Global Assessment of Ocean Carbon Export using Food-Web Models & Satellite Observations

Dave Siegel – UC Santa Barbara

Help from …
Ken Buesseler, Scott Doney, Sevrine Sailley – WHOI
Mike Behrenfeld – Oregon State
Phil Boyd – Univ. Tasmania
Stephane Maritorena, Norm Nelson, Erik Fields - UCSB

Support from NASA Ocean Biology & Biogeochemistry Program

Constraining Global Carbon Export

- Export from the euphotic zone is a major pathway for C sequestration, yet…
  - Global estimates range from ~4 to 12 Pg C y^{-1}
  - Mean & variability of these estimates are similar to anthropogenic emissions (~7 Pg C y^{-1})
  - Most on sinking particles
- Host of food web & environmental processes drive the biological pump
  - Nutrient inputs, phytoplankton uptake & growth, zooplankton grazing, aggregate formation, etc.
  - Size matters…

Global Extrapolation of Carbon Export

- Export modeled as e-ratio * NPP

  We can estimate NPP globally - but need e-ratio

- Empirical modeling for e-ratio

  f(SST) - Laws et al. [2000] GBC; Henson et al. [2011] GRL

  f(SST & Chl) - Dunne et al. [2004] GBC

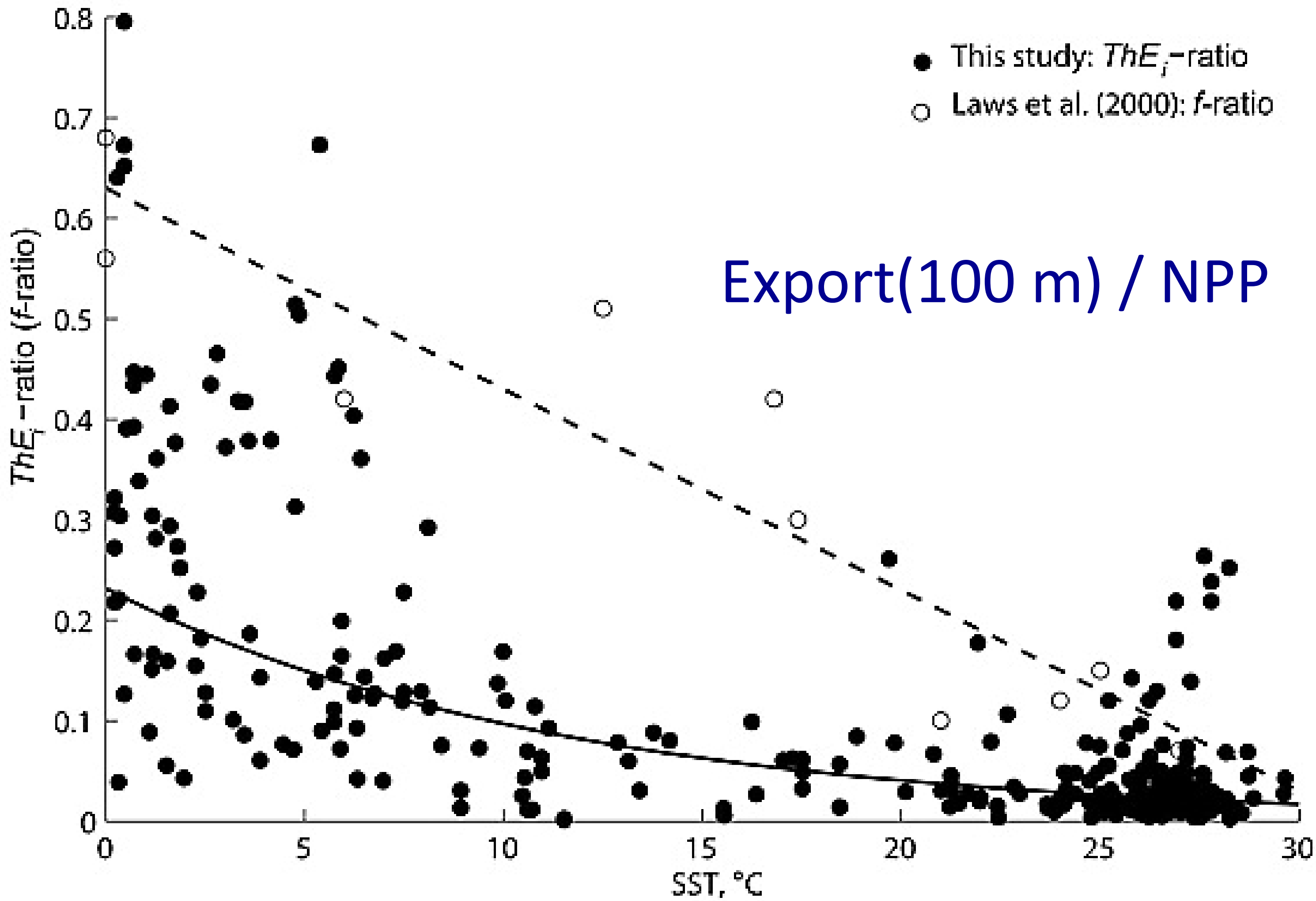
- Problems

  Not mechanistic

  Tuned for a single depth – not export at Z_{eu}

  Not very good…

E-Ratios vs. SST



Henson et al. GRL [2011]

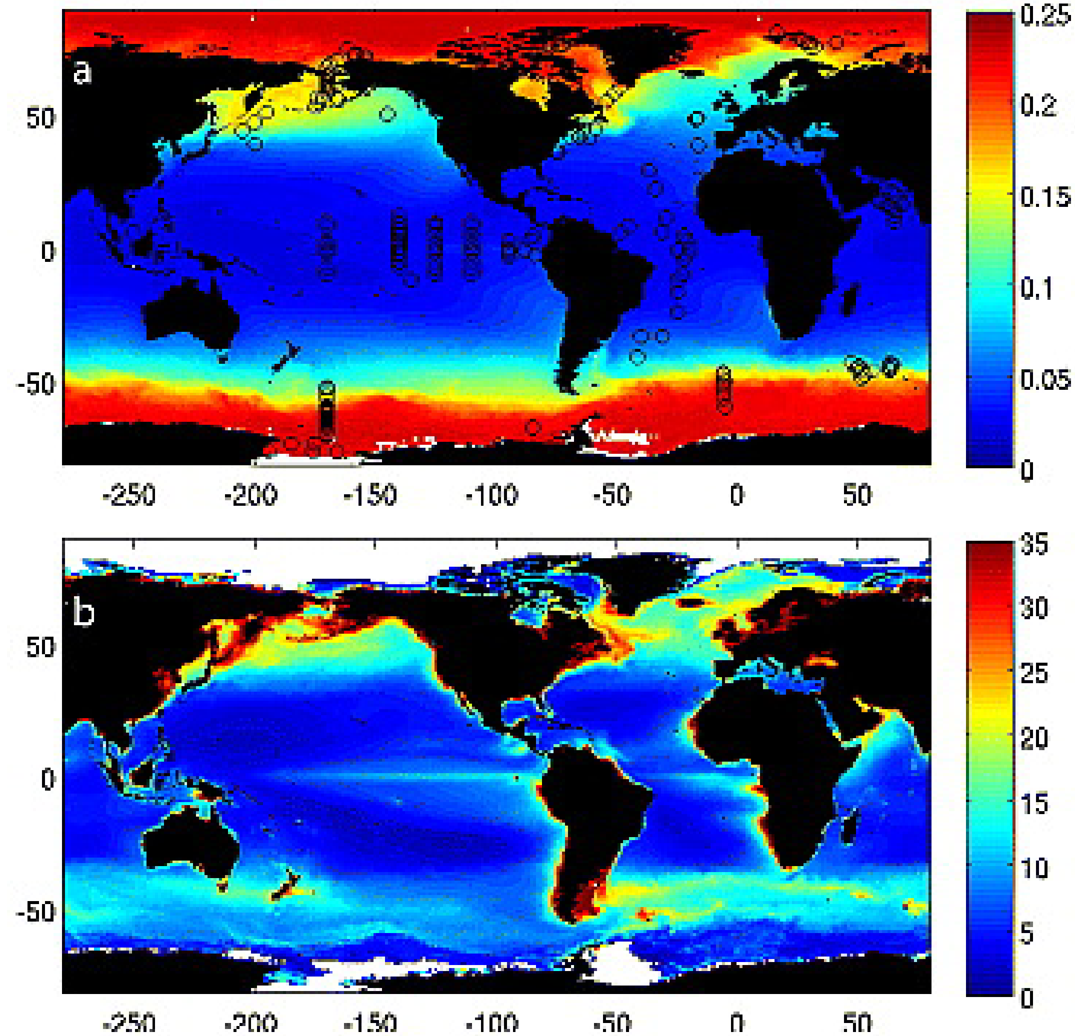
Extrapolated Global Fluxes

Th-E ratio @100m

Export @100 m

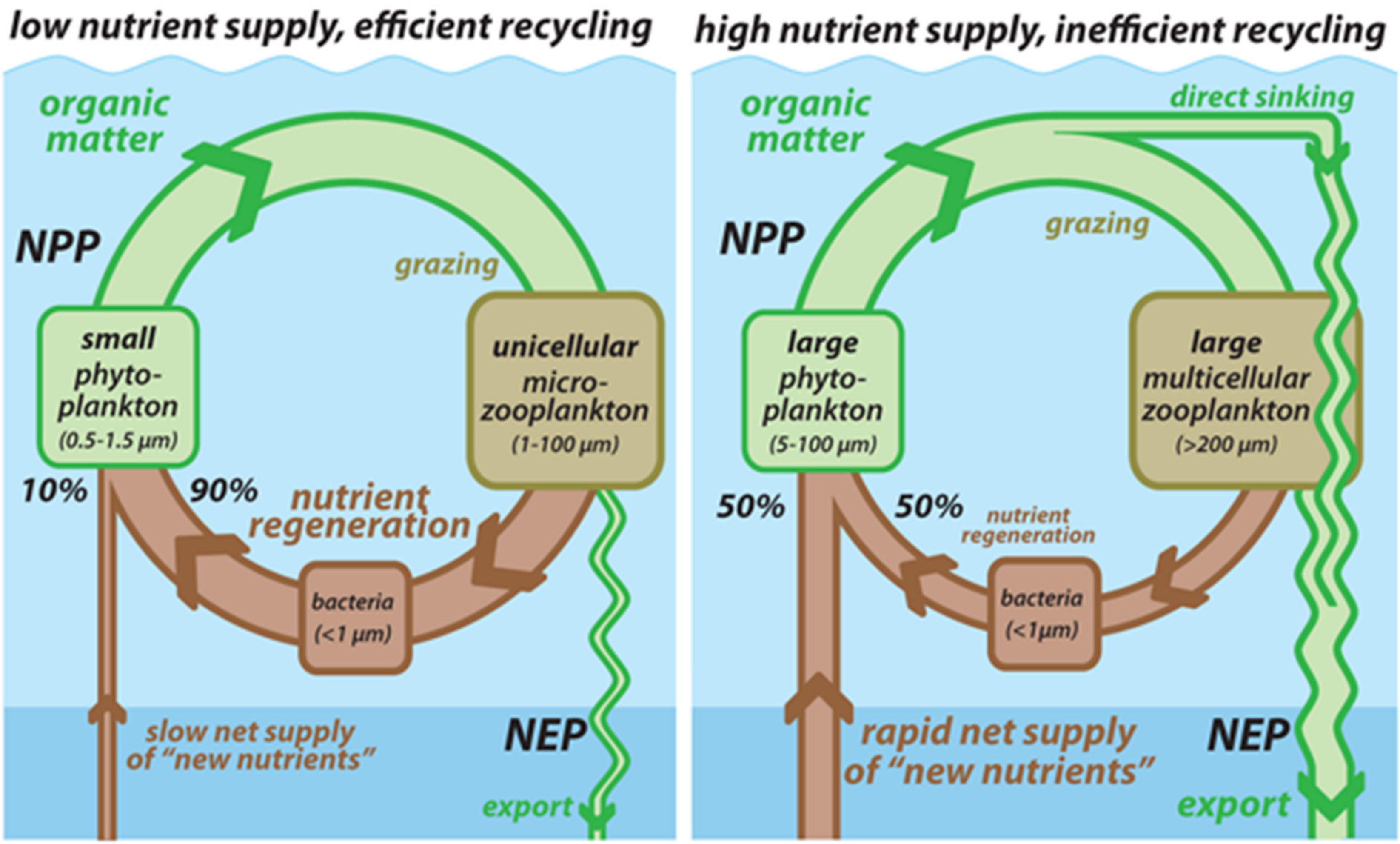
(gC m^2 y^{-1})

Global ~4 Pg C y^{-1}



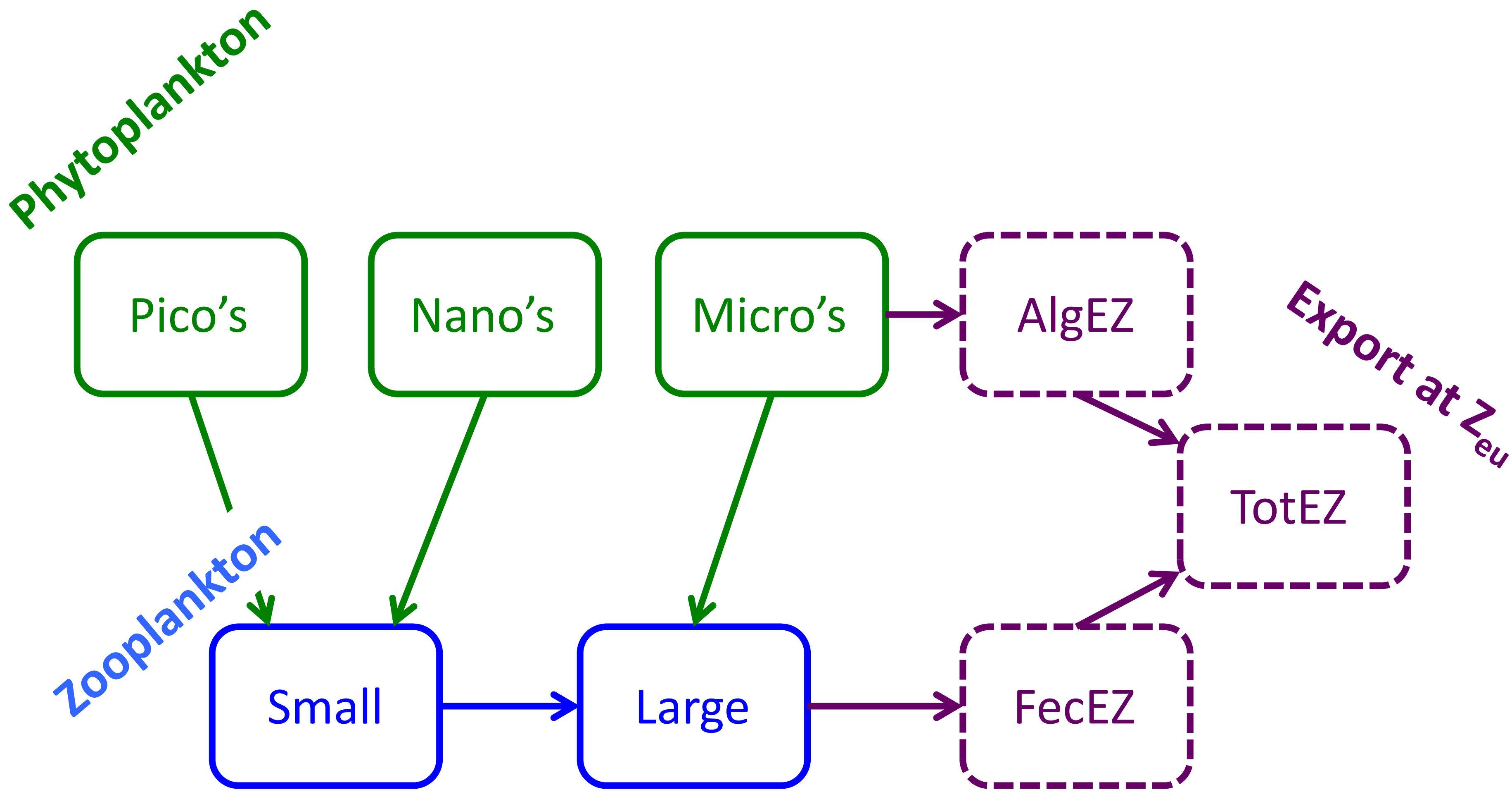
Henson et al. GRL [2011]

Food Web & Export



Sigman & Hain [2012] *Nature Education*

A Mechanistic Approach…



Following Michaels & Silver (1988), Boyd & Stevens (2002), many more…

New Satellite Tools…

- Carbon-based NPP (CbPM)

  NPP & phytoplankton Carbon

  Behrenfeld et al. (2005; *GBC*) & Westberry et al. (2008; *GBC*)

- Particle-size distribution products

  Partitioning of NPP & C stocks by fraction biovolume

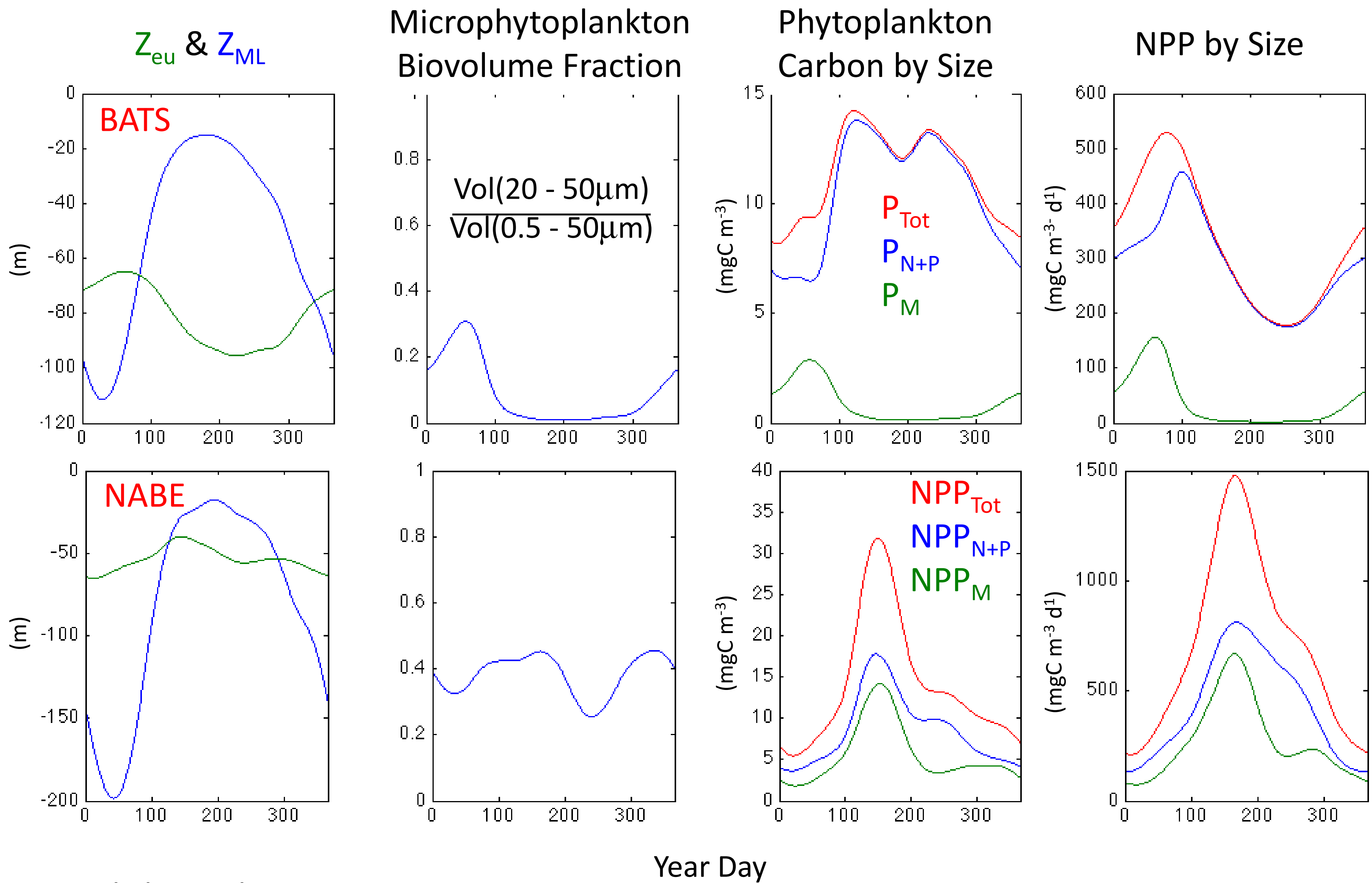
  Kostadinov et al. (2009; *JGR*) & (2010; *Biogeosciences*)

- Mass budgets for phytoplankton C stocks

  Enables upper layer grazing rates to be estimated

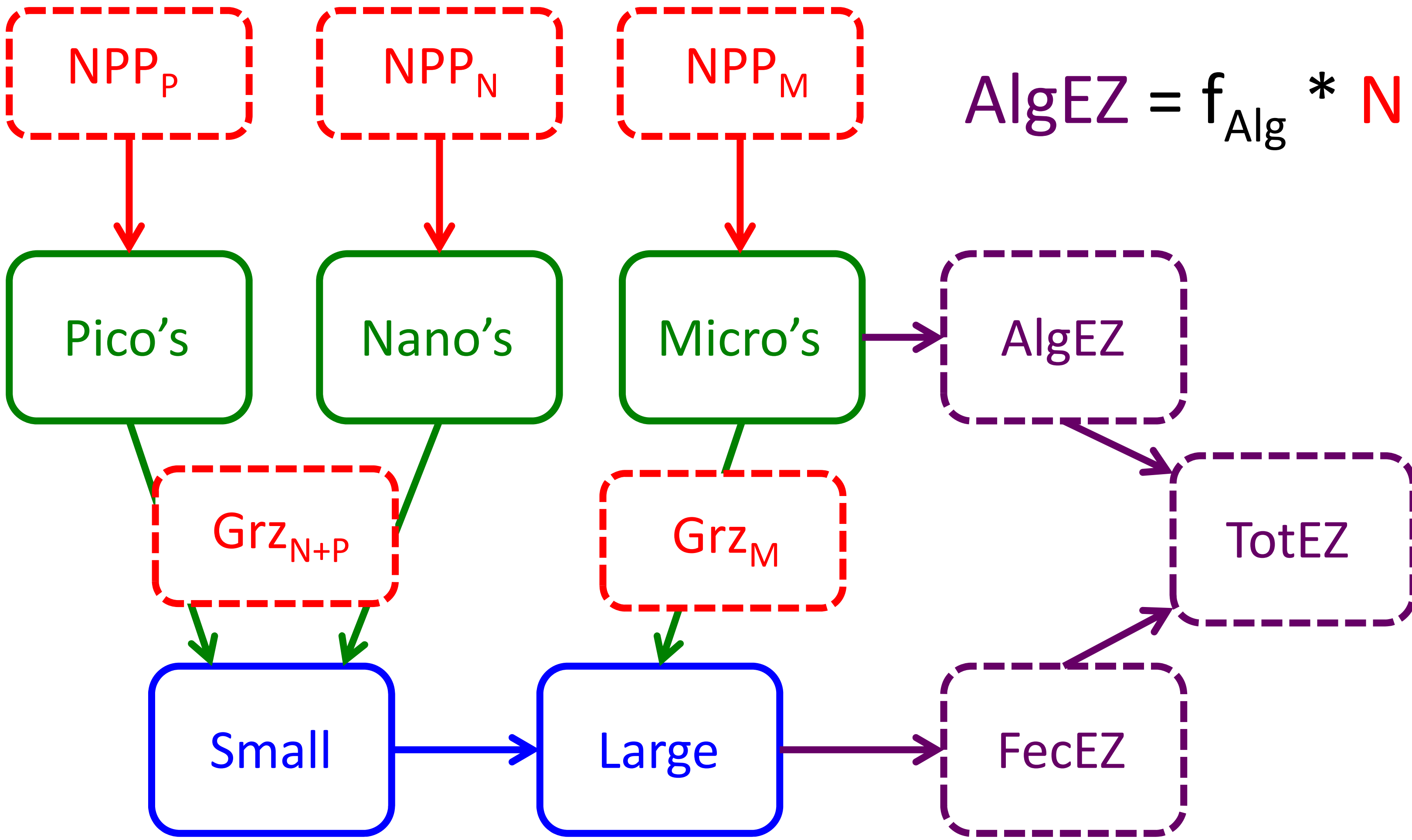
  Behrenfeld (2010; *Ecology*) & Behrenfeld et al. (2013; *GBC*)

New Satellite Tools…



Annual climatologies

A Mechanistic Approach…



$$AlgEZ = f_{Alg} * NPP_M$$

$$FecEZ = (f_{FecN+P} * Grz_{N+P} + f_{FecM} * Grz_M) * Z_{eu}$$

Diagnosing Grazing Rates

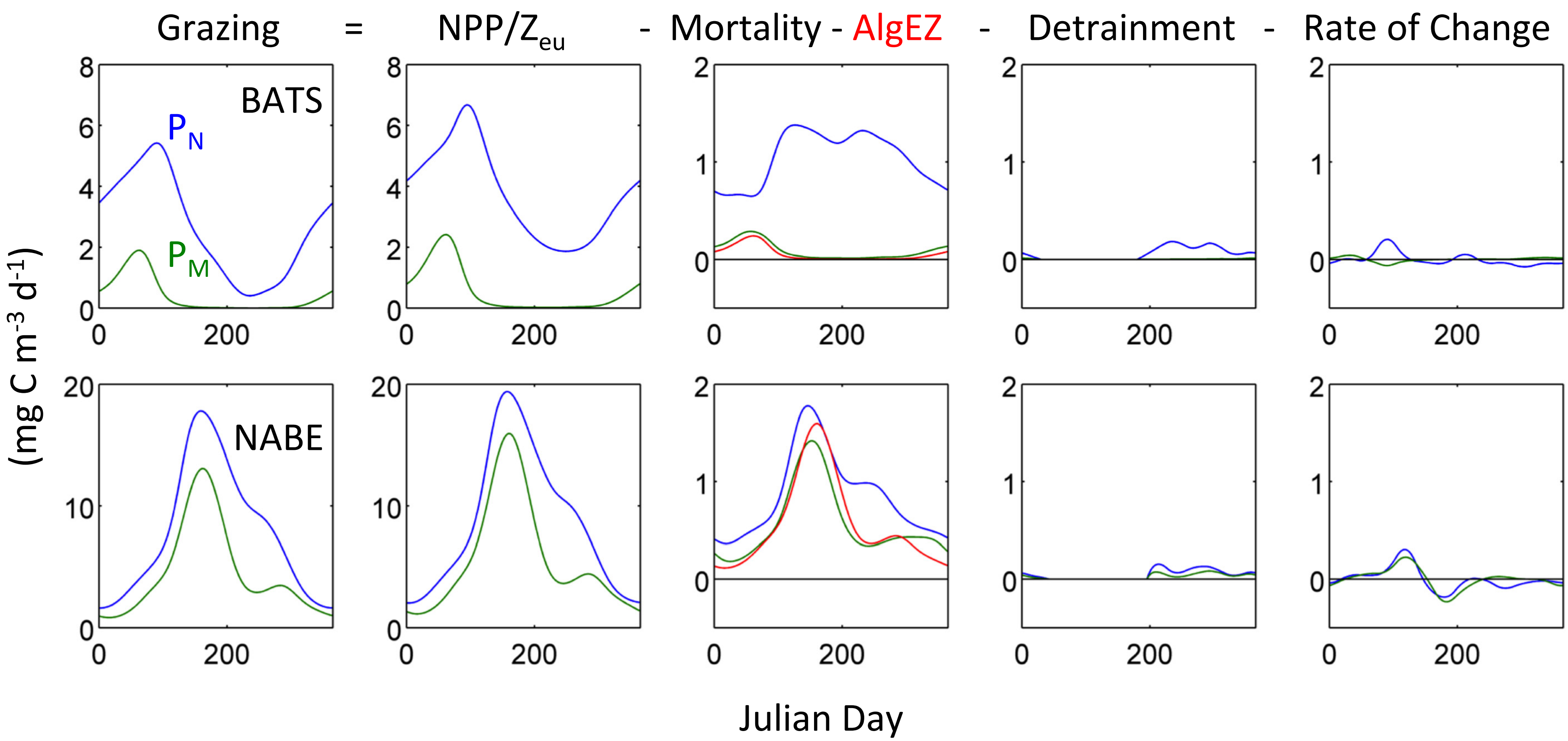
- Upper layer (Z_{ML}) phytoplankton biomass budget

$$\frac{dP_i}{dt} = \frac{NPP_i}{Z_{eu}} - Grz_i - m_i P_i - \frac{AlgEZ_i}{Z_{eu}} - Detrn(Z_{ml}, P_i)$$

unsteady NPP/vol grazing mortality direct sinking loss detrainment

- Grz_i & $AlgEZ_i$ are the only unknowns
- Model $AlgEZ_M = f_{Alg} * NPP_M$ where $f_{Alg} = 0.1$
- Let $m_i = 0.1\ d^{-1}$ (non-grazing, biological losses)
- Solve for Grz_{N+P} and Grz_M

Diagnosing Grazing Rates



- NPP roughly balances grazing
- All other terms are much smaller

Modeling Export Flux

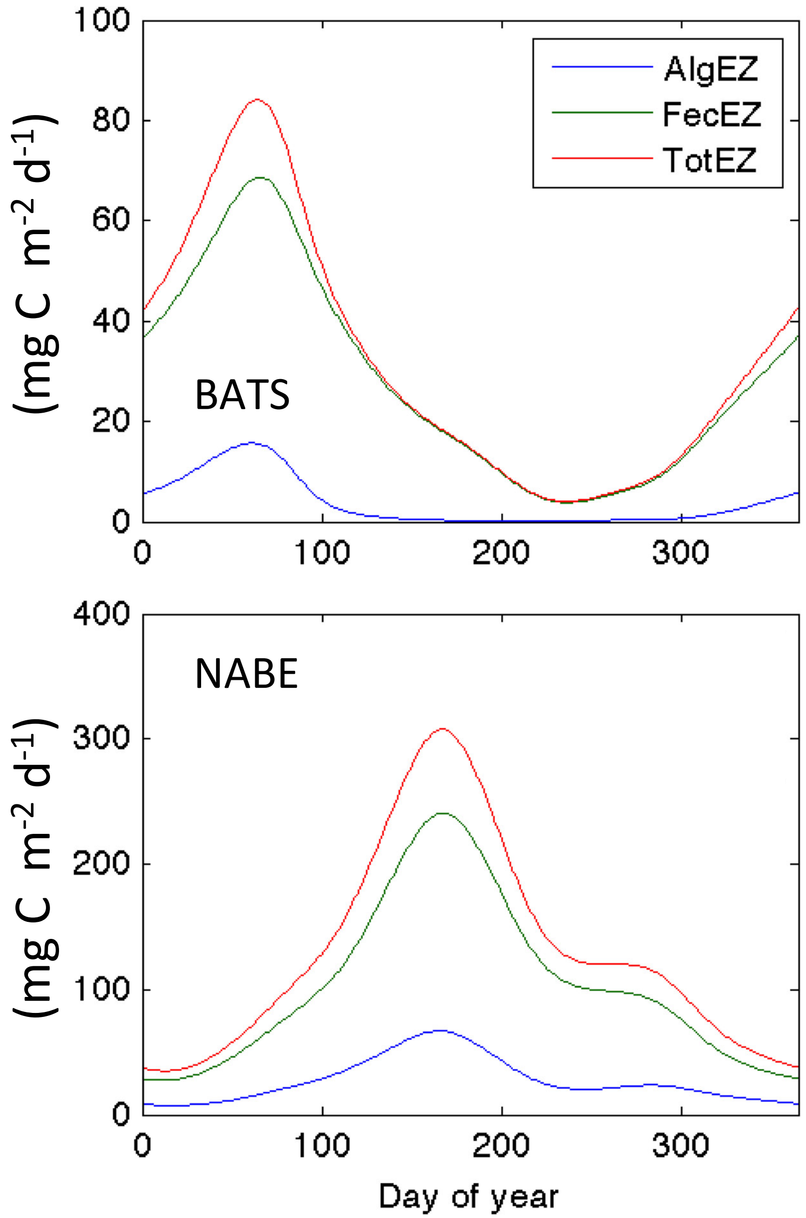
$AlgEZ = f_{Alg} * NPP_M$

$f_{Alg} = 0.1$

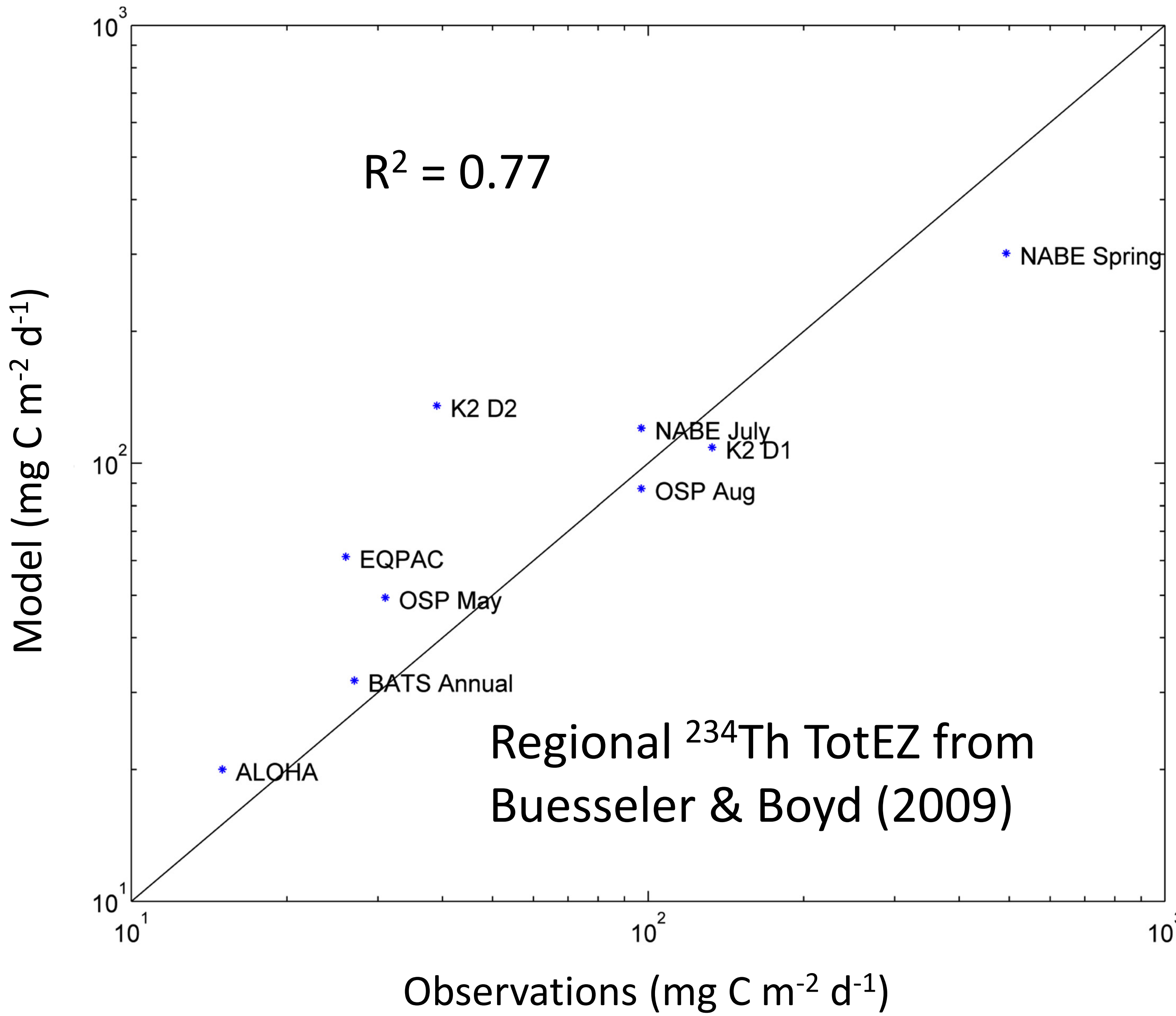
$FecEZ = (f_{FecM} * Grz_M + f_{FecN+P} * Grz_{N+P}) * Z_{eu}$

$f_{FecM} = 0.3$ & $f_{FecN+P} = 0.1$

$TotEZ = AlgEZ + FecEZ$

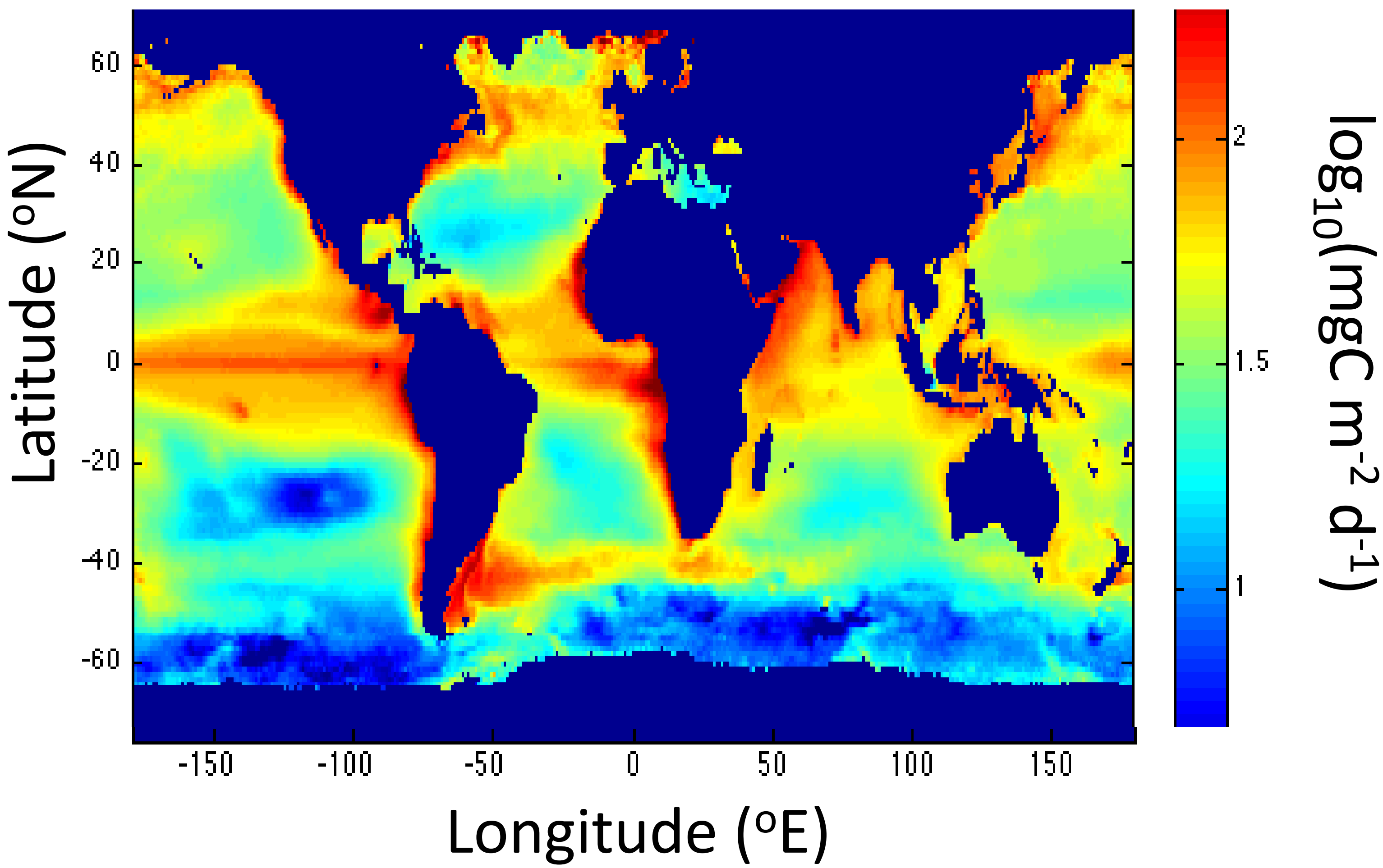


So, Does It Work??



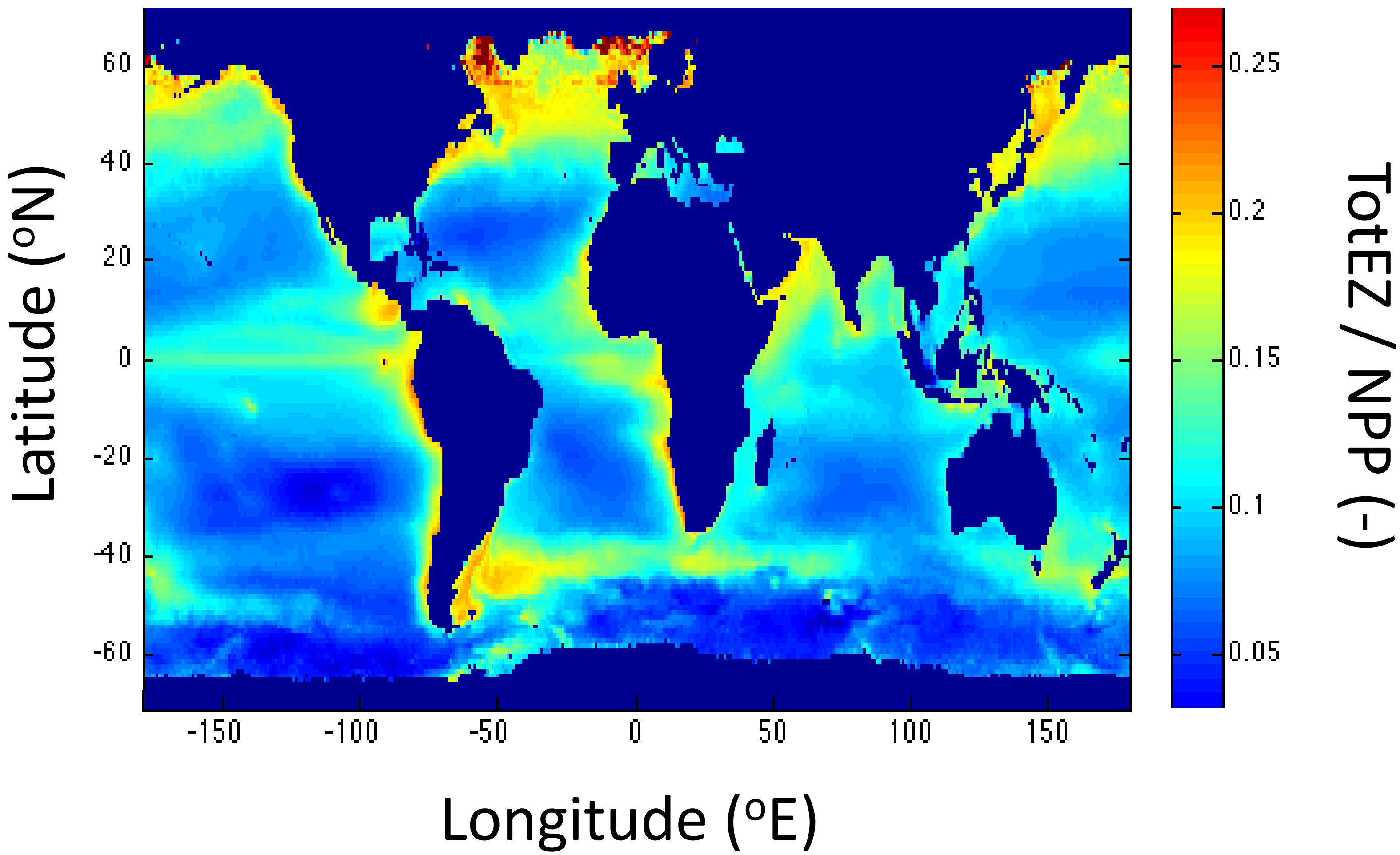
*Not completely fair as model is a climatology and the observations are not

Annual TotEZ



Total = 5.7 Pg C y^{-1}

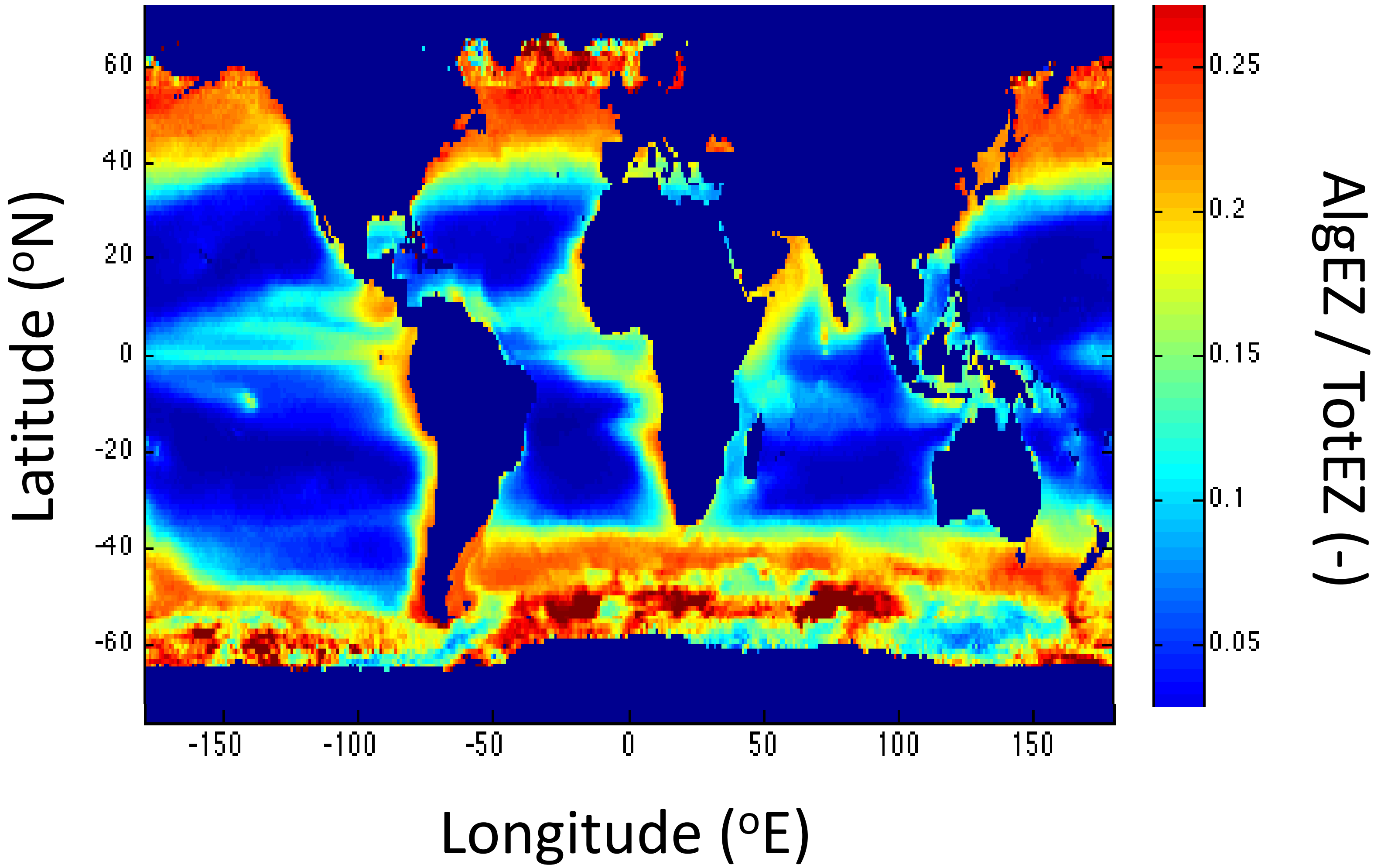
Annual Mean EZ-Ratio



Global average = 0.10 ± 0.05

Does not look like SST!!

Annual AlgEZ / TotEZ



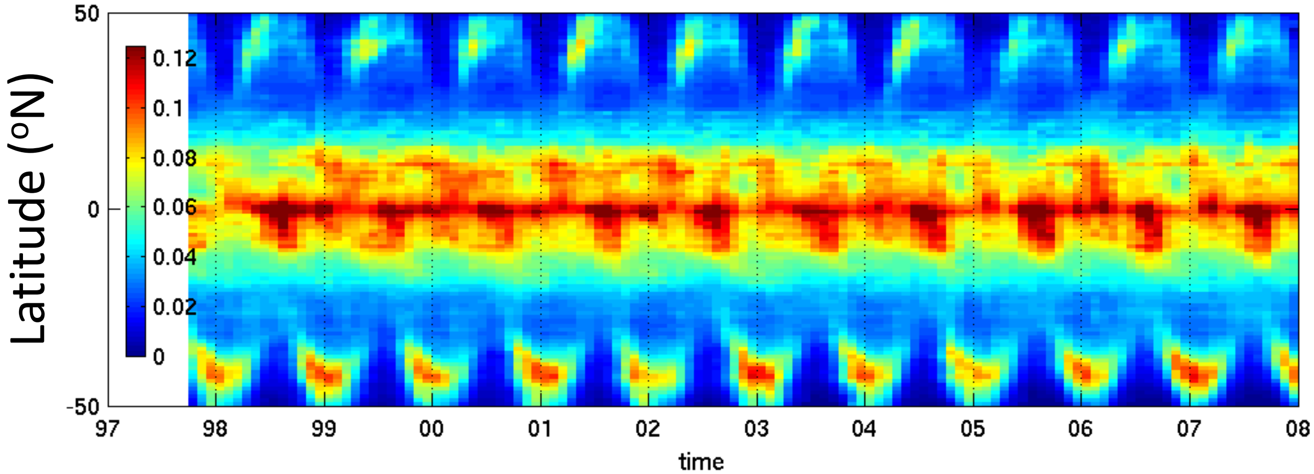
Global average = 0.12 ± 0.06

So, Is It Robust??

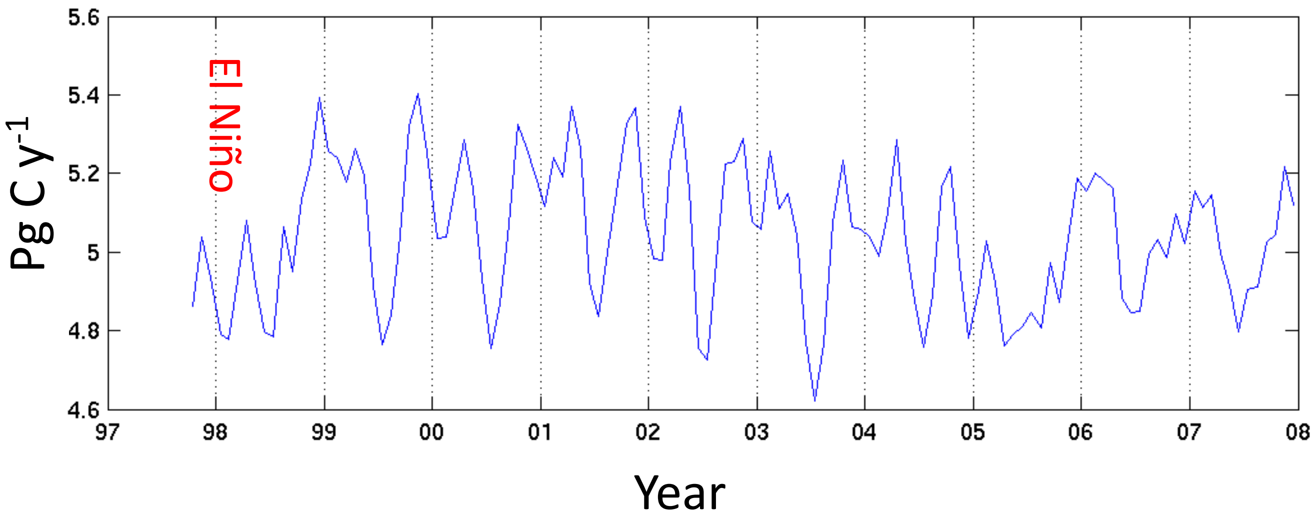
	f_{alg} (-)	m_{ph} (d^{-1})	f_{fecM} (-)	f_{fecN+P} (-)	Global TotEZ ($Pg\ C\ y^{-1}$)
Baseline	0.1	0.1	0.3	0.1	5.69
Alter f_{alg}	0.2	0.1	0.3	0.1	6.20
	0.05	0.1	0.3	0.1	5.43
Alter m_{ph}	0.1	0.2	0.3	0.1	4.52
	0.1	0.05	0.3	0.1	6.32
Alter f_{fecM}	0.1	0.1	0.4	0.1	6.21
	0.1	0.1	0.2	0.1	5.16
Alter f_{fecN+P}	0.1	0.1	0.3	0.05	4.00
	0.1	0.1	0.3	0.2	9.07

Using VGPM for NPP model, we get 5.4 $Pg\ C\ y^{-1}$

Interannual Changes in TotEZ



Contribution from each latitude band to global total

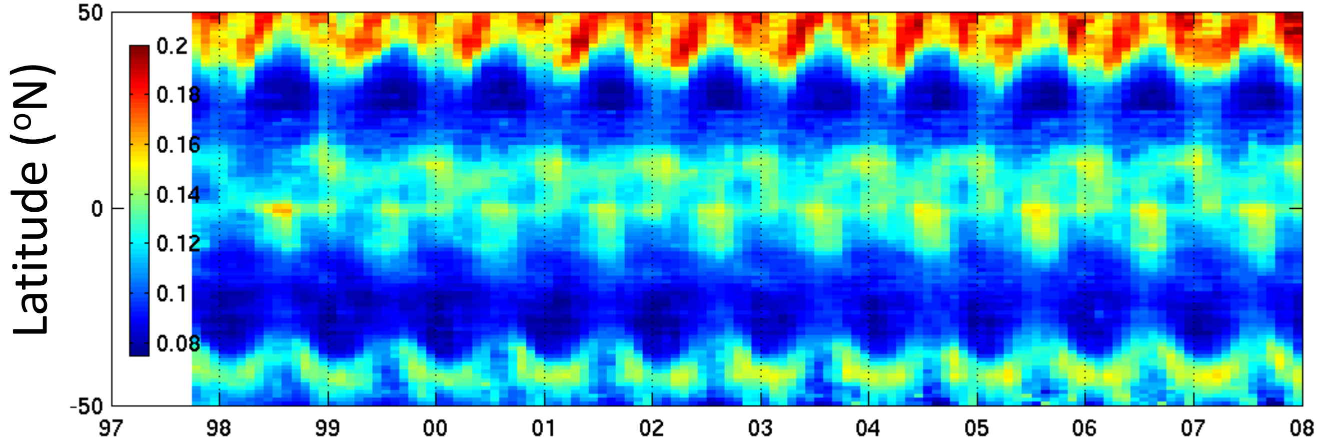


Sum from 50N to 50S

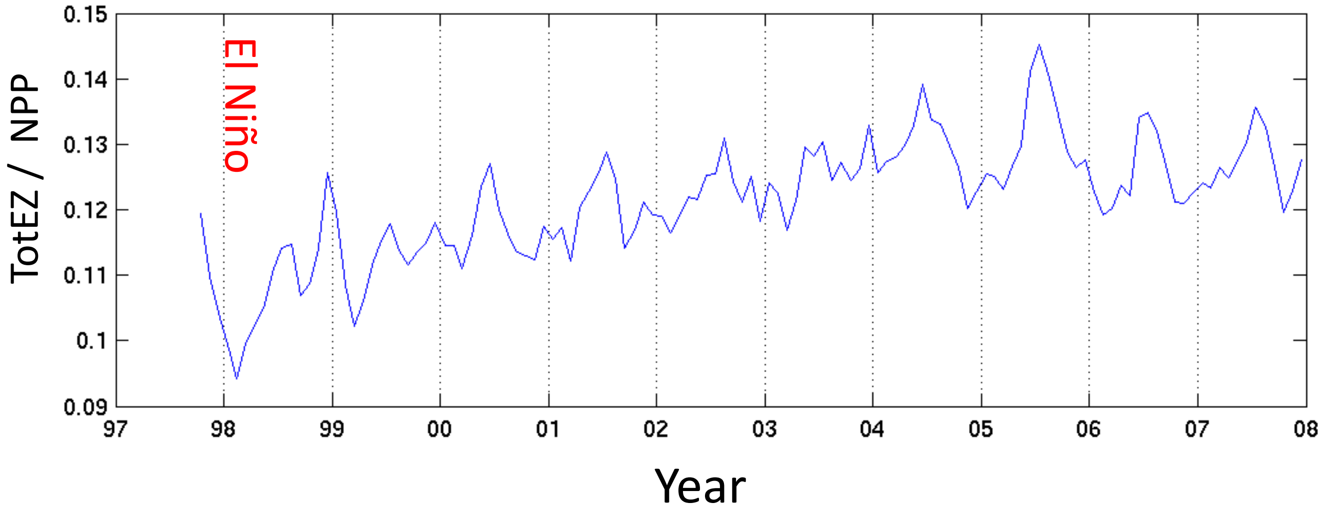
Global variability is ~0.7 Pg C y^{-1}

Very Preliminary!!!

Interannual EZ-Ratio



Average for each latitude band



Areal weighted average from 50N to 50S

Shows an increasing trend in global EZ-ratio (from 10 to 14%)

- related to slope of the PSD as observed by Kostadinov et al. [2010]

Summary of Results

- Mechanistic model for global C export on sinking particles from the euphotic zone

  Four parameters – make sense physically (at least to me)

  Model successfully recreates regional observations &is robust to large parameter variations

- Global TotEZ ~ 5.7 Pg C y^{-1} & EZ-ratio ~ 0.1

- Interannual variations are significant for both global TotEZ and EZ-ratio

Implications

- Global estimates of upper ocean grazing rates

  Mixed layer grazing rates balance NPP to first order

  Global estimates of secondary production are useful for many other applications…

  Predicts zooplankton activity - $Grz_M = \alpha$ [Zoo] $[P_M]$ knowing $[P_M]$, we can solve for α $[Zoo]_M$

- Should focus our attention on ...

  transformations (What really are f_{AlgM}, f_{FecM}, f_{FecN+P}, etc.?)

  improving remote sensing obs (PhytoC, PSD, NPP, etc.)


Thank you for your attention!!