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Research Paper

Vertical Chlorophyll-a Concentration Profiles Observed on The Western Coast of Northern Sumatera During the 2017 Northeast Monsoon

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Abstract

Subsurface chlorophyll-a (chl-a) concentration variability on Sumatera's Northwestern coast is part of the phytoplankton biomass that supports and enriches the region's fisheries supplies. During the 2017 northeast monsoon season from 25th November 25 to 11th December, the Ekspedisi Widya Nusantara (E-WIN) collected data from 16 stations. The finding demonstrates a rise in subsurface chl-a concentration as you get closer to the coast. Furthermore, the deep chl-a maximum (DCM) is only found offshore, with depths between 30 to 50 m and chl-a concentrations of 0.07 to 0.25 mg.m^{-3}. Surface chl-a concentrations near the coast were found to be high, ranging from 0.2 to 0.25 mg.m^{-3}.

Keywords
Deep Chlorophyll-a Maximum, E-WIN Cruise, MODIS Aqua, Surface Chlorophyll-a

1. INTRODUCTION

Located in the tropical Indian Ocean, the Northern Sumatera region is subject to the monsoon system. It has been known that the monsoon system can generate upwelling/downwelling process along the coast. Monsoon systems are thought to play a significant impact in ocean circulation in this area, according to previous research (Sari et al., 2018). The change of ocean circulation as well as nutrient source could affect marine food chain and fisheries production. The concentration of chlorophyll-a (chl-a) has been proposed as the best proxy for phytoplankton biomass, making it valuable for the study of primary production (Huot et al., 2007). It should be noted that this study was conducted for the subtropical water with warm temperature. The photosynthetic parameters and thus primary productivity depend on the environmental variables. The primary productivity response may differ depending on the geography. Surface chl-a, for example, accounts for around 51% of the entire variance in integrated primary output in the Argentine seas (Lutz et al., 2010; Segura et al., 2013).

The MODIS satellite data in Northern Sumatera were used to examine the geographical and temporal variations of the surface chl-a (Sari et al., 2018). The results demonstrate that in Northern Sumatera during the peak of boreal fall (boreal summer), the surface chl-a is high (low). Furthermore, the

monsoon system and associated atmosphere-ocean interactions in the tropical Pacific, namely the El Niño-Southern Oscillation (ENSO), and in the tropical Indian Ocean, namely the Indian Ocean Dipole (IOD), have a significant impact on the abundance of surface chl-a (Sari et al., 2018; Siswanto et al., 2015).

Chl-a maximum is not usually found at the sea surface, but it can also be found deeper than the euphotic zone's bottom. The chl-a maximum cannot be measured using satellite remote sensing in this circumstance. Moreover, seasonal and annual variations of surface chl-a represent unique spatial patterns on a global scale, according to satellite ocean color studies. On regional scales, satellite ocean color studies indicated a strong annual cycle of surface chl-a in the southeastern tropical Indian Ocean and Northern Sumatera, resembling subtropical or temperate regions (Susanto et al., 2006; Siswanto et al., 2017; Iskandar et al., 2009; Amri et al., 2014; Sari et al., 2018).

In this paper, we used vertically observed chl-a concentration from the E-WIN cruise during early of the 2017 northeast monsoon season in the western coast of Northern Sumatera region. The goal of this research is to look at the vertical patterns of chl-a concentration along the cruise track in Sumatera's Northern portion. The rest of the paper is laid out as follows. The study area, data, and techniques are all described in Section

2. In Section 3, we describe and discuss the study's primary findings. The study's result is presented in the final part.

2. EXPERIMENTAL SECTION

2.1 Materials

The research area is located between 12°N - 3°S and 90°E - 102°E on the western coast of northern part of Sumatera (Figure 1). The E-WIN cruise was conducted from 25 November to 11 December 2017 using the RV. Baruna Jaya VIII of the Indonesian Institute of Sciences. The cruise started from the station E1 near Sabang, Aceh to the station E16 in the eastern Simeuleu Island (Figure 1). The cruise tracks are indicated by red line, while the Conductivity-Temperature-Depth (CTD) observation stations are indicated by yellow filled-stars.
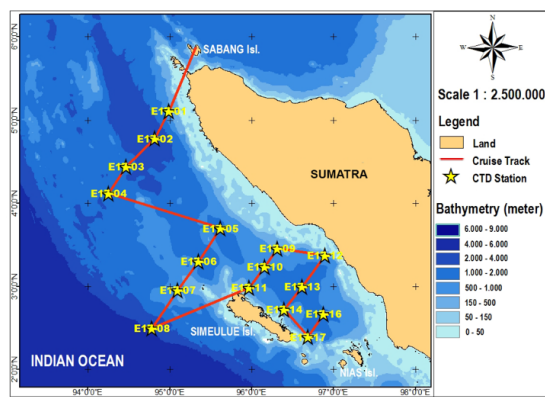

Figure 1. The Transect of The E-WIN Expedition During The Northeast Monsoon of 2017 Is Shown by The Red Line, and The CTD Stations Are Indicated by The Yellow Filled-Circle.

2.2 Methods

Chl-a concentrations were sampled at 16 locations along Northern Sumatera's western coast. With a Rosette sampler from Niskin Bottles installed on a Sea-Bird Electronics conductivity-temperature-depth (CTD) type SBE-911 plus, discrete sea-water samples were taken from 6 fixed depths (5, 50, 75, 100, 150, and 300 m) at each station. Measurements of nutrient concentrations (phosphate, nitrate, and silicate) were carried out using the HACH spectrophotometer (Suzuki et al., 1995). The fluorometric approach was used to measure phytoplankton chl-a concentrations, as recommended by U.S. Environmental Protection Agency (1983). Under a vacuum pump with a pressure less than 30 cmHg, 0.1-1.0 liter of water was filtered using the Whatman CNM porous filter with a 0.45 m and 25 mm diameter. Before being examined, the membrane filters were stored in a cooler (with temperatures below 4°C) for roughly 20 hours after being wrapped in aluminum foil (U.S. Environmental Protection Agency , 1983). After filtration, the samples were extracted using a 90 percent acetone extraction solution (Cochlan and Hendorn, 2012; Holm-Hansen et al., 1965) and centrifuged for 30 minutes at 4,000 rpm to separate the filter from the chl-a-containing solution (Cochlan

and Hendorn, 2012; Holm-Hansen et al., 1965). The vertical profiles of fluorescence are then obtained by reading the fluorescent liquid using the AU-10 Turner Trilogy Fluorometer. The concentration of phytoplankton chl-a is defined as,

$$\text{Chl-a}(\mu g/L) = ((y - b)/m)(v/V) \qquad (1)$$

where y is a fluorescence value, b is the y axis value that intersects the curve calibration, m is a slope of the regression line on the standard curve (calibration), v is a volume of the extract (after addition of acetone 90%) (mL), and V is the volume of filtered sample (mL).

Using CTD dataset, the mixed layer depth (MLD) was calculated as a depth where the density increases by 0.125 kg.m^{-3} from that of the reference point (10 m deep) Zeng and Wang (2017) as shown in Table 1.

Table 1. Calculated Mixed Layer Depth using Density Criterion

Station	MLD (m)
E017-01	31
E017-02	20
E017-03	21
E017-04	15
E017-05	20
E017-06	25
E017-07	14
E017-08	50
E017-09	25
E017-10	22
E017-11	31
E017-12	18
E017-13	23
E017-14	24
E017-15	12
E017-16	19
E017-17	31

The in situ data is also compared to the surface chl-a concentration remotely-sensed by the Moderate Resolution Imaging Spectroradiometer (MODIS) aboard the Aqua satellite between 25th November and 18th December 2017. The NASA Goddard Distributed Active Archive Center provided the satellite data, which had a horizontal resolution of 4 km (https://modis.gsfc.nasa.gov/).

3. RESULTS AND DISCUSSION

3.1 Vetical Profiles of Chlorphyll-a Concentrations and Fluorescences

Based on the distance of stations to the coast, the water characteristics of the western coast of Northern Sumatera can be clustered into two regions (Figure 1), namely the offshore and the coastal waters. The vertical profiles of chl-a along the western coast of Northern Sumatera, along with the vertical profiles

of the observed fluorescene, were used to identify each observation station in the present study. The fluorescene can be employed as an indicator of chl-a concentration, according to the method proposed in early study (Sauzède et al., 2015; Zhao et al., 2019). The water characteristic with deep chl-a maximum (DCM) and high surface chl-a (HSC) profile data was used to characterize the chl-a visual analysis (Lavigne et al., 2015). Vertical chl-a profiles are often described using the DCM and HSC forms (Lavigne et al., 2015). They are characterized by the relative position of MLD and are referred to as "stratified" and "mixed," respectively. The HSC standard shape was generated for profiles with a continuous decrease in chl-a from surface to depth (approximately 100 m), such as those seen during phytoplankton blooms (Chiswell, 2011). Profiles with relatively high values in the mixed layer and a fluoresence peak directly below the MLD are represnted by the DCM form. Table 1 shows that the MLD in the study area was usually between 14 and 50 m. The deepest MLD is at station E017-08, with a depth of 50 m, while the shallowest MLD is at station E017-17, with a depth of 14 m.

Figure 2. Vertical Profiles of (a, d) Chl-a Concentration, (b, e) Fluorescence, and (c, f) Turbidity. The Classification is Based on Avertical Chl-a Concentration Profile, with The Upper Panel Representing Stations with High Surface Chl-a (HSC), and The Lower Panel Representing The Stations with Deep Chl-a Maximum (DCM)

Figure 2 depicts chl-a concentration, fluorescence, and turbidity profiles in Northern Sumatera waters from the surface to 300 m depth. Figures 2a and 2d show that the observed profiles of chl-a concentration are remarkably comparable to the profiles of fluorescence (Figures 2b and 2e). With the exception of station E017-05, where no chl-a was identified in the surface water, the surface chl-a concentration in Northern Sumatera waters was about 0.051 to 0.21 mg.m^{-3} (Figures 2a and 2d). This indicates that the Northern Sumatera waters are oligotrophic waters. The high and low concentration of chl-a is closely related to the supply of nutrients originating from the land through the rivers discharge into these areas. The sur-

face chl-a concentration was found more at the stations located close to the land than that at the stations located toward the sea. The highest concentration of surface chl-a was found at station E017-13, which lies between the Sumatera and Simelue Island with a value of 0.21 mg.m^{-3}. In the east of Simelue Island, we found turbid waters caused by the presence of suspended particles and high levels of sludge which were carried from the land and rivers around the island. Meanwhile, the lowest concentration of surface chl-a was observed at stations E017-03 and E017-07. This is presumably because the location of those stations were heading towards the open sea resulting in little input of nutrients from the land which causes less surface chlorophyll content.

It was confirmed by Figure 2 that the stations located near the coast are having high surface chl-a concentration, while those located offshore tend to have deep chl-a maximum. Moreover, the coastal water is also characterized by high turbid water (Figure 2c). It is worth noting that the land gives a lot of input into the waters. As a result, waters near the land become fertile water which will ultimately be beneficial for phytoplankton to carry out photosynthetic activity. Previous study has suggested that river runoff significantly affect the content of nutrients (Phosphate, Nitrate and Silicate) in the ocean (Zhang et al., 2020). In addition, it can inferred aslo from Figures 2 that high chl-a concentrations are found at the stations located around the estuary (stations E017-11 and E017-17). The degree of acidity (pH) and nitrate play vital roles in the aquatic environment's health. pH fluctuations have an impact on chemical processes and biological organisms in the water as well as the toxicity of a chemical compound in water. The pH of water has a significant impact on its metabolic activities, for example, if the pH is too low, nitrification will cease (Le et al., 2019). While nitrate is a key component of primary productivity, it is also consumed by phytoplankton and is required for photosynthesis (Li et al., 2010).
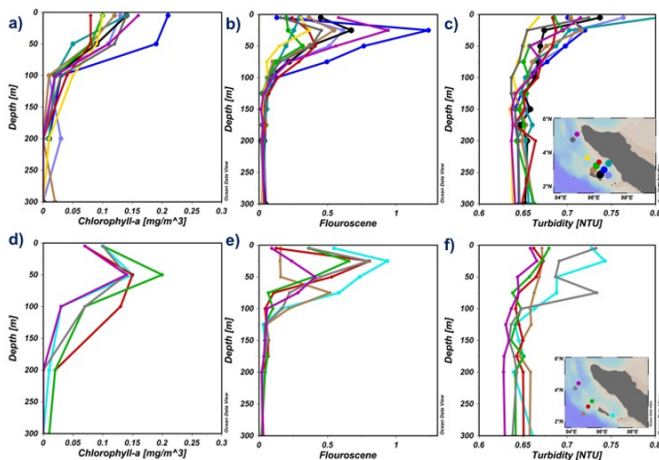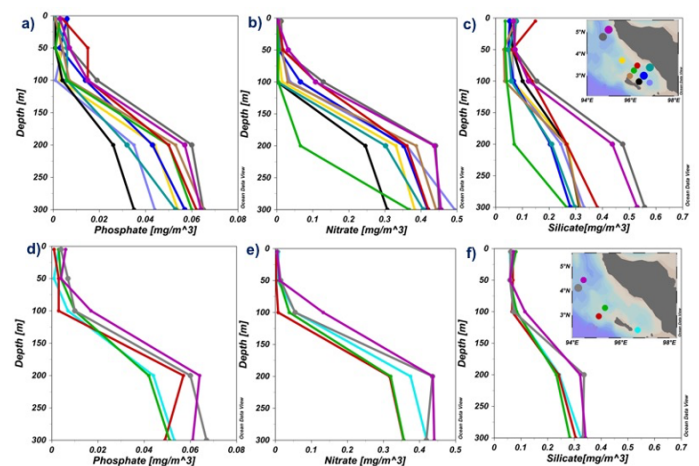

Figure 3. Same as Figure 2 Except for Vertical Profiles of (a, d) Phosphate, (b, e) Nitrate, and (c, f) Silicate.

Phosphate, nitrate, and silicate vertical profiles are shown in

Figure 3. Phosphate has a vertical profile that ranges from 0.01 mg.m^{-3} at the surface to 0.063 mg.m^{-3} at 300 m depth (Figures 3a, d), while nitrate has a vertical profile that ranges from 0 near the surface to 0.49 mg.m^{-3} at 300 m depth (Figures 3a, d) (Figures 3b, e). Silicate has a vertical profile ranging from 0.05 mg.m^{-3} near the surface to 0.57 mg.m^{-3} at 300 m underground (Figures 3c, f). There was no discernible difference in the vertical profiles of phosphate, nitrate, and silicate between the stations along the coast and those offshore, according to our findings.

3.2 The Weekly Satellite Surface Chl-a Distributions

We showed the distribution of surface chl-a before, during, and after sampling in this study. Due to cloud cover, satellite image quality was poor from 25th November to 2nd December 2017. The satellite measurement nicely recorded the surface chl-a concentration during the sample (December 3−10, 2017) and after the sampling (December 11−18, 2017) (Figure 4). The concentration of surface chl-a near the coast (0.3 − 1 mg.m^{-3}) is clearly higher than in the offshore area (0.10 − 0.2 mg.m^{-3}), which is consistent with our in-situ observation.
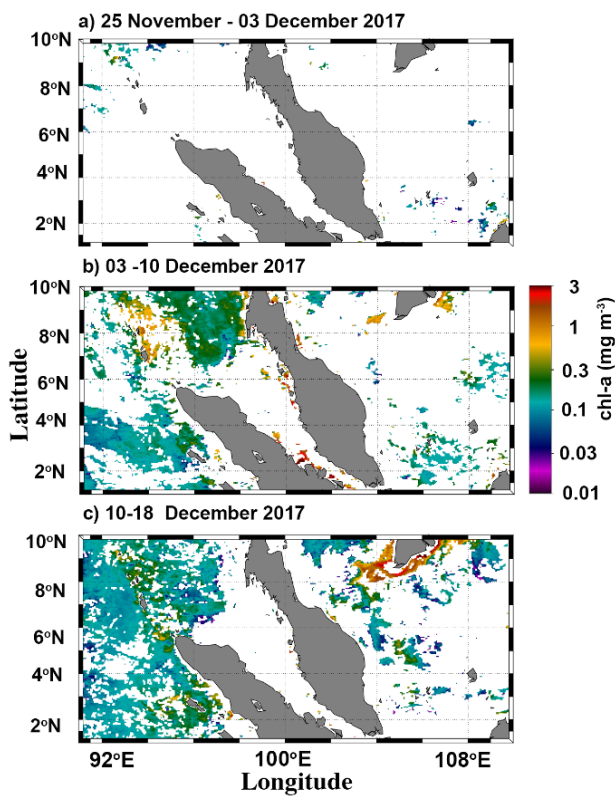

Figure 4. Weekly Composite of Surface Chl-a Derived from MODIS During a) 25 November-03 December 2017, b) 03-10 December 2017 and, c) 10-18 December 2017.

4. CONCLUSIONS

Based on in-situ observations obtained during the E-WIN cruise from 25th November to 11th December 2017, this study analyzed the vertical profile of chl-a concentration in Northwestern Sumatera. Discrete seawater samples were taken at depths ranging from 5 to 300 m. Note that while the HACH spectrophotometer was used to assess nutrient concentrations (phosphate, nitrate, and silicate), the fluorometric technique was used to detect phytoplankton chl-a concentrations.

The results reveal geographical differences in vertical chl-a concentrations, with high surface chl-a concentrations found near the shoreline and DCM detected offshore. Station E017-13, located between Sumatera and Simelue Island, had the highest surface chl-a concentration of 0.21 mg.m^{-3}. The lowest surface chl-a concentrations, on the other hand, were found at open-sea stations E03 and E017-07. Furthermore, the staellite pictures confirmed that chl-a concentrations in the coastal zone range from 0.30 to 1 mg.m^{-3}, which is higher than the 0.10 to 0.2 mg.m^{-3} seen offshore. The vertical profiles of phosphate, nitrate, and silicate showed no substantial regional variation.

5. ACKNOWLEDGEMENT

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