Marine ecosystem operational services : Global Status and prospectus

Nimit Kumar

ISG, INCOIS

nimitkumar.j@incois.gov.in

Discovery and Use of Operational Ocean Data Products and Services

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What are
« Phytoplankton Functional Types » (PFTs) ?

« Phytoplankton Functional Types » (PFTs) are conceptual groupings of several phytoplankton species, which are supposed to have in common a given ecological functionality (in terms of either the food web or the biogeochemical cycles)

For instance :
- Nitrogen fixers (*e.g.*, Trichodesmium)
- Calcifiers (*i.e.*, production of coccoliths)
- DMS producers (e.g., Phaeocystis)
- Silicifiers (*e.g.*, diatoms)

The grouping is not necessarily tightly related to a physiological characteristics, but is often based on “high-level” functionalities or characteristics, such as :
- Efficient export of organic carbon to the deep ocean *versus* local recycling
- Small, medium or large sizes (pico, nano and micro- phytoplankton)

The grouping and the number of groups are related to the scientific questions that are addressed, the answer to which being supposedly better when PFTs are known

Why « Phytoplankton Functional Types » (PFTs) are of interest to the "biogeochemical" community ?

- They are relevant proxies of the ecosystem functioning

- We can learn a lot about the ecosystem functioning from their time change (at all scales)

- Their respective importance will probably evolve as a function of climate change, with an impact on the efficiency of the ocean to eventually sequester carbon

- It is believed that their "incorporation" into biogeochemical models will improve the predictive capabilities of such models (a debate exists, however, as to whether or not this is really feasible and totally relevant; here we take the assertion as granted)

Why is it suspected that PFTs are derivable from OC remote sensing ?

Both a direct and an indirect effect (not exclusive)

Direct effect :
Changes in the phytoplankton species assemblage may lead to significant changes in the spectra of the absorption and backscattering coefficients (through changes of cell size, pigments…), which would lead to palpable changes in the reflectance spectra.

Indirect effect :
Changes in the phytoplankton species assemblage is accompanied by a change in the ensemble of particles (detritus, viruses, bacteria…) and dissolved substances, which would lead to palpable changes in the reflectance spectra.

If the changes of the reflectance are significant enough, they can be detected in the reflectance spectra, either *in situ* or from a remotely-sensed spectra.

If they are not significant enough to be directly detected, empirical relationships have to be established *in situ* between remotely-sensed quantities (*e.g.*, Chl) and the PFTs

Existing techniques (1) : inversion of a reflectance model, based on a data base of forward simulations

Roesler et al., 2005.

1 – Determine specific absorption spectra for phytoplankton species/groups
2 – Generate a data base of reflectance (R) spectra, for varying concentrations, compositions and size distributions
3 – Invert these spectra in terms of the relative contribution to absorption of each of the taxonomic groups

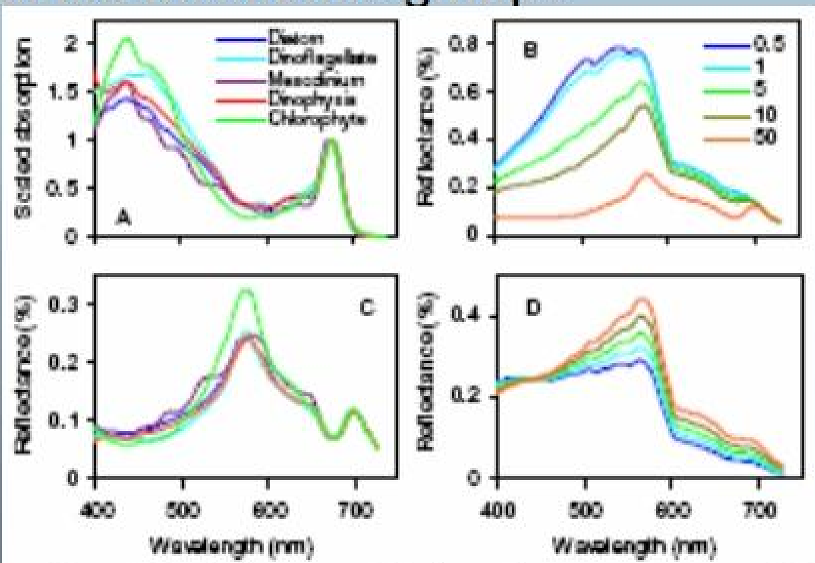


Fig. 1. (A) Scaled taxon-specific absorption spectra for 5 separable groups based upon spectrophotometric analysis of size-fractionated samples and corresponding microscopic species counts. Results of reflectance simulations as a function of (B) algal biomass (µg chl l^{-1}), (C) algal composition at 50 µg chl l^{-1} concentrations, symbols as in part A, (D) particle size distribution, where long wavelength reflectance increases as particle size increases.

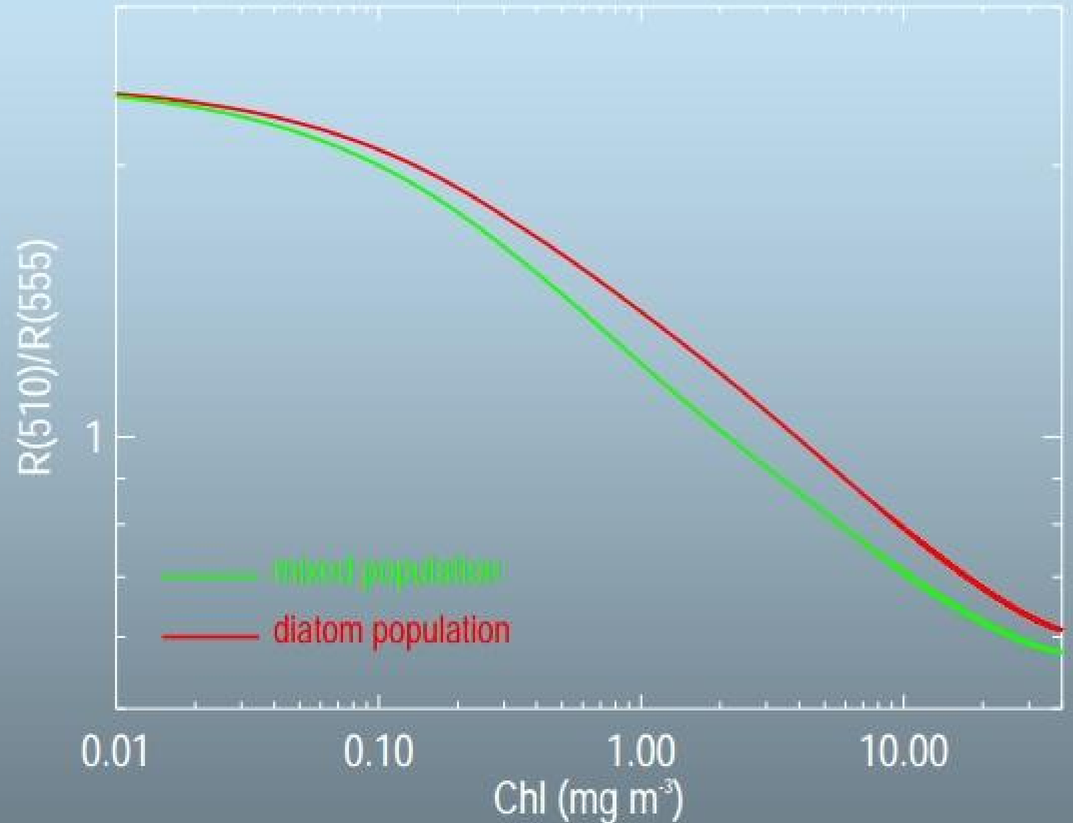
The method was tested, and is quite successful, at very high biomass (~50 mg/m^3).

Roesler, C. S., S. M. Etheridge and G. C. Pitcher. 2004. Application of an ocean color algal taxa detection model to red tides in the Southern Benguela, pp.303-305. In: Steidinger, K. A., Lansdberg, J. H., Tomas, C. R., and Vargo, G. A. [eds.]. Harmful Algae 2002. Florida Fish and Wildlife Conservation Commission, Florida Institute of Oceanography, and Intergovernmental Oceanographic Commission of UNESCO.

Existing techniques (2)

E. Devred, S. Sathyendranath, C. Fuentes-Yaco, T. Platt, H. Mass
Dalhousie Univ. & Bedford Institute of Oceanography, Canada

Reflectance ratio as a function of chlorophyll concentration



From S. Sathyendranath et al. 2004

Same LUT was generated for *R*(490)/*R*(670)

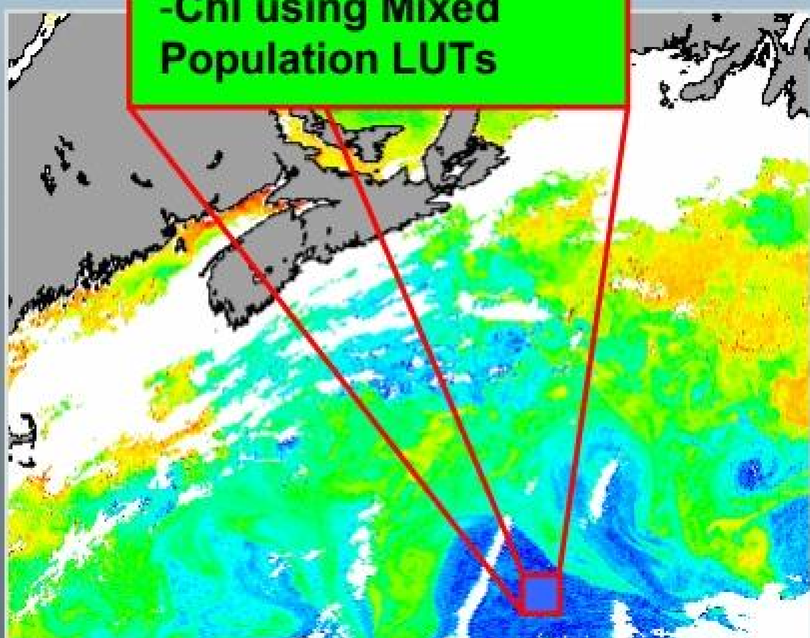
Existing techniques (2, cont'd)

Application to the Northwest Atlantic

-nLw
:490,510,555,670 nm
→ nRw

-Chl using Diatom LUTs

-Chl using Mixed Population LUTs



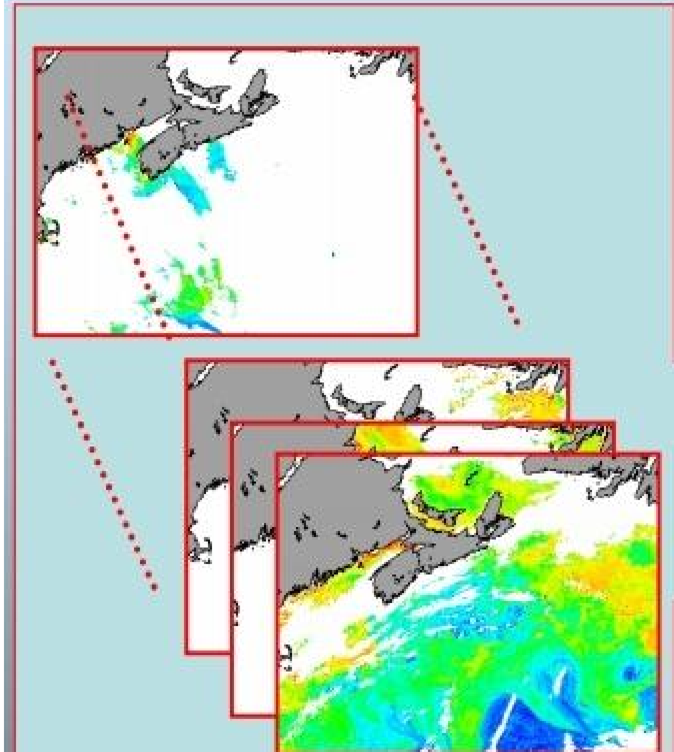
$Chl_{di}(R_{510}/R_{555}) - Chl_{di}(R_{490}/R_{670}) = \varepsilon_{di}$

$Chl_{mp}(R_{510}/R_{555}) - Chl_{mp}(R_{490}/R_{670}) = \varepsilon_{mp}$

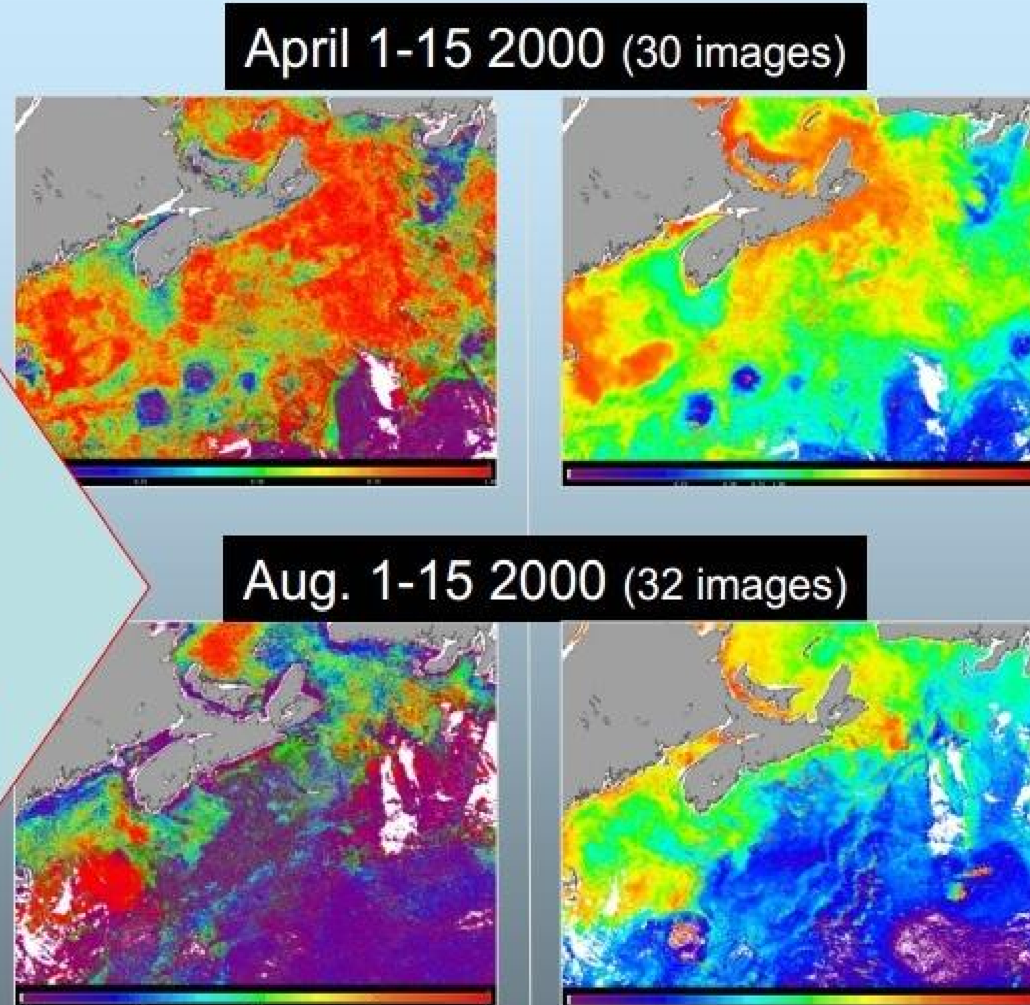
$Min(\varepsilon_{di}, \varepsilon_{mp})$ yields phytoplankton population and chlorophyll concentration

Existing techniques (2, cont'd)

Composite images



$$F_{di} = \frac{\sum_n p_{di}}{\sum_n p_{di} + \sum_n p_{mp}}$$



Probability of occurrence of diatom populations

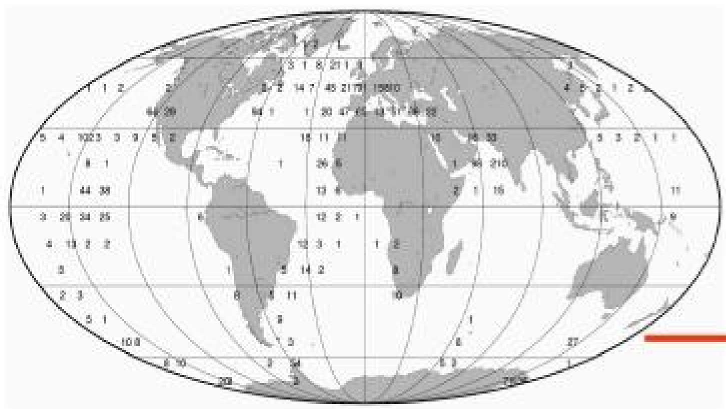
Chlorophyll concentration

From S. Sathyendranath et al. 2004

Existing techniques (3) : relationships between surface chlorophyll, the trophic status and size classes

J. Uitz and H. Claustre, 2005

- HPLC pigment database: 2419 stations sampled between 1990 and 2002



Number of stations per square of 10°x 10°

- From diagnostic pigment (DP) to phytoplankton size classes

$_{w}DP$ = 1.4 Fuco + 1.4 Peri + 1.3 19'-HF + 0.4 19'-BF + 0.6 Allo + 0.9 Zea + 1.0 TChl*b*

~ Micro > 20 µm (1.4 Fuco + 1.4 Peri) ; ~Nano 2-20 µm (1.3 19'-HF + 0.4 19'-BF + 0.6 Allo) ; ~ Pico < 2 µm (0.9 Zea + 1.0 TChl*b*)

Size classes proportion

pMicro = (1.4 Fuco + 1.4 Peri) / $_{w}DP$

pNano = (1.3 19'-HF + 0.4 19'-BF + 0.6 Allo) / $_{w}DP$

pPico = (0.9 Zea + 1.0 TChlb) / $_{w}DP$

TChla associated to size classes: sc-TChla

Micro-TChla = pMicro * TChla

Nano-TChla = pNano * TChla

Pico-TChla = pPico * TChla

After : Claustre (L&O, 1994); Vidussi et al. (JGR, 2001)

- Standardization of the sc-TChla profiles

zeta = z / Z_{eu}

sc-TChla(zeta) = sc-TChla(z) / $TChla_{Zeu}$

- Interpolation of the dimensionless sc-TChla profiles

zeta = 0 (surface) to zeta = 2 (2*Z_{eu}) ⇒ 20 points / profile

- Sorting of the interpolated sc-TChla profiles

⇒ according to the hydrological regime: stratified / mixed

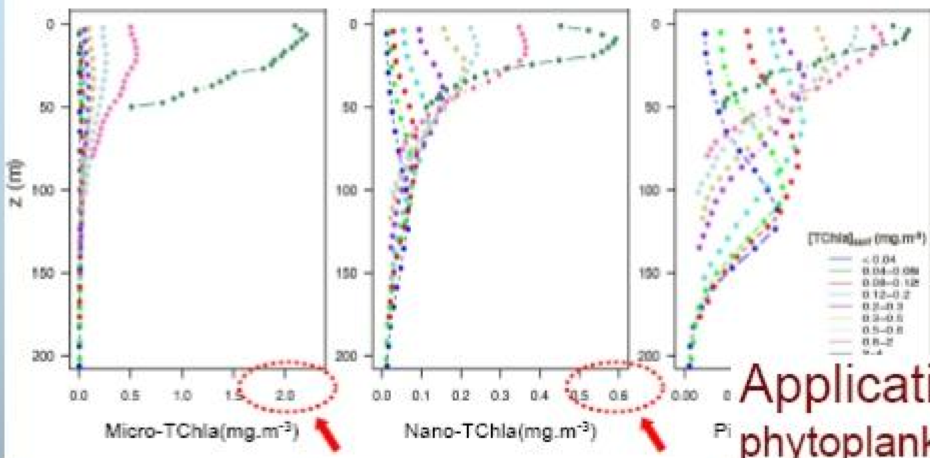
⇒ according to $[TChla]_{surf}$

- Computation of average sc-TChla profiles / trophic class

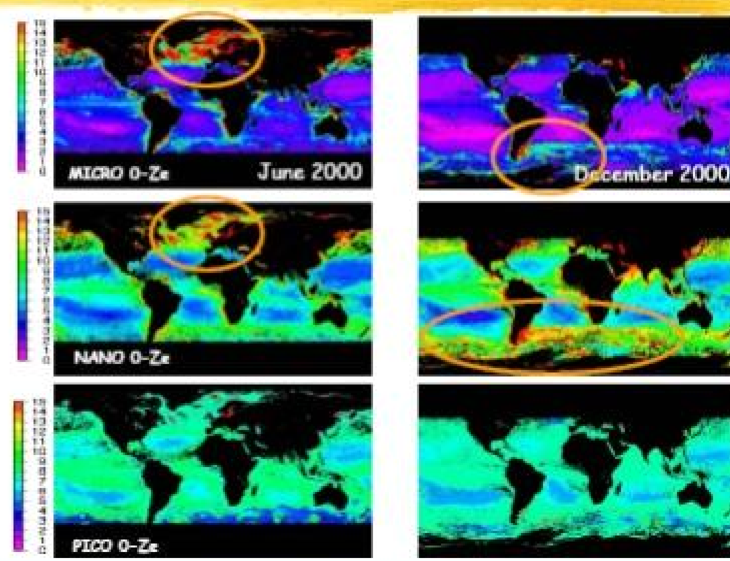
After : Morel & Berthon (L&O, 1989)

Existing techniques (3, cont'd)

- Geometrically rescaled profiles



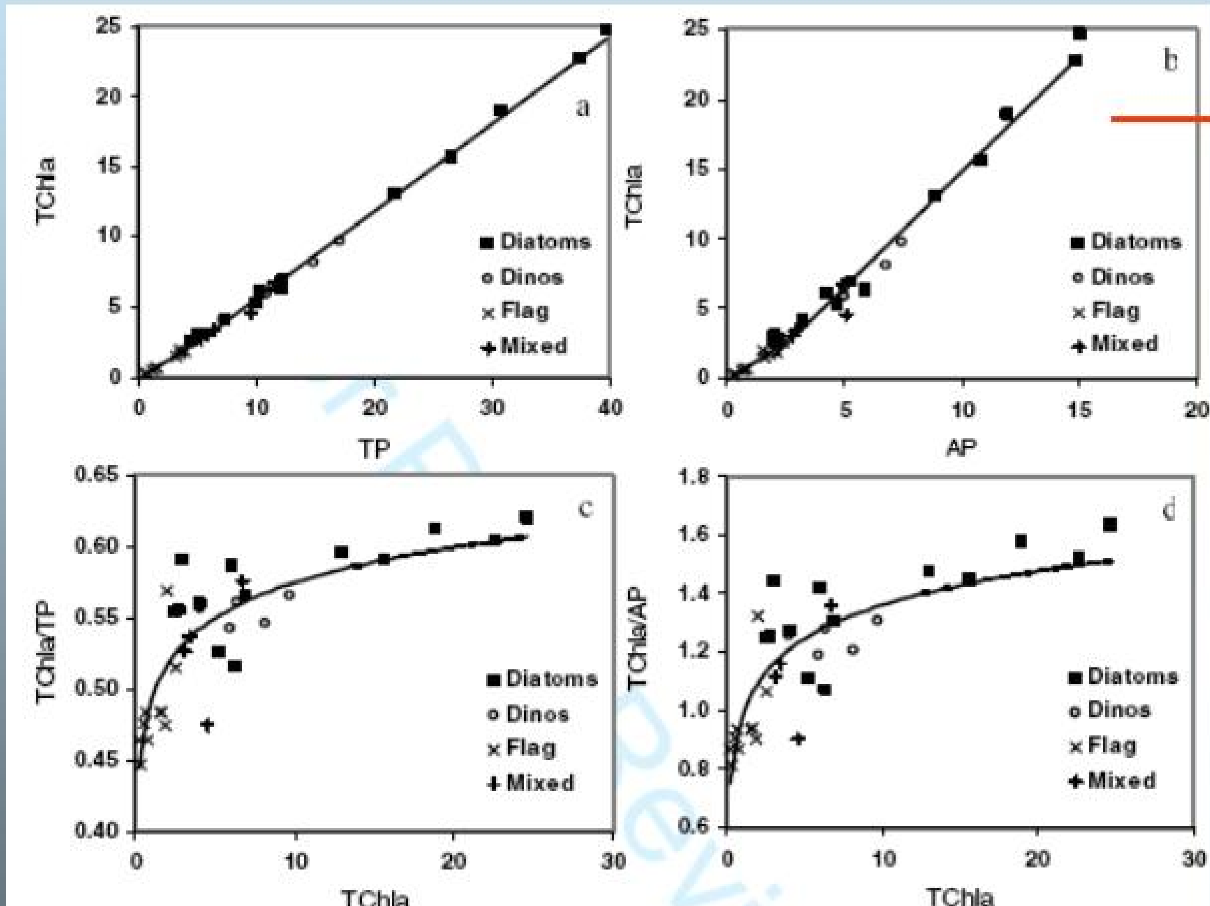
Application:
phytoplankton functional groups climatology



Existing techniques (4) :

Aiken *et al.*, 2005

HPLC-determined pigments are used to distinguish between groups

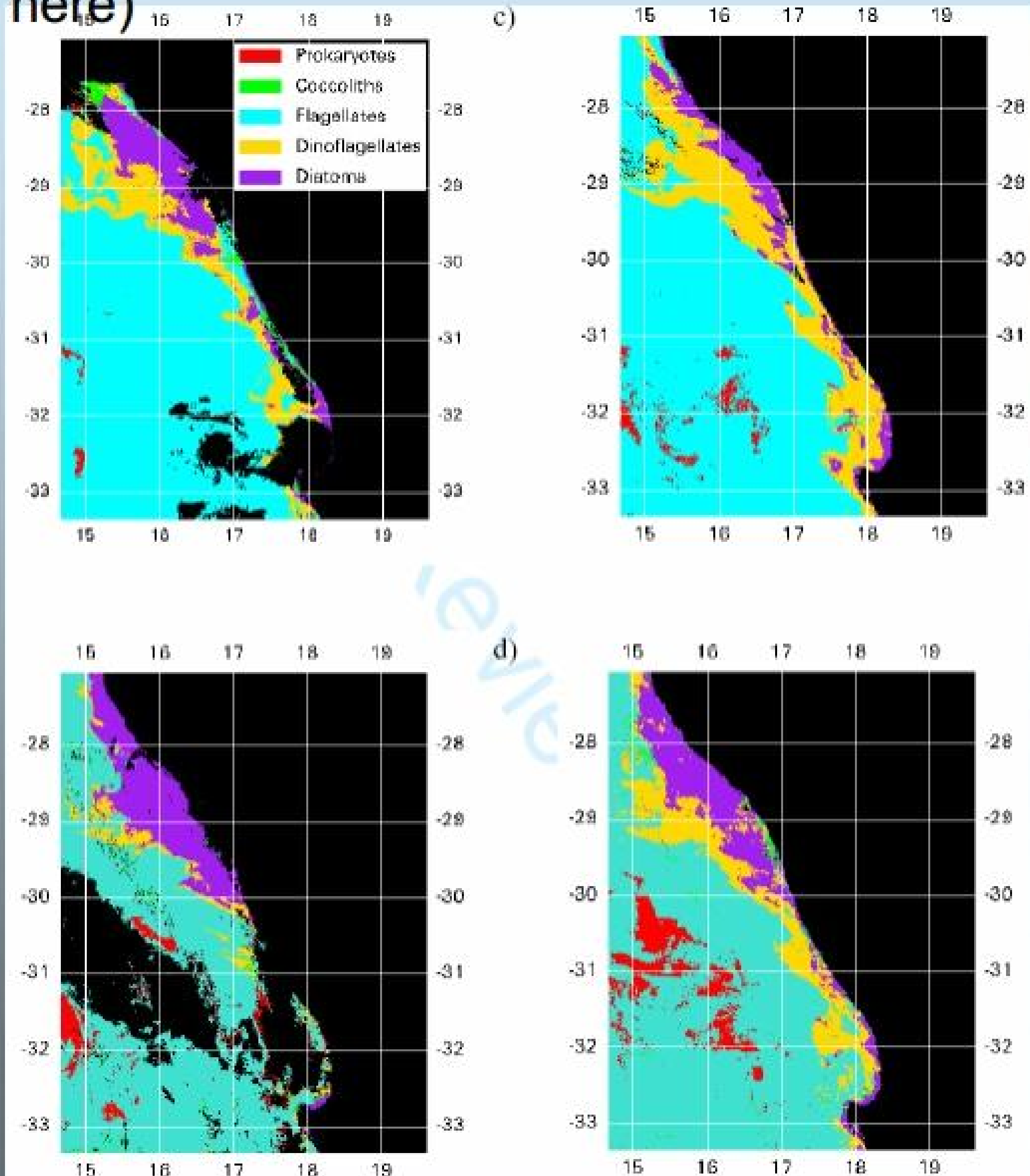


Similar relationships and associated statistics are derived for several phytoplankton groups, based on a data set of inherent optical properties + HPLC pigments.
Therefore, groups can be determined from Chl-a

Courtesy : J. Aiken

Existing techniques (4, cont'd)

The method is then applied to satellite images (MERIS images here)



Example here : the BENCAL cruise (Sept 2002) in the Benguela upwelling

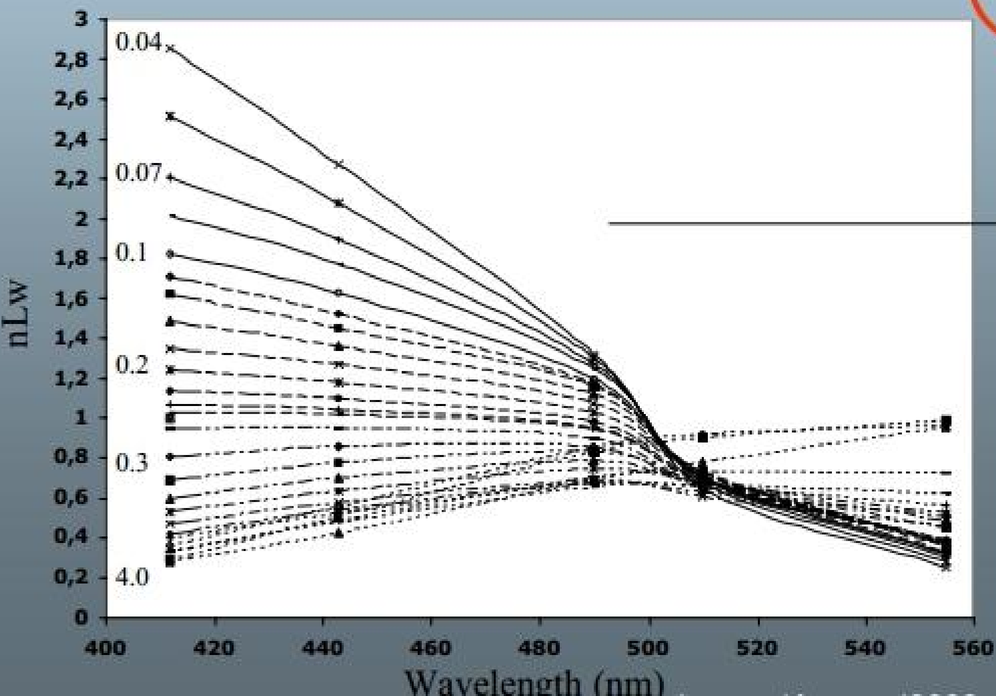
Courtesy : J. Aiken

Existing techniques (5) : empirical relationships between groups (HPLC-determined) and ocean colour

Alvain and Moulin (Deep-Sea Research I, 2005, vol , xx-xx).

1 – Determine the dominant group from HPLC pigment inventories (Gep&CO program)
2 – Put together these groups and the SeaWiFS-derived nLw's, after the 1st order effect of Chl has been removed
3 – Determine specific nLw* spectra for each group
4 – Extend to global SeaWiFS imagery

$$nLw^*(\lambda) = nLw_{obs}(\lambda) / nLw_{mod}(Chl\text{-}a_{swfs}, \lambda)$$

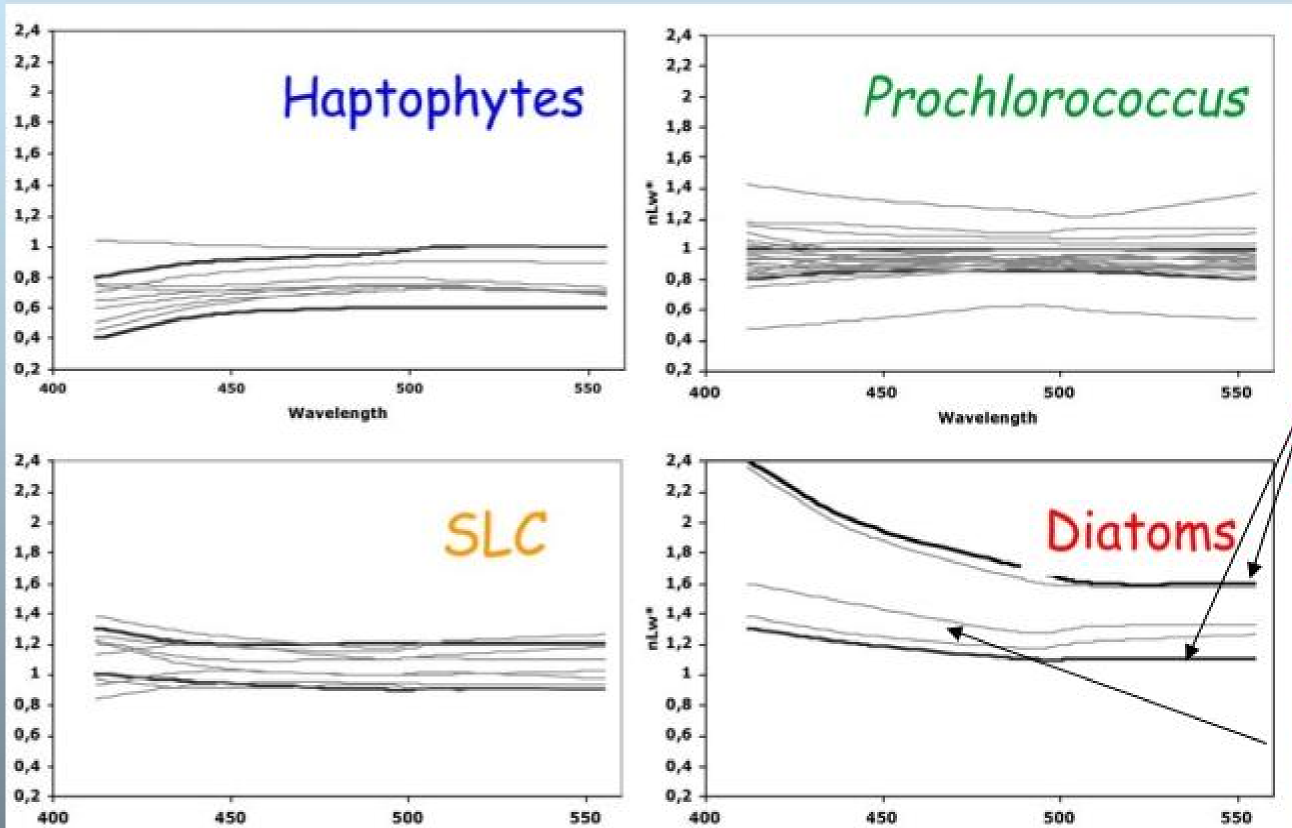


Courtesy: S. Alvain

Existing techniques (5, cont'd)

A specific nlw* for each dominant group !

nLw*



nLw*

Wavelength

Wavelength

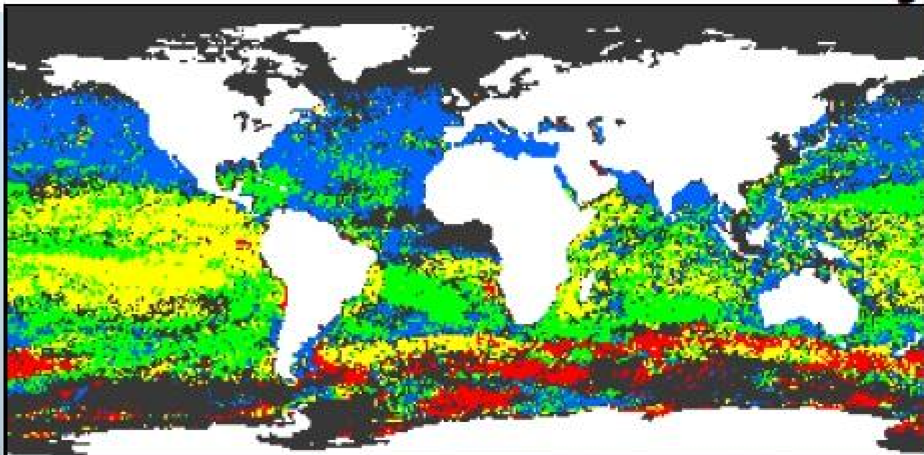
Envelope of nLw* spectrum used to characterized the phytoplankton group

Courtesy:
S. Alvain

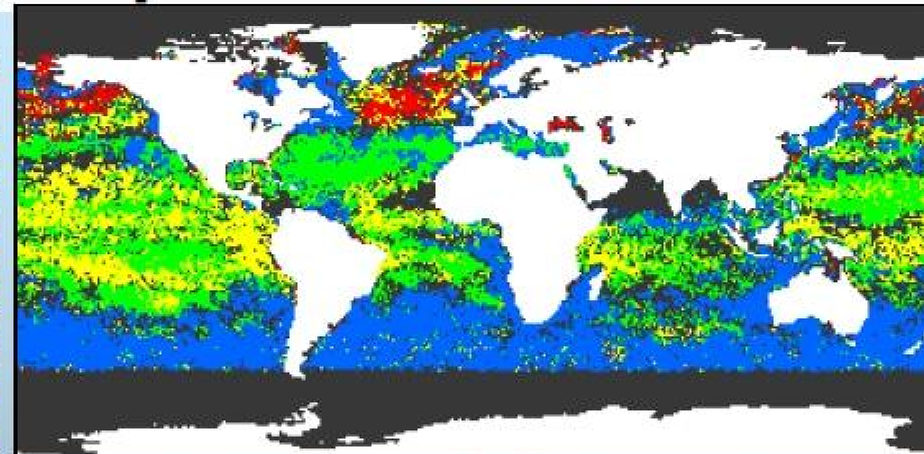
In light grey : Individual spectral signature for the 41 nLw associated with the 41 Gep&Co pigments inventories*

Is the nlw* spectrum usable to detect dominant phytoplankton groups at the global scale ?

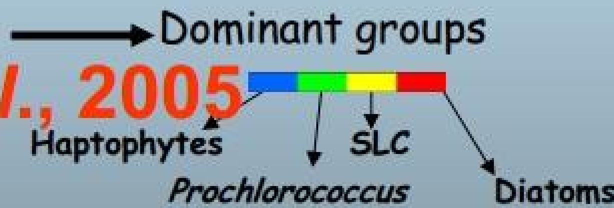
Existing techniques (5, cont'd)
Global monthly maps for 2001



January

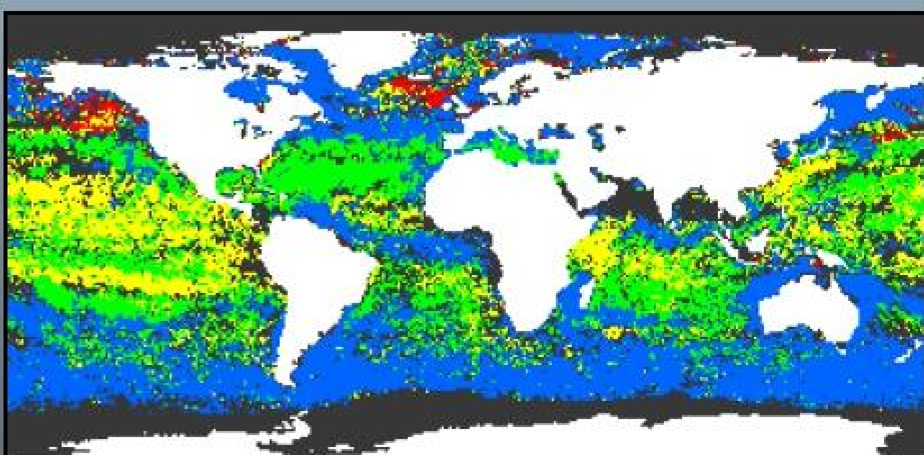


April

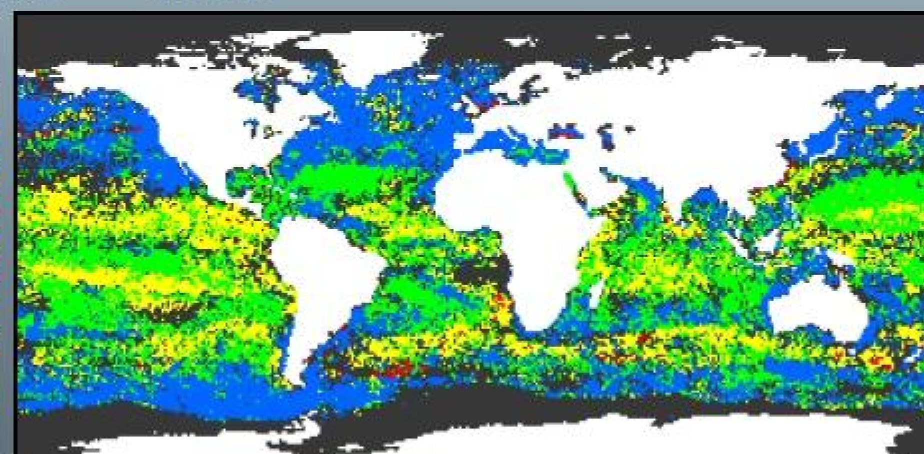


From Alvain *et al.*, 2005

« PHYSAT »

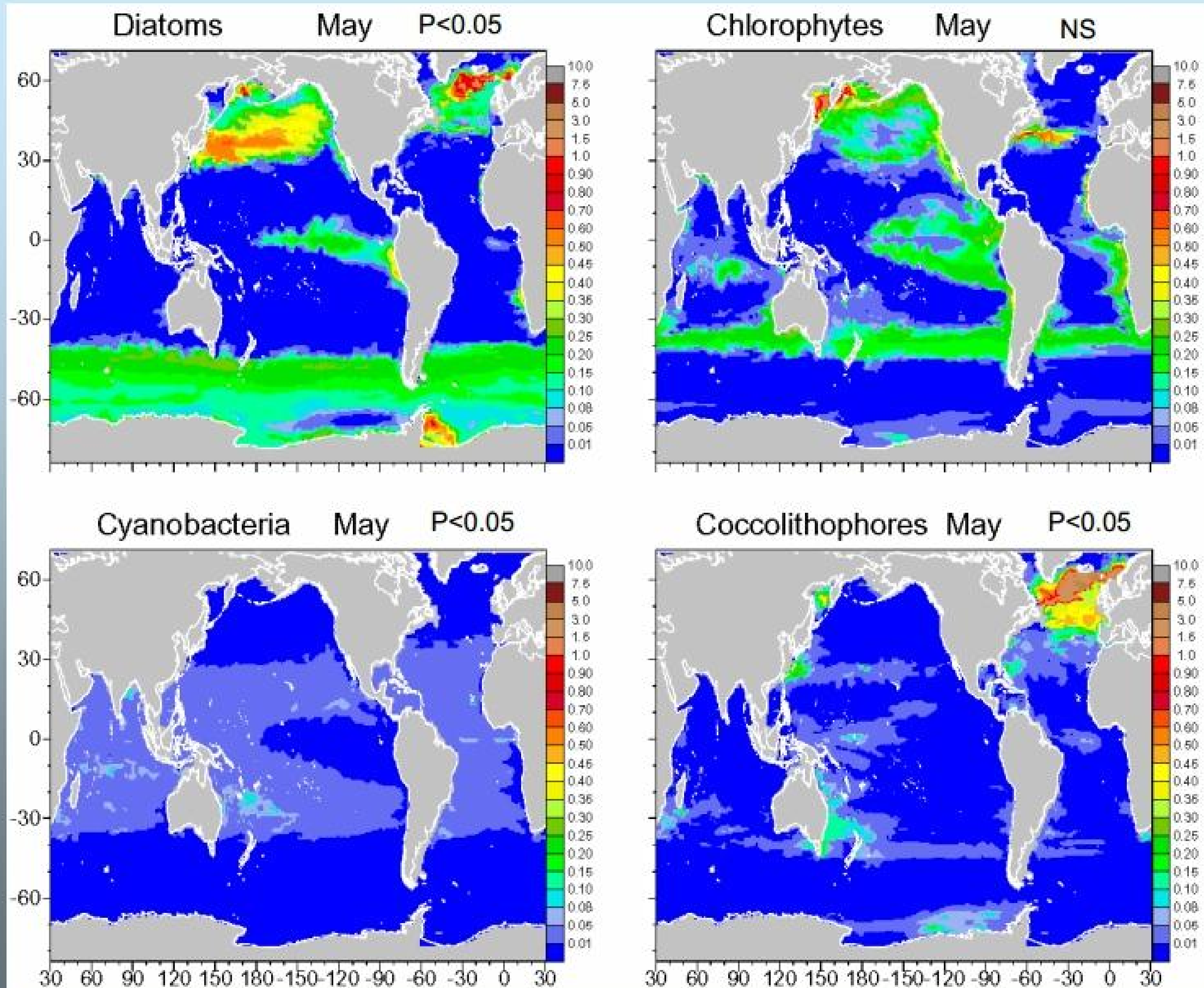


June



October

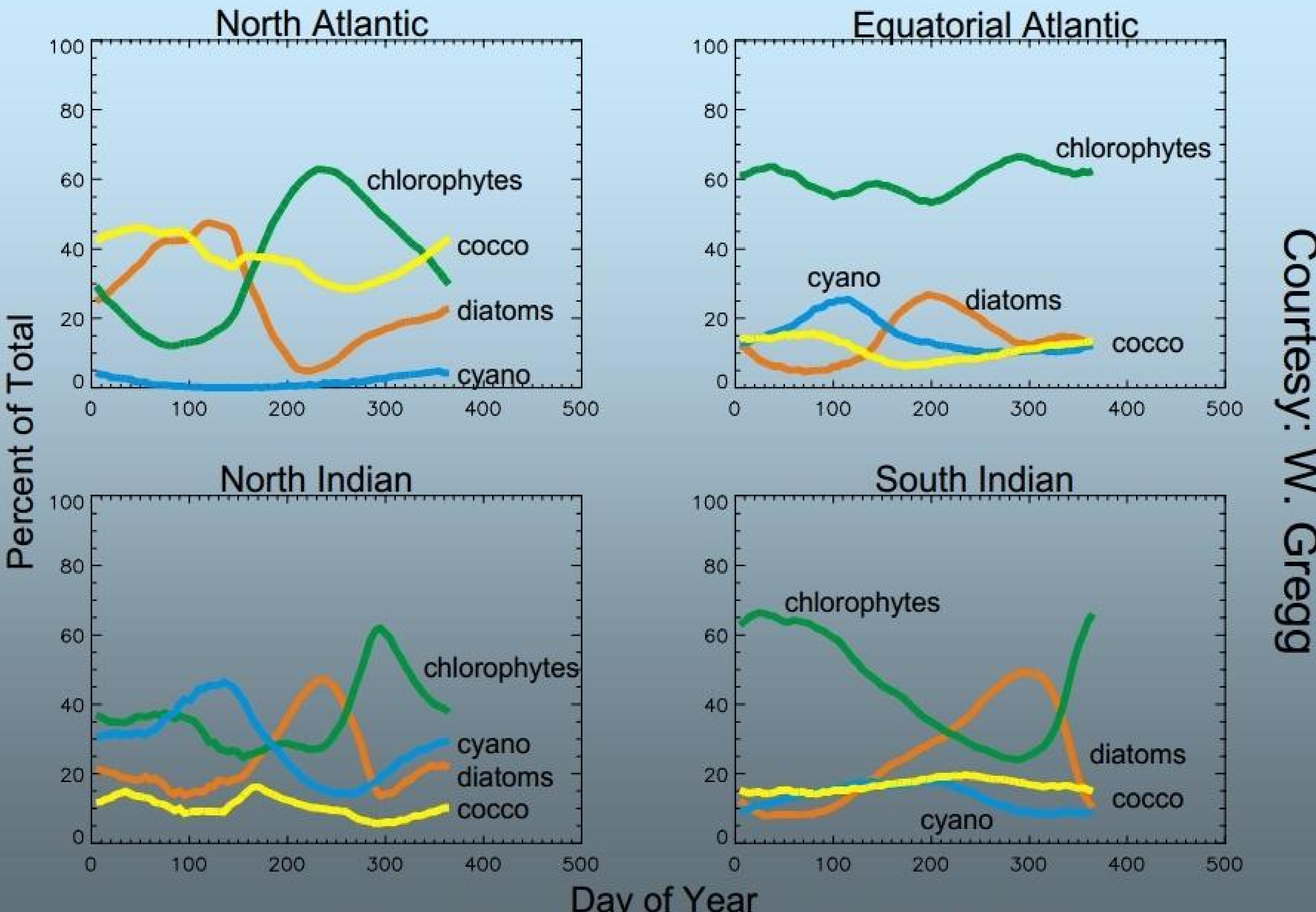
Examples of PFTs from global models (1)



Courtesy: W. Gregg

Model estimates, and statistical significance by basin compared to 359 surface observations (Gregg et al. 2003)

Examples of PFTs from global models (1, cont'd)

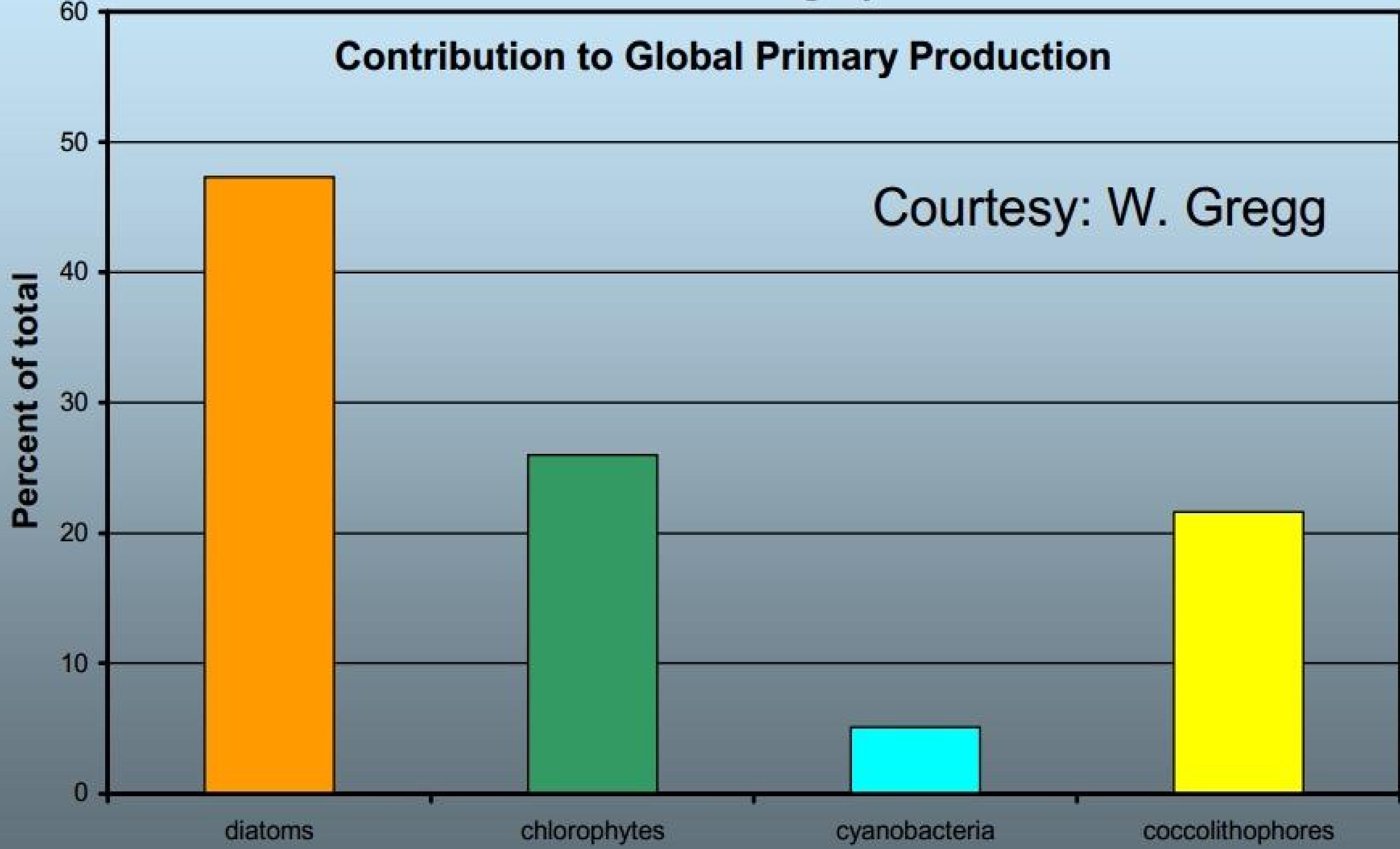


Model-estimated seasonal variability (Gregg et al., 2003)

Examples of PFTs from global models (1, cont'd)

Primary Production

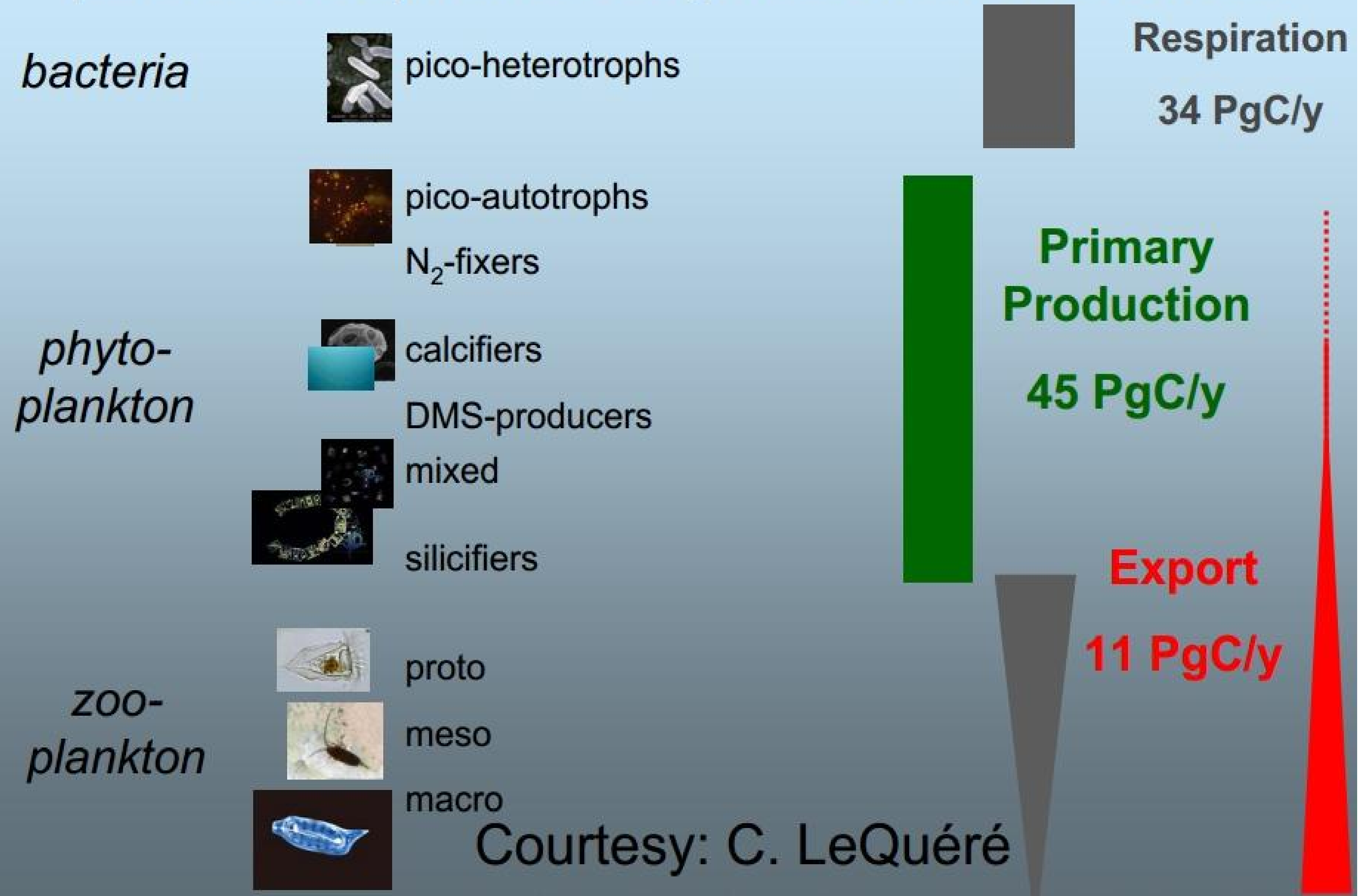
Model = 48.9 PgC y^{-1}
SeaWiFS = 42.7 PgC y^{-1}
Difference = 6.1 PgC y^{-1} or 14.3%



Model estimates of primary production (Gregg, 2005, unpublished)

Examples of PFTs from global models (2)

planned developments of a Dynamic Green Ocean Model

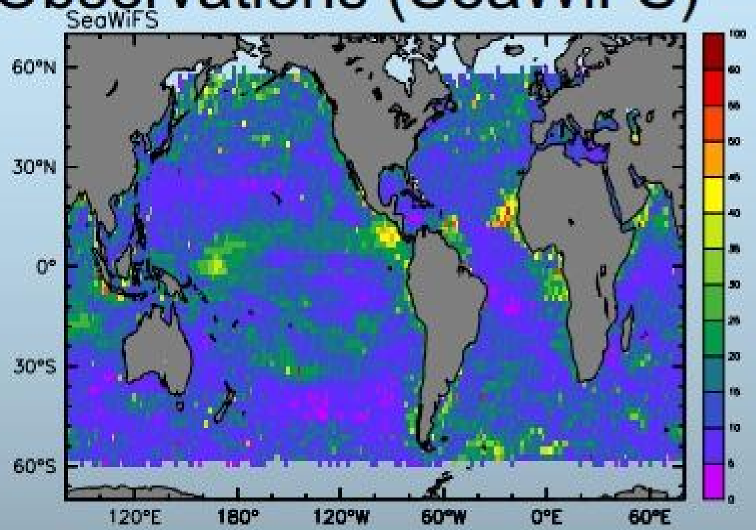


Courtesy: C. LeQuéré

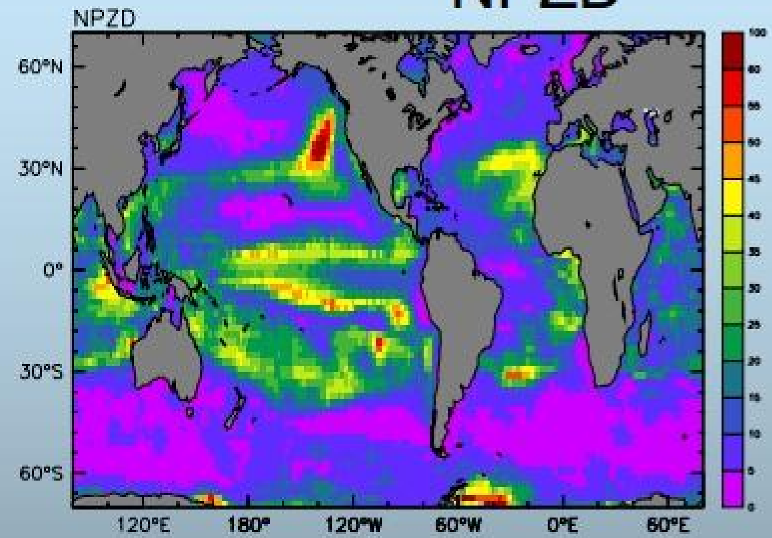
Examples of PFTs from global models (2, cont'd)

Interannual chla variability (percent)

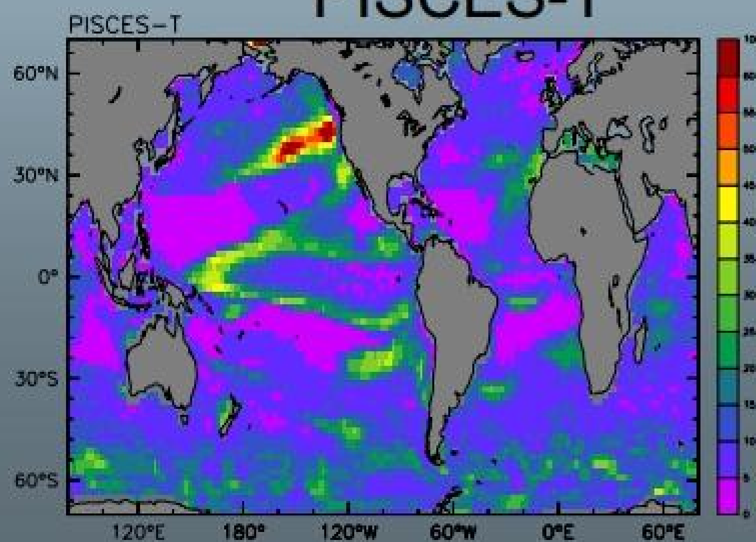
Observations (SeaWiFS)



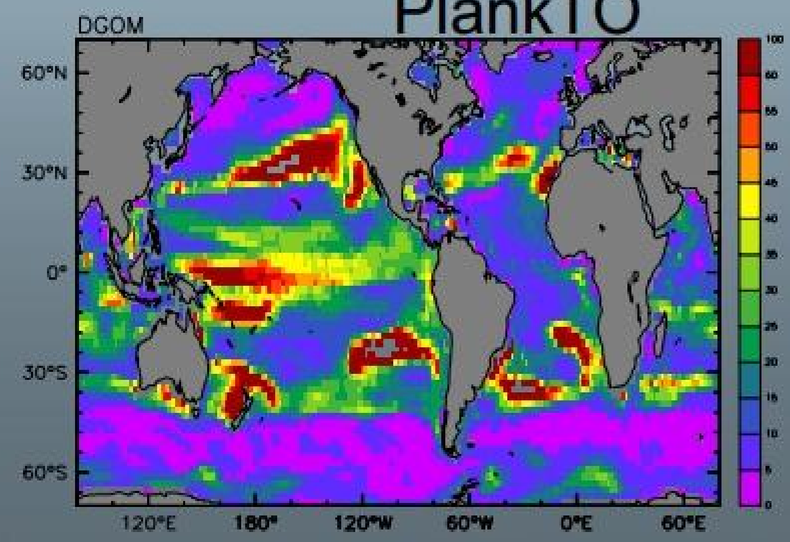
NPZD



PISCES-T



PlankTO

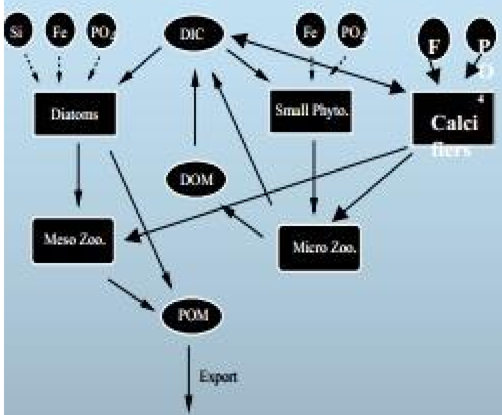


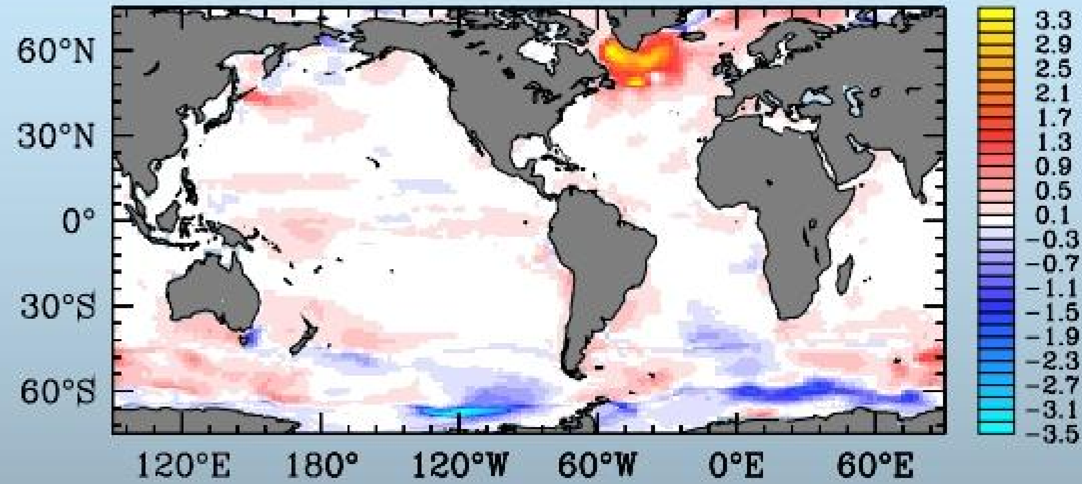
Courtesy: C. LeQuéré

Examples of PFTs from global models (2, cont'd)

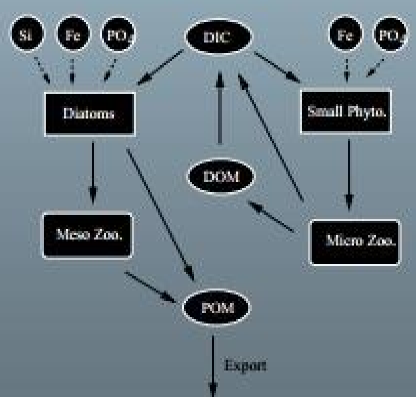
Impact of climate change on the CO_2 sink in 2060 using identical physics but two different ecosystem models (mol/m2/y)

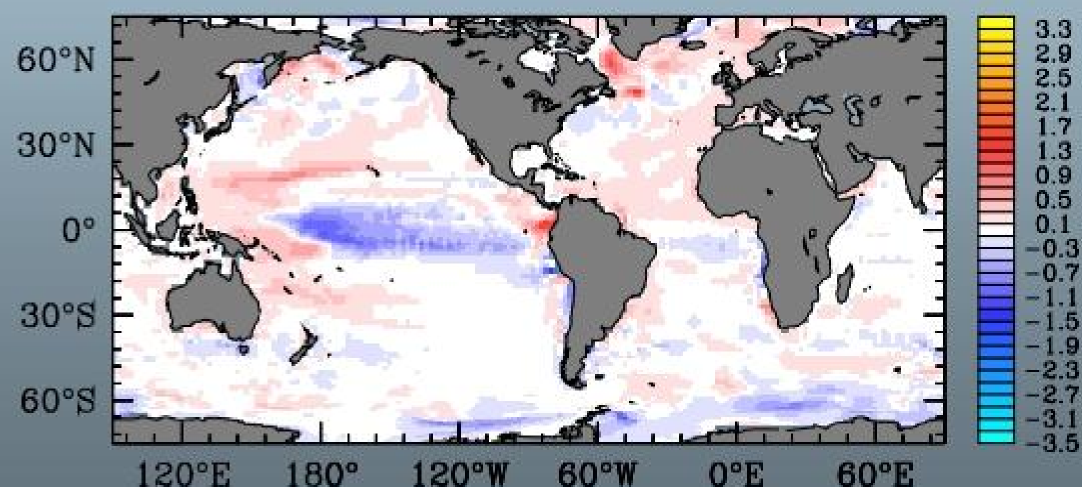
PlankTOM





PISCES-T





Courtesy: C. LeQuéré

(Preliminary result from E. T. Buitenhuis)

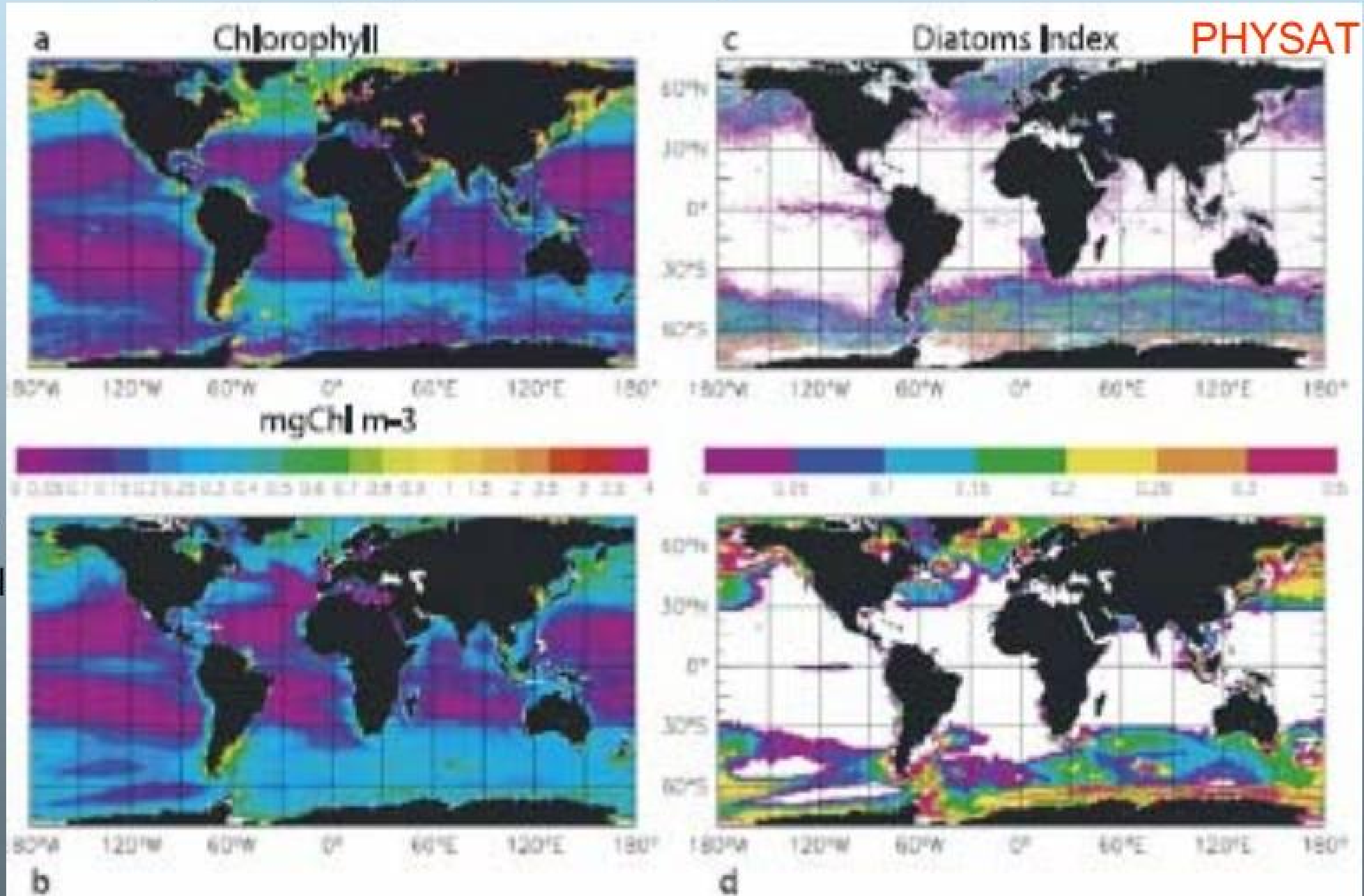
Examples of PFTs from global models (3)

From Bopp *et al.*, 2005

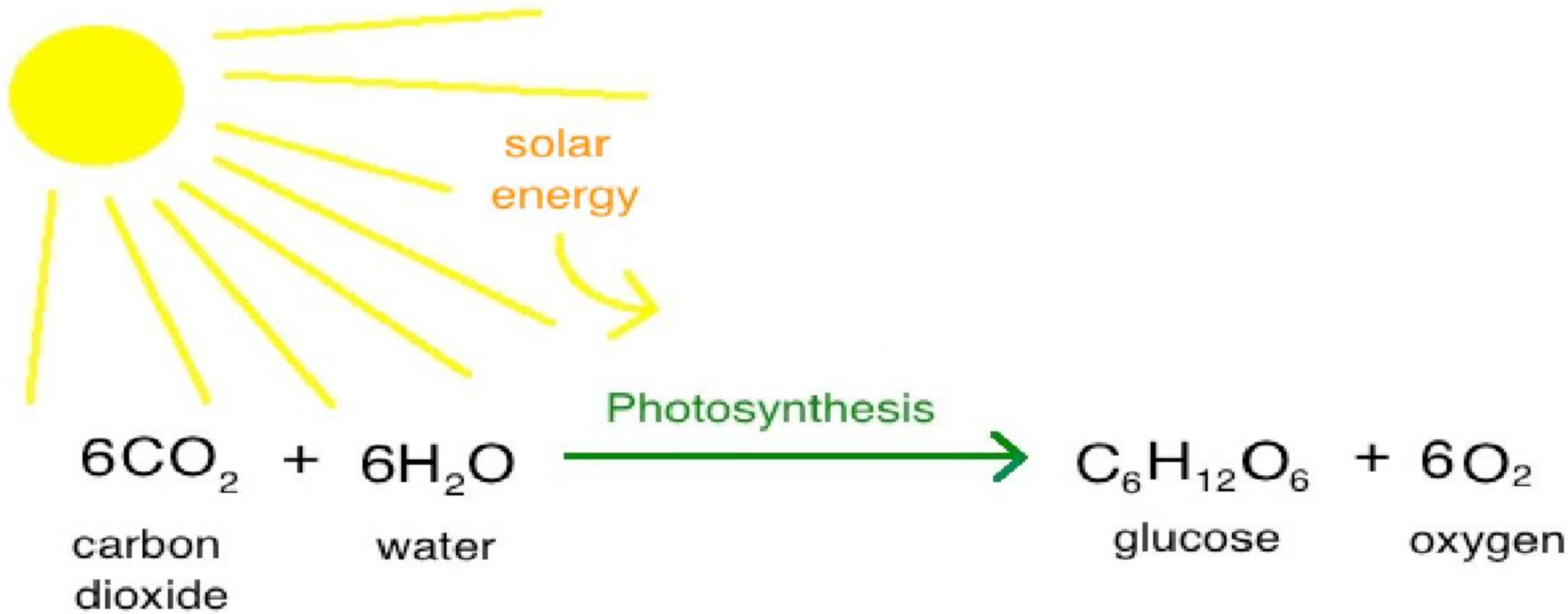
"Response of diatoms distribution to global warming and potential implications: A global model study", GRL, vol 32, 2005

SeaWiFS

IPSL-CM4 / PISCES model

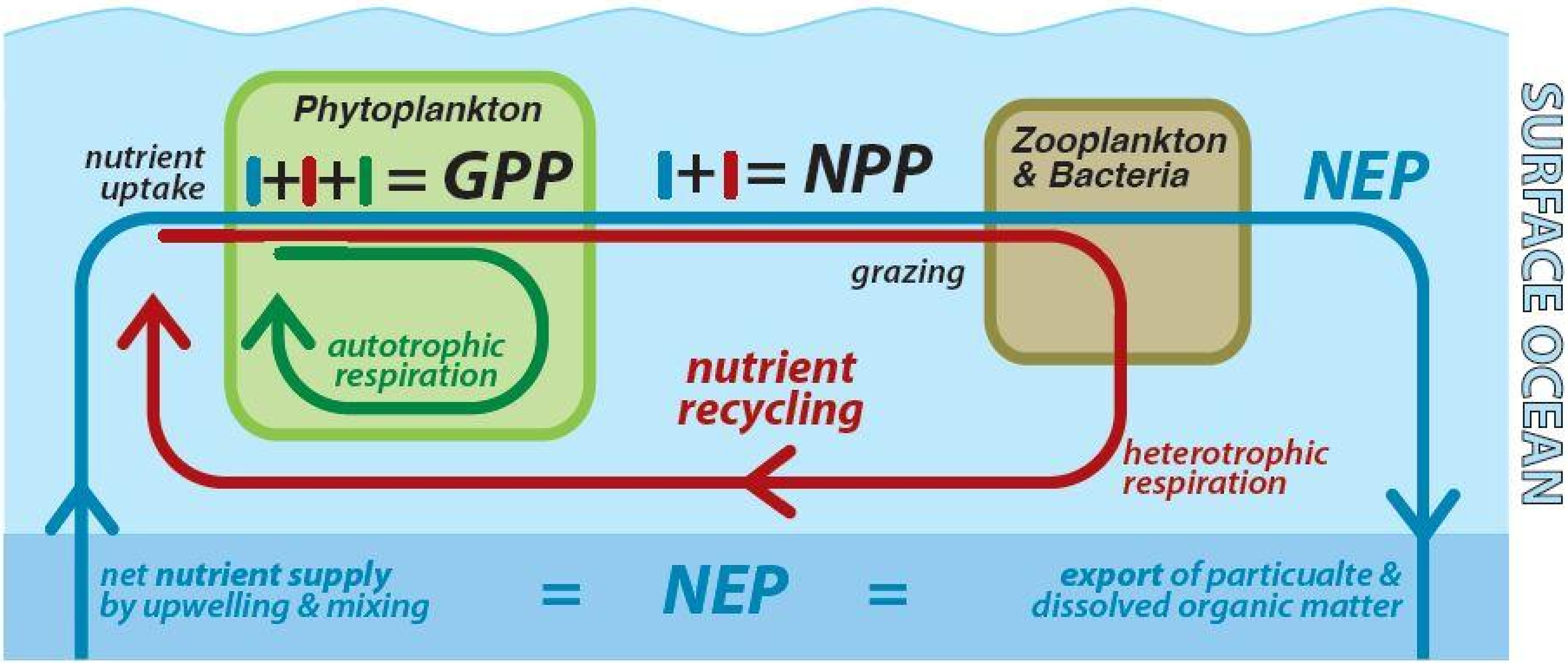


Photosynthesis



- ✓ Primary Productivity is the rate at which light energy or inorganic chemical energy is converted to the chemical energy of organic compounds by autotrophs in an ecosystem.
- ✓ In the ocean, photosynthesis is performed by phytoplankton in the sunlit or euphotic zone.
- ✓ This process takes carbon dioxide and water and combines them with the help of the energy contained in sunlight creates a monosaccharide and oxygen

Upper Ocean Productivity

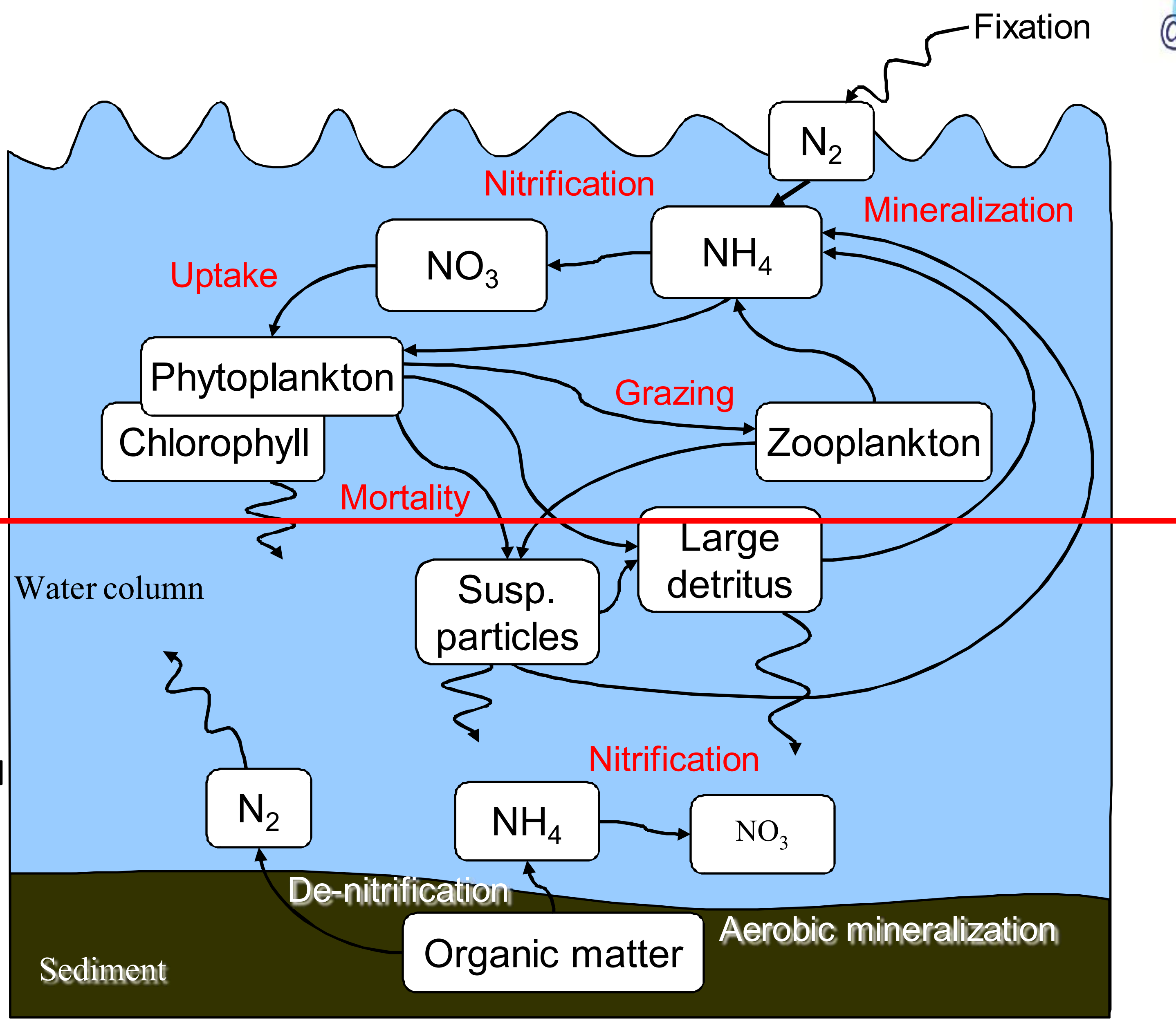


✓"Gross primary production" (GPP) refers to the total rate of organic carbon production by autotrophs

✓ "respiration" refers to the energy-yielding oxidation of organic carbon back to carbon dioxide.

✓ "Net primary production" (NPP) is GPP minus the autotrophs' own rate of respiration; it is thus the rate at which the full metabo-lism of phytoplankton produces biomass.

Mix Layer depth



Continental shelf sediments are responsible for up to 67% of marine N denitrification estimates

De-nitrification – the removal of fixed N, mostly $NO3^-$, resulting in the formation of non-biologically available N, primarily N_2 gas

Partition of Anthropogenic Carbon Emissions into Sinks [2000-2006]

45% of all CO_2 emissions accumulated in the atmosphere

55% were removed by natural sinks

Ocean removes ~ 24%

Land removes ~ 30%

Primary Productivity Models

I. Wavelength-resolved models (WRMs)

$$\sum PP = \int_{\lambda=400}^{700} \int_{t=\text{sunrise}}^{\text{sunset}} \int_{z=0}^{Z_{eu}} \Phi(\lambda, t, z) \times \text{PAR}(\lambda, t, z) \times \text{Chl}(z)\, d\lambda\, dt\, dz - R$$

- ✓ WRM convert absorbed radiation i.e. Photosynthetically Utilizable Radiation (PUR) into net photosynthesis using a suit of empirical quantum efficiency models based on photosynthesis-irradiance variables

II. Wavelength-integrated models (WIMs)

$$\sum PP = \int_{t=\text{sunrise}}^{\text{sunset}} \int_{z=0}^{Z_{eu}} \varphi(t, z) \times \text{PAR}(t, z) \times \text{Chl}(z)\, dt\, dz - R$$

- ✓ WIM eliminated wavelength dependencies and NPP is described as a function of PAR rather than PUR and calculated by integrating PAR dependent photosynthesis-irradiance function over depth and time

Primary Productivity Models

II. Time-integrated models (TIMs)

$$\sum PP = \int_{z=0}^{Z_{eu}} P^b(z) \times \mathrm{PAR}(z) \times DL \times \mathrm{Chl}(z)\, dz$$

- ✓ TIM eliminates time-dependent resolution in solar irradiance. TIM intrinsically integrate a range of photosynthetic rates into a single productivity value.

IV. Depth-integrated models (DIMs)

$$\sum PP = P^b{}_{opt} \times f[\mathrm{PAR}(0)] \times DL \times \mathrm{Chl} \times Z_{eu}$$

- ✓ DIM includes all models lacking any explicit description of the vertically resolved component found in TIM, WRM and WIM.

How?

Primary Productivity (conti.)

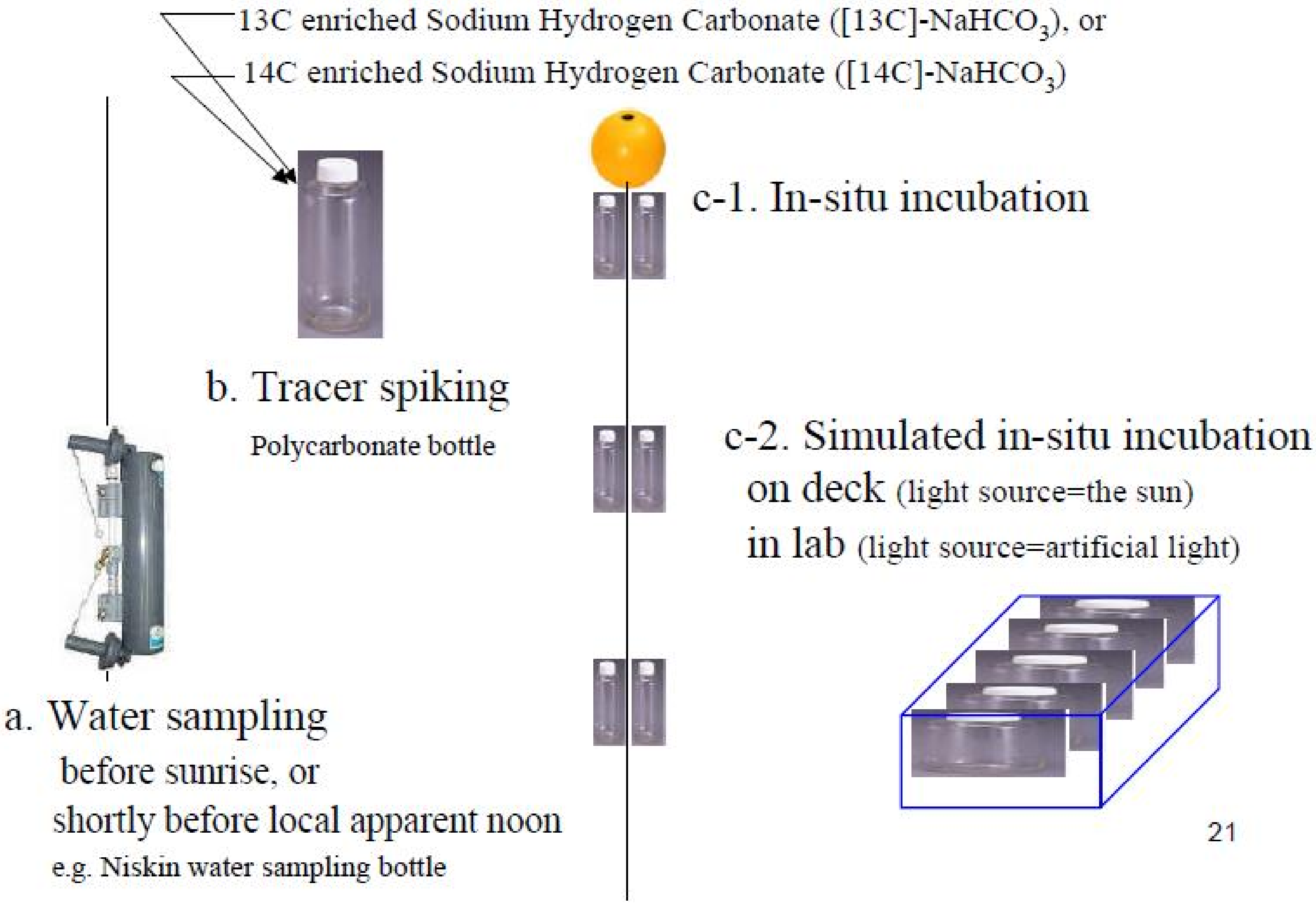
1) Light/Dark Bottle Method

- Calculate DO in both bottles at $t=t_0$, $t=t_1$
- GPP = $(DO^{light}_{t1} - DO^{dark}_{t1})/(t_1-t_0)$
- NPP = $(DO^{light}_{t1} - DO^{light}_{t0})/(t_1-t_0)$
- Quick but only an estimation (based on O_2 consumption)

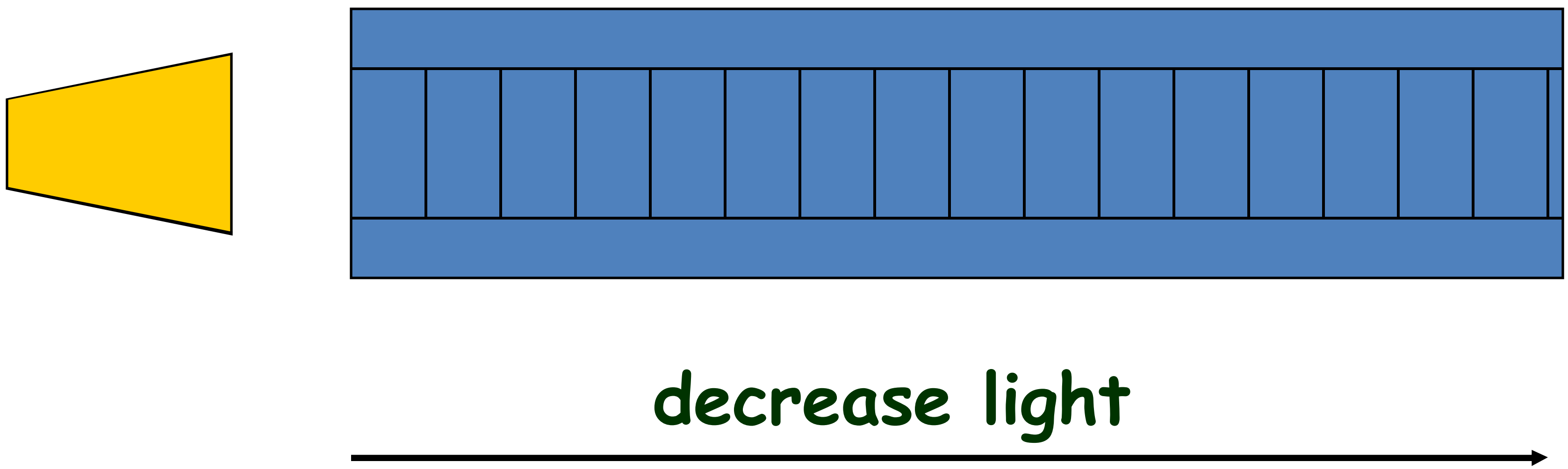
2) Nitrogen/Cabron istotop method

- Inoculate C^{13}/C^{14} (DIC), various light-levels, temp. regulation
- Filter samples, flush excess isotops, POC retained on filter paper
- Measure ratio to C^{12} with IRMS/Mw-IRMS, highly precise

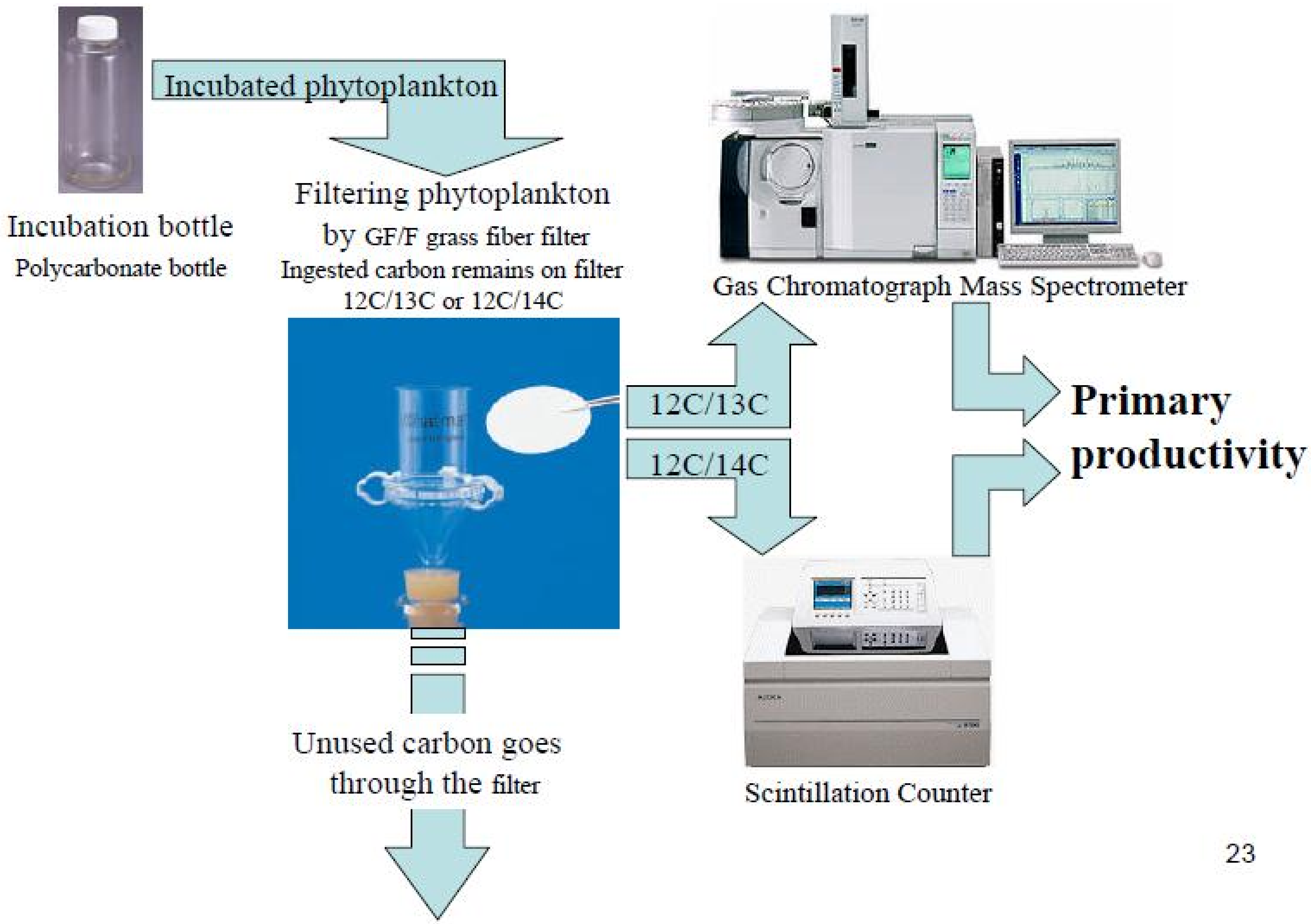
PI experiment



light gradient Incubator



PI experiment



Photosynthesis – Irradiance parameters

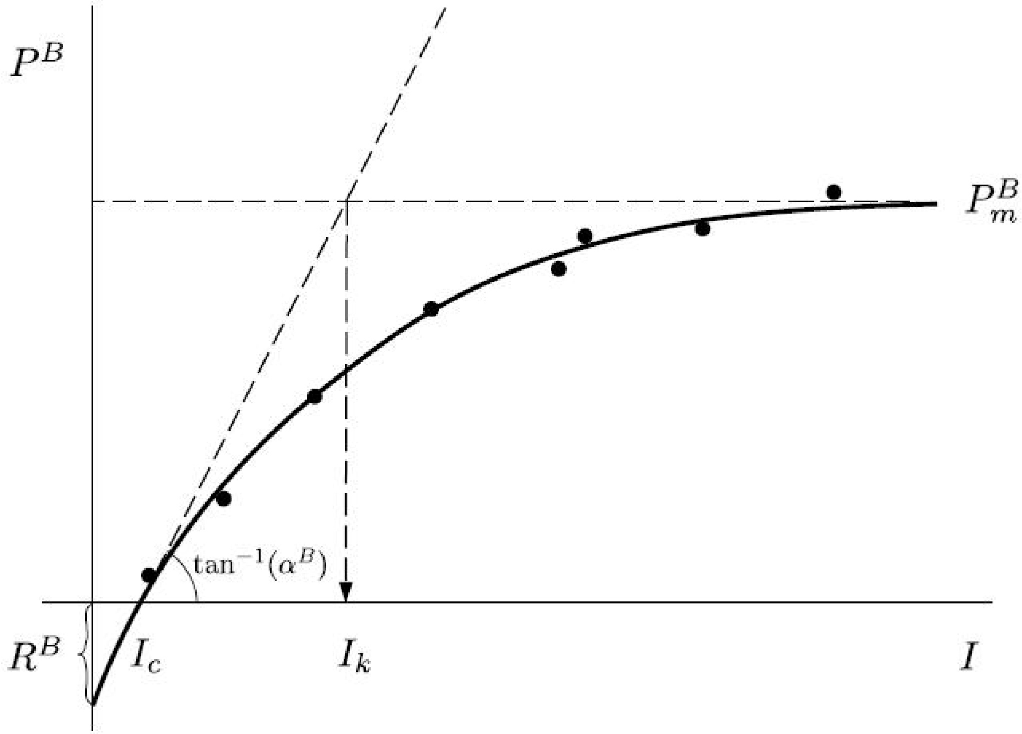


Figure 1. The photosynthesis – light curve (solid line) as fitted to imaginary experimental data (solid circles). The broken lines are construction lines to show the meaning of the parameters.

$R^B = 0$, we have $P_m^B / I_k = \alpha^B$

$$I_k = P_m^B / \alpha^B$$

$$I_* = I / I_k = \alpha^B I / P_m^B$$

PP models using PI parameters

$$P^B(I) = p^B(I;\alpha^B, P^B_m),$$

Table 1. Some commonly-used, two-parameter representations of the P^B vs I curve, with references to their first appearence in the phytoplankton literature. The function p^B is defined by the equation $P^B = p^B(I;\alpha^B, P^B)$. Also given, in the third column, is the equivalent function expressed in terms of the dimensionless irradiance, $I_* = I/I_k$, where $I_k = P^B_m/\alpha^B$.

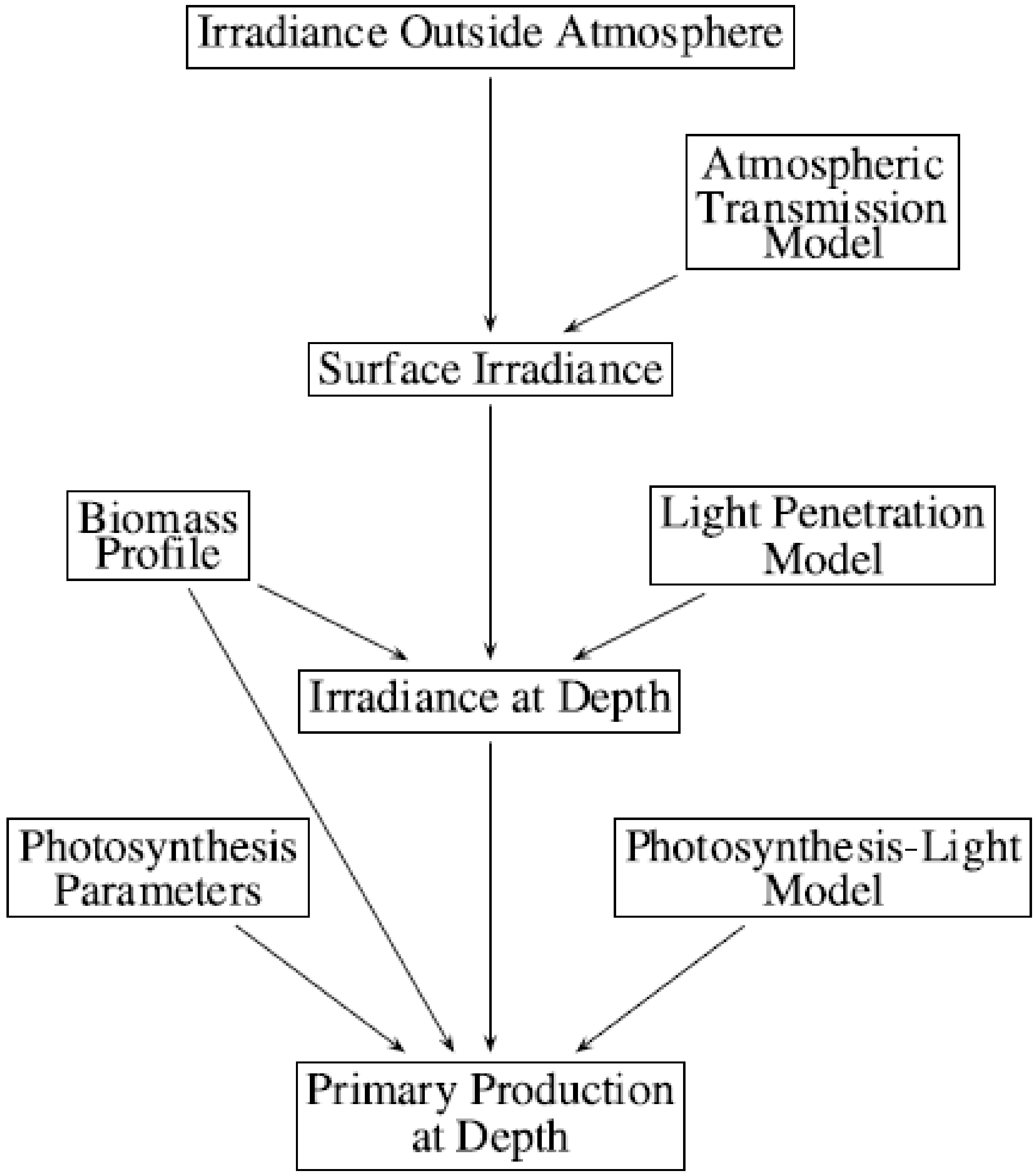
Reference	$p^B(I)$	$p^B(I_*)$
Blackman 1905	$\alpha^B I$ for $I \le I_k$; P^B_m otherwise	$P^B_m I_*$ for $I_* \le 1$; P^B_m otherwise
Smith 1936	$\dfrac{\alpha^B I}{\sqrt{1+(\alpha^B I/P^B_m)^2}}$	$\dfrac{P^B_m I_*}{\sqrt{1+I_*^2}}$
Tamiya 1951 †	$\dfrac{P^B_m \alpha^B I}{P^B_m + \alpha^B I}$	$\dfrac{P^B_m I_*}{1+I_*}$
Jassby & Platt 1976	$P^B_m \tanh(\alpha^B I/P^B_m)$	$P^B_m \tanh(I_*)$
Platt *et al.* 1980 ¶	$P^B_m (1-\exp(-\alpha^B I/P^B_m))$	$P^B_m (1-\exp(-I_*))$

Non-spectral and Spectral equivalent

Table 1. Some commonly-used, two-parameter representations of the P^B vs I curve, with references to their first appearance in the phytoplankton literature. The function p^B is defined by the equation $P^B = p^B(I; \alpha^B, P^B)$. The equations are given in their non-spectral form, $p^B(I)$, and their spectral equivalents $p^B(I(\lambda))$.

Reference	$p^B(I)$	$p^B(I(\lambda))$
Blackman 1905	$\begin{cases} \alpha^B I, & \text{for } I \le I_k; \\ P_m^B, & \text{for } I > I_k. \end{cases}$	$\begin{cases} \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda, & \text{for } I \le I_{k,\lambda}; \\ P_m^B, & \text{for } I > I_{k,\lambda}. \end{cases}$
Smith 1936	$\dfrac{\alpha^B I}{\sqrt{1 + (\alpha^B I / P_m^B)^2}}$	$\dfrac{\int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda}{\sqrt{1 + [(1/P_m^B)(\int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda)]^2}}$
Tamiya 1951 †	$\dfrac{P_m^B \alpha^B I}{P_m^B + \alpha^B I}$	$\dfrac{P_m^B \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda}{P_m^B + \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda}$
Jassby & Platt 1976	$P_m^B \tanh\left(\alpha^B I / P_m^B\right)$	$P_m^B \tanh\left((1/P_m^B) \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda \right)$
Platt *et al.* 1980 ¶	$P_m^B \left(1 - \exp(-\alpha^B I / P_m^B)\right)$	$P_m^B \left(1 - \exp\left(-(1/P_m^B) \int \alpha^B(\lambda) I(\lambda) \mathrm{d}\lambda\right)\right)$

PP computation flowchart



PP modeling

Table 1. Some commonly-used, two-parameter representations of the P^B vs I curve, with references to their first appearence in the phytoplankton literature. The function p^B is defined by the equation $P^B = p^B(I; \alpha^B, P^B)$. Also given, in the third column, is the equivalent function expressed in terms of the dimensionless irradiance, $I_* = I/I_k$, where $I_k = P_m^B/\alpha^B$.

Reference	$p^B(I)$	$p^B(I_*)$
Blackman 1905	$\alpha^B I$ for $I < I_k$; P_m^B otherwise	$P_m^B I_*$ for $I_* < 1$; P_m^B otherwise
Smith 1936	$\frac{\alpha^B I}{\sqrt{1+(\alpha^B I/P_m^B)^2}}$	$\frac{P_m^B I_*}{\sqrt{1+I_*^2}}$
Tamiya 1951 †	$\frac{P_m^B \alpha^B I}{P_m^B + \alpha^B I}$	$\frac{P_m^B I_*}{1+I_*}$
Jassby & Platt 1976	$P_m^B \tanh(\alpha^B I/P_m^B)$	$P_m^B \tanh(I_*)$
Platt *et al.* 1980 ¶	$P_m^B (1 - \exp(-\alpha^B I/P_m^B))$	$P_m^B (1 - \exp(-I_*))$

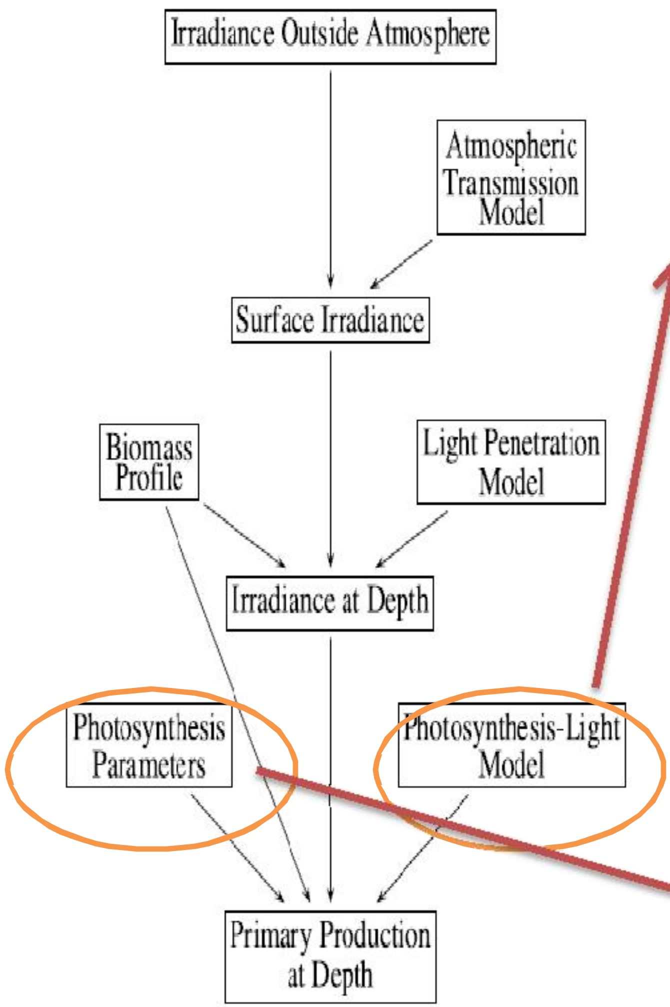


Figure 1. A flow chart describing the steps involved in computation of primary production at depth in the water column, using a light-dependent model of primary production. A number of possibilities exist for the execution of each of the steps involved in the calculation, and the success of the venture will depend on careful selection of suitable protocols for each of the steps.

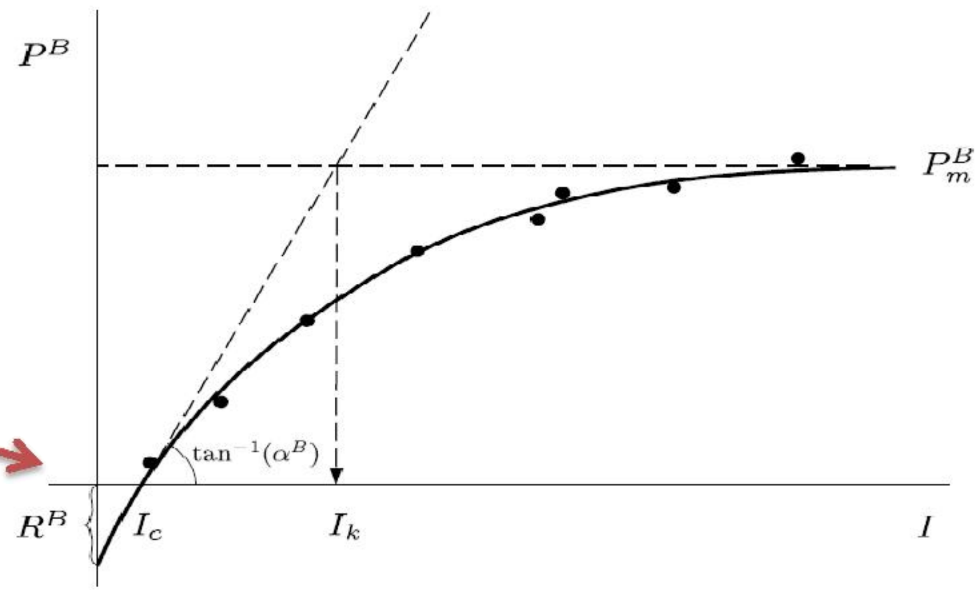
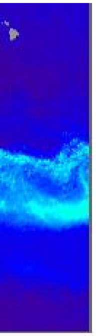


Figure 1. The photosynthesis – light curve (solid line) as fitted to imaginary experimental
(solid circles). The broken lines are construction lines to show the meaning of the parameters.

Lookout



OCEAN PRODUCTIVITY

https://www.science.oregonstate.edu/ocean.productivity/

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Welcome to the *Ocean Productivity* Home Page

The diversity of life on Earth is astonishing, yet most of the ecosystems you and I are familiar with share a common dependence on a miraculous process called ***photosynthesis***. Photosynthesis uses the energy in sunlight to fix carbon dioxide (CO2) into organic material. Aquatic and terrestrial photosynthetic plants use some of their newly formed carbon products immediately for energy and maintenance. The remaining photosynthetic products are available for plant growth or consumption by the heterotrophic community. We refer to this "available" carbon as ***net primary production***, and it is equal to gross photosynthetic carbon fixation minus the carbon respired to support maintenance requirements of the whole plant.

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A consumer's guide to phytoplankton primary productivity models

Michael J. Behrenfeld and Paul G. Falkowski
Department of Applied Science, Oceanographic and Atmospheric Sciences Division, Brookhaven National Laboratory, Upton, New York 11973-5000

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nature Education

The Biological Productivity of the Ocean

Daniel M. Sigman[1] & Mathis P. Hain[1,2] © 2012 Nature Education

Productivity fuels life in the ocean, drives its chemical cycles, and lowers atmospheric carbon dioxide. Nutrient uptake and export interact with circulation to yield distinct ocean regimes.

Remote Sensing of Environment 112 (2008) 3437–3448

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Remote Sensing of Environment

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Operational estimation of primary production at large geographical scales

Trevor Platt[a], Shubha Sathyendranath[b], Marie-Hélène Forget[c,*], George N. White III[a], Carla Caverhill[a], Heather Bouman[d], Emmanuel Devred[e], SeungHyun Son[e,f]

[a] Bedford Institute of Oceanography, Box 1006, Dartmouth, Nova Scotia, Canada B2Y 4A2
[b] Plymouth Marine Laboratory, Prospect Place, The Hoe, Plymouth PL1 3DH UK
[c] Department of Biology, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1
[d] Department of Earth Sciences Oxford University Parks Road, Oxford, OX1 3PR UK
[e] Department of Oceanography, Dalhousie University, Halifax, Nova Scotia, Canada B3H 4J1
[f] STAR/NESDIS/NOAA, Camp Spring, MD 20746, USA

IEEE JOURNAL OF SELECTED TOPICS IN APPLIED EARTH OBSERVATIONS AND REMOTE SENSING

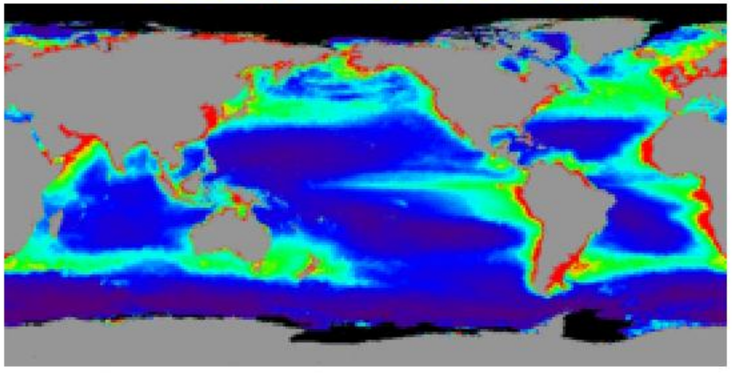
Estimation of Marine Primary Productivity From Satellite-Derived Phytoplankton Absorption Data

Sheng Ma, Zui Tao, Xiaofeng Yang, *Member, IEEE*, Yang Yu, Xuan Zhou, Wentao Ma, and Ziwei Li

Satellite application - VGPM

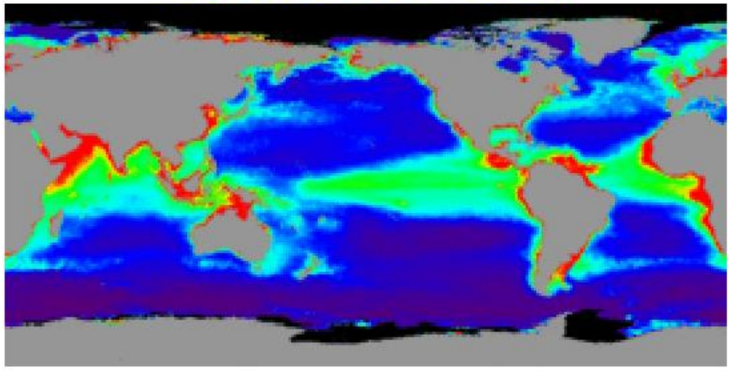
Annual Net Primary Production for 2003

VGPM (chlorophyll based)



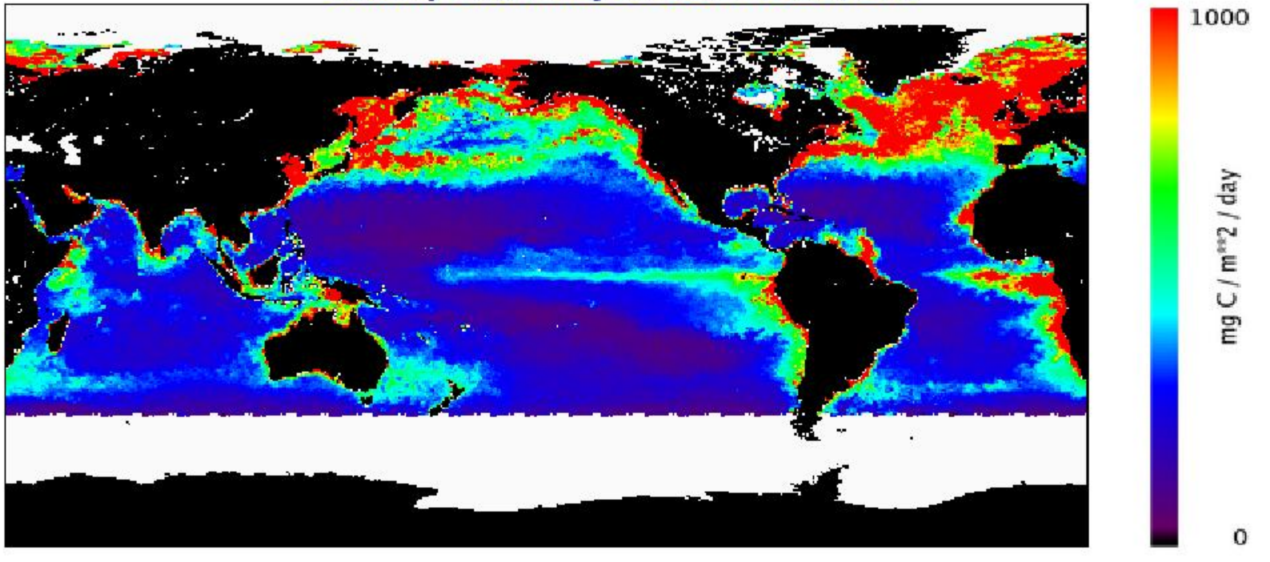
pb_opt = *polynomial* function of SST

Eppley (VGPM variant)



pb_opt = *exponential* function of SST

Monthly Net Primary Production: June , 2005



Standard Product: Net Primary Production using MODIS CHL and SST, SeaWiFS PAR, and z_eu = f(CHL) as inputs to the VGPM

Acknowledgements (Lectures 1 &2)

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