What can we say about long-term changes in the ocean ecosystem as observed from space?

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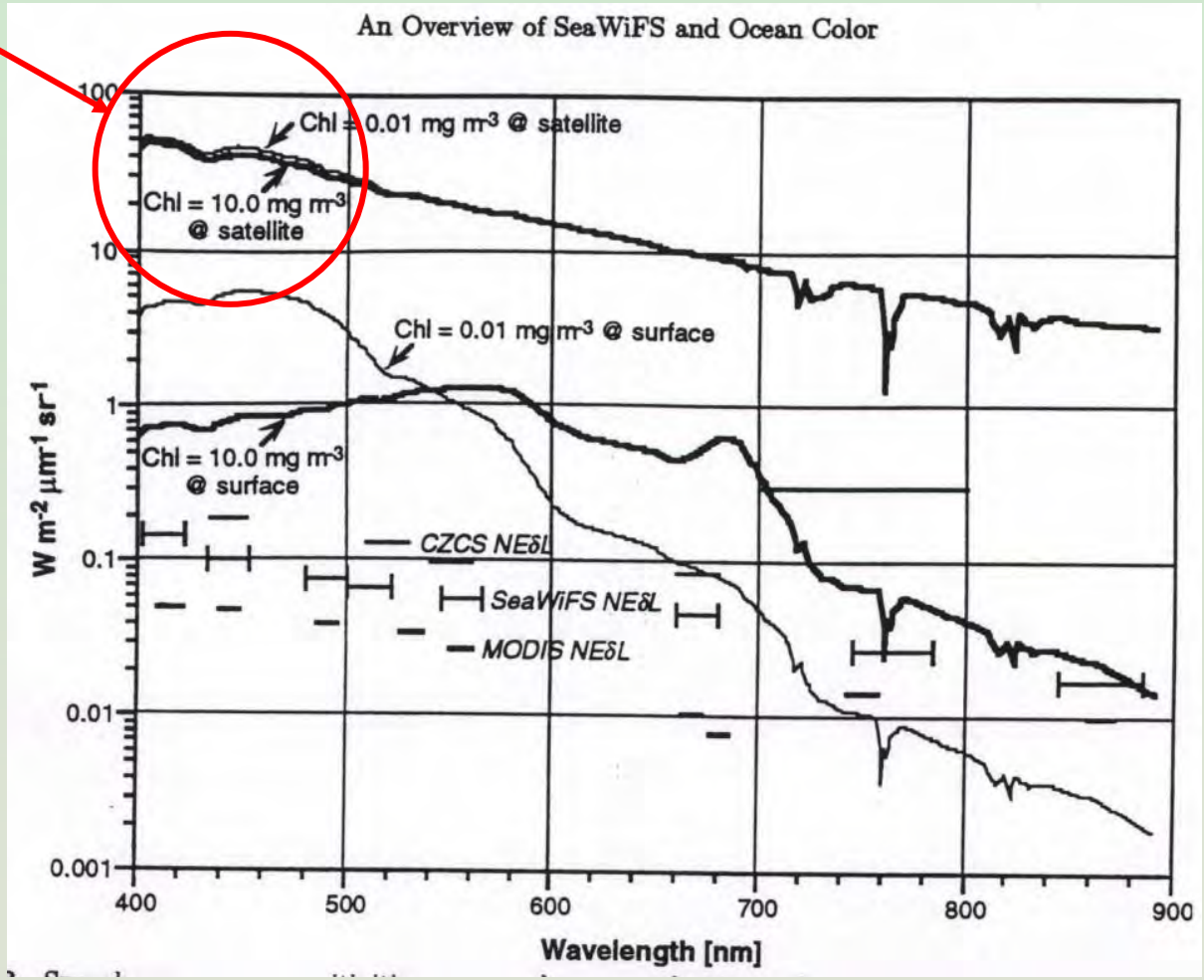
2nd International Ocean Color Science meeting, "Ecosystems and climate change" breakout session, San Francisco, USA, 16-18 June 2015

What can we see about long-term changes in the ocean ecosystem as observed from space?

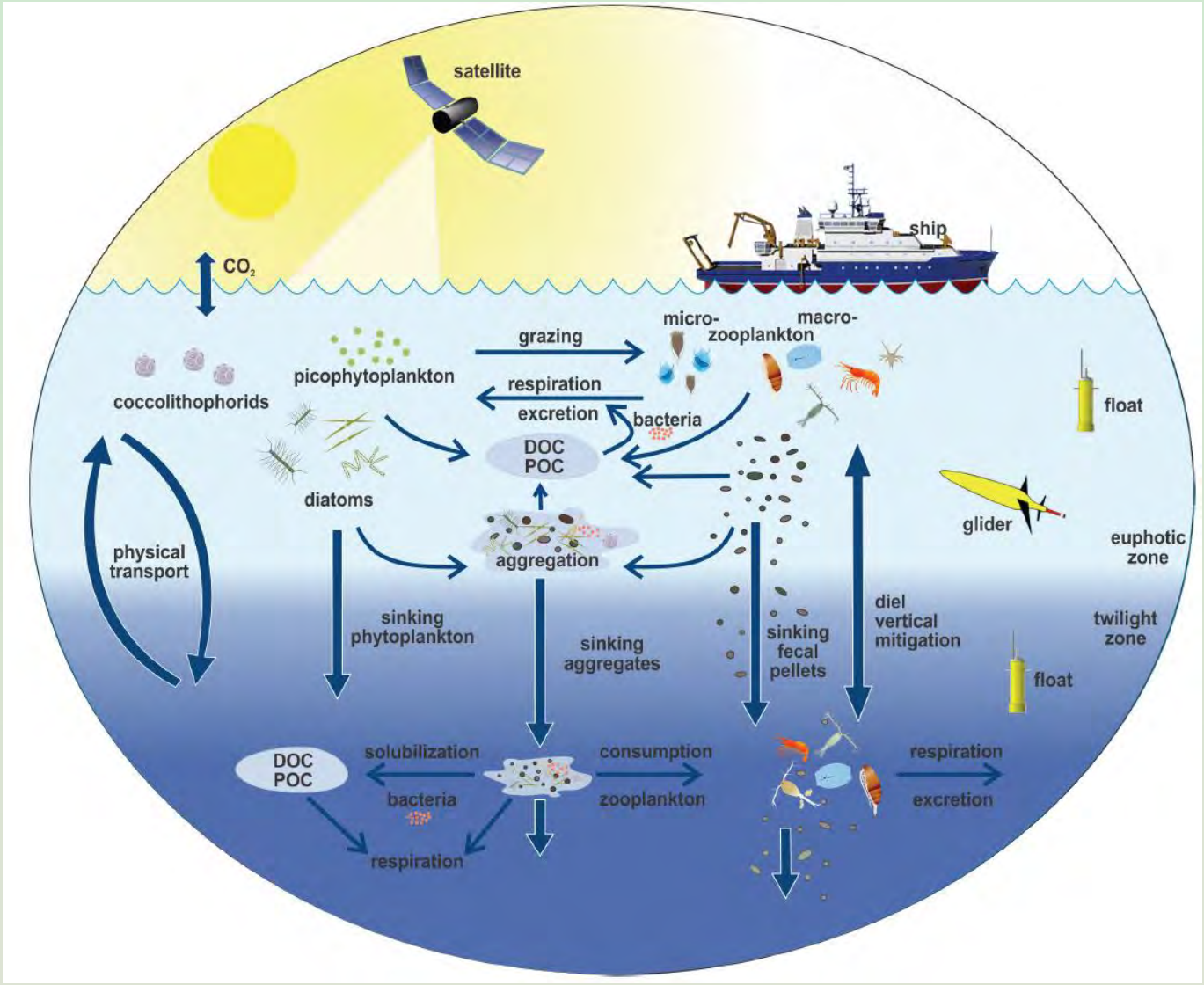
Essentially from satellite OCR

We start from this….



From: Hooker et al., 1992. NASA TM N°104566, Vol; 1, SB Hooker & ER Firestone Eds., NASA/GSFC (Fig. courtesy HR Gordon)

….. and we want to go there:

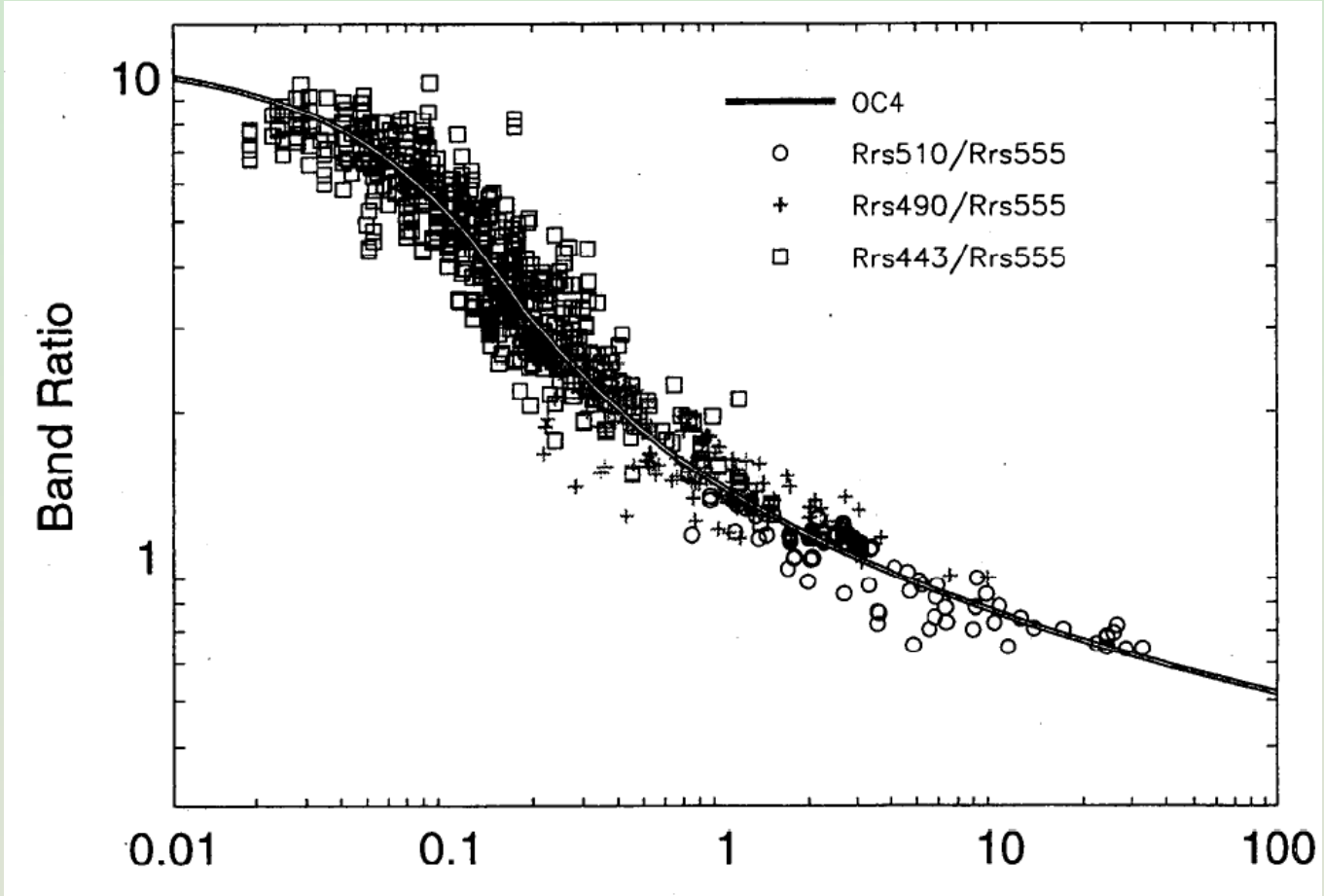


Taken from Siegel et al., 2014. Export **P**rocesses in the **O**cean from **R**emo**T**e **S**ensing **(EXPORTS)**: A Science Plan for a NASA Field Campaign; see http://cce.nasa.gov/cce/ocean_exports_intro.htm

So, we derive the following from the ocean color spectrum:

- Chlorophyll concentration
- Absorption by colored dissolved organic matter
- Total absorption and backscattering coefficient
- Phytoplankton absorption coefficient
- POC
- PIC
- PFTs
- PAR
- iPAR
- ….

however, we use essentially empirical algorithms



O'Reilly J. E., S. Maritorena, B. G. Mitchell, D. A. Siegel, K. L. Carder, S. A. Garver, M. Kahru and C. R. McClain. 1998. Ocean Color Chlorophyll Algorithms for SeaWiFS. *Journal of Geophysical Research*, 103(C11): 24,937-24,953

What does this mean?

Basically:

Field observations are the key to understanding the relationship between ocean ecosystems and ocean color variables, which is a prerequisite before satellite observations plus appropriate algorithms allow detecting and quantifying long-term changes in ecosystems

"Dual" use of field observations: cal/val, and algorithms

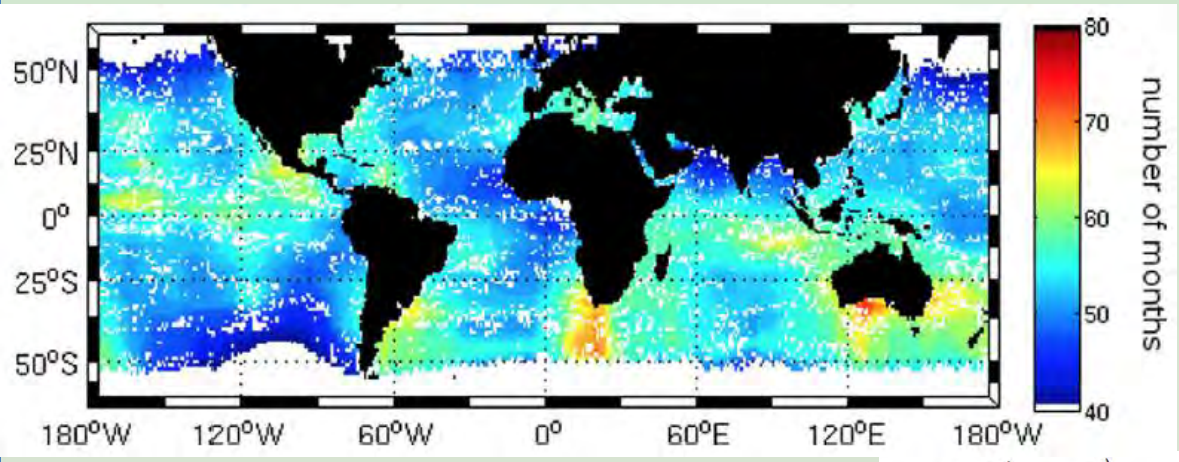
How long is the time window over which we can study long-term changes in the GLOBAL ocean ecosystem from space?

Started in November 1978 with **CZCS**
Interrupted in June 1986, and only resumed in August 1996 with **OCTS**, then September 1997 with **SeaWiFS, OCM, MODIS, MERIS, VIIRS**

So: about **17 years** of continuous global observations, plus about 5 years of observations taken 14 years apart (CZCS).
To some extent: time window of 35 years

Is this enough?

How long should be the time window over which we can study long-term changes in the GLOBAL ocean ecosystem from space?

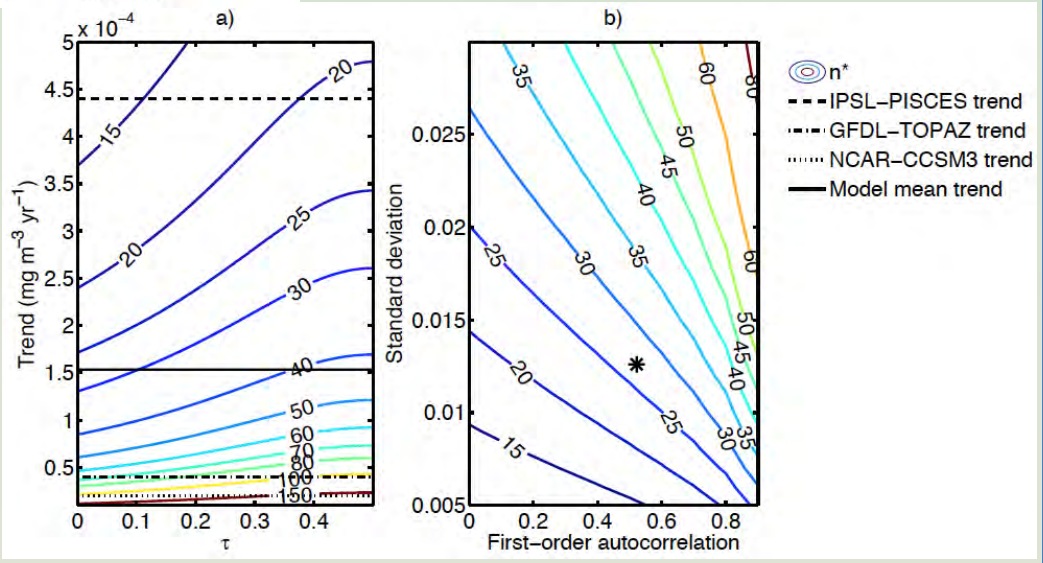


Saulquin, B., R. Fablet, A. Mangin, G. Mercier, D. Antoine, and O. Fanton d'Andon (2013), J. Geophys. Res. Oceans, 118, doi:10.1002/jgrc.20264.

How many Sentinel 3-OLCI months are needed to enhance the detection of long-term linear trends using SeaWiFS plus MERIS?

Number of years of observations (**n**) necessary to detect a statistically significant trend in satellite monthly ocean chlorophyll according to the magnitude of the trend and of the fraction of data before the discontinuity (τ).

Beaulieu C., S. A. Henson , Jorge L. Sarmiento , J. P. Dunne , S. C. Doney , R. R. Rykaczewski , and L. Bopp, 2013. Biogeosciences, 10, 2711–2724



Important factors determining uncertainties in trend detection/quantification

- Number of observations, autocorrelation, and noise variance.
- 30-40 years of observations seem to be a minimum
- Bias correction ("bringing one time series to the other") before determining trends leads to underestimate parameters uncertainties.
- Overlap between missions is critical.
- Uncertainty on trends rapidly increase when gaps are present.

The near future looks quite good in this respect *e.g.*, the European Copernicus program

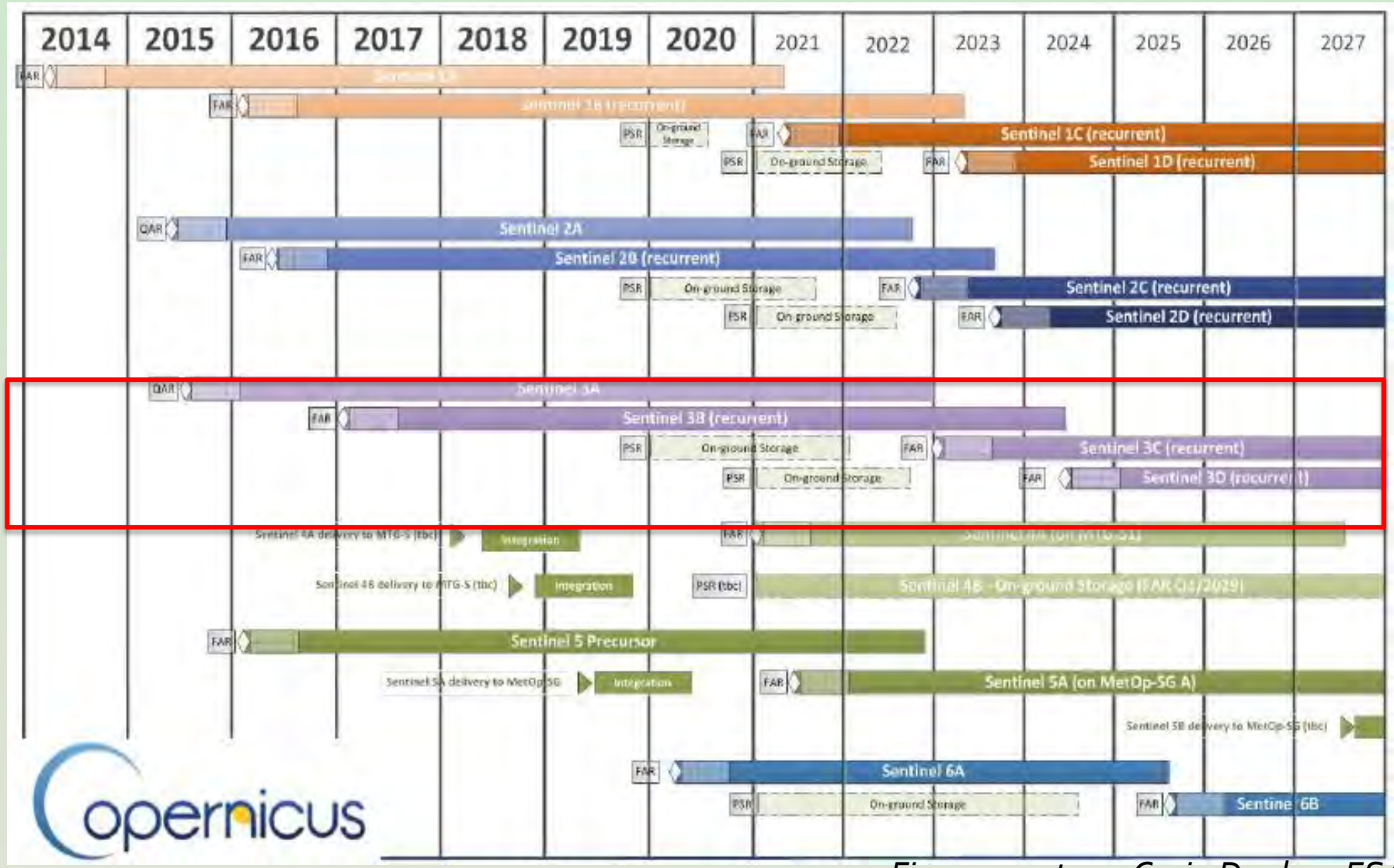


Figure courtesy: Craig Donlon, ESA

However: what is the question?

- Do we have to concentrate on a supposedly existing long-term trend?
- May not exist; may reveal extremely hazardous to quantify
- Even if we manage to do so, what's the meaning of a global long-term trend? Generated by only a few "hotspots"? Or more generalized increases/decreases?
- Should we rather look at changes in phenology? PFTs? Regional trends?…

Some results of recent studies

Changes in Chl (1 / 2)

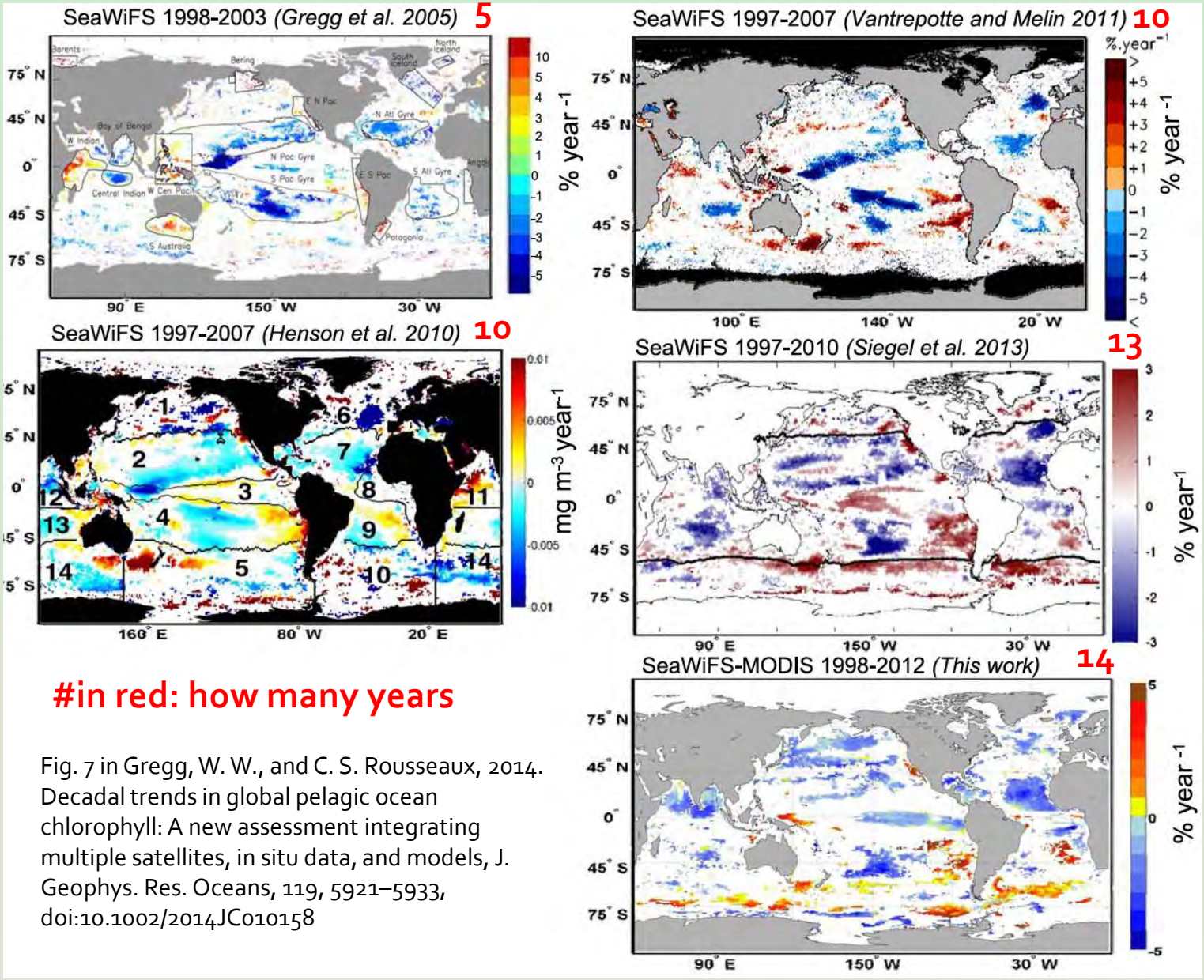


Fig. 7 in Gregg, W. W., and C. S. Rousseaux, 2014. Decadal trends in global pelagic ocean chlorophyll: A new assessment integrating multiple satellites, in situ data, and models, J. Geophys. Res. Oceans, 119, 5921–5933, doi:10.1002/2014JC010158

Changes in Chl (2 / 2)

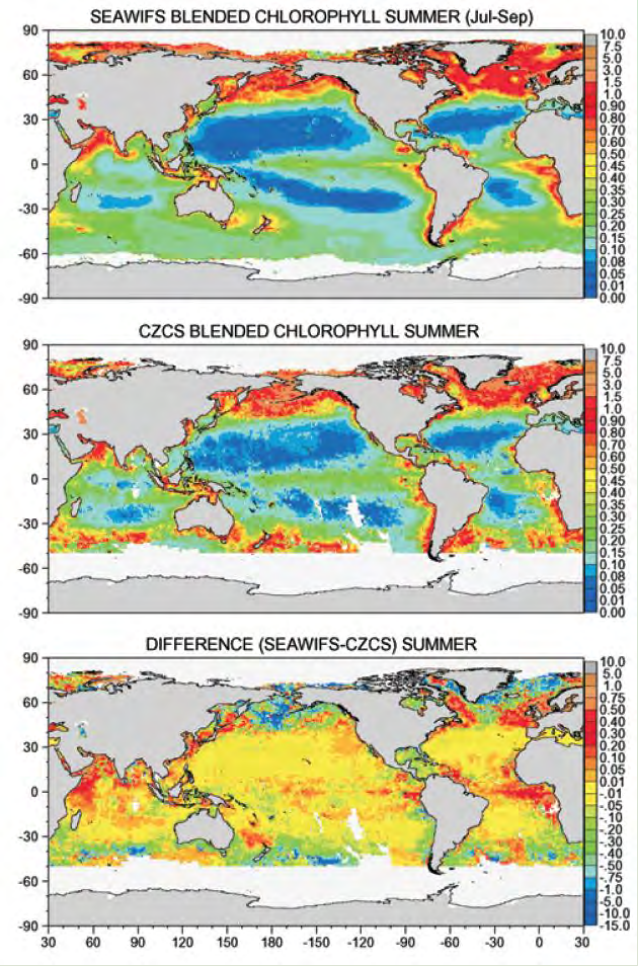
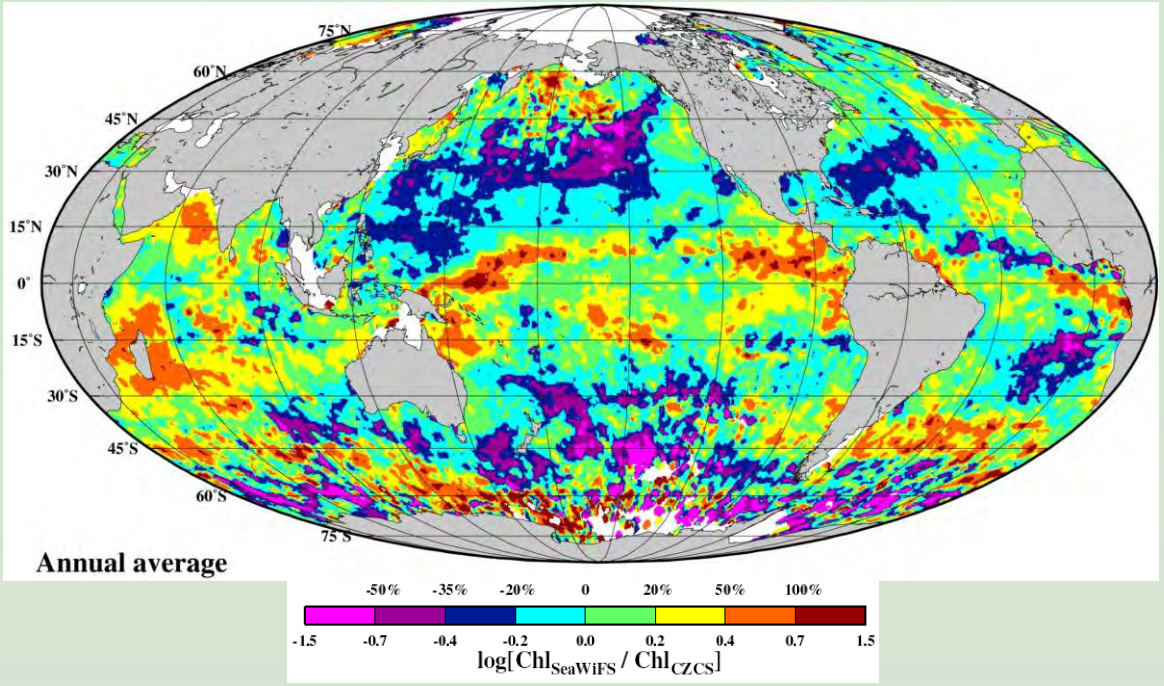


Figure 2 in *Gregg and Conkright, 2002, Decadal changes in global ocean chlorophyll, Geophys. Res. Letters, vol 29, 15, 1730.*

"Overall decrease by 6%"



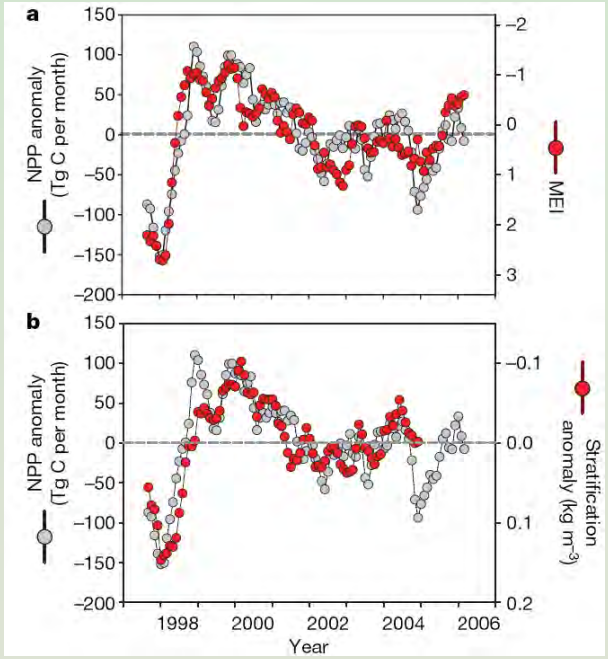
Antoine, D., Morel, A., Gordon, H.R., Banzon, V.F. and R.H. Evans (2005) Bridging ocean color observations of the 1980's and 2000's in search of long-term trends. *J. Geophys. Res.*, VOL. 110

"Overall increase by 20%"

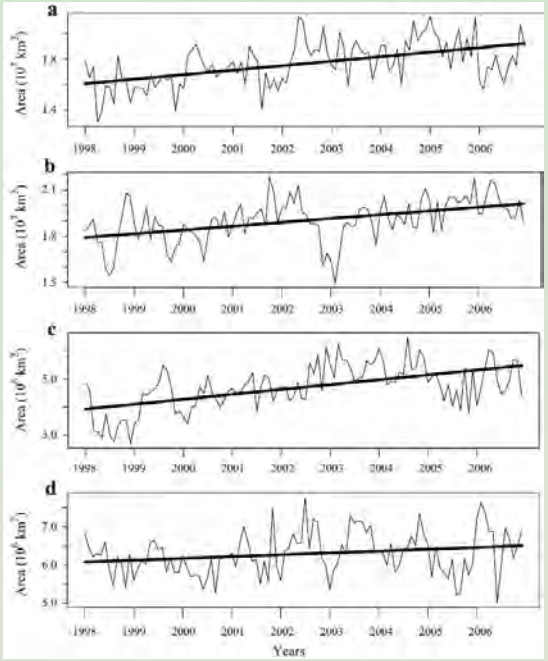
The benefit of a larger time window brought by the CZCS was apparently counter-balanced by the insufficient data quality and the absence of overlap

Relation to physics

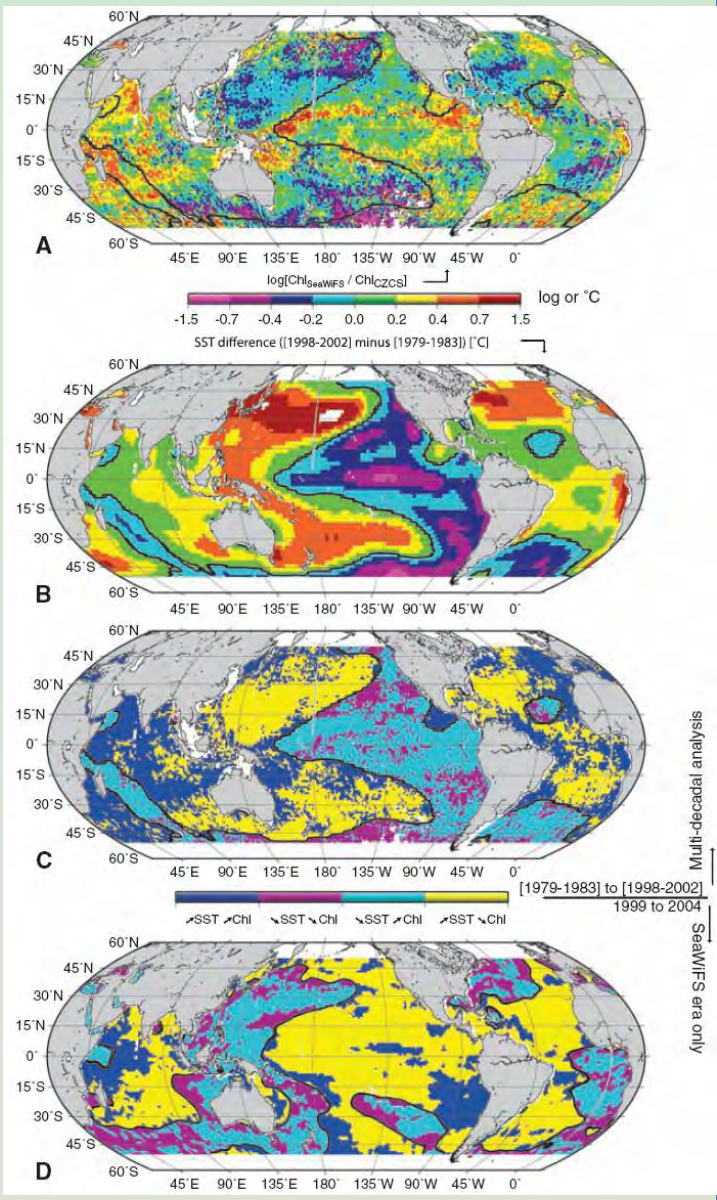
Things that matters a lot:
- The time window
- Decadal oscillations



Behrenfeld *et al.*, Nature, 2006

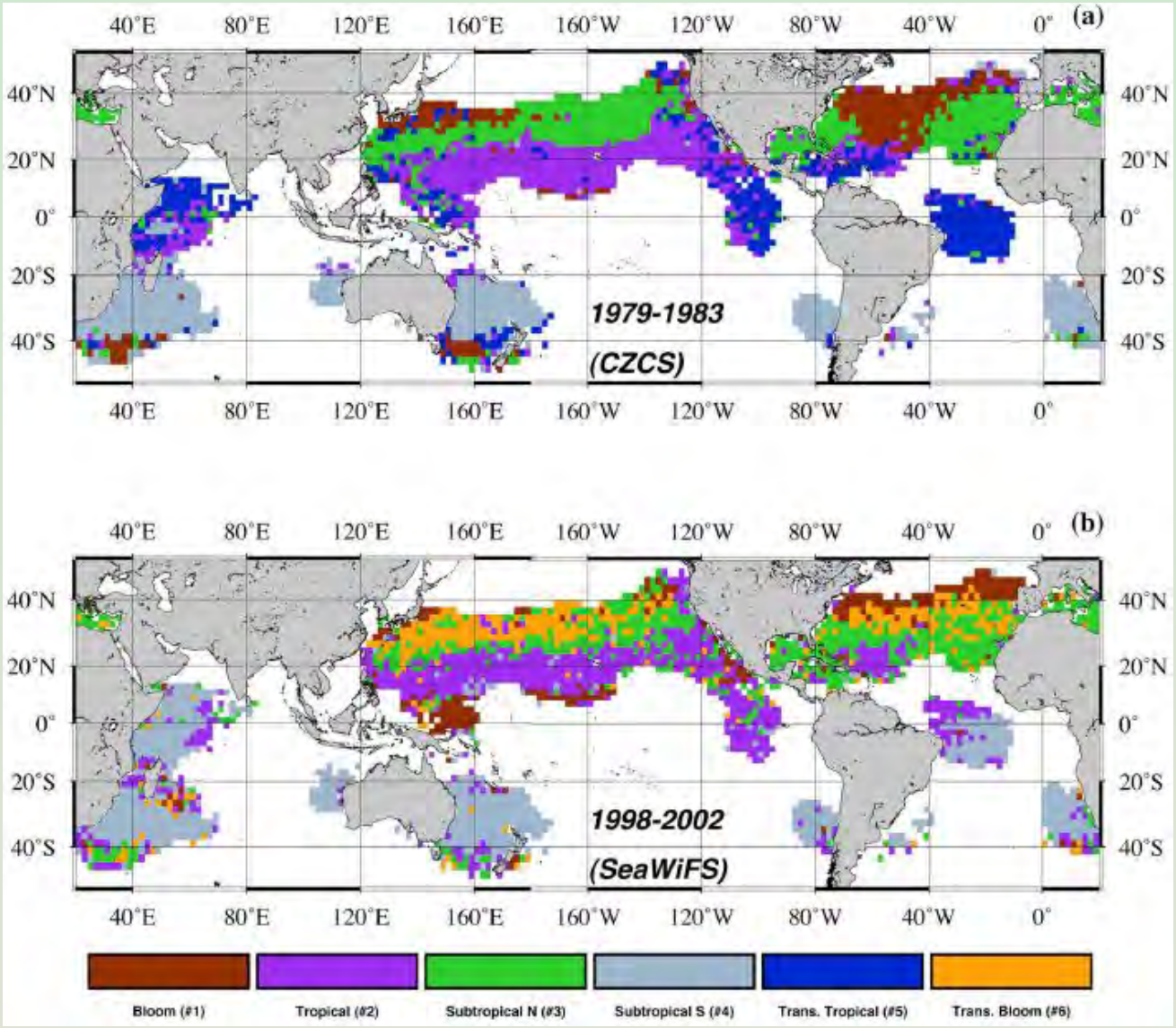


Polovina *et al.*, Geophys. Res. Letters, 2008; Also Irwin & Oliver, GRL, 2009



Martinez *et al.*, Science, 2009

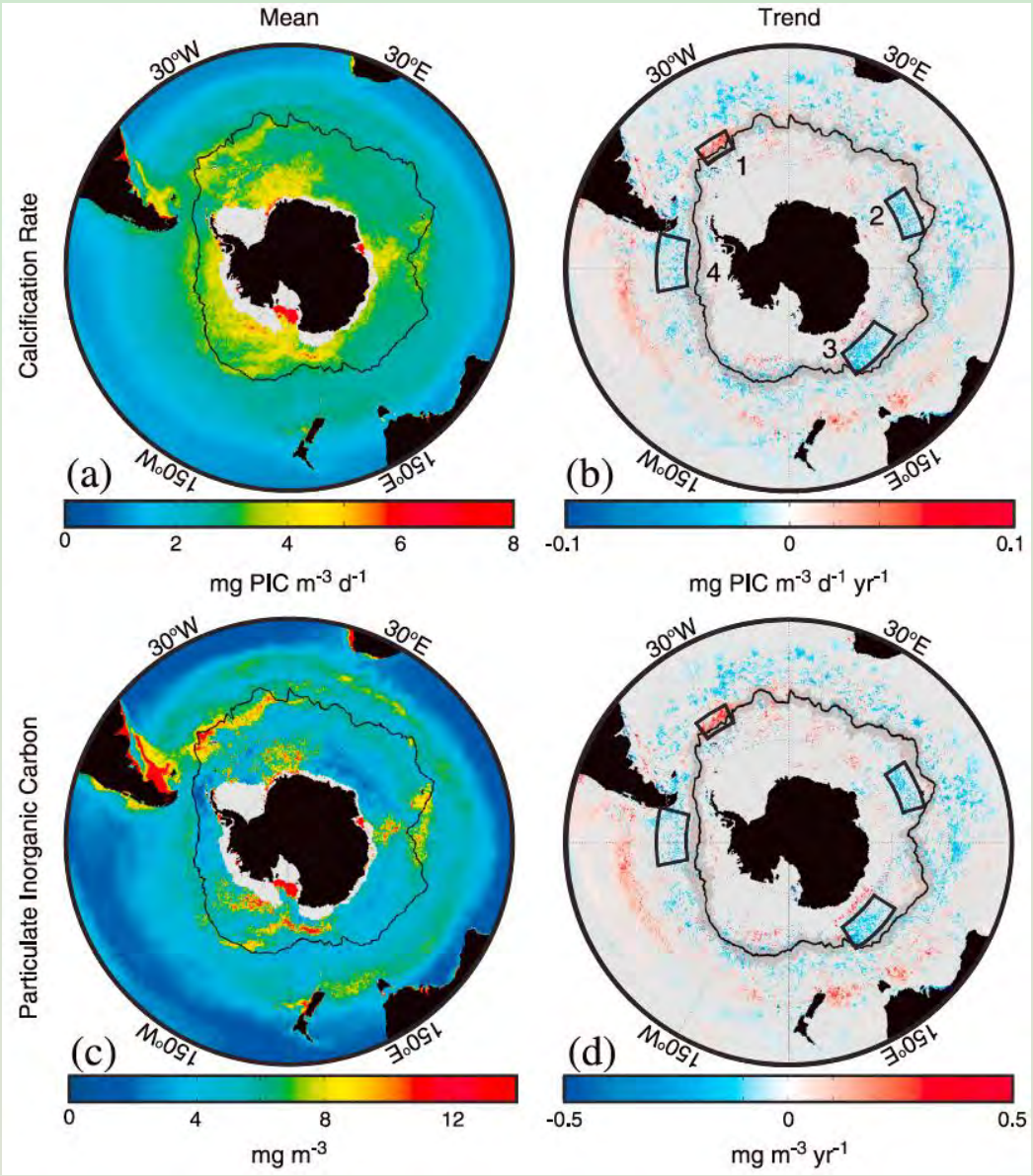
Changes in phenology



Basically:
Most changes are due to spatial changes, i.e., the main phenology traits are preserved, yet their distribution has changed

D'Ortenzio, F., D. Antoine, E. Martinez, and M. Ribera d'Alcalà, 2012. Phenological changes of oceanic phytoplankton in the 1980s and 2000s as revealed by remotely sensed ocean-color observations, Global Biogeochem. Cycles, 26, GB4003, doi:10.1029/2011GB004269

Changes in PFTs, e.g., coccolithophorids

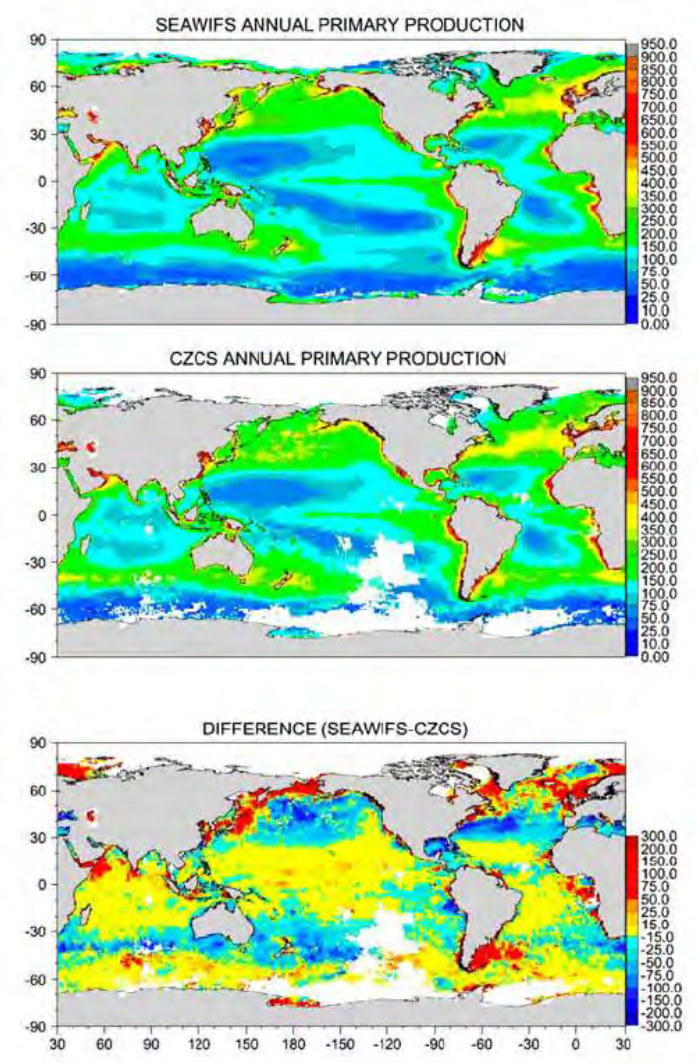


4% basin-wide reduction in summer calcification over 1998-2014

But see poster #124 Cécile Rousseaux, Watson Gregg

Freeman, N. M., and N. S. Lovenduski, 2015. Geophys. Res. Lett., 42, 1834–1840, doi:10.1002/2014GL062769.

Changes in Carbon & primary production



"Satellite-in situ blended ocean chlorophyll records indicate that global ocean annual primary production has declined more than 6% since the early 1980's. Nearly 70% of the global decadal decline occurred in the high latitudes"

Other studies ??
Not sure

Gregg, W.W., M.E. Conkright, P. Ginoux, J.E. O'Reilly, and N.W. Casey, 2003. Ocean primary production and climate: global decadal changes, Geophys. Res. Lett., 30(15), 1809.

Therefore, overall not so many studies about global changes in ocean ecosystems from ocean color satellite observations

Some diverging results as well

What can't we say about long-term changes in the ocean ecosystem as observed from space?

Well, quite a lot…

- Inter-annual / decadal / long-term changes still difficult to quantify and to separate
- Attribution (natural decadal oscillations? Warming/stratification trend? Acidification?…)
- Changes in community structures and their impact on production and export
- ….

Some issues (more work ahead!)

1 About "what we can see"

- Chl *vs*. CDOM
- Chl *vs*. biomass (photo-adaptation)
- Phytoplankton carbon from b_{bp}
- b_{bp} in clear waters
- PFTs validation

2 Assuming (1) is solved, other issues are

- Spatial and temporal coverage
- Length & consistency of the time series (calibration)
- Vertical distribution

3 Assuming (1) & (2) are solved, it still remains to:

- Improve modeling of phytoplankton PP & export
- Assimilate OC-derived parameters into coupled physical-BGC models
- Interpret (joint use of other sources of information)

What do we need to solve these issues?
A few things (far from exhaustive)

1 About "what we can see"

- Hyperspectral measurements (field and satellite)
- Phytoplankton Carbon measurements (*e.g.*, Graff *et al.*, 2012;2015)
- More b_{bp} values in clear waters (appropriate instrumentation?)
- PFTs validation

2 About spatial and temporal coverage, length & consistency of the time series (calibration), and the vertical distribution

- (virtual) constellations, geostationary sensors
- Inter-comparison of time series and of the trends they show
- Permanent long-term cal/val sites+ long-term BGC sites
- BioArgo program to become operational

3 About models & assimilation:

- Photophysiology in Chl-based or absorption-based photosynthesis models (how to make it more dynamic?)
- Assimilation schemes for BGC properties
- Modeling of optical properties and the satellite signal from the state variable of the BGC models (PSD, nutrients, etc..)?

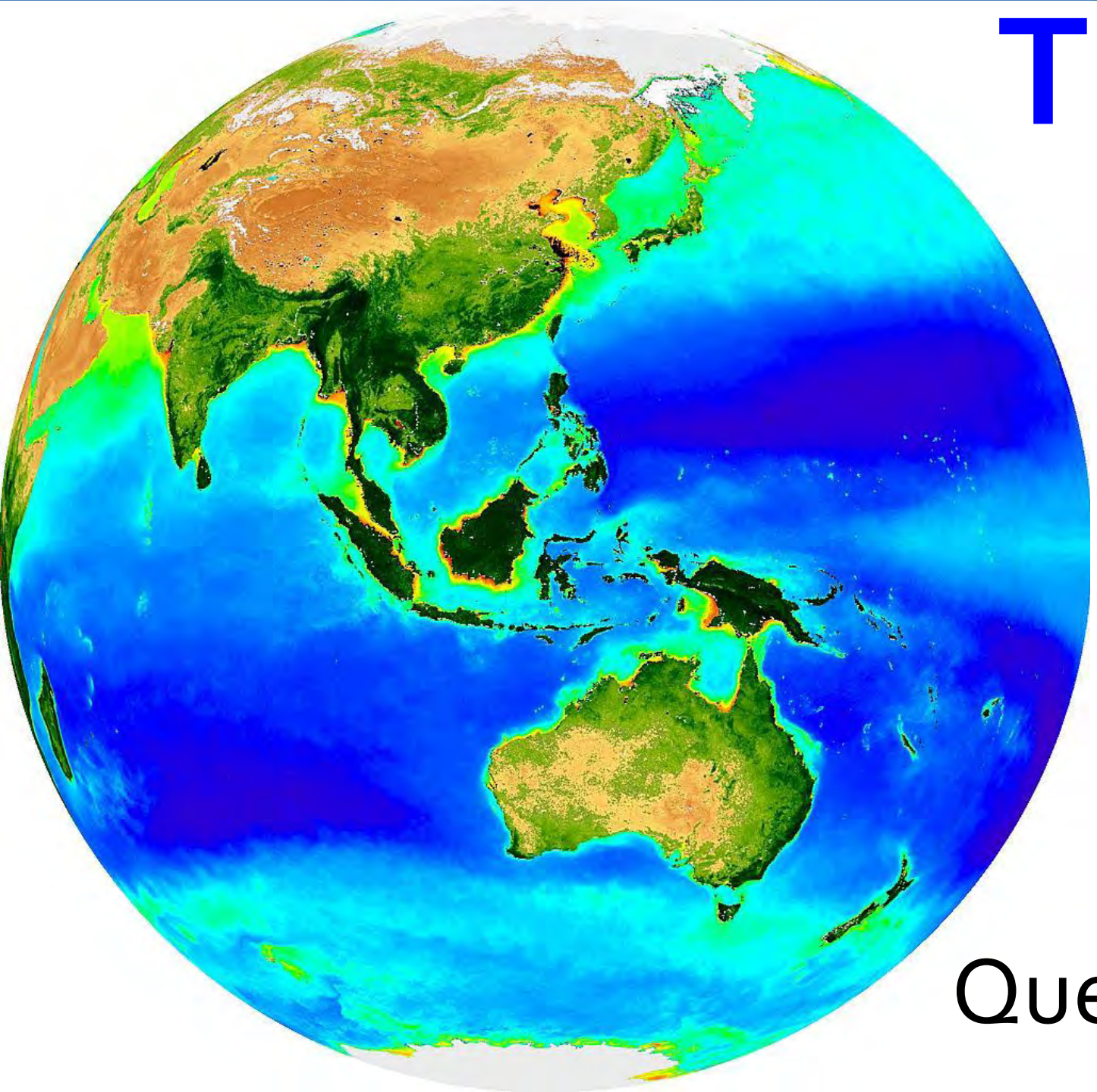
IOCCG Task Force for Ocean Colour Essential Climate Variable (ECV) Assessment

Mission Statement:

The goal of this international scientific expert group is to undertake a critical comparison of available ocean-colour ECV data products and provide guidance on the generation of better, long-term OCR climate data records.

Membership:

David Antoine (Co-Chair)	Curtin University, Australia/LOV, France
Bryan Franz (Co-Chair)	NASA, USA
Stephanie Henson	National Oceanography Centre, UK
Nicolas Hoepffner	Joint Research Centre, EU
Ewa Kwiatkowska	Eumetsat, EU
Hubert Loisel	CNRS, France
Antoine Mangin	ACRI-ST, France
Stéphane Maritorena	University of California, Santa Barbara, USA
Frédéric Mélin	EU Joint Research Centre (JRC), Italy
Hiroshi Murakami	JAXA, Japan
Menghua Wang	NOAA/NESDIS/STAR, USA
James Yoder	Woods Hole Oceanographic Institution, USA



Thank you

Questions ?