Section 9

Development of and studies with coupled ocean-atmosphere models

Introduction of an atmosphere-wave-ocean coupled model into the NHM-LETKF

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1. Introduction

Data assimilation system by using the local ensemble transform Kalman filter (LETKF) has been used for studies on the atmospheres and the oceans more frequently than before. LETKF was incorporated into the Weather Research and Forecasting (WRF) model (WRF-LETKF) (Kunii and Miyoshi, 2012) and the Nonhydrostatic atmosphere model (NHM) developed by the Japan Meteorological Agency (JMA) and Meteorological Research Institute of the JMA (NHM-LETKF) (Kunii, 2014). A recent study suggested that variations in sea surface temperature led to the improvement of track predictions of Typhoon Sinlaku in 2008 (Kunii and Miyoshi, 2012). However, the variation in sea surface temperature was simply provided as ensemble perturbations, arbitrarily determined without any considerations of oceanic physical processes including effects of air-sea interactions, turbulent mixing and upwelling on the variation in sea surface temperature.

The final goal of this study is to construct the air-sea coupled assimilation system using an atmosphere-wave-ocean coupled model and LETKF. This is the preliminary report that documents the installation of the air-sea coupled model to NHM-LETKF. It should be noted that this study only describes the replacement of only the prediction part from NHM to the atmosphere-wave-ocean coupled model. This study is expected to show the effects of the air-sea coupled system on atmospheric analyses.

2. Assimilation system and experimental design

The NHM-LETKF used in this study is based on Kunii (2014). The system has been developed based on the WRF-LETKF system. However, the two systems quite differs each other.

Figure 1 displays a schematic diagram of the NHM-LETKF developed in this study. The original NHM-LETKF system uses merged satellite and in-situ data global daily sea surface temperature (MGDSST). However, this study also uses daily oceanic reanalysis data calculated by the Meteorological Research Institute multivariate ocean variational estimation (MOVE) system (Usui et al., 2006). Both MDGSST and MOVE data are updated at a daily interval and are used as the oceanic initial condition of the atmosphere-wave-ocean coupled model.

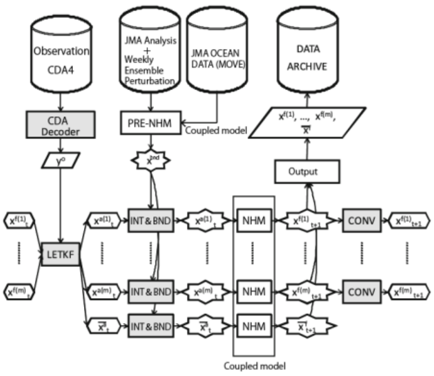

Figure 1 Schematic diagram of NHM-LETKF coupled with the atmosphere-wave-ocean model in the prediction part.

The coupled atmosphere-wave ocean model consists of the NHM, the third generation ocean wave model, and a multilayer ocean model (Wada et al., 2010). It should be noted that sea surface temperature calculated by the coupled model in the prediction part is not used in the subsequent analysis part. The analysis part in the LETKF is not changed from Kunii (2014). This will be a future subject in the future. The ocean state (wave conditions) is assumed to be motionless at the initial time.

This study addresses Typhoon Sinlaku in 2008. The analysis and prediction covered a ~3600 km x ~1900 km computational domain with a horizontal grid spacing of 15 km. The system had 40 vertical levels with variable intervals from 40 m for the near-surface layer to 1180 m for the uppermost layer. The system had maximum height approaching ~23 km. The analysis period is from 1200 UTC 1 to 1800 UTC 19 September in 2008. The number of ensemble member is 20.

3. Results

Figure 2 shows three results of analyzed positions of Typhoon Sinlaku together with the Regional Specialized Meteorological Center Tokyo best track (hereafter the JMA best track). The result indicated that a difference in sea surface temperature between MGDSST (CNTL in Fig. 2) and MOVE did directly affect the analysis of the central position of Sinlaku in particular at an early developing phase (south of 20°N) and a decaying phase (north of 30°N). In addition, there is a clear difference in analyzed central positions between the NHM (MOVE in Fig. 2) the coupled model (MOVECP in Fig. 2) only at an early developing phase (south of 20°N). This result suggests that both the difference in sea surface temperature field and ocean coupling certainly affect the analysis of typhoon position.

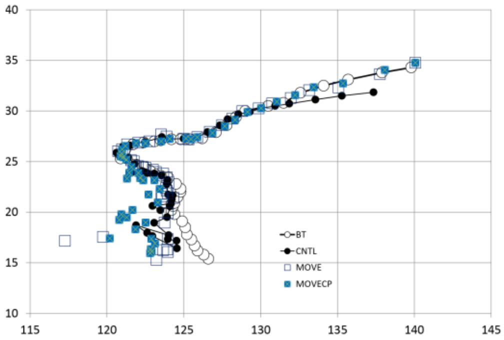

Figure 2 Results of analyzed center positions of Typhoon Sinlaku in CNTL (MGDSST is used), MOVE (Noncoupled system) and MOVECP (Coupled system) together with the JMA best track.

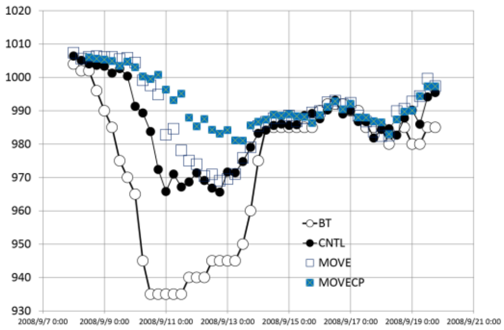

Figure 3 Evolutions of analyzed central pressures of Typhoon Sinlaku in CNTL (MGDSST is used), MOVE (Noncoupled system) and MOVECP (Coupled system) together with the JMA best track central pressure.

Figure 3 exhibited evolutions of analyzed central pressures together with the JMA best-track central pressure. All the three falling rates of analyzed central pressure are moderate compare with the JMA best track one during the intensification phase from 9 to 13 September due to the relatively coarse resolution (~15 km) of the current developing system. However, there is a clear difference in falling rates among the three analyses during the phase. Typhoon – induced sea surface cooling helps suppression of intensification. On the contrary, there is less difference in analyzed central pressures among the three since 14 September when the typhoon underwent the mature or decaying phase.

4. Concluding remarks

Reduction in the falling rate of the analyzed central pressure in MOVECP is a reasonable result in that sea surface cooling induced by a typhoon is calculated by the coupled model and the cooling does affect the intensification of the typhoon as a suppression of the intensification particularly during the intensification phase. If the resolution of the analysis system were finer, the analyses of the central pressure would be improved.

Acknowledgement

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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.

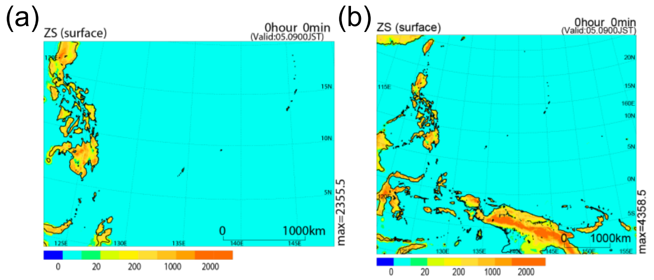

Figure 1 Computational domain with horizontal resolutions of (a) 2.5 km and (b) 4 km.

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

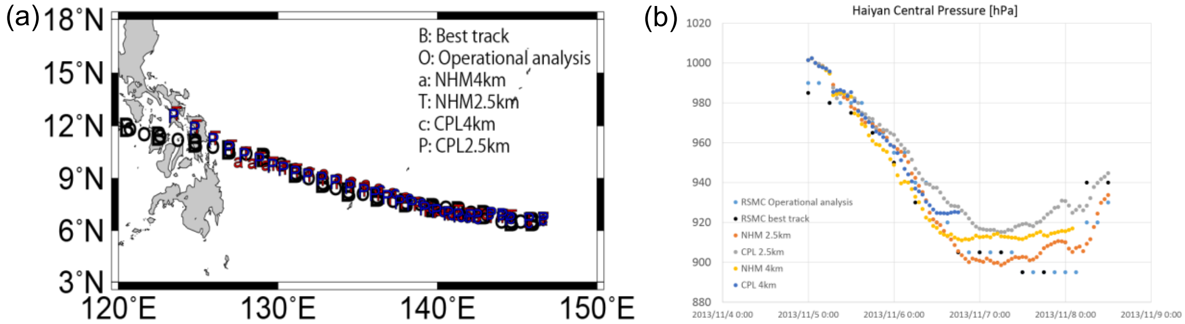

Figure 2 Results of numerical simulations, operational analysis and best track data of Haiyan: (a) Track simulations and (b) evolution of central pressures. 'NHM' indicates results by the atmosphere model, while 'CPL' by the coupled model.

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.

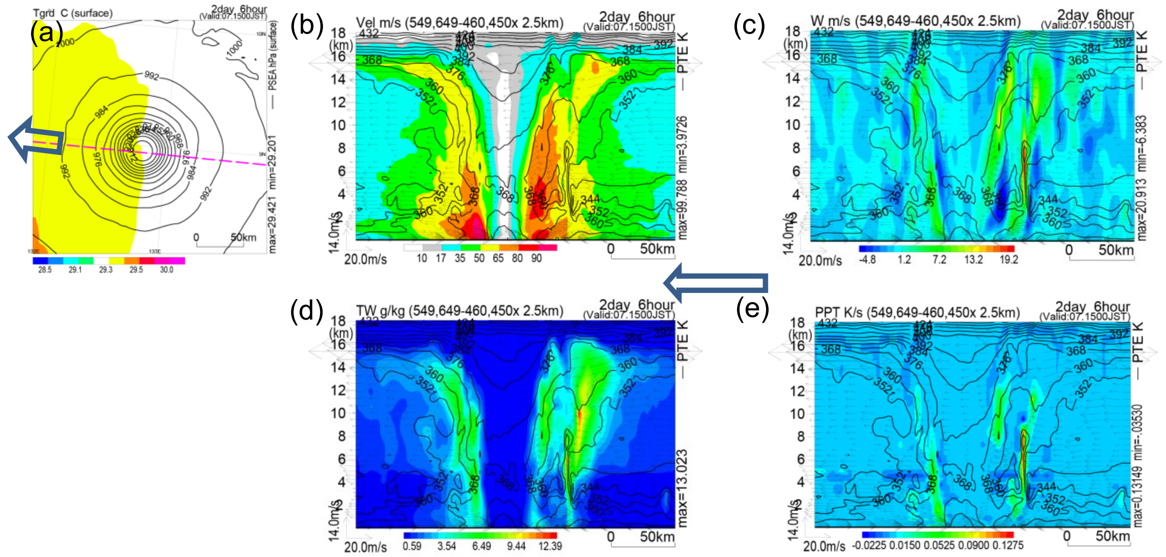

Figure 3 (a) Horizontal distribution of sea surface temperature used in the simulation. The dashed line indicates the line of vertical cross sections. (b-e) Shades indicate vertical cross sections of (b) horizontal wind velocity, (c) vertical wind velocity, (d) total water content and (e) change rates 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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Numerical simulations of intensity changes of Typhoon Man-Yi in 2013

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1. Introduction

Typhoon Man-Yi in 2013 was the second typhoon making landfall in Central Japan. The typhoon caused torrential rains in front of the typhoon. Special warnings launched August 2013 were issued for three western Japan prefectures of Fukui, Kyoto and Shiga. This was the first time to issue special warnings. One of interesting features is rapid intensification south of Shikoku Island. A small eye was formed within the inner core. The falling rate of best-track central pressure exceeded 15 hPa per six hours north of 30˚N (The rate corresponds to 60 hPa per day) according to best track data archived in the Regional Specialized Meteorological Center Tokyo. The purpose of this report is to investigate the role of oceanic environments and typhoon-induced sea surface cooling in the intensity changes of Man-Yi, particularly rapid intensification occurred south of Shikoku Island by using a regional atmosphere-wave-ocean coupled model.

2. Model and experimental design

Numerical simulations were conducted by a regional atmosphere-wave-ocean coupled model developed by Wada et al. (2010). The coupled model covered a ~2000 km x ~2400 km computational domain with a horizontal grid spacing of 2 km. Hereafter, 'A' indicates the regional atmosphere model and the results, whereas 'AWO' indicates the regional atmosphere-wave-ocean coupled model and the results. Both the regional atmosphere and the coupled models had 40 vertical levels with variable intervals from 40 m for the near-surface layer to 1180 m for the uppermost layer. The top height was ~23 km.

The simulations used the Japan Meteorological Agency global objective analysis data for atmospheric initial and boundary conditions (with a horizontal grid spacing of ~20km) and the daily oceanic reanalysis data calculated by the Meteorological Research Institute multivariate ocean variational estimation (MOVE) system (Usui, et al., 2006) with the horizontal grid spacing of 0.5˚, and that of 0.1˚ (for convenience, 'H' added in the latter part). This study also used the daily oceanic reanalysis data in 2011 in order to investigate the influence of oceanic preexisting environments on the typhoon simulations. In fact, water temperatures south of Shikoku Island in 2011 were much lower than those in 2013 due to sea surface cooling induced by Typhoon Talas in 2011. The initial time was 0000 UTC on 14 September in 2013. The integration time was 60 hours. Wad et al. (2010) described details of model and experimental design.

3. Results

Figure 1a shows the results of track simulations of Mai-Yi in A, AH, AWO and AWOH experiments and Fig. 1b shows those except that the track simulations were obtained by using the oceanic reanalysis data in 2011. Figure 1 indicates that both sea surface cooling and a difference in oceanic initial conditions do affect the track simulations north of 30˚N when both the simulated and best track typhoons underwent intensification and changed to the mature phase. This suggests that the central position of Man-yi was affected by the oceanic environmental condition from the intensification to the mature phase.

The results of central pressure simulations shown in Fig. 2 were related to the difference in the track simulations (between Fig. 1a and Fig. 1b). Figure 2 indicates that oceanic initial data do greatly affect the simulation of rapid intensification of Man-yi. In contrast, the results of the central pressure simulations did not reproduce the rapid intensification like high falling rate of central pressure found in the best track data. This is probably due to preexisting sea surface cooling induced by Talas in 2011. This implied that environmental steering flow was relatively weak compared with the effect of ocean coupling on the steering flow.

Figure 3 displays horizontal distributions of radar-amedas composite analysis of total precipitation (Fig. 3a) together with the results of numerical simulations in AH (Fig. 3b) and AWOH (Fig. 3c). Excessive rains in AH around the southeastern side of Kii peninsula were suppressed in AWOH. The result was comparable with the results shown in Fig. 3a. However, torrential rains occurred north of Kinki region was poorly simulated in both AH and AWOH although accumulated precipitation in AWOH partly exceeded 300 mm per day around the region. Changes in the oceanic initial conditions little affected the simulation of total precipitation.

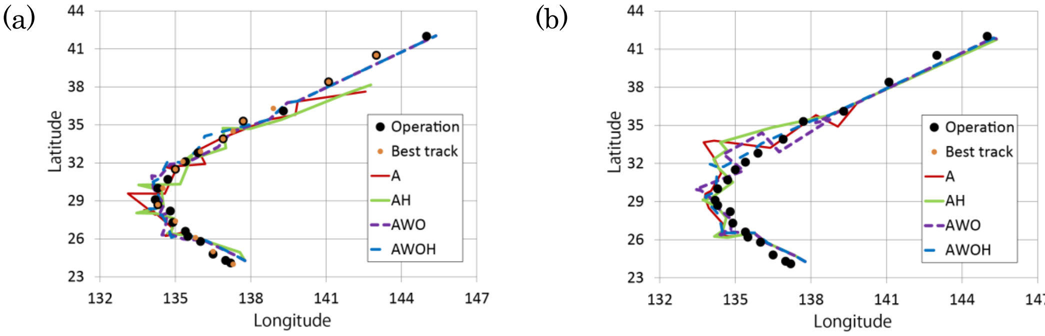

Figure 1 (a) Results of track simulations, the JMA operational and best tracks when the oceanic reanalysis data in 2013 was used. (b) Same as Fig. 1a except when the oceanic reanalysis data in 2011 were used.

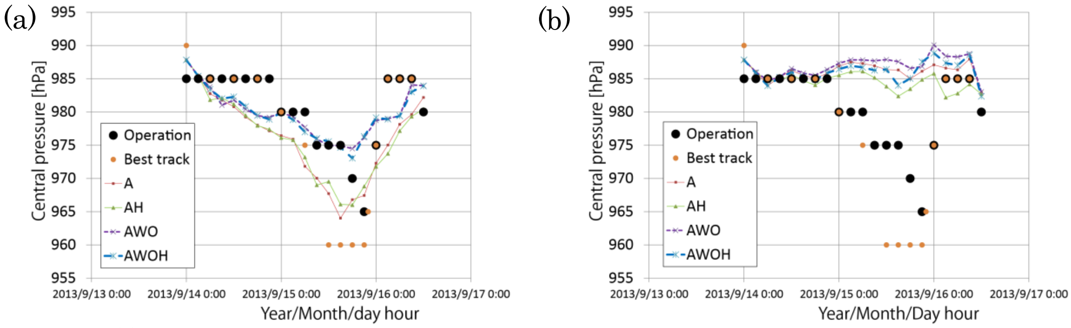

Figure 2 (a) Results of central pressure simulations, the JMA operational and best-track central pressures when the oceanic reanalysis data in 2013 was used. (b) Same as Fig. 1a except when the oceanic reanalysis data in 2011 were used.

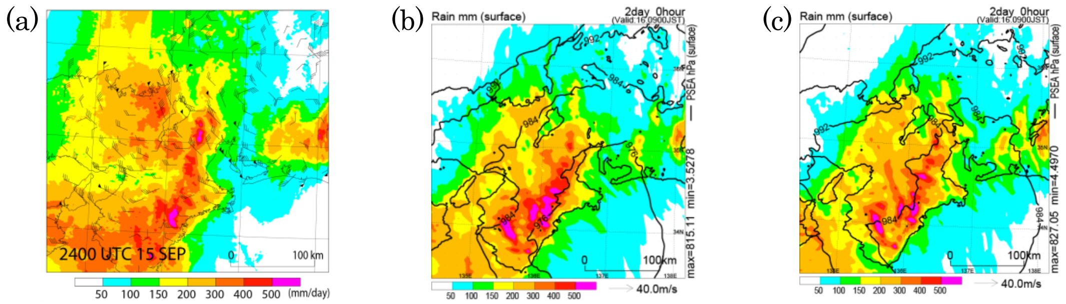

Figure 3 Horizontal distributions of total rains (mm per day) (a) by radar-amedas composite analysis, (b) in AH and (c) in AWOH accumulated from 0000 UTC 15 to 0000 UTC 16 September.

4. Concluding remarks

In addition to poorly simulations of total precipitation north of Kinki region, the simulations hardly simulated rapid intensification of Man-yi around 1200 UTC to 2100 UTC 15 September. Higher horizontal resolution of regional atmosphere and atmosphere-wave-ocean coupled models, more accurate atmospheric and oceanic initial conditions and improved physical processes such as cloud microphysics and boundary processes in the atmosphere and the ocean may be needed to improve the simulations.

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