Sea Surface Temperature Dynamics in Indonesia

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Abstract. Indonesia as a country that has large marine area reserves the large potential of marine resources. One of parameters to identify marine resources is sea surface temperature (SST). Dynamics of SST in Indonesia is influenced by global phenomena, such as ENSO and IOD. This paper aims to understand the spatio-temporal distribution and statistical attribute of SST in Indonesia between 2007 – 2016, respond of SST in Indonesia against ENSO and IOD, and comparison between two infrared sensors for SST measurement. Level 3 Aqua/Terra MODIS monthly dataset are used to obtain spatio-temporal distribution and statistical attribute of SST. Dipole Mode Index and TAO buoy are used to assess the respond of SST in Indonesia against ENSO and IOD. AHI Himawari-8/9 monthly-composite dataset is used to compare SST measured from Aqua/Terra MODIS. From 2007 to 2016, in Indonesia SST is ranging between 27.91 to 30.46 °C. The coldest SST occurred in August (2007, 2012, 2015) while the warmest SST occurred in April (2010 and 2016). Strong correlation has been identified between the SST and IOD (especially in western part of Indonesia) and between the SST and ENSO (especially in WPPNRI 573 and 718). There is no significant difference of SST measurement result between Aqua/Terra MODIS and Himawari 8/9.

Keywords: Sea Surface Temperature (SST), SST dynamic, Aqua/Terra MODIS, Himawari 8/9

1. Introduction
The oceans have large heat-storage play an important role in climate system [1]. Composed of more than 3,000 islands, lying between two ocean basins (Indian Ocean and Pacific Ocean) and two continents (Asia and Australia), also with a cumulative costal perimeter that is more than twice Earth’s Circumference, Indonesia plays the important role in Earth climate, it also acts as an oceanic connection between warm pools of Pacific and Indian Oceans. The SST variations within the Indonesian region are a consequence of complex physiography and connectivity between the two major oceans [2]. The main factors influence the SST variability in Indonesia are ENSO (El Niño Southern Oscillation), Monsoon, IOD (Indian Ocean Dipole) [3][4][5]. One of leading mode in tropical climate variability is ENSO, characterized by warm SST for positive El Niño in eastern tropical Pacific Ocean and cold SST for negative La Niña [6]. Another mode that influences Indonesia is IOD, which is coupled ocean-atmosphere mode with positive phase characterized by warm SST over Eastern Indian Ocean, and negative phase by cold SST over Eastern Indian Ocean [4].
The Sea Surface Temperature (SST) is a result when ocean and the atmosphere interact via turbulent and radiative energy exchange in the sea surface, then energy fluxes in turn depend on a single oceanic quantity [1]. SST is one of important variables in climate observation database [7][8]. In fisheries, SST also plays an important factor to fish for feeding, spawning, and migrating. For example, spawning according [9] the common to all Tunas species is the relationship between spawning activity and SST more than about 24 °C, because of their mode of reproduction, repetitive broadcast spawners, and tunas must have very high lifetime fecundities to be successful. For small pelagic fish, SST also plays important role during spawning, and at the development and survival of the eggs and larvae, as well as influencing distribution, aggregation, migration and schooling behaviour of juveniles and adults [10][11][12]. SST also has been used to investigate productive frontal zones related to feeding ground of fishes [13]. In Sri Lanka high season or high frequencies of Yellowfin Tuna catch were obtained in the areas where SST varied primarily in 28 – 30 °C [14].

SST measurement from satellite is performed by utilizing the infrared and microwave channel. Infrared measurement can present highly accurate SST measurement (~0.5 K) when the atmosphere is clear while microwave measurement is less affected by clouds [15]. Several sensor instruments have been launched and operated to measure SST. Some examples for infrared sensor are AVHRR (Advanced Very High-Resolution Radiometer) sensor carried by NOAA satellite uses its infrared channel (3.7, 11, and 12 µm) [16]; MODIS (Moderate Resolution Imaging Spectroradiometer) sensor on Aqua/Terra satellite uses its mid (3-4 µm) and far (11-12 µm) infrared channel [17]; and AHI (Advanced Himawari Imager) carried by Himawari-8/9 satellite uses its infrared channel on 3.9, 8.6, 10.4, 11.2, and 12.4 µm [18]. Several examples of passive microwave channel used to derive SST are SMMR (Scanning Multi-Channel Microwave Radiometer) carried on Nimbus-7 and Seasat satellite uses its microwave channel ranging from 6.6-37 GHz [19] and AMSR (Advanced Microwave Scanning Radiometer) with its 6.9-89 GHz frequency of microwave channel carried on ADEOS-II satellite [20].

Indonesian Fisheries Management Area (Wilayah Pengelolaan Perikanan Negara Republik Indonesia, abbreviated as WPPNRI) is fisheries management area for fish catchment, fish cultivation, conservation, research, and fisheries development that cover internal sea, island sea, marine territorial, additional zone, and exclusive economy zone of Indonesia [21]. It consists of 11 areas, shown as yellow area in Figure 1 and its coverage area is shown in Table 1.

Figure 1. WPPNRI boundaries.
Table 1. WPPNRI division.

| WPPNRI   | Coverage Area                                                                 |
|----------|-------------------------------------------------------------------------------|
| WPPNRI 571 | Malaka Strait and Andaman Sea                                                 |
| WPPNRI 572 | Indian Ocean of western of Sumatra and Sunda Strait                           |
| WPPNRI 573 | Indian Ocean of southern of Java to Nusa Tenggara, Savu Sea, and western of Timor Sea |
| WPPNRI 711 | Karimata Strait, Natuna Sea, and South China Sea                              |
| WPPNRI 712 | Java Sea                                                                      |
| WPPNRI 713 | Makassar Strait, Gulf of Bone, Flores Sea, and Bali Sea                       |
| WPPNRI 714 | Gulf of Tolo and Banda Sea                                                    |
| WPPNRI 715 | Gulf of Tomini, Maluku Sea, Halmahera Sea, Seram Sea, and Gulf of Berau       |
| WPPNRI 716 | Sulawesi Sea and northern of Halmahera Island                                 |
| WPPNRI 717 | Gulf of Cendrawasih and Pacific Ocean                                         |
| WPPNRI 718 | Aru Sea, Arafuru Sea, and eastern of Timor Sea                               |

Although there is statement that SST in Indonesia generally range at 28 – 31 °C [22], this range may be different as an impact of climate change. This paper aims to 1) assess the spatio-temporal distribution and statistical attribute of SST in WPP-NRI; 2) assess respond of SST in WPPNRI to ENSO and IOD; and 3) compare performance of Aqua/Terra MODIS and Himawari-8/9 in SST detection.

2. Data and Methods

MODIS is a sensor attached in Aqua/Terra satellite. Both satellite have sun-synchronous orbit that view the entire Earth’s surface every 1-2 days, acquiring data in 36 spectral bands, where Aqua passes from south to north across the equator in the afternoon (1.30 pm) and Terra passes from north to south across the equator in the morning (10.30 am) [23]. To determine the SST, MODIS uses certain bands (shown in Table 2) that are chosen based on particular aspect of the atmospheric total column transmissivity in each part of the mid- and far- infrared spectrum [17].

Table 2. Bands for MODIS Infrared SST Determination.

| Band Number | Band Center (µm) | Bandwidth (µm) |
|-------------|------------------|----------------|
| 20          | 3.750            | 0.1800         |
| 22          | 3.959            | 0.0594         |
| 23          | 4.050            | 0.0608         |
| 31          | 11.030           | 0.5000         |
| 32          | 12.020           | 0.5000         |

Based on mid- and far- infrared spectrum, two ocean skin SST products are produced. The first product (SST) is produced from band 31 and 32 while the second product (SST4) is produced from band 22 and 23. Algorithms to obtain those products are respectively shown in Equation (1) and (2). By using these algorithms, the standard deviation of MODIS Aqua/Terra is ranged between 0.42 – 0.51 K by comparing the satellite SST dataset to sub-surface buoy [24].

\[
SST = c_1 + c_2 \ast T_{31} + c_3 \ast (T_{31} - T_{32}) \ast T_{sfc} + c_4 \ast (\sec(\theta) - 1) \ast (T_{31} - T_{32})
\]

\[
SST4 = c_1 + c_2 \ast T_{22} + c_3 \ast (T_{22} - T_{23}) + c_4 \ast (\sec(\theta) - 1)
\]

where

- \( SST \): retrieved surface temperature
- \( T_{22}, T_{23}, T_{31}, \) and \( T_{32} \): brightness temperature from band 22, 23, 31, and 32 respectively
- \( T_{sfc} \): estimate of the surface temperature, based on NOAA/NCEP weekly or daily blended Reynolds 0.25° spatial resolution product
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\[ \theta \]
\[ c_1, c_2, c_3, \text{ and } c_4 \]
\[ B \]

\[ \theta \] : satellite zenith angle
\[ c_1, c_2, c_3, \text{ and } c_4 \] : algorithm coefficients for band 31 and 32, derived using collocated in situ buoy SST and satellite observations

Himawari-8/9 satellite is located at 140.7° E and observes from 80° E to 160° W between 60° N and 60° S. Advance Himawari Imager (AHI) sensor that has 16 spectral bands from visible to infrared wavelengths is attached to the satellite. The infrared bands located at 3.9, 8.8, 10.4, 11.2, and 12.4 μm are used for SST retrieval. Japan Aerospace Exploration Agency (JAXA) produces Himawari-8/9 skin SST from 2 spectral band combinations. The first spectral band combination is 10.4, 11.2, and 8.6 μm and the second spectral band combination is 10.4, 11.2, and 3.9 μm. The result of SST Himawari-8/9 data is obtained from 2 steps. Step one is calculating algorithm SST by using Equation (3) below:

\[ T_{\lambda_{lx}}^s = B_{\lambda_i}^{-1}(\bar{I}_{\lambda_i}^s + \Delta I_{\lambda_i}^s) \]  \hspace{1cm} (3)

where:
\[ T_{\lambda_{lx}}^s \] : SST for the \( \lambda_i \) band
\[ x \] : Vector of orthogonal components
\[ B \] : inverse of the Planck function

Step two is cloud screening by using threshold-based cloud screening with Boolean values and Bayesian method with probabilities. Himawari-8/9 SST has been validated by comparing its data with the nearest drifting and moored buoy data point that was located and observed within 3 km and 3 hours respectively. SST data with more than 0.3 cloud probabilities are rejected, as well as buoy data when the difference exceeded 4 K from Himawari-8/9 SST. The comparison showed that Himawari-8/9 SST data has root mean square difference ~0.59 K against the buoy data [18].

To obtain the environmental data for oceanographic prediction and coastal dynamics monitoring, Institute for Marine Research and Observations have deployed buoys in several marine areas in Indonesia. It also can be used to validate data measured from satellite such as sea surface temperature [25]. SST data in December 2016 from buoys located in Gulf of Tomini and Savu Sea have been extracted as a comparison against SST measured from Aqua/Terra MODIS.

Dipole Mode Index (DMI) is anomalous SST gradient between the western equatorial Indian Ocean and the south eastern equatorial Indian Ocean to represent the intensity of IOD. Positive DMI (positive IOD) results lower temperature in eastern Indian Ocean while negative DMI (negative IOD) results the opposite condition [4]. Comparison between DMI and SST in Indonesia within period 2007 – 2016 is performed to obtain the respond of SST against the IOD phenomenon.

The TAO/TRITON array is developed and supported by National Oceanic and Atmospheric Administration, USA and Japan Agency for Marine-Earth Science and Technology. It was designed as instrument to have better understanding on climate variations prediction related to ENSO. Located in 140° - 180° E and 95° - 180° W, the instrument can provide various information, i.e. wind and SST. Information from TAO buoy is observed and compared to SST in Indonesia to obtain the respond of SST against the ENSO phenomenon.

Aqua/Terra MODIS dataset from 2007 to 2016 are analysed to obtain spatio-temporal distribution and statistical attribute of SST in WWPNRI. Level 3 monthly dataset in 4 km spatial resolution are used to minimize the influence of cloud-cover that often occurred over the Indonesian region. Hourly dataset of Himawari-8/9 close to acquisition hour of Aqua MODIS (1.30 pm) and Terra MODIS (10.30 am) are selected to be composited and compared to monthly dataset of SST Aqua/Terra MODIS to obtain statistical comparison that consists of mean difference test and standard deviation difference test.
3. Result and Discussions

3.1. Spatio-temporal distribution and statistical attributes of SST

The analysis for study area consists of SST monthly average for each WPPNRI and SST monthly average for whole WPPNRI during 2007 - 2016. SST monthly average for each WPPNRI are then classified into three classes of SST: cold (26 – 27 °C), moderate (28 – 29 °C), and warm (30 – 31 °C).

Monthly average SST during 2007 – 2016 in WPPNRI ranging from 26.04 °C (occurs in August in WPPNRI 718) to 30.66 °C (occurs in May in WPPNRI 571 and 711). Figure 2 shows that in January – February all regions in Indonesia are in moderate SST except in Natuna Sea (WPPNRI 711) that has cold SST because of the impact of ocean phenomenon named “cold tongue”. This phenomenon exists because of the influence of winter monsoon that occurred along the Vietnam coast transports through South China Sea [26]. It occurs from November to March and disappears in April [27]. However, previous study showed that the coldest SST of cold tongue phenomenon is around 298 K or 24 °C [28].

![Figure 2. Monthly average of SST data (2007 – 2016). Green for cold SST, yellow for moderate SST, and red for warm SST.](image-url)

In March the warm SST occurs in WPPNRI 571 and 572 from Indian Ocean, then continues in April where the warm SST expands to WPPNRI 711, 712, 713, and 716 while the moderate SST appears in WPNRI 573, 714, 715, 717, and 718. This situation of warm and moderate SST continues in May, but some area become warmer (WPPNRI 715 and 717) and cooler (WPPNRI 713).

The upwelling, indicated by cold SST, occurs in WPPNRI 573 and WPNNRI 718 in June, expands to WPPNRI 714 in July – September, then shrinks to only in WPPNRI 573 in October, then disappears in November. This phenomenon happened during the southeast (SE) monsoon, when southeast wind flows from Australia to generate upwelling along the Java – Sumatera coasts [29],[30]. The warm and
moderate SST occur again in all WPPNRI in November to December with most WPPNRI are in warm SST which indicates rainy season in Indonesia region.

For whole WPPNRI, monthly average of SST ranging from 27.91 °C to 30.46 °C. This range is similar with previous study stated that SST in Indonesia range from 28 – 31 °C [22]. During 2007 – 2016, the coldest SST often occurred in August (2007, 2012, 2015) at around 27.9 °C while the warmest SST occurred in April (2010 and 2016) at 30.46 °C. Figure 3 shows graph of SST monthly average for whole WPPNRI from 2007 to 2016 with blue line symbolized the SST and orange dot symbolized the trendline of SST during 2007 – 2016. In general, there is an average 0.8 °C increase from January 2007 to December 2016.

![SST Monthly Average](image)

**Figure 3.** Graph of SST monthly average from 2007 to 2016.

Four buoys deployed by Institute for Marine Research and Observation located in Savu Sea and Gulf of Tomini that obtain various information such as SST [25] show similar result compared with SST measured from MODIS. Difference between both SST are -0.28 – 0.63 °C with negative sign shows MODIS SST is lower than buoy SST. Figure 4 shows location of buoys and Table 3 shows comparison between SST measured from buoys and MODIS.

![Location of buoys](image)

**Figure 4.** Location of buoys in (a) Gulf of Tomini and (b) Savu Sea.
### Table 3. Comparison of SST measured from buoy and MODIS in December 2016.

| Location            | Unit No. | SST (in °C)   |       |       |
|---------------------|----------|---------------|-------|-------|
| Savu Sea            | 2        | 29.61         | 30.24 | 0.63  |
| (WPPNRI 573)        | 3        | 30.52         | MODIS | -0.28 |
| Gulf of Tomini      | 7        | 30.24         | 30.17 | -0.07 |
| (WPPNRI 716)        | 9        | 29.89         | MODIS | 0.28  |

#### 3.2. SST respond to ENSO and IOD

The geographic location of Indonesian Sea is influenced by two oceans system, IOD for Indian Ocean and ENSO for Pacific Ocean, both of system occur in Indonesia region. IOD impacts western part of Indonesia and ENSO impacts eastern part of Indonesia. The IOD influence in Indonesia sea is clearly shown during upwelling period in WPPNRI 573, when IOD+ occur (June – October) the SST in western part of Sumatera and southern part of Java become colder. The correlation between IOD+ and SST in Indonesia is shown in figure 5.

![Figure 5](image_url)  
**Figure 5.** Correlation between Dipole Mode Index (orange line) and SST (blue bar).

In August 2012, low SST occurred as an impact of IOD+ during that period. This event can be identified by negative (cold) SST anomaly in the tropical eastern Indian Ocean and positive (warm) SST anomaly in the tropical Indian Ocean [4], as shown in figure 6. IOD+ occurrences (Table 4) also impacted SST in September 2007 (SST 28.23 °C) and July 2008 (28.12 °C). The IOD is measured by an index that is the difference between SST anomalies in western part of Indian Ocean and the eastern part called Dipole Mode Index (DMI), the index has two signs of negative and positive [4].
Figure 6. Illustration of IOD+ [31]

Table 4. The peak amplitude of IOD event in 1982 – 2012 [32]

| Year | IOD Index | Peak Month |
|------|-----------|------------|
| 1    | 1997      | 4.71447    | November |
| 2    | 1994      | 4.45823    | October  |
| 3    | 2006      | 2.95482    | October  |
| 4    | 2012      | 2.23291    | August   |
| 5    | 2008      | 1.78743    | July     |
| 6    | 1991      | 1.58422    | May      |
| 7    | 1982      | 1.57511    | June     |
| 8    | 2007      | 1.55126    | September|
| 9    | 2003      | 1.52663    | June     |

The ENSO correlation with Indonesia Sea is shown by Tropical Atmosphere Ocean (TAO) buoy SST image data compare with Himawari-8/9 satellite data. Figure 7 shows that during La Niña in Pacific Ocean, the warm SST from Pacific direction is westward and enter the Indonesia water through WPPNRI 717 with moderate SST, then become warmer in April – December. The warm SST distribution also flows through the southern part of Indonesia via Makassar Strait and Lifamatola, this distribution known as Indonesia Through Flow (ITF).
Figure 7. The correlation between SST from Himawari-8/9 satellite and TAO buoy measurement (a) January – June 2016; and (b) July – December 2016.
3.3. Performance comparison between Aqua/Terra MODIS and Himawari-8/9
Statistical comparisons of monthly SST dataset, mean difference test and standard deviation test, are conducted to compare monthly SST measurement results in 2016 from Aqua/Terra MODIS and Himawari-8/9. Both comparisons show that there is no significant difference of SST measurement results from Aqua/Terra MODIS and Himawari-8/9. Mean difference between both satellites is ranging from -0.19 to 0.19 °C, while standard deviation difference is ranging from 0.01 to 0.27 (see Table 5). Minus sign indicates that Aqua/Terra MODIS has lower SST value than Himawari-8/9. This could be possible because of monthly composite of Himawari-8/9 data is performed to selected data that close to Aqua/Terra MODIS acquisition. However, some conditions have not considered for this comparison. Inclusion of differences in spatial (Aqua/Terra MODIS 4 km – Himawari-8/9 2 km) and temporal (Aqua/Terra MODIS monthly – Himawari-8/9 monthly composite from hourly data) resolution between those data in future research could present different results.

| Month   | MODIS Mean | MODIS Difference | Himawari Mean | Himawari Difference |
|---------|------------|------------------|---------------|---------------------|
| January | 29.85      | -0.04            | 29.89         | 0.01                |
| February| 29.80      | -0.07            | 29.72         | 0.01                |
| March   | 30.23      | 0.08             | 30.15         | 0.01                |
| April   | 30.46      | 0.06             | 30.39         | 0.01                |
| May     | 30.38      | -0.19            | 30.57         | 0.01                |
| June    | 30.20      | 0.18             | 30.02         | 0.01                |
| July    | 29.49      | 0.19             | 29.30         | 0.01                |
| August  | 29.05      | 0.16             | 28.89         | 0.01                |
| September| 29.49     | 0.14             | 29.34         | 0.01                |
| October | 29.87      | 0.12             | 29.75         | 0.01                |
| November| 30.30      | 0.11             | 30.19         | 0.01                |
| December| 29.93      | 0.11             | 29.82         | 0.01                |

| Month   | MODIS Mean | 0.08  | Himawari Mean | 0.18  |
|---------|------------|-------|---------------|-------|

4. Conclusions and Discussions
Cold tongue phenomenon occurred in WPPNRI 711 during January and February when the influence of winter monsoon that flows through South China Sea to this area. Upwelling phenomenon, indicated by cold SST, occurred in WPPNRI 573 and WPNRNI 718 in June, expands to WPPNRI 714 in July – September, then shrinks to only in WPPNRI 573 in October, then disappears in November.

During 2007 – 2016, SST within WPPNRI ranging from 27.91 to 30.46 °C. The coldest SST occurred in August (2007, 2012, 2015) while the warmest SST occurred in April (2010 and 2016). Generally, it is found that SST within WPPNRI has increased 0.8 °C during the last ten years (2007 – 2016).

There is strong influence from IOD to SST in Indonesia, where cold SST will be found on the same period as IOD+. This influence can be found in August 2012 and 2015 where respectively DMI shows 0.948 and 0.863 and SST shows 27.93 and 27.91 °C.

ENSO has influenced SST dynamics on eastern of Indonesia, especially in WPPNRI 717. During La Niña in Pacific Ocean, the warm SST from Pacific flows westward and enter the Indonesia water through WPPNRI 717 to WPPNRI 573 with moderate SST, then become warmer in April – December.

In the future the SST become the important information for indicate the environment change in Indonesia sea, therefore the better spatial resolution and temporal resolution is needed. AHI Himawari-
8/9 that has hourly temporal resolution and 2 km spatial resolution offers similar data as Aqua/Terra MODIS. The mean differences and standard deviation test between Aqua/Terra MODIS and Himawari-8/9 data show no significant difference. SST measurement result from both satellites have mean difference of 0.08 °C and standard deviation difference of 0.18 °C.

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References
[1] Deser Clara, Michael A Alexander, Shang Ping Xie and Adam S Philips 2010 Sea Surface Temperature Variability: Patterns and Mechanisms. 10.1146/annurev-marine-129408-151453.
[2] Qu Tangdong, Yan Du, Jane Strachan, Gary Meyers, and Julia Slingo 2005 Sea Surface Temperature and its Variability in the Indonesian Region Journal of Oceanography Society 18 (4).
[3] Wyrtki 1962 The upwelling in the region between Java and Australia during south-east monsoon Marine and Freshwater Research 13(3) pp 217-225.
[4] Saji N H, B N Goswami, P N Vinayachandran and T Yamagata 1999 A dipole mode in the tropical Indian Ocean Nature 401(6751) pp 360-363.
[5] Susanto R D, A L Gordon and Q Zheng 2001 Upwelling along the coasts of java and Sumatera and its relation to ENSO Geophysical Research Letters 28(5) pp 1599-1602.
[6] Chiang J C H and A H Sobel 2002 Tropical tropospheric temperature variations caused by ENSO and their influence on remote tropical J. Climate 15 pp 2616 – 2631.
[7] Kaplan Alexey, Mark A Cane, Yochanan Kushnir, Amy C Clement, M Benno Blumenthal, and Balaji Rajagopalan 1998 Analyses of global sea surface temperature 1856 – 1991 Journal of Geophysical Research 103 (C9) pp 18567 – 18589.
[8] Banzon Viva, Thomas M. Smith, Toshio Mike Chin, Chunying Liu, and William Hankins 2016 A long-term record of blended satellite and in situ sea-surface temperature for climate monitoring, modelling, and environmental studies Earth Syst. Sci. Data 8 pp 165 – 176.
[9] Schaefer K M 2001 Reproductive biology of yellow fin tunas. In: Block BA, Steven ED (eds) Tuna: Physiology, ecology, and evolution (California: Academic Press) pp 225 – 270.
[10] Laevastu, T and Hayes M L 1981 Fisheries Oceanography and Ecology. 199p., Fishing News (books), Oxford, U.K. ISBN: 9780852381175.
[11] Sund, P N, Balcburn, M and Wiliams, F 1981 Tuna and Their Environment in the Pacific Ocean: A Review. Oceanography, “Oceanography and Marine Biology: An Annual Review 19 pp 443-512.
[12] Gordo A, M Maso and Voges L 2000 Satellites and Fisheries: The Namibian hake, A case study in D. Halpern. Satellite Oceanography and Society, pp. 193 – 205, Elsevier, Amsterdam, The Netherlands. DOI: 10.1016/So422-9894(00)8011-2.
[13] Lu H-J, K-T Lee, H-L Lin and C H Liao 2001 Saptio temporal distribution of yellow fin tuna Thunnus albacares and big eye tuna Thunnus obesus in Tropical Pacific Ocean in relation to large scale temperature fluctuation during ENSO episodes Fish. Sci 67 pp 1046 – 1052.
[14] Rajapaksha J K, Nishida T, and Samarakoon L 2010 Environmental preferences of yellowfin tuna (Thunnus albacores) in the northeast Indian Ocean: an application of remote sensing data to longline catches. IOTC-2010-WPTT-43.
[15] Njoku E G, T P Barnett, R M Laurs and A C Vastano 1985 Advances in Satellite Sea Surface Temperature Measurement and Oceanographic Applications Journal of Geophysical Research 90 (C6) pp 11573-11586.
[16] Robel J and A Graumann 2014 NOAA KLM User’s Guide: with NOAA-N, N Prime, and MetOp Supplements National Oceanic and Atmospheric Administration.
[17] Brown O B and Minnet P J 1999 MODIS Infrared Sea Surface Temperature Algorithm – Algorithm
Theoretical Basis Document Version 2.0 (Miami: University of Miami).

[18] Kurihara Y, H Murakami and M Kachi 2016 Sea surface temperature from the new Japanese geostationary meteorological Himawari-8 satellite Geophys. Res. Lett 43 pp 1234–1240, doi:10.1002/2015GL067159.

[19] Gloersen P and F T Barath 1977 A Scanning Multichannel Microwave Radiometer for Nimbus-G and SeaSat-A IEEE Journal of Oceanic Engineering 2 pp 172-178.

[20] Imaoka K, T Sezai, T Takeshima, T Kawanishi, A Shibata 2002 Instrument characteristics and calibration of AMSR and AMSR-E Proceedings of IGARSS 2002. Toronto. Canada.

[21] Ministry for Marine Affairs and Fisheries (MMAF) 2014 Peraturan Menteri Kelautan dan Perikanan No. 18/PERMEN-KP/2014.

[22] Nontji A 1993 Laut Nusantara (Jakarta: Penerbit Djambatan).

[23] MODIS Specifications. Accessed on September 14, 2017 from https://modis.gsfc.nasa.gov/about/specifications.php

[24] Kilpatrick K A, Podesta G, Walsh S, Williams E, Halliwell V, Szczodrak M, Brown O B, Minnet P J and Evans R 2015 A decade of sea surface temperature from MODIS Remote Sensing of Environment 165 pp 27-41. http://dx.doi.org/10.1016/j.rse.2015.04.023.

[25] Institute for Marine Research and Observation 2016 Final Report of Ocean Observation System Development Project Ministry of Marine Affairs and Fisheries, Indonesia.

[26] Stommel H 1948 The westward intensification of wind-driven ocean currents Trans. Am. Geophys. Union 99 pp 202 – 206.

[27] Chen J M, Chang C-P and Li T 2003 Annual cycle of the South China sea surface temperature using NCEP/NCAR reanalysis Journal of Meteorological Society of Japan 81 pp 879 – 884.

[28] Koseki S, Tieh-Yong Koh, Chee-Kiat Teo 2013 Effects of the cold tongue in the South China Sea on the monsoon, diurnal cycle and rainfall in Maritime Continent Q.J.R. Meteorol.Soc 139 pp 1566 – 1582.

[29] Clarke A J and X Liu 1993 Observations and dynamics of semiannual and annual sea levels near the eastern equatorial Indian Ocean boundary Journal of Oceanography 23 pp 386 – 399.

[30] Sprintall, J, A L Gordon, R Murtugudde and R D Susanto 2000 A semi-annual Indian Ocean forced Kelvin wave observed in the Indonesian Seas J. Geophys. Res 105 pp 17217 – 17230.

[31] Bureau of Meteorology Australian Government. Indian Ocean influences on Australian climate. Accessed on September 14, 2017 from http://www.bom.gov.au/climate/iod/#tabs=Indian-Ocean-climate-drivers

[32] Mo Lan 2013 Analysis of 2012 Indian Ocean Dipole Behavior Accessed on September 14, 2017 from https://www.s.u-tokyo.ac.jp/en/utrip/archive/2013/pdf/05MoLan.pdf