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Satellite observation of hourly dynamic characteristics of algae with Geostationary Ocean Color Imager (GOCI) data in Lake Taihu

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ABSTRACT

Phytoplankton bloom in a shallow inland eutrophic lake (Taihu Lake) is characterized by significant spatial and temporal variation and a high concentration of chlorophyll-a ($C_{chl\text{-}a}$). The observation of the rapidly changing dynamic characteristics of algae is limited by the insufficient temporal resolution of satellite data. The Geostationary Ocean Color Imager (GOCI), launched by Korea, can provide high temporal resolution satellite data to observe the hourly dynamics of algae. In this study, a simple regional NIR-red two-band empirical algorithm of $C_{chl\text{-}a}$ for GOCI is proposed for Taihu Lake. Study results show that the GOCI-derived $C_{chl\text{-}a}$ matches the in situ measured values well. Based on this validated algorithm of $C_{chl\text{-}a}$, we obtained the hourly maps of $C_{chl\text{-}a}$ from GOCI level-1b data during the period August 6 to August 9, 2013. The spatial variation of GOCI-derived $C_{chl\text{-}a}$ also matches synchronous in situ measured values well, and the temporal variation of GOCI-derived $C_{chl\text{-}a}$ coincides with buoy-measured $C_{chl\text{-}a}$. The northwestern area of the lake and Meiliang Bay are worst hit by phytoplankton bloom. GOCI-derived $C_{chl\text{-}a}$ revealed a clear evidence of hourly spatial and temporal variations of $C_{chl\text{-}a}$ in Taihu Lake. The vertical current plays an important role in the hourly scale of spatial and temporal variations in phytoplankton. The horizontal current is important to the distribution of phytoplankton over the long term, but spatially and temporally limited in the short term.

1. Introduction

Algae are vital to marine and freshwater ecosystems because of their key role in keeping the biosphere balanced despite natural forces and food-chain relationships (Cloern, 2001; Rabalais, 2004). Algal blooms, however, which are formed from the excessive growth of algae in freshwater and coastal marine ecosystems, are caused by increased nutrients (i.e., nitrogen and phosphorus) and have become a global problem. Algal blooms (such as *Microcystis aeruginosa*, *Scenedesmus obliquus* and diatom) occur worldwide. Taihu, Dianchi and Chaohu Lakes in China (Huang, Li, Yang, Sun, et al., 2014; Huang, Wang, et al., 2014; Paerl et al., 2011), Lake Erie in the United States (Michalak et al., 2013; Stumpf, Wynne, Baker, & Fahnenstiel, 2012), Lakes Wood and Winnipeg in Canada (Binding, Greenberg, & Bukata, 2011; Schindler, Hecky, & McCullough, 2012), and Lake Nieuwe Meer in the Netherlands (Jöhnk et al., 2008), have received much attention for their harmful toxins. The blooms are generally perceived to result from a rapid increase in biomass, because the algae growth period is much longer than the loss period. Previous studies have proposed that the intensity and frequency of blooms are empirically connected to nutrient status (Abell, Ozkundakci, & Hamilton, 2010; Paerl et al., 2011; Schindler et al., 2008; Xu, Paerl, Qin, Zhu, & Gao, 2010). Temperature, light and water dynamic characteristics are also important influencing factors (Carstensen, Henriksen, & Heiskanen, 2007; Moore et al., 2008; Paerl & Huisman, 2009; Wong, Lee, & Hodgkiss, 2007; Zhang, Duan, Shi, Yu, & Kong, 2012). The formation process of algal bloom is clearly complex.

Indeed, regulating nutrient input is the only realistic method of controlling algal bloom intensity and frequency (Conley et al., 2009; Paerl et al., 2011). As an extremely eutrophic lake, the nutrient input into the Taihu Lake watershed was effectively controlled, but the dynamic release of nutrients from sediment was not. (Dzialowski, Wang, Lim, Beury, & Huggins, 2008; Qin, Xu, Wu, Luo, & Zhang, 2007; Qin et al., 2006). Consequently, eutrophication could not be controlled in a short time period. However, the high rates of algal blooms create an urgent need for effective measures to reduce loss caused by blooms.

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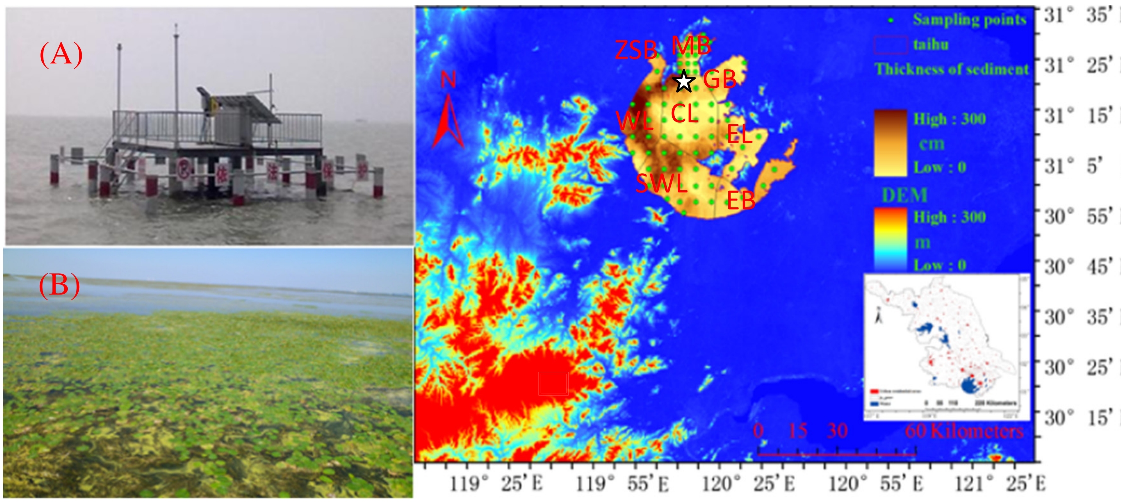

Fig. 1. Study area. The bottom right corner is the location of Taihu Lake in Jiangsu province. The black star is the position of buoy. The background of Taihu Lake is thickness of sediment. Taihu Lake can be separated into seven segments, including: Meiliang Bay (MB), Central Lake (CL), Gonghu Lake (GL), Western Lake (WL), Southwestern Lake (SWL), Eastern Lake (EL) and Eastern Bay (EB), Zhushan Bay (ZSB). A is a photo of the buoy. The main portion of the Eastern Bay is characterized by emergent aquatic plants, such as those shown in chart B.

Monitoring algal bloom and chlorophyll-a to evaluate and predict algal bloom is thus a critical prerequisite to finding effective methods to control the bloom. Satellite remote sensing provides rapid, synoptic, and repeated information on water quality (Duan et al., 2009; Hunter, Tyler, Willby, & Gilvear, 2008a, 2008b; Liu, Wang, & Shi, 2009; Odermatt et al., 2012). Many retrieval algorithms, such as the float algal index (Gower, King, Borstad, & Brown, 2005; Hu, 2009; Hu et al., 2005; Wynne, Stumpf, Tomlinson, & Dyble, 2010) and new chlorophyll-a retrieval models (Huang, Li, Yang, Li, et al., 2014; Shanmugam, 2011), have been developed to study the algal bloom, biological, and ecological processes and phenomena in Taihu Lake (Duan et al., 2009; Hu et al., 2010; Huang, Li, Yang, Li, et al., 2014; Le et al., 2009). Long-term records of algal blooms in the lake based on satellite data have been established to reveal large temporal and spatial variation of algal bloom (Duan et al., 2009; Hu et al., 2010; Wang, Shi, & Tang, 2011). However, there has been little published work on the dynamic characteristics of algae observation based on satellite data. This is due to the challenge of obtaining high temporal resolution, accurate atmospheric correction algorithms and a chlorophyll-a retrieval model for the satellite data. Hydrodynamic force has a significant effect on the formation of algal blooms and on their distribution (Moreno-Ostos, Cruz-Pizarro, Basanta, & George, 2009; Wu & Kong, 2009; Wu et al., 2013). This is particularly true for Taihu Lake because it is a shallow inland lake with a high dynamic ratio ([square root of the area]/depth: 25.4) (Huang, Li, Yang, Sun, et al., 2014), where algal (mainly is *M. aentginosa*) blooms occur every year (Guo, 2007; Huang, Li, Sun, & Le, 2011). The observation of the dynamic characteristics of algae in Taihu Lake using high temporal resolution satellite data is thus necessary and important. The Geostationary Ocean Color Imager (GOCI), launched by Korea, was decided on as a good choice for this observation (Choi et al., 2012; He et al., 2013; Ruddick et al., 2012; Ryu, Choi, Eom, & Ahn, 2011).

In the study, we establish a simple NIR-red band ratio algorithm of chlorophyll-a concentration (C_{chl-a}) for GOCI data using in situ measurements of remote sensing reflectance and C_{chl-a}, and reveal the dynamic characteristics of C_{chl-a} and phytoplankton bloom by retrieval results of C_{chl-a} from GOCI. This provides reliable satellite observation data to better understand the dynamics of phytoplankton bloom and the factors controlling bloom in Taihu Lake.

2. Data and methods

2.1. Study area

Taihu Lake (30°90′–31°54′N and 119°55.3′–120°59.6′E) is located on the Yangtze River delta, and is a very important drinking water source for the cities of Suzhou, Wuxi and Shanghai. It is the third-largest freshwater lake in China with an area of 2428 km^2 (water surface area is 2338 km^2, island area is 90 km^2), and a mean depth of 1.9 m (Fig. 1). It is influenced by the East Asian monsoon climate. The lake can be separated into seven major segments, including: Meiliang Bay

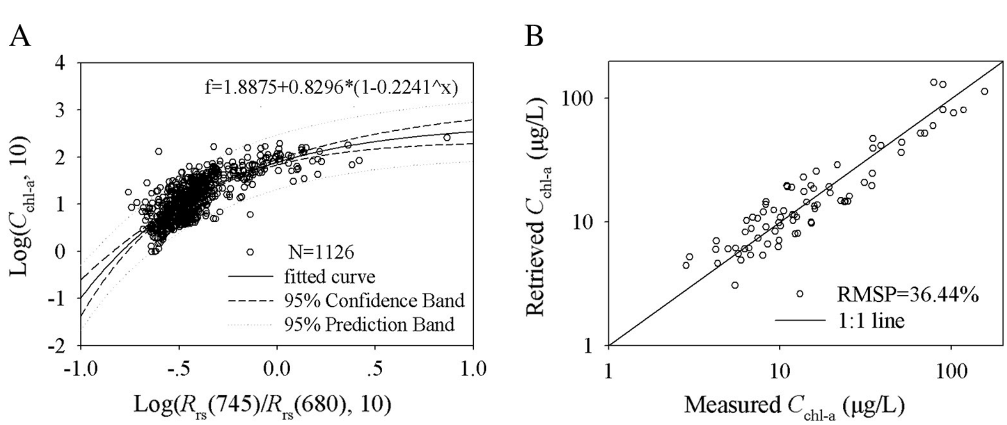

Fig. 2. Calibration and validation of C_{chl-a}NIR-red two-band algorithm.

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