulated. The influence of atmospheric and oceanic environments on the intensification should be taken into account in the future.

However, high turbulent heat fluxes within the inner core enable the typhoon to intensify at an earlier intensification phase as a trigger. To improve the intensification rate at an early integration, the sea spray parameterization may be effective and should be improved.

Acknowledgement

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