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ARTICLE

# Thermal Front Variability during the El Nino Southern Oscillation (ENSO) in the Banda Sea Using Remotely Sensed Data

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ABSTRACT

The Banda Sea is one of the routes of global ocean currents that move from the Pacific Ocean to the Indian Ocean. This flow is known as Indonesian Through Flow (ITF). The Banda Sea is an area where warm and cold water masses meet, so it has the potential for a thermal front. This study aims to understand the variability of thermal front in the Banda Sea during the El Nino Southern Oscillation period. Southern Oscillation Index (SOI) and sea surface temperature (SST) data in 2010, 2012 and 2015 were used in this study. SOI data was obtained from http://www.bom.gov.au and SST data were obtained from http://oceancolor.gsfc.nasa.gov. The data were processed using ArcGIS 10.4 software and Ms. Office 2013. The results showed the La Nina period occurs in July - December 2010, the Normal period occurs in July - December 2012, and the El Nino period occurs in May - October 2015. In general, during La Nina, the mean SST has higher values than the other periods. On the other hand, the highest thermal front occurs during the El Niño period (10584), followed by the Normal period (7544) and the lowest during the La Niña period (5961), respectively.

## 1. Introduction

Geographically, Indonesia located in a tropical area between the Pacific Ocean and Indian Ocean and between Asia and Australia continents [1]. This strategic location causes many natural phenomena in Indonesia. One of the natural phenomena is the El Nino Southern Oscillation (ENSO) phenomenon. ENSO is a global event caused by the interaction between the ocean and the atmosphere [2]. ENSO consists of two periods, namely the El Nino period and the La Nina period [3].

Sea Surface Temperature (SST) is a very important oceanographic parameter since it has a close and mutually influencing relationship with climate [4]. In addition, SST can be used to detect the location of the front [5]. The front area is the meeting point between two water masses that have different characteristics, either temperature or salinity [6]. The front that is detected due to SST differences is called a thermal front [7].

There have not been many studies on the thermal front area in Indonesian waters. Thermal front is an area where plankton productivity increases. The combination of temperature and increase in nutrient content increase plankton productivity, which affects the level of water fertility.

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Therefore, the front area can be used to predict the presence of fish. One of the locations where thermal fronts are suspected to be found is in the Banda Sea.

The Banda Sea is included in the fisheries management area (FMA) 714. These internal waters were more open than the Makassar Strait. The Banda Sea water mass was influenced by the characteristics of the water mass of the Pacific Ocean, ITF and the influence of changes in monsoons. Monitoring the SST conditions in the Banda Sea can be used as an indicator of whether Indonesia is experiencing an El Niño or La Niña event. According to [8] the Banda Sea has variations in SST and most likely forms two water masses. The movement of water masses from the Pacific Ocean to the Indian Ocean through the Banda Sea, causes it a meeting area for warm and cold water masses, so it has the potential for a thermal front.

One method that can be used to identify the thermal front area using remotely sensed data and the Single Image Edge Detection (SIED) method [9, 10]. They reported that the SIED method is quite accurate for detecting thermal fronts. Therefore, this study aims to detect the thermal front event in the Banda Sea waters using the SIED method during ENSO.

## 2. Methodology

### 2.1 Study Area

This research was conducted in Banda Sea waters with a position of 2° N - 9° S and 120° E - 133°E (Figure 1). The Banda Sea was included in the Coral Triangle Initiative, which was known to be rich in high marine biodiversity. The Government of the Republic of Indonesia itself has also designated the Banda Sea as a National Marine Protected Area based on the Decree of the Minister of Marine Affairs and Fisheries of the Republic of Indonesia No. 69/2009 since it was known to have natural resources (biological and non-living). Director General of Capture Fisheries of the Ministry of Marine Affairs and Fisheries in 2011 stated that the potential for large pelagic fish resources in the Banda Sea was estimated to reach 104,100 tons per year [11].

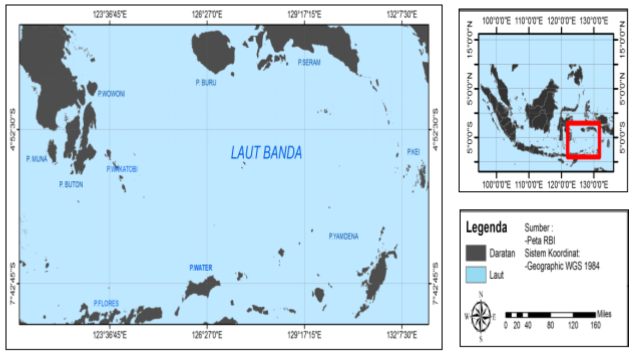


**Figure 1.** Study Area, Banda Sea (Laut Banda)

### 2.2 Data

Southern Oscillation Index (SOI) and sea surface temperature (SST) data in 2010, 2012 and 2015 were used in this study. Data in 2010, 2012, and 2015 were selected as representation for La Nina, Normal and El Nino condition, respectively. SOI data were obtained from http://www.bom.gov.au and sea surface temperature data was obtained from http: // oceancolor.gsfc.nasa.gov.

### 2.2.1 ENSO Data Analysis

ENSO events are predicted using the SOI. There are three periods that can be predicted from this index, namely La Nina, El Nino, and Normal conditions.

**Table 1.** Predicting El Nino, La Nina or Normal event using SOI Value.

| SOI value | Phenomena | Impact for Indonesian waters |
|---|---|---|
| Under -10 for 6 months | Strong *El Nino* | dry |
| -5 s/d -10 for 6 months | Weak – moderate El Nino | dry |
| -5 s/d +5 for 6 months | Normal | rain |
| +5 s/d +10 for 6 months | Weak – moderate La Nina | rain |
| above + 10 for 6 months | Strong *La Nina* | rain |

(Gunawan *dalam* Maulidya 2012)

### 2.2.2 SST Data Analysis

Monthly SST data from Aqua Moderate Resolution Imaging Spectroradiometer (MODIS) level 3 satellite imagery with a resolution of 4 km for 3 years were selected according to the ENSO period (La Nina 2010, Normal 2012 and El Nino 2015). The satellite image data has the



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nc format (Net Common Data File or Net CDF). The data were then processed in ArcGIS into tif format and cropped according to the research location.

### 2.2.3 Thermal Front Analysis

Thermal fronts were processed using marine geospatial ecology tools (MGET) toolbox with the single image edge detection (SIED) method. Sea surface temperature values in the form of floats are converted into integer values. Threshold 0.5 °C in float and 5 °C in integer was used to detect the thermal front in Banda Sea [12].

## 3. Results

### 3.1 El Nino Southern Oscillation

ENSO period was analyzed using SOI. This index illustrates weather deviations were occurring in the Indonesian region. The SOI value can be seen in Table 2. The table showed La Nina events occurred in 2010 (July - December), Normal events in 2012 (July - December) and El Nino events in 2015 (May - October).

**Table 2.** Southern Oscillation Index Value.

| Months | Southern Oscillation Index | | |
|---|---|---|---|
| | *La Nina* (2010) | Normal (2012) | *El Nino* (2015) |
| May | - | - | -13.7 |
| June | - | - | -12 |
| July | 20.5 | -1.7 | -14.7 |
| August | 18.8 | -5 | -19.8 |
| September | 24.9 | 2.6 | -17.5 |
| October | 18.3 | 2.4 | -20.2 |
| November | 16.4 | 3.9 | - |
| December | 27.1 | -5 | - |

### 3.2 Variability of SST and thermal front in the ENSO Period

### 3.2.1 La Nina Period

Figure 2 showed the spatial and temporal variability of SST and thermal fronts in the Banda Sea during La Nina conditions. In general, the average SST value in July was the lowest compared to other months, with a value of 28.15 ± 0.66°C. In contrast, the highest average SST occurred in November with a value of 30.80 ± 0.60 °C (Figure 3).

[13] reported the high SST in the Banda Sea was due to the geographical position. The equator area received the most solar heat. In this area, the highest temperature generally occurs during November – April and the lowest temperature occurs in June – September. [8] reported La Niña causes the waters Indonesia to warm, so the amount of water vapor is above normal. Therefore, during this period a lot of rain, flooding, and high waves occurs in the Indonesian territory. The peak of the highest average SST occurred in November.

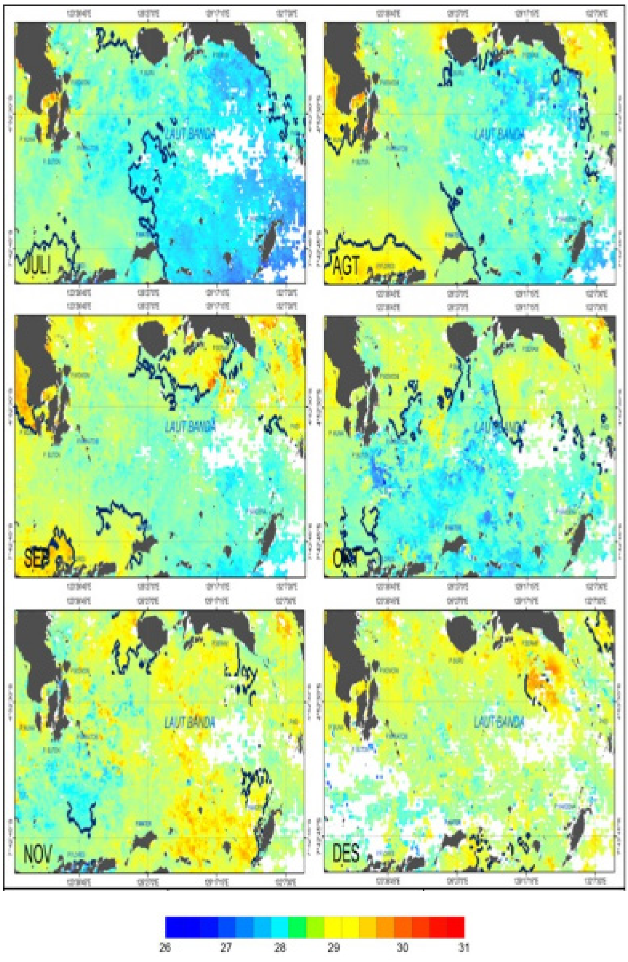


**Figure 2.** Variability of SST and thermal front in the La Niña Period 2010

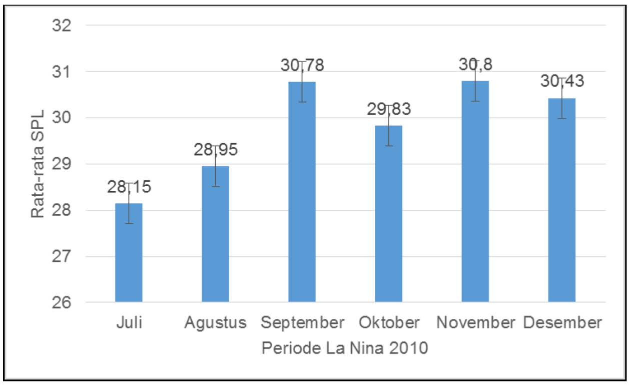


**Figure 3.** SST Variability in the 2010 La Nina Period (I = Standard Deviation).

Figure 4 showed the number of thermal fronts during La Nina conditions. In general, during July - September the number of thermal fonts formed was more than in the other three months (October - December). The number of thermal fronts July – September was highly because during these periods was still influenced by the eastern monsoon. The east monsoon winds tend to be strong and carry a lot of warm water mass to the west, so Indonesia has experienced the rainy season and high SST [14]. During June - September large numbers of upwelling and thermal fronts occurred, although in other months also shows an upwelling phenomenon [15]. The low thermal front in December is during the western season. The west monsoon wind blows from the Asian continent to Australia and causes high pressure in the Asian region and has a low SST in the Banda Sea [8].

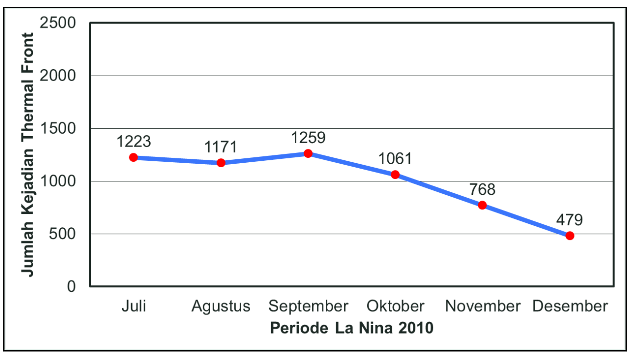


**Figure 4.** Variability of the number of thermal front events in the La Niña Period.

### 3.2.2 Normal Period

Figure 5 showed the spatial and temporal variability of SST and thermal fronts in the Banda Sea during normal conditions. In general, the mean SST value in October is the lowest compared to other months, with a value of 26.8 ± 0.67 °C. In contrast, the highest mean SST occurred in November with a value of 30.92 ± 0.59 °C (Figure 6).

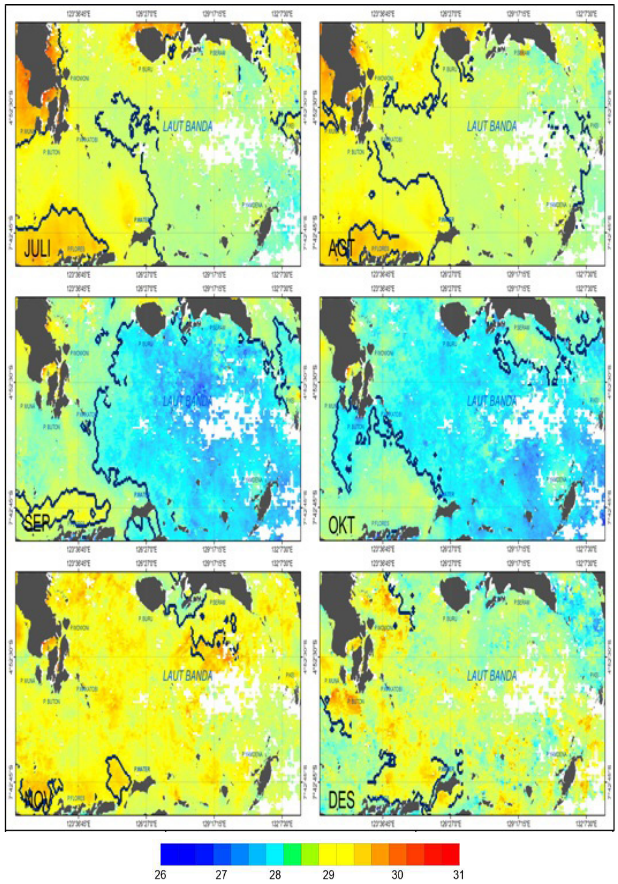


**Figure 5.** Variability of SST and thermal front in Normal Period 2012.

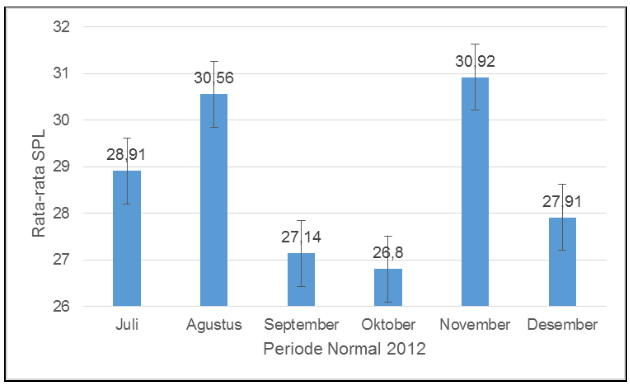


**Figure 6.** Graph of SST Variability in Normal Period 2012 (I = Standard Deviation).

SST in the East Pacific Ocean was cooler than the SST in the West Pacific Ocean during Normal conditions [16]. The wind moved to warmer water mass area. The water mass heats the air above it. The air then rises and is replaced by air from another place. The wind blows pushed the hot water mass westward, thus pushing upwelling in the East Pacific Ocean. The low temperature in October



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was due to the upwelling effect. Upwelling is the process of increasing the mass of water in low temperature. In the Banda Sea upwelling occurs in May-October [17]. In addition, [8] reported the Banda Sea experiences the highest SST in November every year.

Figure 7 showed the number of thermal fronts during normal conditions. In general, during July - October the number of thermal fonts formed was more than in the other three months (November - December). The high thermal front during September was because this month was the peak of upwelling [18]. During August - September the east monsoon wind blows from Asia to Australia. In contrast, thermal fronts in December were low. This was supported by [19] who showed the low thermal front was formed in December. During December the wind blows from the continent of Australia to the continent of Asia (west monsoons). This condition causes high pressure in the Asian region and has low SST in the Banda Sea [8].

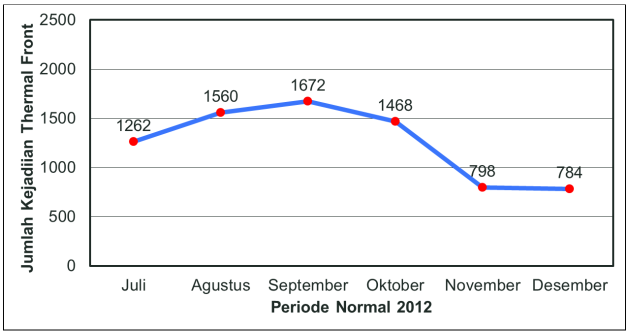


**Figure 7.** Variability of the number of thermal front events in Normal Period.

### 3.2.3 El Nino Period

Figure 8 showed the spatial and temporal variability of SST and thermal fronts in the Banda Sea during El Nino conditions. In general, the average SST value in August was the lowest compared to other months, with a value of 26.31 ± 0.71 °C. In contrast, the highest average SST occurred in May with a value of 28.95 ± 0.43 °C (Figure 9).

In general, during the El Nino period, the mean SST in the Banda Sea was lower than during La Nina and Normal conditions. However, the high intensity of solar radiation causes high SST in May [15]. The weak winds occurred during the transition season I (March - May) cause the heating process at sea level to be stronger. Consequently the SST was higher. The high intensity of irradiation and supported by calm sea surface conditions causes the absorption of heat into sea water to be higher so that the water temperature becomes a maximum.

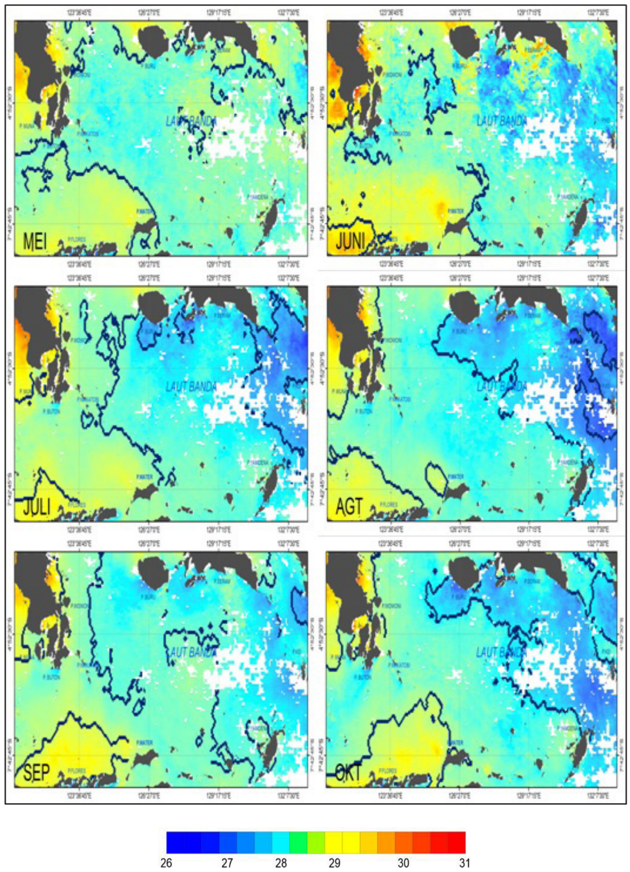


**Figure 8.** Variability of SST and thermal front during El Nino Period 2015.

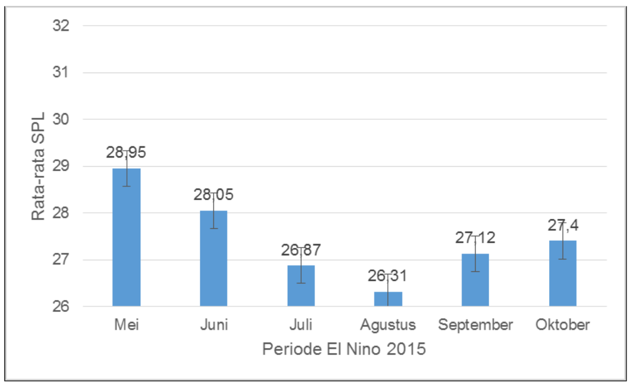


**Figure 9.** Graph of SST Variability in El Nino Period 2015 (I = Standard Deviation).

Figure 10 showed the number of thermal fronts during El Nino conditions. In general, during this condition, the number of thermal fronts fluctuates. The smallest number of thermal fronts occurred in June (1329) while the largest occurred in October (2032). The high thermal front in October was probably caused by an upwelling event. Upwelling causes SST to be cooler than normal conditions [20]. [18] showed the formation of a front during El Nino periods in South Java is influenced by the oceanographic characteristics. One of characteristics was the high intensity of upwelling which causes the formation of a thermal front. In contrast, the low thermal front in June was due to weak upwelling.

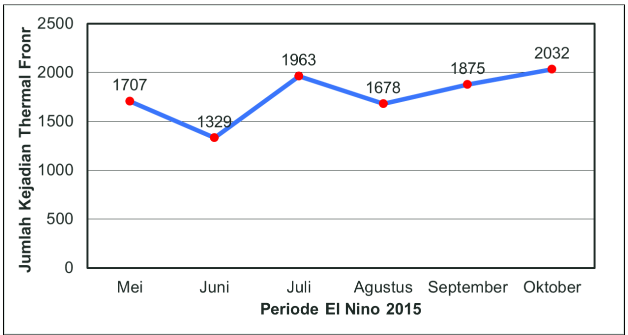


**Figure 10.** Variability of the number of thermal front events in El Nino Period.

### 3.3 Comparison of SST and Thermal Front in the ENSO Period

Figure 11 showed the comparison of the average SST in 3 different conditions. In general, SST was highest during the La Nina period (29.34°C) compared to other periods. La Nina causes waters in Indonesia warm. Consequently the amount of water vapor is above normal. Therefore, during this period, rain, floods and high waves often occur in the territory of Indonesia. However, the positive effect was the number of fish in Indonesia becomes abundant [8]. During La Nina, the east trade wind blowing along the Pacific Ocean strengthens, so the warm water mass was carried more and more towards the West Pacific (Indonesia) [21]. The accumulation of warm water masses in the West Pacific Ocean causes downwelling [22].

Contrast condition occurred during El Nino period. During this period, the mean SST was the lowest (27.45 °C) compared to other periods. During El Nino the east trade winds along the Pacific Ocean are getting weaker. These winds cause the water flow in the surface layer moved towards the East Pacific Ocean and carries warm water masses and cause an accumulation in the East Pacific Ocean. Meanwhile, in the West Pacific Ocean, including Indonesian waters, there was an increase in water mass originating from the deep layers. This water replaces the water masses in the surface layer as a result of the warm water masses transfer to the Eastern Pacific Ocean [22].

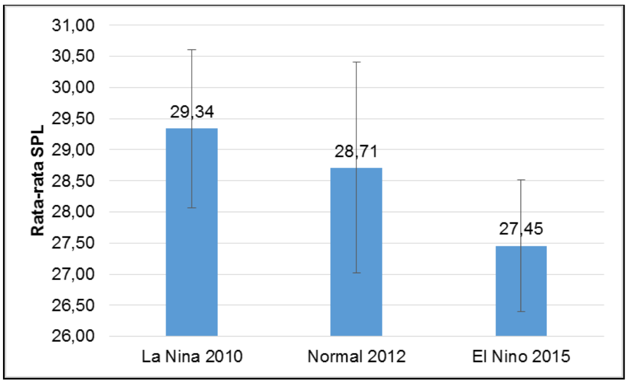


**Figure 11.** Graph of mean SST in the ENSO period (I = Standard Deviation).

The number of thermal front events reached the highest peak (10,584) during the El Nino period and reached the lowest peak (5961) during the La Nina period (Figure 12). This result was supported by [18] who reported that most thermal fronts occur in El Nino conditions. The high intensity of upwelling during the El Nino season causes thermal fronts. Upwelling occurs due to strong winds blowing in the area. Wind has a big influence on the movement of the SST distribution. The main factors causing upwelling in the Banda Sea are the length and strength of the south and southeast winds that blow in the area [23].

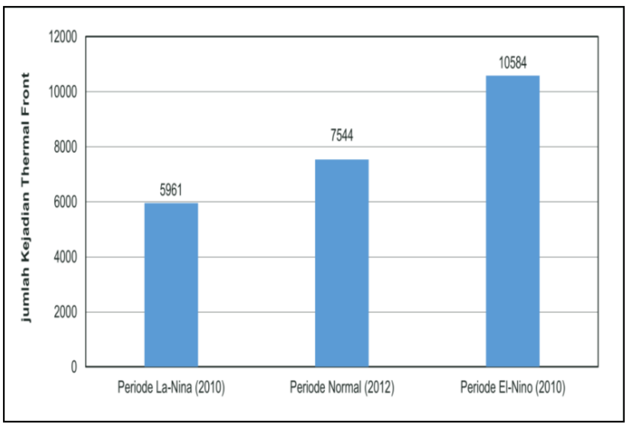


**Figure 12.** Number of thermal front events in the ENSO Period.

## 4. Conclusions

In general, SST during La Nina was the highest compared to other periods. However, the highest number of thermal front events occurred in the El Niño period (May-October 2015) with the number occurrences of 10584 events, followed by Normal period (July - December 2012) with about 7544 events and La Nina period (July - December 2010) with about 5961 events, respectively. Studying the relationship of upwelling, thermal front and potential fishing zones in the future is essential.



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