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An assessment of water quality monitoring tools in an estuarine system

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ABSTRACT

Ocean colour remote sensing (OCRS) has proved to be a powerful tool in monitoring bio-geophysical and optical water quality variables. The different capabilities of OCRS in terms of spatial extent and temporal or revisit cycle dictate some of scientific questions we can resolve in a qualitative or quantitative manner. Typically, near-water surface platform measurements of (R_{RS}) have minimal uncertainties, high spectral and temporal resolution but tend to have limited spatial coverage in contrast to measurements from satellite platforms. To this end, we completed correlation tests among salinity, turbidity and above-water R_{RS} from the Wadden Sea time series station Spiekeroog to determine the extent of their respective associations. Strong correlations were then utilized to establish empirical predictive regression models to infer salinity and turbidity from above-water R_{RS}. These regression models were determined to have reasonable average uncertainties of less than 29%. As satellites generally provide wider spatial coverage, we assessed the feasibility of applying these near-water OCRS regression models to the high spatial resolution (30 m) Operational Land Imager Landsat-8 imagery. Unbiased percent differences between above-water and satellite derived R_{RS} at (443, 483, 561, and 655) nm centred wavebands were less than 22%. At high water level, basin tidal channels and creeks could be identified from Landsat-8 RGB composite imagery. This case study demonstrated potential applications of high spatial resolution (30 m) Landsat-8 imagery in both qualitative and quantitative observations of water quality variables as well as features in an optically complex estuarine systems. The observations of water quality variables from three platforms submerged, near water surface and satellite is also shown to provide comparable measurements giving some form of an accuracy and precision test. The study findings here highlight the need to take advantage and improve high spatial resolution OCRS approaches and predictive regression models for such optically complex estuarine waters for realistic multidisciplinary efforts to continuously observe water constituents.

1. Introduction

Ocean colour remote sensing (OCRS) from different platforms provides an invaluable technology useful in understanding the aquatic environment and changes related to our climate (IOCCG, 2008; Kidd et al., 2009; Watson and Zielinski, 2013). Like any approach in science, OCRS from any platform comes with its benefits and

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limitations, and thus trade-offs (Garaba et al., 2015; Hestir et al., 2015; Zielinski et al., 2009). Near-water surface, in- and above-water platforms provide accurate measurements with minimal influence from meteorological and atmospheric perturbations compared to more distant platforms like satellites. Additionally, near-water surface operational time series observatories offer high sampling intervals, for instance every second or minute, of water quality variables. However, with near-water surface methods it may not always be feasible to make simultaneous observations over a large region due to costs, personnel, environmental conditions and time constraints. Over large areas, satellite OCRS technology complements near-water surface methods, providing simultaneous measurements over large areas at varying repeated temporal intervals (Hestir et al., 2015; Sládeček, 1989; Zielinski et al., 2009).

A common end product of OCRS information is remote sensing reflectance (R_{RS}), which has been extensively studied at a regional to global scale and shown to be a robust variable essential in inferring biogeophysical and optical water quality variables (Arnone, 1987; Baban, 1997; Garaba et al., 2014; Geiger et al., 2013; IOCCG, 2008; Khorram, 1982; Kidd et al., 2009; Lagerloef et al., 1995; Monahan and Pybus, 1978; Moore, 1980; Urquhart et al., 2012). Among some of the widely derived water quality variables (WQVs) using R_{RS} is chlorophyll-a, coloured dissolved organic material (CDOM), salinity and turbidity. The algorithms or regression models used require validation using accurate sea-truth measurements of WQVs which can be costly and time consuming, resulting in most studies investigating variables that are easy to observe or commonly measured.

Several investigations have shown that turbidity can be inferred with reasonable accuracy from ocean colour remote sensing products (Dogliotti et al., 2015; Doxaran et al., 2009; Garaba et al., 2014; Güttler et al., 2013; Moore, 1980; Nechad et al., 2010). More recently, sea surface salinity has been recorded from space using, for example, microwave radiometers like the Soil Moisture and Ocean Salinity (SMOS) and the Aquarius missions, at a coarse spatial resolution (Font et al., 2013; Font et al., 2004; Kidd et al., 2009; Köhler et al., 2015; Lagerloef et al., 1995). Sea surface salinity has also been indirectly derived from OCRS observations that typically offer much higher spatial resolution than the microwave satellites (Geiger et al., 2013; Khorram, 1982; Liu et al., 2015; Monahan and Pybus, 1978; Urquhart et al., 2012). A recent investigation showed that SMOS and the NASA Aquarius products satellite sea salinity retrievals in near shore areas are often contaminated from land, ice, or man-made radio frequency interference (Köhler et al., 2015). Köhler et al. (2015), reemphasized that so long as these ongoing satellite missions, targeted at remote sensing of sea surface salinity, have different measurement principles their estimates of sea surface salinity are to be treated with caution, and stated that 150 km around continental margins are contaminated in the case of Aquarius and approximately 1500 km in the case of SMOS. These remote sensing methods and tools are clearly well developed for the open ocean but in the near shore, optically complex, waters may not be appropriate for the monitoring of WQVs at high temporal and spatial resolutions.

We therefore explore the feasibility of OCRS in an optically complex estuarine system, taking advantage of *in situ* measurements of physical and optical WQVs at the Wadden Sea time series station Spiekeroog (WSS). The WSS platform is an operational observatory located in a tidal channel along the Wadden Sea barrier islands, measuring water quality variables continuously at 1–15 min intervals (Badewien et al., 2009; Garaba et al., 2014). The region is part of an extended North Sea tidal flat system, with shallow water depths ranging from 0 to 10 m, that experiences a semi-diurnal tidal cycle with the distribution of suspended particulate and organic material being driven by tidal currents as well as waves driven by wind (Bartholomä et al., 2009; Reuter et al., 2009). We assume the temporal and spectral resolution as well as location of WSS are optimum for the collection of relevant information about nearby WQVs and sufficient to assess the utility of current state of the art OCRS tools in this region.

In order to assess the utility of the OCRS tools for the first time in the vicinity of WSS we (i) applied correlation tests after normality tests to determine associations among physical and optical WQVs that is salinity, turbidity, and R_{RS}, (ii) these correlations were then used to establish predictive regression models based on near surface R_{RS} to derive water variables, and (iii) a feasibility check was carried out to obtain a wide spatial coverage of the variables inferred from near surface R_{RS} regression models, using the new Operational Land Imager (OLI) Landsat 8 imagery-derived R_{RS}. Landsat 8 provides a wider spatial coverage with high resolution 30 m pixel size and has been used to provide distribution information about surface optical WQVs in various regions such as marshes, rivers, lakes, and estuaries (Aranuvachapun and LeBlond, 1981; Baban, 1997; Bustamante et al., 2009; Moore, 1980). The goal of our case study, among the first such studies carried out using Landsat 8 in the vicinity of WSS, was to also examine the potential utility and trade-offs of Landsat 8 remote sensing of surface WQVs in nearshore estuarine or coastal waters and draw some implications of mitigating gaps in information gathering at a scientific environmental monitoring level. It provides an appropriate intercomparison of obtaining comparable results of WQVs, derived or measured by in-water submerged, above water and satellite sensors.

2. Materials and methods

2.1. In situ WQVs

Turbidity is observed at 1 min intervals with a WETlabs Eco FLNTU sensor at the WSS. This sensor is mounted 12 m above the sea floor (on average about 4 m water depth), on the side of the pile diagonally opposite the radiometers. It is generally submerged in water at low tide except at extreme low tides. Conductivity is observed every minute with a Xylem Aanderaa type 4120 sensor mounted 9 m above the sea bed. The manufacturer provides calibration