



Atmospheric Dynamics of the Tropical Storm Vicente

Chainarong Raktham, Jiemjai Kreasuwun, and Wonchai Promnopas*

Department of Physics, Faculty of Science, Chiang Mai University, Chiang Mai 50200 Thailand.

*Author for correspondence; e-mail :scphi016@chiangmai.ac.th

Received: 15 November 2006

Accepted: 26 December 2006.

ABSTRACT

This research work concerns the numerical simulation of associated atmospheric dynamic processes and tracking of the tropical storm Vicente during September 14-18, 2005 by employing the Weather Research Forecasting Model (WRF).

The model simulation successfully indicated that the storm Vicente developing in the South China Sea moved north-westward to Vietnam, Laos and Thailand and dissipated shortly after leaving Thailand. The cyclonic flow around low pressure area was precisely detected along the storm path according to the positive vorticity. The WRF outputs efficiently revealed the cyclonic flow around low pressure area, low level wind convergence, moist air updrafts, high relative humidity and rainfall during the storm evolution along the storm passage. With the lowest central pressure of 998 hPa but the strongest wind speed of 20 m.s^{-1} and the maximum vertical updraft of 0.25 m.s^{-1} , the storm Vicente actively intensified into the tropical storm on September 17, 2005 prior to making landfall.

The simulated storm track was consistently supported by the MTSAT-IR satellite images while the maximum simulated and reported rainfall amounts of $80\text{-}100 \text{ mm.day}^{-1}$ for Thailand on September 18, 2005 were comparable.

Keywords: numerical simulation, tropical storm, mesoscale model, cyclonic flow, dynamics.

1. INTRODUCTION

The rainy season in Thailand is in the regime of the southwest monsoon prevailing during May-October, which transports humid air from the Indian Ocean to Thailand and its neighboring countries resulting in widespread rainfalls in the region. Sometimes, tropical storms and other tropical disturbances play an important role on heavy rainfalls and flooding events in affected areas along the storm tracks devastating crop yields, infrastructure, lives and economy after all.

During the rainy season in the year 2005, there had been at least three worst floods in the last forty years in Chiang Mai, a city in northern Thailand due to the storms Washi, Vicente and Damrey with casualty and economy losses reported. The tropical storm Vicente, the second storm was detected at its early stage in the South China Sea on September 14, 2005 with maximum wind speed near its center between $5\text{-}14 \text{ m.s}^{-1}$. Later on, the cyclonic storm intensified rapidly as it

moved westward and turned into a tropical storm with the maximum wind speed near its center of 20 m.s^{-1} on September 17, 2005. The storm Vicente lost its strength as it moved over South East Asia where the moisture and energy supplies diminished and the tropical storm subsequently weakened into a depression when the cyclonic flow hit Vietnam on September 18, 2005.

The influence of the depression Vicente caused heavy rainfalls and widespread severe floods in Chiang Mai especially along the Mae Ping River, the city main river where the sewage and drainage systems could not effectively handle the intensive rainfalls. Schools, transportation, business and other daily activities in the city were seriously interrupted for several days while people in rural areas suffered intensively from shortages of necessary supplies and severe damages to their crop lands.

Atmospheric modeling has played an important role in the investigation and prediction of weather and climate systems worldwide with increasing reliability since advancement in computer technology. Qing-Hong Zhang *et al.* [9] simulated the track and circulation of the supertyphoon Winie occurring in the western North Pacific in 1997 by the Penn State NCAR mesoscale model (MM5) and found that the supertyphoon outer eyewall characterized by a ring of high vorticity is closely related to a ring of high wind convergence. Liguang Wu *et al.* [3] used MM5 to simulate the Hurricane Erin development from its early stage to a strong hurricane during September 7-10, 2001 and the MM5 outputs were in good agreement with the observed evolution of Erin. Chun-Chieh Wu *et al.* [6] performed the simulation of the track and mesoscale precipitation distributions associated with typhoon Herb which made landfall over Taiwan in 1996 by MM5. They were successful in simulating the rainfall amounts at Mount A-Li in the Central Mountain Range which could be compared with the observed values. In addition, the

closed relation between Taiwan's topography and the rainfall distribution was also revealed. Charles A. Lin *et al.* [5] employed the Canadian atmospheric Mesoscale Compressible Community Model (MC2) for precipitation simulation and the Chinese Xinanjing hydrological model for hydrograph simulation in the case study of severe precipitation and floods in the Huaihe River Basin, China with reasonable agreement of flood timing and peak discharges as compared with the rain-gauged precipitation.

This study was aimed to simulate the associated atmospheric dynamic processes and track of the storm Vicente employing the Weather Research Forecasting Model (WRF).

Investigation of associated atmospheric processes of tropical storms in the past helps make better understanding of the insight behavior and mechanism of storm development as well as dissipation, which are the essential information in accurately predicting storm formation in the future. Reliable weather forecasting is an important issue since it is closely related to the planning of human activities including contingency programs and utilization of water resources all over Thailand in dry season.

2. MATERIALS AND METHODS

The important mechanism on cloud development is the rising of moist air. Low-level convergence of moist air is normally found in low-pressure area, where the upward moving air or the updraft is expected. When the humid air is rising, its temperature decreases with its increasing relative humidity until the moist air reaches saturation at the condensation level where water vapors condense to form a cloud base. When the condensation process keeps going on under the favorable conditions, big clouds are expected with a likely chance of rainfall.

2.1 Weather Research Forecasting Model (WRF) and Atmosphere Input Data

Simulation of the tropical storm Vicente was employed by WRF, which is the three-dimensional, non-hydrostatic mesoscale model with terrain following vertical coordinate developed in the National Center for Atmospheric Research (NCAR), U.S.A. The model has taken into account the topography, land-surface processes, radiation, turbulent mixing, and cumulus convection as well as other atmospheric processes. Initial and boundary conditions are determined from the atmospheric input data.

The selected model domain lies from latitude 9°N to 22°N between longitude 96°E and 120°E covering the South China Sea and Thailand. The tracking simulation of the storm Vicente was run on the one-way nesting mode on Betts-Miller cumulus parameterization scheme with the resolution of 30 km. The WRF source code and detail can be downloaded with no charge at <http://www.ncar.ucar.edu>

Final Analysis Atmospheric Data (FNL data) from the National Center for Environmental Prediction (NCEP) were used as the atmospheric input data providing the initial

and boundary conditions.

2.2 Grid Analysis and Display System (GrADS)

WRF outputs were analyzed, interpreted and displayed by GrADS. The GrADS is freely downloaded at <http://www.iges.org/grads/grads.html>.

2.3 Satellite Images Outputs

The horizontal wind convergence from the WRF outputs were compared with MTSAT-1R satellite images provided by the Weather Home, Kochi University, Japan.

3. RESULTS AND DISCUSSION

The lifetime of the storm Vicente lasted about 6 days after the day of its initial stage detected at 16°N latitude and 118°E longitude on September 14, 2005.

3.1 Tracking

Tracking of the tropical storm Vicente employed by WRF is shown in Figure 1. The simulated track is consistent with the satellite images which are partly displayed in Figure 8.

Forecasting of the tropical storm Vicente track was also performed by WRF on September 17, 2005 for the time during September 17-20, 2005, the forecast storm

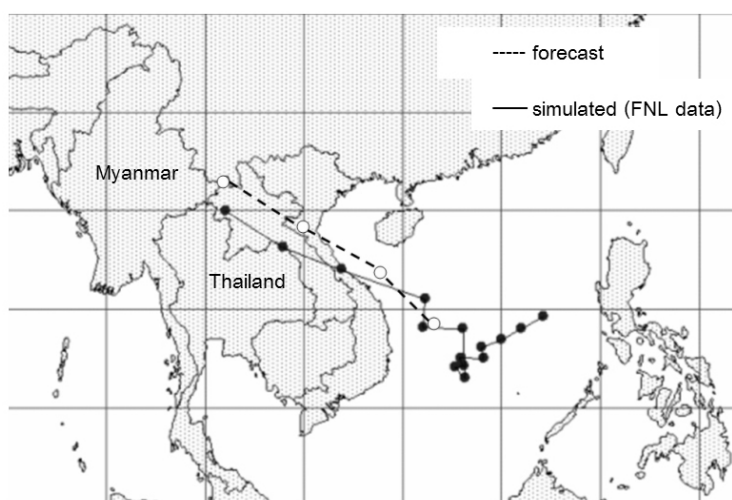


Figure 1. Simulated tropical storm Vicente tracks. Solid line and dashed line denote the real-time track and forecast track respectively.

track complied well with the simulated track using FNL data.

3.2 Mesoscale System

3.2.1 Mesoscale Low

The mesoscale low conditions were considered at 3 different developing stages; the early stage, the mature stage and the late stage.

Mean sea-level isobars illustrate the locations and changing pressure of the storm center at different stages of storm development as shown in Figure 2. The storm was indicated at 16°N latitude, 118°E longitude with the central pressure of 1008 hPa on September 14 and actively intensified into the tropical storm Vicente moving westward to

Vietnam with decreasing central pressure of 998 hPa at 14.5°N latitude 113°E longitude on September 17. The storm subsequently weakened into a depression as it hit Vietnam in Southeast Asia with increased central pressure of 1000 hPa at 18°N latitude, 106°E longitude on September 18. Wind convergence is supposed to take place near the storm center where the pressure is lower. The depression Vicente continued its path to northeastern and northern Thailand bringing intensive rainfalls in the region. Widespread floods had been experienced in northern Thailand especially the second severe flooding due to the depression Vicente in Chiang Mai and the worst flooding in nearby Lampang province.

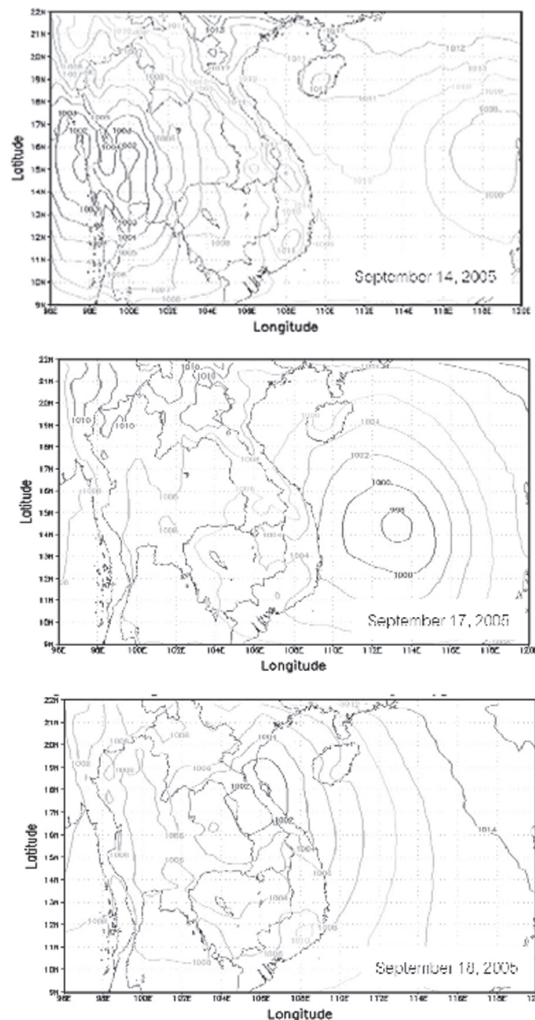


Figure 2. Simulated mean sea level pressure (hPa) during September 14-18, 2005.

3.2.2 Low-level Wind Convergence

Wind convergence is supposed to take place near the storm center where the pressure is lowest.

Cyclonic or anticlockwise flow around the center of a low pressure area at ten-meter

height as shown in Figure 3 strongly supported the existence of the active cyclonic storm with maximum wind speeds near its centers of 7-14 m.s⁻¹, 14-20 m.s⁻¹ and 11-17 m.s⁻¹ at the three different development stages respectively.

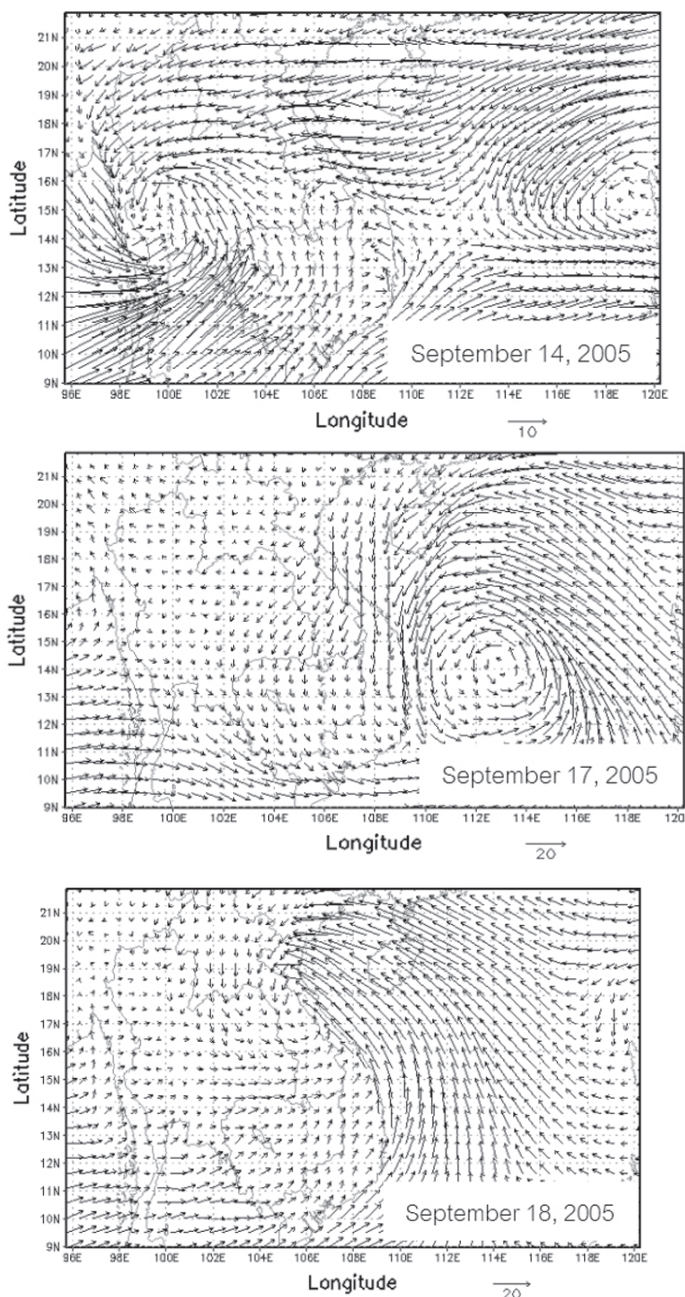


Figure 3. Simulated horizontal wind vector with FNL data at 10 meter height during September 14-18, 2005.

Low level convergence of moist air as indicated by horizontal divergences of $-2 \times 10^{-5} \text{ s}^{-1}$ on September 14, and $-6 \times 10^{-5} \text{ s}^{-1}$

on September 17 as shown in Figure 4 are the favorable conditions for rising air current over the low level convergence.

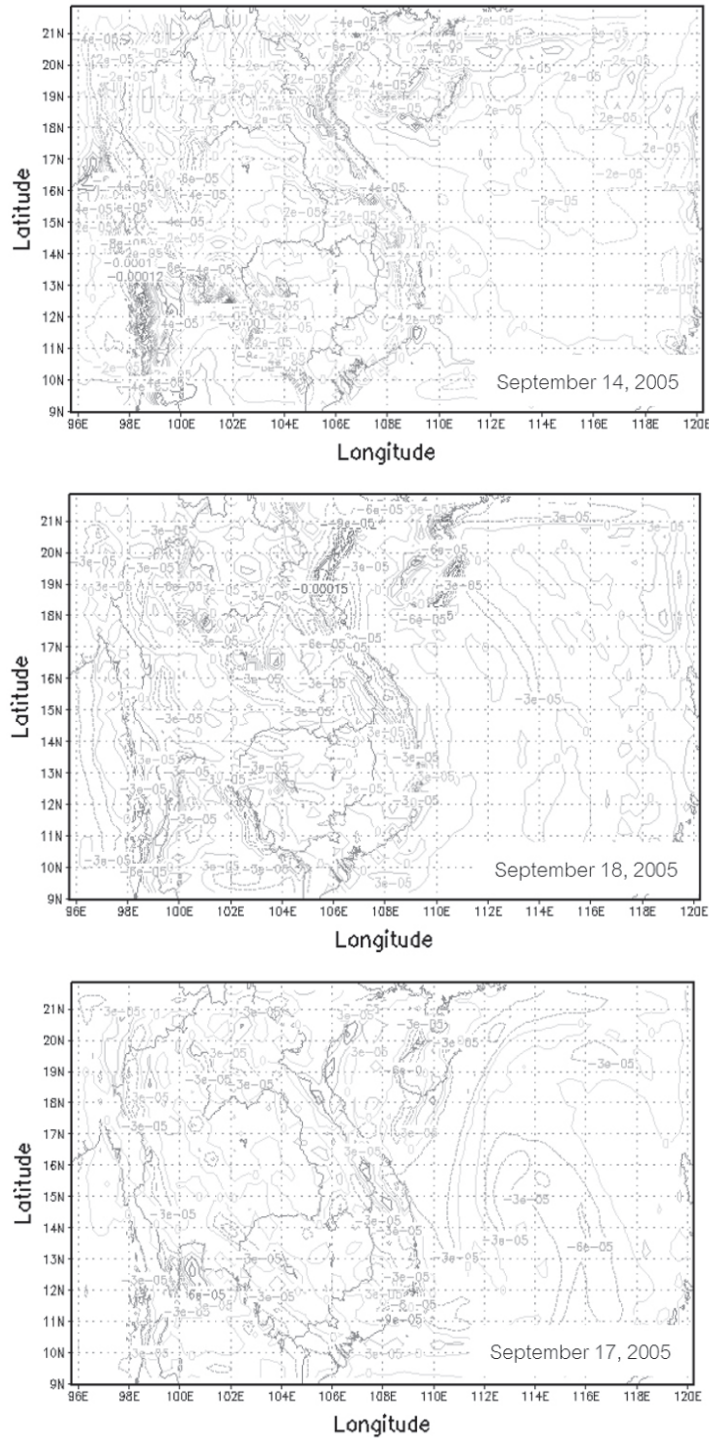


Figure 4. Simulated horizontal wind convergence at 10 meter height during September 14-18, 2005.

3.2.3 The Updrafts

The updraft of moist air over the low level convergence, enhances cloud development by condensation of water vapor.

On September 14, 2005, at the fixed latitude of 15.75°N between longitude 118°E and 119°E, there existed a strong updraft of 0.1 m.s⁻¹ at 600 hPa level and increased to

0.2 m.s⁻¹ at 400-200 hPa level as indicated in Figure 5(a). The surface updrafts of 0.05 m.s⁻¹ were found at the fixed latitude of 14.37°N between longitude 110°E to 116°E and reached the maximum values of 0.2 m.s⁻¹ at 300-200 hPa signifying a strong possibility of cloud development and intensive rainfall when there is enough moisture supply.

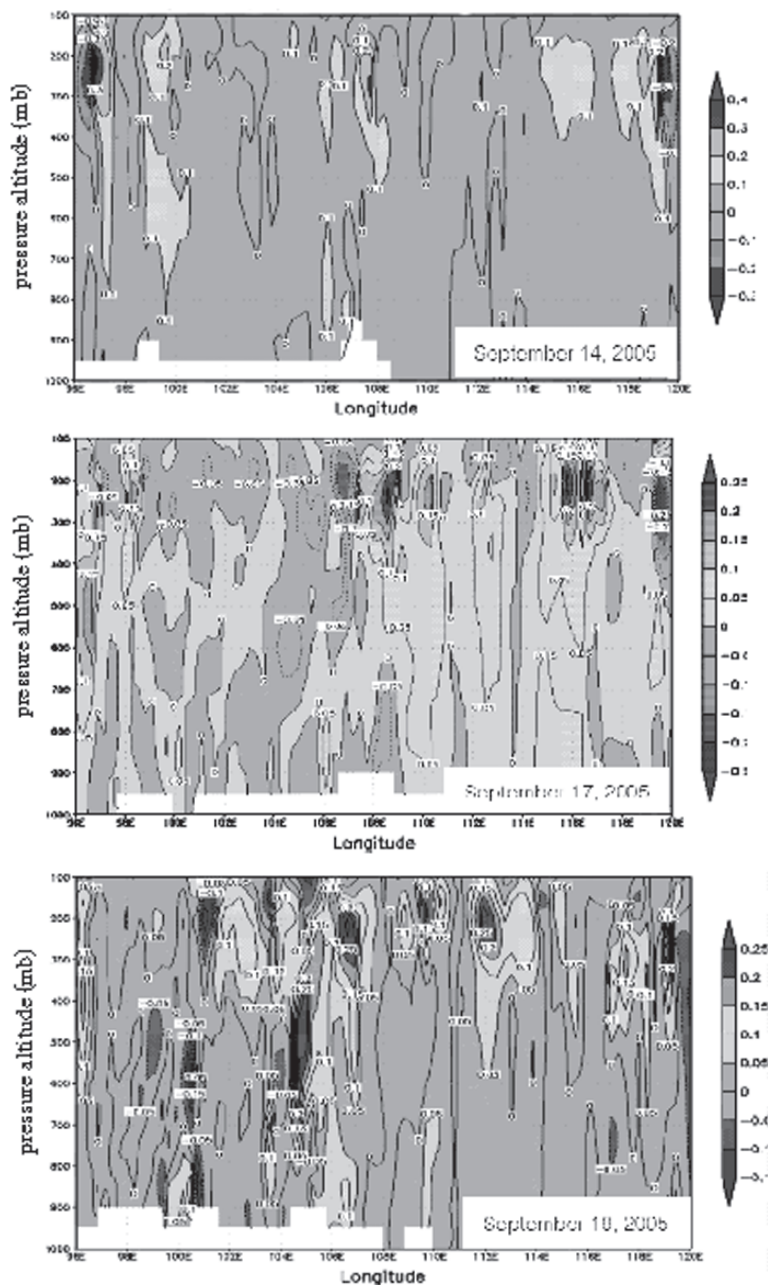


Figure 5. Simulated updrafts at the fixed latitude of 15.75°N during September 14 -18, 2005.

3.2.4 Relative Humidity

Water vapor plays an important factor on cloud development and precipitation process. Condensation in the atmosphere may take place where the relative humidity is higher

than about 80% with the availability of hygroscopic condensation nuclei. Figure 6 shows the high relative humidity in the order of 90-100% over the passage of the storm Vicente during September 14-18, 2005.

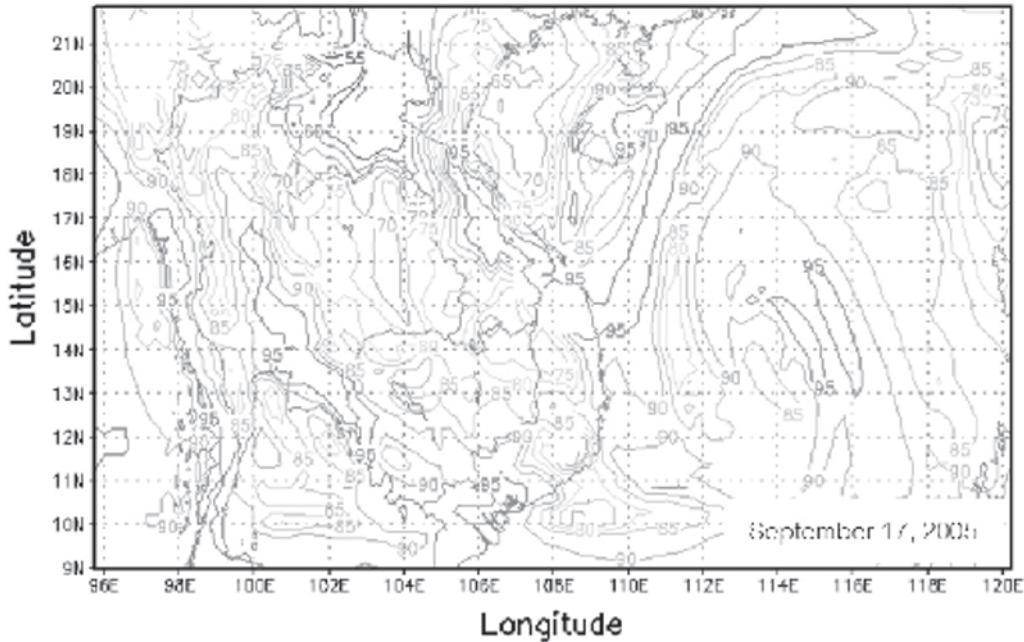


Figure 6. Simulated relative humidity on September 17, 2005.

3.2.5 Vorticity

Positive vorticity indicates anti-clockwise or cyclonic flow in the northern hemisphere. Vorticity of the storm Vicente are illustrated in Figure 7. The vorticity of the storm Vicente was found to be $5 \times 10^{-5} \text{ s}^{-1}$ at 12.00 UTC on September 14, 2005. The storm vorticity increased as the storm intensified and storm center extended wider with the vorticity of $0.5 \times 10^{-4} - 1.5 \times 10^{-4} \text{ s}^{-1}$ at 6.00 UTC on September 17, 2005 when it intensified into a tropical storm in the South China Sea. The storm gained the maximum vorticity of $2.5 \times 10^{-4} \text{ s}^{-1}$ in the South China Sea near Vietnam and significantly decreased when the storm moved over Vietnam on September 18, 2005. All the mentioned atmospheric processes activity enhance the cloud

development and eventually heavy rains.

3.3 Comparison Between Simulation Output and Observed Data

3.3.1 WRF Simulation Output and MTSAT-1R Satellite Images

The center of the storm Vicente is located in the low pressure area with low-level wind convergence where the strong updraft is expected. Low level wind convergences simulated from WRF correspond well with the MTSAT-1R satellite images for the beginning stage on September 14, 2005 and the mature stage on September 17, 2005 of the tropical storm Vicente as shown in Figure 8.

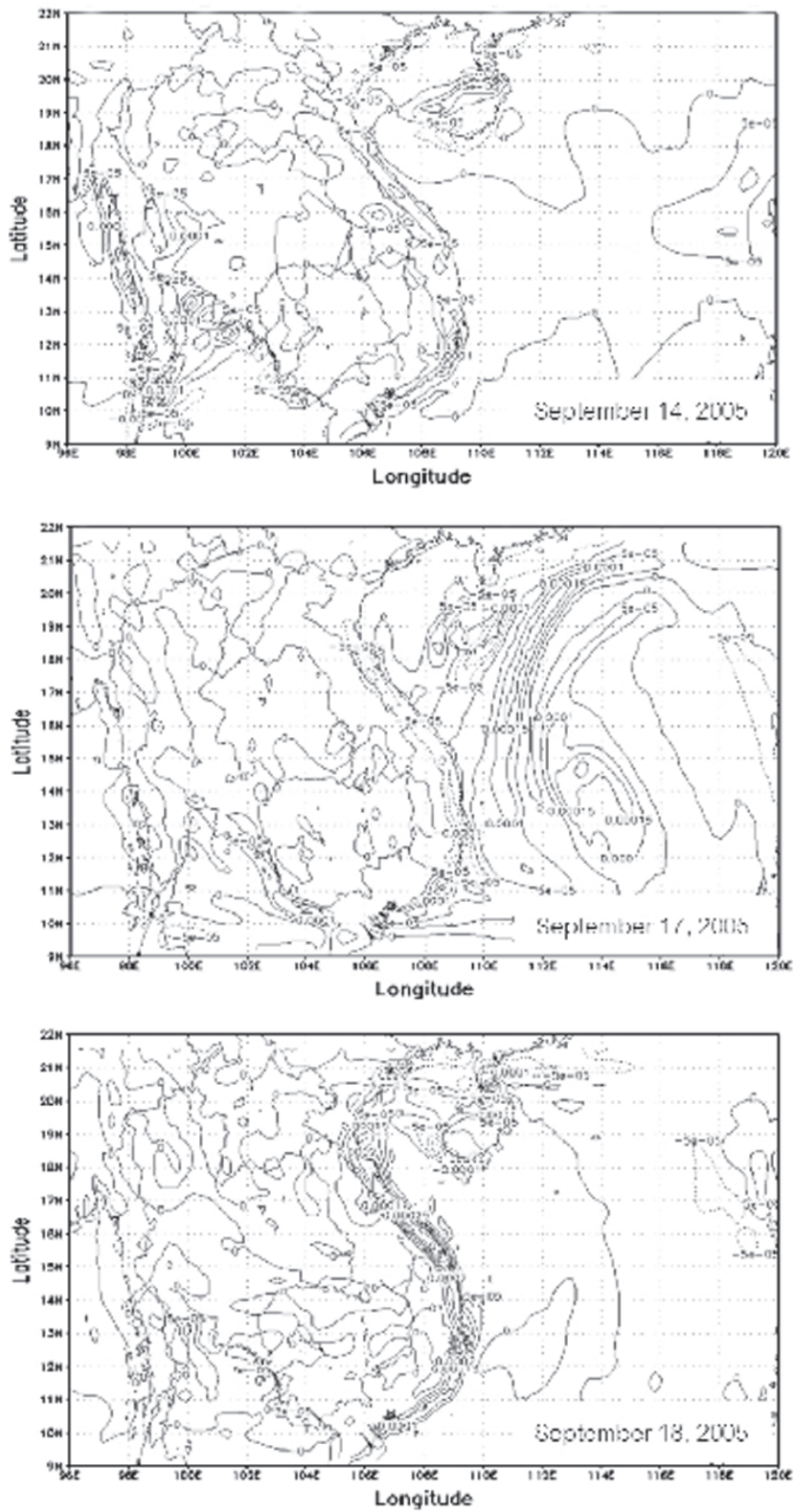


Figure 7. Computed vorticity of the storm Vicente during September 14 -18, 2005.

3.3.2 Simulated and Reported Rainfall

The storm Vicente moved over Thailand, causing widespread rainfalls in upper Thailand, simulated rainfall amounts in northern and northeastern Thailand are shown in Figure 9. Simulated rainfalls and reported rainfalls for some provinces are comparable on September 18, 2005 for Thailand as shown in Table1.

4. CONCLUSIONS

This work presents the simulations of the mesoscale systems, tracking and associated rainfall of the tropical storm Vicente developing in the South China Sea during

September 14-18, 2005 by WRF.

The WRF model satisfactorily reveals the changing central pressure, the low-level wind convergence, the updraft, the availability of moisture and the track of the storm Vicente. The simulated locations of low-level wind convergence where the updraft of moist air and cloud developing are reasonably well consistent with the MTSAT-1R satellite images.

Having gained moisture and energy supplies along the storm path, the storm rapidly intensified into a tropical storm when its central pressure dropped to 998 hPa while the wind speed increased to 20 m.s⁻¹ with the

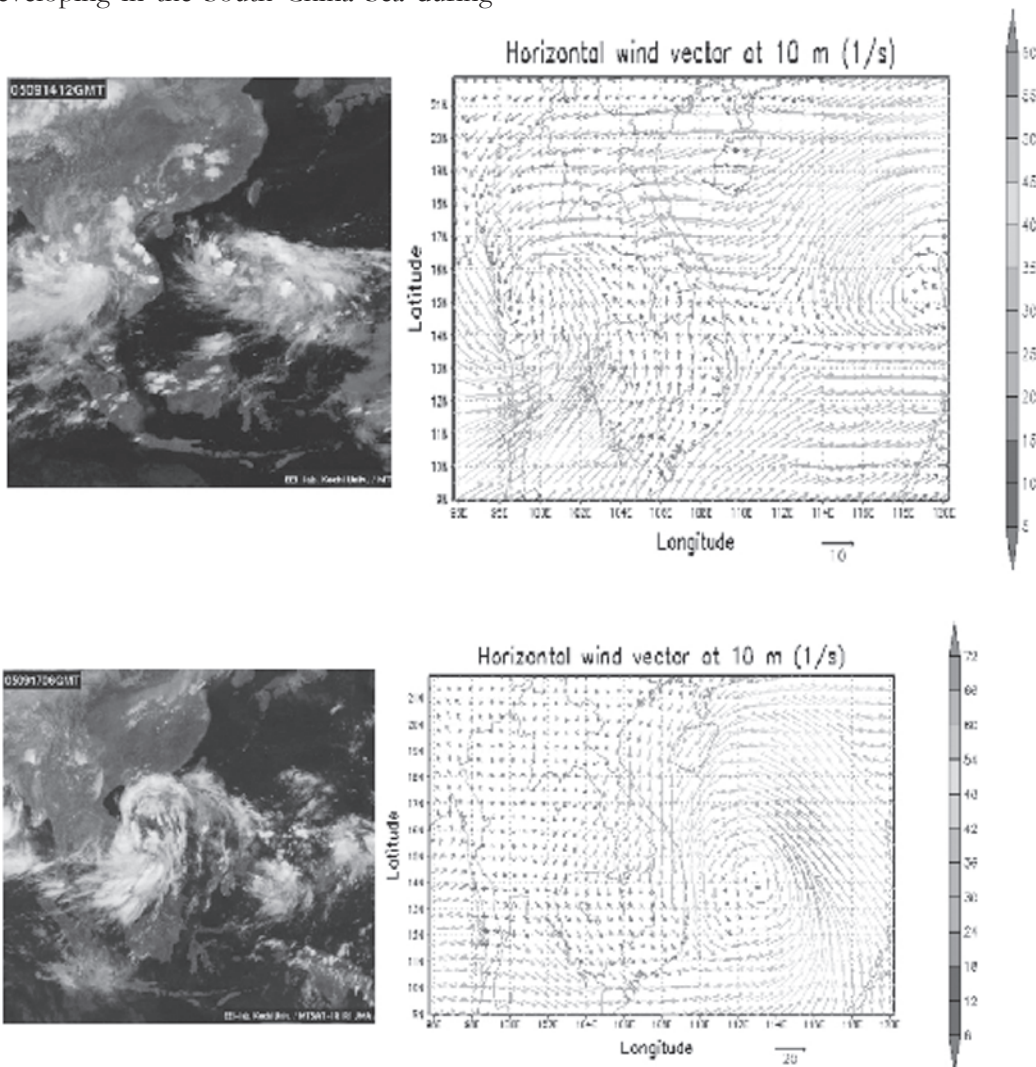


Figure 8. Simulated low level wind convergences and the MTSAT-1R satellite images.

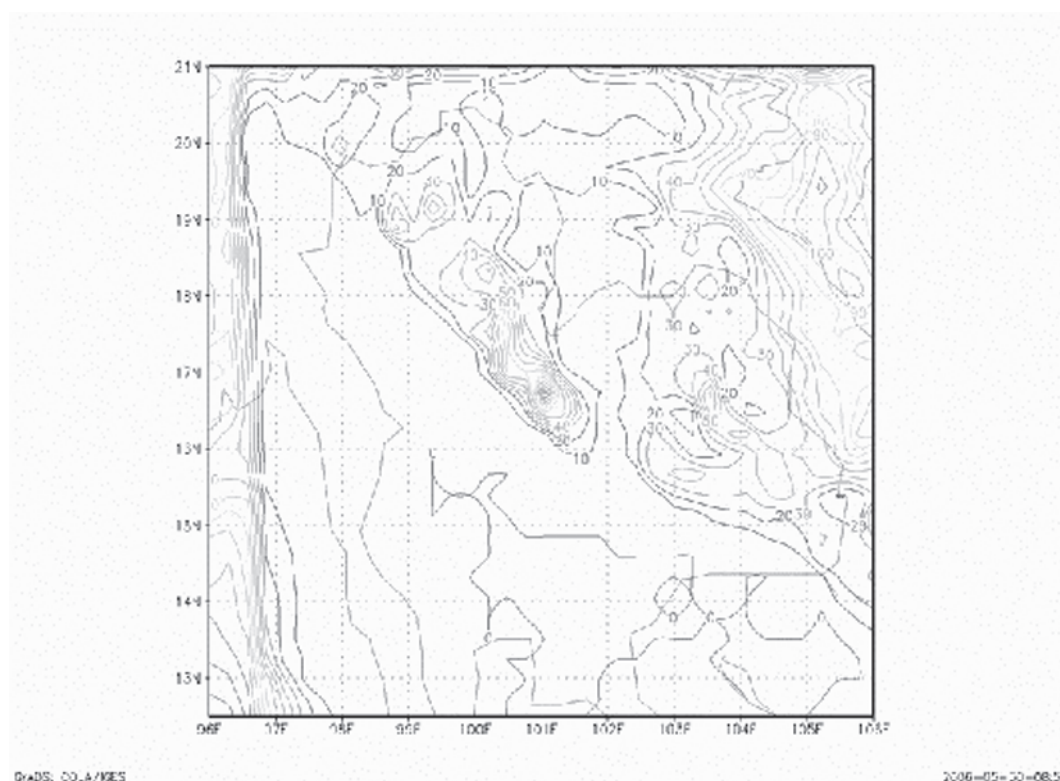


Figure 9. Simulated rainfall distribution (mm.) for northern and northeastern Thailand on September 18, 2005.

Table 1. Reported rainfalls in some provinces in upper Thailand (Thai Meteorological Department, 2005).

Provinces	24 hrs. Accumulated Precipitation (mm) September 18, 2005	
	Simulated rainfall (mm.)	Reported rainfall (mm.)
Mukdahan	30-70	53.8
Nakhon Phanom	30-70	81.9
Nongkhai	30-70	75.3
Phitsanulok	80-100	78.8
Lampang	30-50	61.9
Lamphun	30-50	76.9
Chiang Mai	30-50	50

strongest updrafts of 0.25 m.s^{-1} on September 17 shortly before it made landfall in Vietnam.

After landfall, the tropical storm subsequently slowed down its speed to 17 m.s^{-1} as the central pressure increased to 1000 hPa, signifying its weakening state on September 18.

Unfortunately, comparisons of simulated and reported rainfalls are not feasible due to the limitation of the reported values along the storm track, however the simulated and reported rainfall amounts of 80-100 mm.day^{-1} for Thailand on September 18, 2005 are in good accordance.

ACKNOWLEDGEMENTS

Our sincere thanks are due to the Commission on Higher Education, Ministry of Education, Thailand for the overseas research grant, and to the Promotion of Science and Technology for the partial financial support. Our thanks are also extended to NCAR, U.S.A. for the WRF model and the atmospheric data, and to the Weather Home, Kochi University, Japan for the MTSTAT-IR satellite images.

REFERENCES

- [1] Betts, A. K., Miller, M. J., A new convective adjustment scheme: Part I. Observational and theoretical basis. *Q.J.R. Meteorol. Soc.*; 1986, 112 : 677-692.
- [2] Betts, A. K., Miller, M.J., The Betts-Miller scheme: The representation of cumulus convection in numerical model, *Meteor. Monogr., Amer. Meteor. Soc.*; 1993, 46 : 107-121.
- [3] Braun, Scott A., and L. Wu, A numerical study of Hurricane Erin (2001). Part I: Shear and the organization of eyewall vertical motion, *J. Atmos. Sci.*, 2005, 63 : 65–86.
- [4] Brian, D., The grid analysis and display system (GrADS), <http://www.iges.org/grads/1995>.
- [5] Charles A. Lin, Lei Wen, Guihua Lu, *et al.*, Atmospheric-hydrological modeling of server precipitation and floods in the Huaihe river basin, China. *J. Hydrol.*, 2006
- [6] Chun Chieh Wu, Tzu Hsiung Yen, Wei Wang, *et al.*, Rainfall simulation associated with typhoon Herb (1996) near Taiwan. Part I: The topographic effect. *Weather and Forecasting*; 2002, 17 : 1001–1015.
- [7] Kochi University, Weather Home. <http://weather.is.kochi-u.ac.jp/index-ehtml>
- [8] Kreasuwun J., Srinoi S., Promnopas, W., The South-West Monsoon Orographic Effect over the Thanon Thong Chai Mountain Range, the bordering line between Thailand and Myanmar. *Proceeding, the Fourth International Symposium on Asian Monsoon System (ISAM4)*, Kunming, China, 2004.
- [9] Qing H. Z., Shou J. C., Ying H. K., *et al.*, Numerical study of a typhoon with a large eye : Model simulation and verification. *Mon. Weather Rev.*; 2004, 133 : 725-742.
- [10] Thai Meteorological Department, Annual rainfalls report, Bangkok, Thailand, 2005.
- [11] Wang, W., Barker, D., Bruyere, C., *et al.*, WRF Version 2 modeling system user's guide. http://www.mmm.ucar.edu/wrf/users/docs/user_guide/, 2005