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Time-series observation of POC fluxes estimated from ^{234}Th in the northwestern North Pacific

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Abstract

Time-series measurements of ^{234}Th activities and particulate organic carbon (POC) concentrations were made at time-series stations (K1, K2, K3, and KNOT) in the northwestern North Pacific from October 2002 to August 2004. Seasonal changes in POC export fluxes from the surface layer (~100 m) were estimated using ^{234}Th as a tracer. POC fluxes varied seasonally from approximately 0 to 180 mg C m^{-2} d^{-1} and were higher in spring–summer than in autumn–winter. The export ratio (*e*-ratio) ranged from 6% to 55% and was also higher in spring–summer. Annual POC fluxes were estimated to be 31 g C m^{-2} y^{-1} in the subarctic region (station K2) and 23 g C m^{-2} y^{-1} in the region between the subarctic and subtropical gyres (station K3). POC fluxes and *e*-ratios in the northwestern North Pacific were much higher than those in most other oceans. The annual POC flux corresponded to 69% of annual new production estimated from the seasonal difference of the nutrient in the Western Subarctic Gyre (45 g C m^{-2} y^{-1}). These results indicate that much of the organic carbon assimilated in the surface layer of the northwestern North Pacific is transferred to the deep ocean in particulate form. Our conclusions support previous reports that diatoms play an important role in the biological pump.

Keywords: ^{234}Th; POC flux; *e*-ratio; New production; Northwestern North Pacific

1. Introduction

Global warming resulting from the increase in greenhouse gases, such as carbon dioxide, is of great concern to the world community. In the last few decades, the carbon cycle in the ocean has been studied to clarify the balance of carbon dioxide between the atmosphere and the ocean. One important issue is the quantification of the role played by the biological pump: how much atmospheric CO_2 is assimilated in the sunlit layer (euphotic zone) and how much carbon is exported to the deep ocean?

The short-lived radionuclide ^{234}Th (half-life, 24.1 days) serves as a valuable tracer for studying the rates of particle-associated scavenging and the subsequent particle export from the euphotic zone (Coale and Bruland, 1985; Buesseler, 1998). This tracer is produced in the water column as a dissolved species by radioactive decay of the conservative ^{238}U in seawater and is redistributed between the dissolved and particulate phases depending on particle reactivity and the availability of particle surfaces.

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Particulate organic carbon (POC) fluxes, calculated using the ^{234}Th method, have been reported from oceans worldwide: North Atlantic (Buesseler et al., 1992), Equatorial Pacific (Buesseler et al., 1995; Bacon et al., 1996; Murray et al., 1996), Middle Atlantic (Michaels et al., 1994; Buesseler, 1998), Arabian Sea (Lee et al., 1998; Buesseler et al., 1998), Northeast Polynya off Greenland (Cochran et al., 1995), Antarctic Ocean (Rutgers van der Loeff et al., 1997), the northeastern North Pacific (Charette et al., 1999), North Pacific Subtropical Gyre (Benitez-Nelson et al., 2001), and Southern Ocean (Buesseler et al., 2001; Coppola et al., 2005). Buesseler (1998) proposed that the export ratio (*e*-ratio), which is the ratio of POC flux to primary production, would be less than 5–10% in much of the oceanic area of the world, but would be significantly higher at high latitudes and during episodic export pulses such as spring blooms. Charette et al. (1999) and Amiel et al. (2002) reported the importance of diatoms in elevating POC export.

The northern North Pacific Ocean, especially its western part, experiences intense winter cooling and receives large supplies of nutrients through upwelling, resulting in high productivity in spring and summer. It is well documented that spring blooms, consisting mainly of diatoms, occur only in the western part of the subarctic Pacific (Saito et al., 2002; Yamaguchi et al., 2002). It has been suspected that diatoms in this area play a key role in transporting POC to the deep ocean, because of their relatively large size and resultant high settling velocity (e.g., Tsunogai and Noriki, 1991; Kemp et al., 2000; Smetacek, 2000; Honda et al., 2002). The large decrease of nutrients and surface pCO_2 from spring to autumn also support the high activity of the biological pump in the northwestern North Pacific (Louanchi and Najjar, 2000; Wong et al., 2002; Takahashi et al., 2002). Kawakami et al. (2004) determined export production in the northwestern North Pacific based on the ^{234}Th method and reported that the POC export flux and *e*-ratio in the spring bloom were quite high (up to 520 mg C m^{-2} d^{-1} and 70%, respectively). These values are significantly higher than those reported previously from other oceans. However, their conclusion was based on limited seasonal data and there have been few year-round time-series observations of export production in the northwestern North Pacific.

Since October 2002, we have made time-series observations in the northwestern North Pacific. In this paper, we present vertical profiles of ^{234}Th, POC, and the POC/^{234}Th ratio, and discuss the high POC flux and *e*-ratio in the northwestern North Pacific.

2. Sampling and analysis

2.1. Sampling locations

Samples were collected during 10 cruises of R/V *Mirai*, *Natsushima*, and *Kairei* between October 2002 and March 2005 in the northwestern North Pacific Ocean (Table 1). Samples were collected at stations K1 (51°N, 165°E), K2 (47°N, 160°E), K3 (39°N, 160°E), and KNOT (44°N, 155°E) (Fig. 1). Stations K1, K2, and K3 are time-series stations of the High Latitude Time Series Observatory project (HiLaTS: http://jpac.whoi.edu/hilats/mio/index.html), and station KNOT is the former Japanese time-series station for biogeochemistry under the Joint Global Ocean Flux Study (JGOFS) North Pacific Process Study (special issue of Deep-Sea Research II 49, 2002).

2.2. Oceanographic setting of the study area

In the study area, two western boundary currents, the Kuroshio and the Oyashio, are associated with the subtropical and subarctic gyres, respectively (Fig. 1). To the north of this region, the Oyashio carries waters from the Western Subarctic Gyre and the Okhotsk Sea to the southeast coast of Hokkaido (Yasuda, 2003). Stations K1, K2, and KNOT are in the northern, central, and southwestern parts of the Western Subarctic Gyre, respectively. This region has low temperature, low salinity and nutrient-rich waters (Kusakabe et al., 2002; Saito et al., 2002; Yamaguchi et al., 2002). Station K3, in contrast, is in a region influenced by the Kuroshio extension, which is made up of warm and highly saline water. In general, the upper water column of this subtropical water is nutrient-poor (Takahashi et al., 1985).

2.3. Water sampling and analysis

Seawater samples (30 L) for determination of the activity of dissolved ^{234}Th were taken by Niskin bottle samplers with CTD sensors (SBE 911plus Sea-Bird Electronics Inc., SBE 19plus Sea-Bird Electronics Inc., or 8001-ICTD Falmouth Scientific Inc.) from 8 depths between 10 and 200 m. The seawater samples were filtered through Whatman