Numerical simulations of Typhoon Haiyan in 2013

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1. Introduction

Typhoon Haiyan in 2013 was one of extremely intense typhoons. The minimum central pressure was 895 hPa and 10-minute maximum wind speed was ~65 m s^{-1} according to the Regional Specialized Meteorological Center Tokyo best track data. While keeping the intense intensity, the eye of Haiyan made its first landfall in the Philippines at Guiuan, Eastern Samar at 2040 UTC on 7 November. After the landfall, the typhoon passed through the Philippines while decreasing the intensity, and then moved westward to north-northwestward over the South China Sea.

This study aims at simulating rapid intensification of Haiyan over the north western Pacific warm pool realistically to understand the process of extraordinary rapid intensification and the minimum central pressure of 895 hPa. In fact, operational models could not predict the rapid intensification occurred from 5 to 7 November although the relatively fast translation was well predicted as well as the west-northwestward track of Haiyan.

2. Model and experimental design

Numerical simulations were performed by a coupled atmosphere-wave-ocean model (Wada et al., 2010). The computational domains for the simulations with the horizontal resolution of 2.5 km (Fig. 1a) and that of 4 km (Fig. 1b) are displayed. The coupled model had 55 vertical levels with variable intervals from 40 m for the near-surface layer to 1013 m for the uppermost layer.

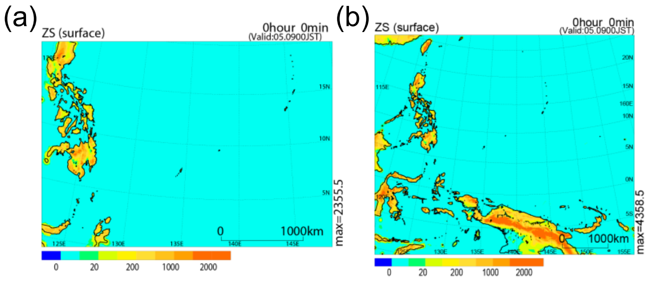

Figure 1 Computational domain with horizontal resolutions of (a) 2.5 km and (b) 4 km.

The coupled model had maximum height approaching nearly 26 km. The integration time was 84 hours (84 h) with a time step of 4 seconds (for horizontal resolution of 2.5 km) and that of 8 seconds (for horizontal resolution of 4 km) 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. These time steps were the same as those in Wada et al. (2010). Oceanic initial conditions were obtained from the oceanic reanalysis datasets with a horizontal resolution of 0.5° calculated by the Meteorological Research Institute multivariate ocean variational estimation (MOVE) system (Usui, et al., 2006). Physical processes used in the simulations were almost the same as those of Wada et al. (2010) except for sea spray effect in the surface boundary layer. The sea spray parameterization (Bao et al., 2000) was used in all experiments.

It should be noted that the integration was not finished due to computational instability occurred when the horizontal resolution of 4 km was used for numerical simulations. In that sense, this study is now ongoing and several sensitivity numerical experiments have been performed by changing experimental design.

3. Results

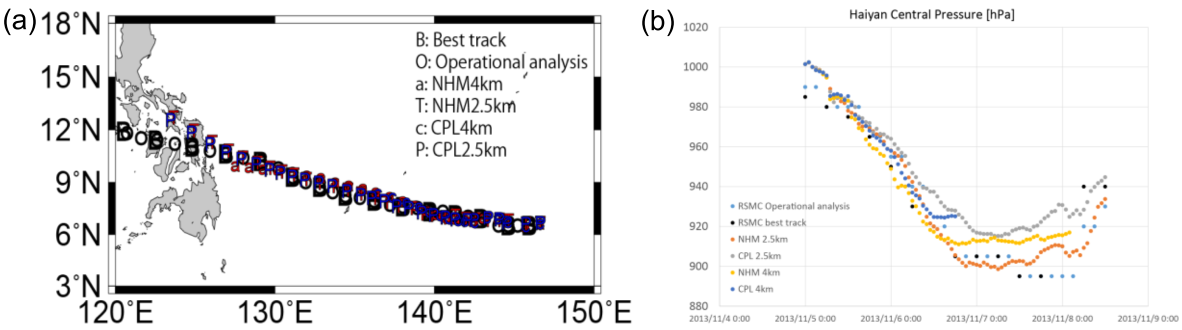

Figure 2 Results of numerical simulations, operational analysis and best track data of Haiyan: (a) Track simulations and (b) evolution of central pressures. 'NHM' indicates results by the atmosphere model, while 'CPL' by the coupled model.

Figure 2 indicates results of track simulations and evolutions of simulated central pressures together with operational analysis and best track data. Haiyan's tracks were reasonably simulated although simulated tracks were deflected northward (horizontal resolution of 2.5 km) or southward (horizontal resolution of 4 km) from the operational analysis and the best track data before making landfall in the Philippines (Fig. 2a). Translation speeds of simulated Haiyan were relatively slow compared with those of operational analysis and best track data.

Both the atmosphere model and the coupled model successfully simulated rapid intensification from 0000 UTC 5 to 1200 UTC 6 November. However, further rapid intensification was little simulated when the horizontal resolution was 4 km or the coupled model was used for the simulation. The simulated minimum central pressure was ~897 hPa, comparable with the best-track minimum central pressure, 895 hPa, when the atmosphere model with a horizontal resolution of 2.5 km was used. Figure 2 suggests that a finer horizontal resolution than 2.5 km, faster translation than that of the simulations and less ocean coupling are needed to realistically simulate rapid intensification of Haiyan. In fact, the simulation by the coupled model reproduced excessive sea surface cooling due to slow translation east of the Philippines in the simulation. Fast translation leads to less ocean coupling realizing rapid intensification.

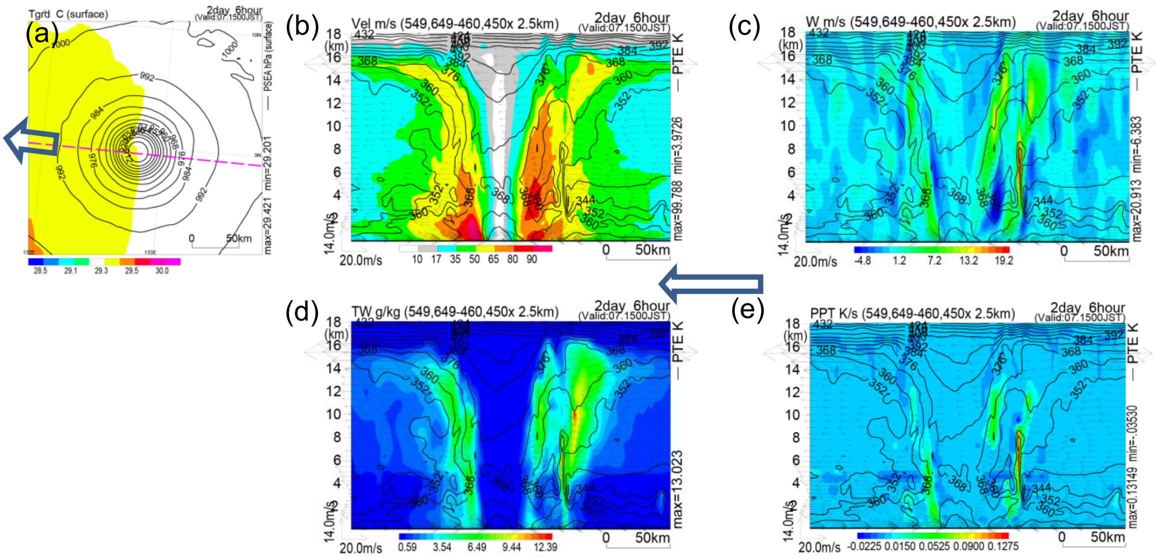

Figure 3 (a) Horizontal distribution of sea surface temperature used in the simulation. The dashed line indicates the line of vertical cross sections. (b-e) Shades indicate vertical cross sections of (b) horizontal wind velocity, (c) vertical wind velocity, (d) total water content and (e) change rates in potential temperature at 54 h. Contours indicate equivalent potential temperature at the interval of 8 K. Vectors indicate wind vectors along the line shown in Fig. 3a.

Figure 3 exhibits the horizontal distribution of sea surface temperature at the initial time and vertical sections of horizontal wind velocity, vertical wind velocity, total water content and change rates in potential temperatures at 54 h when Haiyan underwent the mature phase with the central pressure of ~898 hPa. Under strong easterly conditions, the axisymmetric structure with a distinct warm core and upstanding eyewall was simulated. The distinct warm core was mainly formed by condensational heating caused by updraft and resultant abundant total water content (particularly ice-phased water content) within the eyewall. It should be noted that sea spray parameterization played a crucial role in enhancing vertical transport of moist airs through the increase in the transport of latent heat fluxes from the ocean. In that sense, high tropical heat potential in the western North Pacific, ocean heat contents measured by water temperature above 26°C, helps rapid intensification to some extent, but it was not a major contributor to rapid intensification and resultant minimum central pressure.

4. Concluding remarks and Future works

This study successfully reproduced rapid intensification of Haiyan and resultant minimum central pressure using the atmosphere model with a horizontal resolution of 2.5 km. However, rapid intensification of Haiyan and resultant minimum central pressure should be reproduced by the atmosphere-wave-ocean coupled model because the ocean response to Haiyan is not negligible for numerical prediction of Haiyan. The following two issues remain: A finer horizontal resolution than 2.5 km and faster translation speed that that of the current simulation is needed to improve. However, computational resources are very limited so that it is difficult to perform numerical simulations with a finer horizontal resolution of 2 km covered with the same computational domain

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