

Modeling coupled biogeochemistry and ecosystem dynamics at four stations in the North Pacific: Recent results from the FRSGC-HU Group

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Simulated seasonal variations in physical environments and biogeochemical processes at subarctic North Pacific time series stations

Masahiko Fujii, Yasuhiro Yamanaka, Yukihiro Nojiri and Michio J. Kishi

Introduction

Significant differences in biogeochemical processes between east and west regions in the subarctic North Pacific have been found by observations. These differences are primarily characterized by in situ physical environments (e.g. *Kawamiya et al.*, 2000), but it is still not known to what extent these differences can be attributed to the physical environment. To tackle this issue, we applied a 15-compartment marine ecosystem model to two time series stations KNOT (Kyodo North Pacific Ocean Time series; 44N, 155E) and OSP (Ocean Station Papa; 50N, 145W), located in the western and eastern subarctic North Pacific, respectively. Here we show the 18-year means of simulated results for both physical environments and biogeochemical processes for 1982 to 1999. See the separate poster by *Fujii et al.* for details.

Physical Environments

Solar radiation was 60% greater at KNOT than at OSP in winter, but it did not differ much in other seasons (Fig. a). Wind speed was greater at OSP in summer through early winter (Fig. b). SST was lower in winter and higher in summer at KNOT (Fig. c). The simulated seasonal amplitude was 12°C at KNOT and 7°C at OSP, consistent with the observed. The surface water in summer was strongly stratified due to higher SST, and the mixed layer depth (MLD) was shallower at KNOT (Fig. d). The MLD in early winter was deeper at OSP because of the stronger winds. The MLD deepened in late winter at KNOT, to a maximum of more than 100m in March, as a result of the lower SST.

Biogeochemical Components

Simulated surface nutrients and dissolved inorganic carbon (TCO₂) concentrations represented the observed features, i.e., larger seasonal amplitude at KNOT than at OSP (Fig. e & g). The observed dominance of diatoms (PL) at KNOT was successfully reproduced by the model (Fig. f). Stock size of PL in winter at KNOT was primarily due to the greater solar radiation in this season. The stratification of surface water began earlier, and the spring PL bloom and following transition of the predominant species from PL to non-diatom small phytoplankton (PS) also occurred half a month earlier at KNOT. The fugacity of CO₂ in the surface water ($f(\text{CO}_2)_{\text{sea}}$) had larger seasonal fluctuations at KNOT (Fig. d). The model results indicated that the ocean around KNOT was a sink of CO₂ while that around OSP scarcely absorbed or released CO₂, although the interannual variability induced by short-term atmospheric disturbances is considered to be larger for $f(\text{CO}_2)_{\text{sea}}$ than for other biogeochemical components.

Major features at each station were reproduced using the same values for biogeochemical parameters. This indicates that the differences in the biogeochemical processes were primarily determined by the differences in the physical environments. For more realistic simulations, however, several parameter values should be changed at each site. For example, the best-fit value of the maximum photosynthetic rate at 0°C was 0.45/day for PS and 0.9/day for PL at KNOT. The values were 0.25/day and 0.50/day at OSP, roughly half those at KNOT. This reflects differences in the "bottom-up" control of phytoplankton photosynthesis (e.g., iron limitation) between the west and east regions. Differences in "top-down" control were not addressed in this study, but are considered significant. More information about zooplankton is necessary for calibrating zooplankton parameters.

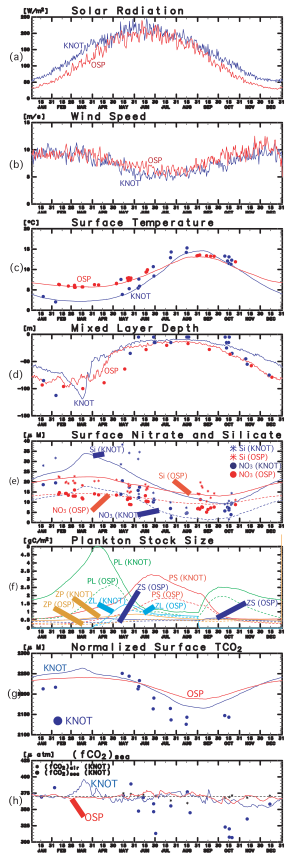


Fig. The 18-year means of simulated results for (a) solar radiation, (b) wind speed, (c) SST, (d) MLD, (e) surface nutrients, (f) plankton stock sizes, (g) surface TCO₂, and (h) $f(\text{CO}_2)_{\text{sea}}$ at KNOT (blue line) and OSP (red line). Solid dots are obs. or climatology data.

Factors controlling silicon/nitrogen ratios in a marine ecosystem during the spring diatom bloom

Naoki Yoshie and Yasuhiro Yamanaka

Introduction

We investigated the silicon/nitrogen (Si/N) ratios in a simulated marine ecosystem using a one-dimensional ecosystem model which explicitly represents diatoms with silicious shells. The model simulates silicon and nitrogen cycles and includes other non-silicious plankton. The model was applied to station A7 (41° 30'N, 145° 30'E) in the western North Pacific, where diatoms regularly bloom in spring.

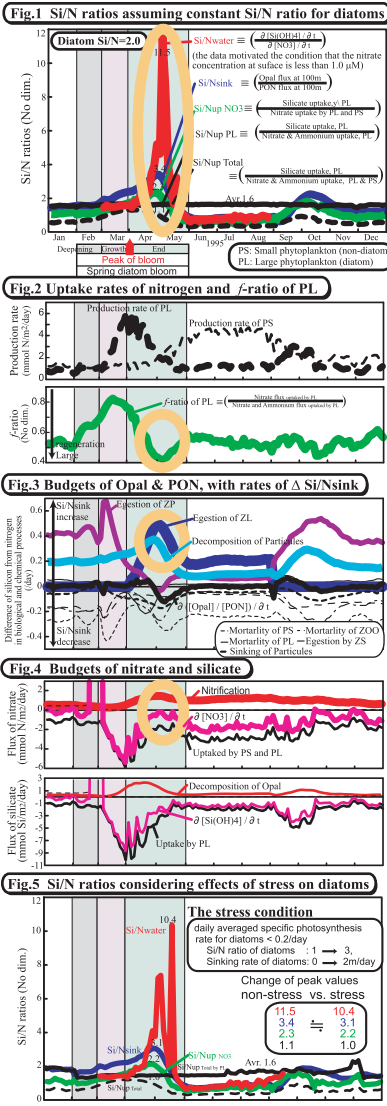
Results and Discussion

Simulations demonstrated seasonal variations and distinct values of Si/N ratios for: (1) uptake by the phytoplanktons; **Si/N_{water}**, (2) composition in the sinking particle; **Si/N_{sink}**, and (3) time change in silicate and nitrate concentrations in the water; **Si/N_{water}** (fig.1). This was true even when the Si/N chemical composition ratio of diatoms was set to a constant value. At the end of the spring diatom bloom, these Si/N ratios reach their maxima, and the differences among them are remarkable (fig.1).

Time variations of these Si/N ratios result from differences between silicon and nitrogen cycles in the ecosystem, most importantly the recycling of nitrogen through ammonium.

The Si/N ratio of total uptake by all phytoplankton (without considering ammonium uptake) is determined by the weighted mean of production rates by diatoms and other phytoplankton, and by the **contribution of ammonium uptake to total uptake of nitrogen by diatoms** (i.e. f-ratio of diatoms) (fig.2). The Si/N ratio of sinking particles is affected by the different degradation rates of biogenic silica (opal) and particulate organic nitrogen (PON) (fig.3). Opal is quickly egested as fecal pellets without being metabolized by zooplankton, and PON decomposes faster than opal. The Si/N ratio estimated from the decreases of silicate and nitrate concentrations in the water column is influenced by the **supply of nitrate from nitrification which compensates for the uptake of nitrate by the phytoplankton** (fig.4). This is the reason for the extraordinary peak in Si/N ratio at the end of the spring diatom bloom.

We investigated the effect of physiological changes in diatoms under stress, when their Si/N composition rates and sinking rates change. The increase in the Si/N composition of diatoms increases the Si/N ratios mentioned above, whereas the sinking of diatoms decreases the Si/N ratios above. These effects on the Si/N ratios counteract one other. Thus, the diatom's physiological changes have a small net effect on the Si/N ratios (fig.5).



A study of seasonal variations in nitrogen isotope ratio of sinking particles using a marine ecosystem model

Chisato Yoshikawa, Yasuhiro Yamanaka and Takeshi Nakatsuka

We developed an ecosystem model for simulating $\delta^{15}\text{N}$ variation in the surface water based on recent ecosystem models (*Kawamiya et al.*, 1997; *Fujii et al.*, 2002; *Yamanaka et al.*, 2002). We applied this model to the Sea of Okhotsk, and successfully reproduced the seasonal variations in $\delta^{15}\text{N}$ and fluxes of sinking particles obtained from sediment trap experiments.

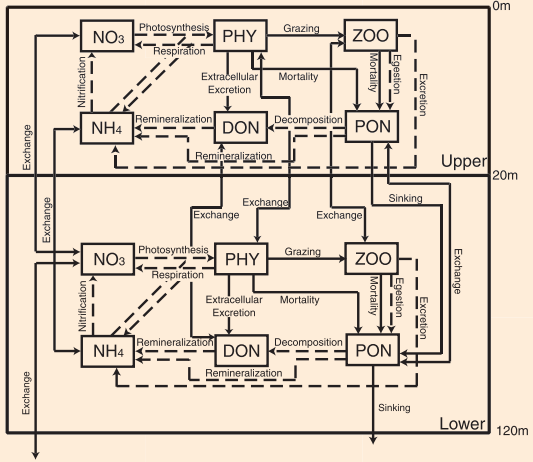


Figure 1. Schematic view of interactions among the six model compartments. The symbol of NO₃ indicates nitrate concentration, NH₄ ammonium, PHY phytoplankton, ZOO zooplankton, PON particulate organic nitrogen, and DON dissolved organic nitrogen. Solid and dashed arrows indicate nitrogen flows without and with Isotope fractionation, respectively.

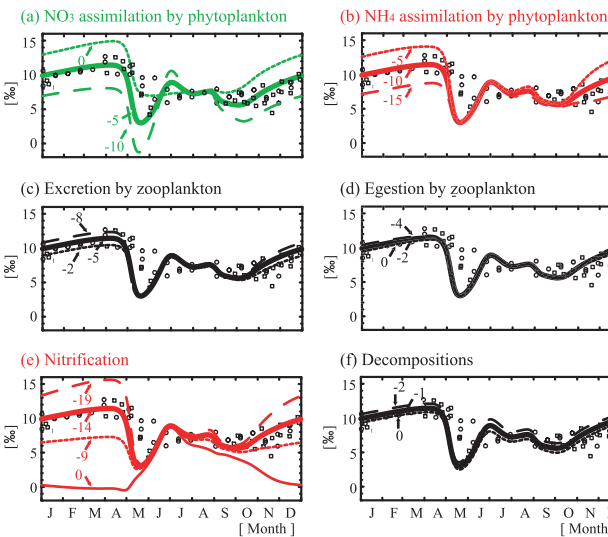


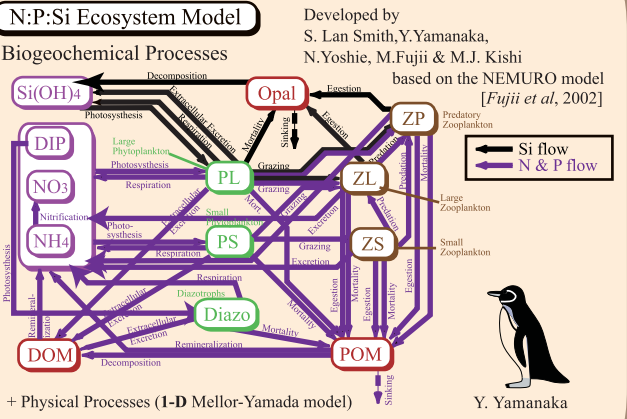
Figure 2. Simulations of $\delta^{15}\text{N}$ of sinking particles, changing the isotopic fractionation factors within the range measured in previous studies: (a) nitrate assimilation by phytoplankton, (b) ammonium assimilation by phytoplankton, (c) excretion by zooplankton, (d) egestion by zooplankton, (e) nitrification and (f) decompositions. Lines are simulated values. Open circles are observed values from sediment trap experiments.

We found that the annual minimum $\delta^{15}\text{N}$ of sinking particles in the **spring bloom** is sensitive to the fractionation factor of **nitrate assimilation** by phytoplankton but insensitive to the other fractionation factors, as suggested by previous studies. On the other hand, the $\delta^{15}\text{N}$ of sinking particles **from summer to winter** is sensitive to the three fractionation factors for **nitrification** and **nitrate** and **ammonium assimilations** by phytoplankton. The annual maximum $\delta^{15}\text{N}$ of sinking particles in winter can be simulated using a large isotopic fractionation for **nitrification**.

An N-, P- and Si- based Model of Primary Production and Export Applied to Stn. ALOHA: Can we get the model to agree with the data for primary production, DOM concentrations and POM fluxes?

S. Lan Smith, Yasuhiro Yamanaka and Michio J. Kishi

We developed a multi-element ecosystem model and applied it to simulate the Hawaii Ocean Time-series Stn. ALOHA for 1997 and 1998. We include diazotrophs as in *Fennel et al* [2002], and their high ratios of DIC:N₂ uptake as measured by *Orcutt et al* [2001]. We included excess (overflow) production of DOC, and in one version of the model, the Microbial Food Web (MFW), based on *Anderson and Williams* [1998]. Our MFW is a C-, N- and P- based extension of theirs, including bacteria & two classes of DOM.



Simulations were conducted with the **Base** model (depicted above) and with a version including the **MFW**, for 1997 and 1998, using wind and radiation data from the HALE-ALOHA buoy. Stoichiometries were fixed (constant) for all organisms, and mass balances were used to determine the stoichiometries for non-living organic matter. Production of DOM by "sloppy feeding", both explicitly from grazing and from mortality of zooplankton, was included.

Both models misrepresent the stoichiometries of both DOM and POM. Simulated POC:PON & PON:POP ratios are significantly lower than observed, and the models export too much N and P for each mole of C.

In the **FixD** simulations, we fix the stoichiometry of detritus (POM) as it is formed (mortality & egestion) to the mean observed value at 150m. The remaining N and P are released as nutrients and DOM. Thus, nutrients are recycled higher in the water column, increasing primary production.

Table 1: Simulations and Data

Quantity (mean for 1997-98)	Data	Standard		FixD	
		Base	MFW	Base	MFW
POC Flux [mg m ⁻² day ⁻¹] @ 150 m	30	7.4	7.9	8.1	9.2
PON Flux [mg m ⁻² day ⁻¹]	4.2	1.3	1.4	1.1	1.3
POP Flux [mg m ⁻² day ⁻¹]	0.36	0.17	0.19	0.1	0.1
Primary Production [mg C m ⁻² day ⁻¹]	478	422	374	476	435
N ₂ Fixation [mmoles N m ⁻² yr ⁻¹]	13 - 77	33	32	35	34

Estimates of N₂ Fixation range from 31 +/- 18 to 51 +/- 26 mmoles N m⁻² yr⁻¹

Conclusions

Fixing the organisms' stoichiometries and allowing mass balances to determine organic matter stoichiometries did Not give realistic stoichiometries for POM or DOM. Profiles of DOM were simulated well with the MFW. Simulated **nutrient cycles** were improved over previous versions of this model by including **"sloppy feeding"** (production of DOM by grazing) and partitioning **zooplankton mortality** among nutrients, DOM and POM. Fixing the stoichiometry for the formation of all detritus further improved the simulations via faster recycling of nutrients within the euphotic zone, increasing Net Primary Production by 10 to 20%.

Simulated **Net Production** is generally lower than the ¹⁴C-based data, as expected. The ¹⁴C method is expected to measure something between Net and Gross Production [*Karl et al.* 2003]

Total **fluxes of POM** are too low, however (if the model is tuned to simulate the profiles of DOM well).

References

Anderson, Thomas R. and P. J. le B. Williams, 1998. *Estuarine Coastal Shelf Sci.* 46, p. 93-109
Fennel, K., Y. H. Spitz, R. M. Letelier, M. R. Abbott and D. M. Karl, 2002. *Deep-sea Research II* 49, p. 149-174
Fujii, Masahiko., Y. Nojiri, Y. Yamanaka, and M. J. Kishi, A one-dimensional ecosystem model applied to time-series Station KNOT, *Deep-Sea Research II*, 49, p. 5441-5461, 2002.

Fujii, M., Y. Nojiri, Y. Yamanaka and M. J. Kishi, 2003. poster presentation at the Third International JGOFS OSC "JGOFS Accomplishments & the Future of Biogeochemistry", Washington D.C., May, 2003
Karl, David M., R. R. Bidigare and R. M. Letelier, 2003. ch. 9 in *Phytoplankton Productivity: carbon assimilation in marine and freshwater ecosystems*, edited by P. J. le B. Williams, D. N. Thomas and C. S. Reynolds, Blackwell Science.
Kawamiya, M., M. J. Kishi, Y. Yamanaka and N. Sugihara, 1997. *Journal of Oceanography* 53, p. 397-402

Kawamiya, M., M. J. Kishi and N. Sugihara, 2000. *J. Mar. Syst.*, 25, p. 159-178.
Orcutt, Karen M., F. Lipschultz, K. Gundersen, R. Arimoto, A. F. Michaels, A. H. Knap and J. R. Gallon, 2001. *Deep-sea Research II*, 48, p. 1583-1608
Yamanaka, Y., N. Yoshie, M. Fujii, M. Aita-Noguchi and M. J. Kishi, 2002. *Journal of Oceanography*, submitted.