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# Thermal front condition through El Niño and Indonesian throughflow phase in southern sea of East Java and Bali on the east monsoon

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**Abstract.** The purpose of this study was to determine the effect of El Niño 2013 and 2015 in the formation of thermal fronts in the southern sea of East Java and Bali and its correlation with Indonesian Throughflow (ITF). The data that is used in this research were the SST from Aqua MODIS, Nino index of 3.4 derived from CPC NOAA, and Geostrophic current from AVISO. The used method was descriptive method with spatial and temporal analysis approach. Front can be detected in the data of SST raster image using a Cayulla Cornilon SPL 1992 algorithm with strong category of SST difference of  $\geq 0.5$  °C and with weak one of SST difference of 0.3 – 0.49 °C. The results show that thermal front formed in the southern water of Java and Bali was the temporary front with weak and strong scale. The presence of El Niño affected the formation of thermal fronts, where it was formed during El Niño more than in normal states and El Niño affected transport ITF as well. It is because upwelling in the El Niño is stronger than at the normal condition.

Keywords : thermal front, El Niño, Indonesian Throughflow, monsoon.

## 1. Introduction

Southern sea of East Java and Bali is very complex because there are many different phenomena such as ITF [1,4,24], South Equatorial Current [26], Java Coastal Current [1], and Monsoon [29]. The ITF flows from the tropical Pacific Ocean to Indian Ocean via Indonesia through the Makassar Strait then out through the Lombok Strait into the Indian Ocean [4]. This water meets the water mass around Java (Java Current) and results thermal fronts because of the different characteristics [3,14].

According to [9,15], *fronts* are found in the southern sea of East Java and Bali on the East Monsoon (EM). *Thermal front* is one of Oceanography phenomena that can be identified by observing the distribution patterns of SST [9]. The studies on the *front* have previously been done by several researchers such as [5,9,27], but only several studies that connected with El Niño and ITF conditions.

The changes of SST in the southern sea of East Java and Bali are influenced by the phenomenon of El Niño Southern Oscillation (ENSO) [18,20,25]. This phenomenon affects SST during El Niño or during La Niña [17]. According to [21,28] the sea temperature can be influenced by the season, the regional seawater circulation process such as warm water mass that flows from the Pacific Ocean to the Indian Ocean passing through parts of Indonesia, such as the Java Sea, and also from the natural



phenomena of ENSO. This phenomenon is a condition where there is an anomaly of SST around the central and eastern Pacific along the equator (around the coast of Peru) [23] characterized by sea surface temperature anomaly in the Niño 3.4 region (figure 1) with the changes of approximately  $0.5^{\circ}\text{C}$  [12].

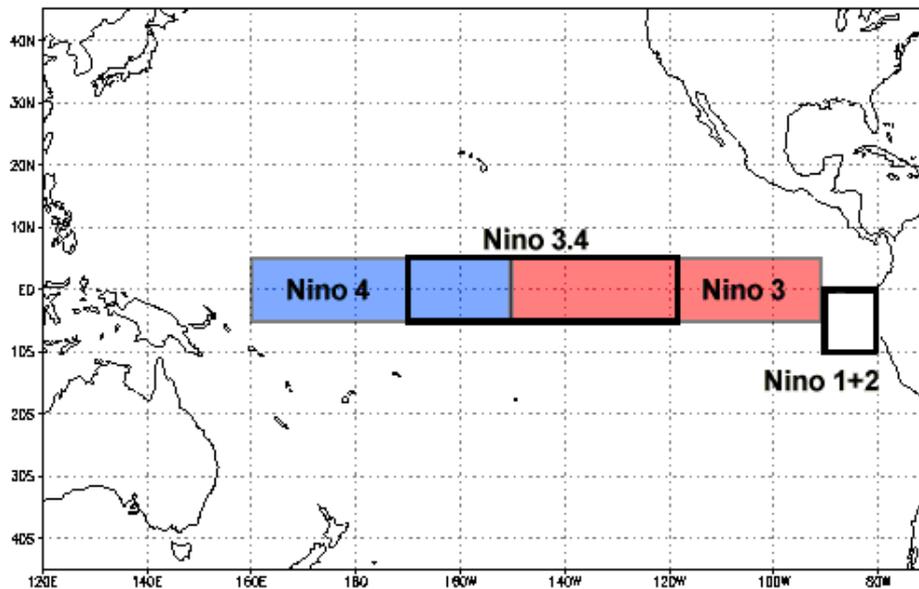


Figure 1. Niño Regions [12].

This sea surface temperature anomaly has been occurring since 1950 until now according to research that conducted by [10]. It is known that the strongest ENSO period occurred in 1997 and according to the information provided by Indonesian Agency for Meteorology, Climatology and Geophysics (BMKG), the strongest ENSO also occurred in 2015. According to [13,22], it is known that ENSO had a moderate effect toward southern water of East Java and Bali during both El Niño and La Niña. These results are reinforced by research that have been done by [20] which states that El Niño causing SST of southern Java tends to be cooler. This study used the conditions in 2013 and 2015 to compare the conditions of the strongest and the weakest.

The contribution of this study was to determining the effect of El Niño in thermal fronts and ITF in the southern sea of East Java and Bali. This study focused on the effect on the number, location and the strength of *thermal front* formation in the southern sea of East Java and Bali during the period of El Niño and its correlation with ITF which occurred on the east monsoon in 2015.

## 2. Material and method

The region of this study was at the southern sea of East Java and Bali on the coordinate of  $7^{\circ}\text{S} - 16^{\circ}\text{S}$  and  $111^{\circ}\text{E} - 117^{\circ}\text{E}$  shown in figure 2 [19]. This area was an area where there was a meeting between the flow of ITF and the flow of AKS [26], there was an upwelling location [20], and the presence of boundaries with subtropical water masses [16].

The data used in this study were the data in 2013 and 2015. They were SST obtained from AquaMODIS satellites (<http://oceancolor.gsfc.nasa.gov/>) with a resolution of 4 km to see the distribution and the average of SST and to detect thermal front [5], Niño 3.4 index obtained from the website of CPC NOAA (<http://www.cpc.ncep.noaa.gov>) to see the SST anomaly [20], and the geostrophic current data obtained from AVISO website (<http://motu.aviso.altimetry.fr/>) to see the distribution of the current velocity [9]. The data had previously been validated by using the standard deviation.

To see the El Niño force, it can be known by observing the SST anomalies, with stages:

SST Anomalies of 0.5 - 1°C = weak,

SST Anomalies 1 - 1.5°C = moderate, and

SST Anomalies over 1.5°C = strong [2].

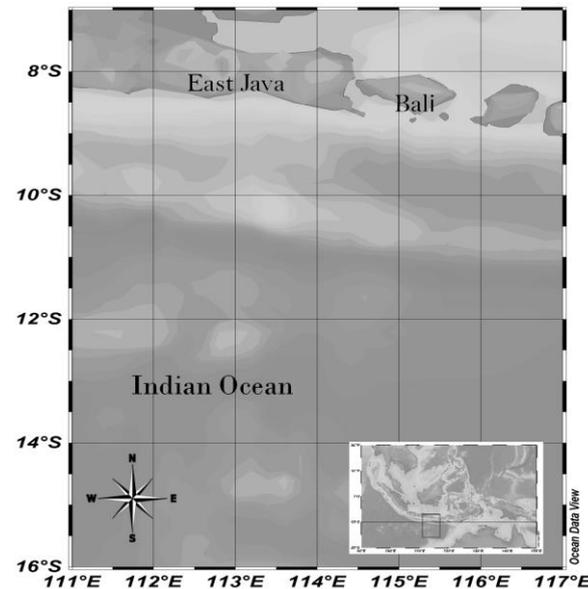


Figure 2. Research Area.

Spatial data processing to detect thermal fronts was using the Algorithms of Single Image Edge Detection (SIED) Cayulla Cornillon in 1992 and was divided into two categories [5] namely:

- Strong Front, formed due to the ST difference of  $\geq 0.5$  OC and
- Weak Front, formed due to the ST difference between 0.3 – 0.49 °C

The results of the analysis were compared to the normal state on the east monsoon in 2013.

### 3. Results

#### 3.1 SST anomalies

The SST anomalies obtained from CPC NOAA were used to see the SST deviations within one month and El Niño force in that month. It can be known in table 1.

From the table above, can be seen that the El Niño force of EM in 2015 has moderate - strong force with a relatively homogeneous SST average. The SST average, when El Niño was lower than normal state, was 27.6 °C in June, 26.6 °C in July and 26.2 °C in August.

**Table 1.** The Anomaly and Average of SST ( $^{\circ}\text{C}$ ).

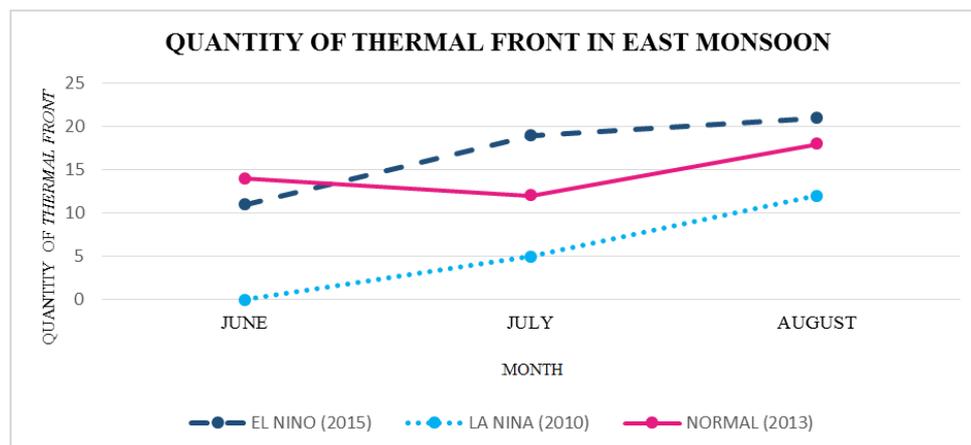
Month	Anomaly	Category	SST Average ( $^{\circ}\text{C}$ )
June 2015	0.97	Moderate	27,6
July 2015	1.2	Moderate	26,6
August 2015	1.51	Strong	26,2
June 2013	-0.25	Normal	28,6
July 2013	-0.21	Normal	27,4
August 2013	-0.18	Normal	26,7

### 3.2 The number and size of thermal fronts

The number and the size of thermal fronts which formed in the southern sea of East Java and Bali had different numbers and sizes in each month both in normal state and in El Niño phase (table 2).

**Table 2.** Quantity and Large of Thermal Front.

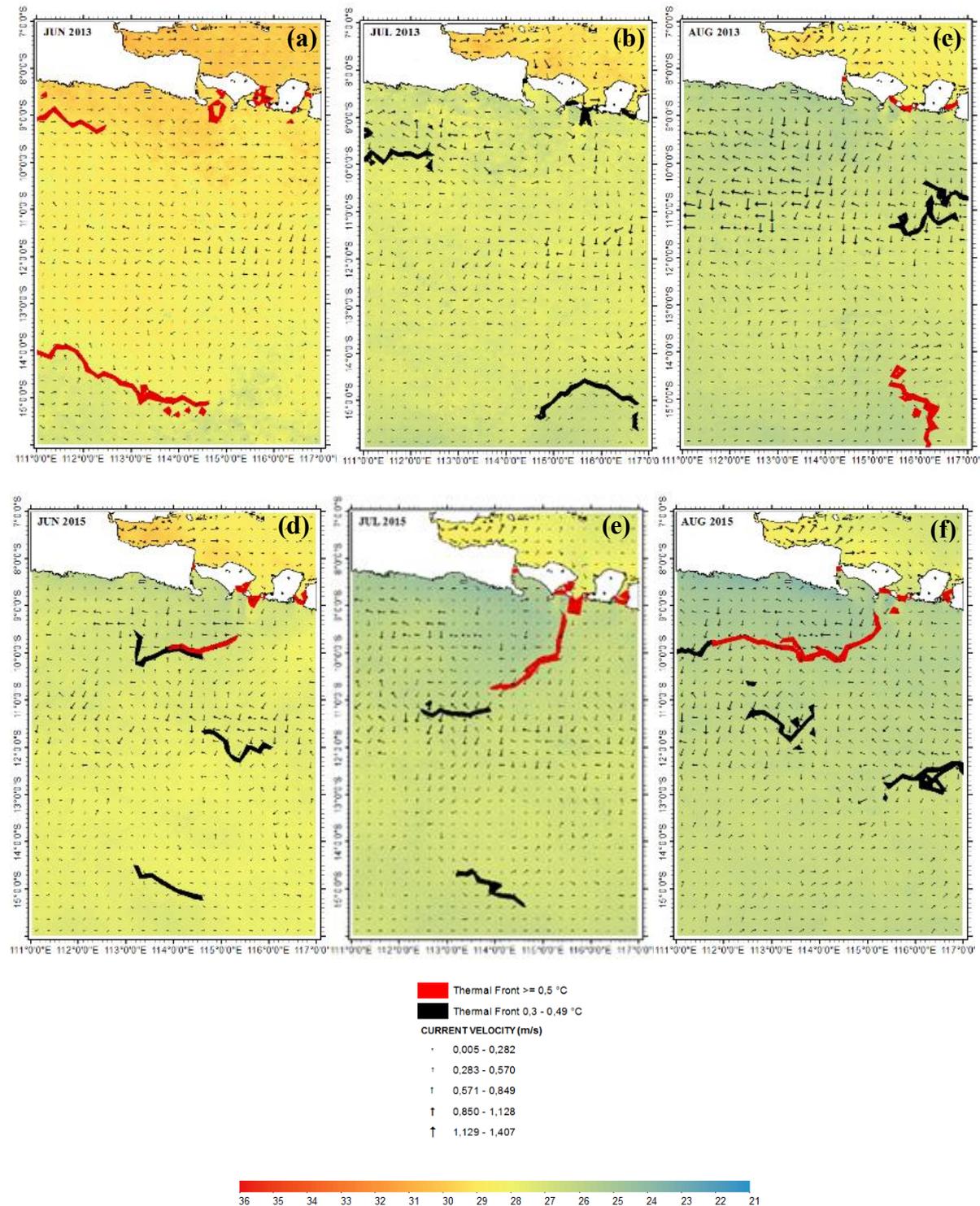
Month and Year	Quantity of Thermal Front			
	Strong	Weak	Max ( $\text{km}^2$ )	Min ( $\text{km}^2$ )
June 2015	7	9	3640,47	49,28
July 2015	8	11	3138,99	49,28
August 2015	7	14	6738,71	49,28
June 2013	14	-	5119,95	49,28
July 2013	-	12	2629,13	49,28
August 2013	8	10	2880,59	49,28

**Figure 3.** Quantity of Thermal Front.

It can be known in table 2 and figure 2 that thermal fronts formed in the El Niño phase have more amounts with the biggest number of 21 in August 2015 and the largest size of 6738.71  $\text{km}^2$  area in August 2015 compared to during normal states.

### 3.3 Spatial distribution of thermal fronts and currents

Thermal fronts in the southern sea of East Java and Bali were temporary fronts whose location and area changed in a certain period of time. The spatial distribution in the El Niño phase can be seen in figure 3 and in normal states it can be seen in figure 4.



**Figure 4.** Spatial distribution of Current and Thermal Front (a) - (c) in normal El Niño condition and (d) - (f) in El Niño Condition.

In six figures above, it can be known that in the area of Lombok Strait and Bali strait thermal fronts are formed due to entering flow from the northern Java and Bali. Other fronts are scattered in different areas varied over each month.

#### 4. Discussion

The southern sea of Java and Bali in normal state in June, July, and August (Table 1) has SST average of 27.6°C and it is relatively homogeneous in each month, 28.6° C in June, 27.4° C in July, and 26.7° C in August. This corresponds to the research that has been done [8] that SST of the sea ranged between 28° C - 31° C. The homogenous SST states based on the warming rays of the sun which is at around the earth's equator [6] and because the geography of southern SST of Java and Bali was very influenced by the monsoon system so that SST is relatively higher in West Monsoon rather than EM. Besides, the SST in this area affected by some oceanographic phenomena such as ENSO and IOD (Indian Ocean Dipole) [20].

In Table 1 that the SST average of the El Niño phase had a lower value than that of the normal state. This decrease was due to the fact that El Niño was an aberration when the Indonesian SST at the time was lower than during normal states. Moreover, the decrease triggered by low SST in EM because how much the impact of El Niño depends on the conditions of SST in each region [7]. In the phase of El Niño and normal front was mostly formed in August. This caused August is the month in which the Upwelling peak occurs so that there are thermal fronts in this phase established more. These results were consistent to the statement of [20] which states that the years of 1997-2009 in August and September are Upwelling peak due to the existence of EM blowing in that month.

Many strong front forms in the El Niño period are because this phenomenon affects the oceanographic characteristics of southern Java [24]. One of them led to the high intensity of upwelling which can cause the formation of thermal fronts. According to [20], the existence of Upwelling in the southern Java affected by the positive IOD and El Niño because during this phase the mass of water at low temperatures entered more so that it strengthens the intensity of upwelling in the southern waters of East Java and Bali at the time of the SST formation had lower ones.

At the time of EM phenomenon in June, July, and August, thermal fronts formed more in the region of 8°Lat - 11 °Lat both in normal and El Niño states. In normal states, the fronts formed during the normal season are pretty much in each month. Because EM was a season that had a high intensity of ITF so that fronts in the region of influx ITF formed more and more powerful. This was consistent with the statement [9] which states that in normal condition, EM had the highest strength than any other season. According to [18] when EM current flows from east to west is in the direction of the ARLINDO transport direction from the east (Pacific) to the west (Hindia), so that it can strengthen the surface currents and the current transport flow.

During the EM with El Niño, more thermal fronts formed in the study area than when the EM in normal condition. It can be seen in Figure 3 in El Niño conditions, the number of fronts formed more than in the normal season. In normal condition, the fronts are formed around 14 to 18 while the El Niño fronts are formed around 11-21. According to [20] at the time of El Niño occurrence, there was a decrease in the volume of water moving from the Pacific Ocean to the Indian Ocean. The vacuum of the water mass will encourage the emergence of Upwelling, namely the increase in the mass of deep-sea water with the characteristics of low temperature, high salinity and rich in nutrients. According to [11] at the time of El Niño occurrence of weakened water mass transport than in normal and La Niña conditions and according to research [18] when El Niño variability of ITF transport decreased by -0.13 Sv.

#### 5. Conclusion

Thermal fronts in the southern sea of East Java and Bali formed more during El Niño. The El Niño phenomenon affected the water mass in these waters where SST in El Niño became lower than in normal state so that it strengthens the intensity of existed upwelling having its peak in EM. Besides, the increase

of Upwelling was triggered by the weakening of ITF transport causing the vacuum of water in the Indian Ocean.

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