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Seasonal variations of particle fluxes in the northeastern equatorial Pacific during normal and weak El Niño periods

Hyung Jeek Kim *Department of Oceanography, Pusan National University, Busan 609-735, Republic of Korea*
Kiseong Hyeong
Chan Min Yoo
Sang-Bum Chi } *Deep-sea & Marine Georesources Research Department, Korea Ocean Research and Development Institute (KORDI), PO Box 29, Ansan 425-600, Republic of Korea*
Boo-Keun Khim *Department of Oceanography, Pusan National University, Busan 609-735, Republic of Korea*
Dongseon Kim* *Climate Change & Coastal Disaster Research Department, Korea Ocean Research and Development Institute (KORDI), PO Box 29, Ansan, 425-600, Republic of Korea*

ABSTRACT: A moored time-series sediment trap was deployed at the Korea Ocean Research and Development Institute Long-term Monitoring (KOMO) Station in the northeastern equatorial Pacific from July 2003 to June 2005. A weak El Niño event was recorded from June 2004 to February 2005, and normal conditions were observed in the remaining periods. The normal period was divided into two seasons based on the cycles of environmental properties in the surface ocean: cold (December–May) and warm (June–November) season. During the normal period, the total mass flux was 1.7 times higher in the cold season than in the warm season. Particularly, the $CaCO_3$ flux was nearly three times higher in the cold season. The enhanced $CaCO_3$ flux in the cold season was attributed to an increased foraminiferal flux, which may have influenced the seasonal variability of the total mass flux at the KOMO station. The enhanced foraminiferal flux during the cold season may have been caused by the environmental changes of the surface ocean in response to wind-driven mixing resulting in supply of subsurface nutrient-enriched water. Particle fluxes during the weak El Niño period were lower by 30% than those during the normal period, which was consistent with previous findings in the central and eastern equatorial Pacific.

Key words: sediment trap, particle fluxes, El Niño, seasonal variations, northeastern equatorial Pacific

1. INTRODUCTION

The equatorial Pacific is an oceanographically important region because of the direct influence of the El Niño-Southern Oscillation (ENSO). This event affects the primary production and carbon dioxide sequestration efficacy of the surface ocean (El-Sayed and Taguchi, 1979; Dymond and Collier, 1988; Honjo et al., 1995; Wanninkhof et al., 1995; Feely et al., 1997; Gupta and Kawahata, 2002; Takahashi et al., 2002). A number of sediment trap studies have been conducted in the eastern (Honjo et al., 1982; Dymond and Collier, 1988; Honjo et al., 1995), central (Dymond and Collier, 1988; Murray et al., 1996; Rodier and Borgne, 1997), and western Pacific (Kawahata et al., 1998, 2000; Gupta and Kawahata, 2002) to understand the effect of ENSO on fluxes of sinking particles. In addition to ENSO, particle fluxes are also affected by the seasonal variation of surface productivity that is associated with temporal changes in the monsoon and upwelling (e.g., Karl et al., 1996; Conte et al., 2001; Hebel and Karl, 2001; Unger et al., 2003; Li et al., 2004). The seasonality of surface productivity in the equatorial Pacific is rather weak, but blooms of micro-phytoplankton are periodically observed in the North Pacific Subtropical Gyre (NPSG) during summer (Karl and Lucas, 1996; Pennington et al., 2006; Dore et al., 2008).

The 10°N thermocline ridge area (9–13°N, 105–140°W) of the northeastern equatorial Pacific is a region of thermocline shoaling located between the equatorial upwelling region (3°S–3°N) and the NPSG. It shows distinct seasonal variations in oceanic (sea surface temperature and sea surface salinity) and atmospheric (wind speed and precipitation) properties (Wanninkhof et al., 1995; Karl and Lucas, 1996; Fiedler and Talley, 2006; Pennington et al., 2006; McGee et al., 2007; Romero-Centeno et al., 2007). These seasonal cycles are governed by the movement of the intertropical convergence zone (ITCZ) and trade wind system (Thunell et al., 1983; Amador et al., 2006; McGee et al., 2007; Romero-Centeno et al., 2007). In winter, when the ITCZ is located farthest from the Korea Ocean Research and Development Institute (KORDI) Long-term Monitoring (KOMO) Station, the surface mixed layer is deeper due to a stronger northeast trade wind. In summer, the ITCZ is located nearer to the KOMO station (El-Sayed and Taguchi, 1979) (Fig. 1). The cyclic fluctuation of these environmental factors can affect primary productivity in the surface ocean and its ecosystem. Indeed, several studies have documented the seasonal fluctuations of primary production and zooplankton abundances near the 10°N thermocline ridge area of the northeastern equatorial Pacific (Blackburn et al., 1970; El-Sayed and Taguchi, 1979; Fernández-Álamo and Färber-Lorda, 2006). For example, El-Sayed and Taguchi (1979) suggested that

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*Corresponding author: dkim@kordi.re.kr

daily primary production (144 mgC m^{-2} day^{-1}) in February and March 1976 was slightly higher than that (120 mgC m^{-2} day^{-1}) in August and September 1975. Blackburn et al. (1970) demonstrated that the standing stocks of phytoplankton and zooplankton showed a large seasonal variation in the eastern tropical Pacific. In addition, mesozooplankton (e.g., copepods) in the eastern equatorial Pacific, including the 10°N thermocline ridge area, showed a similar seasonal fluctuation (Dessier and Donguy, 1985; Fernández-Álamo and Färber-Lorda, 2006). Up to now, however, particle flux studies of natural seasonal fluctuation have not been performed in the northeastern equatorial Pacific. The 10°N thermocline ridge area is of particular interest as it undergoes distinct seasonal variations in its oceanic and atmospheric properties.

The objectives of this study were (1) to investigate the seasonal variations of particle fluxes using a time-series sediment trap for two years from July 2003 to June 2005, (2) to understand the relationship between surface environmental changes and particle fluxes to the deep sea, and (3) to evaluate the effect of a weak El Niño on particle fluxes at the KOMO station in the northeastern equatorial Pacific.

2. METHODS

A time-series sediment trap (PARFLUX Mark 78G-21 model, McLane) was deployed at a depth of 4,950 m for the first year (July 11 2003–June 11 2004) and redeployed for the second year (August 22 2004–June 23 2005) at the KOMO station (10.5°N, 131.3°W, water depth 5,010 m) in the 10°N thermocline ridge area of the northeastern equatorial Pacific (Fig. 1).

Samples were collected in monthly intervals over the deployed period. To prevent sample degradation, the collection bottles were filled with a 5% formalin solution in filtered seawater and buffered with sodium borate. Samples were split for multiple chemical analyses using a McLane WSD-10 divider. Three of the five equal aliquots were rinsed with distilled water to remove residual formalin solution. The washed samples were freeze-dried and weighed for mass flux calculation.

The dried samples were ground with an agate mortar to determine the total carbon (TC), organic carbon (OC), and inorganic carbon (IC) contents. The TC content of the powder samples was analyzed using a Carlo-Erba 1110 CNS elemental analyzer. For the OC measurement, the powdered samples were treated with 5 to 6% sulfuric acid to remove the inorganic carbonate phases, and then analyzed with the CNS elemental analyzer (Hwang et al., 2004). Errors for both analyses were maintained below 3% (1 s) using a standard (Sulfanilamide, CE Instruments). The IC content was calculated from the difference between the TC and OC contents. The calcium carbonate ($CaCO_3$) content was calculated by multiplying the IC values by a conversion constant (8.33). The biogenic silica content was determined by a stepwise dissolution method using a 0.5 N NaOH solution at 85 °C (DeMaster, 1981). The precision of the biogenic silica analyses was 5%, based on duplicate samples. The aluminum content was measured by induced coupled plasma-optical emission spectroscopy (Optima 3000 DV, Perkin Elmer Instruments). The precision for this analysis was lower than 3%, based on a replicate measurement sample of reference material (MAG-1). The lithogenic fractions were estimated by multiplying the aluminum content by a conversion factor of 12.15 (Takahashi and Noriki, 2007). A one-fifth split of each sample was used for the planktonic foraminiferal analysis. An aliquot was wet sieved through a 63-μm mesh, rinsed with deionized water, and dried. All planktonic foraminifera larger than 63-μm were then picked out from the bulk samples using a brush and weighed.

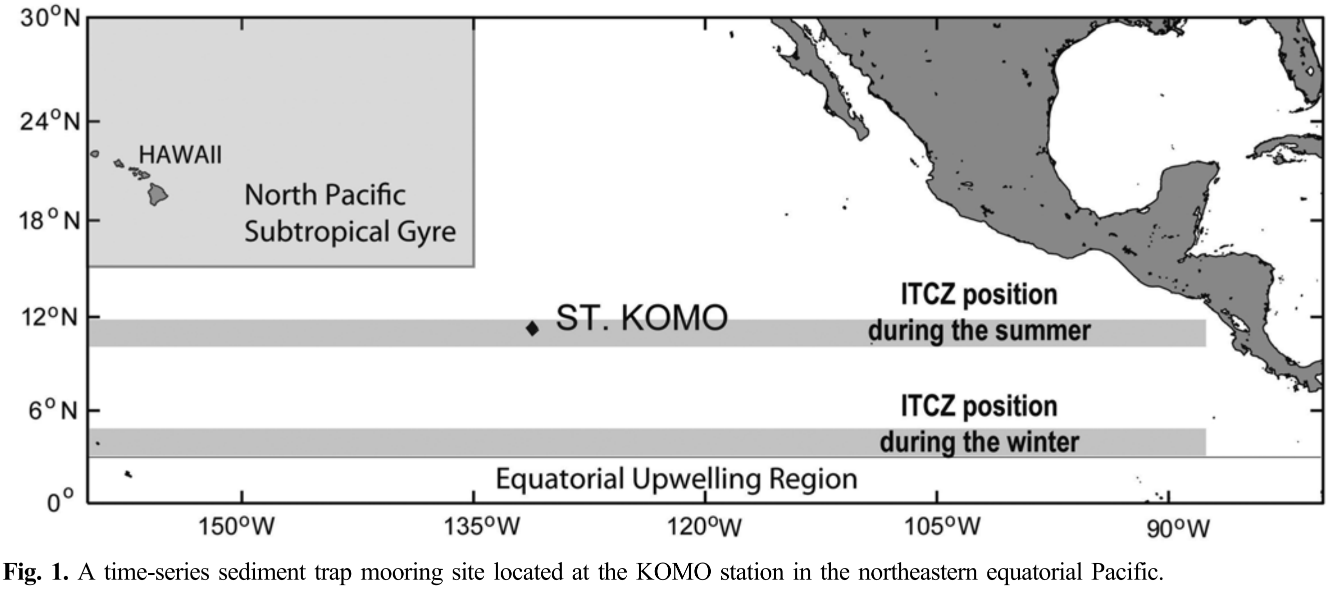

Fig. 1. A time-series sediment trap mooring site located at the KOMO station in the northeastern equatorial Pacific.