Bulletin of Earth Sciences of Thailand

Characteristics of Seasonal Wind and Wind-driven Current in the Gulf of Thailand

Pracha Chaiongkarn[1,*] and Pramot Sojisuporn[2]

[1]*Department of Geology, Faculty of Science, Chulalongkorn University, Bangkok, Thailand,*
[2]*Department of Marine Science, Faculty of Science, Chulalongkorn University, Bangkok, Thailand*
*Corresponding author e-mail: nestnakab@gmail.com

Abstract

The Gulf of Thailand is bounded by Latitude 6° to 14°N and Longitude 99° to 105°E. It is located on the continental shelf connecting to South China Sea via the southern entrance. The Gulf is border by Thailand, Cambodia and Vietnam on the eastern, northern and western side respectively. The Gulf receives high solar radiation throughout the year. The NE and SW monsoon controls the local weather around the Gulf. The monsoonal wind plays an important role in controlling the wind pattern, rainfall over Thailand, and also controlling water circulation in the Gulf of Thailand. The project objective is to simulate wind regime over the Gulf and wind-driven circulation in the Gulf of Thailand during the year 2000-2002. The study time span cover La Niña, normal and El Niño period respectively. The study is accomplished through to use of WRF model and 2-D water circulation model. Wind regime from WRF model was the input to the water circulation model. Statistical analysis was performed on the wind data in order to study the effect of El Niño and La Niña events on the wind pattern over the Gulf of Thailand. Wind pattern from the WRF model was comparable to the satellite (observed) wind. Wind-driven circulation was similar to the results of earlier studies. During rainy season, the westerly and southwesterly wind from the Indian Ocean caused the wind-driven current in the Gulf and the upper Gulf to flow in a clockwise direction. Small eddies existed some locations in the Gulf. During winter, high pressure system from Siberia caused wind in South China Sea to flow from the east to Gulf entrance. While inside the Gulf, the wind deflected to NE wind and caused the wind-driven circulation in the Gulf and the upper Gulf to flow in a counterclockwise direction. During summer, wind from South China Sea blew from the east direction. While inside the Gulf, the wind deflected to SE wind. And the SE wind deflected to S wind when entering the upper Gulf of Thailand. The pattern of wind-driven current in the Gulf was similar to that in during the winter. When easterly wind was strong near the lower eastern coast of the Gulf, there would be a northward flow of water along the coast. The effect of the El Niño event increased wind speed over the Gulf and deflect the wind direction by 10°. On the other hand, the effect of the La Niña event reduced wind speed over the Gulf and deflects the wind direction by the same degree. The wind-driven circulation pattern did not change with the El Niño / La Niña event.

Keywords: WRF Model, Wind-Driven current, Sea surface wind

1. Introduction

The Gulf of Thailand lies in the tropical zone which receives high thermal solar energy throughout the year. The interaction between the atmospheric and ocean surface plays an important role in controlling the local climate stability; in other words, time and spatial variations of the oceanic climate will affect the variability of continental climate conditions. Therefore, climate variability is linked to the changes of weather or regional phenomenon. Located on the Indochina Peninsula that is bordered by the Pacific Ocean on its eastern side and the Indian Ocean on its western side, Thailand is inevitably influenced by the variability of both oceans in terms of climate phenomenon that varies with monsoon regimes. Moreover, climate variability leads to severe weather conditions and natural disasters in both regional and local levels. The NE and SW monsoon controls the local weather around the Gulf. The monsoonal wind plays an important role in controlling the wind pattern, rainfall over Thailand, and also controlling water circulation in the Gulf of Thailand.

Circulations in the Gulf of Thailand is driven by the reversal monsoonal winds, co-oscillation tide and water density gradients (Singhruck, 2002 by Robinson, 1974). Field data and numerical model results indicated that the predominant monsoonal winds caused eddies, mixing and the exchange of water mass in the Gulf (Sojisuporn, et al., 2010 by Robinson, 1974; Siripong, 1984; Buranpratheprat and Bunpapong, 1998; Yanagi and Takao, 1998a) and wind is the major contributor to the eddy generation in the Gulf, while tidal energy contributed very little in the eddy generation (Singhruck, 2002).

Previous studies on circulations in the Gulf of Thailand have either focused for the entire area of the Gulf or just in the Upper Gulf of Thailand which lies in the northern end of the Gulf. The driving forces used were also different. For example, Snidvong and Sojisuporn (1997) assumed a steady wind for the entire Gulf. Archevarahuprock and Wongwises (1994) used averaged measured wind at some stations in the study area. Lopittayakorn (2012) used averaged measured wind from 9 oceanographic buoys in the Gulf. Buranpratheprat and Bunpapong (1998), Singhruck (2002) used predicted winds from multi sources.

The wind data used in earlier studies came from 3 sources: 1) measured data from meteorological station whether on land or in the sea, 2) global wind model, and 3) hypothetical data which was usually constant wind field. The bilinear interpolation must be performed on the measured and global wind data which might result in erroneous output for the circulation model while using the constant wind field might not obtain the right circulation pattern. This study will use the regional model to obtain the realistic wind field for the Gulf of Thailand and the wind-driven circulation would be more realistic.

Thus, the accuracy of obtained ocean circulation extremely depended on the accuracy of wind data used. Reliability of wind data becomes very important since the circulation is very sensitive to the wind patterns (Buranapratherat, et al., 2006). As wind plays a significant role in eddy generation, better accuracy of eddy simulation can be achieved by using regional numerical weather prediction data which should yield better spatial variability than the present global wind data (Singhruck, 2002). This study will use the regional model to obtain the realistic wind field for the Gulf of Thailand and the wind-driven circulation would be more realistic.

2. Study area

Domain for the study extended from latitude 5.5°-14°N and longitude 99°-107.5°E. The Gulf is encircled by Thailand, Malaysia, Kingdom of Cambodia and the Socialist Republic of Vietnam on three sides, and open to South China Sea via the southern side. The average depth of the Gulf is about 45 m with the maximum depth of 80 m in the middle of the Gulf (Aschariyaphotha et al., 2007).

Thailand weather is influenced by the NE and SW monsoon seasons. The monsoons also controlled the climatic and oceanographic characteristics of the Gulf of Thailand.

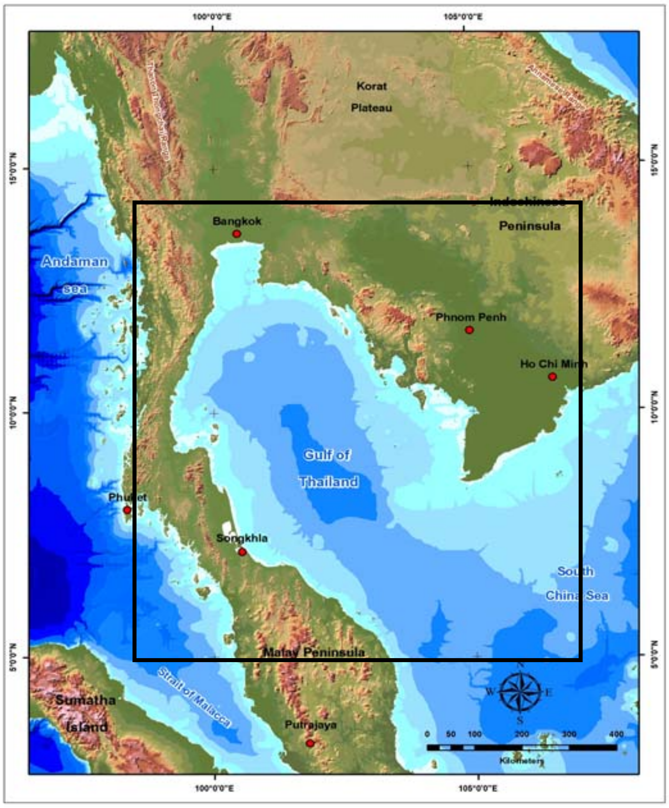


Figure 1. Study area.

3. Methodology

The Weather Research and Forecast (WRF) model is able to produce realistic wind climatology, probabilistic wind distributions and annual cycle. It also reproduces well-known regional winds remarkably well (Menendez et al., 2012). The performance of the WRF model in wind simulation has been evaluated under different numerical and physical options (Carvalho et al., 2012). The WRF model is suitable for use in a broad range of applications over wide scales ranging from meters to thousands of kilometers. It includes one-way and two-way moving nested routines and can be coupled with other models including hydrology, land-surface, and ocean models.

The aim of this research is to simulate the regional wind regimes for the Gulf of Thailand using the WRF model. The tests with the WRF meteorological model were performed, aiming to evaluate the use of different physical options in the simulation of the near surface wind speed and direction. The different sets of parameterizations schemes regarding fixed boundary layer (YSU (PBL) and Noah (LSM)) and radiation scheme (Dudhia (SW) and RRTM (LW)) which deal with cumulus scheme and microphysics scheme were tests for winter season. The cumulus and microphysics parameterizations set composed by the schemes WSM6-class and Betts-Miller-Janjic were the one that gave better performance for winter season. This option was later used for summer and rainy seasons. The simulated wind will be used to drive the 2-D wind-driven current in the Gulf of Thailand under different monsoonal conditions. The result of this study will help better understand monsoonal wind and surface ocean circulation variability under the influence of the ENSO conditions.

4. Result

Wind speed during summer during 2000-2002 (March-April, do not show) was rather weak with the average wind speed of 2.6 m/s. The wind direction varied between 80 to 180 degrees with the average of 107 degree. The main wind blew from South China Sea in the SE direction and gradually changed to S direction when it entered the Gulf of Thailand.

During the rainy season during 2000-2002 (June to September, do not show), the wind came from the SW direction (between 200-250 degrees with the average of 230 degree). The wind speed was quite strong with the average wind speed of 4.8 m/s.

During the winter season during 2000-2002 (November to January, do not show), the wind came from the NE direction (between 40-80 degrees with the average of 58 degree). The wind speed was quite strong with the average wind speed of 4.9 m/s.

Table 1. Statistical analysis performed on seasonal wind speed and direction.

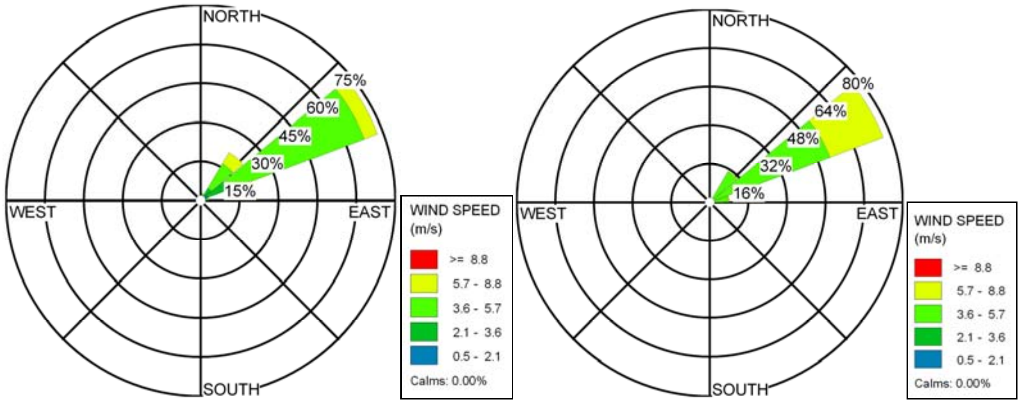
	Wind speed (m/s)			Wind directions (degree)		
Season	RMSE	Bias	STDE	RMSE	Bias	STDE
Summer 2000	1.358	0.048	1.357	68.8	-6.3	68.5
Summer 2001	1.583	-0.199	1.571	57.0	-12.6	55.5
Summer 2002	1.996	-0.675	1.879	66.7	-4.0	66.6
Rainy 2000	1.786	-0.966	1.502	24.2	-11.7	21.2
Rainy 2001	1.965	-0.474	1.907	24.0	-14.7	19.0
Rainy 2002	2.202	-0.863	2.026	26.2	-11.1	23.7
Winter 2000	1.825	-0.824	1.629	12.3	-1.5	12.2
Winter 2001	1.959	-0.437	1.909	10.0	3.2	9.5
Winter 2002	2.009	-0.254	1.993	11.0	-2.3	10.8
Benchmark Adapted from Emery et al., 2001	≤ 2.0	≤ ± 0.5	-	-	≤ ± 10	-

In Table 1, statistics for wind speed and direction during summer and winter fell in the acceptable ranges. However, most statistics for those during rainy period were beyond the acceptable ranges.

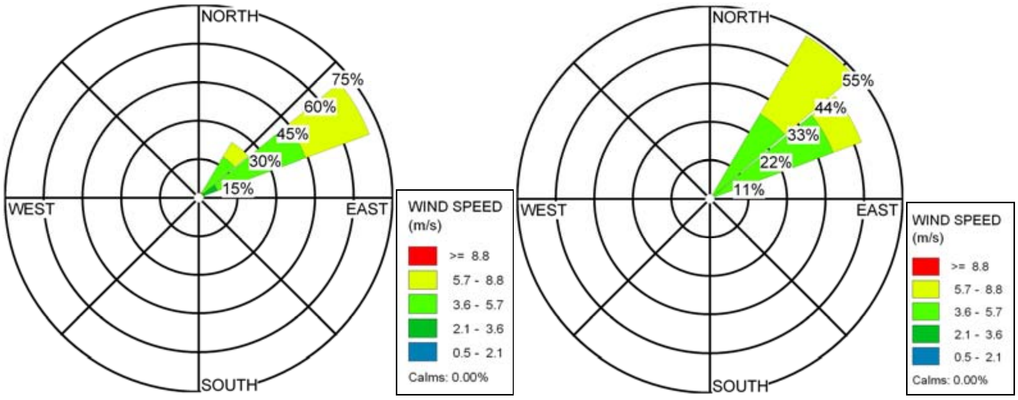
The bias values for wind directions for summer 2000, 2001, and 2002 were negative, indicating that the average wind direction of the simulated data was lower than that of the satellite data (anti-clockwise). The bias value for wind speed for summer 2000 was positive indicating that simulated wind speed was greater than. On the other hand, the bias values for wind speed for summer 2001 and 2002 were weaker than the satellite data.

The bias values for wind directions for rainy season 2000, 2001, and 2002 were negative, indicating that the average wind direction of the simulated data was lower than that of the satellite data (anti-clockwise). The bias value for wind speed for rainy season 2000, 2001, and 2002 were also negative indicating that simulated wind speed was weaker than the satellite one.

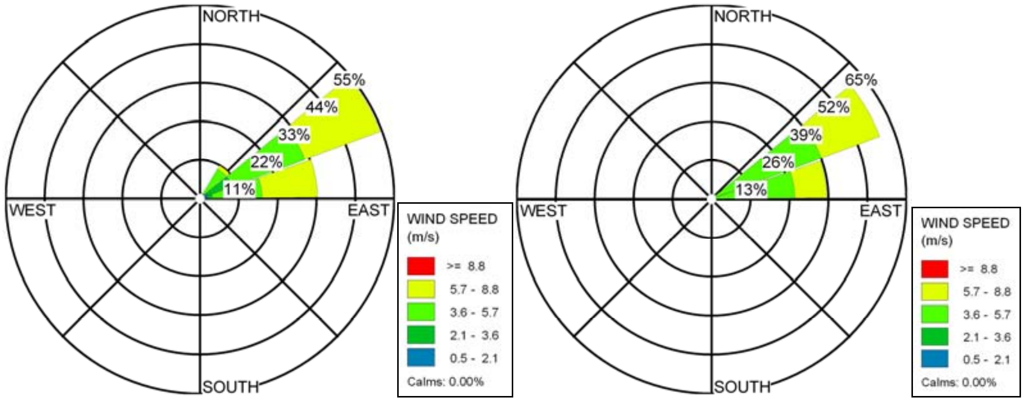
The bias values for wind directions for winter 2000 and 2002 were negative, indicating that the average wind direction of the simulated data was lower than that of the satellite data (anti-clockwise). The bias value for the wind direction for winter 2001 was positive, indicating that the average simulated wind direction was greater than the satellite data (clockwise). The bias value for wind speed for rainy season 2000, 2001, and 2002 were negative, indicating that the simulated wind was weaker than the satellite one.



(Model) winter 2000 (Observed) winter 2000



(Model) winter 2001 (Observed) winter 2001



(Model) winter 2002 (Observed) winter 2002

Figure 2. The wind rose over the Gulf of Thailand in winter season from 2000 to 2002.

Figure 2 showed distribution of wind speeds and directions for the winter 2000-2002. Both the observed and simulated winds came from the NE to ENE directions. Wind direction (do not show) from the model differed significantly with that from the observed data even though the differences in wind direction were 2-4° only.

Wind speeds and directions for the rainy season 2000-2002 (do not show). The observed wind data blew mainly from the SW direction while wind in the model also varied around the SW direction. The mean wind direction of the WRF model veered to the right (clockwise) of the observed data.

Wind speeds and directions for the summer 2000-2002 (do not show). The observed data dispersed unevenly in quadrant II while the model data lumped around E direction. The mean wind direction for the observed data veered to the left (anti-clockwise) of the model directions for all 3 years.

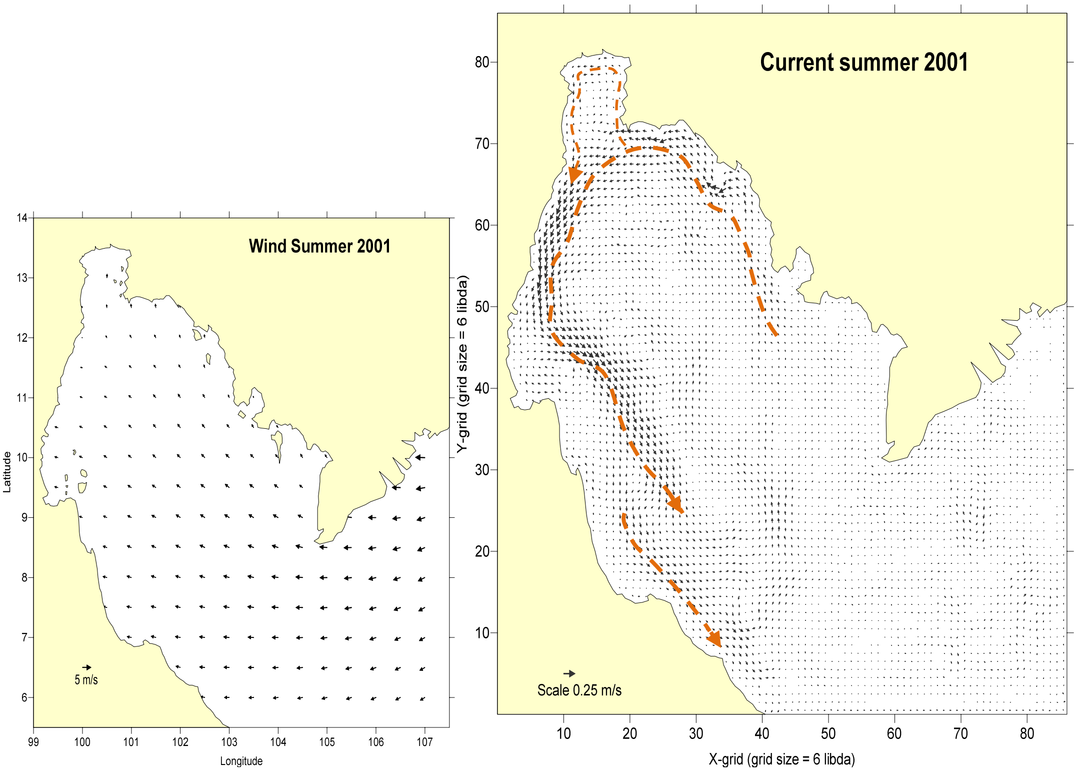


Figure 3. Simulated wind and wind-driven current in summer 2001.

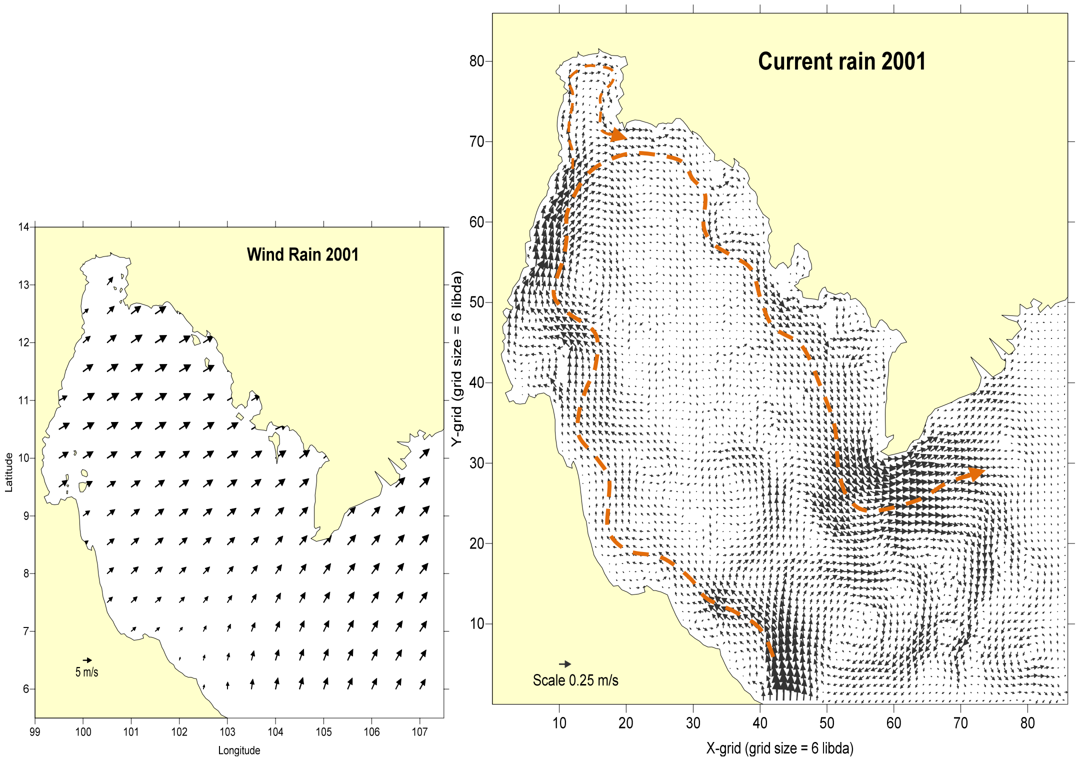


Figure 4. Simulated wind and wind-driven current in rainy season 2001.

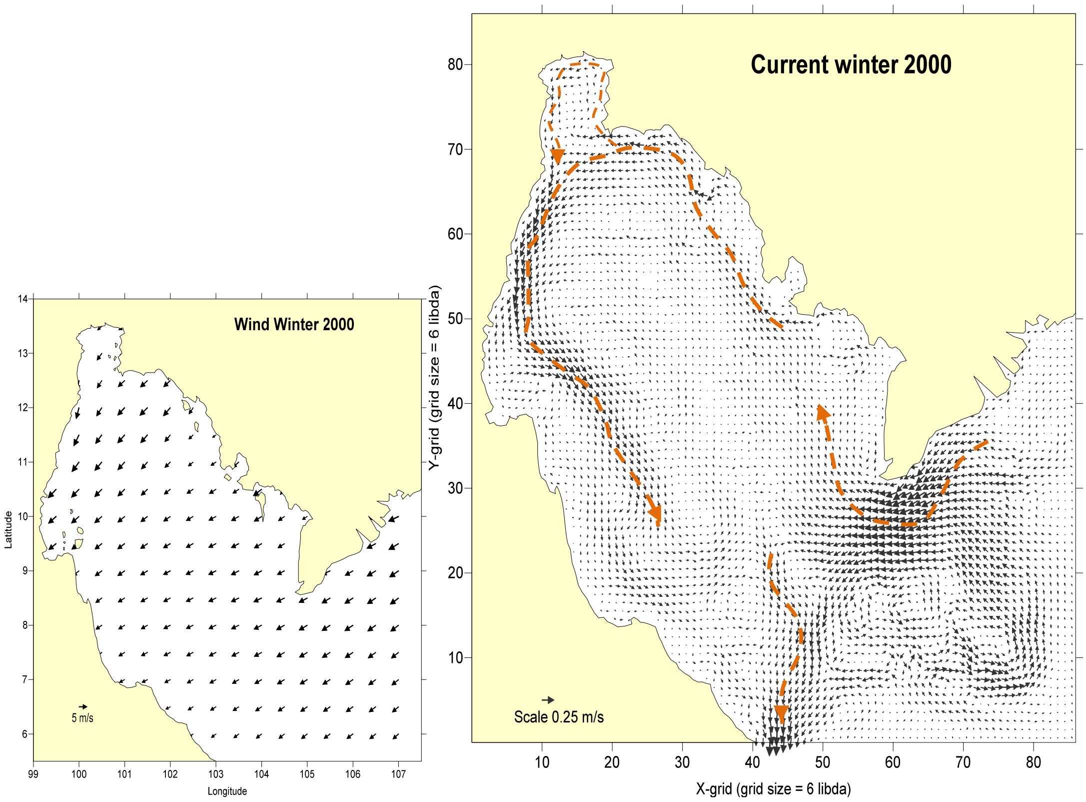


Figure 5. Simulated wind and wind-driven current in winter 2001.

Figures 3-5 the basin-wide CCW circulation occurred in the upper Gulf and lower Gulf during the winter season while the basin-wide CW circulation occurred during the rainy season (do not show). The CCW circulation also prevailed during summer (do not show), but the circulation was rather weak due to weaker wind.

Table 2. The t-test of observed and simulated wind speed and direction during 2000-2002.

Wind speed Observed	Summer 2000/ 2001	Summer 2002/2001	Rainy 2000/2001	Rainy 2002/2001	Winter 2000/2001	Winter 2002/2001
t-test	-3.98	20.05	-49.16	48.97	-16.11	-5.01
Average	2.48/2.60	3.55/2.60	5.06/5.62	6.14/5.62	5.24/5.63	5.48/5.63
Simulated	2000/2001	2002/2001	2000/2001	2002/2001	2000/2001	2002/2001
t-test	3.95	11.08	-38.54	10.28	-30.43	-1.43
Average	2.52/2.40	2.87/2.40	4.09/5.14	5.27/5.14	4.41/5.28	5.22/5.28
Wind direction Observed	Summer 2000/ 2001	Summer 2002/2001	Rainy 2000/2001	Rainy 2002/2001	Winter 2000/2001	Winter 2002/2001
t-test	1.73	0.43	-38.80	-19.68	17.81	55.37
Average	127/120.5	120.6/120.5	238.4/244	237.8/244	58/50	65/50
Simulated	2000/2001	2002/2001	2000/2001	2002/2001	2000/2001	2002/2001
t-test	14.12	7.04	-17.43	-24.63	8.30	29.52
Average	114.4/104.7	102.8/104.7	227.2/230	227.8/230	56.4/54	64/54

La Niña event occurred in year 2000 while El Niño event occurred in year 2002 and normal condition occurred in year 2001. The year 2000 and 2002 were not the year with strong La Niña or strong El Niño event respectively.

Summary from the t-test (Table 2) results was that the wind speed would be weaker than normal during the La Niña event and stronger than normal during the El Niño event. The exception occurred during winter when both the La Niña and El Niño events slowed down the NE monsoon wind. The wind direction turned clockwise or anti-clockwise due to the La Niña and El Niño events, though the angle difference was in the order of 0 to 10 degree.

5. Conclusions and Recommendations

The results of this study suggested that the sea surface wind curl plays a very important role in the determination of residual flow pattern in the Gulf of Thailand. We have to elucidate the detailed horizontal distribution of sea surface wind over the Gulf of Thailand in order to simulate the water circulation in the Gulf.

The effect of the El Niño event during 2000-2002 increased wind speed over the Gulf and deflect the wind direction by 10°. On the other hand, the effect of the La Niña event during 2000-2002 reduced wind speed over the Gulf and deflects the wind direction by the same degree. Wind-driven circulation was salient in the Gulf of Thailand. The circulation pattern in the Gulf was also controlled by the Gulf's shape and topography. The wind-driven circulation was also influence by the El Niño – La Niña event. But the wind-driven circulation pattern did not change with the El Niño / La Niña event.

Influence of El Niño and La Nina during 2000-2002 effects on wind and circulation in the Gulf of Thailand was not conclusive. Further study should focus on time duration when strong El Niño and La Nina condition exist. Thus, solid conclusion cannot be reached. Special care is needed to select the month/season with strong El Niño / La Niña events so that we can see the difference in wind regime and wind-driven current under the El Niño / La Niña events.

The circulation pattern in the upper Gulf of Thailand from this study did not conform to data from the oceanographic buoys. Fine-scale circulation model for the upper Gulf must be implemented which might give real wind-driven circulation for the upper Gulf.

This study used only 2-D circulation model. Since the water in the Gulf is divided into 2 layers, the 3-D model would be better to produce the circulation pattern for each layer.

6. Acknowledgements

This research could not have been accomplished without useful advice from Mr. Kamol Brahmasakha Na Sakolnagara, Mr. Somkuan Tonjan (Meteorological Department of Thailand), Ms. Boossarasiri Thana, and Ms. Malatee Thiyakupt (Department of Geology, Chulalongkorn University). The authors sincerely gratify the Center for Atmospheric Research's (NCAR) Meso-scale and Micro-scale Meteorology (MMM) Division, the National Oceanic and Atmospheric Administration's (NOAA) National Centers for Environmental Prediction (NCEP), for their permission to use software and essential data for this research.

7. References

Amnuaylojaroen, T., and Kreasuwun, J., 2012.Investigation of fine and coarse particulate matter from burning area in Chiang Mai, Thailand using the WRF/CALPUFF. Chiang Mai Journal.39, 2: 311-326.

Aschariyaphotha, N., Wongwises, P., Wongwises, S., Humphries, U.W.,and Xiaobao, Y., 2008.Simulation of seasonal circulations and thermohaline variabilities in the Gulf of Thailand. Advances in atmospheric sciences, 25, 3: 489-506.

Blumberg, A.F., 1977.Numerical tidal model of Chesapeake Bay. Journal of the Hydraulics Division, Proceedings of the American Society of Civil Engineers, 103(HY1):1-10.

Booncherm, C., Vongpintu, V.,and Nutpramoon, R., 2001.The characteristic of the sea surface residual flow and the circulation in the Gulf of Thailand from the long term collected data of the SEAWATCH Thailand program. Proceedings of the 39th Kasetsart University Annual Conference: Science, Natural Resources and Environmental Economics, Bangkok (Thailand), 39: 315-325.

Buranapratheprat, A., and Bunpapong, M., 1998.A two dimensional hydrodynamic model for The Gulf of Thailand. Proceedings of the IOC/WESTPAC Fourth International Scientific Symposium, 469-478.

Buranapratheprat, A., Yanagi, T., Sojisuporn, A., and Booncherm, C., 2006.Influence of local wind field on seasonal circulations in the upper Gulf of Thailand. Coastal Marine Science, 30, 1: 19 - 26.

Carvalho, D., Rocha, A., Gomez-Gesteira, A., and Santos, C., 2012.A sensitivity study of the WRF model in wind simulation for an area of high wind energy. Environmental Modeling & Software, 33: 23-24.

Chotamonsak, C., Salathe, E.P., Kreasuwan, A., and Chantara, S., 2012.Evaluation of Precipitation simulations over Thailand using a WRF regional Climate model. Chiang Mai Journal.39, 4: 623-638.

Emery, C. et al., 2001.Enhanced Meteorological Modeling and Performance Evaluation for Two Texas Ozone Episodes, Environ, International Corporation.

Idris, N.H., and Mohd, M.L.S., 2007.Total sea surface current circulation pattern in the South China Sea derived from satellite altimetry.Asian Conference on Remote Sensing, Kuala Lumper Malaysia, PWTC: (12-17 November 2007).

Kwun, H. J., Kim, Y.K., Seo, U.W.,and Jeong, J.H., 2009.Sensitivity experiments of winds prediction with planetary boundary layer parameterizations. Scientific and Technical Symposium on Storm Surge, COREE, 51: 63-77.

Menendez, F.J. et al., 2012. Using WRF to generate high resolution offshore wind climatolocies. Climate dynamics, 85-91.

Papanastasiou, D.K., Melas, D., and Lissaridis, I., 2010.Study of wind field under sea breeze conditions; an application of WRF model. Atmospheric Research, 98: 102-117.

Phuwieng Prakhammintara, 2000. Impacts of ENSO on rainfall, temperature and tropical cyclone frequency in coastal areas of Thailand. Master’s Thesis, Department of Marine Science, Faculty of Science, Chulalongkorn University. 132pp.

Phuwieng Prakhammintara, 2007.Correlation between heat flux, moisture and wind pattern over the Indian Ocean and southwest monsoon intensity in Thailand by using MM5 numerical model. Doctoral dissertation, Department of Marine Science, Faculty of Science, Chulalongkorn University. 140pp.

Qi, Y., Zhang, A.,and Shi, P.,2010.Extreme wind, wave and current in deep water of South China Sea. The International Society of Offshore and Polar Engineers, 20, 1: 18-23.

Singhruck, P., 2001. Circulation features in the Gulf of Thailand inferred from SeaWiFS data. The Asian Conference on Remote Sensing, 22: (5-9 November 2001), Singapore.

Snidvongs, A., and Sojisuporn, P., 1997.Numerical simulation of the net circulation in the Gulf of Thailand under different monsoon regimes. In Proceeding of the first Technical Seminar on marine fishery resources survey in the South China Sea, Area I: Gulf of Thailand and Peninsular Malaysia, Samutprakarn, Thailand: Training Department, Southeast Asia Fisheries Development Center, 1: 54-72.

Sojisuporn, P., Morimoto, A., and Yanagi, T., 2010.Seasonal variation of sea surface current in The Gulf of Thailand. Coastal Marine Science, 34, 1: 000-000, 2010.

Yanagi, T., and Takao, T., 1998.Seasonal variation of three-dimensional circulations in the Gulf of Thailand. La mer, 36: 43-55.

Yanagi T., Sachoemar I. S., Takao T., and Fujiwara S., 2001.Seasonal variation of stratification in the Gulf of Thailand. Journal of Oceanography, 57: 461-470.