Numerical predictions for Typhoon Hai-Tang in 2005 by an experimental atmosphere-wave-ocean coupled model

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1. Introduction

The predictions of typhoons have been improved for a decade particularly in their track predictions due to the developments of numerical modeling, assimilation and observational technologies. However, their intensity predictions have been still less precise compared with their track predictions. In order to improve the intensity predictions, we need to develop a regional atmosphere-wave-ocean coupled model. The reason for it is that sea-surface cooling (SSC) affects the typhoon intensity predictions directly, while ocean wave affects the structure of typhoon (Kohno and Murata, 2007). In this paper, we have developed a regional atmosphere-wave-ocean coupled model for improving the typhoon intensity predictions and perform numerical predictions for Typhoon Hai-Tang in 2005 using an experimental atmosphere-wave-ocean coupled model.

2. Coupled model

The coupled model consists of nonhydrostatic atmospheric model (NHM), Meteorological Research Institute (MRI) the third generation ocean wave model (MRI-III) and slab mixed-layer ocean model (MLOM). Figure 1 depicts a schematic diagram associated with exchange processes among NHM, MRI-III, and MLOM. Even though various expressions are proposed (Kohno and Murata, 2007), the formula in Taylor and Yelland (2001) is used as the roughness expression.

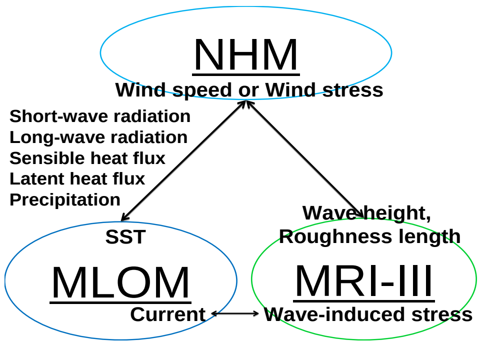

Figure 1 Schematic diagram of exchange processes among NHM, MRI-III and MLOM.

3. Experiment Design

The horizontal grid is 721 x 421 with the grid spacing of 6 km and 1441 x 841 with that of 3 km. The number of vertical layer is 40. The interval of vertical layers is changed from 40 m (near the surface) to 1180 m (upper atmosphere). The top height is nearly 23 km. Cumulus parameterization (Kain and Fritsch, 1990, hereafter KF) is used for simulating sub-grid-scale cumulus convection when numerical predictions are performed by NHM with horizontal-grid spacing of 6 km. A diurnally-varying sea-surface temperature (SST) scheme (Wada and Kawai, 2009) is introduced to the MLOM. The number of layer in MLOM is three (mixed-layer, thermocline and the bottom layer). The depth at the thermocline depth is 600 m and that at the bottom is 2000m at the deepest bottom. The mixed-layer depth is determined from daily oceanic reanalysis data as the depth at which the difference in density is within 0.25 kg m^{-3} from the surface.

The initial and boundary conditions are obtained from the results of numerical simulations by the global spectral model (GSM) and typhoon model (TYM). The resolution version of GSM is T213L40. The horizontal resolution of TYM is nearly 20 km near the center of typhoon. The integration times of both GSM and TYM are 72 hours.

Numerical predictions were performed for Typhoon Hai-Tang in 2005 by an experimental atmosphere-wave-ocean coupled model. The initial time in GSM, TYM and the coupled model is at 1200 UTC on 12 July in 2005. Typhoon bogus has been embedded when the TYM was initiated to run. We used daily SST data as the initial condition in the runs by the GSM and TYM. On the other hand, daily oceanic reanalysis data provided from an ocean data assimilation system were used for the run by the coupled model. Two runs were performed by the coupled model with horizontal-grid spacing of 6 km and with different oceanic preconditions: daily reanalysis temperature and salinity on 12 July in 2005 (hereafter Ex05) year and in 1999 (hereafter Ex99) year. In addition, preliminary numerical predictions by the coupled model with horizontal-grid spacing of 3km were performed by the coupled model only in EX05.

4. Results

Figure 2 plots the results of track predictions by the atmosphere-wave-ocean coupled model (corresponding to 'Wave' in Fig. 3, hereafter Wave) in Ex05 (6 km) and Ex99 (6 km). The best track indicates southwestward translation at the early integration and then westward/west-northwestward translation. The best-track central pressure (CP) reaches 940 hPa during the rapid intensification phase (Fig. 3). Predicted tracks in Ex05 (6 km) and Ex99 (6 km) indicate west-northwestward translation at 0000 UTC on 13 July and then southwestward translation (Fig.2).

CPs by NHM ('Atmos' in Fig. 3, hereafter Atmos) are relatively lower than those in best-track data. On the other hand, CPs by Wave and atmosphere-ocean ('Ocean' in Fig. 3, hereafter Ocean) coupled models in Ex05 (6 km) and Ex99 (6 km) are higher than those in best-track data after 23h. Particularly, predicted CPs hardly change from 12h to 36h and from 48h to 60h when Hai-tang's best track CP shows rapid intensification. After 60h, we can find that Hai-Tang's intensification is well simulated in Atmos, Ocean and Wave. Figure 3 also suggests that the negative feedback is affected by the oceanic precondition represented by its difference between Ex05 (6 km) and Ex99 (6 km). However, it should be noted that a difference in predicted CPs is at most 5 hPa.

Because KF is used as cumulus parameterization in both Ex05 (6 km) and Ex99 (6 km), we performed additional numerical predictions using the models with horizontal-grid spacing of 3km (Ex05 (3km)). The tendency of CPs in Figure 4 is similar to that in Figure 3. At 48h, the value of CP in Wave is 975.7 hPa, that in Ocean is 981.3 hPa and that in Atmos is 942.3 hPa. On the other hand, that in Wave (3km) is 976.8 hPa, that in Ocean (3km) is 979.6 hPa and that in Atmos (3km) is 941.3 hPa. The results suggest that finer horizontal resolution hardly contributes to the improvement of intensity prediction. The effect of lack of KF parameterization on CP may balance with that of the change of resolution from 6 km to 3 km on CP.

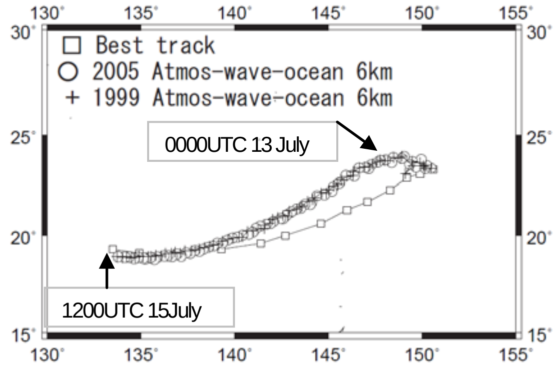

Figure 2 Results of track predictions. Squares show typhoon positions from JMA best track. Circles show those from the prediction with the initial ocean condition in 2005. Plus marks show those with the initial ocean condition in 1999.

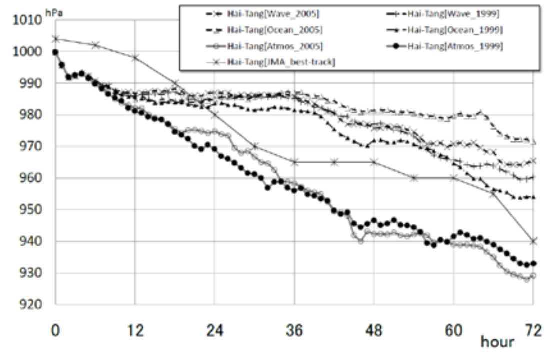

Figure 3 Evolution of best-track and predicted central pressure by models with horizontal-grid spacing of 6km and KF parameterizations. Asterisks show central pressure from JMA best track.

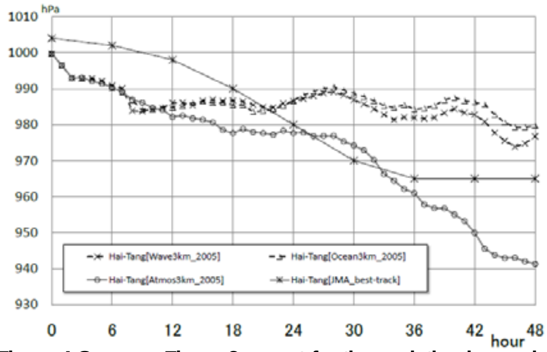

Figure 4 Same as Figure 3 except for the evolution by models with horizontal-grid spacing of 3 km and without KF parameterization.

The reason for high CPs in Ocean and WAVE is that the impact of entrainment estimated by modified Deardorff formulation (Wada et al, 2009) on Hai-Tang-induced SSC is so strong that Hai-Tang hardly intensifies. The tuning parameters (m = 175 and α=5) in modified Deardorff formulation should be determined based on atmospheric forcings. In the future, we will check these parameters, perform more additional numerical predictions and then investigate the rapid-intensification process.

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