Seasonal Current Circulation Patterns in the Waters of the Malacca Strait

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ABSTRACT

The Malacca Strait is a water that connects the Indian Ocean and the South China Sea (Pacific Ocean). The Straits of Malacca is the busiest waters because it is filled with activities in and out of ships, fishing activities, ecotourism, and community sea transportation. These activities significantly affect the condition of the waters in the Malacca Strait. Water conditions are greatly affected by oceanographic parameters. One of the most critical parameters is currents. This ocean current is a horizontal movement of water masses influenced by other oceanographic factors. This research was conducted in June - July 2022. This study aimed to determine the pattern of current circulation, direction, and speed of currents as well as sea level during conditions at full moon (highest tide) and new low tide (Lowest tide) each month and every season in the Straits of Malacca. The method used in this research is descriptive quantitative, where numerical data is collected to support the formation of numerical models such as wind, tidal, and bathymetry data. Numerical modeling is a function of the software to determine the pattern of current movement based on the data used. Based on the four seasons (West Season, Transition I, East, and Transition II) at high tide. The highest current speed ranges from 0.02 to 2.07 m/s, while at high tide, the highest current speed ranges from 0.03 to 2.58 m/s.

Keywords: Malacca Strait, Current circulation, Tidal

1. INTRODUCTION

The Strait of Malacca is a waterway that connects the Indian Ocean and the South China Sea (Pacific Ocean). The Strait of Malacca stretches between the island of Sumatra in western Indonesia, the Malaysian peninsula, and southern Thailand. The Malacca Strait is 500 miles (800 km) long and funnel-shaped, only 40 miles (65 km) wide in the south, and widens northwards for about 155 miles (250 km). The name Strait of Malacca comes from the important trading port of Melaka (formerly Malacca) in the 16th and 17th centuries on the Malay coast. As a link between the Indian Ocean and the South China Sea, the Strait of Malacca is the shortest sea route between India and China. In early times, the Strait of Malacca helped determine the direction of the great migration of Asians through the Malay Archipelago. Arabs, the Portuguese, the Netherlands, and England successfully controlled the Strait of Malacca. Singapore. One of the most important ports in the world, located at the southern end of the strait.

Oceanographic parameters significantly influence the condition of the waters, including the waters in the Malacca Strait. This opinion is supported by Gaol & Sadhotomo (2007), where the distribution and abundance of biological resources in waters are inseparable from the conditions and variations of oceanographic parameters. As is known, the abundance of biological resources is significant for living creatures, especially humans. By humans, many aquatic biological resources are explicitly utilized in fisheries. Humans use fish and other aquatic living creatures as a source of food and medicine.

One of the oceanographic parameters found in water is current. According to Hadi & Radjawane (2009), surface currents are the movement of water masses horizontally, which can be caused by wind blowing on the sea surface, patterns of sea depth, and the influence of sea tides, which cause differences in sea level (sea surface height) and the formation of patterns seawater circulation. Current circulation patterns in a body of water vary depending on the conditions of the oceanographic parameters. The waters of the

Malacca Strait are geographically located strategically, which is often used as a transportation route, so the current pattern is significant to study for ship traffic safety, apart from being a means of transportation.

Research on current circulation patterns, primarily using numerical modeling, has been widely carried out, such as research on current circulation patterns carried out by Anwar (2007), who researched current circulation patterns in the waters of the Rupat Strait using a two-dimensional hydrodynamic model, research by Denny & Agus (2012) regarding circulation patterns. Currents in the coastal waters of West Sumatra province. Furthermore, research conducted by Okol & Dian (2018) was a study of the results of running a surface current model using MIKE 21/3 software to determine the location of the Lombok-Nusapenida Strait Current Energy Station.

2. RESEARCH METHODS

Method

The method used in this research is a quantitative descriptive method. Quantitative descriptive analysis was carried out to examine surface current circulation patterns in the Malacca Strait. The research was divided into several stages: literature study, data collection (covering primary and secondary data), and parameter data processing using horizontal two-dimensional numerical modeling

Apart from using quantitative descriptive methods, this research also uses survey methods where it is necessary to observe current patterns and current speeds in the field as verification of the simulation model results later.

3. RESULT AND DISCUSSION

Hydrodynamic Modeling

The movement of water masses (hydrodynamics) in a body of water can be done using numerical modeling methods. Numerical modeling simulates current circulation patterns based on the law of conservation of mass (continuity) and conservation of momentum. The software that can be used for hydrodynamic modeling is MIKE 21, which has several modules according to the desired study. MIKE 21 Flow Model FM Hydrodynamic Module is used to model the currents.

MIKE 21 Flow Model FM Hydrodynamic Module simulates tide and flow patterns. This module is based on solution numerical two-dimensional shallow water equations–depth-integrated Navier-Stokes equations (Anisa et al., 2017). The Navier-Stokes equations describe the motion of a fluid and are a differential form of Newton's second law. This model consists of continuity and momentum equations. Spatial discretization of the domain model is performed using the finite volume method, in which the horizontal computational domain is divided into non-overlapping elements. In the two-dimensional case, the elements can be arbitrary polygons; however, only triangular and quadrilateral elements are used here. A triangle has three nodes, a centroid (heavy line), and three sides.

The hydrodynamic model in MIKE 21 is a general numerical system for water level and flow in lakes, rivers, estuaries, bays, and coasts. This model simulates non-permanent two-dimensional flow in a single-layer fluid (Vertically homogeneous). The mass and momentum conversion equations can be written in the DHI Software (2007) equation:

In the 2D case of shallow water flow, the following equations are solved in Cartesian coordinates:

$$\frac{\partial h}{\partial t} + \frac{\partial h\vec{u}}{\partial x} + \frac{\partial h\vec{v}}{\partial y} = 0$$

$$\frac{\partial h\vec{u}}{\partial t} + u\frac{\partial \vec{u}}{\partial x} + v\frac{\partial \vec{u}}{\partial y} = F\vec{v}h - gh\frac{\partial \eta}{\partial x} - \frac{h}{\rho o}\frac{\partial \rho}{\partial x} - \frac{gh^2}{2\rho o}\frac{\partial \rho}{\partial x} + \frac{\tau sx}{\rho o} - \frac{\tau bx}{\rho o} + \frac{1}{\rho o}\left(\frac{\partial S_{xx}}{\partial x} + \frac{\partial S_{xy}}{\partial y}\right) - \frac{\partial}{\partial x}\left(hT_{xx}\right) + \frac{\partial}{\partial y}\left(hT_{xy}\right) hu_s S$$

$$\frac{\partial h\vec{v}}{\partial t} + u\frac{\partial \vec{v}}{\partial x} + v\frac{\partial \vec{v}}{\partial y} = -F\vec{u}h - gh\frac{\partial \eta}{\partial y} - \frac{h}{\rho o}\frac{\partial \rho}{\partial y} - \frac{gh^2}{2\rho o}\frac{\partial \rho}{\partial x} + \frac{\tau sy}{\rho o} - \frac{\tau by}{\rho o} + \frac{1}{\rho o}\left(\frac{\partial S_{yx}}{\partial x} + \frac{\partial S_{yy}}{\partial y}\right) + \frac{\partial}{\partial x}\left(hT_{xy}\right) + \frac{\partial}{\partial y}\left(hT_{yy}\right) hv_s S$$

Where the solution indicates the value of the average depth, and$\vec{u}$ $v$is the velocity at the average depth given by:

$$h\vec{u} = \int_{-d}^{n} u\,dz, \qquad h\vec{v} = \int_{-d}^{n} v\,dz$$

General Condition

The study area of this research is the waters of the Malacca Strait, which is in a position in the southernmost region of the Malaysian peninsula (1°16′S 103°31′E) and the coastal area of the northeastern part of Sumatra Island (1°10′S 103°23.5′E) (Figure 1).

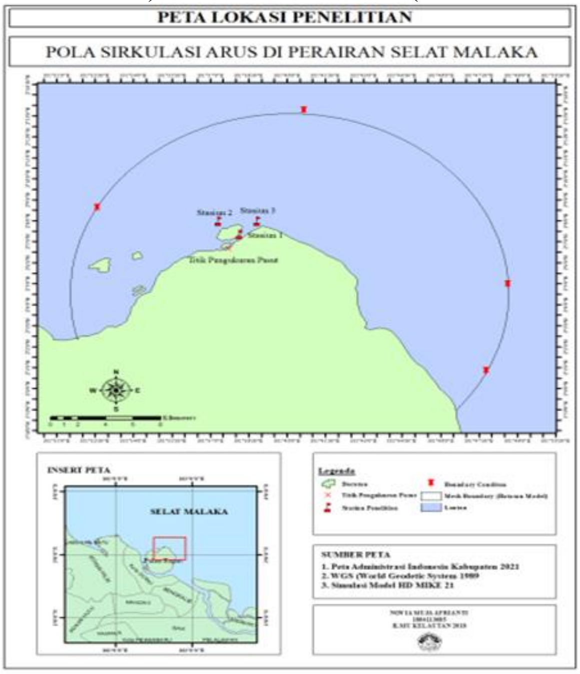


Figure 1. Research location map

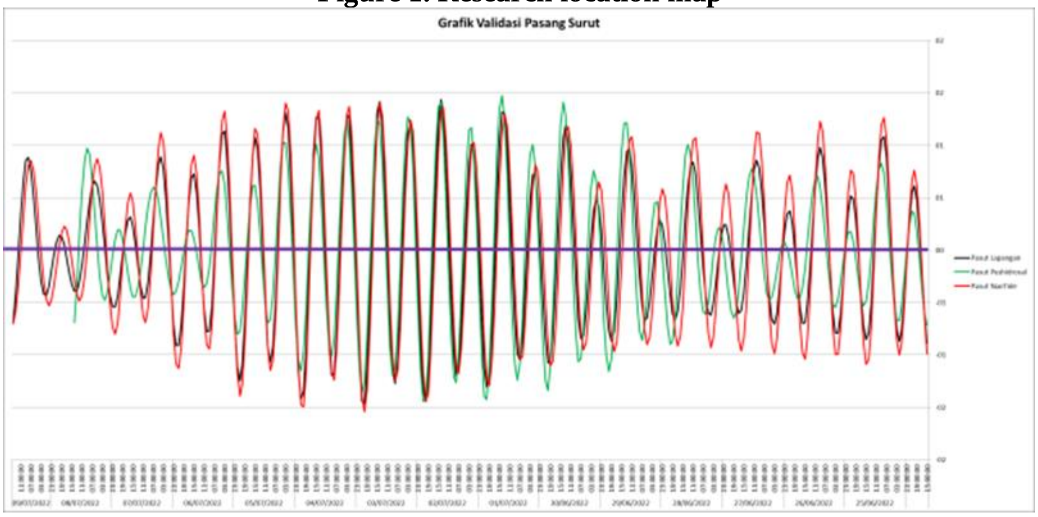


Figure 2. Verification graph of NAOTide tidal values, pushidrosal TNI-AL 2022 tidal value, and field tide values

Current velocity verification was carried out in 3 stations where the observed parameters were current speed and direction in the model and current speed and direction in actual conditions in the field. The position of each current speed measurement station can be seen in Table 3, while the current speed verification can be seen in Figure 3.

In Table 3, the field current speed station coordinates were chosen considering representing the characteristics of the local water area and considering the ease of data collection at the research location. Field current speed is taken by boat and close from land. Station 1 is in front of Panglima Nayan island and still directly faces the port. The depth of the waters is still shallow with calm current conditions. Meanwhile, station 2 is in front of Bird Island and directly facing the Malacca Strait. Depth of deep water with strong current conditions. Station 3 is northeast of Panglima Nayan Island and directly opposite the Malacca Strait. The water depth is deep with reasonably current solid conditions, and many shoals surround it.

Table 3. Field Current Velocity Data Retrieval Station

Station	Latitude	Longitude
1	2.12742	101.65335
2	2.13041	101.63718
3	2.11134	101.63597

In Figure 3, the current velocity based on the station model is 0.09 m/s, 0.3 m/s, and 0.12 m/s, respectively, while the field flow velocity based on the station is 0.08 m/s respectively, 0.33 m/s and 0.11 m/s. The current direction obtained for the three stations is from the northwest direction.

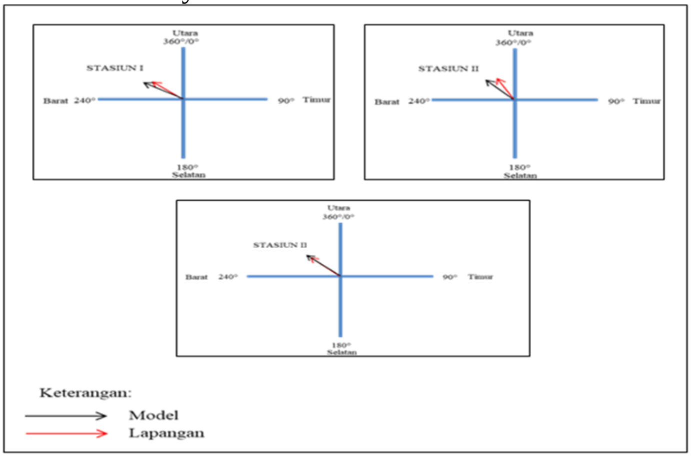
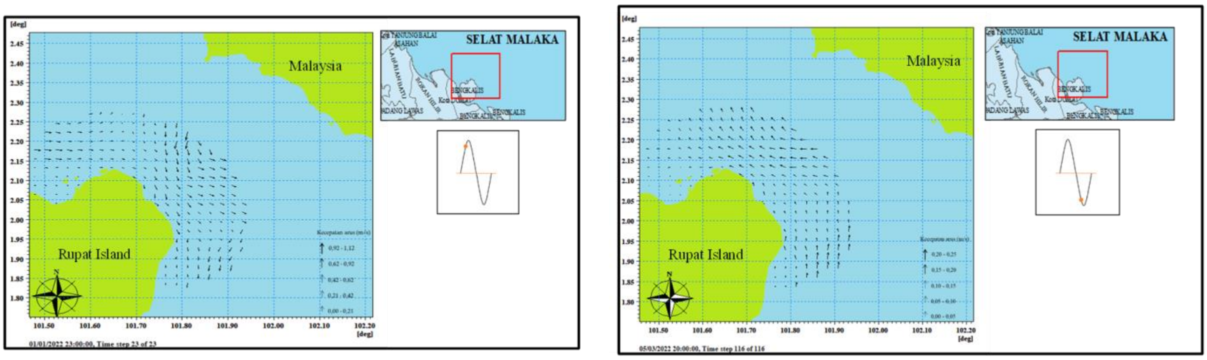


Figure 3. Model and field flow speed and direction values

Based on the comparison results, the model is similar to field conditions. This follows the statement by Amirullah et al. (2014), which states that model results can have the same value, higher or lower than field conditions. Even so, there is nothing wrong with using a model because it simplifies parameters that are used as domains to make it easier to carry out numerical solutions and visualize parameters that match the actual situation.

Current Circulation Patterns in the Waters of the Malacca Strait Based on Season

The current circulation pattern obtained from the processing of a two-dimensional hydrodynamic model in the software is taken to represent one month based on four seasons, namely the west monsoon, transition season I, east monsoon, and transition season II when the tide goes to the ebb and the ebb to the tide. The current circulation pattern is shown in (Figure 4-7).



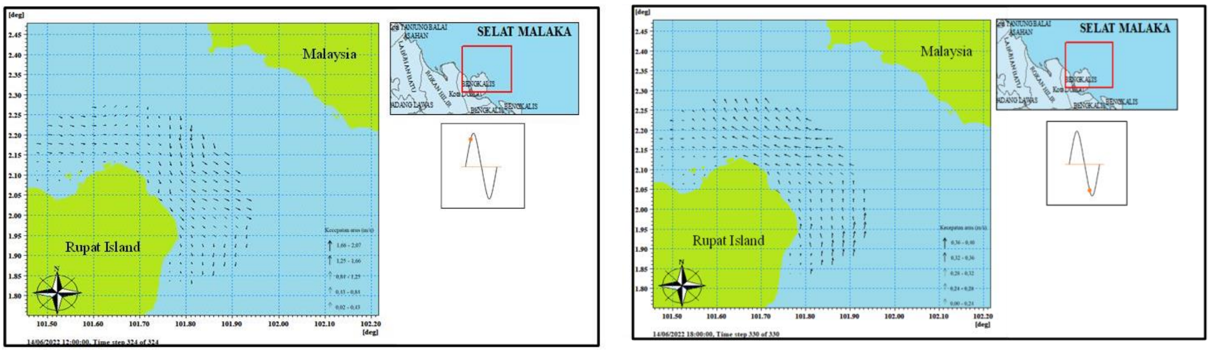
(a) (b)

Figure 5. The circulation pattern of currents in the transitional season I (March) when tide towards ebb (a) and ebb to tide (b)

The value of the current velocity in the transition season I (March) during low tide to high tide is in the range of 0 – 1.06 m/s with the current direction from the Northwest to the Northeast whereas, during the first transition season (March) during high tide, the current speed ranges from 0 – 0.25 m/s with the current direction, namely from the Northeast to the Northwest.

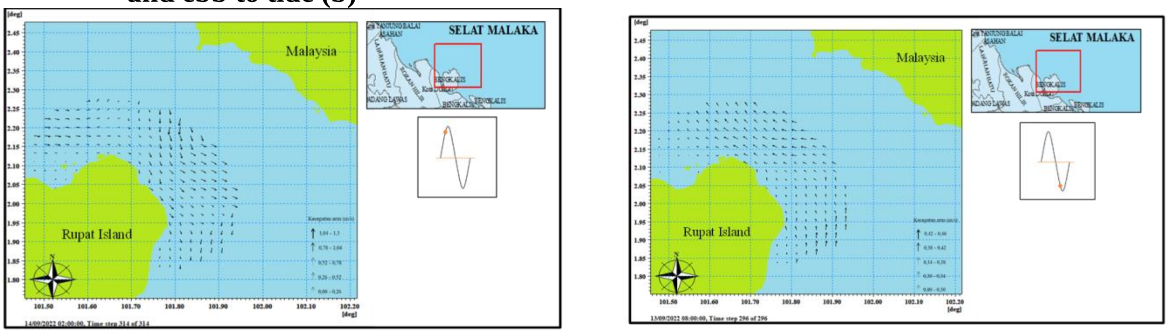
The value of current speed in the east

season (June) during low tide to high tide is in the range between 0.02 – 2.07 m/s with the current direction namely from the northwest towards the northeast, whereas in the east season (June) when high tide to low tide, current speed ranges from 0 – 0.40 m/s with the current direction namely from northeast to northwest.



(a) (b)

Figure 6. Circulation pattern of currents in the east season (June) when tide towards ebb (a) and ebb to tide (b)



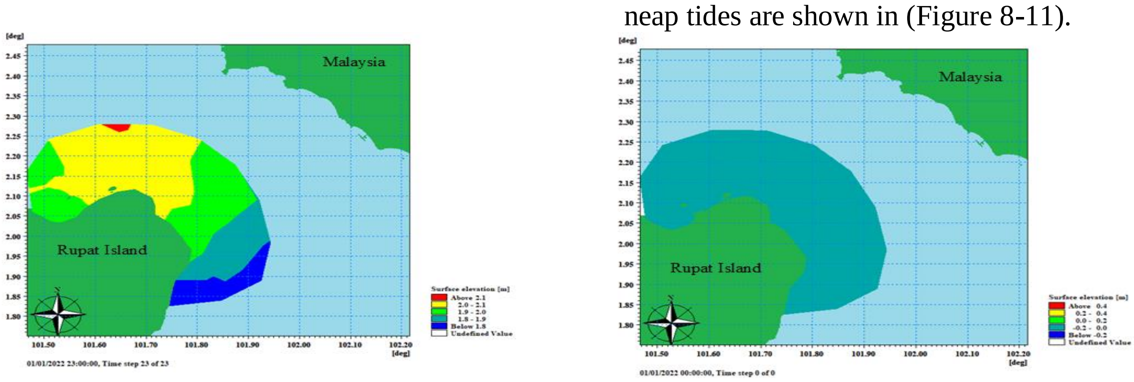
(a) (b)

Figure 7. Current circulation patterns in transition season II (September) when the tide is ebbing (a) and ebbing to tide (b)

The value of the current velocity in the transition season II (September) at low tide to high tide is in the range of 0 - 1.3 m/s with the direction of the current from the Northwest to the Northeast whereas, during the second transition season (September) when the tide is low, the current speed ranges from 0 - 0.46 m/s with the direction of the current, namely from the Northeast to the Northwest.

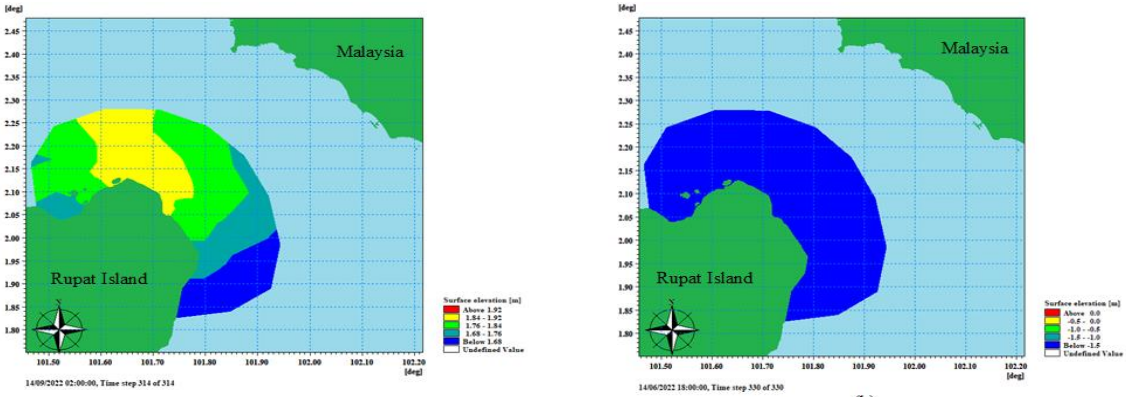
Sea Water Level Height (Surface Elevation) in the Waters of the Malacca Strait Based on Season

Based on the processing of a two-dimensional numerical model of sea level height (Surface elevation) based on one-month representation in 4 seasons, namely the west monsoon, transitions season I, east monsoon, and transition season II during full moon and neap tides are shown in (Figure 8-11).



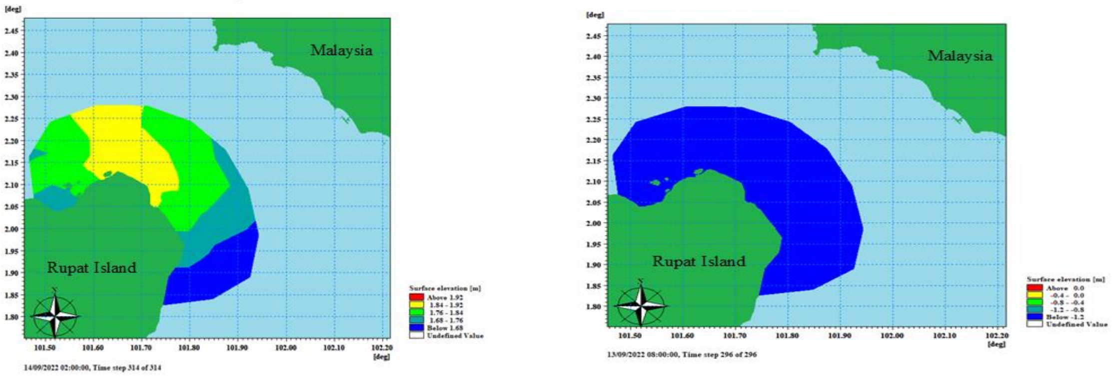
(a) (b)

Figure 8. Sea level height in the west season (January) When the tide is ebbing (a) and ebbing tide (b)



(a) (b)

Figure 9. Sea level height in the east monsoon (June) at ebb to ebb (a) and ebb to tide (b)



(a) (b)

Figure 10. Sea level height in transition season II (September) when the tide is ebbing (a) and ebbing to high tide (b)

Table 4. Flow speed every season

No.	Plug Type	Month	Current speed (m/s)	Flow Direction
1	Ebb towards high tide (West)	January	0 – 1.12	Northwest to Southeast
	Tide towards ebb (West)	January	0 – 0.25	Southeast to Northwest
2	Ebb towards ebb (Transition I)	March	0 – 1.06	Northwest to Southeast
	Ebb towards ebb (Transition I)	March	0 – 0.25	Southeast to Northwest
3	Ebb towards tide (East)	June	0 – 2.07	Northwest to Southeast
	Tide towards ebb (East)	June	0 – 0.40	Southeast to Northwest
4	Ebb towards ebb (Transition II)	September	0 – 1.3	Northwest to Southeast
	Ebb towards ebb (Transition II)	September	0 - 0.46	Southeast to Northwest

The sea level height during the transition season I (March) during successive low tides is between >1.8 m. Meanwhile, in the transitional season I (March), when the tide is between below -1.2 m (Figure 8). Sea level height in the east monsoon (June) from low to high tide is between – above 2.16. Meanwhile, during the east monsoon (June), during high tide and low tide, the sea level ranges from <1.5 m (Figure 9).

The sea level in transition season II (September) during low tide to low tide ranges from below 1.68 – 1.92 m, whereas, in the second transition season (September) during high tide to low tide, the sea level ranges from <1.2 m (Figure 10).

Analysis of Current Circulation Patterns and Sea Water Levels in Each Season

Based on the results, observations of current speed and sea level height based on the season were taken at low tide to high tide, where the tide in question is the highest, and high tide to low tide was observed at the lowest tide (Table 4).

Based on Table 4, it can be seen that the current speed during ebb to high tide is higher than when ebb to ebb. This indicates that the process of the highest tide occurring is faster than the process of the lowest ebb. This opinion regarding differences in current speed was expressed by Poerbandono & Djunasjah (2005), who explained that the maximum current speed would occur between high water and low water.

Hadi & Radjawane (2009) added that the maximum current speed is when there is a phase change from the highest to the lowest or highest tide. Meanwhile, during the highest tides and lowest low tides, it is an equilibrium phase where the current speed is relatively close to zero. This is the opinion that the best observations for current speed are taken at high tide and vice versa.

The current pattern at high tide is inversely proportional to low tide. This supports the opinion expressed by Brown et al. in Pratama et al. (2014), where the direction of the current tends to move back and forth with the direction of the current at the highest tide. The opposite is true at low tide.

Table 5. Sea level height every season

No.	Plug Type	Month	Sea level height (m)	Flow Direction
1	Ebb towards high tide (West)	January	Under 1.8 – above 2.1	Northwest to Southeast
	Tide towards ebb (West)	January	-0.2 - 0	Southeast to Northwest
2	Ebb towards ebb (Transition I)	March	1.35 – above 1.8	Northwest to Southeast
	Ebb towards ebb (Transition I)	March	Below -1.2	Southeast to Northwest
3	Ebb towards tide (East)	June	1.92 – above 2.16	Northwest to Southeast
	Tide towards ebb (East)	June	Below -1.5	Southeast to Northwest
4	Ebb towards ebb (Transition II)	September	Below 1.68 – 1.92	Northwest to Southeast
	Ebb towards ebb (Transition II)	September	Below -1.2	Southeast to Northwest

Based on Table 5, sea level height, commonly referred to as sea level topography, represents the distance between sea level and the earth's ellipsoid reference, commonly referred to as a good. This opinion was expressed by Fu (2014). This parameter is dynamic, and changes can be caused by various processes such as tides (Azis, 2006). Tide is one of the parameters generating currents and tide parameters from sea level. Therefore, based on the model, it is known that the movement of currents is closely related to changes in tides.

The sea level at low tide is higher than at low tide. Sea level height at low tide tends to be above zero, unlike sea level at high tide, below zero. This is because during ebb to high tide, there are very high tides causing sea level to rise. Conversely, during high to low tide, there is a very high tide, which causes the sea level to decrease.

Currents move from high sea level towards low sea level, following the opinion expressed by Supiyati (2005), which states that currents tend to move from high water level towards sea level. The water level is lower, and the currents move at the lowest ebb in both seasons. In the results obtained, the current moves from the northwest towards the southeast if we observe the whole season during full moon tide. This is because the sea level in the northwest direction is more significant than in the southeast direction and vice versa. During neap tide, the current moves from the southeast towards the northwest because the sea level in the southeast is more significant than in the northwest.

4. CONCLUSIONS

The research results show that the current pattern in the Malacca Strait is influenced by wind movement, where the resulting movement is always in the direction of the wind. The current pattern from ebb to tide is inversely proportional to ebb to ebb. From low to high tide, currents tend to move from the lowest to the highest sea level, different from high to low tide, where the dominant sea level is the same, but the currents still have the same pattern of movement. Variations in the value of the current speed and the resulting difference in the direction of the current are caused by the parameters that work to drive the speed and direction of the current.

The height of seawater at low tide is higher when compared to low tide. During low to high tide, based on the whole season, the current pattern originates from the Northwest to the Southeast because the sea level in the Northwest direction is more significant than in the Southeast. In contrast, the current direction originates from the Southeast to the Northwest during high tide.

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