Journal Clean WAS (JCleanWAS)

DOI: http://doi.org/10.26480/jcleanwas.01.2020.01.07

ZIBELINE INTERNATIONAL PUBLISHING

ISSN: 2521-0912 (Print)
ISSN: 2521-0513 (Online)
CODEN: JCOLBF

RESEARCH ARTICLE

HYDRODYNAMIC MODELLING IN INSHORE REEF AREA WITHIN KUANTAN COASTAL REGION

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ARTICLE DETAILS

Article History:

Received 23 December 2019
Accepted 28 January 2020
Available online 11 February 2020

ABSTRACT

Current circulation provides major transport mechanism especially for benthic organism in the ocean. The present study described current circulation in inshore reef area within Kuantan coastal region by applying a numerical modelling of MIKE 21 Flow Model FM software. Model simulation produced good outcomes when compared with field data measurement with root mean square error (RMSE) for surface elevation, current speed and direction were below 20. Results also clearly indicated that current speed in inshore reef area was highly correlated with local tidal pattern in which higher flow speed were observed during high tides compared to low tide. Contrary to previous belief, our results clearly show the prevalence of tidal forcing in shaping current flow pattern in the study area since the impact of wind forcing was minimal during different monsoon seasons. This study gave new insight into how local tidal properties can regulate hydrodynamic pattern especially in fine-scale inshore reef area.

KEYWORDS

Inshore reef, MIKE 21, Hydrodynamic, Tidal forcing, Kuantan coastal region.

1. INTRODUCTION

The dynamic of current circulation within coral reef ecosystem might regulate spatial distribution of temperature, oxygen, nutrient and other planktonic or benthic organism (Zhang et al., 2013; Gruber et al., 2017; Falter et al., 2004; Wyatt et al., 2010). Ocean circulation also is the major transport mechanism in the ocean. The magnitude and direction of current play some important roles in sediment transport, coastal upwelling and dispersal pattern of marine organism. For coral reef, current circulation pattern directly influence population connectivity since coral larvae depends on prevailing current during pelagic larvae duration. Balok reef is an inshore reef located approximately 9 km from the Balok Beach, Kuantan Pahang. This reef has received more attention for the past decades especially for recreational diving and fishing activities. Previous study in five shallow reef sites (less than 20 m depth) in Balok reef has indicated that this inshore reef has 'fair' coral cover with overall coral cover of 39 % and could serve as good nursery and breeding ground for fish within this area (Hanapiah et al., 2019). Although understanding local current circulation in reef environment is fundamental for most study related with coral ecosystem, there has been less documented study available in describing ocean circulation in the study area.

Regional ocean circulation might be influenced by several factors such as wind stress, tidal forcing and surface wave (Zhang et al., 2009). Earlier numerical modelling works in this region suggested that ocean circulation is largely influenced by wind stress forcing (Tangang et al., 2011; Pa'suyaa et al., 2014; Daud et al., 2016). For instance, numerical modelling study on oceanic circulation in the Terengganu coast has concluded that wind stress is a major driving factor for the coastal current pattern (Daud et al., 2016). Therefore, the direction and magnitude of current flow in the study area might also be influenced by seasonal monsoon pattern. The prevailing current flows to southward during Northeast monsoon while moving towards north during Southwest monsoon (Mohd Nasir and Camerlengo, 1997). This variability in prevailing current could influence the dispersal pattern of plantonik larvae since current is the main driving force for larval transport. Therefore, understanding on the general current flow trend in the study area is essential to begin with.

Balok reef resides on submerged shoal off Balok coastal area with approximately 4km^2 area based on the present bathymetry survey. Therefore, fine-scale modelling approach is needed to describe oceanic circulation within the reef area. Previous regional model in the east coast of Peninsular Malaysia used unstructured mesh with resolution between 2 km – 10 km which can be considered as coarse in the vicinity of Balok

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Cite the Article: Muhammad Faiz Mohd Hanapiah, Shahbudin Saad, Zuhairi Ahmad (2020). Hydrodynamic Modelling In Inshore Reef Area Within Kuantan Coastal Region. *Journal Clean WAS, 4(1): 01-07.*

reef. Hence, present model implies finer mesh size with resolution between 100 m to 2 km in order to demonstrate ocean circulation within reef area. Such approach has produced different results in the past in which finer scale model has revealed the emergence of tidal pattern in influencing current pattern in southern part of Johor (Jusoh et al., 2014). Due to proximity to the mainland, it can be postulated that tidal pattern might give greater influence on oceanic circulation pattern in Balok reef. The primary objective of this study is to establish and validate a fine scale hydrodynamic base model for Balok reef using MIKE 21 flow model FM. This numerical modelling software package was developed by DHI (Danish Hydraulic Institute) Water and Environment® and capable of modelling hydrodynamic pattern in coastal region. A validated base model is essential for more application of hydrodynamic modelling such as sediment transport and elucidating coral larvae dispersal.

2. METHODOLOGY

The model domain area spanned approximately 220 km from Kuala Dungun in Terengganu and Kuala Rompin in the south of Pahang as shown in Figure 1a. Due to the extensive size of the model domain area, bathymetry data was generated using secondary input from the Royal Malaysian Navy (RMN) and General Bathymetry Chart of the Ocean (GEBCO) with a resolution of 1 km. Additionally, to increase spatial resolution of the bathymetry in the study area, an extended mesh was generated with finer resolution (100 m resolution) in the Balok reef area by using multi-beam echo sounder (Humminbird 998c). The data input was loaded into Mesh Generator tools in MIKE ZERO to produce domain area by bathymetry natural neighbor interpolation method. The model domain has three open boundaries (North, East and South) as indicated in Figure 1b. For field data collection, a single Acoustic Doppler Current Profiler (ADCP) was deployed in the inshore reef area (3º51'22.26" N, 103º27'8.82" E) as indicated in Figure 2. Four sets of simulation periods were designed for model calibration namely M1 (August 2017), M2 (October 2017), M3 (March 2018) and M4 (April 2018) as tabulated in Table 1.

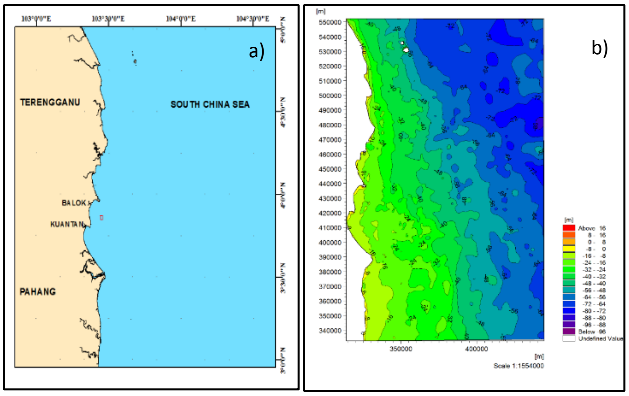

Figure 1: Location of project boundary for hydrodynamic model simulation (a) and resulting computational flexible mesh (b)

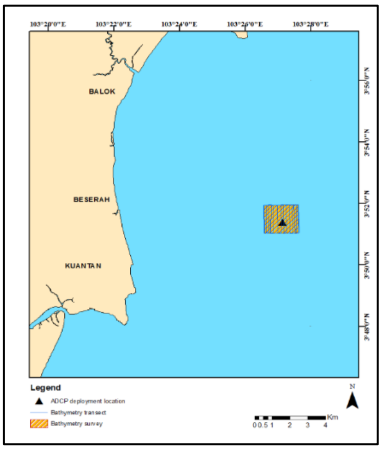

Figure 2: Overview of survey measurement location. The square area indicates extended mesh boundary for Balok reef.

Table 1: Survey activities and schedule in Balok reef, Kuantan

No	Activity	Survey Date	Usage
1	Bathymetry data	18th and 19th September 2018	Establishment of model setup and existing condition
2	Cumulative	M1 : 8th August 2017 M2 : 5th October 2017 M3 : 29th March 2018 M4 : 26th April 2018	Current flow data and current speed data are required for calibration and validation of the simulated model
3	Tidal data	M1 : 5th until 12th August 2017 M2 : 1st until 7th October 2017 M3 : 26th March until 1st April 2018 M4 : 23rd until 29th April 2018	Surface elevation data is pre-requisite for calibration and validation

Surface elevation for each simulation period was generated using tidal elevations data from the Admiralty Chart of Royal Malaysian Navy (Royal Malaysian Navy, 2018). Three sets of surface elevation time series data were used at each open boundary in the model domain which generated from three different secondary port namely Kuala Dungun in the north, Kuantan in the east and Kuala Rompin in the south. Wind flow and velocity are another important factor that may influence the modelling output since local current circulation is mainly driven by wind stress. For present hydrodynamic simulation, wind forcing for each simulation period was obtained from European Centre for Medium-Range Weather Forecasts (ECMWF) with spatial resolution of 0.125º x 0.125º and 6-hour temporal resolution. ECMWF is reliable secondary data which has been used in several previously hydrodynamic model establishment (Afandy et al., 2017). The detail of the model setup is showed in Table 2.

Table 2: Hydrodynamic model setup

Name	Setting
Module Selection	Hydrodynamic
Run length	7 d
Time step	600s
Flooding and Drying Depth (m)	0.005-0.05
Initial conditions	Wind and water level
Boundary conditions (open)	Tidal elevation
Boundary conditions (closed)	No normal flow
Eddy viscosity coefficient	0.28 m^2/s
Bed resistance coefficient	32 $m^{1/3}/s$

3. RESULTS

3.1 Surface elevation

Hydrodynamic model based on MIKE 21 for domain area was calibrated for surface elevation and shows good agreement with the water level in the field (Figure 3). It can be noticed from Table 3 that simulated data has less than 10 % RMS error compared with field data. This could give indication that the model meets the right configuration in terms of bathymetry, hydraulic and geometry. Surface elevation data could explain tidal pattern variation in the study area, either diurnal, semidiurnal or mixed tide. In the present study, it can be noticed that mixed semidiurnal tide pattern dominated tidal pattern during all simulation period. Most tidal pattern observed have two high and two low tide during one tidal cycle.

Table 3: Computed RMSE for surface elevation at each calibration location

Model Simulation	Calibration location	RMSE, %	Remarks
M1 (August 2017)	Kuala Dungun	8.74	≤ 10%
	Kuantan	9.56	≤ 10%
	Kuala Rompin	9.91	≤ 10%
M2 (October 2017)	Kuala Dungun	8.92	≤ 10%
	Kuantan	9.19	≤ 10%
	Kuala Rompin	9.89	≤ 10%
M3 (March 2018)	Kuala Dungun	8.09	≤ 10%
	Kuantan	9.18	≤ 10%
	Kuala Rompin	9.6	≤ 10%
M4 (April 2018)	Kuala Dungun	7.97	≤ 10%
	Kuantan	9.98	≤ 10%
	Kuala Rompin	9.6	≤ 10%

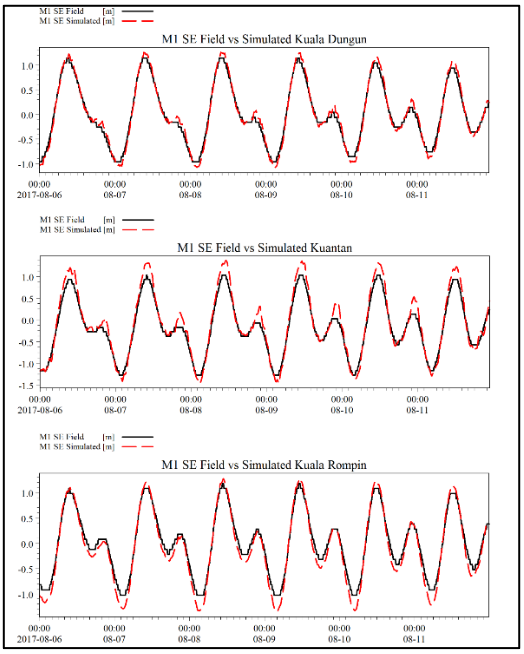

Figure 3: a) Hydrodynamic calibration for surface elevation during August 2017 (M1) simulation.

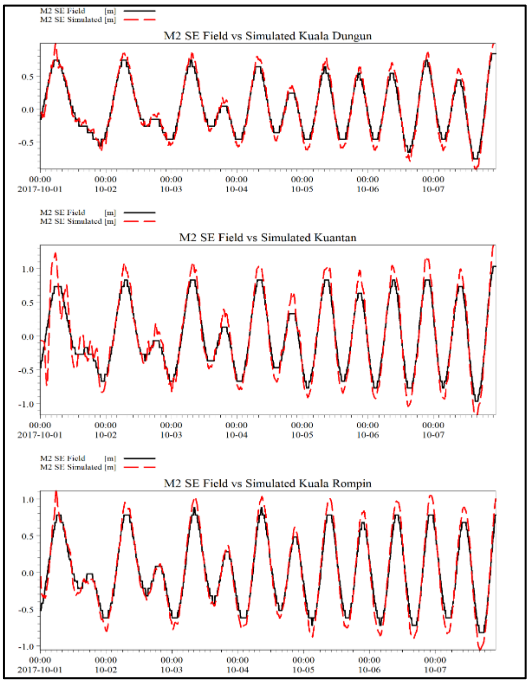

Figure 3: b) Hydrodynamic calibration for surface elevation during October 2017 (M2) simulation.

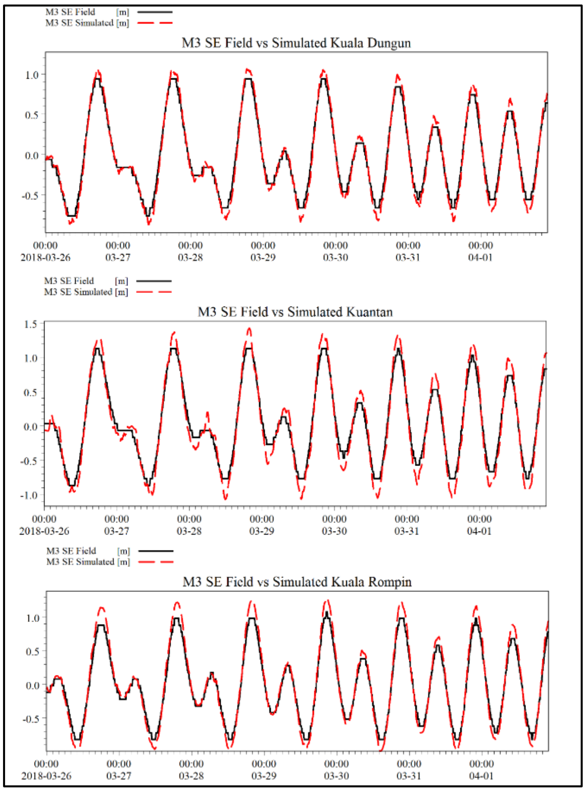

Figure 3: c) Hydrodynamic calibration for surface elevation during March 2018 (M3) simulation.

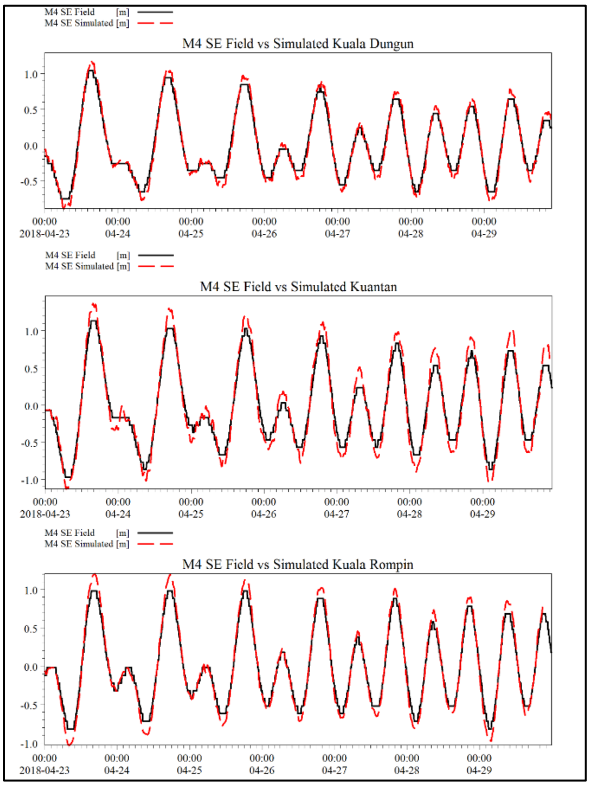

Figure 3: d) Hydrodynamic calibration for surface elevation during April 2018 (M4) simulation.

3.2 Current speed and direction calibration

The calibration results for both current and direction in all four models simulation was demonstrated in Figure 4 – Figure 7. It can be noticed that all model's simulation managed to meet requirement with RMS error ranging from 8.37 % – 13.35 % as shown in Table 4 for current speed and 17.08 % – 19.87% for current direction.

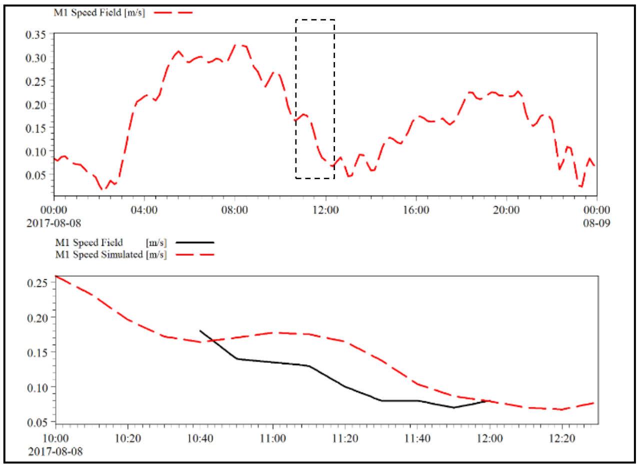

Figure 4: a) Current speed calibration comparison between field data (Black line) and simulated data (Red dashed) for August 2017 (M1). Field data collection were recorded on 8th August 2017 as indicated by dashed bracket in the upper graph.

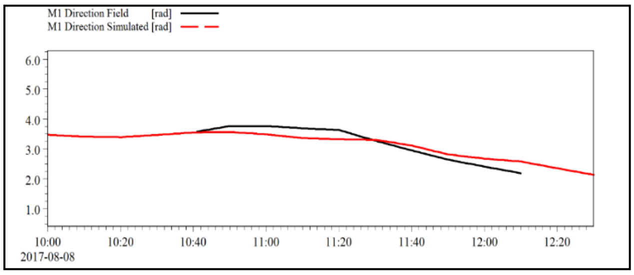

Figure 4: b) Current direction calibration comparison between field data (Black line) and simulated data (Red) for August 2017 (M1).

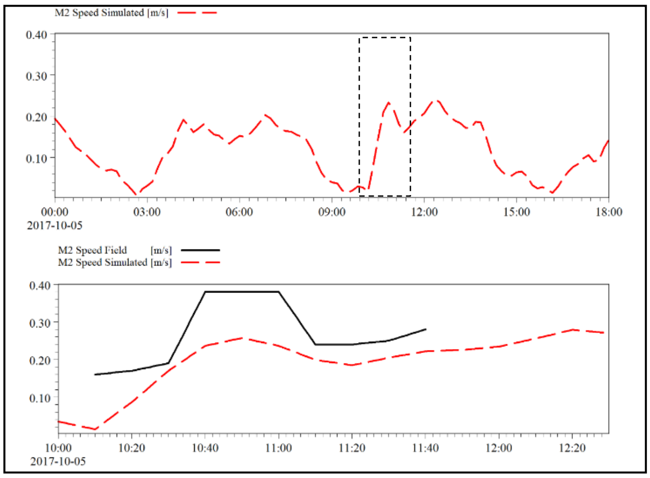

Figure 5: a) Current speed calibration comparison between field data (Black line) and simulated data (Red dashed) for October 2017 (M2). Field data collection were recorded on 5th October 2017 as indicated by dashed bracket in the upper graph.

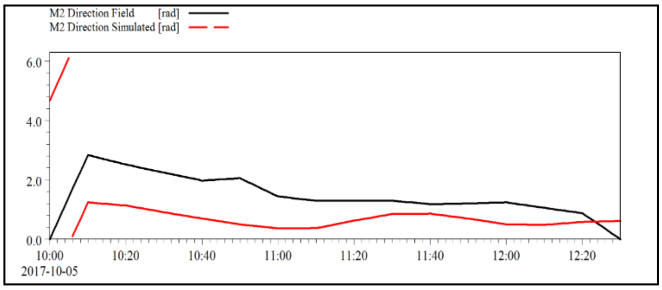

Figure 5: b) Current direction calibration comparison between field data (Black line) and simulated data (Red) for October 2017 (M2).

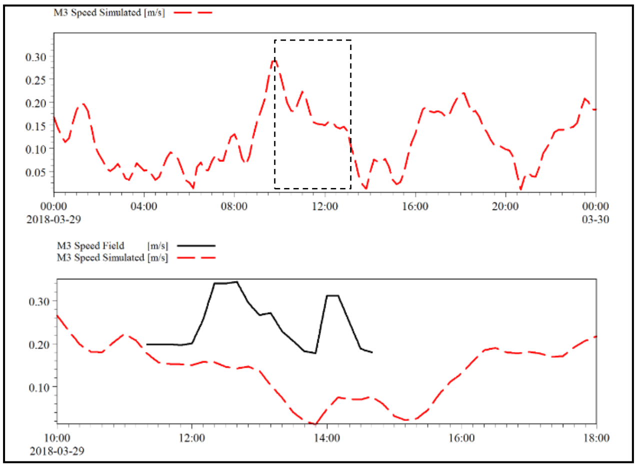

Figure 6: a) Current speed calibration comparison between field data (Black line) and simulated data (Red dashed) for March 2018 (M3). Field data collection were recorded on 29th March 2018 as indicated by dashed bracket in the upper graph.

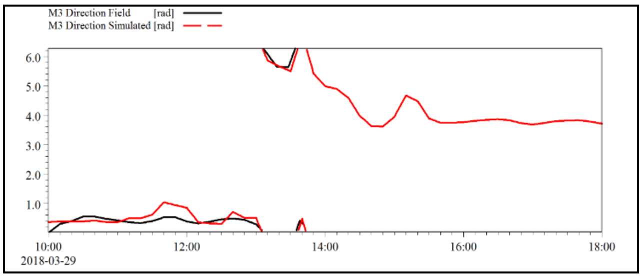

Figure 6: b) Current direction calibration comparison between field data (Black line) and simulated data (Red) for M3.

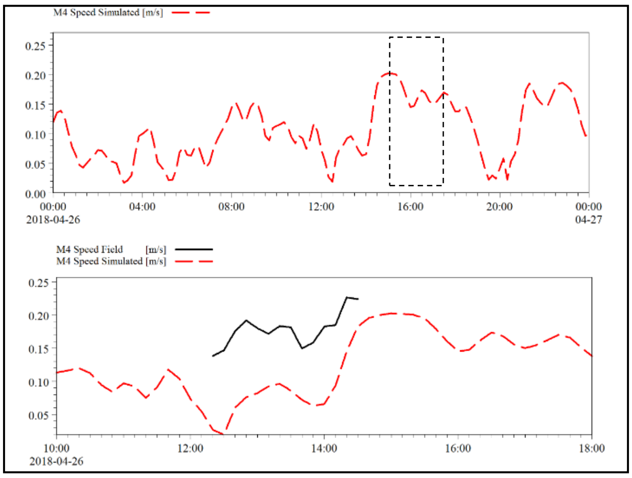

Figure 7: a) Current speed calibration comparison between field data (Black line) and simulated data (Red dashed) for April 2018 (M4). Field data collection were recorded on 26th April 2018 as indicated by dashed bracket in the upper graph.

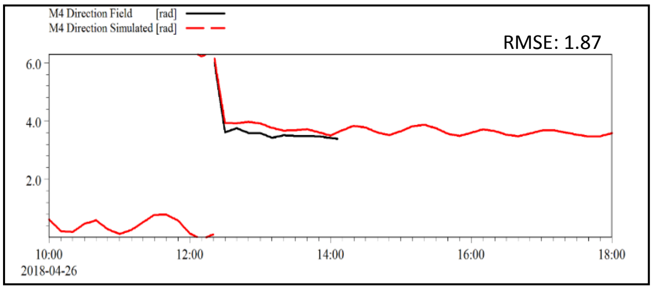

Figure 7: b) Current direction calibration comparison between field data (Black line) and simulated data (Red) for M4.

Table 4: Computed RMSE for current speed and direction for each model simulation.		
Model Simulation	RMSE, %	Remarks
Current Speed		
M1	8.37	≤ 20%
M2	9.27	≤ 20%
M3	13.35	≤ 20%
M4	9.82	≤ 20%
Current Direction		
M1	17.08	≤ 20%
M2	19.5	≤ 20%
M3	20	≤ 20%
M4	19.87	≤ 20%

3.3 Current flow pattern in Balok reef

Current flow pattern can be influenced by both tidal forcing and wind forcing. Simulated current speed were compared with both surface elevation and wind speed to demonstrate the impact of these factors on the hydrodynamic of Balok reef. It can be noticed that current speed strongly correlated with tidal pattern in which higher flow speed were observed during high tides for each model simulated. M1 model simulation indicate the highest maximum current speed (0.351 m/s) while M4 indicated the lowest maximum current speed (0.271 m/s) respectively as tabulated in Table 5. Figure 8 demonstrate the flow pattern during highest high tide (flood) and lowest low tide (ebb) for all four model simulations. Current flow in southward direction during flooding and reversed to northward during ebb. This pattern was observed in all model simulation indicating tidal forcing might influence the current flow in the reef area and could suggest that impact of wind forcing was inconsistent with the flow speed dynamic.

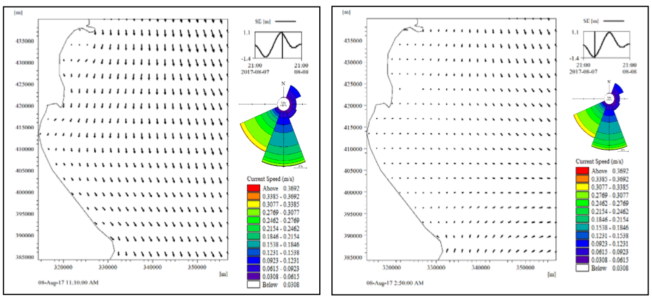

Figure 8: a) Flow pattern during flood and ebb tide for August 2017 (M1) simulation period. Rose plot indicate prevailing current in northward direction

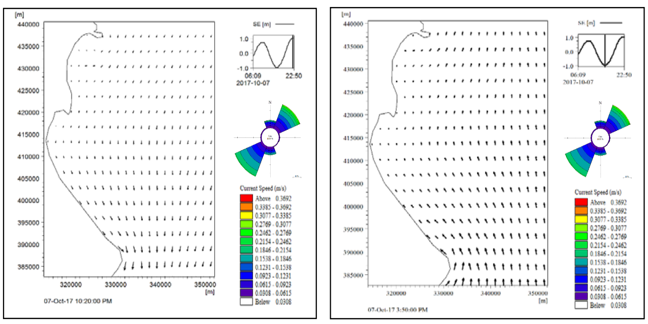

Figure 8: b) Flow pattern during flood and ebb tide for October 2017 (M2) simulation period. Rose plot indicate prevailing current in northeastward direction.

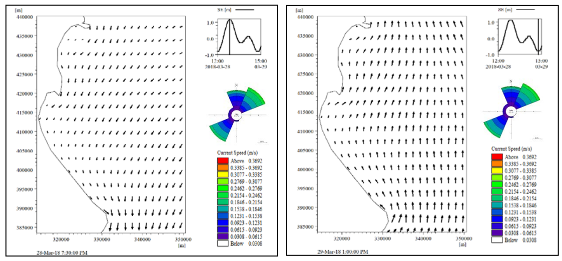

Figure 8: c) Flow pattern during flood and ebb tide for March 2018 simulation period. Rose plot indicate prevailing current in southwestward direction.

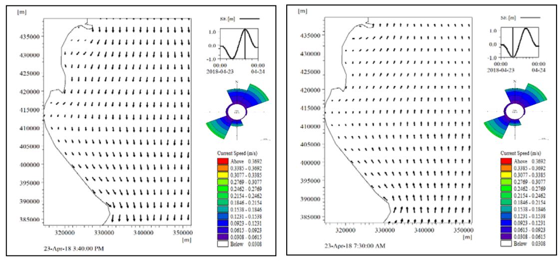

Figure 8: d) Flow pattern during flood and ebb tide for April 2018 simulation period. Rose plot indicate prevailing current in southwestward direction.

Table 5: Statistical analysis from hydrodynamic model simulation				
	M1	M2	M3	M4
Max	0.351	0.289	0.289	0.271
Min	0.004	0.002	0.004	0.004
Average	0.162	0.144	0.120	0.105

3.4 Seasonality of current pattern

To investigate the current pattern in Balok reef, numerical modelling was carried out to simulate current pattern during monsoon season (NE Monsoon, SW Monsoon and Inter-monsoon) for 2018. Figure 9 represent a time series data for current speed and surface elevation during each monsoon season. It can be noticed that wind forcing has little impact in affecting the current speed in Balok reef even though NE monsoon wind has relatively higher wind speed (maximum 9.97 m/s) compared with SW monsoon (4.15 m/s) and Inter-monsoon (3.82 m/s) as shown in Table 6. This month-length simulation clearly showed strong correlation between tidal pattern and current speed in which current speed tend to be high during high tides. SW monsoon shows higher maximum current speed (0.457 m/s) compared to NE monsoon (0.389 m/s) as shown in Table 6. The prevailing current flow varies between these three-monsoon period in which during northeast monsoon current flow in the southward direction with an average speed of 0.148 m/s (Figure 9a). Inversely, the prevailing current in SW monsoon was in northward direction with an average speed of 0.15 m/s (Figure 9b). As for inter monsoon it can be noticed that the prevailing current was in northward direction with an average speed of 0.142 m/s (Figure 9c).

Table 6: Statistical analysis for both wind speed input and hydrodynamic model simulation during monsoon season.			
	NE monsoon (m/s)	SW monsoon (m/s)	Inter monsoon (m/s)
Wind speed			
Max	9.97	4.15	3.82
Min	0.64	0.57	0.2
Average	4.65	1.83	1.42
Current speed			
Max	0.389	0.457	0.399
Min	0.001	0.002	0.001
Average	0.148	0.150	0.142

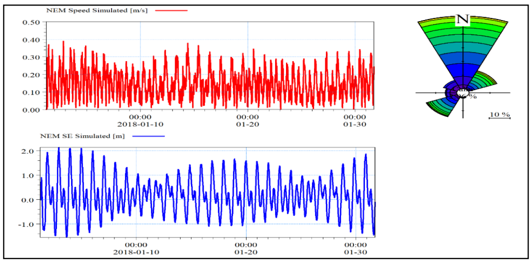

Figure 9: a) Current speed and surface elevation simulation during Northeast monsoon 2018. Rose plot indicate prevailing current in southward direction.

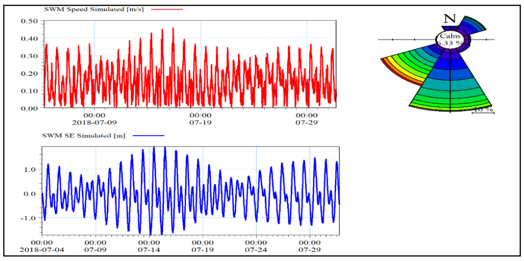

Figure 9: b) Current speed and surface elevation simulation during Southwest monsoon 2018. Rose plot indicate prevailing current in northward direction.

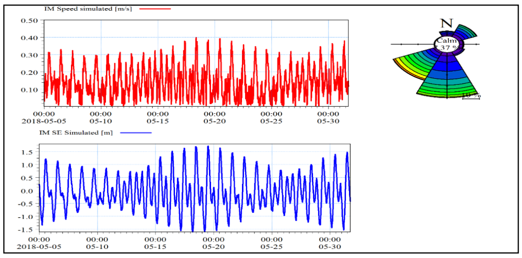

Figure 9: c) Current speed and surface elevation simulation during Southwest monsoon 2018. Rose plot indicate prevailing current in northward direction.

4. Discussion

This study gave new insight into how local tidal properties can regulate hydrodynamic pattern especially in fine-scale inshore reef area. It can be observed in the hydrodynamic simulation that the flow pattern in study area correlate with the influence of mixed tide which has two tidal phases in one tidal cycle (Figure 3). Mixed tide is characterized by having a large inequality in both high and low water height (Jusoh et al., 2014). The exchange between these two tidal phases create substantial flow speed which may resulted in relatively high current speed observed during the high tides.

Tide-driven current pattern was observed in a fine scale numerical model in Southwestern of Johor (Jusoh et al., 2014). They discovered that water flows in the study area were mainly influenced by the adjacent water flow from Malacca and Singapore Strait. They also reported that current reach optimal speed during both flooding and ebb events. Elsewhere, tidal forcing influence was also observed in coral reef atoll and platform reef in Australia (Green et al., 2018). Therefore, present evidence clearly indicated that tidal forcing influence in current pattern in the study area in which high current speed often occur during high tide and vice versa. Such pattern can be observed in all model simulation (Figure 4-Figure 7). Previous studies on ocean circulation have indicated the prevalence of wind forcing in regulating hydrodynamic in the east coast of Peninsular Malaysia region (Daud et al., 2016; Daud et al., 2015). Contrary to this believe, wind forcing influence was inconsistent with the magnitude of current speed in the present study. It can be postulated that such discrepancies occur due to large differences in terms of mesh resolution applied in the model. Lower resolution unstructured mesh (range 5 – 50 km) to demonstrate hydrodynamic pattern in the Terengganu coast (Daud et al., 2016). This might cause the resulting models were majorly influenced by the wind forcing rather than another factor. Our model simulation has finer unstructed mesh size with 100 m resolution in the reef area and 2 km across all model boundary. Finer scale model is essential in hydrodynamic study to describe the current pattern in small scale region. Elsewhere, fine scale unstructed mesh (600- 800 m) was also applied in southern Johore and has produced comparable results to our findings (Jusoh et al., 2014).

Seasonal comparison simulation clearly indicated that different monsoon winds pattern has minimal impact on the current pattern in Balok reef. Evidence clearly shows strong correlation between tidal pattern and current speed for all three model simulations. It can be noticed that there were not many differences in current speed between NE and SW monsoon 2018 even though stronger wind speed observed during NE monsoon. In fact, SW monsoon has higher maximum current speed compared to NE monsoon. This has even strengthened our belief that tidal forcing was indeed prevalence in regulating hydrodynamics in Kuantan coastal region. Nevertheless, it can be noticed that monsoon pattern could shape in the overall current flow in the study area. Current rose plot clearly indicates the differences between prevailing current direction for both NE and SW monsoon. Current flow in southward direction during NE monsoon and reversed back in northward direction during SW monsoon as shown in Figure 9. During NE monsoon, winds blow from the northeast and creating oceanic current known as Vietnam Coastal Current which flow southward along the coast of Vietnam and splitting into two branches; an eastward current towards Natuna Islands and southward current which flow along the east coast of Peninsular Malaysia towards Karimatan Strait (Yang, 2002). It was also suggested that during SW monsoon, oceanic current in the southern part of east coast of Peninsular Malaysia flow north-eastward towards coastal area (Pa'suyaa et al., 2014).

Current pattern plays important role in shaping the coral community structure. Recent study on coral community structure indicated that Balok reef dominated by wave-tolerant taxa such as massive *Porites* and *Dipsastarea*. *Acropora* species, which is the most abundant coral in the east coast of peninsular Malaysia was less abundant in Balok reef (Hanapiah et al., 2019). The nature of branching morphologies for these taxa is vulnerable towards high wave energy (Madin and Connolly, 2006). It is discovered that in Tioman Island, *Acropora* was highly abundant in low current speed reef (0.035 m/s) in Renggis Island while massive *Dipsastraea* dominated higher current speed (0.172 m/s) in Teduh Bay (Halid et al., 2016).

5. Conclusion

We have demonstrated in the present study that tidal characteristic has major influence in regulating ocean circulation in inshore reef area. Observation on all calibration models and seasonal current pattern simulations reveal a strong effect of tidal forcing on current flow in Balok reef rather than wind stress forcing as previously reported in regional scale. The present evidence indicate that hydrodynamic model validation performed reasonable match between modelled and measured current speed even though within limited period of field data input. Balok reef may represent ideal site to study the strength of tidal forcing in regulating hydrodynamic in inshore reef. Such insight can be applied to similar reef systems which are presently undocumented in the literature.

Acknowledgement

We would like to thank Department of Marine Science, Kulliyyah of Science, International Islamic University Malaysia and INOCEM Research Centre, IIUM for technical assistance such as scuba diving equipment and logistic during field data collection. This project was funded by E-Science Grant (SF16-002-0071) under Ministry of Energy, Science, Technology, Environment and Climate Change, Malaysia.

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