Phytoplankton cell size from ocean color imagery: connection to variability in the ocean carbon sink

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Photo David Doubilet

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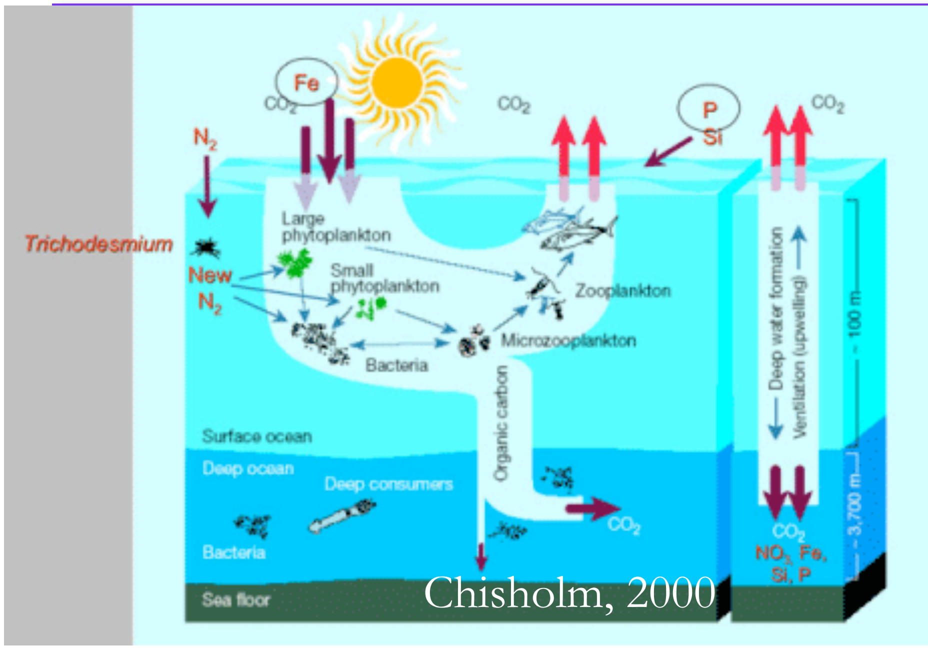
Ecological Importance of Cell Size

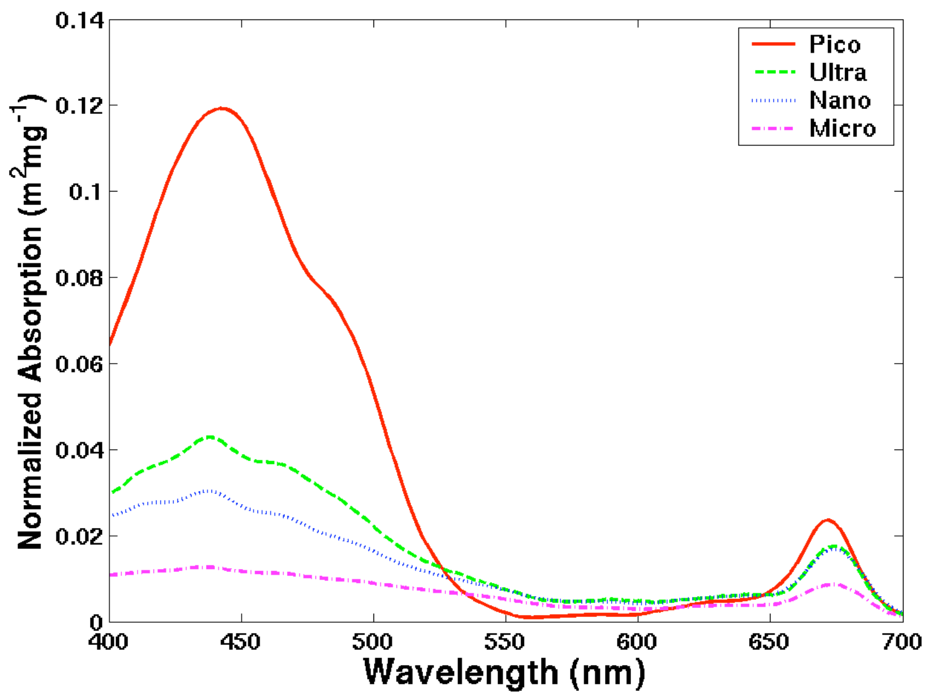


- Small cells:
  - recycled within euphotic zone
  - utilizing regenerated nutrients
  - Prefer stratified high light conditions
- Large cells:
  - sink out of the euphotic zone
  - utilize new nutrients efficiently
  - Prefer turbulent, low light conditions

- Unifying principals that mechanistically explain global, annual mean patterns and seasonal to interannual variations in particulate flux to depth remain elusive.
- Links between variation in export and air-sea CO_2 flux and its temporal variation have only begun to be explored.
- Previous studies suggest [Chl] and PP are not enough to accurately predict flux.
- Phytoplankton cell size is a critical determinant of flux.

Optical Importance of Cell Size

- Despite the physiological and taxonomic variability, variation in spectral shape can be defined by changes in the dominant size class.



Ciotti et al. 2002

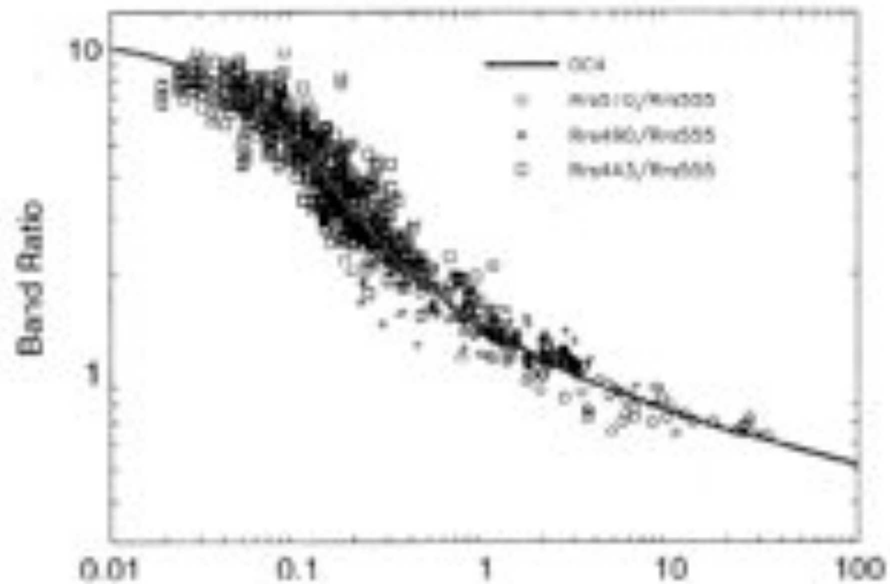
$$a^*_{ph}(\lambda) = [(1-S_f) \times a^*_{pico}(\lambda)] + [S_f \times a^*_{micro}(\lambda)]$$

Package effect

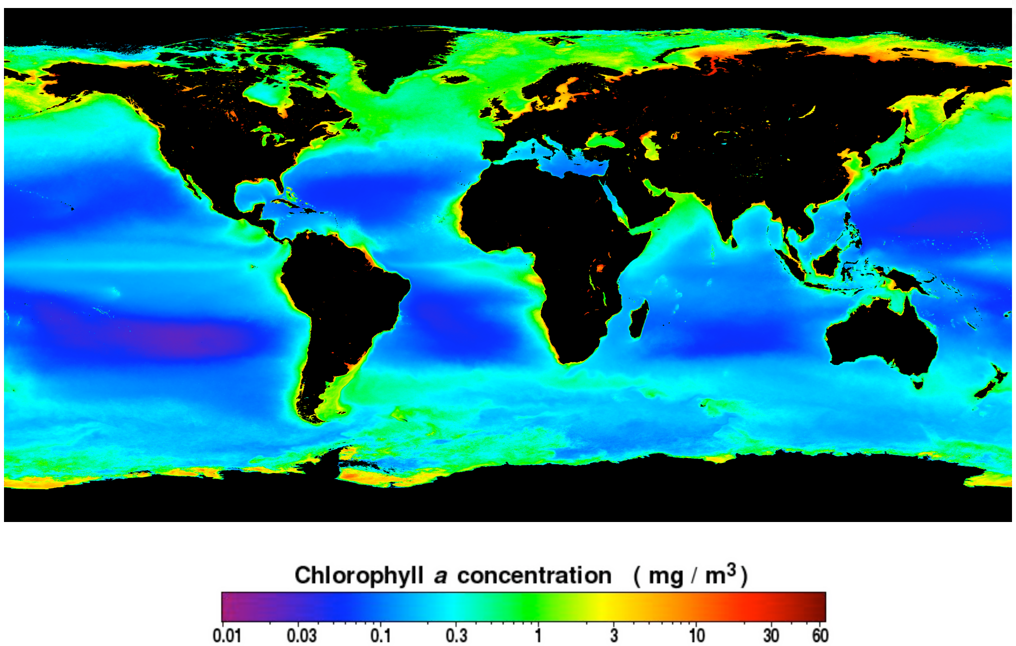
Motivation

- $R_{rs}(\lambda)$ data contains more information than just concentration.

$R = \log\{(R_{rs}443 > R_{rs}\,490 > R_{rs}510)/R_{rs}555\}$



Chl (mg m^{-3})



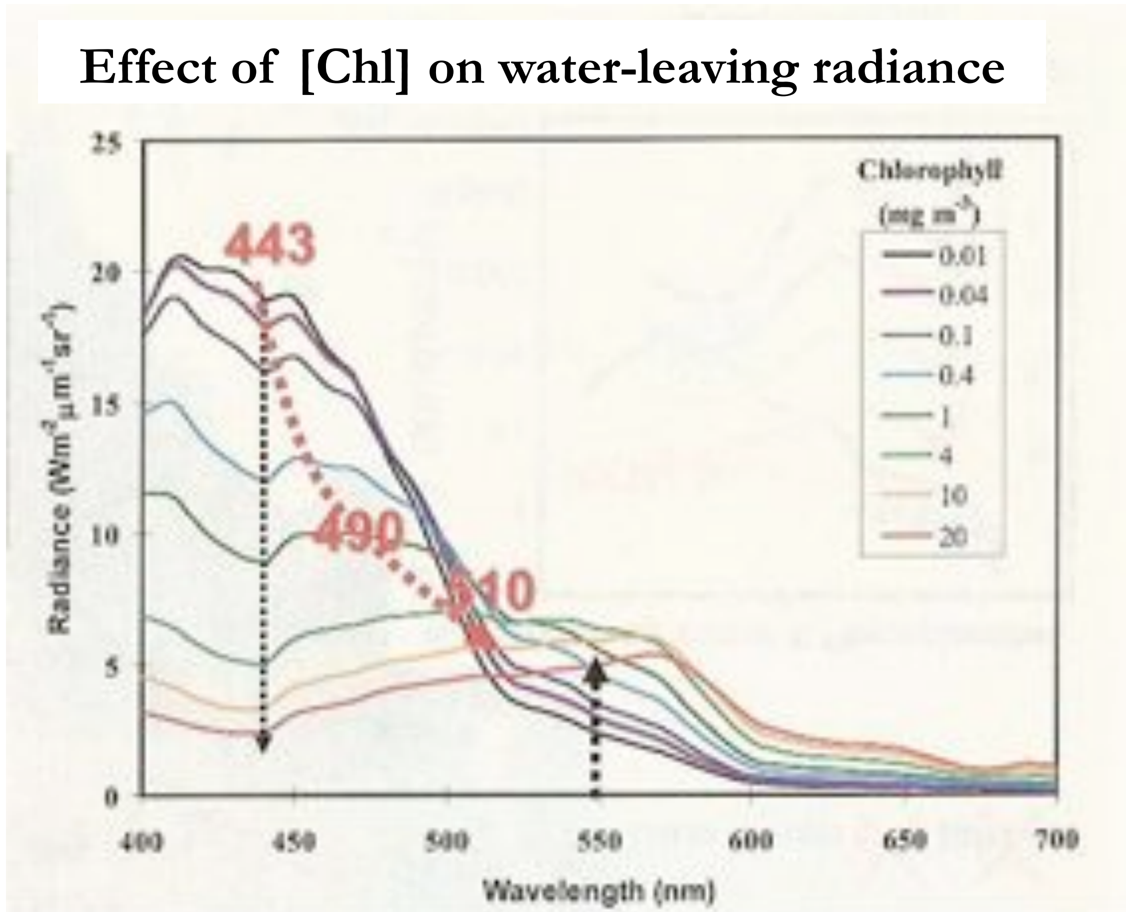
- SeaWiFS standard chlorophyll algorithm (OC4).

O'Reilly et al. 1998

Effect of [Chl] on $R_{rs}(\lambda)$

Maximum **band shifts** from 443 to 490 to 510 nm with increasing chlorophyll concentration

Spectral shift

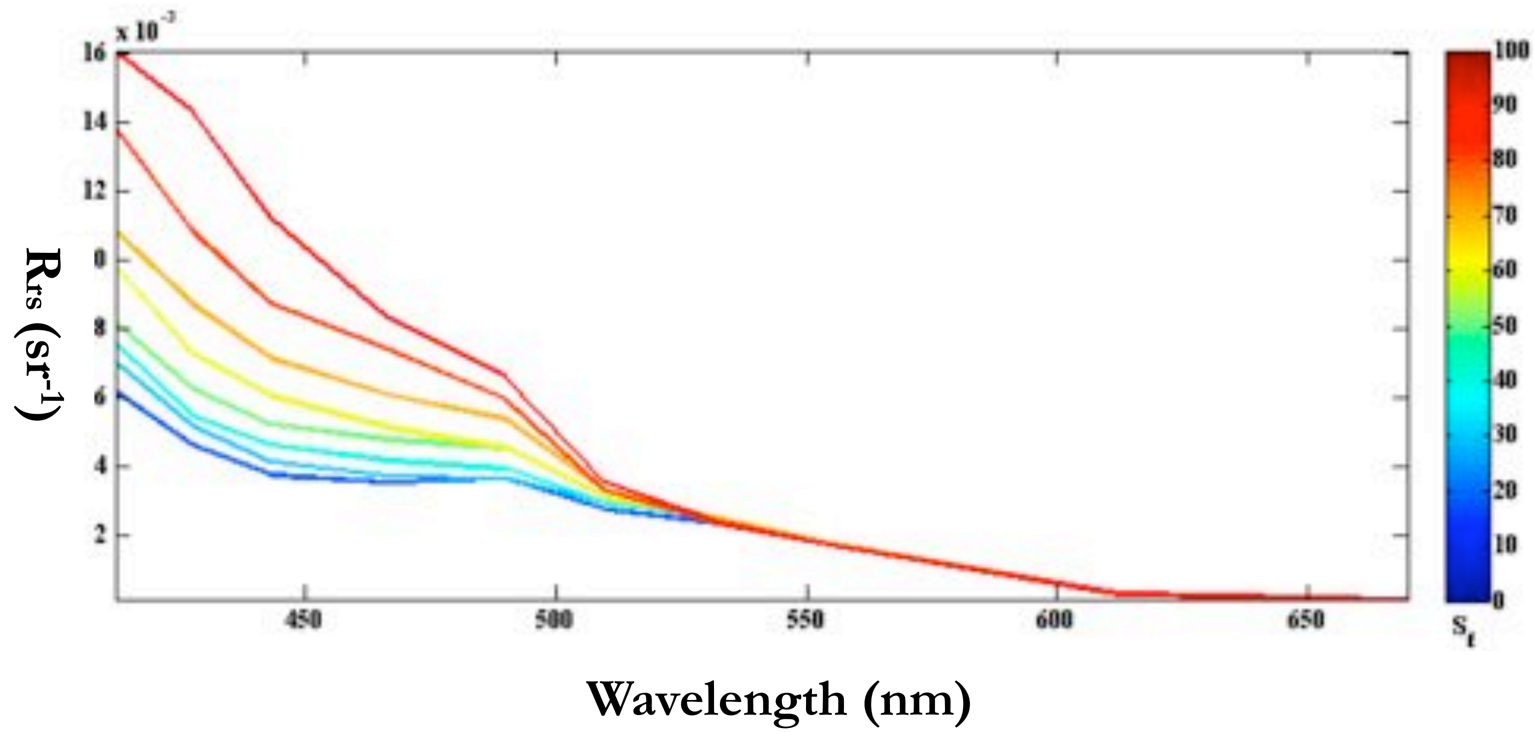


O'Reilly et al. 1998

Effect of Cell Size on $R_{rs}(\lambda)$

S_{fm} varying
Constant [Chl] = 0.5 mg m^{-3}
Constant $a_{CDM}(443)$ = 0.002 m^{-1}

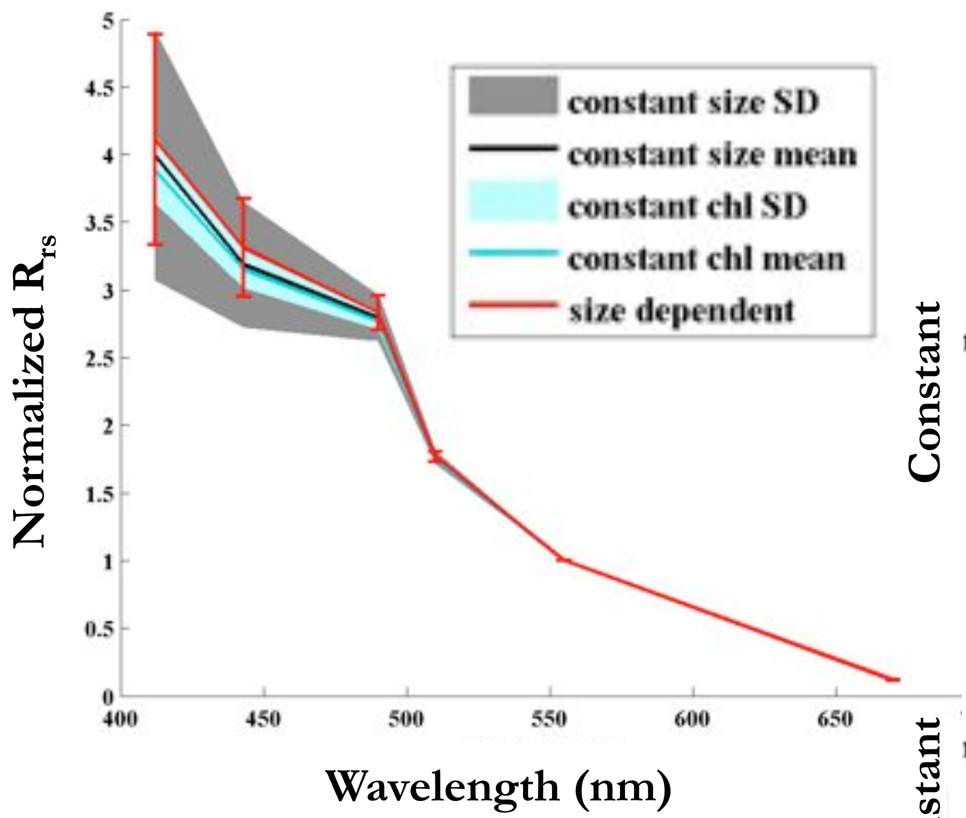
Magnitude shift!

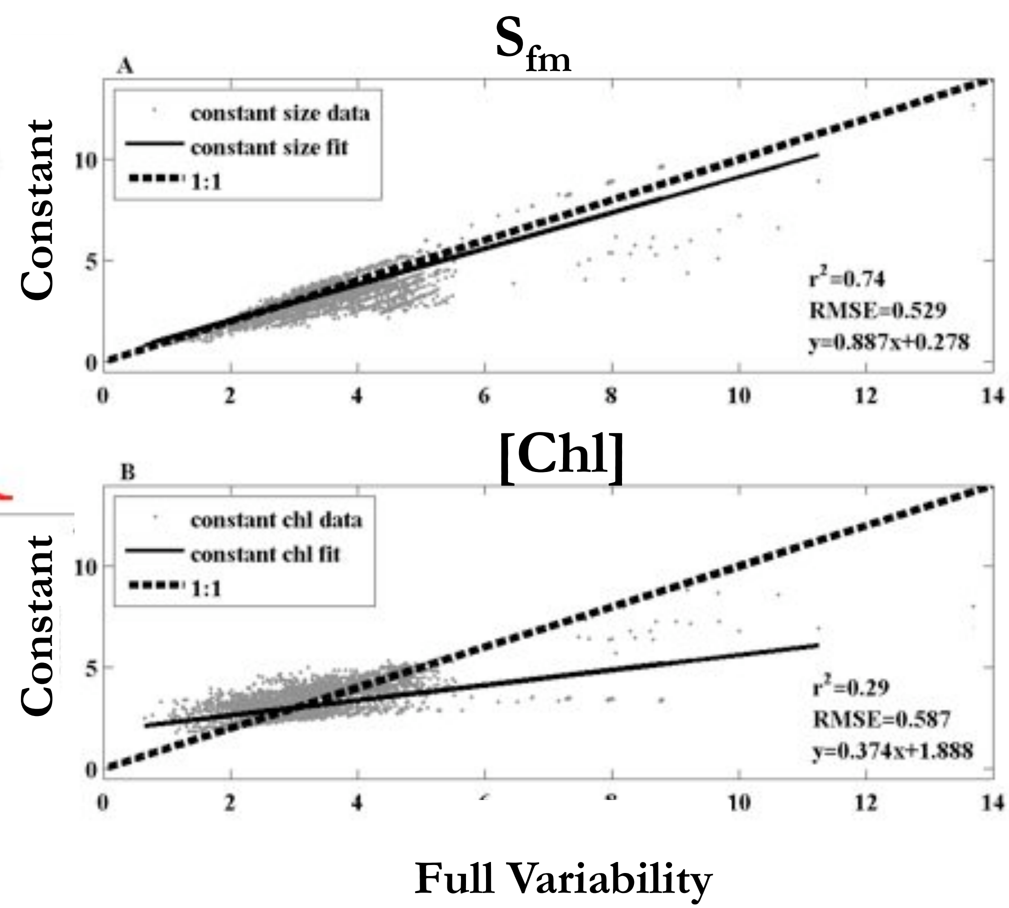


Mouw & Yoder, 2010

Contribution of S_{fm} & [Chl] to $R_{rs}(\lambda)$

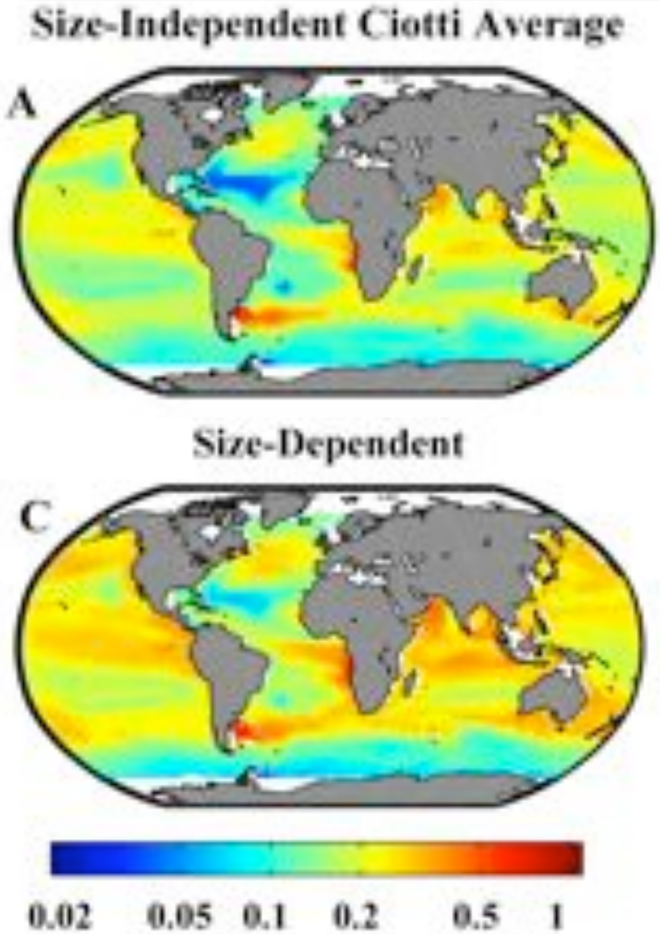
Variations in [Chl] impact $R_{rs}(443)$ more significantly than S_{fm} variations.





Mouw, Yoder & Doney, submitted

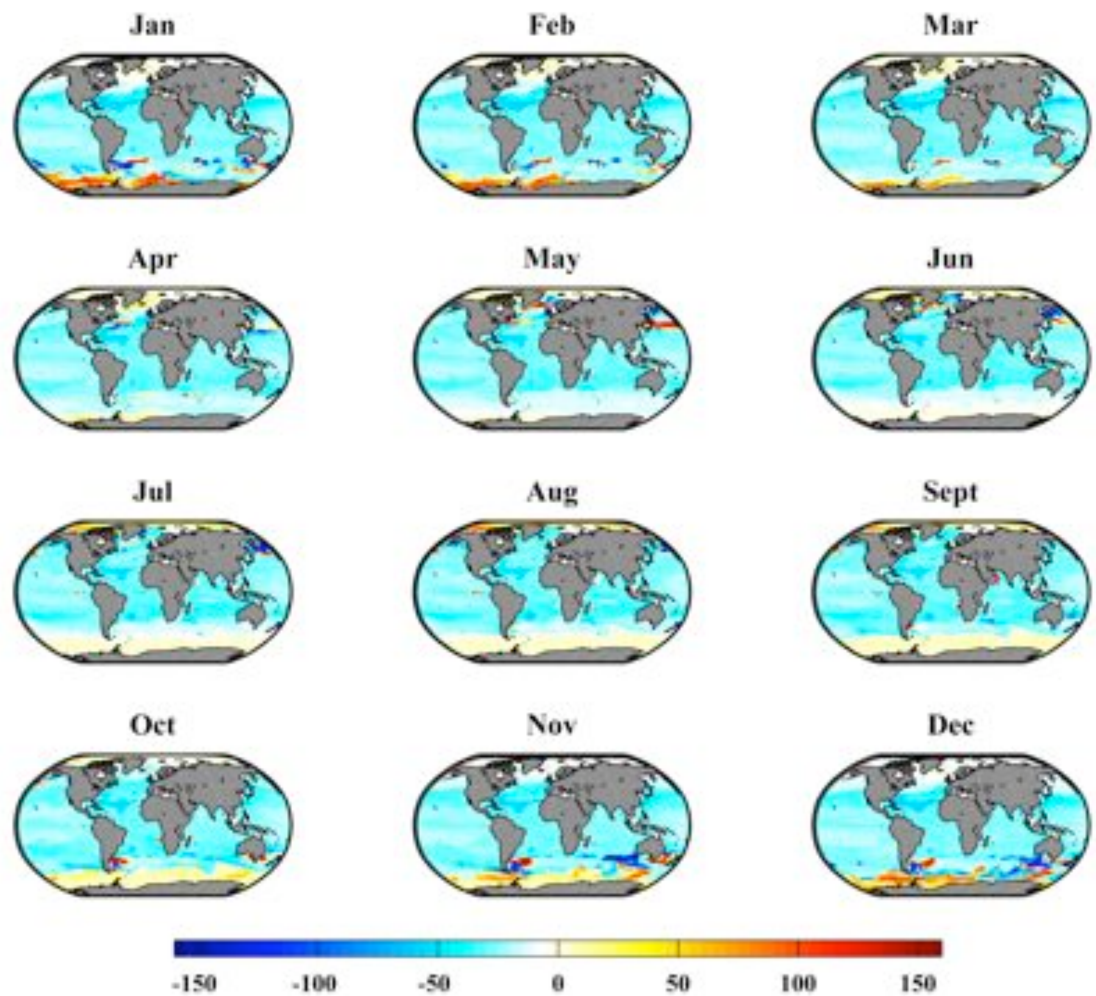
Size Impact on OC4 [Chl]



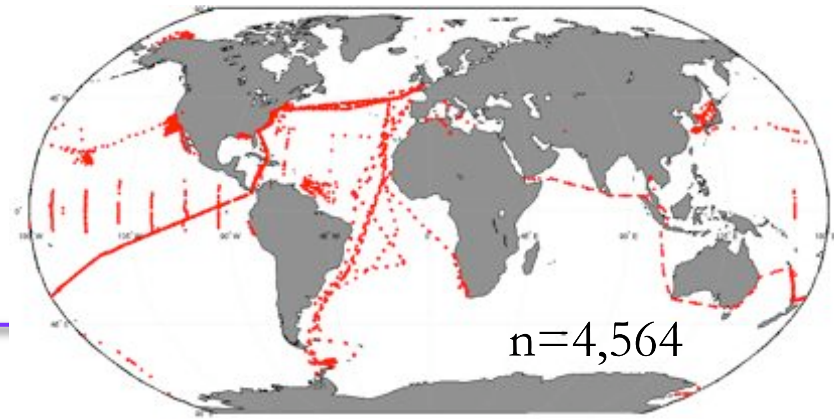
22% Difference

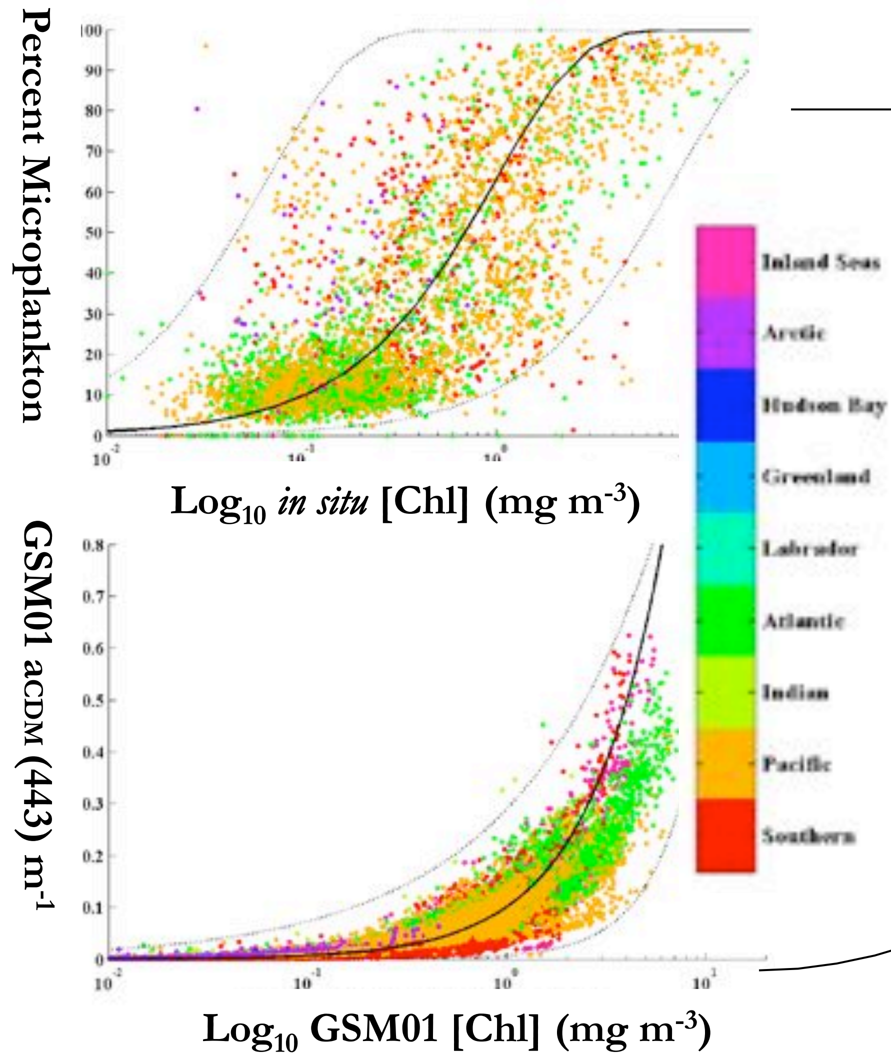
Mouw, Yoder & Doney, submitted

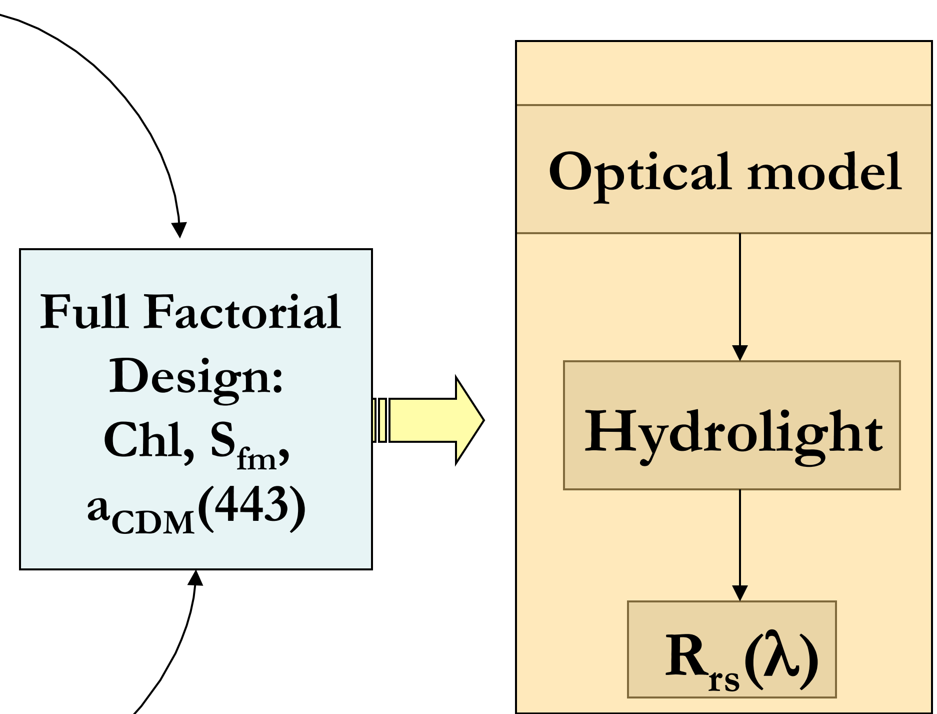
Percent Difference



LUT Construction



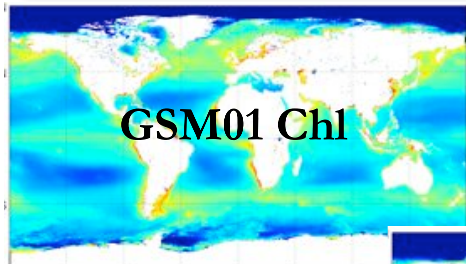




n = 44,343

Mouw & Yoder, 2010

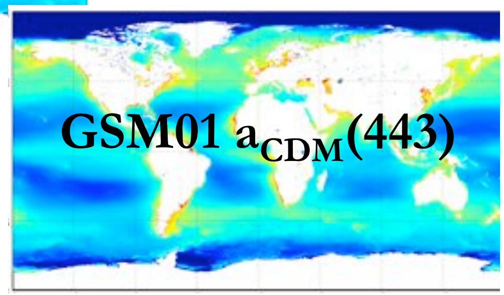
LUT Retrieval



If [Chl] above/below threshold < ⇒ Mask

If [Chl] within threshold ⇒ Continue

0.05 - 1.75 mg m^{-3}



If a_{CDM}(443) > threshold ⇒ Mask

If a_{CDM}(443) < threshold ⇒ Continue

< 0.17 m^{-1}

Hydrolight Normalized R_{rs}(443) (S_{fm} range)

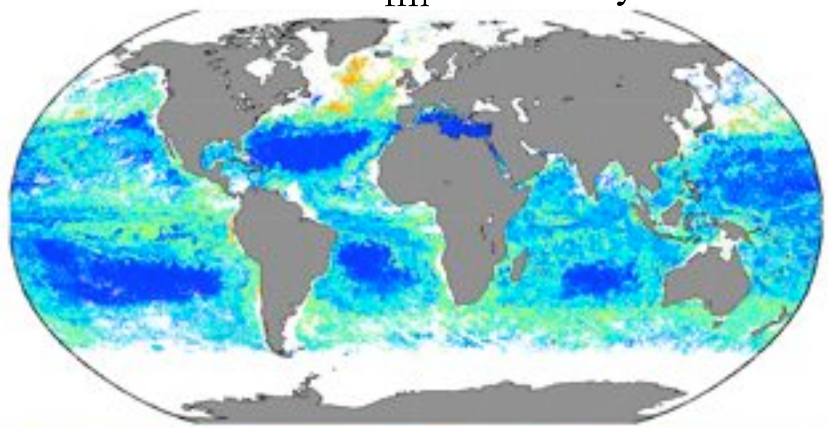
S_{fm}

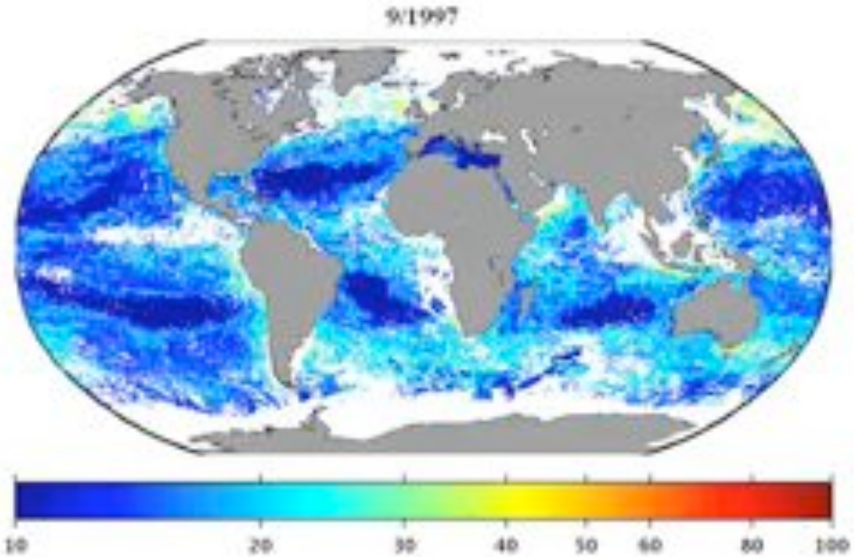
$R_{rs}(\lambda)$ imagery ⇒

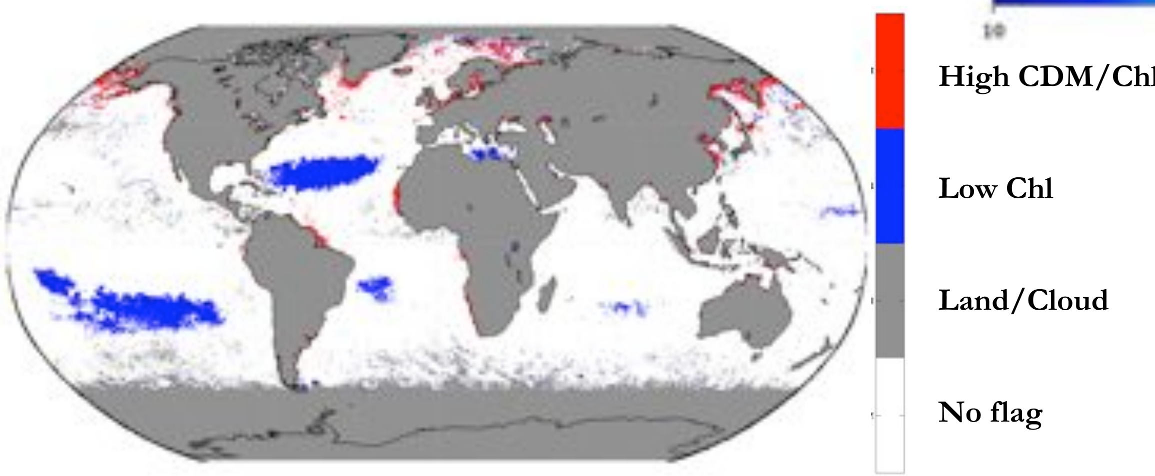
Mouw & Yoder, 2010

Phytoplankton Size Retrieval

Estimated S_{fm} for May 2006







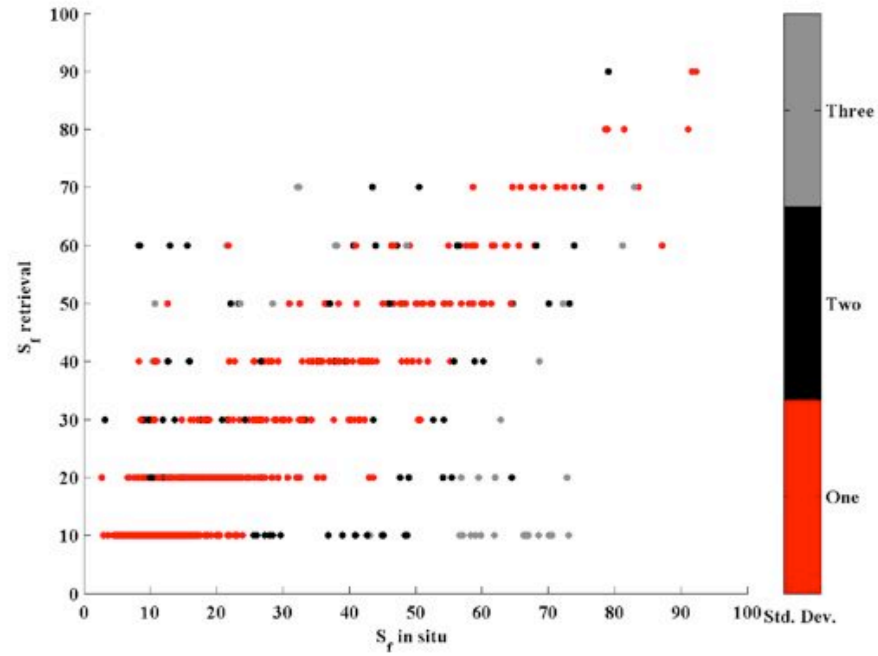
Beyond NEΔR_{rs} thresholds

- Process the remainder of the SeaWiFS mission
- Process MODIS-Aqua for the whole mission

Mouw & Yoder, 2010

Validation

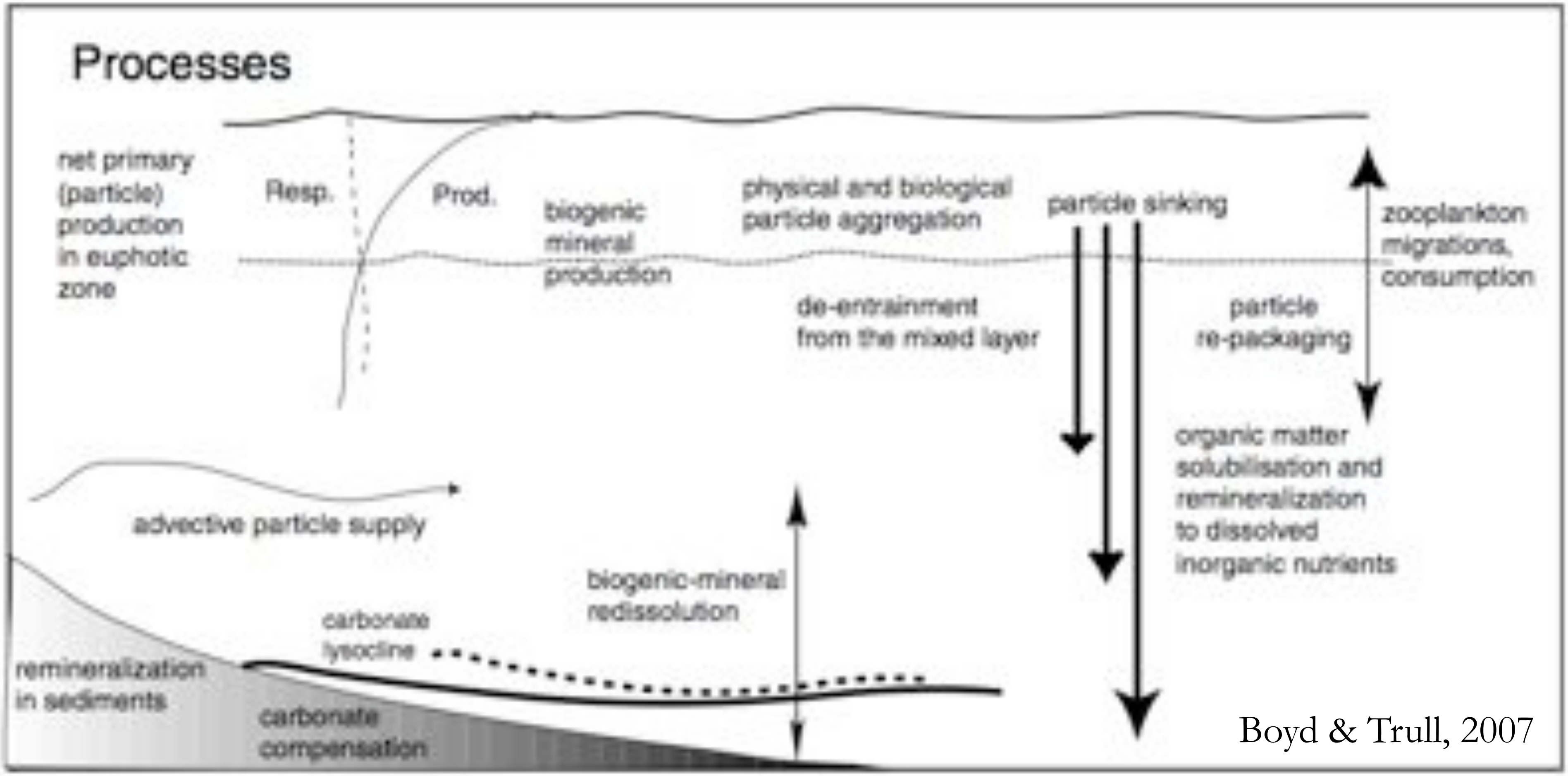
- 85% within 1 standard deviation
- 11%, 2 std. dev.
- 4%, 3 std. dev.



Publication	Validation Measure	Mouw & Yoder, 2010
Kostadinov et al., 2009	$r^2 = 0.21$ for PSD slope	$r^2 = 0.60$ for all data
Kostadinov et al. 2010	r^2=0.415, RMS=17.1	r^2 = 0.60, RMS=12.6
Uitz et al., 2006	$\log_{10}$(predicted/measured) median=0.02 mean= -0.012 std. dev.=0.883	$\log_{10}$(predicted/measured) median=0.0058 mean=0.0054 std. dev.=0.2315
Hirata et al., 2008	classification success all data from AMT-07=73%	classification success within first std. dev. = 84%
Alvain et al., 2008	classification success all data=57%	classification success within first std. dev. = 84%

Mouw & Yoder, 2010

Export Processes

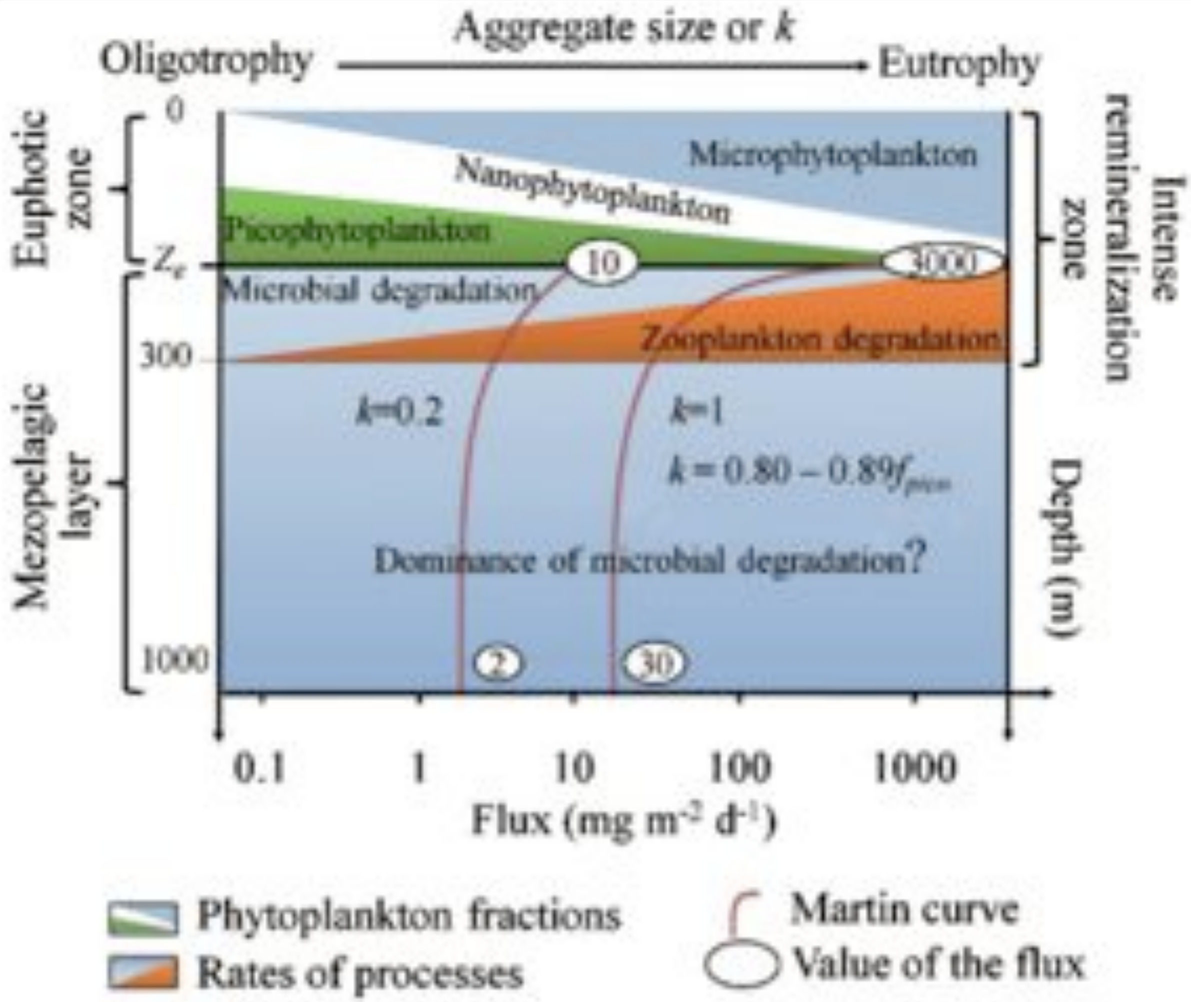


Biological pump efficiency – biologically mediated export of carbon from the surface ocean and its remineralization with depth.

Flux Variation with Depth

Martin Curve

$$F_z = F(z_0)\left(\frac{z}{z_0}\right)^{-k}$$



Guidi et al. 2009

Flux Variation with Depth

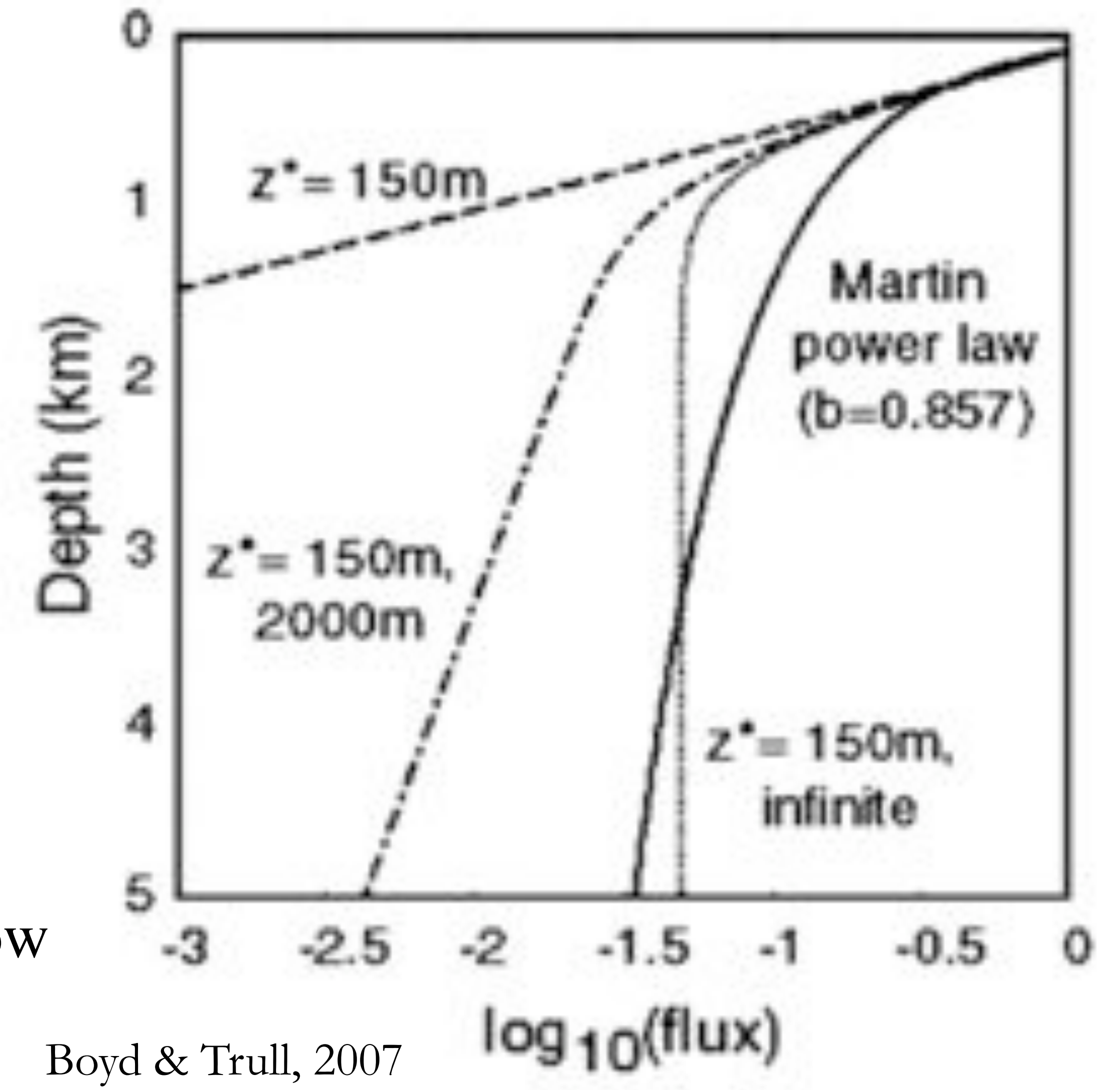
Martin Curve

$$F_z = F(z_0)\left(\frac{z}{z_0}\right)^{-k}$$

Lutz et al. 2002

$$F(t) = F(t_0)e^{\left(\frac{t-t_0}{t^*}\right)}$$

Martine curve - Underestimation of shallow remineralization.

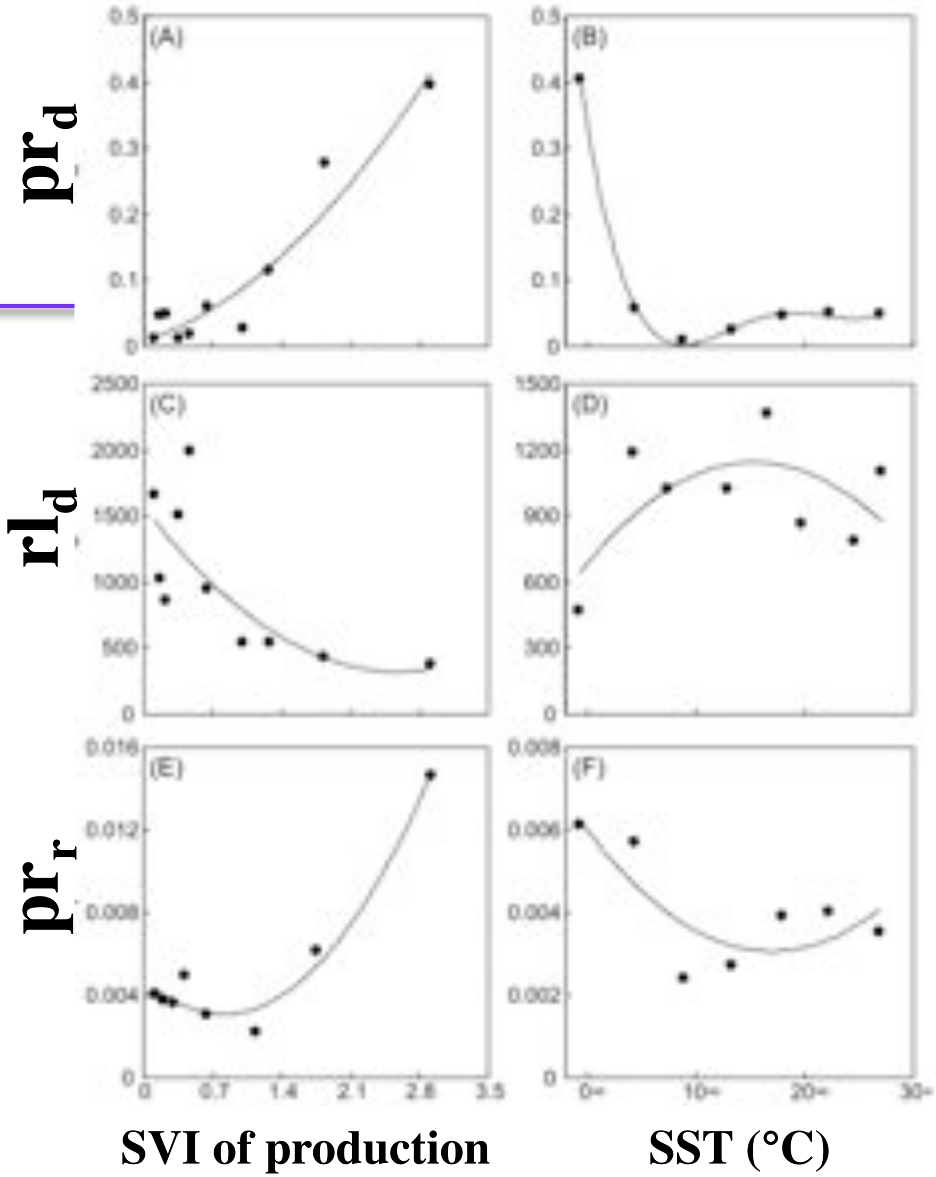


Boyd & Trull, 2007

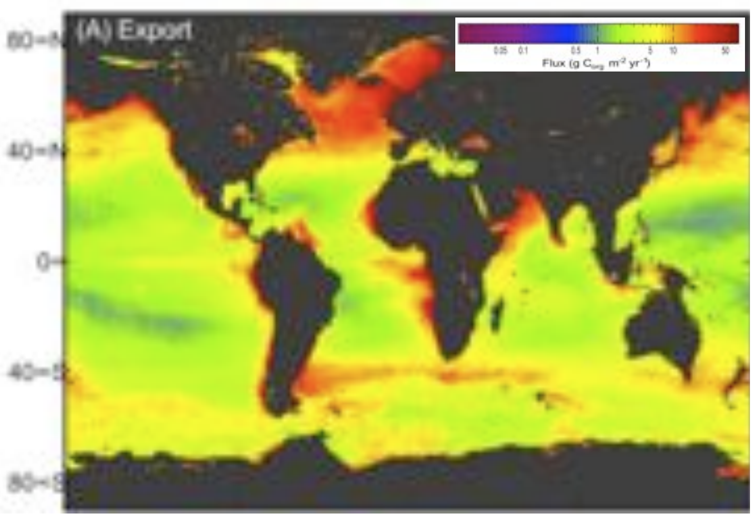
Previous Satellite Retrieval of Export

$$p(\Delta z) = pr_d \ \mathbf{exp}\left(\frac{-\Delta z}{rl_d}\right) + pr_r$$

p(Δz): particulate flux : total production
pr_d: liable export fraction
rl_d: remineralization scale
pr_r: refractory export fraction

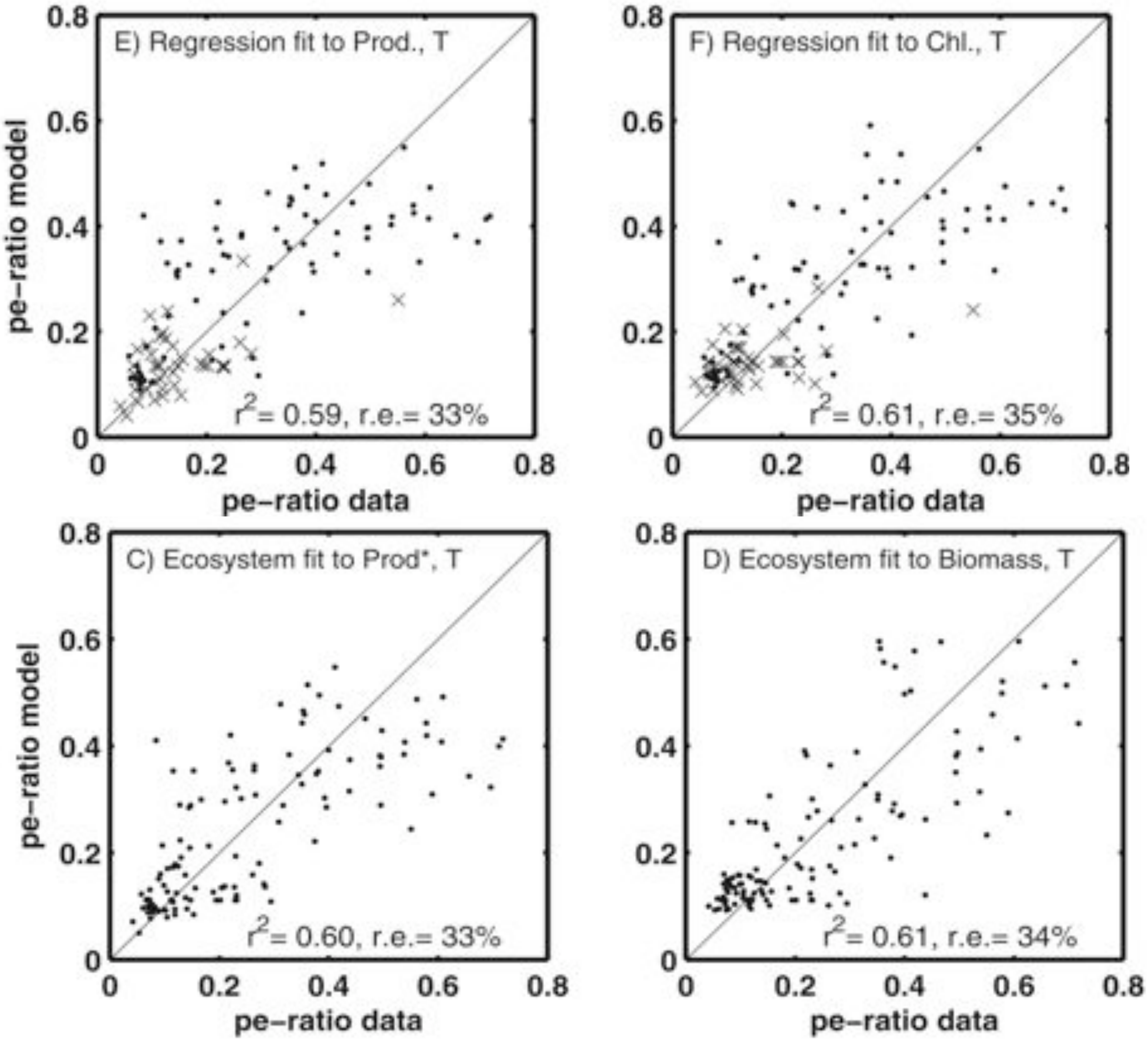


Relationships developed with selection of only data points that yielded a statistically significant fit – Does not add mechanistic understanding



Lutz et al. 2007

Previous Modeling of Export



Empirical

- Captures site-to-site variations, but not variability at specific sites.

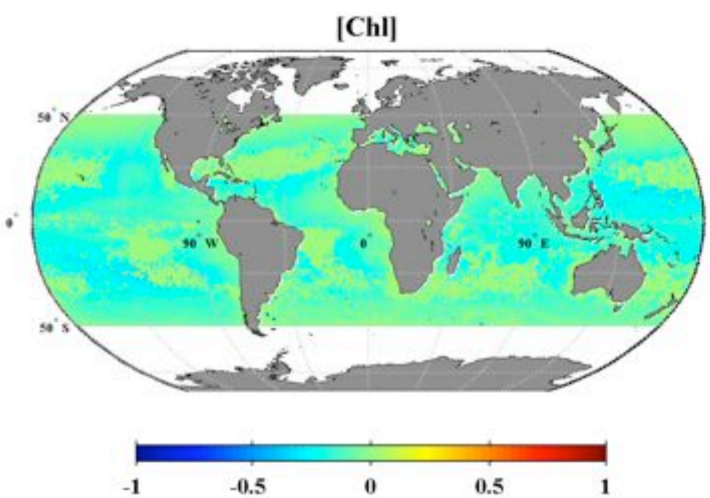
Mechanistic

- Full model (87%)
- Primary control – PP (59%)
- Proximate control – size (28%)

Dunne et al., 2005

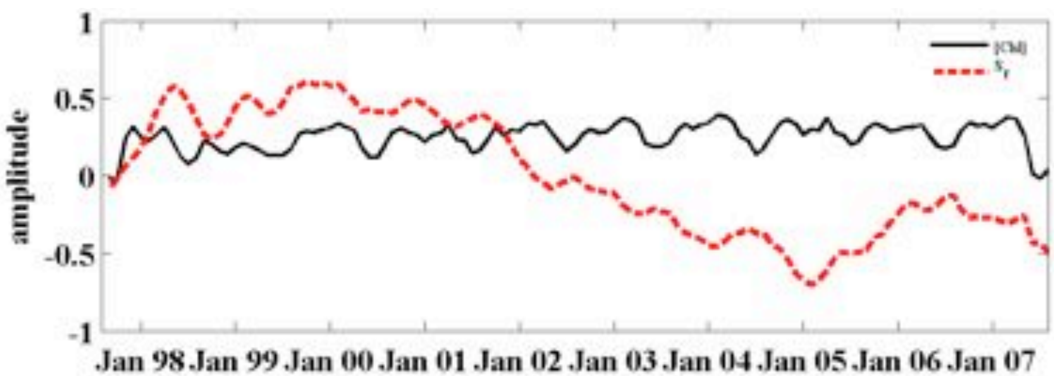
Individual EOF – Mode 1

S_{fm}

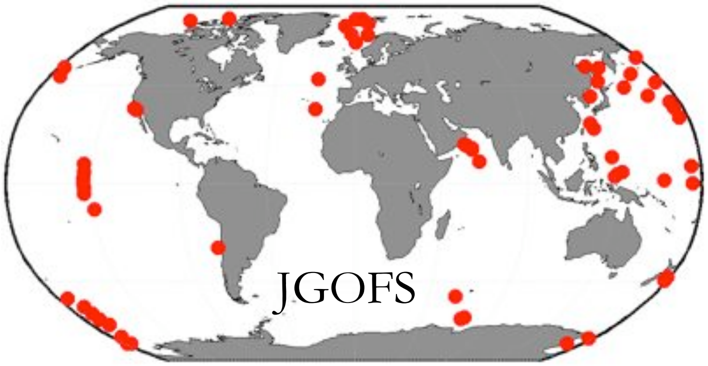


Mouw & Yoder, in prep.

- Global syntheses for particle export & remineralization have done a good job capturing differences between regions, but a poor job capturing seasonal & interannual variations at individual locations.
- Phytoplankton cell size displays greater interannual variability than chlorophyll

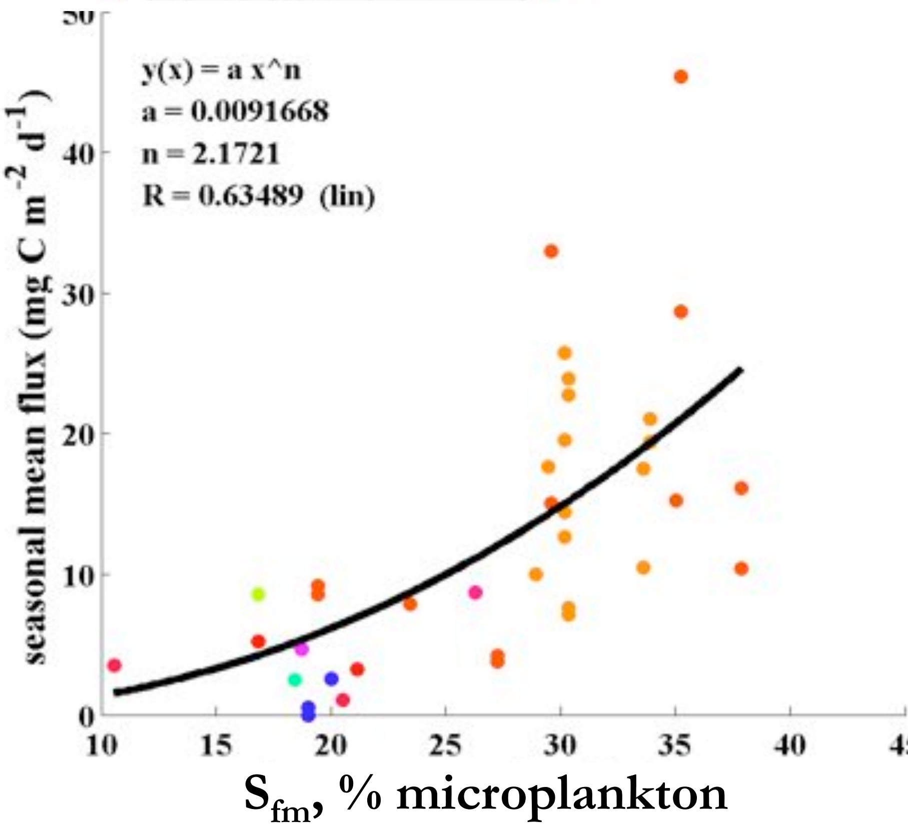


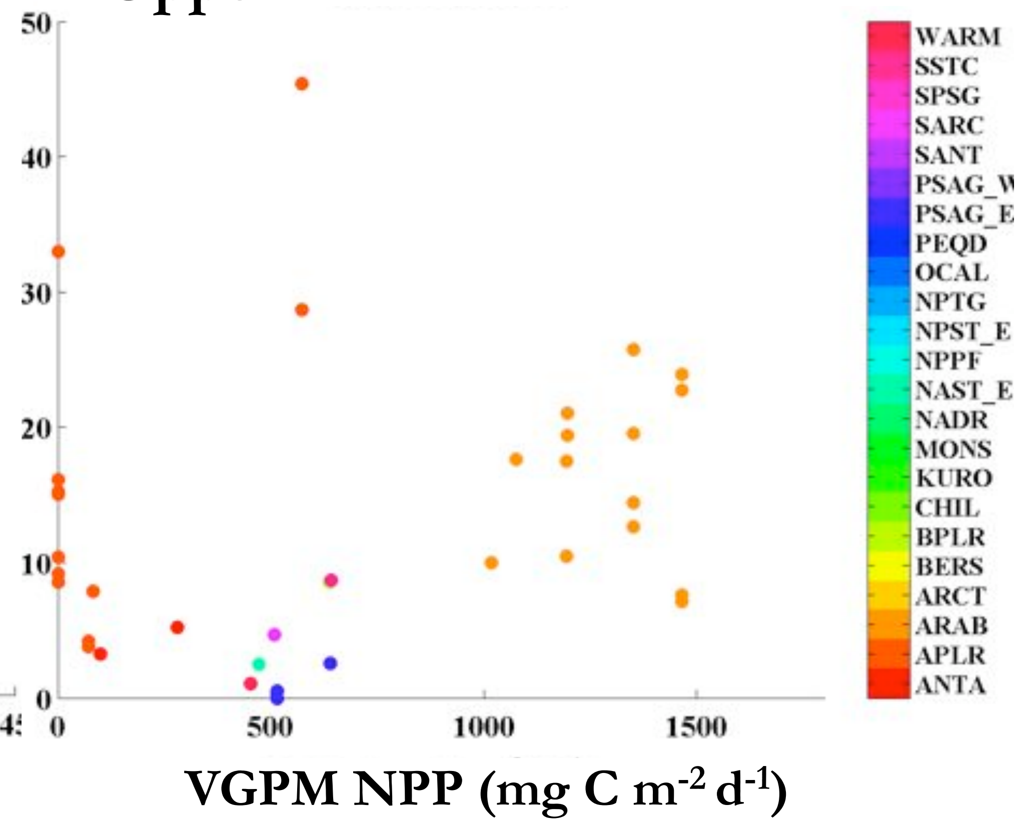
- [Chl] - adjustments to seasonal cycle
- S_{fm} - ENSO relations



Cell Size, NPP & Flux

Upper 1 km

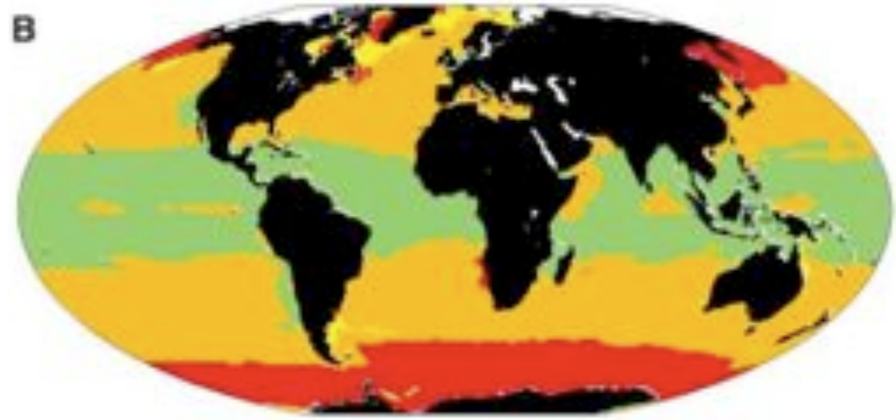




Refine Dunne et al. (2005) & Lutz et al. (2007) using phytoplankton size as a key predictor.

http://darwinproject.mit.edu

Emergent Functional Groups

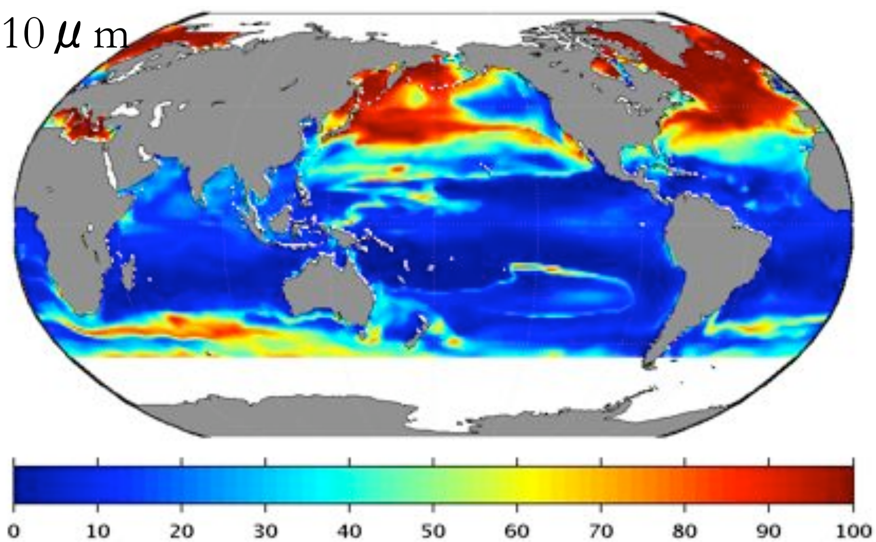


Green: *Prochlorococcus*
Orange: small photo-autotrophs
Red: diatoms
Yellow: large phytoplankton

Follows et al. 2007

Percentage of "r" Strategists

>10 μ m



Figure, Dutkiewicz

1) Update export parameterization to include lithogenic & other mineral ballasting.
2) Incorporate improved understanding of how phytoplankton size structure controls particle export & remineralization.

Objectives & Questions

Objectives -

1) Use newly available satellite retrievals of phytoplankton community size structure to refine algorithms for sinking biogenic particles and their remineralization at depth.
2) Integrate into the Darwin model to improve export parameterization.
3) Use the improved Darwin model to understand connections to ocean carbon uptake and storage.

Questions –

1) Do satellite retrievals of phytoplankton size structure improve empirical algorithms for the export of biogenic particles from the surface ocean and their remineralization at depth?
2) How does the variability in the surface ocean phytoplankton size structure impact the biological pump of carbon to the deep ocean?

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