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Effect of ENSO on the variability of SST and Chlorophyll-a in Java Sea

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Abstract. Sea surface temperature (SST) and chlorophyll-a (Chl-a) are two parameters often used for identifying the marine productivity. Located at the maritime continent, the variability of SST and Chl-a in the Indonesian seas is influenced by El Niño Southern Oscillation (ENSO). The previous studies showed that the effect of El Niño tend to decrease SST and increase Chl-a in the areas within the Indonesian seas. Using long time observation of satellite data (2003-2016), it was found different result in Java Sea. Since Java Sea has strong seasonal variability influenced by monsoon wind, the effect of ENSO depend on the season. During southeast monsoon season, El Niño (La Niña) tend to increase (decrease) the speed of southeasterly wind cause the decrease or increase of SST. On the contrary, during northwest monsoon season, El Niño (La Niña) tend to decrease (increase) the speed of northwesterly wind cause the increase (decrease) of SST. The dependence of Chl-a on wind speed is only observed in the off shore which exhibit the strong seasonal variation. However, the effect of ENSO on the variability of Chl-a is not robust since the effected amplitude is less than the RMSE of Chl-a data.

Keyword: SST, Chlorophyll-a, Java Sea, ENSO, Monsoon

1. Introduction

Sea surface temperature (SST) and chlorophyll-a (Chl-a) are parameters often used for indicating marine productivity which lead to fisheries productivity. Many studies found that high Chl-a concentration and low SST are correlated with high fish catch [1-3]. The increase of Chl-a concentration will increase the population of zooplankton which attract fish schooling. Thus, SST and Chl-a parameters can be good predictors for determining fishing ground and fishing season [4,5].

Lying on the confluence of the Eurasian Plate, the Indo-Australian Plate, and the Pacific Plate Indonesian Archipelago which is also known as the “Maritime Continent” experience strong seasonal variation caused by monsoon wind [6]. Two monsoon seasons alternates every year, i.e. southeast (SE) monsoon which is associated with easterlies from Australia that carry warm and dry air over the region and northwest (NW) monsoon which is associated with westerlies from the Eurasian continent that carry warm and moist air to the Indonesian region. Thus SE (NW) monsoon bring dry (rainy) season in Indonesia [7]. This monsoon wind then forms the seasonal patterns of SST and Chl-a in Indonesian Seas in general.

The mechanisms on how the monsoon wind influences SST and Chl-a is related to mixing process which determined by the speed of monsoon wind. The faster wind speed, the stronger mixing process occurs. Stronger mixing process can carry colder water (more nutrients) from the deeper water which make the SST (Chl-a) decrease (increase) [8]. Moreover, faster wind speed also cause more heat release from ocean to the atmosphere which cooling SSTs. Thus, the peaks of SST cooling and Chl-a blooming within Indonesian Seas occur during NW monsoon i.e., December, January and February and SE monsoon i.e, Jun, July and August. Besides mixing, surface wind also can generate coastal upwelling which can bring deeper, cooler and richer nutrients water to the surface [9-12].



El Niño Southern Oscillation (ENSO) is one of interannual climate variability which indicated by the anomaly of SST in the central equatorial Pacific. Positive (negative) anomaly indicates the El Niño (La Niña) event. This variability has cycle of about 2-7 years. Synoptic scale interaction between ocean and atmosphere associated with this event determines the ENSO effect on the global climate including Indonesia [13-15].

The impact of ENSO on marine and fisheries productivity within Indonesian Seas has been discussed in many studies. Their analysis showed that the effect of El Niño tend to increase (decrease) Chl-a concentration (SST) in the areas within the Indonesian Seas [10,11,12,16]. Conversely, La Niña tend to decrease (increase) Chl-a (SST). The most prominent impact of ENSO on the variability of Chl-a concentration and SST was found along the southern coast of Java and Sumatra Island. In a normal year, higher Chl-a concentration which is associated with monsoon-generated upwelling during the southeast monsoon cycle spread along the southern coast of Java Island and extend only to the southern tip of Sumatra Island. Anomalous easterly winds during the peak of the 1997/1998 El Niño induced strong upwelling which brought cooler water, and lifted the thermocline much shallower than the climatological mean along the coasts of Java and Sumatra [11]. As a result, higher Chl-a concentrations were observed further northwestward along the Sumatra coast. Moreover, the positive anomaly of Chl-a concentration from its climatological mean during this event reached more than 5 mg/m³ along southern coast of Java and Sumatra Island.

Located at the center of Maritime Continent, Java Sea has different characteristics with the seas of the southern coast of Java Island. With relatively shallow bathymetry i.e., maximum about 130 m, Java Sea is surrounded by 3 big Islands i.e., Java, Sumatra and Kalimantan in the southern, western and northern part, respectively. In the eastern part, Java Sea is bordered by the deep Banda Sea. Moreover, Java Sea is known as one of the path of monsoon wind blowing from Southern Asia to Australia and vice versa [7]. This condition causes the variabilities of SST and Chl-a in Java Sea are strongly influenced by monsoon [3]. Although many previous studies pointed out the increasing (reducing) Chl-a concentration (SST) occurred during El Niño in many Indonesian Seas, the present study demonstrates the different result. The effect of ENSO on the variabilities of SST and Chl-a in Java Sea is depended on the season.

2. Materials and Method

For Chl-a and SST data, we used MODIS Aqua Lv3 with spatial resolution of 0.04°×0.04° and observation period from 2003 to 2016 [17]. Specifically, MODIS SST 11μm which cover the observation both for day and night were used instead of MODIS SST 4μm which only covers night time SSTs. Both MODIS SST and Chl-a are developed and distributed by the Ocean Biology Processing Group. The algorithm for generating MODIS SST (Chl-a) is described in [18-20]. The quality of these dataset has been examined against in-situ measurements to ensure the best accuracy [21-25].

To investigate the formation mechanism of Chl-a and SST pattern in Java Sea, we used surface wind data obtained from 6 hourly ERA interim data with grid interval of 0.125° [26]. We composed SST, Chl-a and surface wind parameters into monthly and monthly climatology following [16]. The monthly El Niño and La Niña data were also composited, determined by using Oceanic Niño Index (ONI) provided by <http://www.cpc.ncep.noaa.gov/>. ONI index is the anomalies of SST in the Niño 3.4 region (5°N-5°S, 120°-170°W), based on the basis period of 1971-2000. The threshold for determining El Niño and La Niña period is ±0.5°C.

3. Results and Discussion

3.1. Seasonal variations of SST and Chl-a in Java Sea

The monthly climatology of SST in Java Sea is presented in Figure 1. We show the period of January, April, August and November to represent the season of NW monsoon, transition I, SE monsoon and transition II respectively. In January and August, SST tend to be low ranges about 28°C to 29°C. Lower SST is detected in the north-western and eastern part of Java Island in January and August, respectively. In April and November SST increase for more than 29°C. The peak of SST cooling (warming) occurs in NW and SE monsoon (Transition I and II) season. Thus, semi-annual variation characterize the SST variation in Java Sea. This result is consistent with the SST distribution in Java Sea observed by the previous studies [3,6].

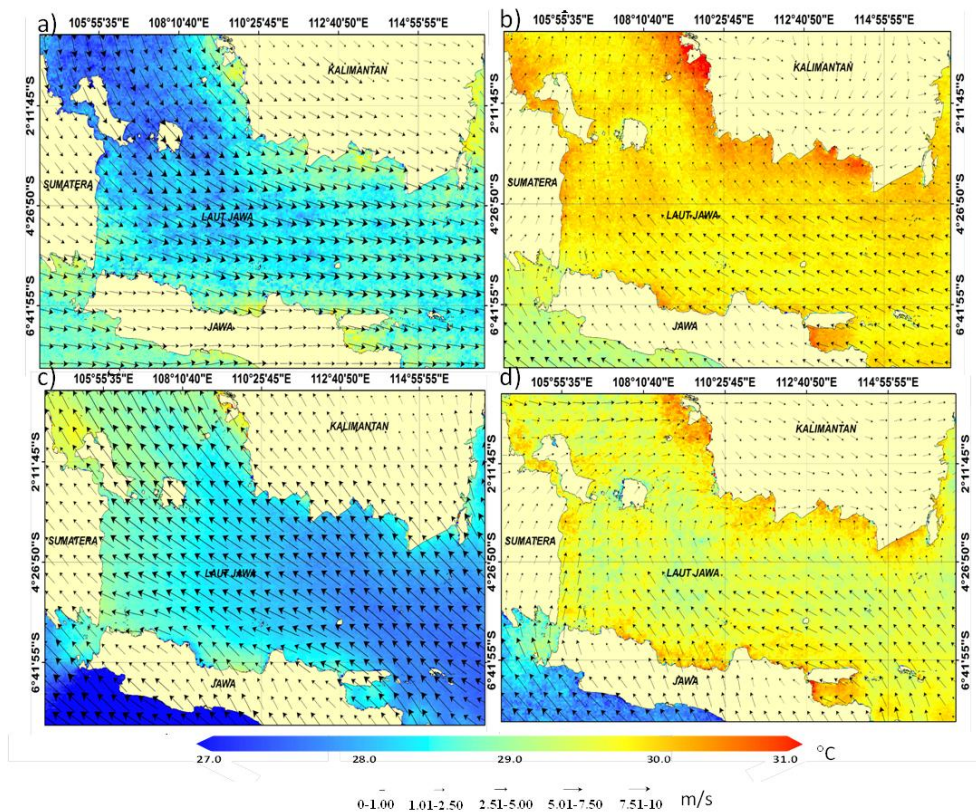


Fig.1. Climatology of SST in Java Sea in (a) January, (b) April, (c) August, and (d) November overlaid with surface wind vector

The mechanisms of the seasonal variation of SST in Java Sea is related to the variation of wind speed. The cooler (warmer) SST in January and August (April and November) correspond to the stronger (weaker) wind speed occurs during those period. In January (August) wind blows north-westerly (south-easterly) cause the lower SST in the north-western (east) part of Java Sea. Thus, the peaks of SST cooling and warming in Java Sea are related to the variation of surface wind.

The spatial distribution of Chl-a in Java Sea shows the different result (Figure 2). Although the peaks of high (low) Chl-a concentration also occur in NW and SE monsoon (Transition I and II) season, the distribution is obviously different between the coastal areas and open seas. Very high Chl-a concentration i.e., more than 1 mg/m² is observed only in the coastal areas. Because of this distribution, we sampled 3 areas in Java Sea which represent the coastal area of Java Sumatra and Kalimantan Island and 1 area in open seas for further analysis. Since maximum Chl-a concentration was found in January, Chl-a distribution in January was chosen as a basis for area selection. The edge of area sample in the coastal areas were determined by the Chl-a concentration of 0.6 mg/m³ and the coastal lines (Figure 3).

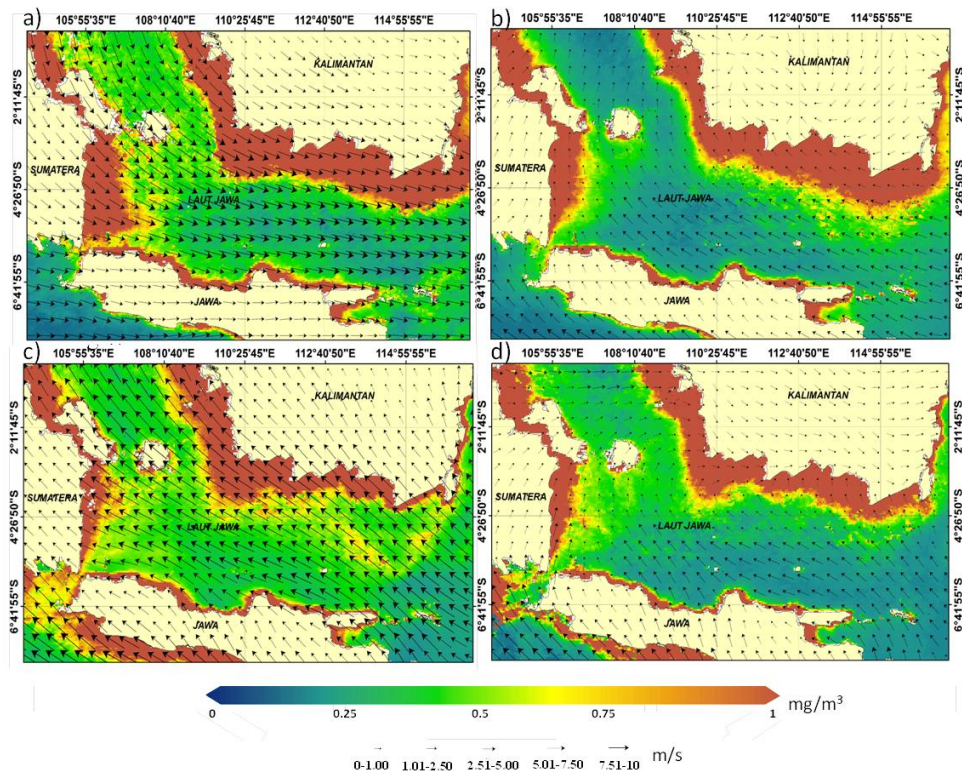


Figure 2. Climatology of Chl-a in Java Sea in (a) January, (b) April, (c) August, and (d) November overlaid with surface wind vector

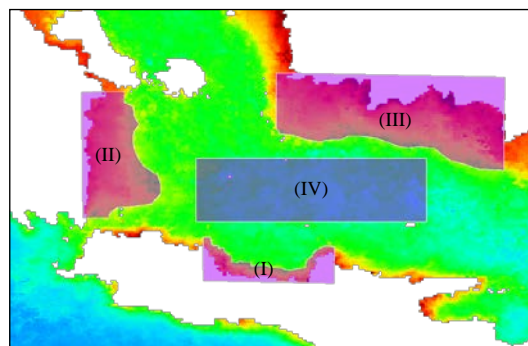


Figure 3. Area selection for time series analysis shown in Figure 4 and 6. See the basis for area selection in text.

The time series analysis of SST and wind speed for all areas is presented in Figure 4a. Semi annual variation is robustly observed for both parameters and all areas. The peak of strong (weak) wind occurred in January and August (April and November) which represent NW and SE (Transition I and II) season, respectively. The strongest wind speed was found in open seas area (area 4) due to the absence of land obstacle which may reduce the wind speed. Conversely, the lowest amplitude of wind speed variation was found in the coastal seas of northern Java (area 1). This may be caused by the position of area 1 which a little covered by the land. Moreover, the peak of strong (weak) wind is negatively correlated with SST variation. The correlations between wind speed and SST for area 1, 2, 3 and 4 are -0.82, -0.72, -0.75, and -0.88, respectively. Stronger wind speed induced stronger mechanical mixing and heat release which reduced SST. However, it is also found the time lag about 1 month between the strongest (weakest) wind speed and lowest (highest) SST in the coastal seas i.e., area 1, 2, and 3. This indicates that other factors may also influence the variability of SST in coastal seas.

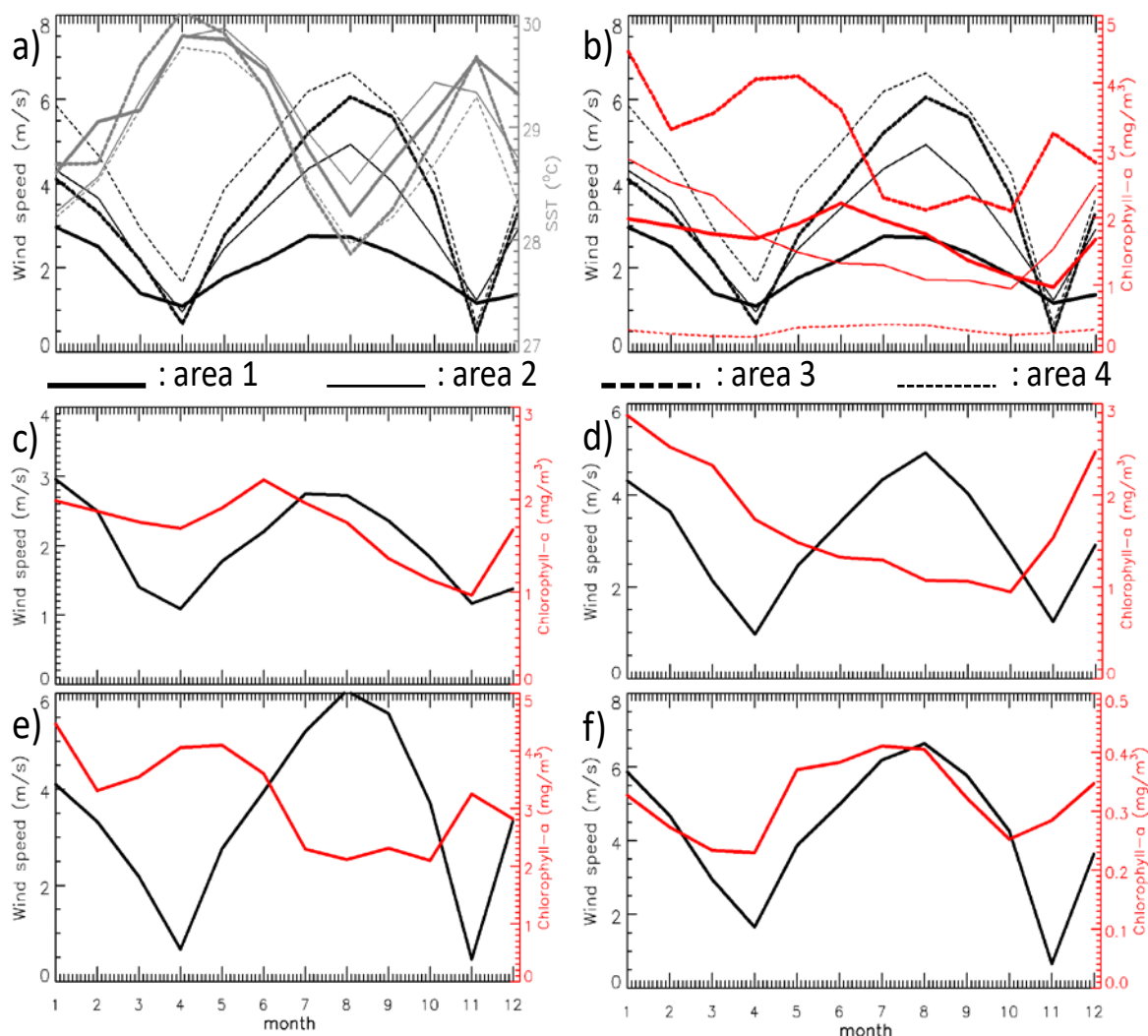


Figure 4. Monthly climatology time series of (a) wind speed and SST and (b) wind speed and Chl-a in area 1, 2, 3 and 4. The adjusted scale axis of wind speed and Chl-a in (c) area 1, (d) area 2, (e) area 3, and (f) area 4.

Chl-a concentration shows the different variation with SST (Figure 4b). The highest (lowest) chlorophyll concentration was found in area 3 (4) ranges from 2.11 mg/m^3 to 4.47 mg/m^3 (from 0.12 mg/m^3 to 0.31 mg/m^3). Area 1 and 2 are in between. In the adjusted scale in Fig. 4c-f, we can see that only Chl-a concentration in the open seas (area 4) has the high positive correlation with the wind speed. The correlations between Chl-a and wind speed for area 1, 2, 3, and 4 are 0.48, -0.002, -0.35, and 0.86 respectively. Although the amplitude of Chl-a variation in area 4 is the smallest one, its highest correlation means that Chl-a variation in the open seas of Java Sea highly depends on the wind speed. Moreover, the small correlations in area 1, 2, and 3 indicate that there are other possible factors influence their Chl-a variability. Since area 1, 2 and 3 are located in the coastal area, the nutrient input transported by the river charge may give significant contribution for Chl-a variabilities in those 3 areas. As discussed by [1,2], the variability of Chl-a in the Lampung Bay is influenced by the nutrient flux transported by the adjacent rivers. Figure 4c-e shows that the high Chl-a concentration mainly occurred during NW monsoon and Transition I season. The high precipitation during these seasons may bring more nutrient rich fresh water to the coastal seas and may increase turbidity in the coastal seas. The fresh water input may also influence the lag correlation between SST and wind speed in this 3 areas. The turbid coastal water may also interfere the Chl-a concentration measured by MODIS sensor due to the contamination of suspended sediment [27]. This possibilities are left for future studies.

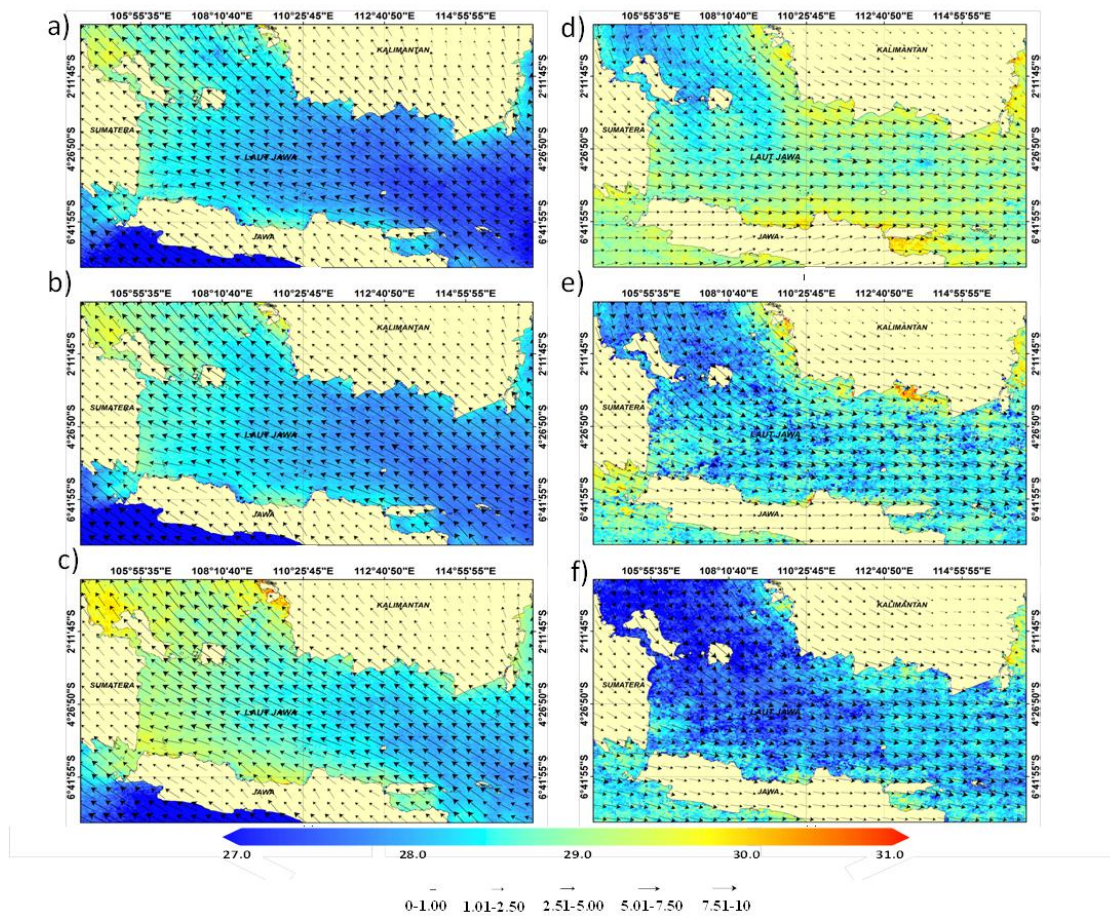


Fig. 5. Composite of SST map overlaid with surface wind vector in (a) August during El Niño, (b) August Climatology, (c) August during La Niña, (d) January during El Niño, (e) January Climatology, and (f) January during La Niña

3.2. Effect of ENSO to the SST and Chl-a variabilities in Java Sea

To investigate the effect of ENSO to the variability of SST in Java Sea, we composed the monthly El Niño and La Niña and compared with monthly climatology data as shown in Figure 5. We chose the period of August and January to be presented in Figure 5 since August and January are the peak of SE and NW monsoon, respectively. In August, SST distribution in Java Sea tent to be cooler (warmer) than its climatology during El Niño (La Niña) (Figure 5a). This is related to the speed of south-easterly wind which is stronger (weaker) during El Niño (La Niña). This result is consistent with the previous studies that found the SST cooling during El Niño in other Indonesian Seas [10-12,16].

The different result is depicted in Figure 5b. In January, SST tent to be warmer (cooler) than its climatology during El Niño (La Niña). This is caused by the weakening of north-westerly wind occurred during El Niño. In the opposite, the north-westerly wind is strengthened during La Niña which makes the decrease of the SSTs. Thus, the present study firstly shows that the effect of ENSO to the variability of SST in Java Sea depended on the season.

For further analysis, we show the time series of SST and wind speed in 4 areas which are described in the previous section. For all areas, the SST difference between the El Niño and La Niña attained more than 0.5°C (Figure 6a-d). It also shows that effect of ENSO to the variabilities of SSTs in all areas depended on the season. In August, El Niño tent to increase wind speed and decrease SST, while in January La Niña took control to increase wind speed and decrease SST. Thus, this result support the analysis in the previous paragraph.

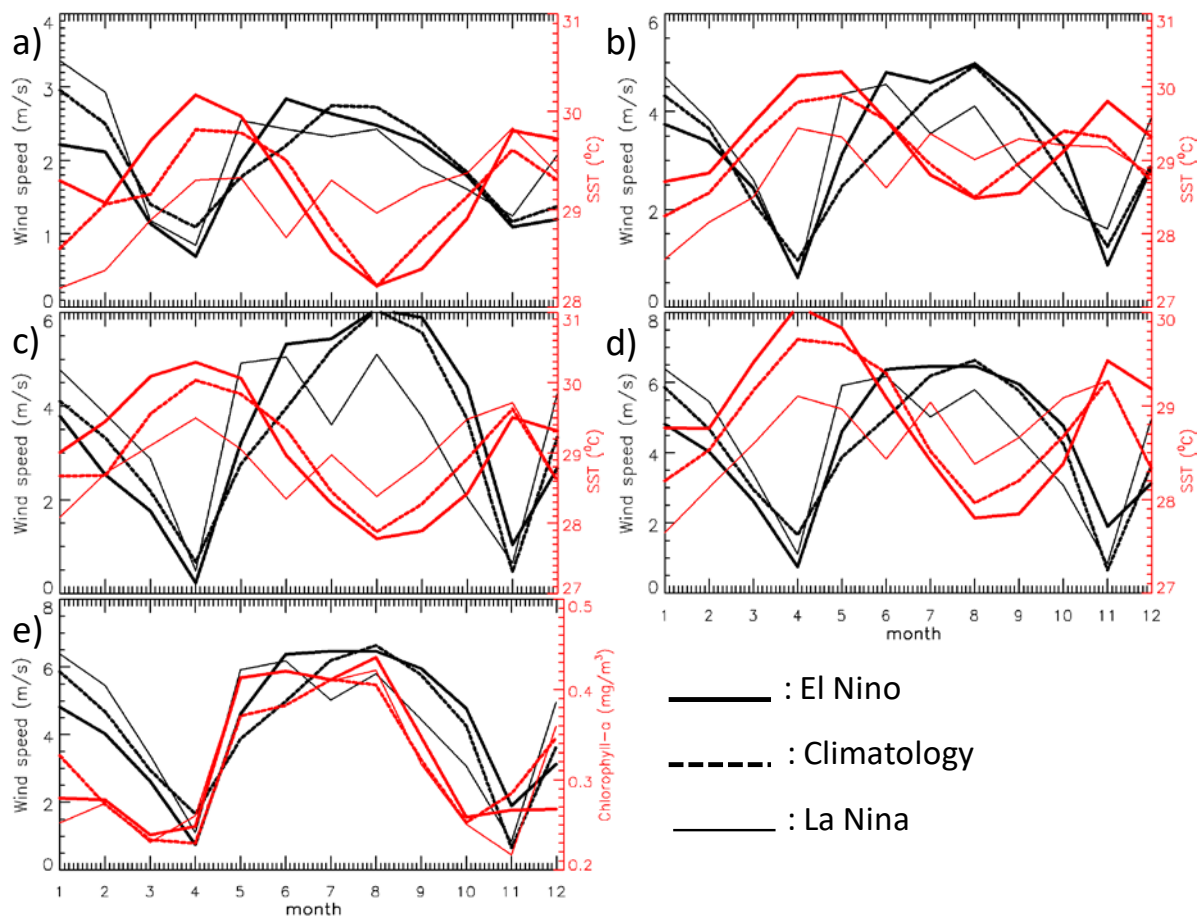


Figure 6. Time series of (a) wind speed and SST in area 1, (b) wind speed and SST in area 2, (c) wind speed and SST in area 3, (d) wind speed and SST in area 4, and (e) wind speed and Chl-a in area 4 under climatology and ENSO condition

For Chl-a variation, we only examined in the area 4 (Figure 6e) since in the other 3 areas, the variability of Chl-a does not depend only on the wind speed. The complex factors influenced the Chl-a variability in the coastal areas increase the difficulties in investigating the ENSO effect on the Chl-a variation in the coastal areas. This problems is potential for future work. In the open seas (area 4), the effect of ENSO to the variability of Chl-a is not robust. The difference Chl-a concentration between El Niño and La Niña period is less than 0.1 mg/m³. This difference is much less than the accuracy of MODIS Chl-a used in the present study i.e., 0.3 mg/m³ [19]. Thus, this analysis should be improved by using the more accurate Chl-a data.

4. Conclusion

The effect of ENSO on the variability of Chl-a concentration and SST in Java Sea has been investigated by using long term observation of MODIS data (2003-2016). The conclusions are as follows:

1. Java Sea shows robust seasonal variation on SSTs. The peaks of high (low) SSTs occur in January and August (April and November) which are influence by the speed and monsoon wind.
2. Seasonal variation of Chl-a in Java Sea only robustly shown in the open seas areas which is strongly influenced by the monsoon wind. In the coastal seas, the variability of Chl-a may be also influenced by the nutrients input from the land carried by the river's charge.
3. The effect of ENSO on the variability of SST in Java Sea depends on the season. During SE monsoon (Jun, July, and August), El Niño (La Niña) tends to decrease (increase) SSTs in Java

Sea. The stronger (weaker) easterly wind during El Nino (La Nina) may enhance (reduce) the mixing process and heat release to the atmosphere which decrease (increase) SSTs. In contrast, During NW monsoon (December, January and February), El Nino (La Nina) tends to decrease (increase) the westerly wind blowing in Java Sea which cause the increase (decrease) SSTs.

4. The effect of ENSO on the variability of Chl-a in the open seas area of Java Sea is not robust since the different of Chl-a concentration between El Nino and La Nina condition 0.1 mg/m^3 . This value is much less than the accuracy of MODIS Chl-a used in this study. The more accurate Chl-a data should be used to investigate the effect of ENSO on the variability of Chl-a in Java Sea.

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