

Simulation of tidal hydrodynamics in Sabang Bay, Indonesia

I Setiawan^{1,2}, M A Alfawirsa¹, Y Haditir², S Rizal^{1,2*}

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

*Email: syamsul.rizal@unsyiah.net

Abstract. Tidal hydrodynamics of currents and sea level in Sabang Bay are simulated by a one-dimensional numerical model. We generate the dynamics by using the amplitude and tidal components of Hamburg direct data Assimilation Methods for TIDEs (HAMTIDE) in the open boundary. HAMTIDE is a model data obtained from the tidal inverse method. The tidal simulation is based on several harmonic constants of M2, K1, K2, S2, O1, and N2. Simulations of the combined harmonic constants are run over a 30 day period and verified by the measurement data of the Hydrography and Oceanography Center, Indonesian Navy. The verification results indicate that the numerical sea level model is quite good, with the correlation coefficient $r = 0.81$.

1. Introduction

Sabang waters are the Aceh archipelago located at coordinates 95°13'02"-95°22'36" E, and 05°46'28"-05°54'28" N. Sabang waters are directly adjacent to the Andaman Sea and the Indian Ocean. Tide is the phenomenon of the long wave up and down motion that occurs periodically due to the gravitational force of the earth-sun-moon and centrifugal force [1]. Tides in the Indian Ocean, Bengal Bay, and Andaman Sea can have an impact on tides in Sabang waters to the Malacca Strait [2, 3, 4].

Tides from the Indian Ocean cross the waters of Aceh and the Andaman Sea. Then it splits partially to the Bay of Martaban and to the Straits of Malacca. This phenomenon can be seen from the increase in tidal phase changes in shallow waters [3]. Based on research by Rizal *et al.*, [3] with a 10-minute model resolution, it is known that tides in Aceh waters are divided into semi-diurnal and semi-diurnal mixtures. Bathymetry and shape effects can produce elevation variations and tidal currents. Thus the resolution of the model is important in obtaining tidal models in Aceh waters [5, 6, 7]. The purpose of this study is to simulate high-resolution tidal waters of Sabang waters using 1-D hydrodynamic models.

2. Material and Methods

The model used is based on the shallow-water one-dimensional model of [8]. This model is built from the equation of laws of Newton's motion and continuity. The equation is as follows:

$$\frac{\partial u}{\partial t} = -g \frac{\partial \eta}{\partial y} \quad (1)$$

$$\frac{\partial \eta}{\partial t} = -\frac{\partial(uh)}{\partial y} \quad (2)$$

where u is the velocity in the x direction, t is the time, g is acceleration due to gravity, η is sea level sea elevation, and h is the total water depth.

Equations (1) and (2) are derived into the finite-difference scheme, as follows:



$$u_j^{n+1} = u_j^n - \Delta t g (\eta_{j+1}^n - \eta_j^n) / \Delta y \quad (3)$$

$$u_j^* = u_j^n - \Delta t (u_j^{n+1} h_e - u_{j-1}^{n+1} h_\omega) / \Delta y \quad (4)$$

$$u_j^* = u_j^n - \Delta t / \Delta y (u_j^+ h_j^n + u_j^- h_{j+1}^n - u_{j-1}^+ h_{j-1}^n - u_{j-1}^- h_j^n) \quad (5)$$

where

$$u_j^+ = 0.5 (u_j^{n+1} + |u_j^{n+1}|) \text{ and } u_j^- = 0.5 (u_j^{n+1} - |u_j^{n+1}|) \quad (6)$$

For lateral boundary conditions, the zero-gradient condition is applied, where the open boundaries, the values of the amplitude, period, and phase of each tidal component (M2, K1, S2, N2, K2, and O1) as can be seen in Table 1 are prescribed. While the equation in the open boundaries is stated as follows:

$$h(t) = \sum_{j=1}^7 f_j A_j \cos[2\pi(V_j(t) + u_j(t) - g_j)] \quad (7)$$

$$\eta_0^n = \eta_1^n \quad (8)$$

where A_j, g_j = Amplitude, and weak phase of constituents, $f_j(t), u_j(t)$ = modulation of central amplitude and phase correction factor for constituents, $V_j(t)$ = Astronomical argument for constituents.

Table 1. Tidal components

Component	Period	Amplitude	Phase
M2	12.42	35	80
S2	12.00	15	90
N2	12.66	6,2	70
K2	11.97	4,2	80
K1	29.93	9,8	220
O1	25.82	42,9	180

(Source: Hamburg direct data Assimilation Methods for TIDEs (<https://icdc.cen.uni-hamburg.de/1/daten/ocean/hamtide.html>))

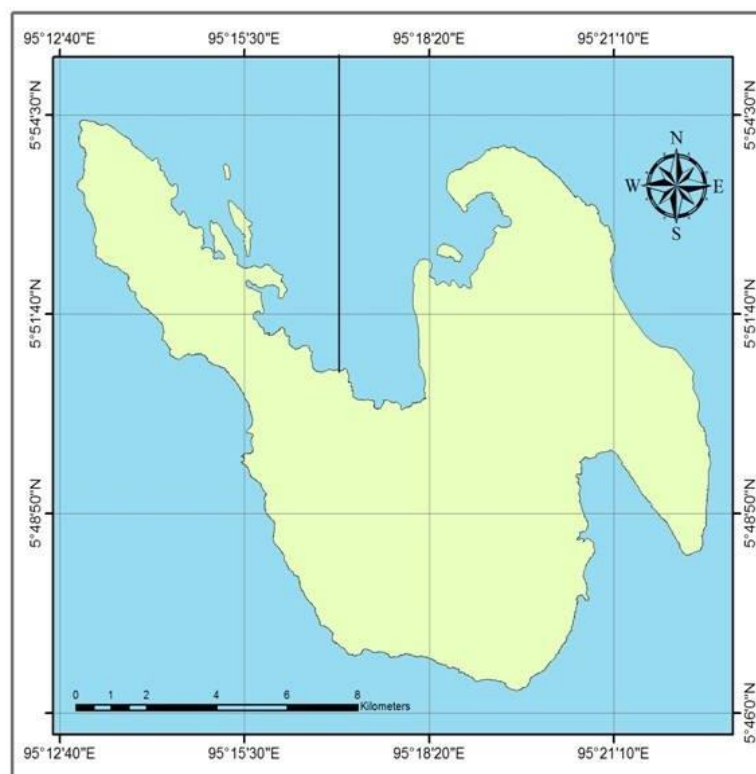
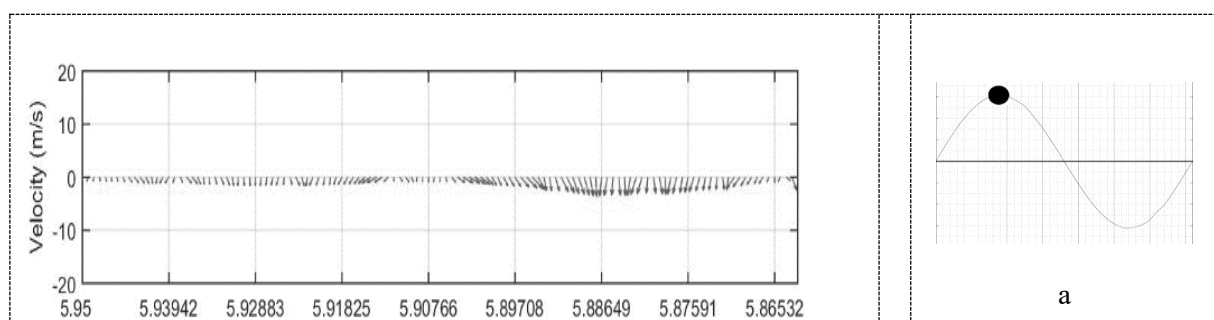


Figure 1. The research domain in Sabang Bay, Indonesia

To evaluate forecasting techniques with a 1-dimensional numerical simulation and the Hydrography and Oceanography Center, Indonesian Navy data, the correlation coefficient (r) is used. The study locations were at (95.27°E dan $5.89\text{--}5.95^\circ\text{N}$). Bathymetry data comes from SRTM30 [9] which has been interpolated to 0.25 minutes (Figure 1). Because the open boundary condition is in the north, numerical simulations start from north to south.

3. Results and Discussion

Figure 2 shows the results of the simulation of sea tides and ocean currents at spring tide conditions. While Figure 3 shows the sea tidal pattern of Sabang Bay at 95.27°E , 5.95°N .



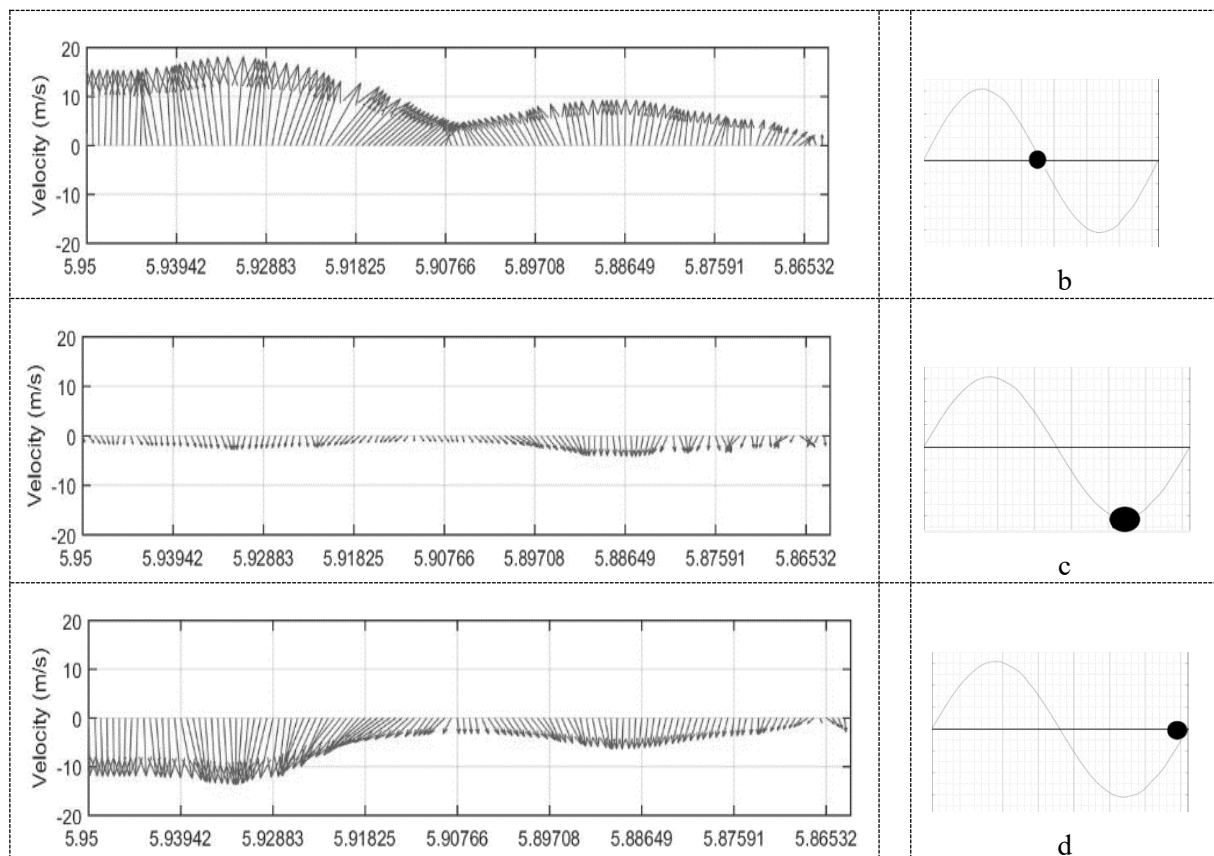


Figure 2. Current velocity at spring tides (cm/s), **a** shows current at high tide, **b** shows current at high tide to the low tide, **c** shows current at low tide, and **d** shows current at low tide to the high tide

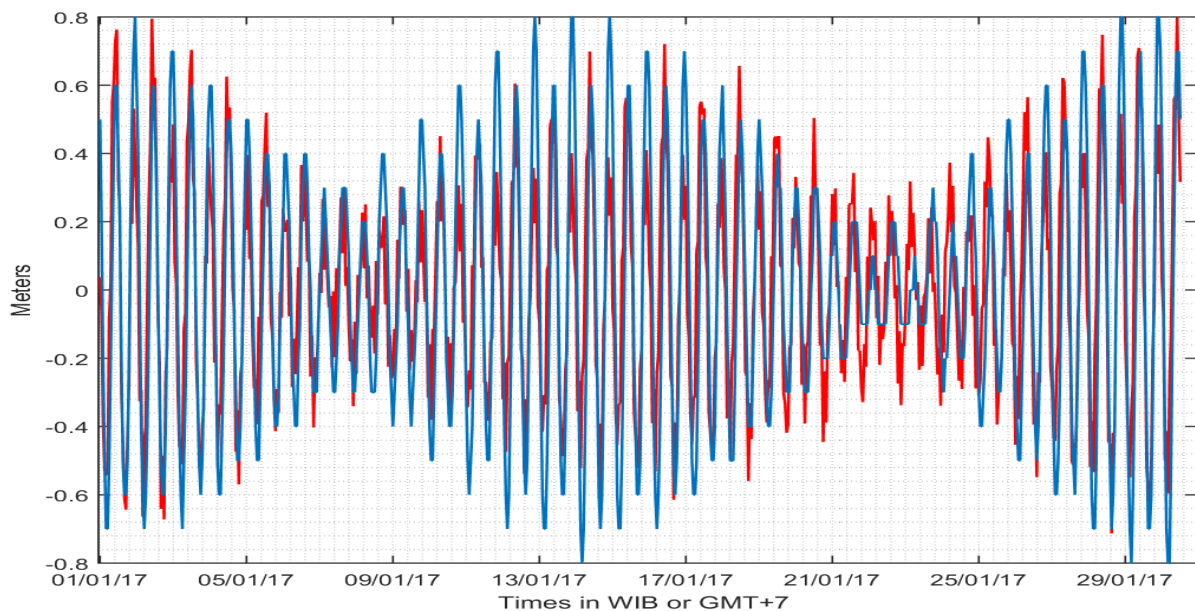


Figure 3. Comparison between the elevation of numerical simulation and the Hydrography and Oceanography Center, Indonesian Navy tides data over 30-day in Sabang Bay waters in the year (January 1, 2017-January 30, 2017 or in Arabic Calendar Rabiul Akhir 1438 H - 2 Jumadil Awal 1438 H). This comparison has a coefficient correlation value of $r = 0.81$.

The simulation of tidal hydrodynamic models at positions $95^{\circ}13' 02''$ - $95^{\circ}22' 36''$ E, and $05^{\circ}46' 28''$ - $05^{\circ}54' 28''$ N has been carried out. In general, the magnitude of the current velocity at low tide conditions towards a full moon is relatively not too different from the current pattern during high tide towards low full tide. This situation is dominated by the flow moving north and south with the maximum current velocity reaching 0.13 m/s - 0.2 m / s (Figure 2). When the water level reaches the lowest in full tide conditions, the tidal current pattern is almost the same as the current flow pattern during full moon tides which are dominated by the northward flow (near the port) with a maximum speed reaching 0.04 m/s (Figure 2).

For the Simulation of tides for 1 month in Sabang Bay, the highest tide occurs during the full moon on the 15th of Rabiul Akhir 1438 H/January 14, 2017. When the full moon is on 29 Jumadil Awal 1438 H /January 28, 2017, the height of tide reaching 0.8 meters (Figure 3). The comparison between Sea tide simulation and the Hydrography and Oceanography Center, Indonesian Navy tide shows good results. The correlation coefficient of this comparison with $r = 0.81$.

4. Conclusions

Based on the simulation results of the 1-D hydrodynamic tide model in Sabang Bay, it can be concluded that the tidal type in the Sabang Bay is a semi diurnal type. It is characterized by 2 hightides and 2 lowtides in one day. The comparison between sea tide height of simulation and that of the Hydrography and Oceanography Center, Indonesian Navy shows a good agreement.

Acknowledgments

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