ESTIMATING CHLOROPHYLL-A VARIATIONS WITH TEMPORAL MODIS DATA TIME SERIES

Phan Minh Thu[1,2], Nguyen Thu Thao[3] and Ho Dinh Duan[4]

[1]Institute of Oceanography, Vietnam Academy of Science and Technology (VAST), Vietnam
[2]Graduate University of Science and Technology, VAST, Ha Noi, Vietnam
[3]HCMC University of Natural Resources and Environment, Ho Chi Minh City, Vietnam
[4]HCMC Institute of Physic, VAST, Ho Chi Minh City, Vietnam
Email: phanminhthu@vnio.org.vn

ABSTRACT

Chlorophyll-a concentration (Chl-a) is an important factor in ecological property of the marine and coastal environment monitoring. It is a crucial index for water quality assessment in addition to others such as BOD, COD, TSS and etc. There exists an abundance of algorithms for estimating Chlorophyl-a concentration using Remote Sensing data, as well as its variation in time. In this study, we focus on analyzing the Chlorophyl-a concentration in surface water time series of Van Phong Bay area during the past 20 years based on the ocean MODIS data (NASA /OCEANDATA /MODIS-Aqua/L3SMI). Our approach used the Google Earth Engine (GEE) algorithms and processing capability of these tools. The study area, Van Phong Bay, is located in the vicinity north of Nha Trang City, a well-known tourism landmark of Vietnam, and also an important aquaculture site of the locality. Our study has revealed certain connection between the variation of Chlorophyl-a concentration in this area with the past incidents of algae bloom, as well as showing some trends and seasonal variation of the Chlorophyll-a index, which can be useful for prediction of water quality in the study area.

1. INTRODUCTION

Marine ecology has strong relationship with status and variation of Chlorophyll-a concentration (Chl-a). It is a key parameter in monitoring the marine and coastal environment, which has long been achieved by combining in-situ observations with remote sensing ocean color radiometry (OCR) (Shao *et al.*, 2011). The importance of understanding Chl-a in coastal waters has furthermore a particular interest, as it is an indicator for the health and nutrient status of the coastal habitats (Ferreira *et al.*, 2011; IOCCG, 2012). Chl-a has been well-known as an index of phytoplankton biomass, which is primarily responsible for the big process of carbon dioxide to organic carbon transformation (Falkowski & Kiefer, 1985; Sathyendranath *et al.*, 2019).

Estimation of Chl-a so far has been successfully achieved with satellite imageries and water sampling work, especially with the utilization of new remote sensing ocean color algorithms such as the OC2-6 for vast ocean regions as well as coastal areas (Gitelson *et al.*, 2011; O'Reilly & Werdell, 2019). Though these algorithms are by their nature either global or localized, which means there is a trade-off between using global models (lower accuracy) and regional models (higher accuracy, but for a specific area). In this aspect, a refined algorithm would be preferable for using the OCx algorithms to calculate Chl-a in coastal areas; but in the absence of an up-to-date formula of the algorithm, a multi-year thorough investigation with the presence of sufficient satellite data would be acceptable (Gitelson *et al.*, 2011; Hu *et al.*, 2012; O'Reilly & Werdell, 2019). One of the present-day tools that enables the harnessing of the huge inventory of satellite imageries for realizing the OCx algorithms, is the Google Earth Engine

(GEE) (Wang *et al.*, 2020). This tool provides a good time series of available cloud-based satellite data as well as a powerful computational capacity to support our study. In this study the temporal L3SMI MODIS dataset was used (NASA OB.DAAC, 2021), in combination with in-situ data of Chl-a.

The relatively rich variations of Chl-a in coastal waters partly reflects the unique features of the regional ecological system of a particular area, especially when it inherits a ubiquitous natural formation such as a half-closed bay with estuaries and a high tidal fluctuation. This is the case of our study. Van Phong bay is located north of Nha Trang city, a medium-size city with not only a unique landscape, but also under the process of rapid urbanization with plenty of tourism and aquaculture facilities. The human activities, together with the seasonal upwellings of the encompassing sea, are main factors that have long been contributing to the high variations of Chl-a in and near the bay (An, 2002). In the past, there have been several harmful algal blooms in these areas, which proved the extreme fluctuation of Chl-a concentration in the region. This kind of marine incidents have been recorded in 2007, 2011-2012, 2014, 2016- 2017, and 2018-2019, and to some extent has been studied and analyzed, which eventually showed a clue to Chl-a boom in the region (Doan-Nhu *et al.*, 2017; Luom *et al.*, 2021). With the data and computation engine provided by GEE, the present study aims at obtaining a picture of the variations through the years and an analysis of its trends and the seasonal behaviors. The mathematical tool used here is Fourier analysis. Through studying the extents of the multi-year Chl-a variations, a relationship with past algal blooms, though not very strong, could be revealed. The effects of upwelling, nutrient sources, and climatological factors, are with no doubt related to the Chl-a fluctuations, but they are beyond the scope of this paper, and should dedicate another discussion.

2. METHODOLOGY

2.1 Study area and materials

Van Phong Bay is located in the north of Khanh Hoa Province (Figure 1). The longitudinal coordinate of the bay has the easternmost position of Vietnam. It has a water surface area of 41,000 ha and a depth of 20-30 m, and is relatively free from wind. Thus, Van Phong Bay does not only contribute to fishing ground and aquaculture and but also targets to development of a region for international container transportation port and marine ecotourism. However, due to the impact of inland activities and marine aquaculture, the environment has been significantly degraded.

This study was conducted using MODIS data of Ocean Color SMI (Standard Mapped Image) MODIS Aqua Data, in which Chl-a (in mg m^{-3}) was collected in the period from 01 Jan 2003 to 31 Dec 2020 (NASA OB.DAAC, 2021). The daily data was used to calculate the monthly value for the inner and outside Van Phong Bay (Figure 1).

In addition, in-situ data from the surveys in 2018 - 2019 were used to compare with remote sensing derived values. The in-situ Chl-a data were analysed from water samples collected at surface layers from stations allocated in the area (Figure 1). The water samples were filtered by Whatman GF/F 47 mm, then samples were extracted in acetone 90% in 4°C for 24 hours, after that the Chl-a concentration was measured in spectrophotometer U2900 following the method of Jeffrey et al. (Jeffrey *et al.*, 1997).

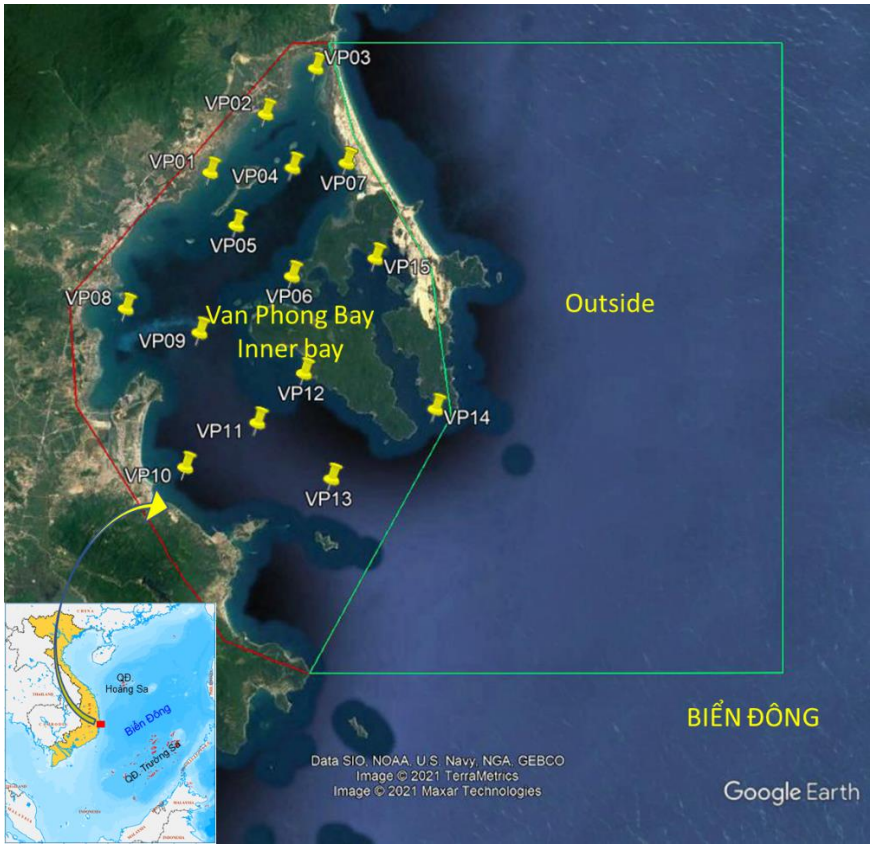

Figure 1. Study area with boundary of Van Phong Bay, Vietnam.

2.2 Data analysis

MODIS images were collected and processed on Google Earth Engine (GEE) platform (https://code.earthengine.google.com/). Daily Chl-a bands in the period of 2003-2020 were calculated for monthly averages for each region of inner and outside Van Phong Bay. The values of Chl-a were analyzed by classical decay method, which has been widely known in marine scientific literature (Mélin *et al.*, 2011; Vantrepotte & Mélin, 2010). According to this method, a time series of Chl-a concentration is described by the following equation (Mudelsee, 2014):

$$\{\mathbf{Y_t}\}_{\mathbf{t=1}}^{\mathbf{N}} = \mathbf{S_t} + \mathbf{T_t} + \mathbf{R_t}$$

Where Y_t is the monthly average time series of Chl-a, S_t is seasonal cycle component repeated with a frequency of 12 months, T_t is the trend component of changes over time; R_t is the seasonal stochastic component.

3. RESULTS AND DISCUSSION

3.1 In-situ vs MODIS Chlorophyll-a concentration

The survey results show the variation of Chl-a in Van Phong Bay between the rainy and dry seasons (Table 1). In-situ Chl-a in the rainy season (with a mean of 3.23±2.38 mg m^{-3}) was significantly higher than that in dry season (with a mean of 2.33±2.28 mg m^{-3}) (p=0.05). The highest values in both seasons were found in the station VP03 in the upper bay; this station is

shallow and influenced by nutrient suppling from wastewater of shrimp culture (An, 2002). A comparison between in-situ data with MODIS data in Figure 2 indicated that the average of Chl-a showed a decrease from in-situ value, to monthly MODIS and climatological monthly MODIS. In terms of spatial distribution, in-situ Chl-a reduced from the upper area to the southern opening of the bay (Minh-Thu *et al.*, 2014). In addition, in-situ, monthly and climatological MODIS Chl-a have the same trend and pattern in rainy and dry seasons. This fact suggests that monthly MODIS Chl-a could be used as a hint for the trend and variation of this index.

Table 1. Statistical values of in-situ Chlorophyll-a concentration in Van Phong Bay (Std: Standard Deviation)

Season	Min	Max	Average	Std
Rainy, 2018	0.67	8.37	3.23	2.38
Dry, 2019	0.57	8.33	2.33	2.28

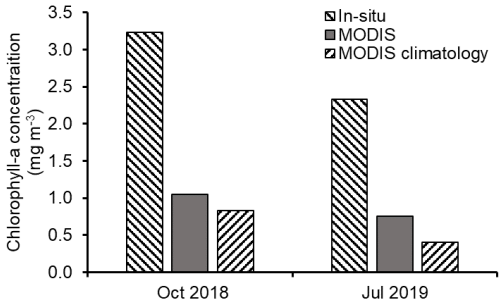

Figure 2. Comparison of Chlorophyll-a concentration in inner Van Phong Bay

Figure 3 shows the variation of monthly MODIS and climatological MODIS Chl-a in Van Phong Bay. In both the inner and outer regions, Chl-a has a reducing concentration from January to April, then a low pattern to August, after that Chl-a increased to the end of the year. The peak of Chl-a could be found in November and December.

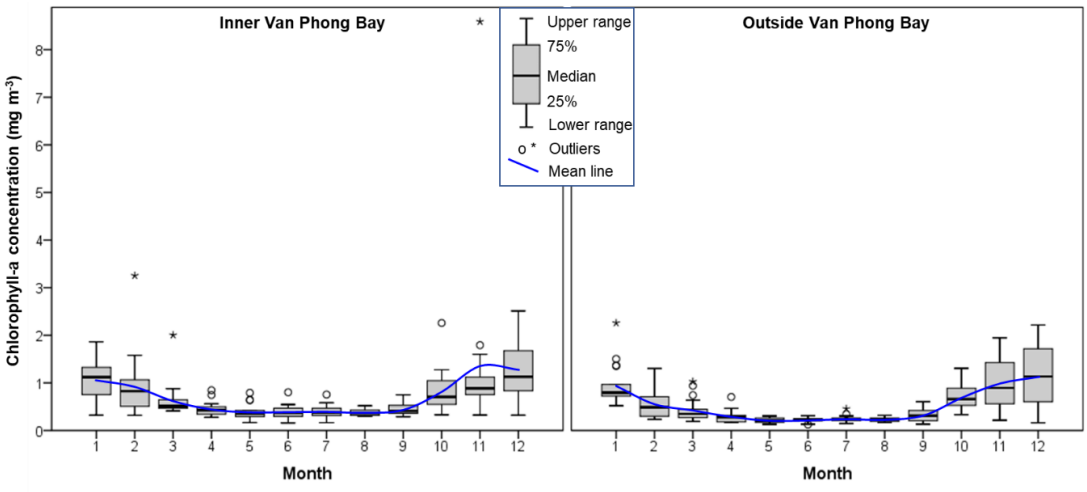

Figure 2. Box-whisker plot of MODIS Chlorophyll-a concentration in Van Phong Bay (p=0.05)

3.3 Trends and variations of MODIS Chlorophyll-a concentration

The seasonal pattern, trend and random components in the inner and outside Van Phong Bay was detected by decomposition of time series for monthly MODIS Chl-a. Figures 3 and 4 indicated the corrected magnitude of seasonal fluctuations as well as baseline of Chl-a. The seasonal fluctuations did not change overtime and the random value was variation around 0, whereas Chl-a trends have increases. However, in the inner bay (Figure 3), trend was significantly increased and slope with the graduated changes within the period of about 12 months. In contract, the trend in outside bay (Figure 4) has more fluctuation.

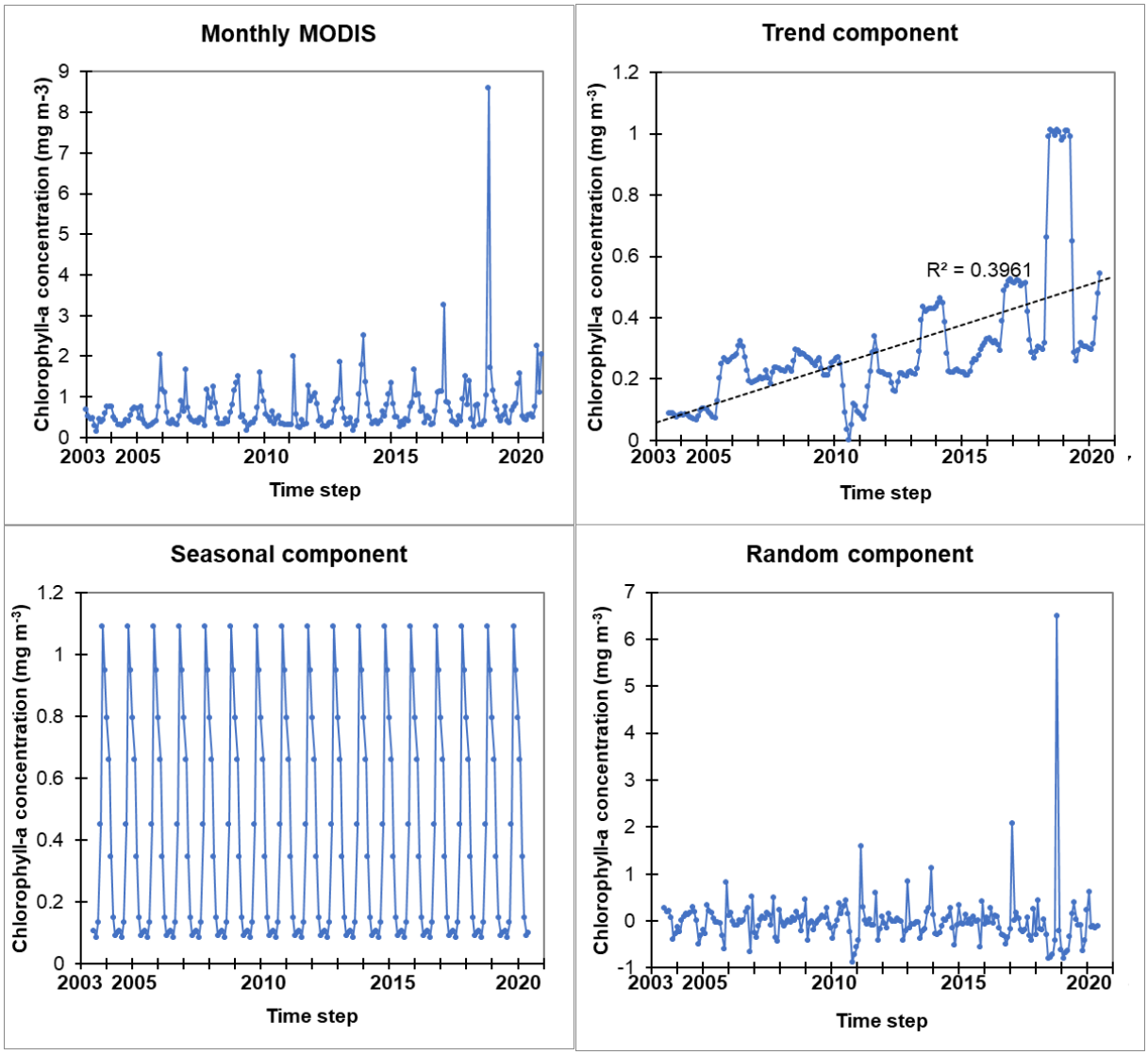

Figure 3. Trend components of monthly MODIS chlorophyll-a concentration in inner Van Phong Bay (from Jan 2002)

Based on the seasonal fluctuations, the baseline of Chl-a in the inner and outer bay are 0.084 mg m^{-3} and 0.049 mg m^{-3}, while the averages are 0.413 ± 0.356 mg m^{-3} and 0.357 ± 0.314 mg m^{-3}, respectively. Figure 2 shows that the in-situ Chl-a has more than three times than that of MODIS Chl-a. It can be observed that the ratio of in-situ vs. monthly MODIS Chl-a does not change much, and the seasonal Chl-a mean in inner bay is 1.275 ± 1.099 mg m^{-3}, with a range of 0.259 - 3.371 mg m^{-3}. Furthermore, based on trend and random components, Figure 3 could reveal the algal bloom events in early 2011, end of 2016 and 2019. The bloom in the end of 2016 was reported in (Doan-Nhu *et al.*, 2017; Luom *et al.*, 2021). As the same time, Chl-a was recorded an increase in the outer Van Phong Bay, without an occurrence of algal bloom.

4. CONCLUSIONS

A outlook on the variations and trends of Chl-a concentration in Van Phong Bay has been presented with in-situ and MODIS data. Seasonal, trending and random components were

detected by decomposition of the time series for monthly MODIS Chl-a. Chl-a time series showed a significantly increase in inner bay and a slightly increase in outer regions. Seasonal Chl-a has an average of 1.275 ± 1.099 mg m^{-3}, with the range of 0.259 - 3.371 mg m^{-3} in the inner bay and having a decreasing content from upper to the southern opening of the bay. Furthermore, the random component can help to determinate algal bloom events with sharply increases of Chl-a. This shows that the Fourier analysis is a powerful tool for studying such time series marine parameter like Chl-a concentration. The information is also helpful to support environmental management, marine culture development and zoning bivalve aquaculture.

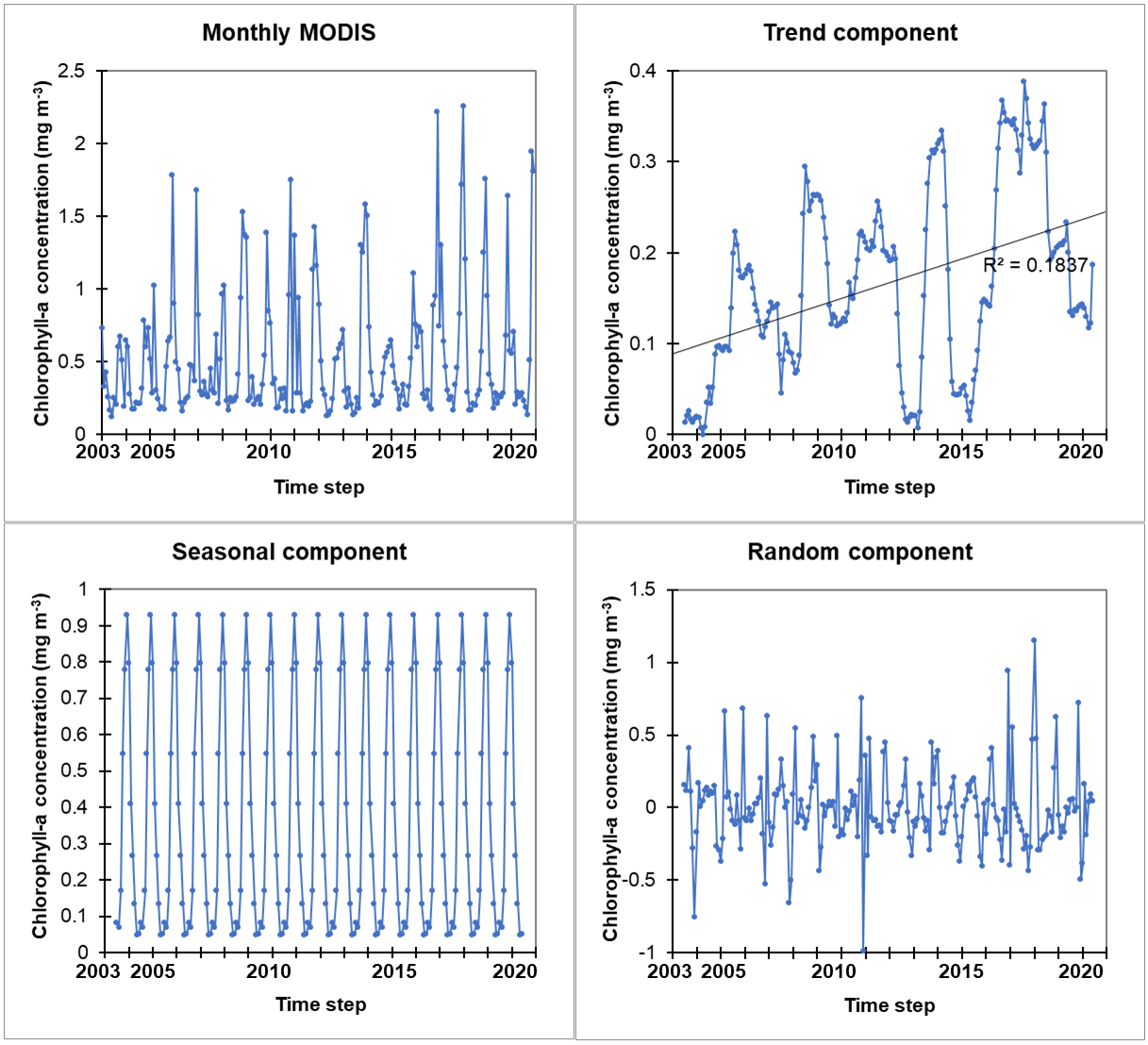

Figure 4. Trend components of monthly MODIS Chlorophyll-a concentration in outer Van Phong Bay

5. ACKNOWLEDGEMENT

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