

Study of current circulation in the Northern Waters of Aceh

I Setiawan^{1,2*}, S Rizal^{1,2}, Y Haditiar^{1,2}, Y Ilhamsyah^{1,3}, S Purnawan¹, M Irham^{1,4} S M Yuni⁵

¹Department of Marine Sciences, Faculty of Marine and Fisheries, Syiah Kuala University, Banda Aceh, 23111, Indonesia

²Graduate School of Mathematics and Applied Sciences, Syiah Kuala University, Banda Aceh, 23111, Indonesia

³Applied Climatology, Graduate School of Bogor Agriculture University, Bogor, Indonesia

⁴Center for Marine and Fishery Studies, Syiah Kuala University, Banda Aceh, 23111, Indonesia

⁵Department of Mathematics, Faculty of Mathematics and Natural Sciences, Syiah Kuala University, Banda Aceh, 23111, Indonesia

*e-mail: ichsansetiawan@unsyiah.ac.id

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 5.13° – 5.97° North and 94.97° – 95.77° 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.



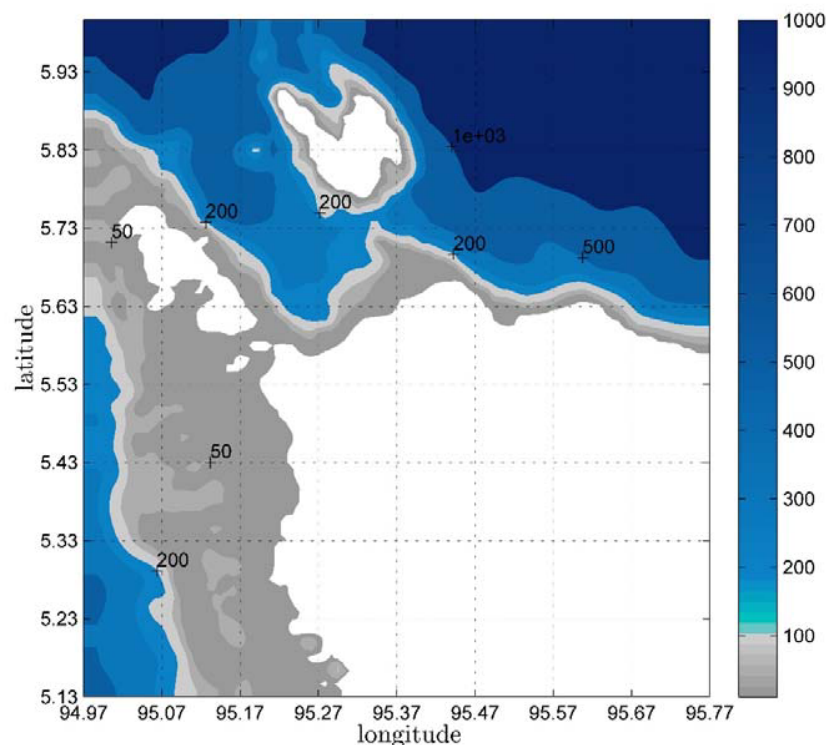


Figure 1. The bathymetry of the Aceh Waters (in meters). It is obtained from the Shuttle Radar Topography Mission (SRTM).

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 dominat 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.

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 calculation, the time-step is determined with Courant-Friedrich-Lewy (CFL) method. On the western part of the domain area, the depth of the water range from 50-100 meters. While on northern part, the water depth is about 50-1400 meters. The maximum depth is located on the eastern part of the sea, which is about 1400 meters. The time-step (dt) used is 5 seconds. For other coefficients such as bottom friction (r), wind friction (C_d) and viscosity (A_h) are 0.038, 1.285×10^{-3} and $500 \text{ m}^2/\text{s}$, respectively. To generate current, wind force from monthly analysis of ECMWF and sea level elevation of ADT is applied at the beginning of the simulation.

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 sea in direction west-east and north-south, respectively. $Adv_h(u, v)$ is component horizontal advection, $Diff_h(u, v)$ 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 $-g \frac{\partial \eta}{\partial x}$ and $-g \frac{\partial \eta}{\partial y}$. While the sum of friction and friction under the sea breeze is $\frac{\tau_x^{wind} - \tau_x^{bottom}}{(\rho_0 h)}$ and $\frac{\tau_y^{wind} - \tau_y^{bottom}}{(\rho_0 h)}$. Seawater depth is h and depth maximum is h_{max} , while g is the force gravity.

$$\frac{\partial u}{\partial t} + Adv_h(u) - fv = -g \frac{\partial \eta}{\partial x} + \frac{\tau_x^{wind} - \tau_x^{bot}}{\rho_0} + Diff_h(u) \quad (1)$$

$$\frac{\partial v}{\partial t} + Adv_h(v) + fu = -g \frac{\partial \eta}{\partial y} + \frac{\tau_y^{wind} - \tau_y^{bot}}{\rho_0} + Diff_h(v) \quad (2)$$

$$\frac{\partial \eta}{\partial t} + \frac{\partial(uh)}{\partial x} + \frac{\partial(vh)}{\partial y} = 0 \quad (3)$$

$$Adv(\psi) = u \frac{\partial \psi}{\partial x} + v \frac{\partial \psi}{\partial y} \quad (4)$$

$$Diff(\psi) = \frac{\partial}{\partial x} \left(A_h \frac{\partial \psi}{\partial x} \right) + \frac{\partial}{\partial y} \left(A_h \frac{\partial \psi}{\partial y} \right) \quad (5)$$

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

$$\Delta t \leq \frac{\min(\Delta x, \Delta y)}{\sqrt{2gh_{max}}} \quad (6)$$

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.

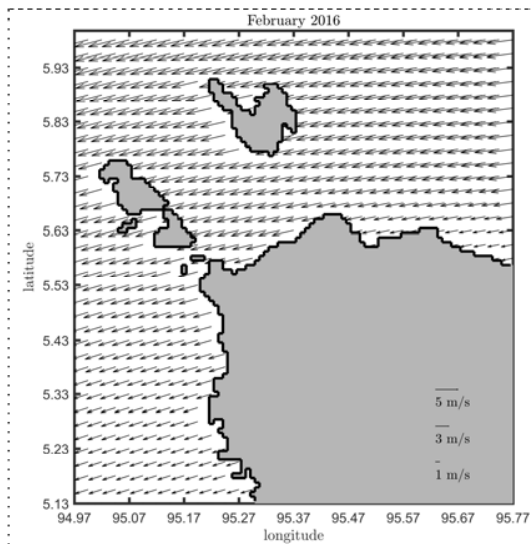


Figure 2. Wind circulation during Northeast monsoon in the northern of Aceh waters (m/s).

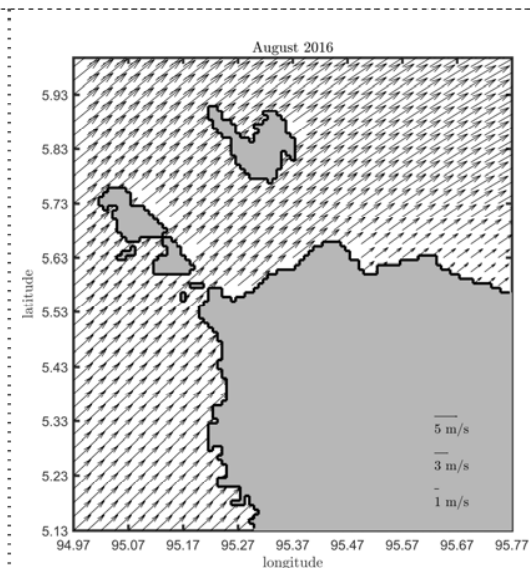


Figure 3. Wind circulation during Southwest monsoon in the northern of Aceh waters (m/s).

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 then 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).

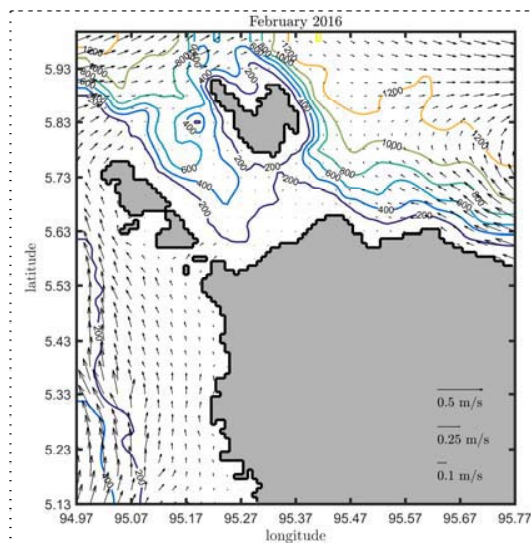


Figure 4. Current circulation during Northeast monsoon in the northern of Aceh waters. Current is depicted by vectors (m/s) and levels of bathymetry are shown by colour contours (m).

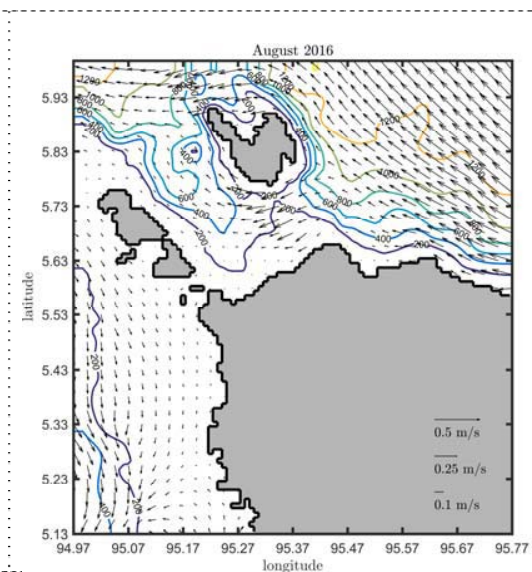


Figure 5. Current circulation during Southwest monsoon in the northern of Aceh waters. Current is depicted by vectors (m/s) and levels of bathymetry are shown by colour contours (m).

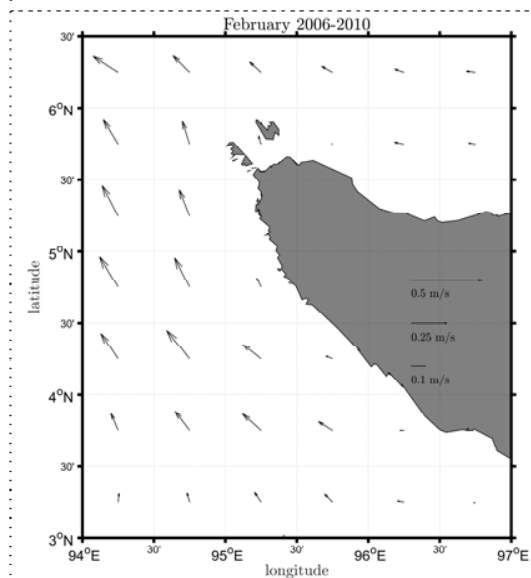


Figure 6. Average surface current circulation during Northeast monsoon (2006-2010) based on SODA (m/s).

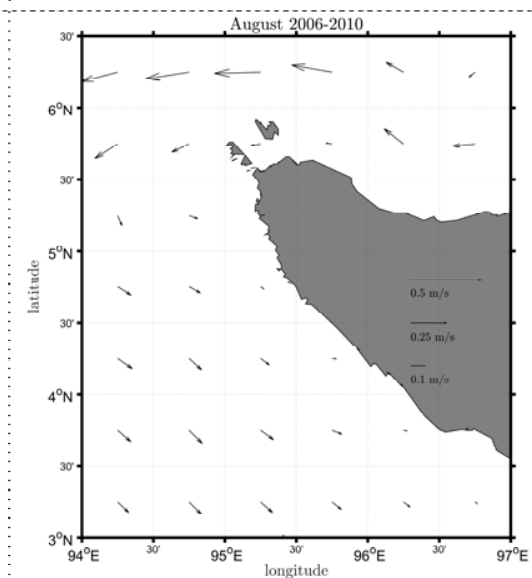


Figure 7. Average surface current circulation during Southwest monsoon (2006-2010) based on SODA (m/s).

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.

Acknowledgments

Authors express gratitude to the Ministry of Research, Technology and Higher Education of Indonesia for financial assistance under 'Fundamental Research Grants', with contract number: 105/SP2H/LT/DPRM/IV/2017. We also thank to Syiah Kuala University through facilities support at Ocean Modelling Laboratory during the research.

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