The Effect of the ENSO on the Variability of SST and Chlorophyll-a in the South China Sea

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Abstract. The South China Sea (SCS) is one of the western marginal oceans of the Pacific Ocean, surrounded by South China, the Indo Peninsula of China, Peninsular Malaysia, the Philippines, and Borneo Island. The effect of the ENSO on the Variability of SST and chlorophyll-a has been investigated by many researchers. However, in the study, there were not still a small number of researchers who studied in this SCS area using high-resolution satellite imagery data. Chlorophyll-a and SST data taken from MODIS data, and wind analysis data from CCMP (Cross Calibrate Multi-Platform). The results obtained, wind speed affects over changes SST and Chlorophyll-a at SCS. The influence of wind speed against the variability of SST is very strong, but otherwise, over variability of Chlorophyll-a is less impact. There is a high correlation between ENSO (El Nino) with the SST which tends to be dominant throughout the west season due to the influence of wind speed in the South China Sea from the Pacific towards Australia throughout the west season. However, this is in contrast to the correlation between ENSO and Chlorophyll-a which appears less dominant, which is suspected of other factors that may affect Chlorophyll-a anomalies in addition to wind and SST factors.

1. Introduction

Global climate change is one of the important global environmental issues. This is due to its negative impacts on various sectors of life. Climate change affects the variability of the ocean and the atmosphere not only the physical process but also the chemical and biological process in territorial waters. One of the climate change aspects that will be examined in this study is related to the interannual variation of SST caused by El Niño Southern Oscillation (ENSO) phenomenon. ENSO is the dynamics of the atmosphere and ocean that affects the weather not only around the Pacific Ocean but also on the global scale. ENSO is an anomaly of sea surface temperature (SST) in the equatorial Pacific. The pattern of the distribution of temperature as a result of the ENSO phenomenon can be used for identifying the currents of the ocean, upwelling, and front [1].

South China Sea (SCS) is a marginal sea of the Western Pacific Ocean, surrounded by Southern China, Indo-China Peninsula, Peninsular Malaysia, the Philippines, and Borneo Island. It is a semi-enclosed basin that is connected to the Pacific Ocean through Taiwan Strait and Luzon Strait, respectively [e.g., 2]. Based on research by [3], indicating that the sea surface temperature anomaly is the SCS and the ENSO impact on winter rainfall in the SCS. Therefore, analyzing how climate variability in the SCS and factors can increase our understanding of the influence of the tropical Indo-Pacific Ocean in East Asia and Southeast Asia. A unique location to determine climate variability in the region affected by anomalous conditions SCS India and tropical Pacific Ocean [4]. A unique location to determine climate variability in the region affected by anomalous conditions South China Sea (SCS) India and tropical Pacific Ocean [5].

There is a study about the relationship between ENSO, SST and winter rainfall in the SCS [4]. The results show the winter rainfall over South China has a significant correlation with ENSO and
SST anomaly. ENSO and positive anomaly of SST in SCS increase the rainfall over South China. Meanwhile, ENSO itself has a positive correlation with SST in the SCS. However, their correlation analysis between ENSO and SST in the SCS is only based on the mean value over the area of SCS. Moreover, the effect of ENSO on the Chlorophyll-a variability on the SCS is not available in the previous studies. In the present study, the effect of ENSO to the variability of SST and Chlorophyll-a in the SCS is investigated by using spatial analysis approach by composing the anomaly map of SST and Chlorophyll-a both for El Nino and La Nina condition. Furthermore, correlation analysis is also conducted spatially to obtain the spatial pattern of correlation between ENSO and SST and Chlorophyll-a in the SCS.

This research has regional studies focusing more on the southern regions of SCS. This location was in the Malacca Strait and the South China Sea Indonesia (SCSI). This research is very useful in the field of fisheries due to the variability of SST and chlorophyll-a as an indicator in determining the fishing ground. The phase of ENSO phenomena occurrence on SCS is inseparable from the Asian monsoon climate anomalies, where climate change will have an impact on the physical parameters of the ocean, such as the fluctuation of chlorophyll-a and SHH. This research was conducted by using the approach of remote sensing and geographic information systems. The approach was chosen because the coverage is quite extensive research using reanalysis data which have high-resolution. Therefore, understanding the relationship between ENSO SST variability against chlorophyll-a investigating the influence of the monsoon accessed using the approach of remote sensing and geographic information systems.

2. Research Methods
The research was carried out in the SCS Region, with its geographical location (4 ° N - 14 ° 30' N and 102 ° 30' BT - 120 ° 30' N) can be seen in Figure 1. This research has a study area focuses more on the southern area of the SCS. This location was on the Strait of Malacca and the South China Sea Indonesia (SCSI).

Chlorophyll-a and SST data were obtained from satellite images of MODIS (Moderate Resolution Imaging Spectroradiometer) Level 3 data format with Common Data File Net (NetCDF). The data can be downloaded from the website http://oceancolor.gsfc.nasa.gov/. The data to be downloaded in the form of daily data and semi-daily 11 µm data with a resolution of 4 km, AQUA data type, data with a resolution of 0.04° x 0.04°. The data used is a collection of reanalysis data of the year 2003-2017. In addition, the data used is wind data CCMP (Cross Calibrate Multi-Platform) which is the data has been calibrated cross combination and observation instruments using Variational Analysis Methods (VAM) to produce an analysis grid high resolution (0.25° x 0.25°) [6].

Figure 1. The study area of Variation of SST at the South China Sea
Satellite of the National Oceanic and Atmospheric Administration (NOAA) was developed and applied in the field of ground-based remote sensing for NOAA National Weather forecast (NWS). Various data provided can be used for applications relating to the oceans, coastal areas, agriculture, forest fire detection, detection of volcanic ash, monitoring the ozone hole at the South Pole, and the environment of space. NOAA satellites flew with Solar Backscatter Ultraviolet Radiometer (SBUV) (radiometer nadir pointing, no spatial, spectral scanning, ultraviolet radiography), while other additional charges such as EUMETSAT sounder cover infrared Interferometer, the scatterometer instrument, ozone, and Global Positioning System (GPS) occultation can be recorded signal sound [7].

ENSO climate variability Index data was taken from the value of the existing temperature anomalies in the NIÑO 3.4. Data of the Oceanic Niño 3.4 Index (ONI 3.4) from the National Oceanic and Atmospheric Administration (NOAA) was used to identified the influence of ENSO on SST and SSS. Period and the strength of El Niño, La Niña, and normal conditions identified by using ONI 3.4 is the SST anomalies in the central equatorial Pacific Ocean (5°N-5°S and 120°W-170°W). SST anomalies > 0.5°C passed as El Nino, 0.5°C < considered La Nina, and between-0.5°C and 0.5°C is a normal condition. ONI 3.4 are taken from the National Weather Service, NOAA’S Climate Prediction Center. Monthly 3.4 ONI data used in this research was data ONI 3.4 for 15 years (2003 – 2017).

These all data must be decomposed into monthly climatology, monthly El Niño, and monthly La Niña to analyze the distribution of chlorophyll-a variability and SST variability over period 2003 – 2017. First, all parameters were sorted into monthly means, and monthly climatology by using the following equation [8]:

$$\bar{X}_b(x,y) = \frac{1}{mh} \sum_{i=1}^{mn} x_i(x,y,t)$$

(1)

Description:
Error! Reference source not found. = The median daily
Error! Reference source not found. = The daily data to – i at position (x) longitude, latitude (y), time (t)
Error! Reference source not found. = the number of hours in 1 day
Error! Reference source not found. = day – i
If xi = Nan, then the data has no value (empty value) and not included in the calculation of average daily.

To see the correlation between Chlorophyll-a, SST, and wind data, towards the ENSO, we used monthly El Niño, and monthly La Niña. Correlation was used to know the relation between the two variables, such as between the SST with ENSO, chlorophyll-a with ENSO. Correlations can be calculated with the formula:

$$r = \frac{N \left( \sum XY \right) - \left( \sum X \sum Y \right)}{\sqrt{\left( N \left( \sum X^2 \right) - \left( \sum X \right)^2 \right) \left( N \left( \sum Y^2 \right) - \left( \sum Y \right)^2 \right)}}$$

(2)

Description:
r = correlation coefficient value
x = the value of the first variable
y = the value of the second variable
N = number of data

3. Results and Discussion
3.1. The seasonal variations of SST, and chlorophyll-a in South China Sea
Seasonal variation of SST and chlorophyll-a showed a unique pattern i.e. a one-time annual patterns of variation that affect change in SST and chlorophyll-a in waters. Affected movements of different SST on each season, a decrease in SST that occurs due to the movement of SST from the Pacific West to Australia (the Northwest Monsoon) and the increase in SST occurs due to the movement of the SST
from Australia headed for the Western Pacific (Southeast Monsoon Wind). Such patterns occur only the 1-time decreases in SST and 1-time increases in SST can occur due to the influence of wind on the SCS region shown in Fig.2. It is in the suspect because the speed of the winds that blow on the region is different, the influence of wind on the distribution of SST is very influential.

The strong monsoon winds can result in an increase in Ekman transport, mixing of water masses vertically, and a high heat loss due to the onset of the rainy season along the evaporating, so that result in the occurrence of surface temperature of cooling water, and vice versa if the winds that blow became weak, resulting in mixing of water masses vertically that occurs will be weak and lose heat through evaporation being reduced too. It is this circumstance which impacted against the high temperature of the surface waters [8,9].

The value of the concentration of chlorophyll-a variation in high areas are on the waterfront, and increasingly weak in the region towards offshore over the season in waters of SCS. This is in accordance with statement of [10], that in the waters of the chlorophyll concentration value of SCS high in comparison with the beachfront area offshore. Where these values influenced the existence of wetter monsoon winds which induce the occurrence of upwelling in the coastal area so that the concentration of chlorophyll-a has increased on the SCS in the West. In addition to the influence of the wind, the influx of nutrients from the land can also affect the concentration of chlorophyll a was at the seaside. Because in the region, has a shallow depth and was still affected by the land [19]. According to reference [11] and [12], the decline in the value of the SST and the increasing concentration of chlorophyll-a due to the influence of the monsoon can cause upwelling. However, it could have been an increase in the concentration of chlorophyll-a variation and a decrease in the value of the SPL, only influenced by wind speed as one of the processes going on the mixing not upwelling on a specific area with a deep bottom topography and the absence of a barrier land can block the wind which forms the coastal upwelling. [19].

**Figure 2.** On the spatial distribution of SST (a), the concentration of chlorophyll-a (b), the surface wind speed (c) in the waters of the SCS with the condition of climatology (2003-2017) in the West (February), and season (August).
So, the influence of the wind towards a change of SST and chlorophyll-a concentration. The strong monsoon winds will affect the movement changes the value of the SST and affect the mixing of water masses vertically related to the concentration of chlorophyll-a in the area of SCS [9]. The existence of the possibility of double peak values at the change of SST and chlorophyll-a dual evolution Summit due in SCS in accordance with research of [13] which States that in the waters of the SCS are having a double peak of evolution occurs when the cold-temperature when SCS and before August, and the entire SCS becomes warm in October with the maximum positive SST anomalies are located in the western part of the basin. After a warming basin scale in October, the entire SCS keep warm towards next year's November. The double peaks of SST anomalies in the SCS are also evidenced by the existence of SST anomalies in the waters of SCS in February reached its maximum towards the month of May and then rising again and peak in August.

Based on Figure 2, can be seen the influence of wind in aquatic SCS is, in the time series of the seasonal variations that occur, also suggests that the influence of the wind against SST and chlorophyll-a (Figure 3). In Fig. 3 shows that the existence of the possibility of double peak values at the change of SST and chlorophyll-a dual evolution Summit due in accordance with SCS research [13] which States that in the waters of the SCS are experiencing double evolution happens when cold-temperature, when SCS and before August, and the entire SCS becomes warm in October with the maximum positive SST anomalies, is located in the western part of the basin. After a warming basin scale in October, the entire SCS keep warm towards next year's November. The double peaks of SST anomalies in the SCS are also evidenced by the existence of SST anomalies in the waters of SCS in February reached its maximum towards the month of May and then rising again and peak in August.

3.2. The influence of ENSO in South China Sea
In Fig. 4. Shows the influence of ENSO against SST and chlorophyll-a in SCS when the West season is represented by February and in Fig.5 Shows the influence of ENSO against SST and chlorophyll-a in SCS when East season is represented by August. On the season, ENSO influences can be seen clearly and all season. Visible changes in temperature when El Niño, look compared to the variability of SST in the climatology. Temperature changes are getting hot it causes anomalies that occurred with a positive anomaly (El Niño). It can occur due to the influence of wind speeds in the SCS. In the southern region of Viet Nam and Cambodia has anomalies of SST is higher compared to the northern
region of Borneo. In the southern region of Viet Nam and Cambodia with wind speeds that blow very fast, compared to the northern part of Borneo with low wind speeds. Characteristics of the wind are different in each region, which can lead to differences in the influence of ENSO. According to [14], that the existence of a link between Asian monsoon with ENSO.

According to [14], that the existence of a link between Asian monsoon with ENSO. The decrease of SST that occurs due to the influence of high rainfall at the time of La Niña. It is no different with the research results [9], where the influence of La Niña, a strong result in rainfall in SCS is very high from a good approximation, so the causes of temperature decline in the phenomenon occur when the SCS. That during La Niña phenomenon occurs, the abnormal sea water intrusion occurs in the Pacific, which increases heat SST in North SCS, and produces warm SST anomalies in the SCS Northeast during the La Niña occurs [15].

The concentration of chlorophyll-a in South Vietnam tends not to change significantly when the El Niño and La Niña. This looks otherwise on North Borneo where the influence of El Niño causes the concentration of chlorophyll-a and is declining, while La Niña causes chlorophyll-a concentrations along the waterfront. This is because at the time of the East season, the influence of the wind that is not too large. The research of [16] stated that the concentration of chlorophyll-a variation in the event El Niño can change compared to the concentration of chlorophyll-a at the time of climatologist in the offshore area tend to be weak, and in the seaside in the South of Vietnam.

Changes of chlorophyll-a in the event El Niño looks to decline compared with the value of the concentration of chlorophyll-a in time of climatology in the seaside territory. This is in accordance with the previous research [10], which stated that the influence of ENSO is high enough in the area of SCS associated with SST and chlorophyll – a. influence on the chlorophyll-a decline when the El Niño, and tend to be influential in the beachfront area compared to the offshore area. Wind patterns that occur in the region of SCS when El Niño seasonally. Wind anomalies that occur during the

![Figure 4. SST variability (a), the chlorophyll-a (b) and (c) wind speed when the El Niño and La Niña on the west season (February) at SCS.](image)
decline of the West and on the East, as the seasons wind patterns that happen quite fast and there is a limit on the autumn wind patterns. Wind anomalies that occur in the region of SCS high effect against an increase in temperature and decrease in chlorophyll a – this is related to the movement of the winds anomalies with seasonally happens more powerful, and affecting change on temperature rise the season of East and decline on the West season [17].

The influence of low monsoon during El Nino phenomenon in SCS. The influence of the El Nino phenomenon that occurs can cause monsoon effect is lowered or lower than the SCS waters causing effect also on SST and the concentration of chlorophyll - a. Whereas when the monsoon effect becomes high it can affect the La Niña phenomenon, which affects the mixing of water masses. In addition, in the surface layer, the Pacific Ocean water intrusion that occurs depends on the strength of the monsoon wind [9].

3.3. Correlation of ENSO on the Variability of SST in the South China Sea

The correlation coefficient indicates the extent of the relationship between two variables, in this case, the value of the correlation between SST with ENSO, the existence of a correlation between SST and ENSO, if seen in Fig. 6. shows that in this South China Sea waters in the northern region has a fairly high correlation with ENSO phenomena that occur on the western border. High correlation levels reach + 1.0 this shows that positive correlation in the South Viet Nam. Where the higher the value the higher the SST also influence positive ENSO (El Niño). As for the high negative correlation shown in the north of Borneo in August to reach the -0.7 with increasingly cold temperature changes.

The difference in correlation can be caused by physical processes that occur in different at South Vietnam and North Borneo. The high correlation of ENSO to the variability of SST in South Viet Nam is influenced by mixing. But in North Borneo with a low correlation, the process that occurs is not only mixing but the possibility of upwelling as well. This is based on the relatively low variation
of monsoon wind speeds in North Borneo but can affect the value of the variability of SST which tends to be relatively low throughout the year season.

This positive correlation in accordance with [3], where the existence of a significant positive correlation (> 0.05 level) in the Central and Eastern Equatorial Pacific. So the peak phase of El Niño has a great influence of rainfall in SCS. In addition, it was found that there was a significant positive correlation was also in the area of SCS. This indicates that the SST anomalies in the SCS have an important influence on rainfall in the West season, where the existence of a significant positive correlation (> 0.05 level) in the Central and Eastern Equatorial Pacific. So the peak phase of El Niño has a great influence of rainfall in SCS. In addition, it was found that there was a significant positive correlation was also in the area of SCS. This indicates that the SST anomalies in the SCS have an important influence on rainfall in the West season.

The correlation between ENSO and the variability of SST is a high value in the west season. During El Niño, SCS has increased temperature, and during La Niña, SCS has decreased in temperature. The ENSO phenomenon has a dominant contribution to the variability of SST in the South China Sea. Different results between ENSO correlations for the variability of SST that depend on season and mean throughout the season are shown in Figure 7. These results show a different matter compared to [3], the correlation value of ENSO was taken based on the mean throughout the season, which was smaller than the results shown in this study. That shows the ENSO correlation value for the variability of SST in SCS with regard to each season. So that the correlation value of ENSO to SST is better taken based on the value that depends on the season.

Figure 6. ENSO Correlation on the variability SST when East season (left) and West Season (right) in the SCS.
3.4. Correlation of ENSO on the Variability of Chlorophyll-a in the South China Sea

Correlation between chlorophyll-a towards ENSO can be seen in Figure 8. Can be seen, the influence of ENSO with the concentration of chlorophyll-a tends to correlate negatively (dominant effect at a time when La Niña). Where in the region of negative correlation reach -0.7 in the northern region, so that in this region the influence of La Niña in the change in the concentration of chlorophyll-a. Influence of wind can cause the value of chlorophyll-a concentration change. The higher the value of the concentration of chlorophyll-a, the lower the influence of ENSO. Neither instead, the lower the value of the concentration of chlorophyll-a, the higher the influence of ENSO with a dominant influence at a time when La Niña.

The correlation between ENSO and chlorophyll-a concentration is dominantly negative which occurs throughout the season. The presence of the influence of correlation between ENSO and SST in the SCS resulted in a positive correlation of ENSO and chlorophyll-a in SCS itself. This is in accordance with the statement of [18] that in general, the SCS monsoon and SST index shows a good correlation of the reverse, while the index of the monsoon SCS and chlorophyll-a indicates a negative correlation, as such, the correlation Relationships visible chlorophyll-a and correlation of SST include reverse correlation is strong. This relationship indicates that the SST influence changes in nutrients when the Ekman upwelling at the time the wetter monsoon winds in the SCS. Therefore, the annual variability of summer chlorophyll-a can be predicted with the evaluation of the annual variability of SST in SCS.

Figure 7. ENSO correlation to variability SST by depending on season (left) and average throughout the season (right) in SCS.

Figure 8. Correlation of ENSO against chlorophyll – a Season when Western (left) and Eastern (right) in the SCS.
Correlation of ENSO on the variability of chlorophyll-a, that looks less clear compared to the Correlation of ENSO on the variability of SST, that is seen clearly. Correlation of ENSO against chlorophyll-a high just at some point, with a narrow area, so that ENSO influence against the chlorophyll-a which seen from the correlation value is not too large. This is due to the presence of very strong ENSO phenomena on SCS in the West, where the increase in SST extreme wind pressure is low, and the concentration of chlorophyll-a result of the influence of the Eastern low Ekman Pumping weak causing a decrease in the supply of nutrients [18].

4. Conclusion
Influence of ENSO SST variability against the views of map SST anomalies shows a considerable influence in the change in SST in the SCS with dominant occurred during the season. Whereas, the influence of ENSO variability of chlorophyll-a against the views of the anomalous maps of chlorophyll-a indicates the influence that no big changes in the value of the concentration of chlorophyll-a in the SCS. But the West remains the season's dominant season is higher than the East. The existence of a correlation between ENSO on variability of SST is high indicates that the impact of the ENSO on variability of SST in the SCS with dominant season occurred in the West. Instead, the correlation of ENSO on variability of chlorophyll-a is low indicates that shows the impact of the ENSO not too great to the variability of chlorophyll-a in the SCS. But the West season remains the dominant season is higher than the East season. So, the influence of the wind against a very strong SST variability also affects the relationship of ENSO SST variability against high in the SCS. But another case with the influence of the wind against the variability of Chlorophyll-a that is not so strong, causing the influence of the wind is not the too large associated relationship between ENSO variability against Chlorophyll-a in the SCS.

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