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Particle sinking dynamics and POC fluxes in the Eastern Tropical South Pacific based on ^{234}Th budgets and sediment trap deployments

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ABSTRACT

Assuming steady-state over seasonal to annual timescales, and limited horizontal export of dissolved nutrients, the vertical fluxes of limiting nutrients into the euphotic zone should be balanced by particle export. Sediment traps and ^{234}Th budgets have both been used extensively throughout the oceans as a means to measure this particulate flux from the upper ocean. One main goal of these efforts has been to determine the amount of CO_2 fixed by primary producers in the surface ocean that is exported as particulate organic carbon (POC) and conversely, the decrease of particle flux with depth has been used to estimate remineralization rates of nutrients. Although disagreement between trap-derived and ^{234}Th-derived fluxes has often been noted, the possible reasons for the imbalance are numerous, and thus often it is difficult to assign causes. Here, we examine many commonly implicated contributors to the disagreement, allowing us to assess data from a recent 2-year study in the ETSP that shows systematic disagreement between the two methods. Averaging results from both years, sediment traps collected 0.2–1.5 mmol C m^{-2} d^{-1} (mean: 0.74 mmol C m^{-2} d^{-1}) of POC, while the thorium-based method estimated an average POC flux of 1.5–14 mmol C m^{-} d^{-1} (mean: 6.2 mmol C m^{-2} d^{-1}). The study area spans regions of differing ecological structure, as inferred from trap mineralogy, and the flux disagreement coincides with this ecological range. We interpret the difference as undercollection of poorly ballasted, slowly sinking particles by the sediment traps. Using both methods simultaneously offers insight into ecosystem structure and resulting particle flux dynamics. The thorium deficit-based flux is 5–10% of previously published estimates of primary productivity based on ^{14}C incubations (Pennington et al., 2006), and 8–20% of concurrent estimates based on ^{14}C incubations and oxygen supersaturation (Capone et al., personal communication; Prokopenko et al., personal communication).

1. Introduction

Over the past few decades, ^{234}Thorium ($t_{1/2}$=24.1 days) has been used as a tracer of particle flux, due to the particle reactive nature of the isotope and the disequilibrium between it and its soluble parent nuclide, ^{238}U ($t_{1/2}$=4.5 by) (Bhat et al., 1969; Coale and Bruland, 1985; Buesseler et al., 1992; Bacon et al., 1996; Moran et al., 1997; Benitez-Nelson et al., 2001). Water column budgets provide estimates of ^{234}Th export flux that have been used to calibrate sediment trap fluxes, the only known direct measurement of vertical particle flux. If the particulate organic carbon (POC):^{234}Th ratio in sinking particles can be established, a ^{234}Th budget can also provide an estimate of POC flux. The depth-integrated Thorium deficiency (DITD) technique has been utilized in particle flux studies at numerous sites in the Atlantic (Buesseler et al., 1992; Rutgers van der Loeff et al., 1997; Charette and Moran, 1999; Kim and Church, 2001; Buesseler et al., 2008), the Antarctic (Shimmield et al., 1995; Cochran et al., 2000), the North Pacific (Coale and Bruland, 1985; Benitez-Nelson et al., 2001; Buesseler et al., 2008), the Central Equatorial Pacific (Murray et al., 1996, 2005; Buesseler et al., 1995; Bacon et al., 1996; Maiti et al., 2008) and elsewhere. This study is focused on the Southeastern Pacific (Fig. 1). The objective of this article is to assess the export of POC from the study area, as part of a larger effort to define estimates for nitrogen fixation in this region.

The rate of change over time of ^{234}Th activity in a unit of seawater is given by:

$$\partial A_{Th}/\partial t = \lambda_{Th}A_U - \lambda_{Th}A_{Th} - R_{Th} \pm V \quad (1)$$

where A_{Th} is the activity of total ^{234}Th (dpm/m^3; *dpm=disintegrations per minute*), A_U is the activity of ^{238}U (dpm/m^3), λ is the decay constant for ^{234}Th (0.0288 day^{-1}), V is net input (or loss) by advective and diffusive transport (dpm/m^3 d), and R_{Th} is removal rate by settling particles (dpm/m^3 d). Assuming steady state, ^{234}Th

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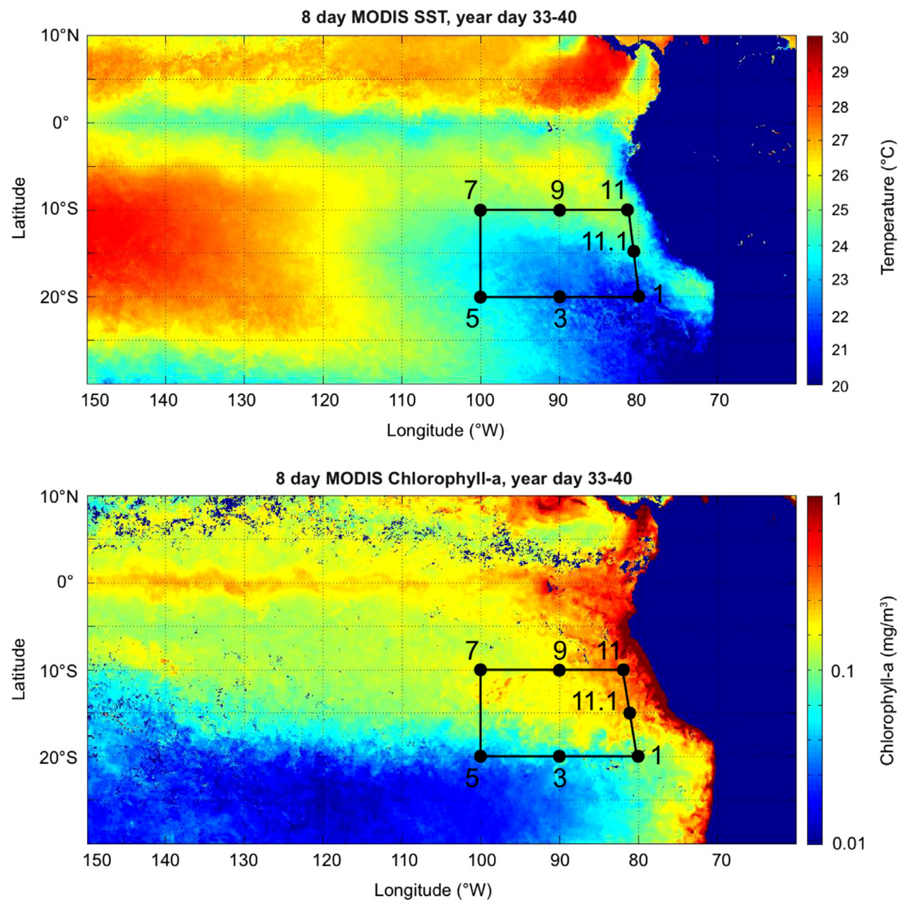

Fig. 1. Composite MODIS satellite sea-surface temperature and Chlorophyll-a concentration from Feb. 2–Feb. 10, 2010 during the 2010 ETSP cruise (NOAA, 2010). The cruise track and station locations are shown in black.

export flux (F_{Th}) from the photic zone per unit area can be calculated from the following equation, neglecting advection and diffusion ($V=0$):

$$F_{Th} = \int R_{Th} dz = \lambda_{Th} \times \int (A_U - A_{Th}) dz; \text{ from depths} = 0 \text{ to } z_e \quad (2)$$

where z_e is the depth at which the ^{234}Th deficiency equals zero, and F_{Th} equals the net removal flux of ^{234}Th by particles (dpm m^{-2} d^{-1}). With a known ratio of nutrients to ^{234}Th on the sinking particles, the export flux of particulate nutrients (i.e. POC, PON, etc.) to the deep ocean can be calculated. Common assumptions applied to this method, which we apply in this study, are: (1) all thorium that has been removed from the water column was done so by adsorption to sinking particles, (2) the POC/^{234}Th ratio measured at the maximum depth of integration is representative of the entire profile, and (3) there is limited time variability (steady-state). These assumptions may introduce considerable error in flux calculation; however, some believe that the model-calculated fluxes are a more accurate measure of particle flux than sediment traps due to the extreme variability of trap flux results (Buesseler, 1991). Sediment trap biases are typically categorized into: grazing of zooplankton swimmers on trap material, solubilization of trap material into DOC, and hydrodynamic effects (Murray et al., 1996), although sinking velocities, preferential remineralization of small particles during descent, and the length of trap deployment may also have an effect on the effectiveness of traps.

As noted by Buesseler (1991), the extent to which trap and Th fluxes agree seems to be independent of the trap depth, total flux, or research laboratory where the analyses were made. Buesseler also noted that the ratio of trap fluxes to Th-predicted flux can be biased in either the positive or negative direction (by a factor of $\pm$3–10), and yet the differences are typically consistent within a given site. The data presented here lies within this wide envelope. We determined the particle flux out of the euphotic zone at seven stations between 80°W to 100°W and 10°S to 20°S, using both the DITD and drifting sediment trap approaches on two cruises in consecutive years, 2010 and 2011 (Fig. 1). The spatial patterns of particle flux observed were similar in both years, as well as a consistent disagreement between the shallow particle interceptor (PITs) sediment trap fluxes and the Th flux method. We suggest that the extent of disagreement is a direct result of structural differences between the marine ecosystems spanning the cruise track.

2. Measurement techniques

2.1. Trap collection

In 2010, three strings of surface-tethered drifting sediment traps of the Particle-Interceptor-Traps (PITs) design (Knauer et al., 1979) were deployed at 200 m with a total surface area that varied with the number of traps used at each station (ave. ~2080 cm^2). Each trap was anchored with a 15 lb. lead weight, and the line was attached in 50-meter sections. One of the middle sections was coupled with 1 in. thick, 50 m bungee cord to allow for elasticity to dampen the movement caused by wave activity. A series of four surface buoys were attached to the line and to a mast buoy, which held a strobe light, radio transmitter, and GPS satellite locator.