Variation of Chlorophyll-a in the East Asian Continental Margin Seas

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Abstract: *Understanding changes in chlorophyll a concentration is important because it affects overall productivity and carbon storage and is an indicator of climate change. The chlorophyll-a concentration in the marginal sea varies significantly due to the influence of land. There are two main marginal seas along the Asian continent in the northwest Pacific, the East China Sea (ECS) and the South China Sea (SCS). To understand the variations in chlorophyll-a concentration in these two marginal seas, this study applied Empirical Orthogonal Function (EOF) to analyze the chlorophyll-a concentration derived from Moderate-resolution Imaging Spectroradiometer from 2003 to 2022. The results show that the chlorophyll-a concentration in the ECS is higher and more variable than in the SCS due to the discharge of Yangtze River water. The first EOF mode accounts for 69.0% of the total variance. It shows that the chlorophyll-a concentration is very different between coastal and open ocean waters. From its spatial distribution, the boundary between the two types of water (Case I and Case II) can be clearly identified. The second EOF mode accounts for 3.8% of the total variance. Its principal component shows that this mode represents seasonal changes. In winter, chlorophyll-a concentration increases in open oceans and decreases in coastal oceans. In summer, it is opposite with chlorophyll-a concentration decreasing in open oceans and increasing in coastal oceans. The chlorophyll-a concentration in the SCS is lower than that in the ECS. The first mode accounts for 65.0% of the total variance. It shows seasonal changes, with the concentration being higher in winter and lower in summer. Spatially, it shows that the chlorophyll-a concentration is higher in coastal waters and lower in open oceans. The second mode accounts for 12.5% of the total variance. The spatial distribution shows that Kuroshio water with low chlorophyll-a concentration intrudes into the north SCS from the Luzon Strait. Especially in the summer of 2007, the concentration dropped significantly.*

Keywords: chlorophyll-a, empirical orthogonal function, marginal sea, MODIS

Introduction

Chlorophyll-a plays a crucial role in marginal seas by serving as a key indicator of phytoplankton abundance and primary productivity, affecting biological processes and fisheries. It is also vital to understanding the dynamics of the ecosystem, primary production, and environmental health in marginal seas. Analyzing the spatial-temporal changes of chlorophyll-a helps to understand the dynamics of ecosystem and environmental monitoring (Hao et al., 2019; Huang et al., 2019; Tiwari et al., 2023). There are two major marginal seas along the east Asian continental, the East China Sea

(ECS) and the South China Sea (SCS). The ECS has input from the Yangtze River, the largest river in Asia. The nutrients and suspended particles brought by the Yangtze River water make the water quality of nearby coastal seawater very different from that of the open ocean. By understanding the changes in chlorophyll-a, it is helpful to understand the impact of Yangtze River water on water quality changes in the ECS. The SCS is the largest Asian marginal sea. It connects to the ECS through the Taiwan Strait and the Pacific Ocean through the Luzon Strait. Changes in its chlorophyll-a concentration are affected not only by the surrounding continents, but may also be affected by the Kuroshio water. Therefore, the purpose of this study is to understand the chlorophyll-a concentration in the ECS and the SCS. The study area is shown in Figure 1.

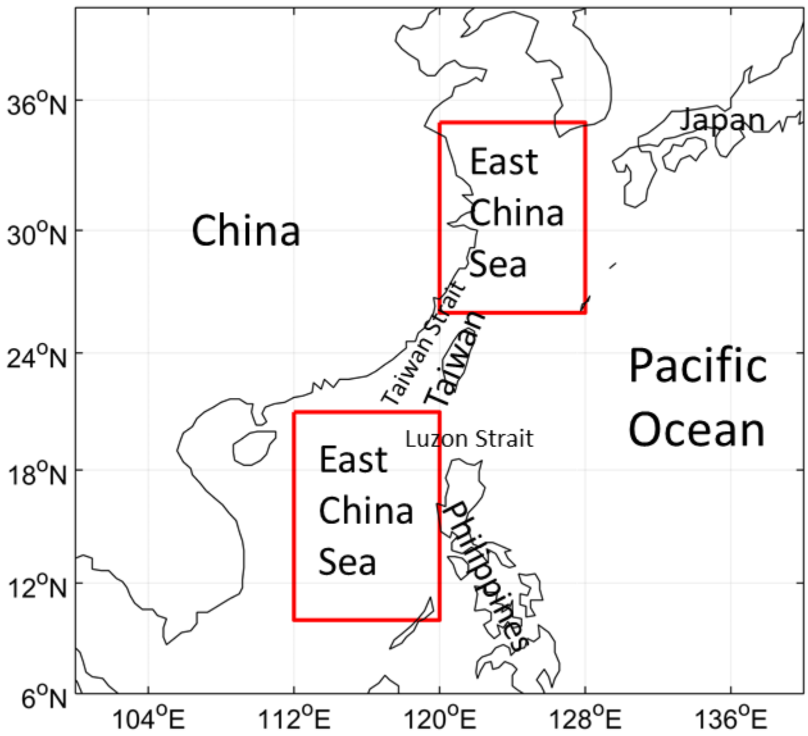

Figure 1: The Study Area.

The dataset used in this study is the product of chlorophyll-a concentration derived from the Moderate-resolution Imaging Spectroradiometer (MODIS) onboard the National Aeronautics and Space Administration (NASA) Aqua satellite from 2003 to 2022. The spatial resolution is 0.25° latitude × 0.25° longitude and the temporal resolution is monthly.

Literature Review

Previous studies have mentioned that wind-driven upwelling promotes phytoplankton growth in active frontal zones (Zhang et al., 2023), and factors such as water temperature and turbidity may cause the chlorophyll-a to change over time (Shang et al., 2023). Furthermore, the correlation between chlorophyll-a concentration and monsoon and sea surface temperatures reflects the importance of seasonal changes and weather variability (Laosuwan et al., 2022; Plybour & Laosuwan, 2023). Chlorophyll-a fronts in marginal seas indicate oceanic fronts, reflect seasonal variations in productivity and water conditions, and are crucial for monitoring marine ecosystems and understanding environmental dynamics (Xia et al., 2021). The chlorophyll-a concentrations in the marginal seas show different trends. Affected by temperature and freshwater input, some regions increase and some regions decreases (Yu et al., 2017), which also causes the variation of spring algal bloom peak with latitude (Chen et al., 2016). In addition, the chlorophyll a concentration of tropical marginal seas decreased, but the chlorophyll-a concentration of high-latitude marginal seas along the Eurasian continent increased, showing different responses to global warming (Bai et al., 2018). In general, chlorophyll-a is important to understand the dynamics of the marginal sea ecosystem, primary production, and environmental health.

Methodology

The empirical orthogonal function (EOF) method has been widely used in ocean and atmospheric research (Ho et al., 2000; 2004; Kuo & Ho, 2004; Zheng et al., 2007; Tseng et al., 2021). It is a statistical technique to divide the variability of a multivariate data set into independent patterns, each containing a percentage of the total variation. These modes are ordered from the highest to the lowest proportion of total variation. Each mode contains a spatial pattern modulated by an associated time series. The first few modes of the decomposed functions with greater variance may generally have physical significance. The EOF decomposition can be expressed as

$$Z(x, y, t) = \sum_{k=1}^{n} PC(t) \cdot EOF(x, y)$$

where $Z(x, y, t)$ is the original spatial data in x and y directions that changes with time t, $PC(t)$ is the time function, that is, principal component, and $EOF(x, y)$ is the spatial function.

Results and Discussion

a. ECS:

The time series of chlorophyll-a concentration in the ECS shows that April has the highest value of the year almost every year, except in 2022, which is in March (Figure 2). This phenomenon indicates the spring bloom of algae. The results of the ECS show that the first EOF mode contains 69.0% of the total variance, as shown in Figure 3. Spatial patterns indicate large differences in chlorophyll-a concentrations in coastal waters and the open ocean, implying a clear boundary between the two types of water, Case I water and Case II water. The principal component of the first EOF mode generally shows higher variation in summer. The second EOF mode accounts for 3.8% of the total variance. Its principal component shows that this mode represents seasonal changes (Figure 4). In winter and spring (December to April), the chlorophyll-a concentration increases in the open ocean, but decreases in the coastal area. In summer (June to August), it is opposite, with chlorophyll-a concentration decreasing in the open ocean and increasing in the coastal area. The possible reason for this phenomenon is that the output of Yangtze River water in summer brings more nutrients to the coast. Coupled with the increase in seawater temperature, algae grow more easily, resulting in more chlorophyll along the coast than in winter. In the open sea, it may be because the stratification phenomenon of seawater is more obvious in summer, and nutrients in the lower layer are less likely to rise to the surface, making the chlorophyll concentration lower than in winter.

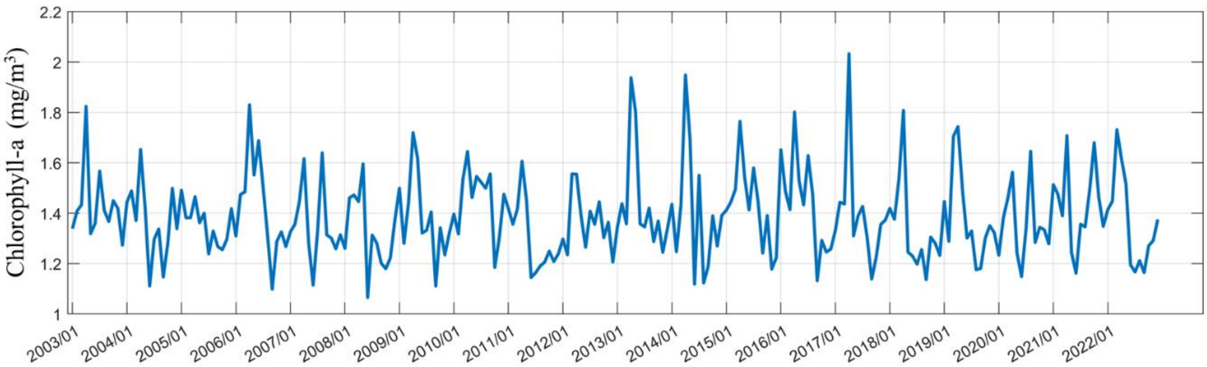

Figure 2: Time series of chlorophyll-a concentration in the ECS.

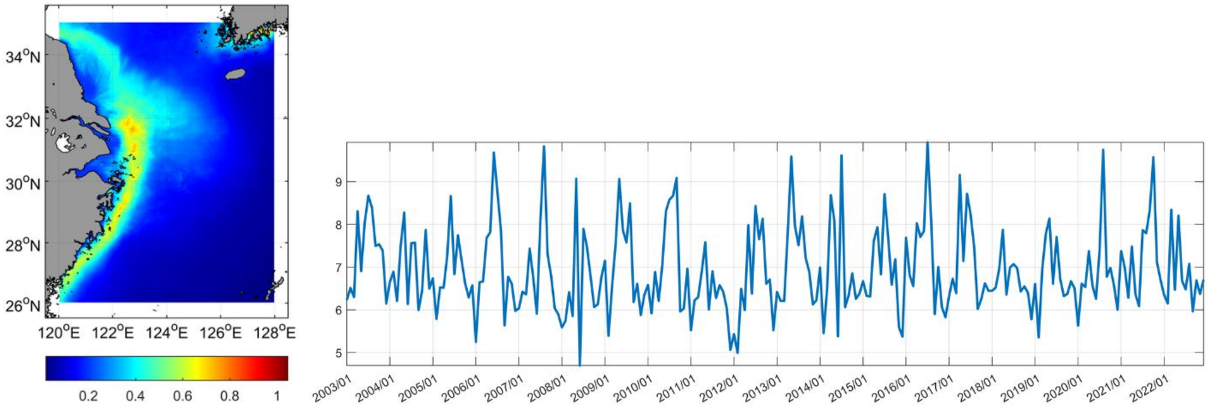

Figure 3: The first EOF mode of chlorophyll-a concentration in the ECS. Spatial pattern (left) and principal component (right).

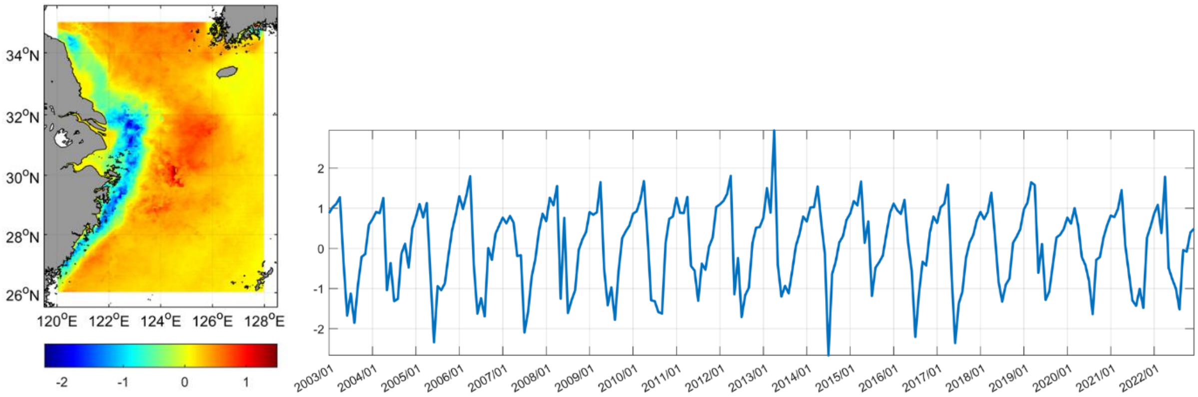

Figure 3: The second EOF mode of chlorophyll-a concentration in the ECS. Spatial pattern (left) and principal component (right).

b. SCS:

The chlorophyll-a concentration in the SCS is much lower than that in the ECS (Figure 5). The average chlorophyll-a concentration in the ECS is about 1.388 mg/m^3, and is about 0.138 mg/m^3 in the SCS, which is inly 1/10 of that in the ECS. Additionally, the chlorophyll concentration in the SCS shows obvious seasonal changes. The chlorophyll concentration is higher in winter, up to 0.25 mg/m^3, and lower in summer, less than 0.1 mg/m^3. The first EOF mode accounts for 65.0% of the total variance and shows seasonal changes (Figure 6). The chlorophyll-a concentration is higher in winter and lower in summer and is higher in the coastal water, and lower in the open ocean. The second mode accounts for 12.5% of the total variance. The spatial distribution shows that Kuroshio water with low chlorophyll-a concentration enters the north SCS from the Luzon Strait most of the time (Figure 7). Especially in the summer of 2007, the concentration dropped significantly.

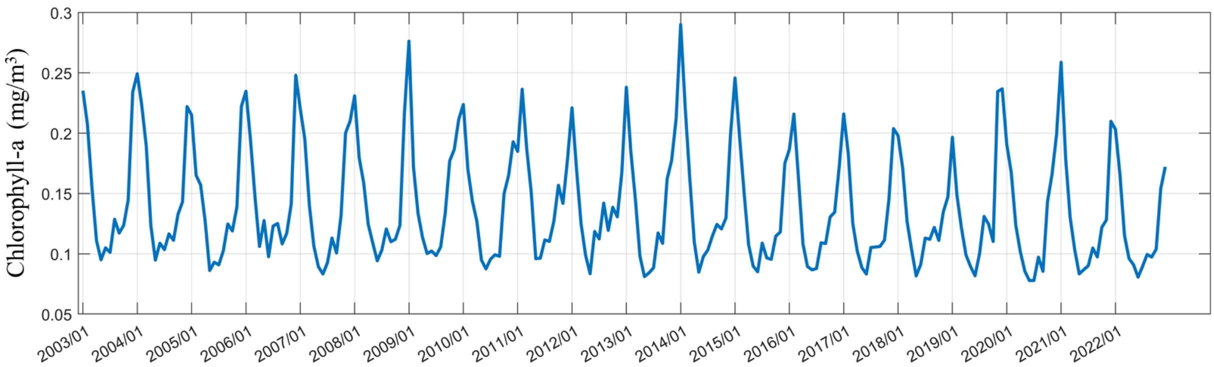

Figure 5: Time series of chlorophyll-a concentration in the ECS.

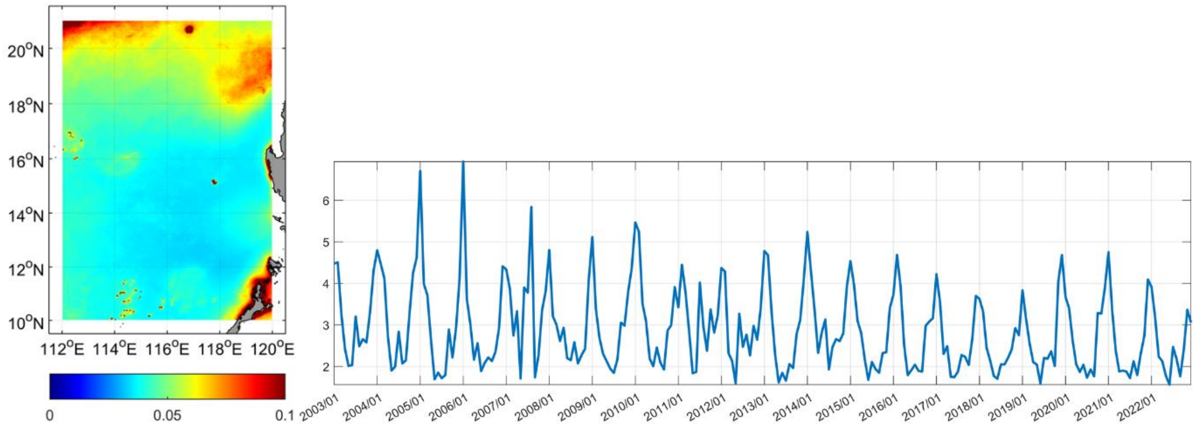

Figure 6: The first EOF mode of chlorophyll-a concentration in the SCS. Spatial pattern (left) and principal component (right).

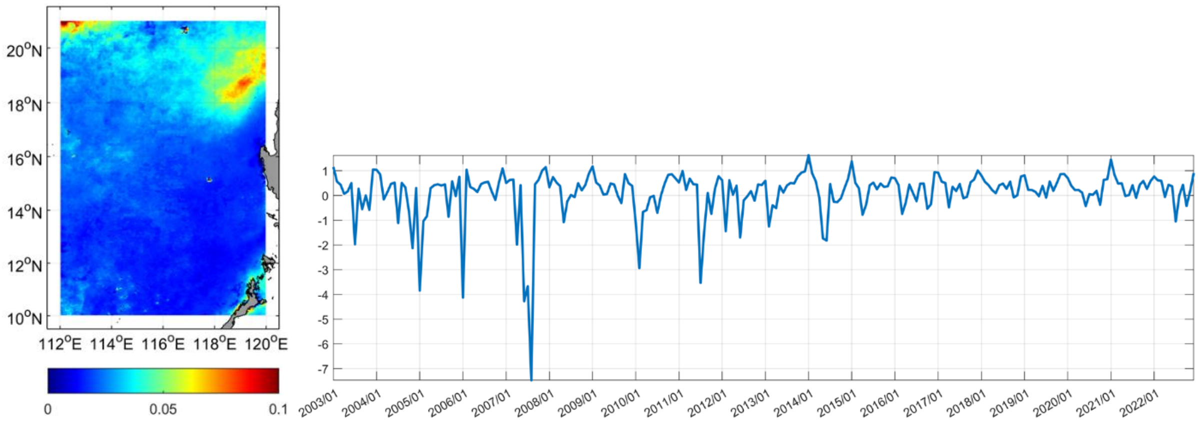

Figure 7: The second EOF mode of chlorophyll-a concentration in the SCS. Spatial pattern (left) and principal component (right).

Conclusion and Recommendation

This study applied EOF to analyze the chlorophyll-a concentration measured by MODIS from 2003 to 2022, focusing on ECS and SCS in East Asian marginal seas. Chlorophyll-a concentrations in the ECS are higher and more variable than in the SCS due to water discharge from the Yangtze River. The first EOF mode in the ECS showed a large difference in chlorophyll-a concentration between coastal and open ocean waters. The boundary between Case 1 water and Case 2 water is identified. The second EOF mode represents seasonal changes. In winter, the chlorophyll-a concentration increases in the open ocean and decreases in the coastal ocean. In summer, the opposite is true for chlorophyll. The chlorophyll-a concentration in the SCS is about 1/10 of that in the ECS. The first EOF mode shows seasonal variation, with higher concentrations in winter and lower concentrations in summer. Spatially, it shows that chlorophyll-a concentrations are higher in coastal waters and lower in the open ocean. The second EOF mode shows that Kuroshio water with low chlorophyll-a concentration intrudes into the northern SCS from the Luzon Strait. Especially in the summer of 2007, the concentration dropped significantly.

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