Roles of the ocean on extremely rapid intensification and the maximum intensity of Typhoon Haiyan in 2013

Akiyoshi Wada
Meteorological Research Institute, Tsukuba, Ibaraki, 305-0052, JAPAN
awada@mri-jma.go.jp

1. Introduction

Typhoon Haiyan was one of extremely intense tropical cyclones ever recorded. Lin et al. (2014) suggested that piling up warm subsurface water to the western part of the North Pacific Ocean and resultant subsurface warming created a very favorable pre-existing oceanic condition for the extraordinary intensity of Haiyan. Wada (2014) reported that rapid intensification of Haiyan and the minimum central pressure were simulated reasonably well using a nonhydrostatic atmosphere model (NHM) with a horizontal resolution of 2.5 km. The purpose of this study is to understand roles of preexisting oceanic conditions and storm-induced sea surface cooling on extremely rapid intensification and the maximum intensity of Haiyan by using the result of numerical simulations by an atmosphere-wave-ocean coupled model (CPL) with a horizontal resolution of 2.5 km.

2. Model and experimental design

Numerical simulations were performed by CPL (Wada et al. 2010). The computational domain is displayed in Fig. 1. 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.

NHM and CPL had maximum height approaching nearly 26 km. The integration time was 84 hours (84 h) 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. These time steps were the same as those in Wada et al. (2010).

Physical processes used in the simulations were almost the same as those of Wada et al. (2010) except for a sea spray parameterization (Bao et al. 2000) in the atmospheric surface-boundary layer.

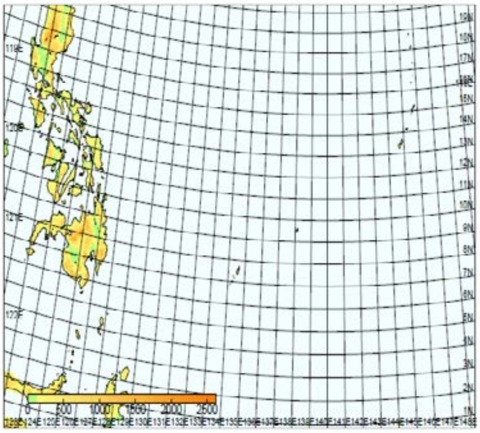

Figure 1 Computational domain with the horizontal resolutions of 2.5 km.

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 two data: One was daily oceanic reanalysis data on 5 November, 2013 and the other was the data on 5 November, 1993. In this study, the numerical experiment by NHM with the daily oceanic reanalysis data on 5 November 2013 calls NHM2013, while that by CPL calls CPL2013. The numerical experiment by NHM with the daily oceanic reanalysis data on 5 November, 1993 calls NHM1993, while that by CPL calls CPL1993.

3. Results and concluding remarks

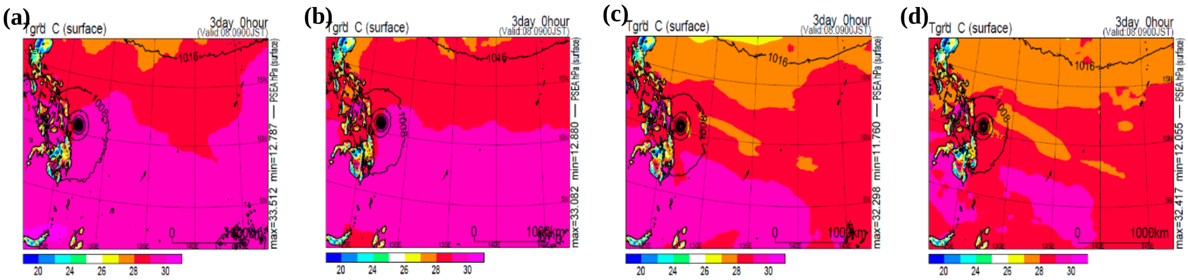

Figure 2 Horizontal distributions of sea surface temperature at 0000 UTC on 8 November (72 h integration time) in (a) NHM2013, (b) NHM1993, (c) CPL2013 and (d) CPL1993.

Figure 2 displays the horizontal distributions of sea surface temperature used in NHM2013 (Fig. 2a), NHM1993 (Fig. 2b), CPL2013 (Fig. 2c) and CPL1993 (Fig. 2d). The comparison between NHM2013 and NHM1993 reveals that the area at which sea surface temperature exceeded 30°C was almost the same. In fact, sea surface temperature around 10°N, 140°E in NHM2013 near the track of Haiyan was lower than that in NHM1993. The comparison between CPL2013 and CPL1993 indicates that storm-induced sea surface cooling in CPL2013 was smaller than that in CPL1993. The result is consistent with Lin et al. (2014) in that subsurface warming in the northwestern Pacific Ocean played a role in suppressing vertical mixing in the upper ocean along the Haiyan's track.

The result of simulated tracks shows that preexisting oceanic conditions and storm-induced sea surface cooling had little impact on track simulations (not shown). In contrast, rapid intensification from 5 to 6 November was well simulated in the four simulations, irrespective of pre-existing oceanic conditions (Fig. 3). Rapid intensification in the CPL2013 and CPL1993 experiments was consistent with the Regional Specialized Meteorological Center (RSMC)-Tokyo Typhoon Center best track data. The impact of storm-induced sea surface cooling was remarkable: Storm-induced sea surface cooling did affect the simulated central pressure from 1800 UTC on 5 November. The difference of simulated central pressures between NHM and CPL increased during the intensification phase. The difference little changed after the storm reached the mature phase.

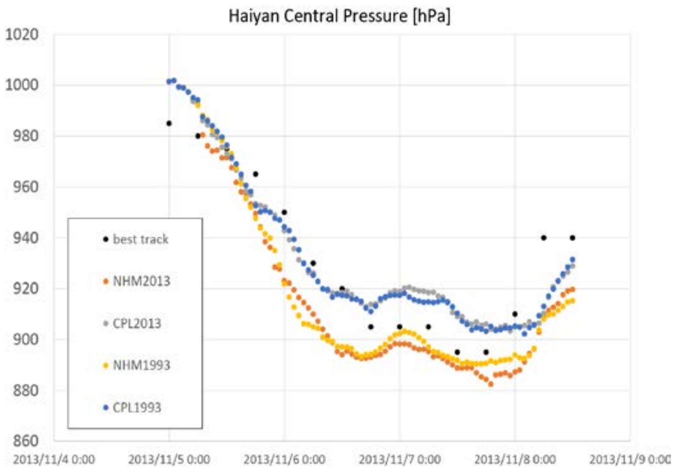

Figure 3 Results of simulated central pressure of Haiyan and RSMC-Tokyo best track central pressure.

Figure 4 displays axisymmetrical mean radial-height profiles of specific humidity and radial flow in the tropical-cyclone boundary layer. The height of the inflow layer exceeded 1000 m and the maximum inflow was located in around 25-50 km from the storm center. Above the edge of the inflow layer, the outflow was remarkable at around the height of 2000 m around the radius of 25 km. The axisymmetrical mean structure indicates that the simulated storm had a small inner-core structure. Simulated specific humidity was relatively high at around the height of 2000 m around the radius of 25 km in the NHM2013 experiment, indicating the occurrence of updraft at the eyewall. Storm-induced sea surface cooling simulated in the CPL2013 experiment affected the strength of the inflow in the tropical-cyclone boundary layer, that of the outflow, above the edge of the inflow layer, the updraft and the associated moisture transport to the upper layer.

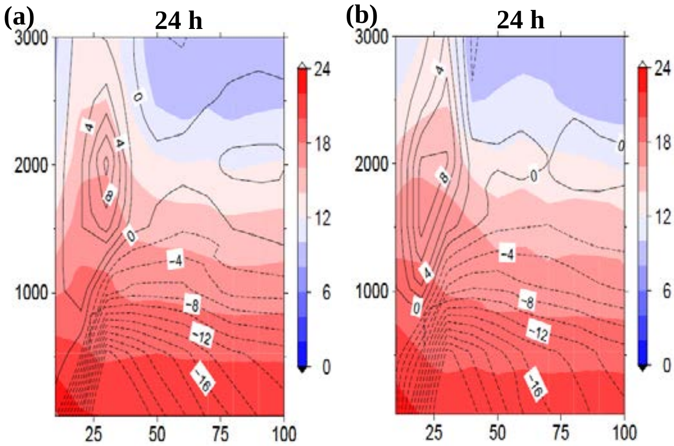

Figure 4 Axisymmetrical mean radial-height profiles of specific humidity (g/kg: Shades) and those of radial flow (m/s: contours) in (a) NHM2013 and (b) CPL2013. Soild contours indicate outflow, whereas dashed contours indicate inflow. Vertical axis shows heights (m) and horizontal axis shows a distance (km) from the storm center.

Therefore, the results of numerical simulations indicate that not only subsurface warming in the northwestern Pacific Ocean but also the ocean response to Haiyan should be considered to understand rapid intensification and resultant extremely strong intensity of Haiyan.

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