Satellite Remotely-sensed Analysis of Temporal-spatial Variations of Chlorophyll-a Concentration in South China Sea

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Abstract—**Taking the South China Sea as the study area, the present paper aims to obtain the spatial and temporal distributions of chlorophyll-a, based on the chlorophyll-a data remote sensed by SeaWiFS from September 1997 to December 2010.Calculate the monthly average of chlorophyll-a concentration through space superposition and analysis the distribution characteristics. In consideration of space regional characteristics of chlorophyll-a concentration in the research area, divide the research area into three zones used the spatial clustering method based on grid density and discuss the seasonal variation in each zone. In order to quantitatively express spatial distribution characteristics of chlorophyll-a concentration, a sinusoidal curve model is established using MATLAB to fit the time series in these zones for simulating the change trends, variation periods and fluctuation ranges of chlorophyll-a.**

Keywords-remote sensing; the South China Sea; chlorophyll-a; SeaWiFS; temporal-spatial variations

I. INTRODUCTION

Chlorophyll-a concentrations and phytoplankton biomass are important to the economy of the ocean with respect to trophodynamics, primary production and fisheries, as well as to global biogeochemical cycles [1]. Accurately studying the spatial-temporal distributions of ocean chlorophyll-a is helpful to understand the biological resources in ocean and their variations of spatial and temporal distribution, which could provide the reference for aquatic resources reasonable exploitation and environmental protection [2].

There have been many studies of the spatial and temporal distribution of chlorophyll-a using remote sensing data [3-8]. But there are few researches about the variation in a long time. The remote sensing dataset make it come true that research the temporal-spatial variations in more than a decade. In addition, the present paper put forward a new method to zone the South China Sea and analysis each zone with a trend model.

Taking the South China Sea as the study area, based on remote sensing data and spatial data processing technology, the present paper tries to obtain the spatial and temporal distributions of chlorophyll-a, then partition the study area by the spatial clustering analysis method and use the sinusoidal model to quantitatively describe chlorophyll-a in the sub-region, with a view to provide a reference for the South China Sea marine ecology and marine productivity studies

II. MATERIALS AND METHODS

A. Study Area

The study area is the South China Sea located at 4 ° N ~ 25 ° N, 105 ° E ~ 122 ° E, north to the Guangdong coastal area, south to the Brunei Bay, west to Gulf of Tonkin, east to east coast of Taiwan Island, about 3,500,000km^2(Fig. 1). The South China Sea is the deepest and biggest sea of China, while it is the third biggest epicontinental sea rank only after Coral Sea and Arabian Sea.

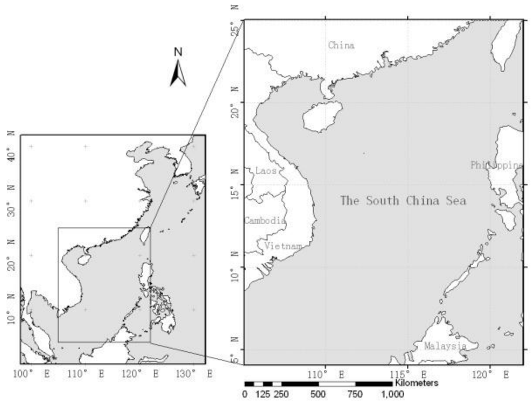

Figure 1. Study area.

B. Dataset

Remote sensing obtained from Sea-viewing Wide Field-of-view Sensor (SeaWiFS) which was launched on ocean color satellite SeaStar of NASA. SeaStar was launched successfully in 1997 August 1st and receive data since September 1997. Regrettably, the SeaWiFS mission was declared to be no longer recoverable in 2010 December. Now we possess the data set for the last 13+ years acquired form SeaWiFS. The remote sensing data with long time series provides important reference for the research of chlorophyll-a concentration evolution in a long-term. The ocean color data processing group of NASA has contrast chlorophyll-a concentration of in situ observations and retrieved from satellite. The result shows that Median

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average relative error is 29.801% and root-mean-square （RMS） is 1.001, so the SeaWiFS data can express the distribution of chlorophyll-a concentration well [9]. The data used in the present paper is the Level-3 monthly average products of 9km-resolution from September 1997 to December 2010.

C. Pocedure

1) Data processing

The raw data was in the HDF format. Through the coordinate registration, mask, computing and other treatments, we got the raster files which are more suited for spatial analysis. Influencing by environment such as cloud, the remote sensing data have many outliers. Compared by test, the inverse distance weighted interpolation method (IDW) can eliminate the outliers best (The correlation of IDW interpolation results of test points and in situ data: R^2=0.807).

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2) Cluster analysis

Spatial clustering is a kind of unsupervised data mining. According to a large number of location-related space information contained in data, it could discover the distribution of spatial objects. This paper analysis the research area used one of the spatial clustering methods based on grid density named ISODATA (Iterative Self-Organizing Data Analysis Technique).

In view of the overall situation of Chinese coast, we got the monthly average in the whole Chinese coastal areas from 1998 to 2010. Spatial cluster the monthly average of chlorophyll-a into different number of classes using ISODATA algorithm. The parameters are： number of iterations: 100；minimum class size: 20；sample interval: 10；reject fraction: 0；a priori probability weighting: equal.

3) Trend analysis using a sinusoidal curve model

In order to quantify the expression characteristics of the spatial distribution of chlorophyll-a concentration, the present paper used method from WEATHERHEAD et al [10]. A sinusoidal curve model was established using MATLAB to fit the time series in these zones, to simulate the change trends, variation periods and fluctuation ranges of chlorophyll-a concentration from September 1997 to December 2010.The model is:

$$Y_t = A_t + B_t * X_t + C_t \sin(2\frac{\pi}{D_t}X + E_t) + N_t. \quad (1)$$

In this model, Y is the mean monthly chlorophyll-a concentration of each zone calculated by the model, X on behalf of the month after September 1997 (When X =1 means September 1997), t represent different zones, A_t, B_t, C_t, D_t, E_t is the model parameters. $A_t + B_t * X_t$ can be expressed as the trend of changes in chlorophyll-a concentration (A_t reflects the overall level of chlorophyll-a concentration in every zones, B_t can be quantitatively compare the monthly changes of chlorophyll-a concentration in different zones). B_t/A_t can be used to indicate that the rate of change of chlorophyll-a concentration in the zones. $C_t \sin(2\frac{\pi}{D_t}X + E_t)$ can be used to describe the chlorophyll-a concentration changes of monthly mean of the cyclical(Where, C_t is the amplitude of variation, D_t is the change in period, the ideal period is 12 months, E_t is the initial phase).

Nt means the residual error between actual values and simulated values. Weatherhead.et al regards *Nt* has autocorrelation and can be described as below:

$$N_t = \Phi N_{t-1} + \varepsilon_t \quad (2)$$

In (2), Φ means the autocorrelation among residual errors. ε_t is the noise of autocorrelation. The autocorrelation among residual will influence the precision of chlorophyll-a concentration variation trend. Weatherhead.et al think the precision of Model simulated trend (σ_B) is function of autocorrelation (Φ), time span (T) and standard deviation of residual (σ_N), and can be approximate represents as:

$$\sigma_B \approx \frac{\sigma_N}{T^{3/2}}\sqrt{\frac{1+\Phi}{1-\Phi}}. \quad (3)$$

Computational formula of standard deviation is:

$$\sigma_N = \sqrt{\frac{\sum_{j=1}^{T}(Y_j-\bar{Y})}{T}}. \quad (4)$$

If trend B_t and precision σ_B meet the condition $\left|\frac{Bt}{\sigma_B}\right| > 2$, we can consider that month average of chlorophyll-a concentration variation trend (*Bt*) is notable when the confidence level is 95%.

III. Results

A. Dynamic Space-time Distribution of Chlorophyll-a Concentration

The month average of chlorophyll-a in 13 years shows in Fig. 2. High concentration region which concentration above 0.3mg m^{-3} mostly distribute in the offshore areas within 200 km apart from coastline, from Taiwan Strait west to the Gulf of Tonkin. The Pearl River is the third biggest river of china, which bring a lot of terrigenous nutrients to the coastal waters. The coastal province of china such as Guangdong, Guangxi, Yunnan and Hainan possess a large number of residents live nearly the shore, a mass of garbage produced by human life and industry discharged into the sea. The above two points are the most important reasons lead to the high concentration of chlorophyll-a. So we have the same opinion with Chen et al [11] who said the spatial distribution of chlorophyll-a concentration in South China Sea was mainly dominated by the spatial distribution of nutrients. The same situation we also can find near Mekong river mouth, Brunei Bay and coast sea Luzon Island.

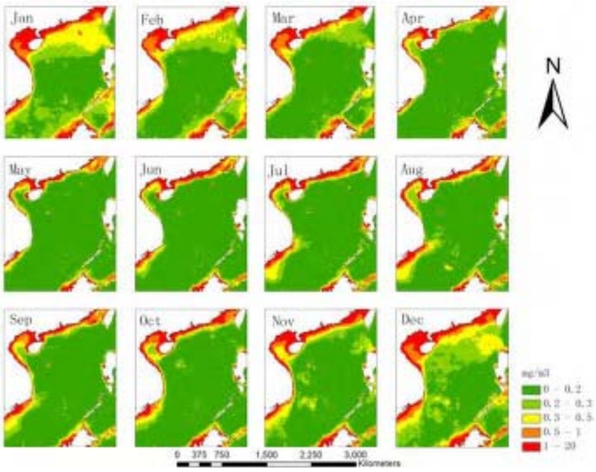

Figure 2. Monthly average of chlorophyll-a concentration of many years.

In January, February and December the proportion of high concentration region will spread to the maritime space 400km apart from shoreline (Fig. 2). Because the South China Sea locates in tropical oceans, the winter temperature is warm which is suitable for phytoplankton growth. While the surface temperature of seawater in summer is reach up to 30℃, which is too high for phytoplankton growing, and the concentration in summer is lowest. The concentration of chlorophyll-a in spring and autumn is in the middle [11].

At the same time, learning from monthly average variation trend of chlorophyll-a concentration (Fig. 3), the lowest concentration appears in April, May and June, while the highest one appears in November and December. However, there is uptrend in autumn. Although the sea surface temperature is higher in summer, wind speed in the South China Sea is strong under the influence of summer monsoon, so the mix influence is enhanced. Shi et al [12] has proved that hybrid layer in most of South China Sea in summer was thicker than spring. In addition, south China is in rainy season, the surface runoff injected into South China Sea carry a great quantity of land-sourced nutrient, the diluted water maybe touch to a bigger range, than lead to the rise of chlorophyll-a concentration in some sea area [13].

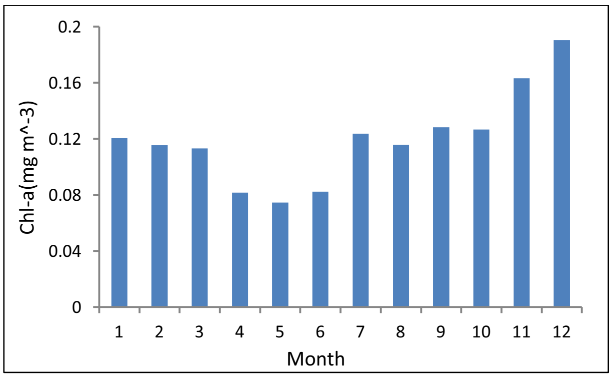

Figure 3. Monthly average variation trend of chlorophyll-a concentration.

B. Zoning Analysis of Chlorophyll-a Concentration

The above analysis showed that the influencing factor and variation of chlorophyll-a between near coast and open sea were different, and obvious regional characteristics exists. The overall analysis will ignore the regional characteristics, so zoning analysis could express details better. Fig. 4 shows the result of zoning analysis when the class number is 3.

The clustering result shows Pearl River Estuary，Brunei Bay，Manila Sea and so on are classified as Zone 1. Take the coastal areas about 200km apart from the coastline as Zone 2. Take the other broad shelf sea and sea basin as Zone 3.

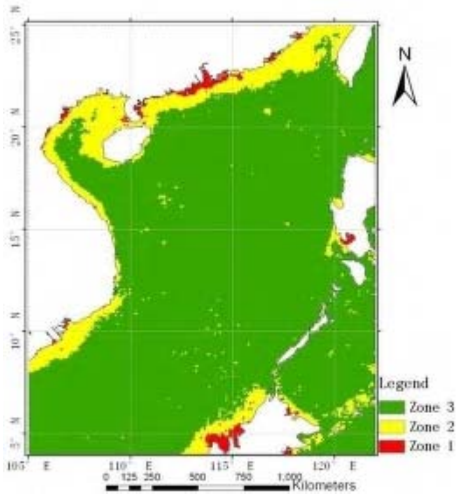

Figure 4. Spatial clustering result of chlorophyll-a concentration.

Learn from the monthly average of chlorophyll-a concentration in each zone (Fig. 5), Zone 1 has obvious peak in June, July and August, because the effect of diluted water is more evident estuary, the high vertical mixing degree lead to high chlorophyll-a concentration. However, the peak is less conspicuous in Zone 2 and Zone 3, because the diluted water has little effect in these zones [14].

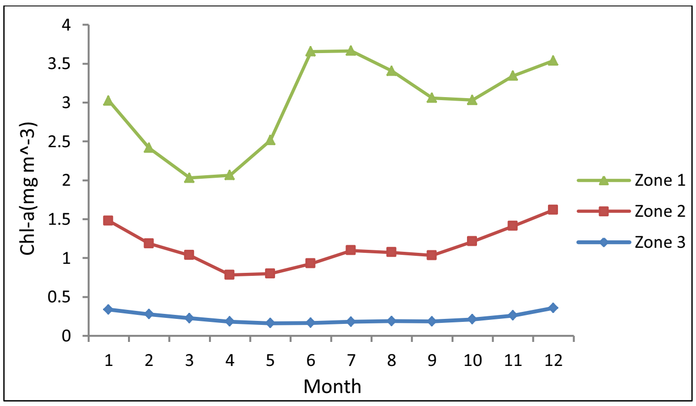

Figure 5. Monthly average of chlorophyll-a concentration in each zone.

C. Month Variations of Chlorophyll-a Concentration in Each Zone

Zoning analysis showed the otherness of chlorophyll-a concentration distribution. Based on this result, sinusoidal curve model was chosen to represent the month variation evolution of chlorophyll-a concentration in each zone. Using (1) to fit the monthly mean chlorophyll-a concentration for each zone separately, the curve fitting parameters are shown in TABLE I.

TABLE I. FITTED PARAMETERS OF SINE MODELS IN VARIOUS ZONES

Zone	At	Bt	Ct	Dt	Et	Bt/At	Curve fitting accuracy	Significance
1	2.517	0.0065	0.561	12.023	2.162	0.0026	0.270	11.888
2	1.028	0.0013	0.302	11.994	0.696	0.0013	0.555	9.858
3	0.162	0.0002	0.060	12.011	6.531	0.0014	0.603	9.519

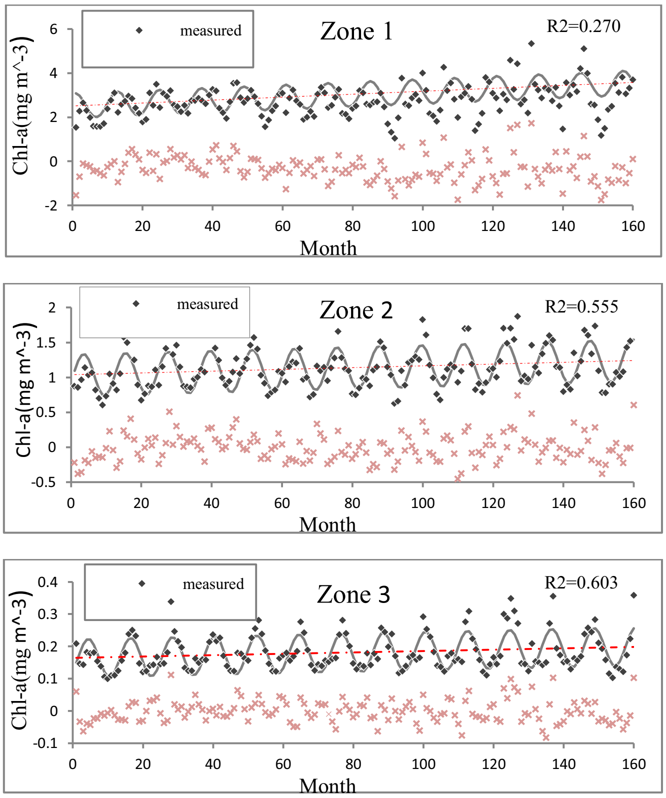

Figure 6. Fitting results of monthly average chlorophyll-a concentration in five zones.

TABLE I and Fig. 6 show the result of model. The overall level of chlorophyll-a concentration (*At*) are respectively 2.517, 1.028, 0.162 mg m^{-3} form Zone 1 to Zone 3. It is according with Chen's research result. The increment (*Bt*) is gradually decreasing from inshore to open sea. Zone 1 has the biggest growth rate (*Bt /At)* 0.0026, and the other two zones' is about half of it. The significance $\left|\frac{Bt}{\sigma_B}\right|$ is much more than 2, so chlorophyll-a concentration in each zone has obvious increase, and Zone 1 is much more notable. Beyond that, we do the linear regression of average of July, August and September, the regression equation is $y = 0.119x + 2.605$, R^2 is 0.550. Chlorophyll-a concentration in South China Sea is increasing especially in coastal sea and autumn. The similar result is proved in the research of Tang et al [15]. Learning from the amplitude of variation (*Ct*), the trend of diminishing is obviously according to the distance from the coastline. The change cycle (*Dt*) was about 12 months, which showed the obviously annual cycle change of chlorophyll-a. From the model fitting accuracy (R^2), R^2 is more than 0.555 in Zone 2 and Zone 3, so chlorophyll-a concentration observed the law of sine shaped periodic. But R^2 in Zone 1 is low to 0.27, because in estuary diluted water and human life come to important influencing factors other than climate factors as temperature.

IV. CONCLUSIONS

Learn from the space distribution of the monthly average of chlorophyll-a concentration, high concentration region which concentration above 0.3 mg m^{-3} mostly distributed in the offshore areas within 200km apart from coastline, especially Guangdong coastal area. However, in January, February and December the proportion of high concentration region will spread to the maritime space 400km apart from shoreline.

Zone the research area through spatial clustering analysis. Take Pearl River estuary and the area near Hainan Island which has the highest concentration as Zone 1. Take the coastal areas about 200km apart from the coastline as Zone 2. Take the broad shelf sea as Zone 3. The season diversity among each zone was obviously. Chlorophyll-a concentration is high in winter and low in summer entirely, but there is obvious high value near the coast in summer in addition.

The simulated result of sinusoidal model showed that chlorophyll-a consistent with the law of sinusoidal function and change with a year cycle, while difference was existed in each zone. There is significant rising trend of chlorophyll-a concentration in South Sea. The nearer to the shore, the more obvious the trend is.

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