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Variability of surface chlorophyll-a distributions in the northwestern coast of Sumatra revealed by MODIS

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Abstract. The variability of surface chlorophyll-a (chl-a) distributions in the northwestern coast of Sumatra are important components associated with the phytoplankton biomass that supports and enrich the fishery resources of the region. This study analyzes satellite data-ocean color derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua for a period of January 2003 to December 2015. The results show that the surface chl-a distribution is strongly associated with the large-scale forcing (e.g. monsoonal winds, EL Niño–Southern Oscillation and the Indian Ocean Dipole). On the seasonal time scale, it is shown that the satellite observed surface chl-a concentration during the boreal fall and winter (September-January) is higher than that observed during the boreal summer (June-August). The highest concentration was observed in September which is about 0.2 mg m^{-3}. In contrast to the western coast, the surface chl-a in the eastern coast of Sumatra has excessive concentration around 0,5-10 mg m^{-3} all year around. In addition, the study also revealed that the anomaly of surface chl-a concentration was observed along the western coast of Sumatra is much higher during the positive IOD (pIOD) and EL Niño events.

1. Introduction

Dynamics of the ocean circulation in the northern Sumatra has the same importance as in the southern Sumatra. Many studies have been conducted to analyzed the dynamics of ocean circulation in the southern Sumatra. However, the dynamics in the northern Sumatra have not been studied in details, especially the dynamical distributions of surface chlorophyll-a (chl-a). The northwestern Indian Ocean is less productive compared to the southeastern Indian Ocean [1, 2].

The northern Sumatra region is part of the northern Indian Ocean that is influence by a semi-annually reversing monsoonal wind system. During the summer monsoons in June-August, the summer monsoon current (SMC) carries saltier and high salinity water mass from Arabian Sea into the northeastern of the Indian Ocean waters (Bay of Bengal). On the other hand, the North Equatorial Current (NEC) lead out warm and low salinity waters from the Bay of Bengal during winter monsoon (December–February) [3].

On the inter-annual time scale, the Indian Ocean Dipole (IOD) and the El Niño Southern Oscillation (ENSO) affect significantly inter-annual changing within the Indian Ocean. Previous study using a coupled biophysical ocean general circulation model showed that two climate modes could form unique pattern of surface chl-a distribution in the tropical Indian Ocean [4].

In addition to the temporal variation, the northeastern of Indian Ocean (especially Bay of Bengal) also experiences mesoscale dynamics namely the eddy current. The eddy variability has important role in enhancing the biological productivity up 2 to 8 times compared to the non-eddy region. The upper ocean region also has high stratified during summer monsoon [1]. The previous study also revealed that the northern Indian Ocean has shown strong intra-seasonal sea surface height (SSH) variability [5]. Meanwhile, meridional currents variability is affected by the Kelvin wave reflection due to the inclined coastline of the eastern boundary [6]. As a result, those conditions are hypothesized to influence the surface chl-a distributions in the northern of the Sumatra Island. Therefore, the main objective of this study is to identify the variability of surface chl-a distribution in that region and to examine the processes that lead the observed chl-a pattern using the important physical and biological-oceanographic properties of the marine ecosystem (the sea surface temperature (SST), the surface winds, the Ekman pumping value, and the surface chl-a concentration). The rest of the paper is organized as follow. Section 2 describes the data and methods. Section 3 explains the results and discussion. Then, the summary of the findings is present in section 4.

2. Data and Methods

The study area is located in the northern of Sumatra bounded by 12°N- 3°S and 90°E -102°E (figure 1). The surface chl-a concentration for the northern of Sumatra region was obtained from the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua satellite. The data were provided by the NASA Goddard Distributed Active Archive Center for a period of January 2003 to December 2015 at 9 km horizontal resolution.

The monthly surface wind data were obtained from the ERA-Interim of the European Center for Medium Range Weather Forecasts (ECMWF). The monthly gridded data at 0.25° × 0.25° resolution from January 2003 to December 2015 were used in this study.

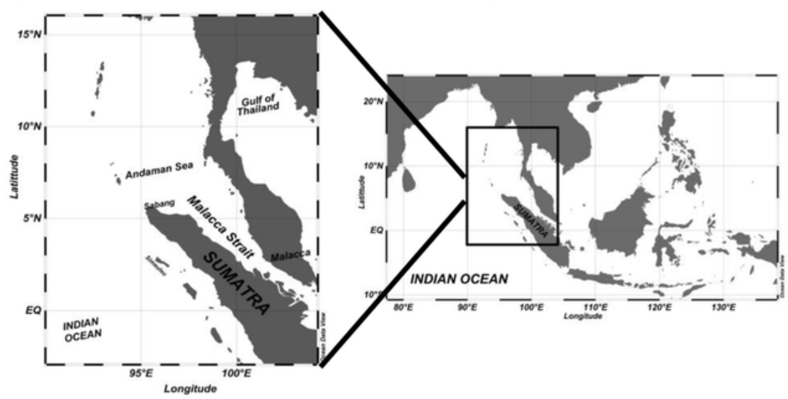

Figure 1. Maps of the northern Sumatra, the study area is bounded by 12°N-3°S and 90°E-102°E.

The monthly SST image was obtained from National Oceanic and Atmospheric Administration (NOAA) Optimum Interpolation (OI) [7].

In order to evaluate the mechanism of surface chl-a distribution, the Ekman pumping as an indicator of upwelling/downwelling processes was computed using the formula $(1/\rho f)\nabla\times\vec{\tau}$, where ρ

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is the density of seawater (kg m^{-3}), f is the Coriolis parameter (rad s^{-1}) and $\vec{\tau}$ is wind stress (N m^{-2}). Note that, the $\vec{\tau}$ (wind stress) was calculated using formula $\vec{\tau} = C_D\ \rho_{air}\ U^2$, following Weisberg [8]. Where C_D, ρ_{air}, and U are constant drag coefficient (C_D=1.43 × 10^{-3}), air density (ρ_{air} =1.225 kg m^{-3}) and the surface wind monthly data (10 m above sea surface), respectively. The monthly climatology of all parameters (surface chl-a, surface wind, SST, and the Ekman pumping) were obtained from monthly time series from January 2003 to December 2015. Then, the anomaly of all parameters was calculated by deviation from the monthly data and monthly climatology.

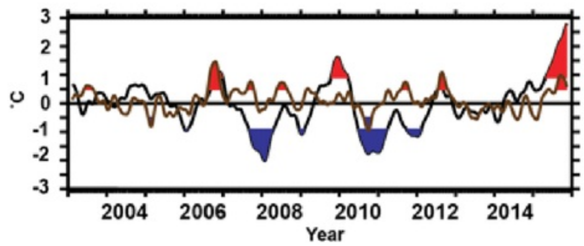

Figure 2. Time series of the Niño3.4 index (*black*) that and the DMI (*brown*) from January 2003 to December 2015. Significant positive value (*red shading* >=+0.5 °C) indicates El Niño or positive IOD events, while significant negative value (*blue shading* <=-0.5 °C) represents La Niña or negative IOD events.

The Dipole Mode Index (DMI) was calculated as a gradient of sea surface temperature anomalies (SSTA) averaged over the western (10°S–10°N, 50°E–70°E) and the eastern (10°S–Equator, 90°E–110°E) regions [9]. In addition, the monthly Niño3.4 index used to represent the occurrence of the ENSO events was defined as the average equatorial SSTA over a region of 5°S–5°N and 120°W–170°W. Note that the ENSO event was characterized by a five consecutive 5-month running mean of SSTA exceeding one standard deviation [10]. Based on those criteria, the IOD and the ENSO events are shows in figure 2.

3. Results and Discussion

3.1. Seasonal Variation

The monthly variability of the chl-a in the northern part of Sumatra is presented in figure 3. Generally, the northeastern coast of Sumatra (including the Malacca Strait) has much higher chl-a concentration than the northwestern coast of Sumatra (along the coast of Aceh, Medan and Padang). It is shown that the observed chl-a concentration in the northeastern coast of Sumatra is up to 0.3- 5 mg m^{-3}, while that in the northwestern coast of Sumatra is only 0.1-0.2 mg m^{-3}. The distribution of surface chl-a in the northeastern coast of Sumatra is strongly affected by the nutrient supply from the river run-off product of the land and the mixing process [11].

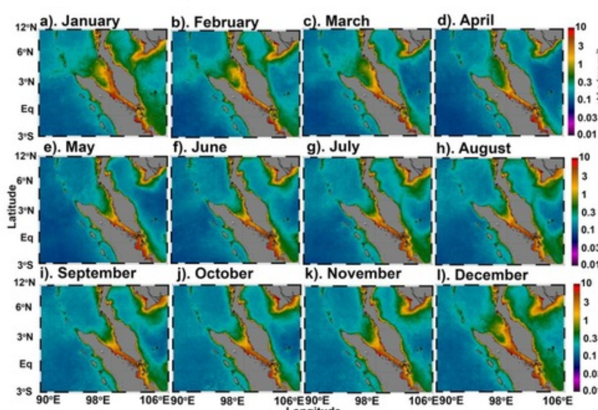

Figure 3. Monthly climatology of chl-a distribution are derived by MODIS satellite-observed.

The concentration of the surface chl-a in the northwestern coast of Sumatra during boreal winter (DJF) and spring (MAM) season is much lower than it is during boreal summer (JJA) and boreal fall (SON). Noted that the increasing of the chl-a concentration during boreal summer (JJA) is related to intensification of upwelling region because of appearance of the eddies current [1].

Figure 4 shows the monthly climatology of surface wind superimposed on the monthly climatology of SST. It clearly shows that the wind direction reverses seasonally from the northeastward (DJF) to the southwestward (JJA). Weak winds (<10 m s^{-1}) are observed during transition periods (MAM and SON). Meanwhile, the SST during the transition periods (MAM) is warmer (29-30°C) along the northern Sumatra than that observed during the boreal summer in JJA (28-29°C).

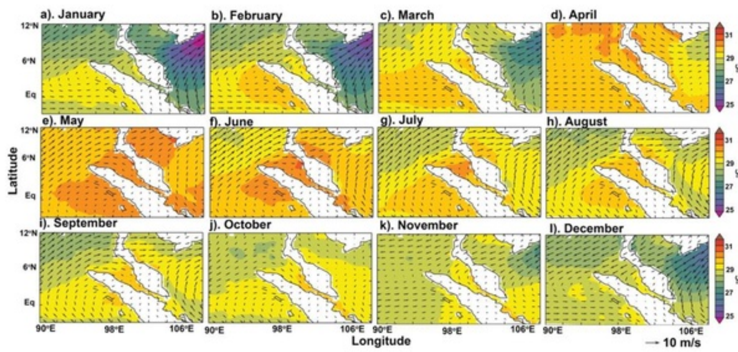

Figure 4. Monthly climatology of surface wind 10 m (vector in m s-1) superimposed on SST (shading °C) in the northern Sumatra.

The evaluation of upwelling region is determined by the wind curl mechanisms. Figure 5 presents the monthly climatology of the Ekman pumping computed from the surface wind data. The positive Ekman pumping indicates upwelling, while negative Ekman pumping indicates downwelling mechanisms. The positive Ekman pumping along the northern Sumatra reached its peak in boreal early winter (DJF) followed by a maximum surface chl-a concentration. On the other hand, the negative Ekman pumping observed during boreal fall (SON) is accompanied by the lower surface chl-a concentration.

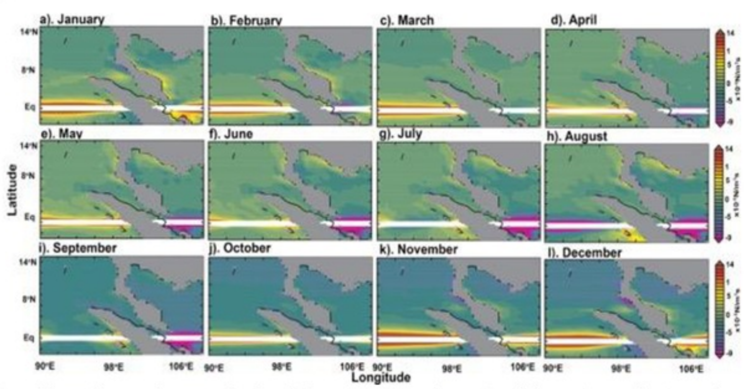

Figure 5. Monthly climatology of the Ekman pumping. Positive (negative) values indicate an upwelling (downwelling) regions.

3.2. Effect of the IOD and ENSO on the Surface Chl-a Distributions

The chl-a distribution in the northern Sumatra is more extensive during 2006 and 2015 than that during the normal year (figure 6). This conditions were associated with the El Niño and positive IOD events that were concurrently occurred [12–14]. During the peak of positive IOD event, almost all of the region in the northern coast of Sumatra experienced positive chl-a anomalies. The significant positive chl-a anomalies first appeared over the northern of Sumatra in July 2006. This condition continued and peaked in September-November 2006. This result was confirmed by previous study about the chl-a distribution in Southern Java [13,15]. The positive chl-a anomalies in the region is increase up to ~1 mg m^{-3}. The surface chl-a anomalies observed during 2006 were more extensive than those observed in 2015. Note that the IOD in 2015 was co-occurred with the El Niño event. However, the 2015 IOD is short-lived event compared to the 2006 IOD event.

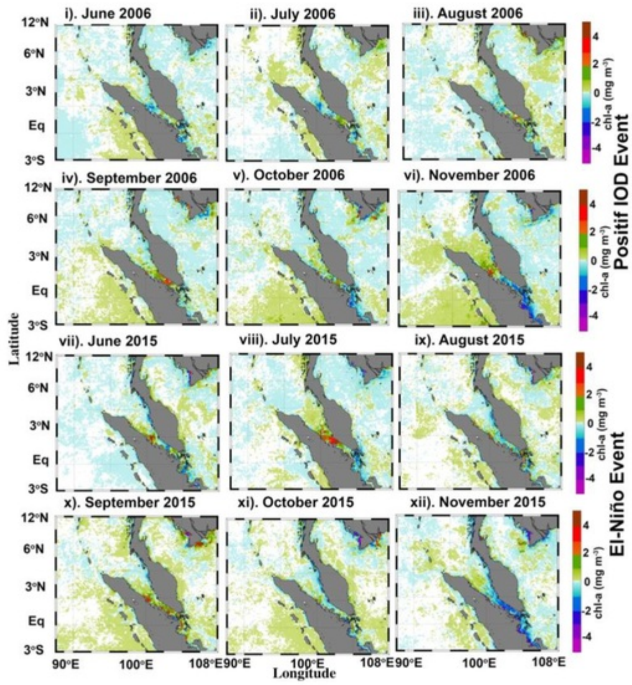

Figure 6. Comparison of the monthly anomalies pattern of chl-a distribution while strong positive IOD event in 2006 (i-vi) and El Niño event (vi-xii) in 2015 over the northern Sumatra (12°S–3°N and 90°S–108°N).

It is clearly shown that a strong pIOD in 2006 and a strong El Niño event in 2015 have caused two different oceanic and atmospheric conditions in the northern Sumatra. During the evolution phase of the El Niño and the pIOD events, the most prominent features are the different in the pattern of SSTA, the surface wind anomaly and the Ekman pumping anomaly. The differences of the SSTA patterns and the surface wind anomaly between two events (e.g. El Niño and pIOD) affect the surface chl-a distribution in the study area. The strong surface winds leaded the cold SSTA in 2006 was more prolonged than those observed in 2015. The results found that the negative SSTA over the northern Sumatra was associated with related changes in the stronger southwesterly surface winds that were shown by figure 7. The positive anomalies of the chl-a concentration pattern agree with the negative SST anomaly. In 2006, the evolution of the SSTA started in the early boreal summer (July) over the northern of Sumatra (figure 7 ii) and reached a minimum of about 0.6°C in boreal fall (October). This condition has been confirmed by Iskandar, *et al* (2009) whose discussed the chl-a blooms in the southern Indian Ocean [13]. Meanwhile, during the El Niño in 2015, the observation did not discover a clear cold SSTA in the northern Sumatra.

It is also interesting to evaluate the impact of the Ekman pumping anomaly on the chl-a distribution in 2006 and in 2015 (figure 8). The results revealed that the positive Ekman pumping coincided with

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higher surface chl-a concentration. This upward Ekman pumping was associated with upwelling causing negative SST anomaly and enhancing surface chl-a concentration. The northeasterly wind anomalies generated downward Ekman pumping (negative anomaly) leading to warm SST anomaly. This downward Ekman pumping caused downwelling that depressed surface chl-a concentration. During both 2006 pIOD and 2015 El Niño events, strong southeasterly wind anomalies were observed leading to upward Ekman pumping (positive anomaly). However, the southeasterly wind anomalies in 2006 were much stronger than those observed in 2015 (figure 8).

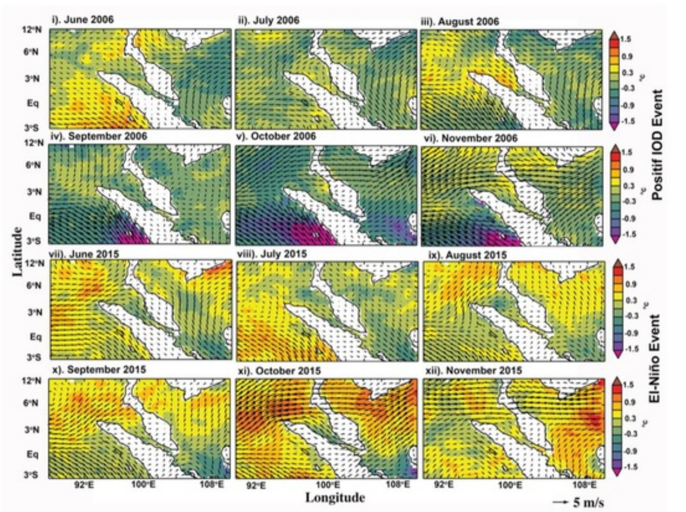

Figure 7. Comparison of the monthly anomalies pattern of SST overlay 10 m surface wind while strong positive IOD event in 2006 (i-vi) and El Niño event in 2015 (vii-xii) over the northern Sumatra (12°S–3°N and 90°S–108°N).

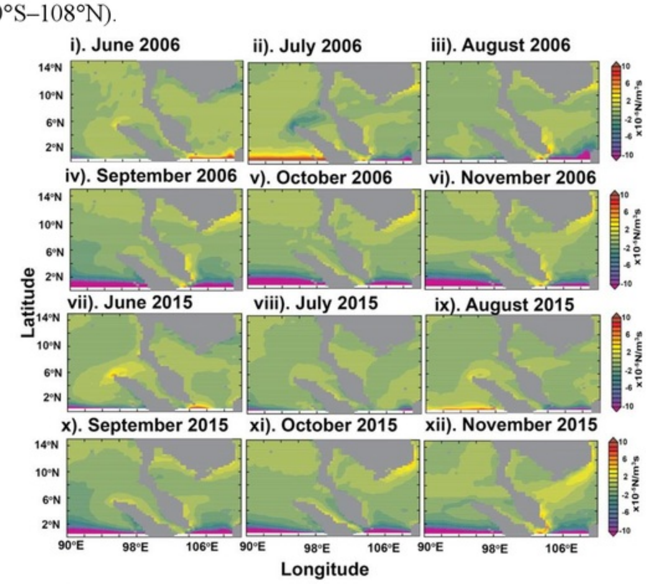

Figure 8. Comparison of the monthly anomalies pattern of Ekman pumping while strong positive IOD event in 2006 (i-vi) and El Niño event in 2015 (vii-xii) over the northern Sumatra (12°S–3°N and 90°S–108°N).

4. Conclusion

In this study, we found that the variability of surface chl-a distribution in the northwestern Sumatra has seasonal variation. The observed chl-a concentrations show higher concentration during the boreal spring and summer compared to those observed during boreal fall and winter. In 2006, the positive IOD event caused higher chl-a bloom almost in the entire northwestern coast of Sumatra. The highest chl-a bloom event occurred in boreal fall (SON) when the northwesterly wind reached its peak. In 2015, the El Niño has lower impact on the chl-a distribution in the northwestern coast of Sumatra in early boreal fall (September-October). The variability of wind direction over the north Sumatra contributed to the chl-a distribution in this region during 2006 positive IOD and 2015 El Niño events.

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References

[1] Kumar S P, Nuncio M, Narvekar J, Kumar A, Sardesai S, De Souza S N, Gauns M, Ramaiah N and Madhupratap M 2004 *Geophys. Res. Lett.* **31** 2
[2] Susanto R D, Gordon A L and Zheng Q 2001 *Geophys. Res. Lett.* **28** 1599
[3] Kumar S P, Narvekar J, Kumar A, Shaji C, Anand P, Sabu P, Rijomon G, Josia J, Jayaraj K A, Radhika A and Nair K K C 2004 *Geophys. Res. Lett.* **31** 4
[4] Currie J C, Lengaigne M, Vialard J, Kaplan D M, Aumont O, Naqvi S W A and Maury O 2013 *Biogeosciences* **10** 6677
[5] Aparna S G, McCreary J P, Shankar D and Vinayachandran P N 2012 *Geophys. Res.* **117** 1
[6] Chen G, Han W, Li Y, Mcphaden M J, Chen J, Wang W and Wang D 2017 *J. Phys. Oceanogr.* **47** 979
[7] Reynolds R W, Rayner N A, Smith T M, Stokes D C and Wang W 2002 *J. Clim.* **15** 1609
[8] Weisberg R H and Wang C 1997 *J. Clim.* **10** 1998
[9] Saji N, Goswami B N, Vinayachandran P N and Yamagata T 1999 *Nature* **401** 360
[10] Trenberth K E 1997 *Bull. Am. Meteorol. Soc.* **78** 2771
[11] Tan C K, Ishizaka J, Matsumura S, Yusoff F M and Mohamed M I H 2006 *Cont. Shelf Res.* **26** 168
[12] Susanto R D, Moore T S and Marra J 2006 *Geochemistry, Geophys. Geosystems* **7** 1
[13] Iskandar I, Rao S A and Tozuka T 2009 *Int. J. Remote Sens.* **30** 663
[14] Annamalai H, Xie S-P and McCreary J P 2005 *J. Clim.* **18** 302
[15] Iskandar I, Sasaki H, Sasai Y, Masumoto Y and Mizuno K 2010 *Ocean Dyn.* **60** 731

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