The Changes in Oceanographic Condition of Makassar Strait Related with El Nino Southern Oscillation (ENSO) Events of 2009 - 2019

N. N. Anugrah1, W. Samad1 and D. Berlianty2

1Marine Science Department, Hasanuddin University, Makassar, 90245, Indonesia
2Institute for Marine Observation, Ministry of Marine Affairs and Fisheries of Indonesia, Negara, Jembrana – Bali 82251, Indonesia

nandaanugraah@gmail.com

Abstract: The Makassar Strait is one of the main gates of the Indonesian Through Flow (ITF) which carries out water masses from the Pacific to the Indian Ocean through Makassar Strait, Indonesia. The Makassar Strait is thought to be one of the waters affected by the ENSO phenomenon. This study aims to determine changes in sea surface temperature, chlorophyll-a content, wind speed and direction and salinity content, as well as to see the upwelling potential in the Makassar Strait waters during the ENSO event from 2009-2019. The data used are sea surface temperature (SST), sea surface salinity, surface current velocity and direction, surface wind speed and direction as well as surface chlorophyll-a obtained from Climate Prediction Centre (NOAA). Based on Oceanic Nino Index (ONI) data, during 2009 - 2019 there were 3 times the ENSO phenomena occurred. The results of the study stated that in each of the ENSO phases fluctuations occurred at sea surface temperature, surface chlorophyll-a, as well as wind speed and direction and sea surface currents. During the ENSO phase, it is suspected that there is potentially area of upwelling in the Makassar Strait. This study highlights that ENSO event could be a reference for determining the location of sustainable fishing.

Keywords: ENSO, Makassar Strait, ITF, Sea Surface Temperature, Sea Surface Salinity, Upwelling.

1. Introduction

Sea surface temperature is one of the factors associated with climate change. Drastic changes in sea surface temperature will affect climate in the area around the waters. One of the phenomena of climate anomaly caused by changes in sea surface temperature is El Nino Southern Oscillation (ENSO) (Figure 1). ENSO is a recurring pattern of climate variability in the eastern Pacific Ocean which is characterized by anomalies at sea surface temperature, which at the time of the warming of the sea surface in the Western Pacific illustrates the La Nina event and vice versa if there is sea
level cooling it becomes an illustration of El Nino, and Sea anomalies Level Pressure (Southern Oscillation) [8].

![Diagram of El Nino and La Nina](http://www.bom.go.au/)

Figure 1. Scheme for the occurrence of El Nino and La Nina (Source: http://www.bom.go.au/).

Indonesia is one of the areas that affected by the ENSO in the Pacific Ocean. [5] mentioned that Indonesia's oceanographic conditions are much influenced by monsoon winds which cause monsoon currents and Indonesian Through Flow (ITF). The mass of water transported by ITF is affected by ENSO events consisting of normal conditions, El Nino, and La Nina.

The Makassar Strait is one of ITF main gates that carries water masses from the Pacific Ocean to Indonesia. The Makassar Strait itself is located between Kalimantan and Sulawesi Island. Based on research [6], the Makassar Strait water mass has a North Pacific Subtropical Water (NPSW) water mass characteristic which is proved by the maximum salinity value found in the thermocline layer. Also, a research conducted by [3] states that the Makassar Strait is the main gate of ITF which carries the largest mass of water with a value of around ± 3.3 Sv.

When the ENSO phenomena occur, the sea surface temperature that experiences anomalies will affect several things in the waters, one of which is the chlorophyll-a concentration in the waters. According to [12] there are some evidence that show a link between changes in sea surface temperature and chlorophyll-a concentration. By the [1] revealed that the pattern of chlorophyll-a distribution is based on the sea surface temperature where the environment is located. However, the ENSO phenomenon also impacts flow and salinity. The changes in sea surface temperature due to ENSO can also affect rainfall intensity. As explained by [11] that the impact of the ENSO phenomenon is it can affect rainfall in Indonesia. El Nino can cause the rainy season to come later and reduce the total rainfall. In La Nina, there was an increase in rainfall in Indonesia and causes the advance of the beginning of the rainy season.

This research was conducted to determine the effect of the ENSO phenomena on the characteristics of oceanographic dynamics in the waters of the Makassar Strait. In this study, the data used from 2009 to 2019 with spatial resolution data about 1° / 12′ (deg).

2. Research Methodology

2.1. Research Location and Time

This research was conducted from July to August 2019. The research was located in the Makassar Strait waters ranging from 4° North Latitude - 7° South Latitude and 116° East Longitude - 120° East Longitude (Figure 2). Data analysis was carried out at two points which were considered capable of representing parts of the Makassar Strait, where point 1 represented coordinates 4° South
Latitude and 118˚ East Longitude and point 2 represented coordinates 1˚ South Latitude and 117.5˚ East Longitude.

Figure 2. Map of Research Location.

2.2. Data collection
NOAA Climate Prediction Center (CPC) data downloaded on NOAA’s official website (http://origin.cpc.ncep.noaa.gov) in the form of the Oceanic Nino Index (ONI) data and oceanographic model data downloaded on Copernicus Marine and Environmental Services (CMEMS) official website (http://marine.copernicus.eu)

2.3. Processing and data analysis
The data processing was using Panoply platform of NASA-CPC NCEP.

There are several stages of data processing carried out in this study. These stages include: (1) Determining the ENSO anomaly phase, (2) Calculating the anomaly values (3) Processing the oceanographic data re-analysis.

In determining the ENSO anomaly phase, the data used is NOAA Climate Prediction data which is processed into Oceanic Nino Index (ONI) data. The ONI index then used to determine the time of the study which is divided into 4 research time ranges, namely El Nino phase (2009-2010), La Nina phase (2010-2011), normal phase (2013) and El Nino phase (2015-2016). The division of these 4-time frames is based on the Oceanic Nino Index starting from 2009-2019 (Figure 3).
In determining the anomaly value, we subtracted the monthly value in the parameters of sea surface temperature and chlorophyll-a in the ENSO phase to the average data value in August 2009-2018. The anomaly value calculation is given by:

\[ A(t) = X(t) - \overline{X}_m \]

Where, \( A(t) \) is the anomaly at the time \( t \) where the “bar” represent averaging over that variable.

Example: SST anomaly = SST(month ENSO - Monthly mean of SST 2009-2018). Further calculation of anomaly were also done to other parameter.

The processing of oceanographic data re-analysis is used a Java-based application as known as Panoply platform. In this study, the value of the data taken for further analysis is the value of the parameters of sea surface temperature and chlorophyll-a and then determines the 2 research location points to be analysed. The values of each parameter then averaged annually. Average sea surface temperature data then used to make the average SST climatology graph and anomaly values graph based on anomaly phases that have been determined using ONI. The average parameter values for sea surface temperature and chlorophyll-a are calculated by the equation:

\[ \overline{x} = \frac{x_1 + x_2 + x_3 + \ldots + x_n}{n} \]

Where:
- \( \overline{x} \): Average annual value
- \( x \): Monthly value of each point
- \( n \): Amount of data averaged

The wind, salinity, and current parameters are processed to produce the distribution pattern of each parameter when the anomalous phase occurs.

During the data analysis stage, the SST climatology average graph is used to temporarily analyse sea surface temperature patterns in Makassar Strait from 2009-2019. The anomaly value graph is used to analyse the SST and chlorophyll-a patterns during the anomalous phase. The average values of the SST and chlorophyll-a parameters were processed using simple linear regression to analyse the correlation between parameters. The average value of these parameters is also used to analyse the potential for
upwelling in Makassar Strait in determined anomaly phase. And the last, the circulation patterns of wind speed and direction, current speed and direction, and salinity are analysed to see the pattern of spatial distribution during the anomalous phase.

3. Results and Discussion

3.1. SST Climatology Average

The average SST climatology describes the temporal sea surface temperature pattern. Figure 4 shows the pattern of sea surface temperature in the Makassar Strait temporarily from 2009 to 2019 at point 1 and point 2.

In both graphs (Figure 4), it can be seen that the lowest sea surface temperature in the Makassar Strait always occurs in August. This is caused by the occurrence of the east monsoon in August. Based on research by [15] revealed that this east monsoon season occurs in April to August and causes rising temperatures in the northern hemisphere, especially in the Asian Continent, and decreasing in air pressure. Increased temperature and low air pressure are characteristics of the dry season, in which a decrease in sea surface temperature occurs.

The highest sea surface temperature occurred in April at point 1 and in May at point 2. April and May are the time of the transition season. As explained by [15], this time is included in the category of transition season I which is known as the starting point of dry season. In the transitional season, the sun moves across the equator causing the wind to become weak and the direction to be uncertain. Weak winds cause the sea surface temperatures to rise. However, [4] also explained that the range of sea surface temperature is strongly influenced by the intensity of sunlight entering the surface, salinity, and global currents.

3.2. SST Anomaly

SST anomaly values in each anomaly phase are illustrated through the graph in Figure 5 at Point 1 and Point 2. The anomaly values in the El Nino phase (2009-2010) range from 0.20 °C to 2.30 °C at Point 1 and 0.40 °C to 0.80 °C (a) at Point 2. In the La Nina phase (2010-2011), the SST anomaly values range from 0.80 °C to 2.20 °C at Point 1 and 0.80 °C to 1.40 °C at Point 2 (b). Then in the El Nino phase (2015-2016), the anomaly values at Point 1 range from -0.90 °C to 2.70 °C and at Point 2 range from -0.10 °C to 1.50 °C to (c).
The positive anomaly value in Figure 5 indicates the impact of the La Nina phenomenon that causes sea surface temperatures to rise. This can be proven by the anomaly value that tends to be higher in the La Nina phase, especially at Point 1. Conversely, the negative anomaly value in Figure 4 indicates the impact of the El Nino phenomenon that causes sea surface temperature to decrease, which is then proven by the negative anomaly values (-) and decreased of SST value in the El Nino at both phases (2009-2010 and 2015-2016). This has been explained by [2], revealed that the anomaly in the sea surface temperature during El Nino and La Nina phases occurred because when El Nino took place, there was a shift in the warm pool area towards the east of the Pacific equatorial region causing the warm pool area cools down. This cold mass of water then carried by ITF to the maritime continent and caused drought due to the inhibition of evaporation caused by the cold sea surface temperatures. The opposite symptoms occurred when La Nina took place, heating up temperature around the warm pool area and shifts further west of the Pacific.

3.3. Chlorophyll-a Anomaly

The anomaly value at Point 1 is not displayed graphically because there is no anomaly at the chlorophyll-a value at that point. While the anomaly values in each anomaly phase at Point 2 are illustrated through the graph in Figure 6. The anomaly values in the El Nino phase (2009-2010) range from 0.0 mg / m³ to 1.20 mg / m³ (a). In the La Nina phase (2010-2011) the chlorophyll-a anomaly values range from 0.0 mg / m³ to 0.70 mg / m³ (b). In the El Nino phase (2015-2016) it ranges from 0.0 mg / m³ to 1.60 mg / m³ (c).
Figure 6. Chlorophyll-a Anomaly Value in (a) El Nino Phase (2009-2010), (b) La Nina Phase (2010-2011), and (c) El Nino Phase (2015-2016).

The chlorophyll-a anomaly value is all positive (Figure 6). This is caused by the value of chlorophyll-a in each month is greater than the average value in the normal phase. As for several months in the anomalous phase which has no value due to the value of chlorophyll-a in the month is the same as the average value in the normal phase, where this also happens to the value of chlorophyll-a at Point 1.

The positive anomaly value in Figure 6 indicates the impact of the El Nino phenomenon causes the sea surface temperatures to cool down. This is evident by observing the anomaly values of chlorophyll-a which tend to be higher in both El Nino phases (2009-2010 and 2015-2016) compared to the chlorophyll-a anomaly value in the La Nina phase. This also happened in a study conducted by [10] where at the time of El Nino in July and August 2015, there was a drastic decrease in temperature and an increase in chlorophyll-a concentration in the Halmahera Sea. Cooler sea surface temperatures can cause upwelling which sends a mass of nutrient-rich water to the sea surface.
3.4. Wind, Current, and Salinity Distribution Patterns in The Makassar Strait at ENSO Anomaly Phase

Figure 7. Patterns of Makassar Strait Surface Wind Circulation in El Nino Phase (2009-2010) in September 2009 (a), October 2009 (b), November 2009 (c).

Figure 7 illustrates the pattern of surface wind direction and speed circulation in El Nino phase (2009-2010) in Makassar Strait in September, October and November 2009. The El Nino phase (2009-2010) started from the 2009 September to March 2010. In the El Nino phase (2009-2010), the lowest wind speed was found in November 2009 with a maximum wind speed of 3.3 m/s while the highest wind speed was in January 2010 with a maximum wind speed of 7.8 m/s.
Figure 8. Patterns of Makassar Strait Surface Current Circulation in El Nino Phase (2009-2010) in September 2009 (a), October 2009 (b), November 2009 (c).

Figure 8 illustrates the pattern of direction and speed currents circulation in El Nino phase (2009-2010) in Makassar Strait in September, October, and November 2009. In the El Nino phase (2009-2010), the lowest surface current velocity was in January 2010 with a maximum current speed of 0.9 m/s while the highest surface current velocity was found in October and November 2009 with a maximum current speed of 1.4 m/s.

Figure 9. Patterns of Surface Salinity Distribution in El Nino Phase (2009-2010) in September 2009 (a), October 2009 (b), November 2009 (c).

Figure 9 illustrates the pattern of surface salinity distribution in El Nino phase (2009-2010) in Makassar Strait in September, October and November 2009. In the El Nino phase (2009-2010), the lowest salinity was found in March 2010 with levels of salinity was 34.1 PSU, while the highest salinity was found in September 2009 with salinity levels of 34.6 PSU.
Figure 10. Patterns of Makassar Strait Surface Wind Circulation in La Nina Phase (2010-2011) in September 2010 (a), October 2010 (b), November 2010 (c).

Figure 10 illustrates the pattern of surface wind direction and speed circulation in La Nina phase in Makassar Strait in September, October and November 2010. The La Nina phase started from July 2010 to March 2011. In the La Nina phase (2010-2011), the lowest wind speed was in November 2010 with maximum wind speed of 2.1 m/s while the highest wind speed was in September 2010 with maximum wind speed of 7.8 m/s.

Figure 11. Patterns of Makassar Strait Surface Current Circulation in La Nina Phase (2010-2011) in September 2010 (a), October 2010 (b), November 2010 (c).
Figure 11 illustrates the pattern of direction and velocity of surface currents circulation in La Nina phase in Makassar Strait in September, October, and November 2010. In the La Nina phase (2010-2011), the lowest surface current velocity was found in February and March 2011 with a maximum current speed of 0.7 m/s while the highest surface current speed was in July 2010 with a maximum current speed of 1.3 m/s.

Figure 12 illustrates the pattern of surface salinity distribution in La Nina phase (2010-2011) in September 2010 (a), October 2010 (b), November 2010 (c).

Figure 12. Patterns of Makassar Strait Surface Salinity Distribution in La Nina Phase (2010-2011) in September 2010 (a), October 2010 (b), November 2010 (c).

Figure 12 illustrates the pattern of surface salinity distribution in La Nina phase (2010-2011) in Makassar Strait in September, October, and November 2010. The highest salinity in the La Nina phase (2010-2011) occurred in three consecutive months starting from August to October 2010 with salinity level of 34.4 PSU, while the lowest was at the end of the La Nina phase, namely in March 2011 with salinity level of 33.8 PSU.
Figure 13. Patterns of Makassar Strait Surface Wind Circulation in Normal Phase (2013) in September 2013 (a), October 2013 (b), November 2013 (c).

Figure 13 illustrates the pattern of surface wind direction and speed circulation in Normal phase in Makassar Strait in September, October and November 2013. The Normal Phase occurs throughout 2013. In the Normal phase, the lowest wind speed is found in November 2013 with a maximum wind speed of 2.3 m/s while the highest wind speed was found in August 2013 with a maximum wind speed of 8.6 m/s.
Figure 14. Patterns of Makassar Strait Surface Current Circulation in Normal Phase (2013) in September 2013 (a), October 2013 (b), November 2013 (c).

Figure 14 illustrates the pattern of surface currents direction and velocity in Normal phase in Makassar Strait in September, October and November 2013. In the Normal phase, the lowest surface current velocity was found in June 2013 with a maximum current speed of 0.6 m/s while the highest surface current velocity was found in August and November 2010 with a maximum current speed of 1.3 m/s.

Figure 15. Patterns of Makassar Strait Surface Salinity Distribution in Normal Phase (2013) in September 2013 (a), October 2013 (b), November 2013 (c).

Figure 15 illustrates the distribution of surface salinity in Normal phase in Makassar Strait in September, October and November 2013. The highest salinity in the Normal phase occurred in three consecutive months starting from August to October 2010 with salinity level of 34.4 PSU in August and September and in October were 34.5 PSU, while the lowest were in February and April 2013 with salinity level of 33.9 PSU.
Figure 16 illustrates the patterns of surface wind direction and speed circulation in El Nino phase (2015-2016) in Makassar Strait in September 2015 (a), October 2015 (b), November 2015 (c).

Figure 16. Patterns of Makassar Strait Surface Wind Circulation in El Nino Phase (2015-2016) in September 2015 (a), October 2015 (b), November 2015 (c).

The El Nino phase (2015-2016) started from May 2015 to May 2016. In the El Nino phase (2015-2016), the lowest wind speed was found in November 2015 with maximum wind speed of 4.0 m/s while the highest wind speed was in August 2015 with maximum wind speed of 9.3 m/s.
Figure 17. Patterns of Makassar Strait Surface Current Circulation in El Nino Phase (2015-2016) in September 2015 (a), October 2015 (b), November 2015 (c).

Figure 17 illustrates the pattern of surface currents direction and velocity in El Nino phase (2015-2016) in Makassar Strait in September, October, and November 2015. In the El Nino phase (2015-2016), the lowest surface current velocity was in May 2016 with a maximum current speed of 0.5 m/s while the highest surface current speed was in December 2015 with a maximum current speed of 1.5 m/s.

Figure 18. Patterns of Makassar Strait Surface Salinity Distribution in El Nino Phase (2013) in September 2015 (a), October 2015 (b), November 2015 (c).

Figure 18 illustrates the pattern of surface salinity distribution in El Nino phase (2015-2016) in Makassar Strait in September, October and November 2015. The highest salinity in the El Nino phase (2015-2016) occurred in three consecutive months starting from August to November 2015 with salinity of 34.7 PSU. While the lowest salinity was found in May 2015 with salinity level of 34.0 PSU.

3.5. Correlation between SST and Chlorophyll-a during ENSO Anomaly Phase
Figure 19. Graphic of Correlation Test of SST and Chlorophyll-a El Nino Phase (2009-2010) at Point 1 (a), and Point 2 (b).

Figure 19 show the differences in the results of simple linear regression at the two points in anomalous phase. In the El Nino phase (2009-2010) the results of simple linear regression obtained a correlation coefficient ($R^2$) of 0.0324 at point 1 which tend to be positive, and 0.3863 at point 2 which tend to be negative (Figure 19). However both value of relations are too small thus irrelevant.

3.6. Potential Upwelling in the ENSO Event in the Makassar Strait

According to [9] the occurrence of upwelling in the ocean can be identified by looking at various indicators such as lower temperatures from the surroundings, salinity, nutrients, and chlorophyll-a which are generally higher than the surroundings.

The upwelling event is closely related to the two main parameters used in this study, namely sea surface temperature and surface chlorophyll-a content with wind circulation patterns that support the data. Analysis to see the potential for upwelling in this study was carried out at the time of the El Nino Southern Oscillation (ENSO) which was divided into 3 phases, namely the El Nino phase 1 that occurred in 2009-2010, the La Nina phase that occurred in 2010-2011 and the El Nino phase 2 which occurred in 2015-2016.

| Table 1. Average value of Sea Surface Temperature and Chlorophyll-a Surface of the Makassar Strait at Point 1 (a), and Point 2 (b). |
|-------------------------------------------------|
| (a) | Point 1 | Chlorophyll-a (mg/m$^3$) |
| Year/Month | Sea Surface Temperature ($^\circ$C) | 2009 | 2010 | 2011 | 2012 | 2013 | 2014 | 2015 | 2016 |
| 2009 | 29.4 | 0.100 |
| 2010 | 30.0 | 0.108 |
| 2011 | 29.1 | 0.100 |
| 2012 | 29.2 | 0.117 |
| 2013 | 29.6 | 0.100 |
| 2014 | 29.4 | 0.100 |
| 2015 | 29.1 | 0.100 |
| 2016 | 30.1 | 0.100 |
| (b) | Point 2 | Chlorophyll-a (mg/m$^3$) |
| Year/Month | Sea Surface Temperature ($^\circ$C) | 2009 | 2010 | 2011 | 2012 | 2013 |
| 2009 | 29.5 | 0.525 |
| 2010 | 29.8 | 0.542 |
| 2011 | 29.5 | 0.442 |
| 2012 | 29.4 | 0.342 |
| 2013 | 29.8 | 0.550 |
To determine the potential of upwelling based on average sea surface temperature values and surface chlorophyll-a concentrations, by [7] were divided upwelling intensities by dividing upwelling levels into three categories, namely weak, moderate, and strong upwelling (Table 2).

| Year     | Temperature (˚C) | Chlorophyll-a (mg/m³) | Upwelling Criteria |
|----------|------------------|-----------------------|--------------------|
| 2014     | 29.4             | 0.442                 |                    |
| 2015     | 29.4             | 0.350                 |                    |
| 2016     | 29.8             | 0.425                 |                    |
| 2017     | 29.2             | 0.292                 |                    |
| 2018     | 29.5             | 0.967                 |                    |

Table 2. Upwelling Criteria [7].

Based on Table 2, it can be stated that weak upwelling had the potential to occur at Point 1 in the El Nino phase 1 that occurred in 2009-2010, in the La Nina phase that occurred in 2010-2011, and in the El Nino phase 2 that occurred in 2015-2016. Whereas at Point 2, weak upwelling had the potential to occur in the El Nino phase 1 which occurred in 2009-2010, in the La Nina phase which occurred in 2010-2011, and in the El Nino phase 2 that occurred in 2015-2016. Determination of the upwelling criteria in each phase at Point 1 and Point 2 adjusts to the ratio of the surface temperature and chlorophyll-a surface values to the upwelling criteria in Table 2 shown in Table 3.

Table 3. Makassar Strait Upwelling Criteria during ENSO Phase.

| Anomaly Phase | Year         | Upwelling Criteria   |
|---------------|--------------|----------------------|
| El Nino       | 2009 – 2010  | Weak Upwelling       |
| La Nina       | 2010 – 2011  | Weak Upwelling       |
| El Nino       | 2015 – 2016  | Weak Upwelling       |

When the El Nino and La Nina phenomena occur, the climate will experience changes caused by warming or cooling sea surface temperatures and changing wind patterns. Both of these phenomena can indirectly affect the potential for upwelling. [14] explained that the intensity and extent of upwelling are influenced by several factors, one of which is the global climate where it can cause changes in wind patterns that move above sea level. With changes in wind patterns above sea level, surface currents will also change, which further affect the extent of upwelling that will occur. Explained by [13] that we have to know and understand the spatial and temporal evolution of upwelling because it is an important factor for coastal fisheries.

4. Conclusion
Based on the 2009-2019 Oceanic Nino Index, the El Nino Southern Oscillation (ENSO) events in that time span occurred 3 times, namely the El Nino phase in the 2009 September to March 2010, the La Nina phase in July 2010 to March 2011, and the El Nino phase from May 2015 to May 2016. In each of these anomalous phases, fluctuations occurred in sea surface temperature, surface chlorophyll-a, surface salinity, as well as wind speed and direction and surface currents. The results obtained are that the sea surface temperature parameters do not have a very strong relationship with the parameters of chlorophyll-a. Moreover, the upwelling system of Makassar Strait seemed to be more governed by the monsoon instead of the ENSO phase.

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