An Accurate Absorption-Based Net Primary Production Model for the Global Ocean

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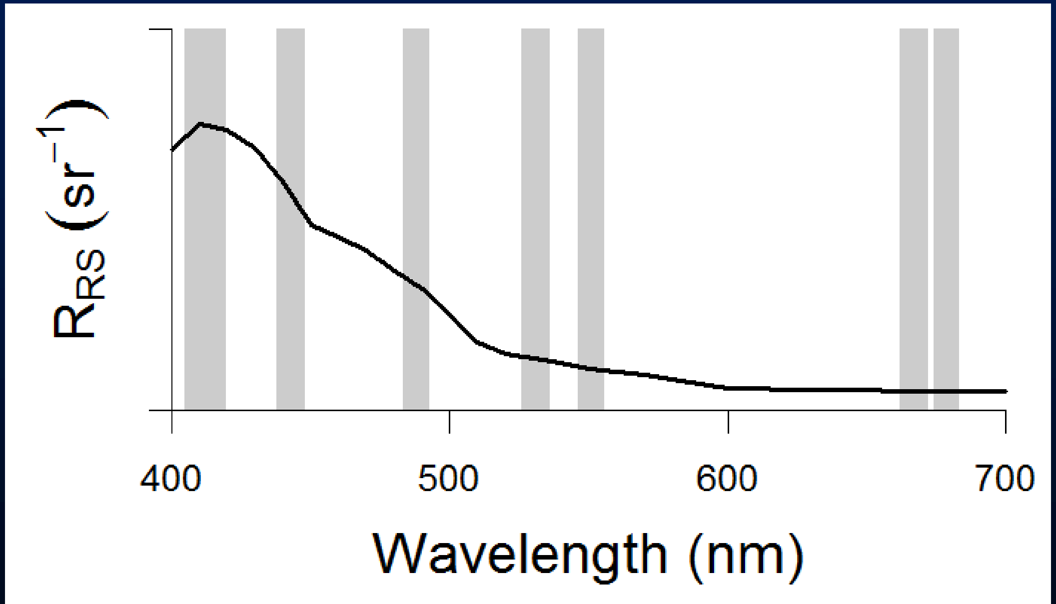
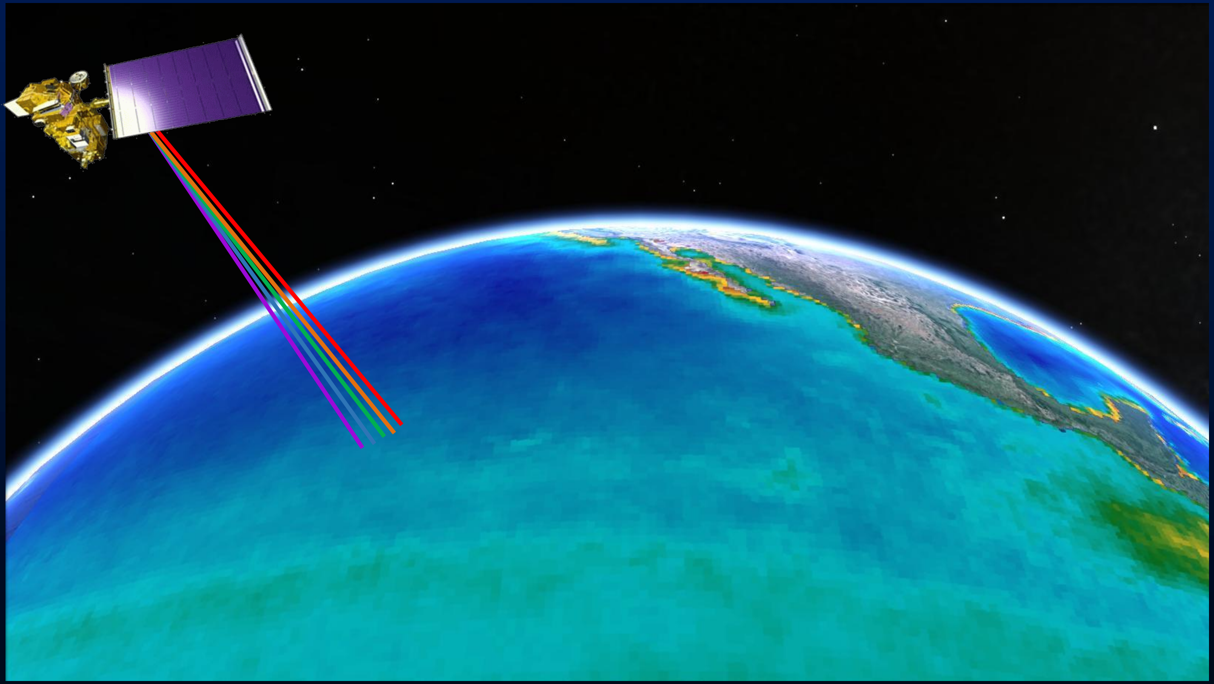
Ocean Color Remote Sensing: Science & Challenges

Ocean Color $(R_{RS}(\lambda))$ $\longrightarrow$ Net Phytoplantkon Production (NPP)

Growth Rates (μ)



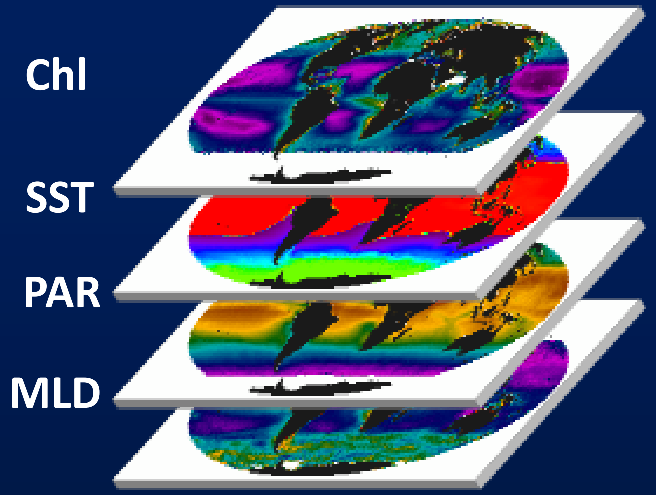


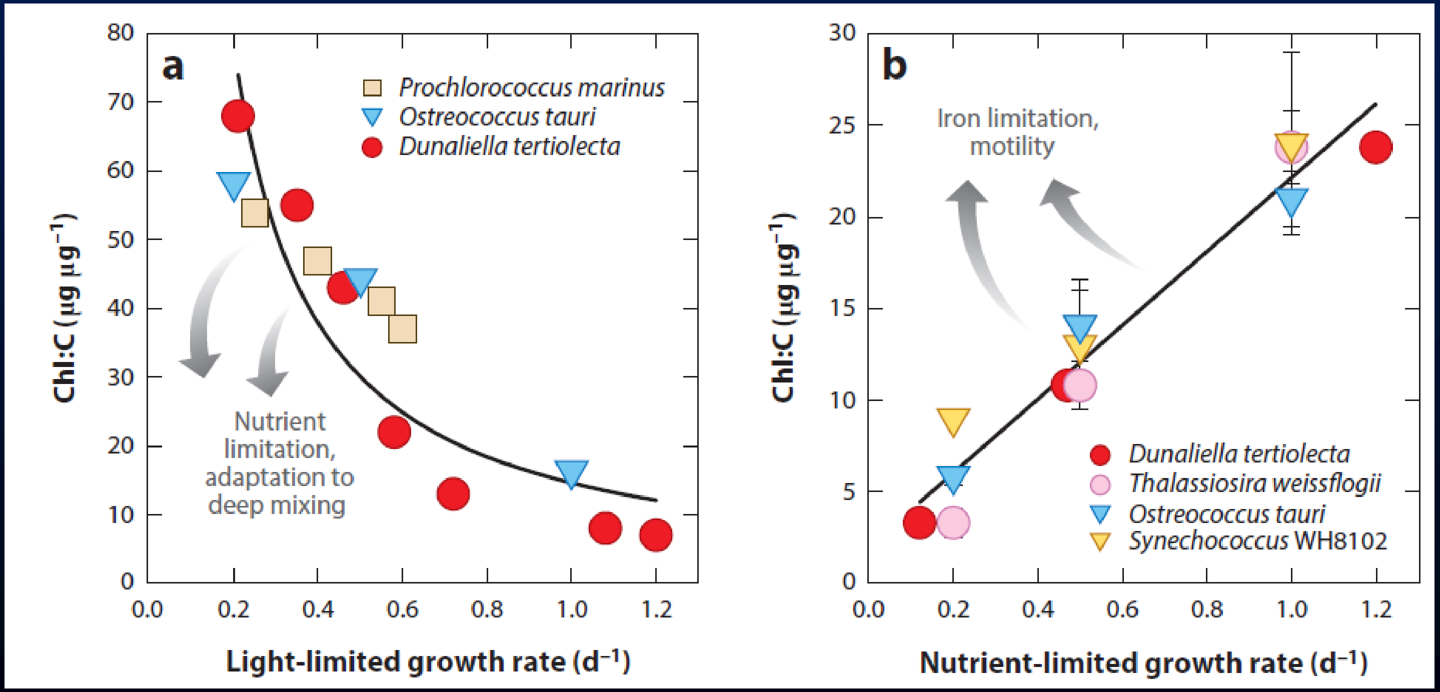
NPP Models

- Most published NPP models use Chl *a* as their central metric of phytoplankton biomass

- Disparate changes in cellular Chl:C in response to light and nutrients confound a direct relationship between Chl *a* and NPP

Traditional Products





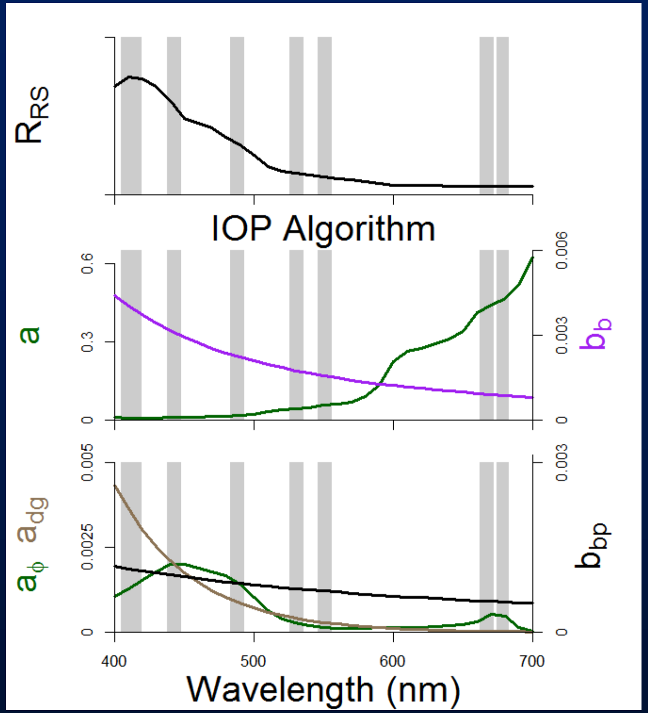
Halsey and Jones 2015. *Annu. Rev. Mar. Sci. 4:*260-280. *Also:* Laws and Bannister 1980. Marra et al. 2007.

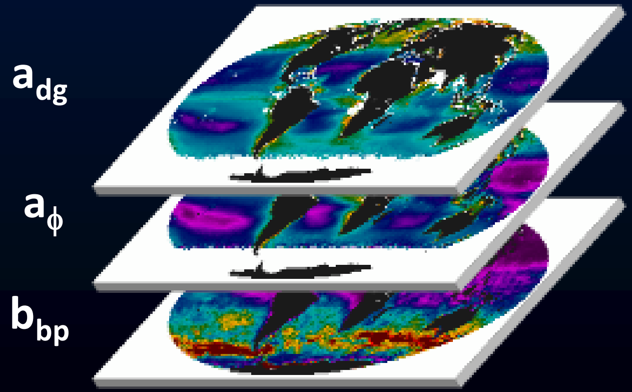
NPP Models

$$R_{RS}(\lambda) \sim \frac{b_b(\lambda)}{a(\lambda) + b_b(\lambda)}$$

- Spectral inversion algorithms now permit retrievals of Inherent Optical Properties (IOPs) from space (Lee et al. 2002; Maritorena et al. 2002; Werdell et al. 2013).

- The Carbon, Absorption, Fluorescence and Euphotic-Resolved (CAFE) model framework seeks to incorporate these products into a mechanistic model of NPP and μ.

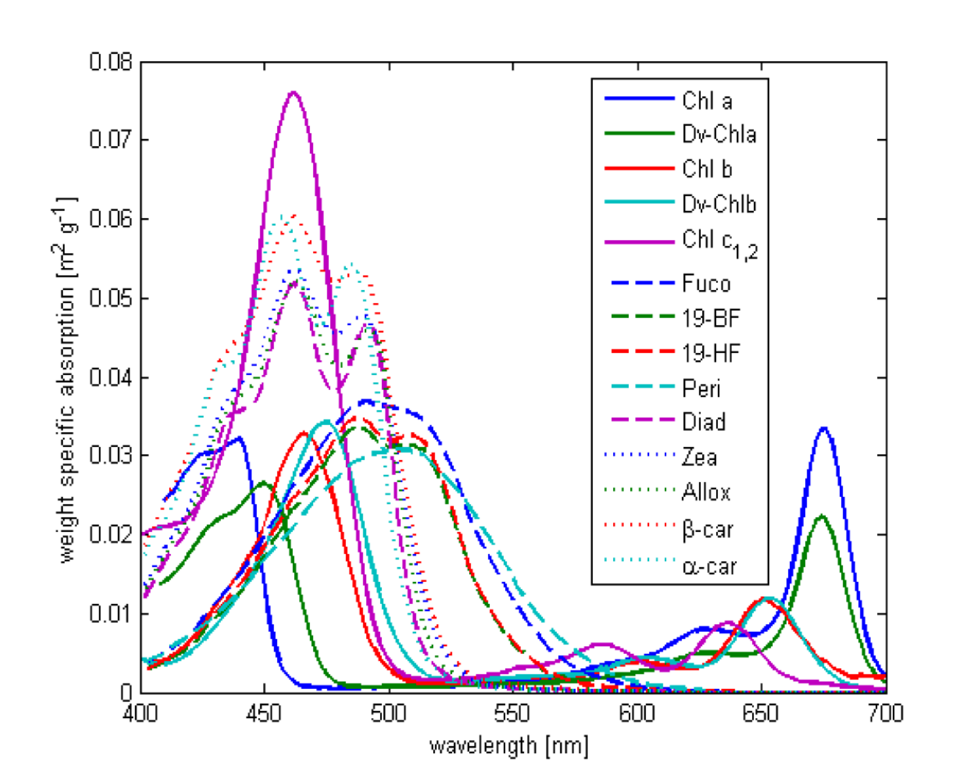




Westberry, T.K. and M.J. Behrenfeld. 2014. Oceanic Net Primary Production. In: *Biophysical Applications of Satellite Remote Sensing*. [ed.] J. Hanes, Springer.

Phytoplankton Absorption Coefficient (a_ϕ): The New Chlorophyll

- The phytoplankton absorption coefficient (a_ϕ) represents the sum of the product of all photosynthetic and non-photosynthetic pigments and the specific absorbance in-vivo



Model Parameterization

Absorption Model: $NPP = E(\lambda) \times a_{\phi}(\lambda) \times \phi_{\mu}$

Carbon Model: $NPP = C_{Phyto} \times \mu$

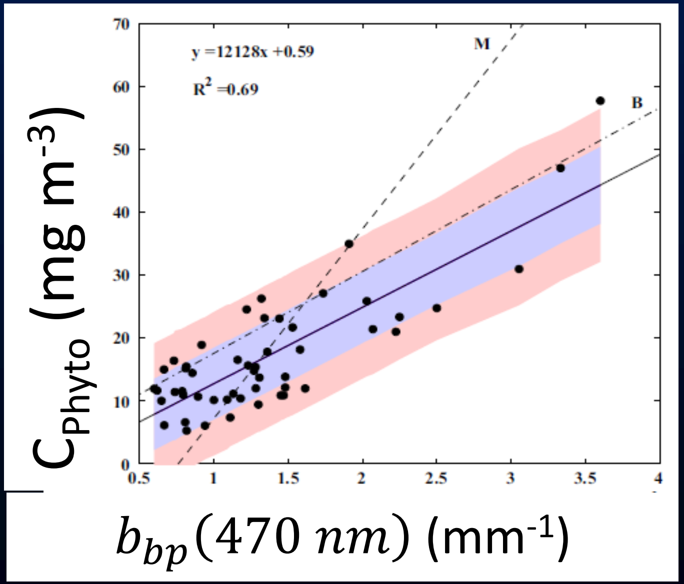
Combined Eqs: $\mu = E(\lambda) \times a_{\phi}(\lambda) \times \phi_{\mu} / C_{Phyto}$

Where: $E(\lambda)$ is spectral extrapolation of PAR

C_{Phyto} is derived from Graff et al. (2015)

$a_{\phi}(\lambda), b_{bp}(\lambda)$ are from the GIOP-DC

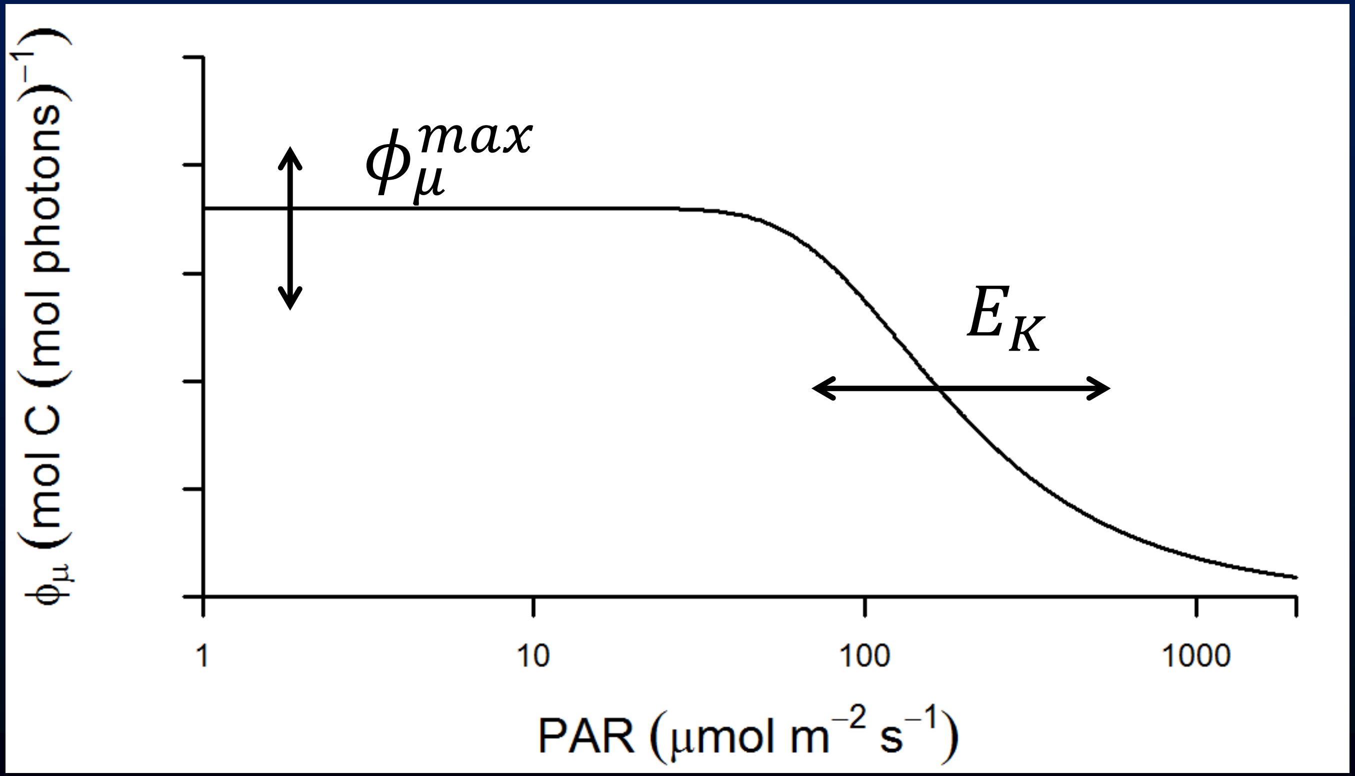
ϕ_{μ} is the quantum efficiency of growth



Graff, J.R. 2015. Analytical phytoplankton carbon measurements spanning diverse ecosystems. *Deep Sea Res. I.* 102: 16-25.

Model Parameterization

$$\phi_\mu = \phi_\mu^{max} \times tanh(E_K/E)$$



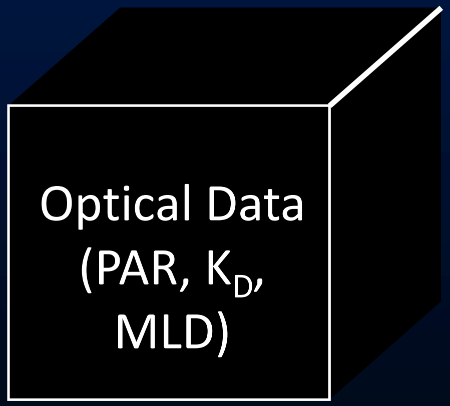
Model Parameterization: E_K

Other absorption-based models:

- E_K is globally constant at 116 mmol m^{-2} s^{-1} (Marra et al. (2007)
- E_K varies with sea-surface temperature (SST) (Antione and Morel 1996; Smyth et al. 2005)

CAFE Model:

- E_K varies with Growth Irradiance (Behrenfeld et al. 2015)

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Revaluating ocean warming impacts on global phytoplankton

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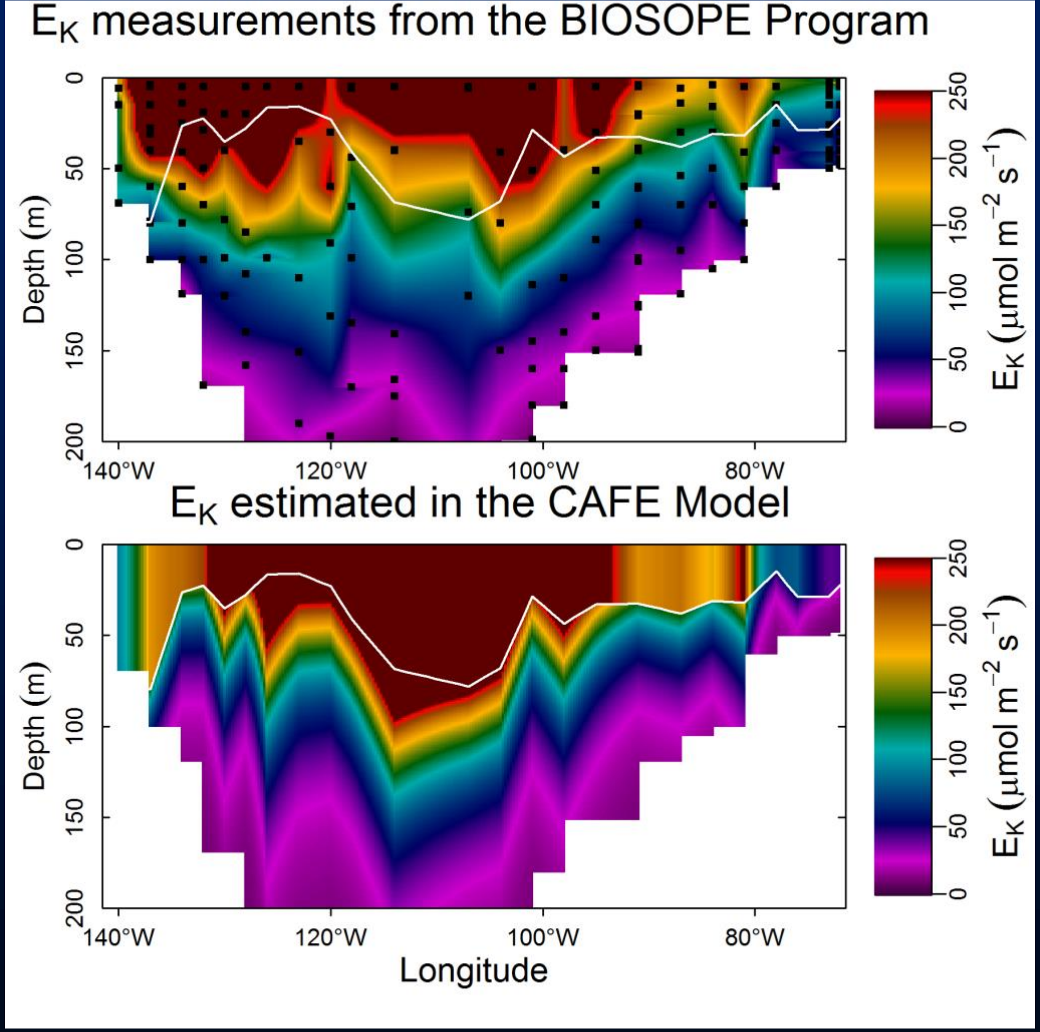
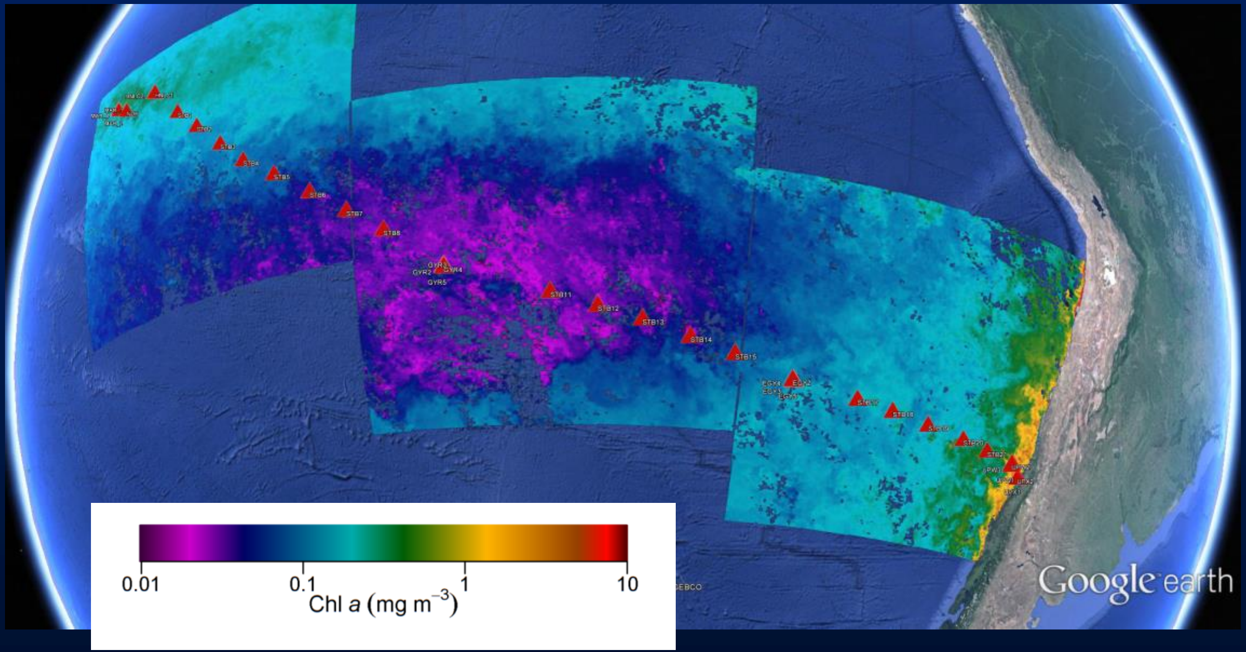
Model Validation: E_K

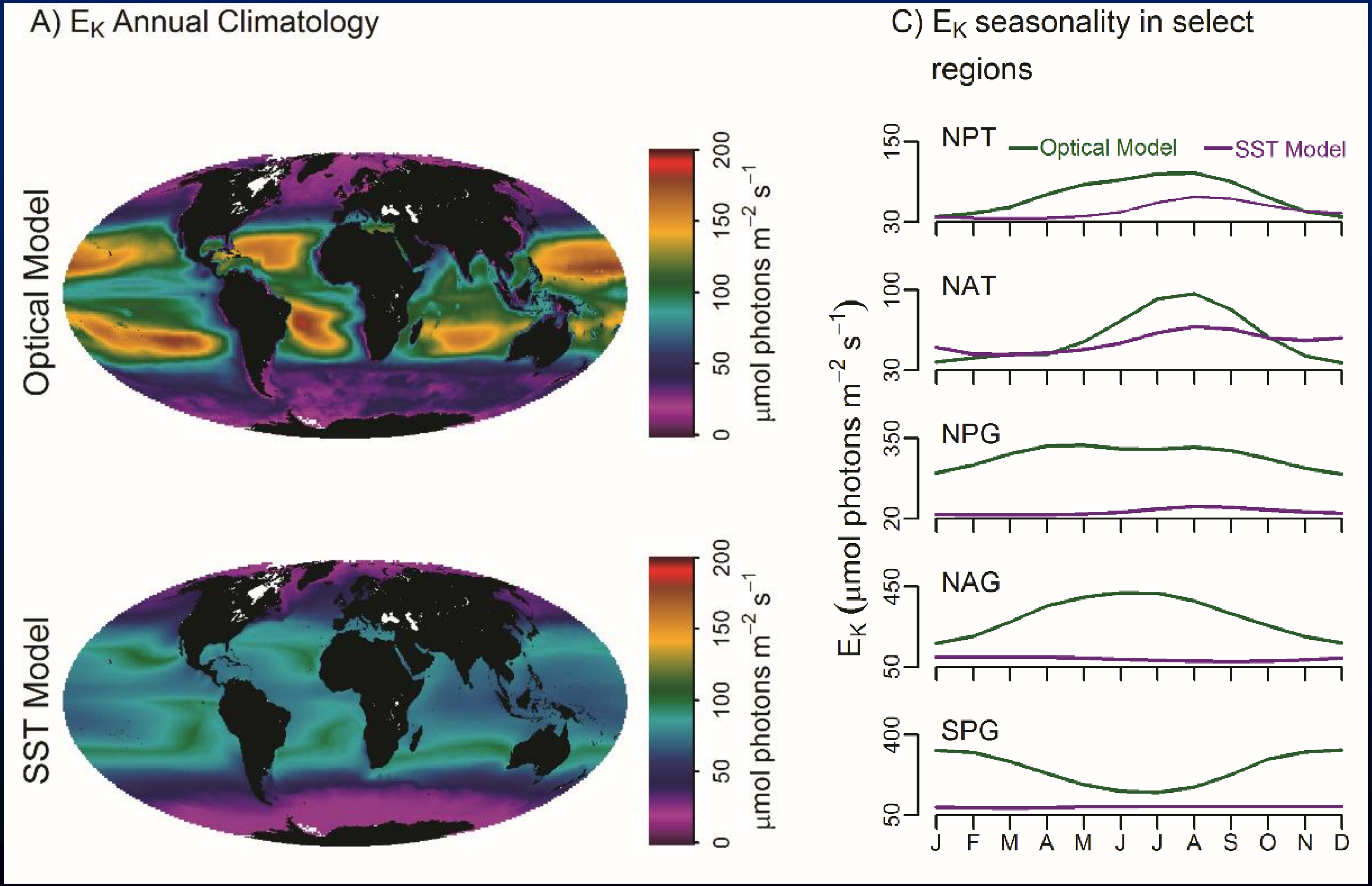




BIOSOPE stations, Nov-2004 Chl overlay

Huot et al. 2007. Relationship between photosynthetic parameters and different proxies of phytoplankton biomass in the subtropical ocean. *Biogeosciences*. **4**: 853-868.

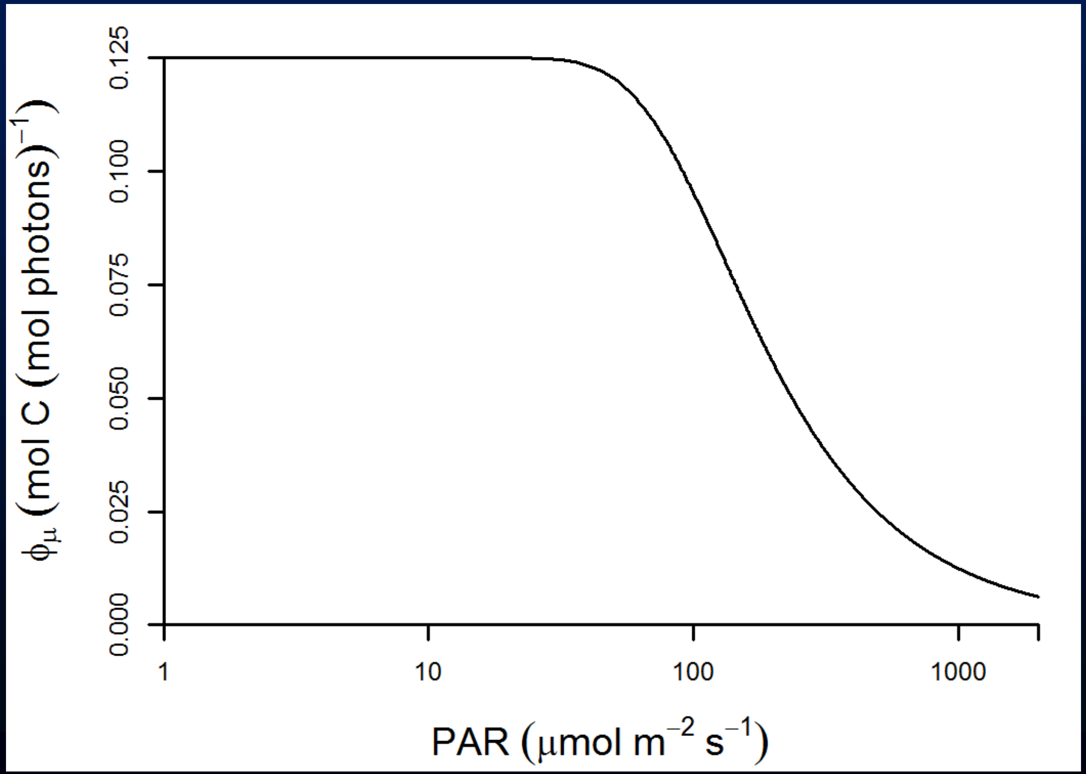
Model Parameterization - E_K



Model Parameterization: ϕ_{μ}^{max}

Other absorption-based models:

- ϕ_{μ}^{Max} is globally constant: 0.060 mol C (mol photons)$^{-1}$ (Smyth et al. 2005; Marra et al. (2007)
- ϕ_{μ}^{Max} is globally variable: 0.058 ± 0.038 mol C (mol photons)$^{-1}$ (Antione and Morel 1996)



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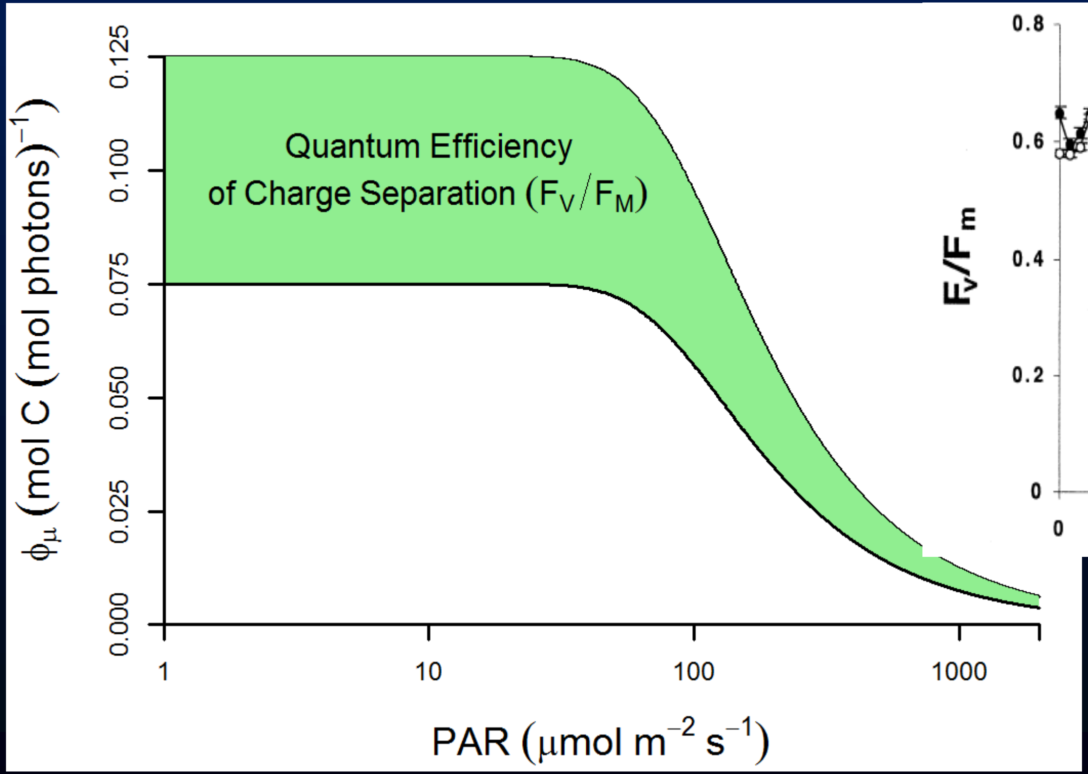

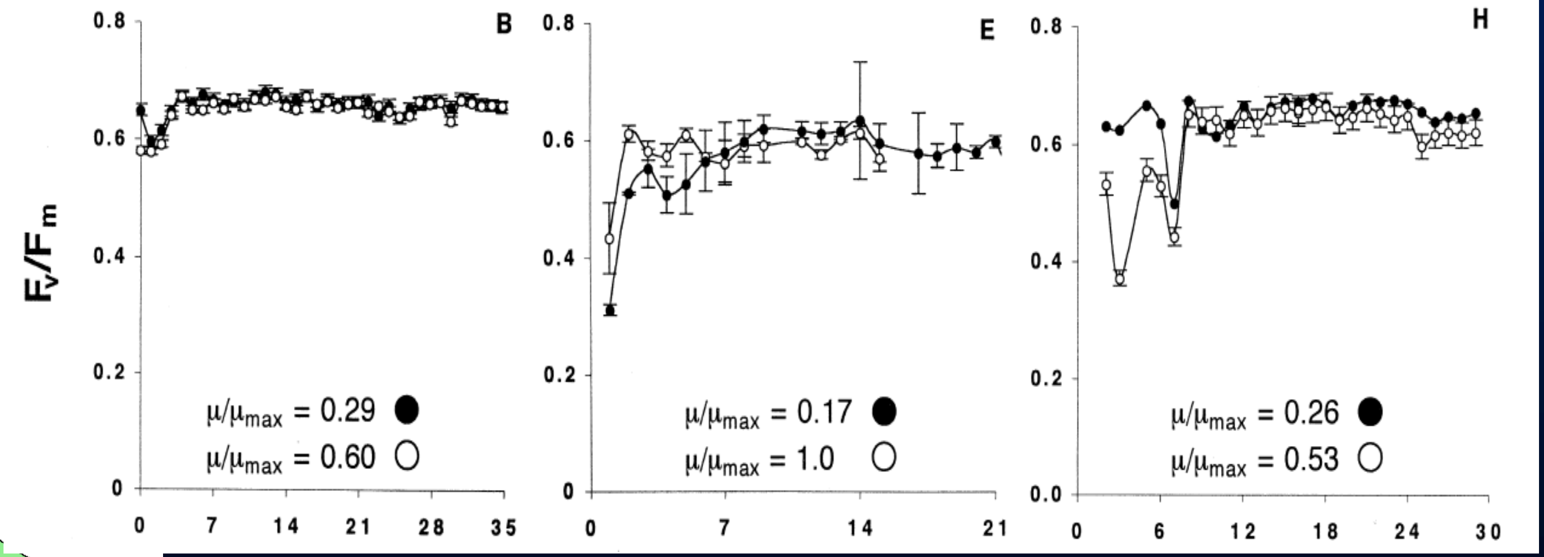

Parkhill et al. 2001. Fluorescence-based maximum quantum yield for for PSII as a diagnostic for nutrient stress. *J. Phycol.* 37:517-529.

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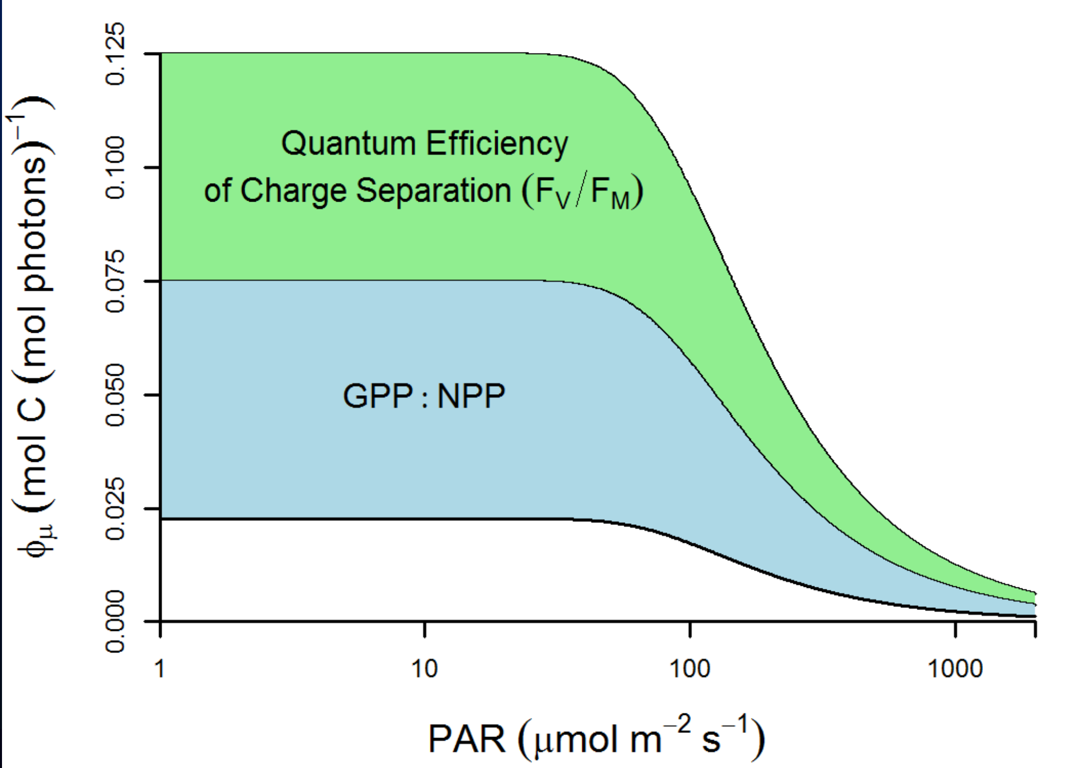

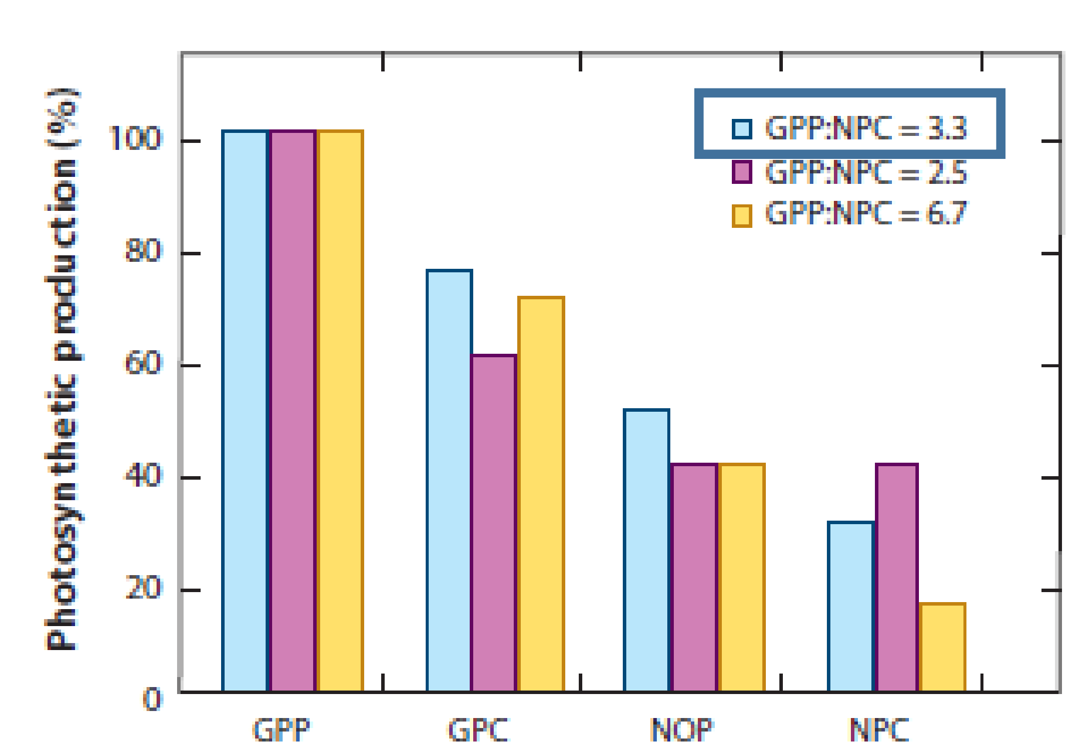

Halsey and Jones 2015. *Ann. Rev. Mar . Sci. 7*:265-280.

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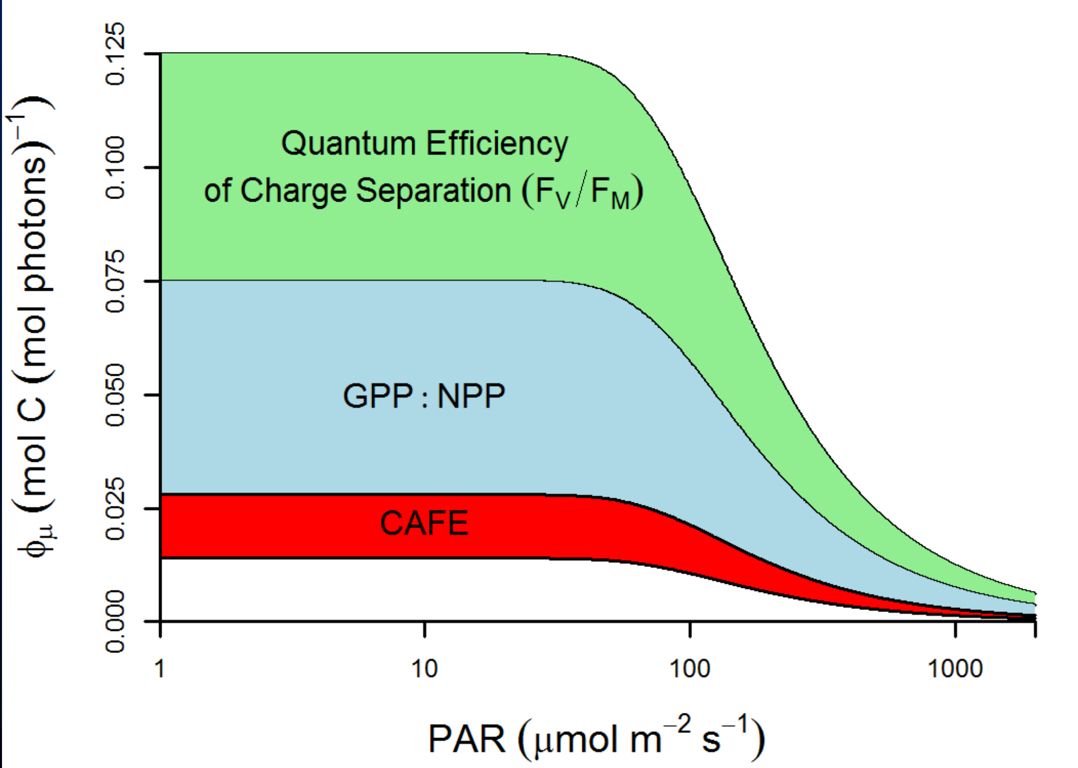
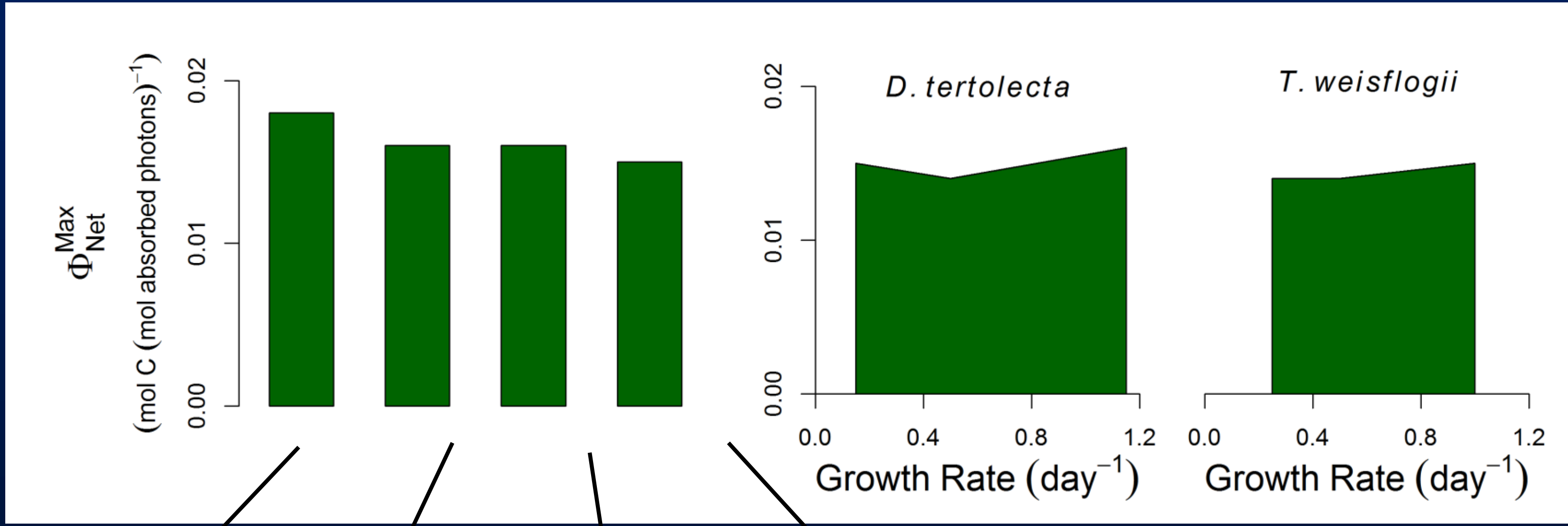


	E_k	P^B_{max}	α^B	$\bar{a}^*$	Φ_{cmax}
E_k	1.000				
P^B_{max}	0.508	1.000			
α^B	−0.500	0.206	1.000		
$\bar{a}^*$	0.177	0.193		1.000	
Φ_{cmax}	−0.451	0.109	0.796	−0.364	1.000
[Chl *a*]		**0.290**		**−0.301**	**0.214**
f_{micro}		**0.258**		**−0.214**	**0.106**
f_{nano}	**−0.234**		**0.229**		**0.165**
f_{pico}	**0.116**	**−0.231**	**−0.176**	**0.261**	**−0.247**
NPP	**0.604**	**0.138**	**−0.468**	**0.283**	**−0.486**
T	**0.378**		**−0.369**	**−0.139**	**−0.150**
[Nut]	**−0.201**		**0.116**	**−0.123**	**0.158**
z/Z_{eu}	**−0.465**	**−0.320**	**0.254**	**−0.220**	**0.317**

Uitz et al. 2008. Relating phytoplankton photophysiological properties to community structure. *Limnol. Oceanogr.* 53: 614-630

Model Validation: ϕ_{μ}^{max}

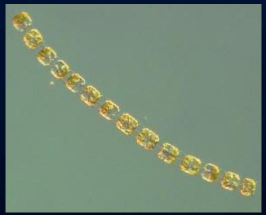
Light-limited cultures   Nitrogen-limited cultures



Micromonas pusilla

Dunaliella tertiolecta

Ostreococcus tauri

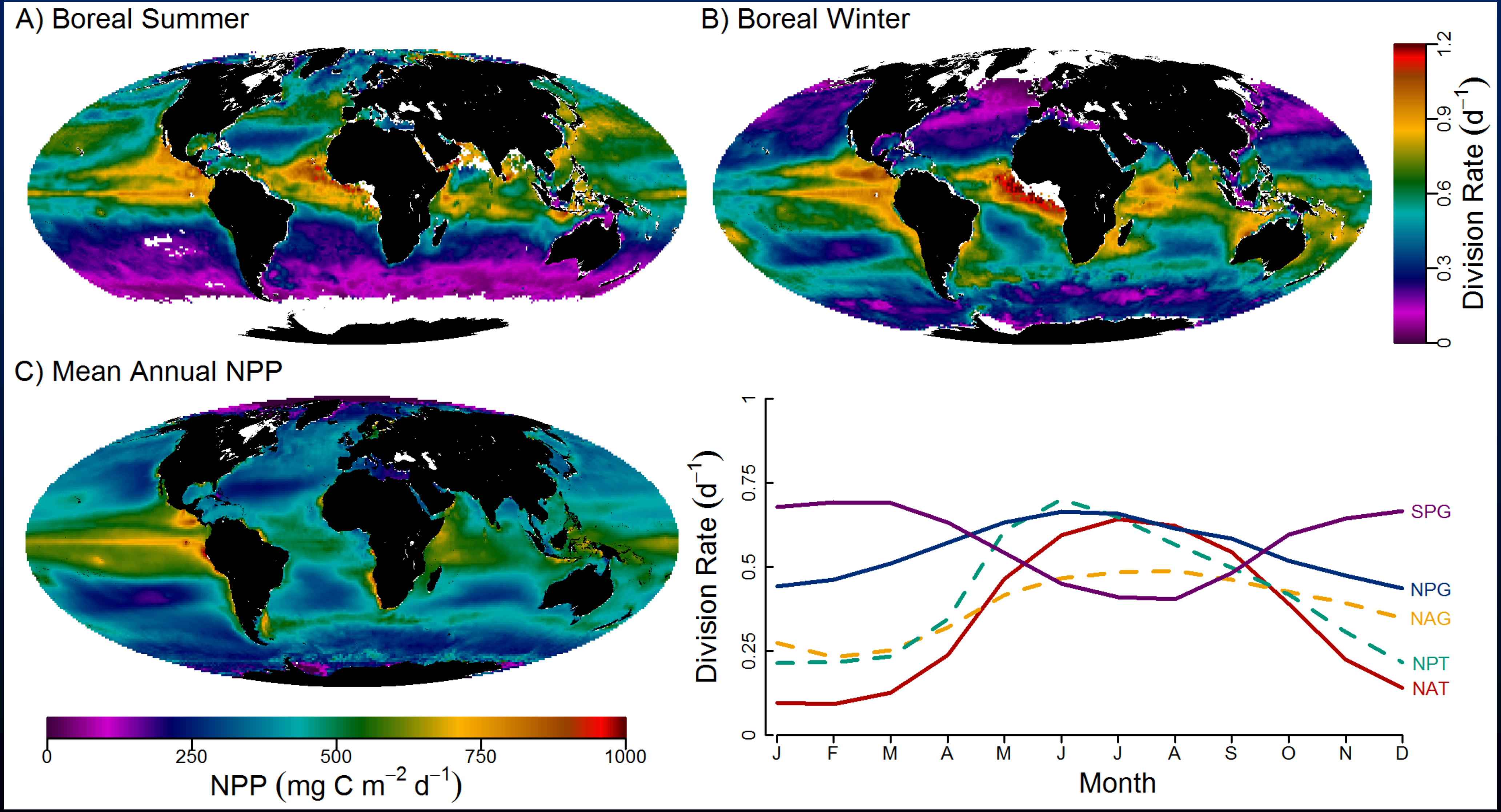


Thalassiosira weissflogii

Halsey et al 2014. *Metabolites. 4:*260-280. *Also:* Laws and Bannister 1980. Marra et al. 2007.

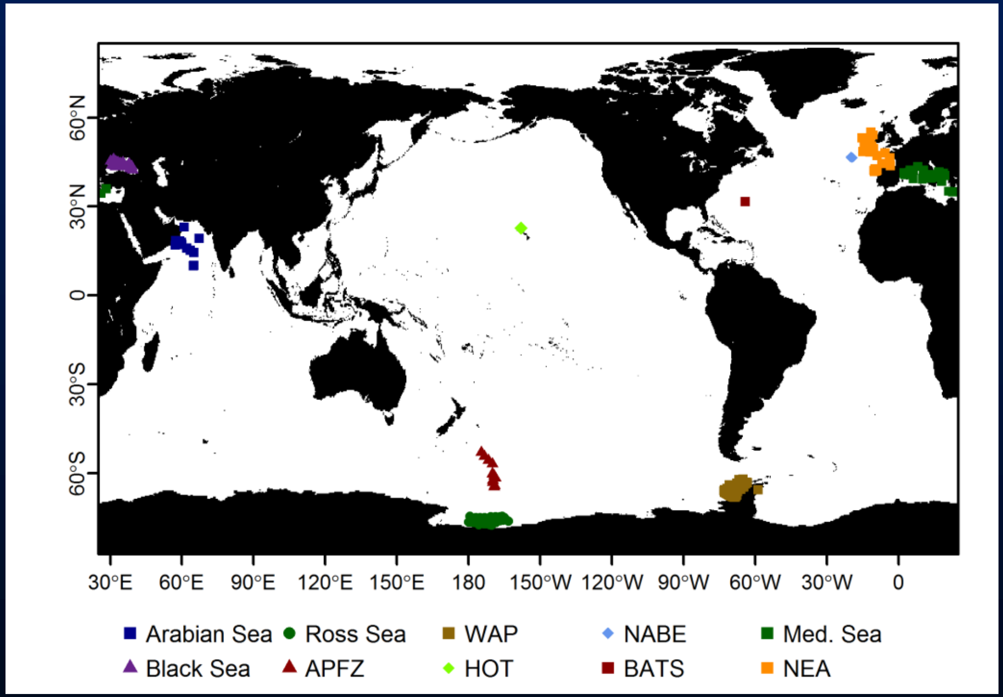
Model Climatology

Global NPP estimated from MODIS monthly climatology is 53.8 Pg C $year^{-1}$



Model Validation – PPARR Approach

- CAFE NPP model results were tested against in-situ NPP measurements at 10 sites (*n=1048)*
- Data and methods follow PPARR4 (Saba et al. 2011)

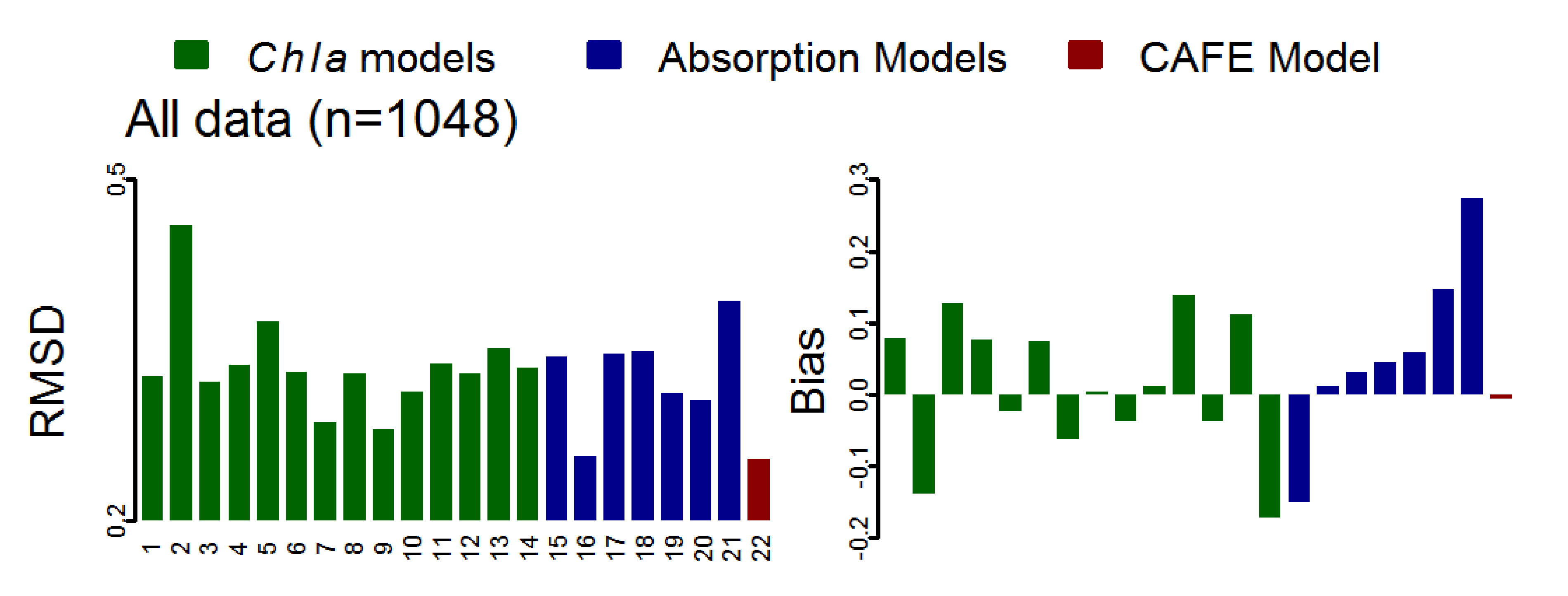


Metadata	*Chl*	*PAR*	*SST*	*MLD*	*NPP*
BATS	0.097	17.8	21.78	83.26	218.98
BATS	0.096	29.38	20.88	123.05	306.06
BATS	0.207	32.16	20.01	125.13	799.44

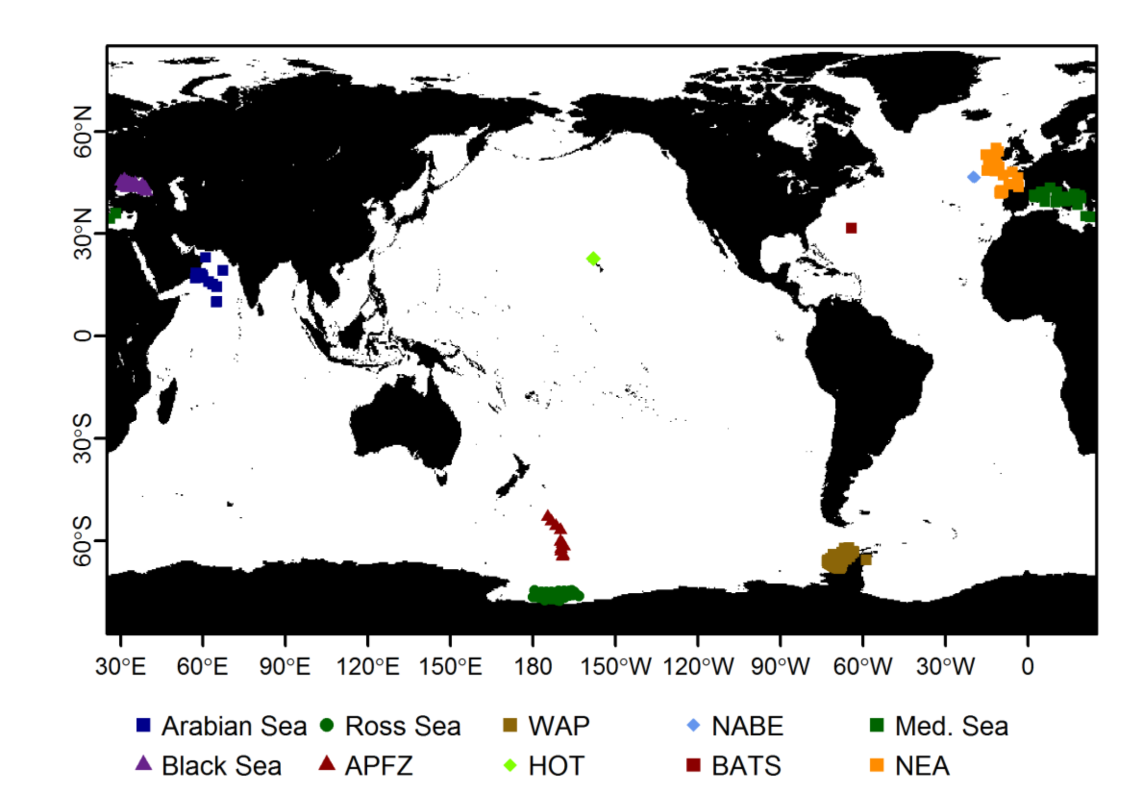
Model Validation – PPARR Approach

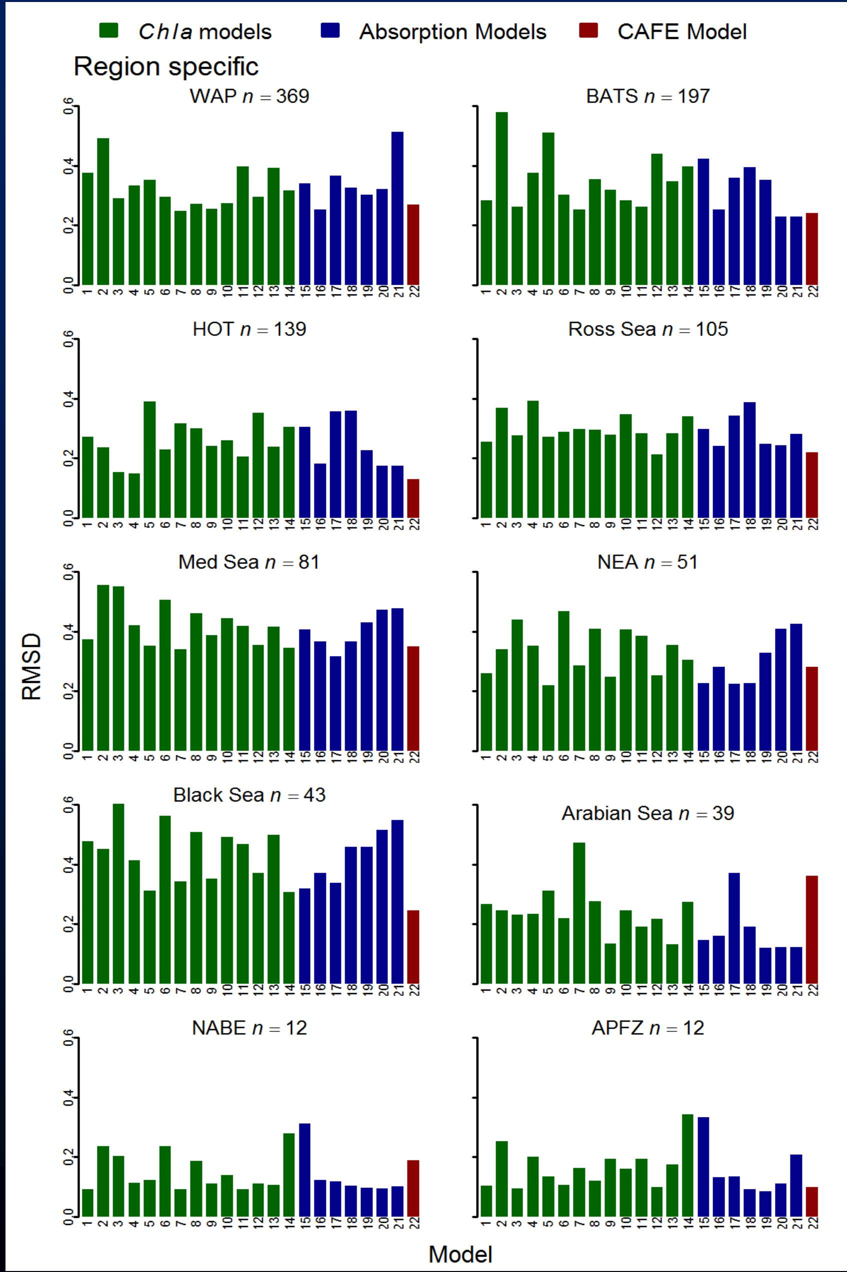
$$RMSD = \left({}^{1}/_{n} \sum_{i=1}^{n} \Delta(|\log_{10} NPP_{mod} - \log_{10} NPP_{obs}|)^2 \right)^{0.5}$$

$$Bias = mean(\log_{10} NPP_{mod}) - mean(\log_{10} NPP_{obs})$$

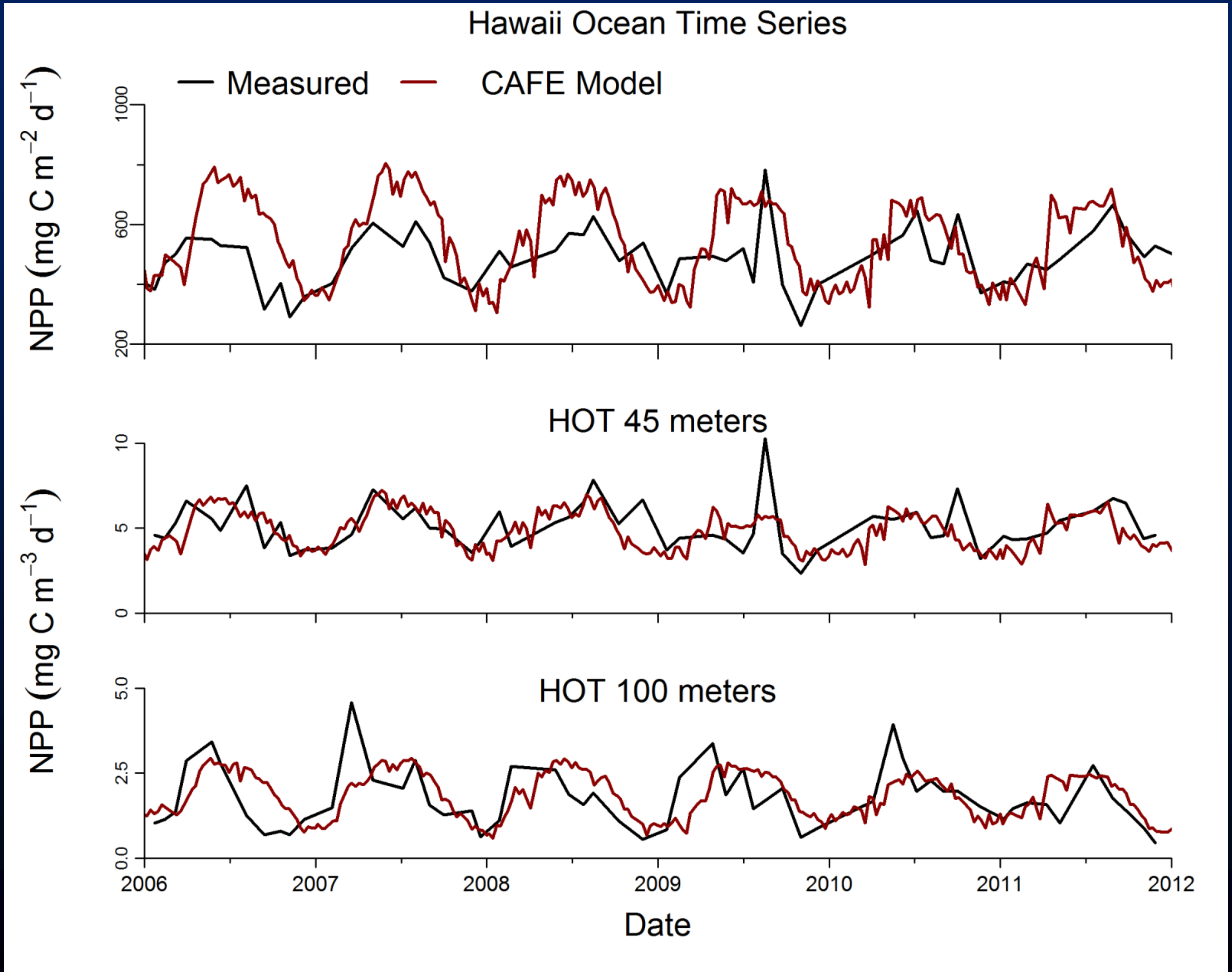


Model Validation – PPARR Approach



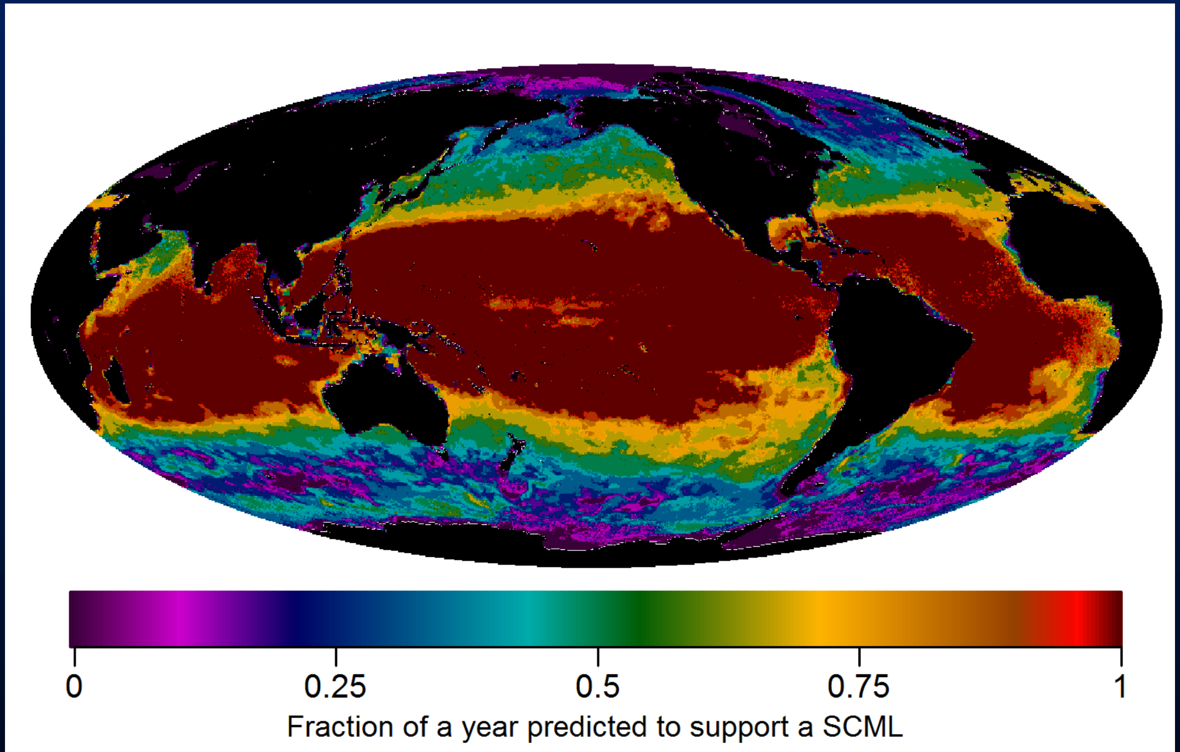


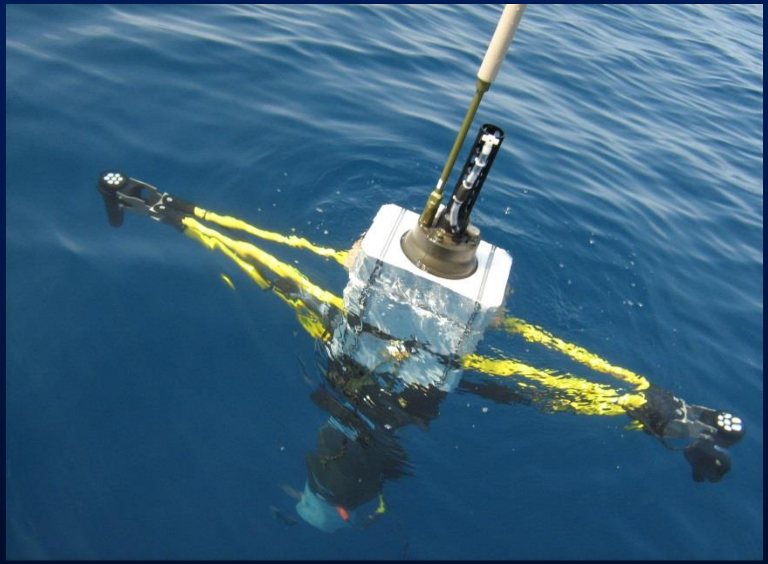
Model Validation – Direct Satellite Measurements



Future Directions

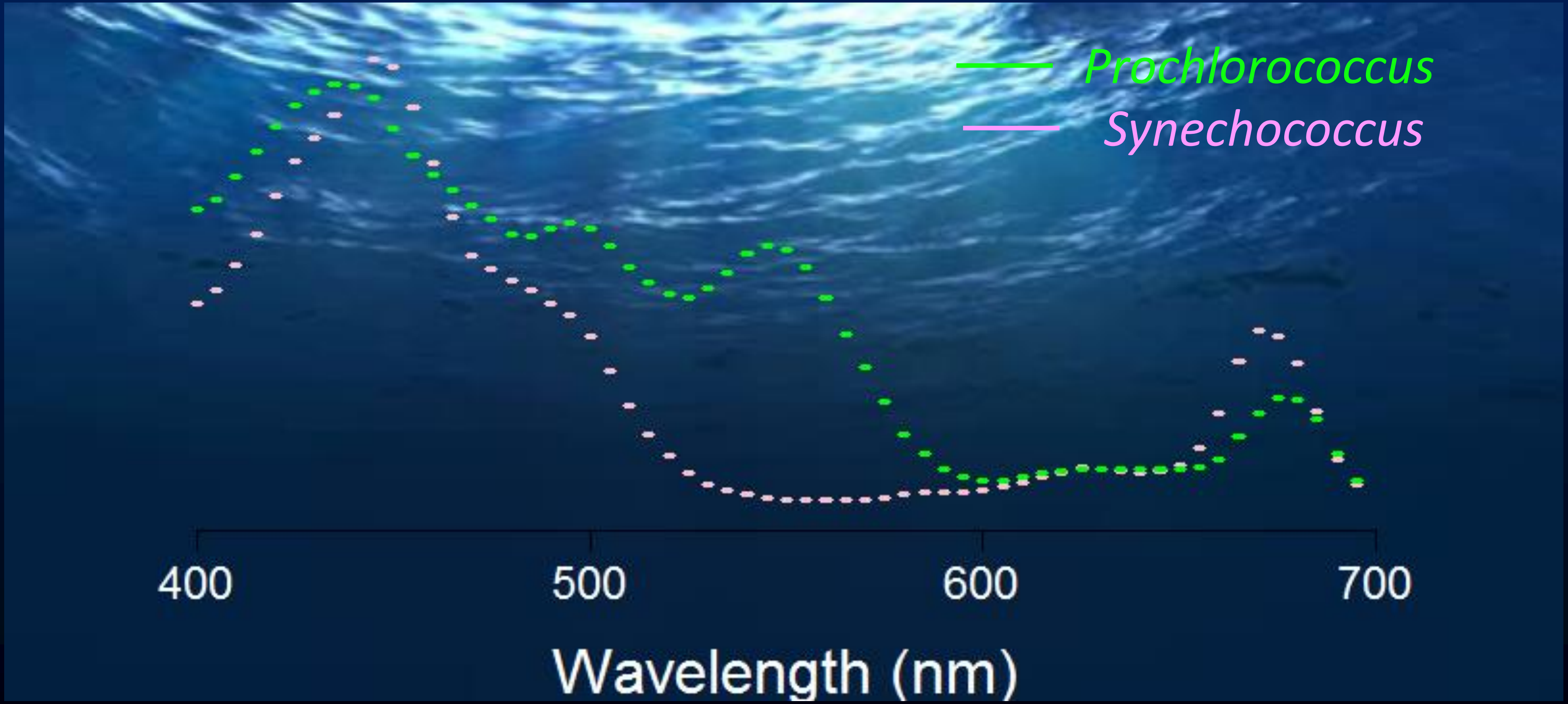
- Most phytoplankton biomass is hidden from satellite measurements of ocean color.
- BIO-Argo profiles can help fill in this missing data





Future Directions

- Hyperspectral ocean color data (e.g. PACE) will provide improved derivation of IOPs, potentially allowing for taxonomic discrimination from space



Acknowledgements

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Questions?