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Seasonal and Interannual Variations of Sea Surface Temperature in the Indonesian Waters

Martono
Centre of Atmospheric Science and Technology (LAPAN)
Jl. Dr. Djundjunan 113 Bandung, West Java
Corresponding author (e-mail: mar_lapan@yahoo.com)

Abstract. *Sea surface temperature plays an important role in air-sea interactions. This research was conducted to understand seasonal and interannual variations of sea surface temperature in the Indonesian waters. The data used in this research was daily sea surface temperature in 1986 to 2015 which was obtained from the Physical Oceanography Distributed Active Archive Center - National Aeronautics and Space Administration. Method used in this study was the anomaly analysis. The result showed that the seasonal and interannual variations of sea surface temperature in the Indonesian waters varied. Seasonal variations of SST in the Makasar Strait, Sulawesi Sea, and Halmahera Sea were low. High seasonal variations of sea surface temperature occurred in the southern waters of Java, Timor Sea, Arafura Sea, and Banda Sea, which were allegedly due to the upwelling process. In addition, interannual variation of sea surface temperature in the Indonesian waters fluctuated. From 1986 to 2000, it showed a negative anomaly dominant. Meanwhile, from 2001 to 2015, it showed a positive anomaly dominant. The effect of Indian Ocean Dipole on the fluctuation of sea surface temperature in the Indonesian waters was stronger than ENSO. Within the last 30 years, the sea surface temperature in the Indonesian water indicated a rising trend. The highest sea surface temperature rise occurred in the Halmahera Sea that reached 0.66 OC/30 years and the lowest was in the Timor Sea of 0.36 OC/30 years.*

Keywords: *Sea surface temperature, Seasonal, Interannual, Indian Ocean Dipole.*

Abstrak. *Suhu permukaan laut mempunyai peranan penting dalam interaksi laut-atmosfer. Penelitian ini dilakukan untuk mengetahui variasi musiman dan antar tahunan suhu permukaan laut di perairan Indonesia. Data yang digunakan dalam penelitian ini adalah suhu permukaan laut harian dari 1986-2015 yang diperoleh dari Physical Oceanography Distributed Active Archive Center - National Aeronautics and Space Administration. Metode yang digunakan adalah analisis anomali. Hasil penelitian menunjukkan bahwa variasi musiman dan tahunan suhu permukaan laut di perairan Indonesia bervariasi. Variasi musiman suhu permukaan laut di selat Makasar, laut Sulawesi dan laut Halmahera kecil. Sementara itu, variasi musiman suhu permukaan laut paling besar terjadi di perairan selatan Jawa, laut Timor, laut Arafura dan laut Banda. Tingginya variasi musiman suhu permukaan laut di perairan selatan Jawa, laut Timor, laut Arafura dan laut Banda disebabkan oleh proses upwelling. Variasi antar tahunan suhu permukaan laut di Indonesia berfluktuasi. Secara umum, dari tahun 1986-2000 menunjukkan dominan anomali negatif dan dari tahun 2001-2015 dominan anomali positif. Pengaruh Indian Ocean Dipole terhadap fluktuasi suhu permukaan laut di perairan Indonesia lebih kuat daripada ENSO. Dalam waktu 30 tahun terakhir, suhu permukaan laut di perairan Indonesia menunjukkan tren kenaikan. Kenaikan tertinggi terjadi di laut Halmahera yang mencapai 0.66 ^{O}C/30 tahun dan terendah di laut Timor yang mencapai 0.36 ^{O}C/30 tahun.*

Kata kunci: *suhu permukaan laut, musiman, antar tahunan, Indian Ocean Dipole.*

1. Introduction

Sea Surface Temperature (SST) plays an important role in the aspects of the ocean and atmosphere. In the ocean aspect, SST affects the metabolism and breeding of marine organism (Emiyati, *et al*., 2014). The rise of SST has caused severe damage to coral reefs that leads to biodiversity loss (Measey, 2010). In the atmosphere aspect, SST affects the exchange of heat flux in air-sea interactions (Reynolds, *et al*., 2007; Shenoi, *et al*., 2009; Anding and Kauth, 1970), global climate and its effects (Desser, *et al*., 2010). Some researchers predicted the rise of SST in the tropical waters would increase the frequency of extreme weather (ICCSR, 2010).

SST in the Indonesian waters is a main trigger of the deep convection which affects global atmospheric dynamics (Qu, *et al*., 2005; Sprintall, *et al*., 2014). Knowledge about seasonal variability of SST in the Indonesian waters is crucial to understand the tropical climate variability (Kida and Richards, 2009). Previous researches related to SST variability have been conducted including SST variability in the southern waters of Java (Syaifullah, 2010) and in the Natuna sea (Nababan and Simamora, 2012); SST mapping in the western waters of Madura (Rini *et al*. 2010); SST variability during ENSO and IOD in the southern waters of Java to Timor (Kunarso *et al*. 2011); SST distributions in the Tomini Bay (Kasim, 2010); the rise of SST in the southern waters of Java, the western waters of Sumatera, the South China Sea, and the northern waters of Papua (Syaifullah, 2015). However, comprehensive research about SST variability in the Indonesian waters was limited.

This activity was an early stage to conduct a comprehensive research of air-sea interaction. Therefore, we believe that a comprehensive understanding about regional SST variability in the Indonesian waters will provide information regarding with the tropical climate variability and can increase the accuracy of regional and global climate prediction. The objective of this research was to understand seasonal and interannual variations of SST in the Indonesian waters.

2. Research Method

The research area was the Indonesian waters, which consisted of the southern waters of Java, Timor Sea, Arafura Sea, Java Sea, Flores Sea, Banda Sea, Karimata Strait, Makassar Strait, Maluku Sea, Natuna Sea, Sulawesi Sea, and Halmahera Sea as illustrated in Figure 1.

In this research, we used the daily SST data in the period 1986-2015 that was obtained from Physical Oceanography Distributed Active Archive Center National Aeronautics and Space Administration (PODAAC NASA) (online service :http://podaac.jpl.nasa.gov/). The horizontal grid resolution, both of longitude and latitude, was 0.25O. Method used in this research was anomaly analysis. Value of SST anomaly was calculated by following equation:

$$SSTA = SST_i - \overline{SST} \quad (1)$$

Where *SSTA* is the value of SST anomaly and is the value of SST climatology.

$$\overline{SST} = \frac{\sum_{i=1}^{n} SST_i}{n} \quad (2)$$

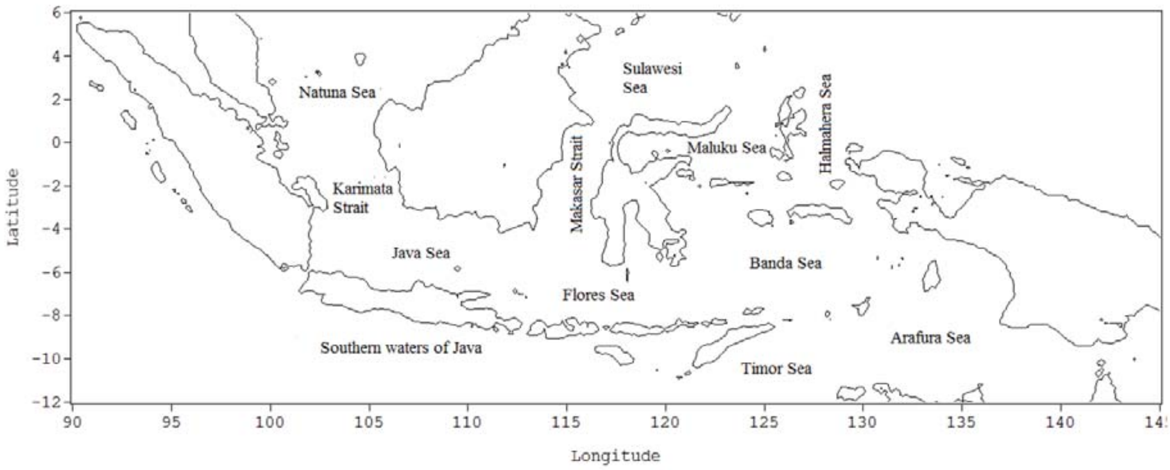

Figure 1. *Research site of the Indonesian Waters.*

2. Results and Discussions

Seasonal pattern of SST in the Indonesian waters varied as shown in Figure 2. In the west season (December-February), SST in the Timor Sea, Arafura Sea, Banda Sea, and Maluku Sea was very warm, which reached <29.8 ^{O}C, while the lowest SST occurred in the Natuna Sea of 27.3 ^{O}C. SST pattern in the first transitional season (March-May) began to change, where higher SST shifted to the north, especially in the central part of the Indonesian waters.

SST in the Timor Sea, Arafura Sea, Maluku Sea, and Banda Sea was colder than the west season. In the period of the east season, higher SST was inclined to move to the north part of the Indonesian waters. SST in the Natuna Sea, Karimata Strait, Sulawesi Sea, and Halmahera Sea are warmer. On the contrary, SST in the southern waters of Java-Sumbawa, Timor Sea, Arafura Sea, and Banda Sea was colder which reached 26 ^{O}C. Generally, SST in the period of the second transitional season showed similar pattern to the east season, but lower SST occurred in the Natuna Sea, Karimata Strait, Sulawesi Sea, and Halmahera Sea while higher SST occurred in the southern waters of Java-Sumbawa, Timor Sea, Arafura Sea, and Banda Sea.

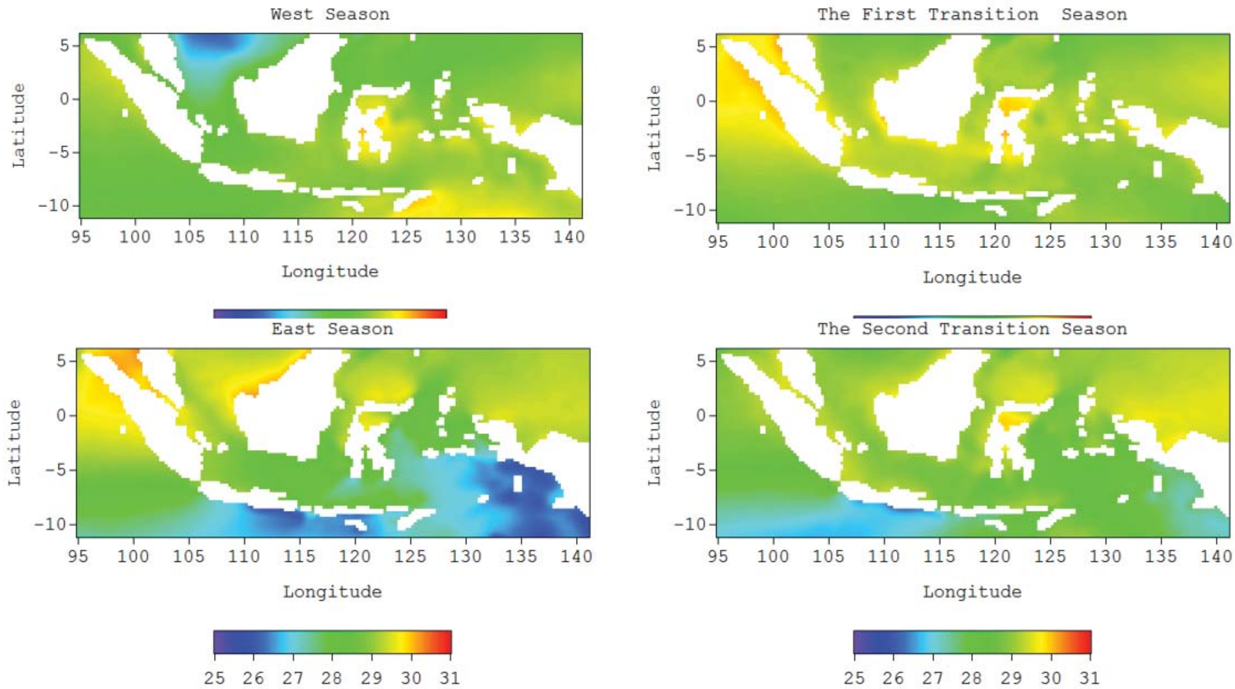

Figure 2. *Seasonal pattern of SST in the Indonesian waters.*

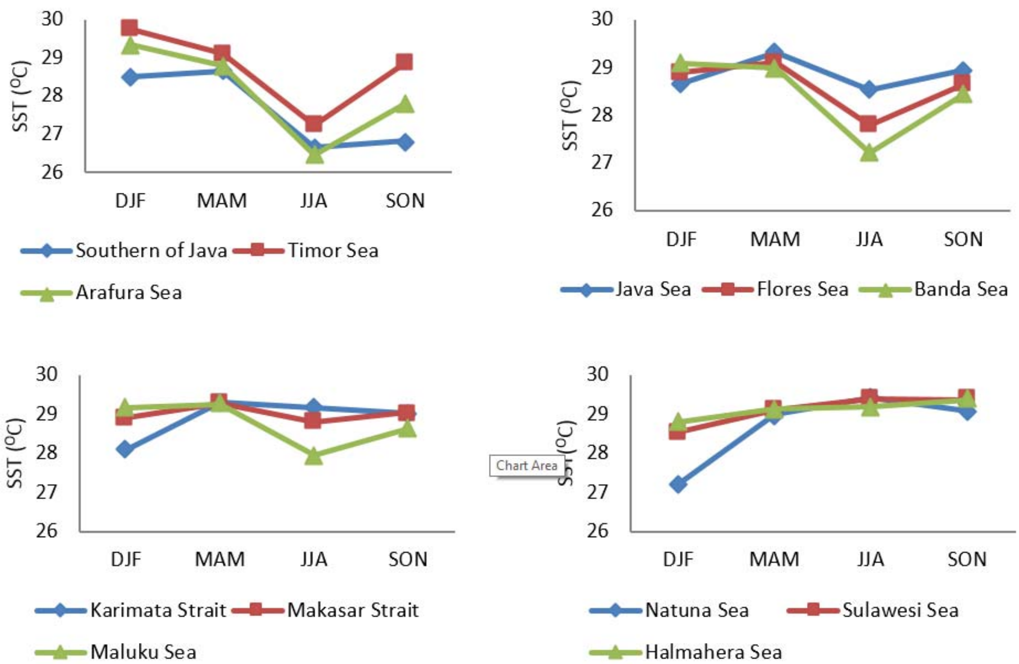

Figure 3. *Seasonal variation of SST in the Indonesian waters.*

Figure 3 showed the seasonal variation of SST in the Makasar Strait, Sulawesi Sea, and Halmahera Sea was low and the temperature was relatively warm throughout the year with an average temperature of 29.1 ^{O}C. Seasonal variation of SST in the Natuna Sea and Karimata Strait showed different pattern. In the period of the west season, SST in the Natuna Sea and Karimata Strait was low which reached 27.2 ^{O}C and 28.1 ^{O}C, respectively. However, in the period of the first transition season to the second transition season, their SST was higher which reached 29.1 ^{O}C. Seasonal variation of SST in the southern waters of Java, Java Sea, and Flores Sea showed similar pattern. Maximum SST occurred in the first transition season and minimum SST occurred in the east season. Meanwhile, SST in the Timor Sea, Arafura Sea, and Banda Sea had the same pattern, with maximum SST took place in the west season and minimum SST was in the east season.

Interannual variation of SST in the Indonesian waters very fluctuated as shown in Figure 4. The lowest fluctuation of SST was obtained by the Sulawesi Sea, Halmahera Sea, and Makasar Strait which reached 0.8 ^{O}C, meanwhile the highest fluctuation was in the southern waters of Java which reached 1.8 ^{O}C. Within the last thirty years, interannual variation of SST in the Indonesian waters indicated a rising trend. However, it varied as shown in Table 1. The highest rise of SST occurred in the Halmahera Sea of 0.66 ^{O}C and the lowest occurred in the Timor Sea of 0.36 ^{O}C.

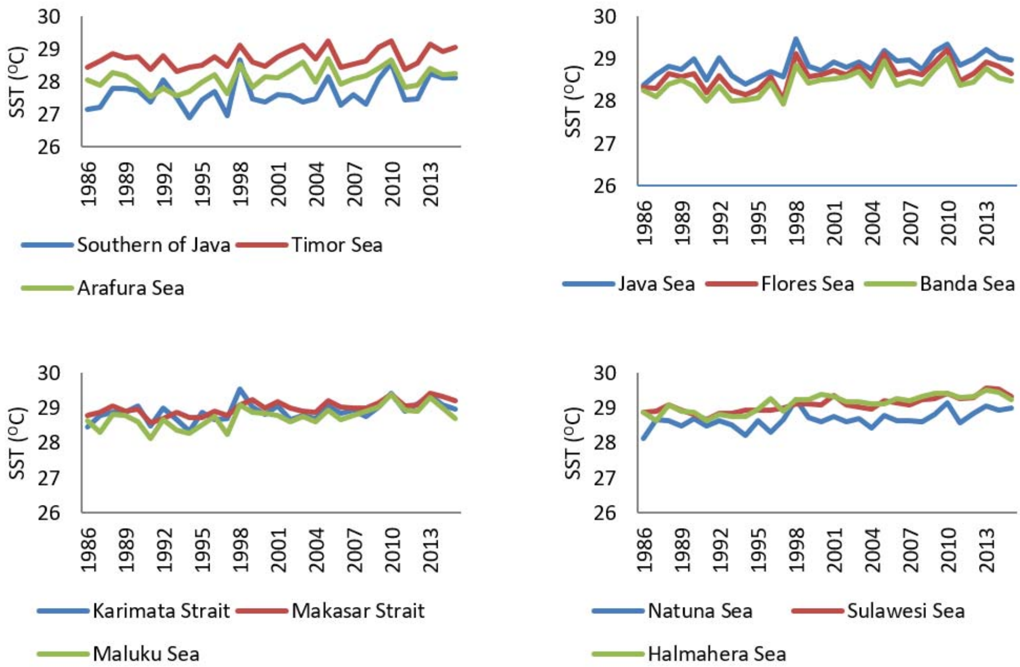

Figure 4. *Interannual variation of SST in the Indonesian waters.*

Table 1. Rising trend of SST from 1986-2015

No	Area	The increase (^{O}C)/ 30 years
1	Southern of Java	0.51
2	Timor Sea	0.36
3	Arafura Sea	0.39
4	Java Sea	0.48
5	Flores Sea	0.51
6	Banda Sea	0.48
7	Karimata Strait	0.42
8	Makasar Starit	0.48
9	Maluku Sea	0.60

No.	Area	The increase (°C)/ 30 years
10	Natuna Sea	0.45
11	Sulawesi Sea	0.60
12	Halmahera Sea	0.66

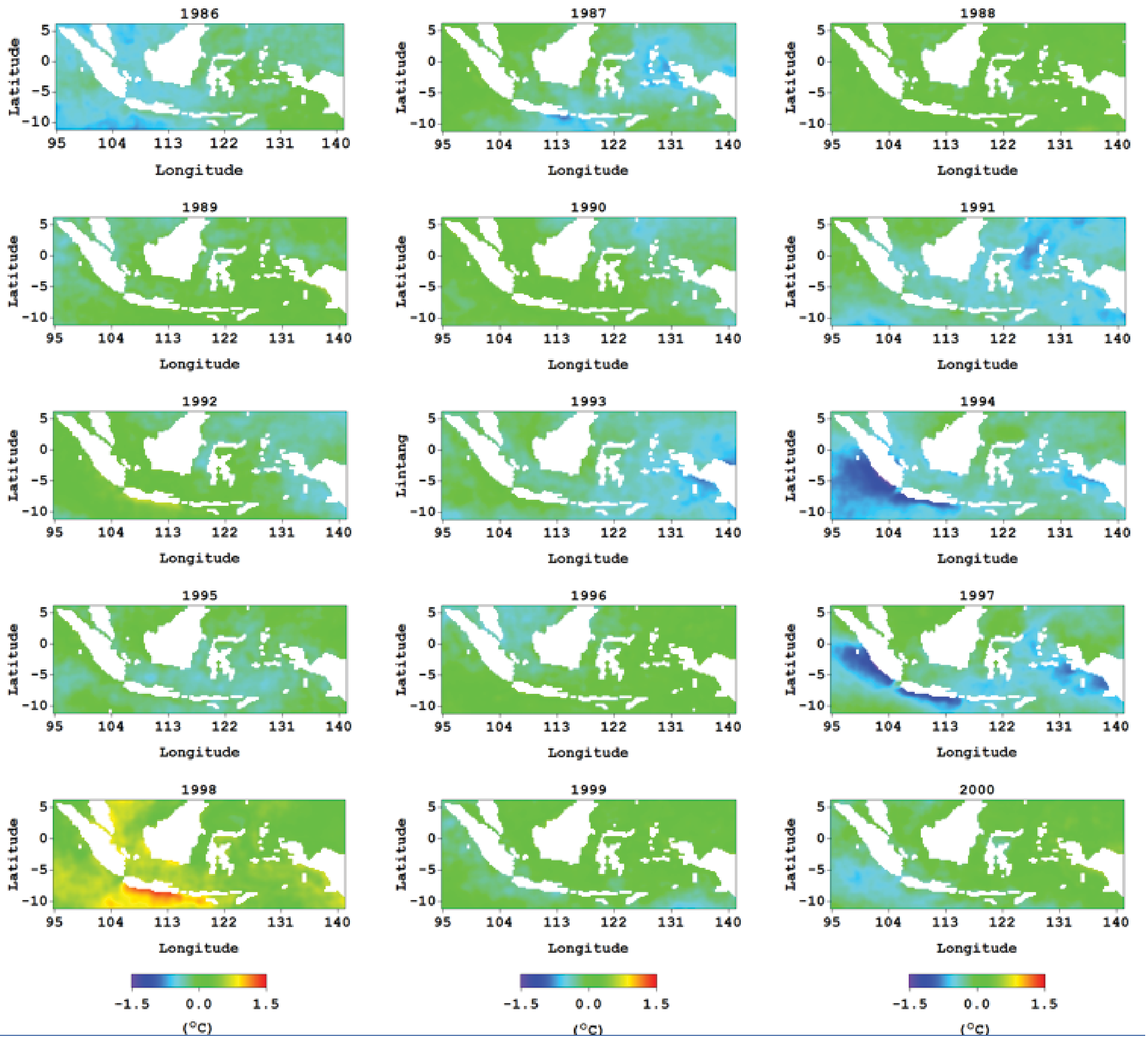

Figure 5. Annual Anomaly of SST in the Indonesian waters in the 1986-2000.

Interannual anomaly distribution of SST in the Indonesian waters in 1986-2000 is demonstrated in Figure 5 and in 2001-2015 is illustrated in Figure 6. Figure 5 and Figure 6 showed that the annual anomaly of SST in the Indonesian waters fluctuated with different intensity. Generally, the anomaly of SST in 1986-2000 had a propensity to show a negative dominant, vice versa, in 2001-2015 it tended to show a positive dominant. High negative anomaly of SST particularly occurred in 1994 and 1997, meanwhile, high positive anomaly of SST occurred in 1998 and 2008. High negative anomaly of SST occurred in the southern waters of Java which reached -0.76 °C in 1994 and -0.69 °C in 1997. Furthermore, high positive anomaly of SST occurred in the southern waters of Java which reached 1 °C in 1998 and 0.9 °C in 2010.

The results showed that seasonal and interannual variations of SST in the Indonesian waters varied. The difference was affected by several factors of both regional and global aspects. The spatial and temporal variations of SST in the Indonesian waters were affected by monsoon and climate change such as Indian Ocean Dipole and El Niño (Gaol, *et* *al*., 2014). The combination of El Niño's effect, Indonesian throughflow, global warming, and environmental change in local, regional, and global in conjunction with monsoon had led to the SST variability in the Indonesian waters (Sachoemar and Yanagi, 2013).

Seasonal variation of SST in the Makassar Strait, Sulawesi Sea, and Halmahera Sea was low and the temperature was relatively warm throughout the year. On the contrary, seasonal variation of SST in the southern waters of Java, Timor Sea, Arafura Sea, and Banda Sea was relatively high. Generally, SST in the most of Indonesian waters in the period of the east season to the second transition season was colder than another season. The same results were yielded by the other studies. The coldest SST in the Banda Sea and Arafura Sea occurred in June to September and the warmest occurs in November to April (Boerly *et al*., 1990). Warm SST in the Banda Sea and Arafura Sea occurred during the period of northwest wind and cold SST occurred in the period of southeast wind (Kida and Richards, 2009), temperature in the mixed layer in the Banda Sea and Arafura Sea was relatively warm in November–May and relatively cold in June–September (Halkides *et al*., 2011). In May to August, the lowest SST took place in the eastern Indonesia and the highest SST too place in the western Indonesia (Setiawan and Habibi, 2010).

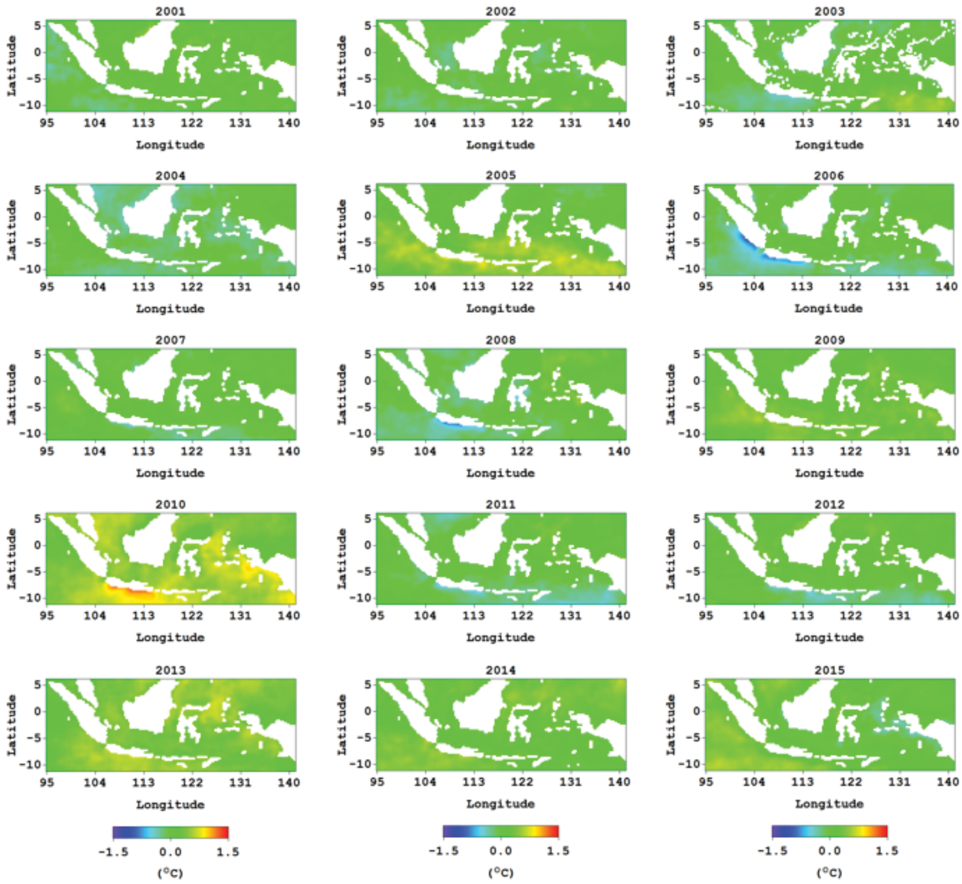

Figure 6. *Annual Anomaly of SST in the Indonesian waters in 2001-2015.*

Upwelling process in the southern waters of Java was caused by a stress of the surface wind over in the southern waters of Java which moved to the west and parallel to the coast as shown in Figure 8. Friction of surface wind will push surface water mass toward the west. Movement of the water mass beneath surface layer is affected by friction and Coriolis forces that form the Ekman Spiral. Because it took place in the southern hemisphere, Ekman Spiral would deflect 45^{O} to the left of the wind direction. The average of transport volume in the Ekman Spiral which is known as Ekman Transport would deflect 90^{O} to the left of the direction of the wind. The Ekman Transport will cause surface water mass in the coast moves toward the off-shore, thus it will form a slope between the off-shore and the coast. In order to restore equilibrium of the water mass, the water mass from the bottom layer of the coast will rise to the surface. The mechanism causes the upwelling process in the southern waters of Java.

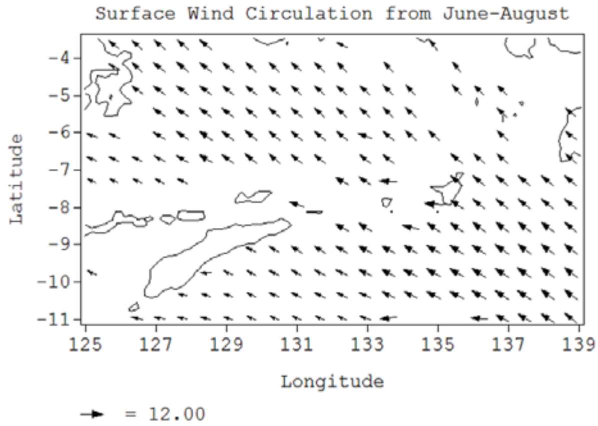

Figure 7. *Wind circulation over the Banda Sea and Arafura Sea.*

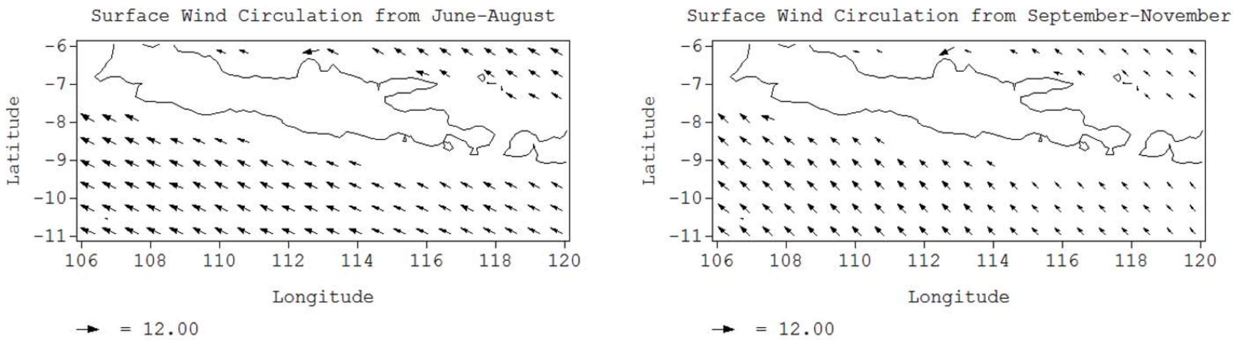

Figure 8. *Wind circulation in the southern waters of Java.*

Interannual variation of SST in the Indonesian waters showed a fluctuate pattern which was affected by the phenomenon of Indian Ocean Dipole (IOD) in the Indian Ocean and ENSO in the Pacific Ocean. Generally, the fluctuation of SST in 1986-2000 tended to show dominant negative anomaly. Meanwhile, in 2001-2015, it tended to show dominant positive anomaly. The maximum and minimum anomaly of SST occurred in the southern waters of Java. The maximum anomaly of SST in 1994 and 1997 was related to high positive phase of IOD and El Niño. Meanwhile, the minimum anomaly of SST occurred in 1998 and 2010 was related to the high negative phase of IOD and La Niña. In 1994 and 2010, El Niño and La Niña did not occur, but SST in the southern waters of Java showed both maximum and minimum anomaly. It explains that the effect of IOD on the SST variability in the southern waters of Java is stronger than the effect of ENSO.

This condition was caused partly due to the location of the southern waters of Java, which is part of the Indian Ocean. IOD was represented by anomaly gradient of SST between 50^{O} E – 70^{O} E and 10^{O} S – 10^{O} N in the western Indian Ocean and between 90^{O} E – 110^{O} E and 10^{O} S – 0^{O} in the eastern Indian Ocean (Saji *et al*, 1999). Therefore, the southern waters of Java are part of the Southern Tropical Indian Ocean SST index. The Southern Tropical Indian Ocean SST index is a part of the Dipole Mode Index. During the period of IOD, pattern change of the South Equatorial Current and the Equatorial Counter Current in the Indian Ocean took place.

Pattern of the South Equatorial Current and the Equatorial Counter Current in the Indian Ocean during positive phase of the IOD is shown in Figure 9. In this period, the intensity and area coverage of the South Equatorial Current is higher and wider, on the contrary, the Equatorial Counter Current was lower and narrower than the normal condition. This process caused the surface water mass in the southern waters of Java that moved westward was greater and as the consequence, it caused the thermocline layer of the waters was shallower. This mechanism caused the upwelling intensity in this waters was higher, hence, the water mass that rises to the surface was colder than the normal condition. Subsequently, pattern of the South Equatorial Current and the Equatorial Counter Current during negative phase of IOD is shown in Figure 10. The intensity and area coverage of the South Equatorial Current was lower and narrower, on the contrary, the Equatorial Counter Current was higher and wider than the normal condition. The surface water mass in the southern waters of Java obtained high supply of water mass from the Equatorial Counter Current that led to the occurrence of downwelling. Downwelling process will cause the thermocline layer in the waters is deeper than the normal condition. In contrast with the upwelling process, the downwelling process will cause SST in waters is warmer than the normal conditions. This mechanism caused the effect of IOD on the SST variability in the southern waters of Java was stronger than the effect of ENSO.

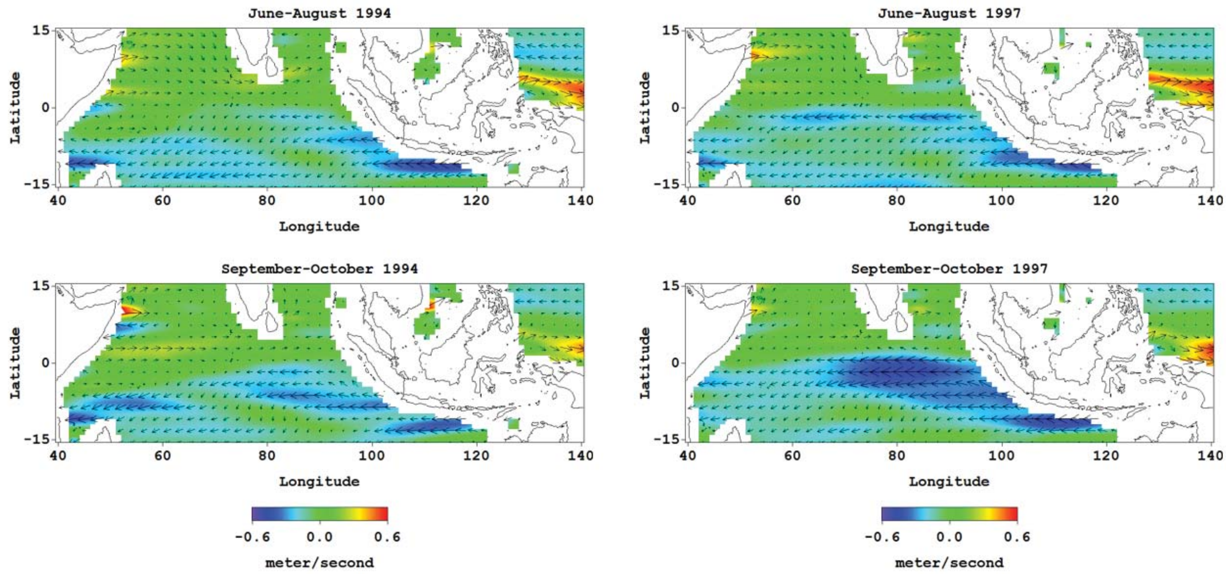

Figure 9. *Pattern of sea surface circulation in June-October, 1994 (left) and 1997 (right)*

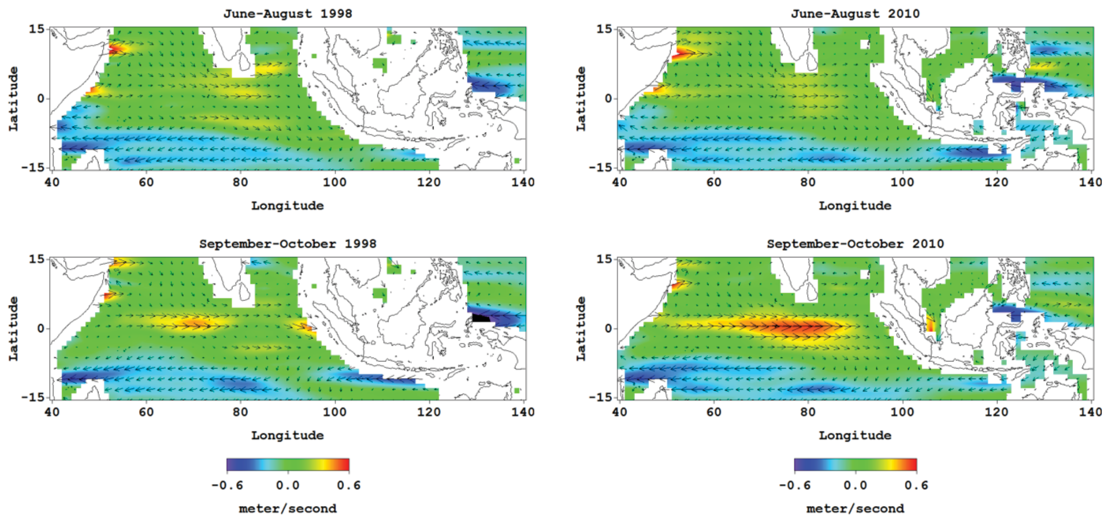

Figure 10. *Pattern of sea surface circulation in June-October, 1998 (left) and 2010 (right).*

Interannual variability of SST in the Indonesian waters in 1986-2015 was inclined to show a rising trend. The rise of SST in the

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Indonesian waters varied and was closely related to global warming. This result confirmed other studies such as the result of SST in the Makassar Strait, Ombai Strait, Lombok Strait, and Timor Sea that increased during 1970-2013 (Manjunatha, *et al.*, 2015), the rise of SST in the Indonesian seas of 0.2-2.5 ^{o}C (DFID, 2007), and the average of SST in the tropics waters increased 0.1 ^{o}C/decade in the last 30 years (Johnson and Xie, 2010). Generally, the lowest rise of SST occurred in the Timor Sea that reached 0.36 ^{o}C/30 years while the highest rise of SST occurred in the Halmahera Sea that reached 0.66 ^{o}C/30 years.

3. Conclusion and Recommendation

Based on the results, it can be concluded that seasonal and interannual variations of SST in the Indonesian waters varies. Seasonal variation of SST in the Indonesian waters was affected by monsoon system. Seasonal variation of SST in the Makasar Strait, Sulawesi Sea, and Halmahera Sea was low and the temperature was almost warm throughout the year. The highest seasonal variation of SST occurred in the southern waters of Java, Timor Sea, Arafura Sea, and Banda Sea. Seasonal variation of SST in the southern waters of Java, Timor Sea, Arafura Sea, and Banda Sea was caused by the upwelling process. Meanwhile, interannual variation of SST in the Indonesian waters showed fluctuate pattern with various values. Generally, interannual variation of SST in 1986-2000 tended to show dominant negative anomaly while in 2001-2015 tended to show dominant positive anomaly. Maximum anomaly of SST occurred in 1994 and 1997 while minimum anomaly of SST occurred in 1998 and 2010. The effect of IOD on the annual variation of SST in the Indonesian seas was higher than those of ENSO. Within the last 30 years, SST in the Indonesian waters tended to show a rising trend. The highest rise of SST occurred in the Halmahera Sea which reached 0.66 ^{o}C/30 years and the lowest occurred in the Timor Sea which reached 0.36 ^{o}C/30 years.

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