Sea surface temperature variability in the Makassar strait during ENSO (El niño Southern Oscillation) from the Terra-MODIS data sets

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Abstract. ENSO (El Niño Southern Oscillation) is an anomaly phenomenon of ocean-atmosphere system in the Pacific Ocean. This phenomenon also affects the condition of SST (Sea Surface Temperature) in Indonesian seas, especially Makassar Strait. The condition of SST is influenced by water mass from the Pacific Ocean that flows into Makassar Strait Indonesian Throughflow (ITF). The purpose of this study is to analyse the relationship between the SST and ENSO phenomenon in Makassar Strait. Oceanic Niño Index (ONI) used to determine the extreme ENSO events (El Niño and La Niña), and we compared the maximum and minimum value of SST between those events. The data used in this study is monthly average of SST level-3 from Terra-MODIS satellite and processed using software SeaDAS (version 7.3.2). During 17 years (2001–2017) there were 6 La Niña Phenomenon and 4 El Niño phenomenon. The result from this research indicates a relationship between SST and ENSO Phenomenon, where the SST range in La Niña condition is higher than El Niño condition. The correlation value is 0.109. The monthly average of SST at La Niña Condition in the Makassar Strait has a value between 29.66 °C to 30.25 °C, while SST in El Niño condition is ranged from 29.91 °C to 30.23 °C.

1. Introduction

The Makassar Strait is located between two large island of Indonesia, in the westward is Kalimantan island and eastward is Sulawesi island. Makassar Strait is on the path of Indonesian Throughflow (ITF), that carry the Pacific water mass into Indian Ocean. [1]Makassar Strait has a high ITF variability. Variability of ITF in space and time is very influences the transport estimation and heat flux. Fluctuation of the throughtflow is affected by monsoonal wind, tidal current and El Niño Southern Oscillation (ENSO).

*El Niño* Southern Oscillation (ENSO) are anomaly phenomenon of ocean-atmosphere system in the Pacific Ocean that affected Indonesia. The appearance of ENSO can be predicted based on several global parameters like a Sea Surface Temperature (SST). SST is related with variability of upwelling and rainfall phenomenon.

*El Niño Southern Oscillation* (ENSO) phenomenon is one of example that SST variability affects rainfall. During El Niño, which is the warm phase of ENSO, there is an increase in SST from the normal condition in the middle and east of the tropical Pacific Ocean, leading to increased rainfall in Peru, Chile, and Ecuador, but in Indonesia, Papua New Guinea, and Philippines, there has been a decline in rainfall receipts with SST which has decreased from normal conditions [2].
Some writings on SST in Makassar Strait have been carried out. [3] Suggested that the distribution pattern of SST in Makassar Strait showed a different pattern. However, although the pattern of each month is different but in general the variability of temperature in Makassar Strait is not too much different or the value that looks relatively homogeneous. Temperature have a values range about 26-31°C.

Based on the description above, this research needs to be done to find out how the variation of SST during ENSO and its correlation with rainfall in Makassar Strait using remote sensing technology. The result of this study is expected to be able to provide complete and comprehensive information, because remembering SST is closely to other oceanographic parameters.

Some study about SST in Makassar Strait already done. [3] put forward that SST distribution pattern in Makassar strait show different pattern, however pattern is different in every month but in general temperature variability in makassard not have a big difference or have a relatively homogenous values. Temperature have a values range about 26°C to 31°C.

2. Data

2.1. Sea Surface Temperature
The monthly average of Sea Surface Temperature (SST) data in Makassar Strait (2001-2017) adjusted to the condition of El Niño Southern Oscillation (ENSO) based on Oceanic Nino Index (ONI). SST data used are in the form of Terra-Modis satellite images and can be accessed at: https://oceancolor.gsfc.nasa.gov/cgi/l3. Various data can be accessed for free, but in this study used level-3 SST data from Terra-MODIS satellite that have been geometrically and radiometrically corrected and already have SST value and ready to use.

2.2. Rainfall
The monthly average of rainfall data in Makassar Strait (2001-2017) adjusted to the condition of El Niño Southern Oscillation (ENSO) based on Oceanic Nino Index (ONI). Rainfall data can be accessed at: https://www.ecmwf.int/.

3. Method
Makassar Strait is a location in this study with a position 10°N – 4°S, 116°E – 120°E for 17 years (2001-2017). In this study, the SST data which is global data then cropping according to the study area using SeaDAS software (version 7.3.2) and visualized using ODV software. Downloaded rainfall data is processed using SeaDAS software (version 7.3.2) and visualized using python software.

After the data has been processed, then the correlation or relation between ONI with SST, SST with rainfall, and ONI with rainfall is sought using Pearson correlation:

$$r = \frac{n \sum xy - (\sum x)(\sum y)}{\sqrt{(n \sum x^2 - (\sum x)^2)(n \sum y^2 - (\sum y)^2)}}$$

nis amount data, xis total number of x variabel, yis total number of y variabel, x2is square of the total number of x variable, xyis square of the total number of y variable, xyis result of multiplication of the total number of x and y variables.
4. Results and Discussion
For 17 years, there have been four time El Niño phenomenon and six time La Niña phenomenon. The occurrence of ENSO in detail can be seen in (Table 1). In addition to the periods mentioned in the table are normal condition.

Table 1. ENSO Intensity (2001-2017)

| Time            | Conditions          |
|-----------------|---------------------|
| June 2002       | February 2003       |
| July 2004       | March 2005          |
| November 2005   | March 2006          |
| July 2007       | June 2008           |
| November 2008   | March 2009          |
| June 2009       | March 2010          |
| June 2010       | April 2011          |
| August 2011     | February 2012       |
| November 2014   | March 2016          |
| August 2016     | December 2016       |
| June 2002       | Moderate El Niño    |
| July 2004       | Weak El Niño        |
| November 2005   | Moderate La Niña    |
| July 2007       | Strong La Niña      |
| November 2008   | Moderate La Niña    |
| June 2009       | Strong El Niño      |
| June 2010       | Strong La Niña      |
| August 2011     | Strong La Niña      |
| November 2014   | Strong El Niño      |
| August 2016     | Moderate La Niña    |

4.1. Correlation between Ocean Nino Index (ONI) with Sea Surface Temperature
In this study, the strongest El Niño in January 2016 with ONI 2.6 and SST 29.55℃.the strongest La Niña in November 2010 with ONI -1.7 and SST 30.25℃.While the maximum SST occurred in November 2010 and minimum SST occurred in August 2004 with ONI 0.7 and SST 27.91℃. Correlation graph between ONI and SST can be seen in Figure 2.
Based on the result of MODIS level 3 satellite images, the monthly average of SST in the Makassar Strait various from 27.91–30.25 °C. [5] said, SST was also influenced by monsoons. The east seasons occurs between May-August, while the western season occurs between November-February. If it is related to the results of observations in this study, it can be observed that the monsoon phenomenon affects the SST in the Makassar Strait. The maximum SST occurred in November 2010 with a value 30.25°C and ONI -1.7 (Strong La Niña) which is the east seasons. Minimum SST occurred in August 2004 with SST 27.91°C and ONI 1.1 (Weak El Niño) which is the western season. Other than the majority of the maximum SST occurs between November-February and some minimum SST occurs between May-August. This is confirmed by statement [6] SST in Makassar Strait during east season is lower than the western season. The high SST during western season is the part of a warm puddle of the tropical Pacific Ocean.

Generally, in El Niño conditions, SST in Indonesia decreases (low) and when La Niña condition SST in Indonesia increases (high). But in this study, SST in El Niño condition doesn’t always show lower temperatures than La Niña condition. For the example, average SST in November 2001(29.81°C) was normal condition higher than the average SST when strong La Niña in November 2011 (29.43°C).

In this study, there was a correlation between ONI and SST in the Makassar Strait showed a negative correlation (-0.11). Negative correlation means that if the ONI value increases, the SST value decreases. But the correlation obtained is very weak correlation.

According to [7], based on experience of the 1990 drought, it was found that the incidence of drought was not always the same time as El Niño. For example in 1961, 1967, and 1997 almost about 75% of Indonesia’s area experienced below normal rainfall but these years not recorded as El Niño.
condition. This shows that local influences in certain conditions can defeat the influence of El Niño. But generally in the El Niño conditions always followed by the occurrence of drought in Indonesia.

4.2. Correlation between Sea Surface temperature (SST) with Rainfall

Based on the data in this study is known that the maximum SPL occured in November 2010 which was 30.25°C, rainfall directed at 13.5mm. Whereas the minimum SST occured in August 2004 with SST 27.91°C and rainfall 1.1mm. The maximum rainfall in January 2004 was 14.3mm with SST 29°C and minimum rainfall occured in December 2002, which was 1mm with SST 29.6°C. The graph of the relationship between SST with rainfall can be seen in Figure 4.

![Figure 4. Correlation Graph between SST with rainfall](image)

![Figure 5. Relationship Graph between ONI and rainfall](image)

![Figure 6. (a) November 2010 (maximum SST, La Niña), (b) Februari 2004 (Normal) (c) August 2004 (minimum SST, El Niño)](image)
Figure 7. (a) rainfall November 2010 (b) rainfall February 2004 (c) rainfall August 2004

In this study found a correlation between SST and rainfall during ENSO phenomenon. The correlation value obtained between SST with rainfall is 0.25. This value is included in sufficient correlation. While the correlation value shows the direction of the correlation between the two variables. When SST higher, rainfall higher too.

If we look at the distribution of rainfall in Figure 7 and adjust the distribution of SST in figure 6, it is known that SST affects rainfall in the Makassar Strait. Rainfall in La Niña conditions (November 2010) 13.5mm, greater than normal conditions (February 2004) of 9.8mm and El Niño (August 2004) 1.1mm. In contrast to El Niño conditions, rainfall is lower than La Niña conditions and normal conditions.

While the correlation between ONI with rainfall in Makassar Strait obtained in this study is -0.23 which is a weak correlation. Negative correlation means that if the ONI value increases, the SST value decreases.

5. Conclusion

Based on the result of this study, we found a relationship between SST and rainfall during ENSO phenomenon. The correlation between ONI with SST is -0.11, negative correlation means that if the ONI value increases, the SST value decreases. Correlation between SST with rainfall is 0.25, positive correlation means that if the ONI value increases, the SST value increases too. Correlation between ONI with SST is -0.23, negative correlation means that if the ONI value increases, the SST value decreases.

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