Journal of Sustainability Science and Management Special Issue Number 1: The International Seminar on the Straits of Malacca and the South China Sea 2016: 81-92

ISSN: 1823-8556

© Penerbit UMT

WATER CIRCULATION IN THE SHALLOW SHELF AREAS OFF THE TERENGGANU COAST AFFECTED BY WIND STRESS FORCE USING A HYDRODYNAMIC MODEL

NURUL RABITAH DAUD[1,2], MOHD FADZIL AKHIR*[2] AND MOHD LOKMAN HUSAIN[2,3]

[1]*Faculty of Civil Engineering, Universiti Teknologi MARA, Selangor, Malaysia.* [2]*Institute of Oceanography and Environment,* [3]*School of Marine and Environmental Sciences, Universiti Malaysia Terengganu, Terengganu, Malaysia.*

**Corresponding author: mfadzil@umt.edu.my*

Abstract: The dynamic of circulation patterns in Terengganu waters largely dominated by wind forcing specifically the monsoon wind. In order to understand this dynamic, a hydrodynamic model is applied to simulate the major circulation patterns in Terengganu waters. The model used is a three-dimensional simulation MIKE 3 Flow Model FM by Danish Hydrological Institute (DHI). The model exhibit that the current flowed in the same direction with prevailing monsoon winds. While the current speed was dominated by magnitude of monsoon winds. The maximum current speed recorded during SW monsoon was 0.327 m/s and 0.478 m/s during NE monsoon. Additionally, the model was able to capture the convergence and divergence current patterns during SW and NE monsoon seasons respectively. This convergence and divergence current features occurred at 5.5°N to 6°N latitude off the Terengganu waters. The convergence–divergence current pattern was suggested due to monsoon winds and effect from circulation in Gulf of Thailand. The study finalize the variability and dynamic of current circulation patterns in Terengganu waters are largely influenced by monsoon winds and effect from the Gulf of Thailand circulation.

Keywords: Current circulation, seasonal monsoon, MIKE3 Flow Model, South China Sea.

Introduction

The Southern South China Sea (SSCS) borders by several countries including Thailand, Cambodia and Vietnam at northern part while Malaysia, Brunei and Singapore at the southern part. The east coast of peninsular Malaysia (ECPM) specifically Terengganu coast is mostly affected by the SSCS condition. Terengganu coastal area is a shallow shelf area with water depth less than 80 m (Figure 1(b)). Recently, scientists reported an upwelling and a thermal frontal zone occur seasonally in this area (Akhir *et al.*, 2015; Kok *et al.*, 2015). The upwelling and frontal zone provide a high biological productivity into this area. These events occur seasonally in this area specifically in August during southwest (SW) monsoon season (Kok *et al.*, 2015).

Terengganu also affected by a tropical monsoon climate. This region experience a relative dry season from April to July, while the heaviest precipitation in November and December which sometimes reaches more than 1,000 mm of rainfall (Camerlengo & Somchit, 2000). This variability of monsoon season in this region gives severe impact on the society, financial, infrastructure and food security of the region (Loo *et al.*, 2014). Therefore, it is important to have a good understanding of monsoon season for sustainable development and management in this region. Thus, the aim of this study is to provide better understanding of seasonal monsoon hydrodynamic in the region.

Unlike in northern and central part of SCS, the southern part of SCS has few documented reports in detail about hydrodynamic and physical events occur in this area. However, a comprehensive understanding of hydrodynamic process and dynamic interaction between Gulf of Thailand (GOT) and ECPM is lacking. Recent study by Akhir *et al.* (2015) has proved the present of upwelling event along ECPM by providing the important evidence of

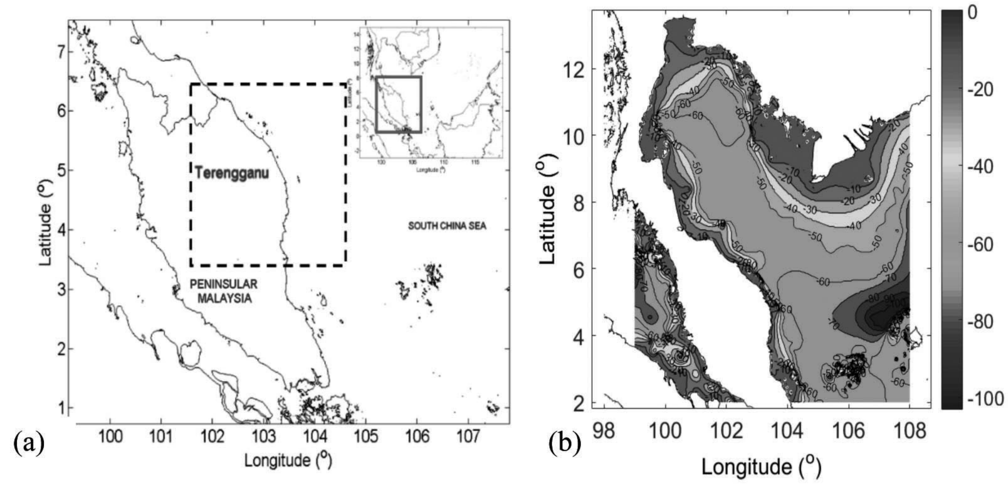

Figure 1 : (a) The study area (in dash box) and (b) bathymetry off the ECPM waters and Gulf of Thailand

upwelling event using sea surface temperature data from several sources including from cruise data. This is an important finding for this region as upwelling event plays important role in biological and productivity aspect of oceanography in this area.

Additional to the upwelling event finding, Kok *et al*. (2015) also found a present of coastal front feature along the ECPM during the Southwest (SW) monsoon. This finding provided additional evidence for the present of upwelling in this region as proved by Akhir *et al*. (2015). However, there is still a gap of this important finding which the current circulation patterns in this region that associate with the upwelling and coastal front event. Therefore, the objective of this study is to define the current circulation patterns off the Terengganu waters with influence by Southwest (SW) and Northeast (NE) monsoon winds using hydrodynamic model. The variability of current circulation is an essential factor to understand the hydrodynamic changes in a particular area in the oceanic environment. This is because current movement is a dominant force that moves the water mass in the ocean and wind is a major controlling factor in an area that largely influences by monsoon wind.

Off the Terengganu waters, the water circulation pattern and physical properties such as temperature and salinity are also mainly affected by monsoon seasons (Akhir *et al*., 2011). The monsoon winds influence sea surface currents as well as the exchange of water in Terengganu coast and adjacent bodies of water. According to the previous study by Fang *et al*. (2012), the surface currents flow north to south along the east Malaysia Peninsula coast to the Java Sea during the NE monsoon in December to February. The flow reverses south to north during the SW monsoon in June to August (Fang *et al*., 2012)

The surface waters are relatively warm 29 °C in the SW monsoon, it is because of the low latitude location and monsoon winds effect create a tendency for the equatorial current which warm water move into this region (Nicholson, 2011; Thompson & Tkalich, 2014). Early evidence of upwelling event was mentioned by Mansor *et al*. (2001). In early SW monsoon, wind from the southwest not only drives the surface water to the northeast but causes it to be displaced off the coast. As a result, small scale of upwelling events spotted by having colder surface temperatures and higher nutrient content off the Terengganu coast. Later, this upwelling events also supported by Phuoc *et al*. (2002) which showed the positive wind stress curls only during SW monsoon and that caused the coastal upwelling at ECPM.

Previous studies (Yang & Liu, 2002; Cai *et al.*, 2003; Zhang *et al*., 2009; Masseran, 2016) had applied numerical model simulation in order to understand the dynamic of current circulation pattern in central part of SCS. However, less attention has been given to the coastal area such as Terengganu coast which has a significant role in term of biological productivity distribution in this region (Akhir, 2014). This study has been designed to simulate the large scale area of SSCS with the purpose to include the dynamic influence of open sea into the small scale of Terengganu coast and results were discussed in detail on the subject of current circulation in Terengganu coast. In a large scale simulation, global wind patterns play an important role to the water movement while in a small scale simulation monsoon winds has a significant impact on current circulation in the area (Su & Weng, 1994; Quanan *et al*., 2007; Marghany & Hashim, 2010). Therefore, in this study the simulation has to consider the global scale wind patterns and also monsoon winds factors for small scale area in order to study the current circulation in this region.

Current circulation patterns in SSCS are defined by the seasonally monsoon winds which are southward current direction during northeast (NE) monsoon and northward current during southwest (SW) monsoon (Camerlengo & Demmler, 1997; Fang, 2002; Akhir, 2014). During NE monsoon from November to March, this region receives strong northeasterly wind approximately 0.3 Nm^{-2} wind stress. While, during SW monsoon in April to August, the region prevails by southwesterly wind with almost 0.1 Nm^{-2} wind stress (Akhir, 2012). While the tidal forcing in the SSCS also has strong impact into this region as reported by Lee & Seng (2009) that tidal forcing in this region has a great potential to be a source of renewable energy in future (Lee & Seng, 2009). Additionally, they described the tides in this area as a mixed tide while Terengganu has a mixed tide dominated diurnal.

The aim of this study is to provide better understanding of seasonal monsoon hydrodynamic in Terengganu waters. The aim will be addressed through the objective to simulate the current circulations forced by NE and SW monsoon winds. This study used MIKE 3 Flow Model FM which specified for hydrodynamic model however it also capable for coastal simulation. This is due to its flexible mesh able to cooperate well with asymmetrical coastline and also combination of sigma and z-level vertical discretization improve vertical distribution of water column and the steep slope of bathymetry (DHI, 2009).

Materials and Methods

The hydrodynamic model from MIKE 3 Flow Model FM by Danish Hydrological Institute (DHI) was used to simulate the current circulations off the Terengganu waters. It is a three dimensional model with the water depth divided into ten equal layers. The model governs by the incompressible Reynolds averaged Navier-Stokes equations. The governing equations for this model has been well explained and can be referred in scientific documentation of MIKE 21 and MIKE 3 Flow Model FM (DHI, 2011).

Model Specification and Numerical Schemes

The model specifications for this study referred to the hydrodynamic module user guide and followed the same setup by Sharbaty (2012). However, the wind condition had been modified into eight cases to manipulate the monsoon winds condition in simulation. The model domain for the SSCS is shown in Figure 2 which encompasses two open boundaries; the north boundary started from east of Vietnam to north of Sabah while the south boundary started at south of Johor to west of Kalimantan. The model domain is composed by unstructured mesh with a low resolution of 50 km in SSCS region and finer resolution of

5 km in Terengganu coastal waters. The model simulation was simulated for 40 days with 10 days for spinning-time. The model simulations run based on seasonal durations in August to represent SW monsoon and December to represent NE monsoon. The detail of the model setup is showed in Table 1.

The model forced by the two sources of bathymetry data which were MIKE C-MAP by DHI and General Bathymetric Chart of the Oceans (GEBCO) for better coverage of water depth in coastal water area. These data loaded into pre-processing tools Mesh Generator in MIKE ZERO to prepare the domain area. The unstructured mesh process involved generating the domain followed by natural neighbour interpolation method for bathymetry data and meshing production.

The model used general forces, recommended setup by DHI (2011) and suggested values based on previous study by Daud and Akhir (2015). The simulation was spin-up by the six-hourly wind data provided by National Centre for Environmental Prediction (NCEP) while temperature and salinity data generated by Hybrid Coordinate Ocean Model (HYCOM). The two open boundaries in domain were initialized by the surface elevation time series data. This was an efficient way to avoid the instability at open boundary when intrusion of stratified density in order to connect the regional scale model with smaller local area model (DHI, 2011).

The eight set of experiments (Table 2) were performed for the sensitivity analysis of wind driven-current in Terengganu waters. The experiments were designed to simulate the wind magnitude conditions almost without the wind influence (0 m/s), with the moderate wind blowing (10 m/s) and extreme wind forcing condition (20 m/s). The wind direction also modified to apply the main seasonal winds in model simulation. The wind direction from the southwest (225°) represented the SW monsoon wind while the northeast (45°) characterised the NE monsoon condition.

The experiment was designed to understand the dynamic changes of current circulation patterns under influenced of monsoon winds. The study region largely dominated by two monsoon winds which are northeasterly wind and southwesterly wind and these two major wind direction adopted into the model simulation. Meanwhile the maximum and minimum wind speed was adopted into the model simulation based on previous record

Table 1: Hydrodynamic model setup

Name	Notation	Setting
Module Selection	-	Hydrodynamic
Wind drag multiple	μ	1.3
Run length	-	40 d
Time step	Δt	21600 sec
Flood & Drying Depth (m)	m	0.2 - 0.3
Initial conditions	-	Wind and water level
Boundary conditions (open)	-	Tidal elevation
Boundary conditions (closed)	-	No normal flow
Forcing ramp	-	10 d
Minimum bottom friction coefficient	$C_{f,min}$	0.0025
Minimum wetted bathymetric depth	h_o	0.1 m
Minimum wetting velocity	V_{min}	0.01 m/s
Eddy viscosity coefficient	V_T	0.28 m^2/s
Bed resistance coefficient	n	32 $m^{1/3}/s$

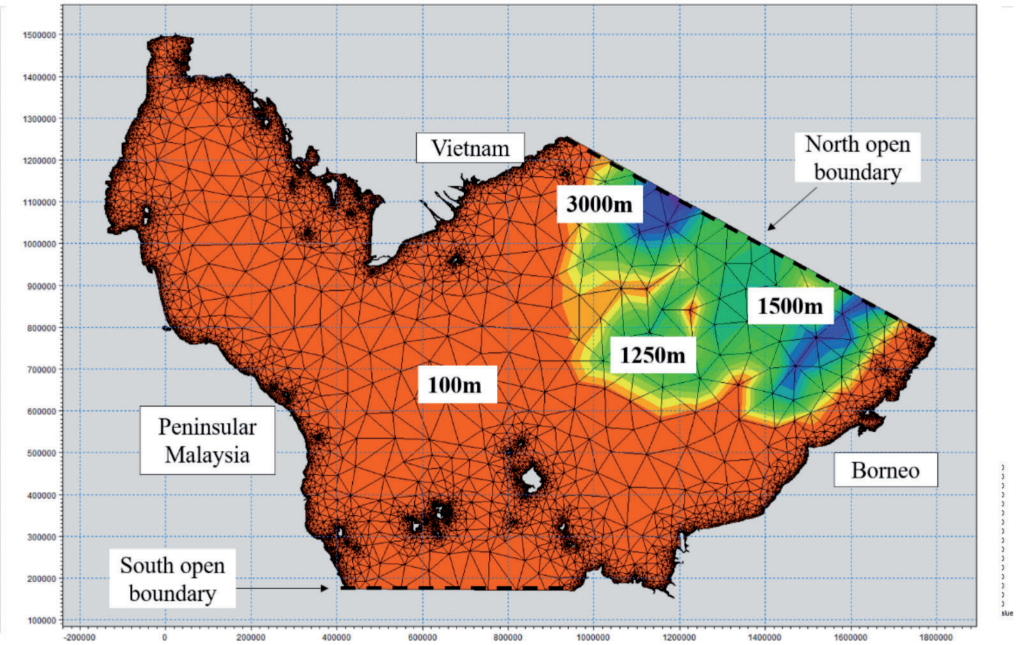

Figure 2: The model domain and bathymetry in Southern South China Sea region

Table 2 : Model study cases with manipulated of wind speeds and directions

	Wind Direction	Wind Speed (m/s)
Case 1	NE	20
Case 2	NE	10
Case 3	NE	5
Case 4	NE	0
Case 5	SW	5
Case 6	SW	10
Case 7	SW	20
Case 8	SW	0

from NCEP data. The 10 m/s and 5 m/s wind speed are categorized as the average range of wind speed in this region.

Field Measurement and Datasets for Model Validation

Numerical model validation was carried out through a four month field work had using an Acoustic Wave and Current Profiler (AWAC) (Pedersen *et al.*, 2007). The AWAC recorded current speed data in nearshore area of Terengganu (5°26’33.936”N, 103°9’37.548”E). The AWAC data measurements were covered 4 months from July to October 2011 with 10 minutes time interval as shown in Figure 3.

The model validation has been calculated in order to verify the simulation output. The root mean square error (RMSE) and bias value between simulated output and field measured value were calculated and compared in Figure 3. In general, the model performed a good agreement throughout the time series with the measured current speed. The bias between measured and simulated values was only 0.06

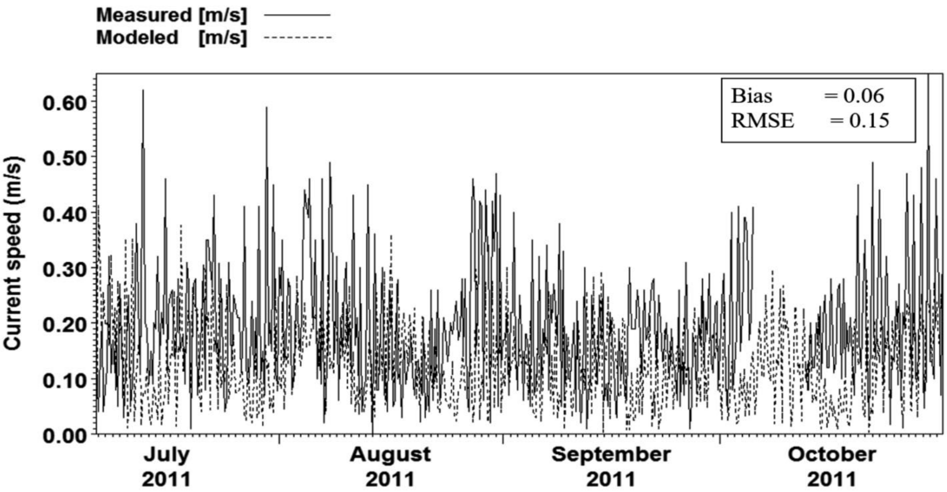

Figure 3: Model Validation and the statistical RMSE value

m/s while the RMSE value was 0.15 which felt in the acceptable range. Throughout the time series the model underestimated the current speed value however, the trend and peak fixed well with the measured current speed. Thus, this verified the model setting and model simulation output for further investigation and discussion.

Result & Discussion

Wind-Driven Current in Terengganu Waters

The result of this analysis indicates that the wind stress, especially in Terengganu waters, is a major driving factor for the coastal current circulation. The result is presented in composite plots of surface currents from the modelling output for different scenario of wind stresses (Case 1 until Case 8 in Table 2).

There are two predominant periods in Terengganu waters; Northeast (NE) monsoon and the Southwest (SW) monsoon. Case 1, Case 2, Case 3 and Case 4 represents the mean surface current during NE monsoon season , under the 45^o wind direction (northeasterly) and Case 5, Case 6, Case 7 under the wind stress of 225^o (southwesterly). Flow fields at surface layer during NE monsoon and SW monsoon in different numerical experiment wind speed are shown in Figure 4 and Figure 5 respectively.

During NE monsoon season, strongest current, 20 m/s wind speed are recorded in Case 1 (Figure 4). A maximum current flow was recorded at 0.478 m/s. The current flows along to the coastline according to the spreading winds. While in Case 2, the southward current flowed from the offshore branch out into a strong western boundary along the Terengganu. In Case 3, the current flows rather weak at the north part of Terengganu coast near to Besut as illustrated in Figure 4(c). The southward current flows along Terengganu coast until south part of coast and flowed into the land near Dungun. The extreme northward wind stress blowing across the sea caused the surface layer of water to move southward.

In general, the current circulation pattern is different in every case. When the wind stress was set to 20 m/s, current flowed at its strongest compare to other cases. Meanwhile at wind stress of 10 m/s, there was a divergence flow along the coastline as shown Figure 4(b). This separation began at the centre of domain around 6 ^{o}N and 105 ^{o}E and diverged into northward and southward along the coast. This separation flowed also could be observed in wind stress of 5 m/s but less in magnitude compare to other cases.

This separation pattern showed similar pattern with sea surface temperature distribution

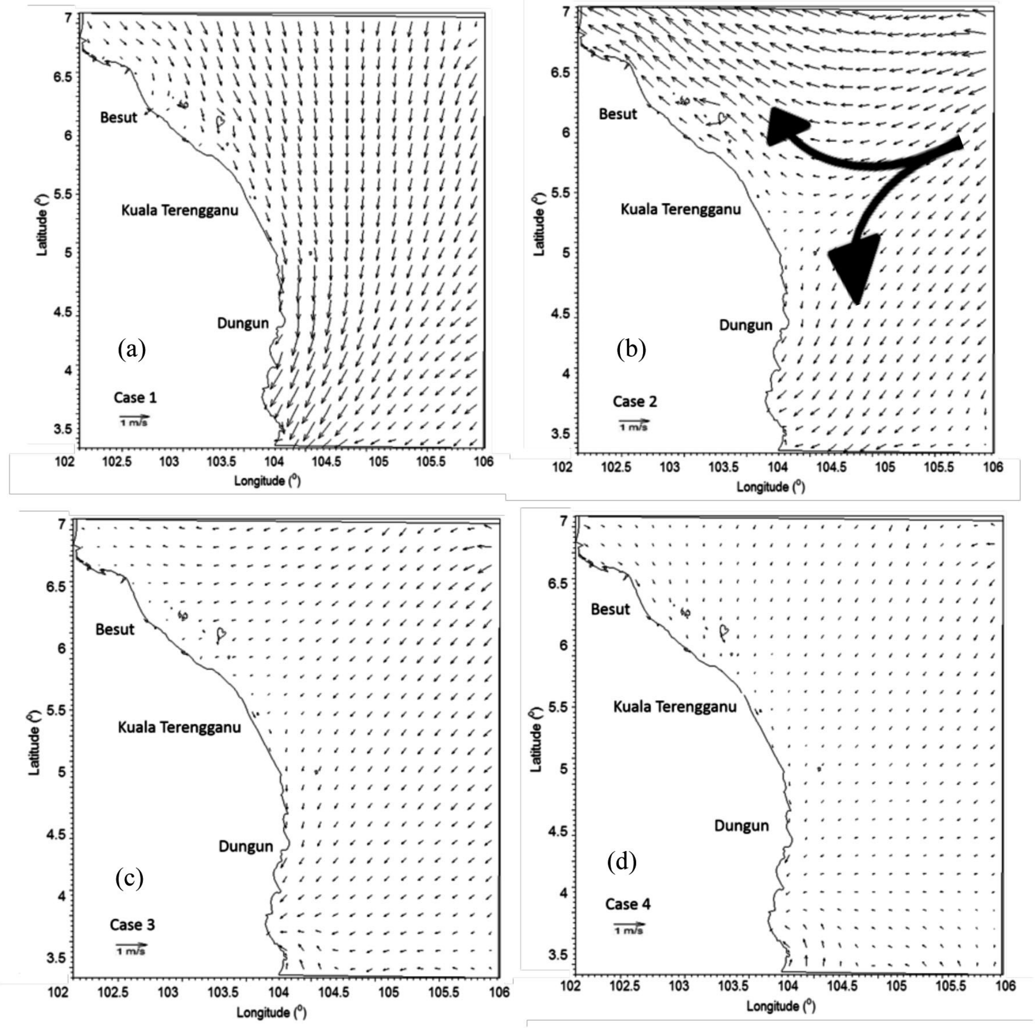

Figure 4: Mean surface current for 30 days of model run during NE monsoon (Case 1- Case 4)

at east coast of Peninsular Malaysia during SW monsoon. During SW monsoon, the present of northward cooler water along ECPM and the upwelling event in this area both are the generating factors for the formation of the sea surface temperature ocean front at ECPM (Kok *et al*., 2015).

Previous study suggested this circulation pattern was also influenced by sea level cause (Taira *et al.*,1996). Based on simulation done by Azmy *et al.* (1991) whenever the wind blows towards the Terengganu coast it caused an upsurge in the sea level. Combination effects of coastal orientation of 45^o with a strong northeasterly wind creates a good setting for current to split into northward and southward direction. The water mass flowing from GOT caused the water mass flows southward along the ECPM coastline (Camerlengo & Demmler, 1997). Buranapratheprat *et al.* (2006) reported that during SW monsoon the lower part of GOT had a southward current direction and this was due to the eddy circulation in the GOT basin. This southward current flowed along the eastern part of GOT and continued to the ECPM coast.

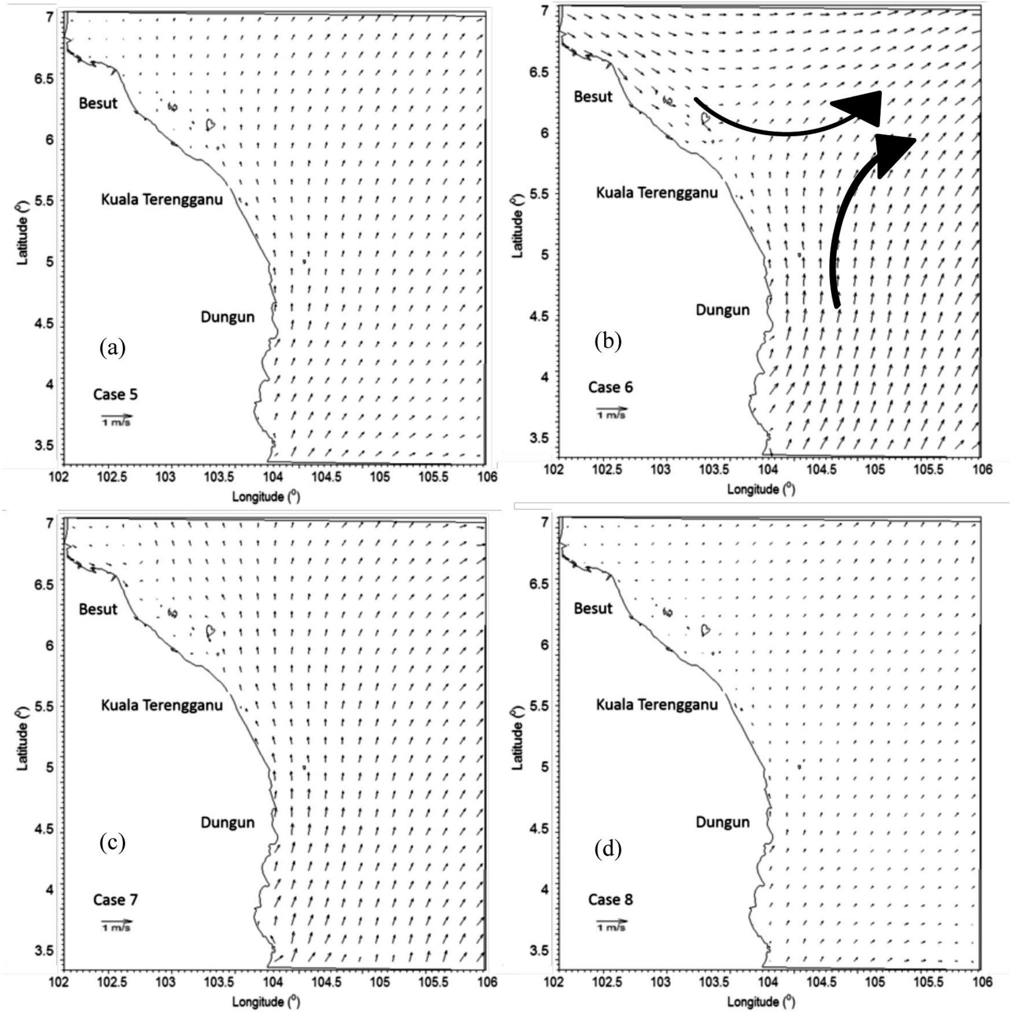

Figure 5: Mean surface current for 30 days of model run during SW monsoon (Case 5- Case 8)

During SW monsoon (Figure 5), for Case 5, Case 6, Case 7 and Case 8, the current with 20 m/s wind speed (Figure 5(a)) shows maximum current speed of 0.327 m/s. This clearly indicates that a wind driven current was higher during the northeast monsoon because of the stronger wind stress.

A quantitative comparison current speed rates along the Kuala Terengganu coast in different seasons was computed. The results indicate that the current speeds for a random location, for SW monsoon in Case 7 is 0.23 m/s while during NE monsoon in Case 1 is 0.32 m/s. Under the 20 m/s, Kuala Terengganu coast recorded less current speed in SW monsoon and stronger current speed during NE monsoon. It was due to the higher monsoon wind magnitude during NE monsoon compared to SW monsoon (see Figure 6). During NE monsoon, the wind dominated with 20% of northeasterly wind of speed ranging between 6 m/s to 8 m/s. However, during SW monsoon the wind speed slightly reduced to between 4 m/s to 6 m/s wind speed and dominated with 20% of southwesterly wind.

In the same manner as for NE monsoon case, water mass flowed parallel to the coastline and in same direction to the prevailing wind. In

Case 7 (Figure 5) stronger wind driven current was noticed in compared to Case 5. In Case 5 and 6 (Figure 5) there were coastal current from northward and southward direction convened and flow from coast towards the open sea in the middle of the domain. This seasonal convergence - divergence current circulation were observed in other models studied by Camerlengo and Demmler (1997); Chu *et al.* (1999); Akhir (2012) and Kok *et al.* (2015) where they found the convergence between the southward flowing current at the Malaysia coast and northward flow current from Karimata straits (Indonesia). As discussed in detail by Kok *et al.* (2015) the presents of sea surface temperature front along ECPM during SW monsoon is suggested due to upwelling event and the advection of cooler water from Karimata straits to the ECPM.

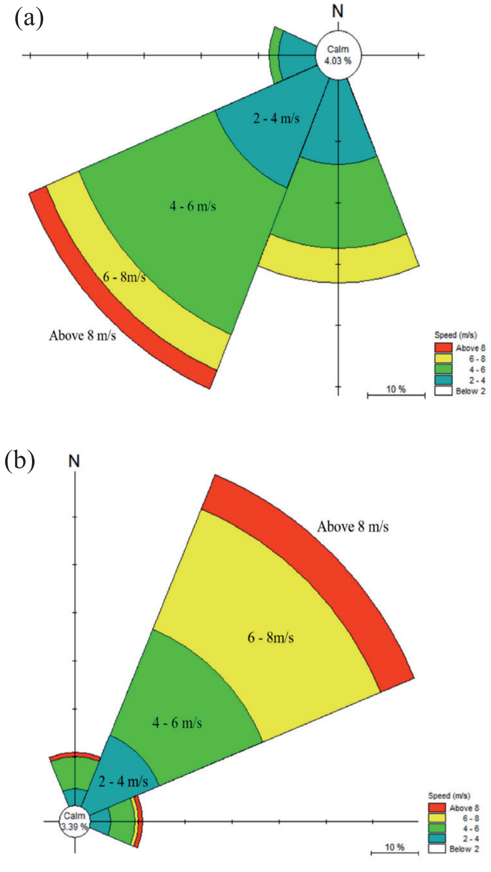

Figure 6: Wind rose plot during (a) SW monsoon and (b) NE monsoon

The upwelling event and the advection of cooler water can clearly be seen at Terengganu waters and this is due to the coastal current was relatively strong even the current near south of Vietnam already started to overturn its direction (Akhir, 2012). However, in a study done by Camerlengo and Demmler (1997) observed model with flat bottom do not resolve the cyclonic gyre. This study suggests that this cyclonic gyre drives the convergence - divergence currents along ECPM and monsoon seasons wind define the direction of currents. The convergence circulation patterns occurred in SW monsoon due to southwesterly wind while in NE monsoon happened in divergence circulation pattern due to northeasterly wind.

Similar with previous studies (Camerlengo & Demmler, 1997; Hu *et al*., 2000; Cai *et al.*, 2002) the results from this study supported the argument that wind has a great influence to strengthen the current speed and dynamic changes of current direction within the coastal area specifically in Terengganu waters. The results also proposed that the monsoon characteristic during SW monsoon the current flows in consistent magnitude compare to NE monsoon current.

In order to support this findings, the field data measurement of current speed and direction in August and December were observed by in Figure 7 and Figure 8. The August measurement represents the SW monsoon season while December measurement represents the NE monsoon season as normally monsoon seasons reached their peak during these two months. In August (Figure 7), current flowed in southward direction with average speed of 0.1 – 0.2 m/s. However in December (Figure 8), northward current direction dominated this month with average of 0.2 – 0.3 m/s current speed. It proves that northeasterly monsoon wind drove stronger current compared to southwesterly wind.

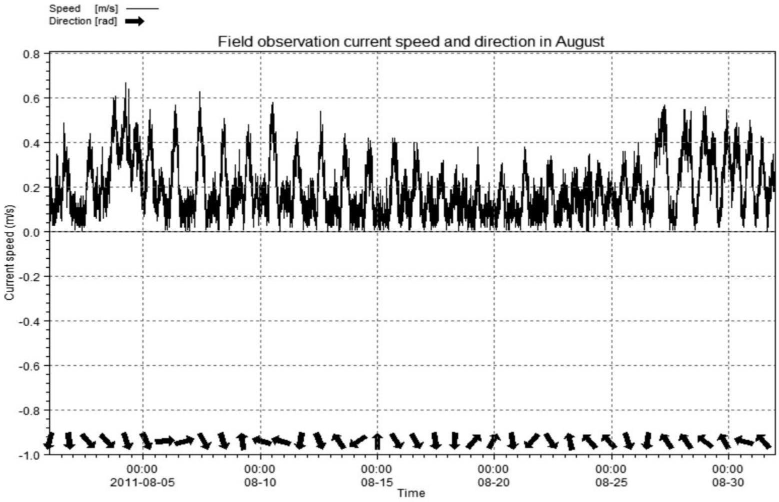

Figure 7: Current speed and direction in August

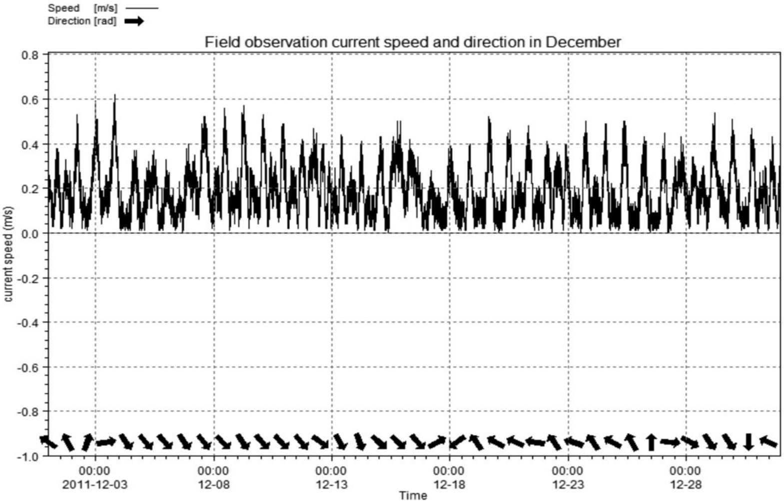

Figure 8: Current speed and direction in December

Conclusion

This study contributes to the understanding in the influence of monsoon winds on the current circulation patterns in Terengganu waters. The eight case studies were performed by applying different magnitude and direction of wind stress forcing. The well-defined circulation features were captured through numerical modelling by applying different wind-stress scenario. Through the analysis, the model subjected to 20 m/s northeasterly wind generated a divergence current pattern off coast the ECPM. Meanwhile using 20 m/s southwesterly wind forcing, the model simulated a convergence current pattern off coast the ECPM. Potentially, the resulting convergence-divergence current pattern is due to the combination of seasonal monsoon wind direction, current circulation from GOT and coastal orientation of ECPM. This convergence-divergence current pattern enables to explain the seasonal monsoon winds, physical process and dynamic interaction between these factors in this region. The effect of wind stress forcing specifically during NE monsoon in the Terengganu waters is large despite it was larger in the offshore area. Based on model, wind is the main controlling factor of the water circulation system in Terengganu and wind forcing should be considered for model simulation for this region in future work.

Acknowledgements

This research was supported by E-Science Funding (Grant VOT 52055). We thank our colleagues from Institute of Oceanography and Environment (INOS) who provided facilities and expertise that greatly assisted the research.

References

Akhir, M. F. (2012). Surface Circulation and Temperature Distribution of Southern South China Sea from Global Ocean Model (OCCAM). *Sains Malaysiana*, 41(6): 701-714.

Akhir, M. F. (2014). Review of Current Circulation Studies in the Southern South China Sea. *Journal of Sustainability Science and Management*, 9(2): 21-30.

Akhir, M. F., Daryabor, F., Husain, M. L., & Tangang, F. (2015). Evidence of Upwelling along Peninsular Malaysia during Southwest Monsoon. *Open Journal of Marine Science*, 5(July): 273-279.

Akhir, M. F., Sinha, P. C., & Hussain, M. L. (2011). Seasonal Variation of South China Sea Physical Characteristics Off the East Coast of Peninsular Malaysia from 2002 - 2010 Datasets. *International Journal of Environmental Sciences*, 2(2): 569-575.

Azmy, A. R., Isoda, Y., & Tanagi, T. (1991). Sea Level Variations Due to Wind around West Malaysia. *Memoirs of The Faculty of Engineering, Ehime University*, XII: 148-161.

Buranapratheprat, A., Yanagi, T. Y., Sojisuporn, P. S., & Booncherm, C. (2006). Influence of Local Wind Field on Seasonal Circulations in the Upper Gulf of Thailand. *Coastal Marine Science*, 1(30): 19-26.

Cai, S., Huang, Q., & Long, X. (2003). Three-dimensional Numerical Model Study of the Residual Current in the South China Sea. *Oceanologica Acta*, 26(5-6): 597-607. http://doi.org/10.1016/S0399-1784(03)00053-7.

Cai, S., Su, J., Gan, Z., & Liu, Q. (2002). The Numerical Study of the South China Sea Upper Circulation Characteristics and Its Dynamic Mechanism, in Winter. *Continental Shelf Research*, 22(15): 2247-2264. http://doi.org/10.1016/S0278-4343(02)00073-0

Camerlengo, A., & Demmler, M. I. (1997). Wind-driven Circulation of Peninsular Malaysia's Eastern Continental Shelf. *Scientia Marina*, 61(2): 203-211.

Camerlengo, A., & Somchit, N. (2000). Monthly and Annual Rainfall Variability in Peninsular Malaysia. *Journal Science and Technology*, 8(1): 73-83.

Chu, P. C., Edmons, N. L., & Fan, C. (1999). Dynamical Mechanisms for the South China Sea Seasonal Circulation and Thermohaline Variabilities. *Journal of Physical Oceanography*, 29: 2971-2989.

Daud, N. R., & Akhir, M. F. (2015). Hydrodynamic Modelling of Bidong Island Vicinity Waters. *Open Journal of Marine Science*, 3:1-18.

DHI. (2009). *MIKE ZERO: Creating 2D Bathymetries Bathymetry Editor & Mesh Generator*.

DHI. (2011). *Mike 21 and Mike 3 Flow Model Scientific Documentation*. Denmark.

Fang, G., Wang, G., Fang, Y., & Fang, W. (2012). A Review on the South China Sea Western Boundary Current. *Acta Oceanologica Sinica*, 31(5): 1-10. http://doi.org/10.1007/s13131-012-0231-y.

Fang, W. (2002). Seasonal structures of upper layer circulation in the southern South China Sea from in situ observations. *Journal of Geophysical Research*, 107(11): 3202. http://doi.org/10.1029/2002JC001343.

Hu, J., Kawamura, H., Hong, H., & Qi, Y. (2000). A Review on the Currents in the South China Sea : Seasonal Circulation , South China Sea Warm Current and Kuroshio Intrusion. *Journal of Oceanography*, 56: 607-624.

Kok, P. H., Akhir, M. F. M., & Tangang, F. T. (2015). Thermal Frontal Zone along the East Coast of Peninsular Malaysia. *Continental Shelf Research*, 110: 1-15. http://doi.org/10.1016/j.csr.2015.09.010.

Lee, K. S., & Seng, L. Y. (2009). Simulation Studies on the Electrical Power Potential Harnessed by Tidal Current Turbines. *Journal of Energy and Environment*, 1(1): 18-23.

Loo, Y. Y., Billa, L., & Singh, A. (2014). Effect of Climate Change on Seasonal Monsoon in Asia and Its Impact on the Variability of Monsoon Rainfall in Southeast Asia. *Geoscience Frontiers*, 6(6): 1-7. http://doi.org/10.1016/j.gsf.2014.02.009

Mansor, S., Tan, C. K., Ibrahim, H. M., & Mohd Shariff, A. R. (2001). Satellite Fish Forecasting in South China Sea. *Asian Conference on Remote Sensing (ACRS)*, (November): 5-9.

Marghany, M., & Hashim, M. (2010). MODIS Satellite Data for Modeling Chlorophyll-a Concentrations in Malaysian Coastal Waters. *International Journal of the Physical Science*, 5(10): 1489-1495.

Nicholson, S. E. (2011). *Dryland Climatology*. Cambridge University Press.

Quanan, Z., Susanto, D. R., Ho, R. C., Song, T. Y., & Xu, Q. (2007). Statistical and Analysis of Generation Mechanisms of Solitary Internal Waves in The Northern Souh China Sea. *Journal of Geophysical Research*, 1: 112.

Pedersen, T., Siegel, E., & Wood, J. (2007). Directional Wave Measurements from a Subsurface Buoy with an Acoustic Wave and Current Profiler (AWAC). *Oceans,* 2007: 1-10. http://doi.org/10.1109/OCEANS.2007.4449153.

Phuoc, T., Lanh, V. Van, Long, B. H., & Khin, L. V. (2002). Main Structures of Sea Surface Temperature (SST) in South China Sea from Satellite Data. *Asian Conference on Remote Sensing (ACRS)*, (1999).

Sharbaty, S. (2012). Simulation of Wind Driven Currents for Continental Shelf of Golestan Province (Iran). *Internatinal Journal of Computational Engineering Research*, 2(2): 439-448.

Su, Y., & Weng, X. (1994). Water Masses in China Seas. *Oceanology of China Seas*, 1: 3-26.

Taira, K., Saadon, M. N., Kitagawa, S., & Yanagi, T. (1996). Observation of Temperature and Velocity in the Coastal Water off Kuala Terengganu , Malaysia. *Journal of Oceanography*, 52: 251-257.

Thompson, B., & Tkalich, P. (2014). Mixed Layer Thermodynamics of the Southern South China Sea. *Climate Dynamics*, 43(7-8): 2061-2075. http://doi.org/10.1007/s00382-013-2030-3.

Yaakob, O., Hashim, F. E., Mohd Omar, K., Md Din, A. H., & Koh, K. K. (2016). Satellite-based Wave Data and Wave Energy Resource Assessment for South China Sea. *Renewable Energy*, 88 (January 2016): 359-371. http://doi.org/10.1016/j.renene.2015.11.039.

Yang, H., & Liu, Q. (2002). A General Circulation Model Study of the Dynamics of the Upper Ocean Circulation of the South China Sea. *Journal of Geophysical Research*, 107: 1-14.

Zhang, H., Sannasiraj, S. A., & Chan, E. S. (2009). Wind Wave Effects on Hydrodynamic Modeling of Ocean Circulation in the South China Sea. *The Open Civil Engineering Journal*, 3(1): 48-61. http://doi.org/10.2174/1874149500903010048.