Research on the chlorophyll-a distribution in Bohai Sea based on the MODIS data

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ABSTRACT

Chlorophyll-a (Chla) concentration data is one of the key parameters for the evaluation of water eutrophication and primary productivity. Compared with traditional monitoring methods, it has the advantages of quasi-real-time, large-scale and long-term by using remote sensing data to retrieve Chla concentration data. Analyzing the temporal and spatial distribution of Chla concentration and its long time series changes will help relevant institutions to comprehensively evaluate and control the water environment. However, there is no consensus on the long-term change mechanism of Chla concentration in coastal waters. In this study, the Modis data from 2003 to 2009 was used to retrieve the Chla concentration data in the Bohai Sea and its temporal and spatial distribution characteristics were analyzed. In addition, the potential relationship between wind speed and Chla concentration was analyzed using Quick Scatterometer wind field data over the same time period. The results showed that there were different seasonalities characteristics in different dynamic regions. The concentration of Chla was the lowest in summer in the Bohai Sea, and it showed an obvious interannual variation trend in summer and autumn in Laizhou Bay and Bohai Bay. The comparison results of wind speed and Chla showed that the seasonal changes of wind speed and Chla were consistent to some extent. It should be considered that the wind field of sea surface was one of the influencing factors of Chla change mechanism in the shallow sea ecological environment system.

Keywords: Chorophyll-a distribution, MODIS data, Bohai Sea

1. INTRODUCTION

The Bohai Sea is a semi-closed sea in China with an area of approximately 77 000 km^2 [1]. It connects the Yellow Sea through the Bohai Strait[2], bordering the Liaoning Peninsula to the east and the Shandong Peninsula to the south, the map was shown in Figure 1.

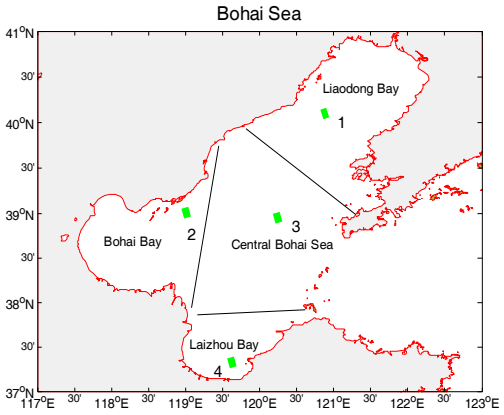

Figure 1. The map of Bohai Sea and the four dynamic regions divided by the lines. The four dynamic regions are: (1) Liaodong Bay, (2) Bohai Bay, (3) The Central Bohai Sea, (4) Laizhou Bay, respectively.

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The Bohai Sea is one of the most productive regions of the world, characterized by high species diversity and fish yield[3]. However, there exists relatively small amount of in situ measurement dataset, concerning data consistency, frequency and accuracy. The limitation of data availability constrains the understanding of the spatial and temporal characteristics of the ecosystem in the Bohai Sea. In addition, the understanding of ecosystem dynamics is also limited due to the lack of in situ measurements. Numerical models were introduced to the Bohai Sea to investigate the ecosystem dynamics[4-5]. Nevertheless, the lack of data is still the largest limitation to the modeling studies, since the simulated spatial pattern and temporal variability needs to validate. Hence, satellite ocean-color remote-sensing data provides a unique approach to improve the understanding of the ecosystem dynamics and the development of the ecological modelling[6-8]. Then many international scholars have applied remote sensing data to study the ecological environmental parameters, for example, chlorophyll-a[9-11], SPM[12], CDOM[13], etc. In this paper, we used the MODIS data and Quickscat wind data from 2003 to 2009 to analysed the spatial and temporal distribution of Bohai Sea. And then we analysed the relationship between Chla and wind speed.

2. DATA AND METHODS

Aqua is the second satellite of NASA EOS (Earth Observation System), which is the sun-synchronous polar orbit satellite, developed by Brazil and United States and Japan. On May 4, 2002, Aqua satellite was launched successfully and it works every afternoon from the south to north, through the equator. MODerate-resolution Imaging Sepctroradiometer is one of the main sensors on the board of Aqua, its mow width is about 2,330 km, and spectral wavelength range is 0.14-14.4um, the common band settings are shown in Table 1.

Table 1. The common bands of MODIS.

MODIS band	MODIS wavelength (μm)
1	0.654
2	0.858
3	0.469
4	0.555
5	1.24
6	1.64
7	2.13

The version 6 MODIS Level1B data were got from the website: http://ladsweb.nascom.nasa.gov/. Then we used the professional software - Seadas to processed L1B data and generated L2 data with the spatial resolution of 250-m. The default atmospheric correction algorithm of Seadas was selected during those data processing. In this study, OC2M-HI algorithm which is suitable for retrieving Chla concentration data from MODIS data was selected, and the formula was as follows:

$$[chl-a] = 10^{(0.1464-1.7953\times R_{rs-MODIS}+0.9718\times R_{rs-MODIS}^{2}-0.8319\times R_{rs-MODIS}^{3}-0.8073\times R_{rs-MODIS}^{4})} \quad (1)$$

$$R_{rs\text{-}MODIS} = \log_{10}[R_{rs}(469) / R_{rs}(555)] \quad (2)$$

The Quick Scatterometer was in orbit for more than 10 years. It was launched in June 1999 and dead on November 2009. Its main task was to monitor the surface wind field in near real time. In this study, we used the improved Version-4 (V4) data products. Its resolution is 0.25°*0.25° and its download site is ftp://ftp.remss.com/qscat/bmaps_v04.

3. RESULTS

3.1 Spatial distribution of Chla in the Bohai Sea

Figure 2 shows the horizontal Chla distribution derived from the MODIS data over the whole Bohai Sea. These monthly composited results provided the comprehensive synoptic views of seasonal chlorophyll variability. Since the Chla concentrations in winter (Figures 2a-2c) were extremely high and patchy it is suspected that these data are detoriated by effects of clouds, cloud shadows and the low sun angle. We skipped the discussion of the MODIS data in winter and focused our discussion on the period between March and November.

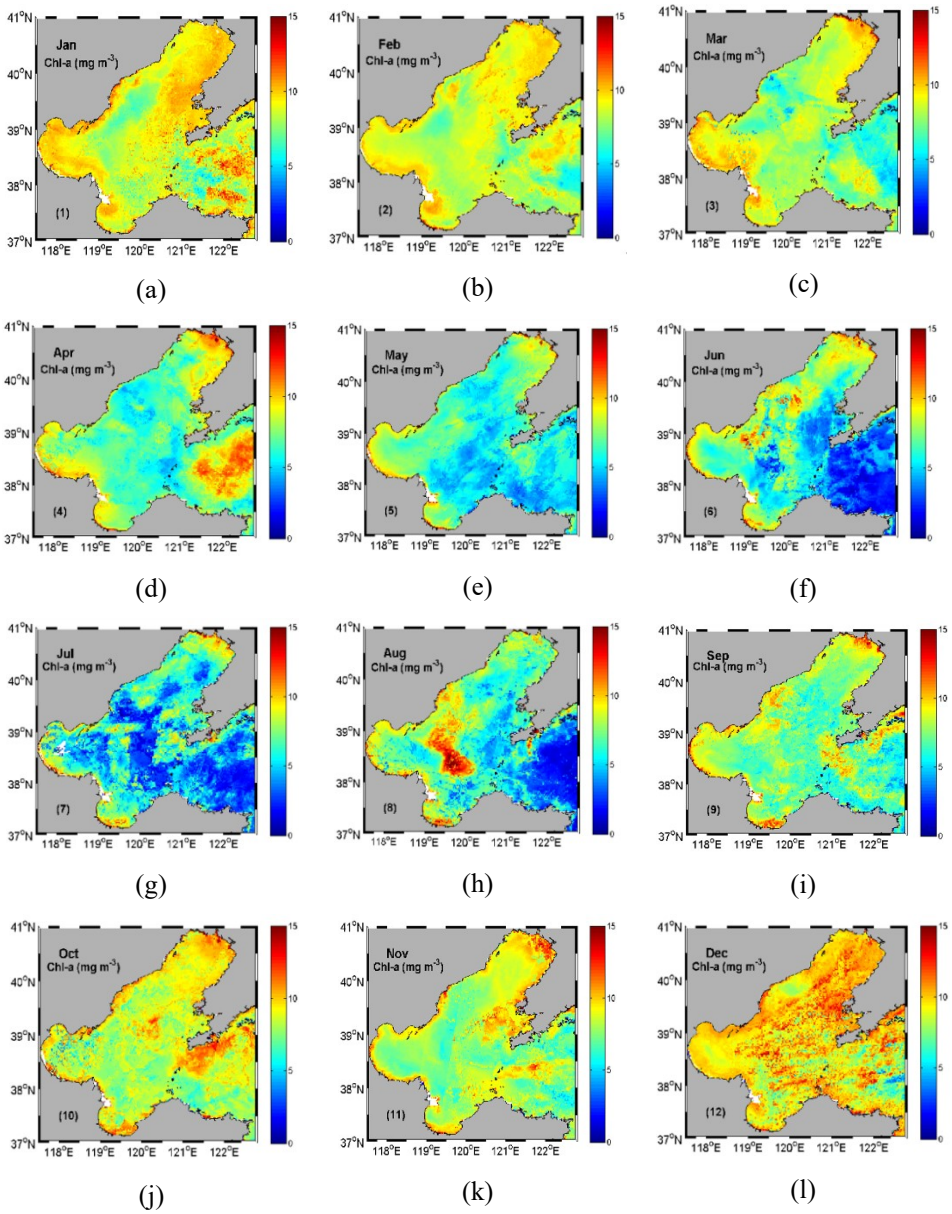

Figure 2. The spatial pattern of Chla derived from the MODIS data in the Bohai Sea. (2003-2009).

In March, high concentrations (>10 mg.m^{-3}) were recorded throughout the three bays and in the central and northern part of the Bohai Sea (Figure 2c). The highest value (>14 mg.m^{-3}) occurred along the narrow margin of the Liaodong Bay. In April, as shown in Figure 2d, the concentration decreased all over the Bohai Sea, leaving the value lower than 7 mg.m^{-3} in the wide Bohai Sea except for few parts such as the north and east part of the Liaodong Bay, northwest and south part

of the Bohai Bay, as well as the west part of the Laizhou Bay. We should note that during this time, there were obvious coastal-offshore gradients. The concentration continued to decrease in May (Figure 2e), resulting in a concentration horizontally homogeneous at a level of 6 $mg.m^{-3}$, which presented the least spatial variation of the year. Significant enhancement of the Chla concentration was observed on the wide shelf region west of the Central Bohai Sea in June (Figure 2f). At the same time, the increase of Chla concentration also showed obvious continental shelf distribution in the three bays. The lowest value of the year occurred sparsely in the Bohai Sea in July (Figure 2g), which was lower than 4 $mg.m^{-3}$. In this period, relatively high values were only observed in the peripheral regions of the three bays. In August (Figure 2h), patches of high Chla concentration extended seaward and a patch of significantly high value (>14 $mg.m^{-3}$) happened around 38.5°N, 119.5°E, which disappeared in September (Figure 2i). The region of high Chla concentration covered the shelf of the three bays and extended to the whole Bohai Sea until October (Figure 2j), which may suggest an autumn bloom.

3.2 Seasonal cycles of the Chla in different regions

Figure 3 shows the annual cycles of Chla in the four sites we selected. The data were shown in a climatologically monthly means which were averaged by month through the 7 years. By analyzing the annual cycles of different sites, we could understand the phytoplankton dynamics in different regions.

In the Bohai Bay and the Laizhou Bay, both of which are shallow waters, there were similar annual cycles characterized by non-significant pattern of seasonality and high inter-annual variability during July to October, while in the deep waters, the Liaodong Bay and the Central Bohai Sea, the seasonality was relatively obvious. The concentration reached its lowest in summer, while in winter and late autumn, the concentration was much higher.

The error bars show the standard deviation due to yearly averaging. The shallow waters (the Laizhou Bay and the Bohai Bay) have the same Chla temporal pattern that shows a relatively low seasonality and high inter-annual variability, while the deep waters (the Liaodong Bay and the Central Bohai Sea) have the same Chla temporal pattern that shows a low value in summer and a high value in winter.

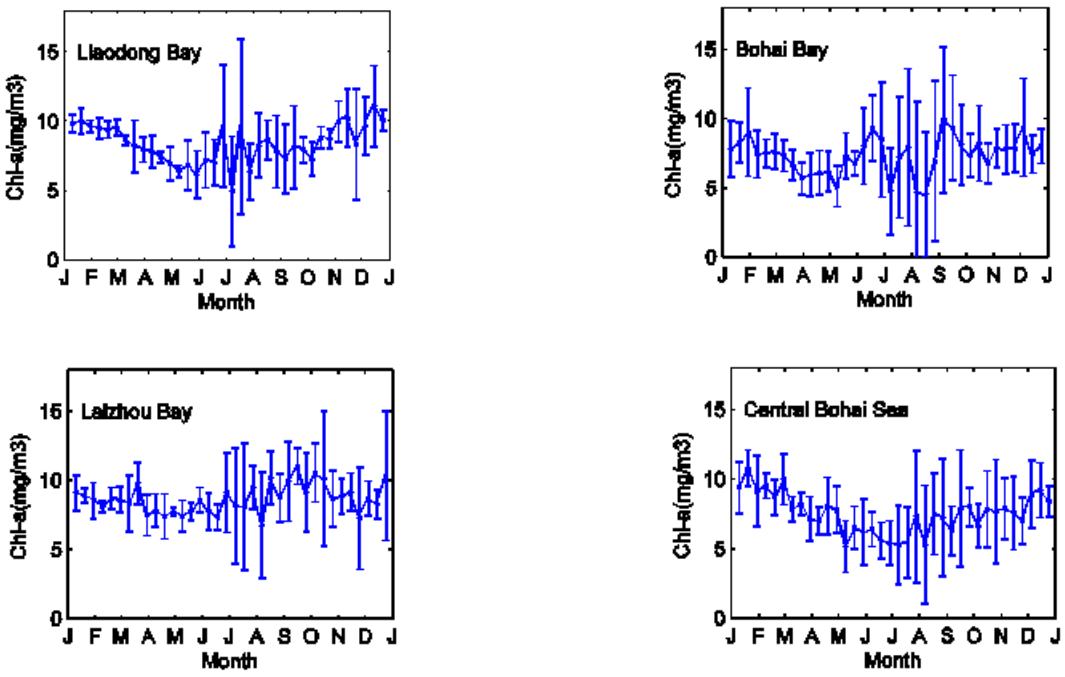

Figure 3. The climatologically annual cycle of Chla ($mg.m^{-3}$) at four selected sites.

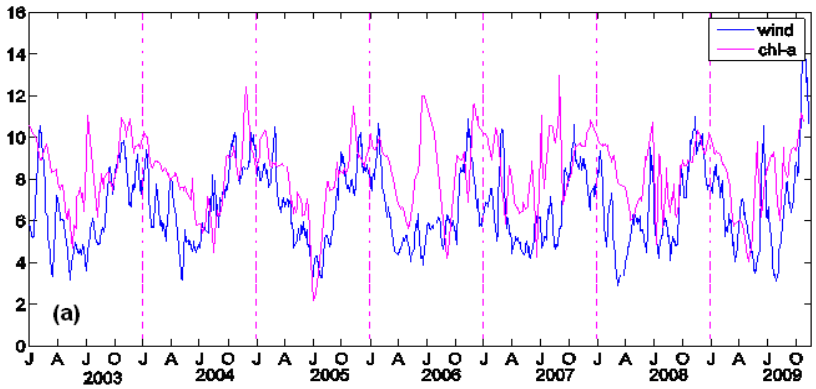

Figure 4. The annual cycle of Chla (mg.m^{-3}) and wind speed (m/s) in the Liaodong Bay in the form of a 10-day running mean during the period from 2003 to 2009.

3.3 The temporal variation of the wind speed

We did a 10-day running mean for the daily wind speed data and Chla data. The annual cycle of wind speed in the Liaodong Bay from 2003 to 2009 was shown to compare with the annual cycle of Chla (Figure 4). It was difficult to draw a good correlation between the two variables across the long time. However, the correlation was much better for the data in 2004 and 2005. Despite the small scale events that couldn't match well, the generally seasonal variations of both match well to some degree. This comparison gave us good evidence to value the importance of the wind to the Chla variation. The effect of wind should be considered in analyzing the mechanism of chlorophyll change.

4. CONCLUSION

According to the MODIS Chla data in the Bohai Sea, we find that annual cycle of Chla depended on the local dynamic characteristics. There were different seasonalities in different dynamic regions. In shallow waters, i.e., the Laizhou Bay and the Bohai Bay, there was no significant seasonal variation but an obvious inter-annual variability during July to October, while in deep waters, i.e., the Liaodong Bay and the Central Bohai Sea, there were low Chla concentrations in summer, when the primary production is high. The vertical turbulent mixing induced by wind accounted for the annual cycle of Chla in deep waters, either though the remineralization of the nutrient in the benthic layer or though the resuspension of the sediment containing Chla.

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