Mesoscale Simulation Study of the Heavy Rain Event Associated with the Southwesterly flow Induced by Typhoon Mindulle (2004) over Taiwan

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Abstract

A heavy rainfall event in Taiwan occurred during the period of 2-4 July 2004 associated with the southwestly flow induced by Typhoon Mindulle is preliminary diagnosed utilizing various observational datasets and the results from numerical modeling. The Navy Global Atmospheric Prediction System (NOGAPS) global analyses with 1° latitude/longitude resolution first revealed the strong southwesterlies prevailed over South China Sea below 700 hPa during the whole diagnosed period. An area with remarkable large low level moisture convergence extended from coastal line over Southern China to Taiwan Strait was found to be associated with confluence by dry northerlies and warm, moist decelerating southwesterlies. The position of east-west oriented convergence line is close to where MCSs development. The atmospheric part of the Coupled Ocean/Atmospheric Mesoscale Prediction Systems (COAMPS) developed by the U.S. Naval Research Laboratory (NRL) is conducted with full physics to further investigate the mesoscale condition associated with continues convective precipitation. Preliminary simulation results indicate the overall rainfall pattern is well captured by the COAMPS. Some of the more detailed results as an effort to investigate the mechanisms in initiating and maintaining the convective precipitations leading to different spatial distribution of rainfall during early July 2004 will be discussed in the future study.

1. Introduction

Typhoon Mindulle is one of the eight tropical cyclones that affected Taiwan in 2004. Typhoon Mindulle formed in the western North Pacific northwest of Guam on 0600 UTC 23 June 2004, while it moved westward toward Taiwan in the following few days. The storm track data from the Taiwan Central Weather Bureau (CWB) indicated that typhoon circulation directly affected Taiwan during the period of 30 June to 1 July 2004(Fig. 1), which brought heavy rainfall to eastern Taiwan (Fig. 2a) with accumulated precipitation to 400 mm within 24 hours. While the wind threat from Mindulle weakens a lot after it landed Taiwan, CWB canceled its land warming by 1500 LST 2 July. But actually the largest amount of rainfall happened after that, which was well known as the 7-2 flood event. Flooding occurred at a lot of places in Taiwan, even brought terrible landslides over central and southern mountain areas. The GOES-9 satellite imagery on 1700 UTC 2 July (Fig. 3) reveals a cloud band extended nearly 1000 km from coastal area of southern China to Taiwan Strait, with a series of embedded mesoscale convective systems (MCSs) developed over it. While the northward propagation of Mindulle during the period of 2-4 July, the development and northeastward propagation of these MCSs brought heavy rainfall to western Taiwan, with a maximum 24-h accumulated rainfall of 450 mm on 2 July (Fig. 2b). Figures 2c and 2d indicated rainfall with a maximum 24-h accumulated amount up to 650 mm and 830 mm over the western Central Mountain Range (CMR) by 3 and 4 July, respectively.

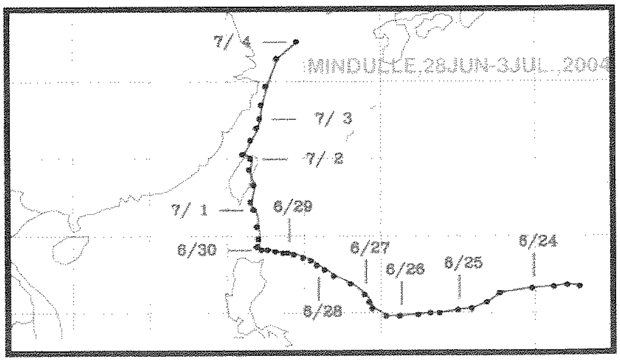

Fig. 1 Storm track of Typhoon Mindulle from Central Weather Bureau, Taiwan.

The Navy Global Atmospheric Prediction System (NOGAPS; Hogan and Brody 1993) global analyses with 1° latitude/longitude resolution revealed the strong southwesterlies prevailed over South China Sea from the low levels up to 700 hPa during the period of 2-4 July 2004. While the center of Mindulle was just at northern Taiwan on 0000 UTC 2 July, the large convergence between dry northerlies associated with Mindulle's circulation and warm, moist southwesterlies occurred at

900 hPa over western Taiwan (Fig. 4a). While Typhoon Mindulle moved further away from Taiwan on 0000 UTC 3 July, an area with remarkable large low level convergence extended from South China Sea to Taiwan Strait was assumed to be associated with warm, moist decelerating southwesterlies (Fig. 4b). One day later, by 0000 UTC 4 July, while the strong southwesterly flow impinging on the CMR, the low level convergence over western Taiwan is attributed to decelerating southwesterlies as well as the orographic enhancement (Fig. 4c). Maximum rainfall distribution over western mountain area during 2-4 July implied the complex terrain may play important roles in this upslope orographic heavy rainfall event.

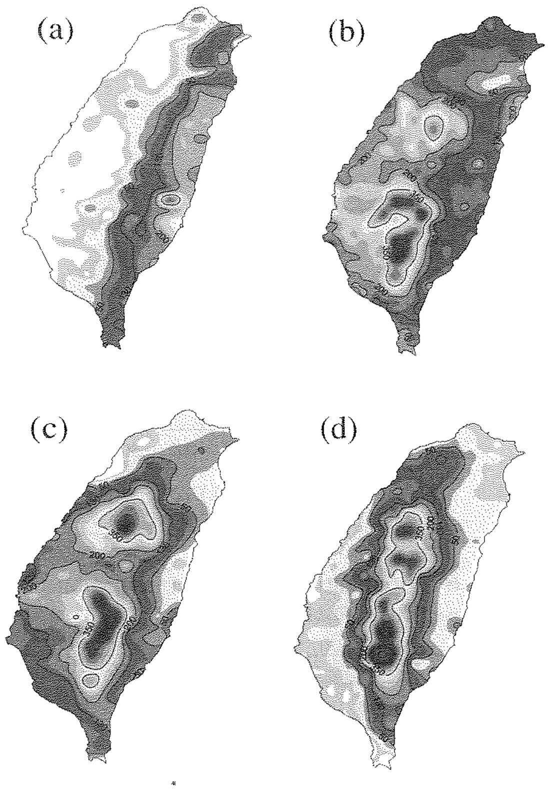

Fig. 2 CWB observed 24-h accumulated rainfall for (a) 1 July, (b) 2 July, (c) 3 July and (4) 4 July, 2004.

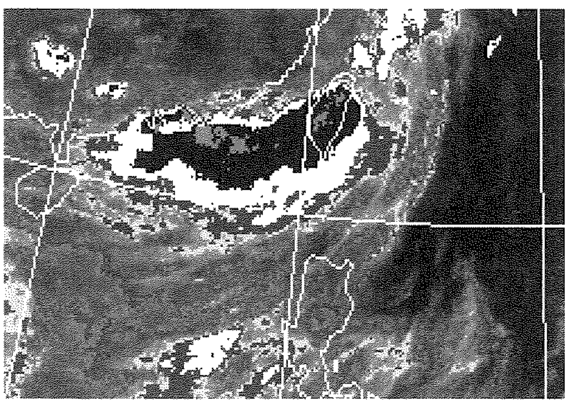

Fig. 3 GOES-9 satellite imagery of 1700 UTC 2 July 2004.

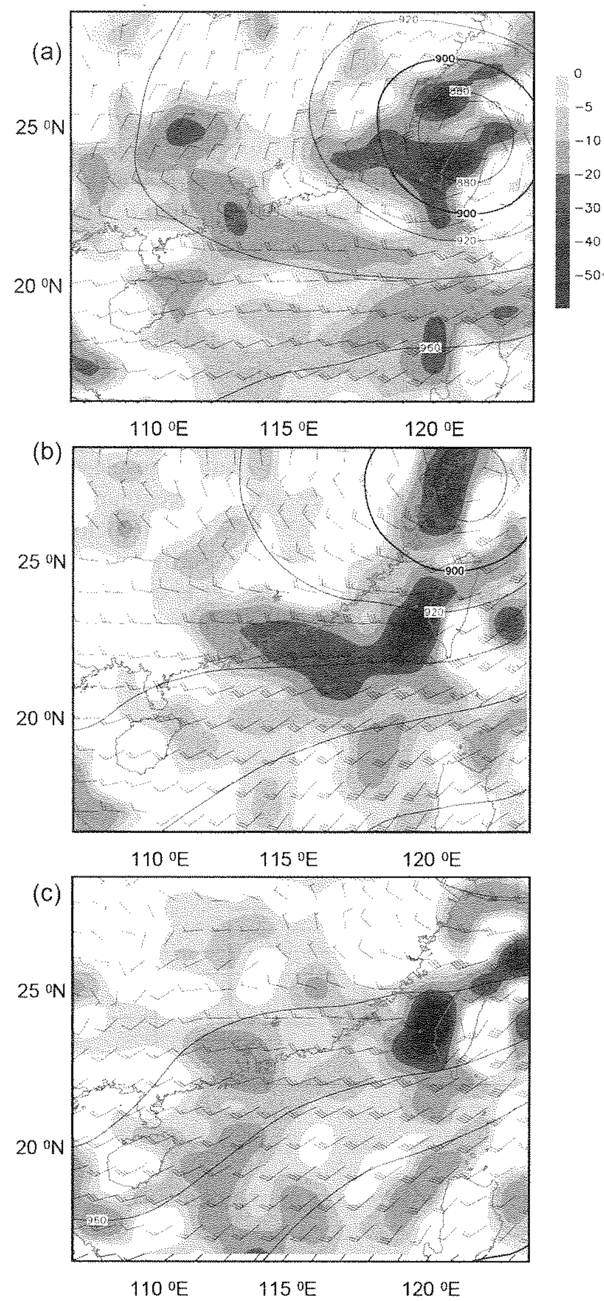

Fig. 4 NOGAPS reanalysis at 900 hPa on 0000 UTC (a)2 July, (b) 3 July and (c) 4 July 2004. Geopotential heights (contours, solid lines) For winds, full (half) barbs are 5 (2.5) ms^{-1}. Shaded area is divergence (unit: 10^{-6} s^{-1}).

2. Model description

The atmospheric portion of the Naval Research Laboratory's (NRL) Coupled Ocean /Atmosphere Mesoscale Prediction System (COAMPS; Hodur 1997) is performed in this study. COAMPS is a nested, three-dimensional model that solves the non-hydrostatic, fully compressible equations of motion on terrain-following sigma coordinate system, σ z. Kain and Fritsch (1993) cumulus parameterization scheme is used to parameterize the sub-grid scale moist convective process, whereas the grid-scale evolution of the moist processes is explicitly predicted from microphysical budget equations following Rutledge and Hobbs (1983). The approach in Louis (1979) is used to compute surface fluxes, while processes in the planetary boundary layer are parameterized with a predicted turbulent kinematic energy (TKE) budget on level-2.5 formulations of Therry and LaCarrēre (1983). Longwave and shortwave radiation processes are parameterized following Harshvardhan et al. (1987).

The simulation has a three nested domains defined by a grid of 67 × 58 points for the coarse-mesh, and 127 × 88 points and 142 ×124 grids for the medium- and fine-mesh. The horizontal grid increment is 45, 15 and 5 km for the coarse-, medium- and fine-mesh grids, respectively (Fig. 5). There are 30 irregularly spaced levels in the vertical, 11 levels of which are below 2 km for sufficiently resolve lower levels. Furthermore, a 1-km resolution terrain and landuse dataset is utilized to setup the domains used in the simulations (not shown).

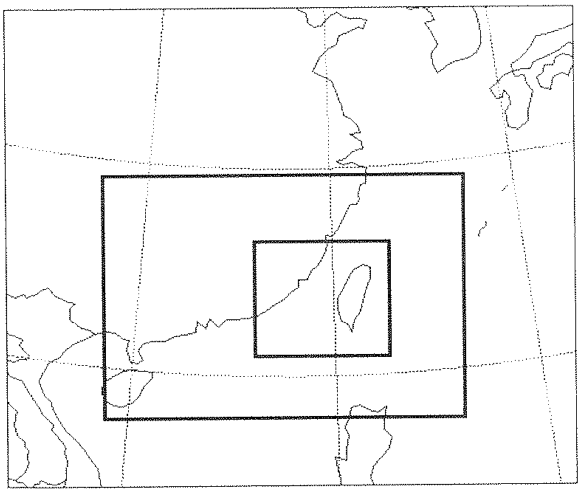

Fig. 5 COAMPS three nested domains.

The control run experiment consists of a 96-h simulation, starting at 1200 UTC 30 June 2004, utilized incremental update assimilation cycles with 12-h periods performed in the COAMPS (Fig. 6). The cycles begin with a cold start that refers to a COAMPS simulation initialized directly from the NOGAPS 1° resolution analyses, while the later warm starts refer to a COAMPS run restarted from a previous 12-h forecast. In every assimilation cycle, model's first guess field is updated with observations using the multivariate optimum interpolation (MVOI) scheme. Throughout the simulation, NOGAPS forecast fields are adopted as the lateral boundary conditions.

3. COAMPS Simulations

The simulated track of Mindulle from the COAMPS takes a more northeastward direction from the beginning of the experiment and hence the typhoon did not make landfall on Taiwan in the simulation (Fig. 7). The simulated track after 1200 UTC 2 July, however, follows the best track very well. Since the simulated typhoon center is further away from Taiwan than actually occurred, the simulated rainfall on 1 July in the eastern part of the island is underestimation (not shown) As Mindulle' s center moved to north of Taiwan, the shift of the rainfall maximum location from southwestern Taipei (over plain areas) to the Central Mountain Range during 2-3 July is quite well captured in the simulation in terms of both spatial pattern and order of magnitude of rainfall (Fig. 8). In these two days, the major rainfall mechanism changed from a MCS embedded in a convergence line formed between Typhoon Mindulle' s circulation and the monsoonal southwesterlies to that purely from the latter. Therefore, the present COAMPS configuration is able to simulate this change in rainfall mechanism to a large extent.

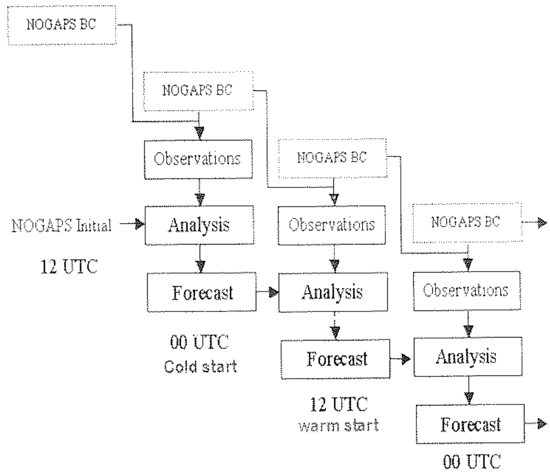

Fig. 6 Initialization and data assimilation cycle of COAMPS.

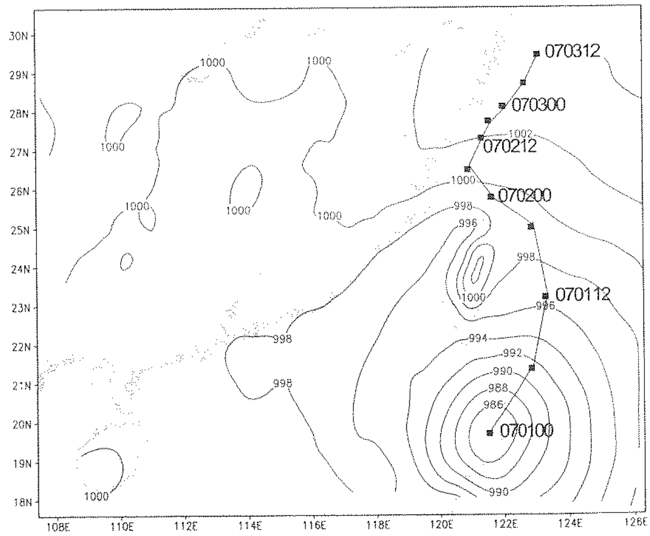

Fig. 7 COAMPS simulated storm track of Typhoon Mindulle.

4. Conclusion

The U.S. Navy's regional model COAMPS is used to simulate the heavy rainfall event in Taiwan in July

2004 brought by Typhoon Mindulle and the associated southwesterly flow. The overall spatial and temporal rainfall pattern is quite well simulated by the model. Future work include investigations on how to improve the track forecast; further diagnosis on how well the present model simulated the mesoscale systems and strength of the induced southwesterlies; and sensitivity of COAMPS simulations to various physics parameterizations.

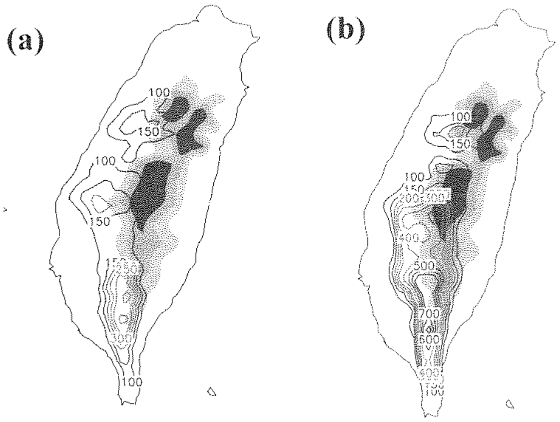

Fig. 8 COAMPS simulated 24-h accumulated precipitation (contour in mm) for (a) 2 July and (b) 3 July, 2004. Terrain above 2000 m is shaded.

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