The seasonal variation of the phytoplankton size class in northern South China Sea

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Abstract. Phytoplankton size class variation is a good indicator of water dynamics changes, alga blooms or ecosystem change, for it usually corresponds to different phytoplankton group composition. Remote sensing technique is a very effective method for studying phytoplankton at large scale by virtue of synoptic view and large area cover. Here we detected seasonal and annual phytoplankton size class variation using remote sensing data based on a bio-optical algorithm in northern South China Sea. Result showed that the phytoplankton size class turned to be smaller during summer time, because of the stability of the water body and lack of nutrients. While in winter, the north-east monsoon made the water dynamics become complex. Upwellings, mesoscale eddy, typhoon and a series of drifts bring underwater nutrients up to the sea surface. As a result, phytoplankton with bigger cell size began to grow and the cell size turned to be bigger. The fraction of micro-phytolankton changed from 7% to 10%, while nano- and pico-phytolankton fraction decreased from 29% to 24% and 64% to 62% respectively. Annual change of phytoplankton size classes was in a relatively slow pace, and no big difference was noticed in the normal year. Usually about 1-5 percent change for each size class. When compared 2008 with 1998, a decade variances could be monitored. All the results in this study showed that phytoplankton size class can be an effective indicator of the ecosystem or environmental change.

1. Introduction

Phytoplankton size class variation is a good indicator of water dynamics changes, alga blooms or ecosystem change, for it usually corresponds to different phytoplankton group composition. Some groups play particular functional roles in earth biogeochemical cycle. These groups were defined as phytoplankton functional types (PFTs). In the last decade, there has been an increasing interest in identifying the PFTs from remote-sensed data. PFTs can be applied in many fields, such as primary-production estimation, biogeochemical cycle model building, harmful algae blooms detection and the aquatic ecosystems monitoring. Phytoplankton size classes are closely related with PFTs.

Remote sensing technique is a very effective method for studying phytoplankton at large scale by virtue of synoptic view and large area cover.

Here we detected seasonal and annual variation of phytoplankton size classes using remote sensing data in northern South China Sea.

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2. Data and method

2.1. Study area

The South China Sea is a marginal sea that is part of the Pacific Ocean, with an area of around 3,500,000 square kilometers. It extends from the Singapore and Malacca Straits to the Strait of Taiwan, from the equator to 23°N and from 99°E to 121°E. It is bordered by the shelf south of China and the Gulf of Tonkin in the north, and through the Taiwan Strait the South China Sea exchanges waters with East China Sea at a sill depth of 60m. The Gulf of Thailand and the Sunda Shelf between Malay Peninsula and Borneo consist of the southern shelf. On the east side, the South China Sea is separated from the Pacific Ocean by the Philippines and Palawan. And along the eastern boundary, the widest and deepest opening Luzon Strait is about 2000m in depth [1].

Complex dynamic processes are found in this area, including: monsoon, circulation, seasonal alternating wind direction and upwelling. Major rivers that flow into the South China Sea include: Pearl River in Guangdong Province, China; Red River in North Vietnam; Mekong in South Vietnam. River input brings terrestrial material into the sea. The dynamic processes and river input make a significant influence on the physical, biological and biogeochemical characteristic of South China Sea[2]. All of these result in its complex bio-optical characteristics. Our study was focused on this area (figure 1).
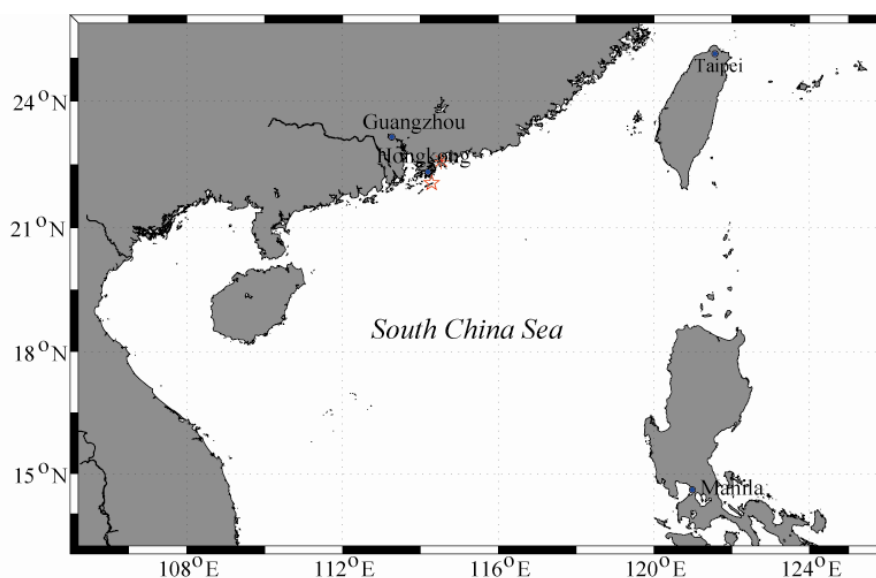

Figure 1. The study area: northern South China Sea.

2.2. Remote sensing data

SeaWiFS L3 data was used to conduct the study. Summer and winter seasonal data of 1998, 2007, 2008 with resolution of 9km were downloaded from the NASA ocean-color website (http://oceancolor.gsfc.nasa.gov/).

2.3. Method

As phytoplankton size class change a lot through coastal to open ocean, and the dominant size class varies from micro-phytoplankton to pico-phytoplankton as the trophic level changes. As coastal water shows different optical properties with open ocean, to derive the phytoplankton size class from optical parameters, two models were used. In coastal area, a modified model of Devred et al. (2011) [3] was used, as this model show good result in coastal area when tested with in situ data. While in open ocean, the model of Brewin et al. (2010) [4] was used, which based on a large dataset clearly shows the statistical relationship between phytoplankton size class and chlorophyll-*a* concentration.

The coastal model based on the assumption that each size class has a specific absorption coefficient [3]. Then the total absorption coefficients at different wavelength can be written as follows:

$$a_{ph}(\lambda) = a_m^* C_m + a_n^* C_n + a_p^* C_p \tag{1}$$

The specific absorption coefficients were shown in Table 1[5].

Table 1. The specific absorption coefficients of three size classes at 5 wavelength.

$\lambda(nm)$	a_m^* : m^2 (mg chl-a)$^{-1}$	a_n^* : m^2 (mg chl-a)$^{-1}$	a_p^* : m^2 (mg chl-a)$^{-1}$
412	0.008	0.081	0.132
443	0.0086	0.0596	0.174
490	0.006	0.035	0.115
510	0.0055	0.033	0.069
555	0.003	0.021	0.025

The open ocean model also localized with in situ data. The model assumed that each size class had a specific relationship with total chlorophyll-a concentration.

$$C_{n+p} = 3.18655(1 - \exp(-0.28997C)) \tag{2}$$

$$C_p = 1.167698(1 - \exp(-0.560135C)) \tag{3}$$

$$C_m = C - C_{n+p} \tag{4}$$

$$C_n = C_{n+p} - C_p \tag{5}$$

Also, as shown in Wang et al.[5], both the accuracy of absorption coefficients and chlorophyll-a concentration were in a reasonable range. Then we apply the models into satellite derived data to discuss the seasonal and annual variances of phytoplankton size classes.

2.4. Error analysis
Before applying the method on remote sensing data, we analyzed the errors of remote sensing data and the method.

Results showed that the relative error of remote sensing chlorophyll-a concentration was about 26%, and when applying on remote sensing data the model's relative errors were about 35%, 49%, 32% for micro-, nano- and pico-phytoplankton respectively. Taking into account of the complex condition and optical properties of the coastal water, this results were reasonable[3].

3. Results and discussion
The month July and December were chosen as the represents of summer and winter. 2007 and 2008 were chosen as the normal year to measure the seasonal and annual variation. 1998 was chosen to compare with 2008 to show the ten year size class variation caused by the climate change. The results of phytoplankton size classes' fraction were shown in the figures bellow.
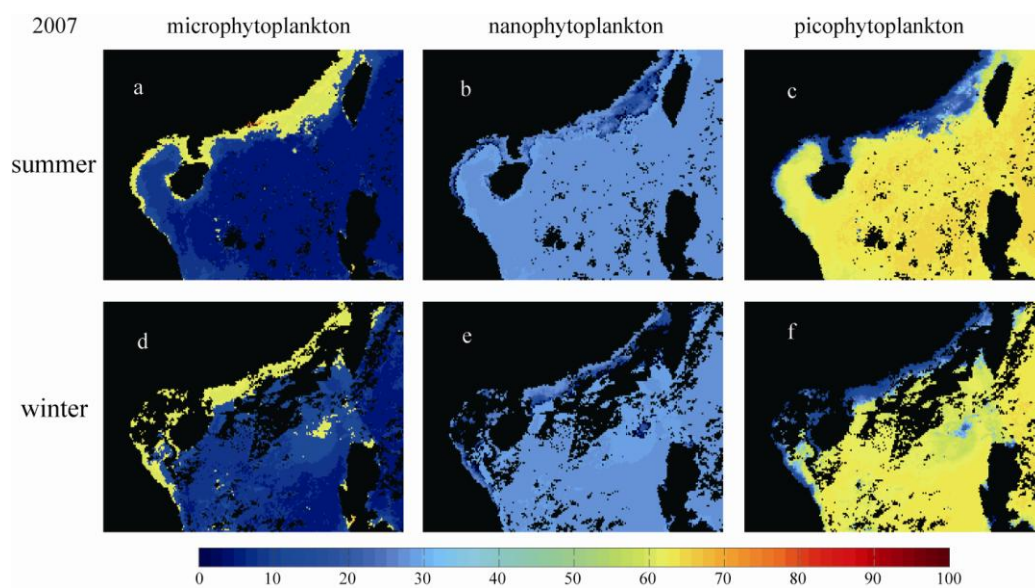
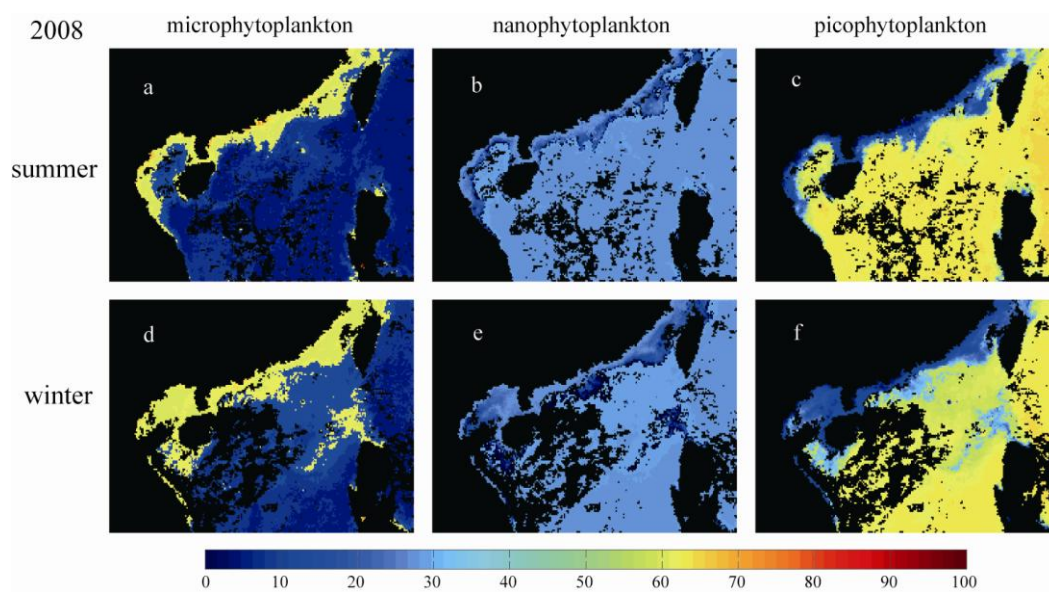**Figure 2.** The phytoplankton size classes fractions of 2007.

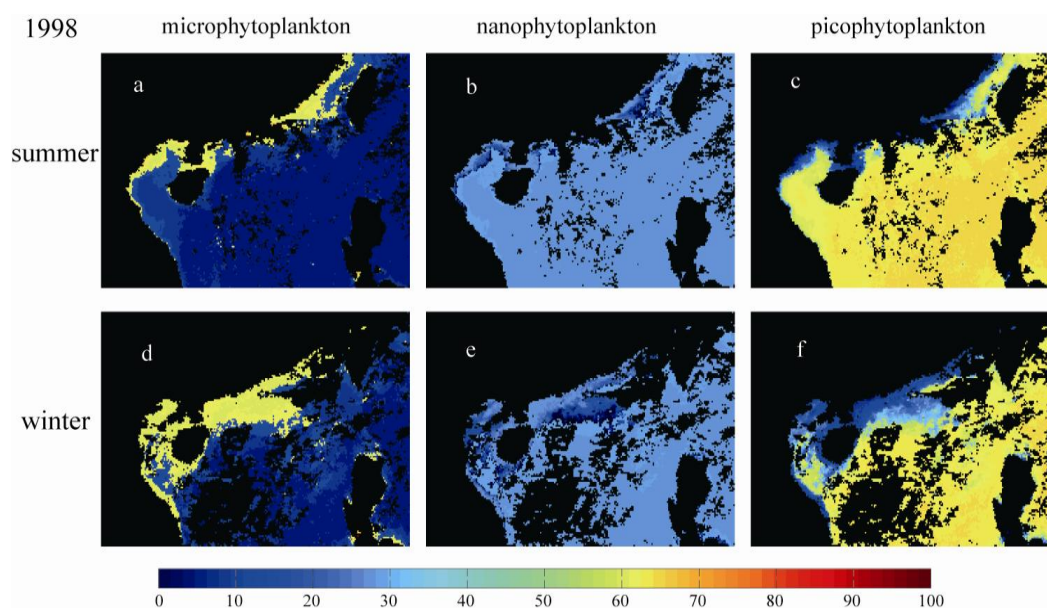**Figure 3.** Phytoplankton size classes fraction of 2008.

Figure 4. The phytoplankton size classes fractions of 1998.

In general, the spatiotemporal distribution of the phytoplankton community structure followed the patterns of ecosystem dynamics [2]. The size-fractioned chlorophyll-*a* concentrations of micro were relatively higher in winter (December) than in summer (July). Pico-phytoplankton were dominant in the open ocean, as shown in figure 2,3,4 c, f. High proportions of micro-phytoplankton were clearly visible over the south China coast in these images. Micro-phytoplankton were also dominant in the winter upwelling area of the Luzon Strait (figure 2,3,4 d).

The result showed that the phytoplankton size class turned to be smaller during summer time, pico-phytoplankton have a higher fraction than in winter time, because of the stability of the water body and lack of nutrients. While in winter, the north-east monsoon made the water dynamics become complex. Upwellings, mesoscale eddy, typhoon and a series of drifts bring underwater nutrients up to the sea surface. As a result, phytoplankton with bigger cell size (micro-phytoplankton) began to grow and the cell size turned to be bigger. The biggest fraction changes for three size classes were micro-phytolankton increasing from 7% to 10%, while nano-and pico-phytolankton fraction decreasing from 29% to 24% and 64% to 62% respectively. While in the Luzon Strait upwelling zone, the change can be much more bigger, and the dominant size class changed from pico-phytoplankton to micro-phytoplankton.

The annual variation of phytoplankton size classes was in a relatively slow pace, and no big difference was noticed in the normal year. In year 2007 and 2008 there was only about 1-5 percent change for each size class. When compared 2008 with 1998, some variances could be monitored in this decade. In this decade the fraction of micro-phytolankton had an average increase of 5% or more, nano kept balance or increase 2-4%, while the pico-phytolankton showed a decrease of 6%. This can be seen through the color changes in the figures. These results can also indicate that the environmental change happened in the last decade and the seasonal nutrient change happened in each year all have an obvious effect on phytoplankton size class. And phytoplankton size class changes can be an effective indicator of the environmental and ecosystem changes.

Taking into account possible errors in the atmospheric correction, the complex effects in the atmospheric correction and the deficiencies of satellite data, the variations and distribution patterns of phytoplankton size classes were in accordance with the observation of Ke et al. (2011)[6] and Zhai et al. (2011)[7].

4. Conclusion

All these results in this study showed that remote sensing can be an effective tool to monitor the phytoplankton size classes' distribution. The seasonal and annual variation can be seen from a large temporal and spatial scale.

What's more, the phytoplankton size class variation could be seen clearly between different season and it varies in different years. The obvious upwelling zone change and the annual variances indicate that phytoplankton size class can be an effective indicator of the ecosystem or environmental change.

5. Acknowledgement

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