Numerical Simulation of Typhoon Dot 1990 and Its Interaction with the Central Mountain Range

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1. Introduction

The Central Mountain Range (CMR) has an average elevation of about 3000 m. As a typhoon approaches Taiwan, the circulation of the storm interacts with the CMR and produces interesting mesoscale wind, temperature, humidity, and pressure features. Moreover, this interaction causes significant deflection of the storm track. Wang (1980) analyzed the path, intensities, propagation speeds and life history of 53 typhoons that hit Taiwan during 1946-75. He found that for typhoons approaching Taiwan from the east, the storm can either cross Taiwan continuously or have a discontinuous track due to the formation of a secondary low that replaces the terrain-blocked low-level center. The prediction of the track and position of the storm is an extremely important forecast problem, because of its intimate relationship with the mesoscale wind and rainfall distribution. Chang (1982), and Yeh and Elsberry (1993a, 1993b) performed idealized numerical experiments to study the interaction of westward propagating typhoons with an isolated mountain, using models with grid sizes ranging from 45 km to 60 km. These numerical experiments successfully simulated the flow deflection and the formation of a secondary vortex as a typhoon approaches Taiwan. They provided much insights into the physical processes responsible for the typhoon track deflection and the formation of the secondary vortex. However, a detailed numerical simulation of an observed typhoon with high resolution models using realistic topography has not been reported in the literature. Such a simulation would allow a close comparison with the observations, and provide further insights into the complex physical processes responsible for the development of mesoscale wind, pressure, temperature and moisture distribution as a result of a typhoon interacting with the CMR. The purpose of this paper is to present a simulation of Typhoon Dot that hit Taiwan in September 1990 using the nonhydrostatic MM5 model with a grid size of 6.67 km, and to compare with the available observations.

** The National Center for Atmospheric Research is operated by the University Corporation for Atmospheric Research under sponsorship of the National Science Foundation.*

2. Description of typhoon Dot

Typhoon Dot affected Taiwan during the period of 6-8 September 1990, which coincided with the period of Tropical Cyclone Motion (TCM-90) Experiment. All the operational rawinsonde and pibal stations released soundings at 3-h intervals. Tsay et al. (1995), hereafter referred to as TWC, performed a detailed analysis of this case based on all the available upper air and surface reports. Figure 1 shows the track of the storm during the period of 0000 UTC 7 to 0600 UTC 8 September 1990 as analyzed by TWC. Dot approached Taiwan from its southeast, with an attack angle of roughly 135°. It landed near Chengkung. According to the analysis of TWC, the primary circulation center quickly dissipated after landfall. Surface analysis during the day of 7 September suggested that two mesolows formed on the west side of Taiwan, one was located between Taichung and Chiayi, and the other near Tainan (Fig. 2). TWC analyzed the three-dimensional wind fields and surface report during this period, and concluded that the northern mesolow formed as a combined result of adiabatic warming due

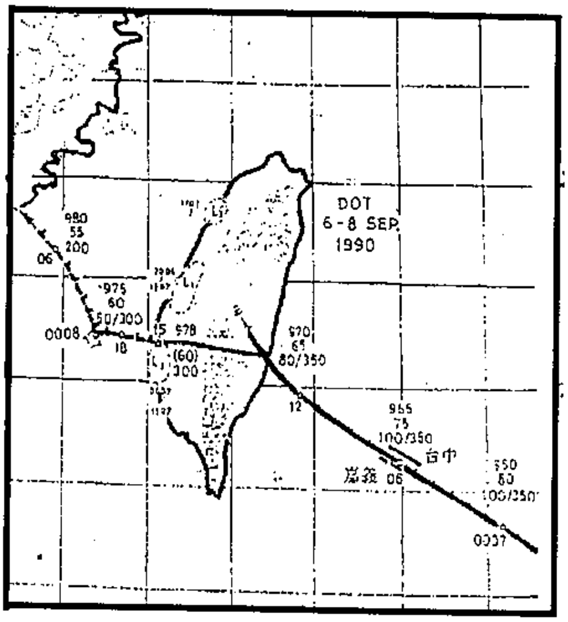

Figure 1 Analyzed track of Dot for the period from 0000 UTC 7 to 0600 UTC 8 September 1990 (from TWC 1995).

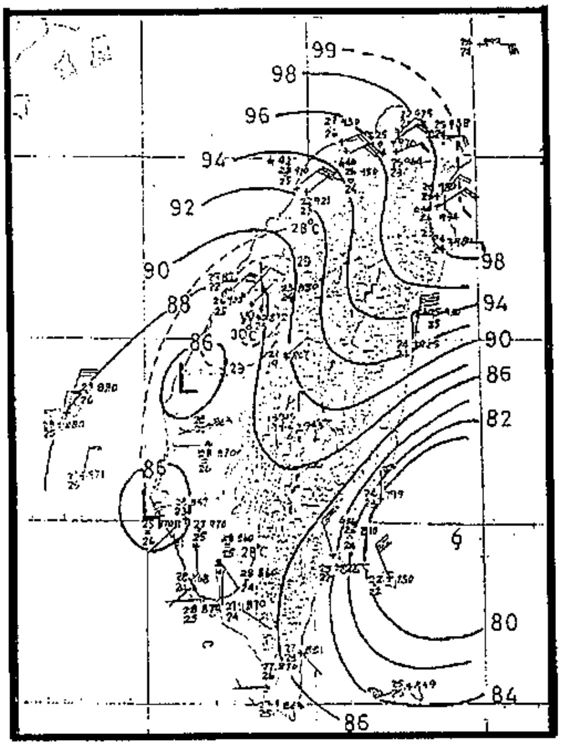

Figure 2 Analyzed sea-level pressure and winds at 1200 UTC 7 September 1990 (from TWC 1995).

to descending airflow above 2 km and diabatic heating due to solar heating below 2 km. The southern low was primarily a heat low due to solar insolation. TWC showed that the southern mesolow developed after 1400 UTC and became the primary low.

3. Model and experiment design

In this study we performed a nested grid simulation of Typhoon Dot using the Penn State/NCAR mesoscale model version 5 (MM5). Our primary interest is to examine the evolution of mesoscale wind and pressure structure as Dot approached Taiwan, in particular, the formation of secondary low and its development into the primary circulation center. The version of MM5 used in this study has three nested domains run in two-way interactive mode. The grid sizes of the three domains are 60 km (A grid), 20 km (B grid), and 6.67 km (C grid), respectively. Both the A and B grids were initialized at 1200 UTC 6 September based on the NMC global analysis (without further enhancement or tropical cyclone bogusing). The C grid was initiated at 1800 UTC 6 September, based on the 6 h forecast of the B grid. The model integration was carried out to 0000 UTC 8 September. The C grid moved 6 times during its 30-h simulation, at hour 3, 6, 9, 12, 18 and 24, respectively. All 3 grids used the same physics package, which includes the Kain-Fritsch (1993) convective parameterization, an explicit moisture scheme with simple ice physics (Dudhia 1989), Blackadar PBL, and the atmospheric radiation scheme described in Dudhia (1989).

4. The 6.67 km model results

Figure 3 shows the C-grid prediction of sea level pressure and surface wind at 1000 UTC, 1200 UTC, 1400 UTC, and 1600 UTC 7 September 1990. At 1000 UTC 7, the simulated Dot is located about 120 km off the southeast coast of Taiwan with a central pressure of 990 mb. At this time, the lee trough on the west side of the mountain is already very pronounced. An elongated mesolow with a central pressure of 990 mb is located near Taichung. This mesolow does not have a closed cyclonic circulation associated with it. In fact, northeasterly flow with wind speeds of 20 m s^{-1} or greater penetrated the center of the mesolow. Near Tainan, a weak cyclonic circulation is faintly visible, with wind speed generally below 5 m s^{-1} near the center of the low. Two hours later, Dot lands near Chengkung, consistent with the observations. Its low-level cyclonic circulation is largely destroyed. A remanent low pressure of 990 mb without a cyclonic circulation is located about 100 km off the coast of Hualien. The Taichung mesolow moves slightly westward into the sea, while the southerly flow to the east of the Tainan mesolow intensifies. A cross section cutting through the Taichung mesolow clearly indicates that this is a lee trough, with descending motion extending from 600 mb down to the surface (not shown). In contrast, no organized sinking motion can be identified above the Tainan mesolow. Together with high relative humidity in the vicinity of the mesolow, this suggests that adiabatic warming is not the primary mechanism for the formation of the southern mesolow. By 1400 UTC, the southerly flow to the east of the Tainan mesolow has further intensified, while the Taichung mesolow has migrated slightly northward and deepened to 988 mb. The pressure field associated with the southern mesolow takes the shape of an elongated trough. Two hours later (1600 UTC 7), the southern mesolow has evolved into a closed cyclonic circulation, which is clearly evident off the west coast of Taiwan. The northern mesolow does not change very much in either its position or its intensity. In fact, the northern mesolow is deeper than the souther mesolow by 1 mb in pressure. The southern mesolow then gradually moves westward and becomes the primary circulation center of the typhoon (not shown).

5. Concluding remarks

Although the MM5 model was initialized with the coarse NMC global analysis (without vortex implanta-

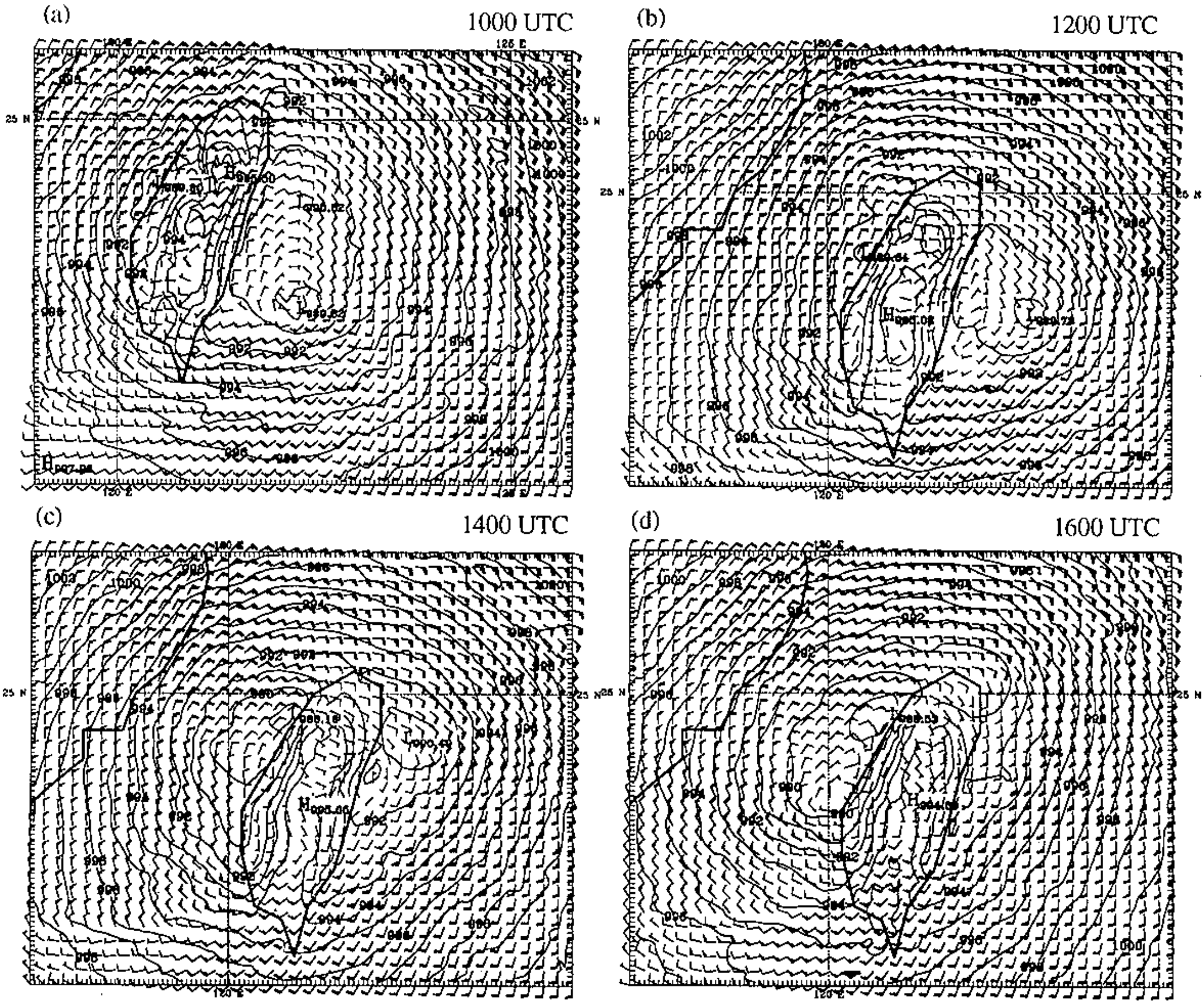

Figure 3 Simulated sea-level pressure and lowest σ level winds for Dot from grid C at (a) 1000 UTC, (b) 1200 UTC, (c) 1400 UTC, and (d) 1600 UTC 7 September 1990. The contour interval for sea-level pressure is 1 mb. A full barb is 10 m s^{-1}, and a half barb is 5 m s^{-1}.

tion or tropical cyclone bogusing), it successfully simulated the dissipation of the primary vortex as it impinged upon the CMR, the formation of two mesolows on the west side of CMR, and the development of the southern mesolow into the primary vortex. The similarity between the observed and modeled southern mesolow is truly remarkable in terms of position and size. Admittedly, this simulation is not perfect. The central pressure of the southern mesolow was higher than the observation by as much as 10 mb. This is mostly related to the relatively weak intensity of simulated Dot due to the lack of a typhoon initialization procedure. According to TWC, the central pressure of Dot was in the range of 960-970 mb before it made landfall. In the simulation, the model consistently maintained a central pressure at 990 mb. We are in the process of performing an experiment with a tropical cyclone bogusing, which might eliminate this deficiency.

An interesting finding of this study is that the sea level pressure is often a poor indicator of the behavior of the storm as it approaches Taiwan. For example, although the primary vortex was destroyed as it landed near Chengkung, a separate low pressure, which was not directly related to the upper-level circulation center, continued to move northward along the east side of CMR. This might create an impression that the typhoon was tracking northward toward northeastern Taiwan, which was clearly not the case according to the analysis of both the model simulation and the observations. Moreover, the northern mesolow on the west side of the CMR has never developed a closed cyclonic circulation, despite the fact that it has a lower pressure than the southern low. In contrast, the southern mesolow, though not as impressive in pressure, developed into the primary cyclone as the upper-level vortex crossed over the CMR and interacted with it. This shows that extreme caution needs to be exercised in interpreting the wind and pressure observations to determine the position and the track of a typhoon in the vicinity of CMR.

The successful simulation of Dot with the 6.67 km MM5 indicate that it is possible to predict detailed mesoscale wind and pressure distribution as a typhoon approaches Taiwan using a high resolution mesoscale model. This demonstrates the potential for using such a model in actual storm prediction. Additional analyses of the model results will be presented at the conference, with a focus on the physical processes responsible for the formation of the southern mesolow.

Acknowledgment:

We thank Mr. Shih-Ting Wang at the Central Weather Bureau for introducing this case to us and for providing his analyses of typhoon Dot and for many fruitful discussions.

References:

Chang, S. W., 1982: The orographic effects induced by an island mountain range on propagating tropical cyclones. *Mon. Wea. Rev.*, **110**, 1255-1270.

Dudhia, J., 1989: Numerical study of convection observed during the Winter Monsoon Experiment using a mesoscale two-dimensional model. *J. Atmos. Sci.*, **46**, 3077-3107.

Kain, J. S., and J. M. Fritsch, 1993: Convective parameterization for mesoscale models: The Kain-Fritsch scheme. The representation of cumulus convection in numerical models, K. A. Emanuel and D. J. Raymond, Eds., *Amer. Meteor. Soc.*, 246 pp.

Tsay, C.-Y., S. T. Wang, and M.-D. Cheng, 1995: User's guide for typhoon forecasting in the Taiwan area. *Research Report,* CWB83-1M-01, Central Weather Bureau, Taipei, Taiwan, 370 pp.

Wang, S. T., 1980: Prediction of the behavior and strength of typhoons in Taiwan and its vicinity. Research Report 108, Chinese National Science Council, Taipei, Taiwan, 100 pp (in Chinese).

Yeh, T.-C., and R. L. Elsberry, 1993a: Interaction of typhoons with the Taiwan Orography. Part I: Upstream track deflection. *Mon. Wea. Rev.*, **121**, 3193-3212.

Yeh, T.-C., and R. L. Elsberry, 1993b: Interaction of typhoons with the Taiwan Orography. Part II: Continuous and discontinuous tracks across the island. *Mon. Wea. Rev.*, **121**, 3213-3233.