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

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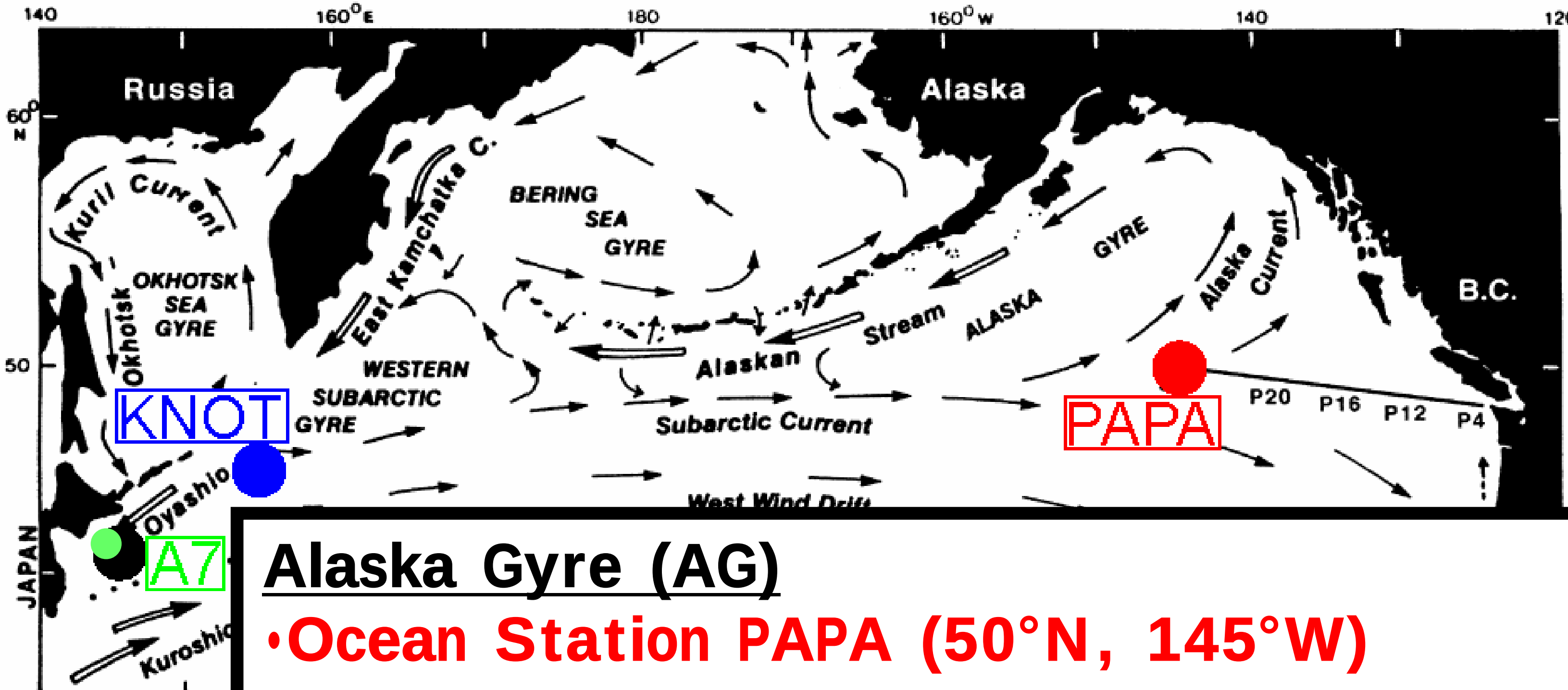
Ecological Modelling, in press

Introduction

Time-series stations in the subarctic North Pacific



Alaska Gyre (AG)

- Ocean Station PAPA (50°N, 145°W)

Western Subarctic Gyre (WSAG)

- A-line including A7 (41.5°N, 145.5°E)
- KNOT (44°N, 155°E)

What have been recognized about the subarctic North Pacific?

- **A high nitrate low chlorophyll (HNLC) region**

- **Seasonality of physical conditions (e.g. SST, MLD) and biogeochemistry (e.g. nutrients): WSAG > AG**

- **Annual chlorophyll and primary productivity: WSAG > AG**

→ These features are characterized by both physical conditions and internal biogeochemistry at each site

What have not been fully understood about the subarctic North Pacific?

- How much of the west-east biogeochemical differences are driven by physical conditions versus internal ecosystem dynamics at each site
- The magnitude of limiting factors on phytoplankton growth

Objective

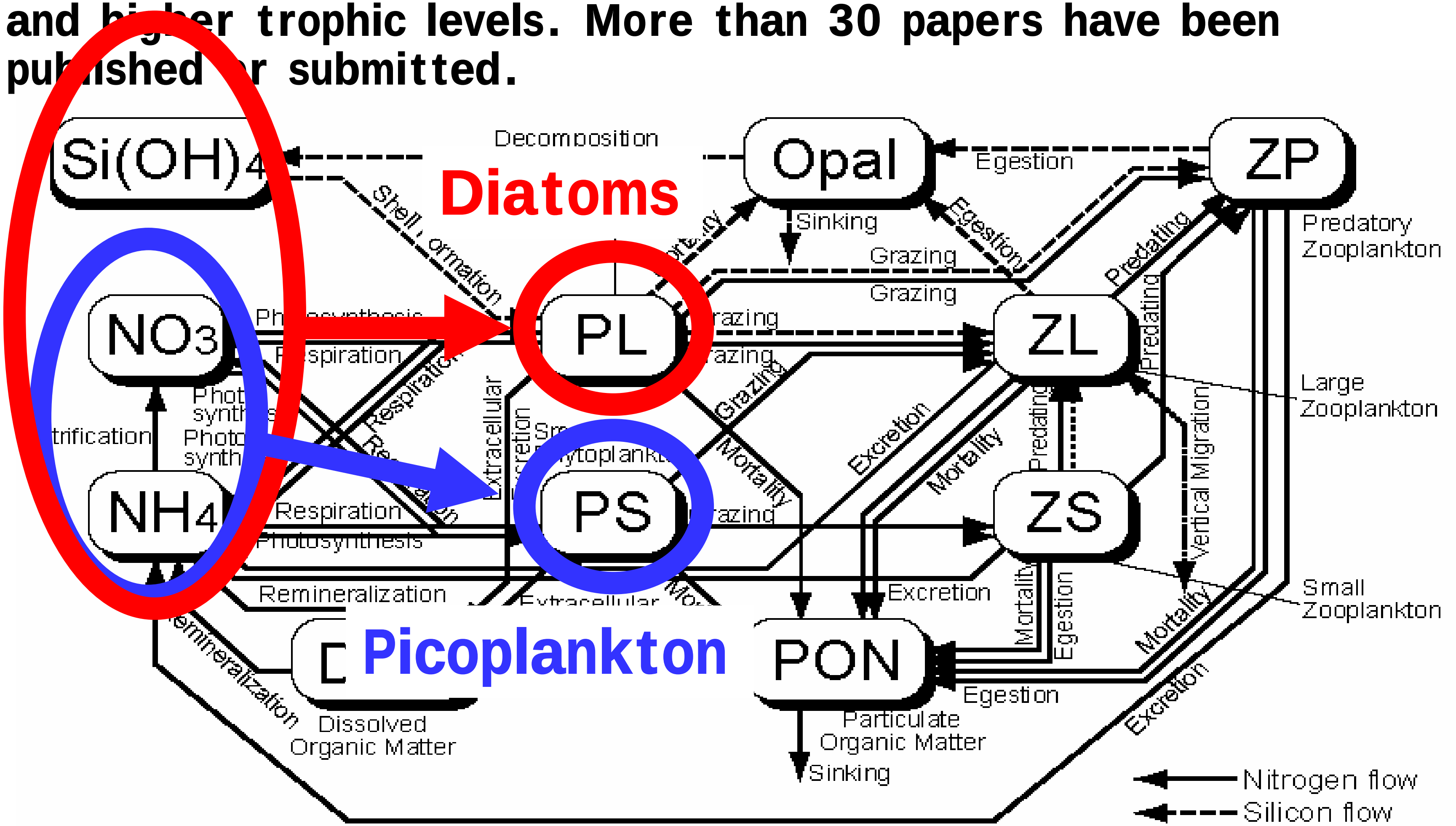
To know:

1. **What factors generate west-east biogeochemical differences in the subarctic North Pacific**
2. **What factors may constrain primary productivity at each site**

→ Ecosystem model may help quantitative comprehension!

An ecosystem model "NEMURO"

A lower trophic level ecosystem model NEMURO (North pacific Ecosystem Model Used for Regional Oceanography) was developed by PICES MODEL Task Team, focusing on a linkage between lower and higher trophic levels. More than 30 papers have been published or submitted.

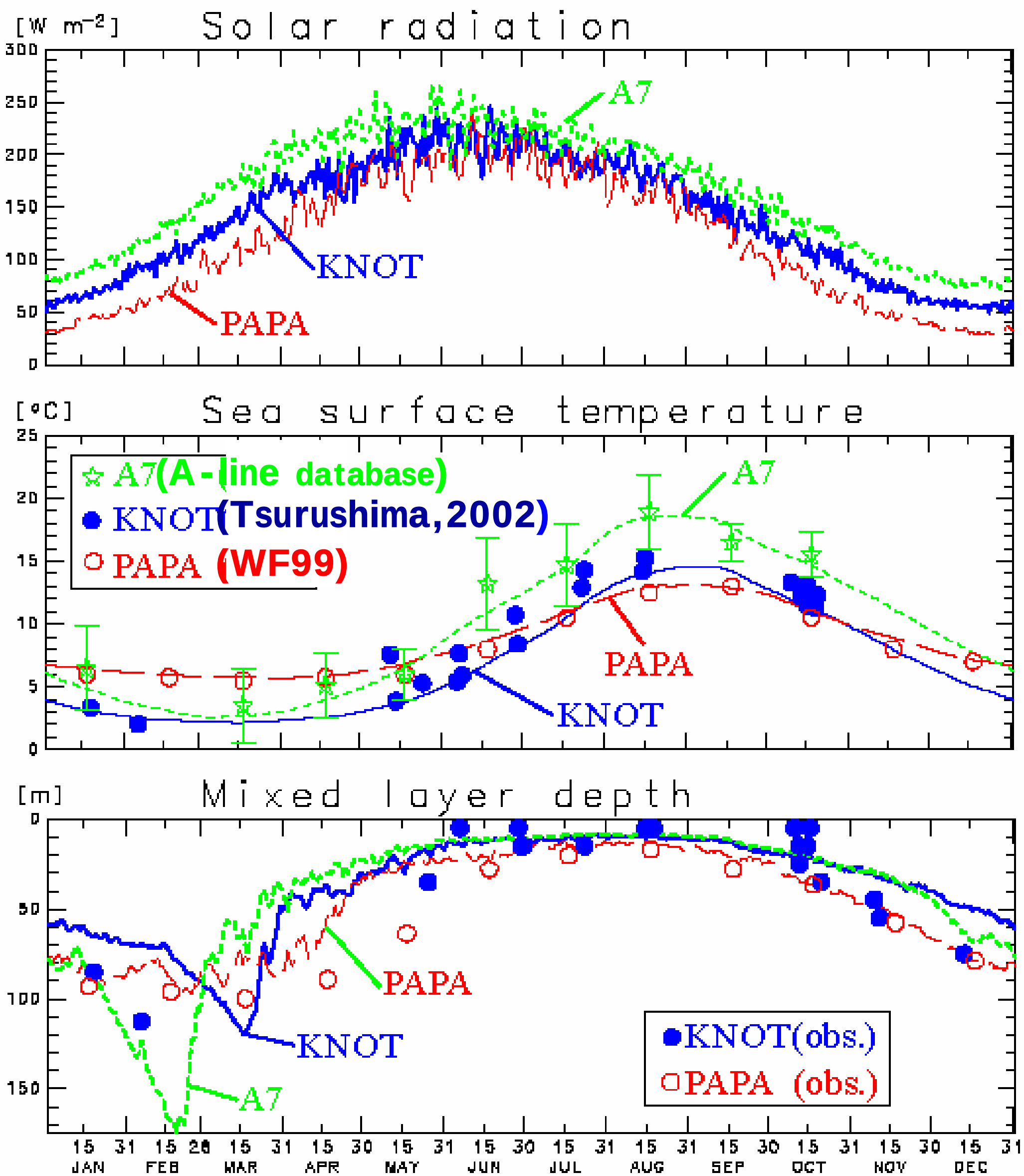


Courtesy of N. Yoshie

Model Experimental Design

- **NEMURO + mixed layer model**
- **Applied to Stations A7 (WSAG), KNOT (WSAG) and PAPA (AG)**
- **Driven by daily wind (NCEP), weekly temperature (Reynolds) and monthly salinity (WOA01) at each site**
- **Eighteen-year (1982-1999) mean results were compared and discussed**

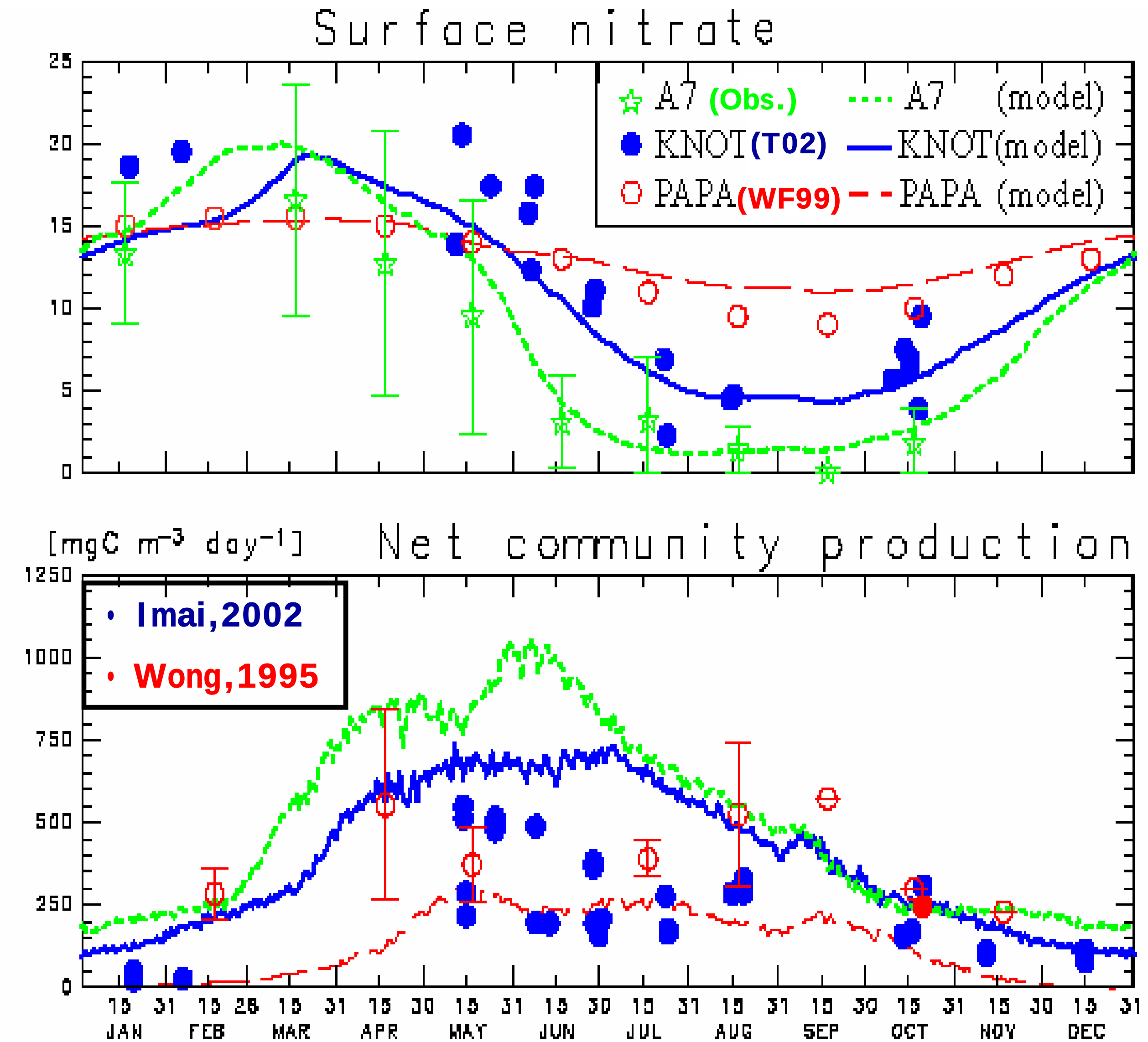
Results: Physical conditions



ΔSST
16°C (A7)
12°C (KNOT)
7 °C (PAPA)

Mixed layer depth max.
> 170m (A7)
> 120m (KNOT)
< 100m (PAPA)

Results: Biogeochemistry



ΔNO_3 [mmol m^{-3}]

19 (A7)

15 (KNOT)

5 (PAPA)

Primary productivity

A7>KNOT>>PAPA

What factors control diatom growth?

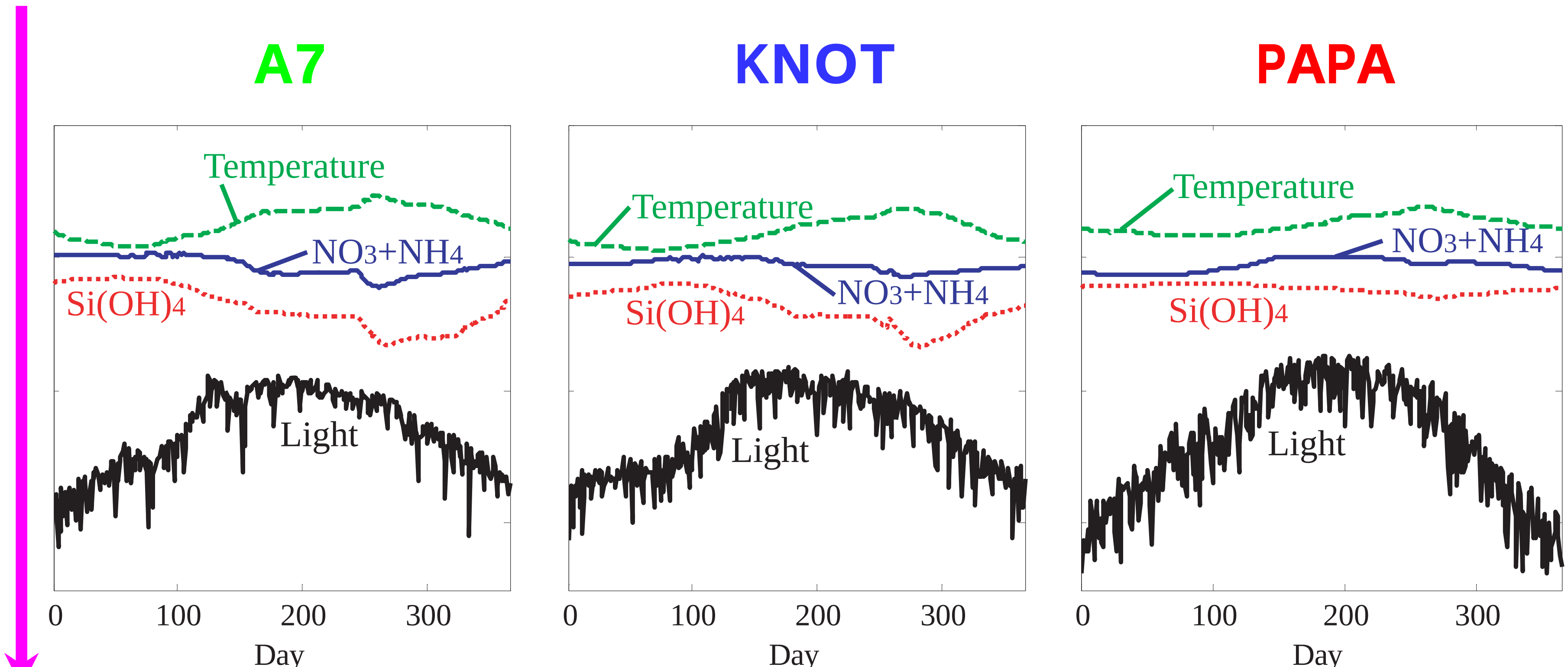
Diatom growth

$$= V_{max\ L} \times \min\left\{ \frac{[NO_3]}{[NO_3] + K_{NO_3}} + \frac{[NH_4]}{[NH_4] + K_{NH_4}}, \frac{[Si(OH)_4]}{[Si(OH)_4] + K_{Si(OH)_4}} \right\}$$

Nitrate + Ammonium **Silicate**

$$\times \left\{ 1 - \exp\left(\frac{-\alpha \times \text{Light}}{V_{max\ L}} \right) \right\} \times \exp(k_L \times \text{Temp})$$

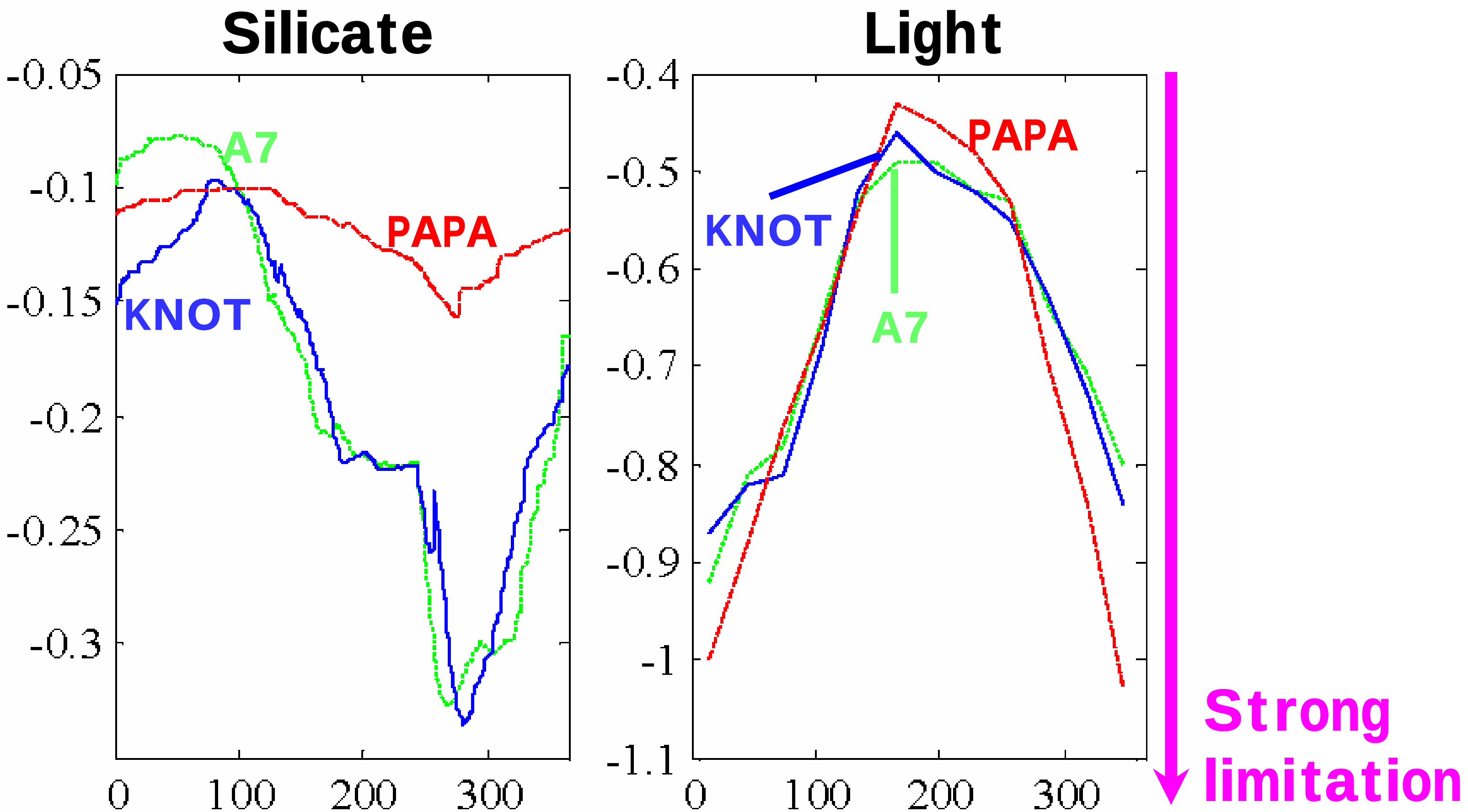
Light **Temperature**



Strong limitation on diatom growth

Limitation:

Light >> $Si(OH)_4$ > NO_3+NH_4 > Temp.



In western subarctic North Pacific

- **Strong silicate limitation in summer**
- **Light limitation in spring and summer due to shelf-shading by phytoplankton**

Diatom growth

$$= V_{\max L} \times \min\left\{\frac{[NO_3]}{[NO_3]+K_{NO_3}} + \frac{[NH_4]}{[NH_4]+K_{NH_4}}, \frac{[Si(OH)_4]}{[Si(OH)_4]+K_{Si(OH)_4}}\right\}$$

$$\times\left\{1-\exp\left(\frac{-\alpha \times \text{Light}}{V_{\max L}}\right)\right\}\times \exp(k_L \times \text{Temp})$$

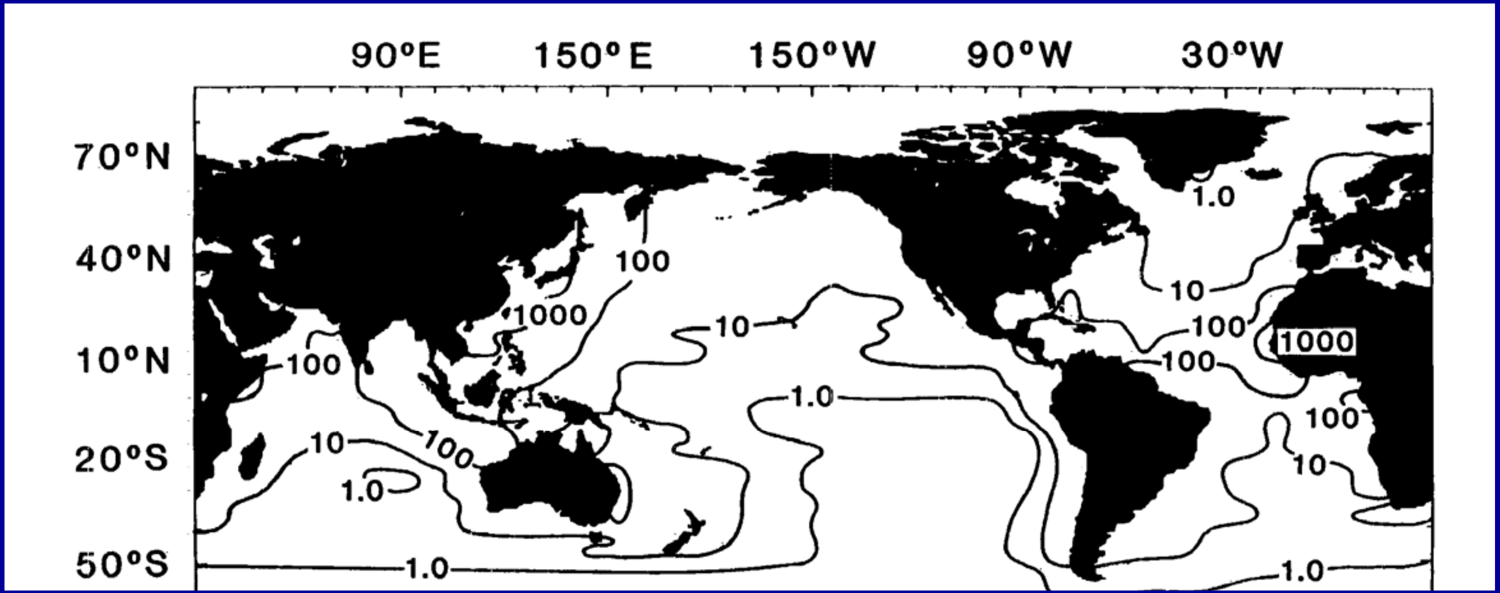
Maximum growth rate: A7 > KNOT >> PAPA

	A7	KNOT	PAPA
V_{maxS} (Picoplankton) [day^{-1}]	0.74	0.59	0.37
V_{maxL} (Diatoms) [day^{-1}]	1.33	1.18	0.71

Previous observational and modeling studies have revealed higher diatom growth rate with higher bioavailable iron concentrations

phytoplankton growth rate: A7 > KNOT >> PAPA

← Iron concentration: A7 > KNOT >> PAPA



Airborne iron to the ocean [mg m^{-2} yr^{-1}]
(Duce and Tindale, 1991)

O: Strong limit., Δ: Weak limit., X: No limit.

AG	Iron	NO_3+NH_4	$Si(OH)_4$	Light	Temp.
Winter	O	X	X	O	X
Spring	O	X	X	O	X
Summer	O	X	X	O	X
Autumn	O	X	X	O	X

WSAG	Iron	NO_3+NH_4	$Si(OH)_4$	Light	Temp.
Winter	Δ	X	X	O	X
Spring	Δ or O	X	Δ	O	X
Summer	O	X	O	O	X
Autumn	Δ or O	X	Δ	O	X

Conclusion

Significant west-east biogeochemical differences are:

- primarily characterized by physical conditions at each site
- Secondary caused by internal ecosystem dynamics due to iron bioavailability at each site

Diatom growth is restricted by:

- light and iron in the Alaska Gyre
- light, iron and silicate in the Western Subarctic Gyre

NEMURO works.

What NEMURO needs next?

- Realistically incorporating the oceanic iron cycling and iron limitation on phytoplankton growth
- Further validation for grazing on phytoplankton (top-down control)