

Determining temporal and spatial variabilities of biological production in sulu sea using multi-remotely sensed data

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Abstract. This study was conducted to investigate the temporal and spatial variation of the chlorophyll-a concentration over the past 13 years of Sea-viewing Wide Field-of-view Sensor (SeaWiFS) mission in the Sulu Sea area. The objectives of this study are to analyze the long term and spatial variability of the Chl-a concentration in Sulu Sea with special emphasize on the relationship between Chl-a concentration with the other oceanographic parameters such as sea surface temperature (SST), wind speed and wind directions. The Chl-a concentration were high during northeast monsoon which experience low SST. The fluctuation of Chl-a and SST are associated by the wind speed variation in this area. This suggests that during northeast monsoon, the increasing of wind speed intensifies water column mixing which entrains submerged cold- and nutrient-rich deep water to the surface layer, resulting in low SST and high nutrient in the surface layer. On the other hand, the southwest monsoon records dramatically decreasing of the Chl-a with regard to lower wind speed and surface water heating occurrence. This promotes the downwelling process and weakens the upwelling one in the Sulu Sea [1] and as a result, this phenomenon influence reduction of nutrient upwelling to the surface layer, and thus produces lower Chl-a throughout the seasonal periods.

1. Introduction

Sulu Sea has been categorized as a deep sea in the Southeast Asian region along the Southwest part of the Philippines [1,2]. The Sulu Sea extends from 6 to 12°N and from 117 to 123°E, bounded by Borneo at the southwest and Palawan Island at the west of Sulu Sea [2]. It also consists of Panay Island and Mindanao Island in the east and Sulu Archipelago in the southeast. As mentioned by Wang et al. (2006), the Sulu Sea is strongly influenced by the East Asian Monsoon systems; northeasterly wind in winter, southwesterly wind in summer and highly variable during the transitional periods. They also reported that in summer, surface currents mostly coming from the southern part, while during the winter, the surface current moves counterclockwise. Occurrence of this phenomena leads to the variation of phytoplankton concentration [3].

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Chlorophyll-a (hereafter referred as Chl-a) are widely being used as a proxy measurement of phytoplankton biomass and photosynthetic potential for many years [2]. Chl-a concentration commonly being used in order to investigate the marine production, temporal and spatial variation of Chl-a concentration commonly influenced by climatic changes, oceanic circulation, upwelling, temperature river runoff (coastal area) and other chemical conditions [5,6]. In order to monitor and investigate the Chl-a concentration at the first trophic level, remote sensing ocean colour is one of the solutions which provides the synoptic spatial and temporal data that are not attainable by sea-truthing [1,2].

Previous study suggests that the Sulu Sea have higher marine production level amongst other sea water in the South China Sea [1] and therefore it mainly supports the regional fishery production [2,3,4]. Though, the knowledge about variation of biological production in space and time (over a long term period), and driven factors underlying the variations are lack and not well documented. Therefore the objectives for this study are to determine the spatial and temporal variation of the Chl-a concentration in Sulu Sea from the synergy of multi remote sensing satellite data and to study the role of oceanographic parameters such as sea surface temperature (SST), wind speeds and wind directions that driven the inter-annual variation of Chl-a distribution.

2. Data and methods

In order to have a comprehensive understanding on the factors determining spatial and temporal variations of Chl-a concentration hence the biological production, remote sensing data from multi sensors, i.e., ocean color sensor, thermal sensor, and scatterometer are used. In this study the the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) provides the ocean colour estimates and the Advance Very High Radiometer (AVHRR) of thermal sensor senses the sea surface temperature (SST). As a compliment, the Multispectral sensor Sensor Moderate Resolution Imaging Spectroradiometer (MODIS-Terra) data is used to assess the Chl-a and SST variation.

The Chl-a data used in this study are the SeaWiFS monthly level 3 data which obtained from the Goddard Space Flight Center (GSFC), NASA website (<http://oceancolor.gsfc.nasa.gov>) within September 1997 until December 2010. These data then were processed and analyzed using SeaWiFS Data Analysis System (SeaDAS) and Matrix Laboratory (Matlab) . The SST monthly data were retrieved from two different thermal sensors which are the Advanced Very High Resolution Radiometer (AVHRR); which been downloaded through Asia Pacific Data Research Center (<http://apdrc.soest.hawaii.edu>) and Moderate Resolution Imaging Spectrometer (MODIS) on Terra satellite; from the Goddard Earth Science Data and Information Services Center (<http://disc.sci.gsfc.nasa.gov/giovanni.html>). Beginning on September 1997 until December 2001, SST data from AVHRR (Pathfinder Version 5.1) were used. Then, to complete the study period until December 2010, MODIS (Aqua) Level 3 SST products were used. The averaged monthly wind speed were obtained from Cross-Calibrated Multi-Platform (CCMP) products data which downloaded from the Physical Oceanography Distributed Active Archive Center (<http://podaac.jpl.nasa.gov>). Meanwhile, the wind direction (U and V component) data were gathered from Fleet Numerical Meteorology and Oceanography Center (FNMOC) product data at Pacific Fisheries Environmental Laboratory LAS (<http://las.pfeg.noaa.gov/las/>).

The SeaWiFS data were undergo a masking processed to eliminate the case-2 water area. This is because, the standard algorithm that been used to retrieved Chl-a concentration by SeaWiFS works well in case 1 water. Besides that, the optical properties of case 1 water determine primarily by phytoplankton biomass and their derivatives product which usually referring to deep

and open ocean [4]. Therefore, in this masking process, we used nLw 555 as an indicator of water quality index. As presented in figure 1, the area with nLw 555 value more than 1 were classified as case 2 water and been eliminated from our study area.

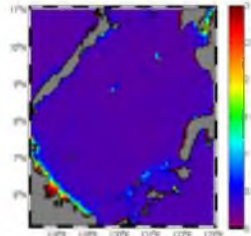


Figure 1. The masking result, case 2 water with nLw 555 more than 1 were discarded from the study region.

The monthly wind speed and wind direction data were downloaded and Matlab were used to calculate the monthly anomalies. In order to display the wind direction, Surfer 9 software was used to map the wind direction over the Sulu Sea.

3. Results and discussions

3.1 Seasonal variations of Chl-a

The analysis of the 13-years SeaWiFS Chl-a monthly data in Sulu Sea showed that, the concentration of Chl-a were varied seasonally and most probably influenced by the tropical monsoon season. Based on the figure 2, the seasonal variability of Chl-a increase during the northeast monsoon (NEM) which prevails from November until January and start to decrease during the Southwest monsoon (SWM) that occurs from June until September.

Starting on November, the monthly mean of Chl-a concentration increased approximately ($\sim 0.10 \text{ mg/m}^3$), then the Chl-a concentration were continue to rise until February and begin to decrease on March. This is strongly because of the occurrence of northeast monsoon. Furthermore, the time series of monthly average Chl-a in this area (figure 3) shows that the maximum peak of Chl-a was occurred in January and the lowest Chl-a concentration recorded was in the September. Based on figure 2, starting December until February the Chl-a concentration were higher at the northern part of Sulu Sea (around the Mindoro Straits and Panay Island) compared to the central part.

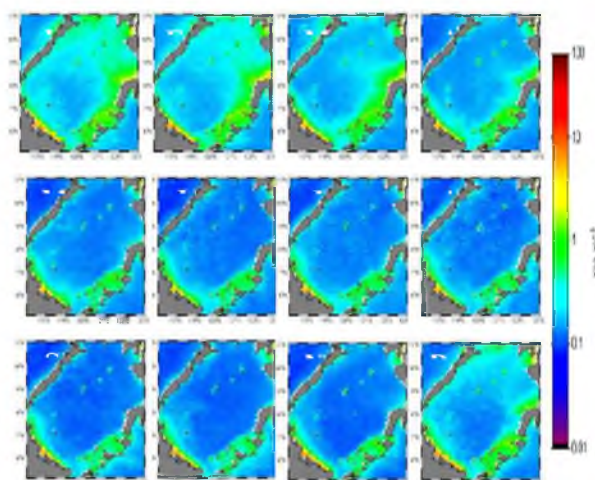


Figure 2. The monthly mean Chl-a concentration of SeaWiFS data beginning September 1997 until December 2010.

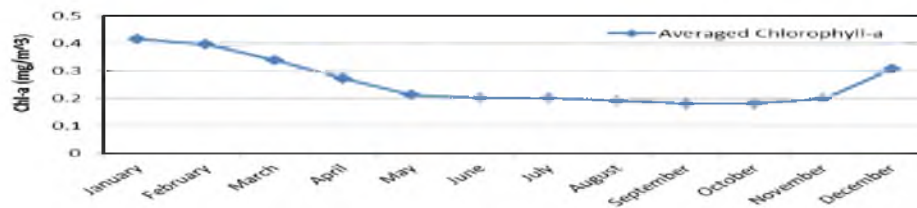


Figure 3. The average chl-a concentration in the Sulu Sea for 1997 until 2010.

Based on the monthly mean of Chl-a concentration in Sulu Sea (figure 3), on June until August the Chl-a concentration decrease dramatically and this can be relate with the southwest monsoon event. Eventhough the climatological map shows high concentration near the southern part and the Sulu archipelagoes but that was because of the narrow and shallow coastal waters. Moreover, from the Figure 2 showed low Chl-a concentration at the central basin ($\sim 0.14 \text{ mg/m}^3$) for most of the month. This result agreed well with the previous result which study Chl-a concentration here using OCTS data [1], which stated that the center part of Sulu Sea was dessert and contain low nutrient.

3.2. Sea surface temperature (SST)

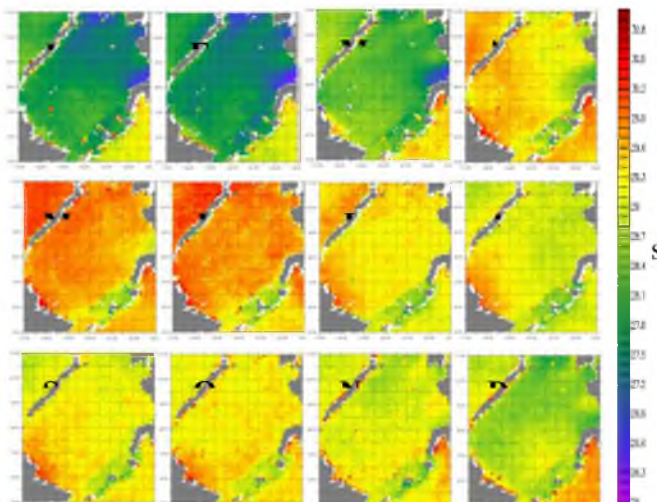


Figure 4. The climatological map for SST in Sulu Sea using AVHRR and MODIS (Aqua).

As Sulu Sea located in the tropical region, the SST range recorded high within the range of 26 until 31°C throughout the year. In the figure 5, the SST's in Sulu Sea were inversely proportional with the Chl-a concentration throughout the year. Generally, the SST in Sulu Sea was recorded low during the northeast monsoon season which occurs in December until February. The SST begins to drop from 29.3°C in November to 28.9°C in December. Then, it keeps decreased in February with average temperature, 27.1°C. As illustrated in figure 4, there were low SST recorded around the northern part of the Sulu Sea compared to the center and southern area. However, these were appositely with the Chl-a concentration which shows high intensity at north part during the same monsoon season.

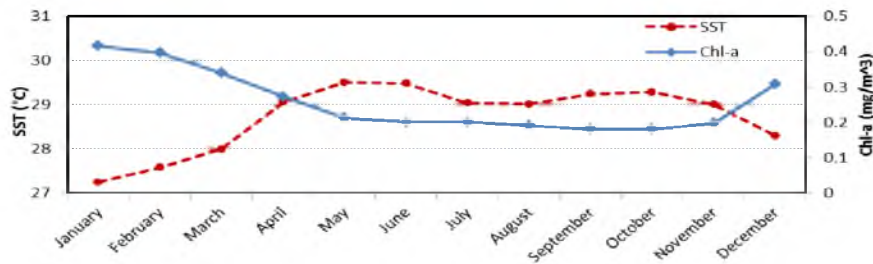


Figure 5. The variation of Chl-a concentration over Sulu Sea with sea surface temperature (SST) in Sulu Sea.

Meanwhile, the surface water temperature keep rising starting March, and the highest SST were recorded in June with the average value approximately 30.5°C to 31°C (figure 4; June). The surface temperatures for the entire basin were quite high during the southwest monsoon which extends from June until August (Figure 4 and Figure 5).

3.3. Wind speed and wind direction

The figure 6 showed the variations on the monthly wind direction in the Sulu Sea, thus the average wind speed varied from 1.0 to 7.3 m/s.

Based on the figure 6, a steady increase of wind speed was observed on December which the winds remain until February and these correspond with the northeast monsoon season, where the wind speeds proportionally increased with Chl-a concentration. Sulu Sea is surrounded with few islands and archipelagoes, which resemble and acts as the boundaries. Because of this topography, the winds from these inter-island gaps produce wind-jet formations which increase the wind speed during the strong northeasterly winds.

However, beginning February the northeasterly winds decreasing slowly and became weaker in March and April. The transition period appear in May and in the following month June until August, Sulu Sea experiencing weak southwesterly wind. Referring to the monthly wind direction map (in figure 6), southwesterly wind blew with low wind speed. This situation can be related well with the low Chl-a distribution during southwest monsoon.

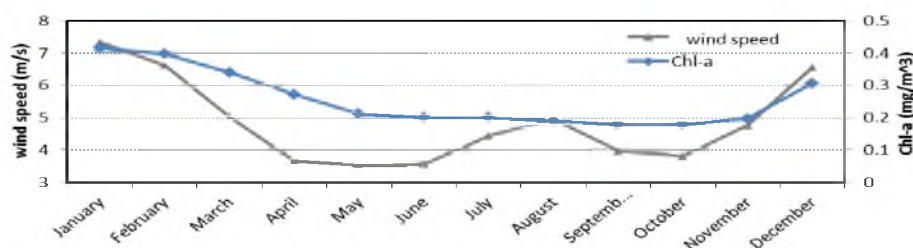


Figure 6. The correlation between the monthly average wind speeds with seasonal Chl-a concentration in Sulu Sea.

3.4. Discussions

In general, the mean of Chl-a concentration for the entire Sulu Sea is quite low (<0.5mg/m³). Moreover, in the previous study by [1, 2], they had classified Sulu Sea as the tropical oligotrophic waters, which referred to little nutrient environment [1,2]. As illustrated in the figure 3 (time series Chl-a), the Chl-a concentration in this area normally increase during northeast monsoon season.

In the present results, high Chl-a concentration were recorded during northeast monsoon season. Furthermore, intense Chl-a distribution were recorded along the northern part of Sulu Sea. Meanwhile, the center and southern area of Sulu Sea shows uniform and low Chl-a concentration. This was related with the influence of the strong northeasterly wind which blew in December until February. These strong northeasterly winds induced the upwelling process which produced a strong vertical mixing process that brought the cold and nutrient rich water from the subsurface layer to the surface. Hence, this process enhancing the Chl-a concentration in the water surface near the northern part of Sulu Sea. The occurrence of this vertical mixing process was led to low SST during this monsoon season.

Low Chl-a concentration were recorded during the southwest monsoon. However, there are still high Chl-a concentration found along the coastal area and shallow water area. These were caused by the nutrients that come from inland runoff [2,7]. Weak southwesterly wind prevails in Sulu Sea during southwest monsoon (June to September) which indicates downwelling process and weaken vertical mixing occurred. Moreover, the weak vertical mixing cycle minimizing the nutrient upwelling and reduced the Chl-a concentration in the Sulu Sea.

4. Conclusion

Low Chl-a can be seen during the southwest monsoon. Moreover, the SST was recorded high during this period (June to September) accompanied by low Chl-a distributions throughout the basin. This shows that, during southwest monsoon, low wind speed and surface water heating occur. In addition, this will promote downwelling process and weakened the upwelling in the Sulu Sea. Therefore, this phenomenon influence reduction of nutrient upwelling to the surface layer, and then produces low Chl-a especially during this period seasonally.

The Chl-a concentration were recorded high during northeast monsoon which experiencing low SST. The fluctuation of Chl-a and SST can be explain by the wind speed variation in this area. This suggest that during northeast monsoon, the increasing of wind speed intensifies water column mixing which entrains cold- and nutrient-rich deep water from deep water to the surface layer, resulting in low SST and high nutrient in the surface layer. This increase in nutrient in turn will lead to induce phytoplankton growth which is observed as high Chl-a. Thus, a conclusion can be made that, Chl-a and wind speed shows a negative correlation to SST in the Sulu Sea. Unfortunately, this finding only can explain the seasonal variation of Chl-a.

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