OCB 2017 Summer Workshop
Session: Stoichiometry and higher trophic levels
Wednesday, June 28th, 2017 @ WHOI

Estimating the Influences of Flexible POC:POP Stoichiometry on Future Carbon Export

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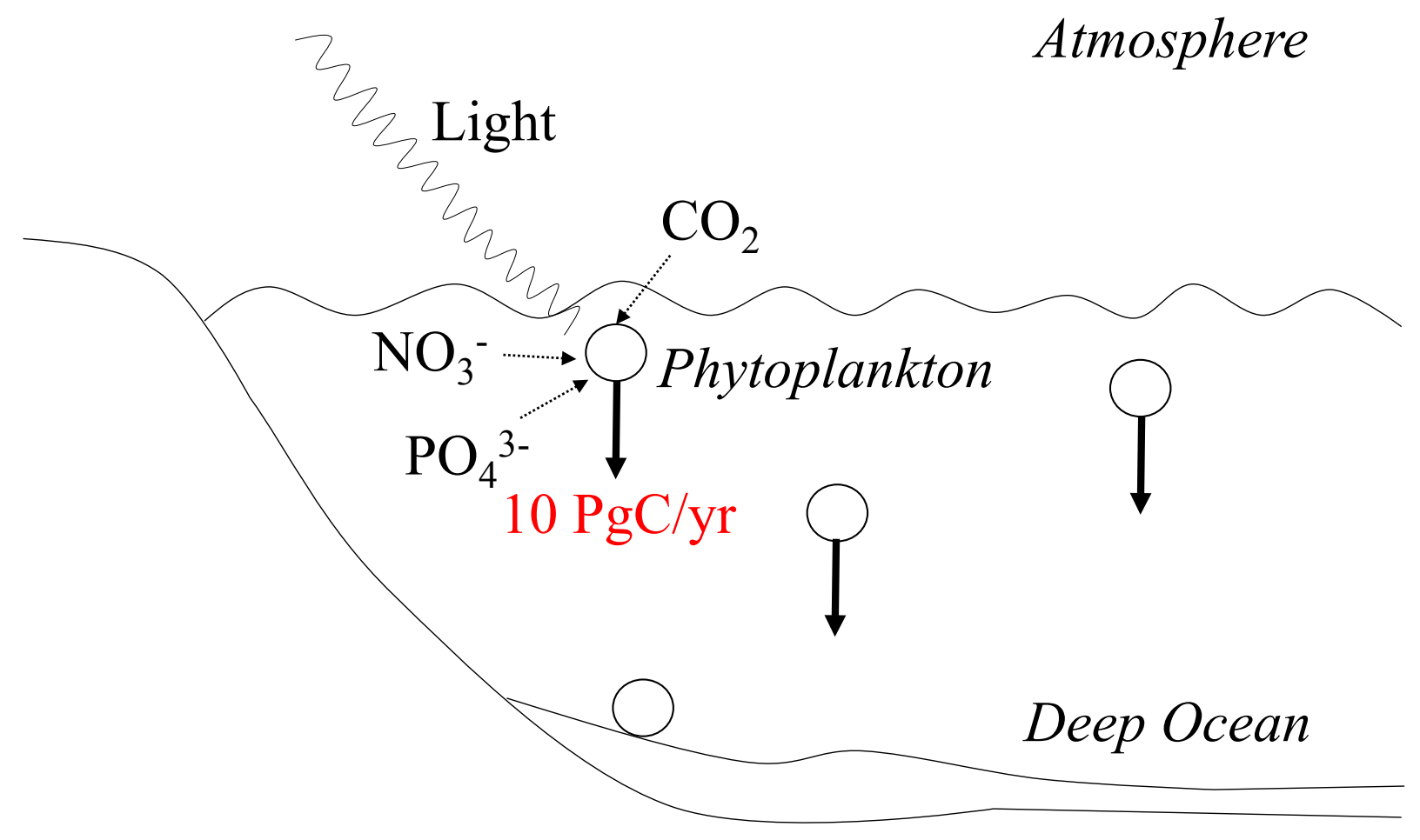
Introduction

Export production of particulate organic matter (POM) from the surface to the deep ocean is a key driver of global carbon cycle. The amount of carbon (C) removed from the surface ocean by this export depends critically on the elemental ratios in POM of C to nitrogen (N) and phosphorus (P), two essential nutrients that limit productivity. Here we developed a simple power law model with a stoichiometry sensitivity factor, which is able to relate a fractional increase in C:P of POM to a fractional decrease in ambient phosphate concentration



Simple Stoichiometry Models

1) Power-law model (this study):
Sensitivity of P:C with respect to surface phosphate, *s*:

$$s = \frac{\partial[\mathrm{P{:}C}]/[\mathrm{P{:}C}]}{\partial[\mathrm{PO_4}]/[\mathrm{PO_4}]} = \frac{\partial \ln[\mathrm{P{:}C}]}{\partial \ln[\mathrm{PO_4}]}.$$

(*s*: stoichiometry sensitivity factor)
This is analogous to the famous Revelle factor, *R*:

$$R = \partial\ln[\mathrm{CO_2}]/\partial\ln[\mathrm{DIC}]$$

Solve (1) to express P:C as a function of PO_4:

$$[\mathrm{P{:}C}]=[\mathrm{P{:}C}]_0\left(\frac{[\mathrm{PO_4}]}{[\mathrm{PO_4}]_0}\right)^s \qquad (1)$$

($[\mathrm{P{:}C}]_0$ = reference P:C)

2) Linear model (Galbraith and Martiny, 2015):

$$[\mathrm{P{:}C}] = 6.9\ ‰\ \mu\mathrm{M}^{-1}\times[\mathrm{PO_4}] + 6.0‰ \qquad (2)$$

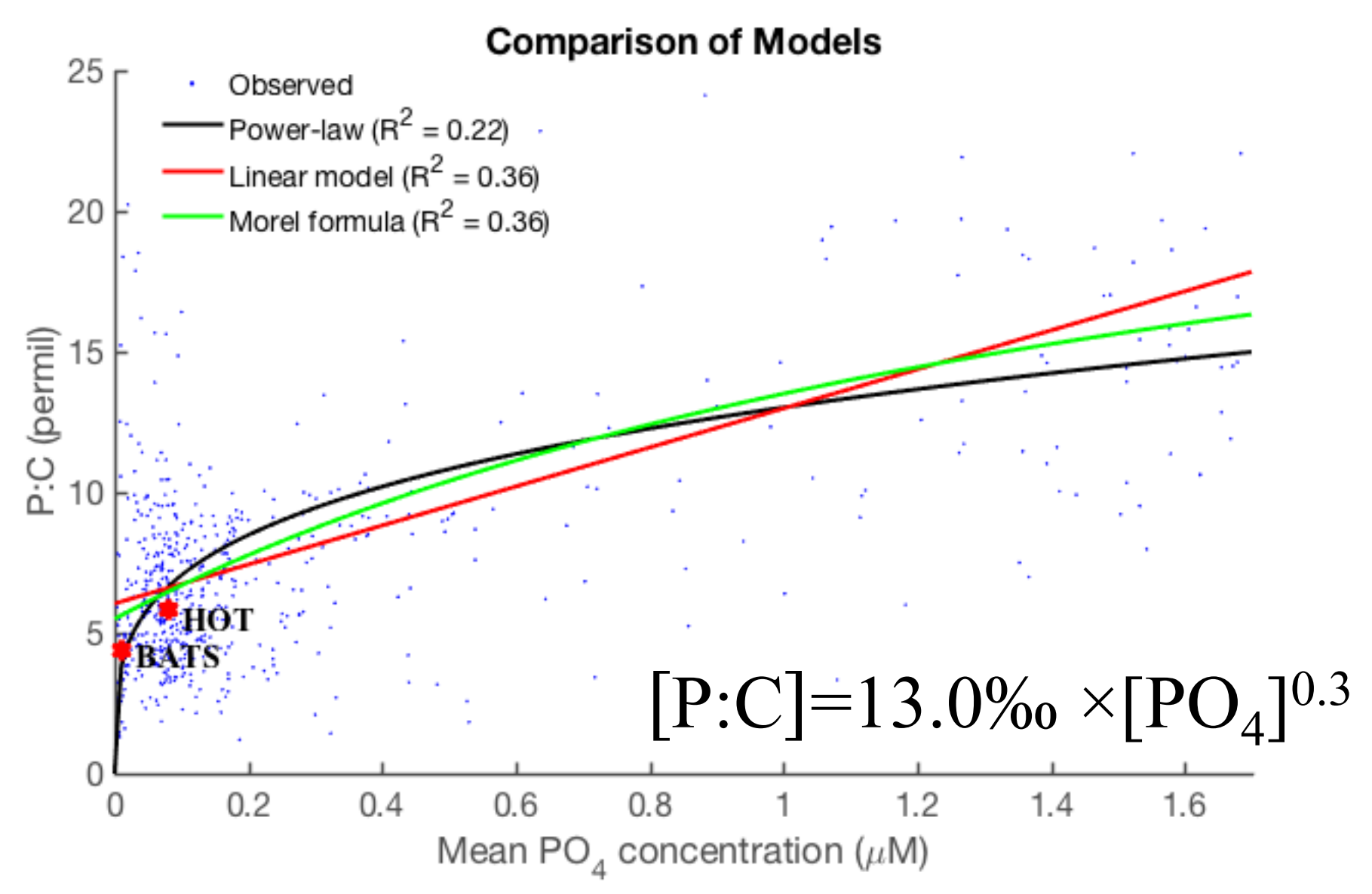
3) Morel's formula (Morel, 1987):

$$[\mathrm{P{:}C}]=[\mathrm{P{:}C}]_{max}\cdot\frac{\mathrm{K_1}+[\mathrm{PO_4}]}{\mathrm{K_2}+[\mathrm{PO_4}]} \qquad (3)$$

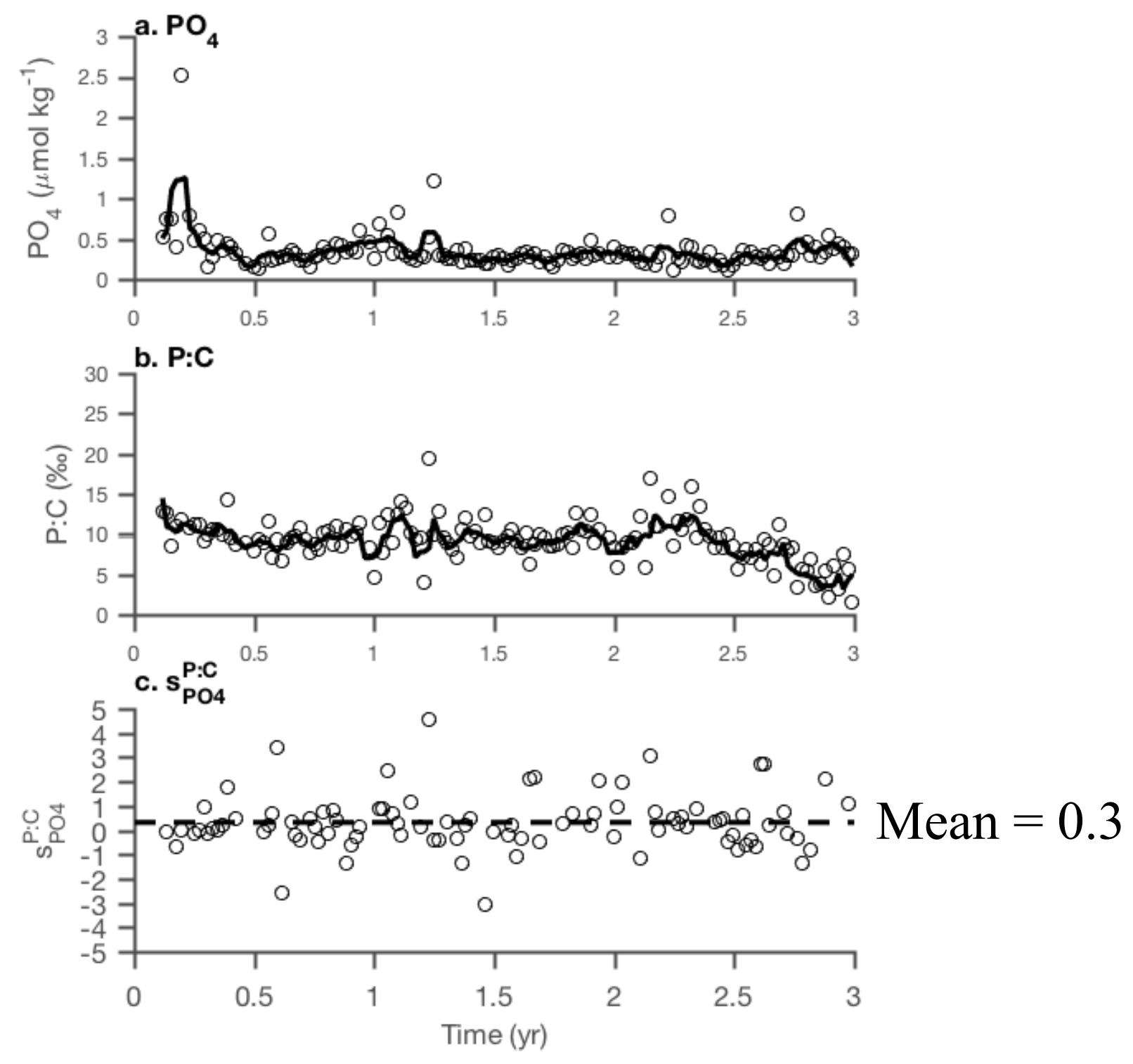
(K_1, K_2: constants)

Estimating stoichiometry sensitivity factor, *s*

1. Against Global Compiled Data (Galbraith and Martiny, 2015)



2. Against California Time-series Data (Martiny et al. 2016)

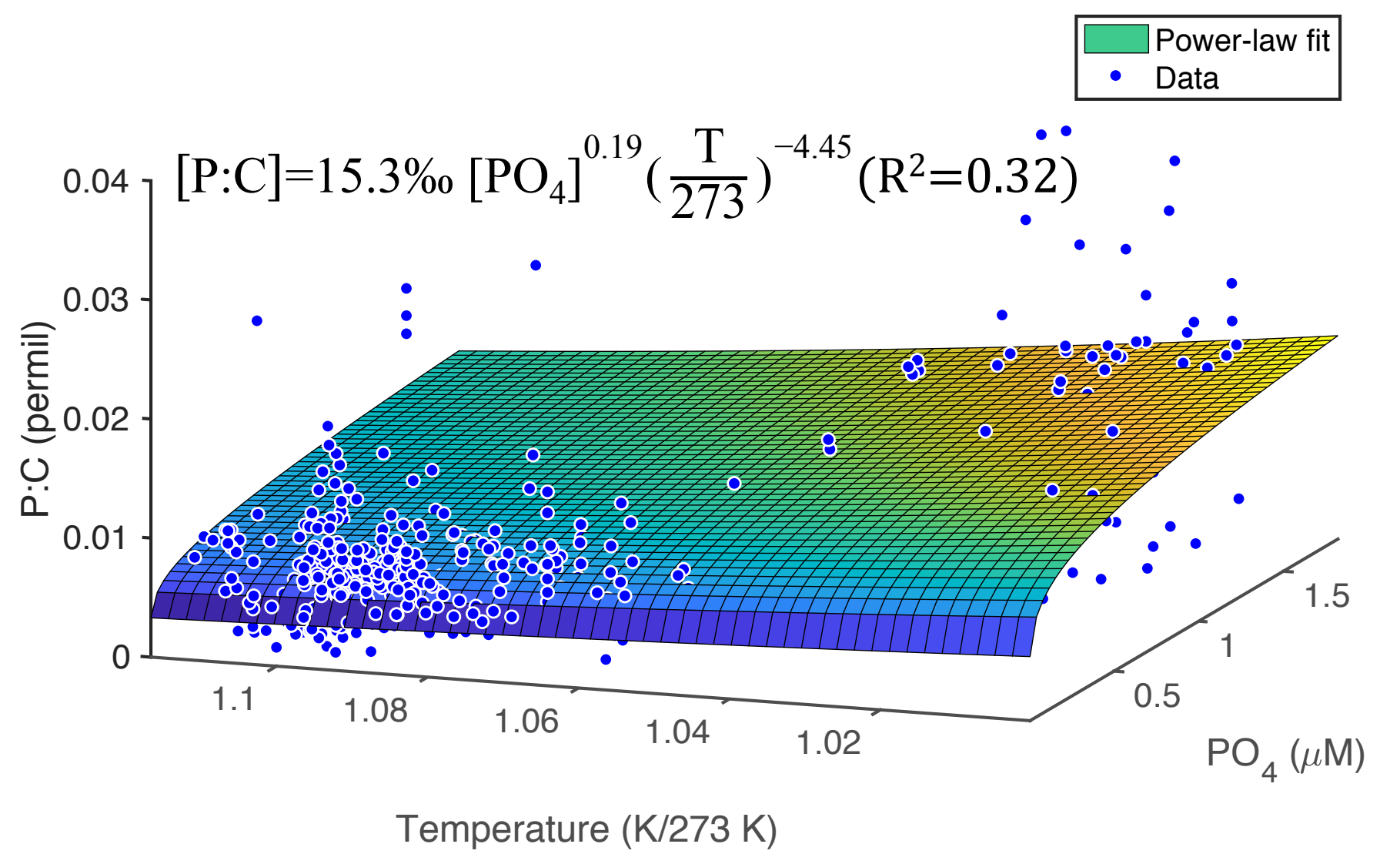


Our best estimate of global mean *s* is 0.3-0.4, i.e. 1% change in PO_4 translates to a 0.3-0.4% change in P:C of POM.

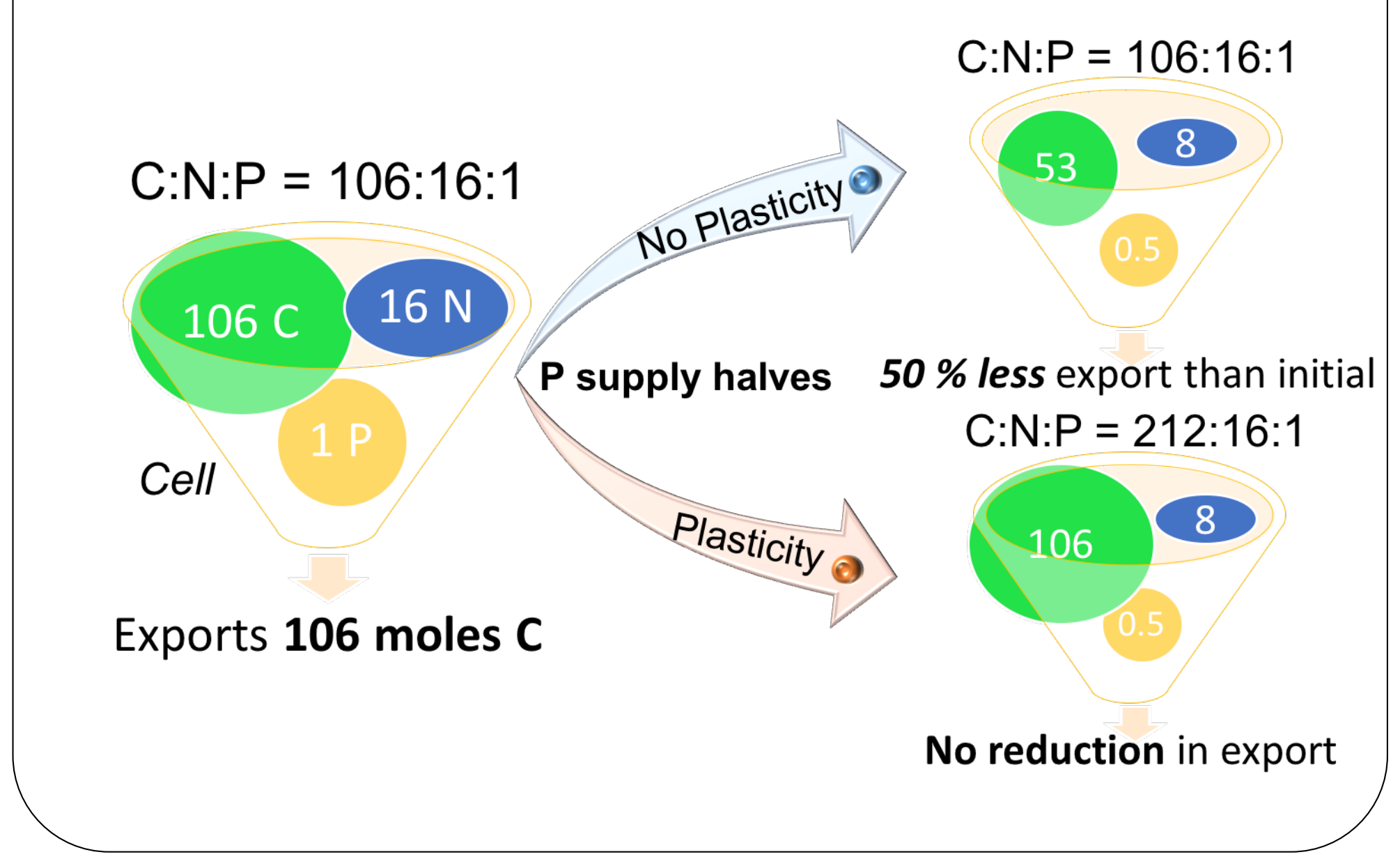
Extension of stoichiometry model: adding temperature dependence

$$s_\mathrm{T} = \frac{\partial[\mathrm{P{:}C}]/[\mathrm{P{:}C}]}{\partial\mathrm{T}/\mathrm{T}} = \frac{\partial \ln[\mathrm{P{:}C}]}{\partial \ln\mathrm{T}}$$

$$[\mathrm{P{:}C}]=[\mathrm{P{:}C}]_0\left(\frac{[\mathrm{PO_4}]}{[\mathrm{PO_4}]_0}\right)^s\left(\frac{\mathrm{T}}{\mathrm{T_0}}\right)^{s_T}$$



Stoichiometric Compensation Effect

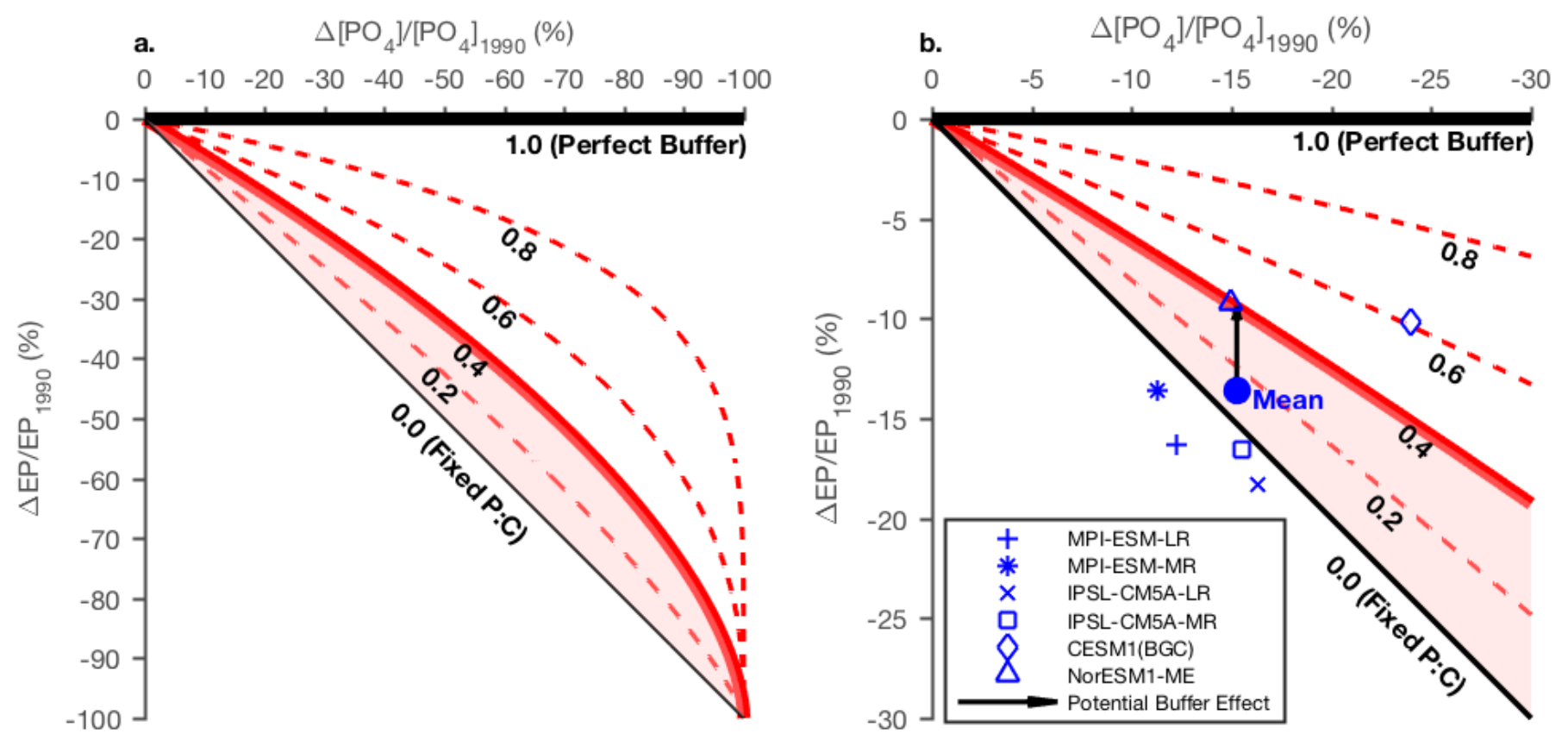


C:N:P = 106:16:1
106 C
16 N
1 P
Cell
Exports 106 moles C
No Plasticity
P supply halves
Plasticity
C:N:P = 106:16:1
53
8
0.5
50 % less export than initial
C:N:P = 212:16:1
106
8
0.5
No reduction in export

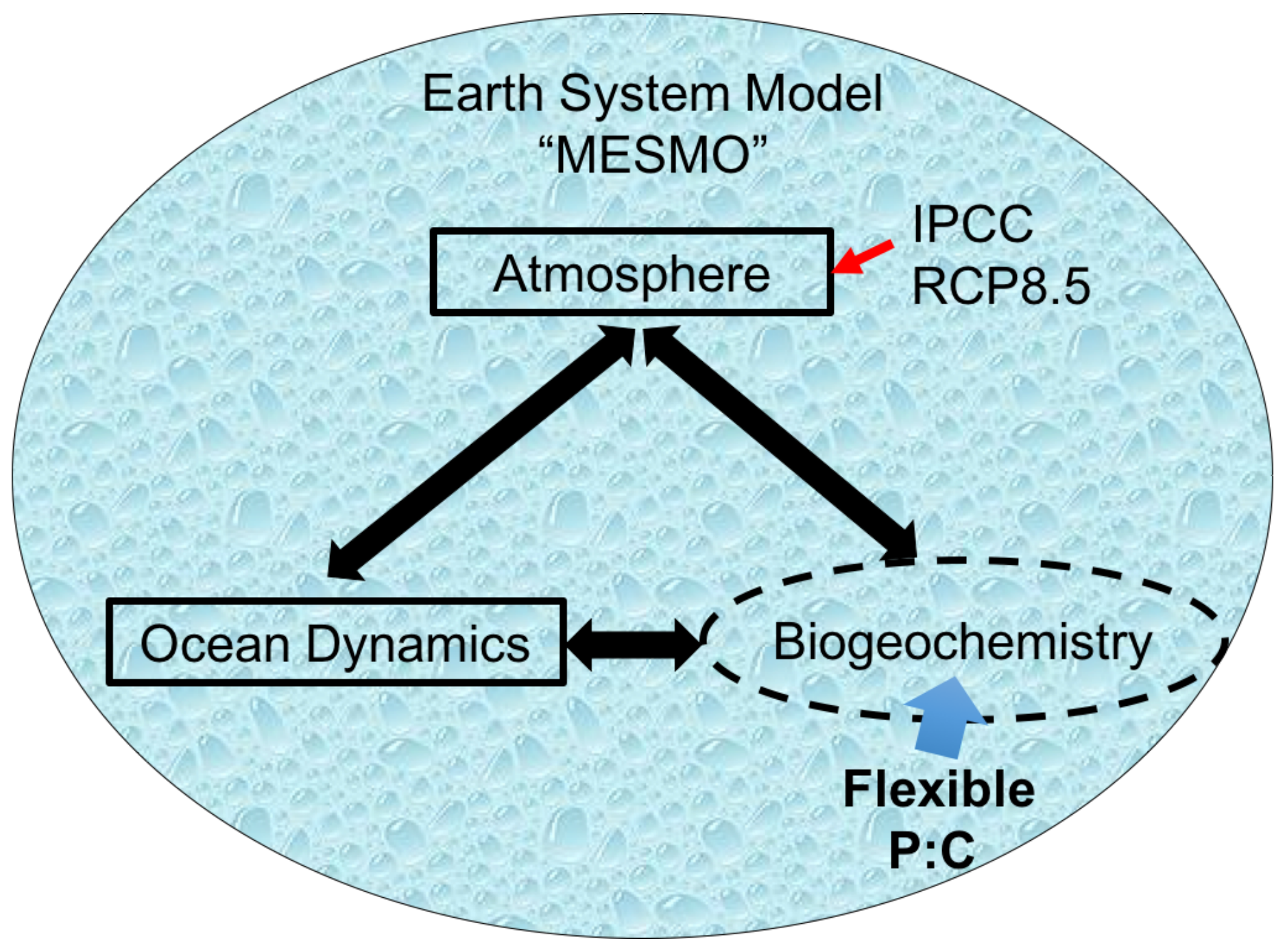
First-order estimation

In the limiting case where export production (EP) of carbon is a function of PO_4 and P:C stoichiometric compensation effect referenced to a recent time (e.g. decade of the 1990s) as,

$$\frac{\Delta\mathrm{EP}}{\mathrm{EP}_{1990}} = \left(\frac{\Delta[\mathrm{PO_4}]}{[\mathrm{PO_4}]_{1990}}+1\right)^{1-s} - 1. \qquad (4)$$

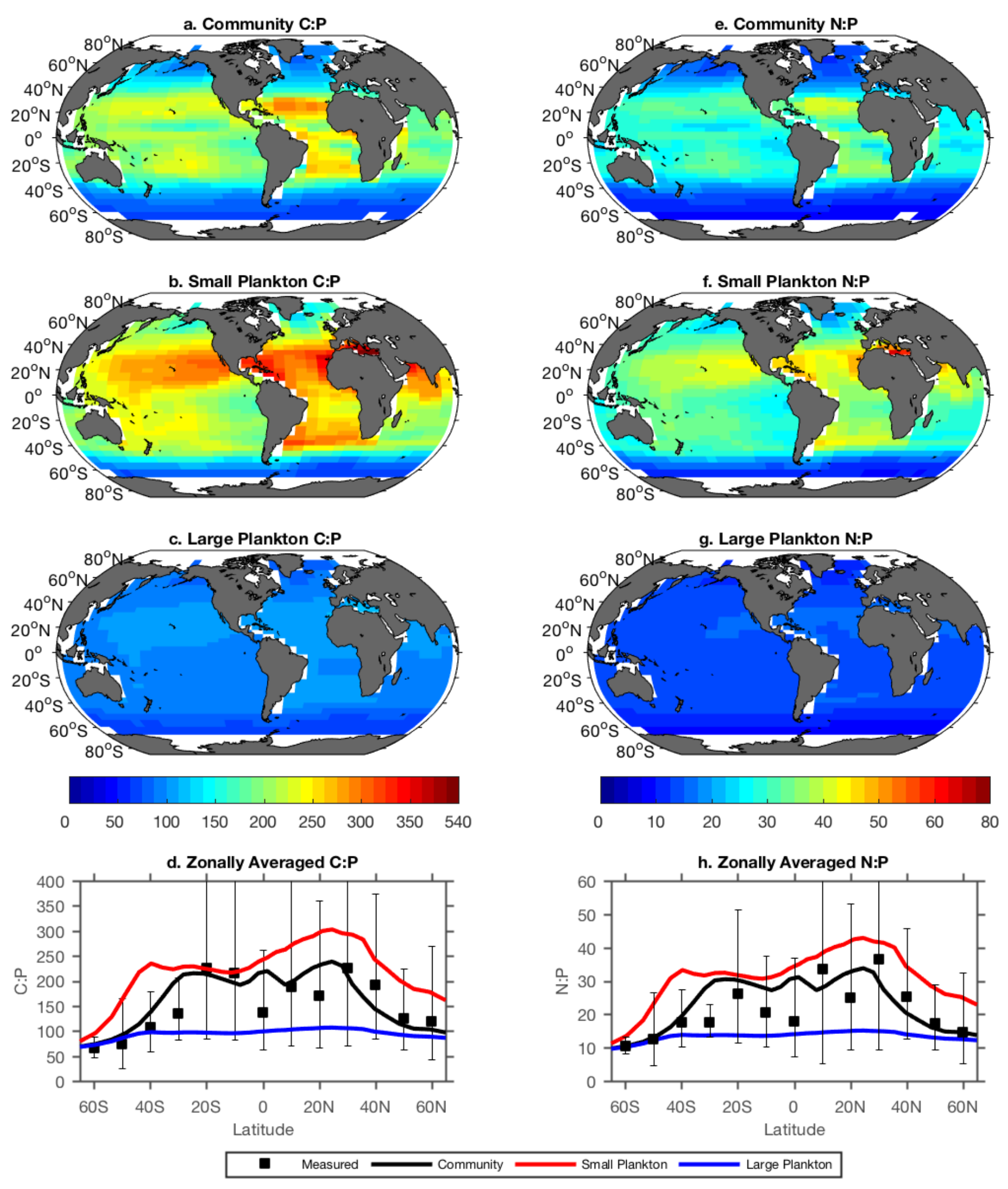


Flexible C:N:P in Global Ocean Model



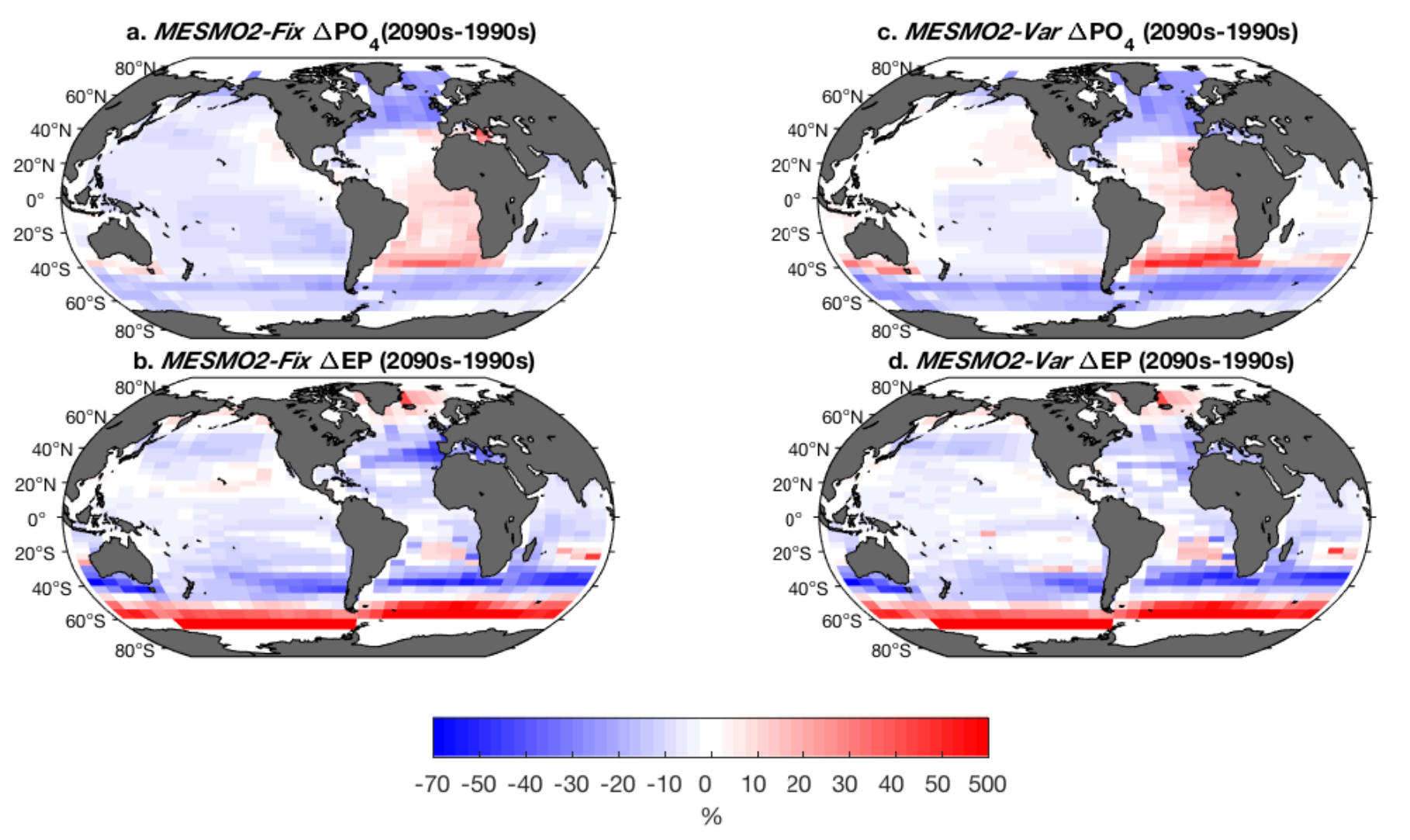
Earth System Model "MESMO"
Atmosphere
IPCC RCP8.5
Ocean Dynamics
Biogeochemistry
Flexible P:C

Results I



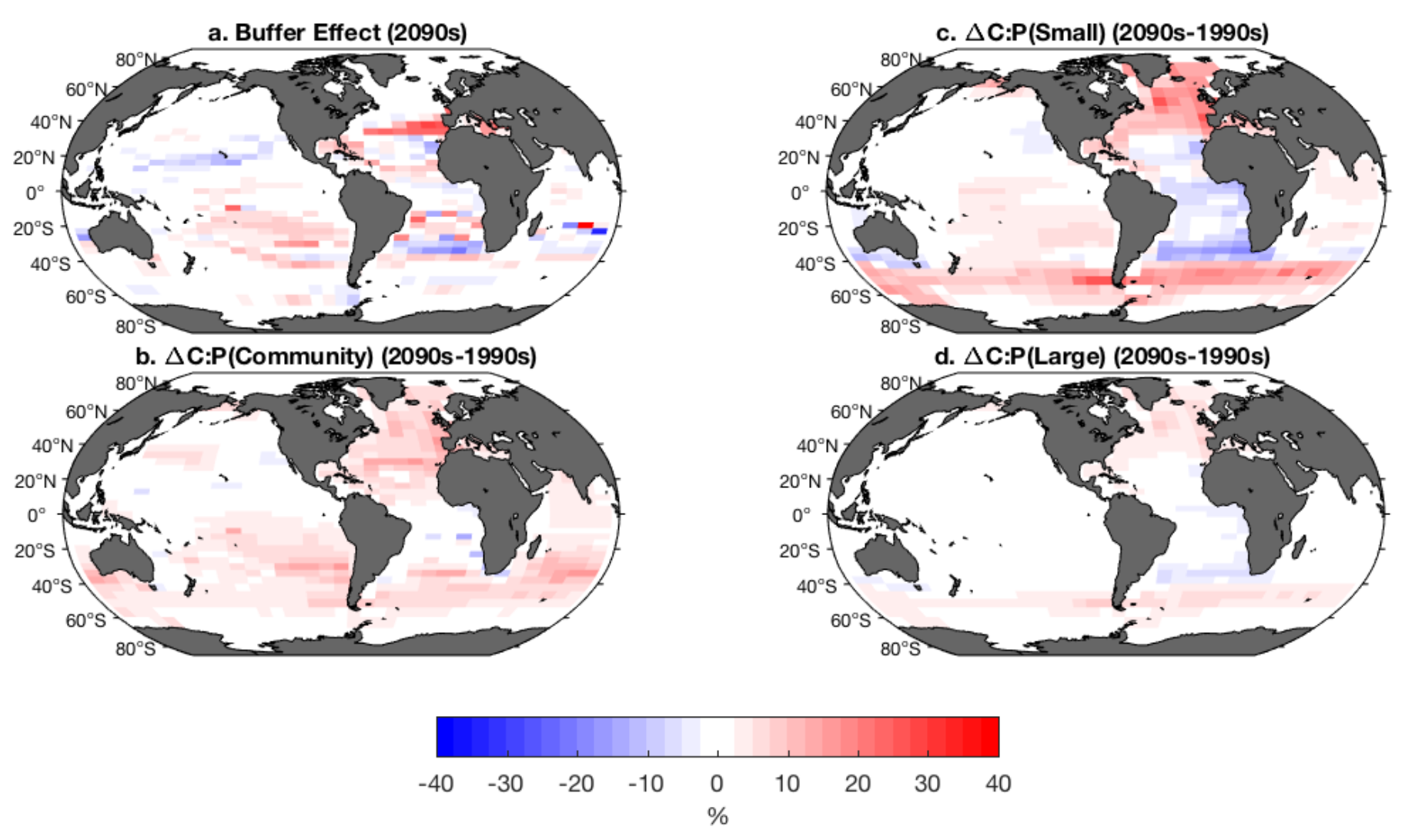
Prediction of POM stoichiometry by a global ocean model enable with the new stoichiometry model (Equation 3) under steady state.(a-d) Modeled C:P ratio of aggregate POM, small plankton, large plankton, and zonal mean. (f-h) Modeled N:P calculated by dividing C:P with a fixed C:N value of 7.06.

Results II



Simulated fractional changes in surface PO_4 (0-100 m) and total EP in 2090s relative to 1990s with fixed C:N:P (a, b) and variable C:N:P (c, d) under RCP8.5 scenario.

Results III



(a) Stoichiometric buffer effect in 2090s. Positive value indicates positive buffer effect (i.e. smaller reduction in EP for variable C:N:P model). (b-d) Percent change of community, small plankton, and large plankton C:P in 2090s relative to 1990s.

Conclusions

- A new, alternative method for predicting C:P of POM as a function of PO_4 is presented.
- New stoichiometry model can be implemented successfully and easily in a global model to reproduce the C:N:P variability in the ocean.
- Flexible C:P can buffer changes in export production under the business as usual global warming scenario by up to 1%.

Reference

- Galbraith, E. D., and A. C. Martiny (2015), A simple nutrient-dependence mechanism for predicting the stoichiometry of marine ecosystems., *Proc. Natl. Acad. Sci. U. S. A., 112(27), 8199-204.*
- Martiny, A. C., A. Talarmin, C. Mouginot, J. A. Lee, J. S. Huang, A. G. Gellene, and D. A. Caron (2016), Biogeochemical interactions control a temporal succession in the elemental composition of marine communities, *Limnol. Oceanogr.*, *61*(2), 531–542, doi:10.1002/lno.10233.
- Morel, F. M. M. (1987), Kinetics of Nutrient Uptake and Growth in Phytoplankton, *J. Phycol.*, *23*(1), 137–150, doi:10.1111/j.0022-3646.1987.00137.x.
- Tanioka, T., and K. Matsumoto (2017), Buffering of ocean export production by flexible elemental stoichiometry of particulate organic matter, *Global Biogeochem. Cycles*, in review.