Integrated 3D numerical modeling during La Niña and El Niño events using Regional Ocean Modeling System (ROMS) in Makassar Strait: preliminary study

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Abstract. This research showed the difference of thermocline layer depth during La Niña and El Niño events in the Makassar Strait, the main passage connecting the Pacific and Indian Oceans. La Niña event represented by 2011 and El Niño event represented by 2015. Three-dimensional numerical modeling using Regional Ocean Modeling System (ROMS) is used to determine ocean dynamic characteristics. The tides and atmospheric factor used as generating forces for coupled Ocean-Atmosphere-Wave-Sediment simulation model. Tidal elevation verification results from January to February 2017 showed a high confidence with RMSE = 0.148 m and MAPE = 13.51 %. Ocean circulation showed that water flows from north to south of the Makassar Strait in both conditions, El Niño and La Niña, indicating a transport from the Pacific to the Indian Oceans during those time. Two-dimensional seasonal sea surface temperature (SST) was used to determine the variability of thermocline layer depth. In general, based on simulation results, the depth of thermocline during La Niña was deeper than that during El Niño. The upper threshold of thermocline layer during El Niño phenomenon was shallower (average 27.29 m) compare to the threshold during La Niña (average 39.25 m). So do the lower threshold, during El Niño was shallower (average 160.47 m) compare to the threshold during La Niña (average 165.70 m). The thermocline thickness during El Niño (133.19 m) was found to be thicker compared to La Niña (126.43 m).

1. Introduction
Makassar Strait, geographically, is water that connects the Pacific Ocean and the Indian Ocean. Many unique phenomena, such as Indonesian Troughflow (ITF) [1, 2], tidal mixing caused by steep slope bathymetry [3], internal Kelvin wave propagated from Lombok Strait [4], and effects of ENSO events to water characteristics [5, 6]. Makassar Strait is also affected with seasonal trade wind that helped mixing in surface layer between sea water and fresh water from river [7].

To understand its complexity, a wind-wave-tide integrated numerical model needed to describe physical phenomenon in Makassar Strait. One of high level model that many others used in previous study is the Coupled Ocean-Atmosphere–Wave–Sediment Transport (COAWST) [8, 9, 10]. Figure 1 showed a schematic high level model COAWST which is comprised of the Model Coupling Toolkit to exchange data
fields between the ocean model ROMS, the atmosphere model WRF, the wave model SWAN, and the sediment capabilities of the Community Sediment Transport Model. This formulation builds upon previous developments by coupling the atmospheric model to the ocean and wave models (figure 2), providing one-way grid refinement in the ocean model, one-way grid refinement in the wave model, and coupling on refined levels [9]. This study only focused to apply an integrated hydrodynamic numerical model using Regional Ocean Model System (ROMS) during ENSO event as main interest of the study.

Figure 1. Basic schematic of the COAWST modeling system, include their ‘link’ between each other, ROMS as ocean model, SWAN as wave model, and WRF as atmospheric model [10].

Objective of this study is to understand the variability of ENSO phenomena, for both El Niño and La Niña conditions, to understand the characteristic water masses changes in Makassar Strait. To know its difference between two conditions, two variables were used as determinant factors; they are thermocline depth and sea surface temperature (SST). We compared these variables among three conditions, the La Niña in year of 2015, normal condition in year of 2013, and El Niño in year of 2011. The interest of this research area showed using figure 3. We compared the model elevation result with tide observation as verification.
Figure 2. An illustration of the COAWST Modeling System that provides exchange between an ocean model, an atmosphere model, a waves model, and a sediment transport model [9].

Figure 3. Study area of ROMS Model, Makassar Strait, and bathymetry isobaths interval is 500 m, verification point showed by red dot symbol.
2. Data

2.1 Tides
Forcing from tides is put to ROMS, and represented with eight tidal constituents of the M2, S2, N2, K2, K1, O1, P1, and Q1. They were imposed on the lateral open boundaries with constituents obtained from global model of ocean tides TPXO8-atlas TOPEX/Poseidon (http://volkov.oce.orst.edu/tides/global.html). TPXO8-atlas is current version of tides model with complex amplitudes harmonic constituents of earth-relative sea-surface elevation with ¼ degree resolution global grid and used a least-squares sense, the Laplace Tidal Equations and along track averaged data from TOPEX/Poseidon and Jason (on TOPEX/Poseidon tracks since 2002) [11, 12]. As a model verification, we used sea surface elevation, field observation data from Compact TD instrument, and compared to model result of 2017. We verified model elevation at latitude of 00°13’26,8” S and longitude of 117°25’11,2” E with date of verification is from January 29th to February 19th, 2017.

2.2 Temperature, Salinity, and Current
Global reanalysis assimilation data sets from Hybrid Coordinate Ocean Model (HYCOM) and Navy Coupled Ocean Data Assimilation (NCODA Global 1/12º), e.g sea water salinity, sea water potential temperature, sea water velocity (u and v), and sea surface elevation, used as initial condition to the model (http://hycom.coaps.fsu.edu/thredds/catalog.html). During the simulation, the interior temperature and salinity were nudged to the tracer fields from HYCOM with a time scale of 1 day for each year simulation.

2.3 Atmospheric Forcing
Atmospheric forcing such as surface wind, air pressure, air temperature, air humidity, net fresh water flux, rainfall rate, net long-wave radiation flux, and solar shortwave radiation flux extracted from European Centre for Medium-Range Weather Forecasts (ECMWF) (http://apps.ecmwf.int/datasets/) and applied to model for each scenario. Surface wind is velocity of wind 10 meters above sea surface elevation and used as generating force for surface current circulation. Surface wind was imposed every 3 hours for a-year long simulation. Atmospheric forcing were computed by ROMS using bulk-fluxes formulation internally and turbulent fluxes for wind, heat, and moisture are computed using Monin-Obukhov similarity theory [13]. These atmospheric forcing were imposed to the model every 3 hours time step.

2.4 Bathymetry
Figure 3 showed bathymetry that was used for the model area. It was extracted from global topography data fusion of NASA Shuttle Radar Topography Mission (SRTM) [14] land topography with measured and estimated seafloor topography (SRTM15_PLUS) (ftp://topex.ucsd.edu/pub/srtm15_plus/). This data is corrected by sounding [15] and gravity data [16] and modified from SRTM30 product distributed by USGS EROS data center. The grid resolution is 30 second which is roughly one kilometer. Land data are based on the 1-km averages of topography derived from the USGS SRTM30 gridded DEM data product created with data from the NASA Shuttle Radar Topography Mission. GTOPO30 data are used for high latitudes where SRTM data are not available. Version 1 of SRTM15 is based on V11 of the SRTM30_PLUS grid. Basically the land data is completely new based on a combination of SRTM, ASTER, and CryoSat-2 ice sheet topography. The ocean data are the same as SRTM30_PLUS but required more extensive editing to remove the bad points mostly along edges of the swath data. Ocean data are based on the global seafloor topography from satellite altimetry and ship depth soundings [17] global 1-minute grid between latitudes +/- 81 degrees. Higher resolution grids have been added from the LDEO Ridge Multibeam Synthesis Project, the JAMSTEC Data Site for Research Cruises, and the NGDC Coastal Relief Model. Arctic bathymetry is from the International Bathymetric Chart of the Oceans (IBCAO) [18]. For model, depth minimum settled to -5 m and deepest depth is -2734 m.
3. Methods

As a part of future goal research, in this study we focused to apply ROMS model to determine characteristic water mass in the Makassar Strait. We forced this model using ECMWF data and HYCOM data as initial condition to the model. We did yet included WRF model and SWAN model to see the good quality of our ROMS model as the main hydrodynamic model. To determine ENSO effect in Makassar Strait, we compiled three different scenarios hence represented El Niño, Normal, La Niña year. La Niña acted by 2011, Normal scenarios by 2013, and El Niño scenario by 2015. These scenarios were taken based on Ocean Niño Index (ONI) Extended Reconstructed Sea Surface Temperature (ERSST) v4 (https://data.nodc.noaa.gov/cgi-bin/iso?id=gov.noaa.ncdc:C00884). The Extended Reconstructed Sea Surface Temperature (ERSST) dataset is a global monthly sea surface temperature dataset derived from the International Comprehensive Ocean–Atmosphere Dataset (ICOADS). It is produced on a 2° × 2° grid with spatial completeness enhanced using statistical methods. This monthly analysis begins in January 1854 continuing to the present and includes anomalies computed with respect to a 1971–2000 monthly climatology. The newest version of ERSST, version 5, is based on optimally tuned parameters using the latest datasets and improved analysis methods [19, 20, 21].

We compared model results from year 2017 model using field observation data and used the setting to be applied to the three scenarios of model. We compared 3-month average temperature profiles (SST and vertical temperature profiles) between each scenario. We collected 7 random points in the model from north part to south part to see the vertical profiles and compared them between La Niña, El Niño, and normal scenario. Thus thermocline layer calculate using gradient criterion 0.05 °C/m to determine the depth of upper and lower threshold of thermocline layer [22].

To see the correlation between model and observation data, we used Root Mean Square Error (RMSE) and Mean Percentage Absolute Error (MAPE) formula that shown by equation (1) and (2) [23] below

\[
RMSE = \left[ \frac{\sum (A_{ij} - B_{ij})^2}{n} \right]^{1/2}
\]

\[
MAPE = \frac{1}{n} \sum_{t=1}^{t_{max}} \left| \frac{A_{ij} - B_{ij}}{A_{ij}} \right| \times 100\%
\]

with \(t\) is time step model in hour, \(n\) is total data, \(A\) is actual value of observation data, and \(B\) is model result.

3.1 Hydrodynamic Model ROMS

The simulation of hydrodynamic process in domain area were conducted by using the numerical model Regional Ocean Modeling System (ROMS). This model was quite popular among modeler, scientist and researcher who wanted to study the coastal application and developed from Princeton Ocean Model (POM). Many literature described this model capability especially in the regional ocean domain. ROMS 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 [24, 25, 26]. It uses a horizontal curvilinear Arakawa “C” grid and vertical stretched terrain-following coordinates [26]. This model also can be configured depending of users application which has several choices for advection schemes, pressure gradient algorithms, turbulent closure, and many types of boundary conditions.
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 (equation 3 and 4) directions are:

\[
\begin{align*}
\frac{\partial (H_u)}{\partial t} + \frac{\partial (u H_u)}{\partial x} + \frac{\partial (v H_u)}{\partial y} &+ \frac{\partial (\Omega H_u)}{\partial s} - f H_u = - \frac{H_z}{\rho_0} \frac{\partial p}{\partial x} + H \frac{\partial \eta}{\partial x} \\
- \frac{\partial}{\partial s} \left( u' w' - \frac{\nu}{H_z} \frac{\partial u}{\partial s} \right) - \frac{\partial (H S_{xx})}{\partial x} - \frac{\partial (H S_{xy})}{\partial y} + \frac{\partial S_{ps}}{\partial s} &= 0
\end{align*}
\]

(3)

\[
\begin{align*}
\frac{\partial (H_v)}{\partial t} + \frac{\partial (u H_v)}{\partial x} + \frac{\partial (v H_v)}{\partial y} &+ \frac{\partial (\Omega H_v)}{\partial s} + f H_v = - \frac{H_z}{\rho_0} \frac{\partial p}{\partial y} - H \frac{\partial \eta}{\partial y} \\
- \frac{\partial}{\partial s} \left( v' w' - \frac{\nu}{H_z} \frac{\partial v}{\partial s} \right) - \frac{\partial (H S_{yx})}{\partial x} - \frac{\partial (H S_{yy})}{\partial y} + \frac{\partial S_{ps}}{\partial s} &= 0
\end{align*}
\]

(4)

\[
0 = - \frac{1}{\rho_0} \frac{\partial p}{\partial s} - \frac{g}{\rho_0} H \frac{\partial \rho}{\partial s}
\]

(5)

with the continuity equation:

\[
\frac{\partial \eta}{\partial t} + \frac{\partial (H_z u)}{\partial x} + \frac{\partial (H_z v)}{\partial y} + \frac{\partial (H_z \Omega)}{\partial s} = 0
\]

(6)

and scalar transport:

\[
\begin{align*}
\frac{\partial (H_z C)}{\partial t} + \frac{\partial (u H_z C)}{\partial x} + \frac{\partial (v H_z C)}{\partial y} &+ \frac{\partial (\Omega H_z C)}{\partial s} = - \frac{\partial}{\partial s} \left( c' w' - \frac{\nu}{H_z} \frac{\partial C}{\partial s} \right) + C_{source}
\end{align*}
\]

(7)

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

\[
\begin{align*}
u' w' &= - K_M \frac{\partial u}{\partial z} , \quad \nu' w' = - K_M \frac{\partial v}{\partial z} , \quad \rho' w' = - K_M \frac{\partial \rho}{\partial z}
\end{align*}
\]

(8)

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 [27], expanded to include both surface and bottom-boundary layers [28]; (iv) Mellor-Yamada level 2.5 (MY2.5) method [29]; and (v) the generic length-scale (GLS) method [30] as implemented in [31] that also includes the option for surface fluxes of turbulent kinetic energy due to wave breaking. and for this study, we applied option (v) to
calculated eddy viscosities and eddy diffusivities. For the details of each variables on the equations are listed in table 1.

### 3.2 Model Design
This model have 160 east-west grid cells and 208 north-south grid cells with 2.6 km grid spacing uniformly. This model have 413.4 km wide and 538.2 km long with width area is about 222.49 \(10^3\) km². We used masking to determine which one is land and which one is ocean using 1 and 0, respectively. This model used sigma vertical coordinate with 30 layers and the shallowest depth is -5 m and deepest is -2734 m. Vertical depth references is mean sea level and no wet and dry scenarios used. We used 3 momentum open boundary (north, south, and east, see figure 4) with tidal elevation as major forcing input and coupled with atmospherics data from ECMWF as mention in Section 2. No nesting model used and no river discharge in domain model used. Time step was calculated using Courant–Friedrichs–Lewy condition (CFL) [32] and obtained 123.32 second. We plotted ocean current pattern 3-months averages based on ONI for 3 scenarios (El Niño, La Niña, and Normal) and so do for SST. Also we plotted temperatures vertical profiles and compared them to see upper threshold and lower threshold for thermocline layer.

#### Table 1. List of variables

| Variables | Description | Dimensions |
|-----------|-------------|------------|
| \(u\)     | Velocity x-direction | m s\(^{-1}\) |
| \(v\)     | Velocity y-direction | m s\(^{-1}\) |
| \(\Omega\) | Velocity z-direction | m s\(^{-1}\) |
| \(s\)     | Vertical sigma coordinate | – |
| \(z\)     | Vertical elevation | m |
| \(\eta\)  | Wave averaged free surface elevation | m |
| \(D\)     | Total water depth (\(D = h + \eta\)) | m |
| \(h\)     | Depth below mean sea level of the sea floor | 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 z-direction | m s\(^{-1}\) |
| \(c'\)    | Turbulent concentration (temperature, salt, or suspended-sediment concentration) | \(^\circ\)C, salinity, or kg m\(^{-3}\) |
| \(p\)     | Pressure | N m\(^{-2}\) |
| \(\rho\)  | Total density of seawater | kg m\(^{-3}\) |
| \(\rho_0\) | Reference density of seawater | kg m\(^{-3}\) |
| \(g\)     | Gravity | m s\(^{-2}\) |
| \(v\)     | Tracer kinematic viscosity | m\(^2\) s\(^{-1}\) |
| \(v_0\)   | Tracer kinematic diffusivity | m\(^2\) s\(^{-1}\) |
| \(C\)     | Tracer (temperature, salt, or suspended-sediment concentration) | \(^\circ\)C, salinity, or kg m\(^{-3}\) |
| \(C_{source}\) | Tracer source/sink term | \(C\) units m s\(^{-1}\) |
4. Results

4.1 Verification Model

Figure 4 showed a tidal verification between observation data (red line) and ROMS model results (blue line). It showed that model still under-estimated with observation data have higher value than output model. This verification is still good with pattern of tidal is match and RMSE value is about 0.148 m and MAPE is around 12.22%.

4.2 Surface Current Circulation in Makassar Strait

Ocean pattern circulation in Makassar Strait was influenced mostly by wind, tidal forcing, and gradient pressure difference between West Pacific Ocean and East Indian Ocean. Figure 5 (a), (b), (c), and (d) showed ocean current pattern seasonal depth-averaged, January February March (JFM), April May June (AMJ), July August September (JAS), October November December (OND), respectively, for 2011 La Niña condition. Figure 6 (a), (b), (c), and (d) showed ocean current pattern seasonal depth-averaged, JFM, AMJ, JAS, OND, respectively, for 2013 Normal condition. Figure 7 (a), (b), (c), and (d) showed ocean current pattern seasonal depth-averaged, JFM, AMJ, JAS, OND, respectively, for 2015 El Niño condition. And figure 8 (a), (b), and (c) is ocean current pattern for yearly averaged for 2011, 2013, 2015, respectively.

![Figure 4. Model verification between tide observation data and ROMS results at Pangempang Muara Badak, west part of domain model. Observation data showed by red line and model result showed by blue line.](image)

Model results showed that current always move along from north part to the south throughout the year. In July, August, and September with ONI is -0.7 at 2011 (weak La Niña condition) (figure 5 (c)), average current velocity is about 0.72 ms\(^{-1}\). In April, May, June, where ONI value is -0.3 at normal condition, figure 6 (b), average current velocity is about 0.88 ms\(^{-1}\). And when weak El Niño (January, February, March) with ONI value is 0.6, model showed ocean current velocity is about 0.64 ms\(^{-1}\). It showed that velocity when La Niña is slower than El Niño condition but still less powerful than normal condition. When strong La Niña happens with ONI -1.1, depth-average value of velocity is about 1.36 ms\(^{-1}\). And when normal condition at October, November, December with ONI -0.2, average velocity is about 0.89 ms\(^{-1}\). And maximum velocity showed at strong El Niño condition with ONI -2.5 at ONJ with value 1.56 ms\(^{-1}\) (darker green in figure 7 (d)). Current velocity showed also that higher velocity is placed at deeper bathymetry thus far from north
part of Makassar Strait to Labani Channel at southern part. Some turbulences induced at west-north part of
the model because characteristic of coastal line, in this case at Sangkulirang Bay and shallow bathymetry.
Water masses passing through from west Pacific Ocean to Makassar Strait using narrow gap at Talok Cape
and move to Sangkulirang Bay, East Borneo (figure 9). When west monsoon occurs, there are counter
current that move from Java Sea to west part of Makassar Strait. This fresher water masses mixed with
saltier water masses from Pacific Ocean therefore it became fresher and disappeared at southern part of
Makassar Strait.

| Table 2. Seasonal depth-averaged maximum current velocity between three scenarios |
|-------------------------------------------------|-----------------|-----------------|-----------------|
|                                                  | Moderate La Nina (2011) | Very Strong El Nino (2015) | Normal (2013)   |
|                                                  | ONI    | Velocity (ms⁻¹) | ONI    | Velocity (ms⁻¹) | ONI    | Velocity (ms⁻¹) |
| JFM                                           | -1.1   | 0.66            | 0.6    | 0.64            | -0.3   | 0.83            |
| AMJ                                           | -0.5   | 0.73            | 1      | 0.8             | -0.3   | 0.88            |
| JAS                                           | -0.7   | 0.72            | 1.8    | 0.81            | -0.4   | 1.04            |
| OND                                           | -1.1   | 1.36            | 2.5    | 1.56            | -0.2   | 0.89            |
Figure 5. Seasonal depth-averaged ocean current pattern at Makassar Strait during La Niña 2011; (a) JFM, (b) AMJ, (c) JAS, (d) OND.
Figure 6. Seasonal depth-averaged ocean current pattern at Makassar Strait during normal condition 2013; (a) JFM, (b) AMJ, (c) JAS, (d) OND.
Figure 7. Seasonal depth-averaged ocean current pattern at Makassar Strait during El Niño 2015; (a) JFM, (b) AMJ, (c) JAS, (d) OND.
Figure 8. Yearly averaged of ocean current at Makassar Strait between (a) La Niña, (b) normal condition, (c) El Niño.

4.3 SST vs ENSO
Figure 9 (a), (b), (c), and (d) showed sea surface temperature seasonal averaged, January February March (JFM), April May June (AMJ), July August September (JAS), October November December (OND), respectively, for 2011 La Niña condition. Figure 10 (a), (b), (c), and (d) showed SST seasonal averaged, JFM, AMJ, JAS, OND, respectively, for 2013 Normal condition. Figure 11 (a), (b), (c), and (d) showed SST seasonal averaged, JFM, AMJ, JAS, OND, respectively, for 2015 El Niño condition. And figure 12 (a), (b), and (c) is SST and STT anomaly for yearly average for 2011, 2013, 2015, respectively.

Result from model showed that SST varying from 27.20 °C – 30.32 °C during La Niña condition 2011. During normal condition, SST is slightly warmer than La Niña with value varying from 27.5 °C – 31.15 °C. This result is not quite correct because SST supposes to be warmer during La Niña than normal condition with warm pool should move to west Pacific and effecting Makassar Strait water mass. This is caused by model input is not good enough to reproduce a warmer SST during La Niña condition. The atmospheric forcing from peak of La Niña period which is OND on previous year is neglected. Another explanation possible is during La Niña SST supposes to be warmer but peak location of La Niña is do not match in the model area in Makassar Strait possibly will get a delay in SST signal. So, SST during La Niña is colder than normal period which is model result do not explain the realistic condition. Reversely, during El Niño condition, SST is colder than La Niña and normal condition with 25.7 °C – 31.23 °C. There are some area that always colder than any other area where placed at south-east part of the model and believed that was caused by input of atmospheric parameter such as heat flux. A warmer area was found at west part of the model where is water mass from Java Sea passing trough along coastal area to Makassar Strait. Higher SST found when strong La Niña 2011 occurred with ONI = -1, January February March (JFM) period. Colder SST found when weak El Niño 2015 occurred with ONI = 2.2, October, November, December (OND) period.

To see distribution and variability of thermocline depth, we took 7 sample points and plot them in vertical profiles of temperature (figure 13). Seasonal vertical profiles of temperature showed by figure 13 (a) for La Niña, figure 13 (b) for normal condition, and figure 13 (c) for El Niño. We calculated upper threshold (UT) and lower threshold (LT) of thermocline layer using gradient criterion ≥ 0.05 °C/m [21]. This criterion is good to used at South China Sea and around seas with 200 m depth or more [21]. We also calculated thermocline thickness during 3 different conditions with simply minus upper threshold to lower threshold. Thermocline layer at Makassar Strait found between 1.5 m – 391 m with thickness 146.5 m – 373.5 m and temperature decreased from 29.92 °C to 8.44 °C [33]. From model results, thermocline layer found around
53.69 m to 145.34 m with average depth around 91.65 m during La Niña 2011 condition. During El Niño 2015, thermocline layer found around 30.3 m to 114.74 m with average depth around 87.29 m. Table 3 showed variability of thermocline thickness, upper and lower threshold during 3 different conditions. Model result showed that thermocline layer during La Niña condition in Makassar Strait is found deeper than during El Niño condition. During La Niña, the thermocline is stable and very stratified and sea level height is lower than normal over the eastern Pacific, resulting in an increase slope of the ocean surface across the basin. Water masses from west Pacific Ocean pushed down the water masses at Makassar Strait hence the thermocline layer affected by it and became deeper as in line with strong La Niña occurred.

Table 3. Upper threshold, lower threshold, and thickness layer of thermocline during El Niño, La Niña, and normal condition at Makassar Strait.

| Condition       | JFM    | AMJ    | JAS    | OND    |
|-----------------|--------|--------|--------|--------|
| **Upper Threshold** |        |        |        |        |
| La Niña (2011)  | 62.47 m| 75.51 m| 26.37 m| 50.40 m|
| Normal (2013)   | 41.47 m| 9.52 m | 31.78 m| 38.44 m|
| El Niño (2015)  | 72.39 m| 40.17 m| 4.77 m | 4.46 m |
| **Lower Threshold** |        |        |        |        |
| La Niña (2011)  | 161.01 m| 151.01 m| 114.71 m| 144.63 m|
| Normal (2013)   | 149.44 m| 143.09 m| 149.45 m| 149.44 m|
| El Niño (2015)  | 154.99 m| 133.09 m| 88.21 m | 94.67 m|
| **Thickness**   |        |        |        |        |
| La Niña (2011)  | 98.55 m| 85.49 m| 88.33 m| 94.22 m|
| Normal (2013)   | 107.98 m| 123.56 m| 117.66 m| 111.00 m|
| El Niño (2015)  | 82.61 m| 92.92 m| 83.44 m| 90.20 m|
Figure 9. Seasonal averaged sea surface temperature at Makassar Strait during La Niña condition 2011; (a) JFM, (b) AMJ, (c) JAS, (d) OND.
Figure 10. Seasonal averaged sea surface temperature at Makassar Strait during normal condition 2013; (a) JFM, (b) AMJ, (c) JAS, (d) OND.
**Figure 11.** Seasonal averaged sea surface temperature at Makassar Strait during El Niño 2015; (a) JFM, (b) AMJ, (c) JAS, (d) OND.
Figure 12. Yearly average of sea surface temperature (top) and SST anomaly (bottom) at Makassar Strait between (a) La Niña, (b) normal condition, (c) El Niño.
Figure 13. Seven sample points (top left) and annual averaged vertical profiles of temperature from surface to 800 m depth: (a) La Niña, (b) normal year, (c) El Niño.
5. Conclusion
This study was an preliminary study of using model to described the effect of ENSO in changes of water mass characteristic and ocean circulation at Makassar Strait. Based on verification of tidal height, model showed a good result, but we cannot determine ocean current pattern and temperature value at Makassar Strait is good enough because lack of observation data of temperature and velocity. Ocean current flows from north to south part of the Makassar Strait. This flow was found stable throughout the year indicating the variability of ITF depends on ENSO phenomena in Pacific Ocean. Current velocity in El Niño is slightly faster than La Niña condition with different is about 0.1 ms⁻¹. Averaged SST showed that during La Niña is higher than El Niño condition but lower than normal condition. The model input is not good enough to reproduce warmer SST during La Niña compared to normal condition. Temperature vertical profiles showed that thermocline layer in La Niña found deeper than El Niño condition.

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