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Seasonal Driven Mechanism of the Surface Chlorophyll-A Distribution along the Western Coast of Sumatra

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ABSTRACT

The chlorophyll-a (chl) abundances on the Fisheries Management Area of Indonesia Republic (WPP-RI 572), as fishery resources over the western coast of Sumatera (WSC) and Sunda Strait, were examined in this study. The extensive investigation on the mechanism ocean dynamics on chl variability along WSC was observed by using remotely sensed data on the surface. The spatial analysis was conducted using the Moderate Resolution Imaging Spectroradiometer (MODIS) Aqua Ocean colour data for a period of January 2003 to December 2015. On seasonal time scale, the surface chlorophyll-a (schl) concentration in the southern tip of Sumatra is higher than the schl in the northern tip of Sumatra. The obtained results showed that the schl concentration in the southern tip of Sumatra increases (decreases) during the southeast (northwest) monsoons. Interestingly, its interactions with the southeast monsoon wind result in intensified coastal upwelling along the monsoon trough in July – August. It triggered a large bloom of the schl concentration from the upwelling region of southern tip Sumatra. Moreover, the schl in the center region followed the peak of the equatorial wind during the period transition in the Indian Ocean which is controlling the dynamics ocean such as upwelling event. Meanwhile, the opposite situation of the schl concentration observed low along the western coast of Sumatra during the northwest monsoon. At the same time, strong upwelling observed at the northern tip of Sumatra was associated with intense cooling on the sea surface temperature. It triggered a large bloom of high schl water from the upwelling region of northern Sumatra Island.

Keyword: coastal, equatorial wind, MODIS, Sumatra, surface chlorophyll-a.

INTRODUCTION

Phytoplankton are mostly microscopic organisms that capture the energy from the sun (Hong et al., 2012). Phytoplankton are important for because their functions are not solely as base of chain food in the marine ecosystem, but they provide at least half the oxygen and take in carbon dioxide (Roxy et al., 2014) Moreover, they also provide food and medicine resources (Chassot et al., 2010). While phytoplankton are abundant in upwelling areas, it is a sign of the world's richest fishing grounds (Chen, Xiu, and Chai, 2014; Iskandar et al., 2009; Susanto et al., 2001; Wirasatriya et al., 2021). For the studies about the measurements of phytoplankton biomass, researchers stated that chl remains the best proxy as a parameter estimated which is contain photosynthetic pigment (Hout et al., 2007).

Recent studies showed that ocean spatial and temporal variability of the surface chl abundance on the climate drivers had become an interesting research topic during last decades (Iskandar et al.,2009; Nuris, et al., 2017; Siswanto et al., 2020; Susanto et al., 2006). Satellite sensors designed to observe ocean color provide estimates of short-term (seasonal and inter-annual) to long-term (decadal) changes in the ocean chl (Frouin et al., 1996; Gregg and Casey, 2004; Moisan et al., 2017; Sari et al., 2018; Son et al., 2017).

The western coast of Sumatra (WSC) waters is part of maritime continent area which is located in tropical eastern of Indian Ocean. WSC waters are very important for fishing ground in fisheries management area (Wilayah Potensial Penangkapan) number 572 that provides the abundant species of demersal fish catch (Mous et al., 2020). Furthermore, WSC waters has unique of ocean atmosphere interactions which fundamentally impact its ocean dynamics. Moreover, the unique geographical position of WSC waters, part of eastern Indian Ocean, bounded by Sumatra Island from the east and located in a tropical area that is mostly influenced by upwelling water regimes from both of the northern and southern area of Indian Ocean (Iskandar et al., 2017; Sari et al., 2018, 2020; Susanto et al., 2006).

The complex ocean-atmosphere interaction in the eastern Indian Ocean, the west off Sumatra and south off Java, lead region a the semi-permanent Java coastal upwelling during July to October in every year. This process causes the high productivity in its region (Pranowo et al., 2016). As a result, the surface chl (chl) and Sea Surface Temperature (SST) is significantly influenced by the existence of continuous upwelling because of strong variation of coupled interaction (Susanto et al., 2006). The previous study stated that the surface chl concentration and SST are important data to determine of the high productivity area distribution. Surface chl as biology parameter and SST as oceanography parameter are beneficial to improve the production of pelagic in Indonesia (Hendiarti, 2008). However, so far there has been limited investigation focused on the local and remote mechanism drive the area based on satellite ocean color within MCW. Therefore, this study focuses on seasonal time scale of the surface chl distribution and drive mechanism that influences the WSC.

MATERIALS AND METHODS

Study area

The western coast of Sumatra is part of the Indian Ocean, located in eastern of Indian Ocean between 8˚N – 8˚S and 90˚E – 105˚E (Figure 1). It is connected to the Andaman Sea in the north,

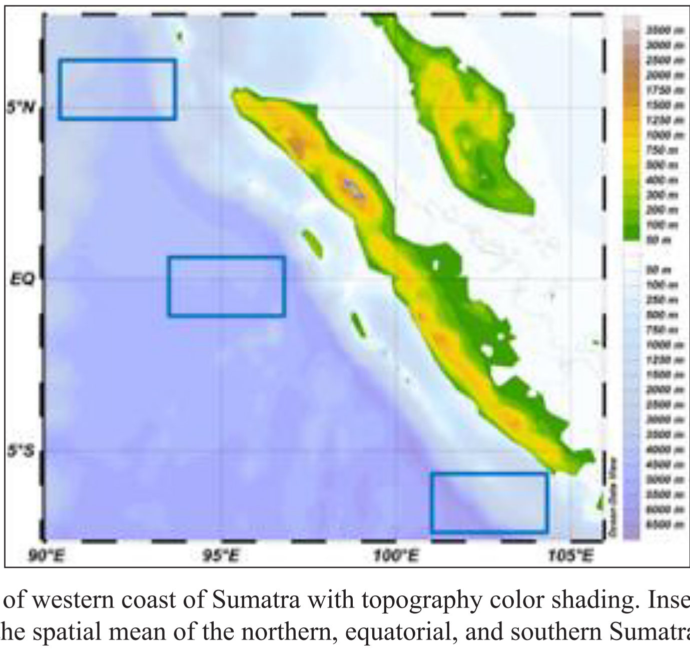

Figure 1. Study area of western coast of Sumatra with topography color shading. Inserted map is Indonesia region. Blue box is the spatial mean of the northern, equatorial, and southern Sumatra Island, respectively

the Sunda Strait in the south, and it is bordered the Sumatra Island in the west. The WCS is one of important Fishery Management Area (FMA) or Wilayah Potensial Penangkapan 572 in the Indonesian Maritime continent. The depth of onshore region is around 0–50 m as shallow water and offshore is reached 4500 m as open ocean.

DATA SETS AND METHODS

Monthly Moderate-resolution Imaging Spectroradiometer (MODIS) Aqua satellites level 3 data of surface chlorophyll-a with uniform horizontal resolution of 9 km were used in the present study. The data from January 2003 until December 2015 were provided by the National Aeronautics and Space Administration/Ocean Biology Processing Group (NASA/OBPG). Note that the satellite remote sensing in the tropical region usually contain many gaps due to heavy cloud cover. In this study, an empirical orthogonal function-based data interpolation (DINEOF) was implemented to remove the cloud effects (Alvera-Azcárate, Barth, Beckers, and Weisberg, 2007). The monthly Optimum Interpolation Sea Surface Temperature (OI-SST) of the National Oceanographic and Atmospheric Administration (NOAA) provided the SST data for a period of January 2003 to December 2015 with spatial resolution of 0.25×0.25° (Reynolds et al., 2007). Meanwhile, the role of surface winds was evaluated by using the monthly wind data from the ECMWF Re-Analysis (ERA) – Interim of the European Centre for Medium Range Weather Forecasts (ECMWF) for the same period of chl and SST data. The data have horizontal resolution of 0.25° both in latitude and longitude. Monthly precipitation data from the ECMWF Re-Analysis (ERA)-Interim which have spatial resolution of 0.25° × 0.25, were also utilized. Note that the monthly climatology was defined by taking the long-term monthly mean of each parameter from January 2003 to December 2015.

RESULTS AND DISCUSSION

Monthly climatological fields of the surface chl in the WCS during the peak of northwest monsoon (January – February) until the spring monsoon-break (April – June) are presented in Figure 2. Apparently, it is shown that high surface chl concentration (> 0.4 mg m^{-3}) was observed in the WCS during January – February (Figures 2a-b). This high surface chl concentration extends northwestward along the eastern coast of Sumatra Island. In the south, the high surface chl concentration reached the Sunda Strait in February (Figure 2b. In March, high surface chl concentration remained in the southern part of the WCS and near the eastern coast of Sumatera and northern coast of Kalimantan (Figure 2c). A southward advection of water with low surface chl concentration from the southern Sumatra can be seen from February until April (Figures 2c-e). Interestingly, the

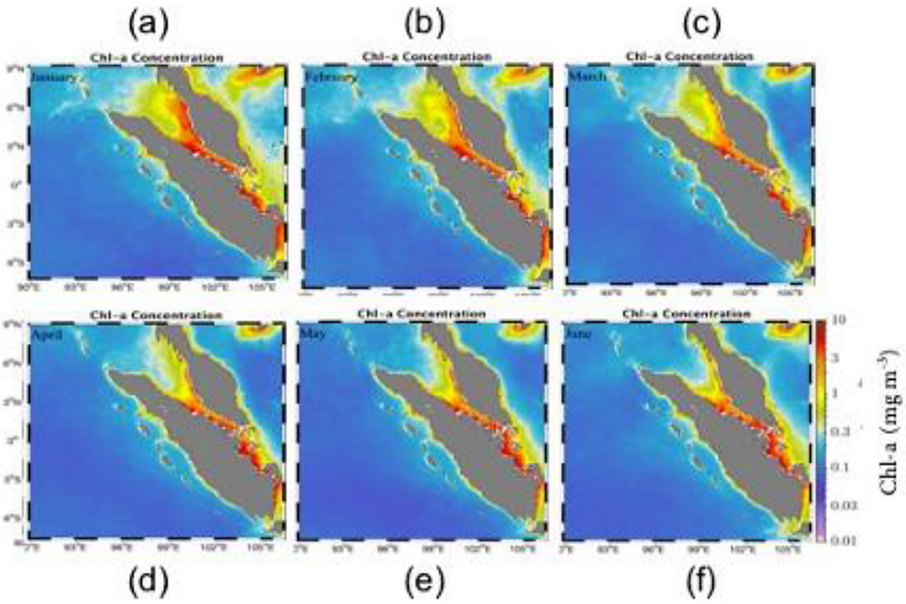

Figure 2. Monthly distribution of surface chl during the southeasterly wind regime

high surface chl concentrations observed in the Sunda Strait during the northwest monsoon indicate a situation opposite to that observed along the west coast of Sumatra and the south coast of Java, indicating that during this season It shows a low surface chl concentration. This may indicate a different mechanism underlying surface chl bloom in WCS. The surface chl concentration in the middle region of the WSC reached its lowest concentration during the spring monsoon-break in April (Figure 2e). Higher surface chl concentration was observed again in the southern part of the WSC in June as the southeast monsoon season starts to develop (Figure 2f). It was noted that higher concentration (> 1 m·m^{-3}) was observed along the coast throughout the season. However, the error in the satellite-estimated surface chl in the coastal water may be expected due to bottom reflectance, total suspended matter (TSM) or color dissolved organic matter (CDOM) (Schalles, 2006). Therefore, it requires an evaluation of the standard OC3/OC4 algorithm used to estimate surface chl concentration in this coastal region. The development of new algorithm for surface chl estimation in this region at the moment is hindered by limited available *in-situ* data.

Spatio-temporal distribution of surface chl concentration in the WSC during the southeast monsoon season (July – September) until the fall monsoon-break (October – November) is presented in Figure 5. It is shown that high surface chl concentration (~0.5 mg·m^{-3}) was observed in the WSC throughout the season from June to November with a slight reduction during the fall monsoon-break in October (Figure 3e). Compared to that observed during the northwest monsoon season (Figures 2a-d), the spatial distribution of observed chl concentration during the southeast monsoon season is more uniformly distributed across the Sunda Strait and extends more northward and southward (Figures 3a-d). In addition, the northward advection of water with high chl concentration from the southern Sumatra Island and Java Island is observed during July – August (Figures 3a-b). It should be noted that high concentration (> 1 mg·m^{-3}) was also observed along the coast throughout the season, which may relate to an error estimate of the chl concentration in the shallow water.

Monthly maps of climatological surface winds and SST during the northwest monsoon and the first monsoon-break seasons are presented in Figure 4. Remarkable seasonal cycle of surface winds and SST was also apparent over the WSC. During the northwest monsoon season (Figure 4a-d), the surface winds were dominated by southwesterly winds over the Sumatra Island and along northern Indian Ocean, which became northwesterly winds over the southern Sumatra. These alongshore winds force coastal downwelling along the eastern coast of Peninsular Malaysia and along the western coast of Sumatra (Johari et al., 2021), while they may induce coastal upwelling along the eastern coast of Sumatera. The SST patterns, however, did not indicate a direct response to these surface winds.

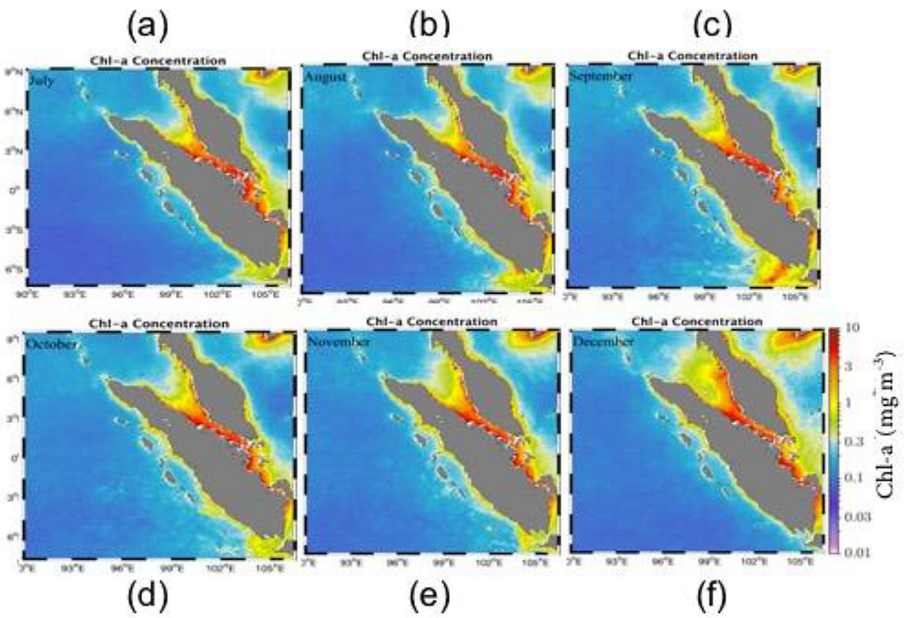

Figure 3. Monthly distribution of surface chl during the northwesterly wind regime

Note that relatively cold SST was observed in the Bay of Bengal in December (Figure 4a) and it shows a southward advection of this cold SST from the northern Sumatra into the WSC and the Java Sea (Figures 4b-c). The SST abruptly increased in March, while the surface winds were still in the same direction though they were weakened (Figure 4c). The surface winds were continuously weakened in April (Figure 4d) before they changed the direction in May when a northward advection of relatively cold SST was observed in the southern part of the WSC (Figure 4e).

In order to evaluate the dynamics underlying the increased surface chl concentration in the WSC during the southeast monsoon season, the surface winds and SST variabilities in the WSC were examined (Figure 4). It is clear that the increase surface chl concentration in the WSC was associated with during the southeast monsoon season. Note that the surface wind upwelling favorable winds observed gradually changed its direction during November (Figure 5f), while the surface chl showed an increased concentration (Figure 5f).

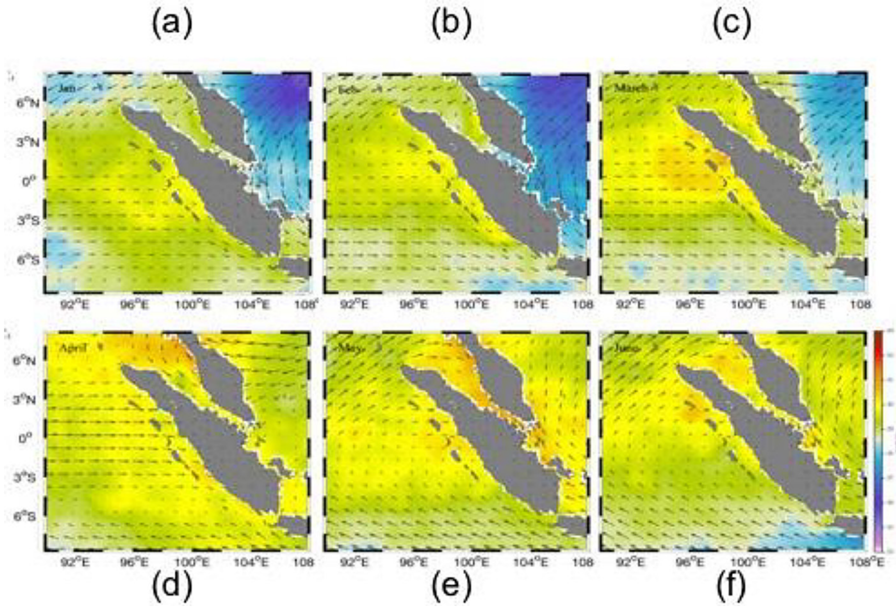

Figure 4. Monthly climatological of surface wind superimposed SST during the northwesterly wind regime in the west Sumatra

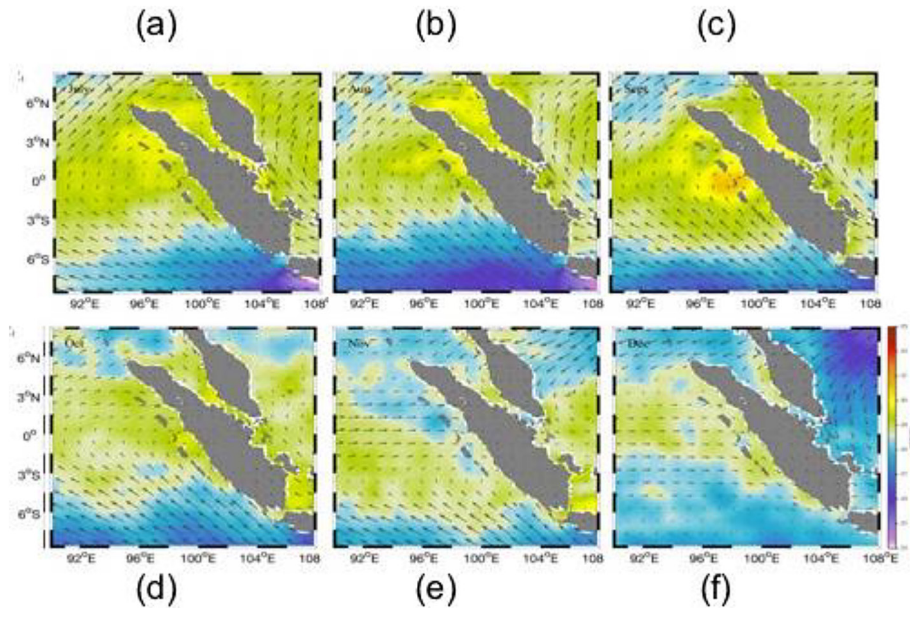

Figure 5. Monthly climatological of surface wind superimposed SST during the southeasterly wind regime in the west Sumatra

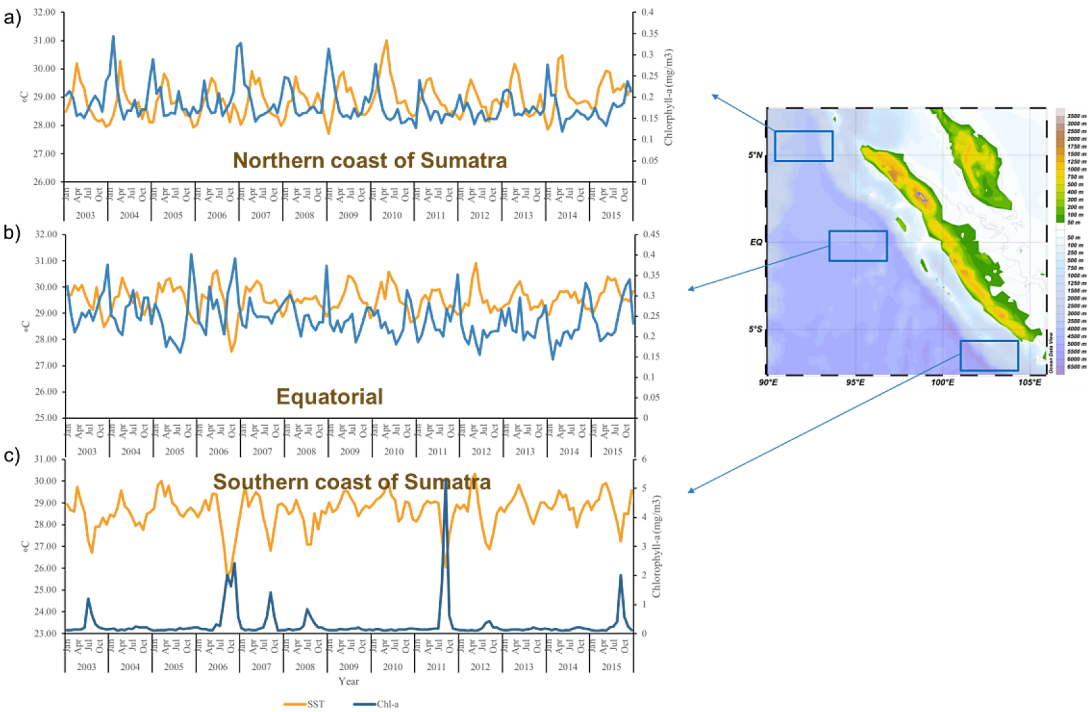

Figure 6. Time series of spatial mean of surface chl (blue line) and SST (orange line) over the northern coast of Sumatra (a), equatorial (b), and southern coast of Sumatra region (c) for the period January 2003 – December 2015

To investigate the pattern of the area in Sumatra, the spatial average of surface chl and SST in northern, equatorial, and southern Sumatra were conducted during January 2003 until December 2015 (Figure 6). The surface chl-a in southern Sumatra has highest concentration than the surface chl in the Equatorial and northern Sumatra. The range of surface chl concentration is ~6 mg/m^{-3}, ~0.4 mg/m^{-3}, and ~0.3 mg/m^{-3} in the southern, Equatorial, and northern part Sumatra, respectively. These results show the cold SST lead around one month the high surface chl in the northern Sumatra. The opposite condition observed that clearly shows the cold SST accompanied with high surface chl in the southern Sumatra. Meanwhile, the condition cold SST and high surface chl in Equatorial was found to have an irregular pattern.

CONCLUSIONS

The different responses of the surface chl and SST peak in western Sumatra followed the wind speed pattern. The surface chl and SST in the southern part of Sumatra Island has strong correlation with the peak of southeasterly wind. The strong southeasterly wind in June, July, and August, generated the upwelling in these areas may influence the high surface chl and cold SST. Meanwhile, the surface chl and SST in the middle part of Sumatra Island has strong correlation with the equatorial wind in fall monsoon-break September, October, and November. The surface chl and SST in the northern Sumatra Island has strong correlation with the northeasterly wind in January, February and March, which is the peak of the wind speed in these areas. In addition, the surface chl variation in the center and northern part or Sumatra is lower than the surface chl concentration southern part of Sumatra, because the feature of the topography may possible influence the concentration instead of the surface wind power.

Acknowledgments

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