Dynamics of Tidal Circulation in Balikpapan Bay: a basic information and study to support a new capital city of Indonesia

Endro Soeyanto* and Akihiko Morimoto**

*Laboratory for Marine Survey Technology (BTSK)-BPPT, Jakarta Indonesia

** Center for Marine Environmental Studies (CMES),Ehime University, Japan

Introduction

Balikpapan bay is a part of the proposed new capital city of Indonesia. The semi-closed bay located between Balikpapan City and Penajam Paser Utara (PPU) district in East Kalimantan (Figure 1). The shipping lane in this bay is very congested because it is the entry and exit points of large vessels, both passenger ships as the primary means of transportation from Balikpapan to Penajam Regency, and fuel transport vessels for industrial purposes. Some development activities are developing rapidly in this bay, such as industry, mining, plantation, fishery, agriculture, and forestry (PPKT, 2004). According to BPS (2013), the number of large and medium-sized industrial companies in East Kalimantan as of 2013 was 115 companies consisting of agriculture, food and beverage, chemical, mining and textile sub-sectors. These various industrial activities have the potential to produce liquid waste and rubbish, which are generally carried along by the flow of rivers along the bay.

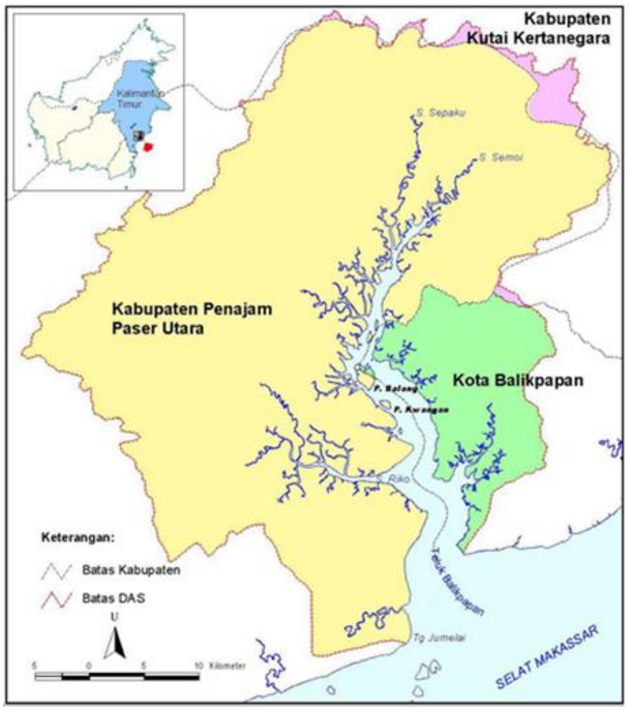

Figure 1. Balikpapan Bay, East Kalimantan

In the near future, the new capital city will be moved around year of 2024 around this area. Government of Republic of Indonesia has announced plans to move its capital from the climate-threatened megalopolis of Jakarta to the sparsely populated island of Borneo, which is home to some of the world's greatest tropical rainforests. Base on this plan, it is important to understand the tidal circulation in the bay as basic dynamics of physical processes.

Objective

This research is to develop the 2D-hydrodynamic model in Balikpapan Bay to understand the mechanism of tidal circulation of the bay.

Methodology

Numerical Model

The Princeton Ocean Model (POM) is a 3-D primitive equations ocean circulation model, which has been described in detail by Blumberg and Mellor (1987) and Mellor (2004). POM is a free surface, sigma coordinate model that uses a time-splitting technique to solve depth-integrated and fully three-dimensional equations with different time steps. The surface elevation, velocity, temperature, and salinity fields are prognosticated assuming the fundamental hypotheses: (i) that the seawater is incompressible, ii) that the pressure in any point of the ocean is equal to the weight of the column of water over it (hydrostatic approximation), and iii) that the density can be expressed in terms of a mean value and a small fluctuation (Boussinesq's approximation).

In this report, POM 2D- Model used to simulate hidrodinamic condition in the bay and adjacent waters.   The flow model consists of continuity and momentum equation, i.e.:

The continuity equation,

$$\frac{\partial \eta}{\partial t} + \frac{\partial \overline{U} D}{\partial x} + \frac{\partial \overline{V} D}{\partial y} = 0 \quad \text{...} \qquad (1)$$

The momentum equation,

$$\begin{aligned} \frac{\partial \overline{U} D}{\partial t} + \frac{\partial \overline{U}^2 D}{\partial x} + \frac{\partial \overline{U}\,\overline{V} D}{\partial y} - \tilde{F}_x - f \overline{V} D + gD \frac{\partial \eta}{\partial x} &= -< wu(0) > + < wu(-1) > \\ \frac{\partial \overline{V} D}{\partial t} + \frac{\partial \overline{U}\,\overline{V} D}{\partial x} + \frac{\partial \overline{V}^2 D}{\partial y} - \tilde{F}_y + f \overline{U} D + gD \frac{\partial \eta}{\partial x} &= -< wv(0) > + < wv(-1) > \end{aligned} \qquad (2)$$

Which $D = H + \eta$, $\overline{U}, \overline{V}$ the component of current velocity averaged against depth respectively for the east-west and north-south directions, $\overline{U} = \frac{1}{D}\int_{-1}^{0} U\, d\sigma$ and $\overline{V} = \frac{1}{D}\int_{-1}^{0} V\, d\sigma$, *t* is time, *H* adalah depth, η is the surface elevation, *g* is acceleration due to gravity, and *f* is Coriolis parameter.

Difussivity on *x* dan y –axis, respectively, i.e.:

$$\widetilde{F}_x = \frac{\partial}{\partial x}\left[H 2\overline{A}_M \frac{\partial \overline{U}}{\partial x}\right] + \frac{\partial}{\partial y}\left[H \overline{A}_M \left(\frac{\partial \overline{U}}{\partial y} + \frac{\partial \overline{V}}{\partial x}\right)\right]$$
$$\widetilde{F}_y = \frac{\partial}{\partial y}\left[H 2\overline{A}_M \frac{\partial \overline{V}}{\partial y}\right] + \frac{\partial}{\partial x}\left[H \overline{A}_M \left(\frac{\partial \overline{U}}{\partial y} + \frac{\partial \overline{V}}{\partial x}\right)\right] \quad \ldots\ldots\ldots\ldots\ldots \quad (3)$$

....

Which A_M is horizontal kinematic viscosity. The bottom stress components are (Ramming dan Kowalik, 1980):

$$< wu(-1) >= \frac{C_z \overline{U}\sqrt{\overline{U}^2 + \overline{V}^2}}{D}$$
$$< wv(-1) >= \frac{C_z \overline{V}\sqrt{\overline{U}^2 + \overline{V}^2}}{D} \quad \ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Which C_z is the coefficient of seabed friction.

Model Setup

The model domain comprises the Balikpapan Bay, East Kalimantan, Indonesia, from 116° 42' 16.2"-116° 58' 22.7"E and from 01° 21' 34'' – 1° 05' 27.9"S. The bottom topography used navigation charts of Pushidrosal TNI-AL. Grid resolution model constructed from the topogarphy data for 0.0010783° x 0.0010783° degree. In this model, there are two open lateral boundaries; at 01° 21' 34''S and 5.825 °N. The model has been configured with a horizontal resolution of 0.0010783° in latitude by 0.0010783° in longitude (250 x 250 grids), with 1 layer (2D Ocean Model). Other significant model parameters are given in **Table-1**.

(a) (b)

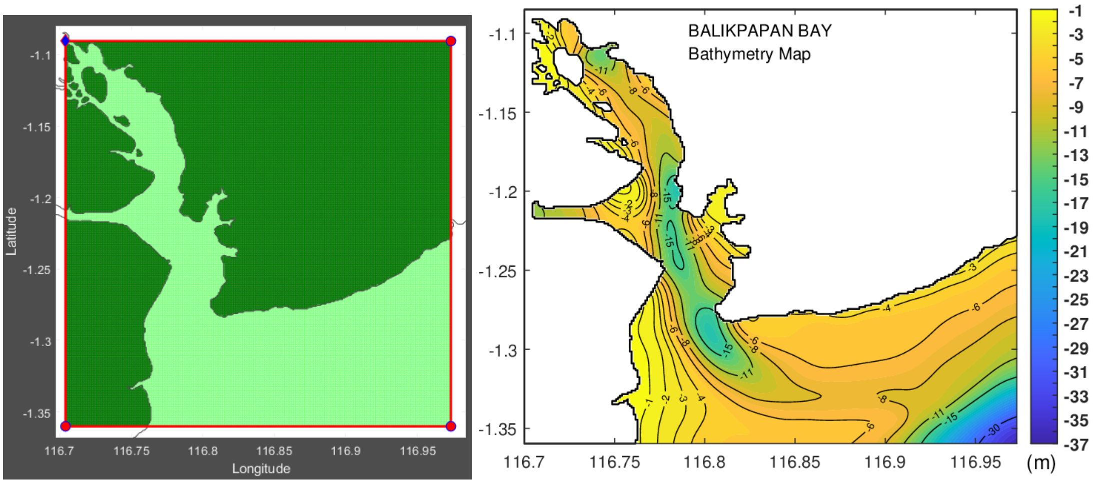

Figure 2. (a) Grid of model domain; (b) Bathymetry map of Balikpapan Bay, East Kalimantan

Table-1. Model Parameter used in Balikpapan 2D-model.

Parameter	Description	Value
C	Non-dimensional constant used in calculating the horizontal viscosity for momentum	0.2
tprni	Inverse horizontal Prandtl Number	0.2
μM	Background viscosity	0.00002
Zo	Bottom roughness length	2.75
Δt_{ext}	External mode time step	3 sec
Δt_{int}	Internal mode time step	30 sec

Open lateral boundaries conditions which are derived from the tidal elevation is predicted from Finite Element Solution ,FES2014 (Lyard,et.al, 2017). Time simulation period for the model is started from October 1, 2020 untill November 02, 2020.

Results

Model Validation

Hourly simulation of the model were completed from October 01, 2020 to November 02, 2020 . The model results validated to a tide gauge's station at Semayang Port, Balikpapan, East Kalimantan

(116.806°E, 1.272°S). Comparison of the harmonic analysis for four tide constituents (M2,S2, K1 and O1) for the model results and observation data can be seen in **Tabel-2**. The model results both of magnitudes and phases present close to the observations at the Semayang Port's tide gauge station.

Table 2. *Comparison of observed and 2D-Model M2, S2, K1 and O1 tidal elevations at the tide gauge at Semayang Port (116.806°E, 1.272°S).*

Constitutents	**Observed*** - **Amplitude (cm)** - **Phase (°G)**	**Model**
M2	55.58 175.38	53.12 194.47
S2	47.71 220.9	36.41 219.43
K1	23.58 288.62	22.26 202.40
O1	19.11 253.91	16.35 23.126

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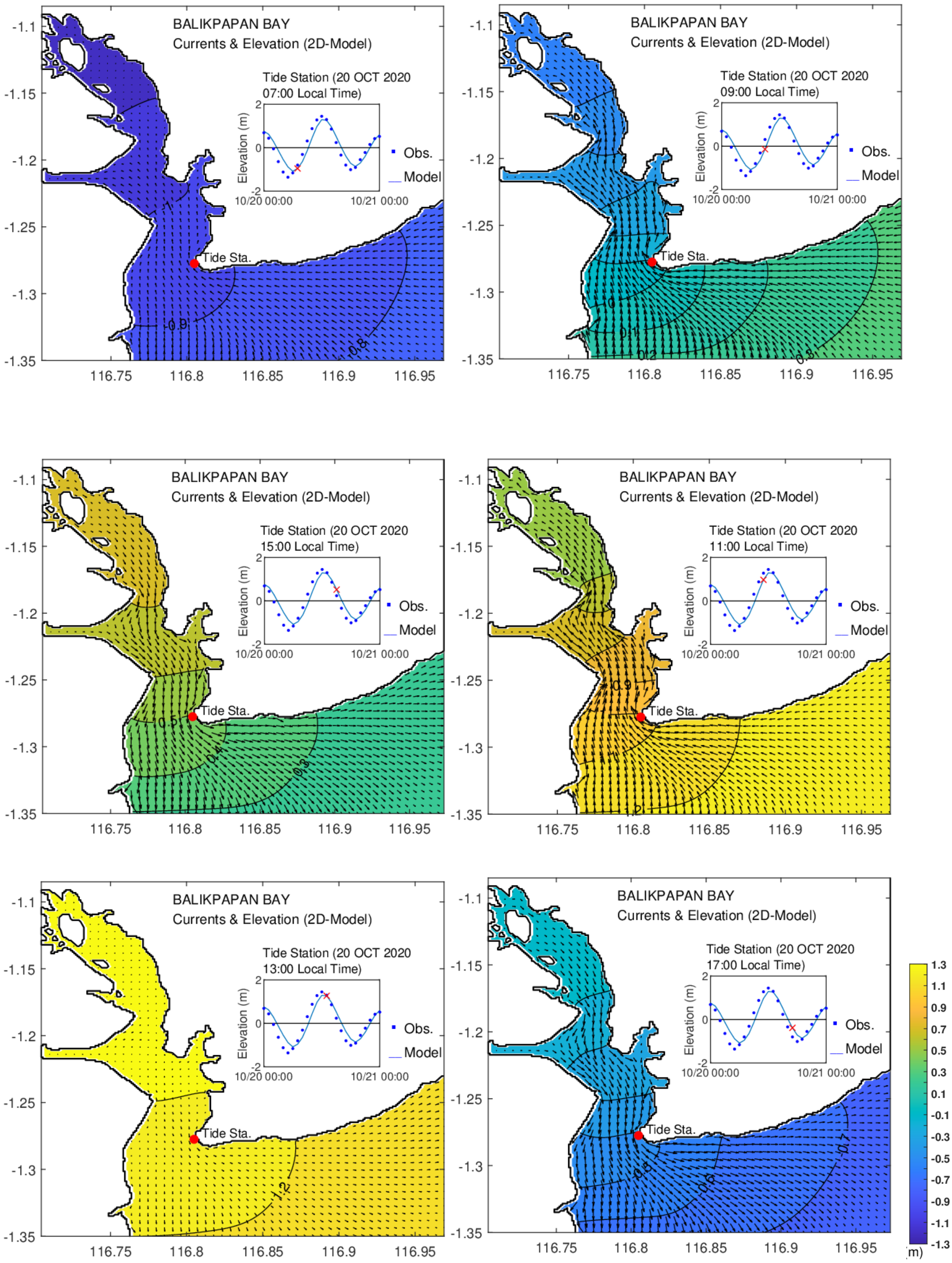

Figure 3. Tide Elevation and Current distribution from the model results

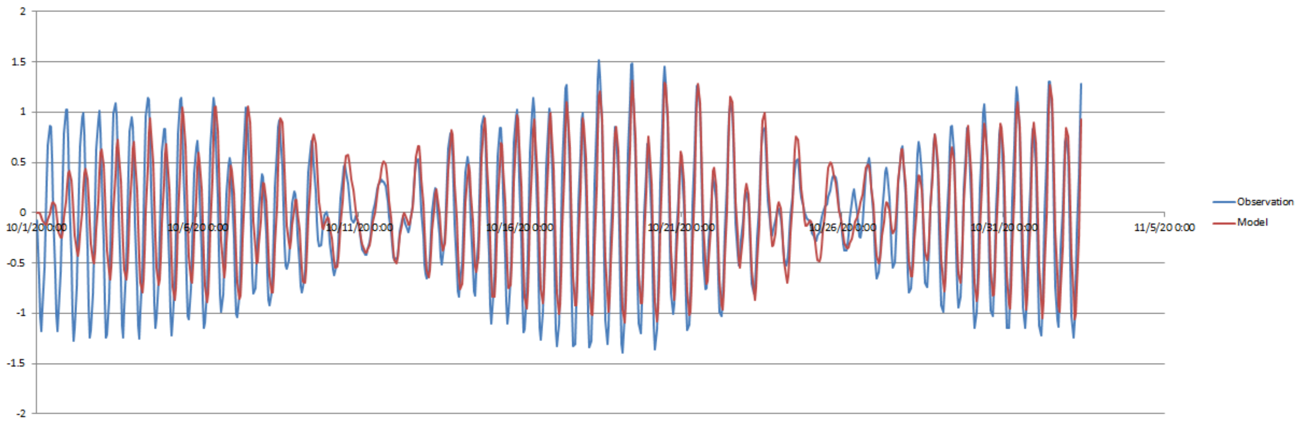

Figure 4. Comparison of model elevation and observation at Semayang Port

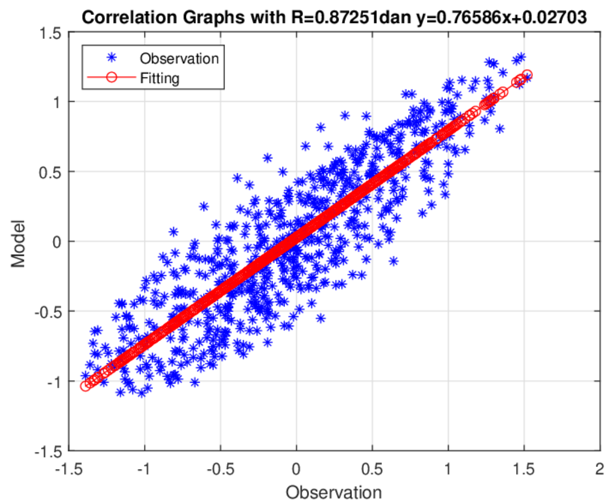

Figure 5. Correlation Coefficient of elevation between model results and observations (06 October ,2020 to 02 November 2020 10:00, hourly) at Semayang Port

<u>*Tide Elevation and Current distribution*</u>

Figure 3 show some panels of horizontal tide elevation and current at Balikpapan Bay. The panels represent a hourly snapshot at October 20, 2020 at 07:00, 09:00, 11:00, 13:00, 15:00 and 17:00 local time, respectively. This time period use as example to show the tide elevation and current propagations from (to) open sea to (from) the bay. Obviously, the tide elevation propagate from and to open sea to inside the bay. A snapshot at October 20, 2020 09:00 local time (i.e. Ebb tide to Spring tide) reveal a strong tidal current flowing from open sea to the bay. Vice versa, at October 20, 2020 15:00 local time (i.e. Spring tide to Ebb tide) show a strong tidal current flow from the bay to open sea.

Figure 4 are displaying a comparison of modeled elevation and observation time series, respectively. Correlation Coefficient of elevation between model results and observations from those hourly series started October 06 ,2020 00:00 to November 02 2020 10:00 is ~0.87 (Figure 5). Some part of modeled elevation results are over and lower estimates to the observations. This condition occurs due to the model calculation is only used 4 tidal components as the open lateral boundaries of tide forcing (M2, S2, K1 and O1) and the 2D ocean model is also not consider the non tidal forcings such as wind stress, river dischare, etc.

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