Int J Appl Earth Obs Geoinformation 62 (2017) 174–182

Contents lists available at ScienceDirect

Int J Appl Earth Obs Geoinformation

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

Tracing high time-resolution fluctuations in dissolved organic carbon using satellite and buoy observations: Case study in Lake Taihu, China

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ARTICLE INFO

Keywords:
Dissolved organic carbon
Geostationary ocean color imager (GOCI)
Optical properties
Carbon cycle
Lake Taihu

ABSTRACT

Field measurements of dissolved organic carbon (DOC) concentration and remote-sensing reflectance were conducted to develop a regional, empirical red-blue algorithm to retrieve surface DOC from Geostationary Ocean Color Imager (GOCI) data for Lake Taihu, China. The auxiliary data (in-situ observations of the optical properties and water quality, buoy measurements of hydrodynamic data and water chemical parameters) were used to investigate the spatial and temporal variations in DOC. GOCI was shown to be capable of successfully obtaining hourly variations in DOC, with a root mean square error percentage (RMSP) of 17.29% (RMSE = 0.69 mg/L) for the match-up data. The GOCI-derived DOC in Lake Taihu confirms that the highest DOC concentration is in northwest Lake Taihu, followed by Meiliang Bay, Gonghu Bay and northeast Lake Taihu. Hourly DOC variation is significant and presents a different trend for each lake segment due to the variety of influencing factors. Discharge of DOC from surrounding rivers is an important factor to the variation of DOC in northeast Lake Taihu. However, organic products of algae will be the primary contributor to DOC when algal bloom occurred. During the period of algal bloom, high DOC levels in Lake Taihu can lead to hypoxia when coupled with high temperatures and low disturbance.

1. Introduction

Lakes regulate the global carbon cycle by emitting large of carbon dioxide and burying huge of organic carbon (Guo and Macdonald, 2006; Tranvik et al., 2009; Raymond et al., 2013). They actively transport, transform and store carbon via high riverine flux, high productivity and carbon sequestration with organic matter (Guo et al., 2007; Stets et al., 2009; Rudorff et al., 2011). Dissolved organic carbon (DOC) and particulate organic carbon (POC) are main carbon store in lakes. Among of them, DOC contains large amounts of carbon, nitrogen, phosphorus and other elements. Appreciable carbon, nitrogen and phosphorus are released as nutrients and gas (CO_2) during the mineralization process of DOC. DOC in surface water regulates the saturation of carbon dioxide (CO_2) in aquatic ecosystems and further affects the CO_2 exchange between water and the atmosphere (Tranvik et al., 2009). DOC also carries heavy metals and persistent organic pollutants and thus affects the toxicity and transport of these pollutants (Khokhotva and Waara, 2010; Branzini and Zubillag, 2012; Mousset et al., 2014; Venegas et al., 2015). Meanwhile, chromophoric dissolved organic matter (CDOM), a type of DOC, defends aquatic ecosystems by absorbing harmful ultraviolet radiation (Zhang et al., 2011, 2012). Previous study also has shown that DOC can help mitigate human-induced acidification (Erlandsson et al., 2011). Consequently, it is important to understand the distribution of DOC and its dynamics in order to clarify its role in biogeochemical processes within lakes and the global carbon cycle (Cole et al., 2007; Battin et al., 2009; Kothawala et al., 2014).

Remote sensing retrieval algorithms have been developed to quickly and economically estimate DOC concentration over large areas (Del Castillo and Miller, 2008; Mannino et al., 2008; Liu et al., 2013;

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http://dx.doi.org/10.1016/j.jag.2017.06.009
Received 26 January 2017; Received in revised form 3 June 2017; Accepted 16 June 2017

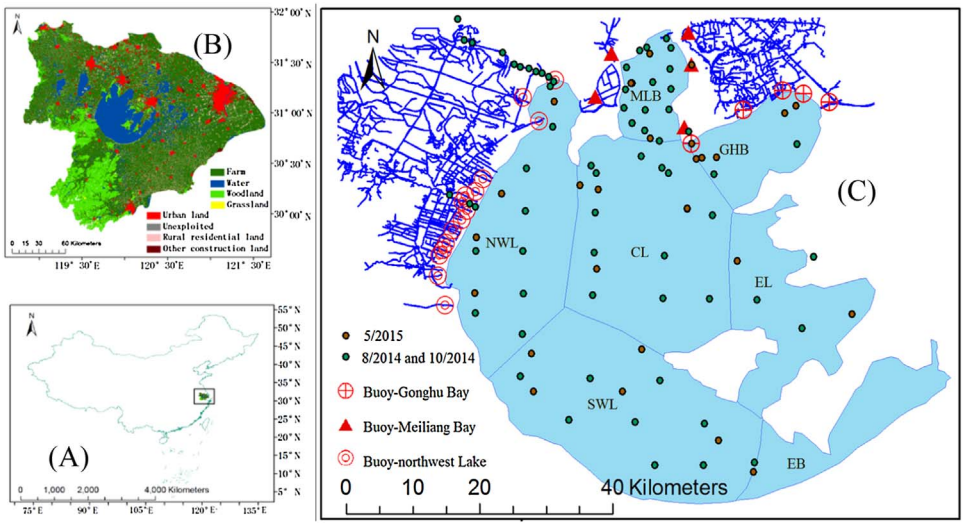

Fig. 1. Study area, Taihu drainage basin, located at the middle and lower regions of the Yangtze River (A). The land use/cover in this area is primarily farmland and woodland. The urbanization is very rapid (B). The river network in southern Lake Taihu is dense. Large numbers of buoys were used to monitor the water quality in the region (C). The lake can be separated into six major segments: Meiliang Bay (MLB), central Lake Taihu (CL), northwestern Lake Taihu (NWL), southwestern Lake Taihu (SWL), eastern Lake Taihu (EL) and the eastern bay (EB).

Shuchman et al., 2013; Kutser et al., 2015). DOC-retrieval algorithms can be divided into two groups. One estimates DOC by first measuring CDOM levels and then utilizing the relationship between DOC and CDOM (Del Castillo and Miller, 2008; Mannino et al., 2008; Fichot et al., 2011; Spencer et al., 2012; Liu et al., 2013; Harvey et al., 2015; Li et al., 2017). For these algorithms, it is particularly important to establish a valid relationship between DOC and CDOM. However, the regression parameters of these linear relationships vary due to the complex components and different sources of DOC (Vodacek et al., 1997; Ferrari, 2000; Newall and Fisher, 2002; Vecchio and Blough, 2004; Mannino et al., 2008; Fichot et al., 2011; Vantrepotte et al., 2015; Cherukuru et al., 2016). The other utilizes the band ratio algorithms of remote-sensing reflectance to retrieve DOC directly (Vertucc and Likens, 1989; Arenz et al., 1996; Chen and Shi, 2001; Zhang et al., 2005; Kutser et al., 2015). This method has been successfully applied in inland waters with high DOC concentrations and did not need a clear relationship of DOC and CDOM.

The spatial resolution of sensors applied in previous studies of DOC retrieval have ranged from 30 m to 1000 m (e.g., Landsat, 30 m; MODIS, 250 m; MERIS, 300 m; SeaWiFS, 1000 m) (Mannino et al., 2008; Liu et al., 2013; Zhu et al., 2014; Kutser et al., 2015). These satellites and their varying spatial resolutions are potentially suitable for the study of carbon in water bodies, ranging from small lakes to oceans. Nevertheless, the importance of satellite temporal resolution for DOC observation has received little attention, although satellite spatial resolution and the ratio of signal to noise have been more fully evaluated. Monitoring DOC levels with high temporal resolution is necessary (Spencer et al., 2007; Müller et al., 2014) because DOC and CDOM are not stable materials. They are utilized and transformed by microbial respiration, photolytic degradation, and flocculation (Sobek et al., 2005; Berggren et al., 2007; Cory et al., 2007; Jaffé et al., 2008; Guillemette and Del Giorgio, 2011; Koehler et al., 2012; Karlsson et al., 2012; Catalán et al., 2012). Images from the Geostationary Ocean Color Imager (GOCI) satellite satisfy the requirements for high temporal resolution (1 h), high radiometric resolution (> 11 bit) and high signal to noise ratio (> 750) (Ruddick et al., 2012; Ryu et al., 2011; Choi et al., 2012; Huang et al., 2015). Thus, utilizing GOCI to monitor hourly dynamic change in DOC is a novel method to provide a detailed study of DOC over large spatial and time scales.

In this study, a simple regional red-blue band ratio empirical algorithm of DOC was calibrated and validated for GOCI satellite imagery using in-situ measurements of remote-sensing reflectance and DOC. Based on this algorithm, we mapped the distribution of DOC from GOCI images over one-hour intervals in May, August and October. The spatial and temporal dynamics of GOCI-derived DOC in the lake were analyzed along with flow and DOC of river (from buoys monitor) to reveal the influence of river plume.

2. Data and methods

2.1. Study area

Lake Taihu is a shallow inland lake in the Yangtze River Delta of China. The lake has an area of 2428 km^2 and a mean depth of 1.90 m (Fig. 1). The dynamic ratio ([square root of the area]/depth) of Lake Taihu can reach 25.40 (Huang et al., 2015), meaning that water disturbances induced by monsoons occur frequently. Other key features of the lake include hyper eutrophication and algal blooms resulting from the discharge of nutrients from surrounding rivers and sediment resuspension (Guo, 2007; Wang et al., 2011). Large algal blooms caused by eutrophication have occurred over the years (Huang et al., 2015). Lake Taihu was seprated into seven major segments, namely, Meiliang

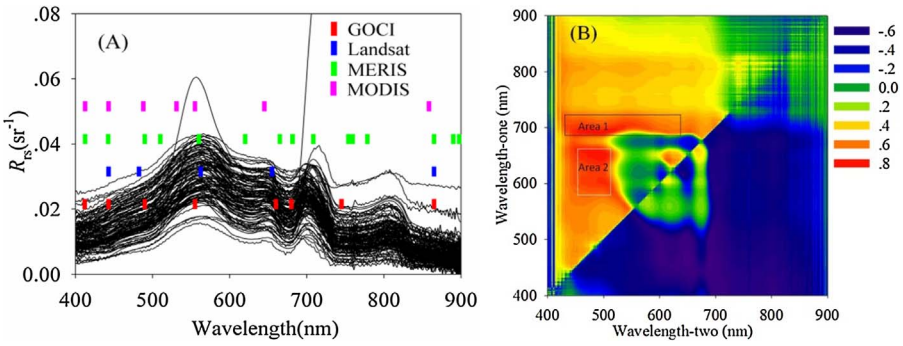

Fig. 2. A) Remote-sensing reflectance from in-situ measurement data in Lake Taihu. Color splashes represent the band settings for four satellite sensors. B) Correlation coefficients between DOC levels and band ratio.