International Journal of Applied Earth Observation and Geoinformation 52 (2016) 149–154

Contents lists available at ScienceDirect

International Journal of Applied Earth Observation and Geoinformation

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

Estimating dissolved organic carbon concentration in turbid coastal waters using optical remote sensing observations

Nagur Cherukuru[a,*], Phillip W. Ford[a], Richard J. Matear[b], Kadija Oubelkheir[c], Lesley A. Clementson[b], Ken Suber[b], Andrew D.L. Steven[c]

[a] CSIRO Oceans and Atmosphere, Canberra, Australia
[b] CSIRO Oceans and Atmosphere, Hobart, Australia
[c] CSIRO Oceans and Atmosphere, Brisbane, Australia

ARTICLE INFO

Article history:
Received 3 February 2016
Received in revised form 25 May 2016
Accepted 9 June 2016

Keywords:
DOC
CDOM
Optical remote sensing
Coastal water
MODIS

ABSTRACT

Dissolved Organic Carbon (DOC) is an important component in the global carbon cycle. It also plays an important role in influencing the coastal ocean biogeochemical (BGC) cycles and light environment. Studies focussing on DOC dynamics in coastal waters are data constrained due to the high costs associated with in situ water sampling campaigns. Satellite optical remote sensing has the potential to provide continuous, cost-effective DOC estimates. In this study we used a bio-optics dataset collected in turbid coastal waters of Moreton Bay (MB), Australia, during 2011 to develop a remote sensing algorithm to estimate DOC. This dataset includes data from flood and non-flood conditions. In MB, DOC concentration varied over a wide range (20–520 μM C) and had a good correlation ($R^2 = 0.78$) with absorption due to coloured dissolved organic matter (CDOM) and remote sensing reflectance. Using this data set we developed an empirical algorithm to derive DOC concentrations from the ratio of $R_{rs}(412)/R_{rs}(488)$ and tested it with independent datasets. In this study, we demonstrate the ability to estimate DOC using remotely sensed optical observations in turbid coastal waters.

1. Introduction

Dissolved Organic Carbon is a major component of dissolved organic matter (DOM) in the aquatic system (Dafner and Wangersky, 2002; Hansell and Carlson, 2014) and it plays an important role in the marine carbon cycle (Evans et al., 2005; Bauer et al., 2013). DOC is generated by the decomposition of plants and microorganisms. DOC concentrations affect the ecosystem functioning through its influence on acidity, transportation and reactivity of toxic substances, light absorbance, photochemistry, and energy supply (Evans et al., 2005; Spencer et al., 2012). Dynamics of DOC also affects the transfer of carbon from terrestrial pools to aquatic bodies and ultimately marine ecosystems. Therefore understanding the transformation and transportation of DOC in aquatic ecosystems is of interest to studies focussing of coastal biogeochemical processes. Thus estimates of DOC is of interest to studies involving environmental monitoring, modelling and management.

Estimation of carbon concentration in turbid coastal environments had been done mainly using analytical techniques (O'Donohue et al., 2000; Eyre and McKee, 2002; Cawley et al., 2012). Continuous in situ measurements of DOC are rarely made and reported, mainly due to the high cost associated with water sampling campaigns. Satellite remote sensing (SRS) has the potential to provide continuous high resolution optical observations, which could be used to estimate DOC in water (Del Castillo and Miller, 2008; Kutser et al., 2015). Many studies have successfully used SRS to estimate BGC parameters such as chlorophyll, suspended sediments and CDOM in the aquatic environment (Morel and Gentili, 2009; Brando et al., 2012; Odermatt et al., 2012). Only few studies, mainly in the northern hemisphere, showed the application of SRS to study DOC dynamics (Del Castillo and Miller, 2008; Tehrani et al., 2013; Vantrepotte et al., 2015). With the availability of continuous MODIS data for the past decade and with the promise of new sensors (such as VIIRS on Suomi NPP and OLCI on Sentinel-3), it is therefore timely to evaluate the feasibility of a SRS algorithm to estimate DOC in turbid coastal waters of Australia.

With the objective to develop an algorithm to estimate DOC concentrations from SRS data we used an in situ bio-optical dataset collected during 2011 in MB. Using the bio-optical dataset we (1) studied the bio-optical properties, (2) developed an empirical

* Corresponding author.
E-mail address: Nagur.cherukuru@csiro.au (N. Cherukuru).

http://dx.doi.org/10.1016/j.jag.2016.06.010
0303-2434/

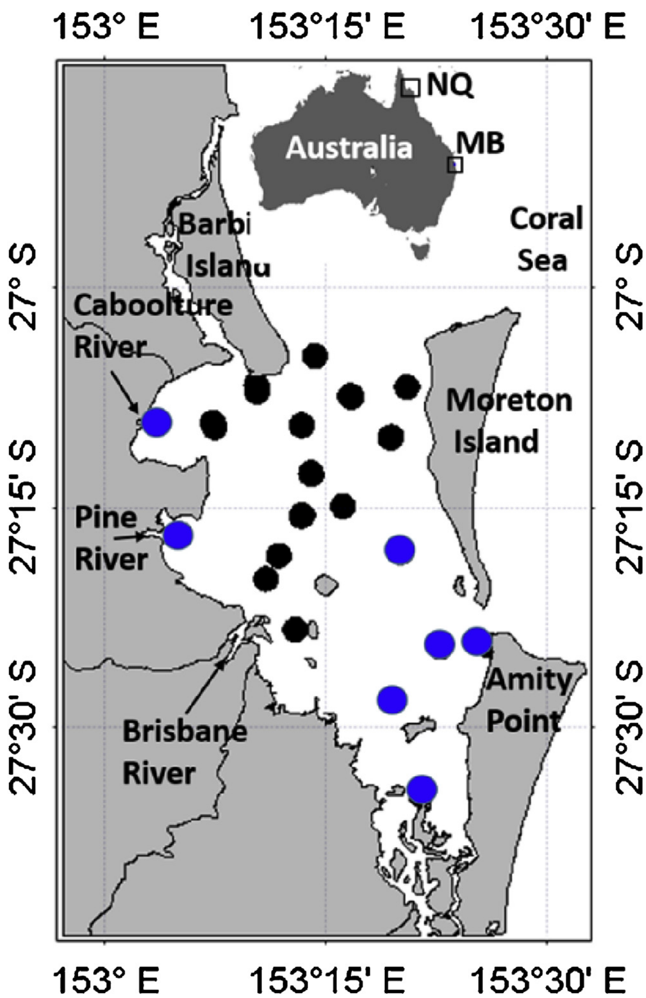

Fig. 1. Map of Moreton Bay with 2011 field stations. Black points are the calibration dataset and blue point indicates the validations dataset. Study areas MB and NQ are marked on the Australian map. (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

algorithm to derive DOC concentrations using in situ remote sensing reflectance measurements, (3) validated the algorithm using independent in situ data sets and (4) finally demonstrated the application using MODIS- AQUA data. Results from this study suggest that estimation of DOC from space is feasible in turbid coastal waters of Moreton Bay.

2. Methods

2.1. Study area

MB in Queensland, Australia is a subtropical, semi enclosed bay (Fig. 1) which is prone to extreme flood events. It has an average depth of 6.8 m and a surface area of 1523 km^2. The Brisbane, Caboolture and South Pine and Logan are the main rivers discharging into MB. River catchment associated with these rivers includes, urban, rural and agricultural regions. These catchments also include large areas of natural vegetation, which are known sources of DOC in the water streams (Smith et al., 2005). Short intense rainfall events during monsoonal depression in summer trigger extreme floods and turbid discharges into MB (Oubelkheir et al., 2014) and low rainfall is common in the rest of the year (Bureau of Meteorology, 2011, http://www.bom.gov.au). Oceanic waters mix with the bay waters by entering the bay through the passages between Moreton and Barbie islands and at Amity Point. The water circulation in MB during summer is clockwise and in winter it is anti-clockwise, overall with an average residence time of 45 days (Dennison and Abal, 1999).

During December 2010 and January 2011 heavy rainfall occurred in South East Queensland (SEQ). Combination of heavy rainfall and dam releases resulted in the flooding of the adjacent catchment and eventual discharge of flood waters into MB. Large fraction of the flood water was discharged through Brisbane River (Gallen et al., 2014; Oubelkheir et al., 2014). The resulting flood plume covered an area of 400 km^2 (Yu et al., 2011) and delivered approximately one million tonnes of sediment into MB (Oubelkheir et al., 2014). In addition, a major release of freshwater from Wivenhoe Dam occurred on 21 February 2011. In the rest of the year (2011) river discharges were similar to long term monthly means as reported by the Bureau of Meteorology (http://www.bom.gov.au).

2.2. Sampling stations

Thirteen stations were repeat sampled in MB as part of five field trips during 2011. Trip-1 (19–21/January) was the first trip after the flood event, Trip-2 was conducted during 26–28/January, Trip-3 was organised during 25–27/February after the major release of freshwater from Wivenhoe Dam (on 21 February 2011), Trip-4 and Trip-5 were conducted during 25–28/May and 18–21 December to sample non flood conditions. An additional seven stations were sampled during Trips 3–5 towards MB validation dataset.

2.3. Water sampling and in situ optical measurements

At each station a WetLabs water Quality meter (WQM) was deployed to measure Temperature (T) and Salinity (S). Stratification in the water column is estimated as the difference in S (Δ Salinity = top −bottom layer). Discrete water samples were collected from surface waters to measure DOC, absorption due to CDOM (a_Y), Total suspended solids (TSS), Total chlorophyll-a (Tchl-a).

Surface water was filtered through a 0.45 μm syringe filters (Sartorius polyethersulfone) to sample DOC. After acidification and purging the carbon-di oxide, DOC was determined by High Temperature Catalytic Oxidation (HTCO) using a 1010 TOC-Analyzer (OI Analytical) (Peltzer et al., 1996). For CDOM, water was filtered through a 0.22 μm Millipore Durapore filter that was pre-rinsed with Milli-Q water. A Cintra 404 UV/VIS spectrophotometer was used to measured CDOM absorption. The spectral slope of a_Y was determined by applying a non-linear exponential model fit to a_Y between 400 and 700 nm. Full details of the methods used in this study are available in Oubelkheir et al. (2014).

Satlantic radiometer (Profiler-II, HyperOCR: 300–1200 nm) was deployed to measure underwater upwelling radiance (L_u), downwelling irradiance(E_d) and above surface downwelling irradiance (E_s). Satlantic data was processed using manufacturer software (ProSoft 7.7, available at www.satlantic.com). Above surface water leaving radiance (L_w) and average E_s was used to compute remote sensing reflectance ($R_{rs} = L_w/E_s$).

2.4. Results and discussion

2.4.1. Environmental and biogeochemical conditions during the sampling period

Salinity varied over a wide range (4.7–29.4) in MB immediately after the flood and the water column was strongly stratified at all the stations. Freshwater discharges delivered large quantities of dissolved and particulate substances (Table 1). Average DOC concentration was 6.5 times higher than that in the non-flood conditions (Trip-5). Concentrations of TSS and TChl-a were three and seven times higher than non-flood conditions. High concentrations