The impact of ENSO on regional chlorophyll-a anomaly in the Arafura Sea

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Abstract. The El Niño-Southern Oscillation (ENSO) is a naturally occurring phenomenon that involves fluctuating ocean temperature in the equatorial Pacific. ENSO influences ocean climate variability in Indonesia including the Arafura Sea. The relationship between oceanic chlorophyll-a and ENSO has been the focus of study over the past decade. Here we examine the impact of ENSO on regional chlorophyll-a anomaly in the Papua waters using 14 years of chlorophyll-a and sea surface temperature (SST) data from AQUA MODIS and sea level anomaly data from AVISO. It is found that when El Niño events occur the negative SST anomaly in the Papua waters as well as the enhanced upwelling cause the increase of chlorophyll-a concentration. The highest chlorophyll-a concentration (> 1 mg cm⁻³) occurred during El Niño and observed around the Aru archipelago. In contrast during La Niña event, the positive SST anomaly in Papua waters and the suppressed upwelling cause the decrease of chlorophyll-a concentration. Our results suggest that during El Niño (La Niña), the enhanced (suppressed) upwelling related to the significant decreasing (increasing) of sea level anomaly.

1. Introduction

Indonesia is one of the largest archipelagic countries in the world. Besides being in the tropics, it’s also located between two oceans and two continents that makes Indonesia as a center of global atmospheric and ocean circulations [1]. The ENSO is a naturally occurring phenomenon that involves fluctuation of ocean temperature in the central and eastern equatorial pacific, coupled with changes in the atmosphere [2]. ENSO has a major influence on climate pattern in Indonesia and many studies have shown the social-economic impacts of ENSO on human. Marine phytoplankton plays a vital role in the global carbon cycle via photosynthetic carbon fixation and produces nearly half of the world’s oxygen via photosynthesis [3]. As the base of marine food chain, marine phytoplankton is also widely used as an indicator for fishing ground. Estimating the amount of marine phytoplankton, the biology variable derived from satellite sensor, chlorophyll-a is used so the term of phytoplankton and chlorophyll-a is used interchangeably [4]. Since September 1997, the ocean color sensor Sea Viewing Wide Field of View Sensor (SeaWiFS) has provided an outstanding data set for a wide range of studies, involving large-scale oceanic biological productivity [4]. And the released of the Moderate Resolution Imaging Spectroradiometer (MODIS) satellite as the new generation of SeaWiFS in 2002 has given a better understanding of physical processes in the ocean. Studies on the relationship between oceanic chlorophyll-a and ENSO has received a lot of attention in Indonesia. Previous study has found that...
during El Niño episodes, the Java-Sumatra upwelling extends spatially and temporally [5]. However, the effect of ENSO on oceanic chlorophyll-a in the Arafura Sea remains lacking until today [6]. In the present study, we investigate the interannual variability of oceanic chlorophyll-a in the Arafura Sea and its relation to ENSO.

2. Materials and Methods

The study area is shown in figure 1. The area of black box (5°S–8°S; 136°E–140°E) is examined for spectral analysis of chlorophyll-a.

![Map of the study area](image)

Figure 1. Map of the study area.

Monthly mean chlorophyll-a data used in this research is the Modis level 3 with spatial resolution of 4 x 4 km² for period of July 2002–December 2016. Chlorophyll-a data were estimated by applying the Ocean Chlorophyll MODIS algorithm (OC3M) and were obtain from The National Aeronautics and Space Administration (NASA) Ocean Color website (https://oceancolor.gsfc.nasa.gov/). Monthly mean SST data were extracted from the NOAA satellite imagery of with spatial resolution of 4x4 km². SST data were analyzed for period of July 2002–December 2016 and were obtain from The National Aeronautics and Space Administration (NASA) website (http://www.podaac.jpl.nasa.gov).

Sea Level Anomaly data used in this research is satellite altimetry data from AVISO. (ftp://ftp.aviso.altimetry.fr/global/delayed-time/grids/climatology/monthlymean/) The data were analyzed for period of July 2002–December 2016. Sea level anomaly was obtained from the following formula:

\[ \text{SLA} = \text{SSH} - \text{MSSH} \]

where,

- SLA = Sea level anomaly
- SSH = Sea surface height
- MSSH = Mean of sea surface height

ONI indices used of the three months mean SST anomaly value for the Niño 3.4 region (5°N–5°S, 120°–170°W). Events are defined as five consecutive overlapping three-month periods at or above the +0.5°C anomaly for warm (El Niño) events and at or below the -0.5 anomalies for cold (La Niña) events. ONI indices were obtained from the National Weather Service Climate Prediction Center (http://www.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/). Based on this category, we grouped the months of ENSO each year (table 1). DJF refers to December, January and February, MAM
refers to March, April, May, JJA refers to June, July, August, and SON refers to September, October and November.

Table 1. List of ENSO months used in this study.

| Year   | El Niño              | La Niña |
|--------|----------------------|---------|
| 2002–2003 | JJA, SON, DJF       | -       |
| 2003–2004 | -                | -       |
| 2004–2005 | JJA, SON, DJF, MAM  | -       |
| 2005–2006 | -                | -       |
| 2006–2007 | SON, DJF          | -       |
| 2007–2008 | -                | SON, DJF, MAM |
| 2008–2009 | -                | -       |
| 2009–2010 | JJA, SON, DJF, MAM | -       |
| 2010–2011 | -                | JJA, SON, DJF, MAM |
| 2011–2012 | -                | SON, DJF |
| 2012–2013 | -                | -       |
| 2013–2014 | -                | -       |
| 2014–2015 | MAM              | -       |
| 2015–2016 | JJA, SON, DJF, MAM | -       |

3. Results and Discussion

3.1. Spatial and temporal variability of chlorophyll-a in the Arafura Sea

In the Arafura Sea, the dominant factor that affects ocean condition is Australian-Indonesian Monsoon. Spectral analysis of chlorophyll-a (figure 2a) shows that chlorophyll-a concentration has a dominant pattern of annual oscillation. This also observed in the wavelength analysis (figure 2b) that temporally the annual oscillation looks dominant in the 12-month period. This indicates that monsoon has dominant impact on the distribution of chlorophyll-a.

During the northwest monsoon, northwesterly wind from Asia blows over the Arafura Sea with relatively low speeds ranging from five to eight knots [6]. The SST over the Arafura Sea ranges from
29–32 °C (figure not shown). This observation suggests that there is no occurrence of upwelling in this season. This condition is supported by chlorophyll-a distribution (figure 3a) that shows relatively low concentration with an exception in the coastal regions. The high concentration of chlorophyll-a in coastal region might be due to the process of surface runoff from the land as a natural source of nutrients [7].

![Figure 3](image)

**Figure 3.** a) Average chlorophyll-a concentration during the northwest monsoon (DJF) and (b) during the southeast monsoon (JJA).

While during the southeast monsoon, southeasterly wind from Australia [6] generates upwelling in the Arafura Sea, Banda Sea, and Timor Sea. The wind speed during this period ranges from 13 to 20 knots. Upwelling brings cooler water from deeper layer to the surface and increases chlorophyll-a concentration in the region (figure 3b).

3.2. Chlorophyll-a anomaly during ENSO

ENSO not only affects climate variability and weather in Indonesia but also the variability of marine productivity [8]. In 2015, a strong El Niño occurred and lasted from June to November (figure 3). Our results show that this strong El Niño affected the chlorophyll-a concentration in the Arafura Sea. During JJA 2015 anomalous negative SST (figure 4c) appeared in the Arafura Sea, followed by positive anomaly of chlorophyll-a concentration (figure 4a). The positive anomaly of chlorophyll-a reached > 1 mg cm⁻³ and the negative anomaly of SST ranged from 0.1 to 0.6 °C. Whereas during SON 2015 the negative anomaly of SST became more significant with values < -0.8°C (figure 4d), indicating the mature phase of El Niño. During this season upwelling around the Aru archipelago demonstrates a decrease.
In contrast to El Niño condition, in particular when moderate La Niña occurred in 2010, positive anomaly of SST appeared and followed by negative anomaly of chlorophyll-a concentration in the northern part of the Arafura Sea. During JJA, the anomalous positive anomaly of SST (figure 5c) ranged from 0.2 to 1.5 °C. During this period the negative anomaly of chlorophyll-a concentration reached >1 mg cm⁻³ (figure 5a) This condition continued during SON with more significant positive SST in the Arafura Sea (figure 5d). The southern part of the Arafura Sea shows a positive anomaly of chlorophyll-a concentration. This might be generated by dynamics of the Arafura Sea like current and tide and it needs further analysis. Overall, the warmer SST during La Niña and low chlorophyll-a concentration indicated a suppressed upwelling in the Arafura Sea.

During El Niño, air pressure in the eastern Pacific is weaker compared to the western Pacific. As a consequence, wind and warmer water flows from the western Pacific to the eastern Pacific. This causes a decrease in SST and sea level in the western Pacific [9]. The decreased temperature in the western Pacific induces a SST decrease in the Indonesia Seas. In addition, the declined sea level in the western Pacific during El Niño might affect the intensity of upwelling in the Indonesian Seas. We hypothesize that this is the reason why the intensity of upwelling during El Niño is stronger than that during La Niña and neutral year [10].

Figure 4. Chlorophyll-a anomaly during (a) JJA and (b) SON 2015. SST anomaly during (c) JJA and (d) SON 2015.
Figure 5. Chlorophyll-a anomaly during (a) JJA and (b) SON 2010. SST anomaly during (c) JJA and (d) SON 2010.

Figure 6. Hovmoler diagram of sea level anomaly in the Arafura Sea.
In the Arafura Sea negative anomaly of mean sea level occurred from June until October, whereas positive anomaly occurred from November until May. The negative sea surface height anomaly suggested the upwelling event and the positive sea surface height anomaly suggested the downwelling event [11]. The influence of El Niño on sea level anomaly in the Arafura Sea is obvious. During strong El Niño 2015, significant decreased of sea level occurred in the Arafura Sea (figure 6), indicating enhanced upwelling. This condition reversed during La Niña.

4. Conclusion
According to the results of this study, it can be concluded that the occurrence of chlorophyll-a anomaly in the Arafura Sea is strongly coupled to ENSO. When El Niño occurred, negative SST anomaly in the Papua waters is associated with the enhanced chlorophyll-a concentration. The highest chlorophyll-a concentration (> 1 mg·cm⁻³) occurred during El Niño and observed around the Aru archipelago. In contrast, when La Niña occurred, positive SST anomaly and low chlorophyll-a concentration are evident in the Papua waters. Results of this study suggest that during El Niño (La Niña) enhanced (suppressed) upwelling is coupled to the decreased (increased) sea level anomaly.

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