Spatial-temporal characteristics of chlorophyll *a* concentration in the Sanya Bay of China

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***Abstract*—The present study investigated the spatial-temporal characteristics of chlorophyll *a* (chl-*a*) concentration in Sanya Bay by shipboard survey data at 12 stations from 2006 to 2008, and discussed the relationship between chl-*a* distribution and influential factors using MODIS sea surface temperature (SST), sea surface wind (SSW) and rainwater runoff data. Results showed that the chl-*a* concentration in Sanya Bay ranged from 0.30 to 13.58 mg·m^{-3}, the average concentration and standard deviation (SD) were 1.49 mg·m^{-3} and 1.74 mg·m^{-3} respectively. The chl-*a* showed a decreased tendency from estuary to offshore, and a decreased trends with the depth increased in the estuary of Sanya River, whereas indicated increased trends in the area offshore. In the river mouth, the relative higher value appeared in autumn. But in the zone offshore, the relative lower value appeared in spring. Summer had a obvious stratification vertically. This changes were associated with environmental factors changes in this area, such as the seasonal monsoon and nutrients from rainfall runoff.**

Keywords- spatial-temporal characteristics; chlorophyll a; Sanya Bay; MODIS SST; QuikScat; Wind

I. INTRODUCTION

China has a long and beautiful coast, but population bloom and recent rapid industrialization have placed a very heavy burden on the regional coastal environment. The noteworthy phenomenon is the increasing algal blooms and red tides. Both pose a serious threat to public health, fisheries and coastal aquaculture industry. Chlorophyll *a* (chl-*a*) is the main photosynthetic pigment, and is an index reflecting the amount of phytoplankton biomass, primary productivity and eutrophication of the water [1]. Consequently, observing and analyzing the spatial-temporal distribution of chl-*a* are useful, especially in the area of studying oceanic ecosystem, evaluating oceanic biology resource, surveying oceanic environment and managing oceanic fishery [2]. Studies on chl-*a* in estuaries and the coastal bays increased in recent years. Attempts have been made to understand the relationship between variability of chl-*a* and the environmental factors [3-5] in local area. Some studies have shown the structure and function of ecosystem, and the controlling mechanism of productivity in estuary and upwelling area [6-7].

Sanya Bay, a typical tropical bay with tropical coral reefs and mangroves, is located in the north of South China Sea and the southernmost coast of Hainan Island, China. With the rapid development of the tourism, industry and fishery, Sanya Bay is facing ecological problem. Study showed that parts of the sea area have been polluted in different degrees, and some of them were very serious, such as the estuary and the harbor [8]. Researches have been carried out about the biology resource and ecology environment in Sanya Bay [1,6,9,10-13]. However, here is lacking of longtime variability of chl-*a* and it's correlative factors. The main aim of the present study was to understand the seasonal and spatial distribution of chl-*a* and discuss its environmental factors, such as satellite sea surface temperature (SST), satellite sea surface wind (SSW) and the nutrient transport from land from 2006 to 2008 in Sanya Bay. The result of this work would help better evaluating the response of marine environment to human activities and natural changes in the bay area.

II. STUDY AREA AND DATA

A. Study Area And Sampling Methods

Four seasonal samplings in Sanya Bay (18°12′ — 18°18′N, 109°21′ — 109°29′E) were conducted from 12 stations in winter (January), spring (April), summer (July) and autumn (October) from 2006 to 2008, respectively. The location of data sampling stations was shown in Figure 1. The water samples were collected at the surface, middle and bottom layers, and the absent samples were showed in the latter figures. A total of 345 chl-*a* data were obtained. And then the samples were passed through 0.7um of Whatman GF/F glass fiber filters (25 mm). The filters were stored in aluminum foil and immediately kept at -20℃ until laboratory analysis within half a month [6]. Fluorescent method was applied to survey the concentration of chl-*a* [14].

B. Satellite Remote Sensing Data

The SST data were derived from the Moderate Resolution Imaging Spectroradiometer (MODIS) onboard Aqua. The Aqua satellite passes the Earth from south to north over the equator in the afternoon and views the entire Earth's surface every 1 to 2 days. Excluding missing data and clouds, we acquired 132 MODIS-Aqua Level-2 SST day files ranging from 2006 to 2008 containing Sanya Bay from the NASA's Ocean Color Working Group (http://oceancolor.gsfc.nasa.gov/). We processed the data and got the seasonal average SST data in Sanya Bay.

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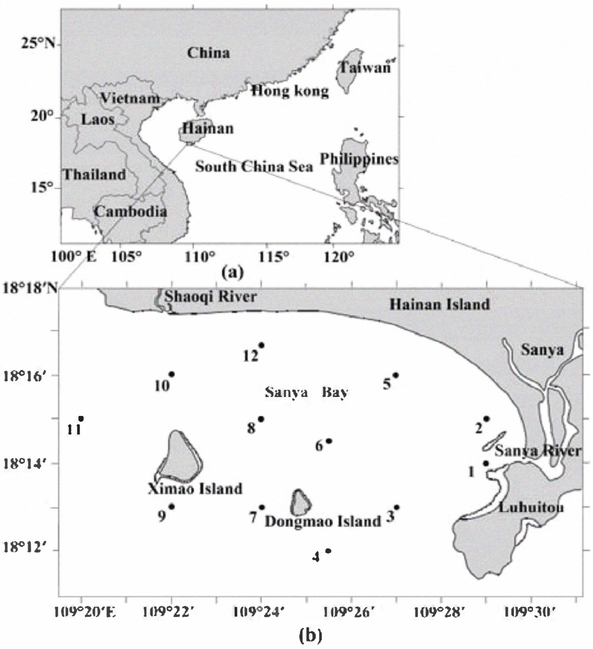

Figure 1. Map of research area: (a) Location of Sanya Bay. (b) Location of the 12 sampling stations in Sanya Bay.

We analyzed sea surface wind conditions to describe air-sea interactions. Wind speed and direction over the ocean surface were retrieved from measurements of the QuikScat Monthly averaged QuikScat wind vector images were produced by Remote Sensing Systems and sponsored by the NASA Ocean Vector Winds Science Team [15]. We get the QuikScat Sea Surface Wind data (http://www.ssmi.com/qscat/) and processed it. And then, we got the monthly average winds speed and direction data from 2006 to 2008.

III. Results

A. Chl-a Spatial distribution

The chl-*a* concentration in Sanya Bay ranged from 0.30 to 13.58 mg·m^{-3}, the average concentration and standard deviation (SD) were 1.49 mg·m^{-3} and 1.74 mg·m^{-3} respectively. The horizontal distribution of chl-*a* Bay was very clear in Sanya (Fig. 2). A relatively high concentration of Chl-*a* was observed in the estuary of Sanya River, and the highest appeared in station 1 (5.63 ±3.90 mg·m^{-3}) (average±SD). Chl-*a* decreased offshore, the chl-*a* concentration was 1.04±0.10 mg·m^{-3} in station 3 to 12. The lowest concentration of chl-*a* appeared at station 4 (0.89±0.40 mg·m^{-3}), near Dongmao Island in the bay. The contour lines were close in the estuarine zone, and sparse offshore. The gradients of contour lines ranked autumn > spring > winter > summer (Fig. 2). The contour lines liked hemispheres surrounding the station 1, and their diameters expanded forth to the connect line of station 3 and station 5. The lowest contour line extended by station 7, 8 and 10 in winter (Fig. 2a), extended by station 8, 9 and 10 in spring (Fig. 2b). However, it closed around station 9 in summer (Fig. 2c) and closed around the zone on the northeast of Dongmao Island in autumn (Fig. 2d).

The vertical distribution of chl-*a* was different in four seasons in Sanya Bay (Fig. 3). Chl-*a* concentration had a obvious stratification vertically in summer (Fig. 3c), but uniform in spring and autumn (Fig. 3b, d). In the station1 and 2 located near the river mouth, the chl-*a* concentration in surface layer was highest. However, In most zone away from the river mouth, the highest concentration of chl-*a* appeared in the bottom layer.

In winter（Fig. 3a）, in station 1, chl-*a* concentration in surface layer（5.37 mg·m^{-3}）and bottom layer（5.13 mg·m^{-3}）were both higher, but lower in middle layer (1.77 mg·m^{-3}). Correspondingly, there was just little difference in the other stations. In spring（Fig. 3b）, except the station 1 with higher value in surface (8.74 mg·m^{-3}) and lower value (2.91 mg·m^{-3}) in bottom, the other stations showed a uniform distribution vertically. We observed that summer (Fig. 3c） was the special season with obvious stratification vertically. The middle layer value in station 1 was absent. The highest concentration difference value (1.11 mg·m^{-3}) was observed in station 6. In autumn（Fig. 3d）, the chl-*a* concentration distributed uniformly except for station 1 with the different value (5.25 mg·m^{-3}) between the surface layer and the bottom layer.

B. Chl-a temporal distribution

The chl-*a* concentration fluctuated largely in station 1 and 2 from 2006 to 2008 (Fig. 4a, b), spatially in station 1, which changed from 1.61 mg·m^{-3} to 13.58 mg·m^{-3}. Comparatively, the value fluctuated between 0.30 mg·m^{-3} and 2.38 mg·m^{-3} from station 3 to 12. Little change was observed yearly with the SD 0.19 mg·m^{-3}. The higher fluctuation yearly appeared in station 1 with SD 3.35 mg·m^{-3}, and station 5 with SD 0.41 mg·m^{-3}.

The seasonal characteristic showed that station 1 and 2 were different (Fig. 4c).The seasonal variation in chl-*a* was in the follow order in station 1: autumn (8.86 mg·m^{-3}) > spring (5.83 mg·m^{-3}) > winter (5.17 mg·m^{-3}) > summer (2.66 mg·m^{-3}), and the order in station 2: winter (2.87 mg·m^{-3}) > autumn (1.78 mg·m^{-3}) > spring (1.59 mg·m^{-3}) > summer (1.06 mg·m^{-3}). However, the order of it was accordant from station 3 to 12: autumn (1.26±0.14 mg·m^{-3}) > winter (1.20±0.23 mg·m^{-3}) > summer (1.01±0.21 mg·m^{-3}) > spring (0.68±0.16 mg·m^{-3}) .

IV. Discussion

A. SST and SSW's influence on chl-a distribution

Figure 5a indicated that seasonal averaged SST in Sanya Bay changed from 24.28℃ in winter to 29.55℃ in summer. The SST in the near shore area such as station 1, 2, 5 and 12 was higher than that in the other stations at the same time in Sanya Bay. In the same season, the SST was uniformed in horizontal in the stations far away from the shore. The characteristic of SST in Sany Bay accorded with the local tropic climate. The correlation coefficient of chl-*a* concentration and SST was 0.65 in winter, 0.02 in spring and summer, 0.28 in autumn. It showed that the distribution of chl-*a* and SST had little relativity. Generally, the availability of nutrients and light radiation are the key factors limiting the growth of phytoplankton. However, the depth of Sanya Bay is less than 30 m (http://www.ngdc.noaa.gov/mgg/gdas/gd_designagrid.html), and the seawater transparence reaches to 6.73 m [16]. So the photosynthesis is well in the whole seawater in Sanya Bay, and light radiation is not the limited factor of chl-*a*. According to the results we analyzed, in the Sanya Bay light was not a key factor. It agreed with previous observation in South China Sea [4].

Monthly averaged wind images obtained from Jan 2006 to Dec 2008 (Fig. 5b) indicated very strong seasonal reversal monsoon in the study area. There were southerly winds in summer and northeasterly winds in winter. In autumn and winter, because of the strong northeasterly monsoon and the sea surface cooling (Fig. 5b), stratification vanished and vertical mixing developed (Fig. 3a, d). Further more, Sanya Bay is open and the seawater in the bay is easy to exchange with the outside seawater, and the high concentration of chl-*a* in the river mouth diffuses easily by the northeasterly monsoon. Accordingly, the surface value of chl-*a* concentration was higher in autumn and winter than that in spring and summer (Fig. 3). In summer, because of the driving of southerly wind, the abundant nutrition intruding the bottom of the bay area, the value of chl-*a* concentration was much higher than that in the surface with obvious stratification vertically (Fig. 3c). Research [12] had shown that there were seasonal cold-water up-welling in the Sanya Bay from June to August, which caused the layering, and the layering disappeared from September to the next March. The result of our observations (Fig. 3) agreed with it.

B. *Rainwater runoff's influence on chl-a distribution*

High Chl-*a* content in the station 1 and 2 (Fig. 2, 3, 4) may be caused by nutrients from runoff from the Sanya River that discharges into the bay. Report [17] showed that rainfall of Hainan Island mainly concentrated from May to October, and the peak value appeared from August to October. Discharge from the Sanya River, rich in nutrients and phytoplankton by the rainfall, caused the highest concentration of chl-*a* in the river mouth (Fig. 2, 3, 4) in autumn, and summer took second place. However, with the diffusion of nutrition, the highest value of chl-*a* at the stations offshore did not appear in autumn (Fig. 4c), and it increased with the depth (Fig. 3). This phenomena expressed that the land nutrition may be not the limited factor of chl-*a* in offshore area. One main reason may be the seawater from the open sea intruding the bay, disturbing the sediment rich in nutrients.

V. CONCLUSION

This study revealed significant spatial and temporal variations of chl-*a* in Sany Bay, northern South China Sea. Chl-*a* concentrations were relatively higher and more variable in the river mouth, and decreased offshore. In the river mouth, the chl-*a* reduced with the depth, and the highest appeared in autumn. But in the offshore zone, the chl-*a* increased with the depth, and the lowest appeared in spring. Summer had a obvious stratification vertically. This changes were related to the seasonal monsoon and rainfall. Hainan Island was passed to be international tour island in January 2010 [18]. Sanya, the sign of Hainan, sustainable development is necessary there. As a consequence, our research was important to the ecosystem environment of Sanya. It was our limit that we did not analyzed the salty and ocean current's influence on chl-*a* because of data limiting, which was our effort for the forth.

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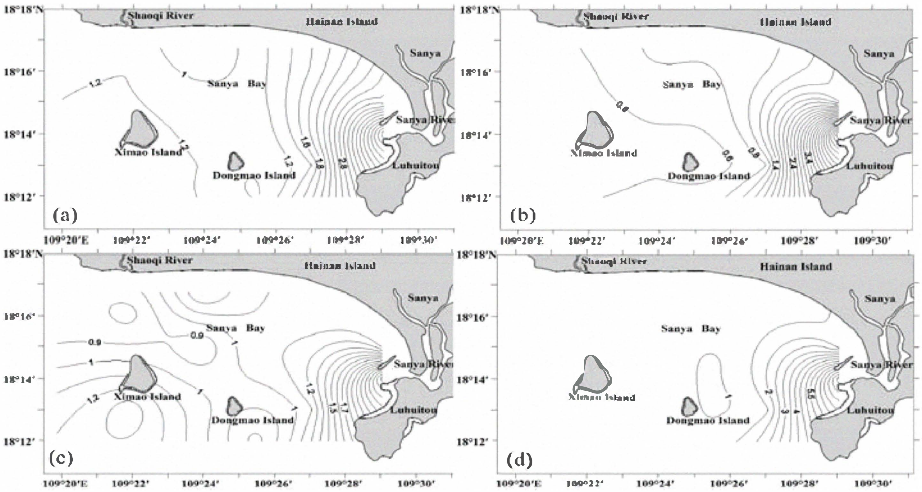

Figure 2. Seasonal horizontal distribution of chl-*a* from 2006-2008 in Sanya Bay（$mg{\cdot}m^{-3}$）(a . Winter; b. Spring; c. summer; d. autumn).

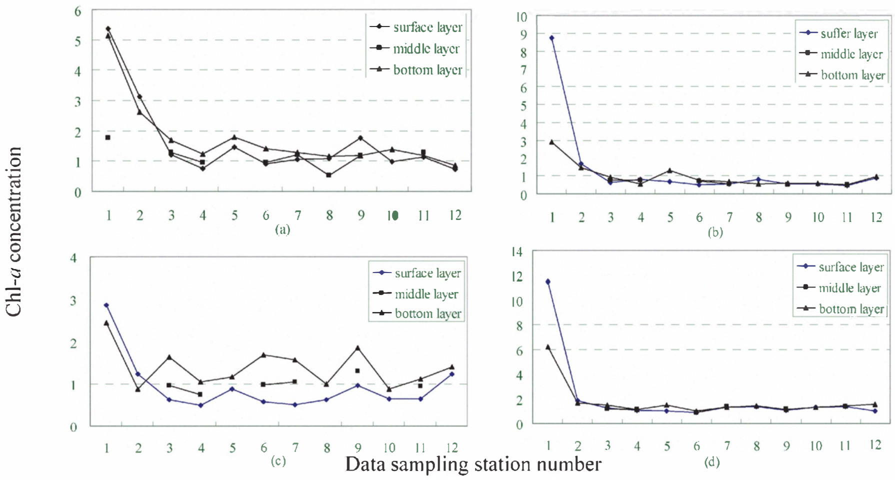

Figure 3. Seasonal vertically distribution of chl-*a* from 2006-2008 in Sanya Bay（$mg{\cdot}m^{-3}$）((a) . Winter;(b). Spring; (c). summer; (d). autumn)

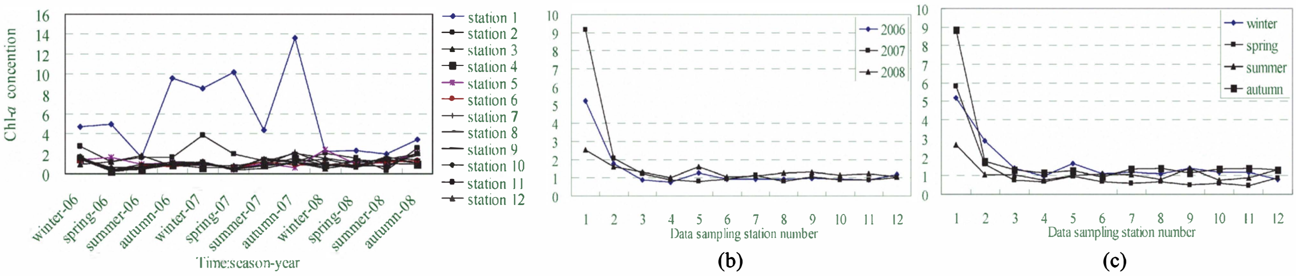

Figure 4. Temporal variation of chl-*a* from 2006-2008 in Sanya Bay（$mg{\cdot}m^{-3}$）

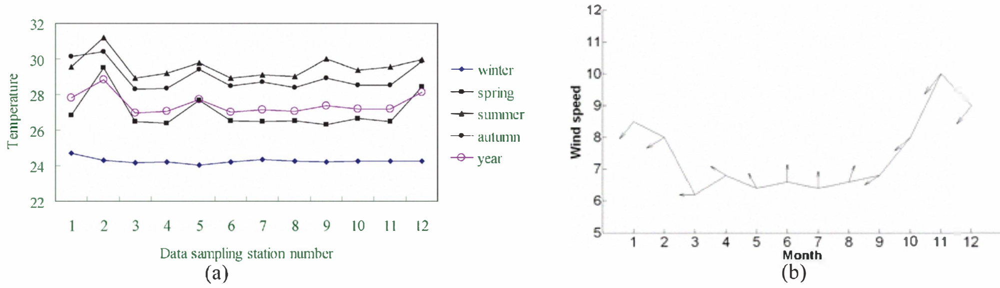

Figure 5. (a) Seasonal SST in Sanya Bay(℃); (b) Monthly averaged wind direct and speed($m{\cdot}s^{-1}$)