Numerical study of tides in the Bay of Sabang

H A A Wahyudi¹, Y Haditijar², M Ikhwan³, R Wafdan¹, I Setiawan¹,², M Muhammad¹, S Sugianto³ and S Rizal¹,²,*

¹Department of Marine Sciences, Faculty of Marine and Fisheries, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
²Graduate School of Mathematics and Applied Science, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia.
³Department of Soil Sciences, Faculty of Agriculture, Universitas Syiah Kuala, Banda Aceh, 23111, Indonesia

*Email: syamsul.rizal@unsyiah.net

Abstract. This study aims to observe tidal sea behavior in Bay of Sabang by using a two-dimensional hydrodynamic model. The research domain was obtained from SRTM15, which had been interpolated so that it has a spatial resolution Δx = Δy = 0.1 minutes (185 meters). As a generator force, the open boundaries model is given five main tidal components (M2, S2, K1, N2, O1) obtained from TPXO 7.2 data. The model is simulated for 31 days with time step based on CFL condition criteria. Our model verification is quite good when compared with TMD prediction data (r = 0.9996). It shows that our model can be used for tidal hydrodynamics studies in Bay of Sabang. The results show that tides in Bay of Sabang are predominantly mixed prevailing semi-diurnal (F = 0.857). The speed of tidal currents in Bay of Sabang is quite small both for spring and neap tides. The difference in velocity between spring and neap tides reaches 0.6 cm/s.

1. Introduction
Bay of Sabang is administratively located on Weh Island, north of Aceh, Indonesia. The hydrodynamics of Sabang Waters are influenced by adjacent waters such as the Andaman Sea, the Malacca Strait, and the Indian Ocean [1].

The Andaman Sea is deep sea waters (an average of 1100 m) located in the northeast of the Indian Ocean, bordering Myanmar, Thailand, Malaysia and Indonesia [2]. Andaman Sea and Indian Ocean are strongly affected by the monsoonal system. It can produce different surface current circulation during NE monsoon and SW monsoon. Likewise, the productivity and temperature of the sea is quite extensive [3, 4]. Meanwhile, the Malacca Strait is very dominantly affected by tides [5].

Tidal phenomena are an event of periodic high and low sea levels that occur throughout the hemisphere due to the attraction of the earth, moon and sun [6]. Tides are the result of the force of gravitational attraction and centrifugal effect (thrust out of the center of rotation) [7]. The process of circulating water masses in coastal waters is dominantly generated by tidal currents [8].

Tides in the Indian Ocean, the Bay of Bengal, and the Andaman Sea have an impact on tides in the Bay of Sabang and the Malacca Strait [9, 10]. Tides of the Indian Ocean cross Aceh waters and Andaman Sea. This phenomenon can be seen from the increase in tidal phase changes in shallow waters.
Based on research [1] with a resolution of 18.5 km, it is known that tides in Aceh waters are divided into semi-diurnal and semi-diurnal mixtures. Bathymetry and island shape produce height variations and tidal currents. Thus the resolution of this model is important in getting tidal models in Aceh waters [11, 12, 13].

According to [14], representation of good seawater conditions is needed in coastal management and sea security. Coastal dynamics, such as waves and tidal currents, greatly affects the abiotic content of the sea [15]. The development of the marine model is currently developing for the prediction of seawater conditions in coastal areas such as tides and sea temperatures [16].

So far, the tidal information at Sabang Bay is still limited. Therefore, this paper aims to prepare and perform the two-dimensional numeric tide model simulation.

2. Materials and Methods
Sabang Bay was previously simulated with a 1D model by Setiawan et al., [17]. They showed good results but did not cover most of the Sabang Bay domain. This research uses numerical model that was derived by [18]. This model has consisted of nonlinear equations and linear Navier-Stokes. Models with linear equations have been applied in western of Aceh [19] and nonlinear equations have been successfully applied in the Malacca Strait [12], Gulf of Thailand [20], Aceh Barat Daya Waters [21], and Aceh Besar Waters [22]. In this study, we use the numerical model based on the nonlinear Navier-Stokes equation [18]. The resolution of the model is \( \Delta x = \Delta y = 0.1 \) minutes, while the time-step is derived according to the CFL condition. The domain bathymetry is obtained from SRTM 15 at coordinate 95.22 - 95.33 E and 5,835-5.92 N.

![Figure 1. The domain of model](image_url)
The data is interpolated at $\Delta x = \Delta y = 0.1$ minutes so that the grid size is 67x52. In open boundary, it was given main tidal components (M2, S2, K1, N2 and O1) obtained from TPXO 7.2. In the bottom friction, the force was given uniformly with parameter $r = 0.0025$ and TVD advection scheme. The results of the model are verified with predictions of Tidal Model Driven (TMD) during January 2017. Descriptions of the components of sea tides can be seen in Table 1.

| Constant | Period   | Amplitude correction | Phase correction | Amplitude | Phase |
|----------|----------|----------------------|------------------|-----------|-------|
| M2       | 12.4206024 | 1.01184              | 126.95103        | 0.4372   | 83.65 |
| S2       | 12.0000000 | 0.99932              | 0.13461          | 0.2060   | 116.5 |
| K1       | 23.9344704 | 0.97829              | 1.63348          | 0.1046   | 114.9 |
| N2       | 12.6583488 | 1.01183              | 47.76974         | 0.0833   | 74.8  |
| O1       | 25.8193416 | 0.96194              | 129.8077         | 0.447    | 182.58|

The tidal motion of the sea water is expressed by the following mathematical equation [17]

$$Z(t) = Z_0 \sum_{k=1}^{m} f_k H_k \cos(\omega_k t + \nu_k - g_k)$$

In the equation, $Z(t)$ is the water level at time $t$, $Z_0$ is the average water level, $f_k$ is the astronomical correction factor for the amplitude of the tidal generating element $H_k$, $\omega_k$ is the angular velocity, $\nu_k$ is the correction factor for phase, and $g_k$ is phase.

3. Results and Discussion
The tidal type in the Sabang bay waters is a semi-diurnal mixture, where the fromzal number obtained is 0.857. This is in accordance with the research conducted by Rizal [1] where the type of tides in the western waters of Sumatra mostly has semidiurnal or semidiurnal mixed tidal.
The verification results show that the model data equal to TMD predictions (see Figure 2). At spring tide, the range is 1.524 m for the model and 1.5216 m for the TMD, while for neap tides it is 0.4508 m for the model and 0.4637 for TMD.

Ebb current is indicated by the seaward flow, while flood current by the inland flow. The highest tidal current occurs during ebb current and flood current in spring tide conditions (Figure 3 and 4). Whereas in neap tide conditions at ebb current and flood current, there is the lowest tidal current (Figure 5 and 6). Spring tide is the highest flood and lowest ebb conditions, while the neap tide is the lowest flood and highest ebb conditions. When the highest flood and the lowest ebb, both conditions are not affected by tidal currents.

![Figure 3](image3.png)

**Figure 3.** Ebb current during spring tides (Jan. 13, 2017). The contour lines show the magnitudes of current while the vectors only show directions of current.

![Figure 4](image4.png)

**Figure 4.** Flood current during spring tides (Jan. 12, 2017). The contour lines show the magnitudes of current while the vectors only show directions of current.

The flood towards the ebb moves out of the coast to the north, but in the northwest, the current turn slightly and move towards the southwest. The highest current velocity is 0.8 cm/s in the east of the Bay of Sabang, and the lowest current velocity is 0.2 cm/s in the west. Current velocity at low tide conditions leads to pairs of Figure 3 not much different even tends to be the same as the ebb tide, where the highest current velocity is 0.8 cm/s and the lowest is 0.2 cm/s. Significant differences occur when flood tide current moves into the shoreline from the north. In other words, the flood tide is
The current velocity that occurs in both conditions has the same. The highest current is in the eastern part of the bay with relatively shallow waters.

Spring tide condition is caused by the full moon attraction with sea water, where this condition is very identical to the high sea level.

Figures 5 and 6 are the results of 2D models of the velocity and direction of tidal currents in the Bay of Sabang in January 2017 when the condition is neap tide. This condition is characterized by a low flood tide and relative high ebb tide. Therefore Neap tide is characterized by a weak current and usually occurs in the second week. In Figure 4, the current moves from the shoreline out towards the north with a weak current on the east side of Sabang bay, which the velocity is 0.2 cm/s. On the contrary, when the ebb toward flood tide, the current moves from the north to the shoreline with a current velocity equal to 0.2 m/s.

Different conditions occur during high tide and low tide. In this condition, the Bay of Sabang was very calm and tended not to flow. It is common in the bay waters such as Sabang bay because of the type of waters that are closed and surrounded the mainland. However, the current direction in both of
these conditions can still be seen in its movement. The current on the high tide condition, the inflow from the east and northeast to the coast, some of the currents turn towards the east of Sabang bay, and the rest turn out towards the northwest of Sabang Bay. The contrary occurs in low tide conditions, where the direction of the current moves in from the southwest and moves towards the southeast and turns out towards the northeast of Sabang Bay.

4. Conclusions
The two-dimensional tidal numerical simulation used five components (M2, S2, N2, K1 and O1) in the Bay of Sabang in January 2017. Numerical simulations show that the velocity of tidal currents when spring tide reaches 0.8 cm/s while neap tide is 0.2 cm/s. In general, the tidal currents that occur in the Bay of Sabang are relatively small, this is caused by deep waters and affects the speed of the current in the bay.

Acknowledgments
Authors would like to express gratitude to the Ministry of Research, Technology and Higher Education of Indonesia for financial assistance in term ‘PenelitianDasar’, under contract number: 72/UN11.2/PP/SP3/2019. We also thank UniversitasSyiah Kuala through facility support at Ocean Modelling Laboratory during the research.

References
[1] Rizal S, Damm P, Wahid M A, Sundermann J, Ilhamsyah Y, Iskandar T and Muhammad 2012 General circulation in the Malacca Strait and Andaman Sea: A numerical model study Am. J. Environ. Sci. 5 479-488
[2] Dutta K, Bhushan R and Somayajulu B L K 2007 Rapid vertical mixing rates in deep waters of the Andaman Basin Sci Total Environ 384 401–408
[3] Haridhi H A,Nanda M,Wilson C R and Rizal S 2016 Preliminary study of the sea surface temperature (SST) at fishing ground locations based on the net deployment of traditional purse-seine boats in the northern waters of Aceh - A community-based data collection approach Regional Studies in Marine Science 8(1) 114-121
[4] Haridhi H A,Nanda M,Haditiar Y and Rizal S 2018 Application of Rapid Appraisals of Fisheries Management System (RAFMS) to identify the seasonal variation of fishing ground locations and its corresponding fish species availability at Aceh waters, Indonesia Ocean and Coastal Management 154 46-54
[5] Rizal S 2000 The role of non-linear terms in the shallow water equation with the application in three dimensional tidal model of the Malacca Strait and Taylor Problem in low geographical latitude Continental Shelf Research 20(15) 1965-1991
[6] Douglas R M 2001 Physical Oceanography Department of Geophysical Science(Chicago: University of Chicago Illinois)
[7] Boyle G 2004 Renewable Energy Power for a Sustainable 2nd Edition(United Kingdom: Oxford University Press)
[8] Duxbury A B, Duxbury A C and Sverdrup K A 2002 Fundamentals of Oceanography(New York: McGraw Hill Companies)
[9] Bhagawati C, Pandey S, Dandapat S and Chakraborty A 2018 Dynamical significance of tides over the Bay of Bengal Dyn. Atmos. Oceans. 82 89-106
[10] Wyrtki K 1961 Physical Oceanography of the Southeast Asian waters Scripps Institution of Oceanography UC San Diego: Scripps Institution of Oceanography Retrieved from: http://escholarship.org/uc/item/49n9x3t4
[11] Irham M, Miswar E, Ilhamsyah Yand Setiawan I 2018 The northern tidal dynamic of Aceh waters: A 3D numerical modelIOP Conf. Series: Material Science Engineering 352 012043
[12] Haditiar Y, Rizal S and Abdullah F 2017 Current simulation in the Malacca Strait and part of South China Sea due to wind12th Int. Conf. Mathematics, Statistic, and Their Application
[13] Rizal S, Haridhi H A, Wilson C R, Hasan A and Setiawan I 2013 Community collection of ocean current data: an example from Northern Aceh province, Indonesia SPC Trad. Mar. Resource Managem. Knowl. Information Bull.31 3-11

[14] Ponsar S, Luyten P and Dulière V 2016 Data assimilation with the ensemble Kalman filter in a numerical model of the North Sea Ocean Dynamics 66 955-971

[15] Curtiss G M, Osborne P D and Horner-Devine A R 2008 Seasonal patterns of coarse sediment transport on a mixed sand and gravel beach due to vessel wakes, wind waves, and tidal currents Marine Geology 259 73–85

[16] Vijith V, Shetye S R, Baetens K, Luyten P and Michael G S 2016 Residual estuarine circulation in the Mandovi, a monsoonal estuary: A three-dimensional model study Estuarine, Coastal and Shelf Science 173 79-92

[17] Setiawan I, Alfawirisma M A, Haditiar Y and Rizal S 2018 Simulation of tidal hydrodynamics in Sabang Bay, Indonesia IOP Conf. Series: Earth and Environmental Science 216 (2018) 012012

[18] Kämpf J 2009 Ocean Modelling For Beginner Using Open-Source Software (Heildelberg: Springer Verlag)

[19] Haditiar Y, Zulfandi Z, Iskandar T, Setiawan I, Sugianto S and Rizal S 2018 Simulation of wave refraction in the western waters of Aceh, Indonesia IOP Conf. Series: Earth and Environmental Science 216 012014

[20] Adliansyah, Haditiar Y, Muhammad and Rizal S 2017 Current simulation in the Gulf of Thailand due to wind and sea level elevation 12th Int. Conf. Mathematics, Statistic, and Their Application (ICMSA) 2016 Conjunction with 6th Annual Int. Conf. Syiah Kuala University (Banda Aceh, Indonesia) (United States: IEEE) p 55-58

[21] Rizal S, Setiawan I, Boihaki B, Iskandar T and Sugianto S 2018 Simulation of current using a two-dimensional numerical model in the Aceh Barat Daya waters, Indonesia IOP Conference Series: Earth and Environmental Science 216(1) 012019

[22] Setiawan I, Yuni S M, Purnawan S, Ilhamsyah Y and Wafdan R 2019 Simulation of two-dimensional currents to the depth and suspended sediment concentration in Aceh Besar Waters IOP Conf. Series: Earth and Environmental Science 284 012026