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Original Article

Numerical weather simulation of the depression 23W over the Gulf of Thailand by the MM5

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Abstract

A numerical weather simulation of the depression 23W moving over the Gulf of Thailand during October 19-26, 2003 expressed in terms of meteorological variables including pressure, humidity, geopotential height, wind velocity, divergence, vertical velocity, vorticity and rain was performed by the fifth generation of PSN/NCAR mesoscale model, MM5 version 3.7. Favorable conditions for the storm development and storm center during its passage were indicated from the model simulation. The favorable weather conditions of the storm evolution were found to be high relative humidity of 90-100% and less than 1003 mb mean sea-level pressure. The central pressure of the storm decreased at the rate of at least 6 mb/24 hrs with the lowest value of 987 mb and the corresponding lowest geopotential height of 1326 m on October 22, 2003.

Cyclonic flows were detected around the areas of negative horizontal divergence of -19.81 x 10^{-4} s^{-1} with gusts over 26 ms^{-1} and the positive vorticities of 128.4-234.1 x 10^{-4} s^{-1} along with moist air updrafts of 10-130 m/s. Continuous updrafts in an unstable atmosphere with adequate moisture supply enhanced the condensation process, and the cloud and rain formation, resulting in heavy rainfall in southern Thailand. Simulated rains are comparable with reported rains of 197-200 mm/24 hr at Prachuab Khiri Khan Province during October 24-25, 2003.

Keywords: MM5, numerical weather simulation, depression, the Gulf of Thailand.

1. Introduction

Numerical weather simulation has been performed in operation and research worldwide with increasing reliability thanks to high performance computer technology. Numerical solutions of the primitive equations based on the physical law of motion as well as on the conservation of mass, momentum, energy and moisture in the atmosphere, can be efficiently solved. Research work on numerical meteorological simulations has been extensively conducted on both global scale and mesoscale. A global scale simulation aims to investigate large scale climate changes while a mesoscale simulation concentrates on weather events that are strongly influenced by convection and topography in addition to large scale weather features.

Chen *et al.* (2002) had performed the Mesoscale Model, MM5, simulations to investigate and analyze the causes of heavy rainfall in Taiwan during the Mei-Yu season. Krihak *et al.* (2000) had used the MM5 to simulate storm track and heavy rainfall in the Southeastern Mediterranean in 1994 while Tuduri *et al*. (2003) and Homar *et al*. (2003) had also performed the MM5 simulations to analyze the hail formation in Northeastern Spain and tornado development in eastern Spain in 1999, respectively. Kreasuwan *et al*. (2004) employed the MM5 to analyze the topographic effect of the Thanon Thong Chai Mountain Range on rainfall patterns in northwestern Thailand. All research work mentioned agrees

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well with the weather features occurred and the observations. Ruktham *et al*. (2007) successfully performed Weather Research Forecasting (WRF) Model on the analysis of the atmospheric dynamics and tracking, associated with the tropical storm Vicente causing heavy rainfall and widespread flooding in Chiang Mai and nearby provinces in 2005.

Southern Thailand and Prachuab Khiri Khan Province were struck from time to time by cyclonic storms over the Gulf of Thailand such as the depression 23W in October 2003 and the depression Muifa in November 2004 with reported flash floods and extensive rainfall in the affected areas.

This research work focuses on the numerical weather simulations of the depression 23W moving over the Gulf of Thailand during October 20-23, 2003. The MM5 was employed in this study to analyze the weather features influenced by the depression 23W in Prachuap Khiri Khan Province and nearby areas.

2. Material and Methods

2.1 Mesoscale Model

The MM5 version 3.7 was employed in this study to simulate the insight behavior and relationship among weather features associated with the depression 23W developing in the South China Sea in October 2003.

Non-hydrostatic scheme and two-way nesting domains with horizontal resolutions of 60 km and 20 km were used for the MM5 numerical simulation. For two-way interaction, the nest's input from the coarse mesh comes via its boundaries, while the feedback to the coarse mesh occurs over the nest interior (Dudhia *et al*., 2005). Figure 1 depicts the two-way nesting domains with the coarse domain covers lat 3-33 ºN, lon 93-112 ºE and the nest domain lies in lat 7-15.5 ºN, lon 96-104 ºE.

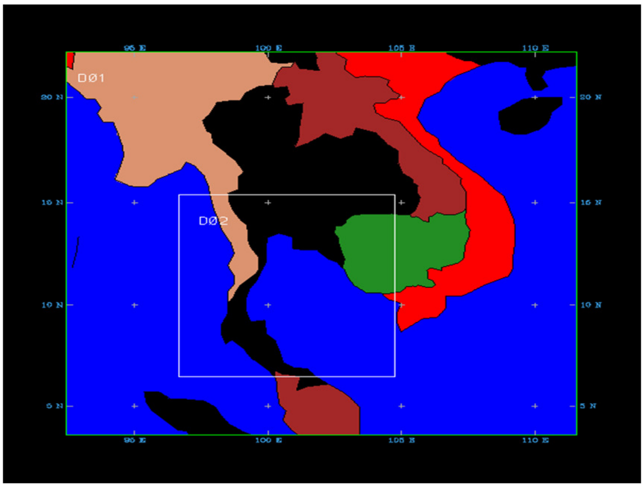


Figure 1. Two-way nesting domains at the resolutions of 60 km and 20 km.

Betts-Miller cumulus parameterization was conducted for both domains on the model simulation. The model integration was performed through the depression 23W passage during October, 20-23, 2003.

The MM5 Source Code is freely downloaded from following website www.ncar.edu.edu

Outputs from MM5 were analyzed and displayed by NCAR Graphics, Read/Interpolate/Plot version 4 (RIP4) which can be accessed at website www.mmm.ucar.edu/mm5/WRF_post/RIP4.htm

2.2 Data

National Center for Environmental Protection (NCEP) Final Analysis (FNL) meteorological data, provided by National Center for Atmospheric Research, NCAR, were used as initial and boundary conditions for the model simulation. NCEP FNL data consists of temperature, geopotential height, pressure, zonal wind, and humidity for every 6 hours at 0000Z, 0600Z, 1200Z, and 1800Z UTC for the sea level, 1000 mb, 925 mb, 850 mb, 700 mb, 500 mb, 400 mb, 300 mb, 250 mb, 200 mb, 150 mb, 100 mb, 50 mb, and 20 mb.

For the comparison with the MM5 outputs. GEOS-9 satellite images were obtained from Thailand Integrated Water Resource System at the website http://tiwrm.haii.or.th and precipitation data was provided from GARY PADGETT' MONTHLY GLOBAL TROPICAL CYCLONE SUMMARY OCTOBER, 2003 at website www.tropicalcyclone2005.com

3. Results and Discussions

The following output variables from the MM5 simulations associated with the depression 23W, namely air pressure, geopotential height, horizontal wind velocity, vorticity, relative humidity, vertical velocity, and rainfall were analyzed and displayed by the RIP4 program.

3.1 Mean sea level pressure and geopotential height

Low pressure is an important initial condition for possible weather disturbances which may intensify into a tropical cyclone when the favorable conditions prevail.

Mean sea level central pressure and its corresponding geopotential height of the depression 23W evolution during October 20-23, 2003 at 0000Z UTZ or 07:00 a.m. local time are shown in Figure 2.

The low pressure of 1002 mb with the corresponding geopotential height of 1,446 m were detected at lat 8.5 ºN, lon 100 ºE on October 20 as the early stage of the storm development. The low pressure system moved westwards with decreasing pressure of 996 mb and geopotential height of 1,388 m at lat 9 ºN and lon 102 ºE on October 21. Continuing its passage, the central pressure dropped to 987 mb with geopotential height of 1,326 m at lat 10.5 ºN and lon 102 ºE on October 22. The storm made landfall at Prachuap Khiri Khan Province with the central pressure of 995 mb and a

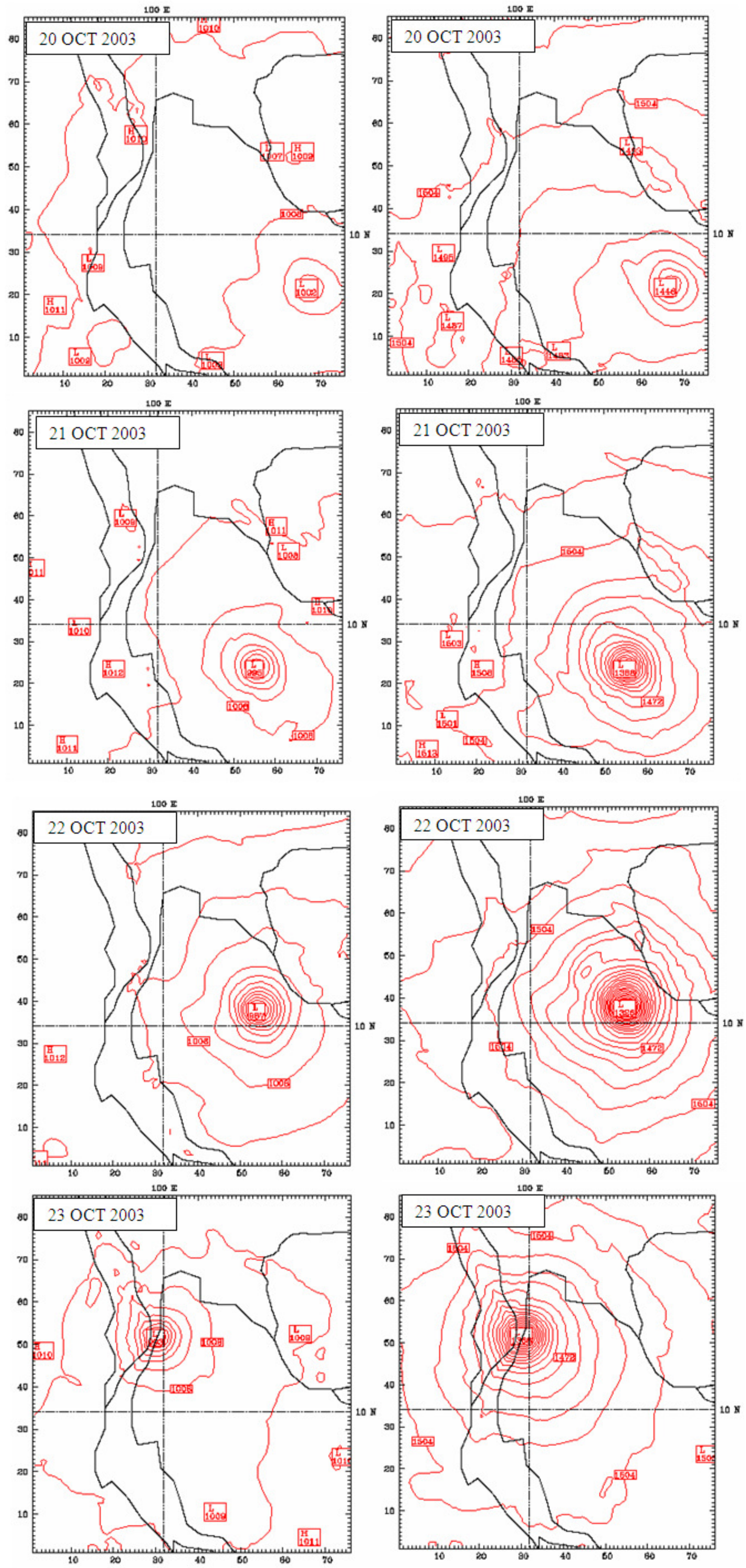
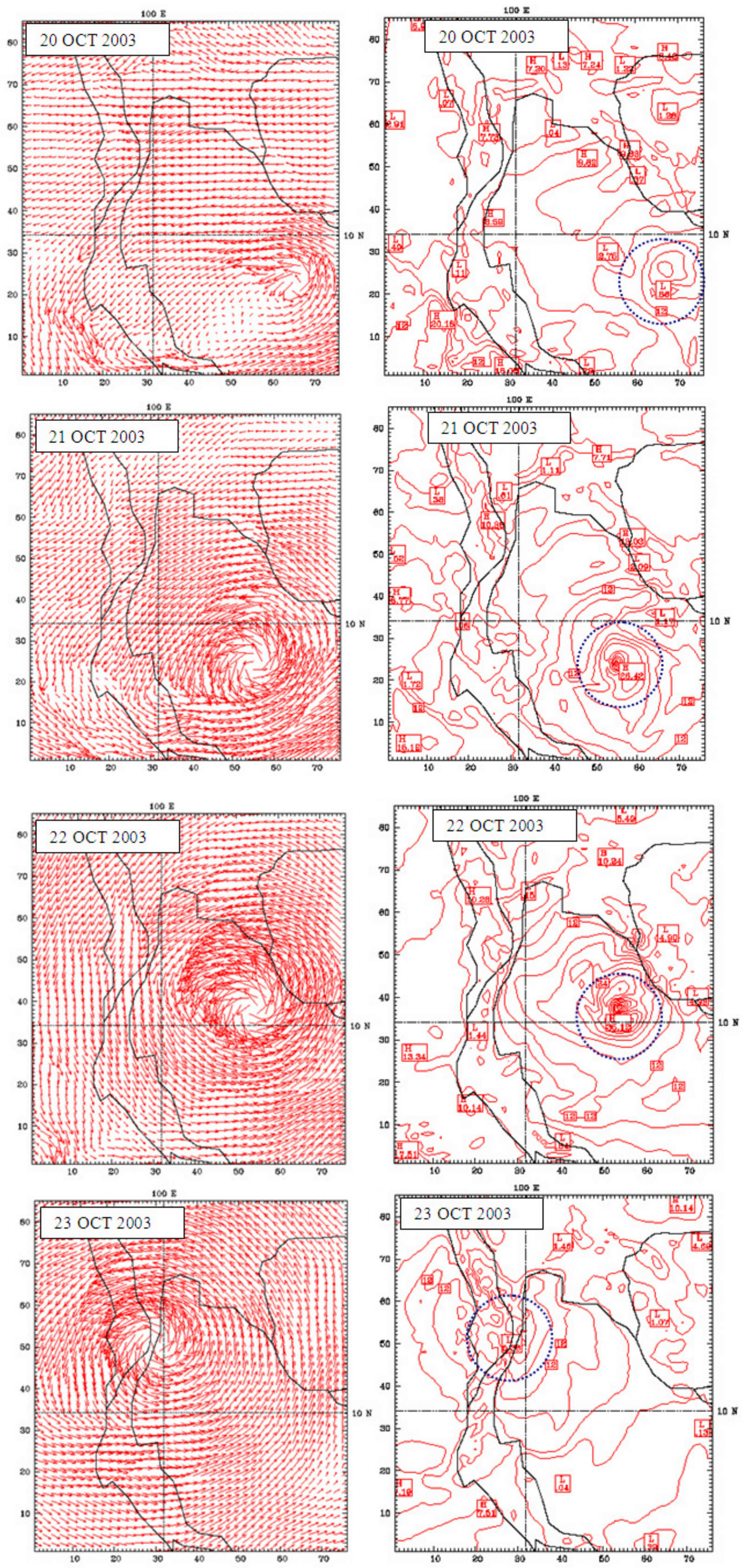


Figure 2. Central pressure (a) and geopotential height (b) during 20-23 October 2003.



a. Cyclonic flow. b. Horizontal wind speed.

Figure 3. The cyclonic flow (a) and wind speeds (b) of the depression during 20-23 October 2003

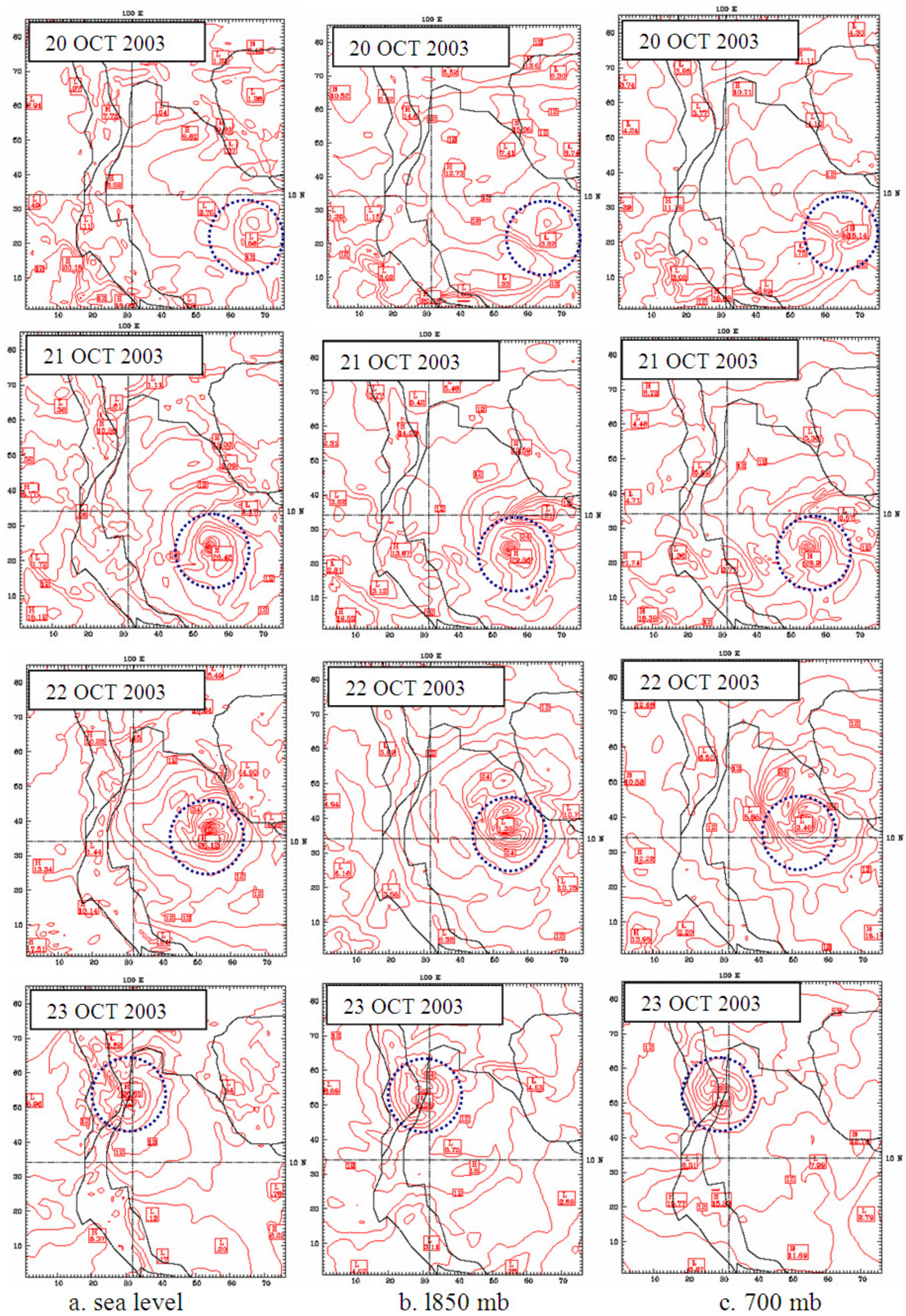


Figure 4. Cyclonic flows at sea level, 850 mb and 700 mb.

geopotential height of 1,384 m on October 23. Low pressure is in good accordance with geopotential height along the low pressure system.

3.2 Cyclonic flow and wind speed

Figure 3 displays the cyclonic flow and wind speeds

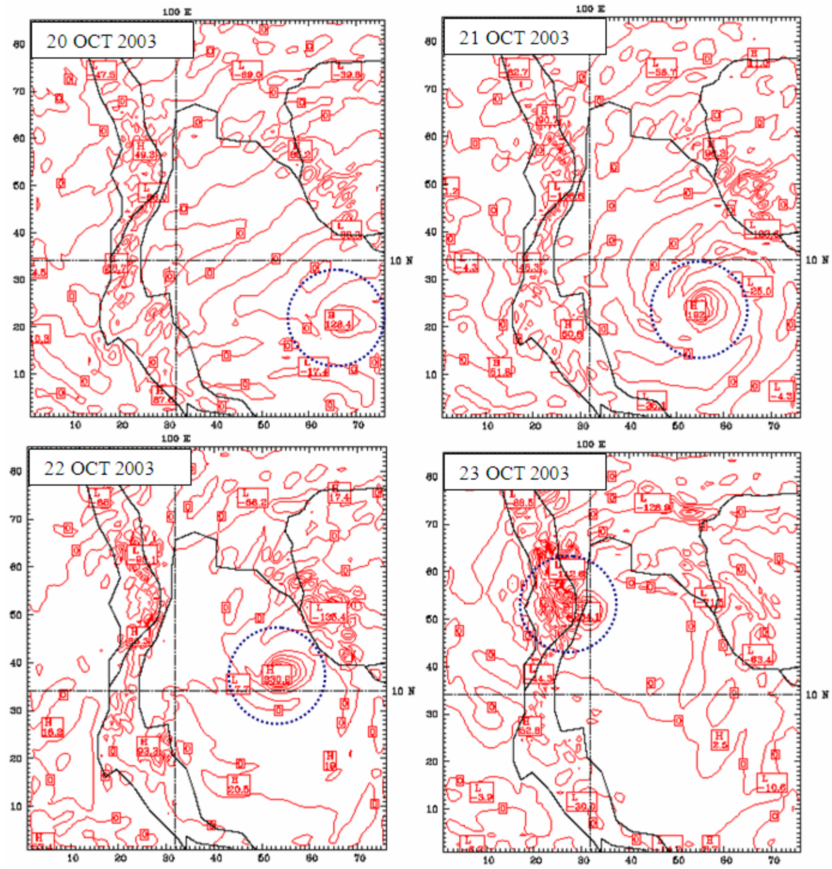


Figure 5. Simulated vorticities during October 20-23, 2003.

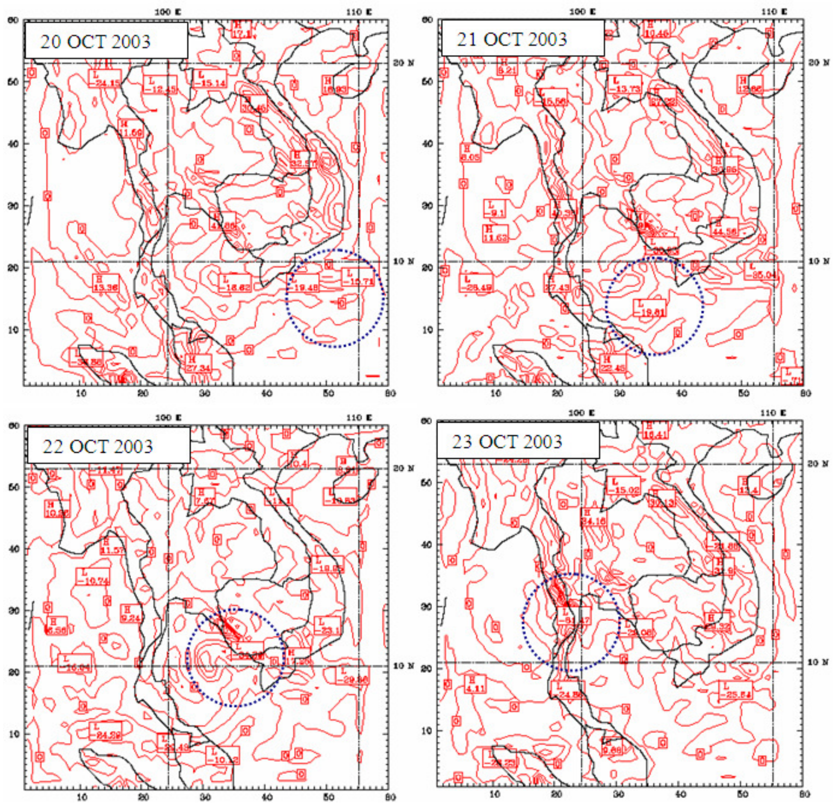


Figure 6. Horizontal divergence during October 20-23, 2003.

of the depression 23W during October 20-23, respectively.

Cyclonic flow of the low pressure system was clearly marked in the South China Sea at lat 8.5 °N, lon 103 °E on October 20, 2003, as shown in Figure 3. The cyclonic flow moved to the Gulf of Thailand with increasing speed of 26.4 m/s and 35.12 m/s on October 21 and October 22, respectively. The depression 23W moved over Prachuab Khiri Khan Province at the slower speed of 5.38 m/s on October 23 as presented in Figure 4.

3.3 Horizontal wind velocity at sea level, 850 mb and 700 mb

Cyclonic wind flows at 3 levels; sea level, 850 mb and 700 mb are displayed in Figure 4.

Deep strong cyclonic flows over the same location at the same time with maximum wind speeds of 26-25 m/s at sea level and 850 mb, respectively, during October 21-23, 2003 signify the active cyclonic storm and hence strongly affect the weather along its path.

3.4 Vorticity

Positive vorticity of air flow denotes cyclonic flow while negative vorticity supports anticyclonic flow. Simulated vorticities of the depression 23W were 128.4 x 10^{-4} s^{-1} on October 20, 192 x 10^{-4} s^{-1} on October 21, 230.2 x 10^{-4} s^{-1} on October 22 and 234.1 x 10^{-4} s^{-1} on October 23.

3.5 Horizontal divergence

Cyclonic flow around the low pressure area takes place when there is a surface convergence of air. Figure 6 shows the negative divergence or convergence over the low pressure system during the storm evolution.

Low level convergence of air is a favorable condition for the updrafts of moist air which eventually produces rain when there is enough moisture supply.

3.6 Relative humidity

Relative humidity over the Gulf of Thailand during October 20-23, 2003 was in the range of 90-100% as shown in Figure 7.

High humidity is an important environmental variable associated with cloud and rain formation. Besides, clouds are unlikely to form with dry air resulting in clear skies.

3.7 Vertical velocity

With cyclonic flow of moist air around the low pressure area, the updrafts with a likely chance of clouds and

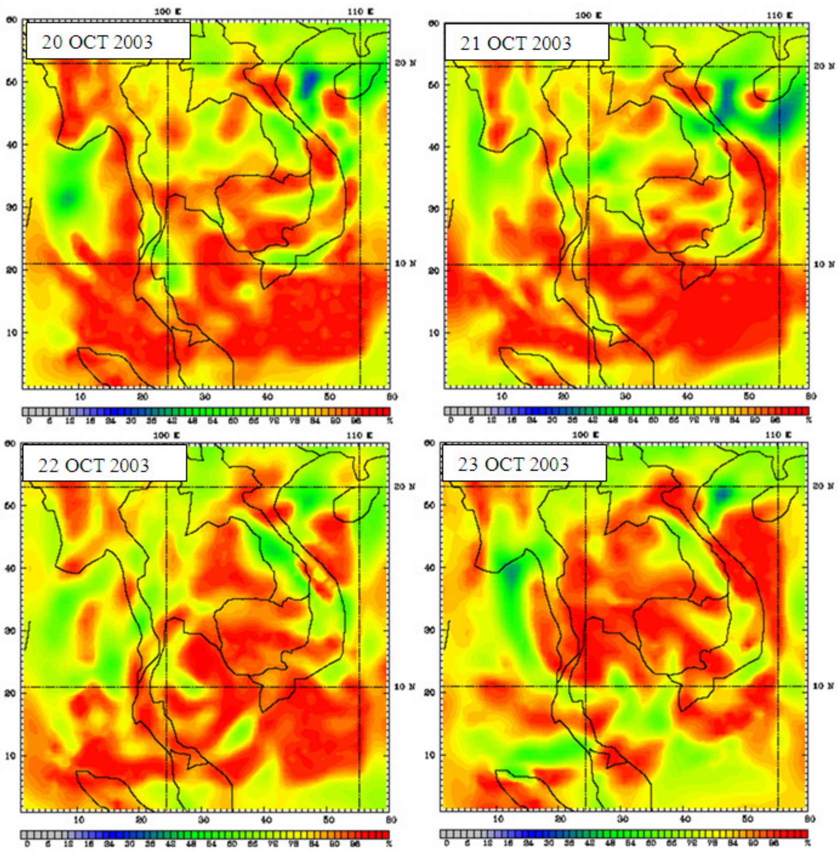


Figure 7. Relative humidity in the Gulf of Thailand during October 20-23, 2003.

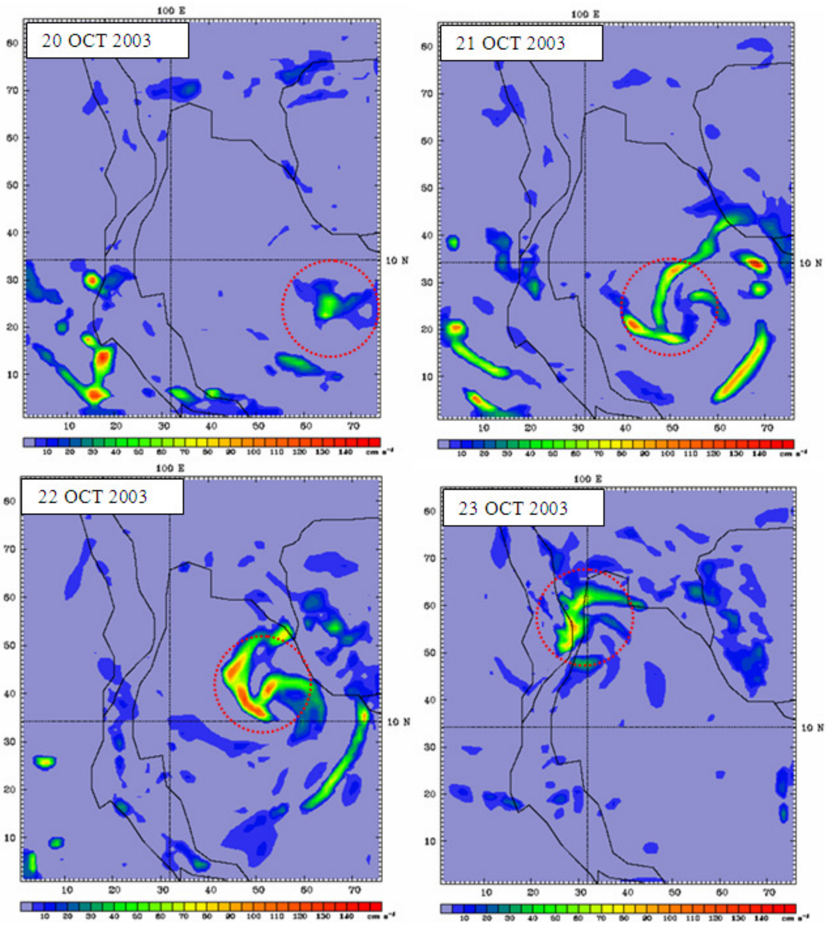


Figure 8. Simulated vertical velocities during October 20-23, 2003.

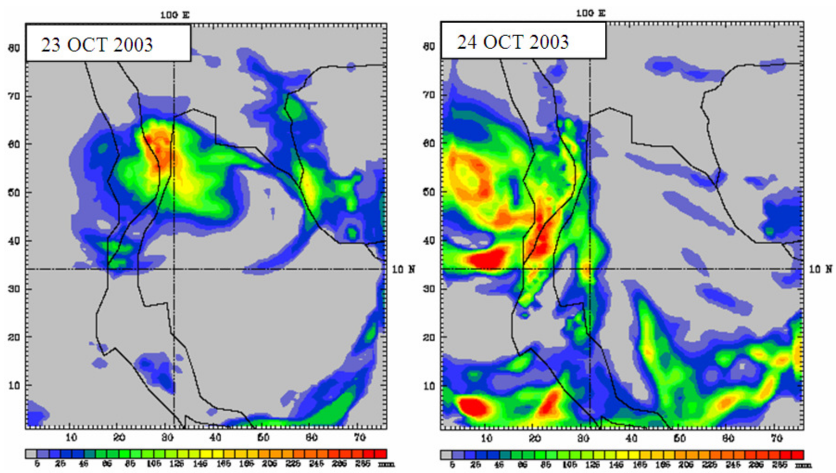
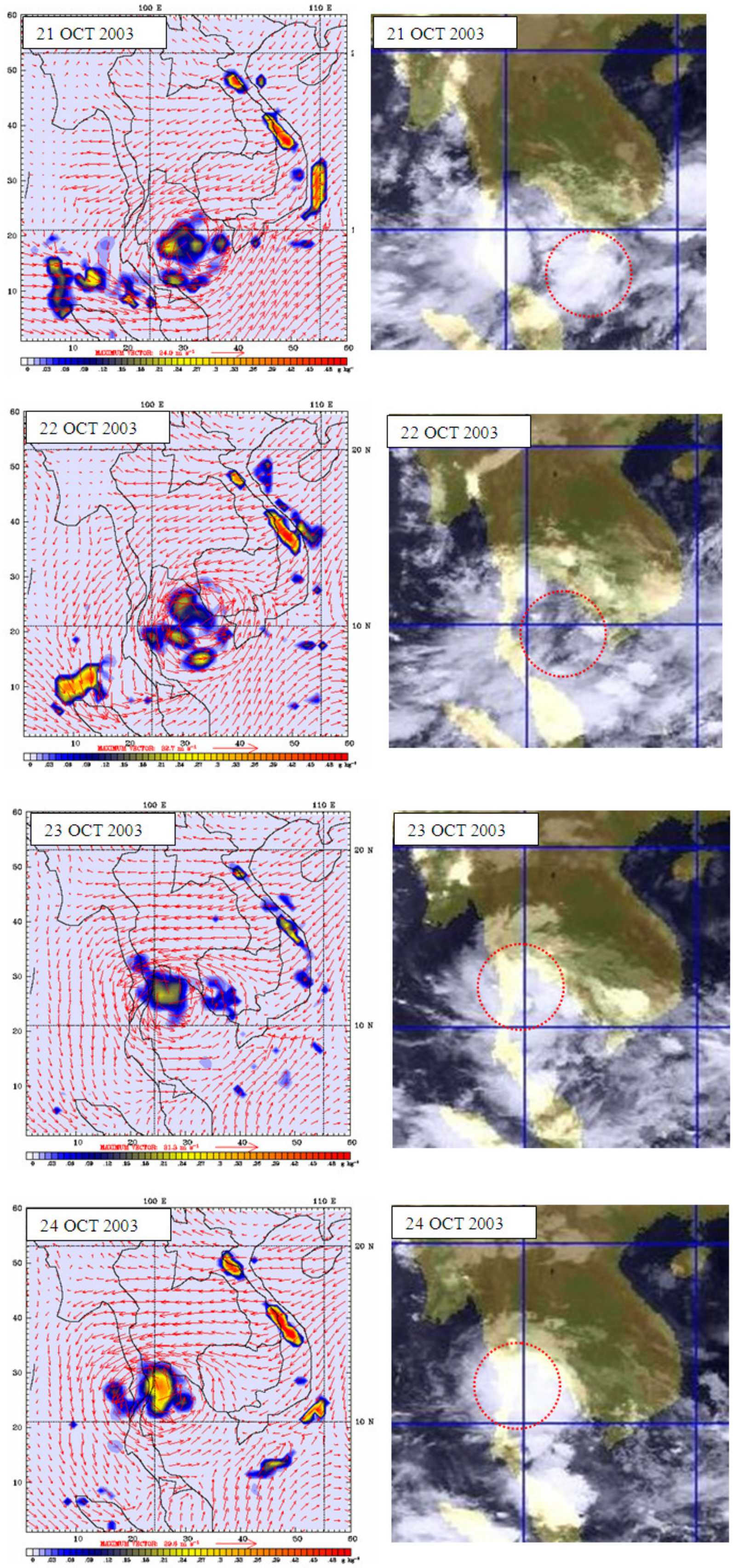


Figure 9. Simulated rain over the study area.

rain formation are expected. Positive updrafts indicating upward motion during the storm passage are displayed in Figure 8. Simulated vertical velocities were 10-60 cm/s on October 20, 10-130 cm/s on October 21, 10-110 cm/s on October 22, and 10-90 cm/s on October 23.

3.8 Rain

With all favorable weather conditions there is a strong possibility for heavy rain to pour down. The simulated 24-hrs rainfall over the affected area is shown in Figure 9.



a. Simulated cloud water

b. GEOS-9 satellite images

Figure 10. Simulated cloud water (a) and GEOS-9 satellite images (b) during October 21-24, 2003

Table 1. Simulated and reported rainfall in Prachuab Khiri Khan and Trang Province.

Province/Metropolis	Station	Period(Date/UTC)	OBS(mm)	MM5(mm)
Trang	Sikao	21/0000 - 22/0000	127.7	126.0
Prachuap Khiri Khan	Hua Hin	24/0000 - 25/0000	197.0	200.0
Prachuap Khiri Khan	Nong Plub (Agromet)*	23/1200 - 24/1200	145.0	145.0
Prachuap Khiri Khan	Nong Plub (Agromet)*	24/0000 - 25/0000	187.0	200.0

MM5 = simulated rainfall, MM5
OBS = simulated rainfall, Thai Meteorological Department
*Agromet = Agrometeorological Station

A comparison of simulated and reported rainfall is shown in Table 1. Simulated rainfall in the affected areas corresponds well with the reported one.

3.9 Comparison of simulated cloud water with GEOS-9 satellite images

Comparison of simulated cloud water with the GEOS-9 satellite images is shown in Figure10. Simulated cloud water is comparable with satellite images which confirmed the existence of the cyclonic storm over Prachuab Kiri Khan Province during October 20-24, 2003.

4. Conclusion

It was found from the analysis of the MM5 outputs and the RIP4 that the mean sea-level pressure of the depression 23W over the Gulf of Thailand was in the range of 1,003-987 mb with the lowest value of 987 mb and the corresponding lowest geopotential height of 1,326 m on October 22, 2003. Strong divergence of -19.81x 10^{-4} s^{-1} and vorticities of 128.4-234.2 x 10^{-4} s^{-1} supported the moist air updrafts of 10-130 cm/s over the storm centers along its passage. With favorable weather conditions for the cyclonic storm evolution, the 23W depression took place over the Gulf of Thailand resulting in heavy rain and flash floods in Prachuap Khiri Khan Province and nearby areas.

Simulated locations of the depression 23W were consistently confirmed by the satellite images while the likely amounts of simulated rains followed the same pattern of the reported values. Timing and intensity of rain are sometimes not well captured by numerical simulation which will be improved for more accuracy in the near future.

Acknowledgements

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