

RADIOMETRIC OBSERVATIONS TO INVESTIGATE THE PHYTOPLANKTON BIOMASS : FROM SEASONAL TO DECADAL VARIABILITY IN THE GLOBAL OCEAN

ELODIE MARTINEZ

LABORATOIRE D'OCÉANOGRAPHIE PHYSIQUE ET SPATIALE
(BREST)





Who am I/what did I do?

- DEA & engineering school “Centrale Marseille” 1999-2002
- Phd. University of French Polynesia 2003-2006 (physical oceanography)
- Postdoctoral fellowship IPRC (Hawaii, USA) 2006-2007 (modeling dev.)
- Postdoctoral fellowship LOV (Villefranche/mer) 2007-2011 (ocean optics)
- IRD permanent research position (Biogeochemistry & physics):
 - MIO (Marseille, 2011-2013)
 - EIO (Tahiti, 2013-2017)
 - LOPS (Brest, 2018-...)

OUTLINE

INTRODUCTION

Le phytoplancton, importance biogéochimique
Pertinence de la télédétection de la couleur de l'océan

1. PRÉMICES DE LA RADIOMÉTRIE SPATIALE

1979-1985: apports de la mission Nimbus7 et du capteur CZCS (les prémices d'une vision globale et de la variabilité saisonnière)

2. CAPTEURS MODERNES

1997-....: apports des capteurs radiométriques modernes et des produits combinés : du saisonnier à l'interannuel

3. RECONSTRUCTION DÉCENNALES

Les produits reconstruits pour tenter d'appréhender la variabilité décennale

4. APPROCHES COMPLÉMENTAIRES

Combinaison des observations et intelligence artificielle: vers de nouvelles perspectives!?

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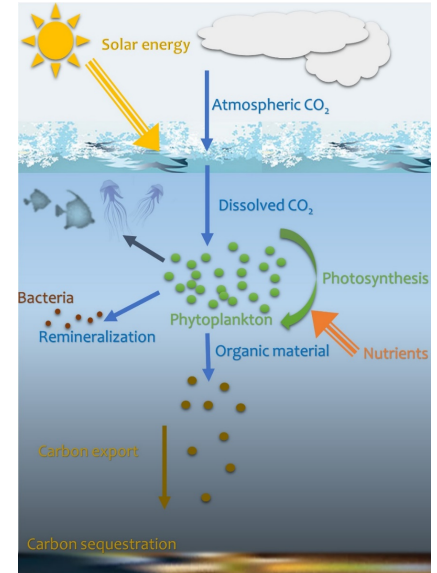
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INTRODUCTION: BIOGEOCHEMICAL KEY ROLE OF PHYTOPLANKTON

Phytoplankton play a critical role in:

Key role in the global carbon cycle

- ~50% of the world's total primary production (Field et al., 1998)
- Biological carbon pump helps regulate the planet's atmospheric CO₂ (Takahashi et al., 2009)

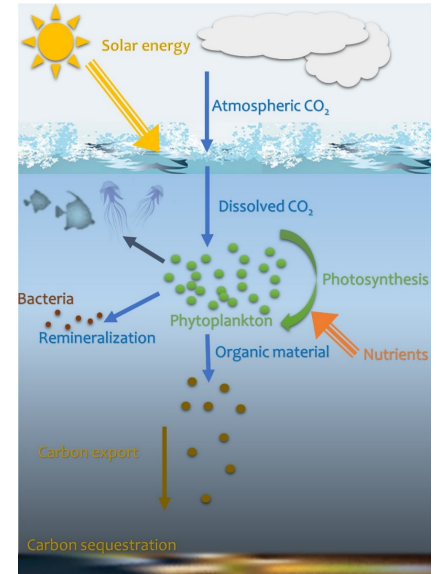
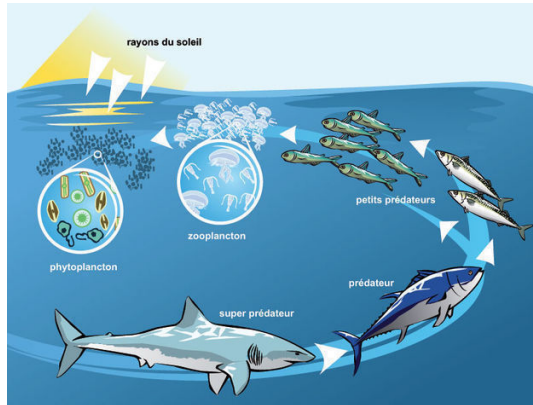


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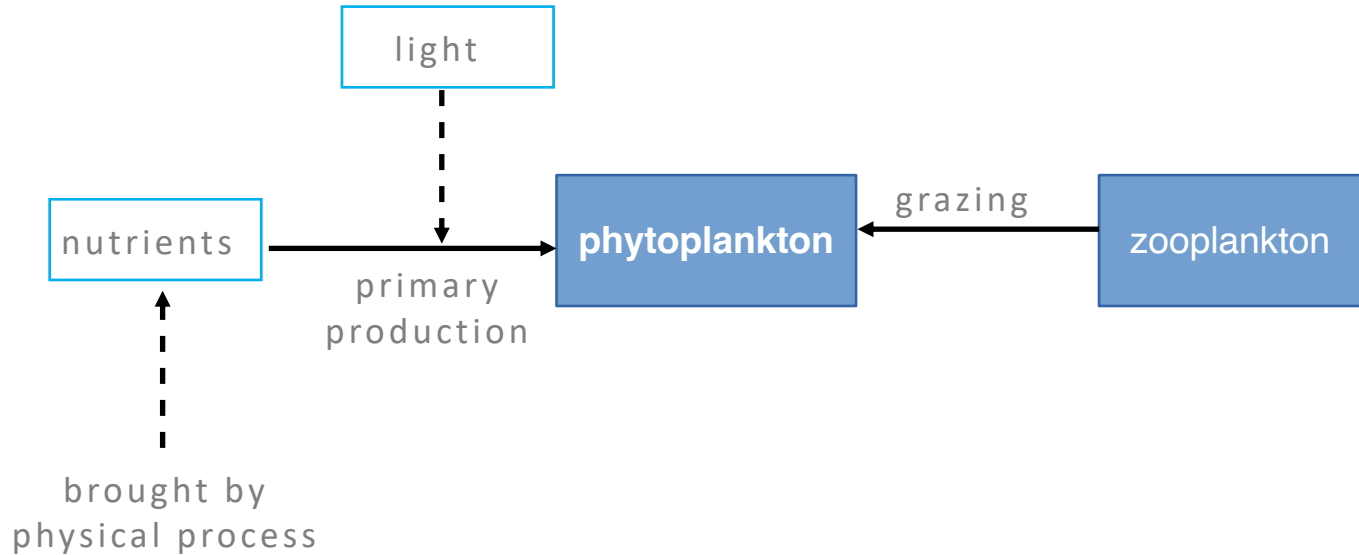


Basis of the trophic interactions

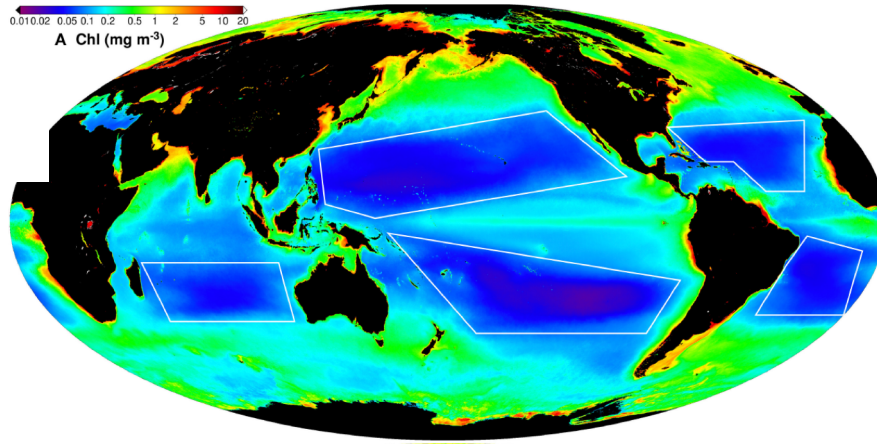
→ impact on the upper trophic levels

These processes are subject to large spatio-temporal variability

INTRODUCTION: PHYSICAL AND BIOGEOCHEMICAL PROCESS

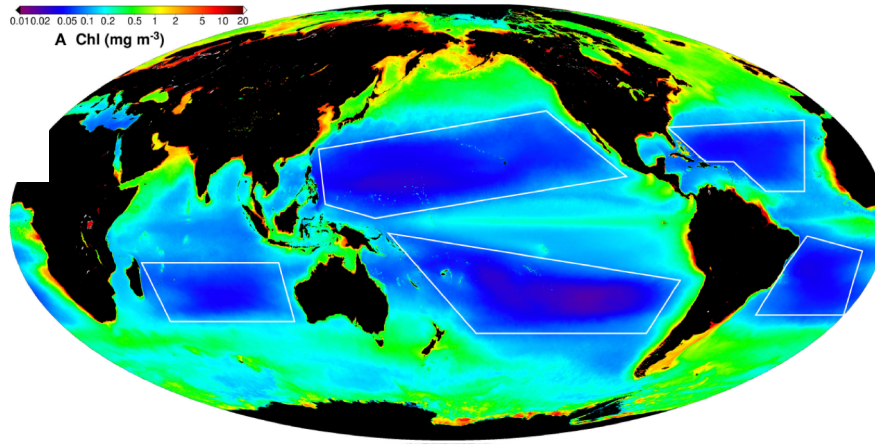


INTRODUCTION: PHYSICAL AND BIOGEOCHEMICAL PROCESS



Signorini et al. (2015)

INTRODUCTION: PHYSICAL AND BIOGEOCHEMICAL PROCESS

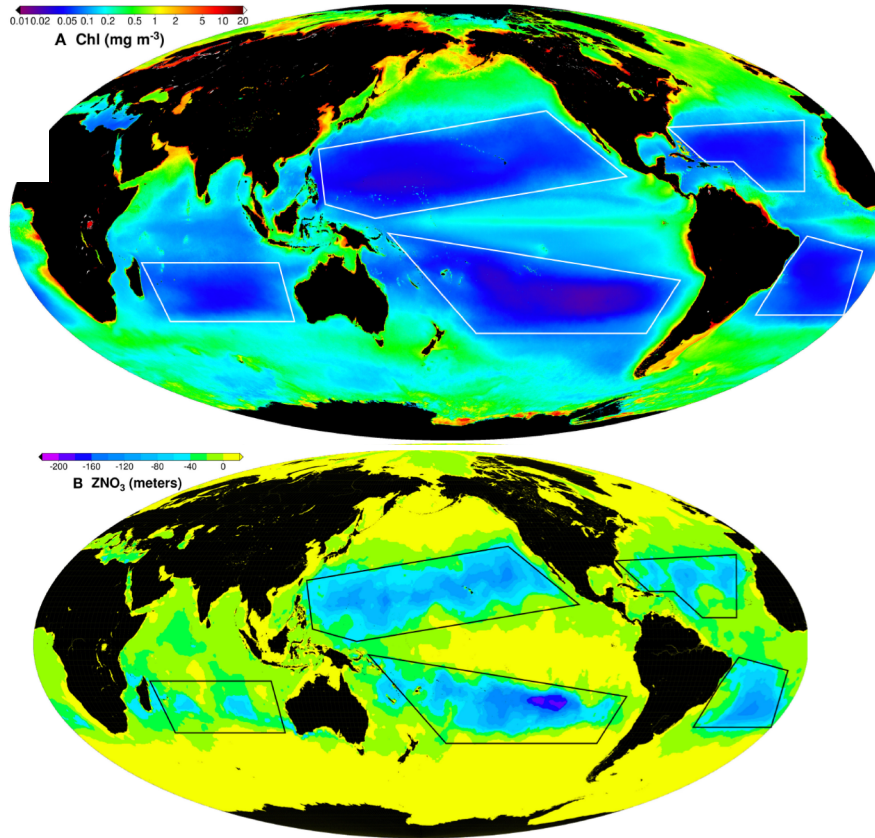


Various dynamical systems, e.g:

- Subtropical gyres
- Subpolar gyres
- Equatorial upwelling
- Coastal upwelling

Signorini et al. (2015)

INTRODUCTION: PHYSICAL AND BIOGEOCHEMICAL PROCESS



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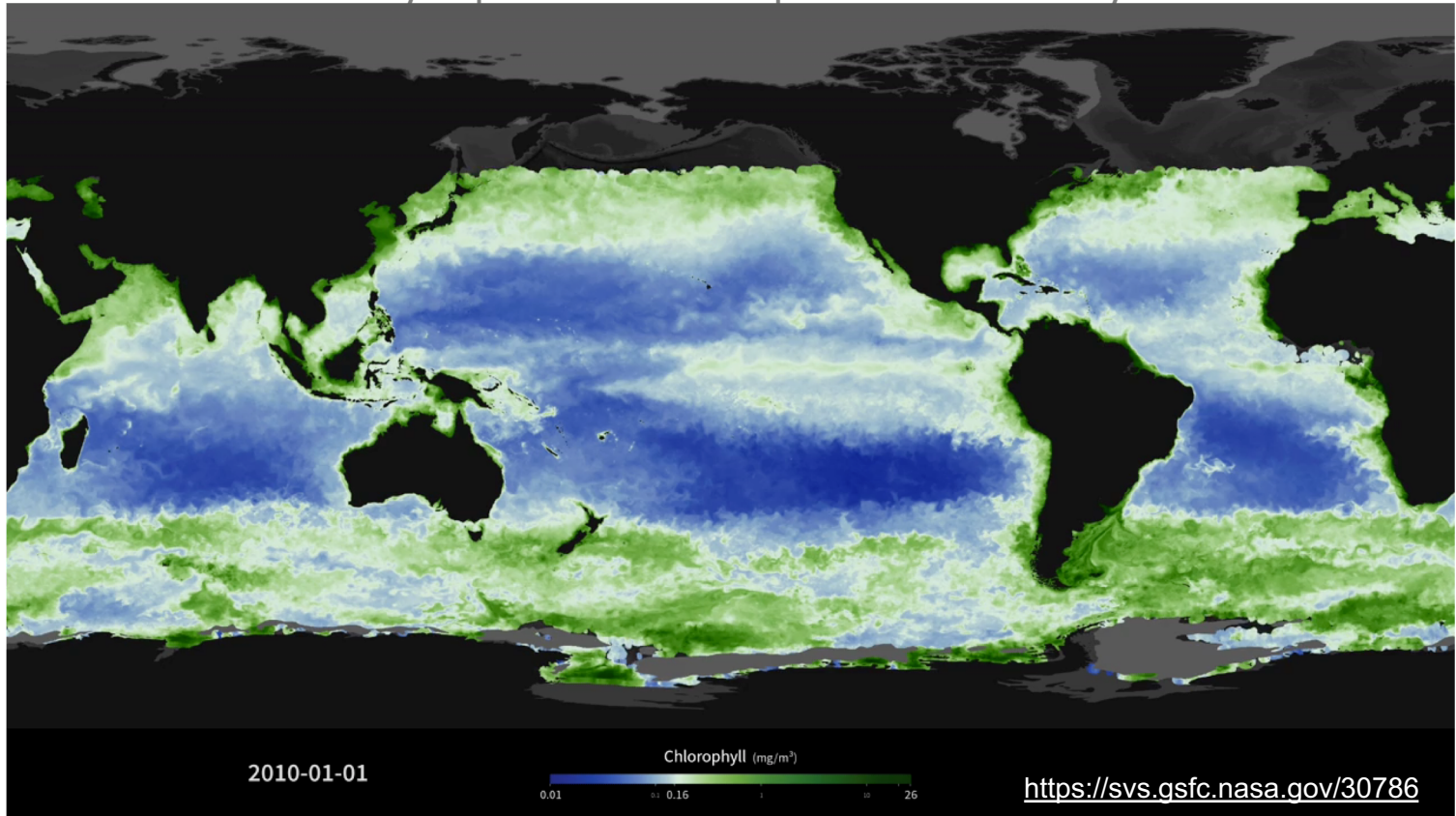
Signorini et al. (2015)

FIGURE 1 | Global maps of 9km MODISA OCI Chl-a mission composite (A) and the depth of the $0.2 \mu\text{M}$ (ZNO_3) nitrate concentration (B) derived from the World Ocean Atlas monthly

climatology. The transition to the yellow color in (B) indicates that the $0.2 \mu\text{M}$ nitrate horizon has reached the surface. The polygons represent the study areas of the 5 gyres.

INTRODUCTION: BIOGEOCHEMICAL KEY ROLE OF PHYTOPLANKTON

Phytoplankton temporal variability



INTRODUCTION: BIOGEOCHEMICAL KEY ROLE OF PHYTOPLANKTON

Large uncertainties remain, in particular

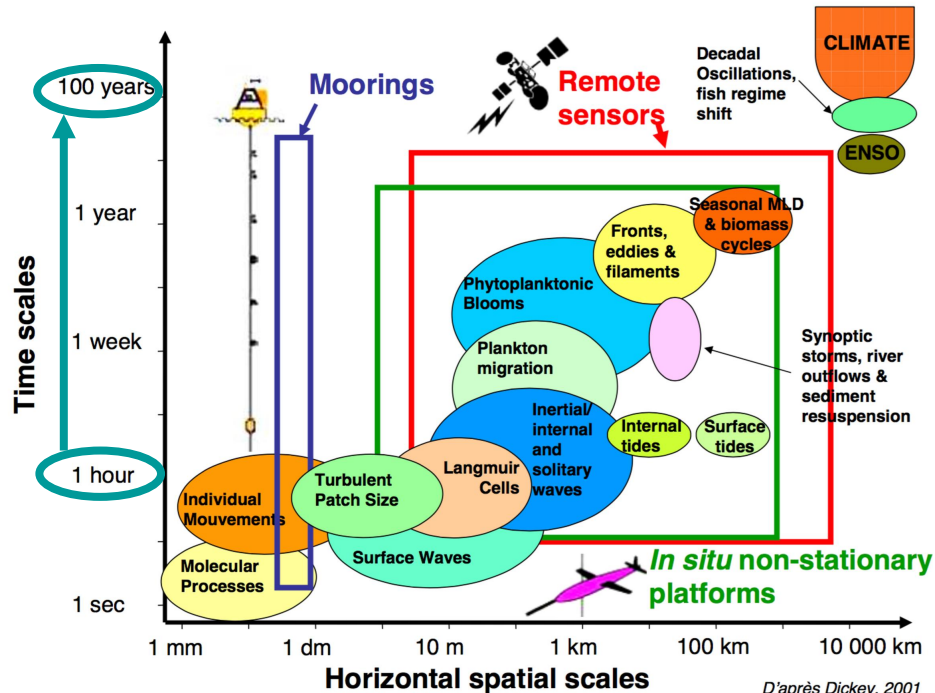
- Global estimates of annual primary production within a factor of 2 (35–78 Gt C yr⁻¹; Carr et al. 2006)
- Inability to resolve interannual variability of primary production

Critically limit our ability to

- Quantify contribution of biological carbon pump to carbon sequestration
- Predict response of marine ecosystems and subsequent carbon cycling to environmental and climate changes

INTRODUCTION: HOW CAN WE OBSERVE/UNDERSTAND PHYTOPLANKTON VARIABILITY?

Large range of spatio-temporal variability



INTRODUCTION: HOW CAN WE OBSERVE/UNDERSTAND PHYTOPLANKTON VARIABILITY?

+: vertical resolution

+: more variables

-: spatio-temporal coverage

Oceanographic vessel



+: Global coverage

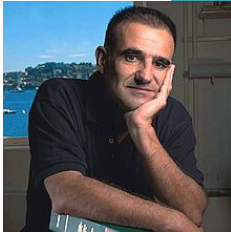
+: High spatio-temporal resolution

-: Surface only (1st optical depth)

Ocean color satellite



In situ autonomous platforms



H. Claustre



A. Petrenko



+: both “+” of satellites and in situ obs.

+: allow to separate the process

-: hard to validate

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l'interannuel, effets d'îles)

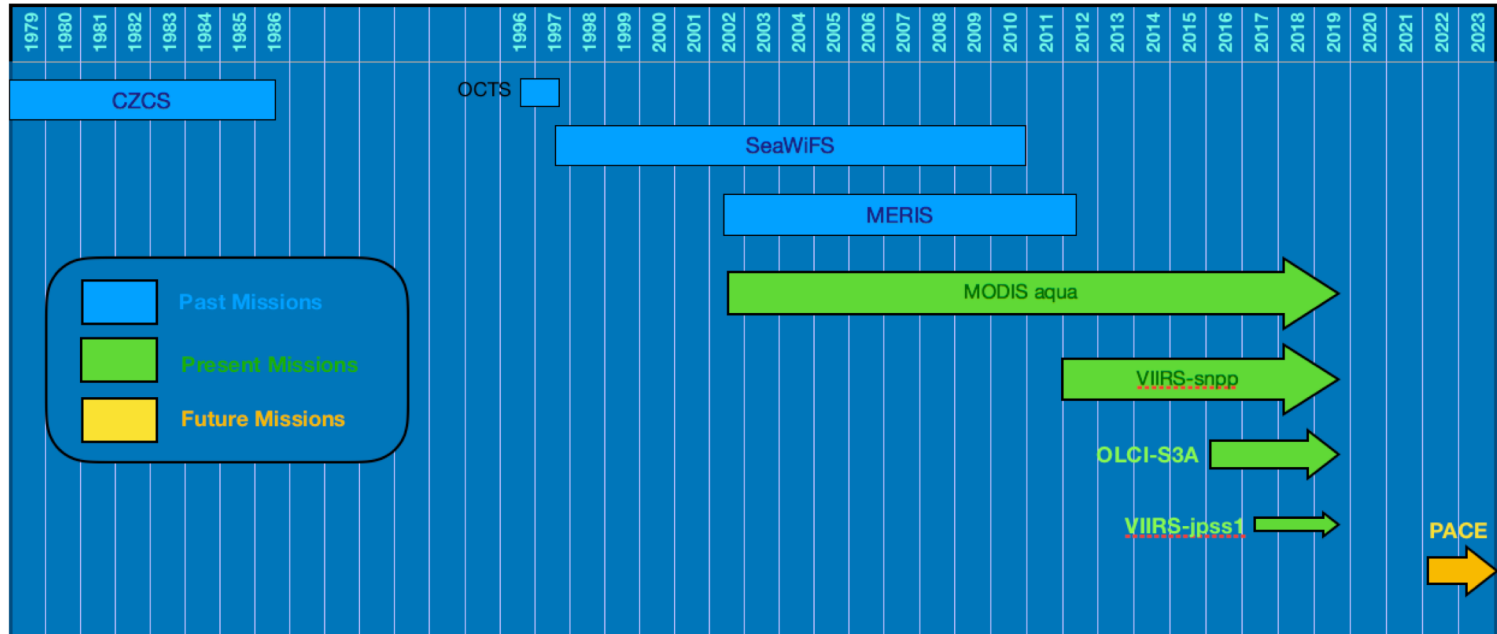
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Les produits reconstruits pour tenter d'appréhender la
variabilité décennale

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Combinaison des observations et intelligence artificielle:
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1. HISTORICAL RADIOMETRIC SATELLITE OBSERVATIONS

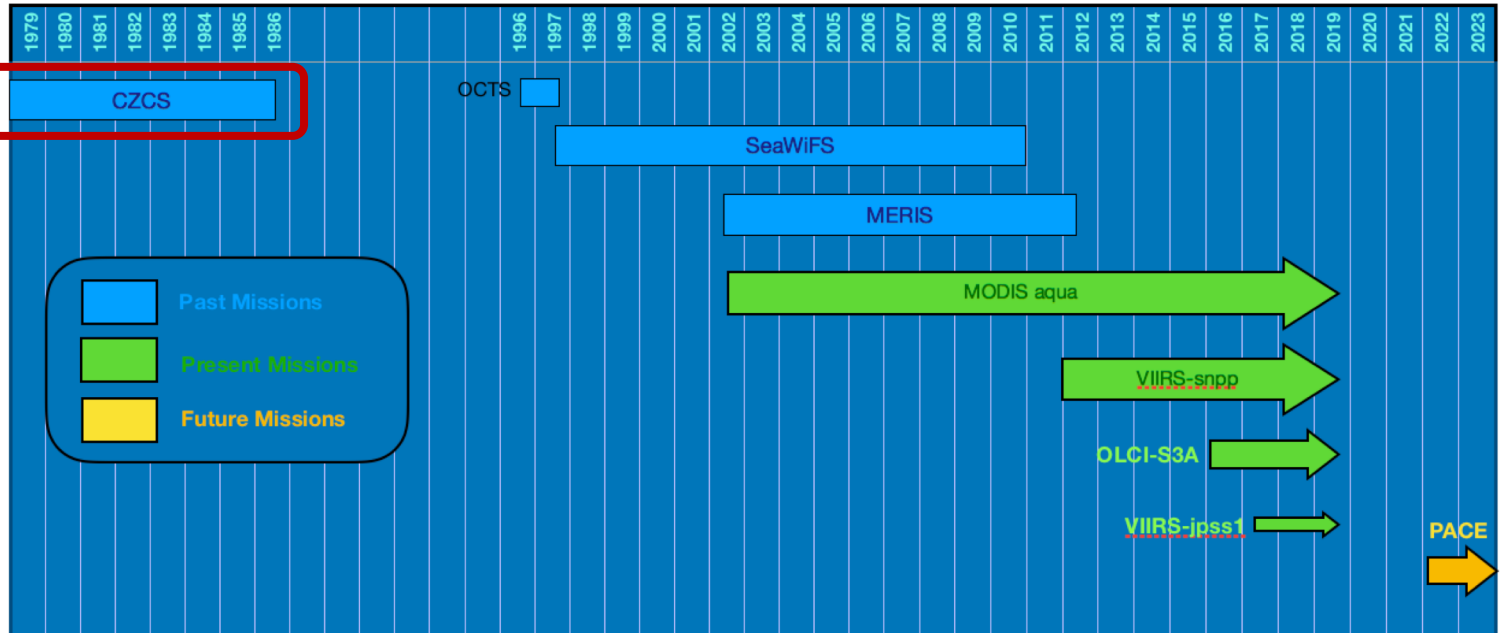


1. HISTORICAL RADIOMETRIC SATELLITE OBSERVATIONS



Coastal Zone Colour Sensor (CZCS) (1978-1986)

Satellite Nimbus 7



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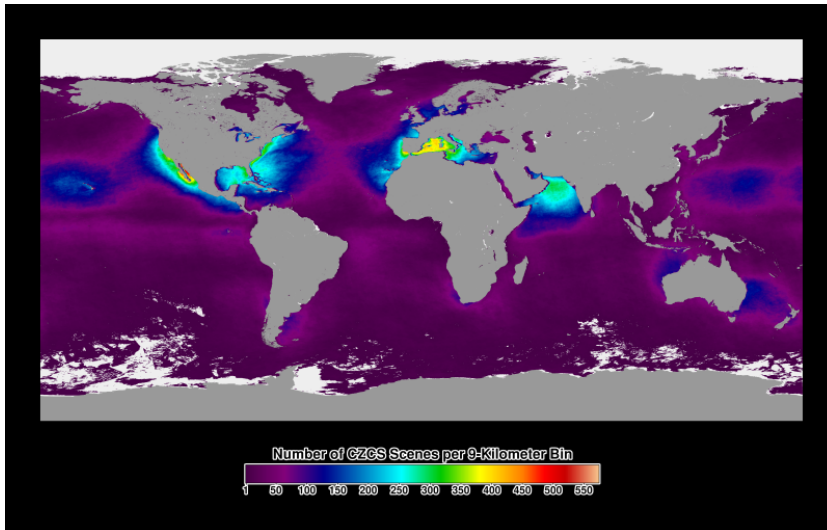
Coastal Zone Colour Sensor (CZCS) (1978-1986)

- Date predominately designed for water remote sensing
- Measured reflected solar energy in six channels, at a resolution of 800m
- was operated on an intermittent schedule and collected data only 2h/d

AGENCY	NASA (USA)
SATELLITE	Nimbus-7 (USA)
OPERATING DATES	24/10/78 – 22/06/86
SWATH (km)	1556
RESOLUTION (m)	825
# OF BANDS	6
SPECTRAL COVERAGE(nm)	433-12500

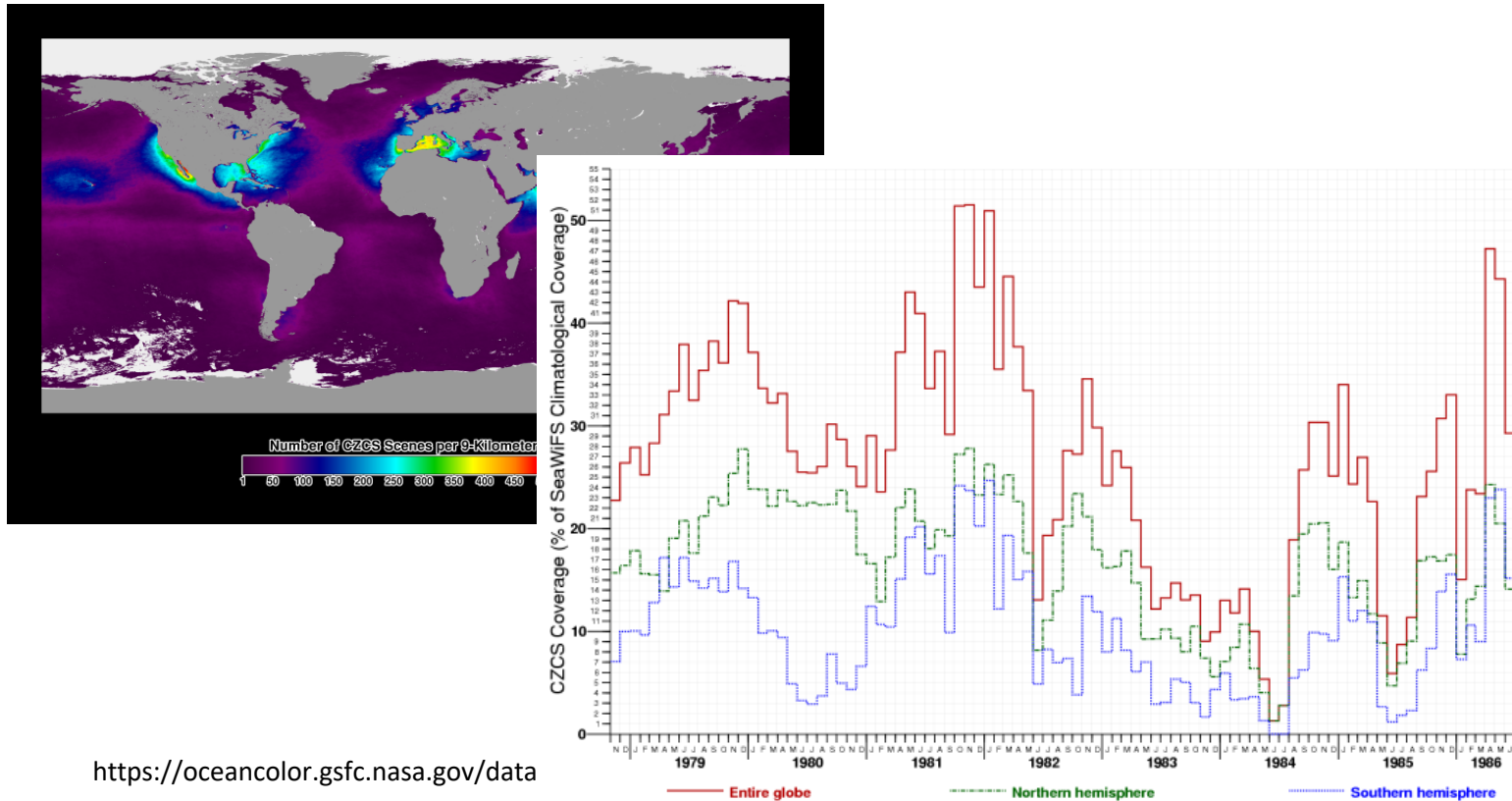
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What did we learned? (some examples)



Deep Sea Research Part A: Oceanographic
Research Papers

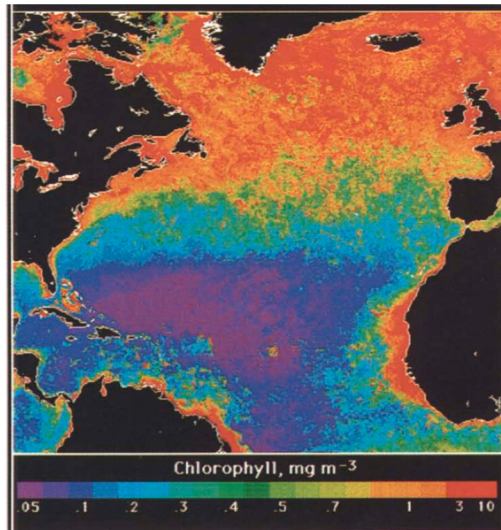
Volume 39, Issue 10, October 1992, Pages 1669-1694



Rapid response paper

New production in the North Atlantic derived
from seasonal patterns of surface chlorophyll

Janet W. Campbell *, Thorkild Aarup *



(b) $C_{\max}$

Fig. 5. Minimum and maximum chlorophyll between January and August based on the 5-year average monthly composite CZCS images.

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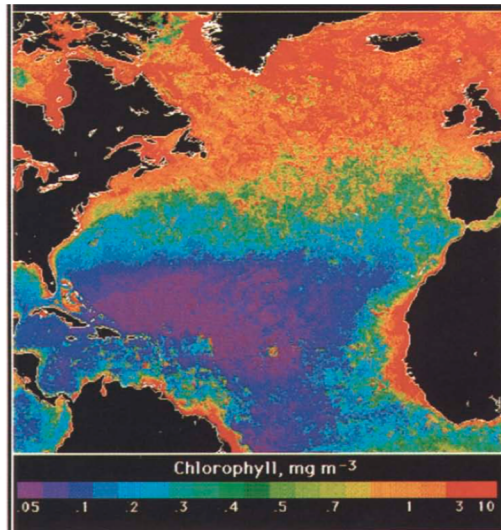


Fig. 5. Minimum and maximum chlorophyll between January and August based on the 5-year average monthly composite CZCS images.

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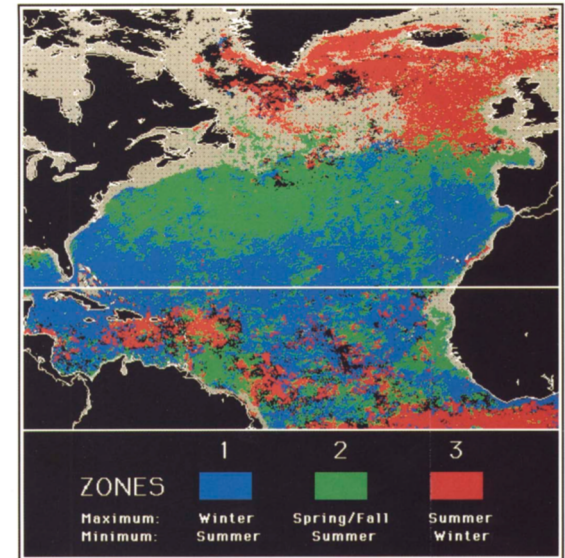


Fig. 7. Geographic distribution of the three zones as defined in Fig. 1. The white line marks the Tropic of Cancer ($23^{\circ}27'N$) as the northern edge of the tropics. Areas excluded from zones 1, 2 and 3 are marked in grey ($C_{\text{max}} > 0.27 \text{ mg m}^{-3}$).

1. HISTORICAL RADIOMETRIC SATELLITE OBSERVATIONS

Coastal Zone Colour Sensor (CZCS) (1979-1986) What did we learned? (some examples)

Journal of Plankton Research Vol.17 no.6 pp.1245-1271, 1995

An estimate of global primary production in the ocean from satellite radiometer data

Alan Longhurst, Shubha Sathyendranath¹, Trevor Platt and Carla Caverhill

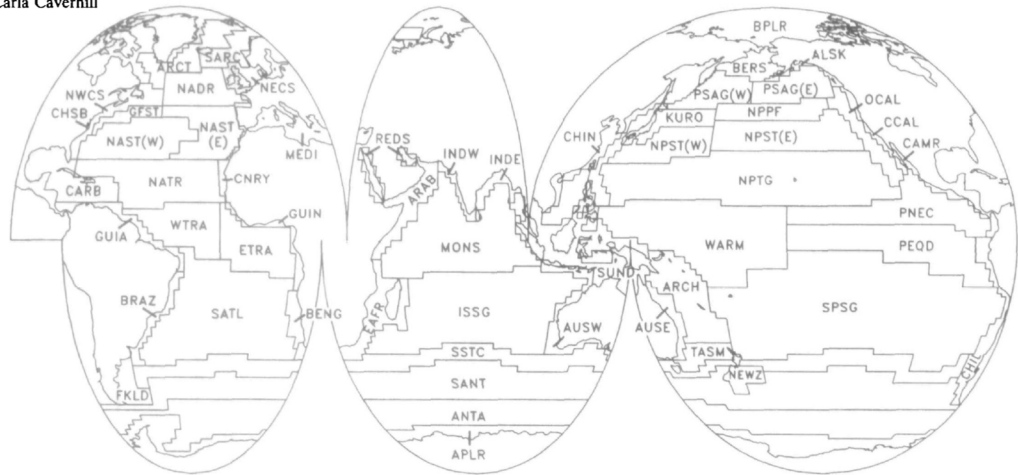


Fig. 2. The 57 biogeochemical provinces used as the compartments for computing seasonal primary production at the global scale; see the text for an explanation of the abbreviations. For the purposes of this computation, boundaries were established on a 2° grid to represent the approximate mean annual shape and location of each province. This approximation suffices for this demonstration, but is a simplification easily improved upon when the method is applied to global sea-surface chlorophyll fields obtained routinely by orbiting radiometers in the future.

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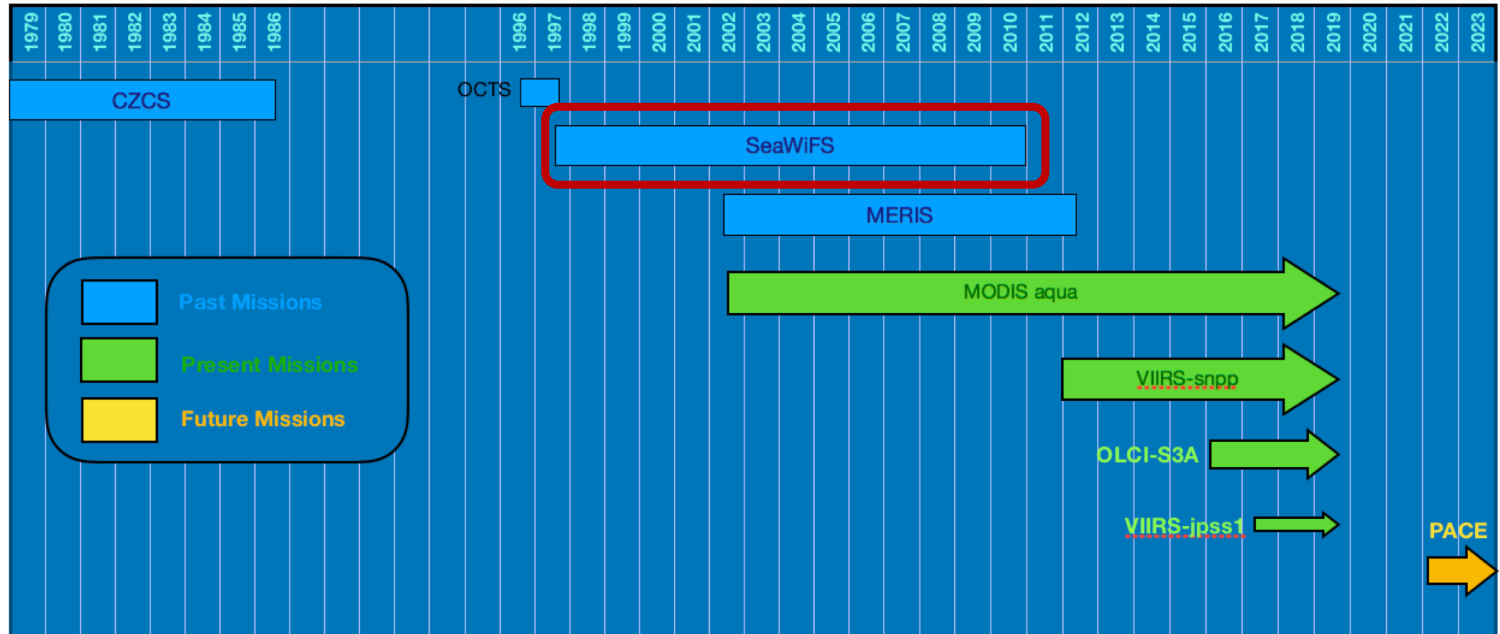
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Sea-viewing Wide Field-of-View Sensor (SeaWiFS) (1997-2010)
Satellite SeaStar– NASA



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Sea-viewing Wide Field-of-View Sensor (SeaWiFS) (1997-2010)

Biogeosciences, 6, 139–148, 2009

<https://doi.org/10.5194/bg-6-139-2009>

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Article

Peer review

On the trophic regimes of the Mediterranean Sea: a satellite analysis

F. D'Orenzio^{2,1} and M. Ribera d'Alcalà³

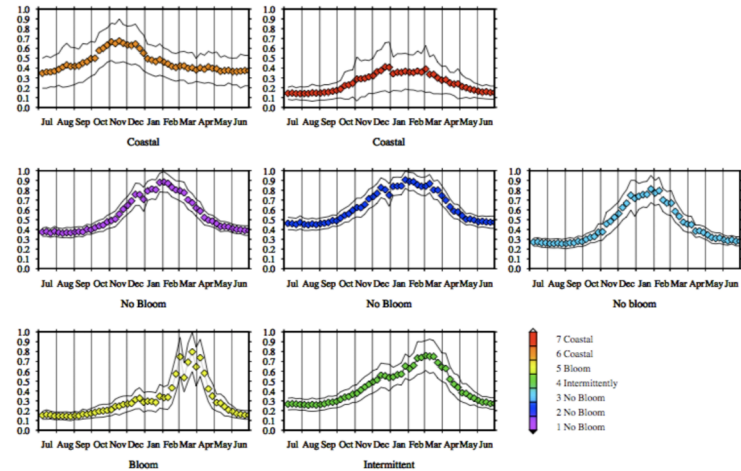
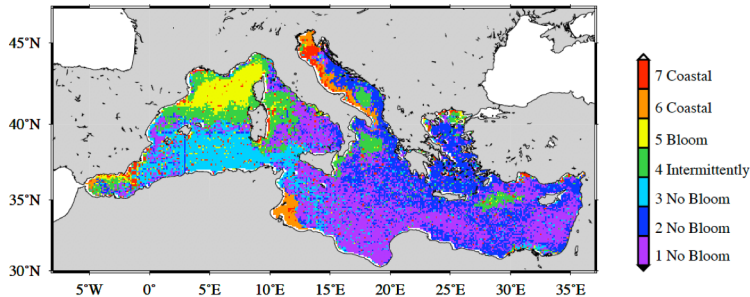


Fig. 4. Spatial distribution of the clusters obtained from the k-means analysis.

2. MODERN RADIOMETRIC SATELLITE OBSERVATIONS

Sea-viewing Wide Field-of-View Sensor (SeaWiFS) (1997-2010)

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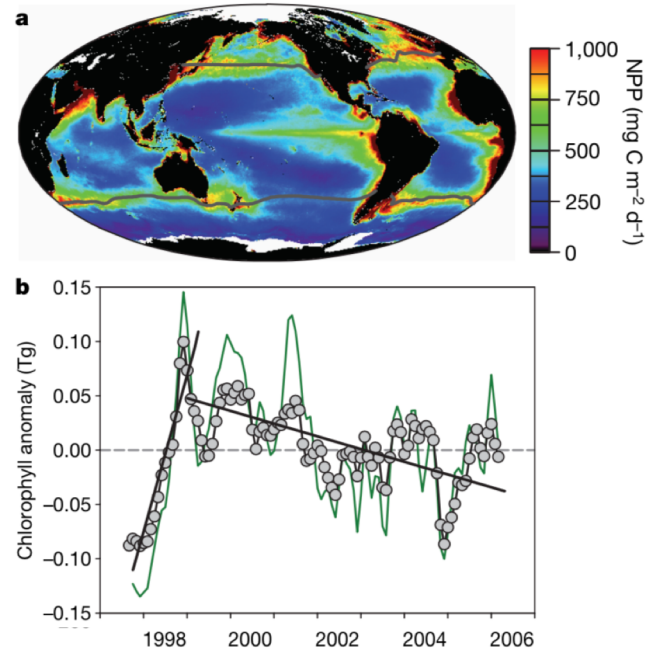


Letter | Published: 07 December 2006

Climate-driven trends in contemporary ocean productivity

Michael J. Behrenfeld , Robert T. O'Malley, David A. Siegel, Charles R. McClain, Jorge L. Sarmiento, Gene C. Feldman, Allen J. Milligan, Paul G. Falkowski, Ricardo M. Letelier & Emmanuel S. Boss

Nature **444**, 752–755(2006) | Cite this article



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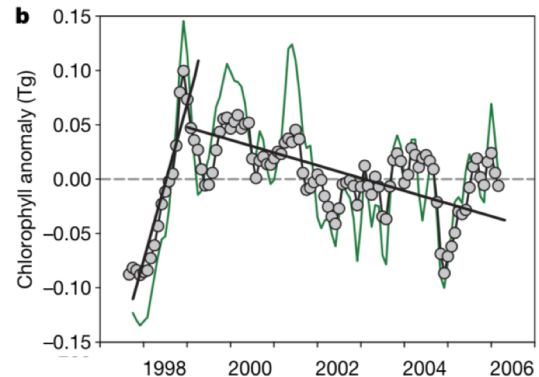
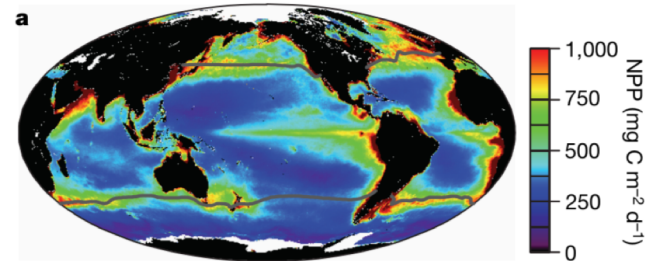
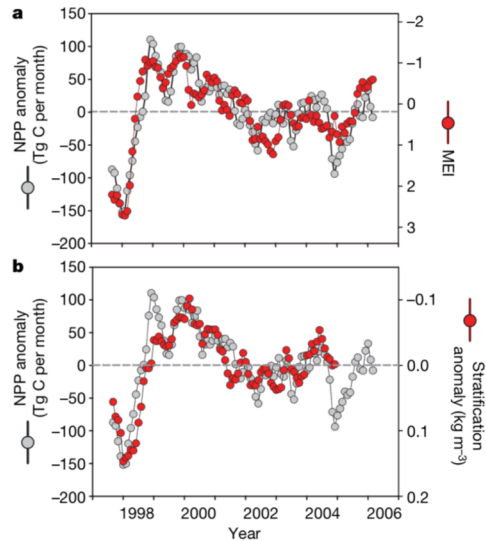


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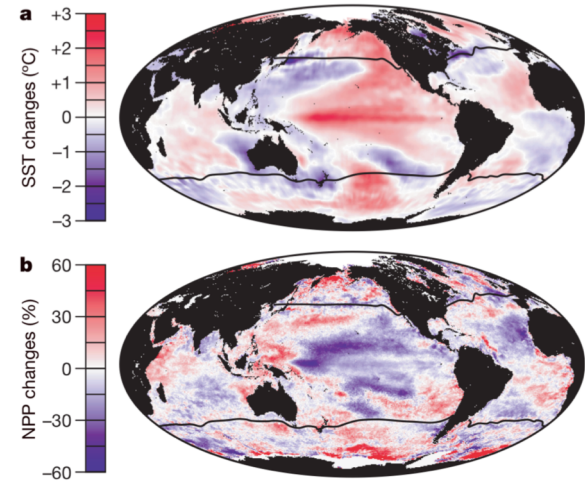
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Figure 3 | Climate controls on ocean productivity cause NPP to vary inversely with changes in SST. Global changes in annual average SST (**a**) and NPP (**b**) for the 1999 to 2004 warming period (Fig. 2). **c**, For 74% of the permanently stratified oceans (that is, regions between black contour lines), NPP and SST changes were inversely related. Yellow, increase in SST, decrease in NPP. Light blue, decrease in SST, increase in NPP. Dark blue, decreases in SST and NPP. Dark red, increases in SST and NPP. A similar inverse relationship is observed between SST and chlorophyll changes. (See Supplementary Fig. 4 for additional information.)



2. MODERN RADIOMETRIC SATELLITE OBSERVATIONS

Sea-viewing Wide Field-of-View Sensor (SeaWiFS) (1997-2010)

nature



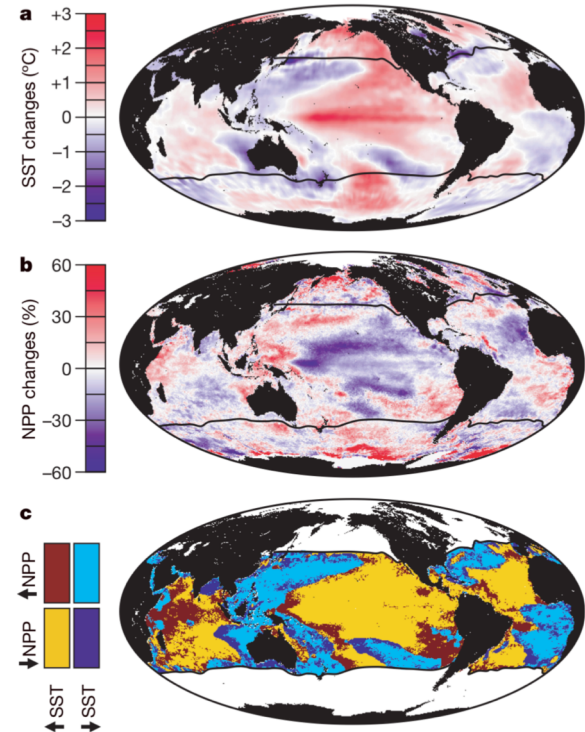
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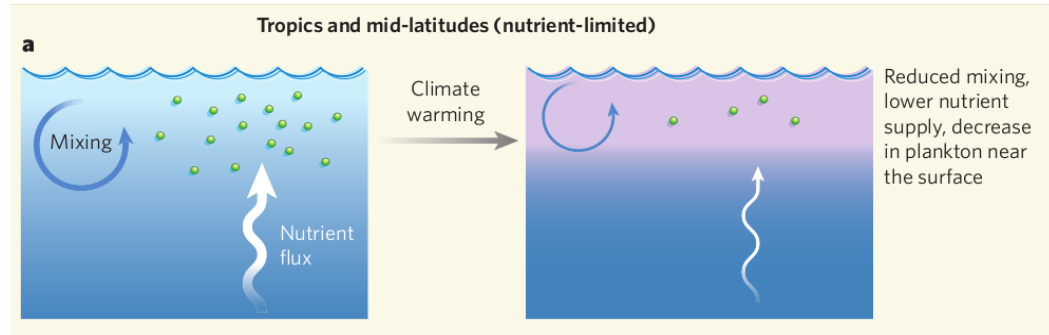
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« Aside 1 »:

Sea-viewing Wide Field-of-View Sensor (SeaWiFS) (1997-2010)



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News & Views | Published: 06 December 2006

Oceanography

Plankton in a warmer world

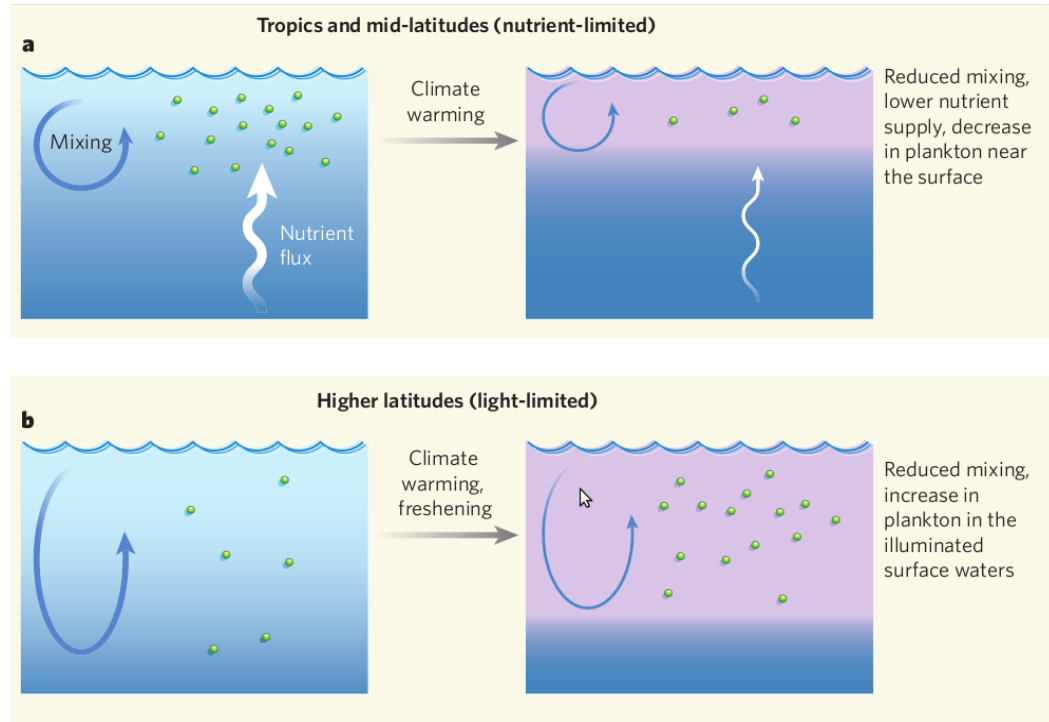
Scott C. Doney

Nature **444**, 695–696 (07 December 2006) | [Download Citation](#) ±

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Geophysical Research Letters

Oceans

Ocean's least productive waters are expanding

Jeffrey J. Polovina , Evan A. Howell, Melanie Abecassis

First published: 14 February 2008 | <https://doi.org/10.1029/2007GL031745> | Citations: 371

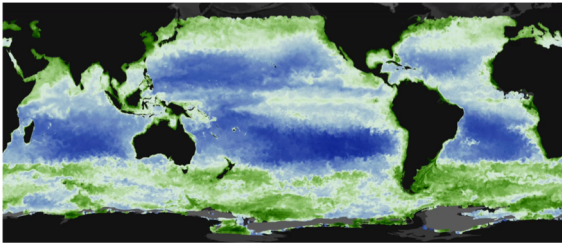
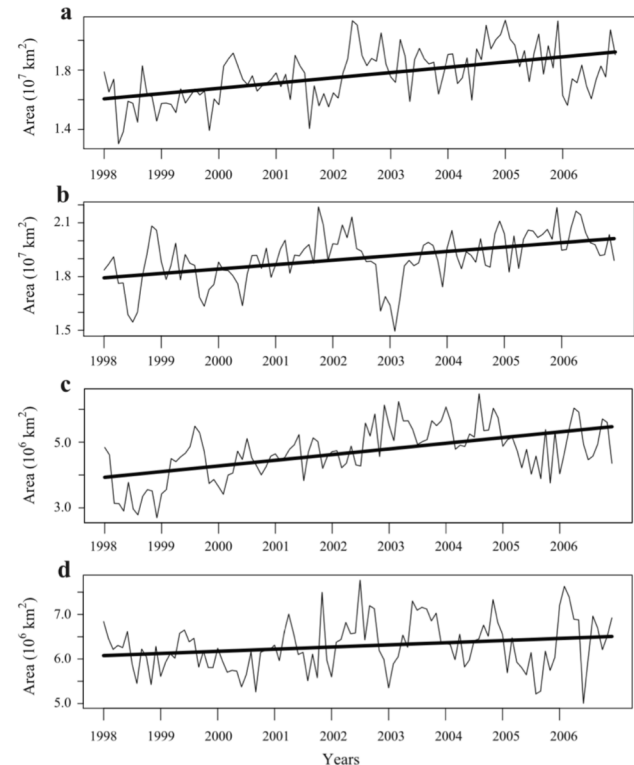
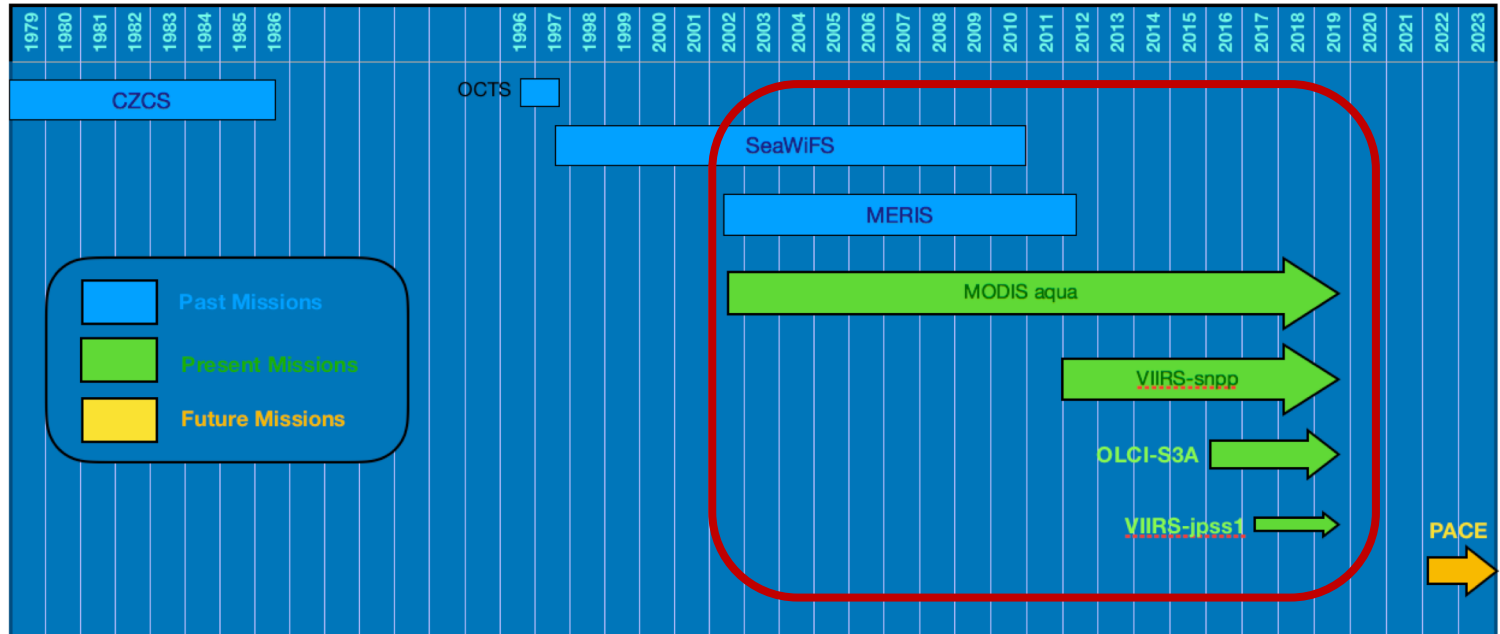


Figure 1. Time series of the monthly mean area (km^2) with surface chlorophyll less than or equal to 0.07 mg chl/m^3 between 5° – 45° N/S latitude with the seasonal cycle modeled removed in (a) the North Pacific, (b) the South Pacific, (c) the North Atlantic, and (d) the South Atlantic. Straight lines are the linear terms from the GAMs.



2. MODERN COMBINED SATELLITE OBSERVATIONS

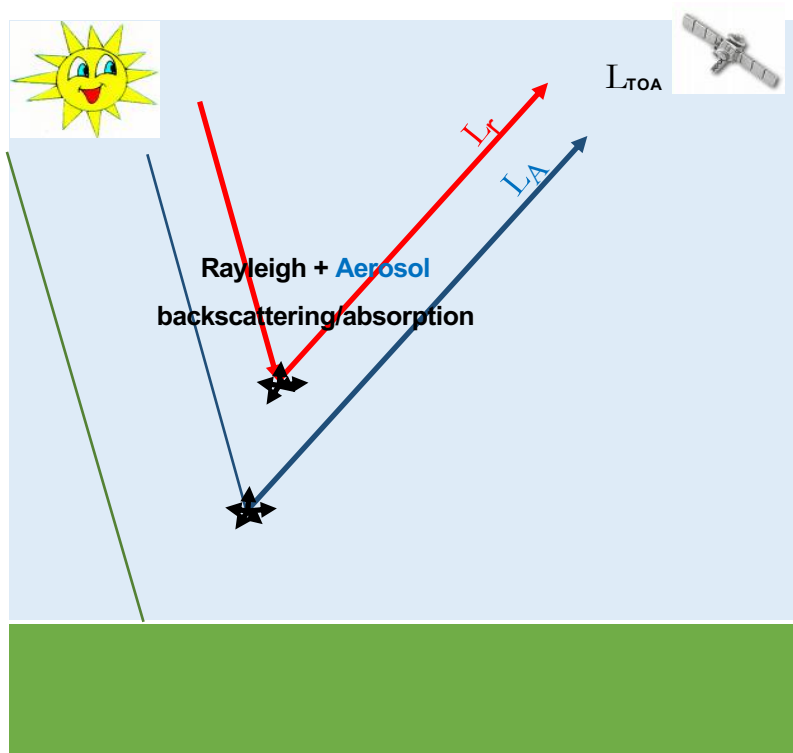
Combined satellite observations



2. MODERN COMBINED SATELLITE OBSERVATIONS

« Aside 2 »:

$$L_{\text{TOA}}(\lambda) = L_r(\lambda) + L_A(\lambda) + t(\lambda) \cdot L_w(\lambda)$$



Radiances :

LTOA=Top of atmosphère

Lr +La= radiation part from molecules and aerosols backscattered from the atmosphere

Lg+Lf= specular reflexion at the ocean surface + seawater foam

Lw= Marine radiance

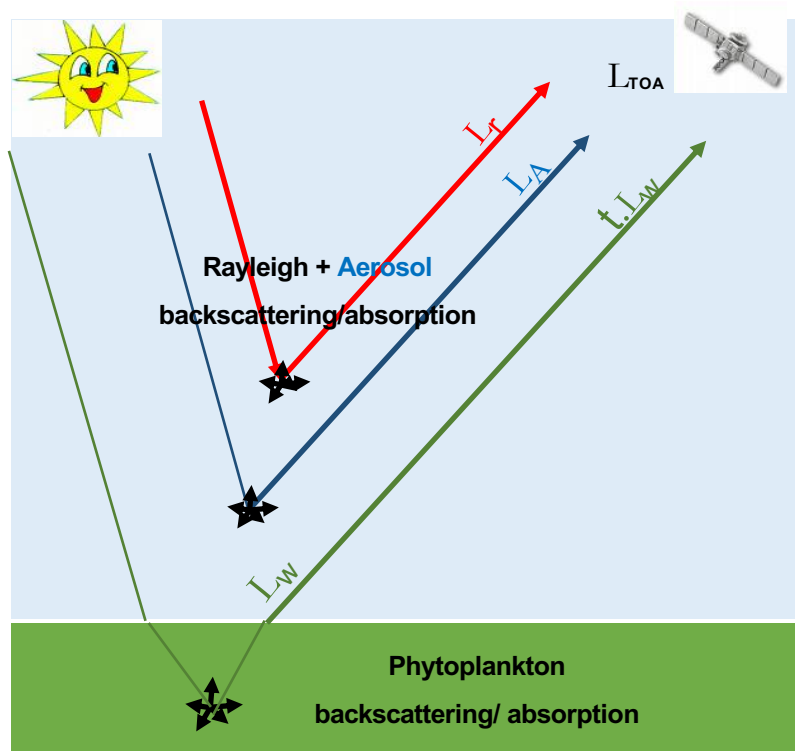
Traitment :

1- Atmospheric correction

2. MODERN COMBINED SATELLITE OBSERVATIONS

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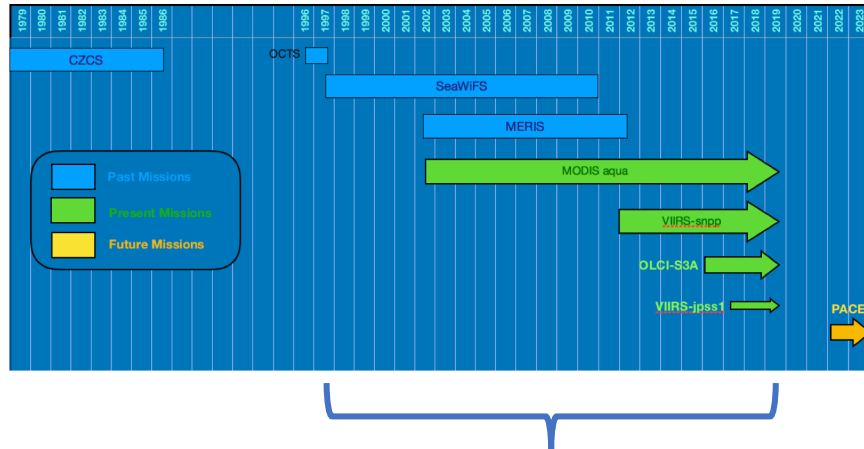
Lw= Marine radiance **10 %!!**

Traitment :

1- Atmospheric correction

2- Bio-optical algorithms

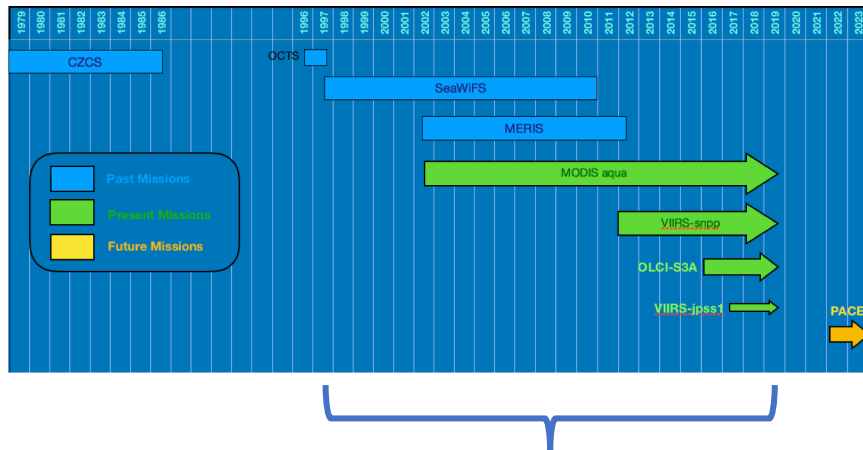
2. MODERN COMBINED SATELLITE OBSERVATIONS



Globcolour : - Ave (L2)
 - GSM (L1)

OC-CCI: - (L1)

2. MODERN COMBINED SATELLITE OBSERVATIONS

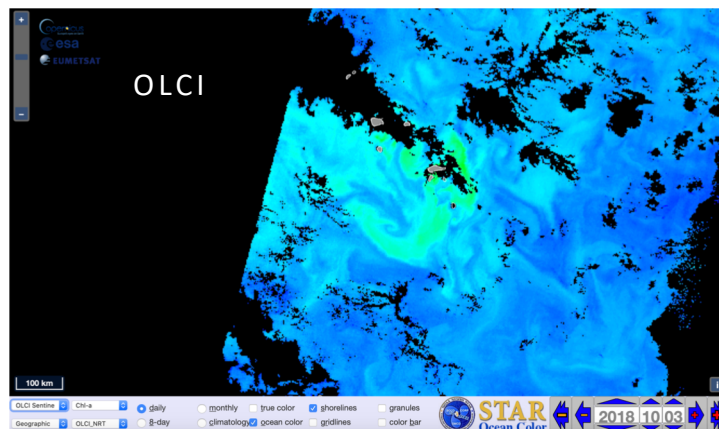
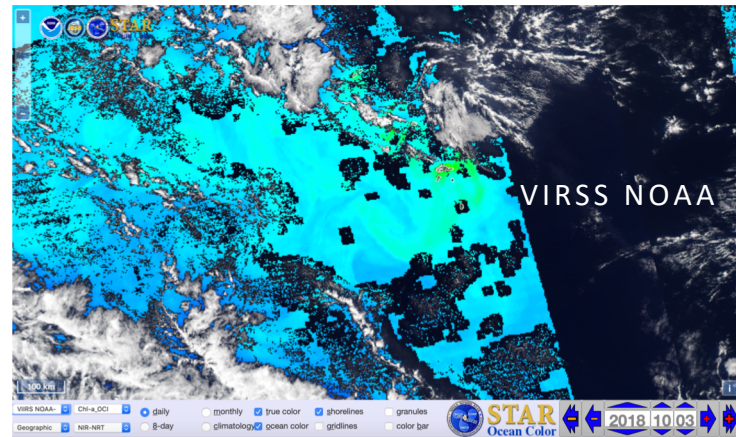
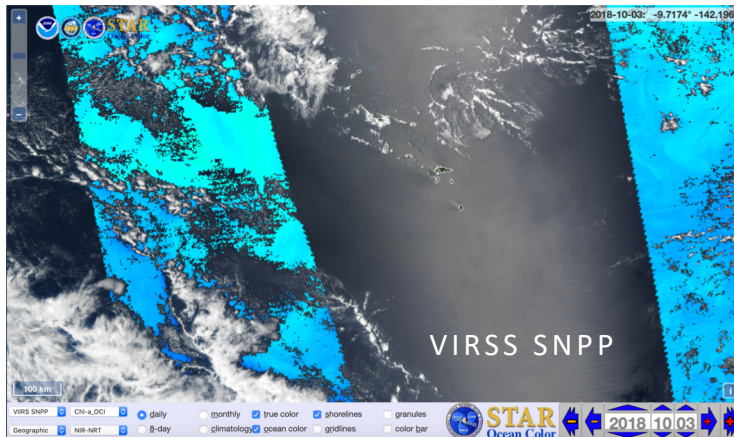


Some of them: Globcolour : - Ave (L2)
 - GSM (L1)
 OC-CCI: - (L1)

- Increase spatio-temporal coverage (i.e. high frequency)
- Allow studying long-term trends (i.e. low frequency)

2. MODERN COMBINED SATELLITE OBSERVATIONS

Increase spatio-temporal coverage



2. MODERN COMBINED SATELLITE OBSERVATIONS

Increase spatio-temporal coverage

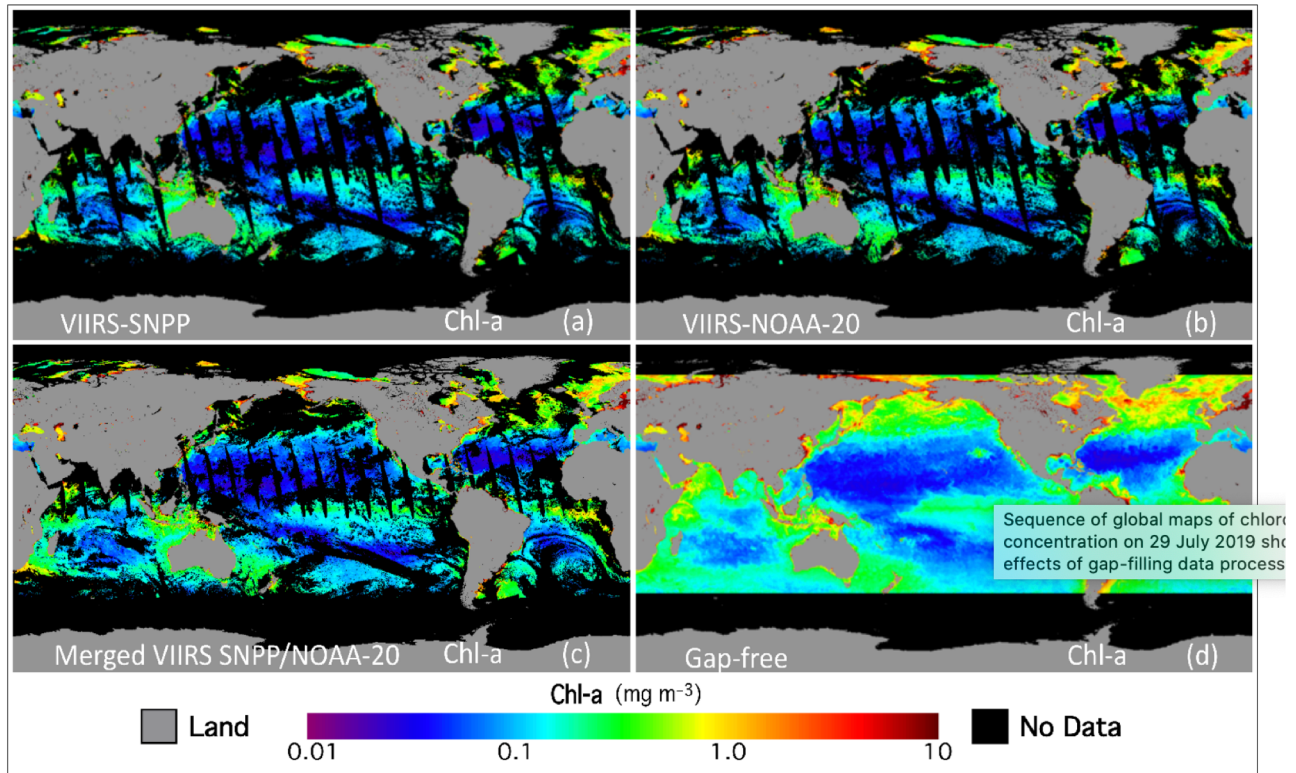


Fig. 1. This sequence of global maps shows VIIRS-measured chlorophyll *a* (Chl *a*) concentrations on 29 July 2019 from (a) SNPP, (b) NOAA-20, (c) the merged Chl *a* image, and (d) the gap-free Chl *a* image. Chl *a* concentrations are in milligrams per cubic meter.

2. MODERN COMBINED SATELLITE OBSERVATIONS

Increase spatio-temporal coverage

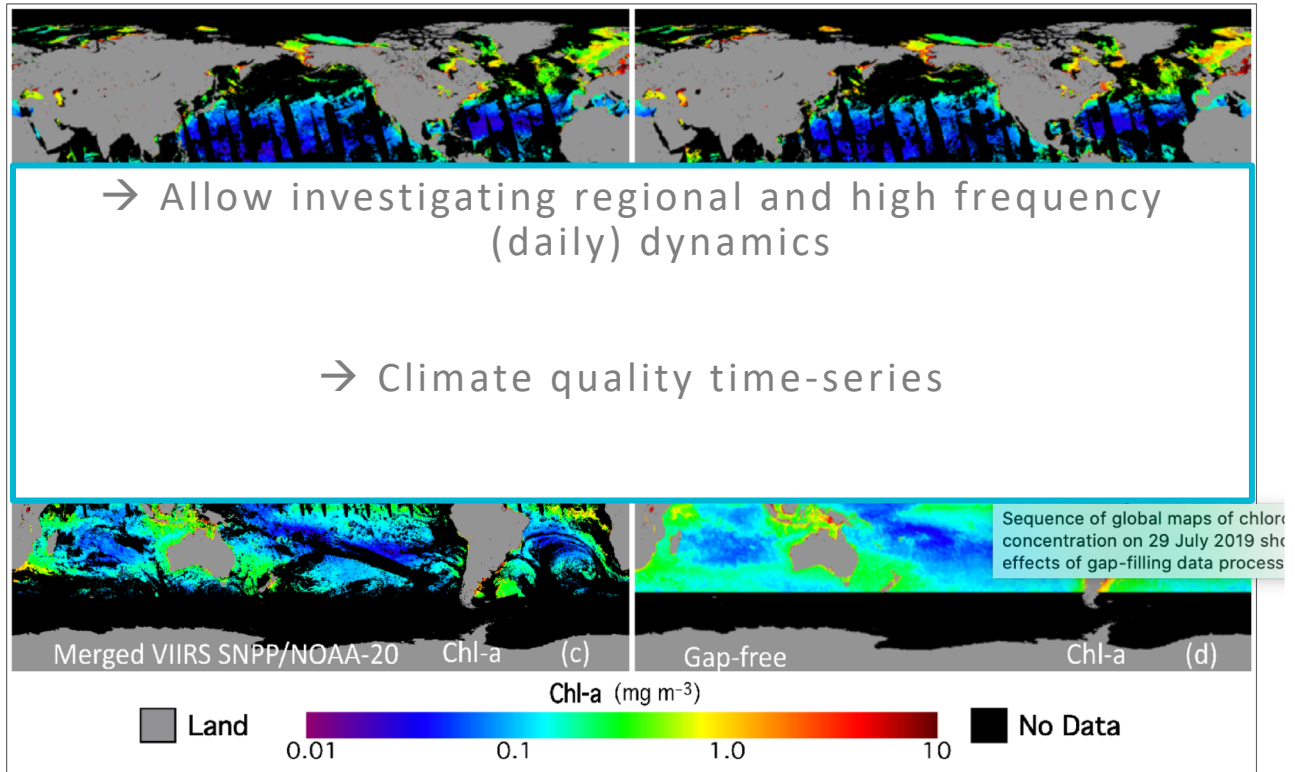


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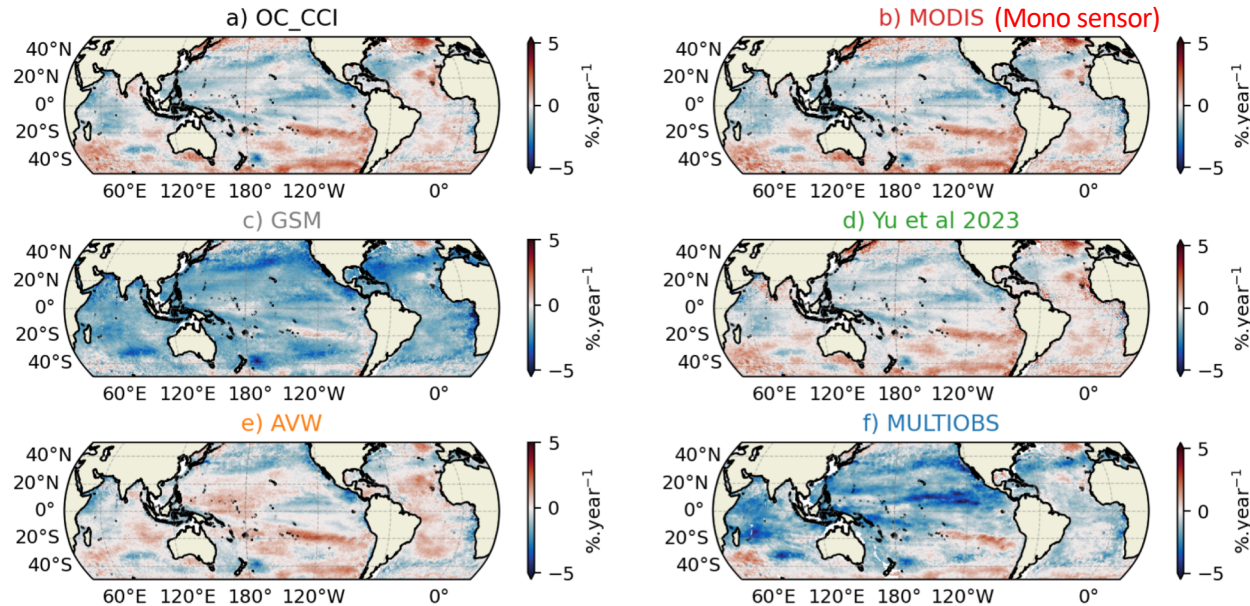
Challenge to build climate quality time-series

→ bias due to observations consistency

2. MODERN COMBINED SATELLITE OBSERVATIONS

Challenge to build climate quality time-series

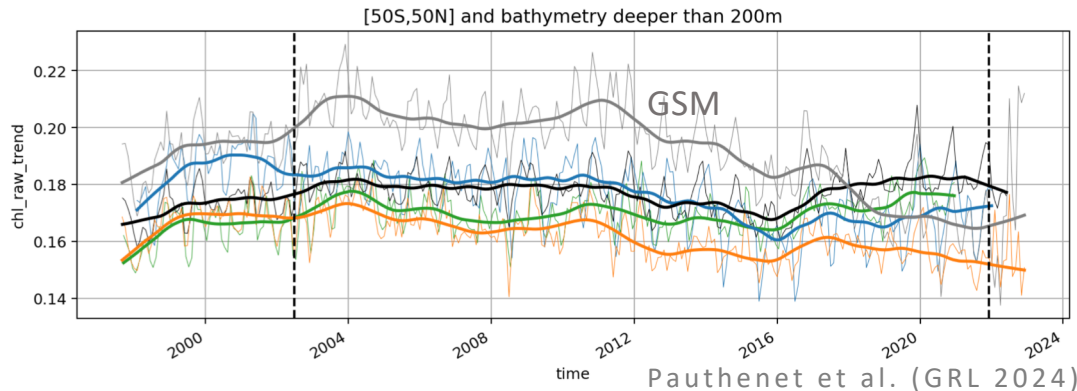
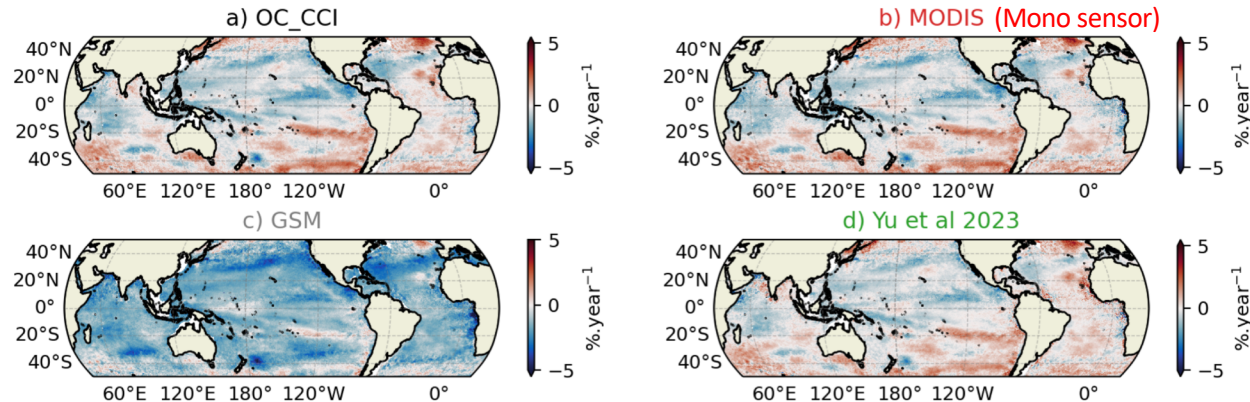
2002-2021 trend analysis of merged Chl product : contrasted results



2. MODERN COMBINED SATELLITE OBSERVATIONS

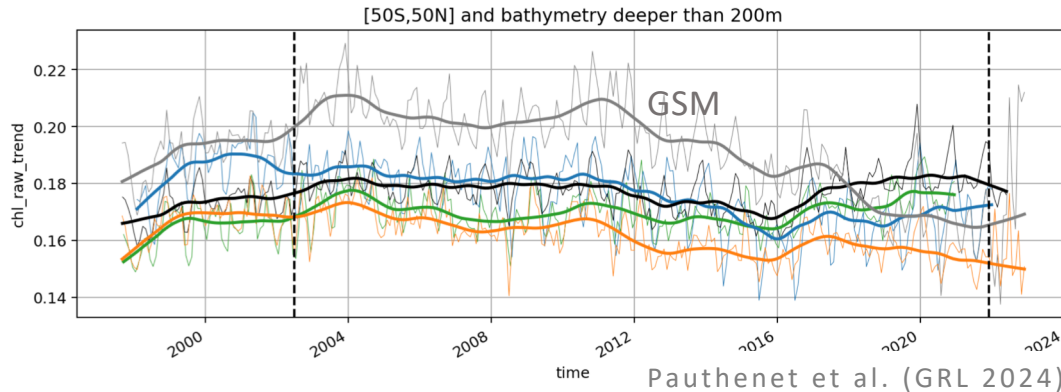
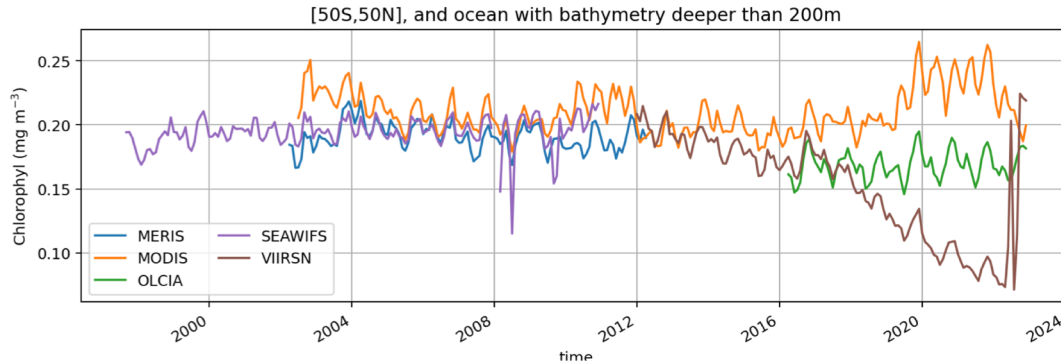
Challenge to build climate quality time-series

2002-2021 trend analysis of merged Chl product : contrasted results



2. MODERN COMBINED SATELLITE OBSERVATIONS

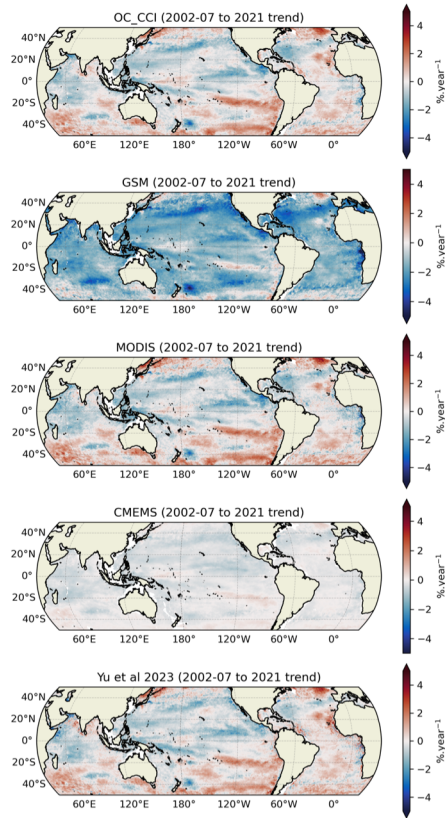
Challenge to build climate quality time-series



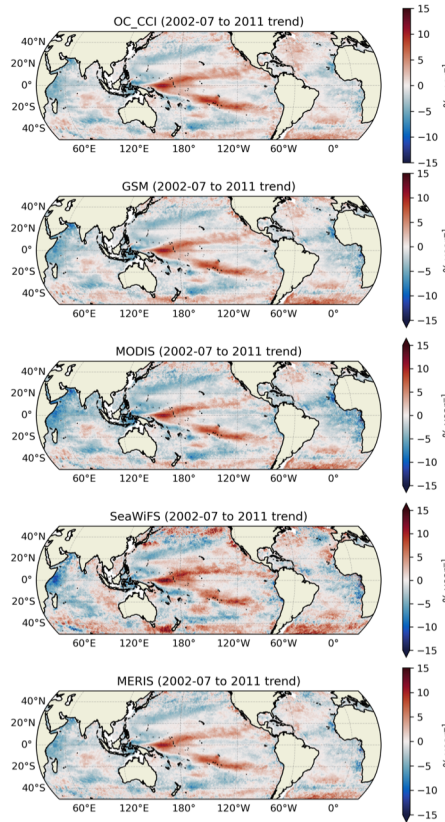
2. MODERN COMBINED SATELLITE OBSERVATIONS

Challenge to build climate quality time-series

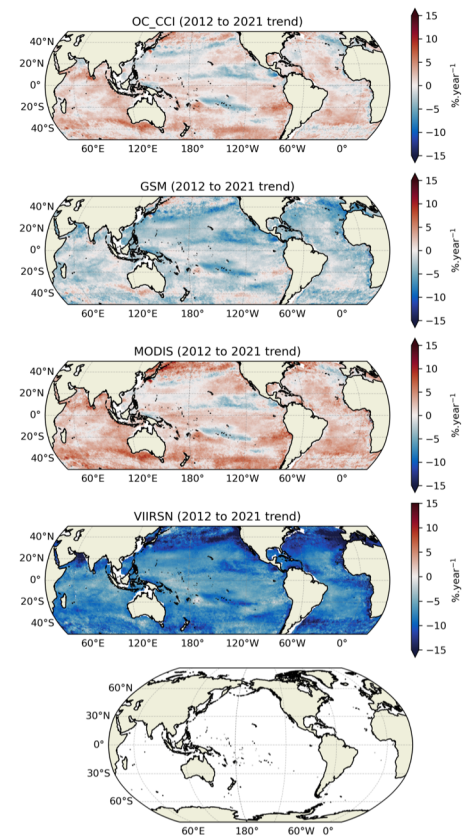
2002-2021



2002-2011



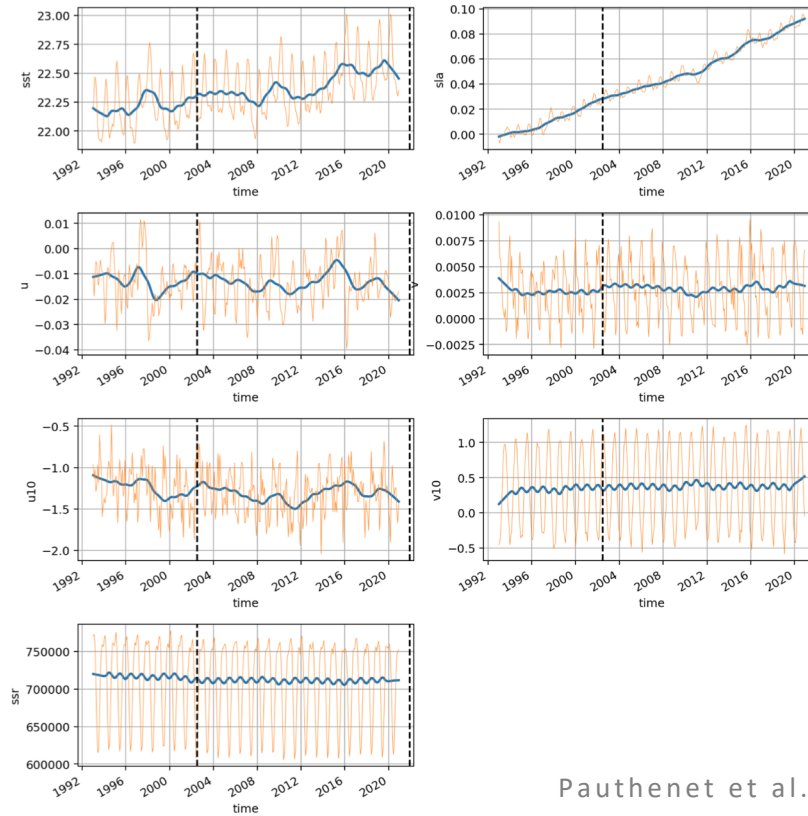
2012-2021



2. MODERN COMBINED SATELLITE OBSERVATIONS

Challenge to build climate quality time-series

Recent trends seems not supported by environmental changes

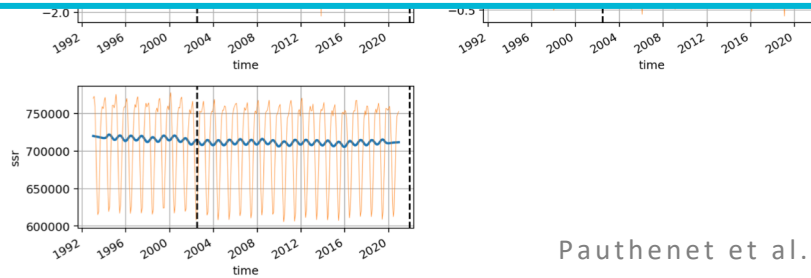


2. MODERN COMBINED SATELLITE OBSERVATIONS

Challenge to build climate quality time-series

Conclusion

- Challenge/biais due to observations consistency
- Be cautious
- Try to double check using different ways



Pauthenet et al. (GRL 2024)