Int J Appl Earth Obs Geoinformation 67 (2018) 173–178

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

journal homepage: www.elsevier.com/locate/jag

Monitoring of chlorophyll-a and sea surface silicate concentrations in the south part of Cheju island in the East China sea using MODIS data

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ARTICLE INFO

Keywords:
MODIS
Chlorophyll-a
SST
Surface silicate
Spring bloom

ABSTRACT

Continually supplied with nutrients, phytoplankton maintains high productivity under ideal illumination and temperature conditions. Data in the south part of Cheju Island in the East China Sea (ECS), which has experienced a spring bloom since the 2000s, were acquired during a research cruise in the spring of 2007. Compared with *in-situ* measurements, MODIS chlorophyll-a measurements showed high stability in this area. Excluding some invalid stations data, the relationships between nutrients and chlorophyll-a concentrations in the study area were examined and compared with the results in 2015. A high positive correlation between silicate and chlorophyll-a concentration was identified, and a regression relationship was proposed. MODIS chlorophyll-a measurements and sea surface temperature were utilized to determine surface silicate distribution. The silicate concentration retrieved from MODIS exhibited good agreement with *in-situ* measurements with R^2 of 0.803, root mean square error (RMSE) of 0.326 μmol/L (8.23%), and mean absolute error (MAE) of 0.925 μmol/L (23.38%). The study provides a new solution to identify nutrient distributions using satellite data such as MODIS for water bodies, but the method still needs to be refined to determine the relationship of chlorophyll-a and nutrients during other seasons to monitor water quality in this and other areas.

1. Introduction

With the development of remote sensing technology, ocean color remotely sensed data have proven to be a useful tool for monitoring the marine ecosystem. Global algorithms of chlorophyll-a (O'Reilly et al., 2000) have been empirically derived from a large in-situ database collected in waters around the world, and several studies analyzed the spatial and temporal distribution of chlorophyll-a using MODIS (Ji et al., 2017; Gong and Wong, 2017).

In surface water mass, researchers have widely acknowledged that the growth of phytoplankton relates to the concentration of nutrients. Numerous attempts have been made to estimate nutrient concentrations in water bodies, especially in oceans, using satellite data. Generally, new production constitutes the fraction of primary production supported by nitrogen imported from outside of the euphotic zone (Dugdale and Goering, 1967) and is essentially related to nitrate consumption. Based on coupled dynamic biological models assimilating sea surface height (Oschlies and Garçon, 1998) or wind data (Stoens et al., 1999), researchers have determined nitrate concentration (Simpson and Sharples, 2012; Yamaguchi et al., 2012). Then Traganza et al. (1983) proposed temperature-nitrate relationships. In recent years, the surface nitrate concentration determination method was improved using sea surface temperature (SST) and surface chlorophyll-a concentration (Silió-Calzada et al., 2008; Gong and Wong, 2017). However, surface silicate concentration retrieved from satellite data has hardly been reported.

Spring blooms occurring in the East China Sea (ECS) have been reported in a large body of extant literature in recent years (Liu et al., 2003; Furuya et al., 2003; Endo et al., 2013; Chen et al., 2013; Fu et al., 2015; Ji et al., 2017). High concentrations of chlorophyll-a (2.9ug/L) appeared in the ECS (32°N, 126°E) between 1 and 10 March 1997 (Son et al., 2006), and 1ug/L chlorophyll-a concentration regions were observed in the western part of the Japan Sea, the ECS and the Yellow Sea in April 2003 (EORC, 2004).

When water temperature is lower than 20 °C, diatoms, such as *Chaetoceros lorenzianus* and *Bidduphia sinensis Greville*, dominate in the

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https://doi.org/10.1016/j.jag.2018.01.017
Received 29 September 2017; Received in revised form 21 January 2018; Accepted 29 January 2018
0303-2434/

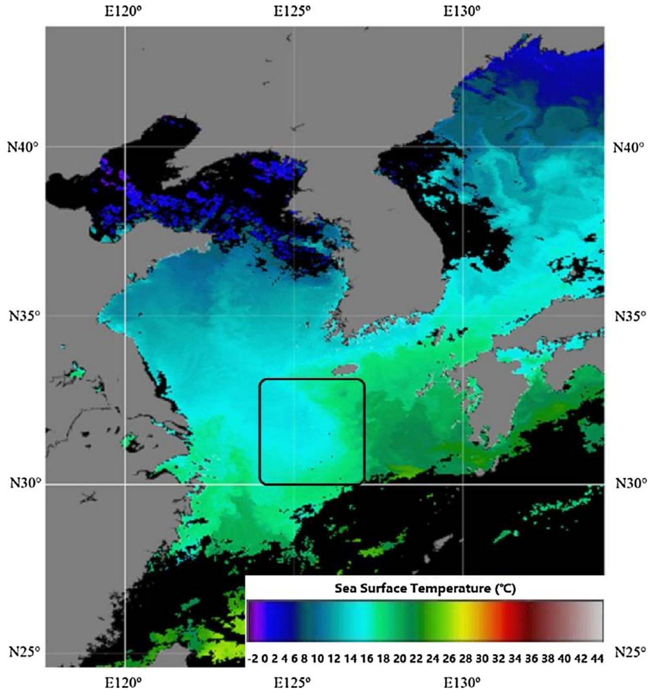

Fig. 1. Standard sea surface temperature image taken at daytime 11 April 2007 by Aqua MODIS (the study area as marked in the black box).

spring in the ECS because they are capable of more rapid growth (Luo et al., 2007). Diatoms are unicellular or chain-forming phytoplankton that used silicon (Si) in cell wall construction. When a water body is richer in nitrates than silicates, with nitrates still available for new production, the diatom bloom is prolonged, where there is a periodic supply of new silicate (Allen et al., 2005).

Owing to discharge from the Changjiang River (Yangtze River), the intrusion of Yellow Sea waters, Taiwan Strait waters and Kuroshio waters, as well as alternating monsoons, the ECS shelf possesses a complex hydrology (Liu et al., 2003). In addition, spring blooms have appeared in the south part of Cheju Island in the ECS, as reported by Son et al. (2006).

A one-month cruise was carried out in the south part of Cheju Island in the ECS (Fig. 1) in the spring of 2007. During the observation, nutrients were pulled up to the sea surface by circulation, which occurs in the spring, and the abundant silicon, the appreciable nitrogen, the phosphorus and the temperature caused a high chlorophyll-a concentration in the study area (Fu et al., 2015). In fact, Fu et al. (2015) observed a linear relationship between *in-situ* measured chlorophyll-a and the silicate concentration with R^2 of 0.7812.

The aims of this study are to: 1) determine the concentration of chlorophyll-a in surface water in the study area using MODIS; and 2) utilize a method that derives sea surface silicate concentrations from SST and surface chlorophyll-a concentration using regression analysis and remotely sensed data.

2. Study area and data collection

2.1. Study area

The field observation was performed at 30°–32.33°N, 124.33°–127.67°E, covering 40,000 km^2, across the shelf edge of the ECS, as shown in Fig. 1, from 9 April to 6 May 2007. In spring, with the rising of the temperature on the upper layer of the water and the appearance of the thermocline, the cold-water mass in the southwest part of Cheju Island possesses the characteristics of low temperature and mesohaline under the shielding effect of the thermocline (Qi et al., 1991; Li, 1995; Yu et al., 2006) with abundant nutrients due to the spreading of the Yellow Sea cold water mass (Fu et al., 2015).

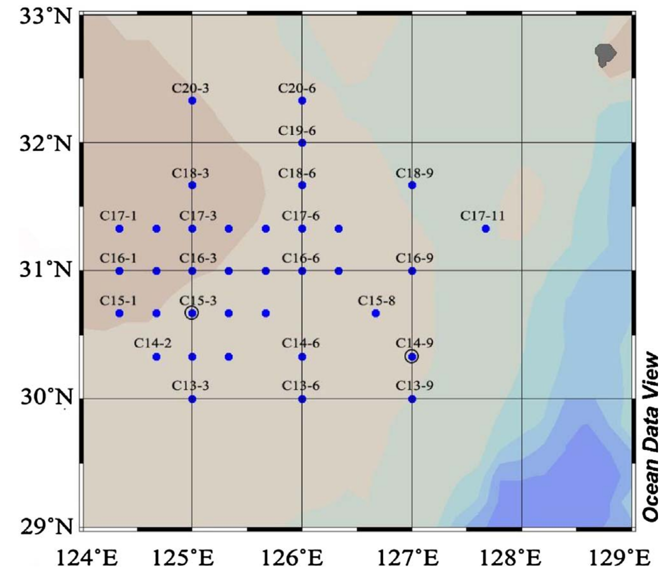

Fig. 2. The sampling stations C13-1 to C13-9, C14-1 to C14-9, C15-1 to C15-8, C16-1 to C16-9, C17-1 to C17-11, C18-1 to C18-9, C20-3 and C20-6 mapped using Ocean Data View.

The study area and the sampling stations (including sections C13-1 to C13-9, C14-1 to C14-9, C15-1 to C15-8, C16-1 to C16-9, C17-1 to C17-11, C18-1 to C18-9, C20-3 and C20-6) are shown in Fig. 2.

2.2. Data collection

2.2.1. Sea surface temperature (SST) and chlorophyll-a (Chl-a) in-situ measurements

Sea surface temperatures were measured using a probe from a RBR water quality sensor (RBR Inc., Kanate, Ontario, Canada). The calibration equipment from RBR permits traceable calibration for oceanography instruments, including that for temperature with accuracy to $\pm$ 0.002° C and conductivity with accuracy to $\pm$ 0.003 mS/cm.

Chlorophyll-a (Chl-a) was filtered using a 47 mm GF/F filter, extracted using 90% acetone and determined with a Shimadzu UV2401 spectrophotometer (Shimadzu, Inc., Tokyo).

In sum, 22 stations were probed from 30.33°N to 31.33°N in one month, as shown in Table 1. SST increased continually, and the mean of SST changed from 12.8° C on 9 April 2007–17.4° C on 5 May 2007. A high concentration of chlorophyll-a ($>$ 10 ug/L) was detected in the study area.

2.2.2. Nutrient data

Covering over 40,000 km^2, 22 stations were investigated from 6 April to 6 May 2007. The sample stations are listed in Table 2.

Nutrient data, including dissolved inorganic nitrates (DINs), dissolved inorganic phosphates (DIPs, PO3- 4) and silicates (SiO2- 3), were acquired by *in-situ* measurements. DIN concentrations can be calculated by summing those of nitrate (NO- 3), nitrite (NO- 2) and ammonium

Table 1
Properties of chlorophyll-a data collected from 9 April 2007 to 5 May 2007.

Station name	*Period*	*Latitude*	*n*
C14-2,3,4,6	03 May 2007	30.33°N	4
C15-1,2,3,4,5,8	26 April–05 May 2007	30.67°N	6
C16-1,2,3,4,6, 9	26 April–04 May 2007	31.00°N	6
C17-1,2,3,4,5,6	09 April–04 May 2007	31.33°N	6
Total	09 April–05 May 2007		22