Comparison of numerical simulations of Typhoon Haiyan in 2013 and Typhoon Mike in 1990

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1. Introduction

In the previous report, Wada (2015) concluded that both subsurface warming in the northwestern Pacific Ocean and the ocean response to the Typhoon Haiyan (2013) should be taken into consideration to understand a rapid intensification of Haiyan and a resultant extremely strong intensity. Subsurface warming in the northwestern Pacific Ocean is an issue of the oceanic environmental conditions, while the ocean response, particularly sea surface cooling induced by a typhoon, depends on the intensity and translation as well as oceanic environmental conditions such as mixed layer depth, upper-ocean stratification and seasonal thermocline. In particular, it is difficult to investigate the sensitivity of the translation to typhoon simulations. Here we address Typhoon Mike (1990) which track is similar to Haiyan, but the translation is relatively slow so that we expect that the ocean response to Mike and the impact on the intensity would be quite different for two typhoons. In this report numerical simulations of typhoons Haiyan and Mike are compared.

2. Model and experimental design

Numerical simulations were performed for Haiyan and Mike by a nonhydrostatic atmosphere model and a coupled atmosphere-wave-ocean model. The coupled model (CPL) has been developed (Wada et al. 2010) based on the Japan Meteorological Agency nonhydrostatic atmosphere model (NHM). The computational domain for both typhoons was same as shown in Fig. 1 with a horizontal resolution of 2 km. Both CPL and NHM had 55 vertical levels with variable intervals from 40 m for the near-surface layer to 1013 m for the uppermost layer with the top height approaching nearly 26 km. The integration time was 84 hours (84 h) for Haiyan and 114 h for Mike with a time step of 4 seconds in NHM. The time step of the ocean model was 24 seconds, six times that of NHM. That of the ocean wave model was 10 minutes.

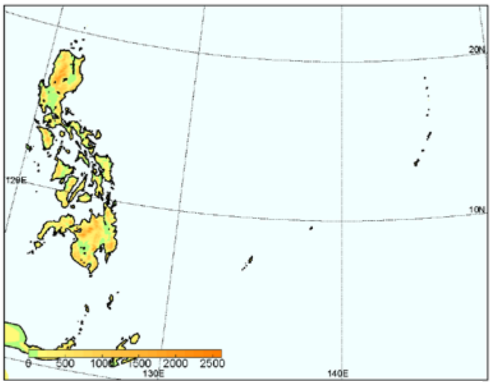

Figure 1 Computational domain with the horizontal resolutions of 2 km.

Physical processes used in the simulations were almost the same as applied in Wada et al. (2010) except for a sea spray parameterization (Bao et al. 2000) in the atmospheric surface-boundary layer. In particular, the the evaporation efficiency β was assumed equal to 1 when the 10-m wind speed exceeded 17 ms^{-1} and β linearly decreased as the wind speed became weak. The setting of β is similar to Bao et al. (2000), however, it was argued in Bao et al. (2000) that for extremely high winds, the droplet size may be so large that the droplets can fall back to the ocean before further evaporation extracts heat from the atmosphere, for which β approaches to zero. Oceanic initial conditions were obtained from the oceanic reanalysis datasets with a horizontal resolution of 0.5º calculated by the Meteorological Research Institute multivariate ocean variational estimation (MOVE) system (Usui, et al. 2006).

This study used the Japanese 25-year Reanalysis (JRA-25) (Onogi et al., 2007) and a subsequent reanalysis data set since 2005 (conventionally known as JCDAS) for producing atmospheric initial and lateral boundary conditions. Hereafter, JRA-25 and JCDAS are referred to simply as JRA-25.

3. Results and concluding remarks

Results of numerical simulations for Mike and Haiyan are shown in Fig. 2. The simulated track is reasonably simulated by both NHM and CPL compared with the best track for Haiyan and Mike, respectively (Fig. 2a). NHM tends to reproduce central pressures lower than the best-track central pressures. The typhoons simulated by NHM reach the minimum central pressure earlier than the best-track analysis, while the central pressures simulated by CPL tend to be still high compared with the best track central pressures (Fig. 2b).

The impact of the ocean coupling on the intensity of simulated typhoons is quite different for Haiyan and Mike. This is mainly caused by the difference in their moving speeds. In Fig. 2c, the moving speeds in Mike are slower than those in Haiyan in both simulations and best-track analysis.

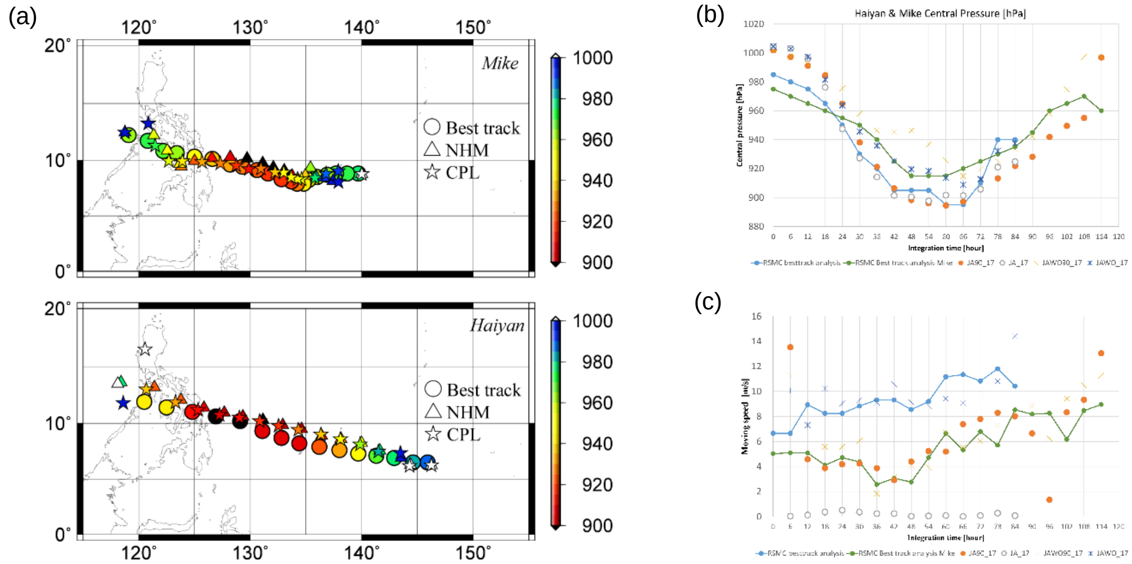

Figure 2 Results of numerical simulations with RSMC best-track data. (a) Simulated (triangles in NHM and stars in CPL) and best tracks with colors indicating central pressures for Mike (upper panel) and Haiyan (lower panel), (b) time series of simulated and best-track central pressures for Mike (green circles and orange crosses) and Haiyan (blue circles and crosses) and (c) as in Fig. 2b except for moving speeds.

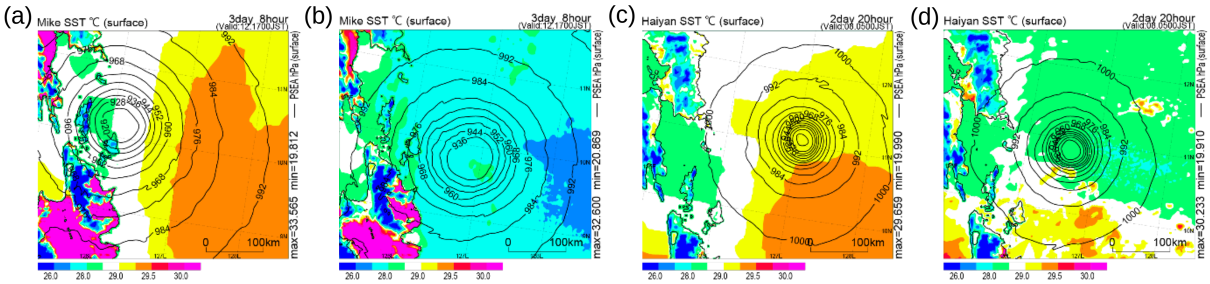

Figure 3 Horizontal distributions of central pressures at 8-hPa intervals (contour) and sea surface temperature (shades) at 70 h integration time for Typhoon Mike simulated by (a) NHM and (b) CPL and those at 68 h integration time for Typhoon Haiyan simulated by (c) NHM and (d) CPL.

The horizontal distributions of simulated sea surface temperature quite differs among the four experiments, two Mike's simulations and two Haiyan's simulations by NHM or CPL, respectively. Interestingly, the minimum central pressure for Mike simulated by NHM is comparable with that for Haiyan (Fig. 2b) even though the horizontal structure in the inner core quite differs between them. The difference of the minimum central pressure becomes remarkable between the simulations of Mike and Haiyan by CPL. The simulated central pressure increases from 36 h to 48 h (Fig. 2b) due to relatively slow moving speeds and resultant sea surface cooling (Fig. 2c). In fact, simulated sea surface temperature clearly decreases around the simulated Mike (Fig. 3b) compared with that around the simulated Haiyan (Fig. 3d). In other words, fast translation is responsible for rapid intensification and resultant maximum intensity of Haiyan. In addition, the area of cold wake represented by lowest sea surface temperature right behind the typhoon quite differs between Haiyan and Mike due to the difference of the size of simulated typhoon defined by the distance to the sharpest gradient of sea-level pressures from the typhoon center. In that sense, extremely intense Haiyan can be explained by fast translation, small size and relevant oceanic response to the typhoon. Subsurface warming in the northwestern Pacific Ocean is the second to explain the uniqueness of Haiyan.

Without coupling with the ocean model, the simulations for Mike and Haiyan show the similar minimum central pressures irrespective of the translation. However, the errors against the best track are quite different. In other words, the ocean response to a storm differs depending on the translation. In that sense, CPL will contribute to the improvement of TC intensity prediction for taking salient sea-surface cooling into account.

Acknowledgement

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