Quantifying feedbacks between phytoplankton elemental stoichiometry and marine biogeochemistry

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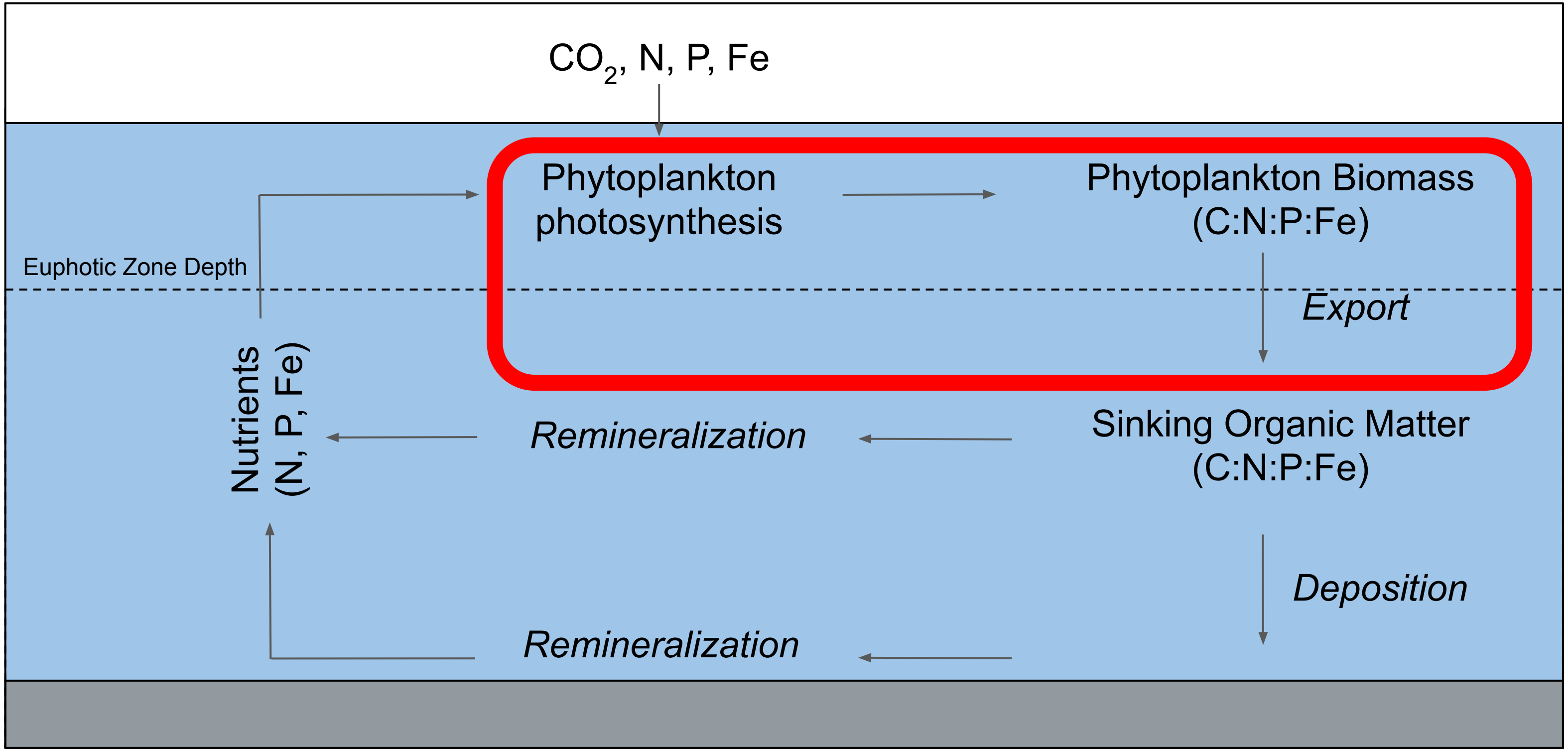
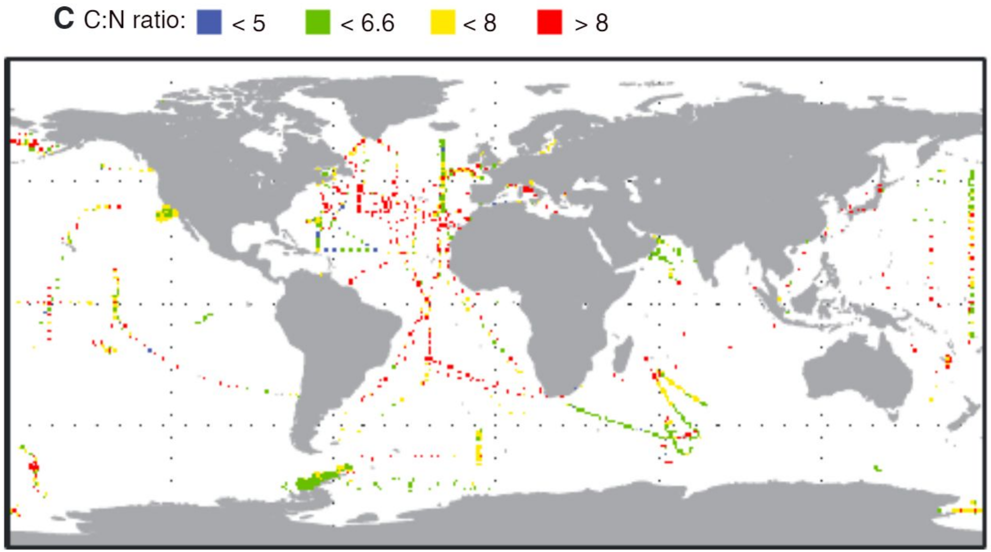
Carbon export is linked to nutrients via stoichiometry



C:N:P Motivation

- Phytoplankton C:N:P plays a key role in the coupling of carbon and nitrogen and phosphorus cycles, with significant variation in different ocean environments
- Variations in phytoplankton N, P are tied to N, P supply
- **What we want to know: What impacts does variable stoichiometry have on the sensitivity of biogeochemical cycles?**



Martiny et al. (2013)

Why do we need variable C:N in models?

- Fixed Redfield C:N in models results in an underestimate of ocean DIC inventory (Schneider et al. 2004)
- The marine nitrogen cycle is more sensitive to biological processes with variable C:N (Buchanan et al. 2018)
    - Marine nitrogen cycle is key to global NPP as much of the oceans are N limited, and perturbations to N export and N-fixation affect the global N supply
    - Denitrification very sensitive to export and O_2, also highly variable in the model

CESM-BEC v1.98.x

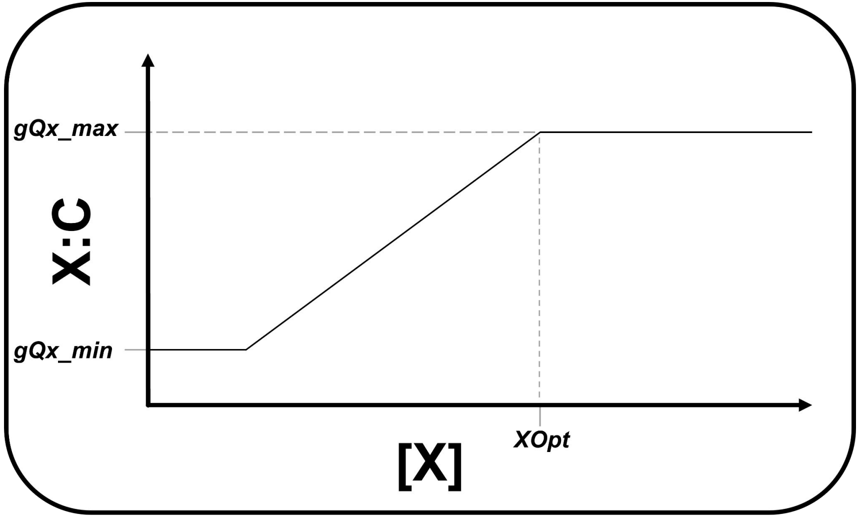
Diatoms Small Phytoplankton Diazotrophs

- 3 phytoplankton classes:
  - Small phytoplankton, diatoms, diazotrophs
  - Fully variable C:N:P:Fe:Si
- Iron sources:
  - Atmosphere, Sediments, Rivers
  - **Recently added**: Hydrothermal Vents, Bottom Scavenging

CESM: Now with Fully Variable Stoichiometry!

Phytoplankton growth is a function of the following, where X is N, P, Fe, or Si:

- gQx_max: Maximum X:C
- XOpt: Optimal X for
- gQx_min: Minimum X:C
- [X]: Nutrient concentration



Allows for variable C:N:P:Fe:Si

P Quotas: When nitrate is low, N and P uptake are both reduced in order to maintain N/P uptake appropriate for ambient phosphate levels

Si Quotas: When [Si] ↓, Si:C ↓ [Si] replete, [Fe] ↓, Si:C ↑

Dynamic Stoichiometry Range for each Plankton Group

	Diatoms	Small Phyto	Diazotrophs
C:N	6-9	6-9	6-7
N:P	15-25	15-20	20-45
C:P	90-225	90-180	120-315
Fe:C	3-90	3-90	6-180
Si:N	0.33-5		

C:N:P ranges constrained by GO-SHIP POM observations (Tanioka et al., in review)

N:P by inverse model estimates (Wang et al. 2019)

Fe:C range constrained by observations from Ben Twining and others (Wiseman et al., submitted to GBC)

Fixed Stoichiometry and Variable Stoichiometry Simulations

Constant Pre-industrial CO_2, 300 years, averaged over last 20 years

Fixed Stoich

- C:N:P = 96:16:1 (C:N = 6.0)
- Fe:C = 7
- Si:N = 1

Most other models: 120:16:1 (C:N = 7.5)

All units in mol/mol except Fe:C which is umol/mol

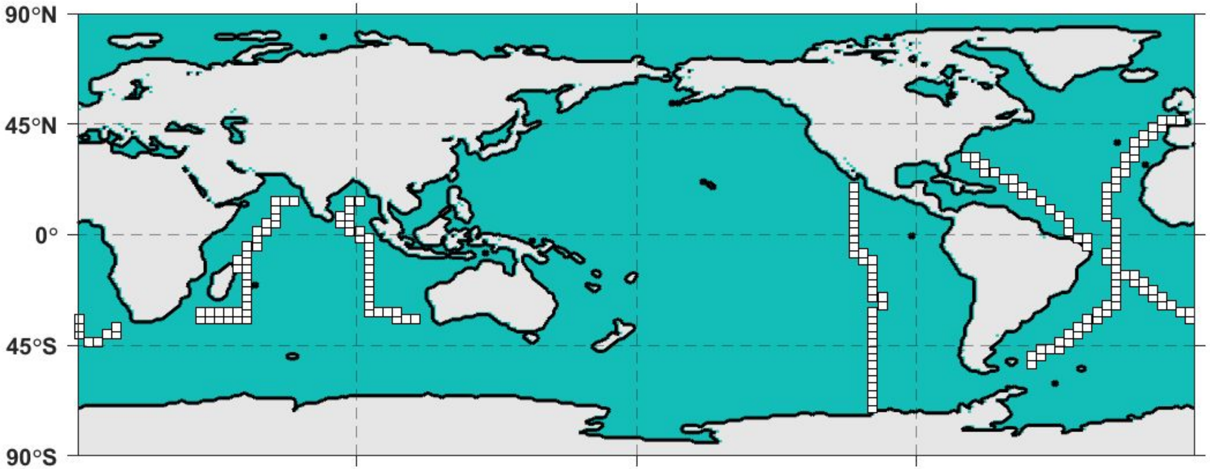
Variable Stoich

- C:N = 6-9 for diat/sp; 6-7 for diaz
- N:P = 15-25, 15-20, 20-45
- C:P = 90-225, 90-180, 120-315
- Fe:C = 3-90 for diat/sp; 6-180 for diaz
- Si:N = 0.33-5

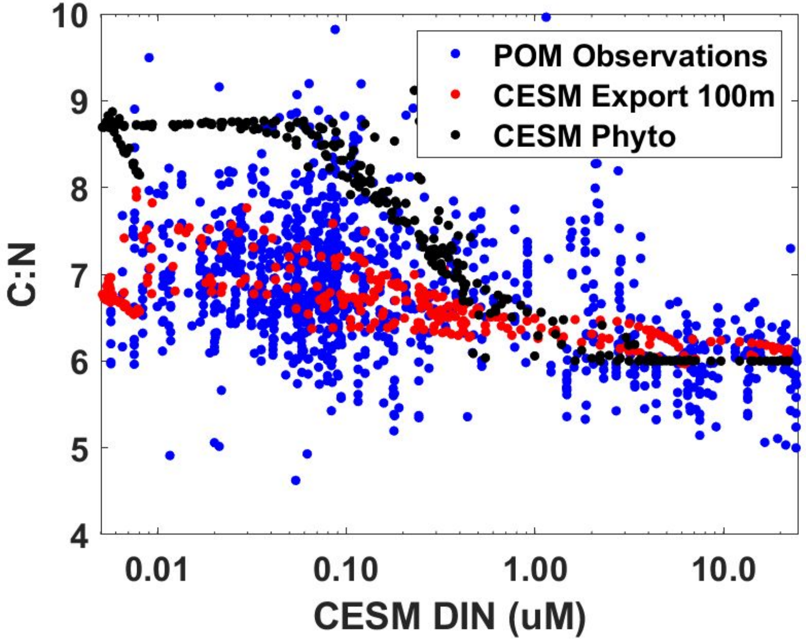
POM Database

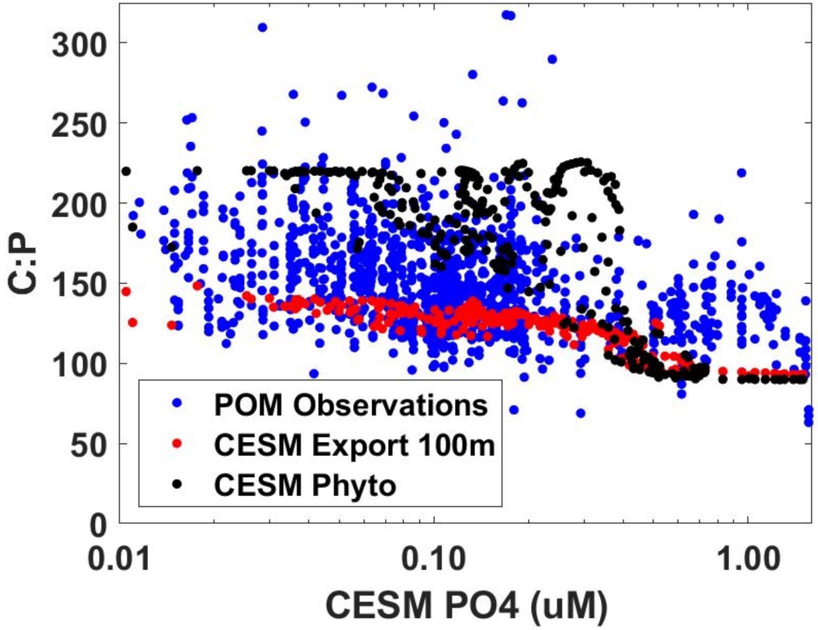
GO-SHIP POM Observations

- AMT (2018)
- C13 (2020)
- P18 (2017)
- I9 (2016)
- I07 (2018)



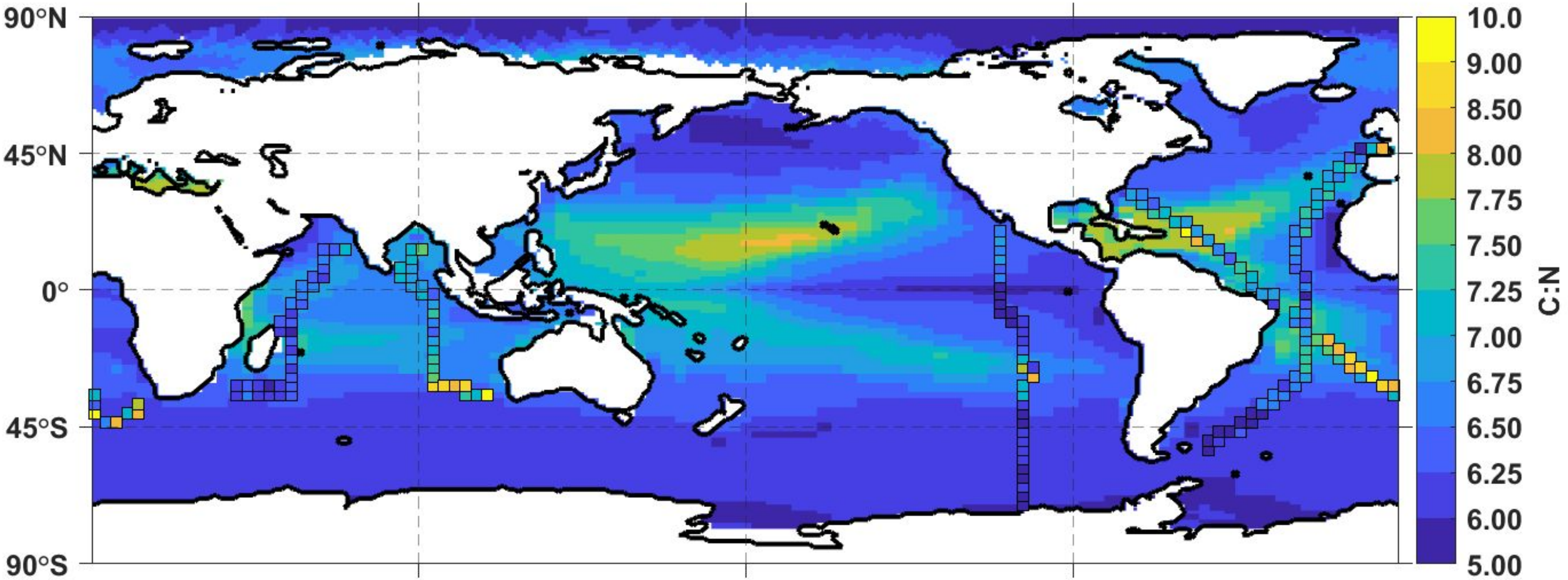
Comparing to CESM export @ 100m, which does not account for heterotrophic bacteria or detritus that is present in POM obseration





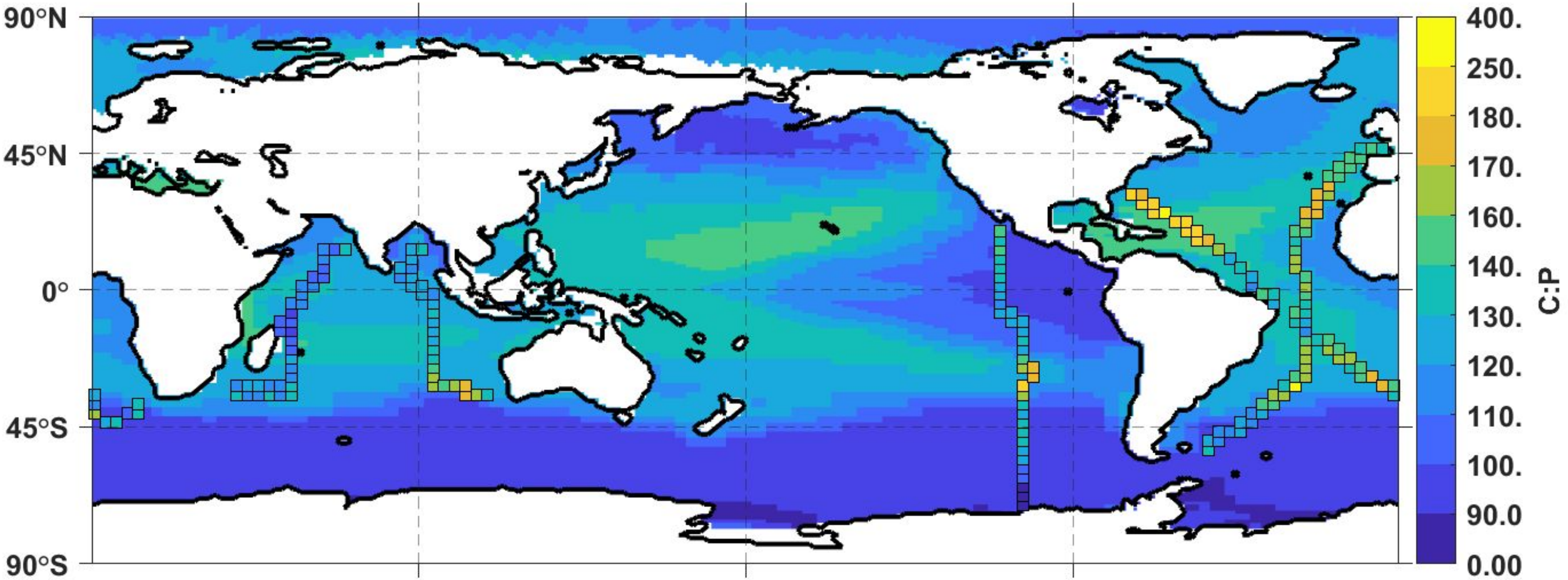
General agreement between model export @ 100m and POM observations of increased C:N and C:P when N and P are limiting. POM observations are bulk and include detritus and heterotrophic bacteria which are not represented in CESM

Global C:N



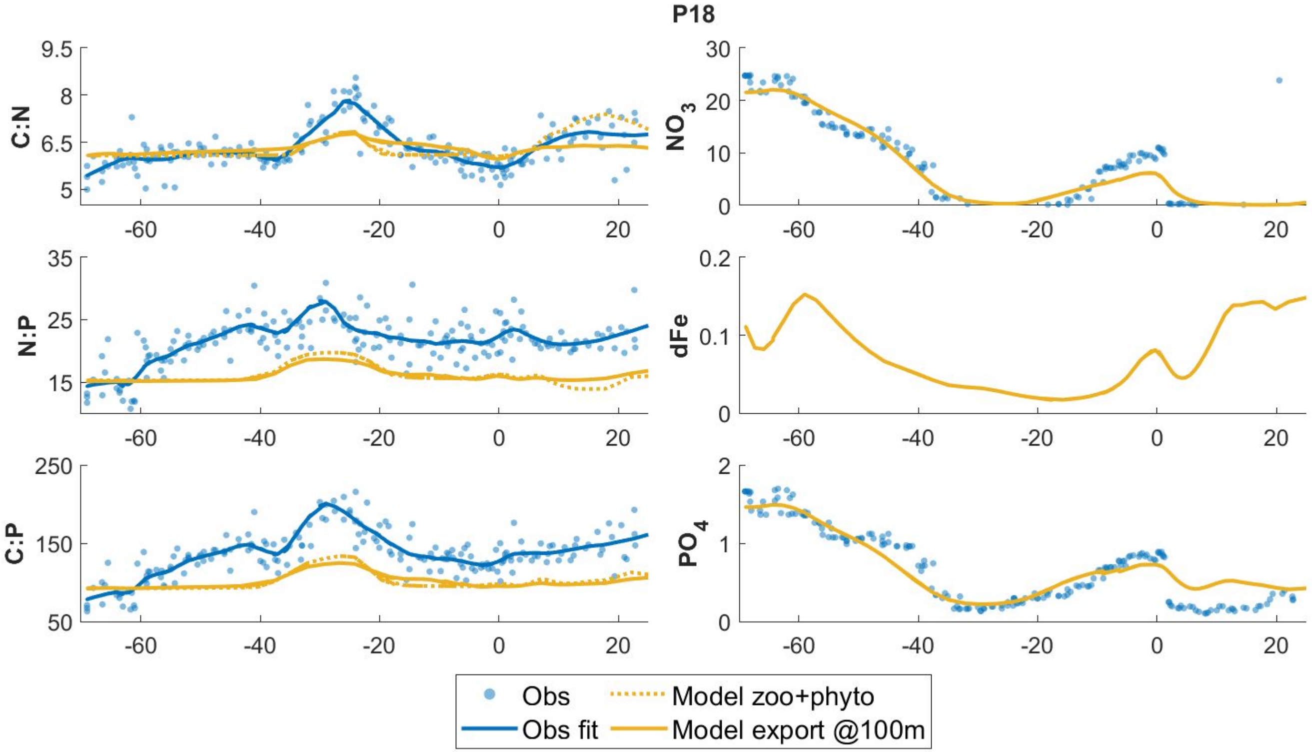
90°N
45°N
0°
45°S
90°S
10.0
9.00
8.50
8.00
7.75
7.50
7.25
7.00
6.75
6.50
6.25
6.00
5.00
C:N

Global C:P



Surface nutrient fields are key to correctly calculating C:N:P.

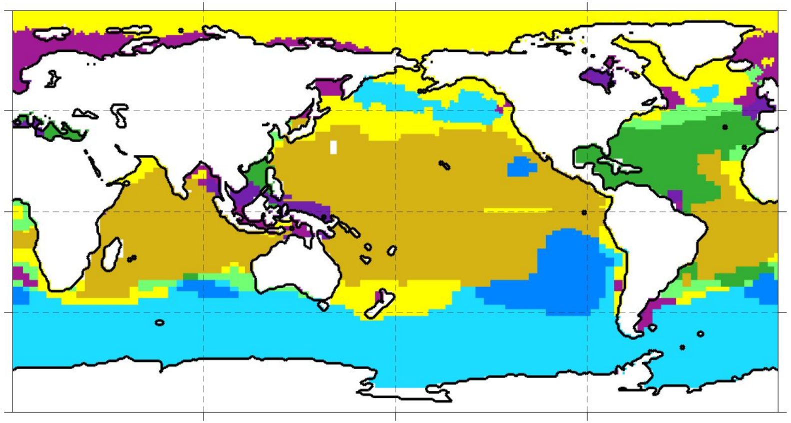
Gradients within nutrient distributions can cause rapid changes in C:N:P that must be resolved in order to accurately represent key nutrient cycling



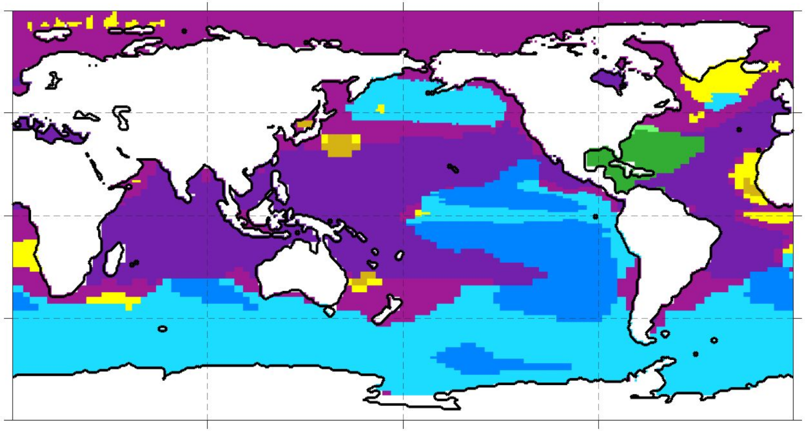
Caveat: C:P is too low in the most recent set of simulations, leading to low N:P as well. Will be addressed immediately.

Diatom Nutrient limitation

Fixed Stoichiometry



Variable Stoichiometry



Nitrogen
Iron
Phosphorous
Silicon
Temperature
Replete

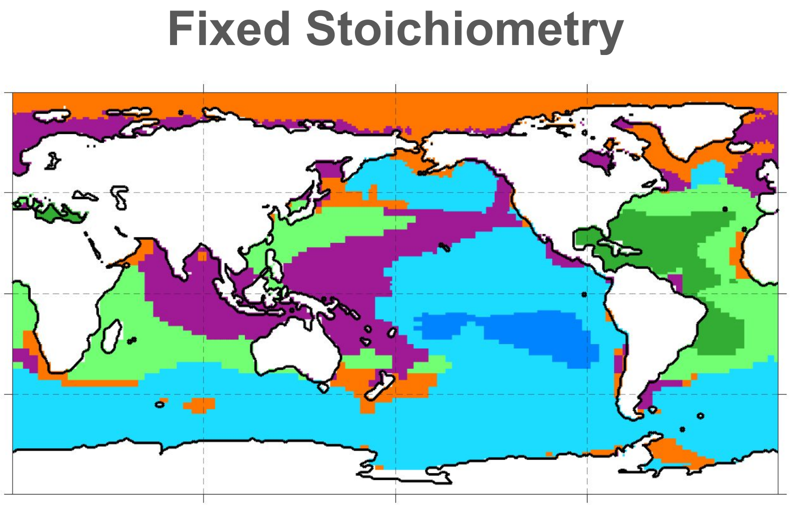
Darker shades indicate nutrient limitation leads to relative growth rates less than 50%

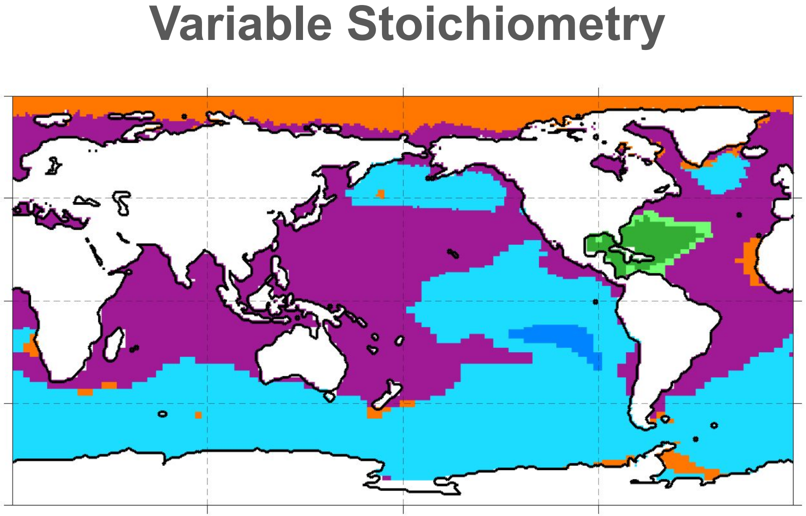
C:N = 6.0
C:P = 96
N:P = 16

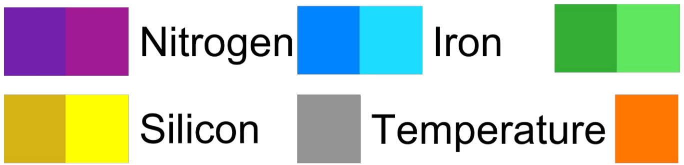
C:N = 6-9
C:P = 90-225
N:P = 15-25

Transition from N limited to Si and P limited surface ocean.
Large increase in Si limitation where N and Fe were previously limiting.

Small Phyto Nutrient limitation







Darker shades indicate nutrient limitation leads to relative growth rates less than 50%

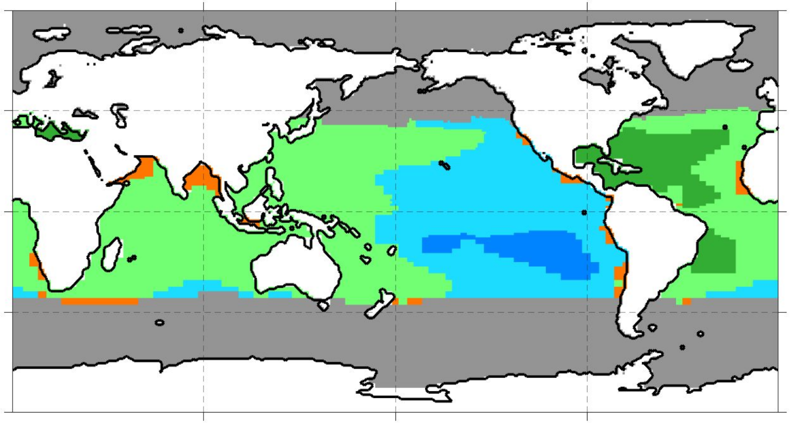
C:N = 6.0
C:P = 96
N:P = 16

C:N = 6-9
C:P = 90-180
N:P = 15-20

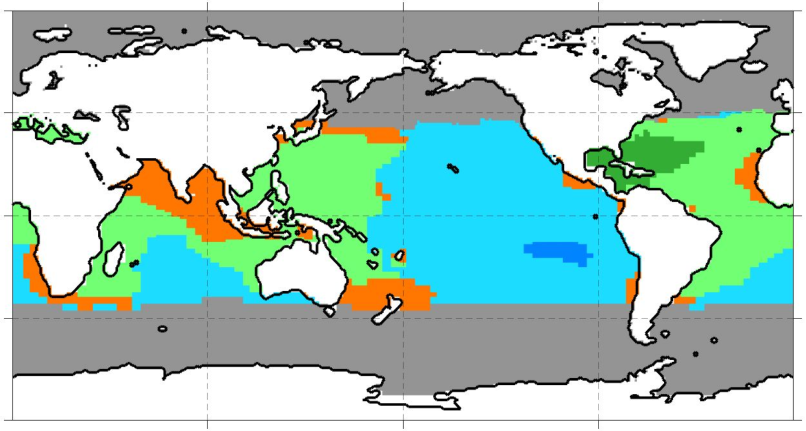
Transition from N limited to P limited surface ocean. Phyto have far greater P flexibility than N, so when that is fixed, P limitation dominates.

N-fixer Nutrient limitation

Fixed Stoichiometry



Variable Stoichiometry



Nitrogen | Iron | Phosphorous

Silicon | Temperature | Replete

Darker shades indicate nutrient limitation leads to relative growth rates less than 50%

C:N = 6.0
C:P = 96
N:P = 16

C:N = 6-7
C:P = 120-315
N:P = 20-45

P limited N-fixers become even more strongly P limited when quotas are not flexible.

Dynamic Stoichiometry Impacts on Carbon and Nitrogen Fluxes

	Variable	**Fixed (% change from Variable)**	**Previous Estimates**
NPP	53.8 PgC/yr	55.6 PgC/yr (+3.3%)	~52 PgC/yr (Westberry et al. 2008)
POC Export	7.76 PgC/yr	6.98 PgC/yr (-10.1%)	9.1 ± 0.2 PgC/yr (DeVries & Weber 2017)
N Fixation	215.4 TgN/yr	162.3 TgN/yr (-24.7%)	163 (126-223) TgN/yr (Wang et al. 2019)
WC Denitrification	68.11 TgN/yr	31.39 TgN/yr (-53.9%)	69 (56-73) TgN/yr (Wang et al. 2019)

Other impacts

- Significant changes in community composition (>15% diatoms in gyres in variable run to <1% diatoms in gyres in fixed run)
- Global increase in N* bias (>20), with positive N* values in all ocean gyres in fixed run (0-315m depth)

Addition experiments (Fixed Si currently running)

	Variable	Fixed All	Fixed N	Fixed P	Fixed Fe
NPP (PgC/yr)	53.8	55.6 (+3.3%)	54.4 (+1.1%)	47.8 (-11.2%)	53.2 (-1.1%)
POC Export (PgC/yr)	7.76	6.98 (-10.1%)	7.77 (+0.1%)	7.12 (-8.2%)	7.73 (-0.4%)
N Fixation (TgN/yr)	215.4	162.3 (-24.7%)	242.0 (+12.3%)	167.6 (-22.2%)	219.1 (+1.7%)
WC Denitrification (TgN/yr)	68.11	31.39 (-53.9%)	73.73 (+8.3%)	57.80 (-15.1%)	75.21 (10.4%)

Summary:

- Dynamic stoichiometry is necessary for understanding ocean biogeochemistry
- Changing stoichiometry will modify climate change impacts
- Fixed nutrients can have opposing impacts on BGC cycling

Thank you!

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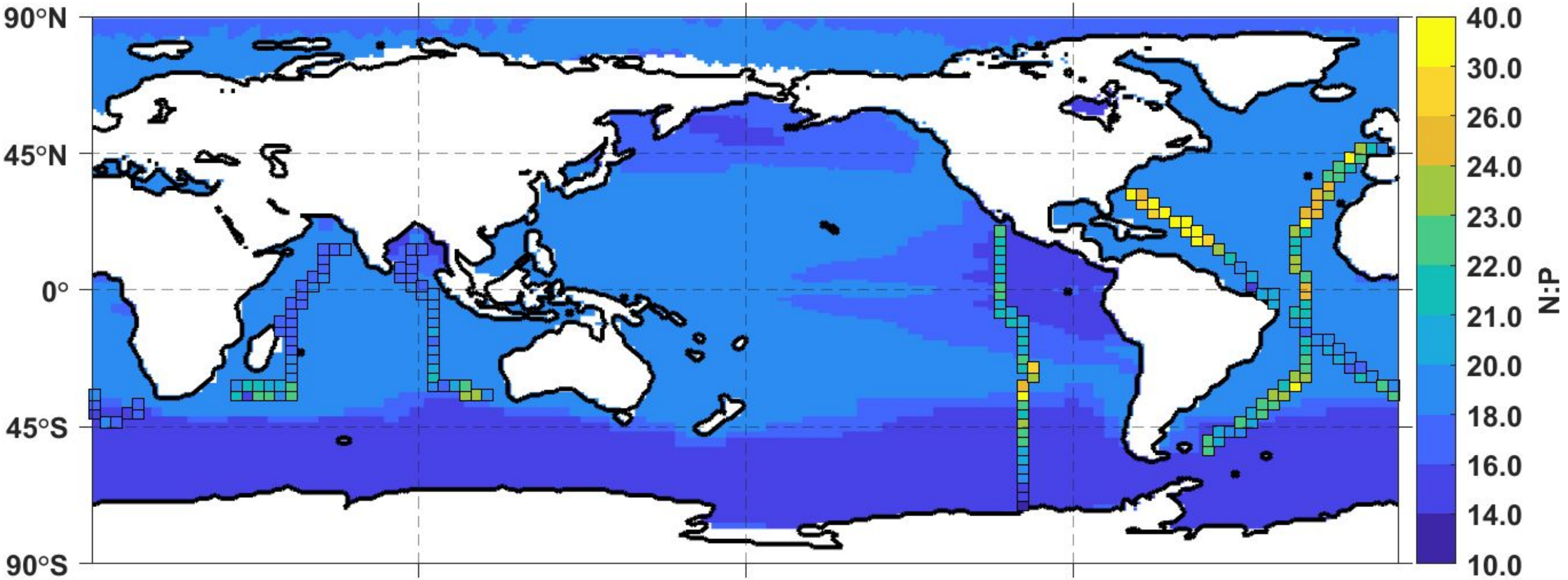
Global N:P



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