A proposal for a new IOCCG working group on the determination of « Phytoplankton Functional Types » (phyto-PFTs) from ocean colour remote sensing

In the rest of this presentation, PFT implicitly means phyto-PFT

- What are PFTs ?
- Why PFTs are of interest ?
- Why is it suspected that they are derivable from OC remote sensing ?
- The existing techniques to determine PFTs from ocean colour
- Examples of PFTs derived from global models
- Rationale for a new IOCCG WG
- Possible terms of references of the new WG

This presentation has been built from contributions by:

- Hervé CLaustre & Julia Uitz, LOV, Villefranche, France
- Cyril Moulin & Séverine Alvain, LSCE, Gif/Yvette, France
- Corinne LeQuéré, University of East Anglia, UK
- Watson Gregg, NASA / GSFC, USA
- Jim Aiken, PML, Plymouth, UK
- Shubha Sathyendranath, Emmanuel Devred, BIO, Canada
- Collin Roesler, Bigelow lab., USA

They are all duly acknowledged for their help

The review of existing techniques is not meant to be exhaustive.

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)

<u>Direct effect</u> :
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.

<u>Indirect effect</u> :
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

Non-exhaustive review of existing techniques to derive PFTs from ocean colour

From “direct” inversion to more and more indirect techniques :

- Roesler et al.
- Devred et al.
- Aiken et al.
- Uitz et al.
- Alvain et al.

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

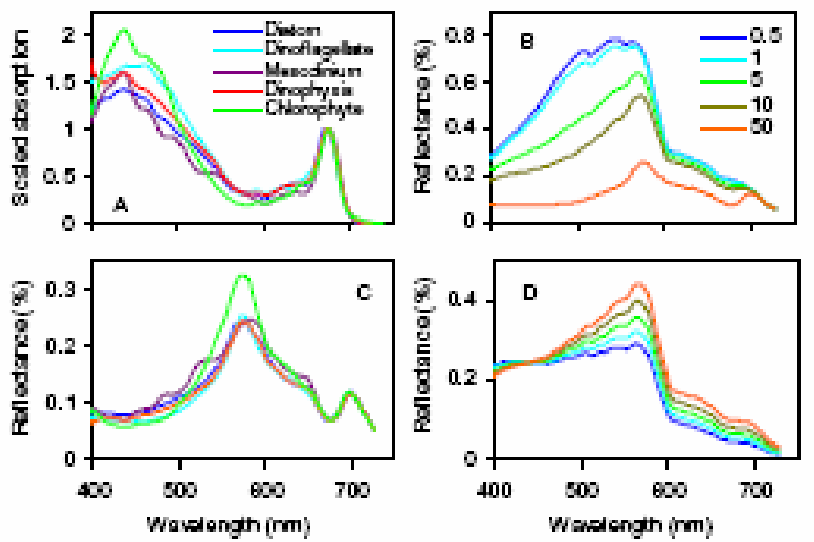


Fig. 1. (A) Scaled taxon-specific absorption spectra for 5 separable groups based upon spectrophotometric analysis of size-fractionated samples and corresponding microscopic species counts. Results of reflectance simulations as a function of (B) algal biomass (µg chl l^{-1}), (C) algal composition at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

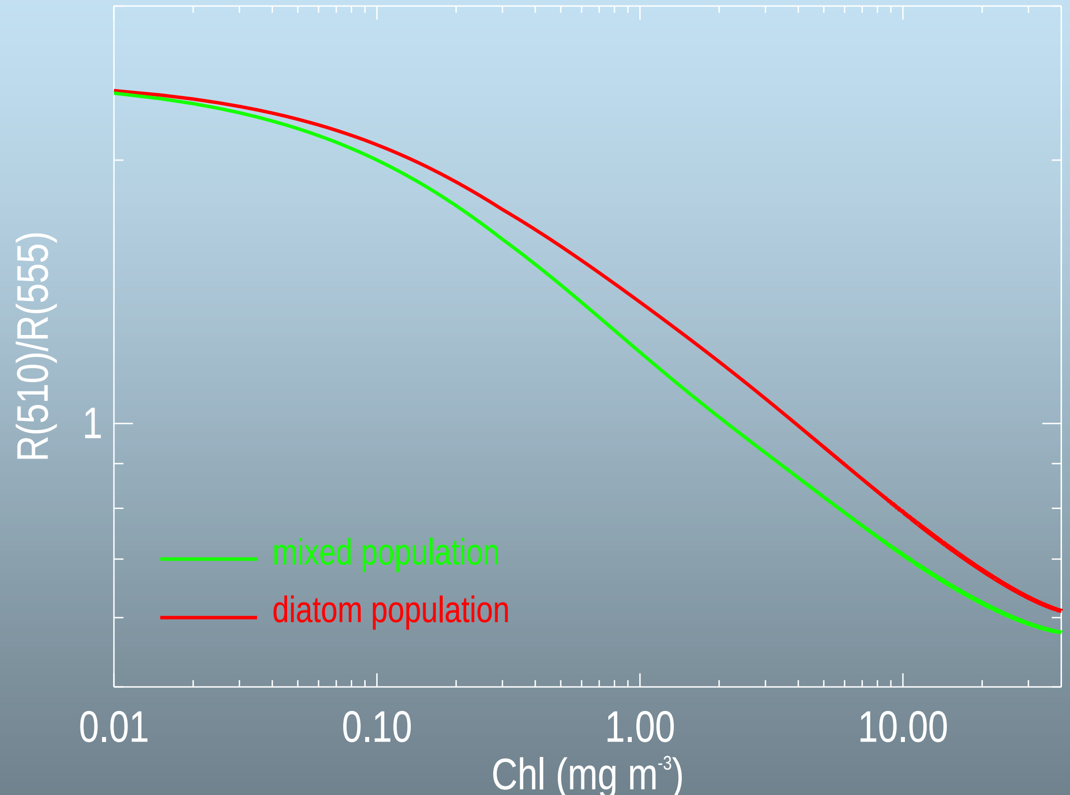
The method was tested, and is quite successful, at very high biomass (~50 mg/m^3).

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 $R(490)/R(670)$

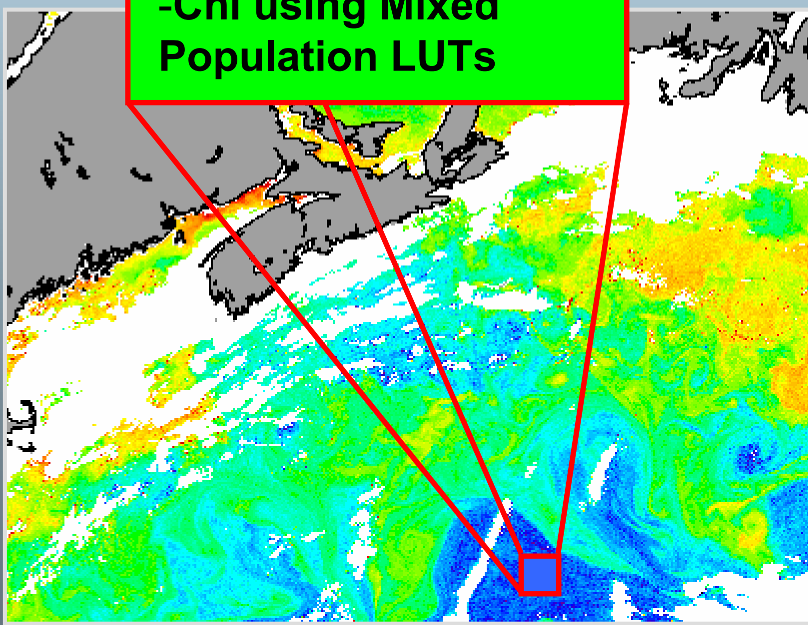
Existing techniques (2, cont'd)

Application to the Northwest Atlantic

- nLw :490,510,555,670 nm → nRw

- Chl using Diatom LUTs

- Chl using Mixed Population LUTs



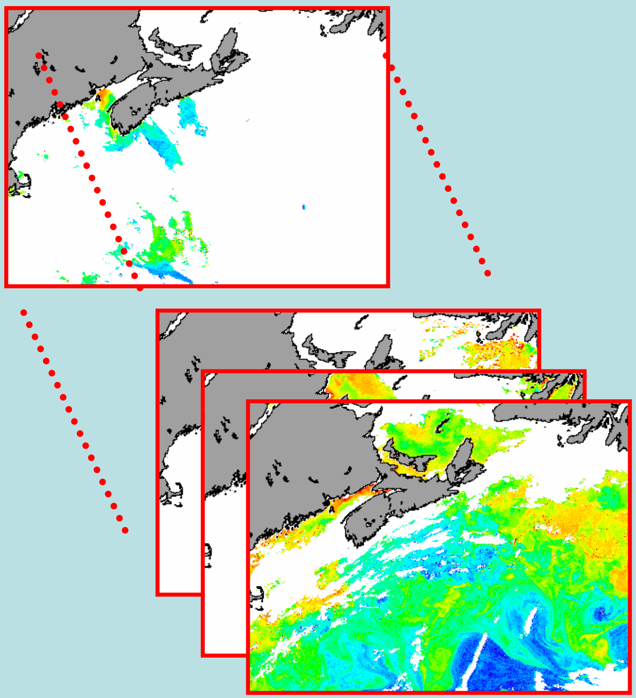
$Chl_{di}(R_{510}/R_{555})$ - $Chl_{di}(R_{490}/R_{670}) = \varepsilon_{di}$

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

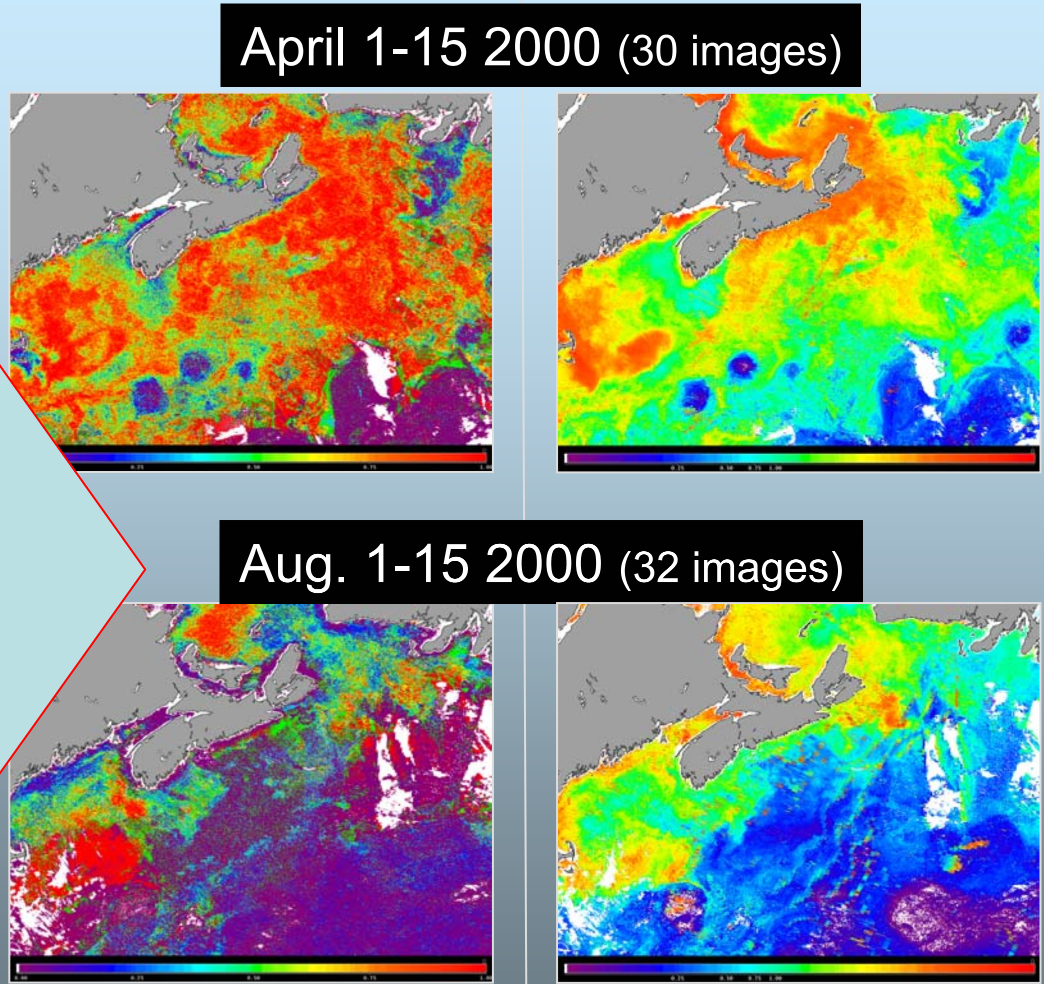
Min(ε_{di}, ε_{mp}) yields phytoplankton population and chlorophyll concentration

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

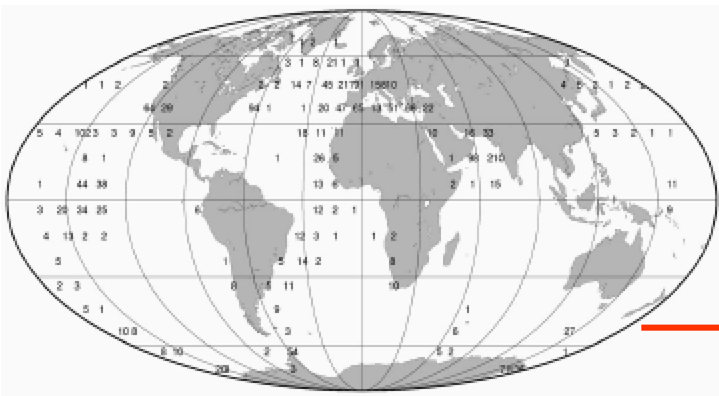
Chlorophyll concentration

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

$$ {}_{w}DP = \underbrace{1.4\ Fuco + 1.4\ Peri}_{\sim\ Micro\ >\ 20\ \mu m} + \underbrace{1.3\ 19'\text{-}HF + 0.4\ 19'\text{-}BF + 0.6\ Allo}_{\sim Nano\ 2\text{-}20\ \mu m} + \underbrace{0.9\ Zea + 1.0\ TChl\mathit{b}}_{\sim\ Pico\ <\ 2\ \mu m} $$

<u>Size classes proportion</u>

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

<u>TChla associated to size classes: sc-TChla</u>

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

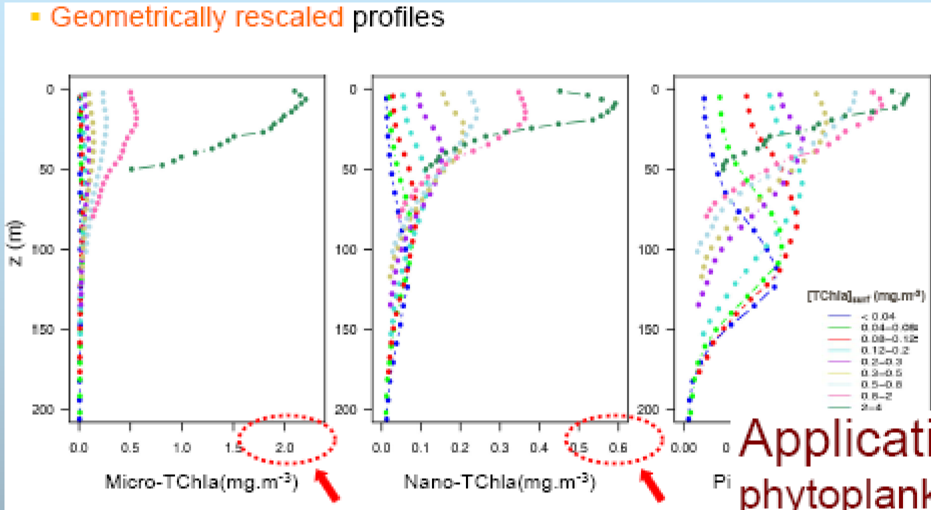
  ⟹ according to the hydrological regime: stratified / mixed

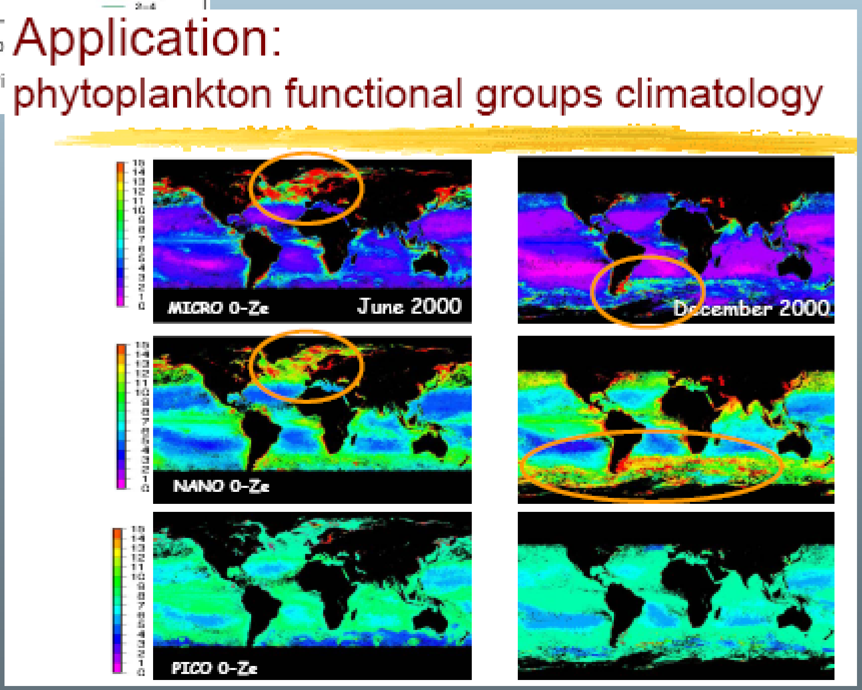
  ⟹ according to $[TChla]_{surf}$

- Computation of average sc-TChla profiles / trophic class

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

Existing techniques (3, cont'd)

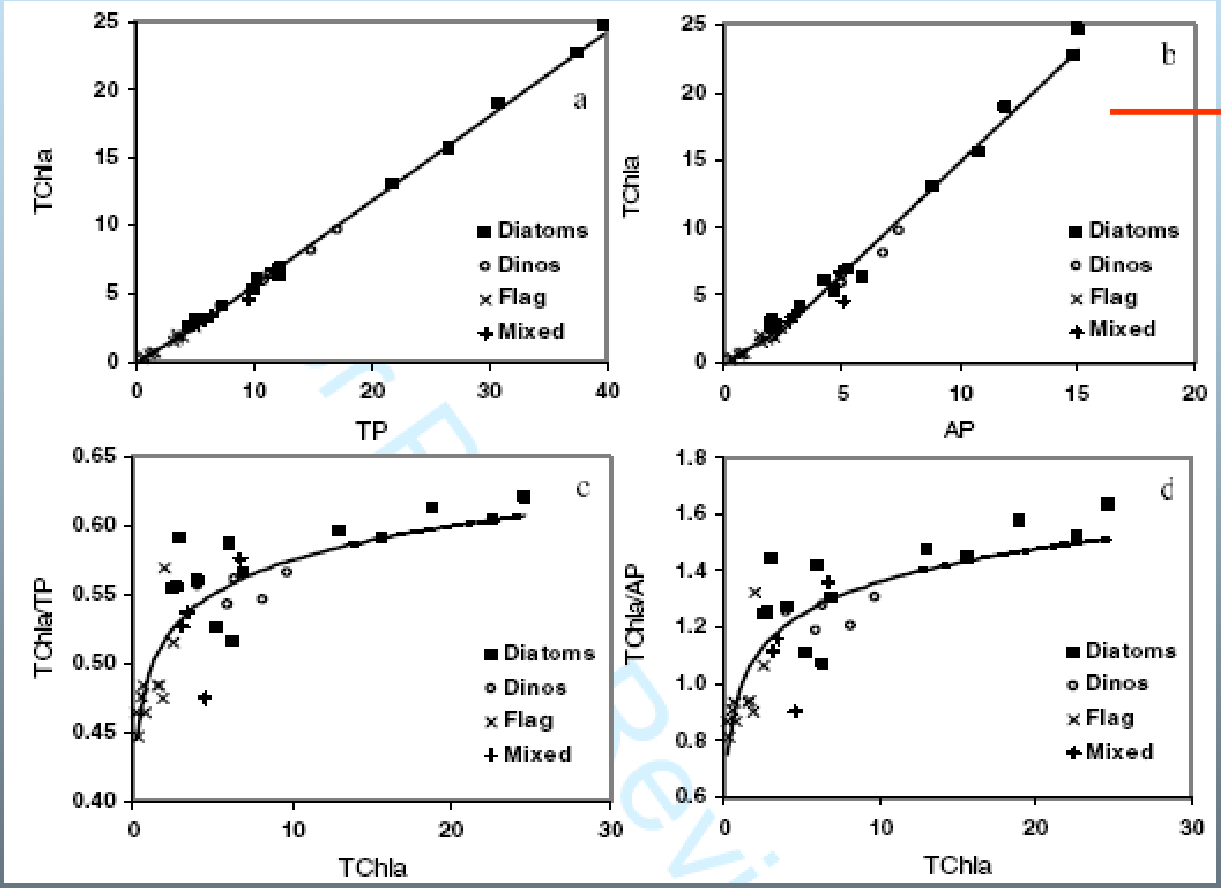




Existing techniques (4) :

Aiken *et al*., 2005

HPLC-determined pigments are used to distinguish between groups

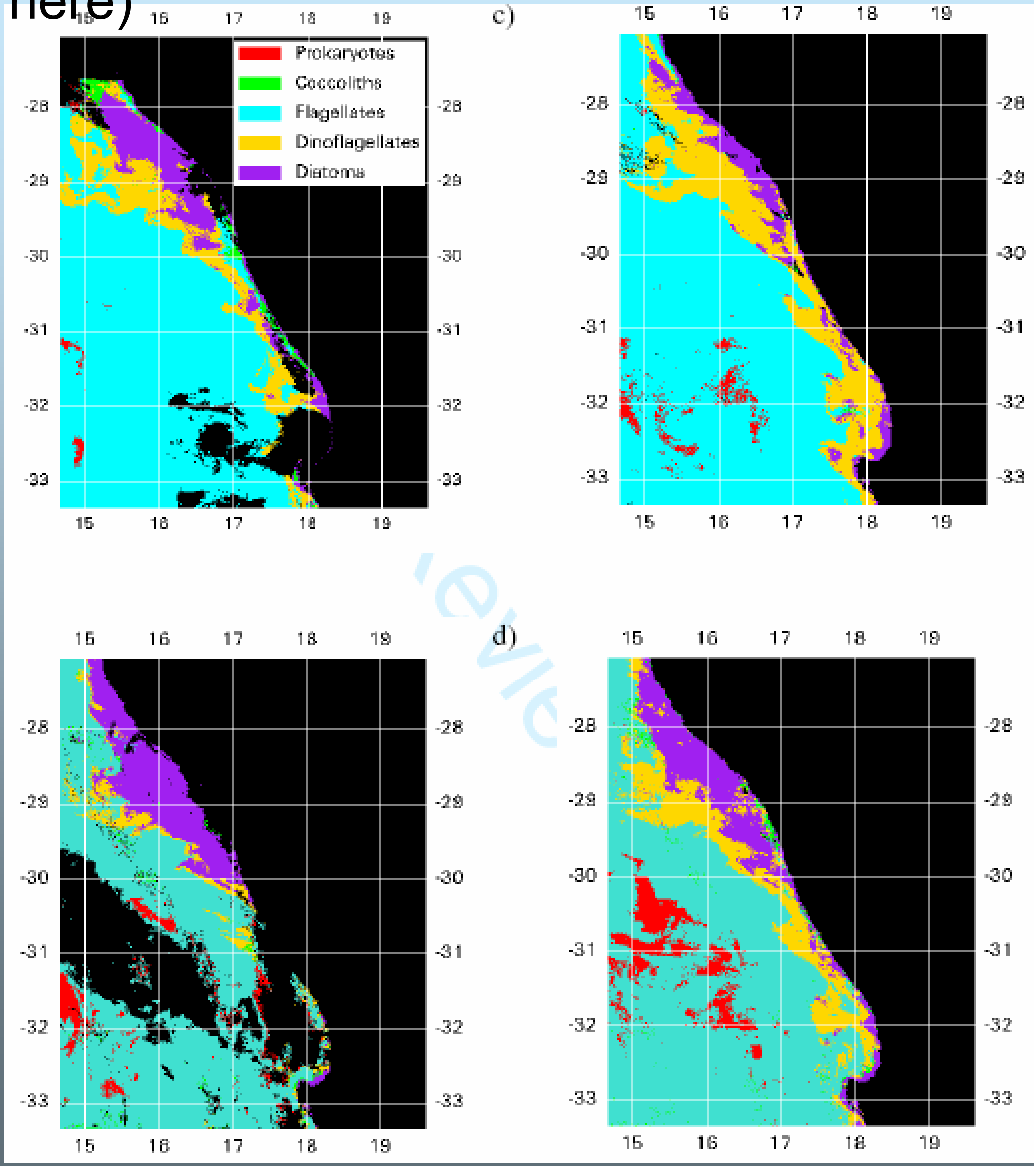


Similar relationships and associated statistics are derived for several phytoplankton groups, based on a data set of inherent optical properties + HPLC pigments.
Therefore, groups can be determined from Chl-a

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

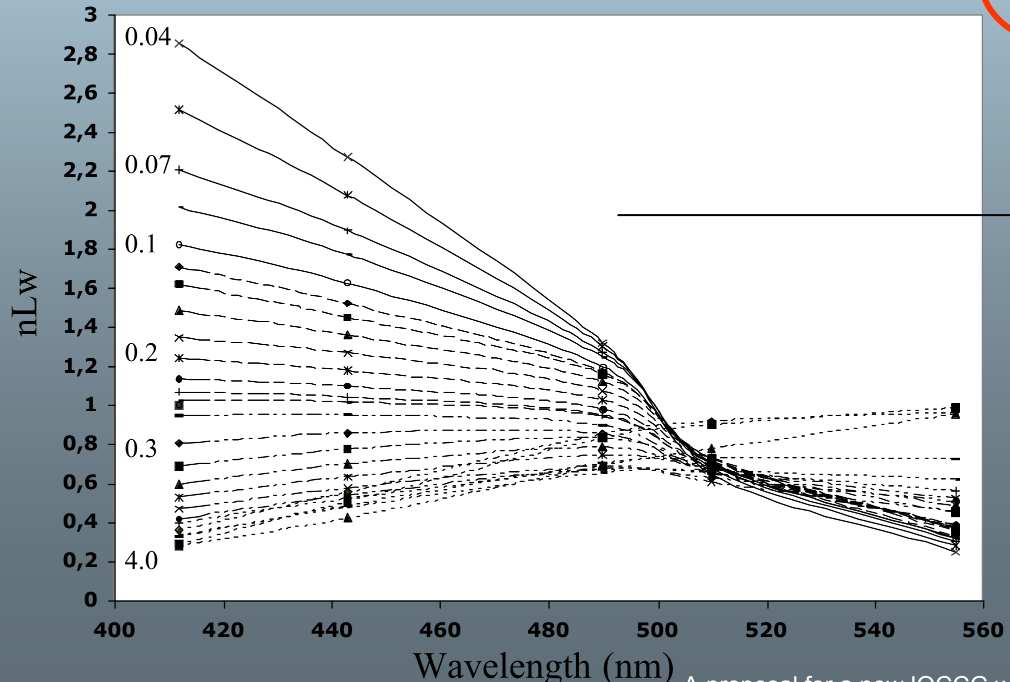
Courtesy : J. Aiken

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

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



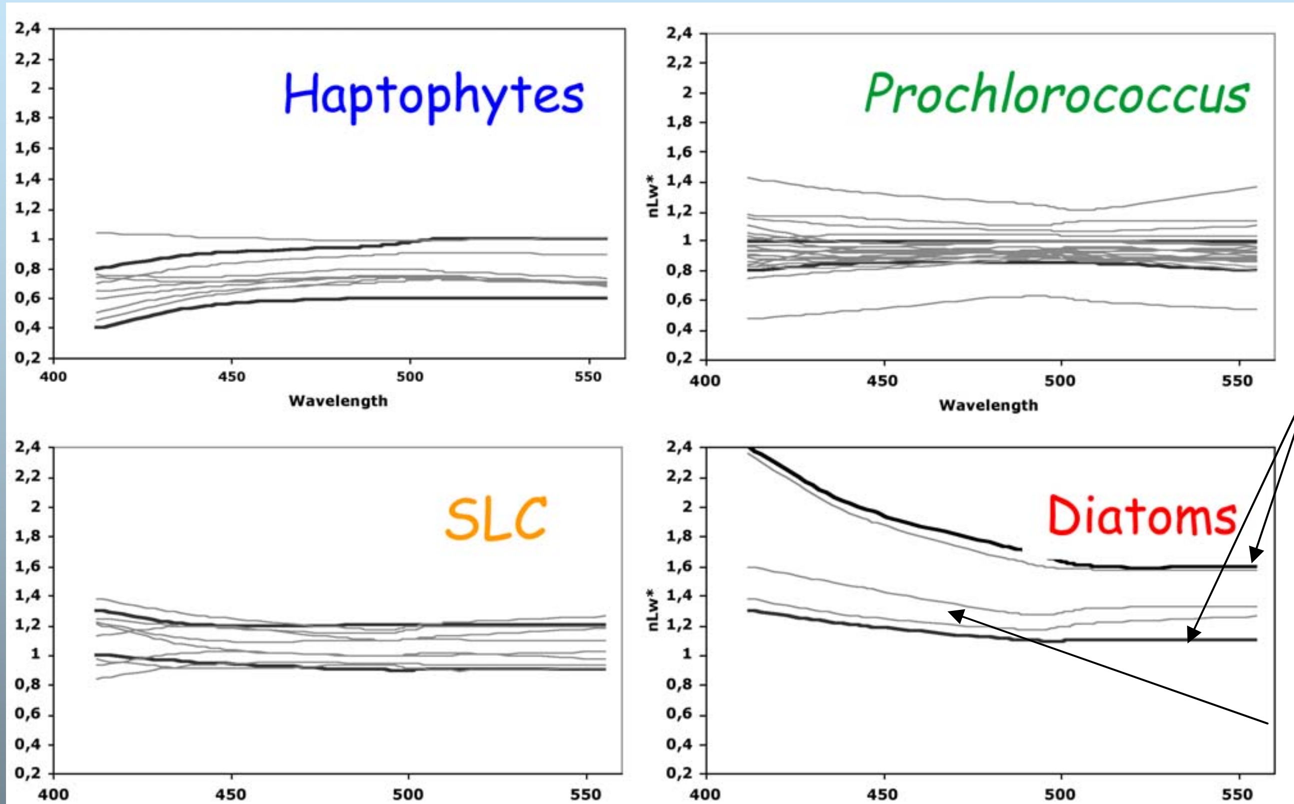
Courtesy: S. Alvain

Existing techniques (5, cont'd)

A specific nlw* for each dominant group !

nLw*

nLw*



Wavelength

Wavelength

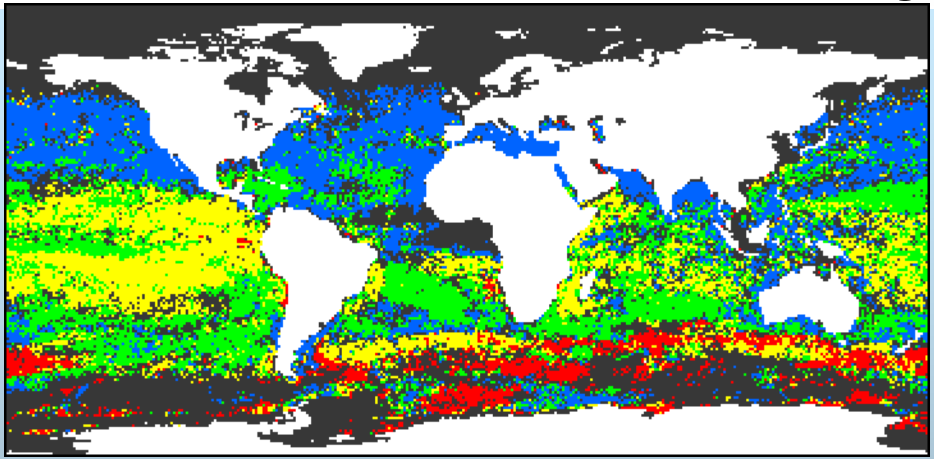
Envelope of nLw* spectrum used to characterized the phytoplankton group

Courtesy: S. Alvain

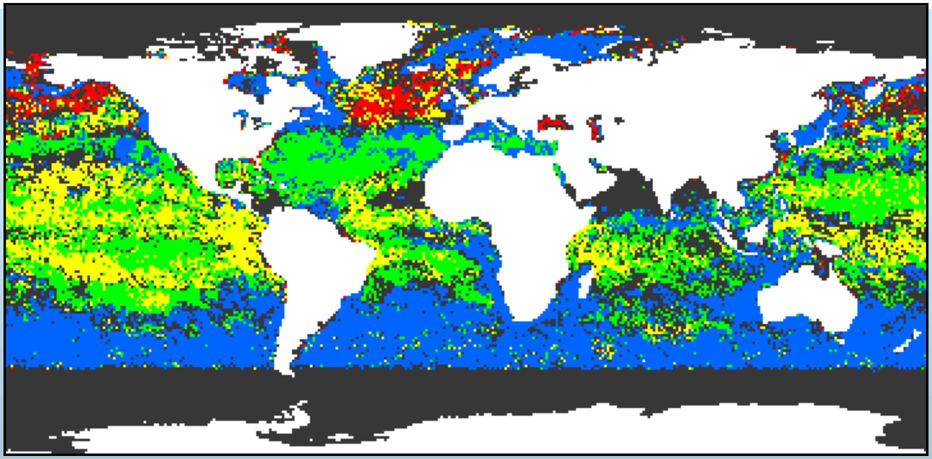
In light grey : Individual spectral signature for the 41 nLw associated with the 41 Gep&Co pigments inventories*

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

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



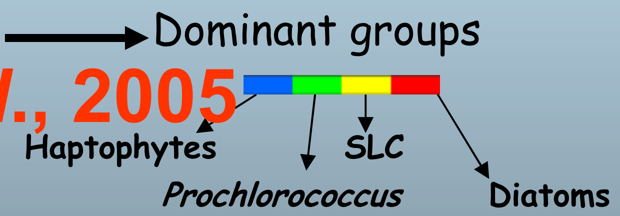
January

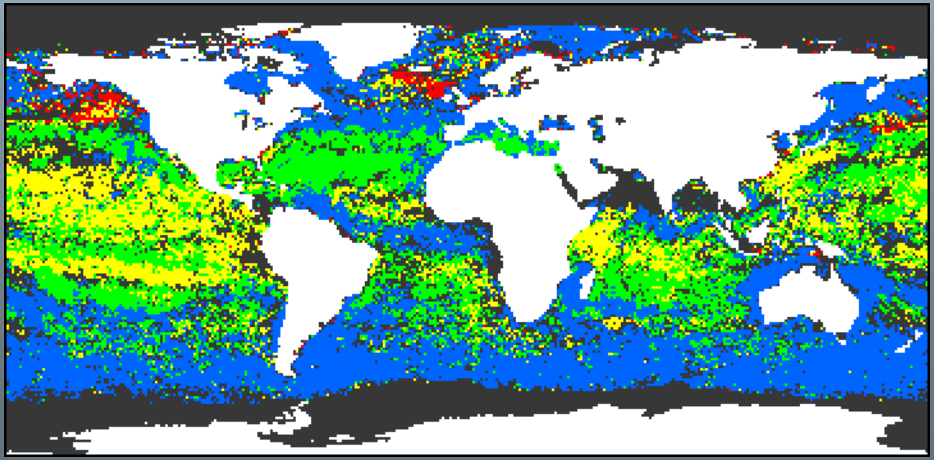


April

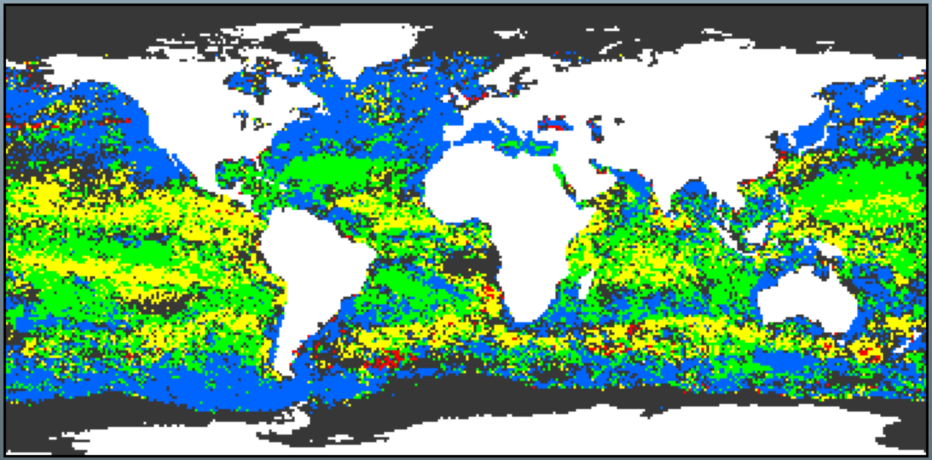
From Alvain *et al.*, 2005

« PHYSAT »



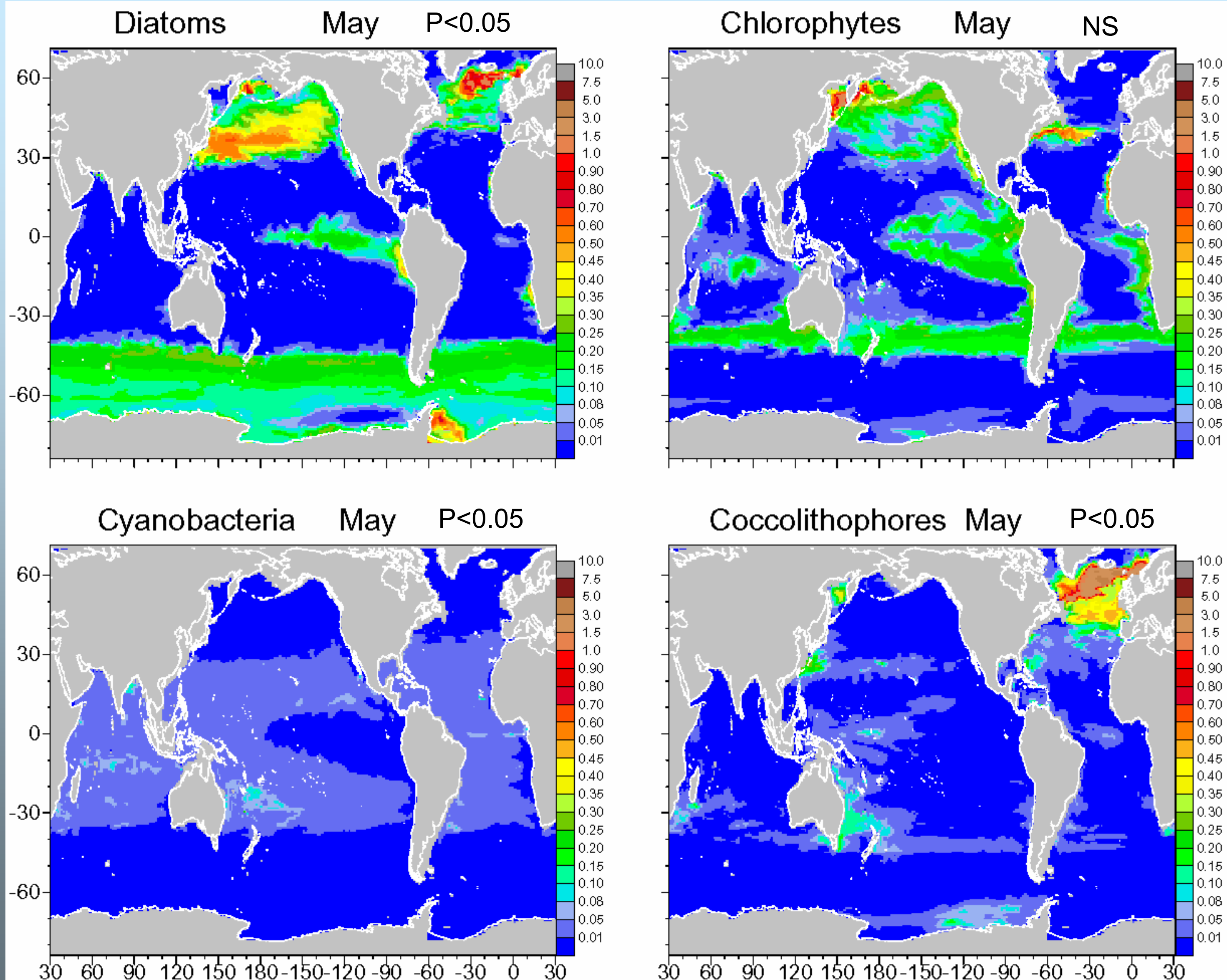


June



October

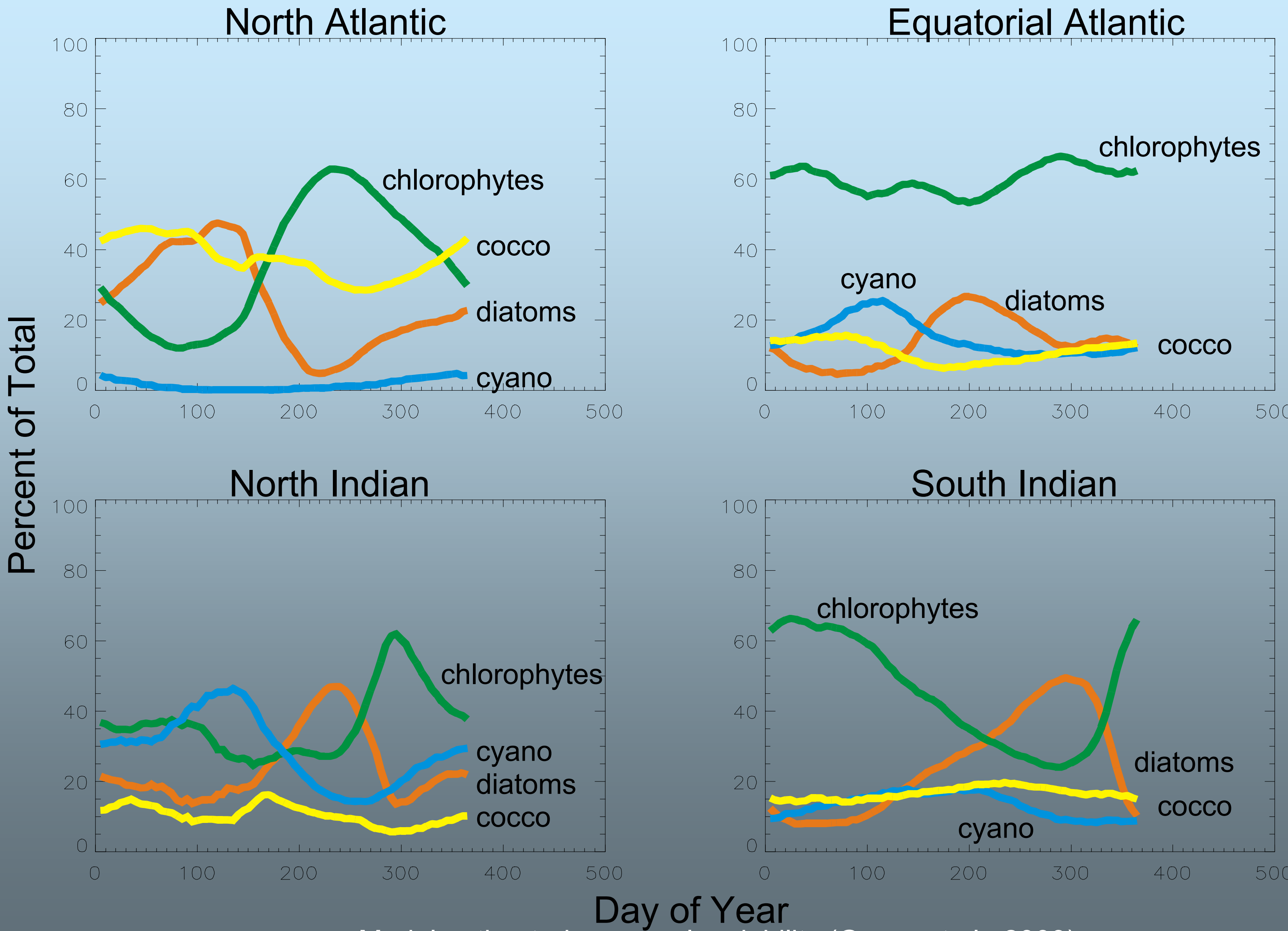
Examples of PFTs from global models (1)



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)



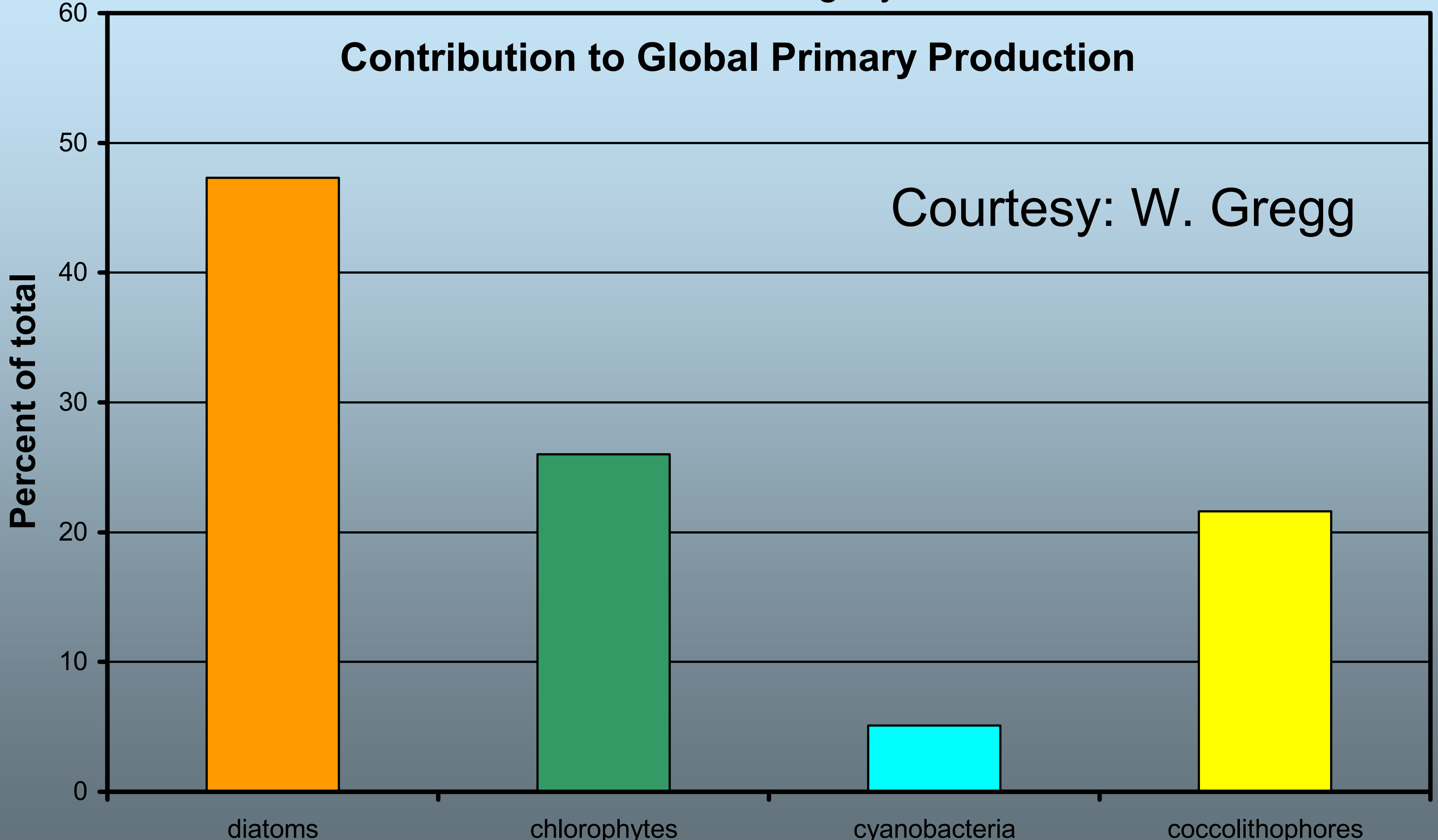
Courtesy: W. Gregg

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%

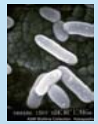


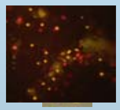
Model estimates of primary production (Gregg, 2005, unpublished)

Examples of PFTs from global models (2)

planned developments of a Dynamic Green Ocean Model

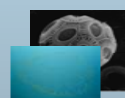
bacteria


pico-heterotrophs


pico-autotrophs

N_2-fixers

phyto-plankton


calcifiers

DMS-producers


mixed

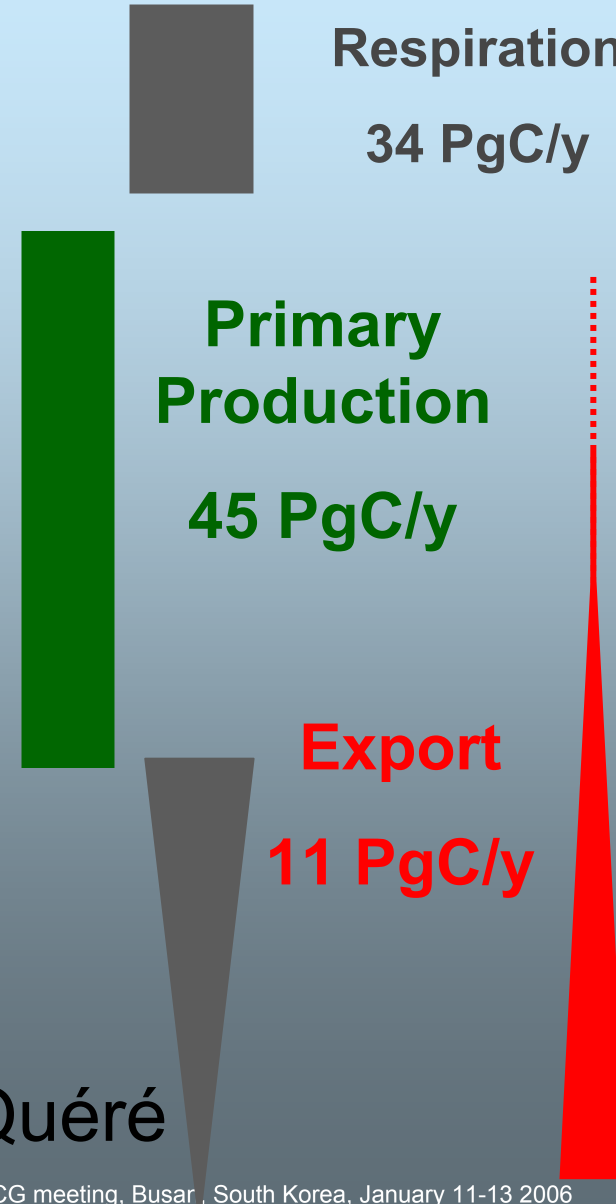
silicifiers

zoo-plankton


proto


meso


macro



Courtesy: C. LeQuéré

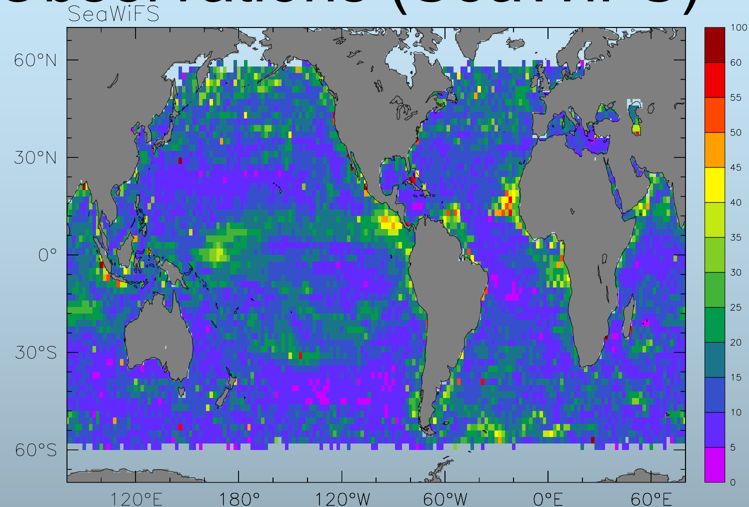
A proposal for a new IOCCG working group. 11th IOCCG meeting, Busan, South Korea, January 11-13 2006

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

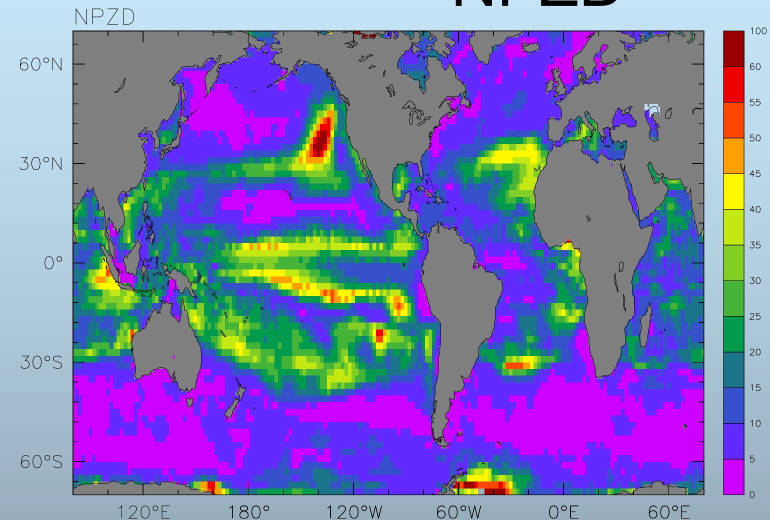
Courtesy: C. LeQuéré

Interannual chla variability (percent)

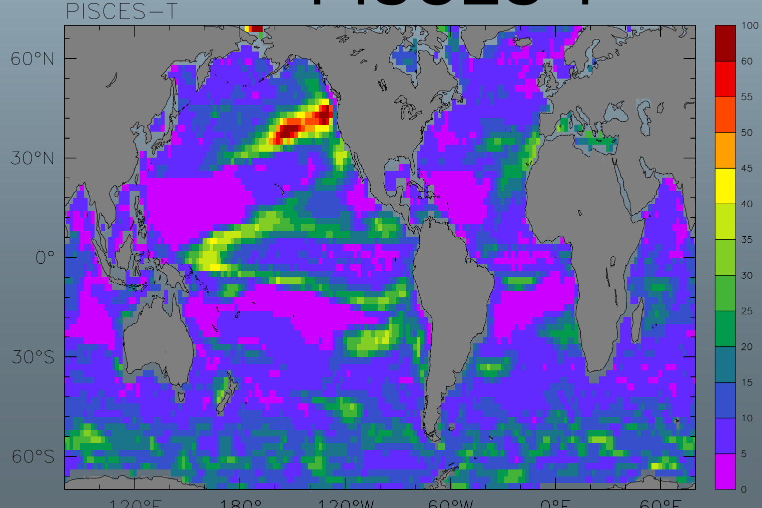
Observations (SeaWiFS)



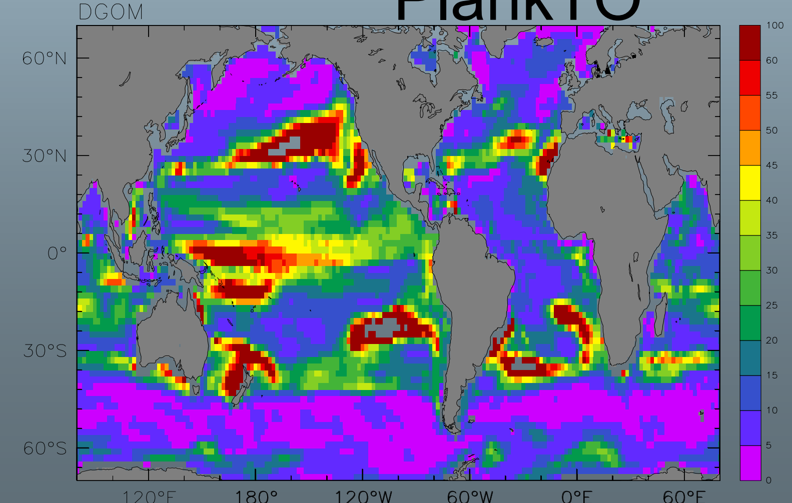
NPZD



PISCES-T



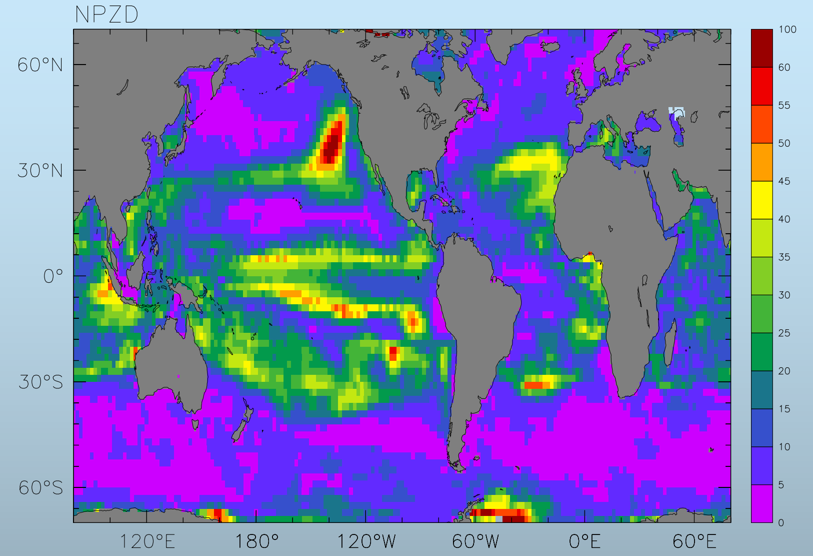
PlankTO



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

Interannual chla variability (percent)

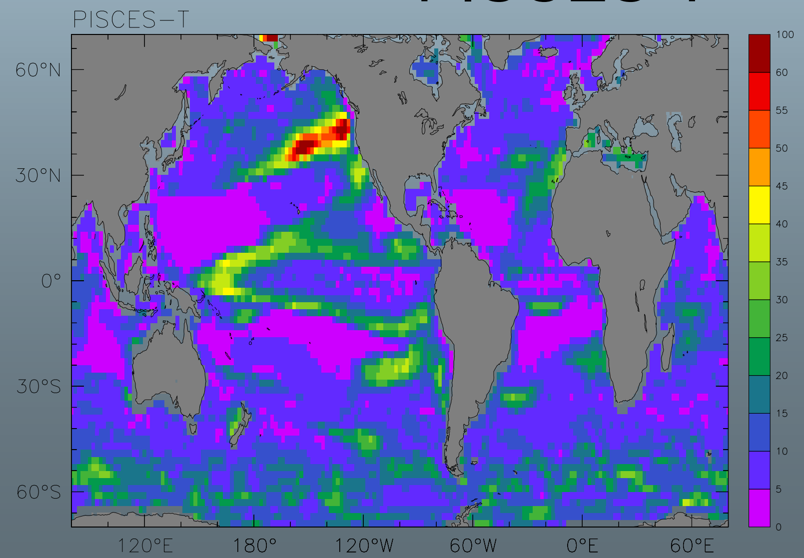
NPZD



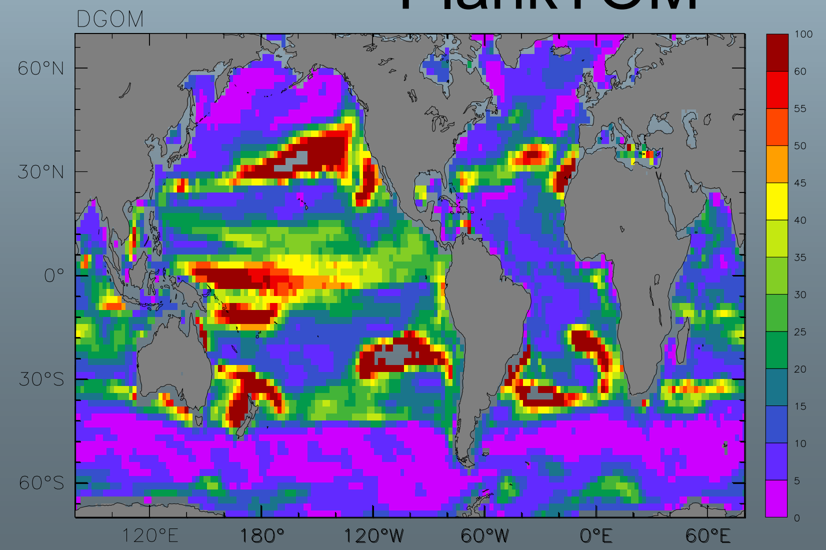
Conclusion: current models do not capture the variability in surface Chl observed by satellite

Courtesy: C. LeQuéré

PISCES-T



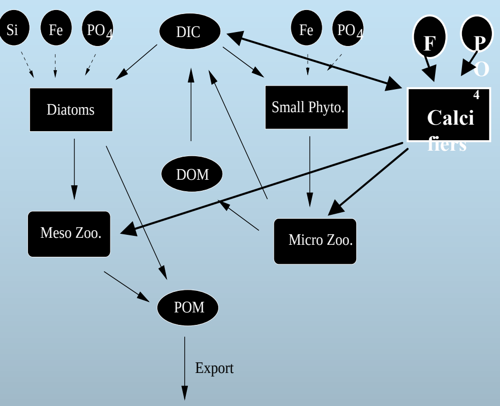
PlankTOM

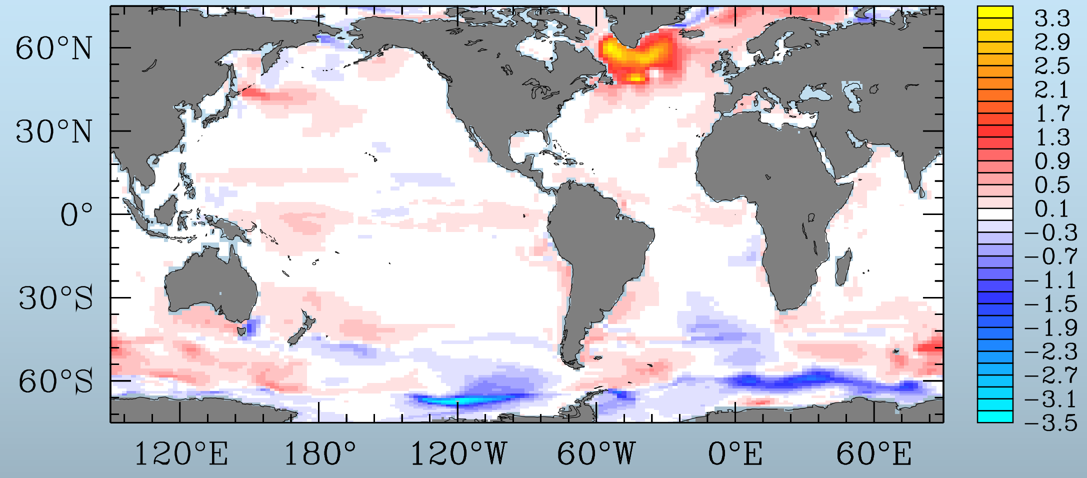


Examples of PFTs from global models (2, cont'd)

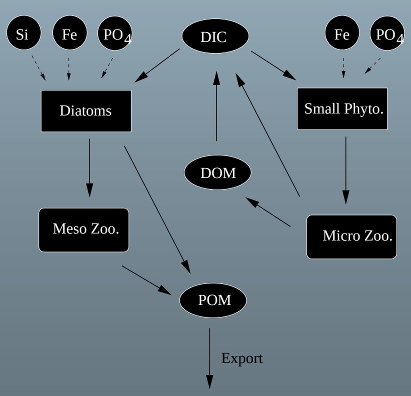
Impact of climate change on the CO_2 sink in 2060 using identical physics but two different ecosystem models (mol/m2/y)

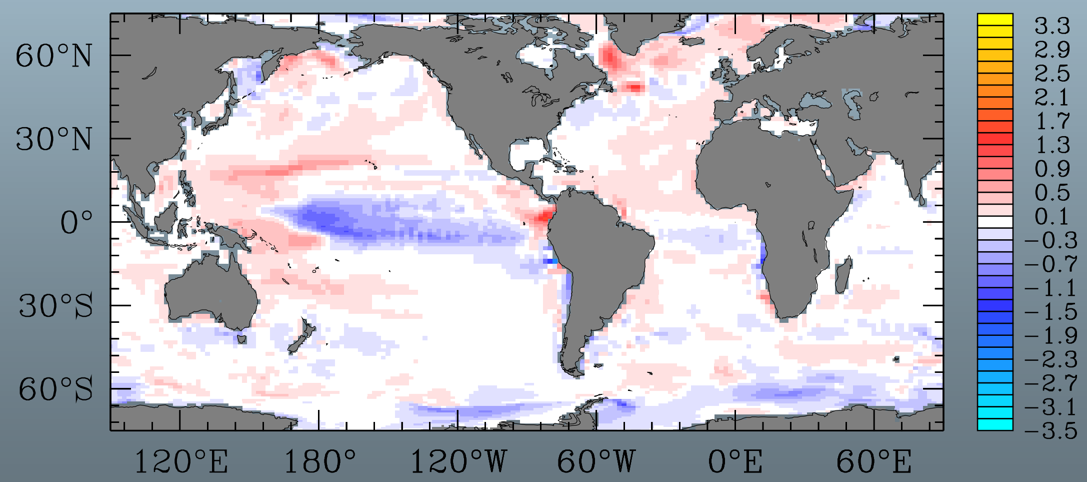
PlankTOM





PISCES-T





Courtesy: C. LeQuéré

(Preliminary result from E. T. Buitenhuis)

Examples of PFTs from global models (3)

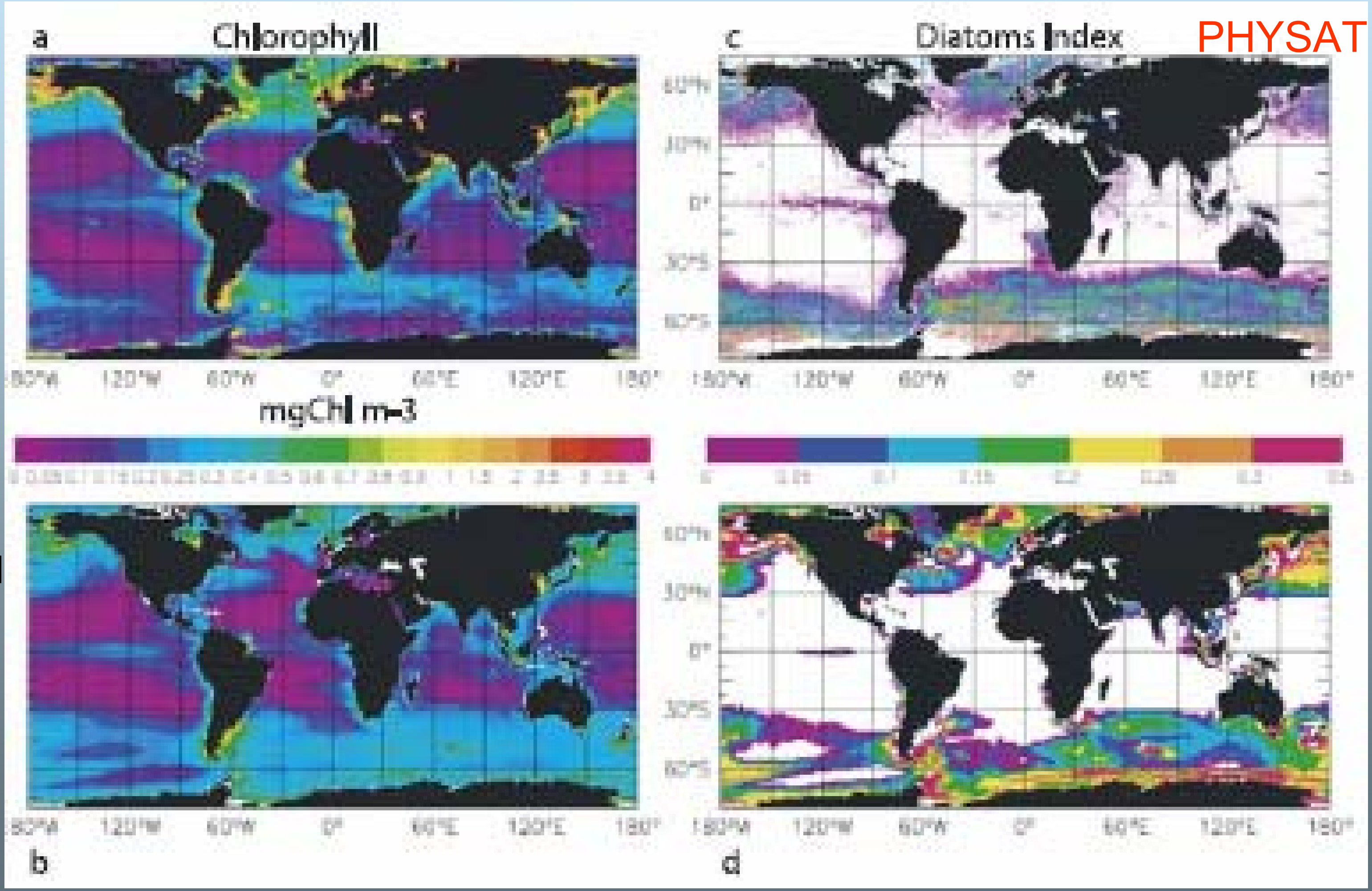
From Bopp *et al*., 2005

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

SeaWiFS

PHYSAT

IPSL-CM4 / PISCES model



Rationale for a new IOCCG WG on PFTs

<u>From the IOCCG web pages</u> :

“.. A major focus of the IOCCG has been the formation of specialized working groups investigating various aspects of ocean-colour technology and its applications. The end product of these working groups is usually the publication of a scientific report, which can be used to provide appropriate advice to Space Agencies, scientists and managers.”…

<u>Questions relevant to the formation of a new IOCCG WG</u> :

Is there enough new elements ?
Is there a large community interested into the topic ?
Is there a need for some “standardisation” ?
Is there a need for recommendations to Agencies and to scientists ?

The answer is probably YES to all these questions, which probably indicates the timeliness of a working group.

Provisional terms of reference

To be completed/amended in case the WG is formed and a chairman is nominated

The WG on PFTs would :

- Establish (advocate for) the relevance of determining PFTs from OC remote sensing
- Review the assumptions that form the basis of PFTs determination from OC r.s.
- Review existing techniques / algorithms
- Propose a common terminology
- Make recommendations about which studies are needed to (1) understand the empirical relationships presently observed, (2) validate the products, (3) further improve algorithms
- Compare the results of various algorithms on selected case studies
- Examine how PFTs derived from ocean colour can be meaningfully used to validate / improve global models
- Examine the adequacy of modern OC sensors and specify how future sensors should be built to give the best chance of determining PFTs
- Prepare a report to be published within the IOCCG series