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High-resolution observations of chlorophyll-a biomass from an instrumented ferry: Influence of the Fraser River plume from 2003 to 2006

Mark J. Halverson *, Rich Pawlowicz

Department of Earth, Ocean, and Atmospheric Sciences, University of British Columbia, Vancouver, British Columbia, Canada V6T 1Z4

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ABSTRACT

An instrumented ferry made eight transects per day across the Fraser River plume over the years 2003–2006 as part of the STRATOGEM program studying biophysical coupling in the Strait of Georgia, British Columbia, Canada. Seawater properties inside and outside the Fraser plume were measured with high spatial and temporal resolution for an extended period. Here the salinity and chlorophyll-a fluorescence records are used to determine how the Fraser River plume affects phytoplankton biomass in the Strait of Georgia over a range of time scales. The fluorescence record is corrected for non-photochemical quenching by comparison of daytime and nighttime samples, and then calibrated in a manner traceable to extracted chlorophyll measurements. Analysis shows that the instantaneous along-track structure of near-surface chlorophyll-a is often sensitive to the presence of the Fraser River plume. However, when averaged over the 4-year time series, the plume has little impact. Depth-integrated chlorophyll-a biomass is then estimated by applying scaling factors derived from vertical profiles. Unlike the near-surface measurements, depth-integrated biomass in the plume is on average only 74% of the amount found in neighboring waters. Potential reasons for this discrepancy are discussed in terms of light attenuation, the vertical distribution of chlorophyll-a, plume fresh water fraction, and flushing time.

1. Introduction

Coastal ocean variability may be driven by fresh water input in the form of a buoyant outflow. In the southern and central Strait of Georgia (SoG), British Columbia, Canada, flow from the strongly seasonal Fraser river forms a large buoyant plume which covers up to 1400 km^2 (Halverson and Pawlowicz, 2008). It introduces a high degree of spatial and temporal variability to the surface water hydrography (Royer and Emery, 1982; LeBlond, 1983; Halverson and Pawlowicz, 2008). Plume salinity and surface area fluctuate over time-scales ranging from less than a day to more than a year.

Biological processes in the vicinity of the Fraser River plume may vary on the same temporal and spatial scales as physical processes (Parsons, 1969; Stockner et al., 1979; Harrison et al., 1991). Some of the short time scale factors, such as tides, wind, and rapid changes in river flow, have been linked to changes in primary productivity in the plume (Yin et al., 1995a, 1995b, 1995c). By contrast, there is little evidence that the plume has any impact on the diatom community, which as a group tends to dominate the biomass for most of the year (Harrison et al., 1983, 1991). On longer time scales, aspects of the annual productivity and standing stock cycles have been reasonably well characterized (Parsons, 1969; Stockner et al., 1979; Harrison et al., 1983), but the observations in multi-year studies have usually compromised high time resolution for good total coverage. Remote sensing might have the ability to bridge this knowledge gap, and recent advances in chlorophyll-a algorithms have shown that it is at least possible to estimate chlorophyll-a concentrations in the optically complex waters of the SoG (Komick et al., 2009; Gower and King, 2012). Even so, the SoG is often covered by clouds, however, making a detailed time series analysis difficult.

The lack of high time resolution sampling programs operating consecutively over a number of years is a significant gap in identifying the effects of physical variability on primary production and the potential consequences for higher trophic level organisms such as copepods (Bornhold, 2000) and salmon (Beamish et al., 2004). Such observations are also necessary to accurately quantify interannual variability, which is important when identifying the effects of decadal (or longer) climate change. High temporal resolution sampling is also necessary so that high frequency phytoplankton dynamics are not aliased (Rantajärvi et al., 1998).

However, sampling with both high temporal and high spatial resolution is difficult, and doing so requires a different approach to sampling than the traditional oceanographic cruise. Ship-of-opportunity systems are one way to overcome the sampling limitations. Traditionally, these observations were based on open ocean merchant vessels, beginning in 1931 with the Continuous Plankton Recorder (e.g. Reid et al., 2003). In the coastal ocean, passenger

* Corresponding author.
E-mail addresses: mhalvers@eos.ubc.ca (M.J. Halverson).
rich@eos.ubc.ca (R. Pawlowicz).

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ferries have become an effective sampling platform, and examples can be found worldwide, including eastern North America (Buzzelli et al., 2003; Balch et al., 2004), northern Europe (Rantajärvi et al., 1998; Petersen et al., 2008), Japan (Harashima et al., 1997), and Chile (Aiken et al., 2011). Ferry sampling can provide a very detailed picture of the marine environment because some ferries make repeated transects of the same body of water in a single day, and operate in all seasons. The range of seawater properties which can be measured is quite extensive: Recent programs have produced reliable measurements of O_2, pH, optical properties, and nutrients (e.g. Buzzelli et al., 2003; Balch et al., 2004; Ensign and Paerl, 2006; Petersen et al., 2008).

In this paper, data from an instrumented ferry is used to study the effect of the Fraser River plume on near-surface and depth-integrated chlorophyll-a biomass over a wide range of time-scales. The high spatial resolution salinity measurements allow the plume location to be accurately identified, while the high temporal resolution and long sampling period mean that changes on diurnal to interannual time scales are captured. Extra care is taken to ensure that in situ chlorophyll-a fluorescence is an accurate proxy for algal biomass, and a relationship between near-surface concentrations and depth-averaged biomass is developed. The combination of good spatial and temporal resolution with a ferry track which crosses a river plume has provided a unique opportunity to investigate the effects of a river plume on algal biomass.

2. Materials and methods

2.1. Ferry sampling

The primary data set used in this paper was acquired from a collection of sensors aboard the British Columbia Ferry Services Inc. vessel, the *M.V. Queen of New Westminster*. For a month in spring 2003, another instrumented vessel, the *M.V. Queen of Alberni*, serviced the same route. The ferry makes four round trips each day between the Tsawwassen and Duke Point terminals (Fig. 1). The track essentially runs along the strait, oriented to the northwest/southeast. The first sailing departs Tsawwassen before dawn at 0515 local time, and the last sailing returns well after dusk at 0045 local time. A complete transect covers 70 km and takes 2 h.

The ferry sampling program began on 13 January 2003, and continued until 29 October 2006. Every winter the ferry was removed for an annual refit, creating month-long data gaps. Occasional instrumentation problems caused additional gaps in the data record, the longest being a month in May 2004. Other gaps typically last a few days and occur infrequently and sporadically through the time series. In total, the dataset contains 8502 transects.

The instrument suite consists of chemistry-free sensors to measure several oceanographic variables. In this paper, we will make use of salinity, measured by a Seabird SBE45, chlorophyll-a fluorescence, measured by a WETLabs WETStar fluorometer, and GPS position. The thermosalinograph samples at 5 s intervals, the fluorometer samples at 2 s intervals, and the GPS samples at 10 s intervals. Salinity is reported on the TEOS-10 Absolute Salinity with $\delta S_A = 0$ (IOC et al., 2010). The thermosalinograph salinity precision is ± 0.005 g kg^{-1}, but regular lab and factory calibrations revealed that fouling occasionally freshened the salinity by up to 0.6 g kg^{-1}. Because the plume was identified by relative changes in salinity along a transect, and because the salinity can vary by 10 g kg^{-1} in a single transect, we do not correct for fouling.

The chlorophyll-a fluorometers presented a number of special problems. First, a number of different WETstar sensors were used,

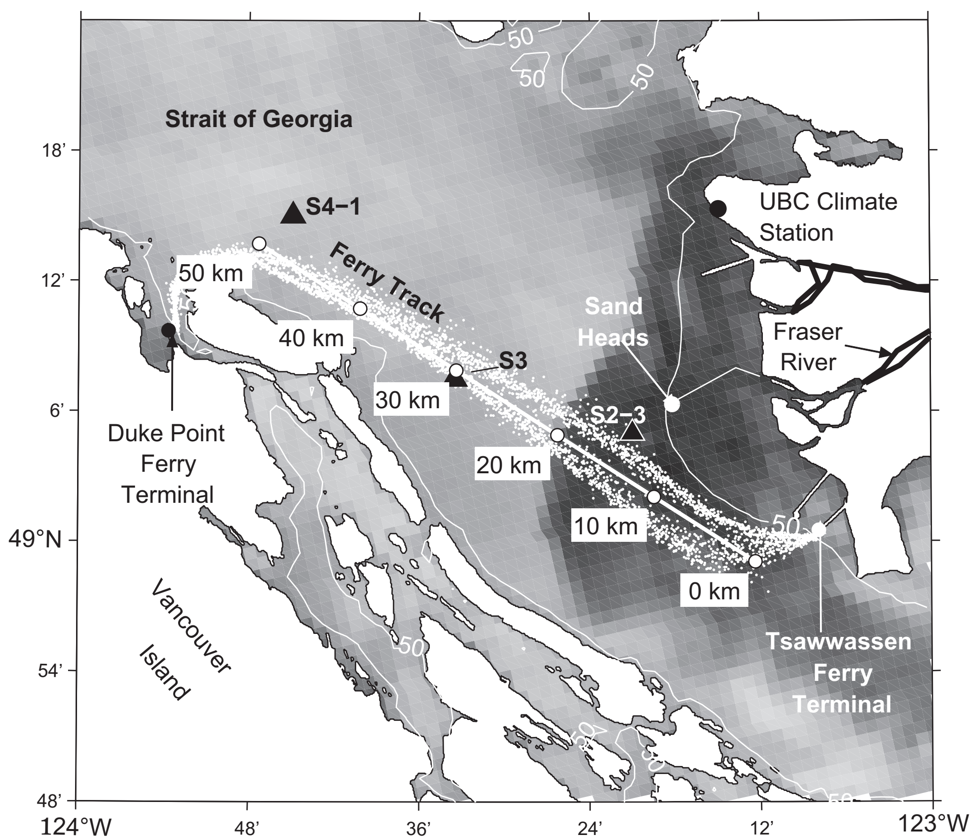

Fig. 1. Map of the lower Strait of Georgia plotted on a MODIS 551 nm 1 km resolution image. The image was taken 19 July 2005, while the river discharge was about 6000 m^3 s^{-1}. The plume appears as dark shades signifying a high reflectance. The small white points are three months of sub-sampled GPS fixes from the ferry. Westbound tracks sail north of eastbound tracks. STRATOGEM hydrographic stations S2-3, S3, and S4-1 are marked by triangles.