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# The Thermocline Upper and Lower Threshold Temperature Variability on the Variation of El Nino Southern Oscillation (ENSO), Indian Oscillation Dipole Mode (IOD), and Monsoon at southern Java waters

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**A B S T R A C T**

The understanding of upper and lower threshold temperature variability is important to the identification of the tuna swimming layer depth. Identification of the vertical temperature stratification and thermocline depth change on the ENSO, IOD, and Monsoon variabilities, be studied based on CTD and Argofloat data accumulated in Word Ocean Data (WOD) from 1985 – 2011. Wind data from NCEP, and global climate index (SOI, SST anomaly at NIÑO3.4 and DMI) data be used for complicated problem analysis. The variability of the thermocline upper and lower threshold at southern Java until Timor waters change with the existence of global climate anomaly variation (ENSO and IOD) and monsoon. The IOD anomaly has the biggest effect on the thermocline upper and lower threshold variability. Thermocline upper and lower temperature thresholds at the east monsoon commonly have lower values than at the west monsoon. The thermocline upper threshold coolest occurs at the La Niña-IOD (+) case, with an annual mean of 26,83°C±0,41°C, and the warmest happens at El Niño-IOD (-) case, with an average of 27,74 °C±0,61°C. The thermocline lower threshold coolest occurred at the El Niño-IOD (+) case, with an annual mean of 12,76 °C±0,83°C, while the warmest occurred at the La Niña-IOD (+) case with an average of 16,71°C±1.25°C.

Keywords: ENSO, IOD, Monsoon, Temperature variability, Thermocline

## 1. Introduction

The thermocline is a layer in the ocean where the temperature decreases rapidly with depth (Nontji, 1993). The absolute value of the vertical temperature gradient in the standard thermocline layer (for the Indian Ocean region) is ≥0.05°C/m (Bureau of Technical Supervision of the P.R. of China, 1992). The temperature in the thermocline layer has an important meaning for the life of large pelagic fish communities, especially tuna. One of the characteristics of tuna fish is they tend to live in a certain optimum temperature range (Sund *et al*., 1981). According to Mohri and Nishida, (1999), Song *et al.*, (2006,2007); and Syamsuddin & Syamsudin, (2009), the thermocline layer and the layer where is located below the lower threshold are more likely to find the tuna, which in the range temperature of 10-16°C and at a depth of 160-280 m. Yellowfin, albacore, and bluefin tuna prefer to live in the thermocline layer, while bigeye tuna prefer to live in layers below the lower threshold of the thermocline layer (Sund *et al*., 1981).

The temperature, at the upper and lower threshold of the thermocline, is an ocean physical parameter that has an inconsistent value and location vertically. Tomzack (2000) explains that several factors can influence changes in the depth of the thermocline layer (including temperature), such as ocean currents, upwelling and downwelling, suspended solid material, latitudinal position, rainfall, and variability in global climate anomalies (El Niño and La Niña). Research regarding changes in thermocline depth and temperature concerning changes in global climate variability in the Indian Ocean, especially waters south of Java to Timor, is still very lacking. Song *et al*. (2007) have identified the depth of the thermocline but its location is in southern Indian waters and not relating it to global climate variability. Research results from Susanto *et al*. (2001; 2007) have found that during El Niño the thermocline depth is shallower and the temperature is cooler than during La Niña, but this research has not included IOD (Indian Oscillation Dipole Mode) parameters in its study and has not discussed them in detail regarding causes of changes in the upper and lower threshold which related to the two global climate variations, ENSO (El Nino Southern Oscillation) and IOD, at once. It is necessary to discuss more comprehensively in understanding changes in temperature variability at the upper and lower threshold of the thermocline, concerning ENSO, IOD, and Monsoon in the southern waters of Java to Timor.

This research discusses more depth about the changes in temperature variability at the upper and lower threshold of the thermocline in variations in global climate anomalies (ENSO, IOD) and the Monsoon. The results of the analysis of the temperature variability of the upper and lower threshold of the thermocline, contained in this research, are expected to help identify the temperature range of tuna swimming layers in the south waters of Java to Timor, with variations in global climate anomalies and the monsoon. This research used various data to analyze thermocline changes, which are data from 1985-

2011, South Oscillation Index (SOI) data, SST anomaly data at NIÑO3.4, Dipole Mode Index (IOD), and wind data from the National Center for Environmental Prediction (NCEP).

## 2. Material and Method

The main material used in this research, which is for processing the upper and lower temperature threshold variability data at the thermocline layer, was argofloat data and CTD (Conductivity-Temperature-Depth) data collected by NODC (National Oceanography Data Center) in the form of WOD (Word Ocean Data). Other data used as secondary data are ENSO (SOI values and SST anomaly in NIÑO3.4), DMI, monthly wind data from NCEP, and rainfall data from BMG.

The method used to know the influence of changes in global climate anomalies on changes in temperature at the thermocline upper and lower threshold is the correlative statistics method. This method is the same as Susanto *et al*. (2005) used. The method used to know the variability of thermocline depth is by using the analysis of changes in temperature gradient vertically as used by Song *et al*. (2007). The first step conducted in this research was collecting data which was obtained from various websites and relevant agencies, as mentioned in the explanations below.

Global climate variability data consists of SOI and SST NIÑO3.4 anomaly data which was obtained from http://www.bom.gov.au/climate/current/soihtml.shtm1 and Dipole Mode Index (DMI) data which was obtained from http://www.jamstec.go.jp/frcgs/research/d1/iod/DATA/dmi_HadISST.txt.

Monsoon data consists of monthly wind speed and direction data obtained from http://www.esrl.noaa.gov/psd/data/gridded/data.ncep.reanalysis.surface.html. The downloaded data was in FNL form (final analysis) and resolution in the range of 1,4 – 2,9 km. These data were then processed by MATLAB software using the same procedure as in Setiawan *et al*. (2007) research.

Argofloat and CTD data, used in order to know the temperature profile vertically in the Hindia Ocean, were obtained from in situ data collection collected by WOD (Word Ocean Data) in 2011. These data were downloaded from http://www.nodc-noaa. Gov /OC5 /WOD11.html. The data used in this research were the collected data from 1985 to 2011 and processed by Ocean Data View (ODV) software, which was downloaded from http://www.nocd/odv.com or http:///www.awibremerhaven.de/GEO/ODV.

The next step after pre-processing data and collecting data was to determine the global climate anomalies in four cases, which was conducted by plotting the graphic between SOI values, SST anomaly in NIÑO3.4, and DMI. The graphical plotting results of the global climate anomaly index are in the form of monthly variability in global climate anomalies that occur in a time series. Based on the variability of the global climate anomaly event index depicted in the graph, four study cases were taken, namely: El Niño-IOD (-) in June 2004 – May 2005 (Case I); El Niño-IOD (+) in July 2002–June 2003 (Case II); La Niña-IOD (-) in June 1998 – May 1999 (Case III); and La Niña-IOD (+) in October 2007–September 2008 (Case IV). The reason for determining the study data for several periods above is because in these periods there is variability in ENSO and IOD according to the study case. Further, what is more important is that in these periods, sufficient oceanographic data is available.

WOD-11 data were used to determine vertical temperature stratification and thermocline depth. This data, which is in NetCDF format, was imported into the ODV software per the periods needed (all WOD data was separated by the periods of the studied cases). The results from data plotting can show the distribution of data stations in the form of points in the ODV global map. The next step was delimiting the area to be studied which was then determined was in the Indian Ocean WPP NRI 573, southern Java waters to the southern of Timor island, latitude 8-17° S; longitude 104-125°E. Separated data based on study cases was then extracted or exported into the ODV spreadsheet or in ASCII format, to make it possible to process it further with Microsoft Excel software. In this software, the values of several measured parameters can be seen, such as water temperature, chlorophyll-a, nutrients, salinity, depth, and dissolved gases). From those parameters, water temperature data was taken specifically for thermocline data processing. Thermocline layer processed data, which consists of the upper temperature threshold, lower temperature threshold, upper depth threshold, and lower depth threshold, is the average data in the research area.

The formulation to know the thermocline layers' depth is according to what was formulated by Stern (1975).

$$H = \{\Delta T / (max \partial T(z) / \partial z)\} \quad (1)$$

Where H is the thermocline's depth, $\Delta T$ is the temperature gradient, $(\partial T(z)/\partial z)$ is the changes of temperature on depth. In this case, the value of the maximum changes of temperature on depth was calculated in a water column which is the temperature changes in the amount of ≥ 0,05°C/m (Bureau of Technical Supervision of the P.R of China, 1992). The vertical temperature gradient was calculated based on the formulation used by Song *et al*. (2007), as shown below.

$$G_j = (T_{j+1} - T_j)/(D_{j+1} - D_j) \quad (2)$$

Where $G_j$ is the value of the vertical temperature gradient between standard depth $D_j$ and $D_{j+1}$ and $T_j$ and $D_j$ is the water temperature and depth in standard depth $D_j$.

After the thermocline layer is known, the upper and lower thermocline thresholds must be determined by identifying the value of $Gj \geq 0{,}05℃/m$ (Bureau of Technical Supervision of the P.R of China, 1992). The temperature values for the upper and lower limits of the thermocline thresholds were then identified and those thresholds were separated by extracting them.

## 3. Results and Discussion

### *3.1 The Variability of the Thermocline's Upper and Lower Temperature*

Based on the analysis of the temperature of the upper and lower threshold of the thermocline layer (**Figure 1**), it appears that the upper and lower temperature thresholds during the east season until the transition to the west season have smaller values than during the west season until the transition to the east season. The temperature of the upper threshold during the west season until the transition to the east season, in between the four cases of global climate variation, appears to be almost the same, ranging from 27.6 – 28.9°C. The temperature of the upper threshold, during the east season until the transition to the west season, is almost the same between cases, ranging from 26.01 – 26.86°C. During that season, the coldest temperature in the El Niño-IOD (+) case was 26.01°C±0,59°C and the warmest temperature in the La Niña-IOD (-) case was 26.86 °C. The average temperature of the upper threshold of the thermocline for each study case was found that the coldest temperature in the La Niña-IOD (+) case was 26.83°C±0.41°C, followed by the El Niño-IOD (+) case which was 27 .19°C±0.46°C, then La Niña-IOD (-) case which was 27.49°C±0.49°C, and the warmest occurs in the case of El Niño-IOD (-) which was 27.74°C ±0.61°C. The lower threshold of the temperature during the west season to the transition to the east season between the four cases of global climate variation had quite a large range, ranging from 12.83 – 18.1°C. The smallest lower threshold temperature occurs in the El Niño-IOD (+) case which was 12.83 °C±0.57°C, and the largest occurs in the La Niña-IOD (+) case which was 18.1°C±1.1 °C.

Meanwhile, the lower threshold of the temperature during the east season until the transition to the west season had quite a large range, ranging around 12.68 – 15.31°C, the coldest in the El Niño-IOD (+) case was 12.68°C ±1.1°C and the warmest occurred in the case of La Niña-IOD (+) was 15.31 °C. An interesting phenomenon is the lower threshold of the temperature in the case of La Niña-IOD (-) in both the west and east seasons, which has almost the same value in the 14.46 – 14.78 °C range. Based on the average temperature at the lower threshold of the thermocline for each study case, an interesting phenomenon was found, the warmest temperature occurred in the La Niña-IOD (+) case at 16.71°C. Another interesting phenomenon is that the lower threshold of the temperature of the thermocline layer between the El Niño-IOD (-) and La Niña-IOD (-) cases is almost the same, which was 14.30°C and 14.62°C respectively, whereas for the El Niño-IOD (+) had the coldest average of 12.76°C.

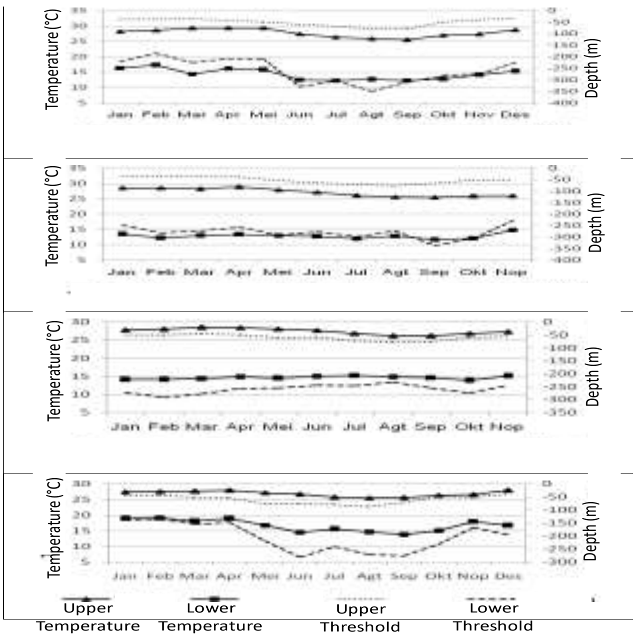


**Figure 1.** The upper and lower thresholds of the temperature of the thermocline in various study cases,

a). El Niño-IOD (-), b). El Niño-IOD (+), c). La Niña-IOD (-), and d). La Niña-IOD (+)

Based on the analysis above, three phenomena were found. The first phenomenon is the temperature of the upper and lower thresholds of the thermocline in the east season is generally smaller than in the west season, the range is 26.09 – 26.86°C and 27.6 – 28.9°C respectively. The cause of this phenomenon is that the upper threshold of the thermocline depth in the east season is deeper (63.22-69.03 m) than in the west season (38.68-51.33 m). The factor that causes the thermocline to be deeper in the east season is that the speed of the monsoon wind gusts in the east season is stronger (range 5.1-8.73 m/s) than the wind gusts in the west season (range 0.2-6.1 m/s) (Kunarso et al. 2012). This stronger wind will generate stronger currents and waves which will stir the water masses in the seawater column so that the mixing layer becomes deeper and the thermocline layer also becomes deeper. The higher the wind speed blowing over water, the deeper the thermocline layer will generally be, thus causing the upper and lower threshold temperatures to be colder. The correlation between wind speed (monsoon) and upper threshold temperature generally has a correlation value of -0.58, which means the close relationship between the two is strong. In the case of La Niña-IOD (+), the correlation between wind and upper limit temperature shows a greater value, which was – 0.65 (**Table 1**). This statement is under that made by Tomzack, (2000) who stated that the stronger the wind, the stronger the current and wave speed which will push the thermocline deeper.

**Table 1.** Correlation between Dipole Mode Index (DMI), SST anomalies in NIÑO3.4, and wind with upper threshold temperature (Upper. T), lower threshold temperature (Lower. T), Depth of upper threshold (Upper. B) and depth lower threshold (Lower. B)

**Correlations**

| | | IOD | NIÑO3.4 | Wind | Upper. T | Lower. T | Upper. B | Lower. B |
|---|---|---|---|---|---|---|---|---|
| IOD | Pearson Correlation | 1 | .953** | .764** | -.809** | -.786** | .938** | .849** |
| | Sig. (2-tailed) | | .000 | .004 | .001 | .002 | .000 | .000 |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| NIÑO3.4 | Pearson Correlation | .953** | 1 | .703* | -.691* | -.717** | .943** | .789** |
| | Sig. (2-tailed) | .000 | | .011 | .013 | .009 | .000 | .002 |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Wind | Pearson Correlation | .764** | .703* | 1 | -.653* | -.554 | .841** | .675* |
| | Sig. (2-tailed) | .004 | .011 | | .021 | .062 | .001 | .016 |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Upper. Temp | Pearson Correlation | -.809** | -.691* | -.653* | 1 | .787** | -.714** | -.778** |
| | Sig. (2-tailed) | .001 | .013 | .021 | | .002 | .009 | .003 |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Lower. Temp | Pearson Correlation | -.786** | -.717** | -.554 | .787** | 1 | -.670* | -.980** |
| | Sig. (2-tailed) | .002 | .009 | .062 | .002 | | .017 | .000 |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Upper. Thres | Pearson Correlation | .938** | .943** | .841** | -.714** | -.670* | 1 | .780** |
| | Sig. (2-tailed) | .000 | .000 | .001 | .009 | .017 | | .003 |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |
| Lower. Thres | Pearson Correlation | .849** | .789** | .675* | -.778** | -.980** | .780** | 1 |
| | Sig. (2-tailed) | .000 | .002 | .016 | .003 | .000 | .003 | |
| | N | 12 | 12 | 12 | 12 | 12 | 12 | 12 |

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

The second phenomenon is the coldest average upper threshold temperature of the thermocline occurred in the La Niña-IOD (+) case at 26.83°C and conversely the warmest lower threshold temperature also occurred in this case at 16.71°C. This phenomenon occurs in close relation to the depth of the thermocline, where in this case the upper threshold layer of the thermocline was identified as the deepest (69.03 m) and the lower threshold layer was shallower than the other three cases (244.32 m). The cause of the depth of the upper threshold layer of the thermocline is due to strong current pressure, both surface currents and Indonesian Throughflow currents which push the thermocline downwards, this follows what Gordon (2005) and Gordon *et al.*, (2008) explained. Apart from the current pressure, it is also due to the strong winds blowing during this case period (Kunarso et al. 2012). The wind speed in August reached 8.73 m/sec, the fastest compared to the other three cases. Strong wind speeds cause the dynamics of currents and surface waves to become stronger, this causes the mixed layer to become deeper so that the thermocline layer drops (Stewart, 2002). The cause of the rise in the lower threshold of the thermocline and it becomes the shallowest is due to strong upwelling currents influenced by strong IOD (+) events. In the vertical temperature stratification, the upper threshold of the thermocline in the east season is 26°C, and the lower threshold of the thermocline is 15°C. It can also be observed that the thermocline slopes upward towards land (low latitude), This shows that there is a process of increasing water mass (upwelling). The temperature of 24.5°C appeared to rise to sea level, this indicates that a very strong upwelling process occurred in the La Niña-IOD (+) case.

The third phenomenon is the average temperature of the upper and lower limits of the thermocline in the El Niño-IOD (+) case during the east season until the transition to the west season shows the coldest compared to what occurred in the other three cases, 26.01°C and 12.69°C respectively. Theoretically, El Niño and IOD (+) occur causing sea level slope in the eastern Indian Ocean (including Indonesia) to be very low (Marsac & Le Blanc, 1998; Saji *et al*., 1999), this has the effect of very strong upwelling, which pumps cold water from deep layers up to the surface, so that the upper threshold of the thermocline becomes shallow (Kunarso, 2011). In this case, the upper threshold of the thermocline shows the shallowest value among the three other cases, 50.95 m, but the lower threshold of the thermocline shows the deepest value, 281.83 m. The depth of the lower threshold of the thermocline in the El Niño-IOD (+) case is thought to be due to the small amount of cloud cover in the atmosphere, this can be identified from the small amount of rainfall that occurs in this case (Kunarso et al. 2012). Theoretically, during El Niño-IOD (+), the wind from Indonesia blows strongly westward towards the western Indian Ocean and eastward towards the eastern Pacific Ocean. Strong winds in both directions east and west carry clouds from the upper atmosphere of Indonesia to the west and east. This results in when this case occurs, Indonesia will experience a strong drought because the intensity of the rain that falls is small (140 ml/month) (Kunarso et al. 2012). Further, because the clouds above the Indonesian atmosphere move to the west and the east, the light intensity of the atmosphere is high and the intensity of sunlight received by the land and sea in Indonesia is high. This condition causes heat energy entering the ocean column to become deeper and the lower boundary of the thermocline becomes deeper, which results in the temperature of the lower threshold of the thermocline in the case of El Niño-IOD (+) becoming the coldest.

Based on the description above, it shows that the temperature of the upper and lower limits of the thermocline and its depth in the waters south of Java to Timor varies with variations in global climate anomalies and monsoons.

### *3.2 Ground Check of Field Data*

Based on field ground data checks, carried out in August, during the La Niña-IOD (-) 2010 period, it appears that there is a match between the results of the Word Ocean Data data analysis described in the discussion above and the results of the field survey. Field data measurements carried out for 10 days with a minilogger installed on a tuna long line showed similar results, sea water temperature in August at a depth of ±250 m showed ±15°C (**Figure 2**). This result follows the calculation of the lower threshold of the thermocline during La Niña-IOD (-) and also shows this value (**Figure 1 c**). This location is the lower threshold layer of the thermocline which is the location of the big eye tuna swimming layer, where during sampling many tuna fish were caught from that depth.

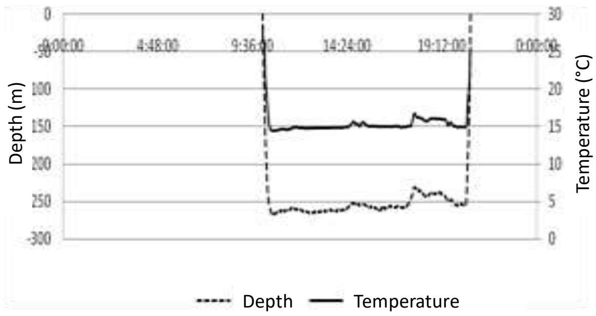


**Figure 2.** Results of temperature measurements with a minilogger on August 12 2010 during La Niña-IOD (-) at a depth of ± 250 meters, water temperature ± 15°C

### *3.3 The Correlation Between the Thermocline's Temperature with ENSO, IOD, and Monsoon*

Based on the results above in almost all cases, the IOD appears to have a strong influence on the threshold of the temperature, with an average correlation coefficient of -0.74. This means that there is a strong relationship between the upper threshold temperature and IOD, the greater the DMI value, the lower the upper threshold temperature value. Especially for the case of La Niña-IOD (+), in this case, La Niña has moderate intensity and the highest positive DMI value compared to the other 3 cases is 0.695. It turns out that IOD has a very strong influence on the temperature of the upper and lower threshold of the thermocline, each with a value correlation coefficient of -0.809 and -0.786 (**Table 1**). ENSO and Monsoon in this case also have a strong influence on the temperature of the upper and lower threshold of the thermocline but are not as strong as the influence of IOD (**Table 1**).

## 4. Summary

Generally, the temperature of the upper and lower threshold of the thermocline and its depth in the waters south of Java to Timor vary with variations in the cases of global climate anomalies (ENSO and IOD) and seasons (the west, east, and transition season). IOD anomalies appear to have the most dominant influence on the temperature variability of the upper and lower threshold of the thermocline. The upper threshold temperature of the thermocline in the east season is generally smaller than in the west season, the range is 26.09 – 26.86°C and 27.6 – 28.9°C respectively. The coldest annual average temperature at the upper threshold of the thermocline occurs in the case of La Niña-IOD (+) at 26.83°C±0.41°C, and the warmest occurs in the case of El Niño-IOD (-) at 27.74 °C± 0.61°C. The lower threshold temperature during the east season until the transition to the west season is smaller than the lower threshold temperature during the west season until the transition to the east, respectively, the range is 12.68 – 15.31°C and 12.83 – 18.1°C. The smallest annual average lower threshold temperature occurs in the El Niño-IOD (+) case of 12.76 °C±0.83°C, and the largest occurs in the La Niña-IOD (+) case of 16.71°C±1.25 °C.

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