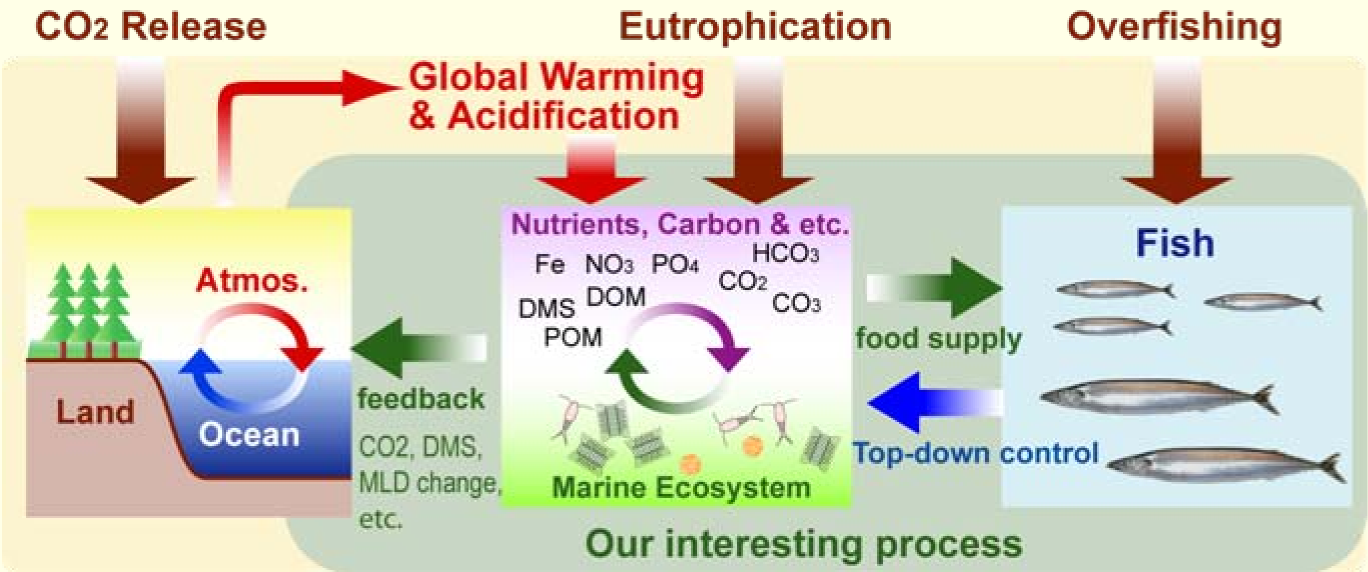
Observational data for determining physiological parameters and validating model simulations: suggestions by NEMURO developers

Y. Yamanaka[1,2,3] , Y. Naoki[4,5] , M. N. Aita[2], T. Hashioka[2,3], H. Sumata[1], N. Okada[1] , T. Okunishi[4] and S. Ito[4]



We are developing an integrated marine ecosystem model linking climate change with fish resources

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2 Frontier Research Center for Global Change, Japan Agency for Marine-Earth Science and Technology
3 Creation of Technological Seeds Responding to Social Demands (CREST), Japan Science and Technology Agency (JST)
4 Tohoku National Fisheries Research Institute, Fisheries Research Agency
5 Japan Society for the Promotion of Science,

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Today' talk is

(1)Improving parameterization: focus on basic process

(2)Additional groups of plankton: seasonal cycle data by repeating cruses

(3)Model intercomparison Project: systematic data set in the global domain

Thank to M. Vogt, C. Le Quéré, S. Alvain, L. Bopp, E. Buitenhuis for providing MareMIP data

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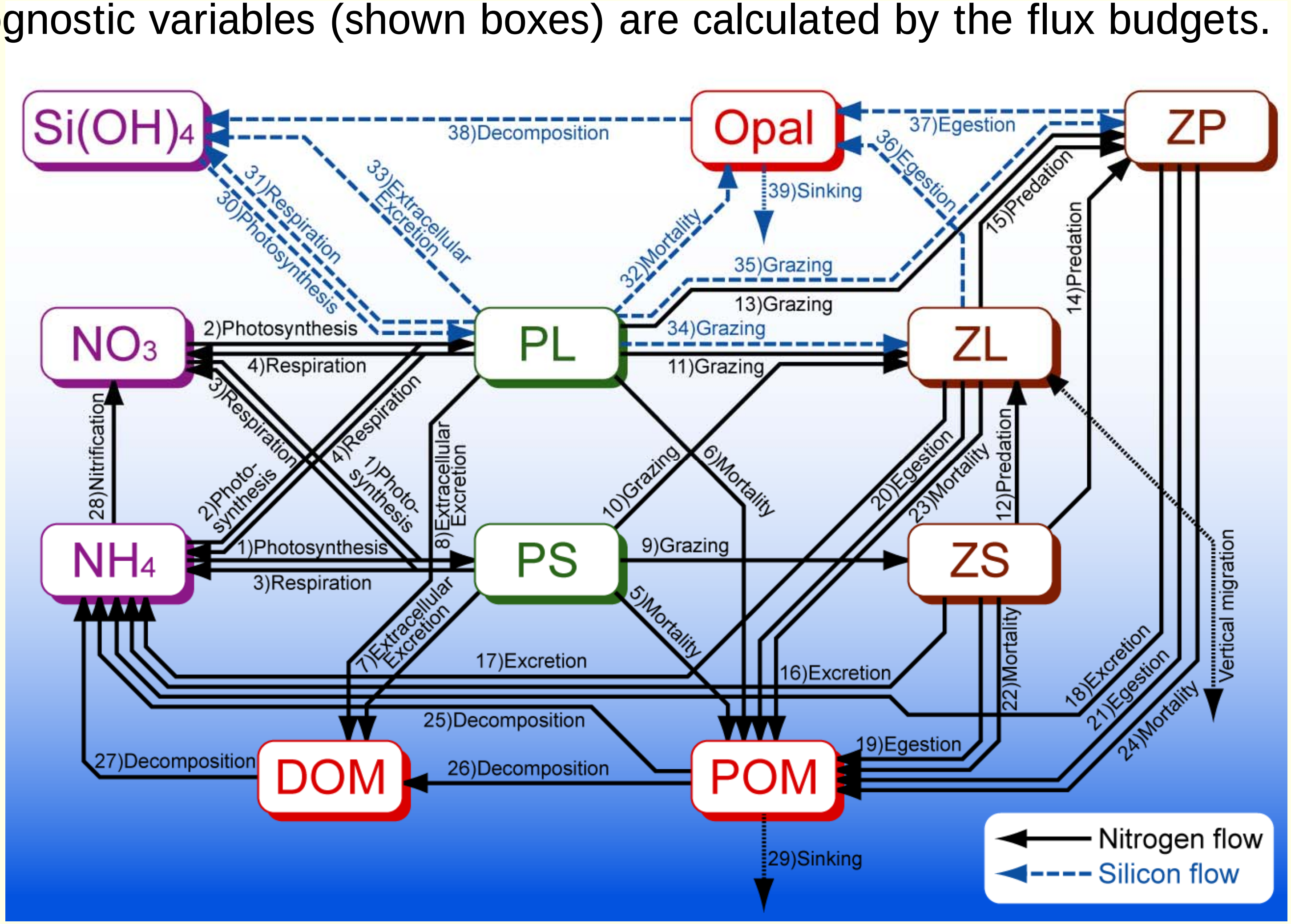
NEMURO looks high complexity (5 plankton groups), but adopts simple processes compared with others.

Each flux (shown line) is estimated by each specific process, and time tendency of prognostic variables (shown boxes) are calculated by the flux budgets.



Example of improving parameterization: Photosynthesis rate

Michaelis-Menten's empirical formulation in the original NEMURO

$$V_{maxL}\,\mathrm{Min}\left[\frac{[NO_3]}{[NO_3]+K_{NO_3L}}e^{-\psi_L[NH_4]}+\frac{[NH_4]}{[NH_4]+K_{NH_4L}},\ \frac{[Si(OH)_4]}{[Si(OH)_4]+K_{SiL}}\right]e^{k_{GppS}Tmp}\frac{I}{I_{optL}}e^{\left(1-\frac{I}{I_{optL}}\right)}PL$$

Nutrient dependent Temp. dependent Light dependent

This process has 7 parameters. If more complex (or sophisticated) process introduced such as optics or nutrient-depended half-saturation constants, number of parameters would increased.

Akaike's Information Criterion (AIC, a quantitative criteria of Occam's Razor)

$AIC = 2k - 2\ln(L)$ *k* is number of parameters, *L* is likelihood function.

Model with smallest AIC is the best model, so model with many parameters tends to be no good model.

Cell Quota Models with Optimal Uptake Kinetics for single nutrient (Pahlow, 2005) and for multi-nutrients (Smith & Yamanaka, 2007)

which adopts V_0 (uptake rate constant), A_0(Affinity) instead of V_{max}, K_s in MM eq., has the same number of classical MM's empirical formula.

That is, OU kinetics is better process if its residual sum of square (RSS) is small.

$$AIC = 2k + n[\ln(2\pi RSS/n) + 1]\,.\quad RSS = \sum_{i=1}^{n}\hat{\varepsilon}_i^2,$$

We are developing Q-NEMURO as a cell quota model.

of components is the same as NEMURO, but C/N/Fe/Chl-a ratios in each group of plankton are variables, for fusion of biogeochemical cycles and ecosystem.

Example of improving each process: nutrient uptake as primary production.

For the Growth-Limiting Nutrient

The New

OU Equation for a single nutrient (Pahlow, MEPS, 2005):

$$V_{OU} = \frac{V_0 S}{\left(\frac{V_0}{A_0}\right) + 2\left(\frac{V_0 S}{A_0}\right)^{0.5} + S}$$

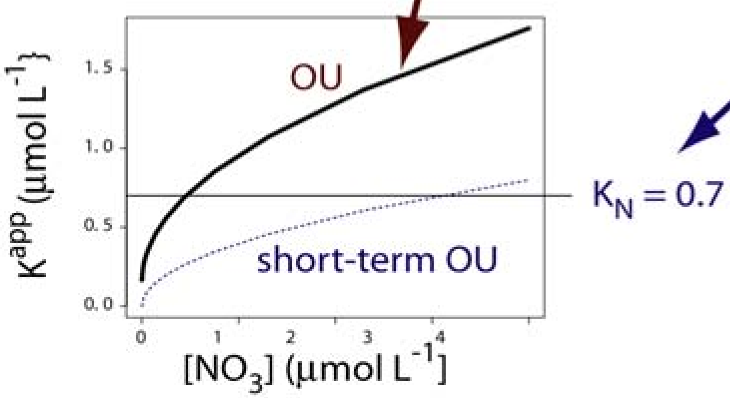
The Classic

Michaelis-Menten (MM) Equation:

$$V_{MM} = \frac{V_{max} S}{K_S + S}$$

where S is nutrient concentration

Acclimated (long-term) response

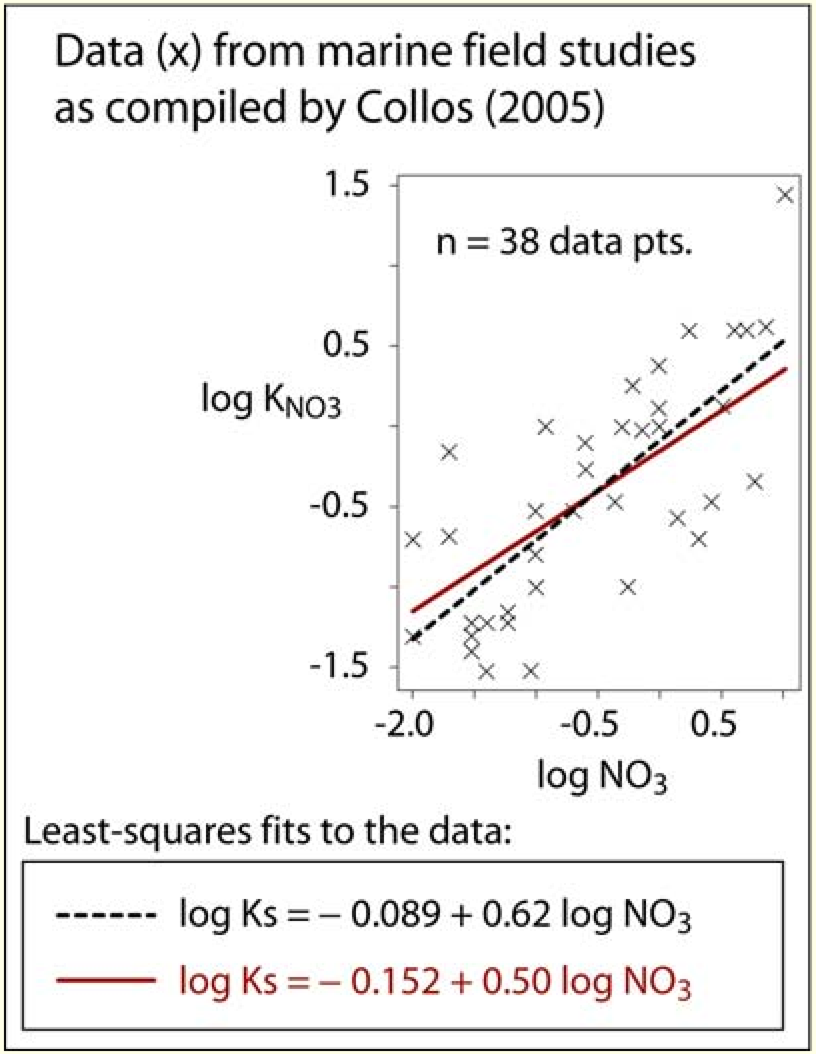


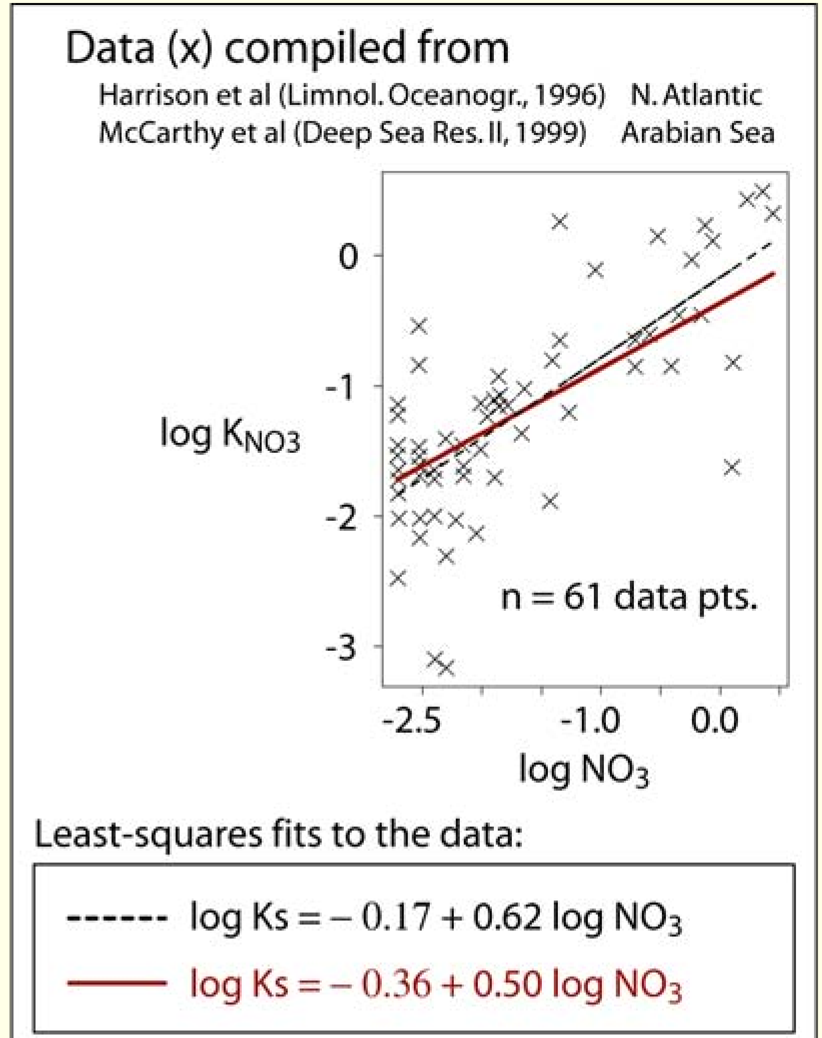
No increase in model complexity (V_0, A_0) replacing (V_{max}, K_s)

Better model of biological response as shown here for nitrate and for multiple nutrients by Smith and Yamanaka (*Limnol. Oceanogr.*, 2007)

Short-term approximation of OU kinetics provides

theoretical relationship of Ks





As test of OU kinetics, we built OU kinetics into NPZD model (Not NEMURO)

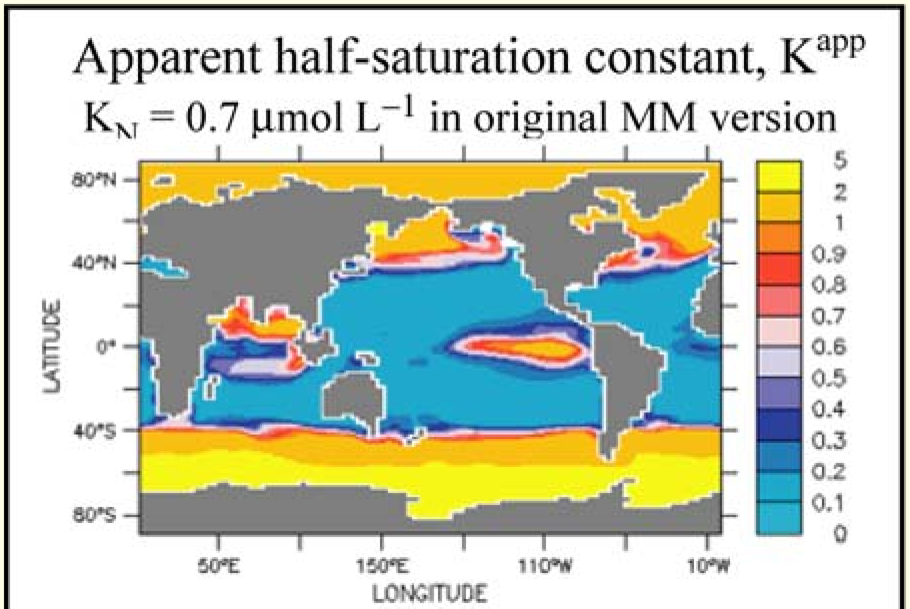
OU kinetics (The SPONGE from Smith & Yamanaka, *Limnol. Oceanogr*. 52, 2007) was substituted into a marine ecosystem model:

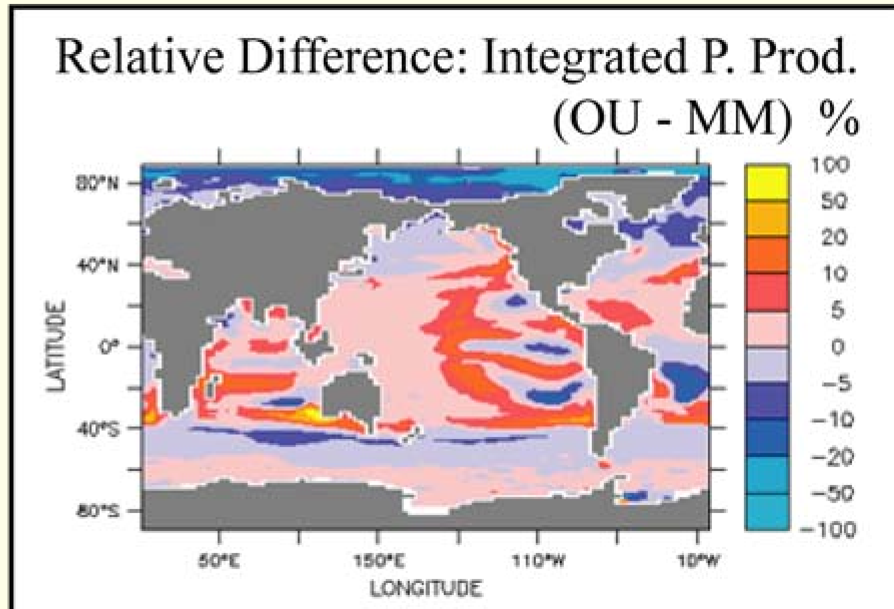
Univ. of Victoria Earth System Climate Model

(Schmittner et al, *GBC* 19, 2005; Schmittner et al., *GBC* 22, 2008)

- Two nutrients (N & P)
- fairly coarse resolution OGCM (1.8 x 3.6 degrees)
- Long simulations: years 1865-2000

We Compare the OU version to the Original, which applied MM kinetics.

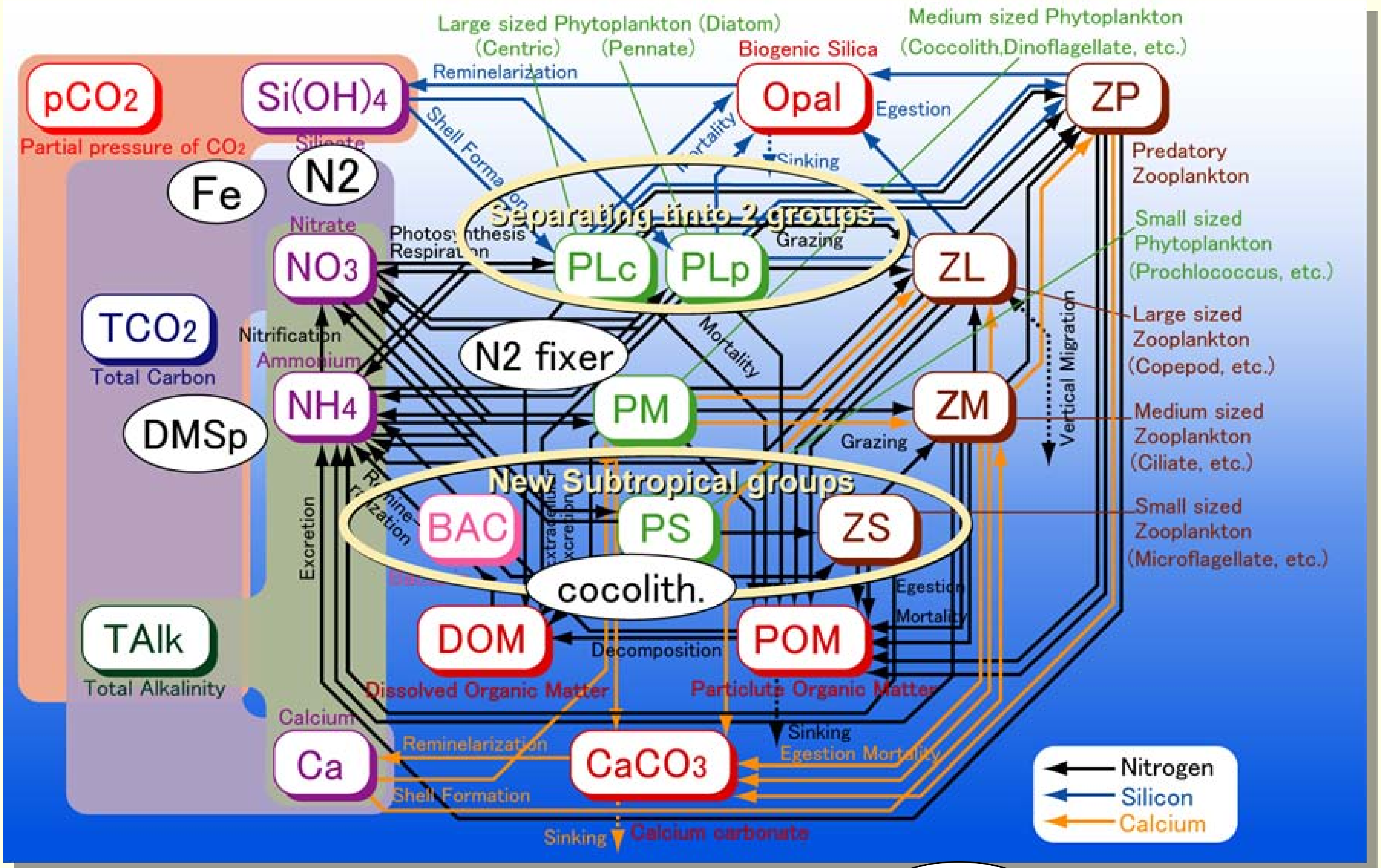




S. L. Smith, Y. Yamanaka, M. Pahlow, A. Oschlies: Optimal acclimation kinetics for nutrient uptake by phytoplankton in the ocean, submitted to MEPS

Extended NEMURO (eNEMURO) with 9 groups

explicitly to represent geophysical distributions of subtropical & subarctic groups



Not explicitly included

Physiological parameters in eNEMURO

In eNEMURO, phytoplankton is categorized four groups by temperature and nutrient dependencies of physiological parameters: subarctic, subtropical and global types.

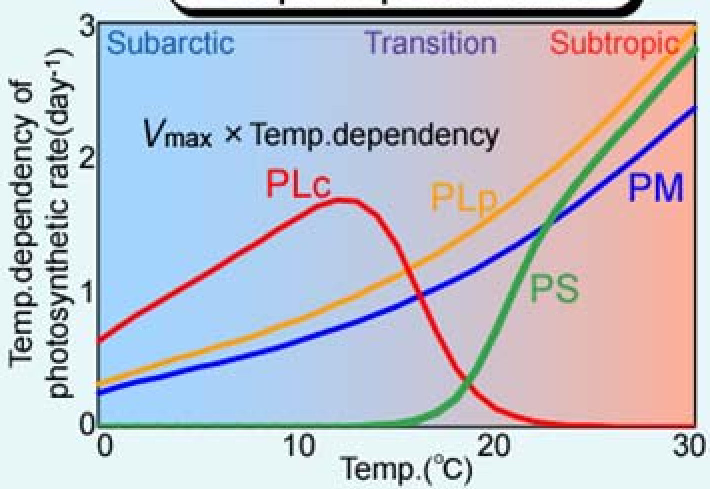
Phtosynthetic parameters

Phytplankton group		Haitant region (temp. dep.)	V_{max} (day^{-1})	K_{NO3} (mM)	$K_{Si(OH)4}$ (mM)
PLc	Micro phytoplankton (Chain-forming diatom)	subarctic	0.80	3.0	6.0
PLp	Micro phytoplankton (No chain-forming diatom)	global	0.40	1.0	3.0
PM	Nano phytoplankton (Green algae, Coccolith, Dinoflagellate)	global	0.32	1.0	-
PS	Pico phytoplankton (Prochlococcus, Cyanobacteria)	subtropic	0.36	0.5	-

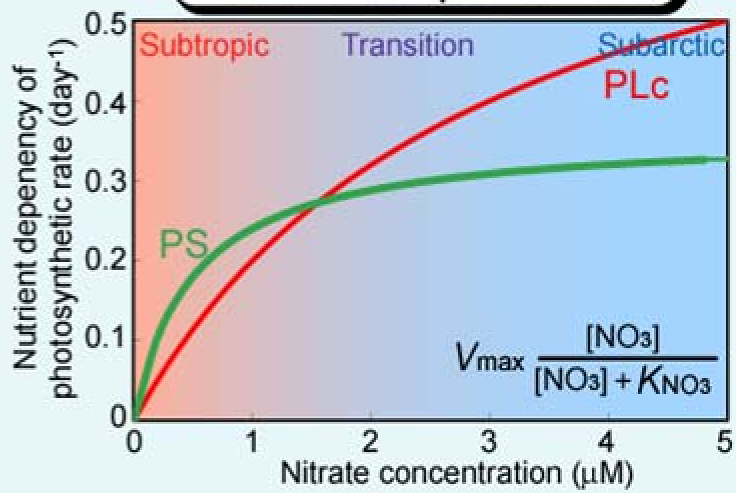
Grazing parameters

Zooplankton group		G_{Rmax} (day^{-1}): max. grazing. rate PLc	PLp	PM	PS
ZP	Macro zooplankton (Euphausiid etc.)	0.20	0.20	-	-
ZL	Meso zooplankton (Copepod etc.)	0.44	0.40	0.05	-
ZM	Micro zooplankton (Ciliate etc.)	-	-	0.60	-
ZS	Nano zooplankton (Heterotrophic dinoflagellate etc.)	-	-	-	0.90

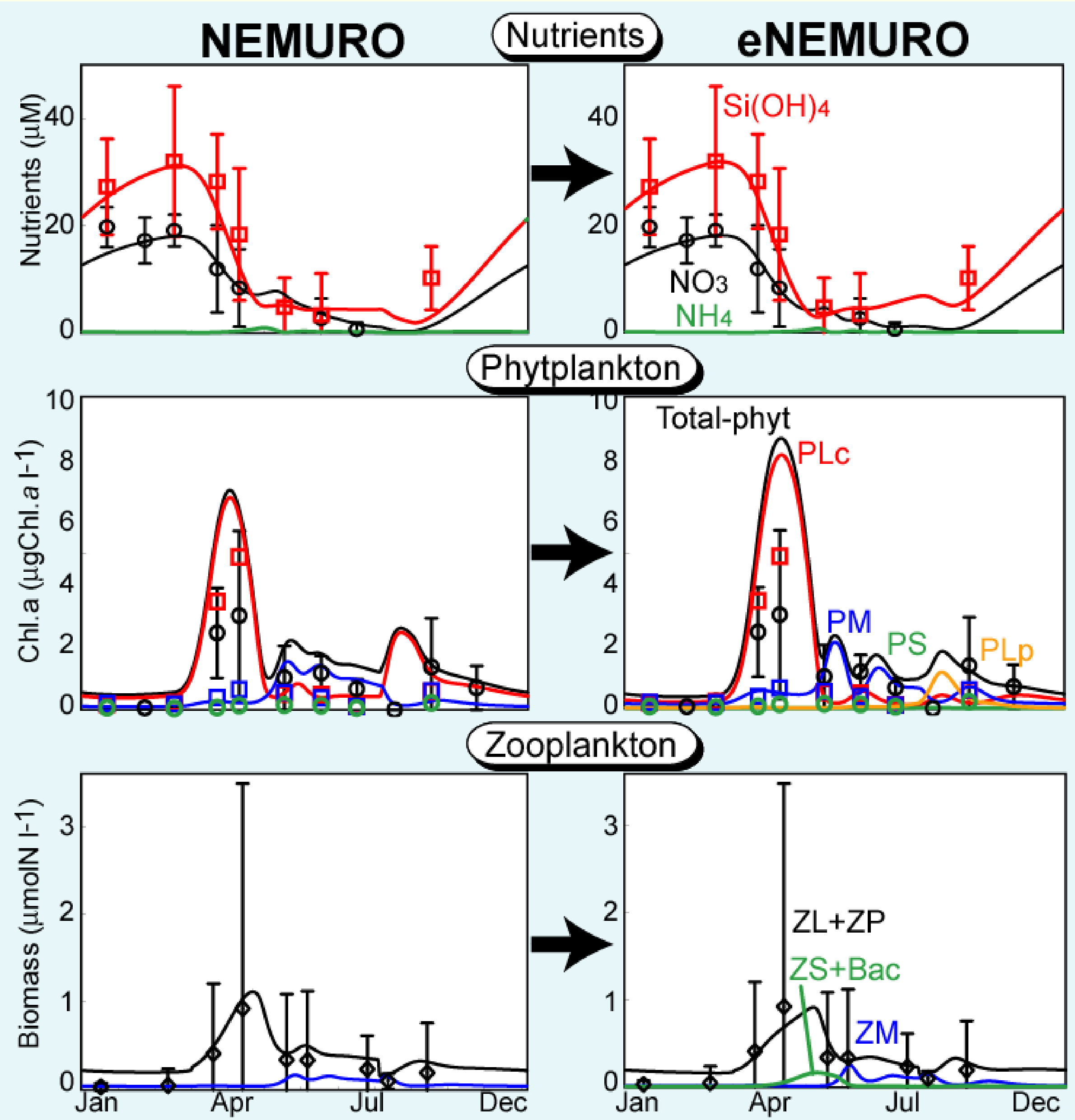
Temp. dependencies



Nutrient denpendencies



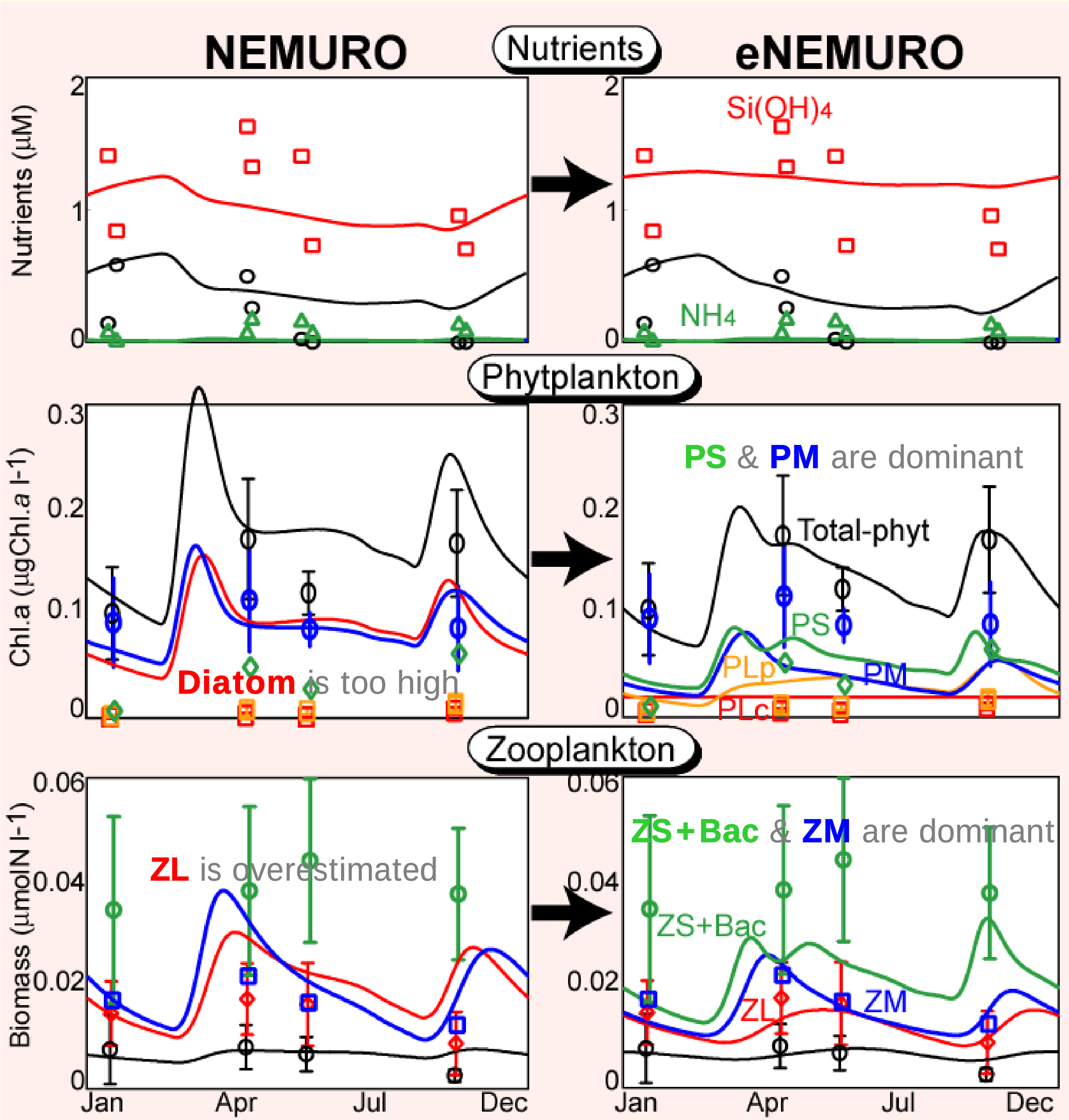
Comparison of seasonal changes at OY (subarctic)



We conducted best parameter tuning for both NEMURO and eNEMURO to fit the observed data using PEST, a software program.

Both NEMURO and eNEMURO well reproduced the seasonal changes of phytoplankton and zooplankton observed in the subarctic region.

Comparison of seasonal changes at B1 (subtropical)



eNEMURO performance looks more good than that of NEMURO, especially in the reproduction of zooplankton.

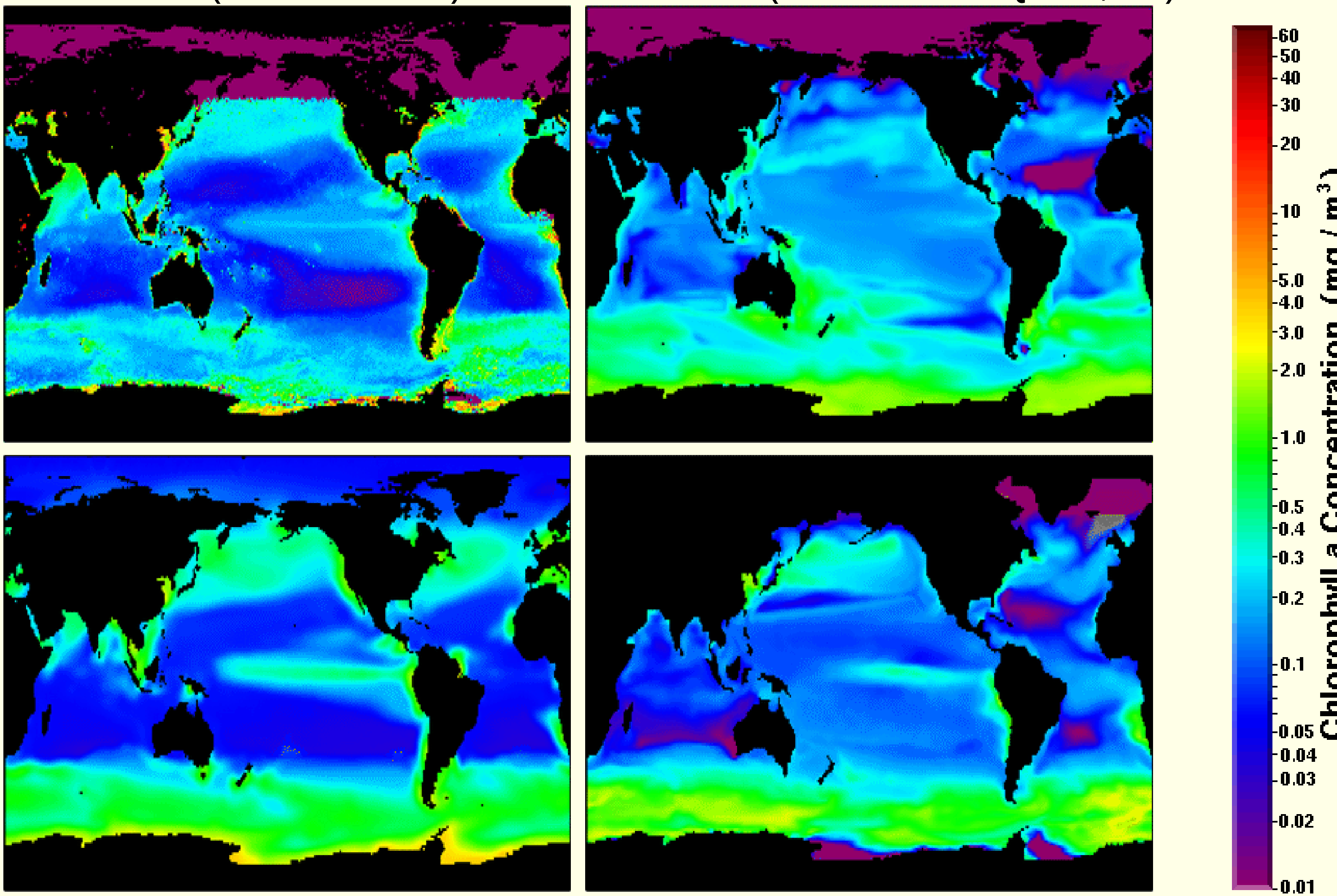
To expect good model performance for zooplankton, the observed data of detailed zooplankton itself are required.

I would like to say as follows. NEMURO has good, if If we focus only on the subarctic or on nutrients and phytoplankton. Otherwise (we focus also on the subtropical zooplankton), eNEMURO is required.

Seasonal cycle of Surface Chl-a Conc. (1996-2007)

forced by NCEP re-analysis data

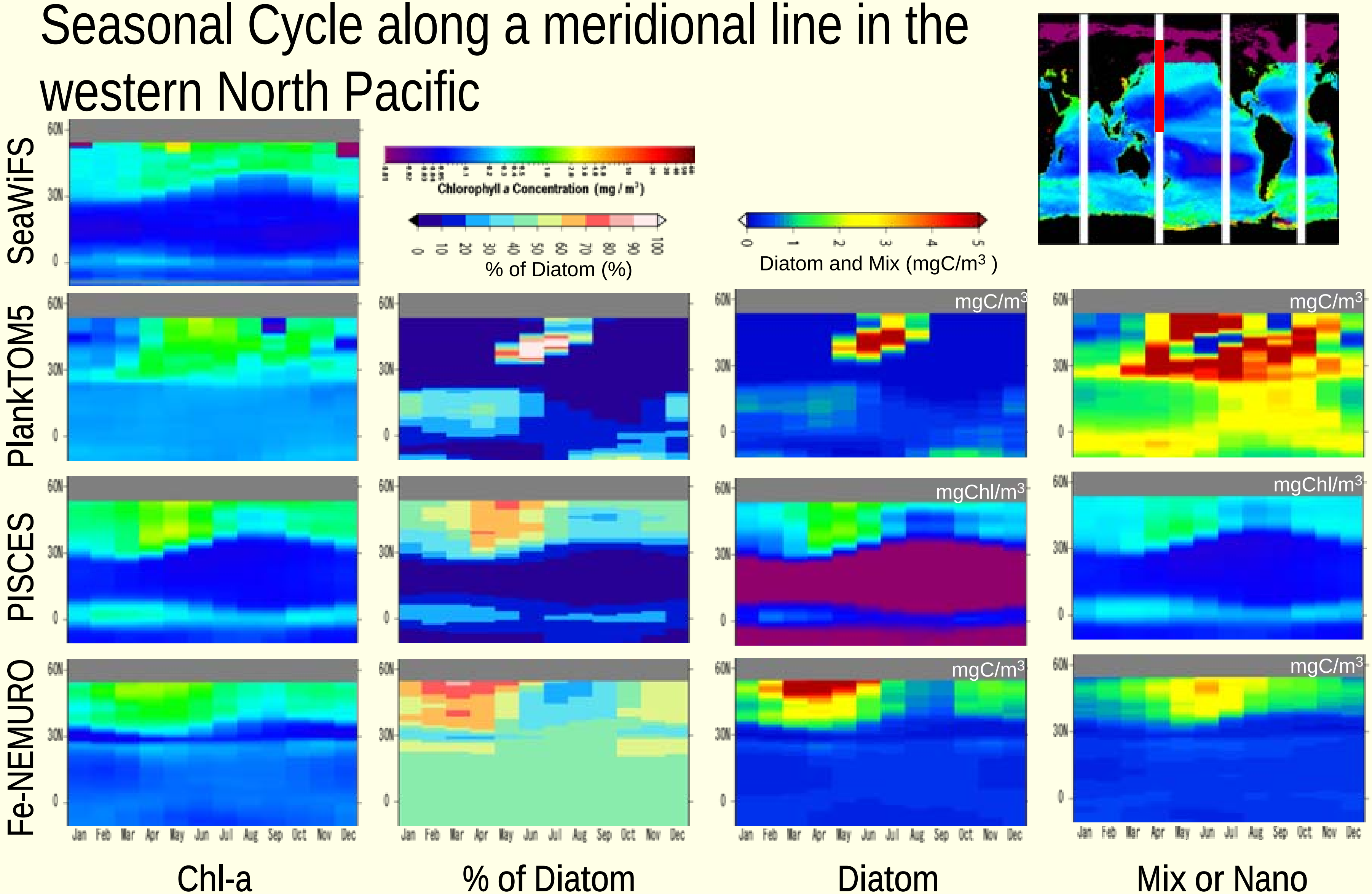
SeaWiFS (Observed data)   PlankTOM5 (Corinne C. Le Quéré, UK)



PISCES(Laurant Bopp, France)   Fe-NEMURO(Yasuhiro Yamanaka, Japan)

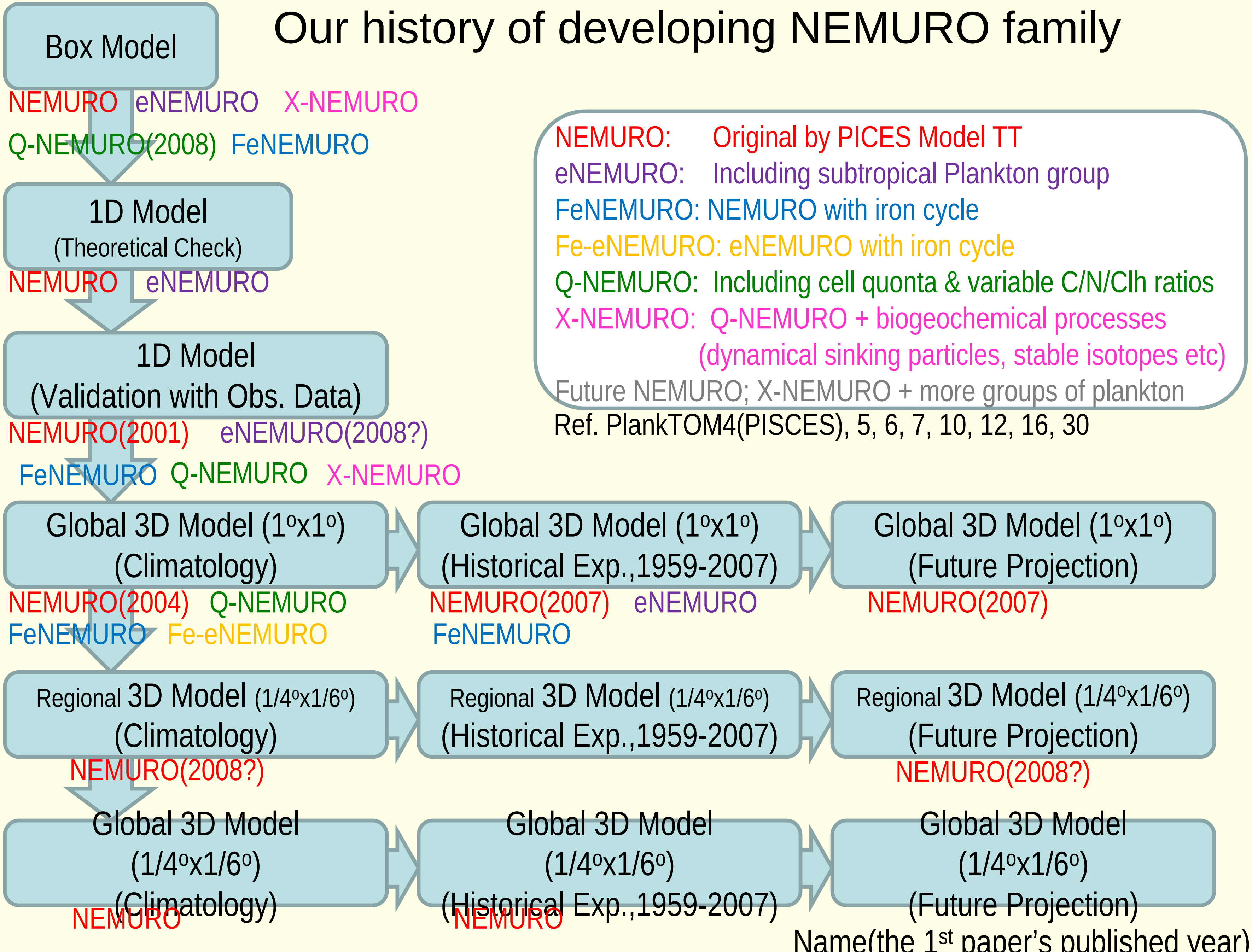
MareMIP data provided by M. Vogt, C. Le Quéré, S. Alvain, L. Bopp, E. Buitenhuis

Seasonal Cycle along a meridional line in the western North Pacific



We need to the biomass data for each plankton group, not only total biomass.

Our history of developing NEMURO family



3-D High-Res. Ecosystem Model

COCO-NEMURO

Ocean General Circulation Model

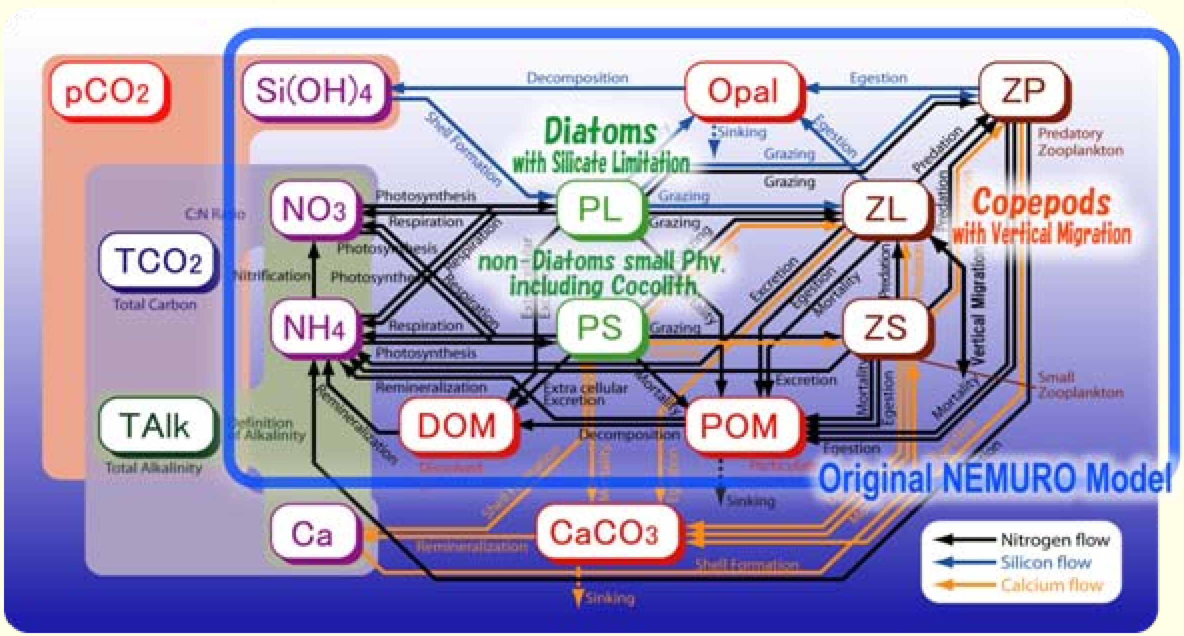
COCO (CCSR Ocean Component model), Hasumi *et al.*, 2002

COCO is the same with the ocean part of a climate model, MIROC

Ecosystem Model

PICES NEMURO with Carbon Cycle, Yamanaka *et al.*, 2004

Horizontal Resolution 1/4° x 1/6°,   Vertical: surface 26 Layers (1800m), Offline Model



NEMURO :
North Pacific
Ecosystem
Model for
Understanding
Regional
Oceanography
(*e.g.*, Kishi *et al.*, 2007)

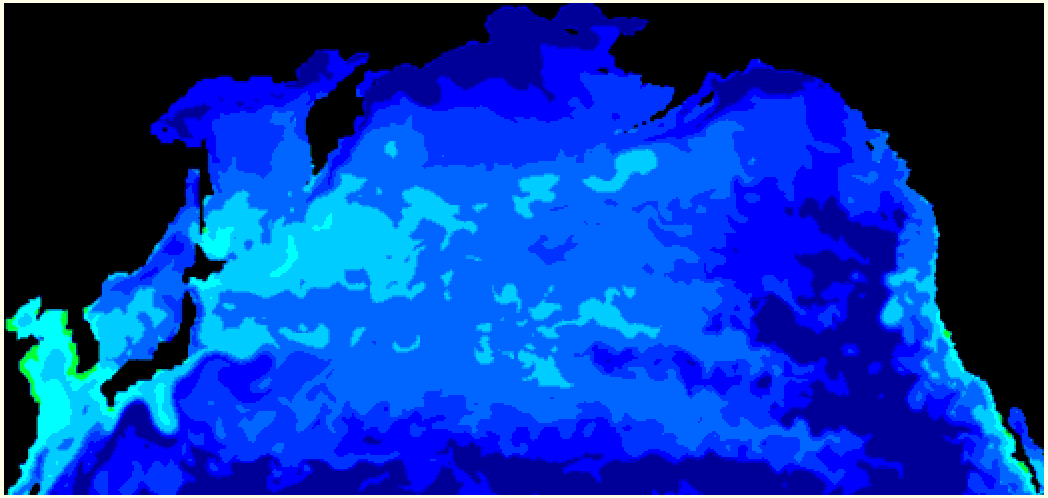
“State of the art model in our group”

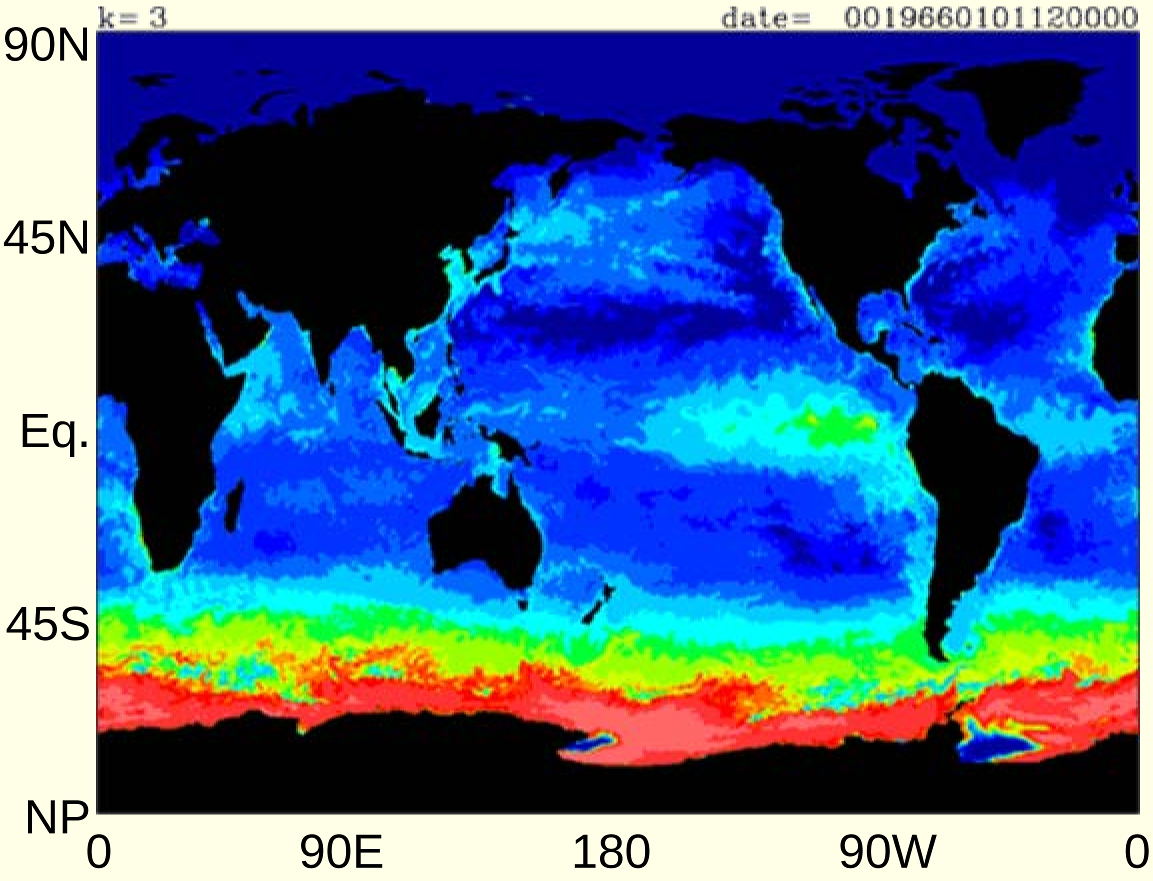
Seasonal variation of surface chlorophyll-a in 1966

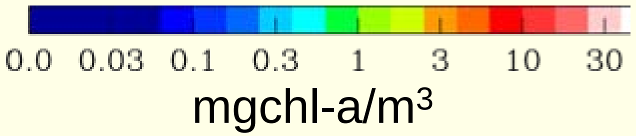
Interannual Variability simulation from 1959 to 2004
by COCO-NEMURO,
Global domain with 1/4^{o}x1/6^{o}

This model driven by CORE (Large and Yeager, 2004).

To reproduce coastal region, Spatial high resolution data is required (QuickSCAT (~20km) is better than NCEP reanalysis data (~200km).

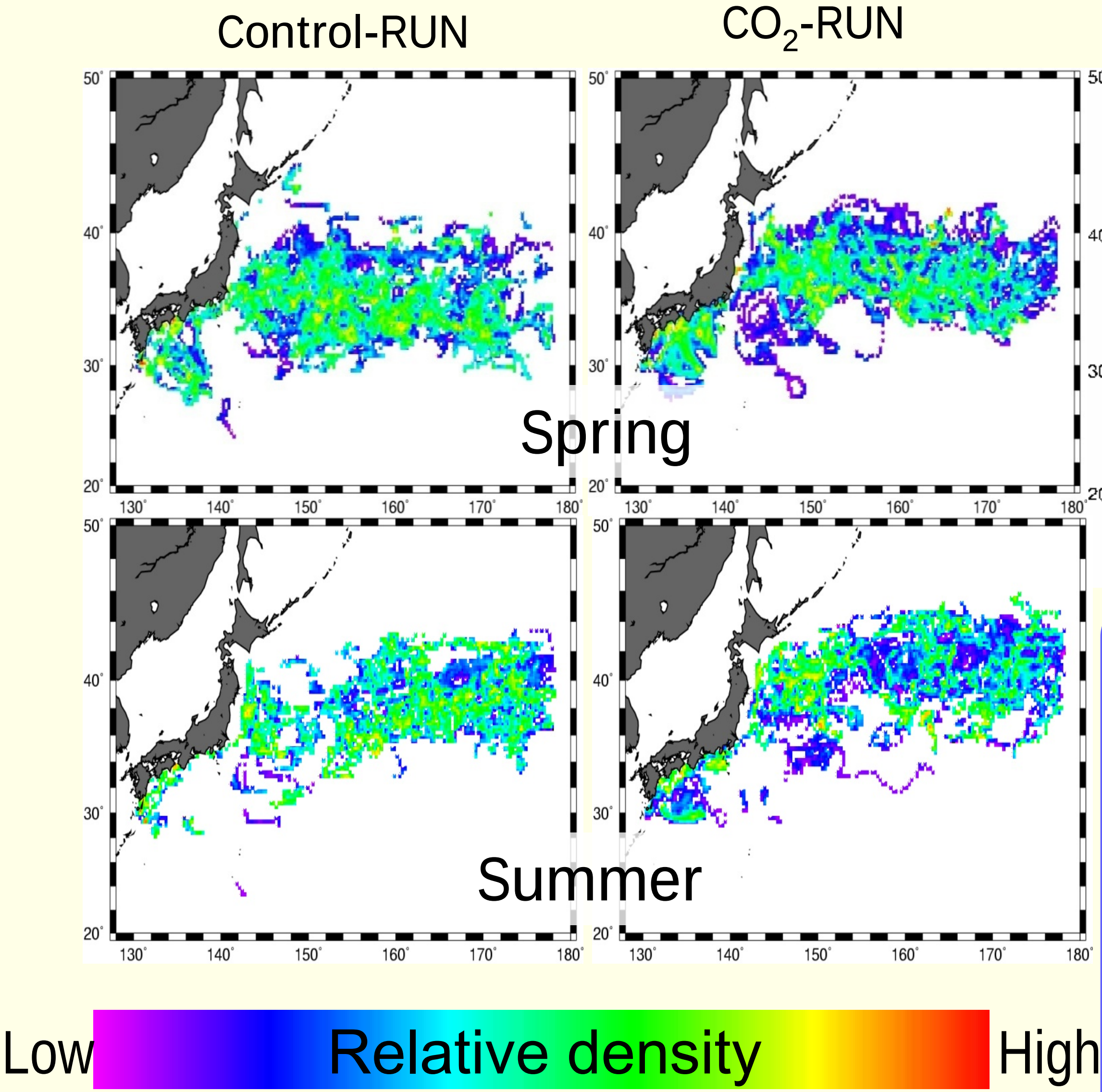


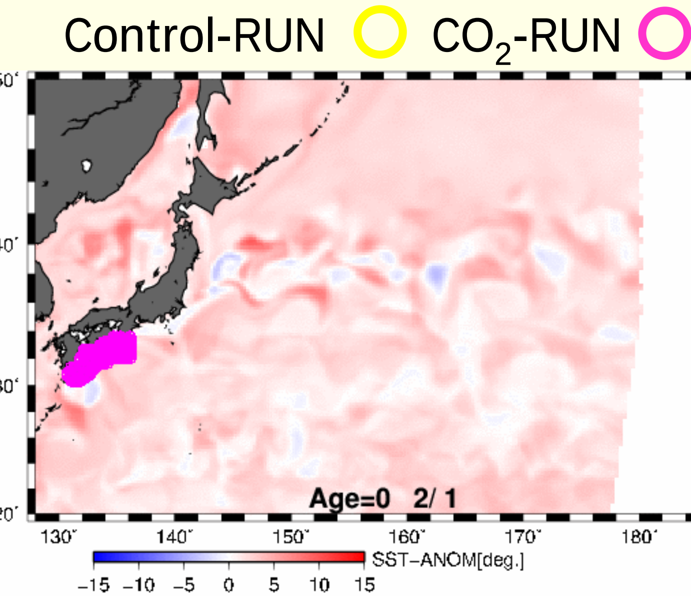


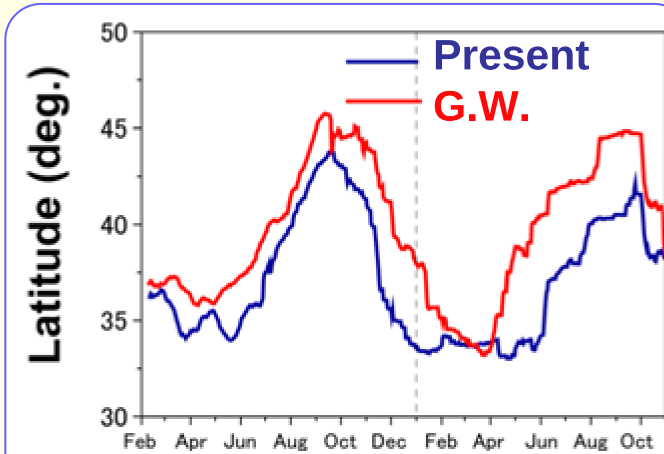


“State of the art model in our group”

Geographical change in Japanese Sardine due to Global Warming







Meridional distribution in145E – 180E

Summary of my talk

As a feeling by old-type modeler, most essential is dialogue between researchers who conduct model and observation studies, and we cannot find almighty recipes.

- Models give theoretical (quantitative) explains to the observed data: modeling joining observation project such as Iron fertilization experiments, compiled data such as nutrient-dependent Ks.
- The observed data greatly help introducing new process or plankton groups into the ecosystem models: especially biomass *etc.* of focusing plankton groups.
- Model Intercomparison Projects (MIPs) lead to systematic validations: it is difficult to improve model performance by themselves but they give us hint why each model has different performance for each other.