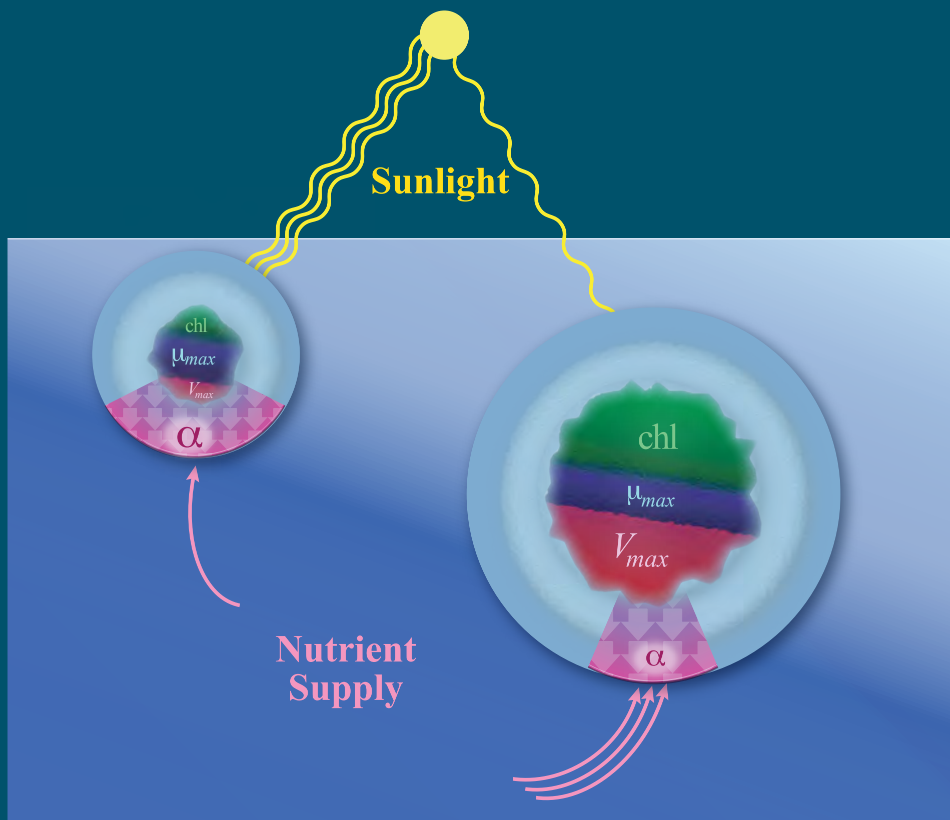
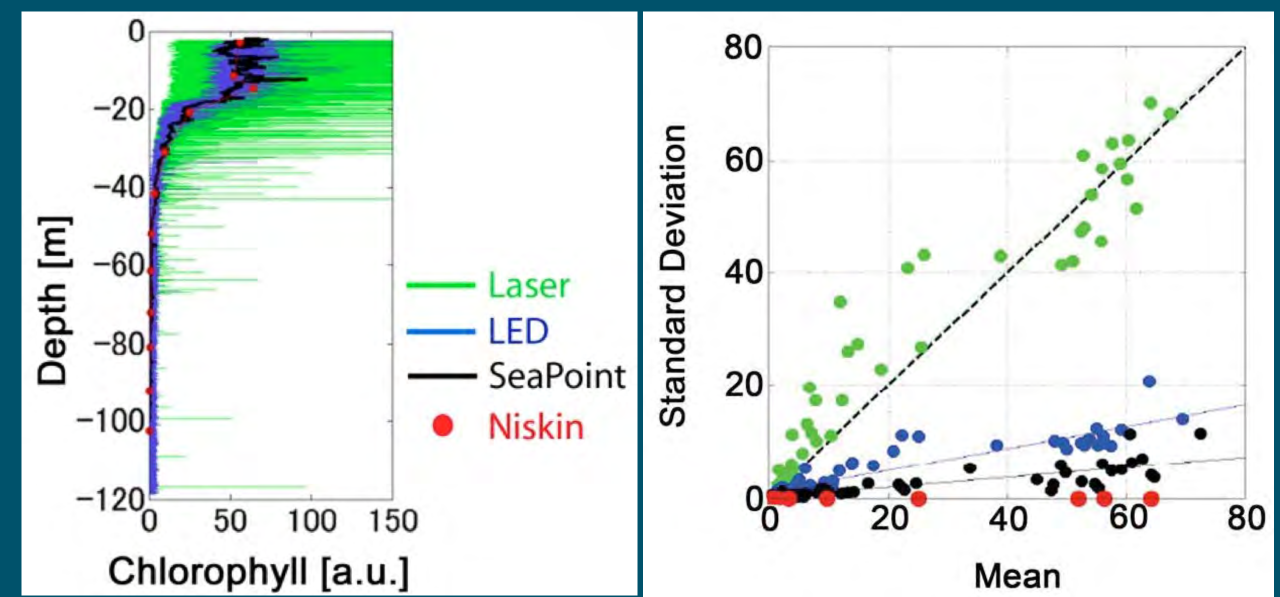
Trait-based modeling of phytoplankton under realistic sub-scale variability



Smith et al. (*JPR Horizons* 2014)



Mandal et al. (*PLoS One* 2014)

S. Lan Smith[1,2], Kai Wirtz[3], Hidekatsu Yamazaki[2,4], Sandip Mandal[5]

[1] Marine Ecosystem Dynamics Research Group, RCGC, JAMSTEC, Yokohama, Japan
[2] CREST, Japan Science and Technology Agency, Tokyo, Japan
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[4] Tokyo Univ. of Marine Science and Technology, Tokyo, Japan
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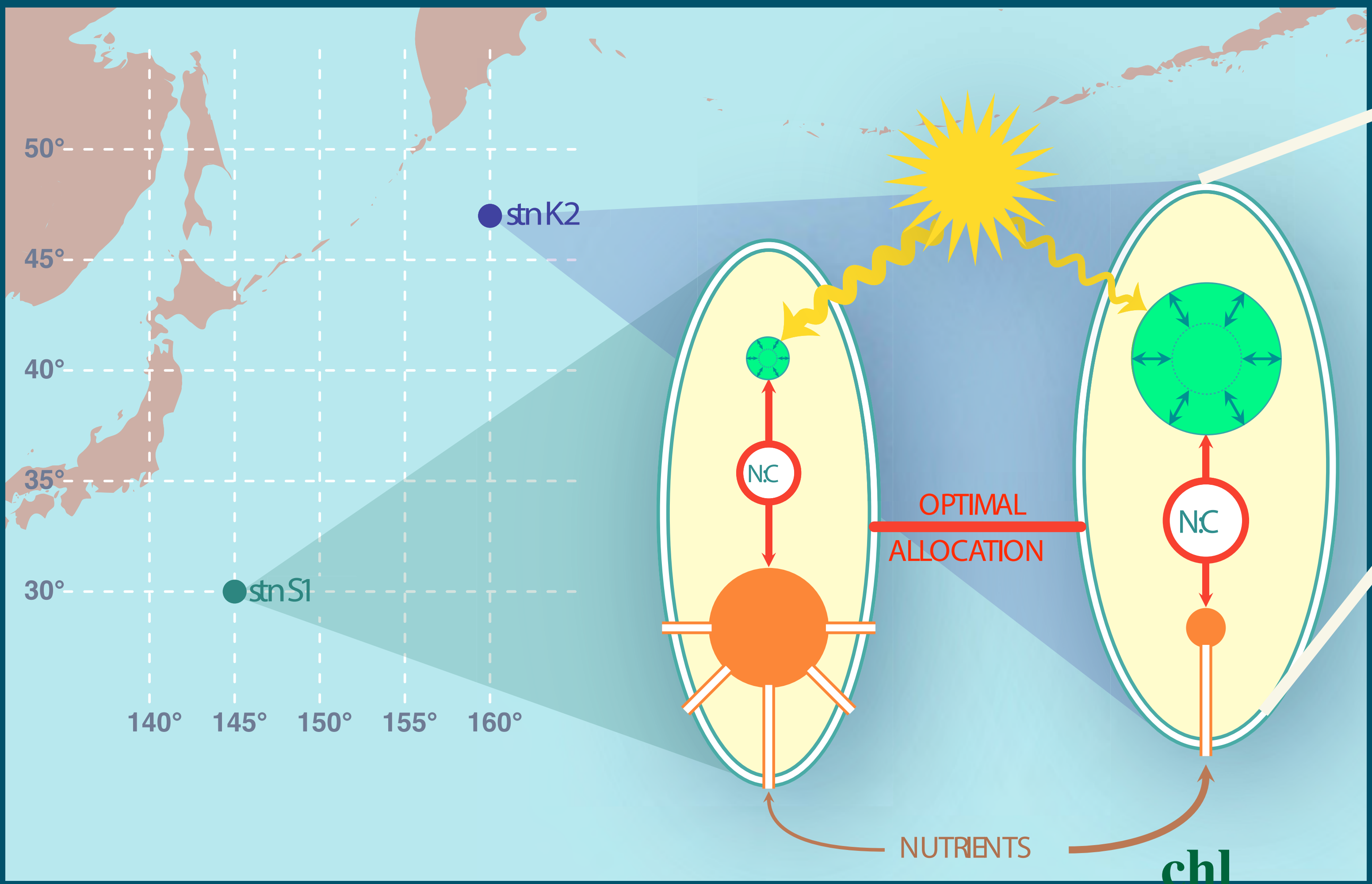
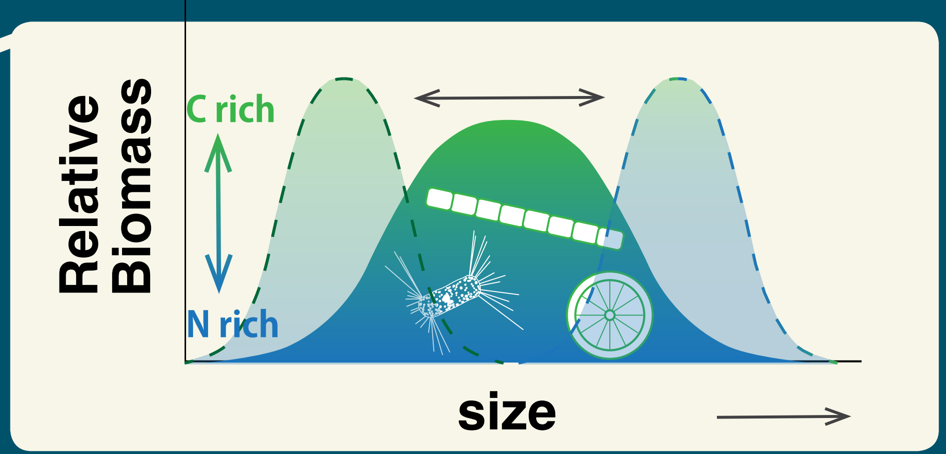
New Flexible Trait-based Phytoplankton Model



(figure at left by M. Pahlow and R. Erven, GEOMAR)

Results from Smith et al. (*J. Plankton Res.* 2015)

New FlexPFT model

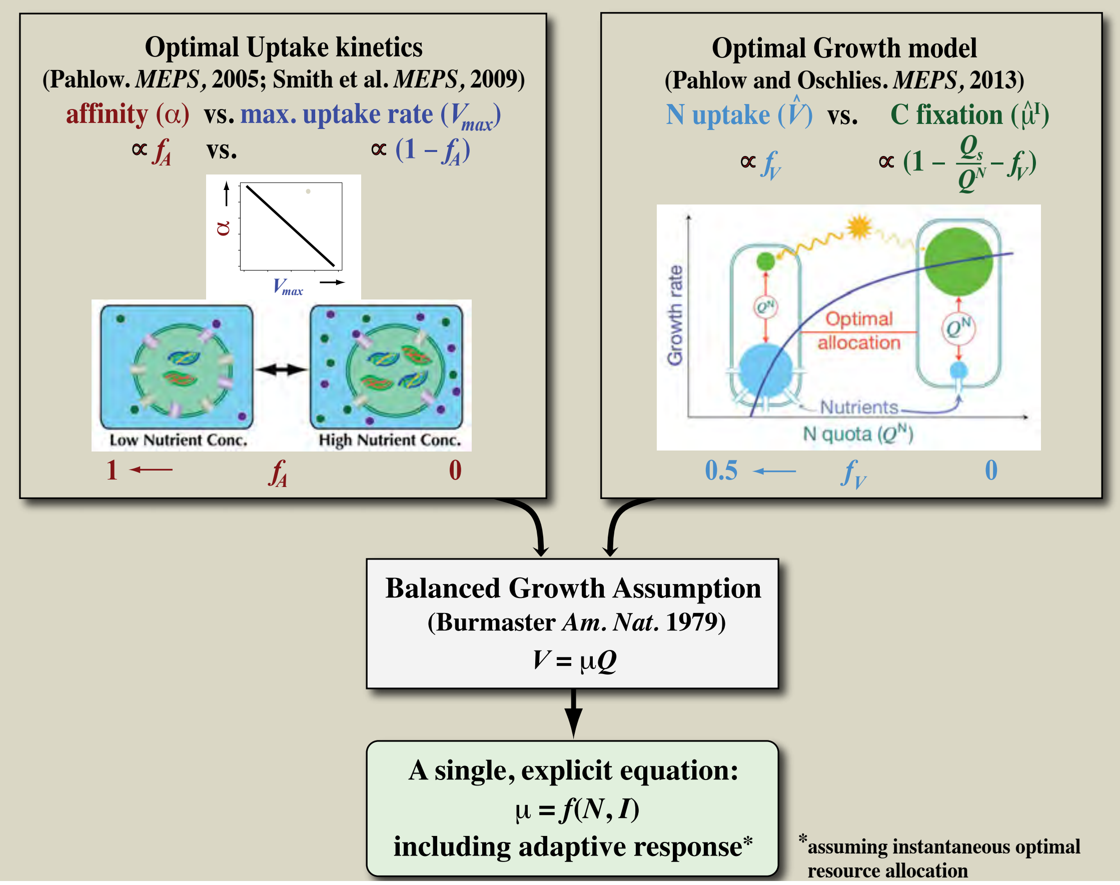


applied to JAMSTEC time- series obs. sites by

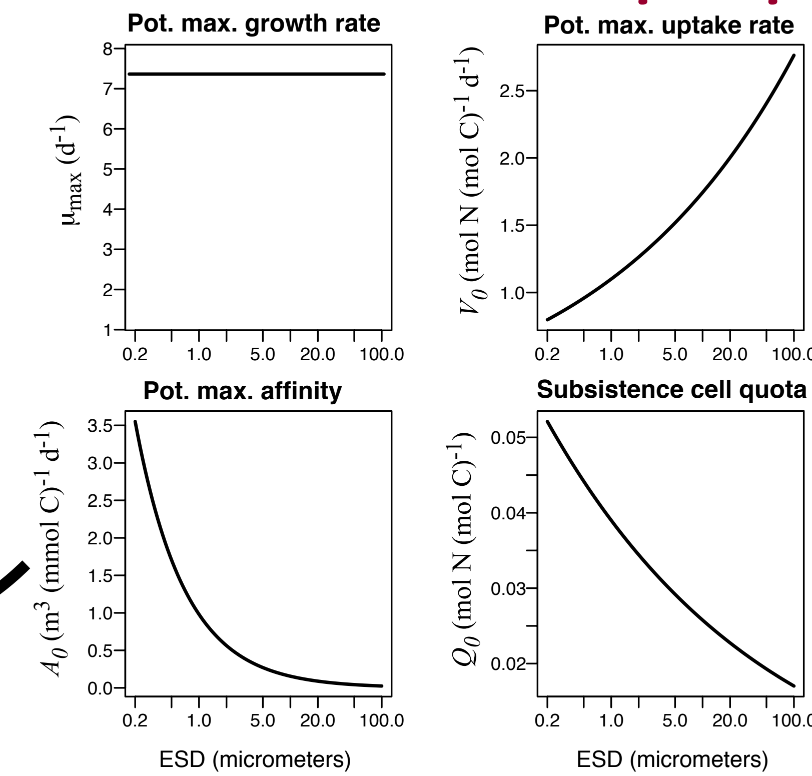
7 JAMSTEC researchers
+ 3 international colleagues

Flexible Response agrees better with obs.
& impacts biodiversity results.

New size-based Flexible Phy model



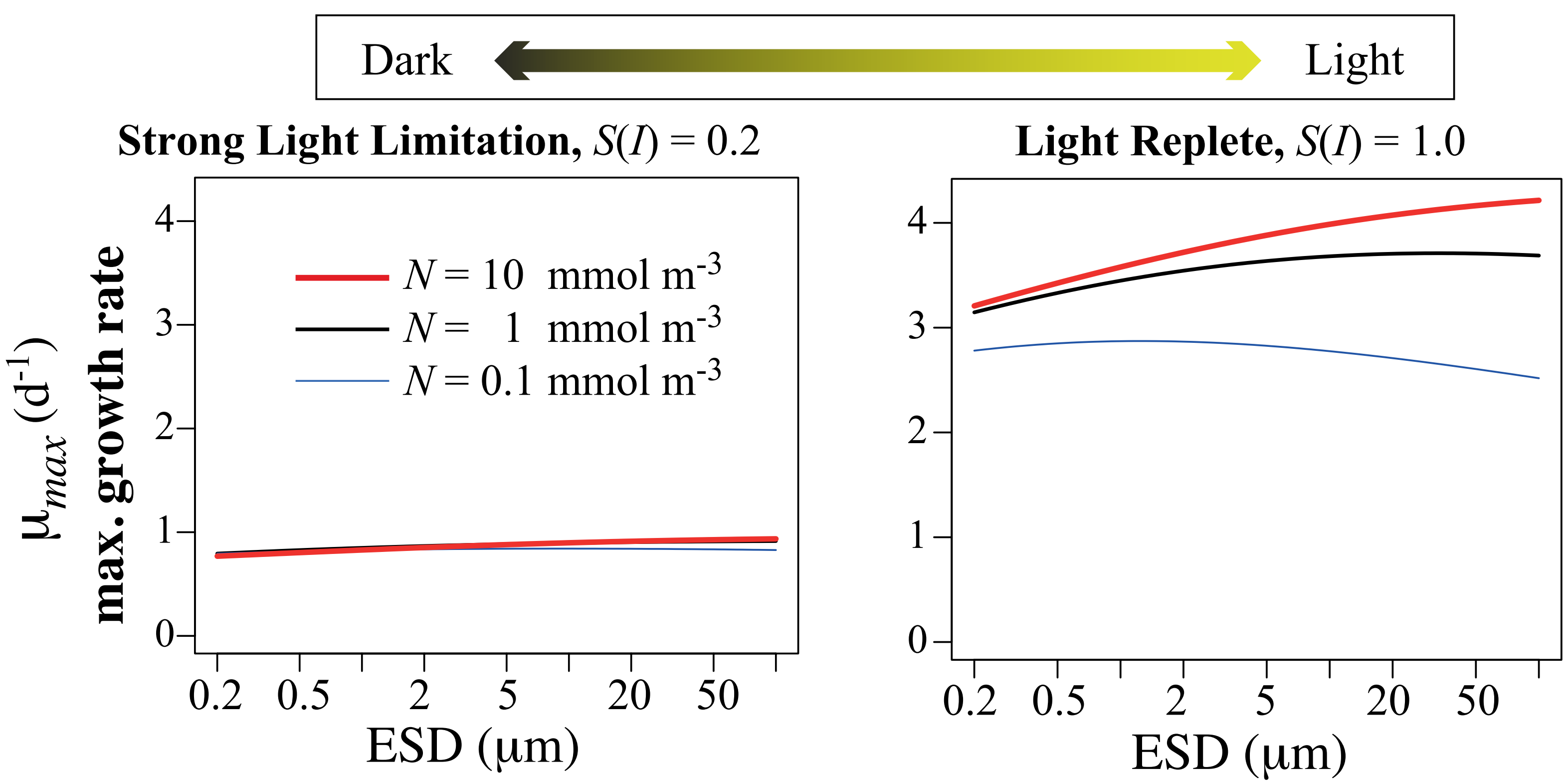
Size scaling of Traits (input params.)



Based on reported size-scalings (Edwards et al., Litchman et al., Marañón et al.)

Smith et al. (*JPR* 2015)

as in Wirtz (*Mar. Biol*. 2013)



Adaptive Response to env. (light & N)

Big is better at high N

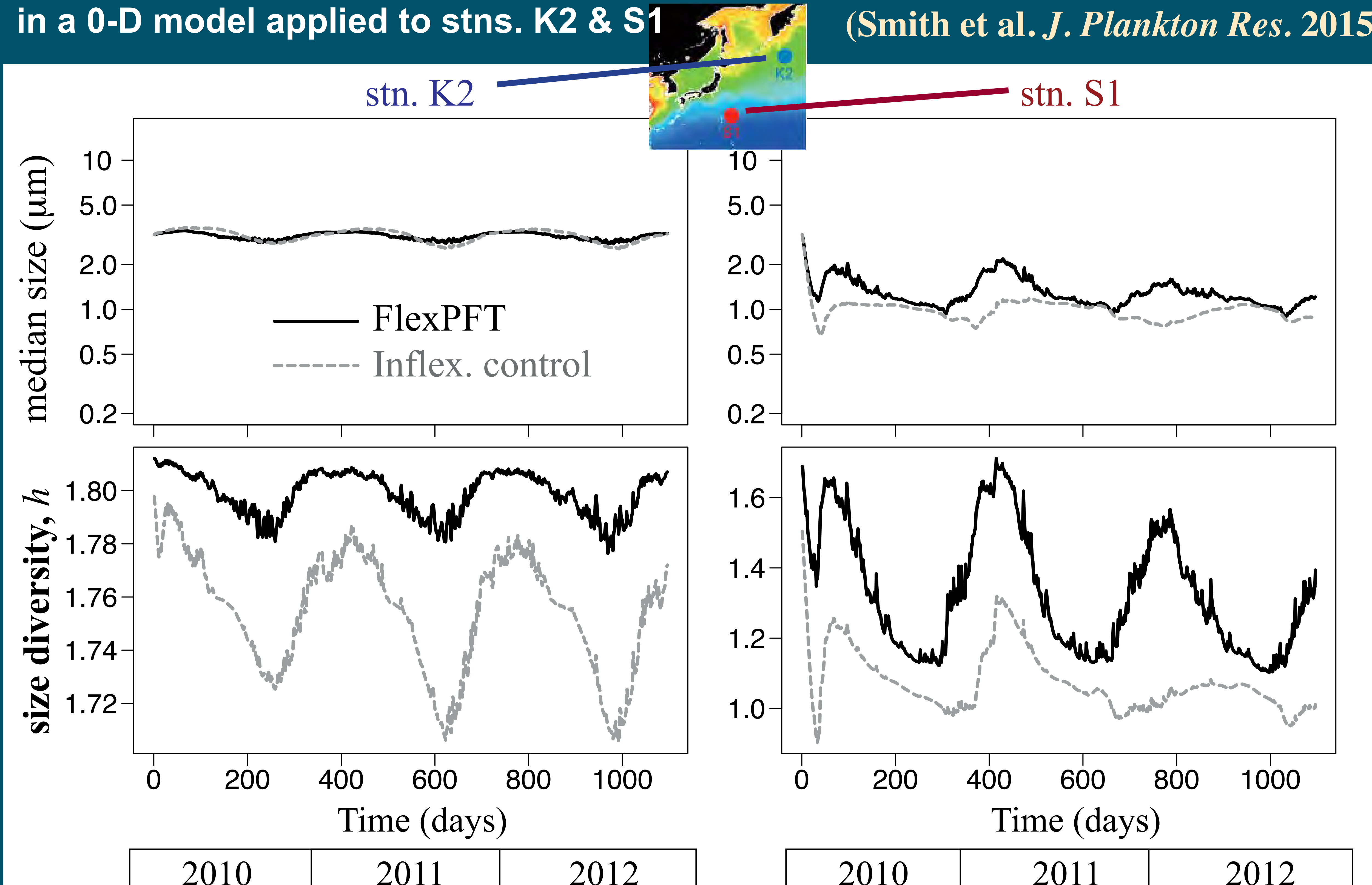
Small is better at low N (esp. at high light)

New Flexbile Phy model gives different biodiversity

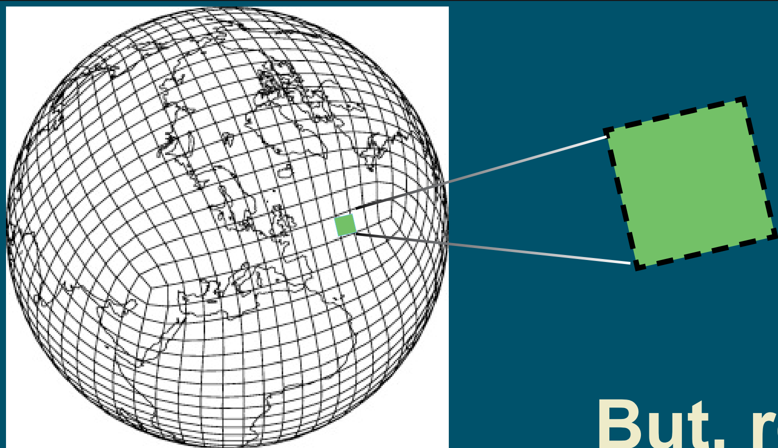
Greater (& seasonally different) size diversity with FlexPFT (vs. inflexible control) in a 0-D model applied to stns. K2 & S1

Probably Flexible Phy find more 'refuge' during the seasonal cycle.

(Smith et al. *J. Plankton Res.* 2015)



Sub-scale Variability

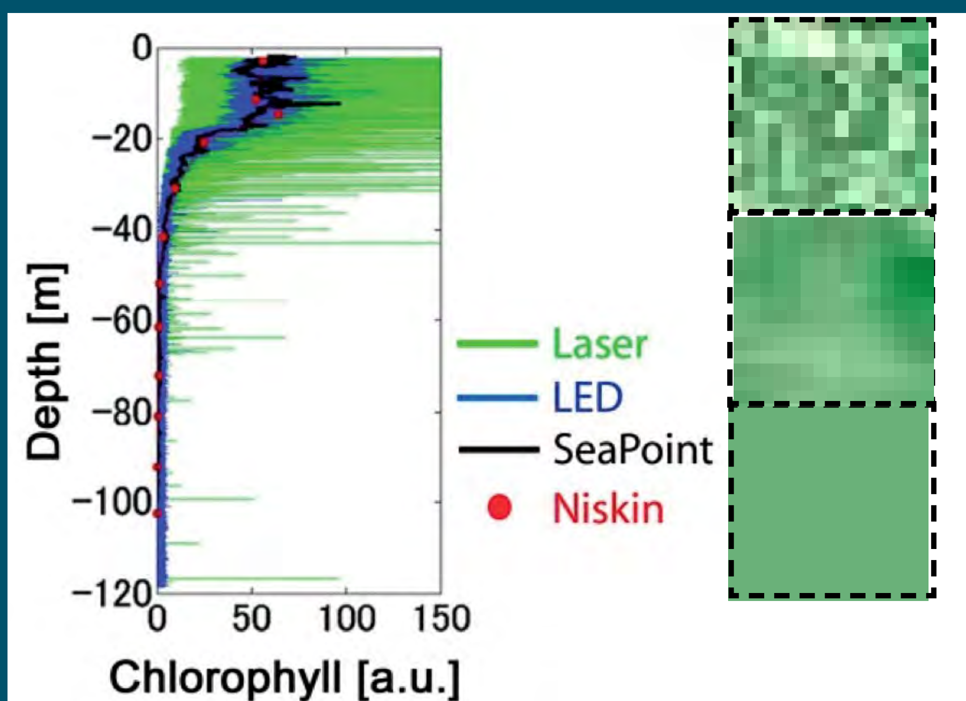


Challenging, Long-term Objective

Existing models assume uniform concentrations within each grid cell, even at the scale of many km

But, recent observations reveal common sub-scale patterns:

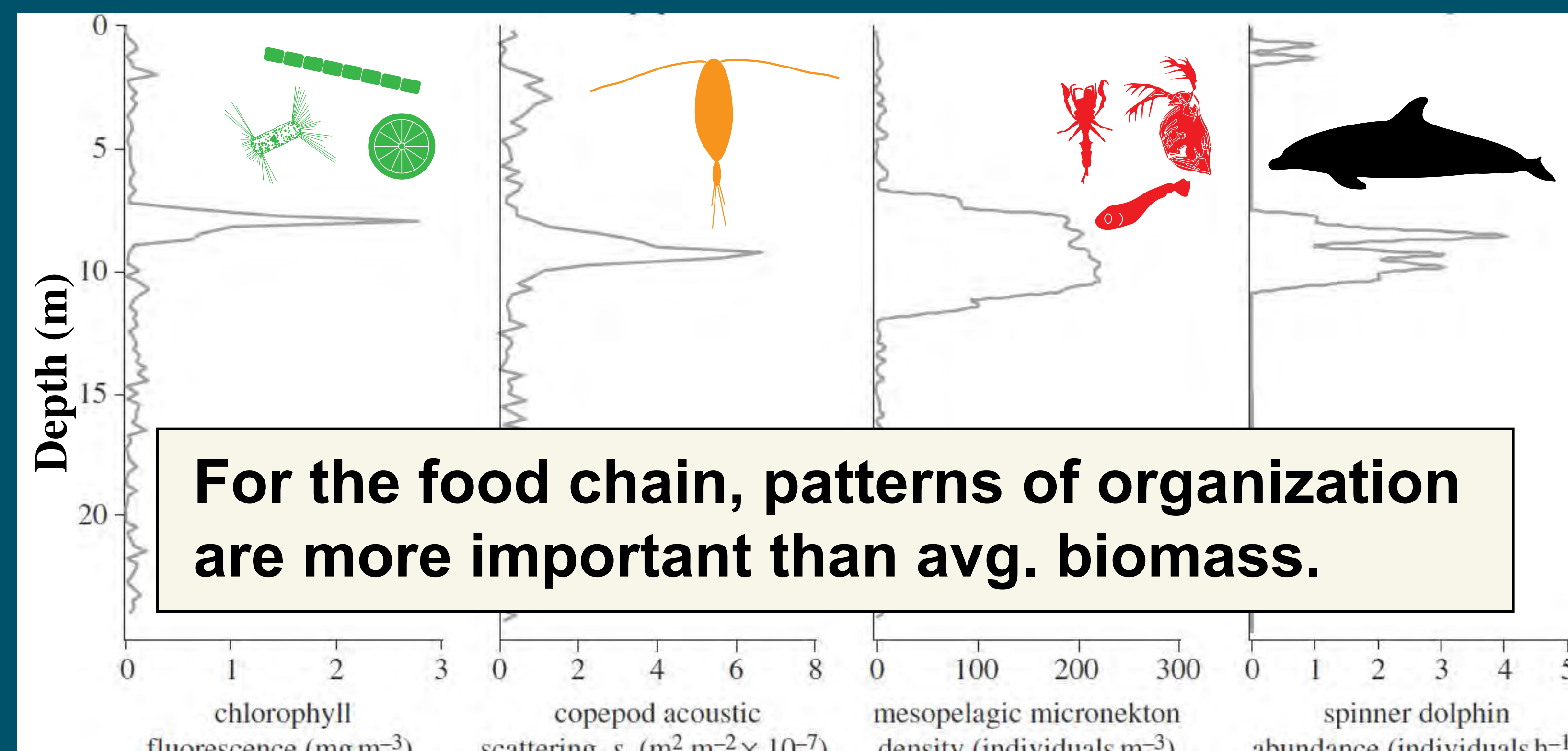
Aggregation (mm scale)



Mandal et al. (*PLoS One* 2014)

Foloni-Neto et al. (*JPR* 2015)

Layering (cm to m scale)



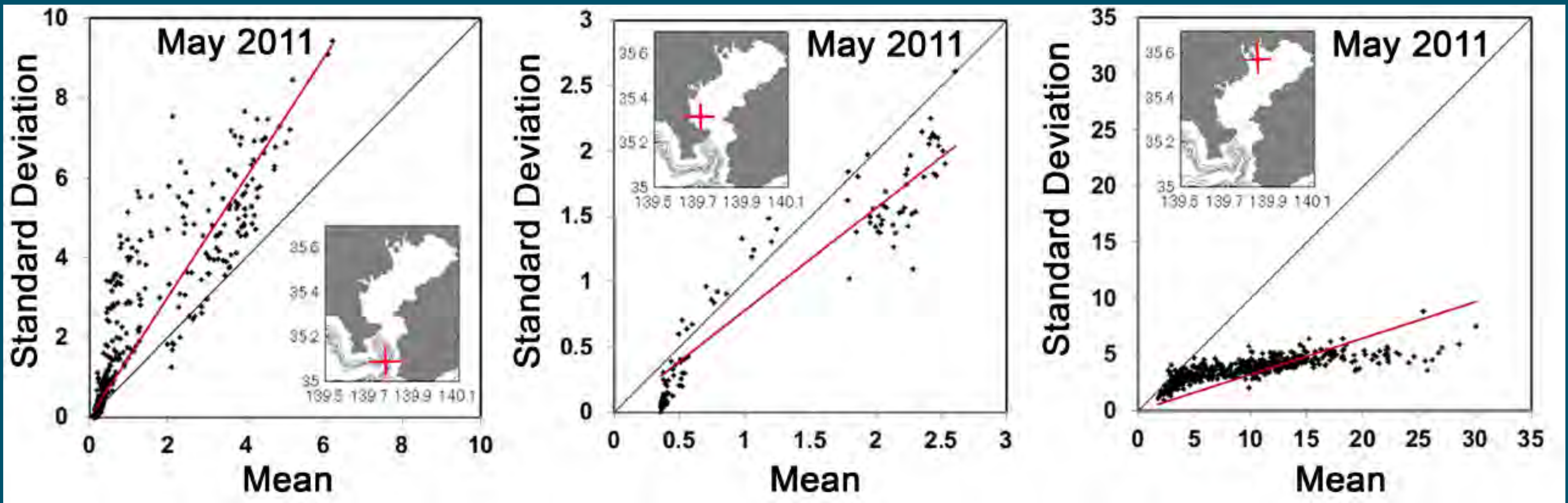
Benoit-Bird & McManus (*Biology Letters* 2012)

See also our session at the Ocean Sciences Meeting 2016, in New Orleans

Observed sub-scale variability

At different locations in Tokyo Bay.

CV decreases with increasing freshwater inputs (within the bay).



How does Variability affect Plankton Growth?

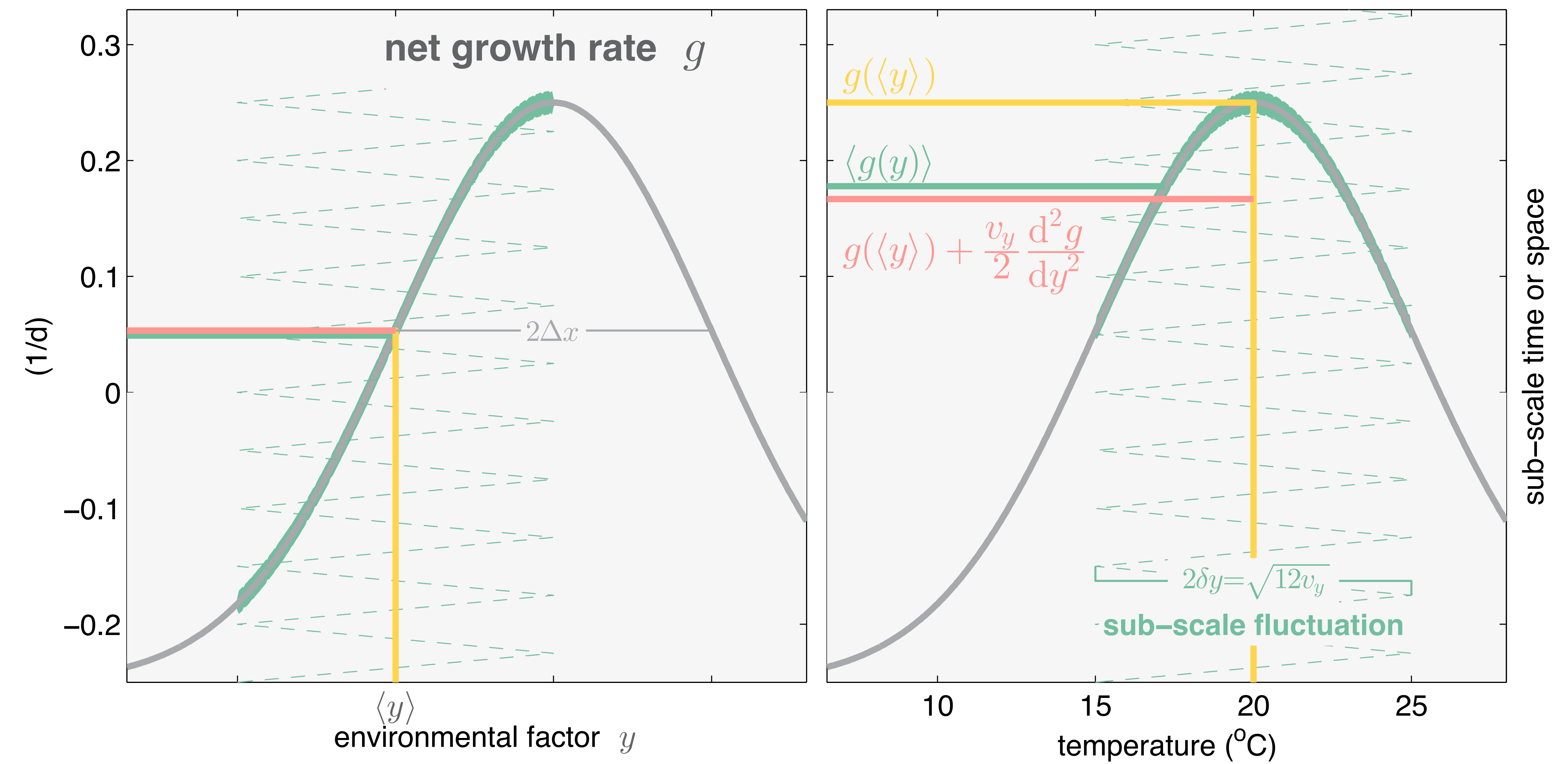
This case is quite common.

No curvature of growth function: $g'' = 0$

Avg. growth rate is well approximated by the growth rate at the avg. condition.

Negative curvature: $g'' < 0$

Avg. growth rate is lower than the growth rate at the avg. condition.



Wirtz, Smith & Prowe, *in prep*.

'Closure Model' for Variability of nutrient & plankton

1st Version: Simple NP model with Monod-type growth

Mandal et al. (*PLoS One* 2014)

$$\frac{dP}{dt} = C\frac{N}{K+N}P - DP$$

Phytoplankton

$$\frac{dN}{dt} = -C\frac{N}{K+N}P + DP$$

Nutrient

$$P = P_0 + P'$$

$$N = N_0 + N'$$

Mean and fluctuating compoents of each.

Substitute into the above eqns.,

Non-dimensionalize

$$N_0 + P_0 = A$$

$$< N'^2 > + < P'^2 > + 2 < N'P' > = B$$

$$\beta = \frac{B}{A^2}$$

Total normalized Variability

‘Closure Model’ for Variability of nutrient & plankton

$$\frac{dP_0}{dt} = C\left(\frac{N_0 P_0}{K + N_0} + \frac{K < N' P' >}{(K + N_0)^2} - \frac{K P_0 < N'^2 >}{(K + N_0)^3}\right) - D\, P_0$$

$$\frac{dN_0}{dt} = -C\left(\frac{N_0 P_0}{K + N_0} + \frac{K < N' P' >}{(K + N_0)^2} - \frac{K P_0 < N'^2 >}{(K + N_0)^3}\right) + D\, P_0$$

$$\frac{d < P'^2 >}{dt} = 2C\left(\frac{N_0 < P'^2 >}{K + N_0} + \frac{K P_0 < N' P' >}{(K + N_0)^2}\right) - 2\, D < P'^2 >$$

$$\frac{d < N'^2 >}{dt} = -2C\left(\frac{N_0 < N' P' >}{K + N_0} + \frac{K P_0 < N'^2 >}{(K + N_0)^2}\right) + 2\, D < N'\, P' >$$

$$\frac{d < N'\, P' >}{dt} = C\left(\frac{N_0(< N'\, P' > - < P'^2 >)}{K + N_0} + \frac{K P_0(< N'^2 > - < N' P' >)}{(K + N_0)^2}\right) + D\, (< P'^2 > - < N'\, P' >)$$

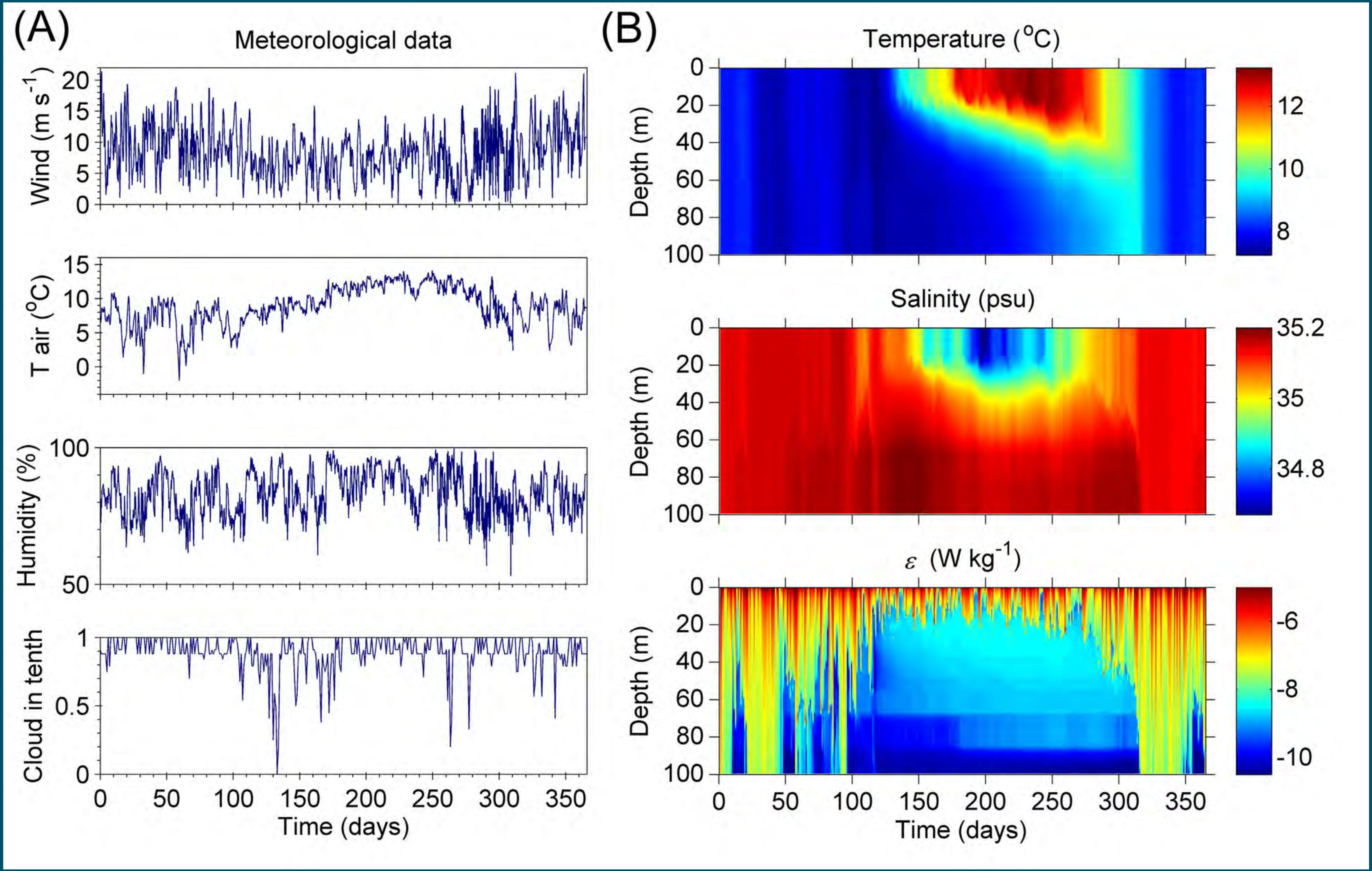
Mean values of N & P also depend on the Variances & Co-Variance.

Dynamic eqns. for

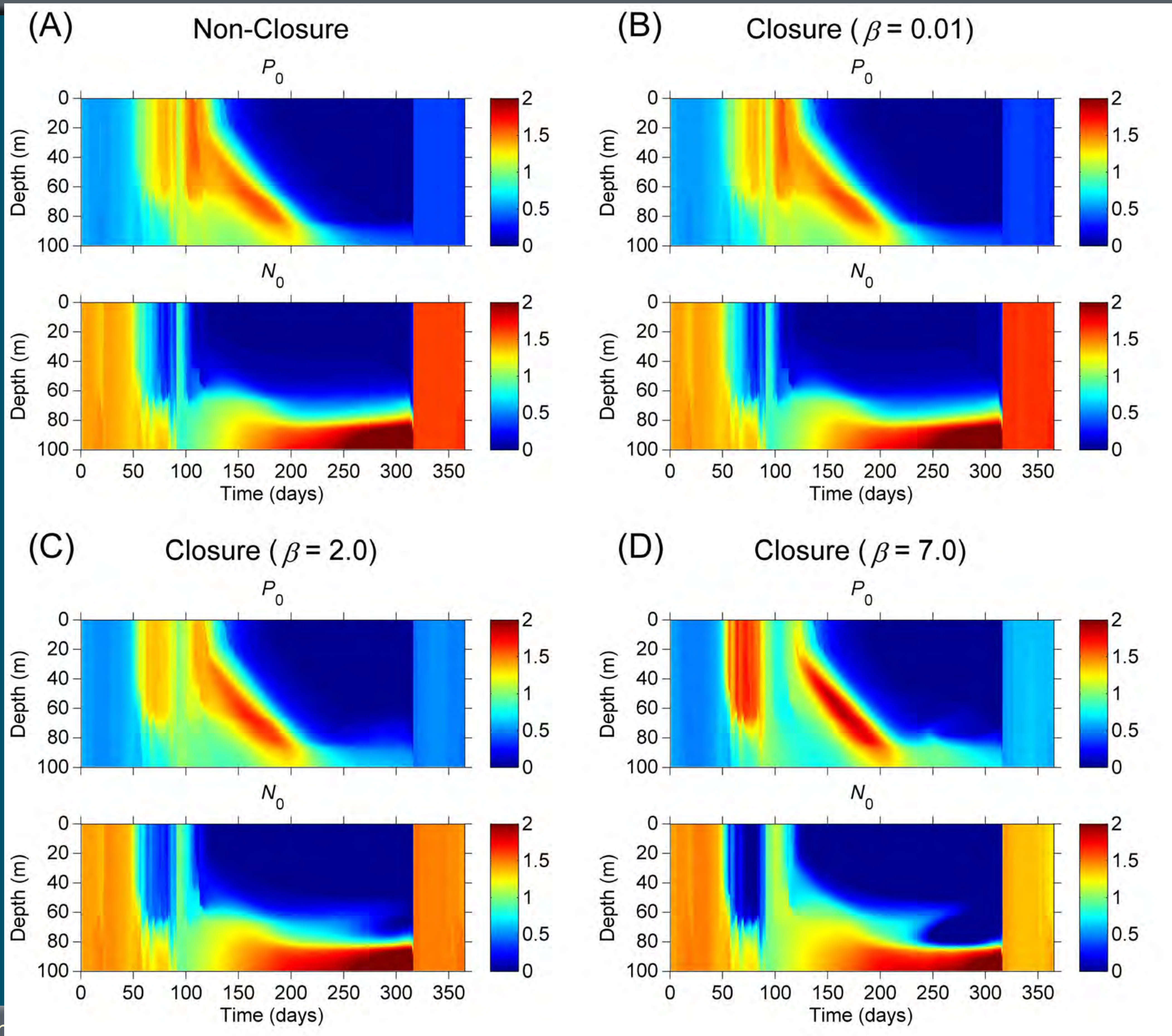
- Variance of P
- Variance of N
- Co-Variance

Physical Forcings for 'Closure Model' in 1-D GOTM simulations

Just a typical seasonal pattern at high latitudes. (Mandal et al. ***in revision*** for *JPR*)

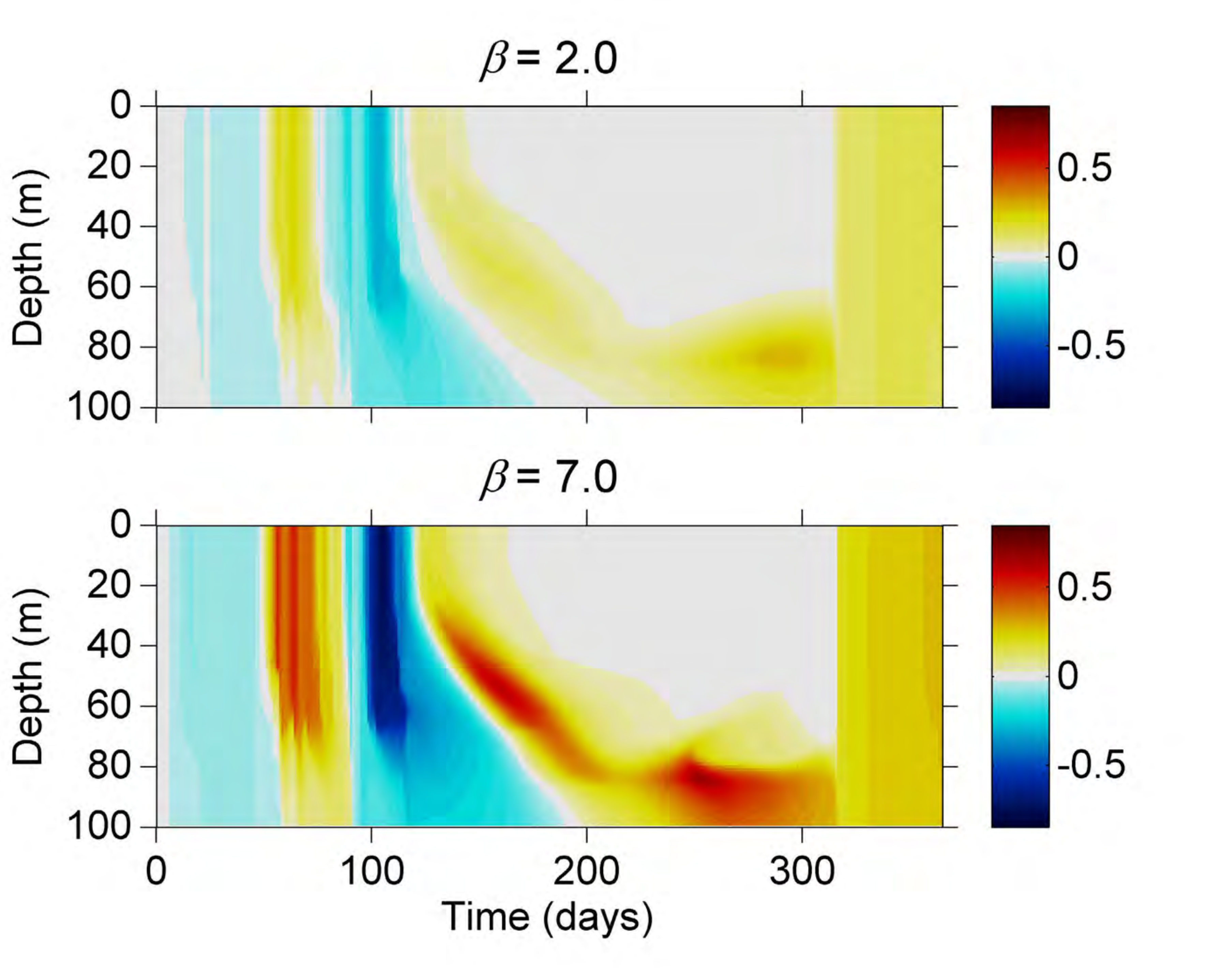


‘Closure Model’ in 1-D GOTM simulations



Difference: 'Closure Model' - NP model in 1-D GOTM simulations

For mean-field Phy biomass, P_0

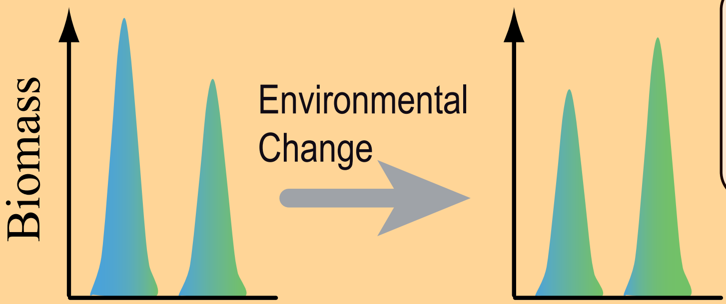


Sub-scale variability impacts macro-scale patterns of growth rate and biomass.

Mandal et al.
(***in revision*** for *JPR*)

On-going collaboration: Modelling Flexibility under Variability

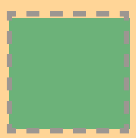
Flexible Phytoplankton FlexPFT model



- Adaptive response to changing light & nutrients

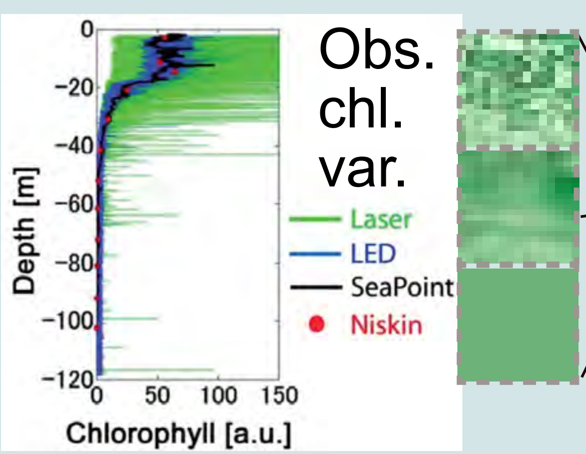
Different Response from existing models
(Smith et al. *MEPS* 2014; *JPR* 2014)
incl. different biodiversity (Smith et al. *JPR* 2015)

*** But NO Variability**



Only mean conc. within each grid cell

Variability Closure model
(Yamazaki Team, CREST)

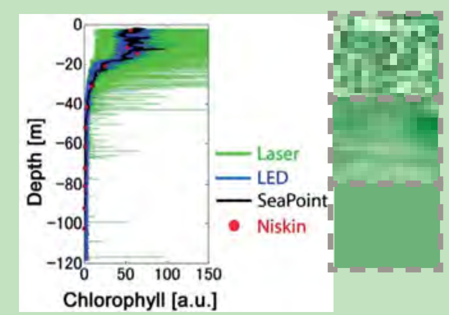


- Mean & **Variability** of concentration in each model grid cell
- Less Variability with increasing depth based on obs.

Different Response from existing models
(Mandal et al. *PLoS One* 2014)

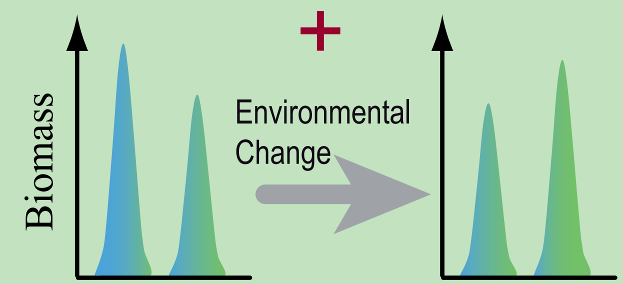
*** But NO Flexible Response**

New Flexi-Vari model
(CREST Collaboration, funded by JST)
first prototype now being tested



- Adaptive Response depends on both mean & **variability.**

+

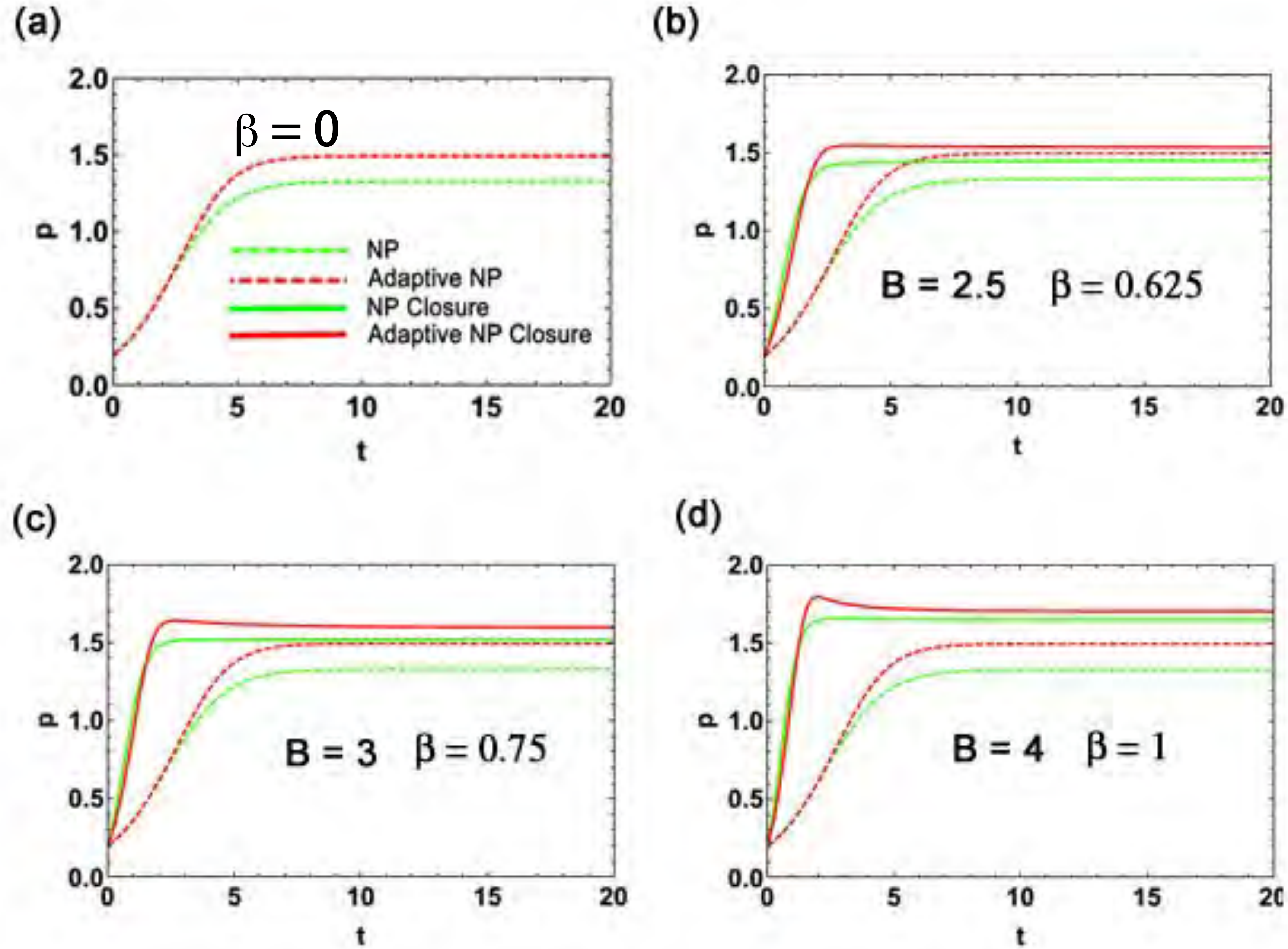


0-D Comparison of Flexible (Adaptive) vs. Inflexible NP models

In batch (0-D) simulations,

at early times, when N is high, the Adaptive NP model predicts a stronger increase of growth rate with total Variability, β, compared to the inflexible NP model.

For both models, growth rate and hence P biomass increase with β.



$Q_s = 0.0185$, $\zeta = 0.6$, $A_0 = 0.11$, $V_0 = 5$, $\mu^I = 5.2$, $\mu_{max} = 5.2$, $A = 2$, $M = 0.5$, $k = 6.3$.

Conclusions

Accounting for realistic levels of sub-scale Variability impacts macro-scale response, and therefore cannot safely be ignored in coupled physical-ecological models.

Variabiity in many cases enchances growth, which suggests that the co-variance terms must be important.

The Flexible model responds differently to variability.

On-going work:	**Stability analysis, Flexible Closure Model**
Next:	**Impact on Community Size Composition**
Challenges:	**How to treat the Transport of Variability?**

Thank You for Your Attention!