The changes of water mass characteristics using 3-dimensional Regional Ocean Modeling System (ROMS) in Balikpapan bay, Indonesia

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Abstract. Balikpapan Bay is located in the East Borneo Province of Borneo, Indonesia and directly connected to the Makassar Strait and also has very important role in determining the dynamics of ocean current, heat and freshwater content in the Makassar Strait. Numerical model has been used to simulate the dynamic process such as the changes of water mass in the Balikpapan Bay. We have used the terrain following three-dimensional Regional Ocean Modeling System (ROMS). Tides, river discharges, and atmospheric forcing (surface fields) have been used as generating forces for the model. The model has been simulated for three months from 1 October 2012 to 1 January 2013. The model has been validated by computing the *RMSE, MAPE* and Willmott's index of agreement (d) using water level observation at the sampling station in Semayang port, Balikpapan. The verification showed a good agreement between model prediction and field observation data with *RMSE* = 7.8 cm, *MAPE* = 14.3% and d = 0.995 (with a value of perfect agreement equals to 1.0). The results analysed using vertical profile of salinity and temperature from 22 sampling stations with 11 stations located at the inner part of Balikpapan Bay. While the other stations located outside the Balikpapan Bay were used to analyse watermass. Water circulation is mostly dominated by the forcing from tides. The model results showed that the outer part of Balikpapan Bay is saltier than the inner part of Balikpapan bay. The highest average temperature occurred along coastal areas with value ~31 ^{0}C. The distribution of vertical salt transport showed that the water masses tend to be stratified during neap tides and mixed during spring tides condition.

1. Introduction

The Indonesian seas are the tropical regional sea that lies between two major oceans, Pacific and Indian oceans and also known as the Indonesian throughflow (ITF) because they provide a pathway for the Pacific and Indian inter-ocean exchange. They also the only tropical pathway global thermohaline circulation [1]. Makassar Strait is one of the Indonesian throughflow that has been known has major impact to the global ocean circulation. From the research [2], it reveals that the Pacific and Indian ocean heat and freshwater budgets have depended on the Indonesian sea throughflow. Heat and freshwater flux into the Indian ocean at the expense of the Pacific may affect tropical sea surface temperature (SST) pattern and air-sea coupling with potential impact on the *El Nino Southern Oscillation* (ENSO) monsoon

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phenomena [3]. Observation data also showed that the throughflow is composed mostly of North Pacific thermocline and intermediate water flowing through Makassar Strait [4].

In the middle part of Makassar Strait, there are two areas in the Borneo island that have become periodic sources of the heat and freshwater flux which always input these fluxes straight into the strait, they were Mahakam delta and Balikpapan bay. These two areas geologically have been formed in the different process and produced different coastal morphology respectively. Mahakam delta is an active delta system which has been formed by large tidal amplitude, low wave energy, and large fluvial input [5]. Meanwhile, Balikpapan Bay is semi-enclosed bay and strongly affected by waves distribution in the southern part of the bay. By its location, Mahakam Delta and Balikpapan Bay have their respective roles to the current and transport pattern in the Makassar Strait

Balikpapan Bay is located in the East Borneo Province of Borneo, Indonesia (figure 1) and is one of the bay that directly connected to Makassar Strait. That means, the hydrological conditions in the bay was strongly influenced by the Makassar Strait. Periodically, the freshwater inputs moving through the bay from the rivers in the north, west and east to the downstream area in the southern part of the bay, and at the same time the seawater from the strait comes into the bay and affecting the heat and salinity vertical structure of water masses in the Balikpapan bay. The width of the bay channels varying significantly and have ranges from ~ 6 km in the mouth of the bay to <1 km on upstream side. With a length of channel about >40 km, there are many possibilities of dynamical process that can be happened along the bay channel, like partial mixing, salt intrusion and sediment transport from the rivers.

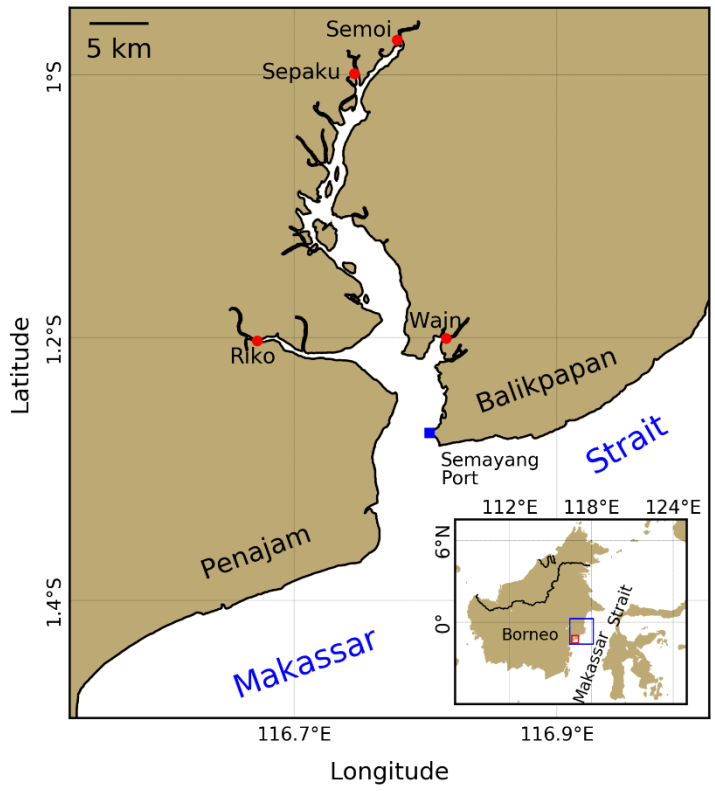

Figure 1. Map of Balikpapan Bay, East Borneo, Indonesia. The blue square denotes the water level station at Semayang port and red dot denotes the source of river discharges for the model. In the inset map, the blue line square indicates a parent domain (ECB) and red line square indicates a child domain (BPP).

Based on introduction above, we aim to know the effect of tidal mixing alternated water mixing column between freshwater from Balikpapan Bay and saltier water from Makassar Strait. We also like to know how temperature and salinity transform between two areas, inner part and outer part of Balikpapan Bay. Thus, in this research we have objective to studied the changes of water mass characteristics because of exchanges of heat and freshwater flux from Balikpapan bay into the Makassar Strait and vice versa.

To see its changes, we used the Regional Ocean Modeling System (ROMS) from COAWST modeling system distribution. COAWST is stands for Coupled Ocean Atmosphere Waves Sediment Transport and it is an agglomeration of open-source modeling components that has been tailored to investigate coupled processes of the atmosphere, ocean, and waves in the coastal ocean [6]. Further, we also planned to modified a high resolution ROMS model that could describe many physical phenomena at Makassar Strait especially Balikpapan Bay.

2. Data

2.1. Field Measurement

Hourly time-series of sea surface elevation data were conducted by *Geospatial Information Agency* (http://www.bakosurtanal.go.id) during October 2012 until December 2012. This data was measured using a tide gauge instrument to monitoring water level and deployed at the port of Semayang, Balikpapan that was located in the southernmost part of Balikpapan or south-eastern part of Balikpapan Bay. This data will be compared to the model prediction for the same variable to measure performance of the model. River discharges were obtained from *The Erosion and Sedimentation Working Group* (Kelompok Kerja Erosi dan Sedimentasi) which conducted the field observation in the watershed of Balikpapan Bay. Unfortunately, it has only a month-averaged data which made us use repetitive value for river discharges input. River discharges data are listed in detail at **Table 1**. We also could not find observation data for temperature and salinity at the model domain on this period. The closest observation point for those data is only Makassar mooring (INSTANT program), but it was located outside of the study area.

Table 1. River discharges data

River	Discharges (m^3s^{-1})
Wain	2.477
Semoi	83.496
Sepaku	42.189
Riko	16.852

2.2. Model Input

Usually, the data input demanded by ROMS consists of: bathymetry, temperature, salinity, velocity, sea surface elevation, atmospheric (surface) forcing and river discharge. In this research, bathymetry data was obtained from the high-resolution topography SRTM15 PLUS (http://www.topex.ucsd.edu) and has 15 arcsecond resolution or ~450 m. This topographic data was based on SRTM30_PLUS grid with some improvements. The Hybrid Coordinate Ocean Model (http://www.hycom.org) analysis system has been used for the two-dimensional and three-dimensional components (sea surface elevation, temperature, salinity and velocity). This system uses the Navy Coupled Ocean Data Assimilation (NCODA) and has 1/12 arcdegree grid resolution. The surface (atmospheric) forcing datasets obtained from the ECMWF (European Centre of Medium-Range Weather Forecast datasets (http://www.apps.ecmwf.int). The ECMWF dataset is chosen because the data is available on the study area (Balikpapan Bay). Tidal amplitude was obtained from global ocean tides model TPXO8-ATLAS (http://www.volkov.oce.orst.edu), and have a better resolution in the research domain (1/30 degree of resolution) compared to other solution of tide models. Unlike the previous model (TPXO7.2) solutions, the new tides model keeps resolution in the higher resolution rather than averaging them on coarser grid (TPXO grid). As a result, this provides much improvement in tidal predictions for coastal areas.

3. Method

The simulation of hydrodynamic process at Balikpapan Bay coastal domain were conducted by using the numerical model of Regional Ocean Modeling System (ROMS). Many literatures [7][8][9] have

described the model capability, especially in the regional ocean domain. ROMS itself is a three-dimensional, free surface, terrain-following numerical model that solves finite difference approximation of the Reynolds-averaged Navier-Stokes (RANS) equation using the hydrostatic and Boussinesq assumption with a split-explicit time stepping algorithm [10][11]. It uses a horizontal curvilinear Arakawa "C" grid and vertical stretched terrain-following coordinates [12]. This model also can be configured depending of user application which has several choices for advection schemes, pressure gradient algorithms, turbulent closure, wet-dry, and several types of boundary conditions.

3.1. Governing Equations

The governing equations used in ROMS were presented in flux form on the Cartesian horizontal coordinates and sigma vertical coordinates. For the momentum equations on the x- and y- axis directions are:

$$\frac{\partial(H_z u)}{\partial t}+\frac{\partial(uH_z u)}{\partial x}+\frac{\partial(\upsilon H_z u)}{\partial y}+\frac{\partial(\Omega H_z u)}{\partial s}-fH_z\upsilon=-\frac{H_z}{\rho_0}\frac{\partial p}{\partial x}-H_z g\frac{\partial \eta}{\partial x}$$
$$-\frac{\partial}{\partial s}\left(\overline{u'w'}-\frac{\nu}{H_z}\frac{\partial u}{\partial s}\right)-\frac{\partial(H_z S_{xx})}{\partial x}-\frac{\partial(H_z S_{xy})}{\partial y}+\frac{\partial S_{px}}{\partial s} \quad (1)$$

$$\frac{\partial(H_z \upsilon)}{\partial t}+\frac{\partial(uH_z \upsilon)}{\partial x}+\frac{\partial(\upsilon H_z \upsilon)}{\partial y}+\frac{\partial(\Omega H_z \upsilon)}{\partial s}+fH_z u=-\frac{H_z}{\rho_0}\frac{\partial p}{\partial y}-H_z g\frac{\partial \eta}{\partial y}$$
$$-\frac{\partial}{\partial s}\left(\overline{\upsilon'w'}-\frac{\nu}{H_z}\frac{\partial \upsilon}{\partial s}\right)-\frac{\partial(H_z S_{yx})}{\partial x}-\frac{\partial(H_z S_{yy})}{\partial y}+\frac{\partial S_{py}}{\partial s} \quad (2)$$

$$0=-\frac{1}{\rho_0}\frac{\partial p}{\partial s}-\frac{g}{\rho_0}H_z\rho \quad (3)$$

with the continuity equation:

$$\frac{\partial \eta}{\partial t}+\frac{\partial(H_z u)}{\partial x}+\frac{\partial(H_z \upsilon)}{\partial y}+\frac{\partial(H_z \Omega)}{\partial s}=0 \quad (4)$$

and scalar transport:

$$\frac{\partial(H_z C)}{\partial t}+\frac{\partial(uH_z C)}{\partial x}+\frac{\partial(\upsilon H_z C)}{\partial y}+\frac{\partial(\Omega H_z C)}{\partial s}=-\frac{\partial}{\partial s}\left(\overline{c'w'}-\frac{\nu_\theta}{H_z}\frac{\partial C}{\partial s}\right)+C_{source} \quad (5)$$

These equations are closed by parameterizing the Reynolds stresses and turbulent tracer fluxes as

$$\overline{u'w'}=-K_M\frac{\partial u}{\partial z},\quad \overline{v'w'}=-K_M\frac{\partial v}{\partial z},\quad \overline{\rho'w'}=-K_M\frac{\partial \rho}{\partial z} \quad (6)$$

where K_M is the eddy viscosity for momentum and K_H is the eddy diffusivity. Eddy viscosities and eddy diffusivities are calculated using one of five options for turbulence-closure models in ROMS: (i) Brunt-Väisälä frequency mixing in which mixing is based on the stability frequency; (ii) a user-provided analytical expression such as a constant or parabolic shape; (iii) the *K*-profile parameterization [13],

expanded to include both surface and bottom-boundary layers [14]; (iv) Mellor-Yamada level 2.5 (MY2.5) method [15]; and (v) the generic length-scale (GLS) method [16] as implemented in [17] that also includes the option for surface fluxes of turbulent kinetic energy due to wave breaking. For the details of each variables on the equations are listed in **Table 2**.

Table 2. List of variables

Variables	Description	Dimensions
u	Velocity *x*-direction	m s^{-1}
υ	Velocity *y*-direction	m s^{-1}
Ω	Velocity *s*-direction	m s^{-1}
s	Vertical sigma coordinate	–
z	Vertical elevation	m
η	Wave averaged free surface elevation	m
H_z	Grid cell thickness	m
f	Coriolis parameter	s^{-1}
u'	Turbulent velocity *x*-direction	m s^{-1}
v'	Turbulent velocity *y*-direction	m s^{-1}
w'	Turbulent velocity *s*-direction	m s^{-1}
c'	Turbulent concentration	^{o}C, salinity, or kg m^{-3}
p	Pressure	N m^{-2}
ρ	Total density of seawater	kg m^{-3}
ρ_0	Reference density of seawater	kg m^{-3}
g	Gravity	m s^{-2}
ν	Tracer kinematic viscosity	m^2 s^{-1}
ν_θ	Tracer kinematic diffusivity	m^2 s^{-1}
C	Tracer (temperature, salt, or suspended-sediment concentration)	^{o}C, salinity, or kg m^{-3}
C_{source}	Tracer source/sink term	C units m s^{-1}

3.2. Model scenario

Single grid refinement method has been used to increase resolution in Balikpapan bay coastal domain. It started from the coarser grid (referred as the "ECB" model) with horizontal resolution ~750 m and downscaling it to the area of interest (referred as the "BPP" model) with ~150 m of horizontal resolution. The ECB domain include more than 200 km eastern coastline of Borneo island extending from south of Balikpapan Bay to the north of Bontang city, whereas BPP domain only focusing at the Balikpapan bay area from south coastline of Penajam regency to the east of Balikpapan city. These model domains have different open boundaries respectively, the ECB model domain has open boundary at the north, south, and east section of the domain, whereas the BPP model domain only just has open boundary at the south and north section (figure 2).

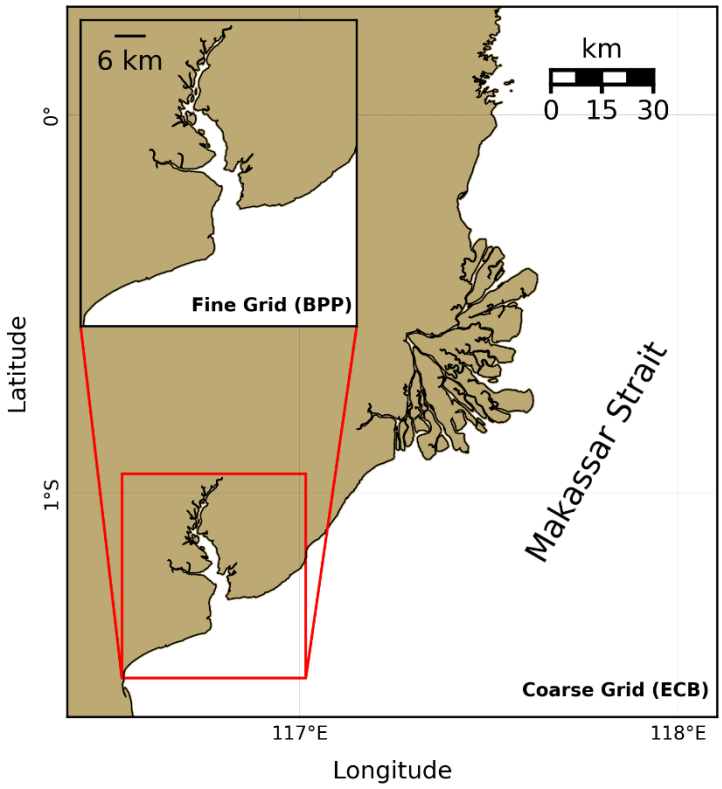

Figure 2. Model domain with nested grids (refinement ratio 1:5)

Bathymetric data for the BPP model grid was obtained using interpolation method by ratio 1:5 of its parent grid and then smoothed to limit the "Beckman and Haidvogel number" rx_0 (topographic stiffness ratio) less than 0.2 [18] and the "Haney number" rx_1 (hydrostatic instability number) under 10 [19]. To achieved the stability of computation, minimum depth (h_{min}) of ECB and BPP domain have been modified to be a positive value because the original bathymetry has negative values. In ROMS, the depth of sea floor (h) value has need to be a positive number because it represents the vertical water column thickness (meters) from ocean rest state ($\eta = 0$) and cannot have h value equal or less than zeros in any horizontal grid point even it masked by land. And also in the terrain-following vertical coordinates, h value is used to computed the vertical level thickness H_z and division by zero or other negative value is not allowed in the internal numerical kernel of ROMS model. As we know, in mathematics the division by zero is not defined and computers will lead to Inf or Nan. On the other hand, all the vertical levels in ROMS are located above h_{min} ($h_{min} > 0$) to limit the vertical time-step of the model due to the Courant-Friedrichs-Levy (CFL) condition [20].

The hindcast simulation of parent grid were initialized beforehand to provide boundary condition for BPP model by using offline one-way nesting scheme. The hindcast of ECB model initialized from 28 September 2012 to 3 January 2013 meanwhile the BPP model running exactly for three months from 1 October 2012 to 1 January 2013. The offline nesting technique actually has a weakness compared to two-way nesting technique, because the interaction between both domain grid just occurred from the parent grid (ECB) to the child grid (BPP) causing no feedback of information from finer to coarser resolution model. However, we could not use two-way nesting scheme due to limited computational resource at the time and after several tests we found that one-way nesting scheme was good enough for this study. Without nesting, the only way to resolve physical phenomena in estuary region and coastal features at smaller scales is increasing the grid resolution on the entire ECB domain that would putting heavy task on computational process and also dealing with big output data afterwards.

Initial and lateral boundary condition of ECB for two-dimensional surface elevation fields and three-dimensional components such as velocity, temperature and salinity fields were extracted from HYCOM

model analysis. The lateral boundary values for ECB have been imposed with the cycle period of once every five days by using mixed radiation-nudging boundary condition (RadNud) [21]. The RadNud boundary condition has been chosen because it has better solution compared to original radiation boundary condition (Rad) after doing several tests of the model. For the free-surface and two-dimensional momentum component like elevation and depth-integrated velocity, we have applied the Chapman-Shchepetkin boundary condition (Che-Shc) combination [22], which was the best option for this application. Shchepetkin boundary condition [23] is implemented a new solution, and more stable condition compared to Flather [24] boundary conditions because it has been founded that this boundary condition (Flather) has numerical instability under certain circumstance. Furthermore, the solutions from ECB model will be used for the initial and boundary values of the BPP model. The BPP model has the same boundary condition configuration just like its parent domain, except the nudging period was set to once every three days because of the smaller domain size it has. The detail of model parameters for ROMS configuration are showed in **Table 3**.

Table 3. Model variables of each domain model

Model parameter	Variable	Domain 1	Domain 2
Number of grids	*Lm, Mm, N*	254, 278, 30	360, 400, 20
Time step	*Dt*	30	30
Simulation steps	*Ntimes*	293760	285120
s-coordinate surface parameter	*theta_s*	7	4
s-coordinate bottom parameter	*theta_b*	2	0.2
Critical depth	*Tcline*	250	50
Factor between outflow and inflow open boundary condition	*Obcfac*	72 (every 5-days)	120 (every 3-days)

The momentum boundary condition for each model domain on the surface has been parameterized by activating ocean-atmosphere boundary layer, it means we tell ROMS to compute net heat flux and wind stress from atmospheric fields. Surface forcing was computed internally by ROMS using bulk-flux formulation, therefore the turbulent fluxes for wind, heat, and moisture are computed using Monin-Obukhov similarity theory [25]. The surface fields that should be prepared are wind component (usually 10 m above sea level), air temperature (2 m above sea level), air pressure, air relative humidity (2 m above sea level), cloud fraction, rain fall rate, and shortwave radiation flux. This surface fields have three hours cycles frequency, because the higher time-frequency of the surface forcing then it would be better to resolve the air-sea interaction.

ROMS has freely allowed user to obtain tidal elevation data from the tidal models. In this study, tidal forcing at the open boundary will be provided by output from ocean tides model TPXO8-ATLAS. In ROMS, this tidal forcing is super-imposed on the sea surface elevation if the user activated Flather or Shchepetkin boundary conditions. For the better barotropic solution of the models, we have been used 9 major tidal harmonic components: M2, S2, N2, K2, K1, O1, P1, Q1, and M4. The tidal forcing data for each tidal component consists of: angular period, elevation amplitude, elevation phase angle, current phase angle, current inclination angle (angle between ellipse major axis and u-axis), maximum tidal current (ellipse major axis), and minimum tidal current (ellipse minor axis) [20].

3.3. Model Validation

The hindcast model quality were quantitatively compared to the field observation by calculating of its root-mean-square-error (*RMSE*), mean absolute percentage error (*MAPE*), and index of agreement (*d*) as defined by [26]

$$skill = 1 - \frac{\sum \left| X_{model} - X_{obs} \right|^2}{\sum \left(\left| X_{model} - \overline{X_{obs}} \right| + \left| X_{obs} - \overline{X_{obs}} \right| \right)^2} \quad (7)$$

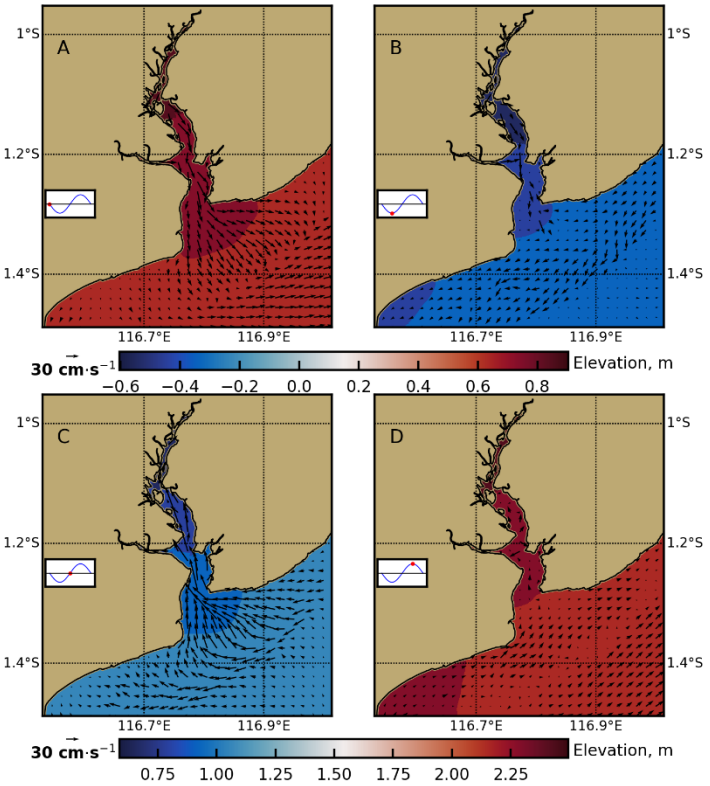

Figure 4. Spatial distribution of surface elevation and surface current during 4 different spring tide condition (a) flood, (b) low water, (c) ebb, and (d) high water.

where X is the variable being compared with $\bar{X}$ (time-averaged of X). Perfect agreement between the model prediction and field observation yields a skill of one whereas complete disagreement will yield a skill of zero. The variable being used to compute the *RMSE, MAPE*, and *d* is sea surface elevation data.

4. Results

4.1. Sea Surface Elevation and Current

The water level output from BPP model shows that tides at Balikpapan bay has semidiurnal type, marked by two high and two low tides pattern for one lunar day. Sea surface elevation has been analysed in the neap and spring tide condition because of these tidal conditions play an important role in the dynamic process in the model domain. At neap tide condition (figure 3), the ranges of sea level only changed about 10 cm from the lowest level at low tide to peak amplitude at high tide condition. Tidal current in the bay was dominantly moving outside and have magnitude <30 cm/s and then decreased near coastline area shortly after leaving the bay. The flow on the offshore of domain constantly directing from southwest to northeast with magnitude of >30 cm/s. At spring tide condition (figure 4), the sea level and current flow seems to have different attitude from the previous condition. During ebb tide condition, the tidal current flows strongly from inside to outside of the bay with the speed reaching >50 cm/s. When the low tide occurred, the direction of current has changes and the magnitude decreased to <30 cm/s. After that, the tidal current reaching its maximum speed by magnitude about >50 cm/s coinciding with the flood tide condition and mostly flowing from the northeast direction. At high tide condition, the tidal

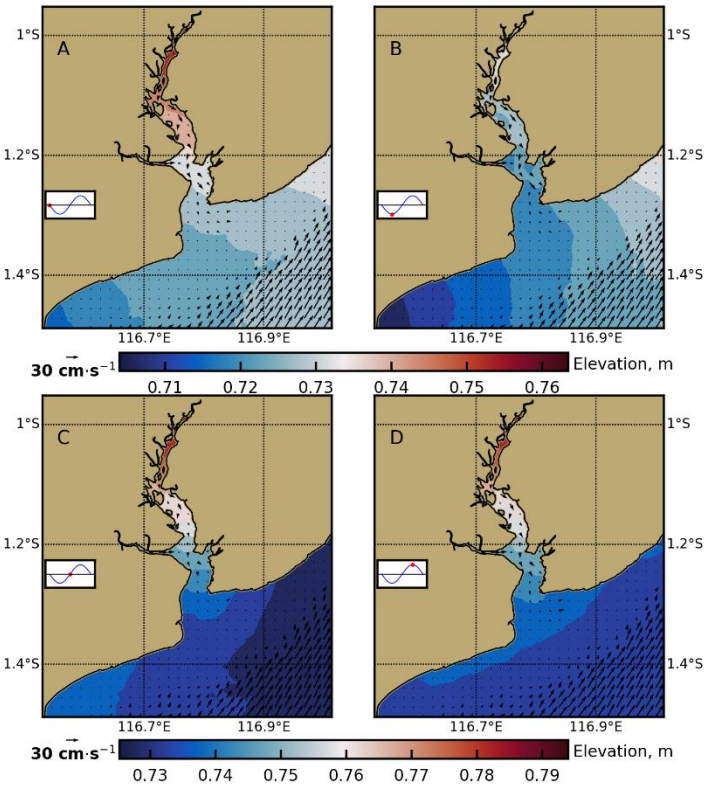

Figure 3. Spatial distribution of surface elevation and surface current during 4 different neap tide condition (a) flood, (b) low water, (c) ebb, and (d) high water.

current speed decreases to <30 cm/s and change direction from southwest to northeast. Oppositely from the neap tide, spring tide has a very large range about 3 m from low tide to high tide condition.

4.2. Spatial Temperature and Salinity

The time-averaged of temperature and salinity at surface level used to analyse the effect of air-sea flux exchanges to sea surface characteristics in the inner and outer part of the Balikpapan bay. Averaged Sea Surface Temperature (SST) at the model domain (figure 5a) has a range around 27.6 - 30.8 ^{0}C and the higher temperature occurred along the coastline of Penajam and Balikpapan where the temperature reaches the highest value compared to the offshore in the Makassar strait. Temperature increase gradually from inner part to the middle part and again decreased at the outer part of the bay, although the temperature also warmed up at the coastal area all over of model domain. The warmer area that located in the middle part of the bay and the coastal area are exactly occurred because of the net heat flux (surface forcing) penetration that occurred in the shallow-depth area. The wind stress also give effect for the occurrence of mixing at the surface layer which then leads to increase or decrease the surface temperature in the Balikpapan bay. This indicates that ocean-atmosphere interaction has a great contribution to changes surface temperature characteristic besides the advection-diffusion process from the ocean itself.

The three-month averaged Sea Surface Salinity (SSS) shows that the surface layer of Balikpapan Bay was strongly dominated by low salinity water masses (figure 5b). This could happen due to river discharges from the upstream which flows constantly into the bay, although values of river discharge should be varying with the time to produce more realistic solution. The visible surface velocity pattern also confirms the previous statement where mostly the current flow direction inside the bay is heading south and moving towards Makassar strait. Surface salinity from model output ranges from around 6 - 34 psu where inside the bay the salinity limited to ~26 psu. After leaving the mouth of the bay, the concentration of this low saline water spread at radius of ~6 km on the Balikpapan coastal area towards

Makassar strait. This means surface salinity along-channel of the bay was dominantly affected by air-sea flux interaction and freshwater input.

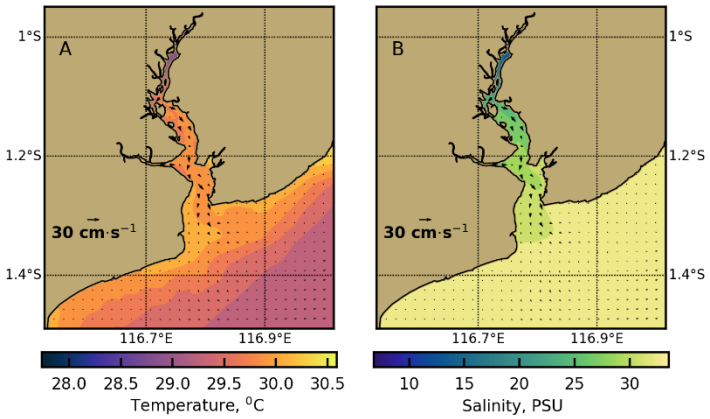

Figure 5. Three-month averaged of (a) sea surface temperature and (b) sea surface salinity overlay with three-month averaged of sea surface current.

4.3. Vertical profiles

Balikpapan bay coastal area have very complex bathymetry, making the maximum layer depth at every station sample also varying inside and outside with maximum depth about >40 m (figure 6a). The time-averaged of vertical temperature shows that the inner stations only have the temperature difference about 1 ^{0}C with minimum temperature about 29.7 ^{0}C – 30.8 ^{0}C (figure 7a) whereas at the outer part, temperature increases from 26.4 ^{0}C in the deepest layer to surface layer where one of the outer stations recorded maximum temperature about 30 ^{0}C (figure 7b). Similar with SST, vertical temperature inside the Balikpapan bay tending to be warmer than the outside because the influence of surface forcing like we mentioned before (figure 7c). Vertical salinity structure at every station samples tend to have the same trends, which have low salinity at the surface and gradually increases proportional to the depth. The surface fields influence the surface layer by freshwater flux and makes water mass in this layer to be more freshened. Generally, the outer part of the bay always much saltier than the inner part of the bay because of the existences of river inflow which can be reflected by the results of the model (figure 7d).

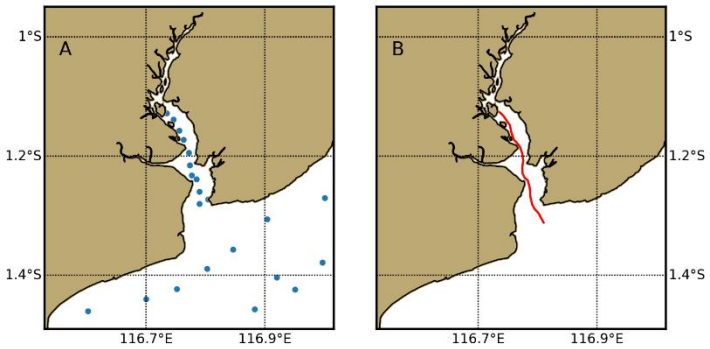

Figure 6. (a) Stations sample for vertical profiles and (b) the transect path of vertical distribution.

4.4. Vertical Distribution of Salinity

The vertical distribution of salinity shows variation values during neap and spring tidal condition. During neap tides the distribution pattern is changes slightly, and freshwater shown moving along surface layer from upstream to downstream of the bay. The higher salinity with value >34 psu is concentrated in the middle to deeper layer and extends almost vertical due to intrusion of freshwater toward outer of the bay (figure 8a). The mass of water which contains more freshwater from inner bay seems to holding this salt water to near km 9 and causes the salt distribution in water column is stratified

uniform with depth (figure 8b). On the other hand, the salt distribution at spring tides act very different compare to previous tidal condition. At the lowest spring tide (figure 8c), the freshwater moving farther than neap tidal condition and the salinity decreased by >4 psu. At the highest spring period, two water masses from the opposite direction meet each other and causes the water column in this domain strongly mixed and as a consequence, the salt front tend to a vertical orientation near km 20 (figure 8d).

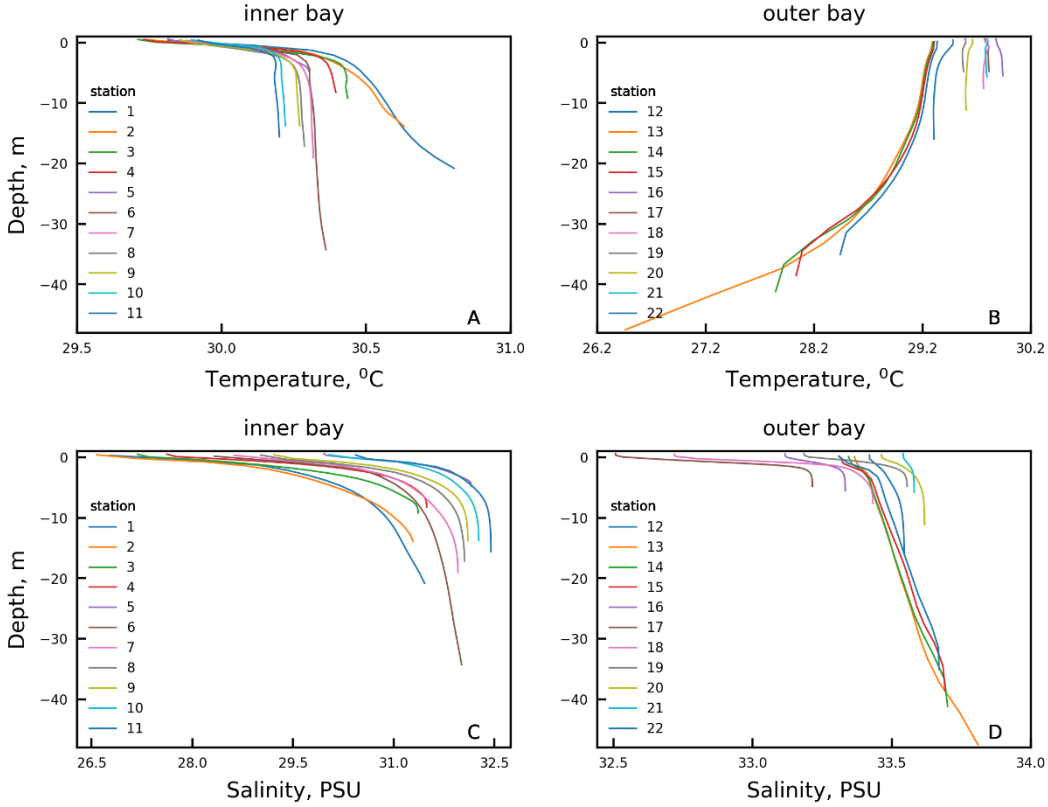

Figure 7. Vertical temperature and salinity profiles at Balikpapan Bay; (a) temperature profiles of inner stations sample, (b) temperature profiles of outer stations samples, (c) salinity profiles of inner stations sample, and (d) salinity profiles of outer stations sample.

4.5. Validation Result

The model predicts very well the observed water elevation at Semayang port (figure 9). The computed RMSE of water elevation between model solution and observation data is only about 7.8 cm. The MAPE is about 14.3 % and the model has very good agreement about 0.995 (perfect agreement = 1.0) indicating that the hindcast model has a great success to correctly simulates the observed sea level. However, an overestimation and underestimation also seen from data comparison due to unrealistic river inflow scenario (constant value of river discharges) which is used as input model.

5. Conclusions

A three-dimensional ROMS model has been successfully simulated the hydrodynamic process in the Balikpapan Bay on period 1 October 2012 – 1 January 2013. During the process, the one-way nesting method proven to offer the model a better solution when it was nested to coastal zone. In this study, the model is almost accurate to estimate the water level at Semayang port with good agreement between model solution and observed data.

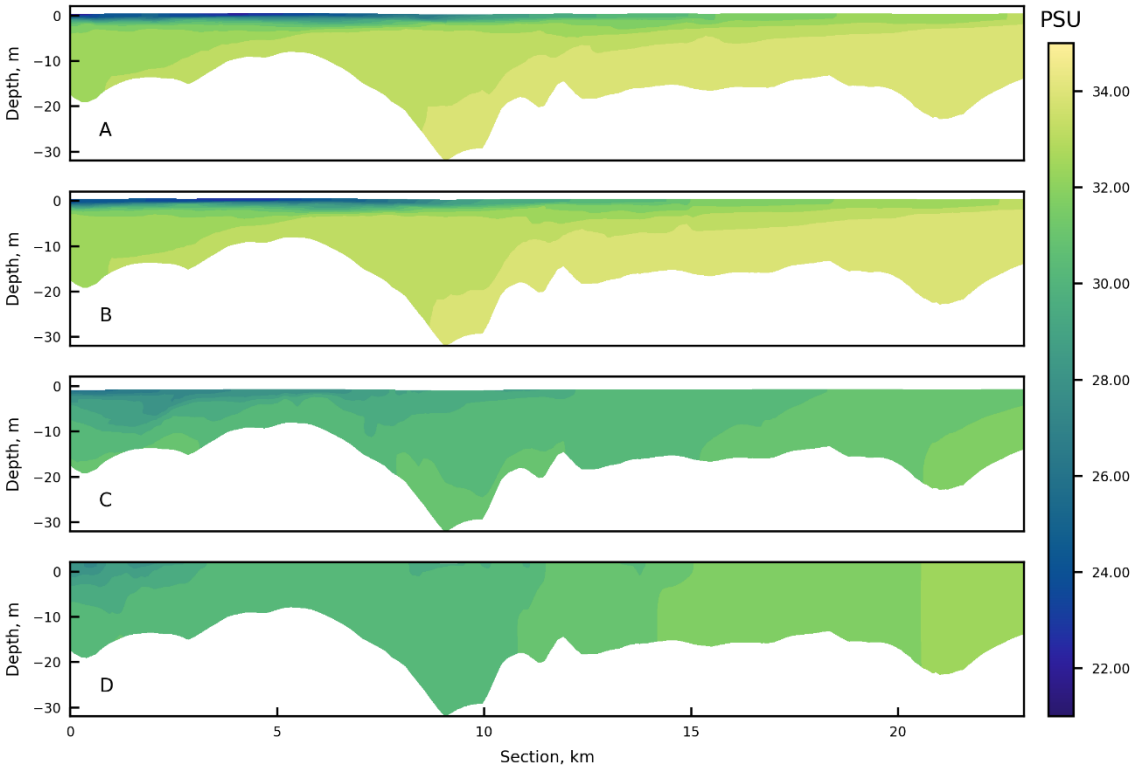

Figure 8. Cross-sectional distribution of salinity from inner to outer part of the Balikpapan bay during (a) low water and (b) high water at neap tide period and then (c) low water and (d) high water during spring tide condition.

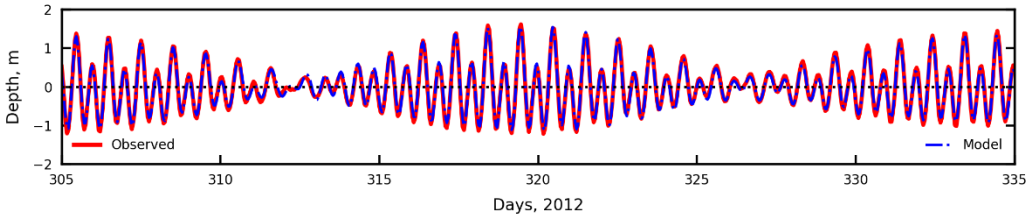

Figure 9. Comparison of observed and prediction time series of water level at the Semayang port, Balikpapan.

The model results showed that on the surface layer, the outer part of Balikpapan Bay is saltier than the inner part of the bay as expected with difference in salinity between inside and outside is about 8 psu. The same thing also happened for temperature though the difference is only about 1 ^{0}C where the warmer area occurred in the mid-section of the bay and along coastal areas. Freshwater from the rivers and salt water from the outer bay causes the water column near mouth of the bay stratified during neap tides and strongly mixed at spring tidal condition. Finally, we can conclude that the tidal mixing, atmospheric forcing and also input of river discharges have played important roles to dynamic process and water masses characteristic at Balikpapan bay.

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