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journal homepage: www.elsevier.com/locate/dsriSeasonal POC fluxes at BATS estimated from ^{210}Po deficitsGillian M. Stewart^{a,*}, S. Bradley Moran^b, Michael W. Lomas^c^a School of Earth and Environmental Sciences, Queens College, CUNY, Flushing, NY 11367, USA^b Graduate School of Oceanography, University of Rhode Island, Narragansett, RI 02882, USA^c Bermuda Institute of Ocean Sciences, St Georges GE01, Bermuda

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ABSTRACT

In this study at the Bermuda Atlantic Time-series Study (BATS) site we demonstrate that the polonium–lead disequilibrium system may perform better as a tracer of organic carbon export under low-flux conditions (in this case, $< 2.5 \text{ mmol C m}^{-2} \text{ d}^{-1}$) than under bloom conditions in an oligotrophic setting. With very few exceptions, the POC flux predictions calculated from the water-column ^{210}Po deficit were within a factor of 2 of the POC flux caught in surface-tethered sediment traps. However, we found higher correlation between size-fractionated particulate ^{210}Po activity and POC concentration in November 2006 ($r=0.93$) than in January ($r=0.79$) and during the spring bloom in March 2007 ($r=0.80$). We suggest that this is due to the ability of polonium to distinguish between bulk mass flux and organic carbon export under oligotrophic and lithogenic-driven flux regimes. Further, we found that the POC/Po ratio on particles was largely independent of size class between 10 and 100 μm ($P=0.13$) during each season, supporting the notion that export in this oligotrophic system is driven by sinking aggregates of smaller cells and not by large, individual cells.

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1. Introduction

1.1. POC export

The sequestration of atmospheric carbon in the ocean is partially driven by the biological pump, wherein primary producers fix between 10 and 20 Gt (Falkowski et al., 2000) of dissolved carbon dioxide into particulate organic carbon (POC) that sinks from the euphotic zone (e.g. Volk and Hoffert, 1985; Ducklow et al., 2001; Boyd and Trull, 2007). Assessing the efficiency of the biological pump (defined as export production *sensu* Eppley and Peterson, 1979) is important in order to estimate the ocean's potential as a sink for anthropogenic CO_2 in the atmosphere. Traditionally, models involving nutrient drawdown could be applied to ecosystems to estimate export, but a direct measurement of sinking material via sediment traps provided additional insight into this process (e.g. Honjo et al., 1982). However, sediment traps can only provide an estimate of flux during the time in which they are deployed, and the collected material may be subject to confounding biological, chemical, and physical processes (reviewed in Buesseler et al., 2007).

1.2. ^{234}Th and ^{210}Po

Particle-reactive short-lived natural radionuclides provide another possible mechanism for quantifying POC export from the surface ocean, and because of variations in half-lives, these tracers can integrate vertical flux over different periods of time. In the case of ^{234}Th ($t_{1/2}=24.3 \text{ d}$), the activity deficit from its long-lived, conservative parent ^{238}U in surface waters is assumed to be caused by scavenging onto sinking particles (Eppley, 1989; Buesseler et al., 1994; Smith et al., 2006). The export of POC can be calculated by accurately measuring the ratio of thorium to organic carbon on sinking particles. ^{210}Po ($t_{1/2}=138 \text{ d}$) can also be used, but, because its grandparent ^{210}Pb ($t_{1/2}=22.3 \text{ yr}$) is also particle reactive, the determination of POC export is more complicated. However, the higher affinity of ^{210}Po than ^{210}Pb for scavenging onto organic matter does produce a deficit, and this system has also been used successfully to predict POC export (Friedrich and Rutgers van der Loeff, 2002; Murray et al., 2005; Verdeny et al., 2008).

Thus far, fewer than a dozen studies have employed both ^{210}Po and ^{234}Th to estimate POC export (reviewed in Verdeny et al., 2008); most studies use only one radionuclide pair. There is a general consensus, however, that the use of both tracers, because of their different particle affinities, source terms, and half-lives, together provide more information than either tracer in isolation (Stewart et al., 2007b; Verdeny et al., 2008). Previous studies have concluded that ^{234}Th is a better estimator for POC flux under

* Corresponding author. Tel.: +1516 524 2696; fax: +1 718 997 3049.
E-mail address: gstewart@qc.cuny.edu (G.M. Stewart).

high-flux conditions, and especially when POC flux is a larger fraction of the mass flux driven by rapidly sinking biogenic particles (Buesseler et al., 1992a,b; Buesseler et al., 1995; Murray et al., 1996; Cochran et al., 2000; Brew, 2008). In this study we provide further evidence that ^{210}Po is an effective POC flux tracer and is quantitatively better at estimating POC flux under non-bloom, low-export oligotrophic conditions, when lithogenic materials dominate the mass flux.

2. Methods

2.1. Location

The Bermuda Atlantic Time-series Study site (BATS, $31^{\circ}40'\text{N}$, $64^{\circ}10'\text{W}$) was chosen for this study because of its well-established yearly cycle of primary production (Michaels et al., 1994a,b) and export (Brix et al., 2006). Seasonality of the quantity and quality of material leaving the euphotic zone has been observed since the late 1980s, originally as part of the Joint Global Ocean Flux Survey (JGOFS). Briefly, primary production and POC export is relatively low throughout the year except during spring stratification and the bloom period between January and April (Fig. 1). Brix et al. (2006) characterized the site as a carbon recycling and retention site during the summer and fall and a carbon export site during late winter and spring.

Much of this seasonal trend in production and export is driven by the plankton species composition changes throughout the year. Another key to the seasonality is the input of both wet and dry iron deposition, particularly during the spring and summer (Nelson and Brzezinski, 1997; Kim and Church, 2001). Because the Fe input is temporally offset from the input of nutrients in the winter due to convective mixing, it is generally less effective in generating phytoplankton blooms or carbon export than might be predicted.

Recently a paper (Buesseler et al., 2008) was published on radionuclide tracers of POC export in the Sargasso Sea, and this continues a tradition of investigation into the topic that started

over a decade ago (Buesseler et al., 1992a,b; Kim and Church, 2001). At BATS, there is seasonal and yearly variation between primary production and carbon export, and commonly geochemical measurements of carbon export have exceeded POC caught in sediment traps, implying a temporal or spatial bias in measurements (Jenkins, 1988; Steinberg et al., 2001). These factors all lead to continued interest in the accurate assessment of POC export in this region. This study focuses on the BATS site itself, whereas the Buesseler et al. (2008) study (which contains both ^{234}Th and limited ^{210}Po data) primarily focuses on mesoscale eddies, which pass through the Sargasso Sea near the BATS site, and their effect on export flux.

2.2. Sample collection

All samples were collected during three BATS cruises between November 2006 and March 2007 aboard the R/V *Atlantic Explorer*. On each cruise (BATS #217, #219, and #221), large volumes (200–1000L) of seawater were filtered at five depths in the upper 500 m via *in situ* pumps (Challenger and McLane) through a series of Nitex screens ranging from 10 to 100 μm using a modified PVC 3-place filter holder in each pump. At each depth, seawater was pumped sequentially through 100, 70, and 53 μm (one cast), and 53, 20, and 10 μm (second cast) screens (142 mm diameter) and a 1 μm Hytrec II cartridge filter. Size-fractionated particles were later resuspended from the screens into pre-filtered seawater using an ultrasonicator and re-filtered onto pre-combusted glass fiber (GF/F) filters (0.7 μm nominal pore size) using a light vacuum at a flow rate of 2–3 L min^{-1} (Buesseler et al., 1995; Charette and Moran, 1999; Charette et al., 2001).

During the cruises (November 2006 (#217), February 2007 (#219), March 2007 (#221)), a CTD rosette was used to collect 4L seawater samples from 9 to 10 of the standard BATS sampling depths in the upper 500 m of the water column for total (non-filtered) polonium and lead analysis. Onboard, the samples were acidified, spiked, precipitated, and decanted following the methods of Masqué et al. (2002). Samples were sent to Queens College for radionuclide analysis (see below). During those same cruises,

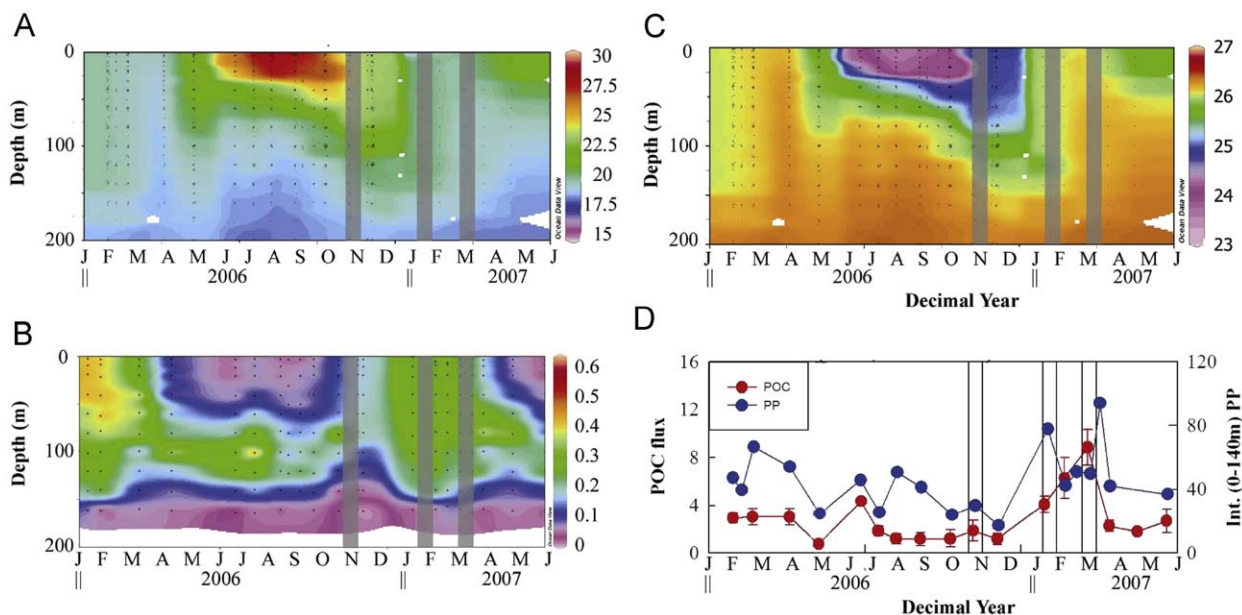


Fig. 1. Upper ocean (0–200 m) temperature (A, $^{\circ}\text{C}$), chlorophyll-a (B, $\mu\text{g l}^{-1}$), sigma-theta (C, kg m^{-3}), and integrated primary production and POC export at 150 m (D, $\text{mmol m}^{-2} \text{d}^{-1}$) at the BATS site from April 2006 through April 2007. Data from <http://bats.bios.edu>. The three shaded bars indicate when samples were taken for this study.

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