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THE INFLUENCE OF THE ZHOUSHAN ARCHIPELAGO TERRAIN ON THE TROPICAL CYCLONE TODD (NO.9806) BY NUMERICAL SIMULATION

GONG Yan (龚　奕) [1, 2], LU Wei-song (陆维松)[1], QIN Jun (覃　军)[1], SHAO Di-qing (邵迪青)[2]

(1. Key Laboratory of Meteorological Disaster and Environmental Variation, Nanjing University of Information and Science Technology, Nanjing 210044 China; 2. Zhoushan Meteorological Bureau, Zhoushan 316004 China)

ABSTRACT: Taking Tropical Cyclone (TC) No.9806 (Todd) as an example, the effects of Zhoushan archipelago terrain on landfall TC are investigated by use of numerical simulation. Results show that, under topographic influences of Zhoushan Islands, the westward-moving landfall TC deflects. And, small orographic highs and enhanced rainfall caused by climbing airflow on the windward slope of main mountains of these islands are a result of effects of Zhoushan Islands. These results display some particular laws of effects of small-sized islands on the landfall of TC.

Key words: Zhoushan Islands topography; TC No.9806 (Todd); Numerical simulation

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1 INTRODUCTION

Tropical cyclone is one of the most severe weather types that heavily influence China. According to the statistics[1], every year, 8 typhoons make landfalls in China. Damaging wind, torrential rain, and the storm tide brought by typhoon pose significant threat to lives and properties. It is critical in disaster mitigation to issue correct track forecast of typhoons, especially of the landfall ones. And it is also a hot issue for researchers inside and outside China. In general, the factors affecting the tropical cyclone track are known as steering flow, internal structure of typhoon, underlying surface (terrain and friction), β-effect, and the interactions between weather systems of different scales[2-12]. The influence of the island terrain as underlying surface on landfall typhoon has been widely recognized, but the researches tend to focus on the large islands such as Taiwan Island, Hainan Island and Luzon Island, with the role of islets hardly reported.

Zhoushan Archipelago is the largest archipelago in China, which locates in the southeast waters offshore the Yangtze River Mouth, extending north-south about 150 km and about 100 km east-west. Zhoushan Archipelago consists of Zhoushan Island, Daishan Island, Zhujiajian Island, Liuheng Island, Jintang Island and other islands, among which, Zhoushan Island is the largest one in the archipelago and the fourth largest in China. The group of islands aligns southwest-northeast. Larger islands distribute in the south, closely to each other with higher elevation. Among them, the altitudes of Mt. Huangyangjian and Mt. Dadou on the islands are both above 500 meters; smaller islands dot about the northern sea surface with lower elevation. This paper investigates the influence of small islands (especially the archipelago) on the landfalling tropical cyclone by means of numerical experiment, using Zhoushan archipelago as the target.

2 BRIEF INTRODUCTION TO THE NUMERICAL SIMULATION CASE

In this paper, Tropical cyclone Todd (9806) is used for numerical simulation case study. Todd was a tropical cyclone with an abnormal track of turning westward in the East China Sea. Seven abrupt left-turns and a sudden acceleration had occurred to tropical cyclone Todd since its genesis over sea surface to the east of the Philippines on September 15,1998 (Fig.1). At the time from 1400 UTC to 1500 UTC 19

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Biography: GONG Yan (1970-), male, native from Zhejiang Province, Engineer, Ph.D. candidate, mainly undertaking the study on tropical cyclones and atmospheric dynamics.
E-mail: gongyan1234@sohu.com

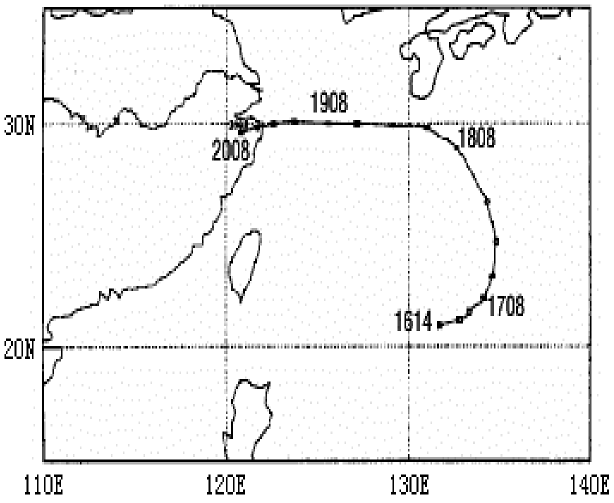

Fig.1 Track of the Tropical cyclone Todd [13].

September, Todd made landfall in Putuo district, Zhoushan city, Zhejiang province, before degrading as a tropical depression at 0600 UTC 20 September. The tropical cyclone can be summed up as one with multiple abrupt turns, which is hard to predict, and therefore drew the attention of researchers. Shi [13] analyzed the weather situations and pointed out that the blocking of the West Pacific Subtropical High (hereafter WPSH), the attraction of the westerly trough, and the steering by the southerly current in the west side of WPSH, caused the first important abrupt left-turn of Todd; then the westward extension of the WPSH brought the second important left-turn. Zheng et al. [12] investigated the offshore west-turn of the tropical cyclone Todd, and found, using synoptic and statistic methods that, the adjustment of the westerly belt, the intensification of the WPSH, the prevailing northeast wind at lower levels, and the activity of other typhoons can answer the question why the tropical cyclone made an abrupt turn offshore and then moved on a steady westward track. Deng [14] studied the physical mechanism of the west-turn of the tropical cyclone Todd, and pointed out that the alternation of the weak and strong environmental fields might be the reason. This paper, from another aspect, discusses if the island terrain played any role in the last left turn of the tropical cyclone by means of numerical simulation.

3 NUMERICAL MODEL AND THE EXPERIMENT SCHEME

3.1 Numerical Model in use

A PSU/NCAR MM5 model with triply nested grids and two-way interactions is used for numerical simulation. The elevation data of the Zhoushan Archipelago are modified to be more realistic (Fig.2). The triply nested grids are 59×81 grids with 45-km horizontal resolution (the first mesh), 97×121 with 15-km resolution (the second mesh) and 43×37 grids with 5-km resolution (the third mesh), with the most outward mesh centering at 28.0 °N, 126.5 °E. Time steps of the integration for the nested grids are 120, 40 and 13.3 seconds respectively. Vertically, a terrain-following sigma coordinate of 26 levels is adopted in the model with the Anthes-Kuo cumulus parameterization scheme. Global objective analysis of T106 model is used as the initial field and boundary conditions.

3.2 Numerical Experiment scheme

Due to the lack of observational data, the tropical cyclone in the initial field of the numerical model was weaker than the reality obviously, so a self-designed Bougussing scheme, which is modified from the NCAR-AFWA scheme in the MM5 model [15], is adopted. The modified one keeps the non-vortex component of the initial TC spin, and uses the Rankine vortex wind field as the vortex component of the bogus tropical cyclone, then, according to the center of the initial TC spin at each layer respectively, overlaps the vortex wind back to the analysis wind field. Thus a leaning non-axis- symmetrical bogus tropical cyclone wind field is constructed by keeping the non-vortex component of the wind field. The modified version retains the vertical leaning structure of the initial TC spin; while the original one directly uses the wind field from Rankine vortex model without the non-vortex component of the initial TC spin to construct the bogus tropical cyclone wind field which is a barotropic and symmetrical structure. By comparison analysis of the numerical simulation of the tropical cyclone Todd after its west-turn, the modified version was found to have

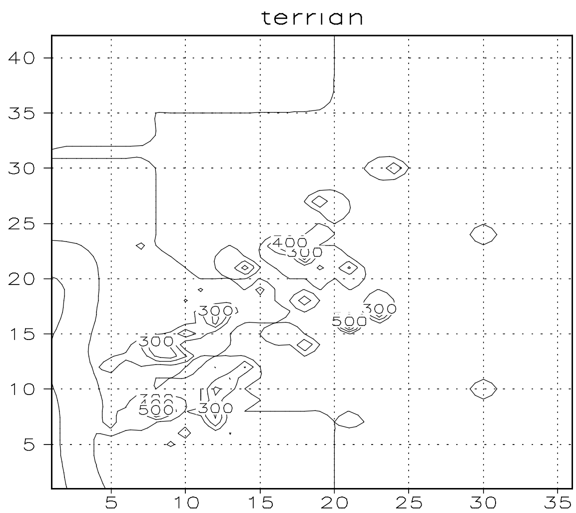

Fig.2 Terrain of the Zhoushan Archipelago in the third mesh.

better results.

The start time of the integration in this case study is 1200 UTC 18 September 1998, and the integration lead time is 54 hours. Both the controlled experiment and sensitive experiment are presented here:

(1) Controlled experiment B: The scheme included the topography of Zhoushan Archipelago to find out the influence of the Archipelago topography on the tropical cyclone landfall with higher spatial and temporal resolution data from the numerical simulation.

(2) Sensitive experiment BNZ: The scheme replaced the Zhoushan Archipelago topography by the sea surface to investigate the impact of the Zhoushan Archipelago topography as the comparison for Scheme B.

(3) Sensitive experiment BLZ: The scheme doubled the elevation of the Zhoushan Archipelago to further study the influence of the Zhoushan Archipelago.

(4) Sensitive experiment BMZ: The scheme connected the Zhoushan Archipelago with the mainland continent to investigate the influence of the area of the Zhoushan Archipelago.

4 NUMERICAL MODEL OUTPUTS AND THE ANALYSIS

4.1 TC track

The low center of the sea level pressure is defined as the tropical cyclone center in this article. Since no more tropical cyclone location was determined officially after its degradation as a tropical depression at 0600 UTC 20 September, 1998, Table 1 only lists the TC track error of Controlled experiment B for the 42 hour lead time. Table 1 shows relatively large errors of the simulated track for the first 6 hours in the controlled experiment due to the TC position difference between the initial field and the observation. The simulated track becomes better in the lead time of 6 to 30 hours, and after that, errors increase.

Table 1 TC Track error simulated by Exp. B on the second mesh

Time/hour	0	6	12	18	24	30	36	42
Error/km	121.3	103.6	66.7	64.4	31.0	75.3	167.1	241.9

It can be learned from Fig.3 that, during the integration time span of 6 to 30 hours, both the controlled experiment B and the sensitive experiment BNZ got TC tracks close to the observational one. But with the TC center approaching the Zhoushan Archipelago (after 18 hours of integration time), the tracks simulated by the controlled experiment B and the sensitive experiment BNZ differed. The track by the controlled experiment B is more left-turning than the one by sensitive experiment BNZ. The mean difference between the TC positions given by the two experimental simulations on the finest grids (the third mesh) is 10 km, which indicates that the topography of the Zhoushan Archipelago does affect the track of the landfalling tropical cyclone Todd. To further investigate the influence of the topography of Zhoushan Archipelago, Fig.3 also gives the tracks simulated by sensitive experiment BLZ and the experiment BMZ, which shows that if the elevation doubles, the track simulated by Experiment BLZ is more left-turning than the one simulated by controlled experiment B, and if the islands are connected with the mainland continent, the track simulated by the experiment BMZ is nearly the same as the one by controlled experiment B. Thus it can be inferred that it is the elevation of the Zhoushan Archipelago that influence the TC track rather than the size of the islands.

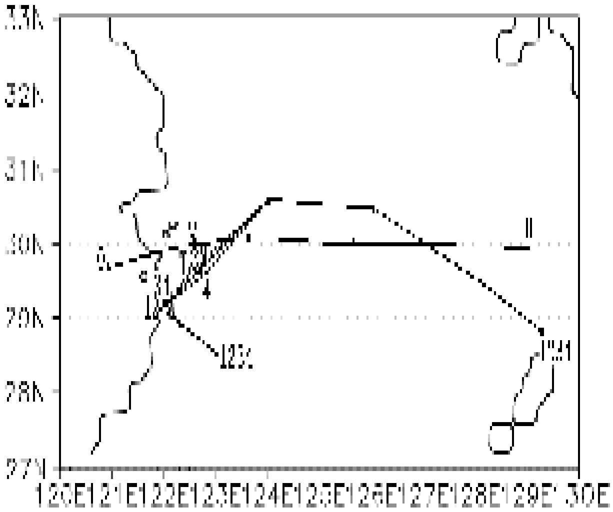

Fig.3 Track of Todd from 1200 UTC 18 September (the second mesh). 0 denotes the observed track, 1 by Experiment B, 2 by Experiment BNZ, 3 by Experiment BMZ and 4 by Experiment BLZ.

4.2 Rainfall distribution

Fig.4a and Fig.4b are the observational rainfall distribution and the simulated rainfall distribution by the controlled experiment B during 1200 UTC 18 September to 1200 UTC 19 September. Experiment B simulated a rainfall center in Zhoushan Archipelago and the adjacent areas. Though the simulated rainfall is larger than the observed one, the distribution of the

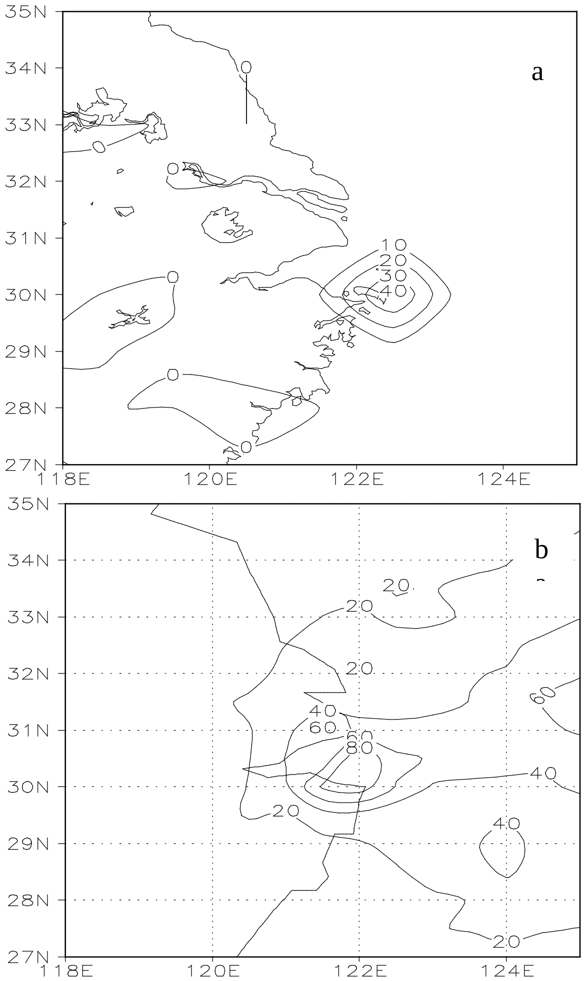

Fig.4 The observed rainfall distribution (a) and the simulated rainfall distribution by the controlled experiment B (b) during 1200 UTC 18 September to 1200 UTC 19 September on the second mesh (Unit: mm).

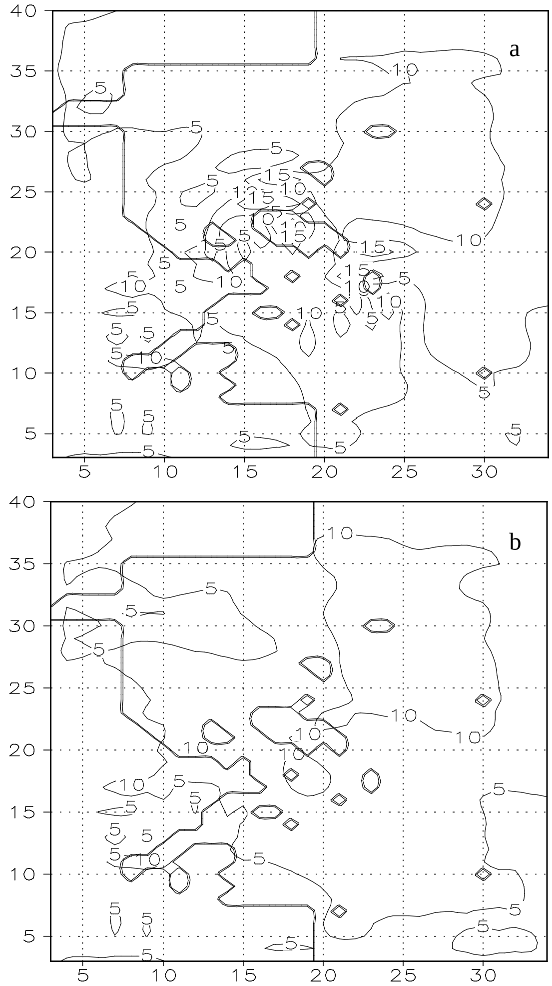

Fig.5 Simulated precipitation on the third mesh from 1200 UTC 18 to 1200 UTC 19, September 1998. Unit: mm X coordinate: Grid number, the same as in the flowing figures a: Exp. B b. Exp. BNZ.

rainfall in this area is fine.

Fig.5a and Fig.5b show the rainfall distribution on the finest grid mesh (the third mesh) by the controlled experiment B and the sensitive experiment BNZ from 1200 UTC 18 September to 1200 UTC 19 September. As is illustrated by the figure, because of the terrain effect, the rainfall distribution by controlled experiment B is more uneven than the one by experiment BNZ. When the tropical cyclone moved to the sea surface to the northeast or east of the Zhoushan Archipelago, with the northerly or the easterly upslope flow climbing the mountains like Huangyangjian, Dadou, and Duizhi, the vapor ascended along the hill, piled up and condensed into rain by adiabatic cooling (figure omitted), which caused the precipitation augmentation in the east or the north side of the mountains (Fig.5a). In the same manner, when the tropical cyclone moved to the west of the Zhoushan Archipelago, the southeast air stream climbed the hill, causing the precipitation augmentation in the southeast side of the mountains of Huangyangjian, Dadou and Duizhi (Figure omitted).

4.3 Orographic high pressure

Comparison of the sea level pressures (Fig.6a and Fig.6b) shows that the mountains on the islands like Huangyangjian and Dadou, which are relatively high and wide, can alter the pressure distribution and induce the small orographic high pressure, which locates in the upslope of the mountains. Since Mt. Huangyangjian is higher and wider than Mt. Dadou, the small high pressure near Mt. Huangyangjian prevailed over the one near Mt. Dadou in the aspects of intensity and horizontal scale. Vertically, the small high pressure near Mt. Huangyangjian extended upward to 950 hPa while the one near Mt. Dadou only extended to 975 hPa. Because of the lack of high resolution observational data, the phenomenon of orographic high pressure is in need of the further validation.

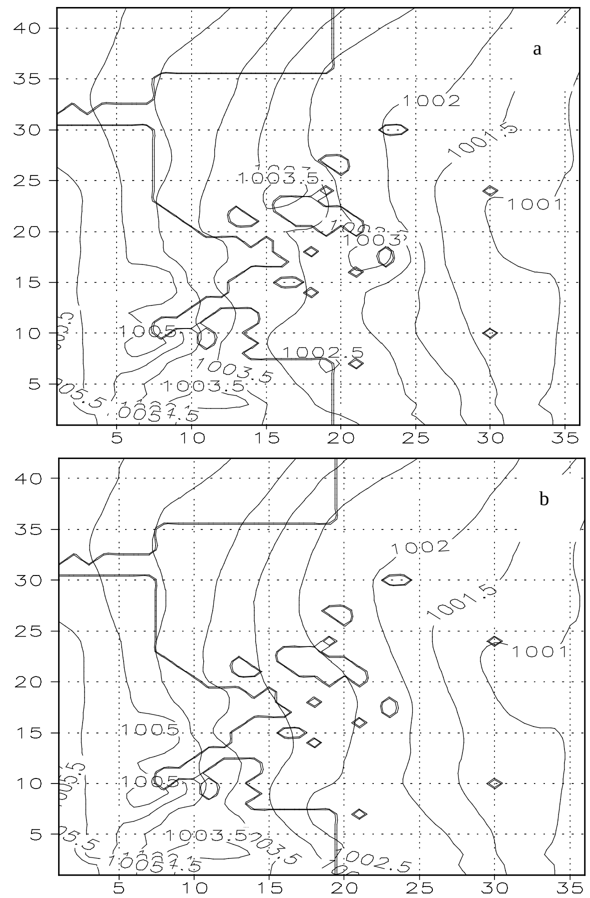

Fig.6 Simulated sea level pressures on the third mesh at 0200 UTC 19 September 1998 Unit: hPa a: Experiment B; b. Experiment BNZ.

5 CONCLUSIONS

This paper uses MM5 model to simulate the activities of the landfalling tropical cyclone Todd (No.9806) after its west turning. Results show that the terrain of Zhoushan Archipelago can influence the track of the landfalling tropical cyclone and its related precipitation and pressure distribution, which shall not be ignored in the forecast practice.

However, it is just a case study of Zhoushan Archipelago and the tropical cyclone Todd, and it can only reveal some specific laws, by which small island topography affects the activities of landfalling tropical cyclones. To fully understand the influences of the small islands on the landfalling tropical cyclones, more studies on the interaction between tropical cyclones and islands at different latitudes are still needed to be carried out to supply more references for the tropical cyclone landfall forecasting.

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