Continental Shelf Research ∎ (∎∎∎∎) ∎∎∎–∎∎∎

Contents lists available at ScienceDirect

Continental Shelf Research

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

Research papers

Influence of river discharge and ocean currents on coastal optical properties

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ARTICLE INFO

Article history:
Received 23 September 2013
Received in revised form
27 January 2014
Accepted 25 April 2014

Keywords:
Tasmania
Inherent optical properties
River discharge
Ocean currents
Light propagation

ABSTRACT

The variability in the optical properties of a coastal region influenced by river runoff and multiple ocean currents in a southern hemisphere setting has been studied. The study area, Tasmanian coastal waters, is influenced by subtropical currents such as the East Australian Current (EAC) and the Zeehan Current (ZC) mix with cooler sub-Antarctic water (SAW). Freshwater discharges from rivers around the island and their mixing with the ocean currents also influence Tasmanian coastal waters. This study was performed to understand the influence of hydrodynamic processes on coastal optical properties and underwater light propagation. Physical, biogeochemical and optical properties were measured in Tasmanian coastal water during the austral autumn of 2007. In this study we found that physical properties have a good correlation with optical properties indicating the role played by hydrodynamic processes in distribution of optically active substances, optical properties of the water mass and underwater light propagation. Analysis of in situ salinity and temperature confirmed the presence of relatively cooler ZC in the South-West region, a cooler mixture of the ZC and SAW in the South-East, warm and saline EAC waters along the East coast and relatively cooler and fresh Bass straight waters along the North coast. In Tasmanian coastal waters light absorption in the water column is controlled by Coloured Dissolved Organic Matter (CDOM) with regionally varying contributions from Non-Algal Particulate (NAP) matter and phytoplankton. Absorption due to CDOM and NAP show a conservative mixing behaviour indicating that these biogeochemical components were delivered by the river and diluted in the coastal water. Suspended particulate matter in Tasmanian coastal water are highly scattering in nature and the beam attenuation is mainly due to light scattering. Variability in probability of light backscattering was mainly due to varying availability of non-algal particulate matter in the surface waters, which is controlled by river discharges in the region. Beam attenuation was high in coastal waters that are influenced by river runoff and increasing beam attenuation had constrained the underwater light propagation in these coastal waters. In the absence of major rivers along the East coast, optical properties were mainly influenced by the EAC water mass. Optical properties of the East coast were clearly different from the rest of the Tasmanian regions. In other regions the influence of ocean currents is subtle due to strong mixing between river discharges and ocean water mass. Overall, analysis of bio-optical properties shows that optical properties are constrained by regional hydrodynamic processes. Results presented highlight importance of using hydrodynamic process specific bio-optical properties and parameterisation in modelling light propagation in coastal ecosystems that are influenced by multiple ocean currents and river discharges.

1. Introduction

Hydrodynamic processes in coastal regions are generally more complex than in open oceans both on spatial and temporal scales. Because of the highly dynamic nature of estuarine and coastal processes, the concentration, composition and size distribution of particulate and dissolved substances are continuously transformed. The optical nature and underwater light climate of the coastal waters are thus continually influenced due to changing biogeochemical characteristics, size distribution and inherent optical properties of suspended substances. Further in such coastal waters, the optical environment becomes complex as optically active substances discharged by rivers mix with constituents of oceanic waters transported by ocean currents into the coastal region. For this reason, in coastal waters understanding the physical processes and its influence on bio-optical complexity is necessary to develop accurate coupled ecosystem models and to interpret ocean colour remote sensing data.

Many studies based on in situ observations have reported on optical variability in open ocean regions (Morel and Maritorena,

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http://dx.doi.org/10.1016/j.csr.2014.04.022
0278-4343/© 2014 Published by Elsevier Ltd.

2001 and references therein). For example, studies by Bricaud et al. (2004, 2010) explained the variability in phytoplankton absorption as a function of algal population size structure, Babin et al. (2003a, 2003b), Boss et al. (2004) and Stramski and Kiefer (1991) discussed the variability in light scattering due to particulate composition and size of marine particles and Nelson and Siegel (2002) detailed the dynamics of CDOM in the open ocean. Such studies mainly focussed on explaining the observed optical variability as a function of varying biogeochemical properties of particulate and dissolved substances in the open ocean. But very few studies in the open ocean regions directly related optical variability to ocean water mass dynamics (Dickey, 1991; Strutton et al., 2011).

Recently there has been increased reporting on optical variability in the near-surface and upper ocean. This is due to advances in bio-optical instrumentation and infrastructure (Dickey et al., 2012 and references therein). Observational and modelling research reported lately describe optical variability as due to meteorological, physical, biological and chemical processes acting over a range of time and space scales. In particular, researchers used in situ measurements to study passing sediment plumes and wave injected bubble plumes and their influence on optical volume scattering function (Twardowski et al., 2012), organic coatings of bubbles and their contribution to optical signal (Vagle et al., 2012), role of transparent exopolymer particles on light propagation near the air–sea interface (Czerski et al., 2011) and factors influencing light polarisation in the water column (Bhandari et al., 2011). Modelling results from the above research programs focussed on topics such as, radiative transfer of natural light in turbulent flows in the upper ocean (Xu et al., 2012) and variability in polarised light fields under dynamic ocean (You et al., 2011).

Intensive research programs have also been carried out in coastal waters such as, the New York Bight (Chang et al., 2002), at Imperial beach, California (Woźniak et al., 2010) and in the Long island sound region (Aurin et al., 2010) to study optical variability and its dependence on biogeophysical processes in coastal waters. These studies investigated the physical properties along with inherent optical properties using time series data. Chang et al. (2002) concluded that optical and biological variability observed on the New York Bight continental shelf locations was mainly due to semidiurnal tides and the coastal jet present in this region. Woźniak et al. (2010) related the observed optical variability to winter rain storm events and summer phytoplankton blooms at Imperial Beach. Aurin et al. (2010) sampled throughout Long island sound during 2004–2007 and reported that the variability in the magnitudes of optical properties observed in this region was mainly due to riverine deposits and to a lesser degree due to seasonal changes. In Australian coastal waters, Oubelkheir et al. (2006) presented examples of tidal influence on light scattering and absorption in the near surface waters. All the above regional studies that used in situ inherent optical measurements highlighted the role of various biogeophysical processes in influencing the optical variability in coastal regions. Other studies specifically studied the impact of river discharges on optical variability on a wider spatial scale, for example, Del Vecchio and Subramaniam (2004) investigated the western tropical north Atlantic ocean and concluded that Amazon River strongly influences the optical properties of the Atlantic ocean at distances over 1000 km from the river mouth. Similarly D'Sa et al., 2006 showed the influence of Mississippi River discharge and its interaction with a cold front on the surface optical variability. Some work has also been done combining optical observations and a 3-dimensional bio-physical models to examine the effect of variable light attenuation on the hydrodynamics (Cahill et al., 2008). All the above mentioned studies show the link between physical processes and optical variability.

The island of Tasmania is to the south of mainland Australia, between 40–44°S and 144–149°E (Fig. 1). The Tasmanian region is

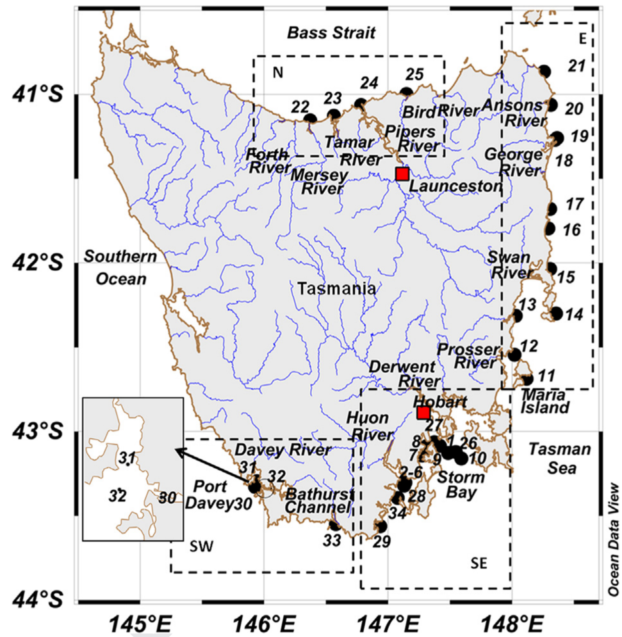

Fig. 1. Sampling sites in Tasmanian coastal waters studied during 21–30 May 2007. Dashed boxes indicate South West (SW), South East (SE), East (E) and North (N) subsets used in the data analysis.

a unique marine environment as it forms one of the very few oceanic connection zones between major ocean basins (Pacific and Indian oceans). EAC in the east, the ZC in the west and SAW in the south (Ridgway,2007) influence Tasmanian coastal region. The optical complexity in these coastal waters is further increased as the ocean water mix with tannin rich river discharges at various locations along the coast (Clementson et al., 2004). Coupled ecosystem models could help understand the biogeochemical dynamics in such a complex coastal environment (Wild-Allen et al., 2010). But such models should include realistic representation of variability in bio-optical properties and their dependency on the hydrodynamic processes in the region, to make accurate biogeochemical estimates in the ecosystem model (Allen et al., 2010).

Earlier optical studies (as referred above) conducted in oceanic and coastal regions in other regions of the world mainly focussed on a single hydrodynamic process and its influence on the optics at a regional scale. But the hydrodynamic complexity in Tasmanian coastal waters is different, it is due to presence of multiple ocean currents along the coast, their interactions and the mixing with various river discharges and with the water mass transported by the ocean currents. Hence, the primary question we address here is: how do hydrodynamic processes influence optical properties and underwater light propagation in Tasmanian coastal regions?

Towards this we investigated:

(1) Spatial patterns in hydro-meteorological parameters;
(2) influence of fresh water discharge on coastal water;
(3) distribution of optically active substances;
(4) variability in inherent optical properties and its influence on underwater light propagation.

2. Study area

2.1. Geography and hydro-meteorology of the region

Tasmania has a temperate, maritime climate with prevailing westerly winds and an annual average rainfall varying regionally between 600 and 3200 mm with the west coast receiving most of

Please cite this article as: Cherukuru, N., et al., Influence of river discharge and ocean currents on coastal optical properties. Continental Shelf Research (2014), http://dx.doi.org/10.1016/j.csr.2014.04.022