Effect of wind-driven currents circulation in Sabang Waters

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Abstract. Sabang Waters is located in the Aceh Province, Indonesia, directly adjacent to the Andaman Sea which is dominated by the influence of the monsoon wind. Sabang Waters is a strategic area and one of the zones of coral reef ecosystems in Indonesia. Hydrodynamics in Sabang waters is studied to support the management of Sabang Waters in the future. The motivation of this research is as a preliminary study of wind-driven circulation in Sabang Waters. The method applied is a 2D numerical model simulation with 6-hourly wind data during January - March 2019. The results of the simulation of ocean currents are verified by monthly surface wind conditions. Based on current analysis during January - March 2019, wind-driven circulation in Sabang Waters is quite weak, especially in the Sabang Bay. The flow looks a little stronger in the northeastern part of Sabang Waters especially during January (3 ms⁻¹).

1. Introduction
Sabang Waters is tropical waters inhabited by coral reef ecosystems. Most of coral reef formed by volcanic slope eruptions [1]. The condition of Sabang Waters is relatively deep with an average depth of 77 m and a maximum depth reaching 484 m. After mega-earthquake and tsunami in 2004, Sabang Sabang Water has been reestablishing fisheries through the reconstruction projects such as Community-Based Bathymetric Survey (CBBS) [2] and Rapid Appraisals of Fisheries Management Systems (RAFMS) [3]. However, the data collection of Sabang Waters still lacks for fishing and conservation management [2, 3].Sabang Bay is directly adjacent to the Andaman Sea, so the dynamics of the seawater are quite influenced by the Andaman Sea.

The Andaman Sea is influenced by monsoons that occur during December-February (NE monsoon) and June-August (SW monsoon). During the NE monsoon, wind circulation moves from north and northeast to southwest, and the wind drives from the southwest to the northeast during SW monsoon. Global currents distribution in the Andaman Sea is influenced by tides, heat flux and wind for both the NE and SW [4,5].

The effect of wind on the mixed layer spread from the surface to the depth divided by the stratification of the temperature or density[6, 7].The disturbing in the stratified depth cause the current and interface displacement [8]. Monsoon wind also affects sea surface circulation [9] and fishing ground in Sabang Bay and adjacent sea [2, 3].
The barotropic wind-driven circulation is important to inshore current [10]. Also, the residual causes of wind current are significant to mass and bedload transport [11]. Our research is to study the barotropic wind-driven circulation of Sabang Bay based on the monsoon impact. The monsoon is derived from the six-hourly NCEP / NCAR Reanalysis wind data.

2. Materials and Methods
The location of this study includes Sabang Waters at coordinates 95.22° - 95.33° E and 5.835° - 5.92° N. Model domains and bathymetry were obtained from SRTM 15 [https://topex.ucsd.edu]. The data has a spatial resolution of 0.25 minutes. To obtain data from the narrow Sabang Waters, the data was interpolated and discretized in 0.1 minute resolution so that 67 x 52 grid sizes were obtained.

Figure 1. Bathymetry of Sabang Waters

The model used in this paper is based on a modified two-dimensional numerical model by Kämpf [12]. This model had been used in the wind-driven circulation simulation in the Malacca Strait [13], and Aceh Waters [14, 15, 16, 17, 18]. Different from previous studies, we included surface wind information every 6 hours during January - March 2019 as the current generation force. Wind data is obtained from 6 hourly National Centers for Environmental Prediction/National Center for Atmospheric Research (NCEP/NCAR) Reanalysis [19], which had been discretized according to the model domain. Equations in the model are derived into continuity and momentum equations which are vertically integrated [12]:
\[
\frac{\partial u}{\partial t} + \text{Adv}(u) - f v = -g \frac{\partial u}{\partial x} + \frac{\tau_{\text{wind}} - \tau_{\text{bot}}}{\rho_0 h} + \text{Diff}(u) \tag{1}
\]

\[
\frac{\partial v}{\partial t} + \text{Adv}(v) + f u = -g \frac{\partial v}{\partial y} + \frac{\tau_{\text{wind}} - \tau_{\text{bot}}}{\rho_0 h} + \text{Diff}(v) \tag{2}
\]

\[
\frac{\partial \eta}{\partial t} + \frac{\partial (\eta h)}{\partial x} + \frac{\partial (\eta h)}{\partial y} = 0 \tag{3}
\]

where \(u\) and \(v\) are currents velocity in zonal and meridional term, \(\rho\) is sea water density, \(\eta\) is sea level elevation, and \(h\) is total depth added to sea elevation. The parameter used is \(f\) as the Coriolis parameter and \(\tau\) as a friction effect. Seafloor friction \(\tau_{\text{bot}}\) changes based on location and wind friction \(\tau_{\text{wind}}\) changes every six hours. The numerical solution follows the model developed by Kämpf [12].

### 3. Results and Discussion

The current and wind profile simulation results are shown in Figure 2.

![Figure 2](image_url)

**Figure 2.** January 2019 (a) Wind circulations and (b) vertical integrated ocean currents
Figure 2 (a) shows that sea surface average circulation in Sabang Bay in January 2019. The global wind is relatively uniform towards the southwest with a velocity of about 3 ms\(^{-1}\). The northern part of Sabang Waters is the Andaman Sea so that the wind came from the Andaman Sea. Wind causes a variation in the velocity of the weak currents in Sabang Bay. The current looks slightly stronger in the northeast or outside of the bay. It is because the bathymetry is relatively shallow while in other parts, especially the inside of the bay is relatively deep.

In Figure 2 (b) the currents in the bay area have different current strengths in the picture above. It is seen that the most significant current force is located in the northeast region, whereas in the regions that have low current strength that is in the southwest and surrounding areas, and generally a weak current is located in near the coast.

Figure 3. February 2019 (a) Wind circulations and (b) vertical integrated ocean currents

Figure 3 (a) shows the average sea surface wind circulation in February. The wind is also generally relatively uniform towards the southwest, with an average speed of 2 ms\(^{-1}\). The currents look weaker than the monthly wind circulation average in January. It is because the terrain contours listed on the bathymetry tend to be relatively shallow.
In Figure 3 (b) it also has a current strength that is relatively different from January, seen in the picture above the current power in February is lower than in January, the highest current strength in February is around 0.006 ms\(^{-1}\) while in January it has a strength of 0.001 ms\(^{-1}\).

![Figure 3](image3.png)

**Figure 3.** Current strengths in (a) January and (b) February

In Figure 3 (b) it also has a current strength that is relatively different from January, seen in the picture above the current power in February is lower than in January, the highest current strength in February is around 0.006 ms\(^{-1}\) while in January it has a strength of 0.001 ms\(^{-1}\).

![Figure 4](image4.png)

**Figure 4.** March 2019 (a) Wind circulations and (b) vertical integrated ocean currents

Figure 4 (a) also shows the average circulation of sea surface wind in March. In this month, the wind direction is still relatively uniform to the southwest, with an average speed of 1 ms\(^{-1}\). It can be seen in Figure 4 (b) that the current strength in March is weaker than the current force in January and February. This is because the terrain contours listed on the bathymetry tend to be relatively shallow.

In March the current strength was found to be greatest between January and February, as seen in Figure 4(b), the largest current strength is in the northeast with a strength of 0.0014 ms\(^{-1}\) while the lowest current strength is in the southwest with a power of 0.0002 ms\(^{-1}\).
4. Conclusions
Two-dimensional numerical simulation with winds in January - March 2019 has been applied in Sabang Waters. Numerical simulations show that the depth and wind speed contours affect the current movement in Sabang Waters. Wind circulations have different wind speeds in January, February and March, one of which is influenced by seasonal changes. The highest wind speed is in January, which is at the speed of 3 ms⁻¹ from the northeast to the southwest and the lowest wind speed in March, which is at the speed of 1ms⁻¹ in the same direction. Wind speed and direction are also influenced by weather change in the bay area.

The average currents velocity of the strongest in January - March is at the point of location in the northeast Sabang Waters. The highest current velocity is in January with velocity of 0.01 ms⁻¹, and the lowest current velocity is in March with a rate of 0.0014 ms⁻¹, while bay areas tend to have weak currents and tend to be steady.

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