ECOLOGICAL MODELLING 202 (2007) 52–67

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ScienceDirect

journal homepage: www.elsevier.com/locate/ecolmodel

Comparison of seasonal characteristics in biogeochemistry among the subarctic North Pacific stations described with a NEMURO-based marine ecosystem model

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ARTICLE INFO

Article history:
Published on line 13 November 2006

Keywords:
Air–sea CO_2 flux
NEMURO
Physical forcing
Phytoplankton dynamics
Subarctic North Pacific
Time series stations

ABSTRACT

A NEMURO-based 16-compartment marine ecosystem model is applied to Stations A7 (41.5°N, 145.5°E) and KNOT (44°N, 155°E) in the subarctic western North Pacific and Station PAPA (50°N, 145°W) in the subarctic eastern North Pacific. Model results show significant west-east differences in seasonal characteristics of physical environmental conditions and biogeochemistry, such as larger seasonal amplitudes in sea surface temperature, mixed layer depth, surface nutrients, chlorophyll and partial pressure of CO_2 at the sea surface $(pCO_2)_{sea}$, and higher primary productivity, at Stations A7 and KNOT than at Station PAPA. The modeled annual-mean *e*-ratios are higher at Stations A7 (0.32) and KNOT (0.33) than at Station PAPA (0.27) due to higher plankton biomass and mortality in the western North Pacific. Modeled annual-mean *f*-ratios are systematically higher than *e*-ratios under the influence of nitrification. The *f*-ratios are lower at Stations A7 (0.57) and KNOT (0.58) than at Station PAPA (0.64) because of higher ammonium concentrations in the western North Pacific. The *e*-ratio increases and *f*-ratio decreases with primary productivity, and the relationships can be described by exponential functions at any of the sites. The sea-to-air CO_2 flux increases at Stations A7 and KNOT when calculated using daily wind data, instead of climatological wind data, which have been used in most of the previous studies. The increase is attributed to the strong winds in late winter in the daily wind data, suggesting that the sea-to-air CO_2 flux was probably underestimated in previous studies and that frequent monitoring of winds and $(pCO_2)_{sea}$ is necessary to reduce uncertainties in estimating air–sea CO_2 flux. Phytoplankton growth is severely limited by light at any of the stations throughout the year. Diatom growth is regulated by silicate rather than nitrate and ammonium at each site, particularly in late summer and early autumn at Stations A7 and KNOT. We conclude that the west-east differences in the biogeochemistry are primarily caused by differences in the physical environmental conditions. The biogeochemical differences are also suggested to

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doi:10.1016/j.ecolmodel.2006.02.046

be caused by differences in the ecosystem dynamics resulting from differences in the iron bioavailability among the stations.

1. Introduction

Previous observational studies have revealed significant differences in physical environment and biogeochemistry between the subarctic western North Pacific (WNP) and the subarctic eastern North Pacific (ENP), both of which have been considered as high nitrate, low chlorophyll (HNLC) regions (Harrison et al., 2004). However, compared to the ENP typified by Ocean Station PAPA (50°N, 145°W) located at the southeast edge of the Alaska Gyre (AG) (Fig. 1), observations in the WNP have been scarce, particularly in winter due to its rough weather. Since the 1990s, two extensive time-series of observations, namely the A-line time-series and the KNOT (*Kyodo* North Pacific Ocean Time series) time-series, have been implemented in the WNP (Fig. 1). Observations for the A-line time-series have been collected in the Oyashio region five or six times each year since 1987 (Saito et al., 1998). Observations from the KNOT time-series have been collected 27 times at Station KNOT (44°N, 155°E) located at the southwest edge of the Western Subarctic Gyre (WSAG) from 1998 to 2000. These two time-series revealed significant seasonal cycles in the physical environmental conditions such as sea surface temperature (SST) and mixed layer depth (MLD) and in the biogeochemistry such as surface nutrient, total carbon dioxide (TCO_2) and chlorophyll concentrations, and relatively higher primary and export productions in the WNP compared to the ENP (Honda et al., 2002; Imai et al., 2002; Saito et al., 2002; Tsurushima et al., 2002).

Although the time-series data directly tell us general features in seasonal and interannual variations of the physical environmental conditions and biogeochemistry, data have not been sufficient in the WNP to draw similar conclusions. At Station KNOT, for example, the observational time-series ran for a relatively short period of 3 years. Therefore, interannual variability has not been well characterized, preventing us from determining if Station KNOT really characterizes the WSAG. No observations have been made in March and April when the SST minima, MLD maxima and surface nutrient and TCO_2 maxima appear, and in September when surface nutrient and TCO_2 minima occur.

In addition to the time-series observations, several studies have focused on the WSAG and have revealed further characteristics of the biogeochemistry in this oceanic region. Using satellite images, Sasaoka et al. (2002) showed that chlorophyll-rich coastal plume occasionally extends to vicinity of Station KNOT, suggesting that coastal waters may influence the biogeochemistry at this site. Honda et al. (2002) and Honda (2003) showed higher export production to deep water in the WSAG than in the AG by continuous sediment-trap experiments. Both of these studies showed remarkable interannual variability in the biogeochemistry at Station KNOT, and therefore, this station may not always represent conditions in the WSAG. Results from a ship-of-opportunity monitoring program across the North Pacific (Wong et al., 2002a,b) revealed higher seasonal silicate:nitrate and lower TCO_2:nitrate drawdown molar ratios at the WSAG, suggesting higher silicification and lower calcification, respectively, compared to the AG.

Along with the observations, numerical modeling is a powerful method to help to fill gaps in the observational data, to gain further understanding of the ecosystem dynamics, and to estimate material fluxes among plankton, which cannot be easily obtained by the observations. To simulate the ecosystem dynamics in the WNP, several marine ecosystem models have been developed with the assumption that diatoms, which produce frustules made of biogenic silica, are dominant phytoplankton species in this oceanic region (Kishi et al., 2007). Based on the North pacific Ecosystem Model Used for Regional Oceanography (NEMURO; Kishi et al., 2007), Fujii et al. (2002) and Yamanaka et al. (2004) have constructed a 16-compartment marine ecosystem model which includes calcium and carbon cycling to reproduce the ecosys-

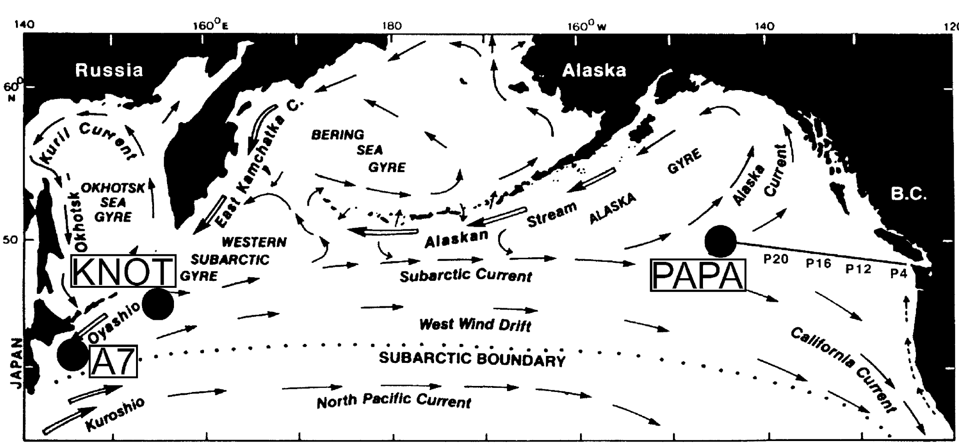

Fig. 1 – General circulation in the North Pacific. The Subarctic Boundary separates the subarctic North Pacific to the north from the subtropical North Pacific to the south. Double arrows indicate intense boundary currents (from Thompson, 1981; Harrison et al., 1999; Kishi et al., 2007). Sites of Stations A7 (41.5°N, 145.5°E), KNOT (44°N, 155°E), and PAPA (50°N, 145°W) are shown.