The northern tidal dynamic of Aceh waters: A 3D numerical model

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Abstract. The northern tidal dynamic of Aceh waters studied by employing three-dimensional (3D) numerical hydrodynamic model. The purpose of this study is to understand the phenomena and the characteristic of the northern tidal dynamic of Aceh waters. The research used the explicit-splitting scheme numerical model of Navier-Stokes formulation. The result displays that the vertical rotation of flow movement (vertical eddy) at a depth of 15 to 25 meter eastern part of the study area. Hence, the result also informs that the current circulation identically to the upwelling in the western region of Aceh during the wet season and vice versa. However, during the transitional season, the flow circulation depends on how the tidal dynamic occurs in the area.

1. Introduction
Aceh is one of the provinces in Indonesia, which is directly adjacent to the oceans. Geographically, the Aceh waters become the gateway or the world’s sea transportation routes [1]. The vast sea area makes the Aceh waters have great potential in the marine field especially the current movement [2], [3], [4], [5]. This phenomenon is still under-researched and becomes an interesting object to be studied specifically. Aceh waters, similarly to other waters, changing the seasons and the transitional seasons are a distinct phenomenon that plays a role in reviewing the dynamics of the currents [6]. In January to March is the west monsoon, April to May is the season of transition, and June to September representing the east monsoon and November and December seasons of transition.

From the above explanation, it turns out that the waters of Aceh are interesting oceanographically to be investigated not only field study but also numerical model analysis. This is because of the complexity of topography and forces acting on these waters [2], [7], [8]. In numerical model analysis, however, there are inadequate studies about the dynamics of the current in Aceh waters. The research was conducted in a large coverage area and limited to the circulation of tidal currents in Indonesian waters, the Malacca Strait, and the Andaman Sea [6]. Therefore, to enhance the research about waters of Aceh, in this paper we try to describe the dynamics phenomenon of tidal currents in the waters of northern Aceh using the three-dimensional hydrodynamic numerical model.

2. Method
The method used in this research is as follows: literature study, secondary data collection, interpretation of satellite data, mathematical modeling of hydrodynamic model, and field data for verification. For the mathematical modeling, the discrete solution of Navier-Stokes hydrodynamic equations was used by applying the explicit-splitting finite different scheme method.
The study was conducted along the north of coastal waters of Aceh starting from north of Sabang island to east Aceh. The location of the research station is focused on the front, which is the area of the encounter of two opposite currents. Physical data such as tides, temperatures, salinity, and currents are secondary data, which then discretized and analyzed to process the data.

The basic equation used in this research can be written as [9]:

\[
\frac{\partial t}{\partial t} + u \frac{\partial t}{\partial x} + v \frac{\partial t}{\partial y} + w \frac{\partial t}{\partial z} - f v = -\frac{1}{\rho} \frac{\partial p}{\partial x} + \frac{\partial}{\partial x} \left( A_x \frac{\partial u}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_y \frac{\partial u}{\partial y} \right) + \frac{\partial}{\partial z} \left( A_z \frac{\partial u}{\partial z} \right)
\]

(1)

\[
\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} + w \frac{\partial v}{\partial z} + f u = -\frac{1}{\rho} \frac{\partial p}{\partial y} + \frac{\partial}{\partial x} \left( A_x \frac{\partial v}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_y \frac{\partial v}{\partial y} \right) + \frac{\partial}{\partial z} \left( A_z \frac{\partial v}{\partial z} \right)
\]

(2)

In z-direction, the hydrostatic equation then simplified in the form of

\[
\frac{\partial p}{\partial z} = -\rho g
\]

(3)

Equations 1, 2, and 3 used to model the dynamic of Aceh water through the process of the discretized method.

3. Result and Discussion

Based on the bathymetry map of the study area (Figure 1), the topography condition of northern Aceh varies widely. Shallow water with a depth of 100 to 200 m can be found along the east coast of Aceh from Lhokseumawe to Langsa. The gentle slope increase of topography to the depth of 1000 m from south to north shows in the region of Bireuen to Samalanga offshore. However, the northern of Aceh Besar to Sabang a drastic increase of depth occurs significantly to 1500 to 3000 m. The topographic feature in this region is complex, the trench and steep slope of the north of Sabang up to Andaman sea near the Nicobar waters varies. Geologically, the topographic variation in this area is because of the ring of fire of active subduction zone resulted in the lifting and folding ocean floor [10].

The simulation results in figure 2 show the average daily result of northern Aceh. The simulation results show the pattern of current movement following the tidal pattern, which is the existence of periodic alternating movement. Meanwhile, figure 3 shows the result of current dynamics generated by tides and winds during west monsoon from January-March 2014 showing that the current movement is highly concentrated in the tip of the island of Sumatra. This concentration changes as a wind change the direction monthly. The pattern of current movement shows that the current shifted every month during this west monsoon heading towards the northern part of Aceh.

![Figure 1. Bathymetry of study area showing a 2D horizontal contour of 100 contour interval.](image-url)
During the season of transition (April to June) in figure 3, the current condition shows almost similar everywhere. However, at the end of the transition year where the condition of the season tends to enter the east monsoon, the pattern of the current gradually increases especially in the eastern part of Aceh water.

The result of simulation in the east season from July to September (Figure 4) shows that the pattern of current movement is dominant in the east of Aceh while the western part of Aceh is dominated only in the area close to the Pulo Aceh. On the north part of Aceh, the seasonal influence for the current pattern movement is consider small which does not affect the east monsoon. This pattern occurs because of the topography of that area is a shallow region which the influence of wind is less dominant compared to another season.

During the second transition season from east monsoon to west monsoon (October to December) the current concentrated in the northern area of Aceh (figure 5). The pattern of currents moves from east to west of study area with an average ~20 cm/s. The pattern of current movement during this season steadily moves toward western part which a sign of the new season of west monsoon is approaching.

The cross-section of vertical velocity distribution in figure 6 shows the contour distribution pattern that is identical to the sinking and upwelling movement. This happened because of the massive water mass movement on the west coast of Aceh causing a vacuum of water masses on north and east coasts [1], [11]. The void of water volume was further filled by the mass of water coming from the West coast of Aceh.

**Figure 2.** The tidal dynamic monthly average of 3D current on March 2014 during west monsoon
Figure 3. The tidal dynamic monthly average of 3D current on June 2014 during transition season

Figure 4. The tidal dynamic monthly average of 3D current on July 2014 during east monsoon
4. Conclusion
From the results, it is concluded that the seasonal wind movement profoundly dominates the dynamics of tidal currents in Aceh. During west monsoon, a dominant current occurs at the tip of the Sumatra Island, on the contrary in east monsoon, the dominant currents occur on the North and East coast of Aceh. Meanwhile, in the transitional season, the current conditions are almost similar. Furthermore,
the pattern of current vertically is almost equal to the pattern of upper layer currents. This is because the stratification layer is not deep enough to occur the pattern of changing in current direction.

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 American Journal of Environmental Sciences 8 479-488
[2] Irham M and Setiawan I 2017 The Study of Flow Resulting from wave on Lhonga Beach, Aceh Besar Omni Akuatika 13 5-12
[3] Setiawan I and Irham M 2017 Wave trajectory study on the coast of Lhoknga, Aceh Besar: A numerical model approach Civil Engineering Dimension (review in press)
[4] Irham M and Setiawan I 2018 The numerical model of the sediment distribution pattern at Lampulo National Fisheries Port IOP Conference Series: Earth and Environment Science 106 (012067) 1-6.
[5] Irham M, Fadla Y, and Setiawan I 2018 The spatial distribution of suspended sediment analysis along Krueng Cut River, Banda Aceh IOP Conference Series: Earth and Environment Science 106 (012066) 1-6.
[6] 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. Res. Management and Knowledge Information Bulletin 31 3-11
[7] Purnawan S, Setiawan I, Haridhi HA, Irham M 2018 Granulometric analysis at Lampulo Fishing Port (LFP) substrate, Banda Aceh, Indonesia IOP Conference Series: Earth and Environment Science 106 (012067) 1-6.
[8] Gomes E R, Mulligan R P, Brodie K L, and McNinch J E 2016 Bathymetric control on the spatial distribution of wave breaking in the surf zone of a natural beach Coastal Engineering 116 180-194.
[9] Rizal S, Muhammad, Iskandar T, Setiawan I, Satriadi A and Radinal 2011 Simulation of Sea Surface Temperature (SST) and Sea Surface Salinity (SSS) in the Bay of Bengal Proceedings of Annual International Conference Syiah Kuala University (AIC Unsyiah) 153-159
[10] Setiawan I, Ilhamsyah Y, Miswar E dan Haddrevi A 2008 A prediction study of wave propagation before and after tsunami in Ulee Lheue coastal waters, Aceh, Indonesia International Symposium Land Use after the Tsunami-Supporting Education, Research and Development in the Aceh Region 249-254
[11] Chen G, Wang D, and Hou Y 2012 The features and interannual variability mechanism of mesoscale eddies in the Bay of Bengal Continental Shelf Research 47 178-185