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THE ROLE OF OROGRAPHIC EFFECTS ON OCCURRENCE OF THE HEAVY RAINFALL EVENT OVER CENTRAL VIETNAM IN NOVEMBER 1999

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ABSTRACT: In this study, the WRF model is used to investigate the role of Central Vietnam terrain on occurrence of the heavy rainfall event in November 1999 over Central Vietnam. Two model experiments with and without terrain were performed to examine the orographic blocking effects during the event. In the terrain experiment, the results from a three-day simulation show that the model reasonably well captures northeast monsoon circulation, tropical cyclones and the occurrence of heavy rainfall in Central Vietnam. The topography causes a high pressure anomaly intensifying northeast monsoon. When the terrain is removed, the three-day accumulated rainfall decreases approximately 75% in comparison with that in the terrain experiment. The terrain blocking and lifting effects in strong wind and moisture laden conditions combined with convergence circulation over open ocean are the main factors for occurrence of the heavy rainfall event.

Keywords: Heavy rainfall, WRF, terrain effect.

INTRODUCTION

The Central Vietnam (CV) region stretches from north to south with a narrow width. The narrowest area is only about 50 km at Quang Binh province. The terrain is characterized by the Truong Son Mountain Range in the northwest and southeast directions, and a number of mountain ranges such as Hoanh Son, Bach Ma [1]. With such characteristics, the high mountainous terrain in the CV region prevents incoming airflows, especially the monsoon winds resulting in orographic effects. In the summer, under the influence of the Truong Son Mountain Range, the southwest monsoon moisture air flow is blocked on the western side. To the eastern side of the mountain range, the air is dry and hot. In the winter, the northeast monsoon dominates, the orographic effects cause heavy rainfall events in the region. The interaction among terrain, cold surge, and tropical cyclones is one of the main causes for occurrence of heavy rainfall in the CV region.

The heavy rains in November 1999 caused severe flooding in the CV region. Heavy rains mainly focused on November 2 and November 3. The rainfall maximum center was located in Thua Thien Hue. The total accumulated rainfall at the Hue station in these two days reached over 1800 mm which is higher than the climatic total rainfall in November and December. Although the previous studies [2-4] suggested that the moisture transport from low latitudes to high latitudes, the terrain effects of the Truong Son Mountain Range, and strong northeast wind and their interaction are the main causes for occurrence of the heavy rainfall event, the terrain effect has not been deeply investigated. In this study, the role of orographic effects on occurrence of the heavy rainfall event is further examined with numerical experiences using the Weather Research and Forecast (WRF) model. The model configuration and data are presented in Section 2. Section 3 presents simulation results and the role of terrain effects. Section 4 presents summary and discussion.

DATA AND MODEL CONFIGURATION

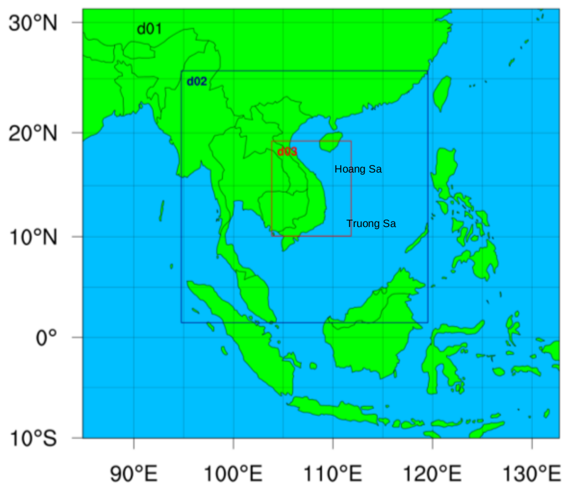

Fig. 1. The three nested domains employed in the model

The Weather Research and Forecast (WRF) model is used to simulate heavy rainfall event. The model runs with 3 nested domains with horizontal resolution of 45 km, 15 km, 5 km and 47 vertical levels. The number of grid points for the three domains is 121 × 107, 184 × 187, 181 × 217, respectively (fig. 1). Initial and boundary conditions are from the CFSR re-analysis data provided by the US National Center for Environmental Prediction (NCEP) with a resolution of 0.5 × 0.5 degree. Physical options include: WSM6 microphysic scheme, Grell 3D for convection scheme, RRTM scheme for long wave radiation, Dudhia for short wave scheme, MM5 surface model schemes, and Yonsei University scheme for boundary layer.

Other data used in this study for model verification and heavy rainfall mechanism analysis include: (1) TRMM 3B42 Precipitation Data from the Tropical Rainfall Measuring Mission with a resolution of 0.25° × 0.25° [5]; APHRODITE (Asian Precipitation - Highly - Resolved Observational Data Integration Towards Evaluation of Water Resources) with resolution of 0.25° × 0.25° [6]; the NASA's Quick Scatterometer satellite data [7]; SSMI (Special Sensor Microwave Imager) data [8], satellite cloud image [9]; and rainfall data at rain gauge stations in the CV region.

RESULT

WRF model simulation

The WRF model is used to do a three-day simulation from 00Z November 2 to 00Z November 5, 1999. The model initial time is 00Z November 1st, 1999. Simulation results show that the precipitation from 12Z November 2 to 12Z November 4 reached the highest value of over 600 mm. The observed maximum is about 1000 mm. Although the maximum value is underestimated, the local maximum rainfall region is agreed with observation with the heavy rainfall mainly in Hue, Da Nang, Quang Nam, Quang Ngai (fig. 2). Simulation of right location of heavy rainfall with reasonable rainfall amount allows using the model output for analysis of the role of terrain effects in this heavy rainfall event.

Fig. 3 (left) shows the simulated wind at 10 m level at 00Z November 2, 1999. There is a region of northeasterly wind speed of about 16 ms^{-1} over the Northern East Sea. The wind speed in the tropical depression in the Southern East Sea region is about 10 ms^{-1}. The simulated local wind speed maxima agree with the wind in the QuickScat satellite estimation (fig. 3, right). There is a region of low level convergence between the northeast monsoon and tropical cyclone at about 16N which can be a favorable condition for occurrence of the heavy rainfall event in the central region. The rainfall can increase as the intensified northeast monsoon flows interact with the Truong Son Mountain Range resulting in a strong orographic forcing.

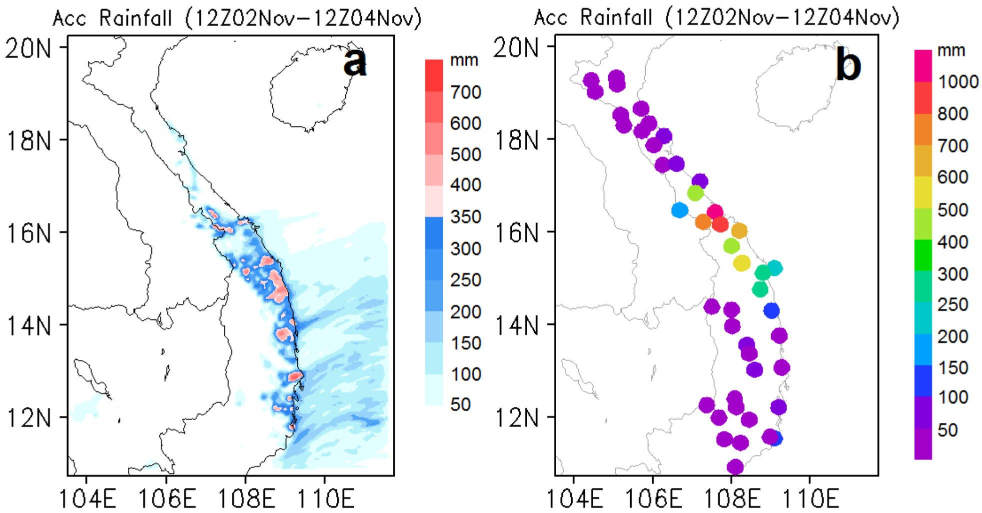

Fig. 2. Accumulated rainfall (mm) from 12Z 02/11 to 12Z, 04/11/1999 for a) simulation and b) rain gauge observation

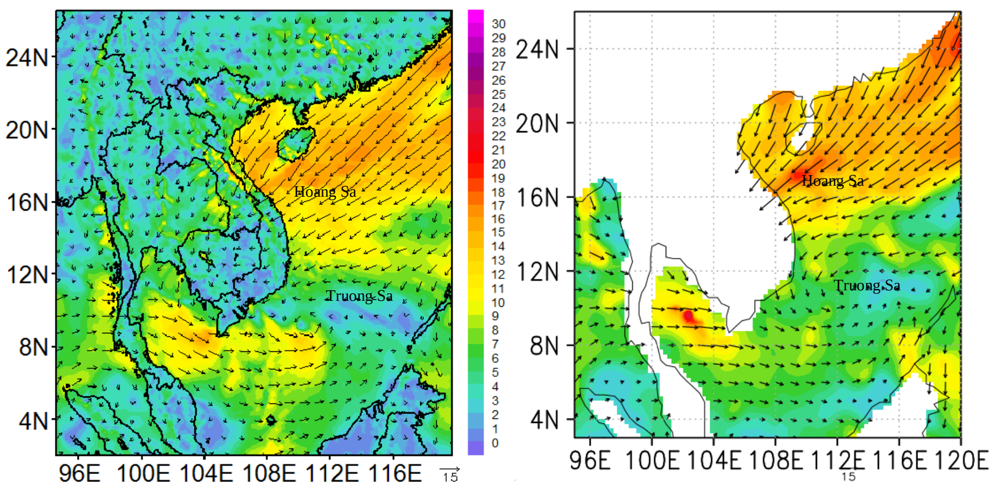

Fig. 3. Wind speed (shaded) and wind vector (ms^{-1}) at 10 m level for model simulation (left) and QuickScat (right) [7] estimation at 00Z 2/11/1999.

The role of terrain on the heavy rainfall event

To further investigate the role of terrain on this heavy rainfall event, a vertical cross section is conducted through 16.2°N at 18Z 2/11/1999. Those were the time and location of simulated and observed heavy rainfall occurrence. Fig. 4a shows at 18Z on November 2, strong low-level winds of about 25 ms^{-1} at the height of 500 to 1500 m in the eastern side of the Truong Son Mountain Range (fig. 4a). Due to the orographic lifting effect, the moist air mass is forced upwards inducing a strong vertical flow of about 3 ms^{-1} (fig. 4b) to enhance the heavy rainfall in Hue at the longitude of about 107.5°E.

Fig. 5 shows the sea level pressure anomalies at 18Z November 2, 1999 for the cases of with terrain (fig. 5a) and without terrain (fig. 5b) simulations. It can be seen on fig. 5a that with full terrain there is a low pressure anomaly associated with the tropical depression located to the south of the East Sea. There is a high pressure anomaly in the northern coast of Vietnam (about 16°N-22°N). The high pressure anomalies are formed due to the difference in density of the air at the same altitude. The anomalies induce anomaly winds to rotate clockwise in the Northern Hemisphere. Because the wind anomalies over Northern East Sea are almost parallel to the northeast monsoon winds in the region, they enhance the northeast monsoon. The enhanced monsoon flow increases orographic lifting and moisture flux toward mountain region which are favorable conditions for occurrence of the heavy rainfall event. When the terrain is removed (fig. 5b), high pressure anomaly in the northern coast of Vietnam (about 16°N-22°N) due to orographic blocking effect is almost disappeared that further confirms the role of terrain and its blocking effect on occurrence of the heavy rainfall event.

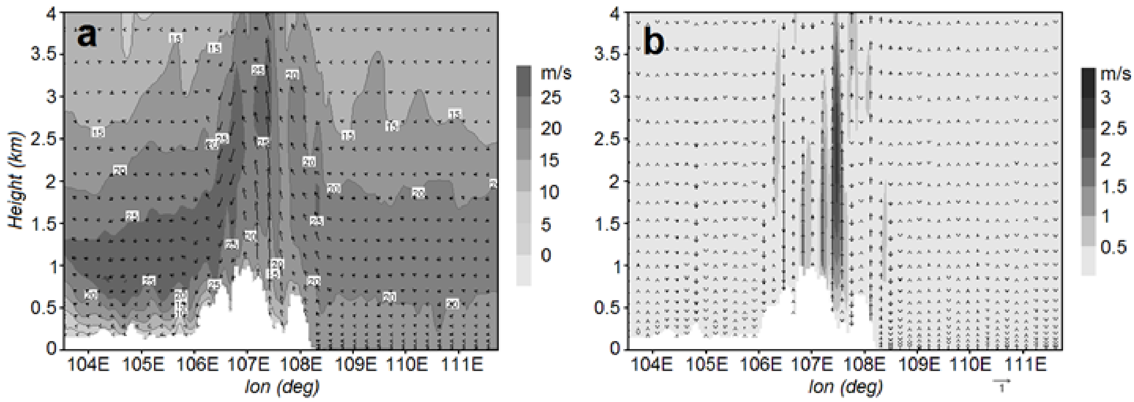

Fig. 4. The vertical cross section along 16.2°N at 18Z, November 2, 1999 for a) simulated wind speed (ms^{-1}) (contour and shaded), the interval is 5 (ms^{-1}) and the total wind vector (vector) in which vertical component is multiplied by 100; and (b)vertical wind speed and vertical wind vectors (ms^{-1}). The white color regions at the bottom of the figures represent mountain terrain

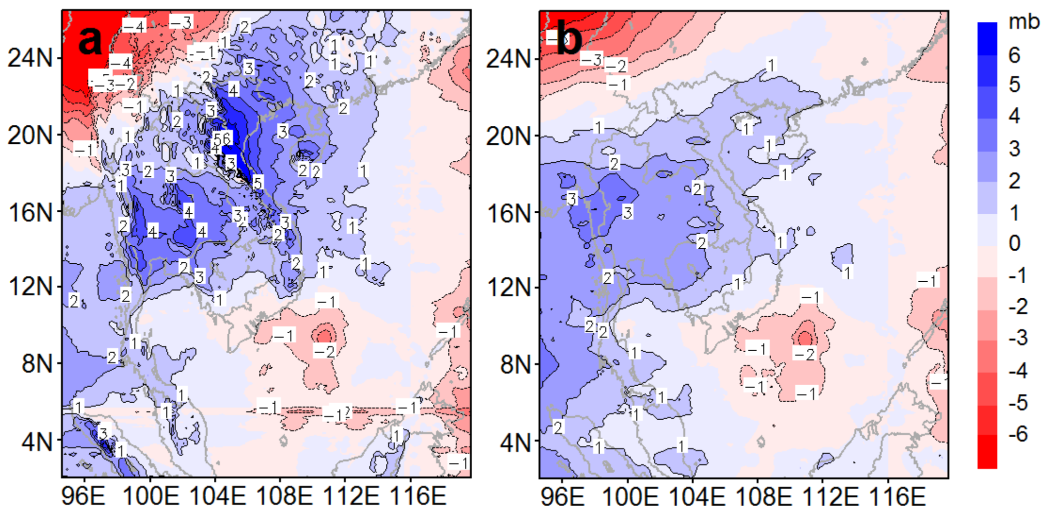

Fig. 5. Simulation of sea level pressure anomaly at 18Z 2/11/1999 for a) with and (b) without terrain

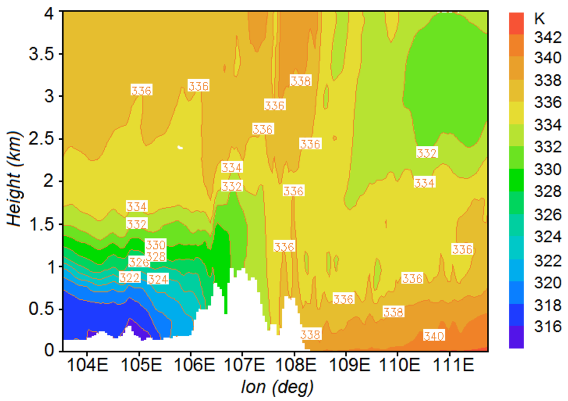

Fig. 6. Vertical cross section along 16.2°N at 18Z November 2, 1999 for equivalent potential temperature (K). The interval is 2K

Equivalent potential temperature of an air parcel is conserved during the saturated adiabatic processes, so that the equivalent potential temperature lines can imply the origin of an air parcel and where it goes. Fig. 6 shows that at 18Z on November 2, the 336 K equivalent potential temperature line strongly fluctuates. The line is at the height of about 800 m to 1000 m at longitudes of 109-111°E. It reaches the height of about 1900 m at longitude of 108°E indicating a strong upward movement of the air parcel due to orographic lifting. The strong orographic lifting disappears in the case of no terrain simulation (figures not show).

Fig. 7 shows simulated accumulated rainfall from 12Z 01/11/1999 to 12Z 2/11/1999 for with terrain, without terrain simulations, and rain gauge observation. The figure shows that observed maximum value is more than 700 mm (fig. 7c). With terrain simulation the maximum rainfall can reach over 600 mm (fig. 7a) which is about 90% of the observed values. When terrain is removed, accumulated rainfall only reach over 150 mm (fig. 7b) which is about 75% lower than in the with terrain simulation (fig. 7a) and 85% lower than in observation. The high pressure anomalies in the northern coastal region of Vietnam also disappear (fig. 5b). Thus, terrain of the mountain ranges in the CV region plays a very important role in the occurrence of the heavy rain event. The role of terrain in this case is similar to that in the heavy rainfall case caused by Typhoon Barb in Taiwan suggested by Wu et al., (2009). He showed that the simulated cumulative rainfall for terrain removal case reached only about a half of the rainfall in the topographic simulations [10]. One should also note that the terrain does not always plays a major role on heavy rainfall occurrence, for example, in case of heavy rains due to indirect impacts of Typhoon Songda in Japan, terrain only contributes about 10% and is a subsidiary mechanism in the case [11].

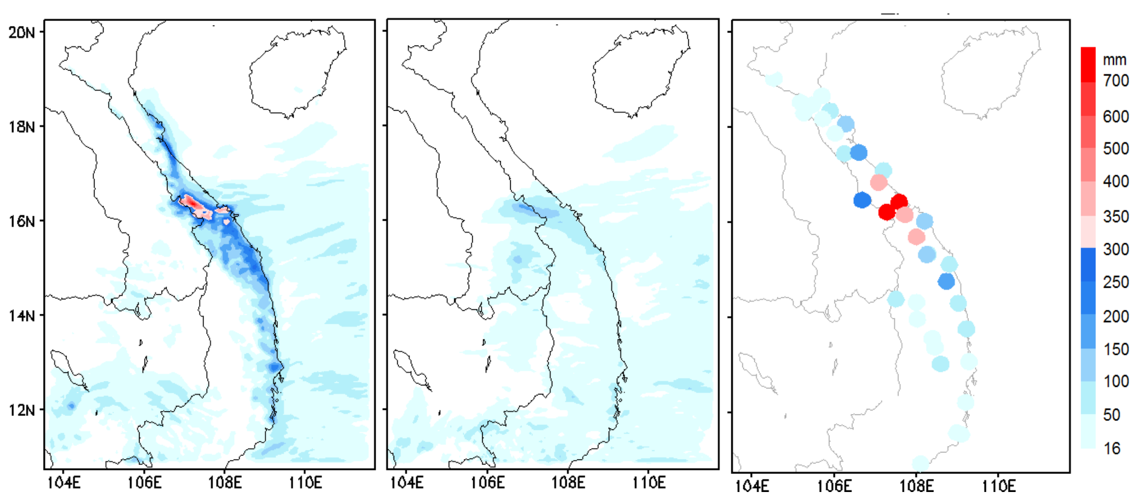

Fig. 7. Accumulated rainfall (mm) from 02Z 01/11/1999 to 12Z 02/11/1999 for a) with terrain simulation, b) without terrain simulation, and c) rain gauge observation

SUMMARY AND DISCUSSION

In the case of the heavy rainfall event in November 1999 over Central Vietnam, the heavy rainfalls are enhanced by the blocking and forcing effects of the terrain as the moisture-laden air currents associated with the interaction of strong northeast monsoon with the terrain. The blocking effect of the terrain in this case is characterized by the formation of a high pressure anomaly on the northern coast of the East Sea to increase the intensity of the coming northeast monsoon flow. The role of the terrain is further illustrated by the terrain removal experiment. The results of the terrain removal case show that the 3-day accumulated rainfall (00Z on November 2 - 00Z on November 5) decreases by about 75% compared to that in the case of with terrain.

From the suggestion of Matsumoto et al. (2008) [4], Dang and Nguyen (2015) [2] and results of this research, it can be concluded that the main mechanism for occurrence of the heavy rainfall event in November 1999 in the CV region includes: (1) the existence of strong cold surge waves, strong northeasterly winds associated with the cold surge helping to bring moisture laden air from the Northern East Sea to the mainland; (2) the existence of a persistent and slow-moving tropical depression in the Southern East Sea which brings moisture-laden air from low latitudes to the higher latitude CV region, moisture convergence between tropical depression and northeast winds enhancing deep convections over open ocean and inland regions; and (3) the orographic blocking and lifting effects due to interaction of the strong northeast monsoon winds with high terrain of the northern Vietnam and CV region. The results show that the high pressure anomalies are not located near the region of highest terrain of the Truong Son Mountain Range where the heavy rainfall occurred. That means the local terrain in this case may only be important for orographic forcing effect, not orographic blocking effect. In fact, the center of the high pressure anomalies is located over the coastal region of the Gulf of Tonkin. It can be implied that the terrain of the mountainous areas in the northern region of Vietnam creates orographic blocking effect to enhance the heavy rainfall over Central Vietnam in the strong northeasterly winter monsoon condition.

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