Study of current circulation in the Northern Waters of Aceh

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Abstract. The northern waters of Aceh are directly adjacent to the Malacca Strait, the Andaman Sea, and the Indian Ocean. These waters are an important route in the activities of shipping, fishing and others. The study of current circulation was studied by using the 2D hydrodynamic models. The purpose of this study is to determine the current patterns during the Northeast (February 2016) and southwest (August 2016) monsoons. To generate the models, we use the wind force obtained from European Center for Medium-Range Weather Forecast (ECMWF) 2016. The results show that the current circulation generally follows the bathymetry pattern and monsoonal direction.

1. Introduction
The Northern Waters of Aceh is geographically located at 5.13º – 5.97º North and 94.97º – 95.77º East (figure 1). These waters border Sumatra Island, Indian Ocean, the Gulf of Bengal, the Andaman Sea, and the Strait of Malacca. Earlier studies on current circulation have been done in the Strait of Malacca, the Andaman Sea and the Indian Ocean that divides the regions into two seasonal circulation, i.e., northeast and southwest monsoons [1-3]. The activity in northern Aceh and surrounding waters is quite active, which include shipping, mining, mariculture, capture fisheries, tourism and climate outdoor activities [4-8].

Based on these activities, the study of current dynamic is essential to study further on wave, sediment transport and coastal morphology changes, and pollutants distribution [9-13]. Thus the investigation of current dynamic of northern of Aceh waters aims to examine the current circulation process during the northeast monsoon on February 2016 and southwest monsoon on August 2016 by employing numerical model simulation.
2. The methods of the research

2.1. The data

The bathymetric data used for the model was obtained from Shuttle Radar Topographic Mission (SRTM). The data is a digital elevation model (DEM) supplied globally free of charge by the National Aeronautics and Space Administration (NASA) and the United States Geological Survey (USGS). The resolution of the data considerably high that reaches 1 arc second (~ 30 meters) to region of America and 3 arc-second (~ 90 meters) to the rest. However, the data still has a gap to high resolution, especially in a region with detail profile. Therefore, some of the SRTM data is based on 30 arcs second resolution [14]. To prevent a good result, we are expected to use SRTM with 30 arcs second resolution by modifying the data and correcting the error. The data is projected uniformly to 30 seconds Cartesian resolution.

Surface wind speed play a dominant role to drive the sea current. Generally, the wind speed produces tangential friction toward the sea. The wind speed data used to model the current dynamic is the wind speed data analysis from 10 meters high above the sea surface based on interpolated measurement of the high resolution of European Center for Medium-Range Weather Forecast (ECMWF) data (figure 2 and figure 3) [15].

Absolute Dynamic Topography (ADT) is the data used to determine geostrophic current. These data obtained from the reduction of geoid altitude from Mean Sea Surface (MSS) height on an ellipsoid reference. These data also originate from the calculation of Mean Dynamic Topography (MDT) and Sea level Anomaly (SLA). The accuracy of the data can reach several centimeters, with a resolution up to 15 minutes. Currently, the ADT is a measurement of sea surface data from some satellites including Envisat, TOPEX / Poseidon, Jason-1 and OSTM / Jason-2 referring the geoid [16, 17]. These data used as the input of open boundaries for the two dimensional (2D) numerical model.

Figure 1. The bathymetry of the Aceh Waters (in meters). It is obtained from the Shuttle Radar Topography Mission (SRTM).
The current models are validated with [18]. The result will also be validated using surface current average data of Simple Ocean Data Assimilation (SODA) v2.2.4 from 2006 to 2010 [19].

2.2. Hydrodynamical model

The model derived from numerical finite different method from the Navier-Stokes 2D dynamics of seawater [20]. This equation involves pressure gradient force from sea level elevation, wind friction at surface sea, sea bottom friction, advection and diffusion components in two dimensions and Coriolis force.

The study area covers 5.13° N – 5.97° N and 94.97° E – 95.77° E. In the Cartesian coordinate, it is discretized at \( dx = dy = 30 \) seconds. For the stability of the model and to avoid the overflow condition, the time-step \( dt \) used is 5 seconds. For other coefficients such as bottom water depth is about 50-1400 meters. The maximum depth is located on the eastern part of the sea, which is about 1400 meters.

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Equations (1-6) this is equation dynamics of seawater two dimensions [20] and had been applied by [21] in the Gulf of Thailand and in the Malacca Strait by [2]. Where \( u(t, x, y), v(t, x, y) \) speeds current in direction west-east and north-south, respectively. \( \text{Adv}_h(u) \) is component horizontal advection, \( \text{Diff}_h(u) \) is component horizontal diffusion. While \(-fv\) and \( +fu\) is style Coriolis. Component style Coriolis completed semi-implicit manner. So that on early calculations, Coriolis calculated from estimation speed \( u, v \). Style gradient pressure on field two dimensions is \( -g \frac{\partial h}{\partial x} \) and \( -g \frac{\partial h}{\partial y} \). While the sum of friction and friction under the sea breeze is \( \frac{g^{\text{wind}} - g^{\text{bottom}}}{(\rho_0 h)} \) and \( \frac{g^{\text{wind}} - g^{\text{bottom}}}{(\rho_0 h)} \). Seawater depth is \( h \) and depth maximum is \( h_{\text{max}} \), while \( g \) is the force gravity.

\[
\begin{align*}
\frac{\partial u}{\partial t} + \text{Adv}_h(u) - fv &= -g \frac{\partial h}{\partial x} + \frac{g^{\text{wind}} - g^{\text{bottom}}}{\rho_0} + \text{Diff}_h(u) \\
\frac{\partial v}{\partial t} + \text{Adv}_h(v) + fu &= -g \frac{\partial h}{\partial y} + \frac{g^{\text{wind}} - g^{\text{bottom}}}{\rho_0} + \text{Diff}_h(v) \\
\frac{\partial h}{\partial t} &= 0 \\
\text{Adv}(\psi) &= u \frac{\partial \psi}{\partial x} + v \frac{\partial \psi}{\partial y} \\
\text{Diff}(\psi) &= \frac{\partial}{\partial x} \left( A_h \frac{\partial \psi}{\partial x} \right) + \frac{\partial}{\partial y} \left( A_h \frac{\partial \psi}{\partial y} \right)
\end{align*}
\]

Courant-Friedrich-Lewy (CFL) criterion for stability:

\[
\Delta t \leq \frac{\min(\Delta x, \Delta y)}{2g h_{\text{max}}}
\]

3. Results and discussions

3.1. The wind circulation

February 2016 and August 2016 are months of northeast monsoon and southwest monsoon, respectively. On this situation the pressure and the influence of monsoon winds is relatively large. In general the wind circulation on northern Aceh water is depended on the monsoon system. In northeast monsoon (figure 2), the wind circulation on northern waters of Aceh flow from east to west with the velocity magnitude of 3-4 m/s. On the western part of Aceh waters, the wind tends to deflect toward southwest, however, the speed of wind is relatively constant and no change in magnitude. On this occasion, the wind visibly blows along the eastern part Sabang and Breueh Islands and form lee wind along the the east coast region, covering Sabang, Island of Breueh and Aceh Besar. On northern coast
of Aceh Besar, wind tends to flow down the coast toward east. On the southwest monsoon (figure 3), the dominant wind circulation flows from southwest toward northeast with the speed of 4-6 m/s.

Figure 2. Wind circulation during Northeast monsoon in the northern of Aceh waters (m/s).

Figure 3. Wind circulation during Southwest monsoon in the northern of Aceh waters (m/s).

3.2. The current circulation
The 2D flow simulation results are displayed in figure 4 and 5, respectively. The circulation pattern on the month of February 2016 (figure 4) follows the wind direction and Coriolis force. The current circulation, it is seen to flow toward north. However, current circulation on Sabang water is relatively weak, while offshore of western of Aceh Besar, relative strong flow occurs on this area as well as on the north-eastern of Aceh Besar. On the western of Aceh Besar, current flows toward north follow the topography contour. The current circulation is relatively fast offshore and linearly decrease toward shoreline. The current circulation of west offshore is about 0.25 m/s, while near the coast is approximately 0.1 m/s.

In the month of August 2016 the current flows faster on north-eastern part compared to the western part (figure 5). On north-eastern part the current flows to the northwest with speed of 0.3 m/s. The currents than split and accelerate due to the effect of Sabang island topography. Meanwhile, western offshore part of Aceh Besar, the currents flow toward South follow the wind force and Coriolis force direction.

Based on the result of numerical model of current produced in this research, it has a good agreement with SODA (figure 6 and 7), the work of [16,22,23]. The influence of monsoon toward the current circulation can be clearly described as the season change, especially on the western part of Aceh waters. Generally the northeast monsoon current can be seen during the month of February 2016 and the southwest monsoon current is visible during the month of August 2016. On the western part, the northeast monsoon current has stronger flow than the southwest monsoon current. However, the north-eastern bordering with Malacca Strait and the Andaman Sea, the southwest monsoon current is visible greater (figure 5).
4. Conclusions
In general, the results show that the dynamic of current circulation follows the bathymetry pattern. In the western part of the model, the direction of current heading toward north during February 2016 and change toward south during August 2016. The model has good agreement with the other results for verification.
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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 Science 5 479-488
[2] Haditiiar Y, Rizal S and Abdullah F 2016 Current simulation in the Malacca Strait and part of South China Sea due to wind 12th International Conference on Mathematics, Statistics, and Their Applications (ICMSA) pp 47-50 doi: 10.1109/ICMSA.2016.7954306
[3] Joseph S and Ravichandran M 2013 Validation of 0.25° x 0.25° Indian Ocean HYCOM. INCOIS Report. 43 pp. http://incois.gov.in/documents/hycom/hycom_0.25x0.25_tech_rep.pdf
[4] 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 Traditional Marine Resource Management and Knowledge, Information Bulletin 31 3-11
[5] 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 2352-4855
[6] Haridhi H A, Nanda M, Haditiiar 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 & Coastal Management 154 46-54
[7] Ilhamsyah Y, Fadli N, Setiawan I, Haridhi H A 2014 Notes: coral reef bleaching in Weh Island, Indonesia, a natural climate variability or global climate change impact? AACL Bioflux 7(6) 508-515
[8] Rizwan T, Dewiyanti I, Haridhi H A, Setiawan I, Ilhamsyah Y and Alirudin J 2014 Analysis of fish catches by traditional purse seine boat in Aceh waters based on setting and hauling duration AACL Bioflux 7(2) 63-67
[9] Setiawan I, Yuni S M, Mariana and Ilhamsyah Y 2017 Modelling of waste concentration distribution at Iskandar Muda Fertilizer Company Proceeding on Nasional Seminar of Post Graduate of Syiah Kuala University
[10] Irham M and Setiawan I 2017 The study of flow resulting from wave on Lhonga beach, Aceh Besar OmniAkuatika 13(1) 5-12
[11] Chen, W -B, Liu W -C, Hsu M -H and Hwang C -C 2015 Modeling investigation of suspended sediment transport in a tidal estuary using a three-dimensional model Applied Mathematical Modelling 39(9) 2570–2586 https://doi.org/10.1016/j.apm.2014.11.006
[12] Irham M, Setiawan I 2018 The numerical model of the sediment distribution pattern at Lampulo National fisheries port IOP Conf. Ser.: Earth Environ. Sci. 106 012067 doi: 10.1088/1755-1315/106/1/012067
[13] Purnawan S, Setiawan I, Haridhi H A and Irham M 2018 Granulometric analysis at Lampulo Fishing Port (LFP) substrate, Banda Aceh, Indonesia IOP Conf. Ser.: Earth Environ. Sci. 106 012070 doi: 10.1088/1755-1315/106/1/012070
[14] Jarvis A, Reuter H I, Nelson A and Guevara E 2008 Hole-filled SRTM for the globe Version 4 available from the CGIAR-CSI SRTM 90m Database (http://srtm.csi.cgiar.org)
[15] Balsamo G, Albergel C, Beljaars A, Boussetta S, Brun E, Cloke H, Dee D, Dutra E, Muñoz-Sabater J, Pappenberger F, de Rosnay P, Stockdale T and Vitart F 2015 ERA-Interim/Land: a global land surface reanalysis data set Hydrology and Earth System Sciences 19(1) pp 389-407 doi: 10.5194/hess-19-389-2015
[16] Rio M -H, Mulet S and Picot N 2014 Beyond GOCE for the ocean circulation estimate: Synergetic use of altimetry, gravimetry, and in situ data provides new insight into geostrophic and Ekman currents Geophys. Res. Lett. 41 doi:10.1002/2014GL061773

[17] Ablain M, Cazenave A, Larnicol G, Balmaseda M, Cipollini P, Faugère Y, Fernandes M J, Henry O, Johannessen J A, Knudsen P, Andersen O, Legeais J, Meyssignac B, Picot N, Roca M, Rudenko S, Scharffenberg M G, Stammer D, Timms G and Benveniste J 2015 Improved sea level record over the satellite altimetry era (1993–2010) from the Climate Change Initiative project Ocean Science 11(1) pp. 67-82 doi:10.5194/os-11-67-2015

[18] 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

[19] Giese, B S and Ray S 2011 El Niño variability in simple ocean data assimilation (SODA), 1871–2008 J. Geophys. Res. 116 C02024 doi:10.1029/2010JC006695

[20] Kämpf J 2009 Ocean Modelling For Beginner Using Open-Source Software Springer Verlag, Heildelberg

[21] Adliansyah, Haditirar Y, Muhammad and Rizal S 2016 Current simulation in the Gulf of Thailand due to wind and sea level elevation 12th International Conference on Mathematics, Statistics, and Their Applications (ICMSA) pp 55-58 doi: 10.1109/ICMSA.2016.7954308

[22] Diansky, N A, Zalesny V B, Moshonkin S N and Rusakov A S 2006 High Resolution Modeling of the Monsoon Circulation in the Indian Ocean Oceanology 46(5) 608–628 https://doi.org/10.1134/S000143700605002X

[23] Schott F A, Xie S P and McCreary J P 2009 Indian Ocean circulation and climate variability Reviews of Geophysics 47(1) 1–46