Estimation of mixed layer depth from argo float data in Makassar strait during el niño southern oscillation

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Abstract. Makassar Strait is a pathway of water mass passing trough from the Pacific Ocean to the Indian Ocean. Makassar Strait is also one of the waters in Indonesia which passed by Indonesian Throughflow (ITF). Movement of water masses due to the ITF, wind system, and complex bathymetry conditions will cause the movement of vertical water masses (mixing). This makes the upper layers homogeneous, the objective of this study is to assess the variation of MLD using Argo Float data adjusted for ENSO (El Niño Southern Oscilation) events, under El Niño, La Niña, and normal conditions. MLD determination using temperature gradient criterion with value ≤ 0,1 oC/m. The data processing using Ocean Data View 5.0.0 software shows that the depth of homogeneous layer in Makassar Strait waters during El Niño years is various, between 37,73 – 73,62 m with temperature 25,7 - 28,99 oC. During La Niña, MLD found varying around 30,59 – 97,89 m with temperature profile slightly colder (26,7 – 29,8 oC). And during normal year, MLD located around 28,55 m to 112,98 m, shallowest and deepest from all data set, respectively. Average value of MLD in is vaguely normal deeper than La Niña and El Niño condition, as it should be shallower, showed that temperature gradient criterion with value ≤ 0,1 oC/m is not quite good to determine the MLD layer in Makassar Strait.

1. Introduction
Indonesia Waters have natural conditions with diverse topography, because it is the connecting system between two oceans, Pacific Ocean and Indian Ocean, then the properties and condition of Indonesia Waters are affected by these two oceans, especially the Pacific Ocean [1]. The Makassar Strait has an important role as a shipping lane in the central zone of Indonesia, because the Indonesian ThroughFlow (ITF) that connects the Sulawesi Sea in the north and the Java Sea in the south [2].

Vertical temperature is divided into three layers, namely a mixed layer, thermocline layer and deep layer. The depth of the mixed layer is characterized by a temperature value in depth have same value as the surface [3]. The homogeneous layer is also called the mixed layer depth (MLD), because has interactions between the ocean and the atmosphere. According to [4], mixed layer found on the surface is characterized by a layer that is almost homogeneous with variations in temperature, salinity and inconspicuous density (very small changes) in relation to temperature, salinity and depth [1] and also explained that due to the movement of water masses and seasonal wind changes, this homogeneous layer can vary in depth between 0 - 100 meters in West Season and 0 - 50 meters in East Season.

In a previous study [5] the method for determining the upper limit of the thermocline using temperature gradient criteria was smaller than 0,1 °C / m. According to [6] in [5] the definition of the
thermocline layer as a depth or position where the temperature gradient is greater or equal to 0.1 °C / m. Based on the definition, the depth of the upper and lower limits of the thermocline layer can be determined. The upper limit is the minimum depth where the temperature difference has begun to occur smaller or equal to 0.1 °C / m with the depth below.

2. Materials and Methods
This study includes secondary data, Argo Float data downloaded from the official website of http://www.ARGODatamgt.org. It is adapted to ENSO conditions (El Niño, La Niña and normal). When El Niño conditions spread the Argo Float data occurs in the year 1998, 2009 and 2015 in this condition there were 20 data collection points, whereas in La Niña conditions the Argo Float distribution occurred in 1996, 2017, and 2018, as many as 115 Argo Floating profiles and the Argo Float data distribution occurred in 1194, 1996, 2012, 2013, 2014, 2017 and 2018 there were 252 Argo profiles scattered. As shown in figure 1 the distribution of Argo Float in the Makassar Strait in El Niño, La Niña and normal conditions.

3. Methodology

3.1. Data
This study was conducted in Makassar Strait. Astronomically, the location of the study was located at coordinates 4°0'15"S to 0°53'45"N and 116°0'0" E to 119°57'25.19"E. Data processing and analysis of the El Niño Southern phenomenon (ENSO) on the Mixed Layer Depth (MLD) was carried out in the Makassar Strait area, which was adjusted to ENSO events / phenomena and Argo Float data in 1994, 1996, 1998, 2008, 2009, 2012, 2013, 2014, 2015, 2016, 2017, and 2018.

3.2. Data Processing Method
This study, analysis of MLD variation using Ocean Data View (ODV) software 5.0.0. Argo Float data has NetCDF format (network Common Data Form), data that has been downloaded, then imported into ODV software for processing. The file that is imported is the ARGO data format for its profile, to find the MLD value of the data that has been imported and then extracted into MS. Excel, in this study used temperature gradient criteria 0.1 °C / m to find the depth of the mixing layer written in equation 1, then ARGO data was plotted using ODV software.

To calculate the vertical temperature gradient according to the equation used by [7]:

\[
G_j = \frac{T_{j+1} - T_j}{D_{j+1} - D_j}
\]  

(1)
where:

\( G_j \) = vertical temperature gradient value
\( T_j \) = temperature
\( D_j \) = depth

Correlation calculations are used to see the relation between mixed layer depth or layer depth mixing with the Ocean Nino Index (ONI). The correlation that used is a correlation analysis between two variables, there are variable \( x \) which is represented by the depth of the mixing layer, and variable \( y \) is represented by the Ocean Nino Index (ONI). The equation used is the Pearson linear correlation equation as follows [8].

\[
    r_{xy} = \frac{\sum(x_i-\bar{x})(y_i-\bar{y})}{\sqrt{\sum(x_i-\bar{x})^2 \cdot \sum(y_i-\bar{y})^2}} \tag{2}
\]

where:

\( r \) = Pearson correlation coefficient
\( x_i \) = variable that is correlated in the form of layer depth mixing
\( x \) = variable \( x \)
\( y_i \) = variable correlated in the form of ONI
\( y \) = average variable \( y \)

3.3. Data Analysis Method

Data analysis method used is descriptive statistical analysis, it is a statistics methods that used to analyze data by describing or describing data that has been collected as it is without intending to make conclusions that apply to the general [9].

The presentment of data analysis was done by grouping the data based on the conditions of ENSO (El Nino, La Nina and normal) in this study the depth of the mixing layer can be displayed in tabulation table and vertical profiles of temperature. Mixed Layer Depth structure was calculated by data distribution through average calculations, besides the results of the analysis are also displayed in the form of temperature vertical distribution.

4. Results and Discussion

This study analyzing the depth of mixing layers in the Makassar Strait using phenomenon (ENSO) adjusted Argo Float data, namely El Niño, La Niña, and normal. The parameters examined in this study are parameters of temperature, salinity and depth.

The results of ARGO data processing in the form of vertical temperature profiles provide an overview of changes in temperature to depth, starting from a depth of 0 m to 500 m. The temperature on the surface is relatively higher compared to the temperature values below the surface layer, which ranges from 28-30°C, this happened because the location of the Makassar Strait waters is in the tropics that are close to the equator so it has an effect from warm pool of tropical in Pacific Ocean. According to [10] tropical warm water columns are characterized by surface temperatures greater than 28°C.

This study, changes in the depth of the mixing layer with a gradient temperature of 0.1 °C / m are presented in Figure 1 based on the image formed by the pattern of water mass coating consisting of 3 parts namely mixed layer depth, thermocline layer and deep layer. This study, the thickness of the homogeneous layer (Mixed Layer Depth) that occurred in the ENSO phenomenon of La Niña, El Niño years, and normal years was observed.

4.1. El Niño Conditions

The results of the temperature distribution in the form of a vertical profile in the condition of el nino presented in Figure 3 based on the image can be seen that there is a change in temperature to the depth of the surface of the gate. The average mixed layer depth layer ranges from 53.18 m, with an average temperature range of 27.9 oC with an average salinity of 34.19 psu.

In Weak El Niño condition occurred in 2009 with 12 ARGO profiles available in 2009 in July where the ONI (Ocean Nino Index) value was 0.5. The average depth of the mixing layer on WE conditions ranged from 56.77 m with an average temperature of 28.58°C while the mixing that
occurred in the WE condition was the deepest at the coordinates 119.34°E/0.502°S with the lower limit of the Mixed Layer Depth at a depth of 73.62 m with a temperature of 28.38 °C with a salinity of 34.16 PSU.

Where in Very Strong El Niño conditions occurred in 1998 and 2015 with 5 CTD profiles. 4 CTD profiles in 1998 and 1 CTD profile in 2015 the average mixing layer depth in VSE conditions ranged from 53.18 m to an average temperature of 27.86 °C and salinity of 34.19 PSU. The depth of the mixing layer was the most in condition VSE is 60.16 m with a temperature of 27.39 °C in profile 1 (118.406 °E/3.928°S) in 1998 in February where in February the Ocean Nino Index (ONI) table was 2.0

Figure 2. Vertical Profile in El Niño, La Niña, and Normal conditions.

Figure 3. Vertical profiles of MLD maximum and minimum value in El Niño Conditions.

Table 1. Table Mixed Layer Depth in El Niño

| Items          | Average | Min  | Max  |
|---------------|---------|------|------|
| MLD (m)       | 53.18   | 37.73| 73.62|
| Temperature (°C) | 27.9    | 25.7 | 28.9 |
| Salinity (PSU) | 34.1    | 33.9 | 34.8 |

The MLD layer is seen as a straight line from the surface and the curved part is the thermocline layer. While the transverse temperature results are clearly seen in the color change between the MLD layer, the thermoclinic layer and the deep layer presented in Figure 4. Changes in the temperature in the MLD layer are characterized by changes in gradient ≤ 0.1 °C.
4.2. La Niña Conditions

Mixed layer depth in the Makassar Strait on the La Niña phenomenon, that is, when Weak La Niña conditions available from Argo Float occur in 1996, 2016, 2017 and 2018.

In Weak La Niña conditions the average depth of mixing layer in WL conditions ranges from 54.63 m with an average temperature of 28.67 °C while mixing that occurs in the most WE condition occurs in October 2017 at coordinates 117.731° E/-3.916° S where the ONI (Ocean Nino Index) value is -0.6 with MLD at a depth of 97.79 m with a temperature of 26.95 °C with a salinity of 34.04 PSU.

The MLD layer is seen as a straight line from the surface and the curved part is the thermocline layer. While the transverse temperature results are clearly seen in the color change between the MLD layer, the thermocline layer and the inner layer presented in Figure 6.
4.3. Normal Conditions
In normal conditions data are available in 1994, 1996, 2012, 2013, 2014, 2017 and 2018 with 252 ARGO profiles spread across the Makassar Strait. In this condition the MLD average in the Makassar Strait ranges from 65.53 m with an average temperature of 27.96°C and a salinity average of 33.96 PSU the most in-depth mixing depth occurred in 2013 in October at coordinates (Profile 112) with mixing layer depth of 112.98 m with temperature and salinity, respectively 27.46 °C and 34.315 PSU where the ONI (Ocean Nino Index) value is -0.2. The lowest mixing layer depth under normal conditions occurred in 2018 in June with a mixing depth of 28.55 m with a temperature of 28.164 °C and a salinity of 34.02 PSU where the value of ONI (Ocean Nino Index) is 0,1.

Table 3. Table Mixed Layer Depth in Normal

| Items          | Average | Min  | Max   |
|----------------|---------|------|-------|
| MLD (m)        | 66.82   | 28.55| 112.98|
| Temperature (°C)| 27.9    | 25.6 | 29.9  |
| Salinity (PSU) | 33.9    | 32.4 | 34.7  |
5. Discussion
According to [11] the depth of the homogeneous layer is effective for defining the depth of the upper limit of the thermocline layer, so that if the homogeneous layer of a deep water can be ensured that the thermocline layer will be deep as well. One of the factors that influence mixing is wind. According to [12] weak winds will cause stirring which does not reach deep depths so that the homogeneous layer above is thin. A thin homogeneous layer will be followed by a shallow depth of the mixing layer. The turn of the monsoon that changes regularly is marked by the blowing of monsoons alternately causing a direct impact on changes in the physical properties of seawater.

Model result showed that thermocline layer during La Niña condition in Makassar Strait is found deeper than during El Niño condition. In this study the Mixed Layer Depth and Ocean Nino Index relationship in the Makassar Strait has a Pearson correlation value of -0.27 negative linear correlation is low, this indicates that the second relationship is inversely proportional to where the deeper the depth layer depth, the smaller the ocean nino index value. This shows that the effect of ENSO NINO 3.4 on the mixed layer depth is not as strong as shown in figure 9.

6. Conclusion
The depth of the mixed layer which is inversely proportional to this indicates that the NINO 3.4 ENSO is not very strong. Where the average depth of MLD was found to be deeper in Normal conditions which was 66.82 m. The average depth of La Niña is 54.63 m. Whereas, in flood El niño conditions around 53.18 m.
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