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TERRAIN IMPACT ON THE PRECIPITATION OF LANDFALLING TYPHOON TALIM

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Abstract: The impact of terrains on the precipitation of landfalling typhoon Talim (2005) over mainland China is investigated using the fifth-generation Pennsylvania State University-National Center for Atmospheric Research Mesoscale Model. The simulated precipitation of simulated typhoon (the control) matches the observations closely. To compare with the control simulation, four sensitivity simulations were carried out in which terrains of Wuyi Mountain, Lushan, Dabieshan, and both Lushan and Dabieshan are completely removed respectively, but other surface properties were retained. It is found that the complex terrains of Wuyi Mountain, Lushan and Dabieshan have a significant impact on the rainfall intensity and distribution of Talim. As the terrains are removed, the rainfall is decreased very greatly and the rainfall in inland area is decreased much more than that in the coastal area. Besides, the rainfall distribution near the Lushan and Dabieshan is spread much more westward compared with the control simulation. Further analysis shows that the Wuyi Mountain would increase both the lower level air convergence and the upper level air divergence for Talim that just made landfall and thus it would contribute to the convection and increase rainfall intensity. It can be concluded that the terrains of Wuyi Mountain, Lushan and Dabieshan have obvious impacts on the Talim rainfall, and their impacts are different in various landfalling periods. The present study is a useful attempt to explore the influence of orography on the TCs in mainland China.

Key words: typhoon, terrain, precipitation

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1 INTRODUCTION

Tropical cyclones (TCs) are an annual threat to China each year, often with devastating consequences. The southern and eastern region of China (see exact location in Fig. 1a) is significant because the complex terrain in close proximity to the coastline acts to enhance the destructive potential of landfalling TCs. TCs that impact the far southeast coast pose an extreme threat to large metropolitans such as Hong Kong and Shenzhen, small coastal communities, and the agricultural industry of the region.

Previous studies of the influence of orography on TC structure and intensity have focused mainly on idealized numerical simulations (e.g., Chang[1]; Bender et al.[2]), or on TCs that interact with the Central Mountain Range (CMR) of the island of Taiwan (e.g., Bender et al.[3]; Chang et al.[4]; Yeh and Elsberry[5, 6]; Lin et al.[7 - 10],; Wu and Kuo[11]; Wu 2001[12]; Wu et al.[13]). The Sierra Madre mountains of Mexico have also been shown to influence TCs that approach from the Gulf of Mexico (e.g., Zehnder[14], Farfan and Zehnder[15]). Other mountainous regions affected by TCs include Luzon in the northern Philippines (Brand and Blelloch[16]) and the Caribbean Islands of Cuba, Hispaniola and Puerto Rico (Bender et al.[3]).

The above studies have provided considerable understanding of how orography affects the track and structure of TCs. While the importance of orographic influences on landfalling TCs over southeastern mainland China has long been recognized, to our knowledge there have been no comprehensive high-resolution numerical simulations that have explored the influence of orography on the TCs in

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mainland China. Though there has been some progress in TC track forecast, the quantitative precipitation forecast of TCs still poses a great challenge to us (Chen[17]). Our main objective is to understand how the complex terrain of the southeastern region of mainland China affects TC precipitation and to assess how different the impact on Talim precipitation would have been if the region was flat.

Section 2 is a summary of the major observational aspects of Talim, including its track and its characteristics during and after landfall. Section 3 describes the MM5 model configuration and the proposed numerical experiment. The results are given in sections 4, 5, 6, and section 7 summarizes the findings and conclusions in this study.

2 OBSERVATIONAL ANALYSIS OF LANDFALLING TYPHOON TALIM

After landing in Hualian of the island of Taiwan at 0600 September 1, 2005 (Beijing Standard Time used in this paper), Talim moved to the northwest (Fig. 1b). It landed in Putian of Fujian Province again at 1430 (Fig. 1b).

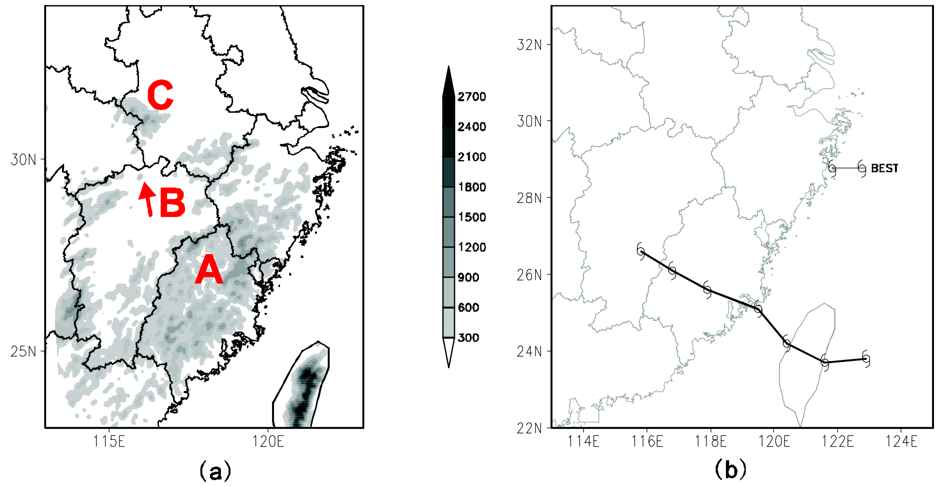

Fig.1 (a) Terrain height distribution (Units: m), and A, B, and C represent the Wuyi, Lushan, and Dabieshan Mountains respectively. (b) Observed track of typhoon Talim.

From the 500-hPa geopotential height field analyzed from NECP reanalysis data (Fig. 2a), a subtropical high is shown to be to the northeast of Talim and a continental high to its northwest at 1400 September 1. To the north of 40ºN, there was a trough with the deepest line 15 degrees of latitude far away from the typhoon center. So under the effect of the southeastern wind flow around the subtropical high, Talim moved to the northwest continuously. In the water vapor field, relative humidity distributed quite like quite like the figure “6” (Fig. 2a). Afterward, the 588 contour line in the 500-hPa geopotential height field extended to the west and gradually approached the continental high (figure omitted). Until 0800 September 2, the two highs were connected (Fig. 2b). The geopotential height of the Talim center was substantially increased, that is, the intensity was weakened. At 2000 September 3, the subtropical high and continental high disconnected from each other and moved to the east and west respectively (Fig. 2c). A northern trough moved southward to near 35°N. The ‘6’-like water vapor distribution was destroyed. Although the remnant depression center of the typhoon still existed, the cyclonic circulation was weakened. At 2000 September 3, the northern trough moved to the south of 35°N and the remnant cyclonic depression circulation disappeared.

During the landfall, Talim brought very heavy rain, especially to some terrain areas such as Wuyi Mountain, Lushan and Dabieshan. The duration was long and the precipitation intensity was high, which caused the death of 129 people in Zhejiang, Anhui, Fujian, Jiangxi, Henan and Hubei provinces and resulted in direct economic loss of 15.46 billion yuan. This is a very classic heavy rain disaster caused by a landfalling typhoon.

3 MODEL CONFIGURATION AND EXPERIMENTAL DESIGN

This study utilizes the Penn State University - NCAR Mesoscale Model (MM5) version 3.6 to do a control simulation. The computational domains consist of a 45-km grid with a mesh size of 101×101 (D01), which is three-way nested (Dudhia et al.[18]) with a 15-km grid with a mesh size of 181×181 (D02) and a 5-km grid with a mesh size of 214×214 (D03). The domain center is at 25.0°N, 119.0°E. All grids have 30 levels in the vertical and the σ values on each level are 1.00, 0.99, 0.98, 0.97, 0.96, 0.95, 0.94, 0.93, 0.92, 0.91, 0.90, 0.85, 0.80, 0.75, 0.70, 0.65, 0.60, 0.55, 0.50, 0.45, 0.40, 0.35, 0.30, 0.25, 0.20, 0.15, 0.10, 0.05, and 0.00. The model physics include the Grell convective scheme for cumulus parameterization, the Graupel (reisner2) scheme for microphysics and the MRF scheme for Planetary Boundary Layer (PBL) parameterization (Grell et al.[19]). No cumulus parameterization is used in D03.

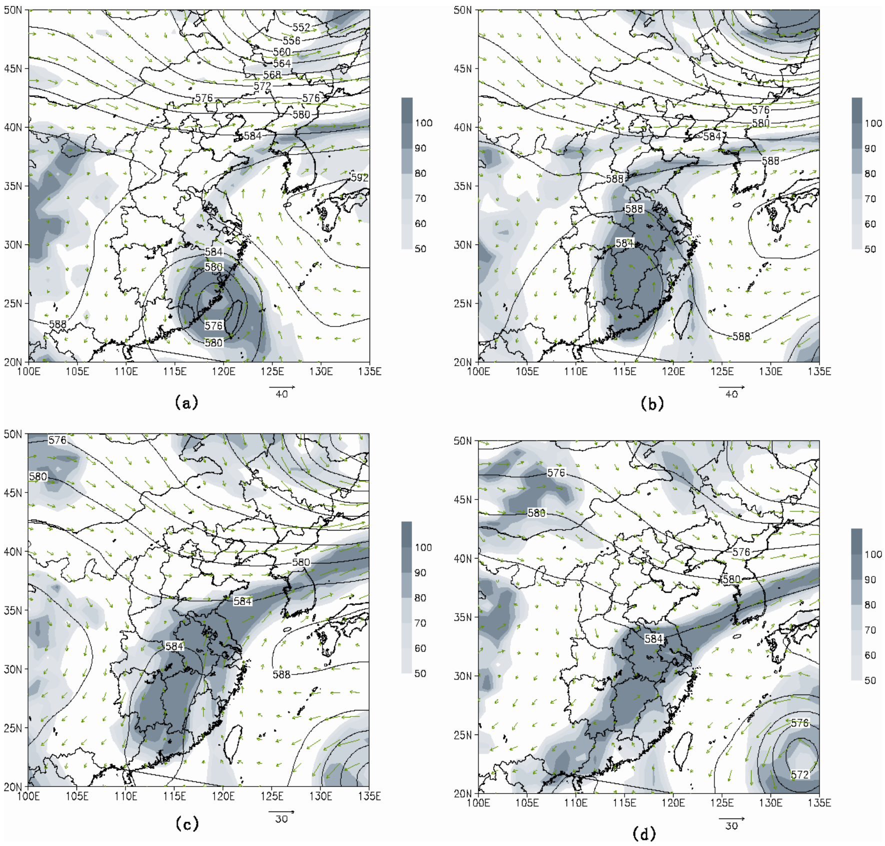

Fig.2 500-hPa geopotential height (contours), relative humidity (≧50%, shaded), and wind vectors from reanalysis data of NCEP. (a): 1400 September 1; (b): 0800 September 2, (c): 0200 September 3; (d): 2000 September 3.

Global Final (FNL) analyses of the National Centers for Environmental Prediction (NCEP) with 1° latitude x 1° longitude horizontal resolution are used as the model first guess field and boundary conditions. At the initial simulation time, a bogus scheme (Low-Nam and Davis [20]) is used to adjust the initial location, scale and intensity of the typhoon in the initial forecast field. The simulation is initialized at 2000 September 31, 2005, and integrated for 72 h. It is output every 1 h.

4 OVERVIEW OF THE CONTROL SIMULATION

The simulated track of typhoon Talim with the control reflects the landfall location well and it is quite close to the observation, except that there is a little northern deviation (figure omitted).

Seen from the conventional surface rain gauge data when it was around the time of Talim making landfall in Fujian, the 24-h total rainfall distribution from 0800 September 1 to 0800 September 2 was mainly located in the Fujian province and the southern Zhejiang area, with the most intensive precipitation area located to the right of the Talim track (Fig. 3a). The station of the largest daily rain was Fuding station with the daily rainfall of 236.8 mm, while the rainfall to the left of the typhoon track was much weaker.

The next rain period was from 0800 September 2 to 0800 September 3, when Talim had landed at Fujian for 18 hours (Fig. 3b). The main rain areas were moved further inland and were located in the area adjoining Jiangxi, Hubei and Anhui provinces. The two rain centers were very obviously near the terrains of Lushan and Dabieshan areas. Probably because of the topographic effects of Lushan and Dabieshan, the two maximum daily rain centers were Lushan station in Jiangxi and Huoshan station near Dabieshan of Anhui respectively, with daily rain amount of 494.6 mm and 254.8 mm. The rain maintained in the Lushan and Dabieshan areas for more than 42 h.

The control simulated rain patterns are quite similar to the observational ones (Fig. 3c, 3d). From

0800 September 1 to 0800 September 2, the most intensive simulated rainfall was also located in the adjoining areas of Fujian and Zhejiang provinces. From 0800 September 2 to 0800 September 3, the main rain areas were moved to the inland and were located near Lushan and Dabieshan areas. So the simulated rainfall in the control simulation is quite reasonable.

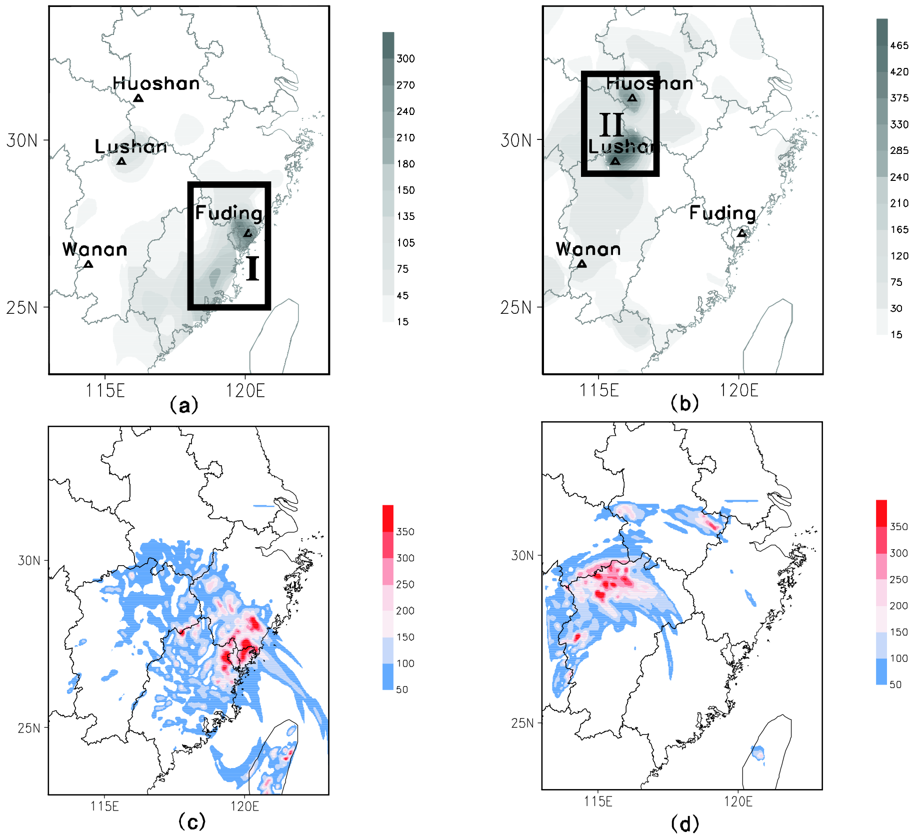

Fig.3 Total observed rainfall (a, b) and total control simulated rainfall (c, d) during Talim landfalling periods. (a) & (c): 24-h rainfall from 0800 September 1 to 0800 September 2; (b) & (d): 24-h rainfall from 0800 September 2 to 0800 September 3. Units: mm.

In short, from the above basic observational analyses based on the gauge rainfall data, the rain process is known to produce two maximum rain center areas of I and II (Fig. 3a, b). Moreover, the rain centers were just located near the terrains of Wuyi Mountain, and Lushan and Dabieshan areas. Whether those terrains had some impacts on the precipitation of the landfalling typhoon Talim is a question in this study to answer. If the terrains had effects on the precipitation, what was the physical mechanism? It will be studied here and the control simulation will be used to do further analysis in this paper.

5 NUMERICAL SENSITIVITY SIMULATION ANALYSES

To study terrain effects on the precipitation of the landfalling typhoon Talim, four sensitivity numerical simulations are performed based on the control simulation, that is, the terrain heights of Wuyi mountain (A shown in Fig. 4a), Lushan (B shown in Fig. 4b), Dabieshan (C shown in Fig. 4c), and both Lushan and Dabieshan (B and C shown in Fig. 4d) are set to be zero, while the same surface properties are retained as in the control simulation.

First, the simulated tracks of sensitivity simulations are not obviously different from those of the control simulation (figure omitted). That is, the terrains of Wuyi Mountain, Lushan and Dabieshan have no obvious effects on the tracks of the landfalling typhoon Talim.

For the precipitation, the intensive rain area of the domain I is much weakened and the rain area has arrived at Jiangxi province in the sensitivity simulation without the Wuyi Mountain (Fig. 5a), while the observed rain pattern is still mainly in Fujian and Zhejiang provinces. Thus without the Wuyi mountain, the typhoon precipitation spreads much more quickly but is a little weaker than in the control simulation. For the simulations without either Lushan or Dabieshan and both Lushan and Dabieshan, however, their rain patterns are very similar to those in the control simulation for the rain area I (Fig. 5b, 5c, 5d). Their most intensive rain areas are also in the joint area of

Fujian and Zhejiang, which is close to the observation (Fig. 3a). It could indicate that Lushan and Dabieshan have no direct effects on the precipitation in Area I when Talim just made landfall.

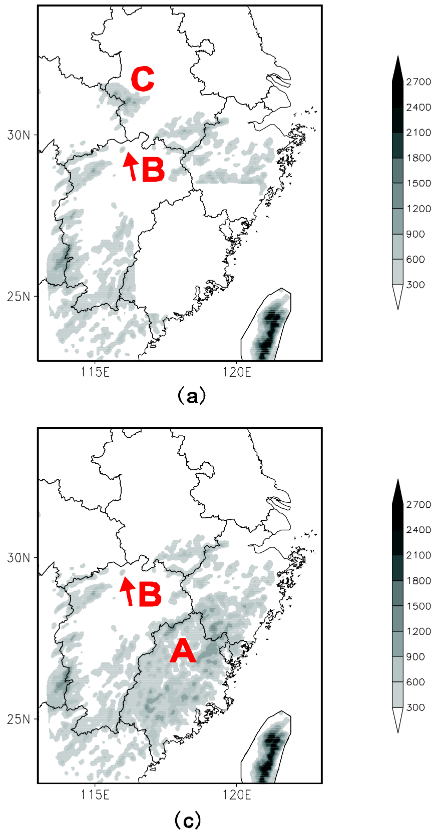

Fig.4 (a), (b), (c), and (d) are for terrain height (Unit: m) distribution for the four terrain sensitivity simulations on Wuyi, Lushan, and Dabieshan Mountains, and both Lushan and Dabieshan Mountains respectively.

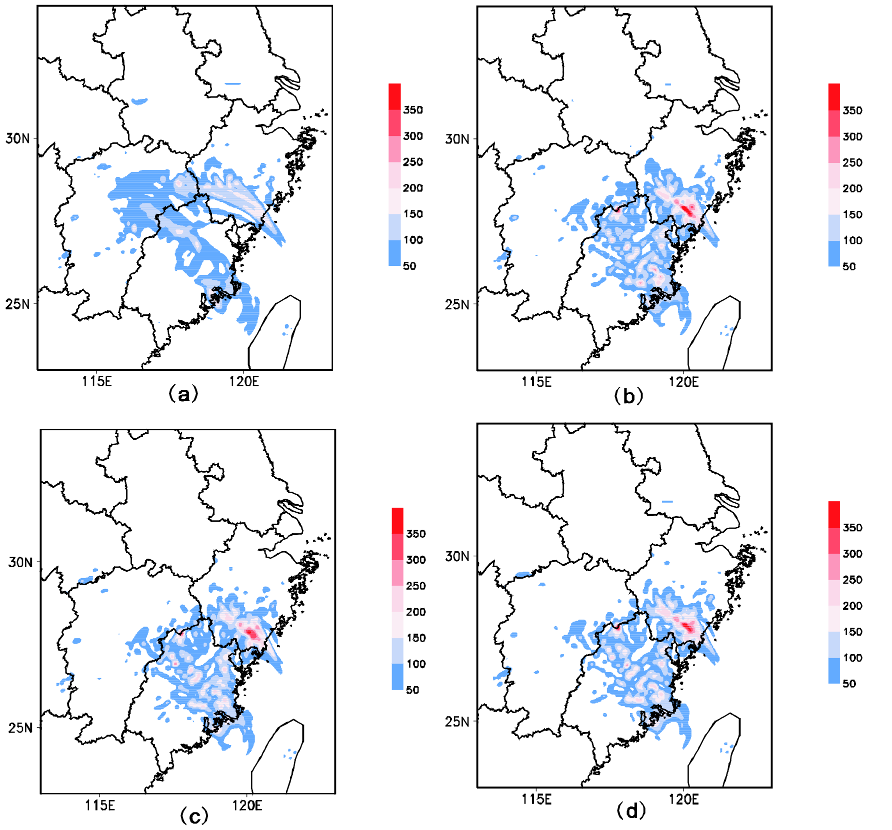

Fig.5 Simulated 24-h rainfall from 0800 September 1 to 0800 September 2. (a), (b), (c), and (d) are for the four terrain sensitivity simulations on Wuyi, Lushan, Dabieshan Mountains, and both Lushan and Dabieshan Mountains respectively. Units: mm.

When Talim continues moving inland, the main rain areas near terrains of Lushan and Dabieshan change in the sensitivity simulations (Fig. 6). Without the Wuyi Mountain, the main rain center is near Lushan and Dabieshan, but the most intensive rain was distributed more northward than that of the control simulation (Fig. 6a cf. Fig. 3b). For the simulation without Lushan, the rain area in the west of Lushan turns smaller than in the control simulation and the rain intensity decreases, while the rain area near the Dabieshan seems a little more westward from the control simulation (Fig. 6b). Without Dabieshan, the rain area disappears in Dabieshan area and moves to the west of Dabieshan area (Fig. 6c). Without both Lushan and Dabieshan, both the intensity and area of precipitation near Lushan and Dabieshan decrease and the rain area of Lushan and Dabieshan moves to the west respectively, which is similar to that of the simulations without Lushan and Dabieshan respectively (Fig. 6b, 6c, 6d).

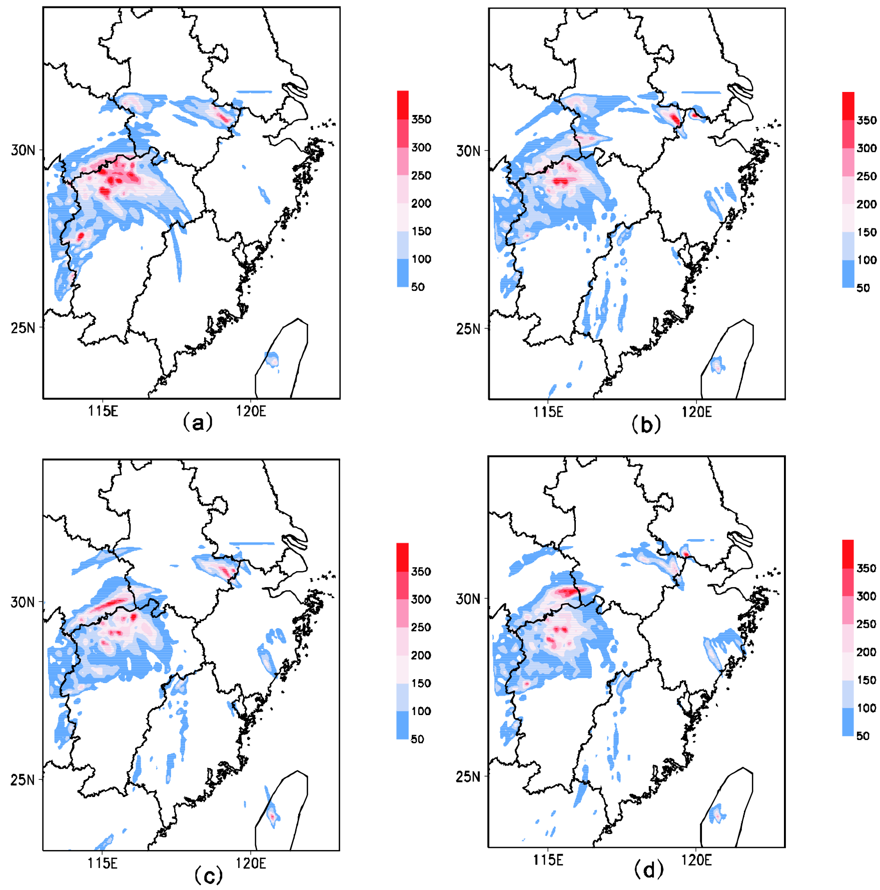

Fig.6 Simulated 24-h rainfall from 0800 September 2 to 0800 September 3. (a), (b), (c), and (d) are for the four terrain sensitivity simulations on Wuyi, Lushan, Dabieshan Mountains, and both Lushan and Dabieshan Mountains respectively. Units: mm.

To see more clearly the extent of terrain impact of Wuyi Mountain, Lushan and Dabieshan on the precipitation of Talim, Figure 7 presents the averaged hourly rainfall in Area I and II from the five numerical simulations (the control simulation and four sensitivity simulations) from 2100 September 31 to 2000 September 2. For rain area I, the maximum averaged rainfall is about 7 mm/h in the control simulation, but it is lowered to 5 mm/h with a decrease of about 30% by deleting the Wuyi Mountain effects in the sensitivity experiment (Fig. 7a). However, though Lushan and Dabieshan are still very far from rain area I, it seems it still has some small influences on the rain of Area I. For rain area II, the rain intensity seems to be halved by all terrains of Wuyi Mountain, Lushan and Dabieshan (Fig. 7b). Thus the terrain effects could be larger for rain area II than rain area I.

6 POSSIBLE TERRAIN EFFECTS ON PRECIPITATION

From the above synoptic diagnosis, it can be concluded that the terrains of Wuyi Mountain, Lushan and Dabieshan have obvious impacts on the Talim rainfall, and their impacts are different in various landfalling periods. But what is the main reason for their impacts on the precipitation.

Vorticity could reflect the horizontal circulation vortex intensity, but the vorticity differences between the five simulations in Area I of this study are not obvious (Fig. 8a). For divergence in Area I, its absolute value is weakened at both 925 hPa and 200 hPa without the Wuyi Mountain when compared with the control simulation (Fig. 8b, 8d), that is, there would be less convergent air in the lower levels and less divergent air in the upper levels. But for the simulations without either Lushan or Dabieshan, and without both Lushan and Dabieshan, though the divergence at 925 hPa is also decreased but it remains largely unchanged in the upper levels of 200 hPa. So though Lushan and Dabieshan are still very far from rain area I, they would still have relatively small influences on the precipitation. The Wuyi Mountain may intensify the rainfall of Area I by increasing the lower-level air convergence and upper-level divergence. Thus the vertical velocity would be greatly decreased when the Wuyi Mountain is removed from the sensitivity simulation (Fig. 8c).

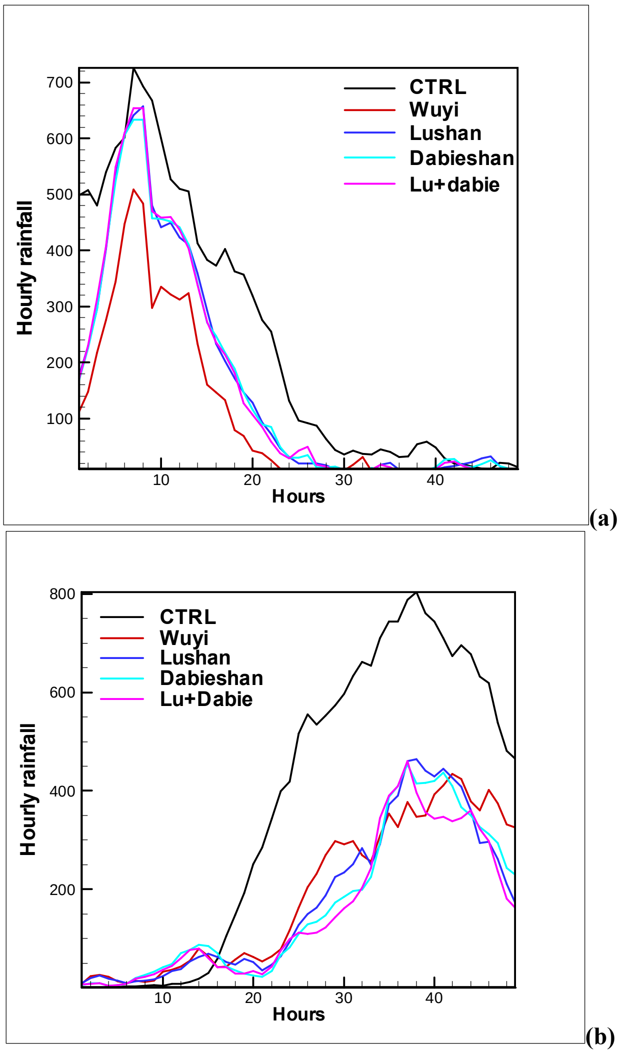

Fig.7 (a) and (b) are for averaged rainfall, respectively, in the main rain areas of I and II for the five numerical simulations from 2100 August 31 to 2000 September 2. Unit: 1×10^{-2} mm.

When the main rain area moves to the area II, the terrain effects on precipitation would be more closely linked with other factors like mid-latitude troughs (Fig. 2b, 2c). When Talim continued to move inland, its intensity was decreased and thus the relative vorticity in Area II is much less than that in Area I (Fig. 9a). The 925-hPa divergence in the four sensitivity simulations is very similar though it is about half as much when compared with the control simulation during the main rain period of Area II (from Hour 20 to Hour 40 in the simulation). On the other hand, the 200-hPa divergence in Area II during this period remains largely unchanged at all in these sensitivity simulations compared to that of the control simulation (Fig. 9d). Hence, during this main rain period in Area II, the terrains could cause the lower-level air convergence to increase, and it seems they have no major influence on the upper-level divergence. In fact, the mid-latitude tough is much closer to the cyclone of Talim at this time, and then the terrains of Lushan and Dabieshan are in the impact region of the tough (Fig. 2b, 2c). Therefore, rain area II would be under the co-impact of the terrains of Lushan and Dabieshan and the upper-level divergence. Since the upper-level divergence is not changed in the sensitivity simulations, the terrains may only affect the lower-level divergence, and thus the vertical velocity or convection would decrease to some extent (Fig. 9c). So without the terrains it may cause the local rain rate to decrease.

Besides, without the terrains of Lushan and Dabieshan, the rain areas near them are moved a little westward compared with the control simulation, which would be connected with the cyclonic winds of Talim (Fig. 10). In fact, the terrains of Lushan and Dabieshan would block the cyclonic winds and then the precipitation or slow down the speed of cyclonical, down-wind spread of rain. But without the local terrains blocking the winds of Talim, the rain band would spread cyclonically with higher speed, which would be one reason for the fact that the rain distribution areas without Lushan and Dabieshan are much more westward relative to those of the control simulation and then the terrain effects of Lushan and Daibeshan6 on rainfall seem to be greater than that in the coastal area I.

7 CONCLUSIONS

The MM5 mesoscale model has been used to investigate the effects of complex terrain on the precipitation of the landfalling typhoon Talim. The simulated precipitation of the typhoon (in the control) matches the observations closely. To compare with the control simulation, four sensitivity simulations are carried out in which the terrains of Wuyi Mountain, Lushan, Dabieshan, and both Lushan and Dabieshan, are completely removed while other surface properties are retained.

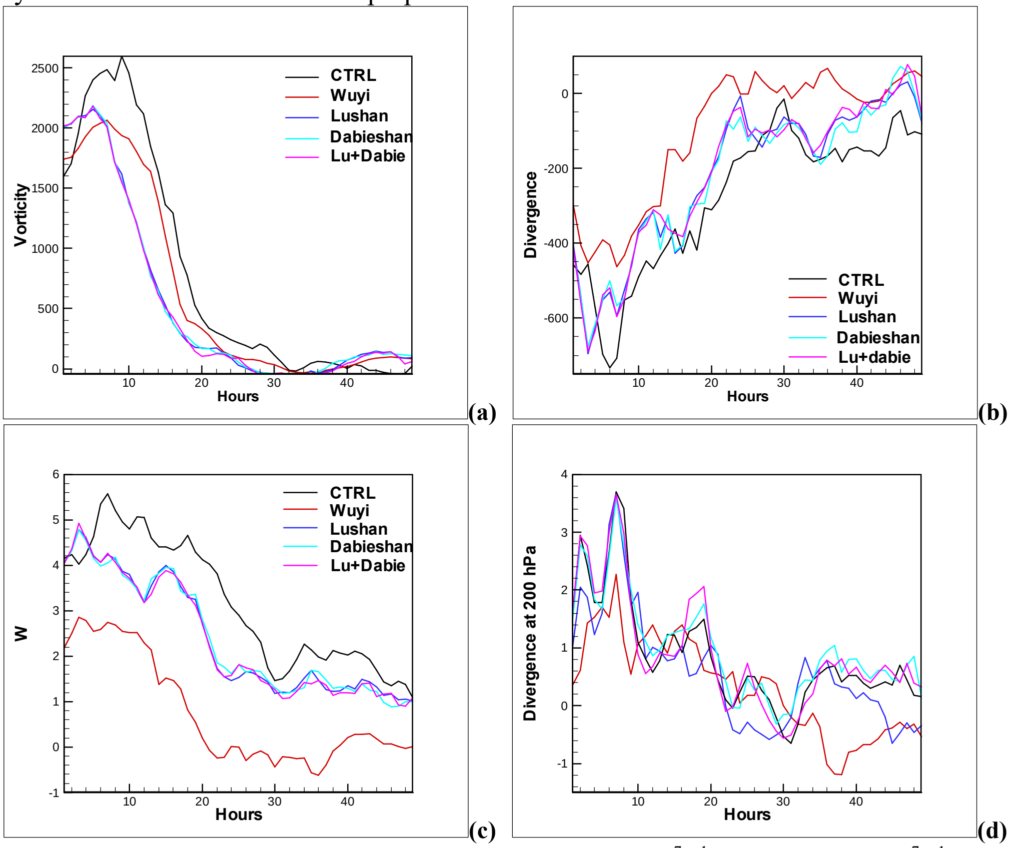

Fig.8 (a), (b), (c), and (d) are for 925-hPa averaged relative vorticity (1×10^{7} s^{-1}), divergence (1×10^{7} s^{-1}) and vertical velocity (1×10^{2} m s^{-1}), and 200-hPa divergence (1×10^{5} s^{-1}) respectively in the main rain area of I for the five numerical simulations from 2100 August 31 to 2000 September 2.

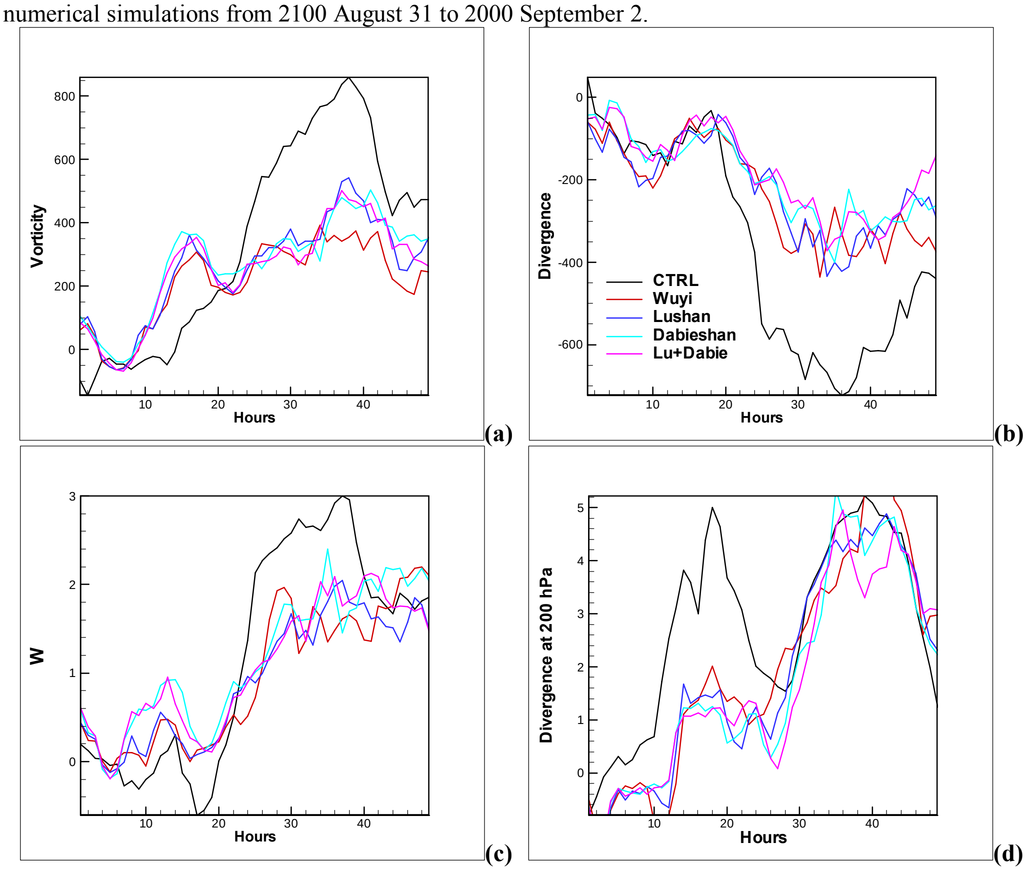

Fig.9 Same as Fig.8 but for the main rain area of II.

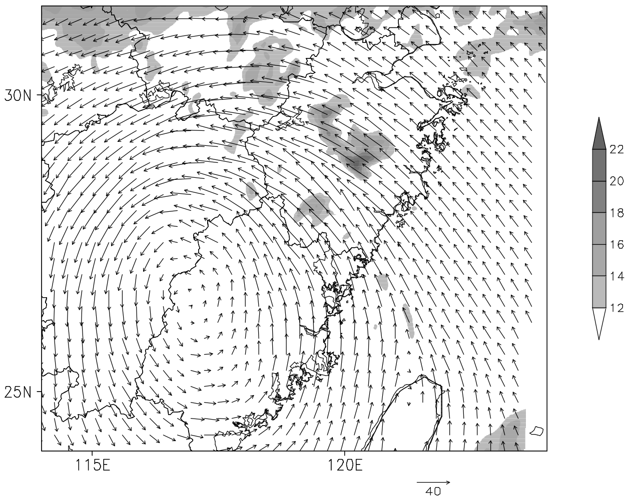

Fig.10 Wind vectors at 850 hPa and wind speed at 200 hPa at t = 30 h of simulation at 0200 September 2.

Previous studies on the orographic influence of TCs have focused mainly on the effects of mountain ranges on TC motion. Examples of mountain ranges that affect TC motion include the Central Mountain Range of the island of Taiwan and the Sierra Madre of Mexico (e.g., Chang[1]; Zehnder[14]; Zehnder and Reeder[21]; Lin et al.[8 - 10]). The problem of orographically enhanced mesoscale precipitation associated with landfalling TCs has been the focus of a number of studies (e.g., Wu[12]; Lin et al.[8]; Wu et al.[13]). Here, the focus is on the precipitation and on how complex terrains act to influence the precipitation intensity and location. This is an important issue because the damages from landfalling TCs are often connected with the heavy rain. The present study explores these complex terrain effects on the precipitation of landfalling typhoon Talim using a fine nest domain (D3) with grid spacing of 5 km.

It is found that the complex terrains of Wuyi Mountain, Lushan and Dabieshan have a significant impact on the rainfall intensity and distribution of Talim. In the control simulation, the orography is found to have a large impact on rainfall distribution during the landfall. As the terrains are removed, the rainfall is decreased very greatly and the rainfall in inland area (Area II) is decreased much more than that in the coastal area (Area I). Besides, the rainfall distribution near the Lushan and Dabieshan is spread much more westward compared with the control simulation.

Finally, an analysis of the vorticity, divergence and vertical velocity in Area I and II are made respectively. It is found that the Wuyi Mountain would increase the lower-level air convergence and the upper level air divergence for the just landfalling typhoon Talim, and then it may contribute to the convection and increase rainfall intensity. But when Talim has moved further inland, it is under the co-impact of the local terrains of Lushan and Dabieshan and the mid-latitude trough. During the main rain period of Area II, the terrains of Lushan and Dabieshan would increase the lower-level air convergence, but they have no obvious impact on the upper air divergence, which might be connected with the fact that there is a large trough in the north of the typhoon maintaining near the Lushan and Dabieshan areas. Therefore, even though the topographies of Lushan and Dabieshan are deleted, it only influences the lower-level air convergence and the upper-air divergence is maintained. So the rain intensity would be decreased to some extent. But under the cyclonic wind field effects, the rain band would spread cyclonically with higher speed, since there is no terrain blocking effects on the winds of Talim. That would be one reason for the fact that the rain distribution areas are much more westward relative to that of the control simulation and then the terrain effects of Lushan and Daibeshan on rainfall seem to be greater than those on the coast (Area I).

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