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Spatial and temporal variability of satellite sea surface temperature in the Makassar Strait and the Java Sea

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Abstract. Sea surface temperature (SST) data obtained from the Aqua-MODIS satellite from 2002 to 2012 were analyzed to determine the spatial and temporal variability in the key region of small pelagic fisheries between Makassar Strait and the Java Sea. Results of the Empirical Orthogonal Function (EOF) analysis show that the characteristics of this region are described by 60% based on the greatest contribution value respectively. The largest contribution of 52% shows that the SSTs in this region is warm. A strong indicator of these conditions appears in the east through the southern part of Kalimantan Island while the weak indicator is in the south to western part of Sulawesi Island. The temporal variation shows that the annual oscillation is dominant in this area where maximum SSTs occurs in the first transitional monsoon (April), while the minimum occurs in the southeast monsoon period (August). The influence of southeast monsoon formats the minimum SSTs area in the south of South Sulawesi that is generated by parallel wind-driven induces to the coast and the divergent current close to the coast. Due to inter-annual variability, minimum SSTs occurs before the El Nino episode whereas the maximum occurs before the La Nina event.

Keywords: Java Sea, Makassar Strait, monsoon, satellite, sea surface temperature,

1. Introduction

The Java Sea and the Makassar Strait are interconnected and interacted with each other. Makassar Strait is known to be the main entry point of the Indonesian Throughflow (ITF) where characteristics of the water mass are more influenced by circulation originating from the North Pacific [1]. The ITF water mass flowing through the Makassar Strait continues towards the Flores Sea, the Banda Sea, and through the Timor Sea into the Indian Ocean. Due to the influence of the east monsoonal winds, the water mass that is channelled east to the Timor Sea is pushed from the opposite direction, causing oscillations towards the Java Sea when it reaches the Flores Sea. These oscillations then return to the Flores Sea and partially enter the Makassar Strait [1].

Many events related to physical, chemical, and biological processes, as well as their impact on organisms and biota, are inextricably linked to the existence of ITF. Previous research has shown that the presence of ITF passing through the Makassar Strait can affect the depth of the mixed layer, the thermocline layer, and the occurrence of seasonal upwelling [2]. Furthermore, The Java Sea has distinct characteristics as a body of water heavily influenced by runoff of numerous rivers, which originate from Java and Kalimantan [3].

Satellite remote sensing for exploiting natural resources including marine and fisheries sectors makes an important contribution in revealing various marine events and potentials. Compared to field observations, this method has the ability to monitor synoptically and long observation ranges. Biological hotspots are phenomena that can be revealed in relation to marine potentials. It is used to indicate the existence of an area in the sea where biological interactions between organisms and biota occur. This area is a gathering place for organisms to conduct their life processes [4]. Temperature is an important component in controlling the survival of organisms such as growth, activity, and mobility of movement, spawning, etc. In addition, temperature is used as an indicator of processes in the ocean such as coastal upwelling, advection, fronts and eddies. [5-6].

Various physical processes and climatic factors -monsoon and El Nino Southern Oscillation (ENSO)- take place in the Makassar Strait – Java Sea region. These factors have significat role in the formation of spatial patterns and temporal variability that characterized the waters in the region of interest, as stated by [7] who have analyzed the surface temperature variability of the Java Sea from 1985 to 2002. Results of the spectral analysis show that there are variations in surface temperature with a period of 6 and 12 months where this is a representation of annual and semi-annual variability, and a period of 32 months which is an inter-annual variability [7].

This study aims at analyzing the spatial pattern and temporal variability of sea surface temperature in the region of the Makassar Strait and the Java Sea, which are known as the prominent fishing area, especially for purse seine fleets [8]. Hence, results of this study is expected to have significant contribution to the management of fishing industry.

2. Methodology

2.1. Data and research location

The observation area covers the northern part to southern part of the Makassar Strait. Then, it continued from the eastern part to western part of the Java Sea limited to the coordinates of 108 °E – 121 °E and 0° – 8 °S (Figure 1). The data used for the estimation of sea surface temperature were obtained from Aqua-MODIS (Moderate Resolution Imaging Spectroradiometer) Level-3 satellite image with a spatial resolution of 0.05° x 0.05° and a temporal resolution of 8 daily covering the time from July 2002 to December 2012. The data were obtained from the Pacific Islands Fisheries Science Center (PIFSC) which is part of the National Oceanic and Atmospheric Administration (NOAA) - USA through its website (http://oceanwatch.pfeg.noaa.gov).

From these data pixel values containing sea surface temperature were generated making use of the Miami Pathfinder SST (MPFSST) algorithm as follows [9]:

$$modis_{sst} = c_1 + c_2 * T_{31} + c_3 * T_{3132} + c_4 * (sec\,(\theta) - 1) * T_{3132} \tag{1}$$

Where T_{31} is brightness temperature (BT) on band 31(on AVHRR or Advanced Very High Resolution Radiometer channel 4). T_{3132} is BT difference on band 31-band 32 (on AVHRR channels 4 and 5). c_1, c_2, c_3, c_4 is the coefficient of band 31 dan 32. θ is the satellite zenith angle.

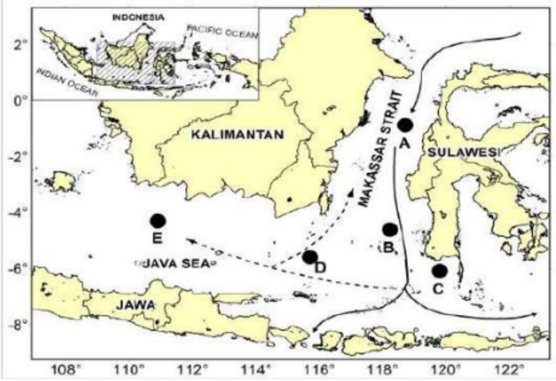

Figure 1. Map of research locations in the Makassar Strait and the Java Sea. The solid arrows indicate the water-mass flow of Indonesian Throughflow via Makassar Strait. The dotted arrows indicate the surface monsoon currents in the Java Sea. The letters from A to E show the sampling area for time series data.

This study also used supporting data namely the surface wind stress and surface water current at 5 meters depth. The data was used to explain the patterns of water masses circulation in order to obtain an overview of the water mass transfer resulting in SST changes spatially and temporally. Surface wind stress data was obtained from QuickSCAT (Quick Scatterometer) satellite imagery-Seawinds Level 3 with the spatial resolution of 0,25° x 0,25°, the temporal resolution of once every eight days and time coverage from January 2002 to November 2009. The data were also obtained from PIFSC-NOAA, USA (http://oceanwatch.pfeg.noaa.gov). Furthermore, the surface water current data derived from the results of the Infrastructure Development of Space Oceanography (INDESO) program, a cooperation project between the IRD (Institut de Recherche pour le Development)-France and CTF (Clean Technology Fund)-Indonesia. The INDESO program is a combination of satellite technology and numerical calculations to produce some products that can be used in various applications in coastal and marine areas of Indonesia (http://www.indeso.web.id). This data has a spatial resolution of 1/12° x 1 /12° and a temporal resolution of once a day with coverage data from January 2007 - December 2012.

2.2. Analysis of the spatial pattern of sea surface temperature

General description of sea surface temperature could be seen from the condition of its average and standard deviation spatially. The distribution of sea surface temperature was obtained by applying the equation to each pixel value at the same coordinate position for the entire observation period [10]. The spatial patterns and temporal variability were analyzed using Empirical Orthogonal Function (EOF). The purpose of EOF analysis was to decompose time series signals in an area into spatial and time functions, resulting the variance that sorted from largest to smallest. The resulting image distribution pattern was a structure both spatially and temporally indicated by the eigenvector values in the form of percentages. This eigenvector value also showed the magnitude of its contribution to each structure produced which was called the mode. The formula used to generate the spatial pattern and temporal variability of sea surface temperature was as follows [11]:

$$X(t,s) = \sum_{k=1}^{M} c_k(t)u_k(s) \tag{2}$$

where,
$X(t,s)$ is a space-time function where M is the number of modes or the M-mode of the decomposition of a space-time signal with a space function $uk(s)$ and time function $ck(t)$. This time function in the EOF is also known as the expansion coefficient or principal component (PC) and hereinafter referred to as the expansion coefficient.

After the spatial pattern and temporal variability were generated for each structure, then the energy density spectrum was applied to determine the period of fluctuation in which energy was significant or dominant in each of these EOF modes. The value of the energy density spectrum was determined using the Bendat and Piersol equation as follow [12]:

$$S_x = \frac{2\Delta t}{N}\left|X\left(f_{(k)}\right)\right|^2 \tag{3}$$

where,
Sx is the energy density value of a time series data record at the k^{th} frequency (fk),
X(f(k)) is the Fourrier component of the time series data (xt) at the k^{th} frequency (fk),
t is the data retrieval interval (8 days)
N is the number of data

2.3. Analysis of the temporal variability of sea surface temperature

Analysis of temporal variability for the entire observation time was used continuous wavelet transform and then a bandpass filter was performed to produce semi-annual, annual and inter-annual variability for each observation parameter [13]:

$$\mathrm{W_n(s)} = \sum_{\mathrm{n'=0}}^{\mathrm{N-1}} \mathrm{x_{n'}}\, \psi * \left[\frac{\mathrm{(n'-n)\delta t}}{\mathrm{s}}\right] \tag{4}$$

where,
It was assumed that a time series, x_n had the same time interval, δt, and $n = 0 \ldots N-1$. Also assumed the wavelet function wavelet ψ, depending on nondimensional 'time'. To be categorized as a wavelet, this function must have a mean of 0 and be between the same time and frequency range. Symbol *(*)* indicates a complex interpretation. By varying the scale of the wavelet *s* and changing it over the localized time index *n*, then an image could be constructed to show the amplitude of some components concerning scale and how the amplitude varied with time

3. Result and discussion

3.1. General conditions of the sea surface temperature

In general, the conditions and variations of sea surface temperature in the Makassar Strait and the Java Sea can be explained by the average value and standard deviation (Figure 2 and Figure 3). The sea surface temperature range in the observation area is dominated by the range of 29.25 – 29.75℃. This temperature ia almost entirely located in the Java Sea where the bulge of this range is to the west showing a gradual increase. The standard deviation of this area in the east of Java Sea is 1.15 and then it decreases to 1.05 when it goes to the west of Java Sea. This indicates that the eastern part of the Java Sea has low temperatures with higher variations, while the western part of the Java Sea the opposite condition occurs.

The southern part of the Makassar Strait haa a very striking difference with the northern part on the west side of Sulawesi Island. The average temperature is very low which reaches < 28.5 ºC, but with a high standard deviation of > 1.5. This shows that the southern part of the Makassar Strait is an area with low temperatures and a very high rate of fluctuations through time. [14] stated that throughout the year, the southern tip of the Makassar Strait had a lower sea surface temperature than the northern part and this condition spread to the Flores Sea and west of the Banda Sea.

As for the northern part of the Makassar Strait on the east side of the island of Kalimantan, the conditions are similar to the western part of the Java Sea. The average temperature was 29.50 – 29.75 ºC with a standard deviation of 1.05 – 1.15.

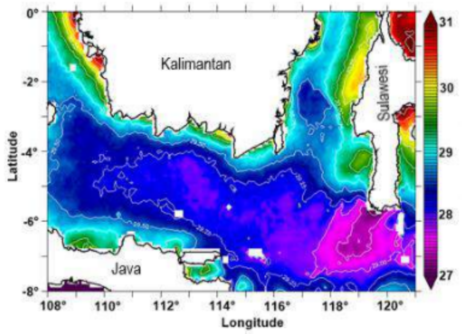

Figure 2. The average of sea surface temperature distribution for the 2002-2012 period

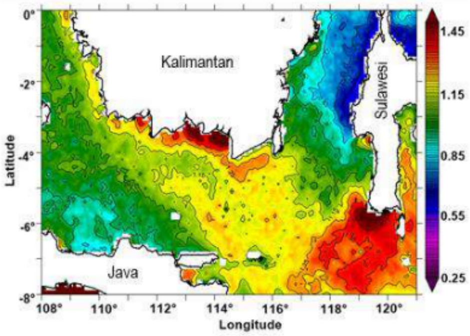

Figure 3. The standard deviation of sea surface temperature distribution for the 2002-2012 period

3.2. Spatial and temporal variations of the sea surface temperature

The distribution pattern of sea surface temperature in the Makassar Strait and the Java Sea are shown in Figure 4a and 4b. The spatial structure of sea surface temperature is 60% variance value of the two EOF modes indicates that there is a pattern formed with a clear boundary between the two temperature characters. In EOF mode-1 the variance value is 52% which shows that the overall sea surface temperature range is above the average value (positive anomaly). These conditions show a low range of values where higher eigenvectors are formed in the eastern to the southern part of Kalimantan Island which covers the middle of the Java Sea. On the other hand, from the southern to the western part of Sulawesi Island has a low eigenvector.

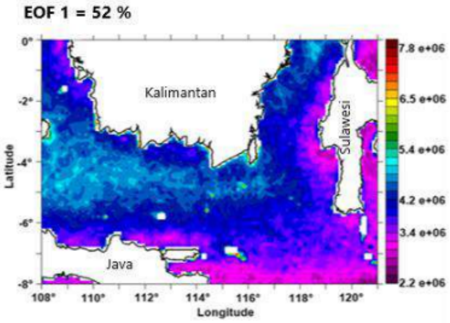

Figure 4a. Spatial structure EOF Mode 1 of the sea surface temperature in the Makassar Strait and the Java Sea

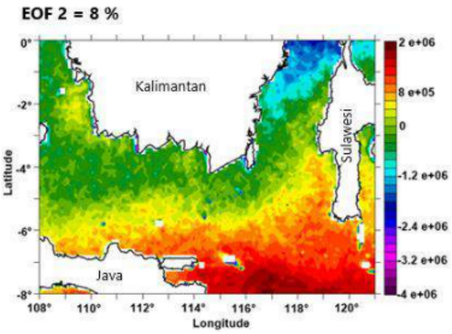

Figure 4b. Spatial structure EOF Mode 2 of the sea surface temperature in the Makassar Strait and the Java Sea

As for the EOF mode-2 with a variance value of 8%, it still shows the division of the area with two different sea surface temperature groups. In mode 2, the pattern was relatively opposite to mode 1 where the higher eigenvector values are above the average value (positive anomaly), and vice versa. The pattern formed in mode 2 is a positive anomaly of sea surface temperature that occurs from the south to the western part of Sulawesi Island and then spread to the northern coast of Java Island. In other hand the negative anomaly is from the eastern part to the southern part of Kalimantan Island.

The temporal variation shown in Figure 5 with two PC curves show that there is a difference in the amplitude of each PC mode. PC curves could be referred to the variance of temporal variability. In PC mode 1 the overall sea surface temperature is below the average value (negative anomaly) with the largest amplitude occurring in 2005-2006, 2009-2010, and 2010-2011. Based on the temporal fluctuations shown by PC Mode-1, it shows that the time cycle follows an annual cycle where all of them are in the negative anomaly of sea surface temperature.

The fluctuation period shows that the significance occurs in the annual period. In this period, maximum of sea surface temperature occurs in July, while the minimum occurs in December. The period of low significance is also seen in the semi-annual and inter-annual periods. This condition is similar to what happened in the PC mode 2 fluctuation pattern, namely the maximum sea surface temperature in August and that the minimum in December. The dominant period is also the annual cycle which has the highest significance, while the semi-annual and inter-annual periods have the lowest significance. The high fluctuations in this mode occurs in 2007-2008 and 2010-2011. The temporal variations are shown in PC modes 1 and 2 provides a strong signal regarding the influence of the ENSO which indicates El Nino and La Nina events in the observed area of interest.

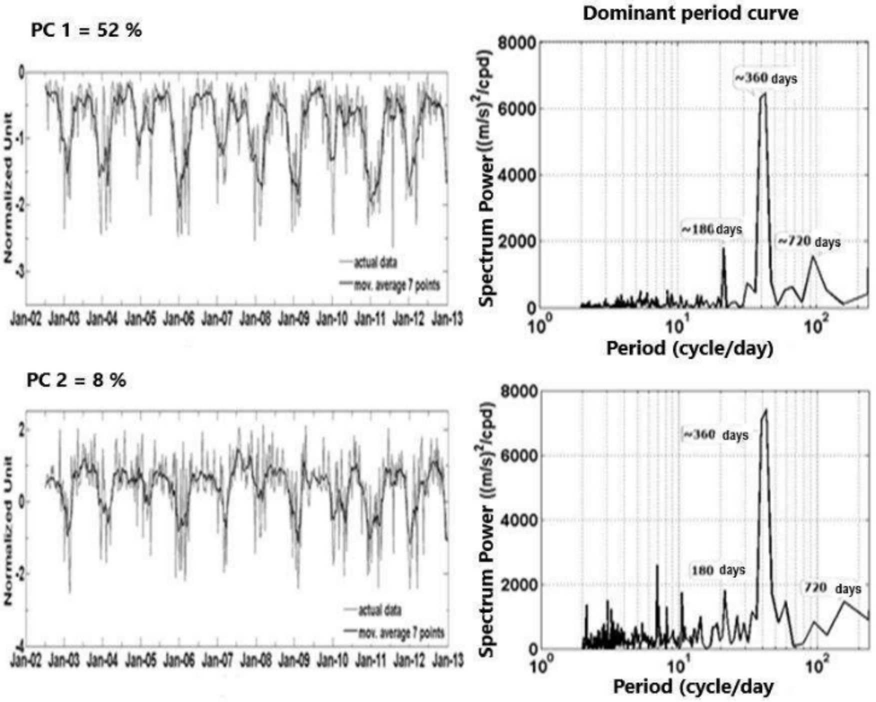

Figure 5. Temporal variation mode 1 and 2 PC (Principle Component) (left) and dominant period (right) of the sea surface temperature in the Makassar Strait and the Java Sea.

3.3. *The annual pattern of sea surface temperature*

The annual pattern of the sea surface temperature is shown in Figure 6. In the northwest monsoon period (represented by the month of January), the initial period in December is the sea surface temperature reaching its maximum at 31°C in the southern part of the Makassar Strait and the eastern Java Sea. However, when entering the months of January and February, it suddenly decreases to around 28.8 °C. At this time, overall, the sea surface temperature is relatively evenly distributed with a range between

29.5 – 31.0 °C. The distribution of low temperatures is only seen in a small part of the southern part of South Sulawesi and the western part of the Java Sea.

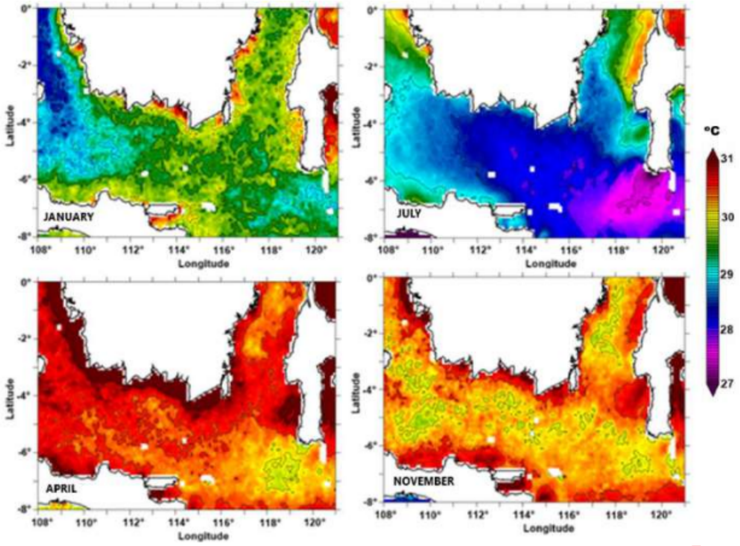

Figure 6. Annual mean of the sea surface temperature distribution in the Makassar Strait and the Java Sea. Note: The designated month is listed at the bottom left of each Figure.

In transitional season 1 (represented by the month of April), sea surface temperatures has increased where the peak occurs in April. At this time, a downward trend towards the west in the Java Sea is evident which can be seen in April and May. Furthermore, there is a formation of low sea surface temperatures in the southern part of South Sulawesi. Meanwhile, the northern part of the Makassar Strait on the western side of Sulawesi Island there is an increase in sea surface temperature which has consistently a warm condition from time to time.

During southeast monsoon period (represented by the month of July), the trend of cold temperatures (27.0 – 29.2 °C) from east to west of the Java Sea is formed with an ongoing decline and expanding coverage area. Likewise, the formation of low temperatures in the southern part of South Sulawesi is also experiencing a consistent decline and wider coverage which reaches its peak in August. Meanwhile, in the northern part of the Makassar Strait on the west side of Sulawesi Island, the sea surface temperature was relatively high and only slightly decreased compared to the previous season which was consistent in the range of 29.5 – 30.0 °C.

When entering transitional season 2 (represented by the month of November), the outflow of cold temperatures is still visible until October with the condition of sea surface temperatures continuing to increase and the coverage area becoming smaller. This condition completely disappears in November along with the increasing sea surface temperature and is distributed almost evenly in all respective waters.

The pattern of surface wind stress and surface currents (Figure 7) show that this area is strongly influenced by the monsoons [15]. During the northwest monsoon (December – February) wind stress flows from the Karimata Strait into the Java Sea and continues to the east. When passing through the southern part of the Makassar Strait it veers to the southeast. As for the Makassar Strait, wind stress flows from north to south and when it meets the wind flow coming from the Java Sea, it then is deflected slightly towards the southeast direction as well. At this time the maximum wind stress occurs in February ranging from 0.02 to 0.04 Pa.

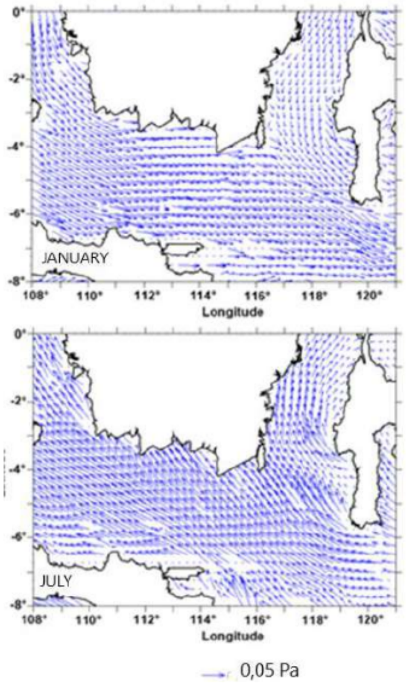

Figure 7. Annual mean of surface wind stress (Pa) in the Makassar Strait and the the Java Sea. Note: The designated month is listed at the bottom left of each map.

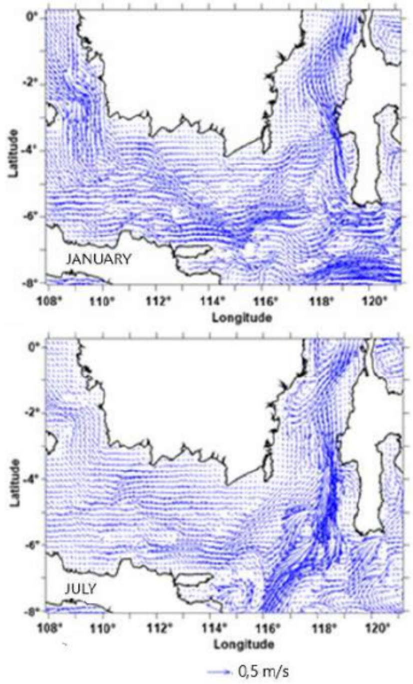

Figure 8. Annual mean of surface water current 5 m depths (m/s) in the Makassar Strait and the Java Sea. Note: The designated month is listed at the bottom left of each map.

The opposite occurs during the southeast monsoon (June-August) where the direction of the surface wind stress towards the northwest becoming very intensive when it enters the Flores Sea. Wind stress with this direction continues to enter the southern part of the Makassar Strait, the Java Sea, and Karimata Strait. As for during southeast monsoon period, wind direction is partially deflected towards the north when it reaches the southern part of the Makassar Strait. The maximum strength of wind stress occurs in August ranging from 0.05 to 0.08 Pa.

Comparison of sea surface temperatures between the two monsoon periods with the northwest monsoon and southeast monsoon where the northwest monsoon period has a warmer sea surface temperature. This conditions were explained by [14] who suggested that it was the result of a decrease in solar radiation on the southern hemisphere and heat loss driven by low-humidity air masses from Australia. Likewise, the condition of lower sea surface temperature in the south than in the north was also explained by both that this was the result of vertical mixing. In line with that, [15] stated that the high sea surface temperature during the northwest monsoon period was also related to the level of precipitation which at this time had a longer precipitation time and wider coverage than the southeast monsoon. The amount of precipitation that crossed an island would increase the flux (continuous change) in freshwater. This continuous change occurred around Kalimantan Island. This freshwater flux would warm the sea surface temperature by limiting the release of latent heat and mixing processes at the surface.

The surface water current pattern as shown in Figure 8 exhibits that in the northwest monsoon period (represented by the month January), surface currents that move from the Java Sea split into two branches when they entered the Makassar Strait. One branch enters the northern part of the Makassar Strait and the other branch towards the southern part of the Makassar Strait which then flows east into the Flores Sea. As for the southeast monsoon (represented by the month of July), the opposite condition applies, namely the flow of currents from the north of the Makassar Strait advances into the Java Sea and some continued to the south where it splits into two branches. One branch flows to the south of the Lombok Strait and the other branch advances to the east of the Flores Sea. Peviously study revealed that the North Pacific water mass was carried from the Mindanao Current and followed the western flow from its entrance in the northeast of the Sulawesi Sea to the Makassar Strait and so on to the Flores Sea [16]. From here, about 20% of the currents flowed out into the Indian Ocean via the Lombok Strait and to the east through the Banda Sea, before entering into the Indian Ocean via the Ombai Strait and the Timor Pass.

Low sea surface temperatures in the southeastern monsoon period are due to upwelling events that occurs in the south of Sulawesi Island [17]. Furthermore, [18] found that the main upwelling power plant in the south of Makassar Strait was a strong wind boost that produces Ekman transport to the southwest in the southern region of Sulawesi Island. This surface wind stress could increase vertical diffusivity and release of flux material into the atmosphere. Thus, the process increases the activity of vertical mixing of the water mass, which has implications of the decrease in sea surface temperature.

3.4. Variability of sea surface temperature in the Makassar Strait and the Java Sea

Based on the Continuous Wavelet Transform (CWT) analysis, sea surface temperature image data with 8 daily sampling intervals (Figure 6) was calculated on three sampling box areas. There is a dominant period in the range of period values 45 (annual variability) and 90 - 270 (inter-annual variability). In more detail, the level and pattern of its fluctuation can be seen more clearly through the filter according to the specified time as previously mentioned.

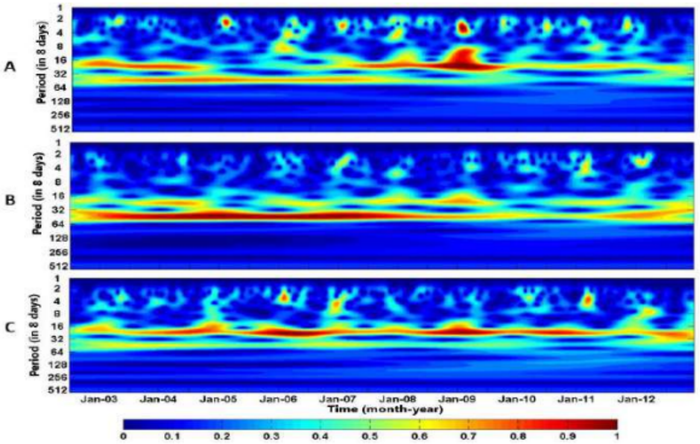

Figure 9. Dominant period of sea surface temperature based on Continuous Wavelet Transform. Note: A= South of South Sulawesi, B= South of Makassar Strait, C= West of Java Sea.

Fluctuations in the annual variability of sea surface temperatures in the Makassar Strait and the Java Sea (Figure 10) show that the difference in patterns is only shown in the northern part of the Makassar Strait. The low fluctuations that occurs in 2002-2005 with the peak of the positive phase have a tendency to occur in the southeast monsoon (May-June) and the negative phase during the northwest monsoon

(October-November). Meanwhile, in the southern part of Makassar Strait, the southern part of South Sulawesi, and the eastern part of the Java Sea, the pattern has a similar tendency where the lowest fluctuation occurs in 2007-2012 and that of the highest in 2002-2006.

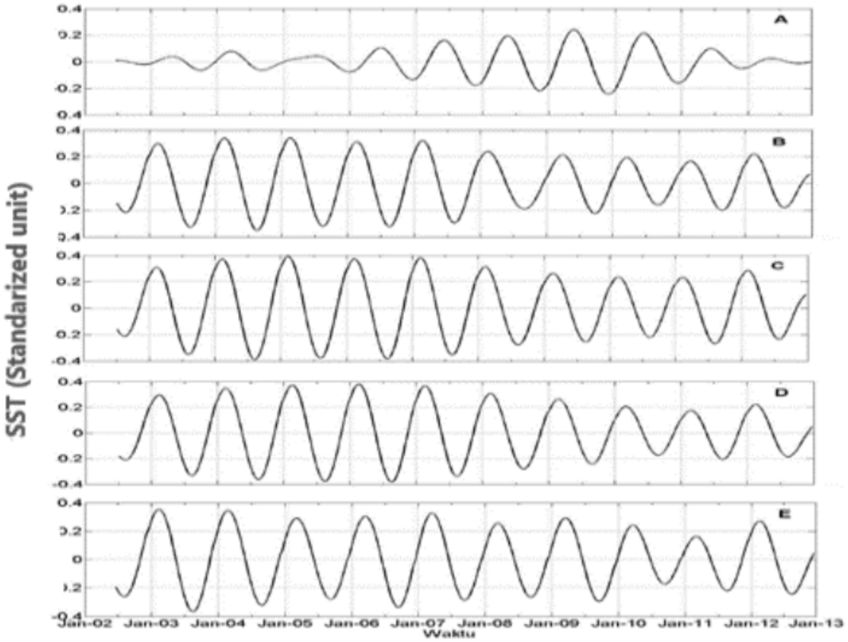

Figure 10. Annual variability of sea surface temperature in Makassar Strait and the Java Sea in 5 sampling box areas. **Note**: A=North of Makassar Strait, B=South of Makassar Strait, C=South of South Sulawesi, D=East of Java Sea, E=West of Java Sea.

The peak of positive phase shows a tendency to occur in February-March (northwest monsoon), whereas the negative phase tends to occur in August-September (southeast monsoon). This condition indicates that low sea surface temperature fluctuations occurs in the north of the Makassar Strait, while high sea surface temperature fluctuations occur in the south of South Sulawesi and east of the Java Sea. Furthermore, this condition also shows that fluctuations in sea surface temperature in Makassar Strait - the Java Sea are dominated by a one-year cycle, namely experiencing one peak of maximum and one minimum.

The occurrence of high and low oceanographic parameters including sea surface temperature in the annual and semi-annual periods are all influenced by the monsoon system. The predominance of this annual monsoon cycle in the tropics and subtropics are due to the influence of the sun's apparent motion, although not all of these areas experience monsoonal occurrence. This is due to the differences in land and oceanic exposure. As defined before, the monsoon regime is an area that changes with an annual cycle of wind parameters, water vapor content, and rainfall [19].

Many monsoon regimes applied to ocean-atmosphere interactions in the world; the observation location is in the Australian Summer Monsoon System which is limited to the area of 110° E – 130° E and 15 °S – 5 °S. Hence, warm sea surface temperatures occur in December - March which are referred to the northwest monsoon, while the cold sea surface temperatures occur in April - October which are referred to the southeast monsoon.

Furthermore, the identification of inter-annual phenomenon is an important thing to observe in a changing oceanographic conditions. Previous study suggested that the sea surface temperature anomaly generated by the Nino index 3.4 with a positive temperature anomaly above 0,5 °C and persisted for 6 months indicated the occurrence of El Nino, while a negative temperature anomaly below 0,5 °C and persisted for 6 months indicated the occurrence of La Nina [20]. The indication of strength levels of ENSO are determined from the anomaly values. Values between 0.5 – 1.5 are categorized as weak ENSO, while those above 1.5 are regarded as strong ENSO.

The inter-annual variability of sea surface temperature as shown in Figure 11 show that -with reference to the above mentioned criteria-, strong El Nino events occur in July 2002 – March 2003, July 2004 – January 2005, and June 2009 – April 2010, while strong La Nina occur in August 2007 – May 2008 and June 2010 – May 2011. Based on this condition, it is observed that sea surface temperature decreases before the El Nino event and that increases before the La Nina event.

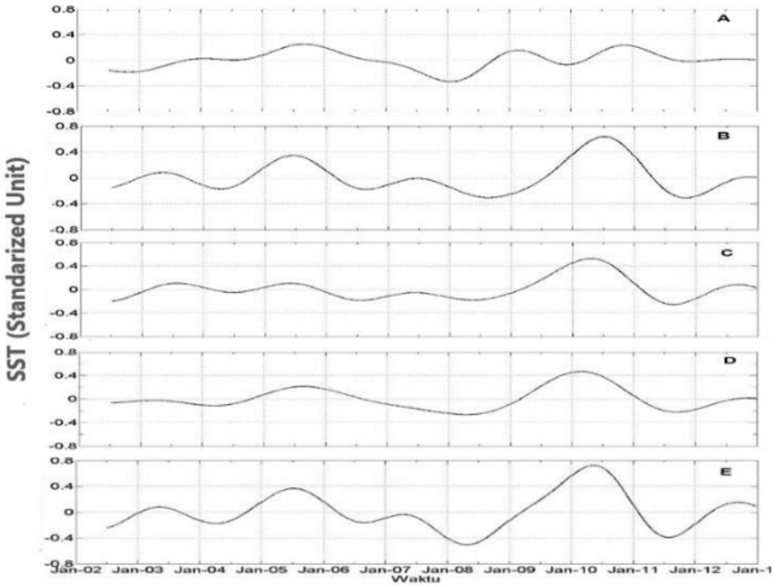

Figure 11. Annual variability of sea surface temperature in Makassar Strait – the Java Sea in 5 sampling box areas. Note: Note: A=North of Makassar Strait, B=South of Makassar Strait, C=South of South Sulawesi, D=East of Java Sea, E=West of Java Sea.

In general, ENSO events are correlated with the amount of water mass transport from the Pacific Ocean to the Indian Ocean, and the ENSO phenomenon was closely related to the shift of warm water pools in the western Pacific Ocean which affects the temperature increase at the ITF crossings. The effect of ENSO on ITF, as stated in previous researches, showed that El Nino events decreases ITF transport. Consequently, there exist a decrease in the input of warm temperatures from the warm water pool in the western Pacific Ocean, thereby lowering the temperature on the route.

In addition, the movement of the warm water pool to the eastern Pacific Ocean before the El Nino event will further reduce the mass transport of warm water. In contrast, during the La Nina event, the opposite process applies, and hence, it increases water mass transport and surface temperature on the ITF crossings [21-23]. The correlation between ITF transport and ENSO phenomenon was analyzed in more detail by [24] with the result that there was a lag correlation based on wavelet analysis that with an ENSO period of 4 – years, it was found that ITF experienced a delay of 8 – 9 months with regard to sea surface temperature anomalies.

Regarding the response of sea surface temperature in the sampling box of the observation area to El Nino – La Nina events, it can be seen that the southern part of Makassar Strait and the western part of Java Sea have the strongest response, while the northern part of Makassar Strait exhibits the weakest response. It is likely that the position of Java Sea that causes a more sensitive response to interannual climate variability than that of Makassar Strait.

4. Conclusion

Formation of the spatial pattern of sea surface temperature is dominated by higher eigenvectors in the waters from the east to the south of Kalimantan Island, while the low eigenvectors are in the south to the west of Sulawesi Island. In terms of temporal variation, this area is dominated by a one-year cycle, where the maximum sea surface temperature occurres in April and the minimum occurres in August. The highest fluctuations occur in the southern part of South Sulawesi and the eastern part of the Java Sea.

The effect of the southeast monsoon winds causing upwelling in the southern part of South Sulawesi is characterized by sea surface temperatures. A minimum sea surface temperature in this area compared to its surroundings is produced by strong wind gusts along the coast and the formation of divergent currents approaching the coast. In this period there is also the formation of a cold temperature channel in the Java Sea with a distribution direction from east to west which increased gradually. This cold temperature distribution pattern followed the depth contour of the area which is thought related to the tidal mixing processes.

In the inter-annual period, a period of decreasing sea surface temperature has taken place before the El Nino event, while an increase in sea surface temperature can also occur before the La Nina event. Spatially, the area in the southern part of the Makassar Strait and the western part of the Java Sea have the strongest response to the ENSO phenomenon, while the northern part of the Makassar Strait exhibits the weakest response.

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