The CAFE Model: A Next-Generation Net Primary Production Model

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OUTLINE

Carbon **A**bsorption **F**luorescence **E**uphotic Resolving NPP Model

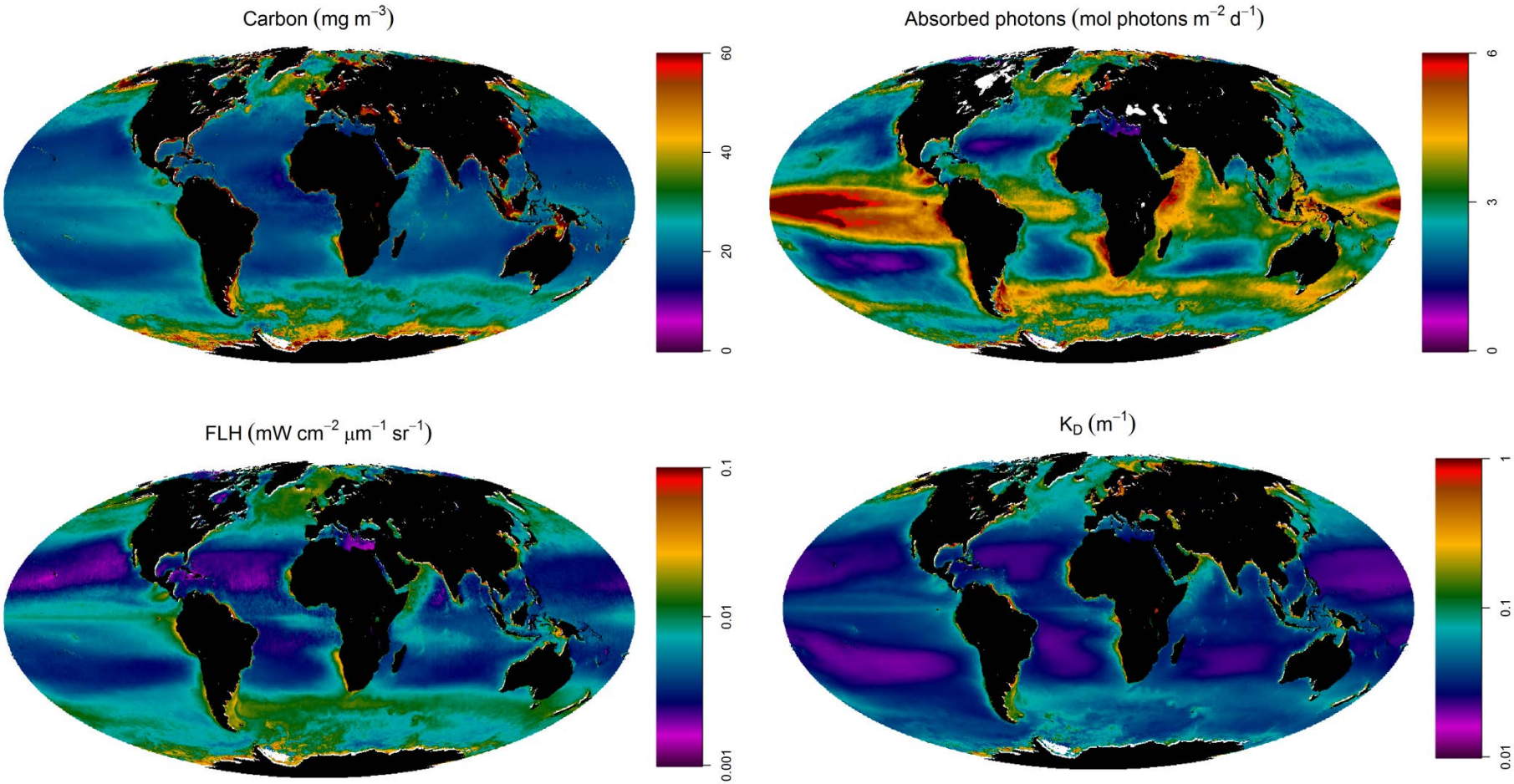


Fig 1. Annual climatology of various ocean colour products used in the CAFE model.

OUTLINE

Project focuses on 4 key developmental activities

1. Growth irradiance assessments using alternative criteria

2.Physiological assessments based on absorption:carbon ratios, rather than Chl:C

3. Correction for iron-stress effects by employing MODIS fluorescence quantum yield data

4. Chlorophyll-independent partitioning of production among phytoplankton size groups

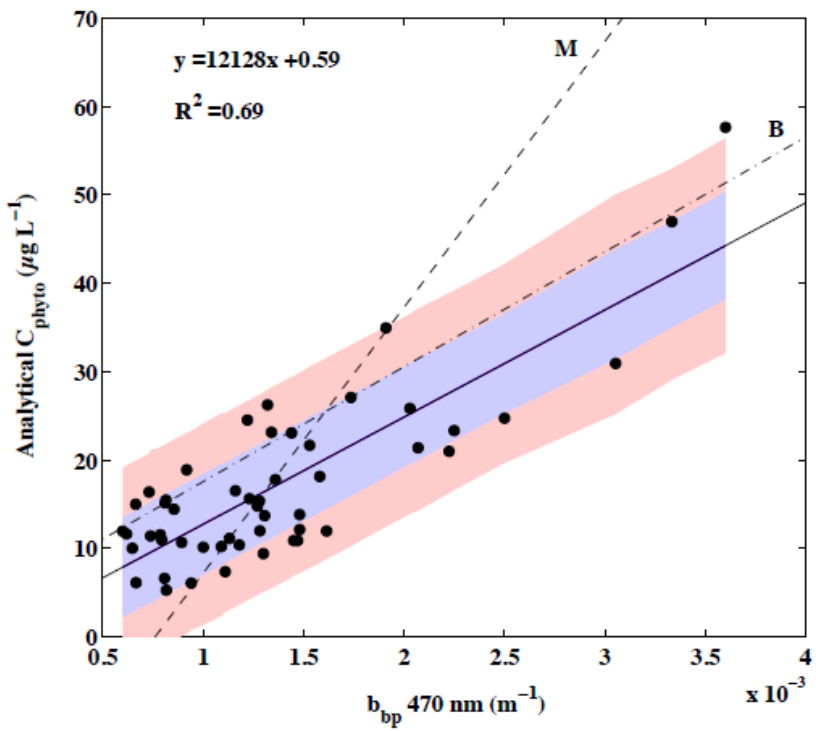
Carbon Absorption Fluorescence & Euphotic Resolved NPP

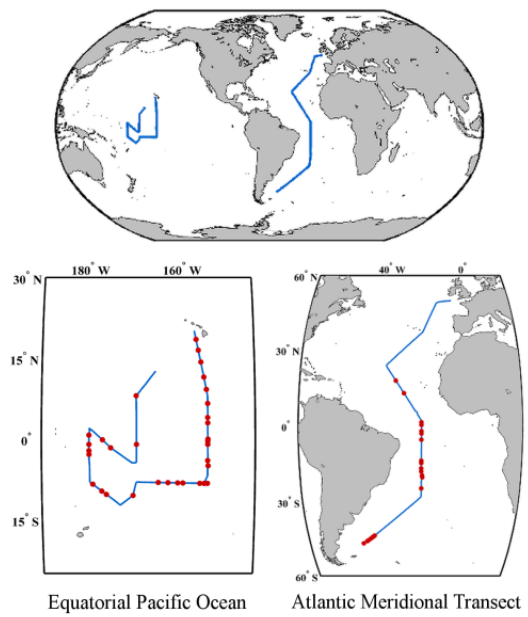
LIMNOLOGY and OCEANOGRAPHY: METHODS

Limnol. Oceanogr.: Methods 10, 2012, 910-920

The measurement of phytoplankton biomass using flow-cytometric sorting and elemental analysis of carbon

Jason R. Graff, Allen J. Milligan, and Michael J. Behrenfeld
Oregon State University, Department of Botany & Plant Pathology, Cordley Hall, Corvallis, OR 97330





Jason Graff et al. 2015. Analytical phytoplankton carbon measurements spanning divserse ecosystems. *Deep-Sea Research I. In press.*

Carbon Absorption Fluorescence & Euphotic Resolved NPP

The Chlorophyll to Carbon ratio varies predictably with light and nutrient limitation growth rates across diverse taxa

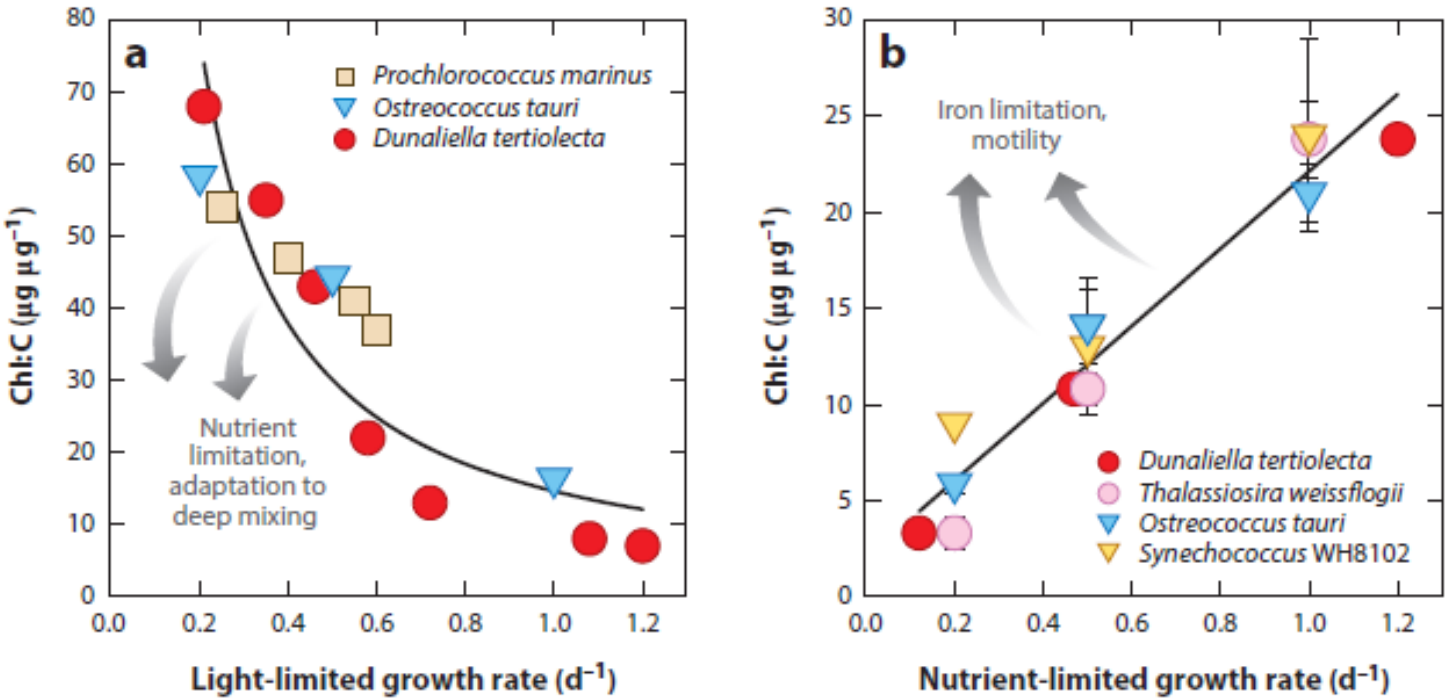


Fig 2. From Halsey, K.H. and B.M. Jones. 2015. Phytoplankton strategies for photosynthetic energy allocation. Ann. Rev. Mar. Sci.

Carbon Absorption Fluorescence & Euphotic Resolved NPP

Carbon based Productivity Model (CbPM, Westberry et al. 2008)

$$NPP = C_{Phyto} \times \mu$$

$$\mu = 2.0 \times \frac{Chl/C_{Phyto}\,(MODIS)}{Chl/C_{Phyto}\,(CbPM)} \times f(I_G)$$

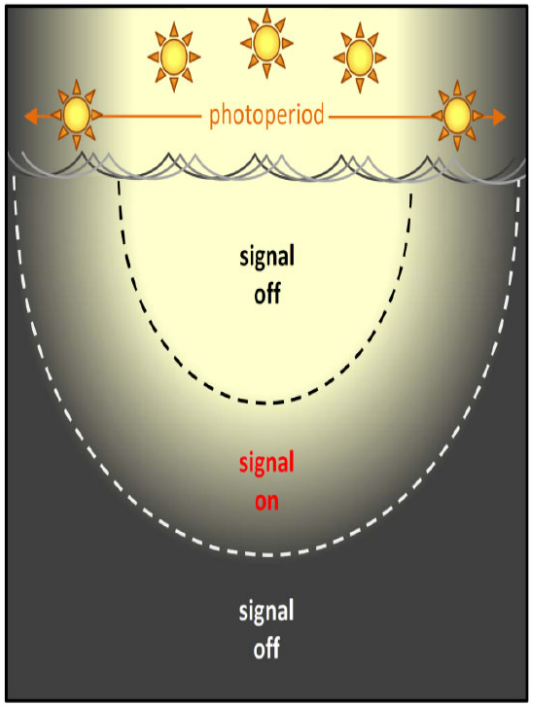
NPP	Net Primary Production	(mol C m^{-2} d^{-1})
μ	Carbon specific growth rate	(d^{-1})
C_{Phyto}	Phytoplankton Carbon Concentration	(mol C m^{-3})

Westberry, T.K., M.J. Behrenfeld, D.A. Siegel, and E. Boss. 2008. Carbon-based primary productivity modeling with vertically resolved photoacclimation. Global Biogeochem. Cy. 22, GB2024.

Carbon Absorption Fluorescence & Euphotic Resolved NPP

Plastiquinone Redox Model (Redox, Behrenfeld et al. *submitted*).

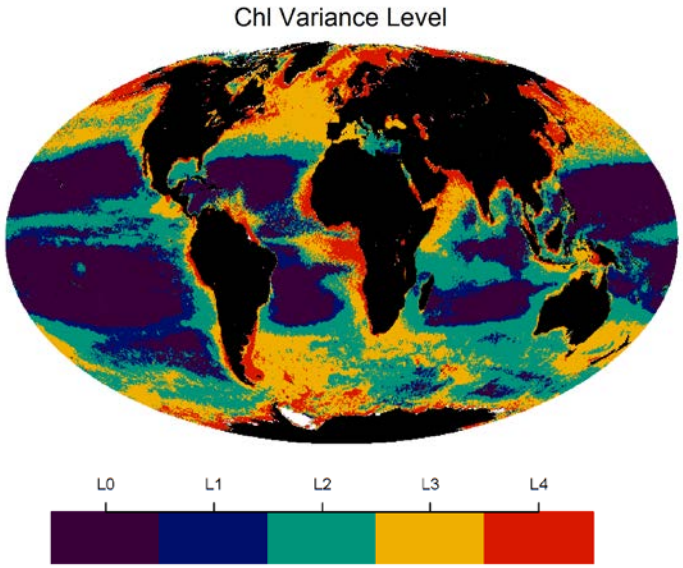
Provides new Chl/C ratio and the light saturation parameter E_K

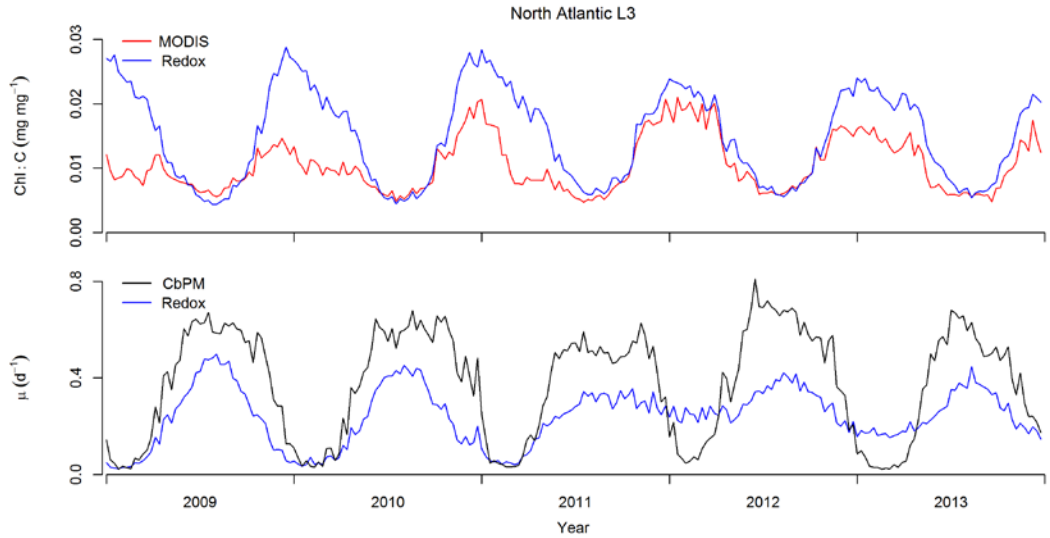


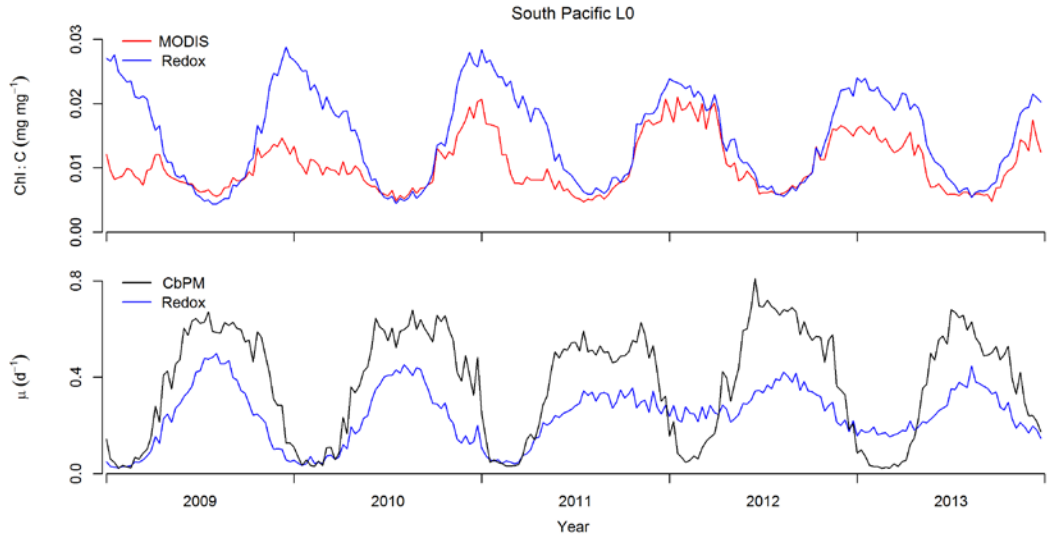
$$\mu = 0.4 \times \frac{Chl/C_{Phyto}\,(MODIS)}{Chl/C_{Phyto}\,(Redox)} \times f(I_G)$$

M.J. Behrenfeld et al. A Physiological twist to apparent warming impacts on global ocean phytoplankton. Submitted to Nature Climate Change. (Presentation May 21, 11:40)

Carbon Absorption Fluorescence & Euphotic Resolved NPP

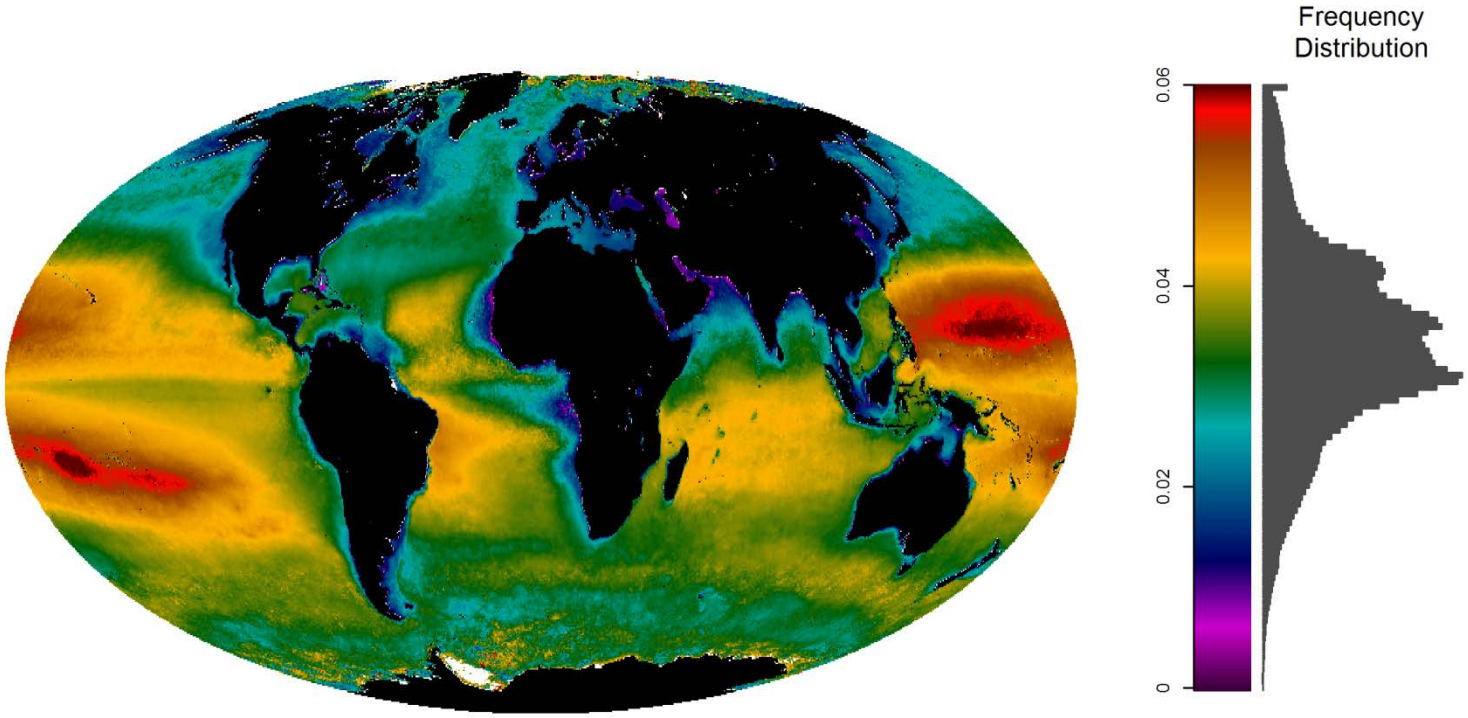






Carbon Absorption Fluorescence & Euphotic Resolved NPP

The empirical algorithm for the standard *Chl* product (O'Reilly et al. 1998) implicitly assumes $\bar{a}_{\phi}^{*}$ is constant.

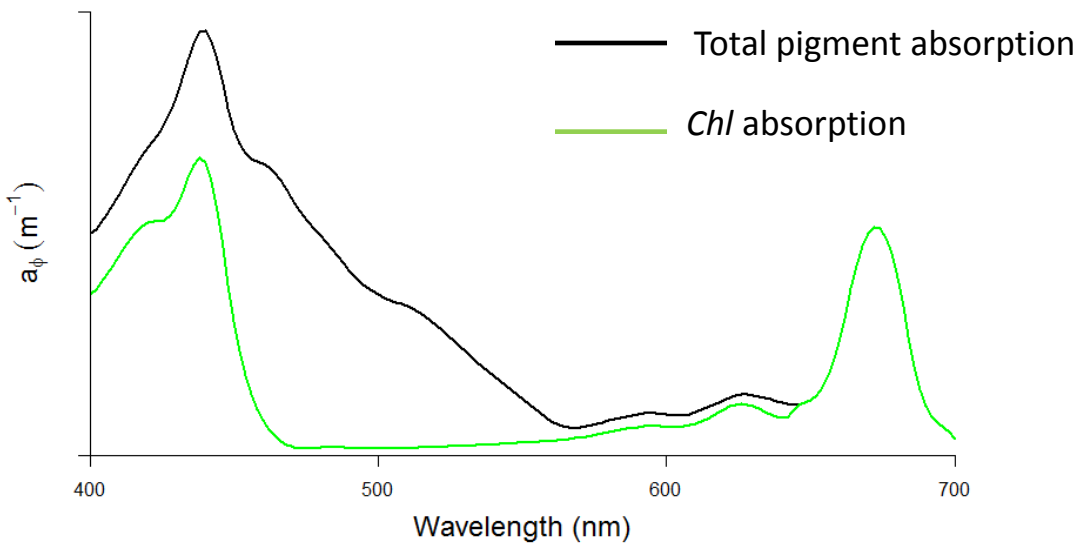


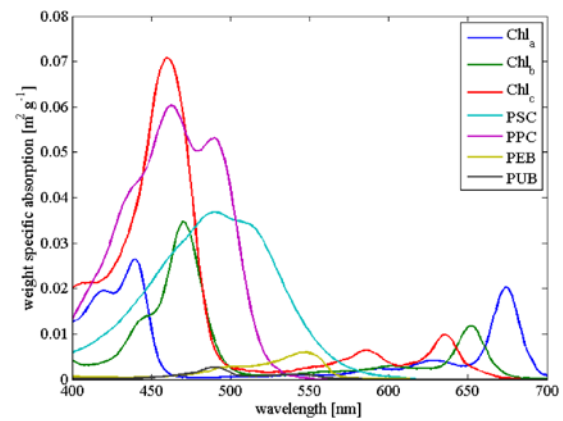
Annual a_{ϕ}^{*} (m^{-1}) Climatology (GIOP-DC)

Carbon Absorption Fluorescence & Euphotic Resolved NPP

The empirical algorithm for the standard *Chl* product (O'Reilly et al. 1998) implicitly assumes $\bar{a}_{\phi}^{*}$ is constant.

Chl constitutes a variable fraction of total phytoplankton pigment absorption





Carbon Absorption Fluorescence & Euphotic Resolved NPP

$$NPP = \int_{0}^{Zeu} \int_{400\,nm}^{700\,nm} \phi_{Net}(E) \times a_{\phi}(z,\lambda) \times E(z,\lambda)\ dz\, d\lambda$$

$$\mu = \frac{C_{Phyto}}{NPP}$$

$\phi_{Net}(E)$	Quantum Yield of net photosynthesis	(mol C (mol photons)$^{-1}$)
a_{ϕ}	Phytoplankton pigment absorption coefficient	(m^{-1})
E	Irradiance	(mol photon m^{-2} day^{-1})

Carbon Absorption Fluorescence & Euphotic Resolved NPP

A multitude of studies have examined the quantum yield of photosynthesis (ϕ):

Babin et al. 1996; Bannister and Weidemann 1984; Bidigar et al. 1987; Carder et al. 1995; Cleveland et al. 1989; Halsey et al. 2013; Hiscock et al. 2008; Kiefer and Mitchell 1983; Kishino et al. 1986; Kunath et al. 2012; Marra et al. 1992, 2005; Morel 1978; Smith et al. 1989; Sorensen and Siegel 2001; Wozniak et al. 2002.

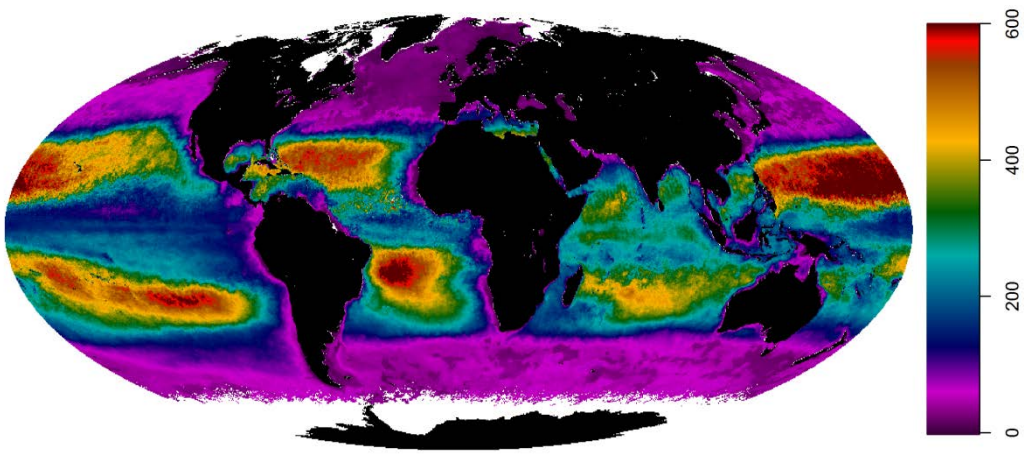
However, ϕ measurements are predominantly based on short-term (1-4 hr) ^{14}C incubations, and therefore **do not** represent the quantum yield of **net** photosynthesis.

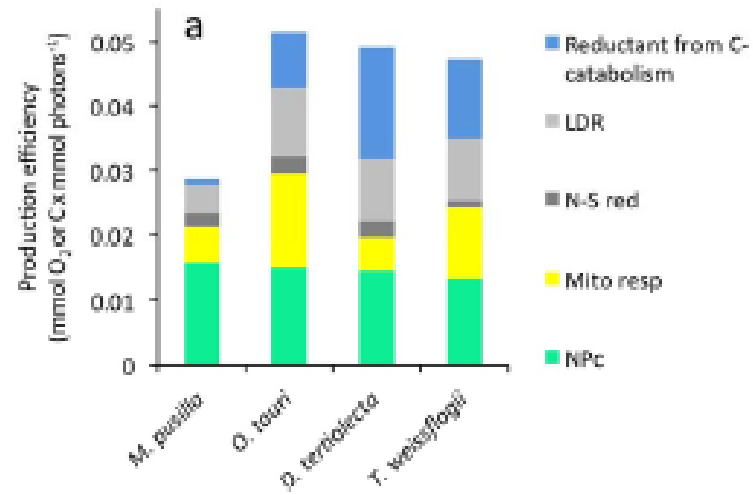
Carbon Absorption Fluorescence & Euphotic Resolved NPP

The maximum quantum yield is taken as 0.015 mol photons/mol Carbon (Halsey et al. 2014).

The irradiance dependency of ϕ is modeled using E_K data from the redox model.

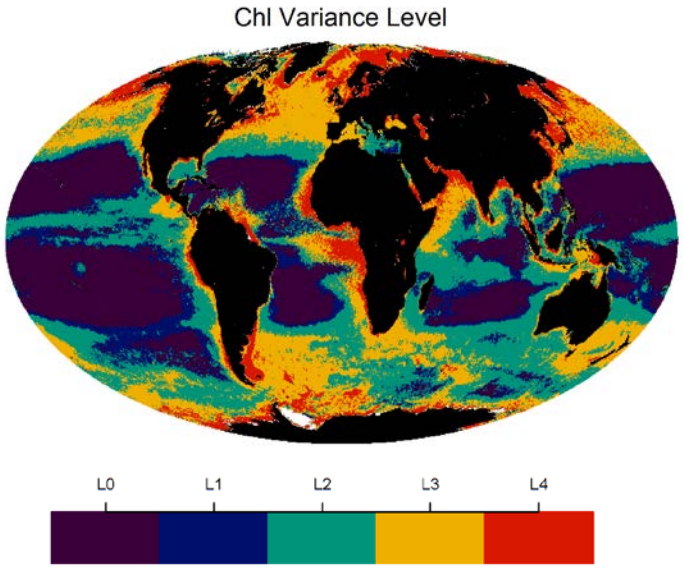
E_K (μmol m^{-2} s^{-1})

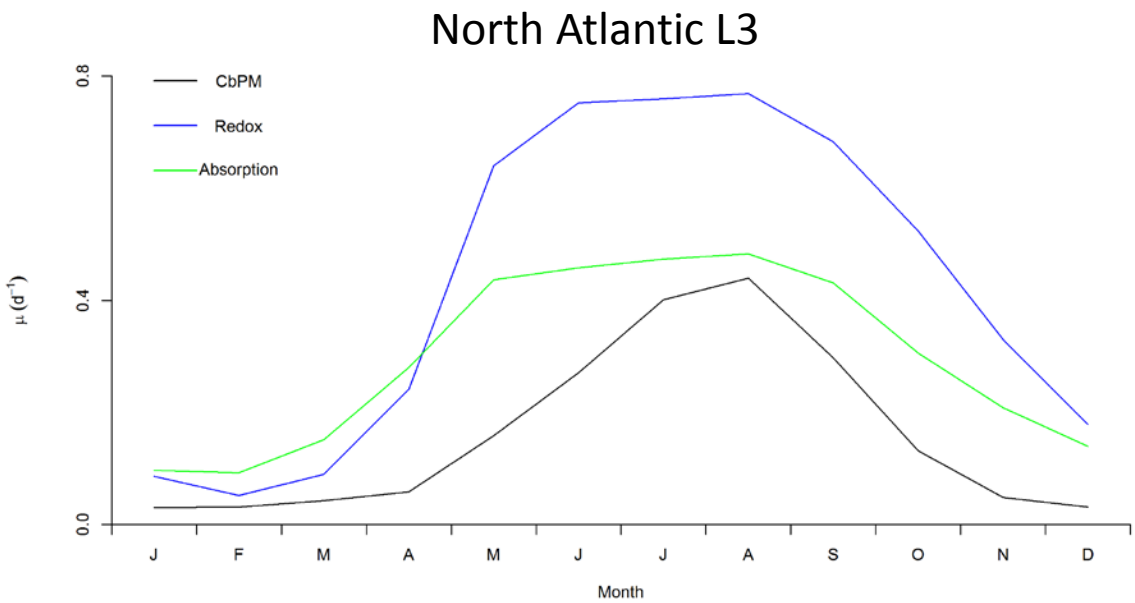


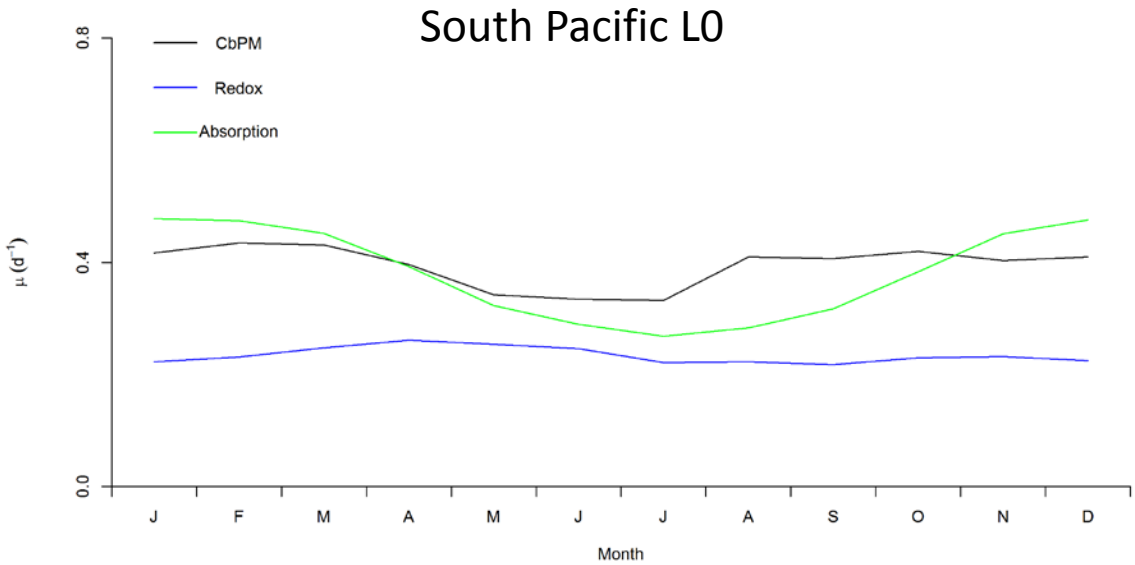


Halsey et al. 2014. Metabolites. 4: 260-280.

Carbon Absorption Fluorescence & Euphotic Resolved NPP

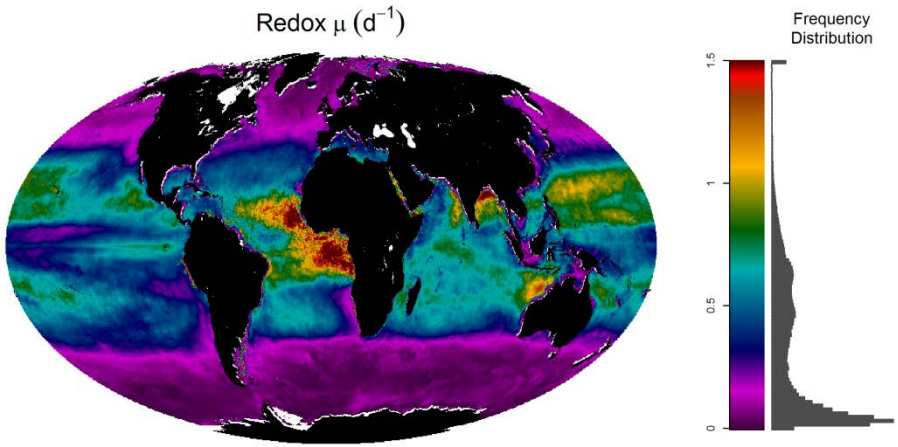


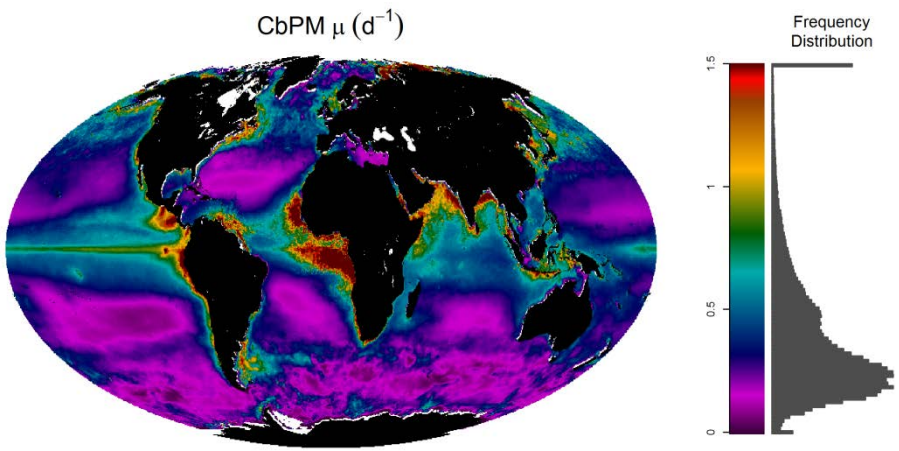


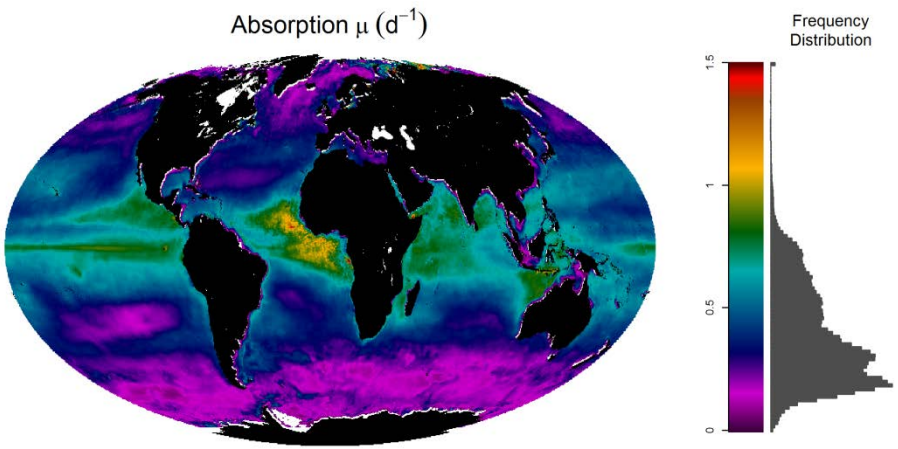


Carbon Absorption Fluorescence & Euphotic Resolved NPP

Annual growth rate climatological maps and histograms.



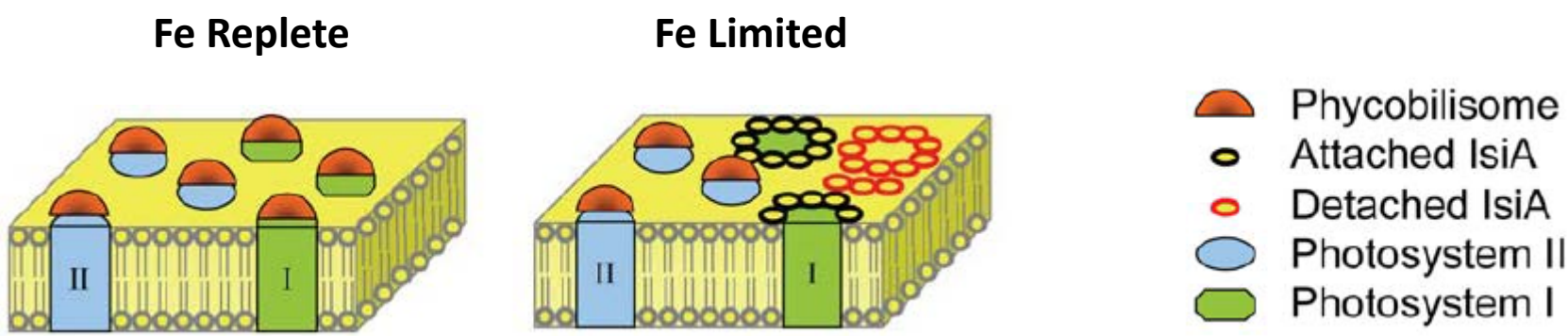




Carbon Absorption Fluorescence & Euphotic Resolved NPP

Iron-limited phytoplankton contain high amounts of chlorophyll complexes (IsiA) that are not bound to either photosystem.

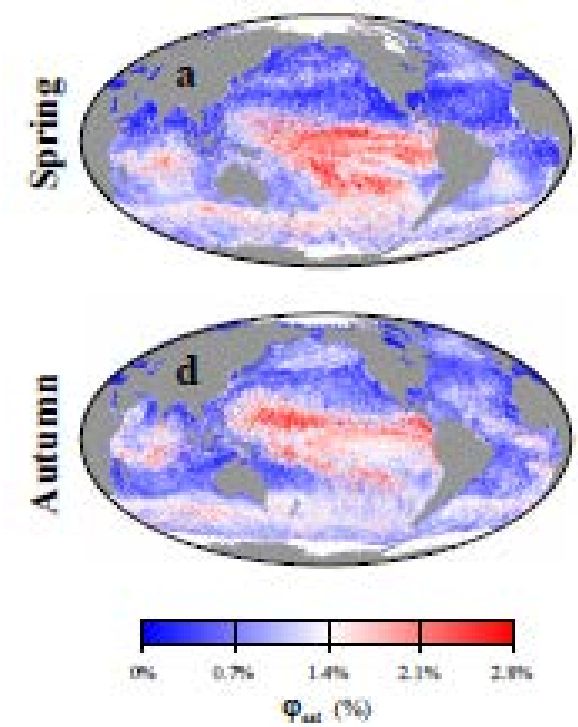
These unbound complexes have a unique optical signature, as they emit more chlorophyll fluorescence than non-iron limited phytoplankton.



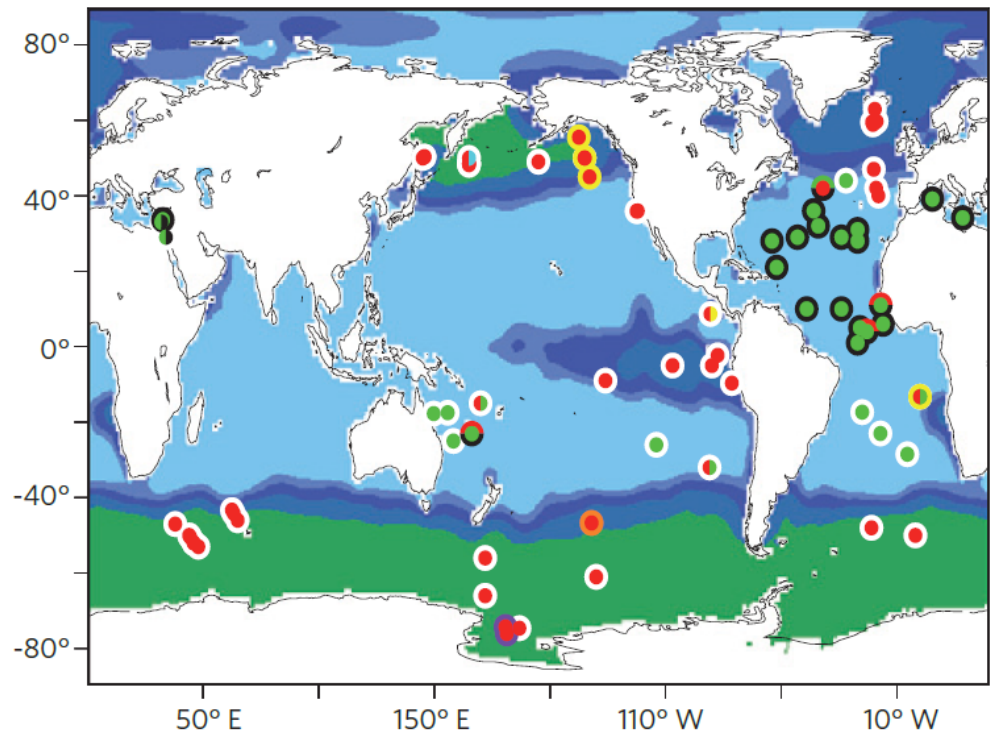
Schrader, P.S., A.J. Milligan. & M.J. Behrenfeld. 2011. Surplus photosynthetic antennae complexes underlie diagnostics of iron limitation in a cyanobacterium. PLOS ONE. 6: e18753.

Carbon Absorption Fluorescence & Euphotic Resolved NPP

Published estimates of the quantum yield of chlorophyll fluorescence assume static non-photochemical quenching parameterization (E_K constant).



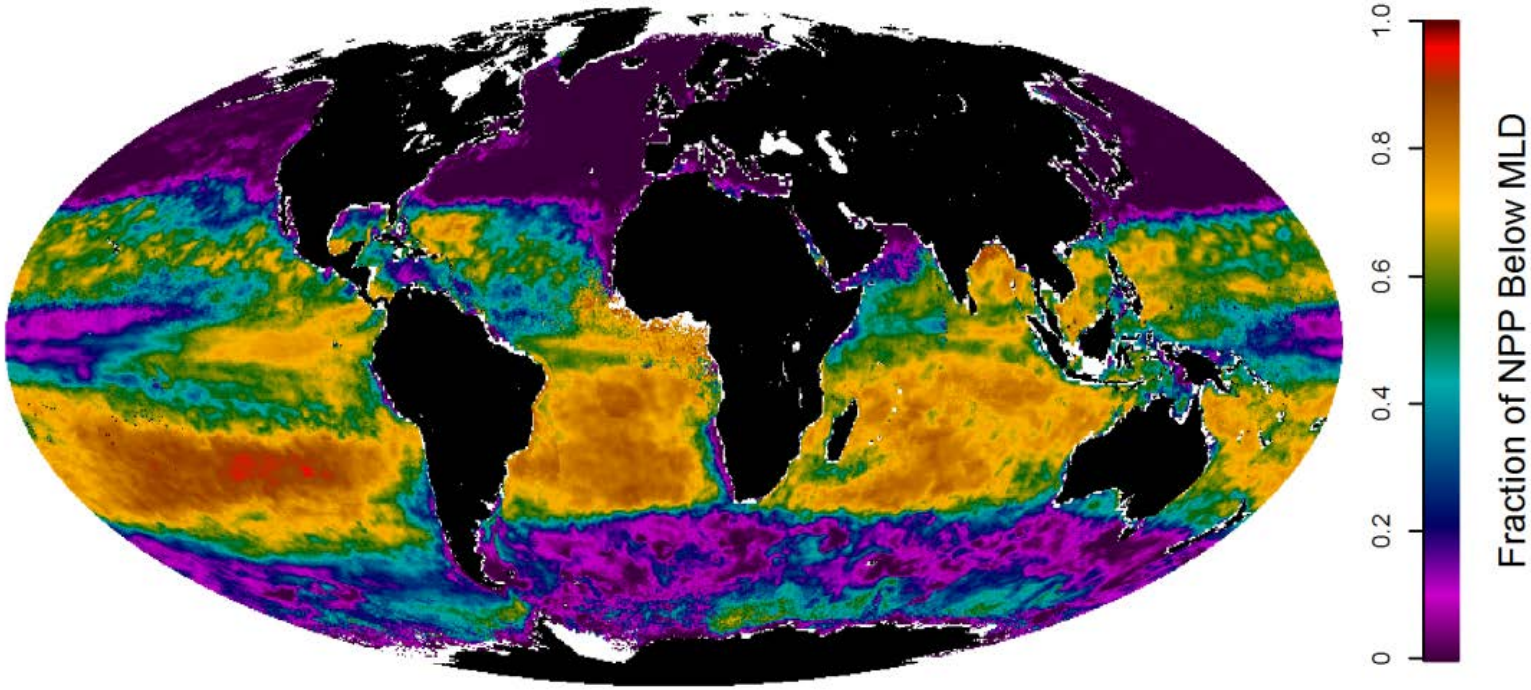
Behrenfeld et al. 2009. Biogeosciences. 6: 779-794.



Moore et al. 2013. Nature Geoscience. 6: 701-710.

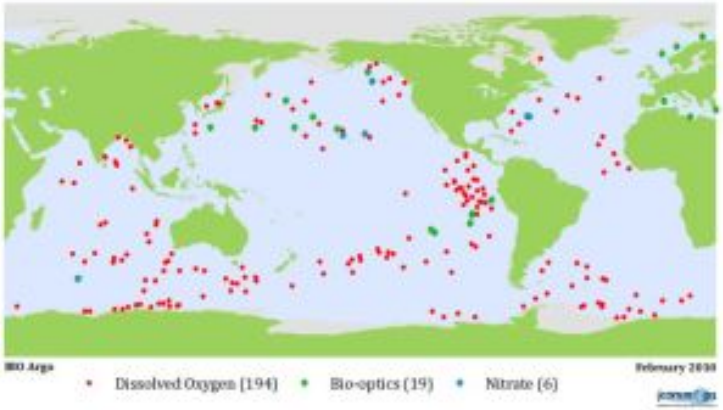
Carbon Absorption Fluorescence & Euphotic Resolved NPP

~35% of Global Oceanic NPP occurs beneath the MLD



Carbon Absorption Fluorescence & Euphotic Resolved NPP

Bio-Argo Profiles provide vertically resolved optical data to help inform and validate parameterization beneath the MLD.



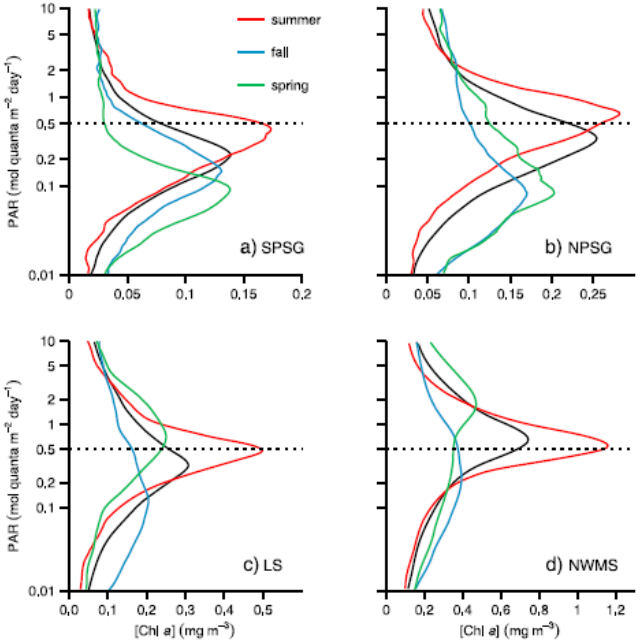
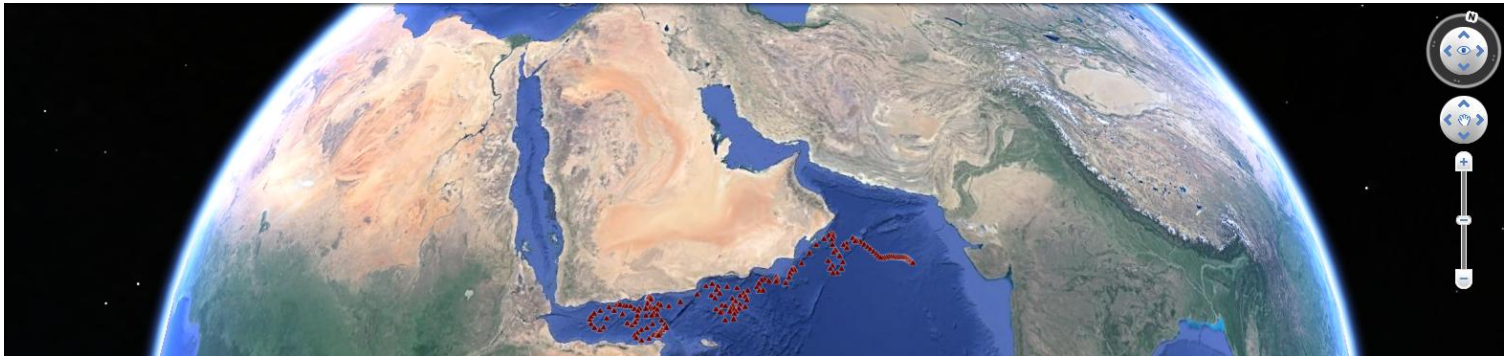


Figure 8. Vertical distribution of [Chl *a*] as a function of PAR for the four oligotrophic regions and over different time periods: (a) SPSG, (b) NPSG, (c) LS, and (d) NWMS. The dashed line corresponds to the 0.5 mol quanta m^{-2} d^{-1} isolume.

Understanding the seasonal dynamics of phytoplankton biomass and the deep chlorophyll maximum in oligotrophic environments: A Bio-Argo float investigation

Alexandre Mignot[1,2,3], Hervé Claustre[1,2], Julia Uitz[1,2], Antoine Poteau[1,2], Fabrizio D'Ortenzio[1,2], and Xiaogang Xing[4]

Carbon Absorption Fluorescence & Euphotic Resolved NPP



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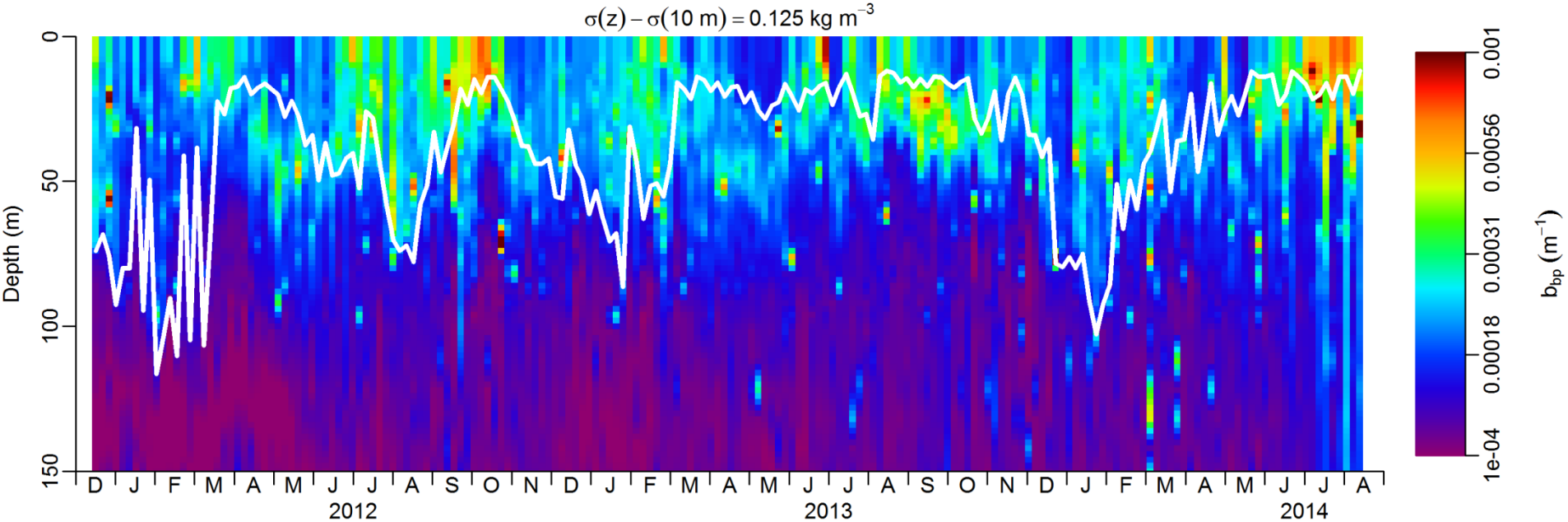

CONCLUSIONS & FUTURE WORK

- The CAFE model will implement a field-tested method to convert b_{bp} to C_{phyto} (Graff et al. *in press).*
- The CAFE model will exploit a improved parameterization of the Chl:C ratio (Behrenfeld et al. *submitted)*.
- Absorption based models require an accurate assessment of the irradiance dependency of the quantum yield of net photosynthesis.
- Bio-Argo data will be used to help validate parameterization beneath the mixed layer.