→ 4th ESA ADVANCED TRAINING ON OCEAN REMOTE SENSING

Ocean colour retrievals in Case 1 waters

David Doxaran
Marine Optics & Remote Sensing Group
Laboratoire d'Océanographie de Villefranche (CNRS/UPMC)
doxaran@obs-vlfr.fr   http://www.obs-vlfr.fr/LOV/OMT/

Outline

1. Definition and spectral signatures of Case-1 waters

Introduction
Definition
Spectral signatures = f (Chla)

2. Atmospheric corrections

Methods / Algorithms
Validation

3. Level-2 products (inversion algorithms)

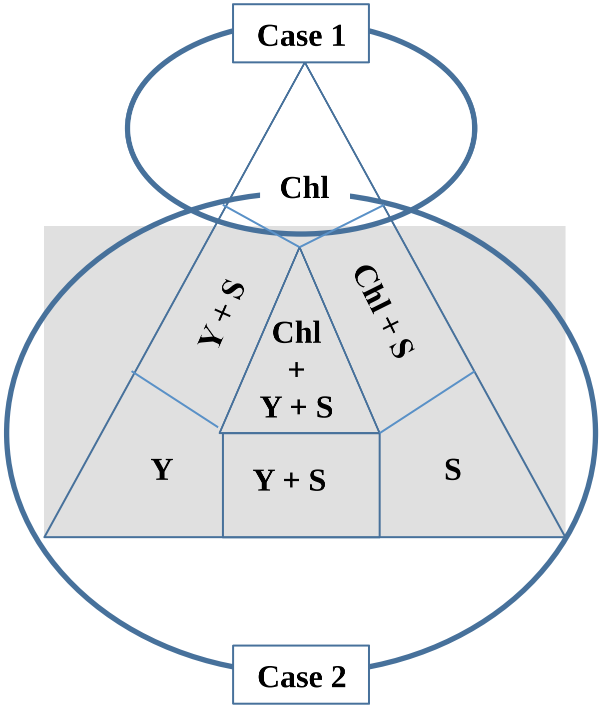
Seawater reflectance
Diffuse attenuation coefficient / Euphotic depth
IOPs
Chla concentration / Phytoplankton groups

4. Derived (level-3) products and applications

- Primary production(s)
- Biogeochemical cycles / Climate change

5. References

Classification of natural waters



- **Phytoplankton chlorophyll (and degraded products) is the unique coloured constituent in Case 1 waters**
(Morel & Prieur 1977)

- **Case 2 waters are also influenced by terrestrial substances (NAP, gelbstoff)**

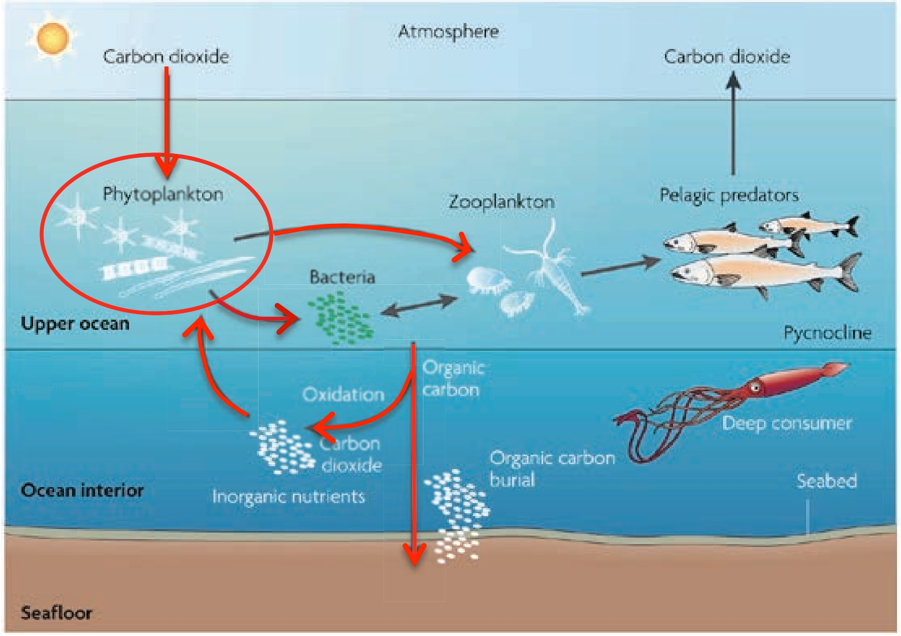
Morel / Antoine MERIS Case 1 water ATBD

Morel / Antoine MERIS Case 1 water ATBD

Introduction

BIOGEOCHEMICAL SIGNIFICANCE OF PHYTOPLANKTON

- Phytoplankton are key players in the ocean's carbon pump
- Phytoplankton diversity is an important factor that affects carbon cycling
- What's the role of phytoplankton in today's oceans?
- How phytoplankton will respond to future climate changes with interactions between climate and biogeochemistry?
- We need observations of phytoplankton and associated processes on appropriate spatial and temporal scales



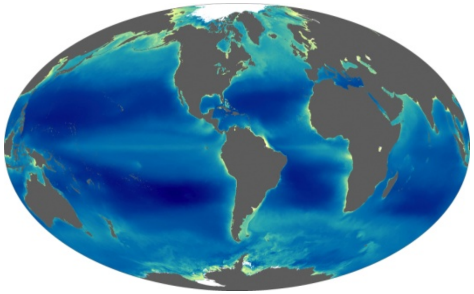
Falkowski et Oliver (2007) – The carbon biological pump

Nature Reviews | Microbiology

Introduction

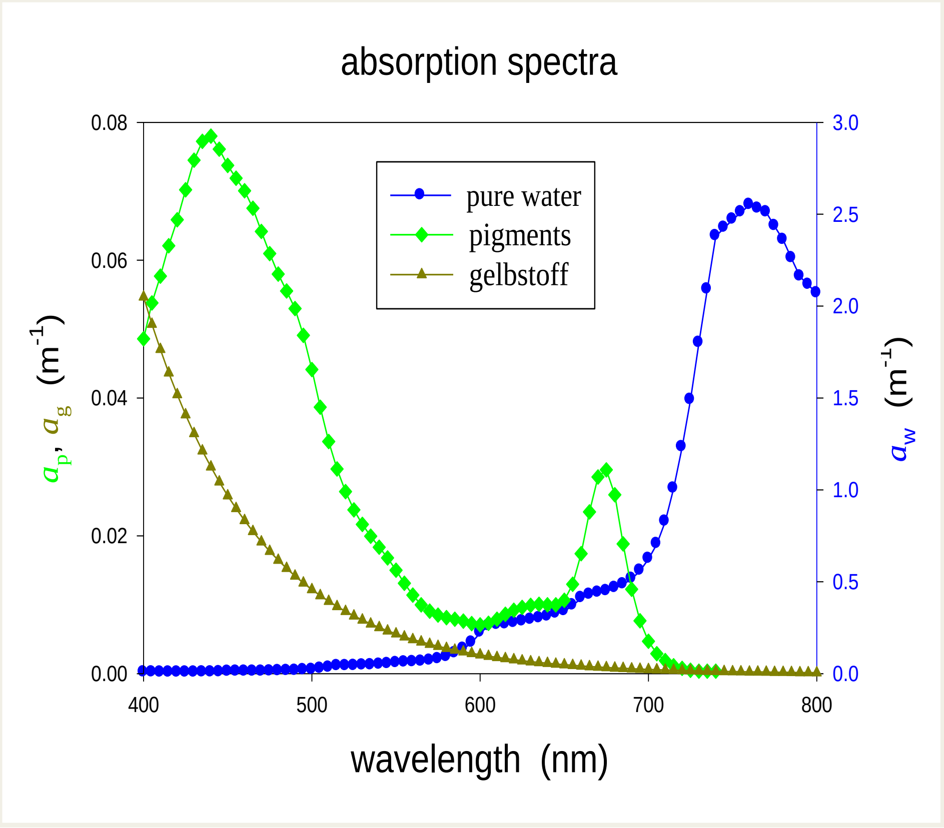
SATELLITE REMOTE SENSING OF OCEAN COLOR: A POWERFUL TOOL FOR STUDYING PHYTOPLANKTON

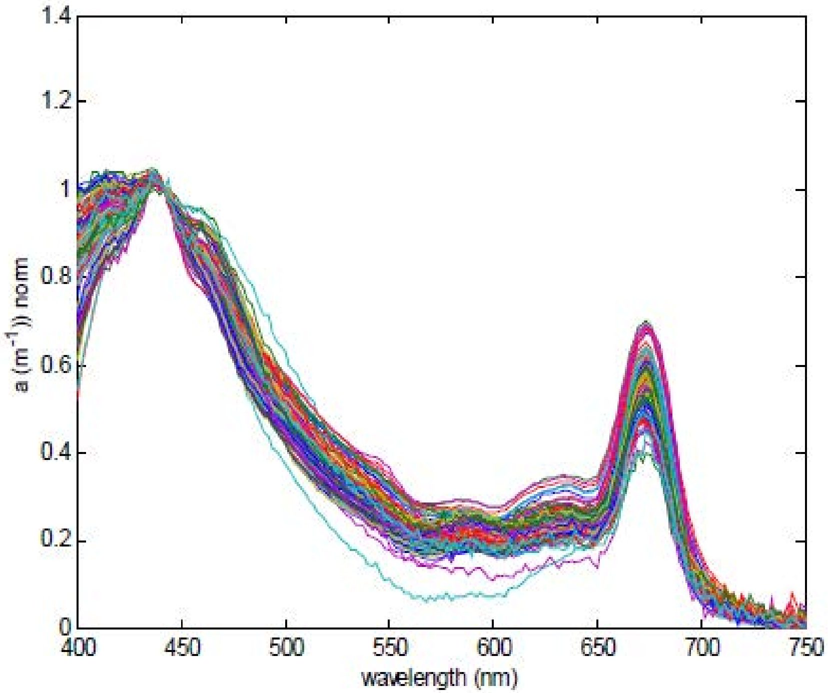
+ Provide information of
  - Surface Chl (proxy for phytoplankton biomass)
  - Spatial domain: fine (km) to **global ocean**
  - Temporal domain: day to decade
+ Global estimates of ocean-color based primary production
+ Active development of new biogeochemical products, (phytoplankton diversity, POC, carbon export)



See review:
McClain (2009). A decadal of satellite ocean color observations. Annual Reviews of Marine Sciences, 1, 19-42

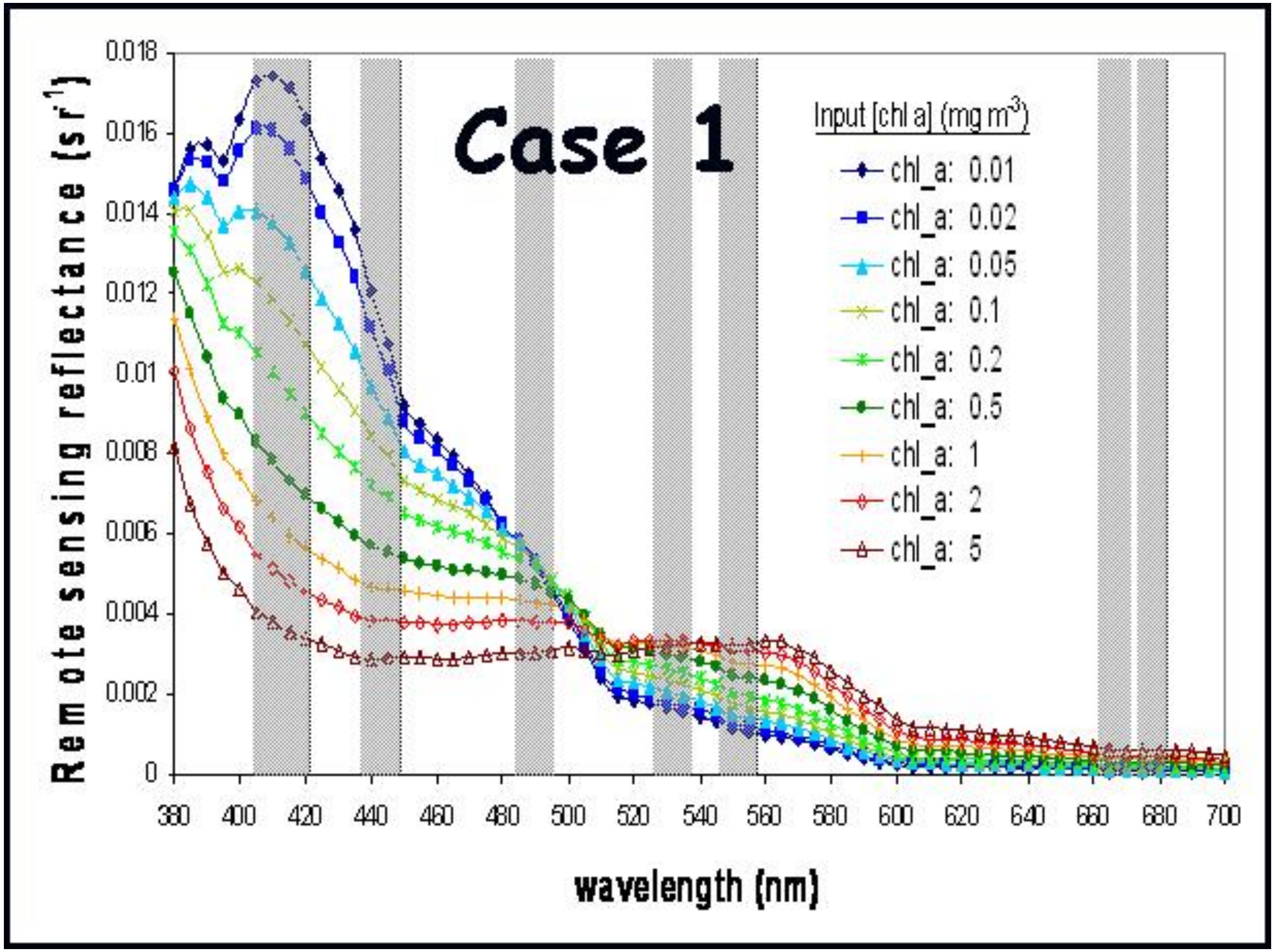
Spectral signatures





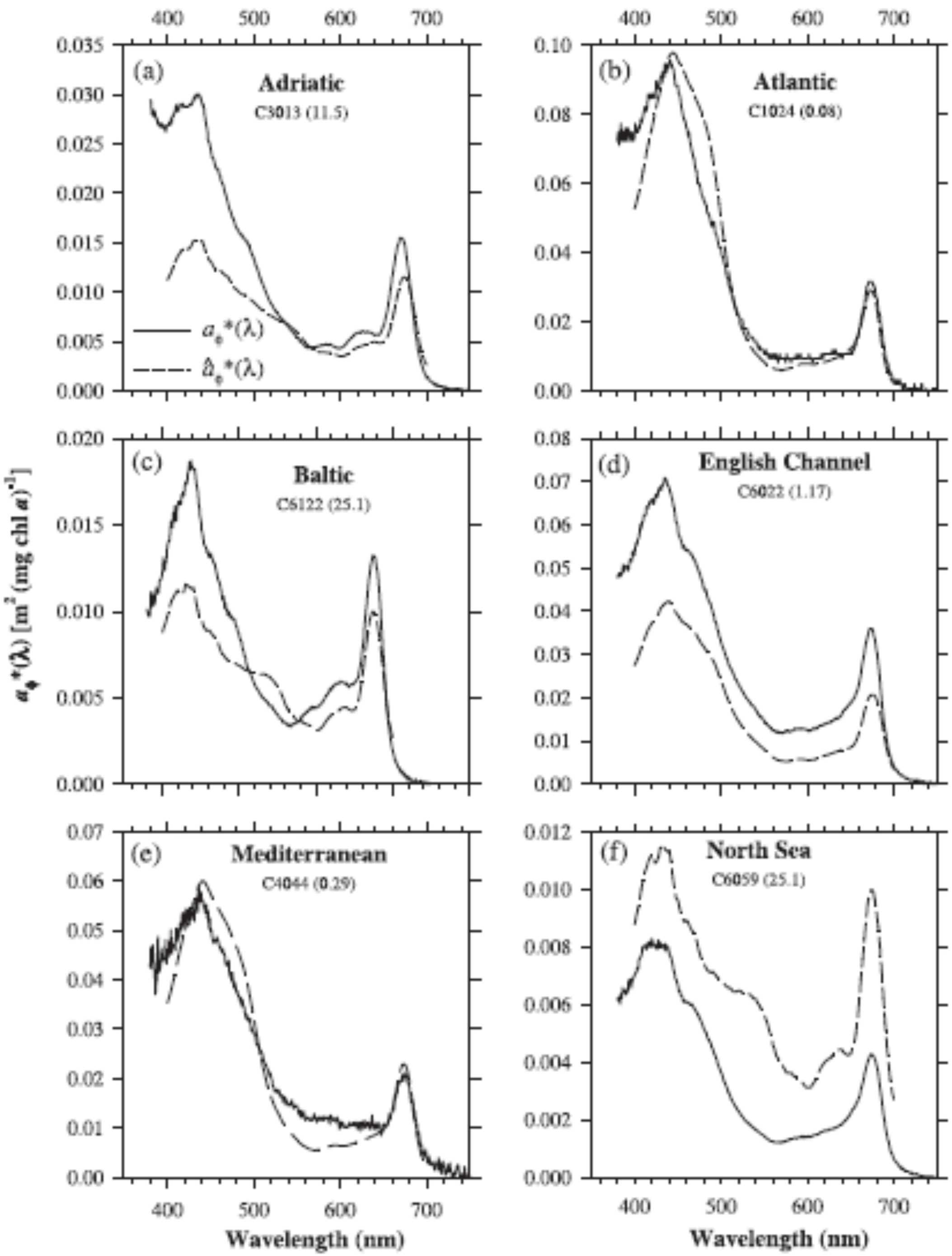
Results from light absorption by pure water and light absorption (and backscattering) by phytoplankton cells

Spectral signatures



Slopes between blue and green wavelengths decrease with increasing chlorophyll

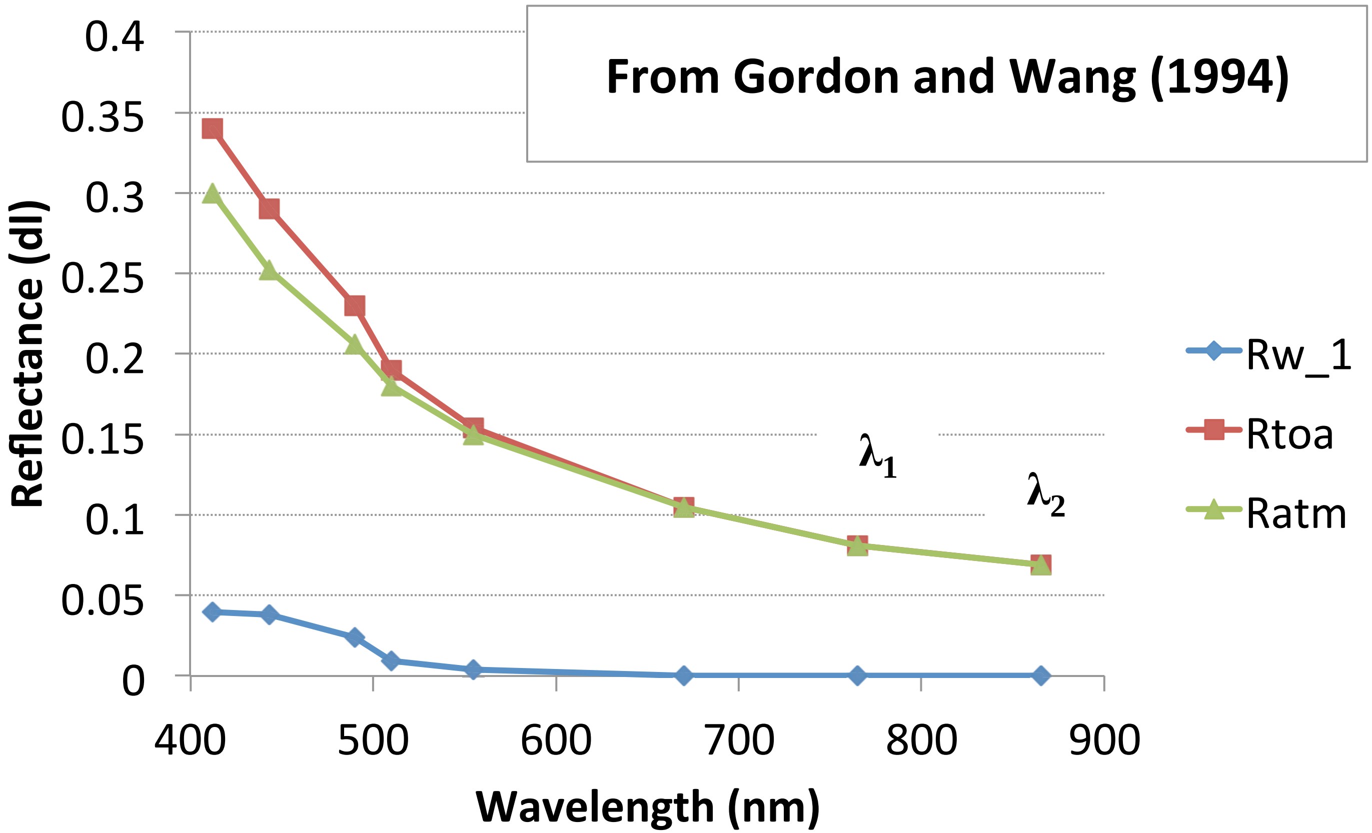
But...



Different phytoplankton species absorb light slightly differently… resulting in different Rrs spectral signatures (regional and seasonal natural variatsions)

Babin et al. 2003

2. Atmospheric corrections

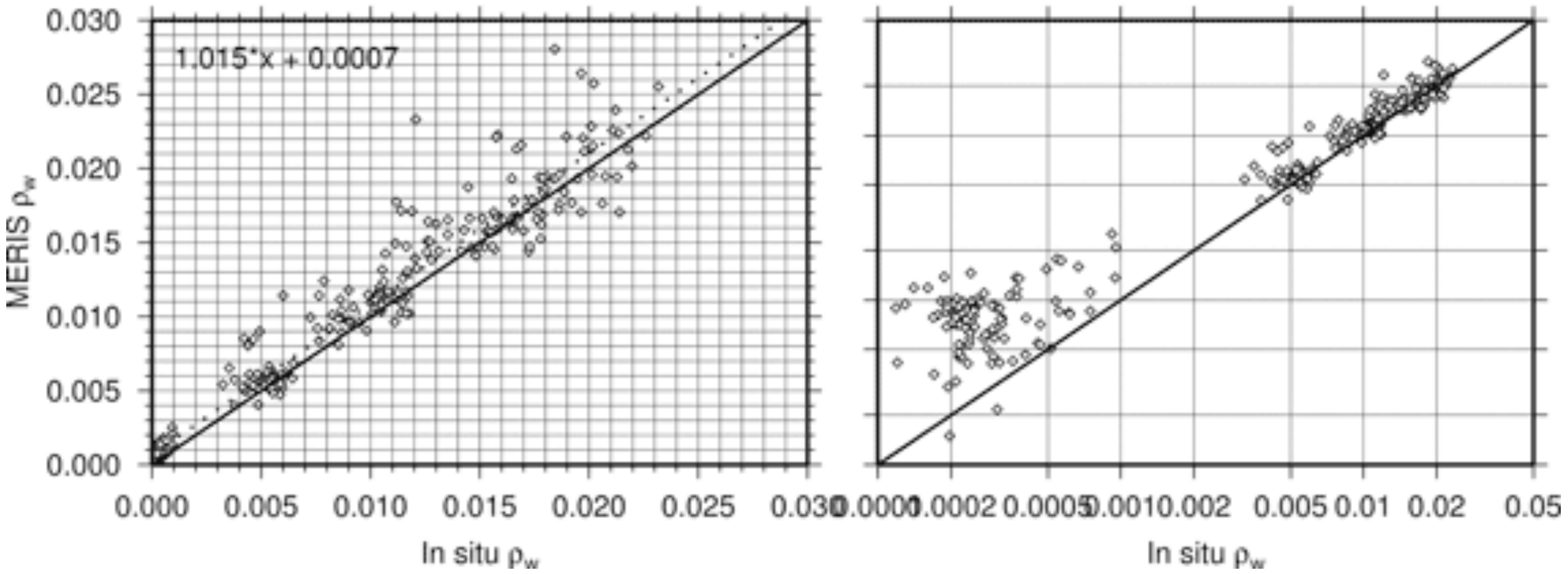


$$Rtoa(\lambda) = Rr(\lambda) + Rra(\lambda) + t \times Rw(\lambda), \qquad \varepsilon(\lambda_1,\lambda_2) = Rra(\lambda_1) / Rra(\lambda_2) = (\lambda_1 / \lambda_2)^n$$

Light absorption and scattering by air molecules (Rayleigh) is computed

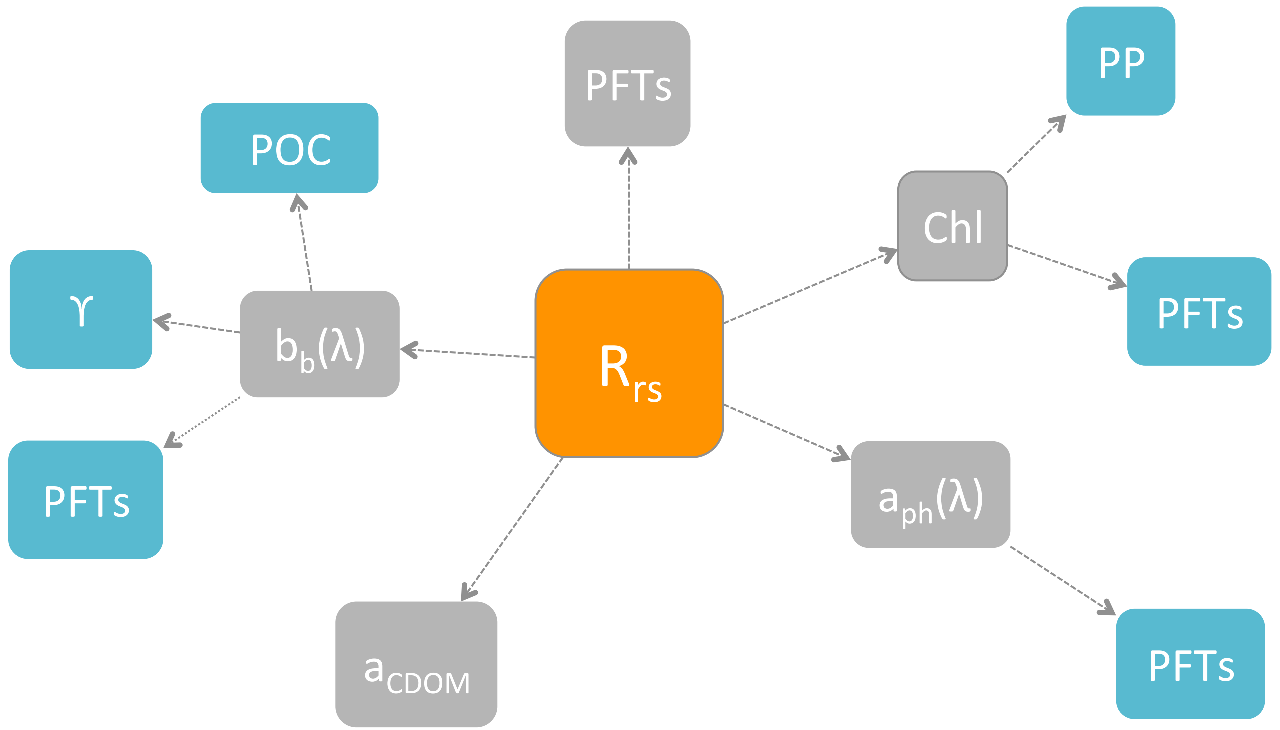
Light scattering by aerosols is computed in the NIR and extrapolated to the visible

Validation (match-ups with in situ data)



MERIS matchups (in terms of rw) at the BOUSSOLE site, including the following wavelengths : 412, 443, 490, 510, 560, 670, 683 nm. The same data are plotted with a linear scale on the left and a log scale on the right, in order to highlight the low reflectance values of the red wavelengths. The solid line is the 1:1 line. The dotted line is a simple linear fit on the data. The slope and intercept of this curve are also indicated.

3. Inversion algorithms



POC: Particulate Organic Carbon

ϒ: b_{bp} spectral slope

PFTs: Phytoplankton Functional Types

PP: Primary Production

3. Inversion algorithms

AOPS then IOPS

1. Atmospheric corrections
   Directionnal effects → $R_{rs}(\lambda)$ → empirical (Mueller (2000), Werdell (2005)) → $K_d(\lambda)$

$$K_d(490) = K_{dw}(490) + 0.1853\times[R_{rs}(490)/Rrs(555)]^{1,349}$$

2. Semi-analytical relationships:

$$K_d \cong (a + b_b) / \cos(\theta_{sw})$$
$$R \cong f \times b_b / (a + b_b)$$

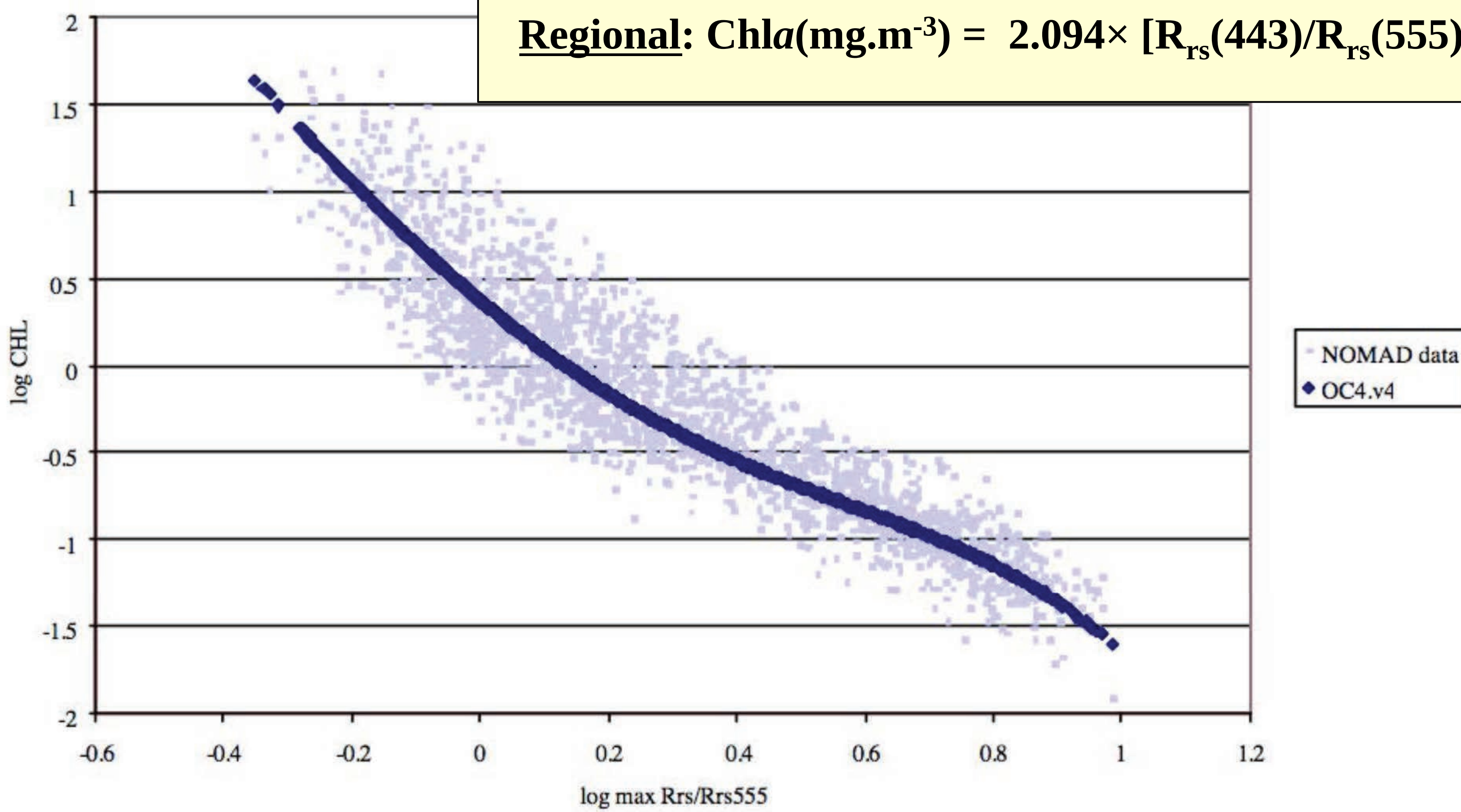
→

$$a = a_w + a_{Chla} + a_{NAP} + a_y$$
$$b_b = b_{bw} + b_{bChla} + b_{bNAP}$$

3. Inversion algorithms

General: OC4v4

Regional: $Chl\textit{a}(mg.m^{-3}) = 2.094\times [R_{rs}(443)/R_{rs}(555)]^{-2.357}$



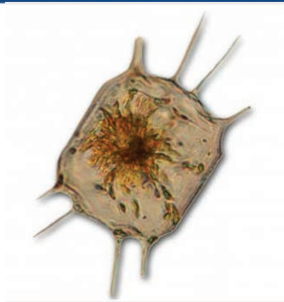
Going further….to phytoplankton groups

The so-called **Phytoplankton Functional Types** (PFTs) are conceptual groupings of phytoplankton species, which have a ecological functionality in common (either in terms of the food web or biogeochemical cycles).

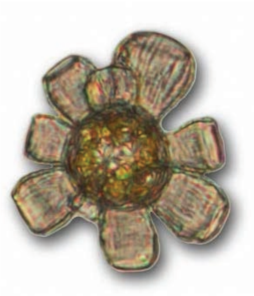
3. Inversion algorithms

- Size-based classification (Sieburth et al. 1978)
  - Picophytoplankton (< 2 µm; prochlorophytes, *Prochlorococcus*, *Synechococcus*)
  - Nanophytoplankton (2–20 µm; chromophytes, nanoflagellates, chryptophytes)
  - Microphytoplankton (> 20 µm; diatoms, dinoflagellates)
- Size is recognized to influence many processes
  - Optical properties
  - Ecological distribution (light-nutrient regime)
  - Photophysiological properties
  - Carbon fluxes

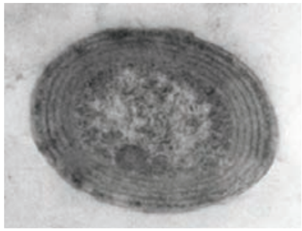
More info in:
IOCCG Working Group Report 15 (2014). Phytoplankton functional types from space.
www.ioccg.org/reports/IOCCG_Report_15_2014.pdf



Diatom *Odontella*
(*Photo: S. Marro*)



Coccolithophorid
(*Photo: S. Marro*)

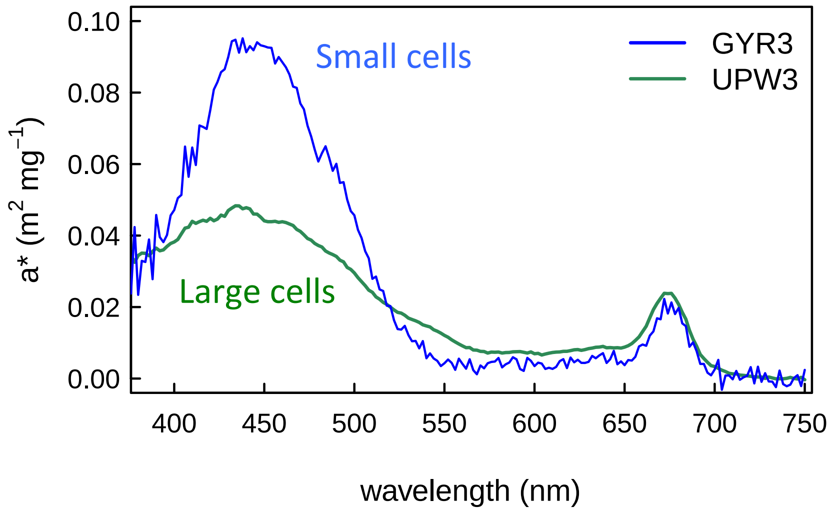


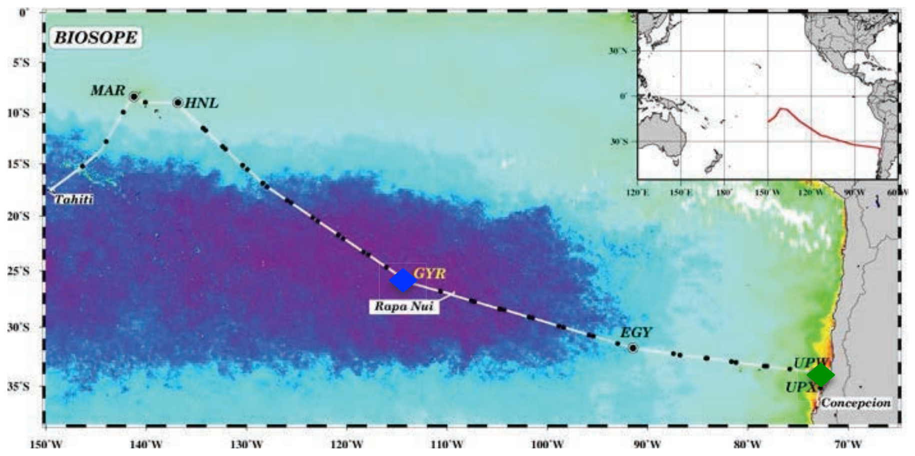
Prochlorococcus marinus
(*Photo: Li & Partenski*)

OVERVIEW OF PFT ALGORITHMS

Approach	Product	References (non-exhaustive list)
Abundance-based	Size classes	*Uitz et al. (2006)* *Hirata et al. (2008, 2011)* *Brewin et al. (2010, 2011)*
Spectral-based	Single group (*Trichodesmium*, diatom, coccolithophorid)	*Subramaniam et al. (1999)* *Sathyendranath et al. (2004)* *Brown & Yoder (1994)*
	Taxonomic groups	*Alvain et al. (2005, 2008)* *Bracher et al. (2009)*
	Size classes	*Ciotti et al. (2002)* *Ciotti & Bricaud (2006)* *Devred et al. (2006, 2011)* *Uitz et al. (2008)* *Mouw & Yoder (2010)* *Kostadinov et al. (2010)* *Roy et al. (2013)*
ANN-based	Taxonomic groups	*Raitsos et al. (2008)* *Palacz et al. (2013)*

SPECTRAL-BASED PFT ALGORITHMS

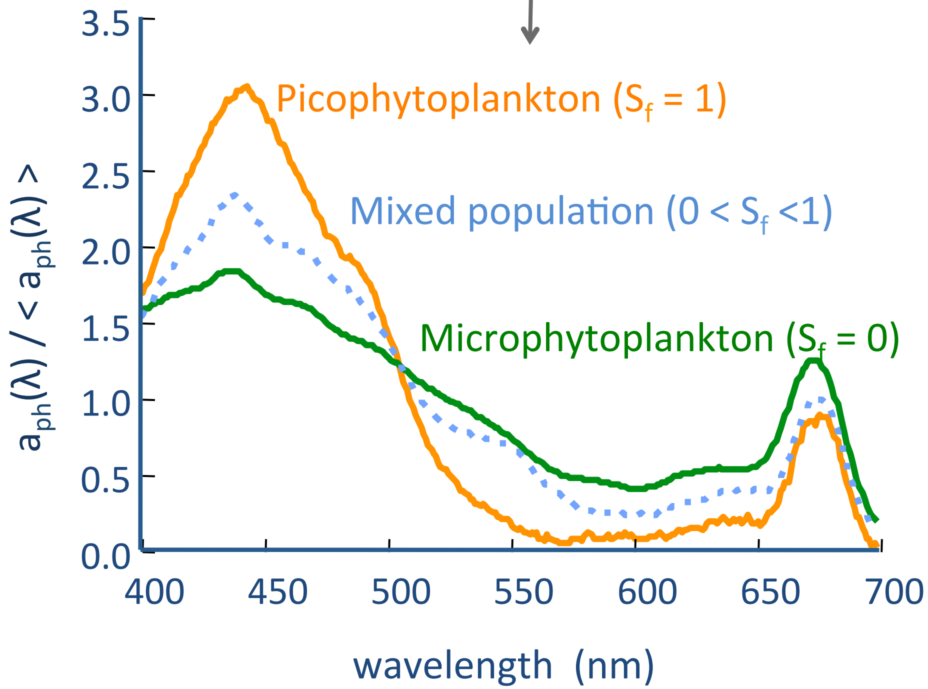


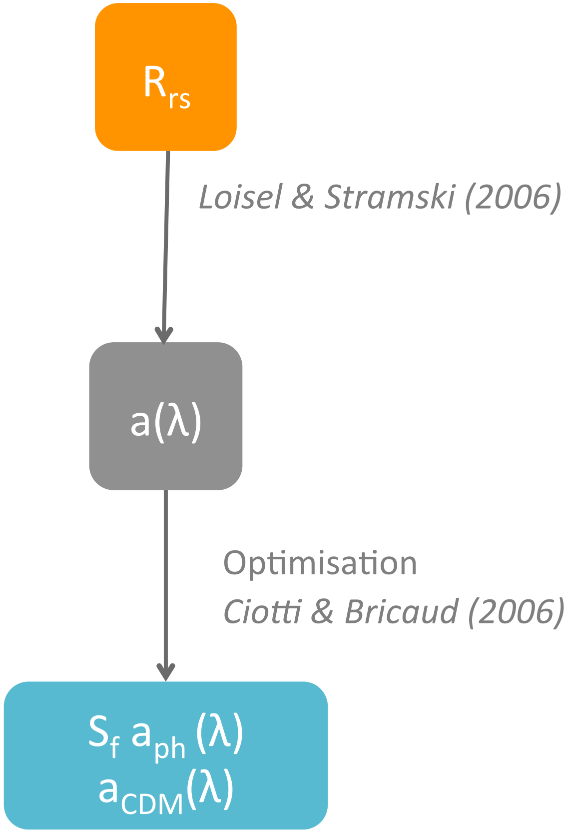


- Large changes in the shape of phytoplankton absorption spectra
  - Dominance of small cells: Large peak in the blue
  - Dominance of large cells: Flat spectra

3. Inversion algorithms

Field data of concomitant phytoplankton absorption spectra and size fractionation experiments



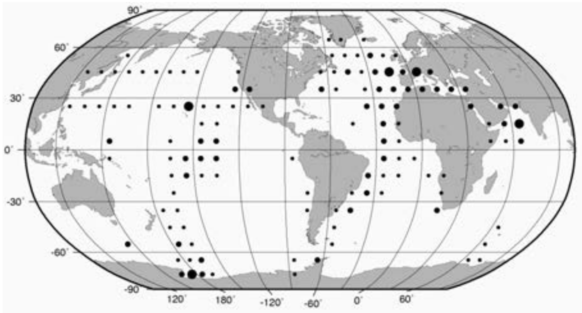


Sources:
Ciotti and Bricaud (2006). Limnology and Oceanography Methods, **4**, 237-253
Ciotti et al. (2002). Limnology and Oceanography

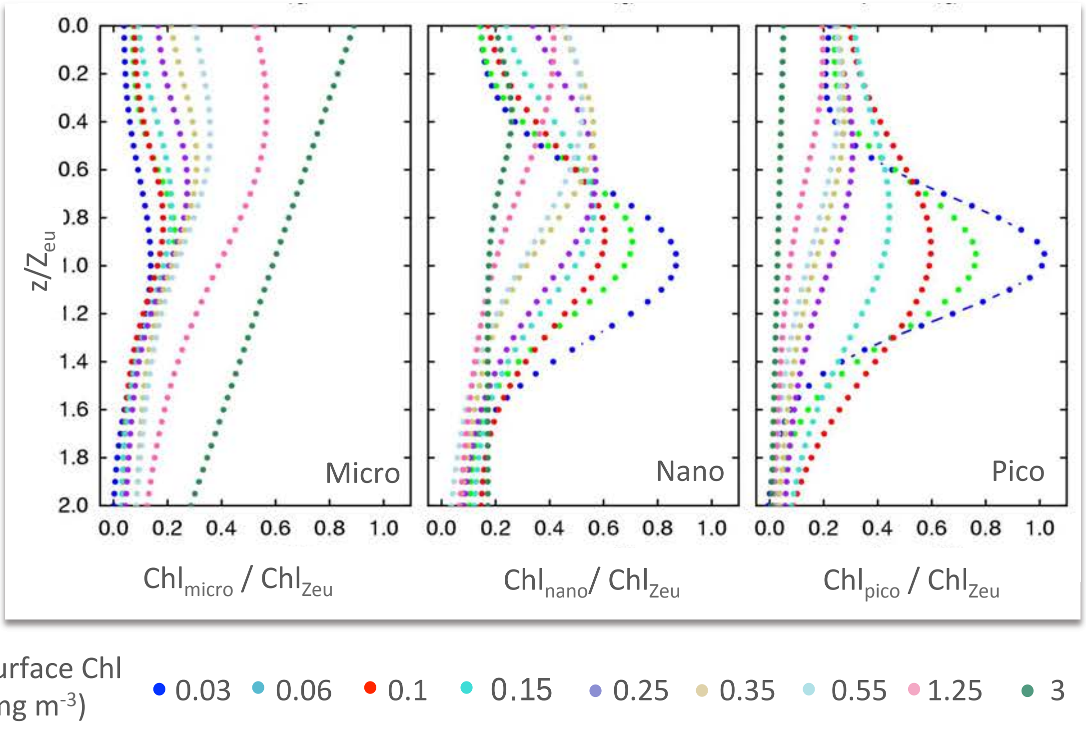
3. Inversion algorithms

Uitz et al. approach: Based on the analysis of a "global" HPLC pigment database

- Chl biomass
- Accessory pigments



Surface Chl → Phytoplankton group-specific vertical profiles of Chl



Source:
Uitz et al. (2006). Vertical distribution of phytoplankton communities in open ocean: An assessment based on surface chlorophyll, Journal of Geophysical Research, doi:10.1029/2005JC003207

3. ...to Primary Production

+ Ocean color coupled bio-optical primary production model

$$P(\lambda,z,t) = \boxed{Chl(z,t)\ a^*(\lambda,z,t)\ E(\lambda,z,t)}\ \boxed{\varphi_c(z,t)}$$

Absorbed light energy — **Conversion to carbon**

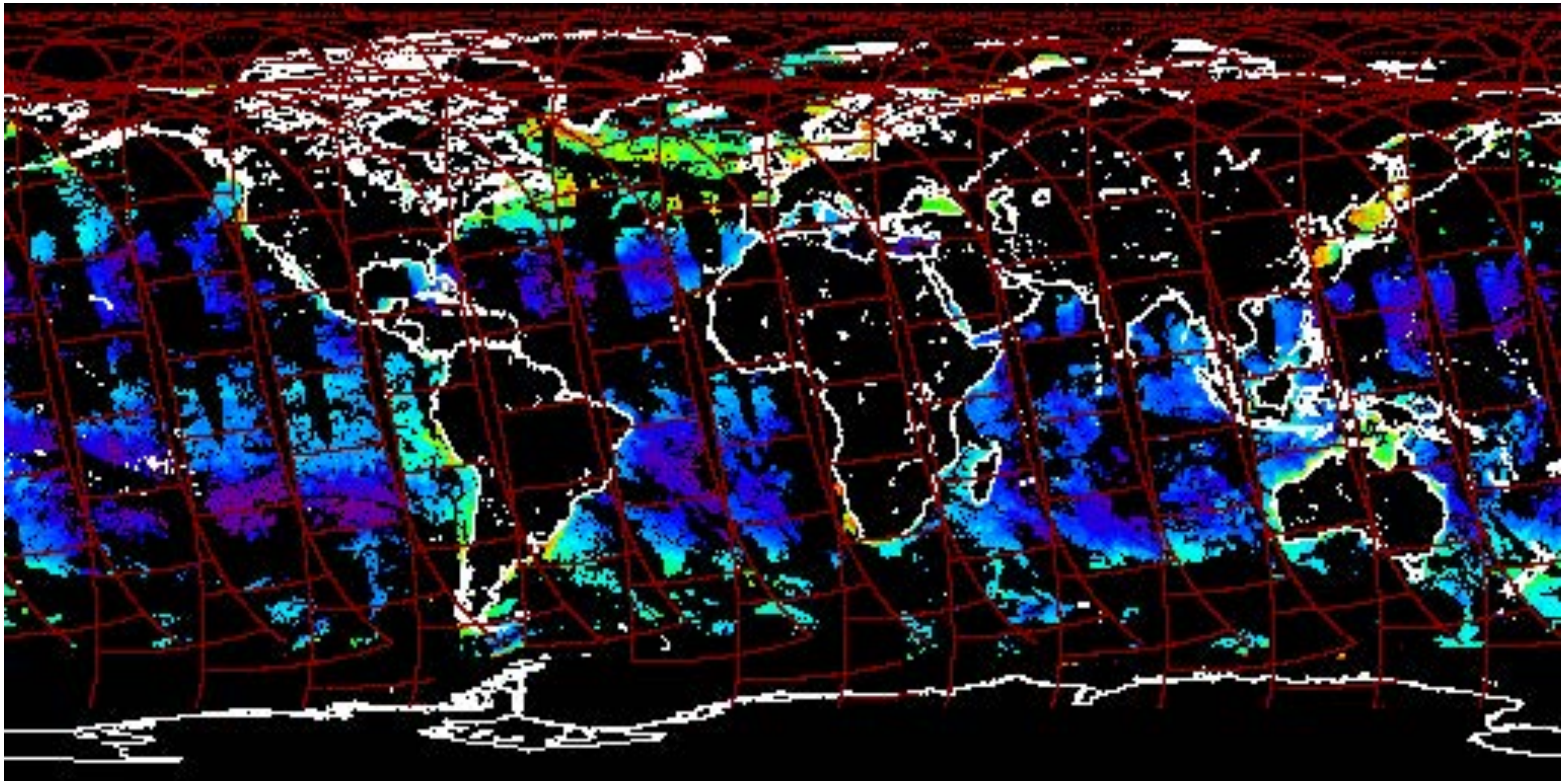
- P : Primary production rate (g C m^{-3} s^{-1})
- Chl : Concentration of chlorophyll *a* (mg m^{-3})
- E: Irradiance (mol quanta m^{-2} s^{-1})
- a* : Phytoplankton absorption coefficient [m^2 $(mg\ Chla)^{-1}$]
- φ_c : Quantum yield for carbon fixation [mol C $(mol\ quanta)^{-1}$]

Source:
Morel A. (1991). Light and marine photosynthesis: A spectral model with geochemical and climatological implications, Progress in Oceanography, 26, 263-306

4. Applications

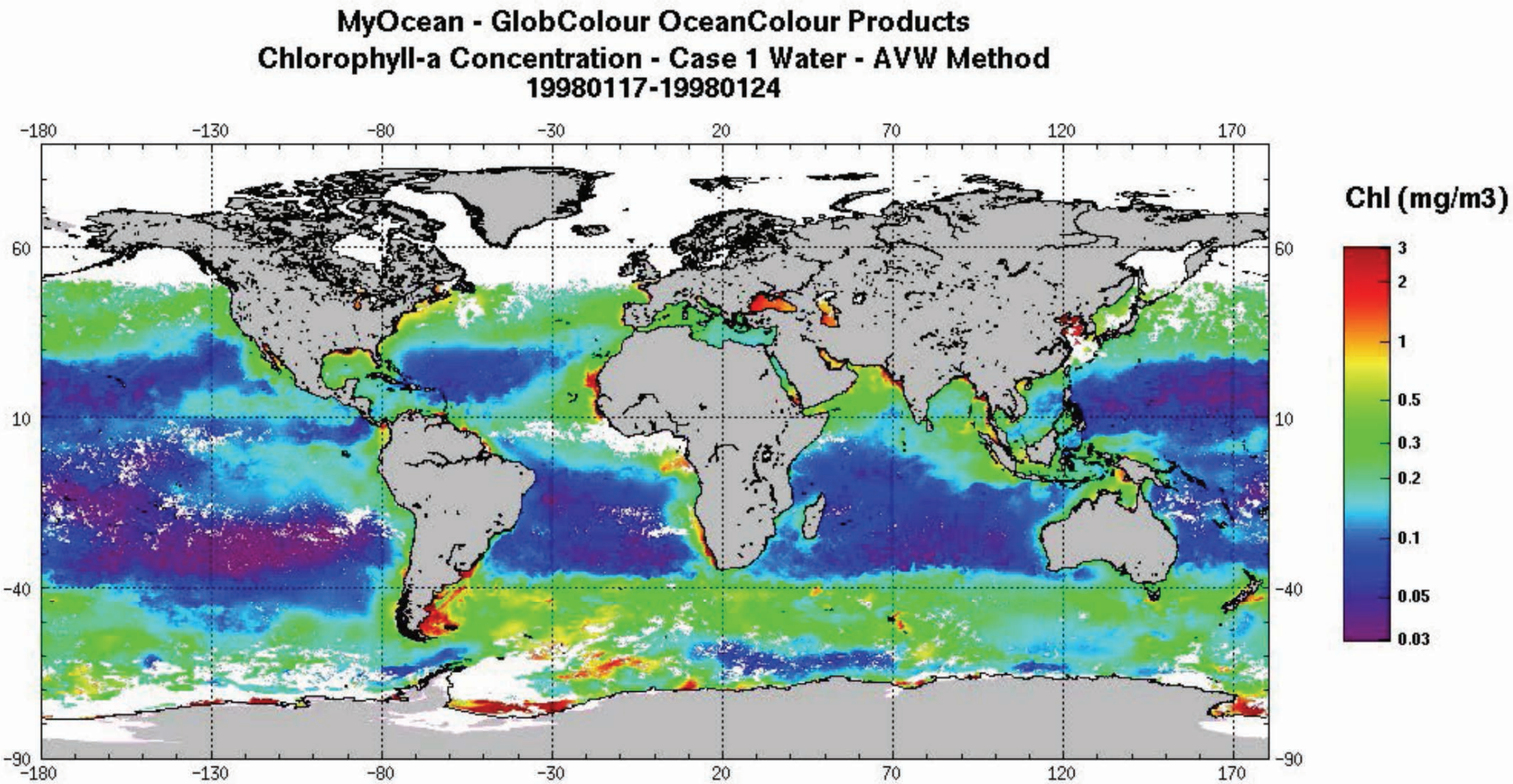
Mapping and analyzing bio-optical and biogeochemical products at different spatial and temporal scales…

4. Applications



Daily mapping of Chlorophyll-a concentration by MODIS-AQUA
7 May 2015

4. Applications



Acknowledgment: ACRI & the GlobColour. GlobColour is funded by ESA with data from NASA, ESA and GeoEye

4. Applications

Ocean-Colour Component of ESA's Climate Change Initiative

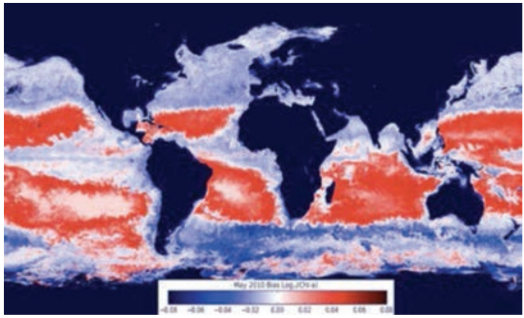
Objective: produce an uncertainty-characterised, inter-sensor bias-corrected, merged time series of ocean-colour products for climate research, and engage with users

V2 of the merged time series (SeaWiFS, MERIS and MODIS-A) released in March 2015

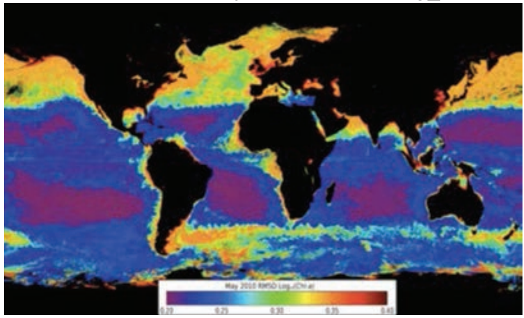
Specific aims of this version 2.0 release:

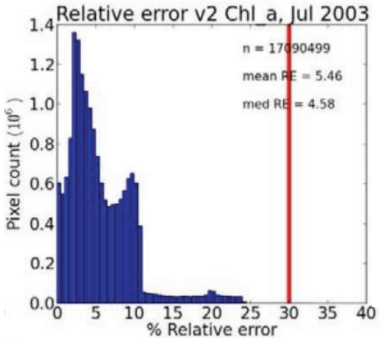
- improves the in situ database used for uncertainty characterisation
- optimizes the uncertainty generation for the CCI data
- improves consistency in many areas, including unifying the binning/mapping processing
- improves bias correction, able to respond to temporal variation (primarily seasonal)
- incorporates an improved cloud mask for MERIS
- benefits from a more automated quality assurance process
- extends the time series to the end of 2013
- refreshes the input datasets to the latest versions

May 2010 bias, log_10 Chl



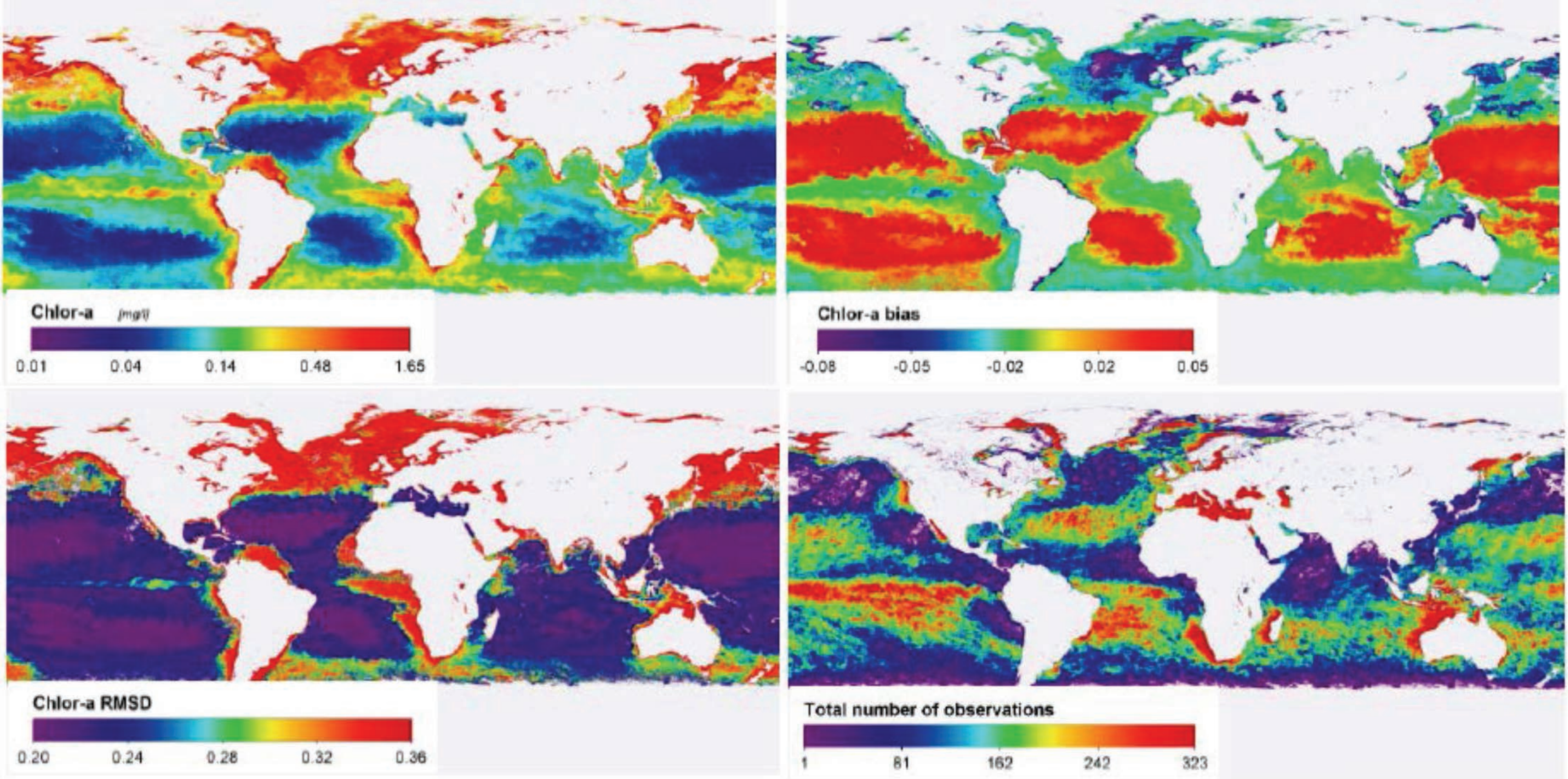
May 2010 RMSD, log_10 Chl



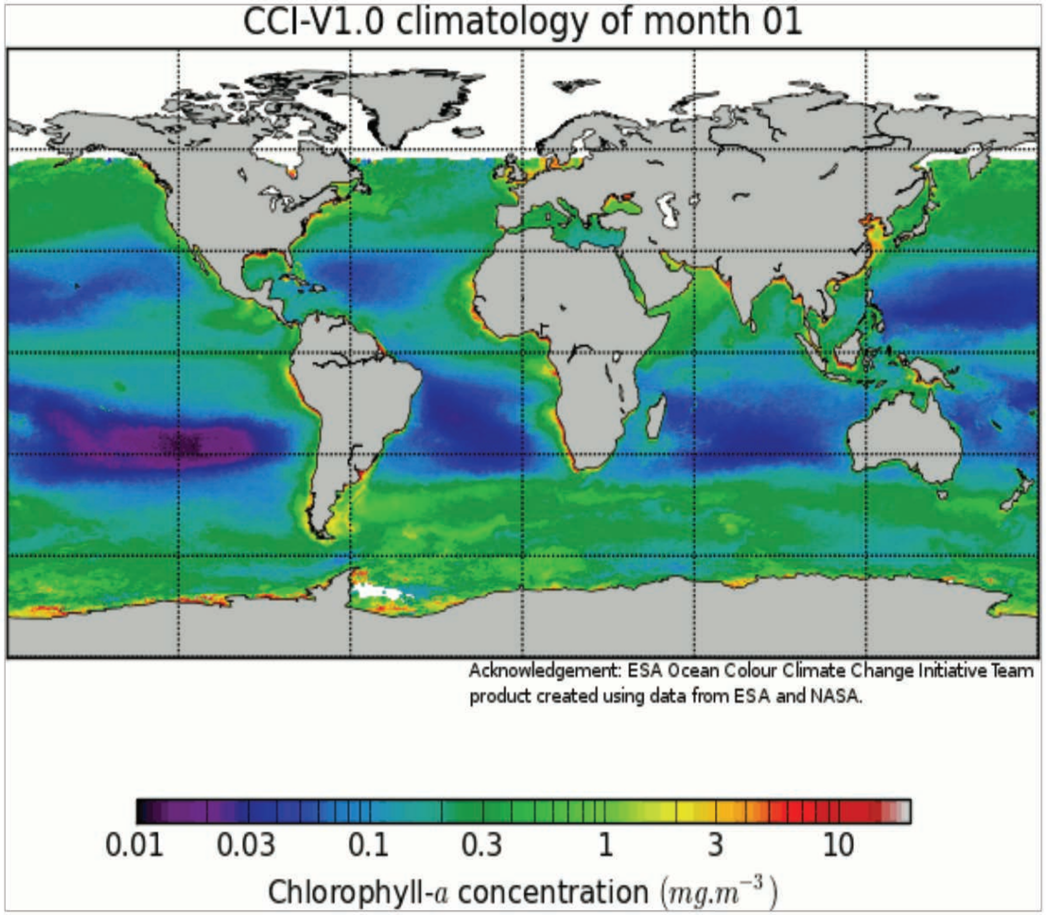


Relative error in V2 Chl based on bias.

Red vertical line: GCOS requirement for accuracy



Global maps of (top left) Chlorophyll-a concentration, (top right) Chlorophyll-a bias, (bottom left) RMSD and (bottom right) total number of observations for the merged monthly v2 products, June 2003.
Produced by the Ocean Colour CCI Team, 2015



http://www.esa-oceancolour-cci.org

Primary production of the global ocean
(Antoine et al. 1996)

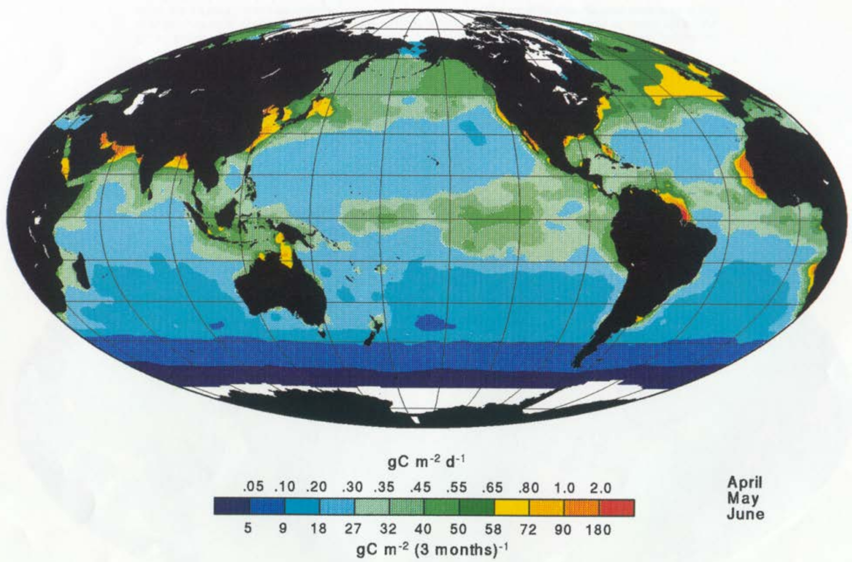


Plate 1b. As in Plate 1a, but for the April - May - June period.

ANTOINE ET AL.: OCEANIC PRIMARY PRODUCTION 65

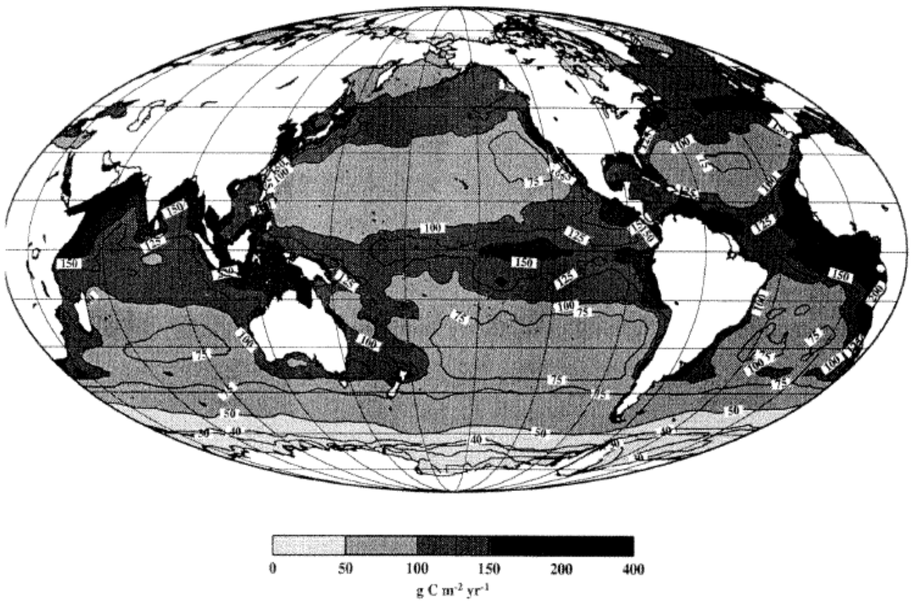


Figure 3. Annual primary production within the world ocean (equal surface "Mollweide" projection), obtained by summing the 12 monthly maps. This map shows the values obtained through the "standard" computation, which leads to a global annual carbon fixation of 36.5 Gt C yr^{-1} (Table 1, line 1). This map can be compared to the historical primary production maps, as derived from compilations of in situ carbon fixation [e.g., *Koblentz-Mishke et al.*, 1970; *Berger et al.*, 1987].

4. Applications

Bosc et al. (2004)

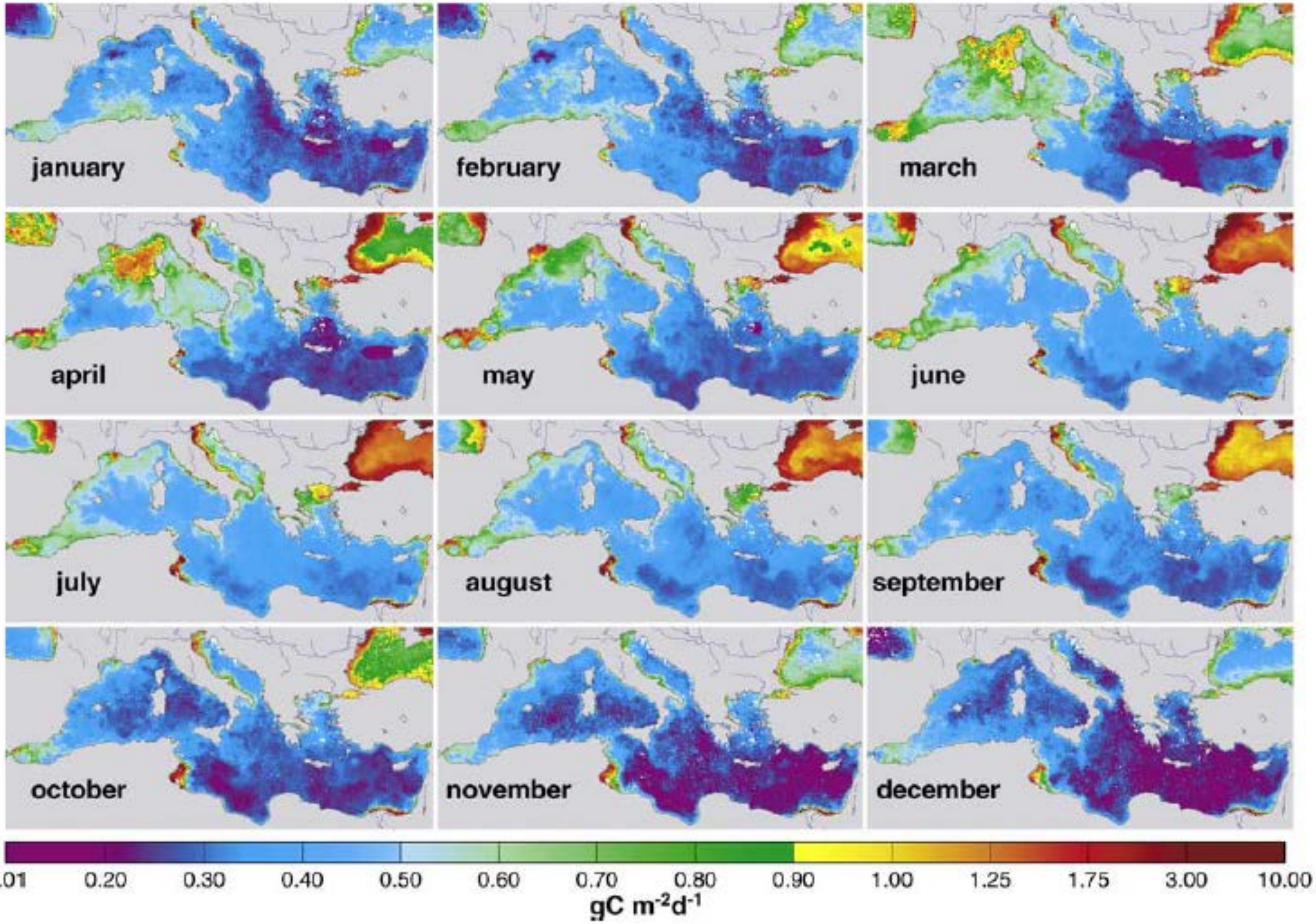
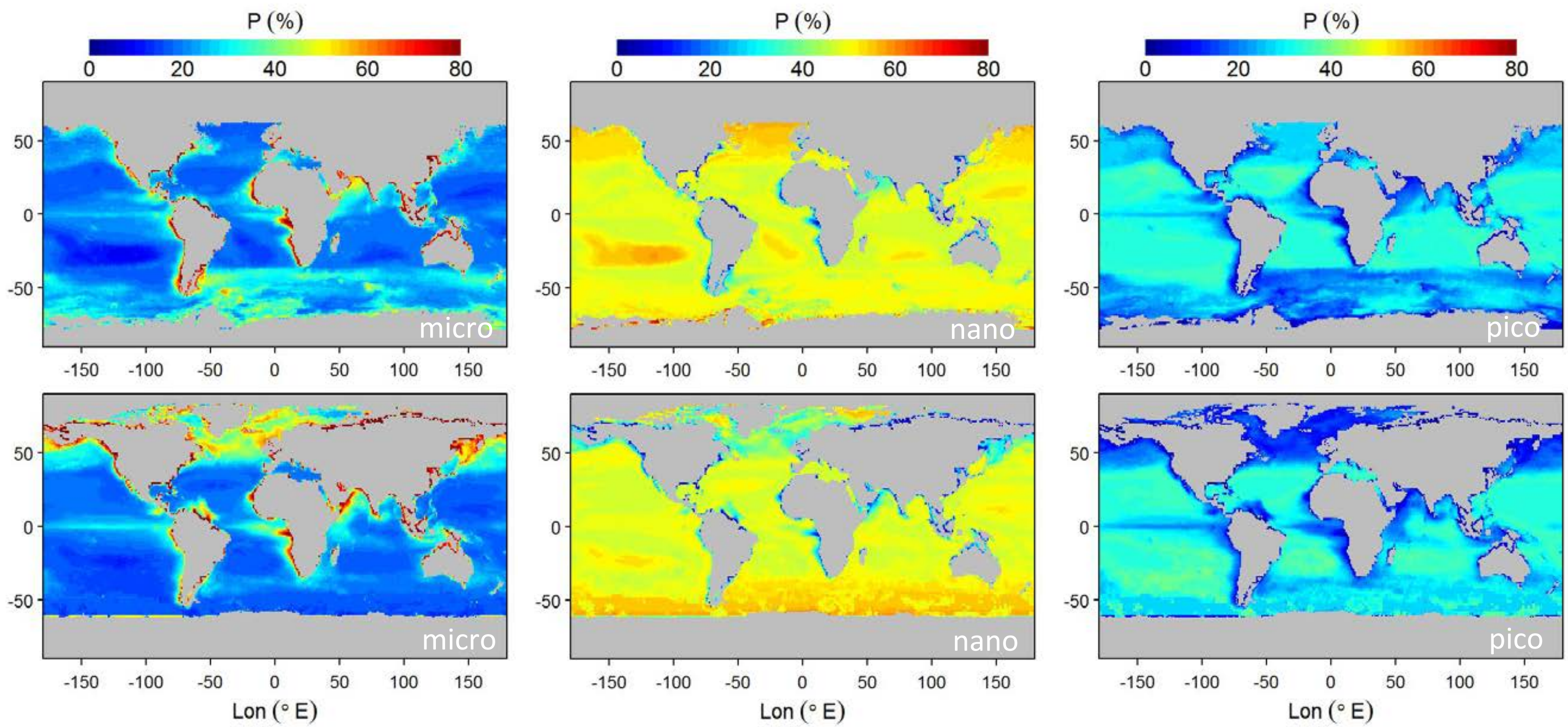


Figure 11. Monthly maps of primary production, for the year 1999.

4. Applications

PHYTOPLANKTON GROUP-SPECIFIC PRIMARY PRODUCTION

Boreal winter/Austral summer



Boreal summer/Austral winter

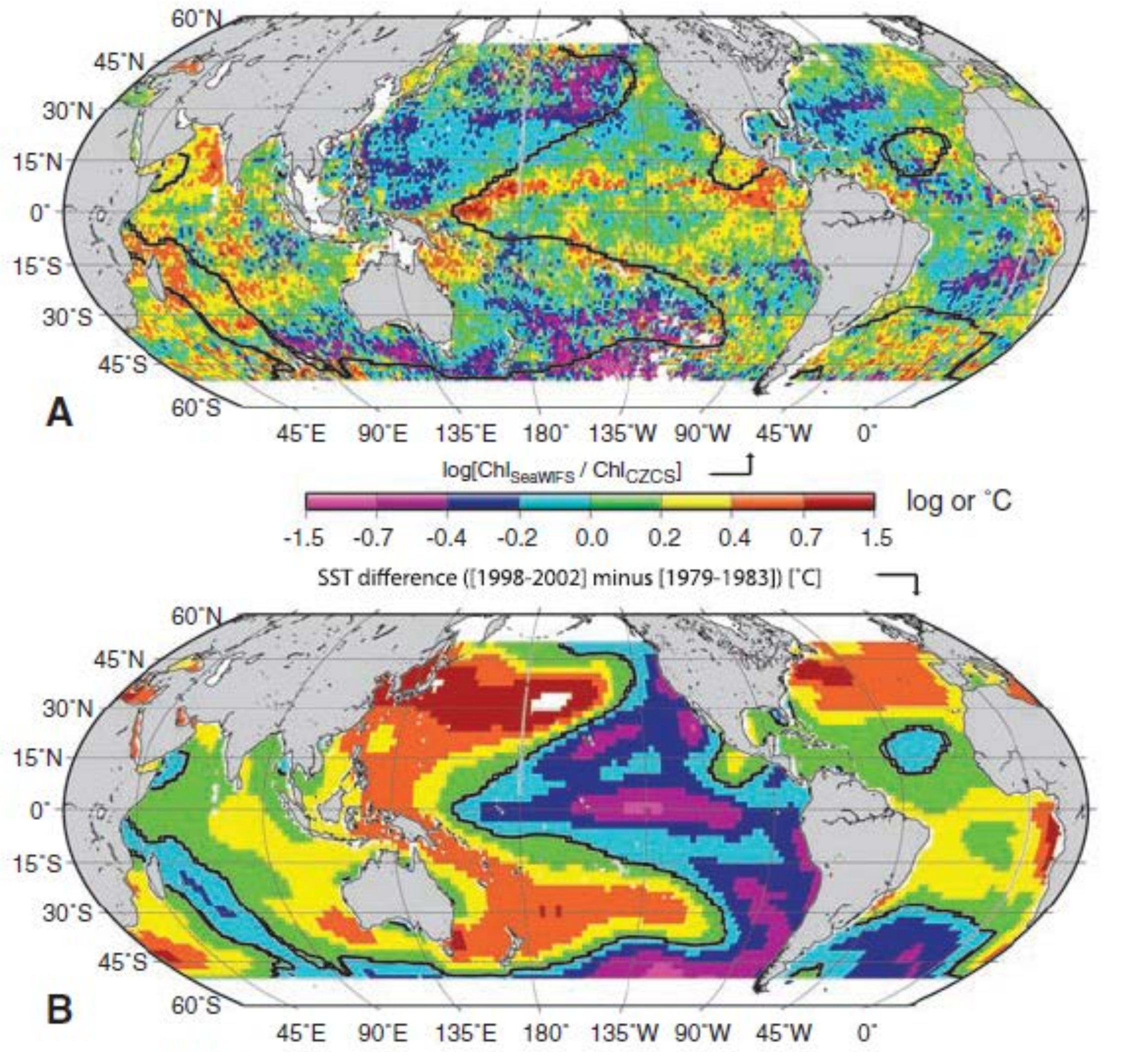
:Uitz et al. (2010). Phytoplankton class-specific primary production in the world's oceans: Seasonal and interannual variability from satellite observations, Global Biogeochemical Cycles, doi:10.1029/2009GB003680

Applications

Impact of Climate Change
(Martinez et al. 2009, Science)

Multidecadal changes in global phytoplankton abundances are related to basin-scale oscillations of the physical ocean, specifically the Pacific Decadal Oscillation and the Atlantic Multidecadal Oscillation.

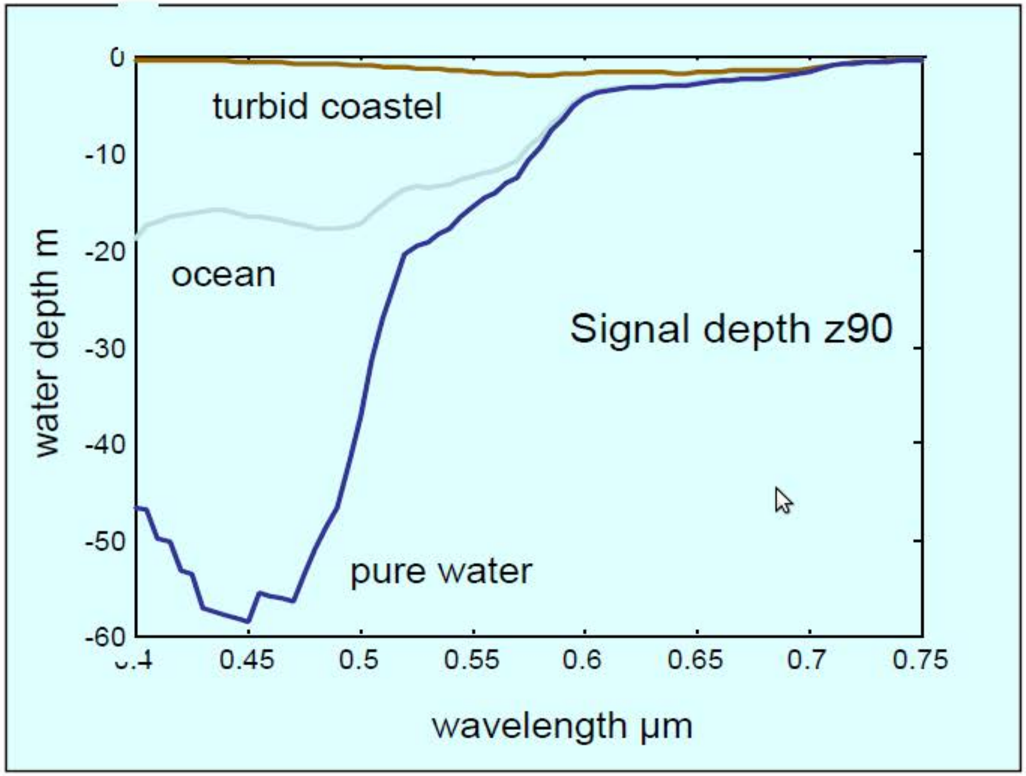
This relationship is revealed in ~20 years of satellite observations of chlorophyll and sea surface temperature.



But optical depth is a limit of ocean colour satellite observations

Signal depth at different spectral bands

Multiband algorithms: the information for each band may come from a different water layer



$z_{90}=1/k$

coastal:
TSM=5 mg/l
Chlor.=5µg/l
Gelb=a_{380}=1m^{-1}

open ocean:
Chlor.=1µg/l

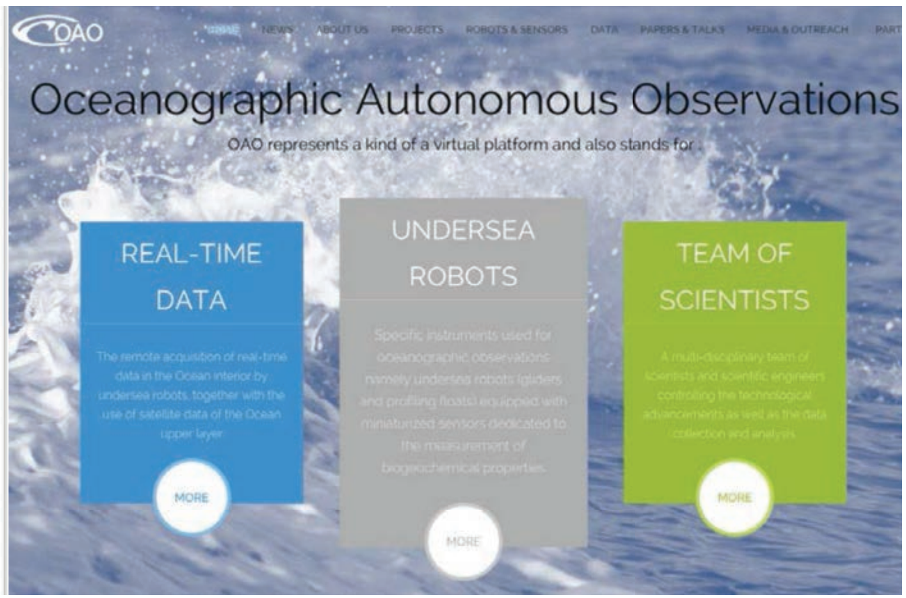
SATELLITE REMOTE SENSING OF OCEAN COLOR

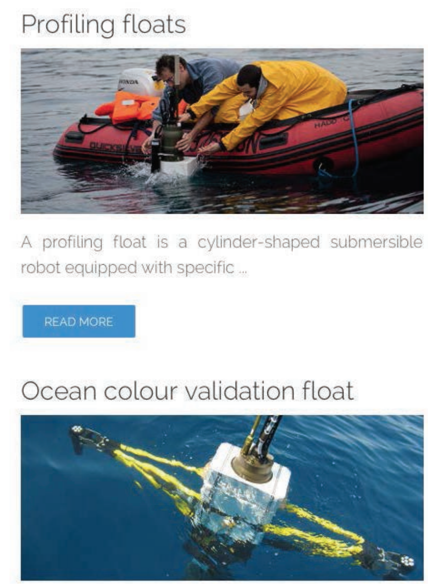
COLLECTING FIELD OBSERVATIONS

+ Strong requirement for in situ data representative of "global" open ocean conditions

HPLC Analytical Service

Network of Bio-Argo profiling floats





Source:
http://www.sapigh.obs-vlfr.fr
http://www.oao.obs-vlfr.fr/web/index.php

Conclusions / Perspectives

OCEAN COLOUR REMOTE SENSING OF CASE-1 WATERS

OC sensors measure
the color of the ocean = light

Excellent space-time
coverage – SYNOPTIC!

Great variety of
biogeochemical products

→ **Data assimilation into models**

Surface layer only

Some areas are not seen

ABSOLUTE REQUIREMENT
for large in situ datasets

→ **Bio-optical profiling floats**

References / Acknowlegments

International Ocean Colour Coordinating Group
http://www.ioccg.org/

European Space Agency MERIS Handbook
https://earth.esa.int/handbooks/meris/

NASA Ocean Color homepage
http://oceancolor.gsfc.nasa.gov/cms/

LOV Remote Sensing Group publications as pdf files
http://omtab.obs-vlfr.fr/

Special thanks to Julia Uitz for her contribution

Thank you for attention!