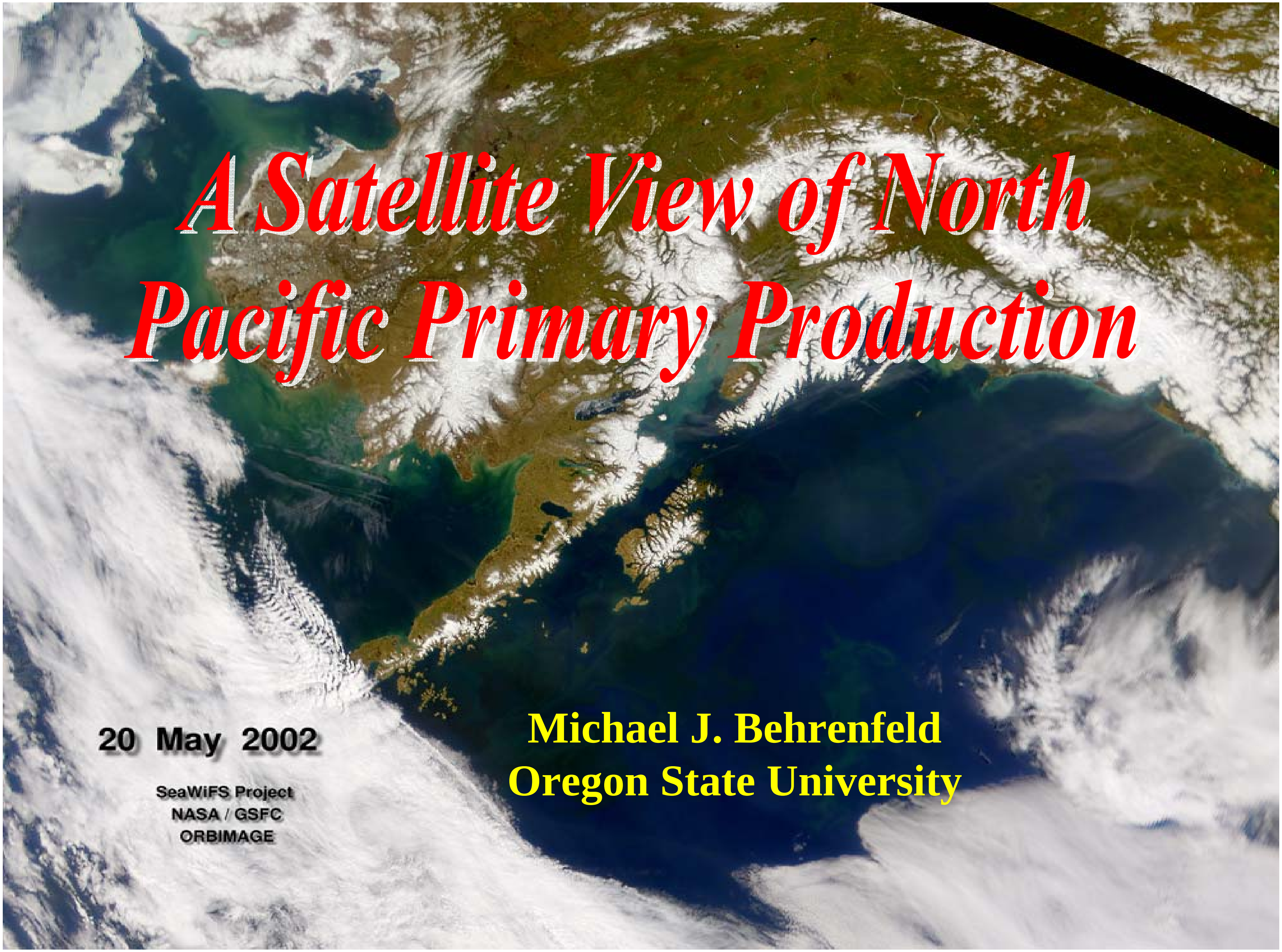
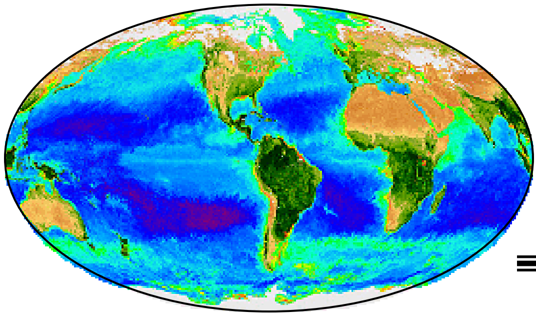
A Satellite View of North Pacific Primary Production

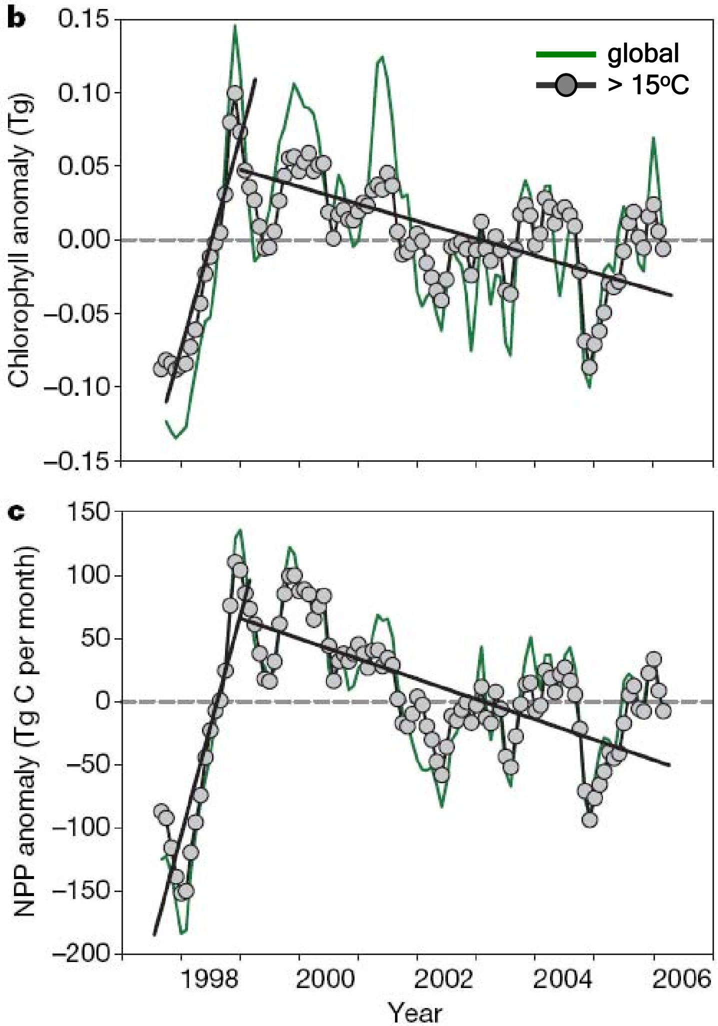
Michael J. Behrenfeld
Oregon State University





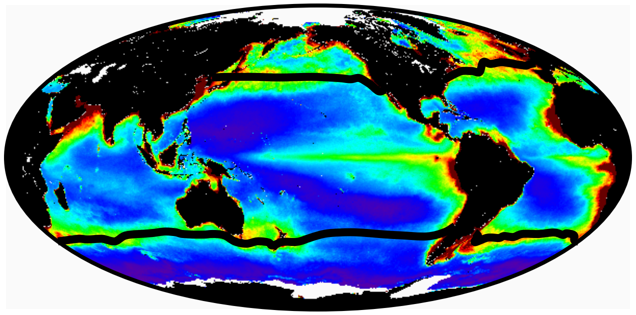
Climate-driven trends in contemporary ocean productivity

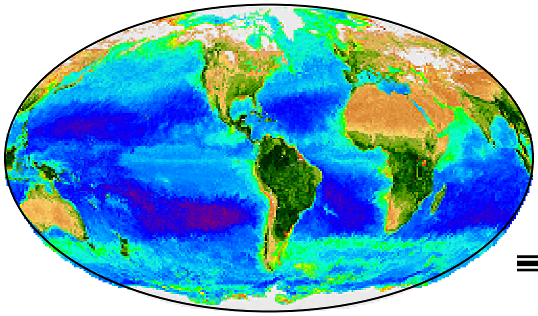
Michael J. Behrenfeld[1], Robert T. O'Malley[1], David A. Siegel[3], Charles R. McClain[4], Jorge L. Sarmiento[5], Gene C. Feldman[4], Allen J. Milligan[1], Paul G. Falkowski[6], Ricardo M. Letelier[2] & Emmanuel S. Boss[7]



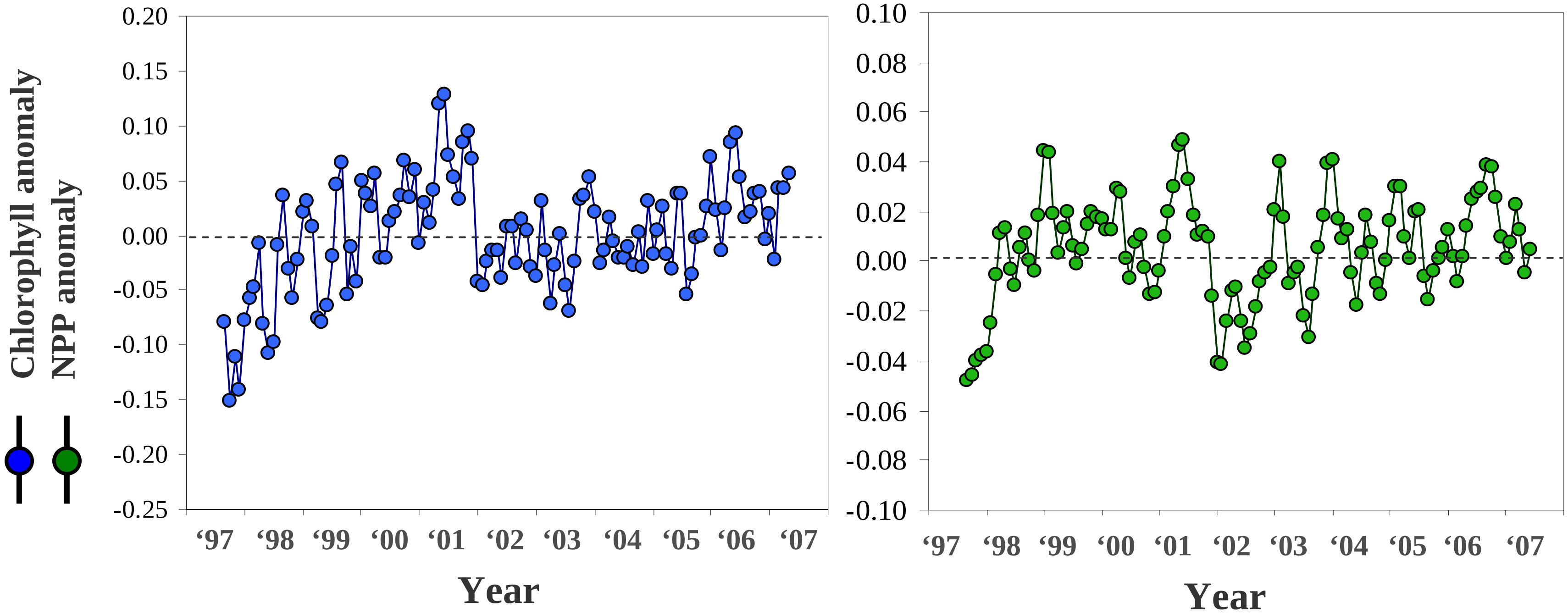
Tidbits

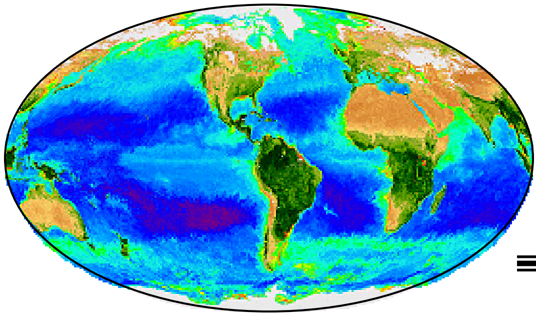
- Based on Vertically Generalized Production Model (VGPM)
- Initial increase = 1,930 TgC/yr
- Subsequent decrease = 190 TgC/yr
- Global trends dominated by changes in permanently stratified ocean regions (ann. ave. SST < 15ºC)





High-latitude anomalies





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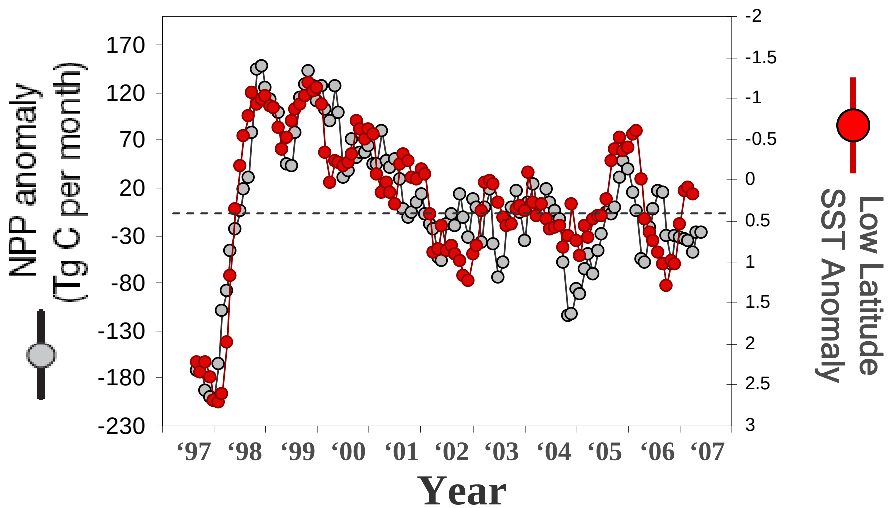
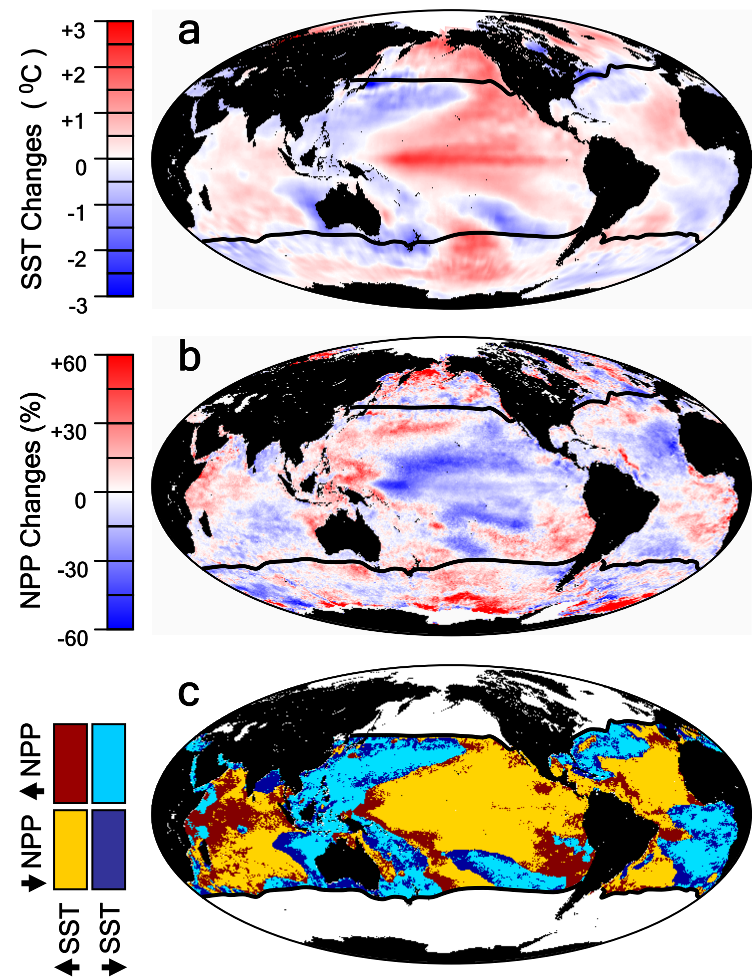
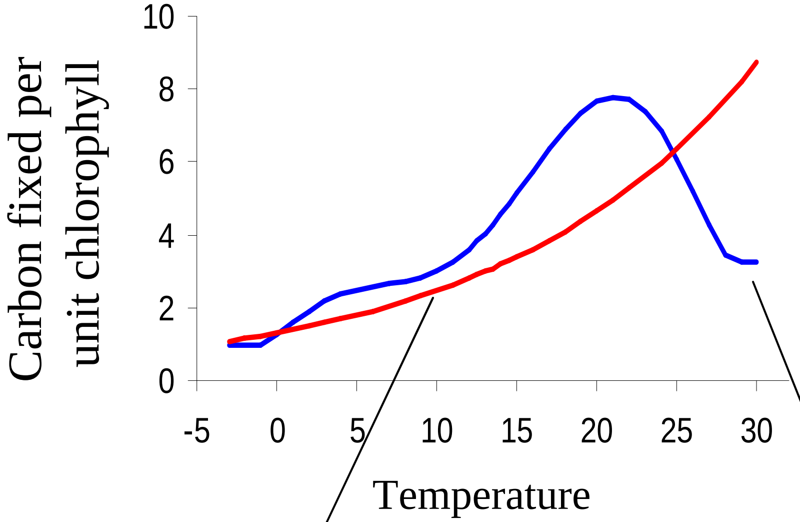
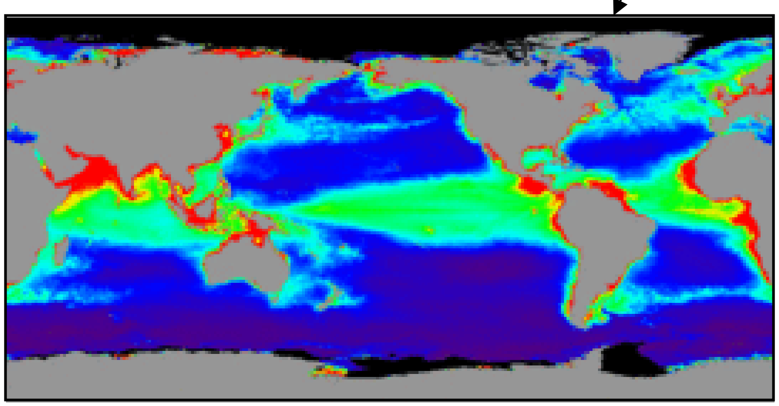


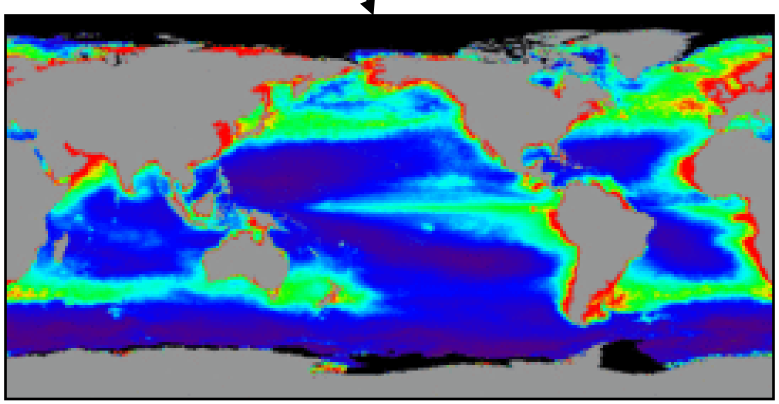


…but how good is the chlorophyll-to-NPP conversion?...

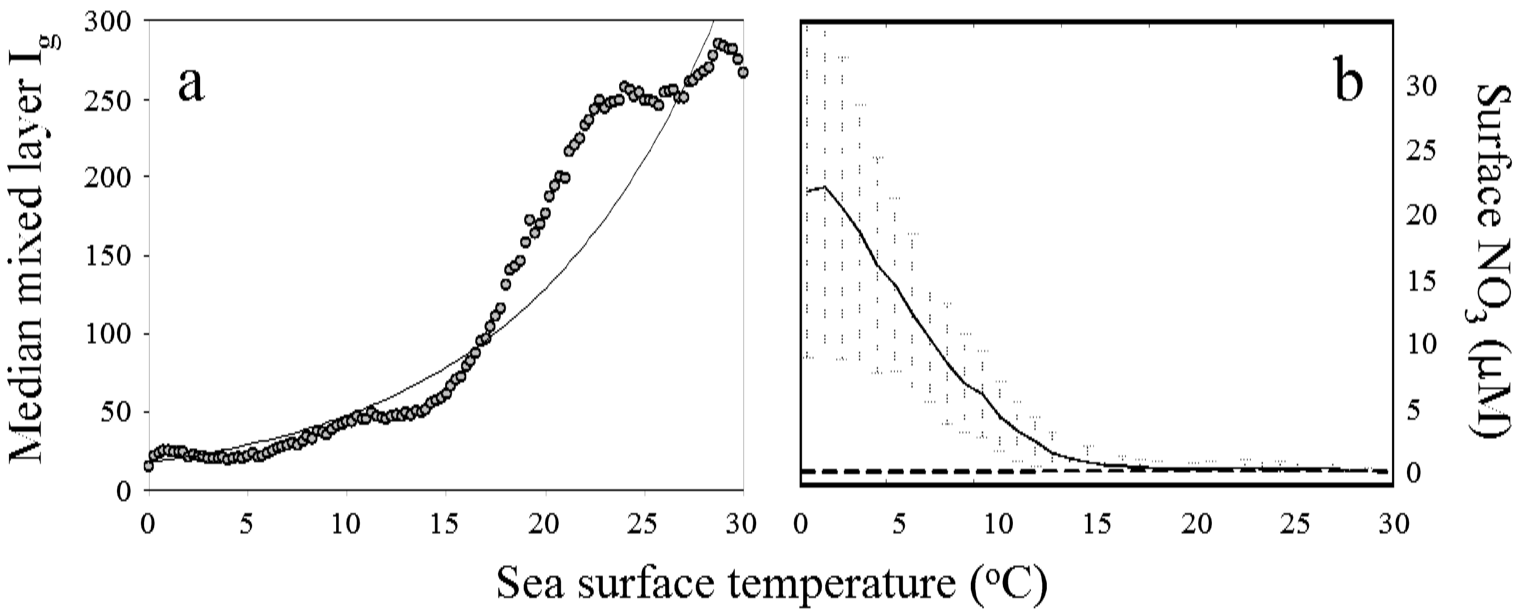
The ‘chlorophyll-approach’ problem



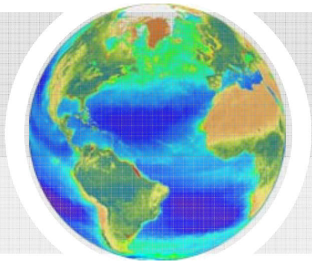




Physiology and Temperature

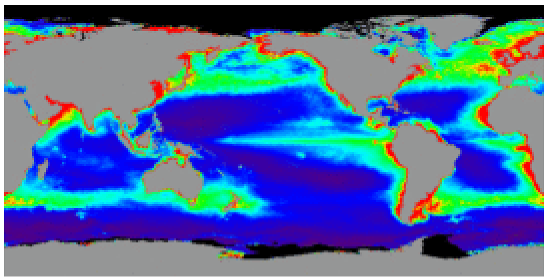


Behrenfeld, M.J., K. Halsey, A. Milligan. 2007. Proc. Royal Acad. Sci. B

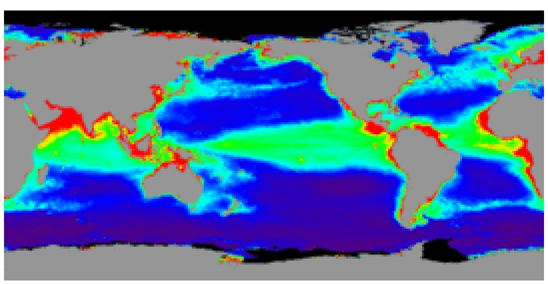


A New Solution to an Old Problem

Chlorophyll-based approach is a ‘dead end’



Same satellite input,
Different model of physiology



The “Carbon-based” approach – $\mathrm{NPP} = \mu \times \mathrm{C}$

- Scattering coefficients covary with particle abundance
- Scattering coefficients covary with phytoplankton carbon
- Chlorophyll variations independent of C are an index of changing cellular pigmentation
- Chl:C can then be used as an index of the *rate* term

▶ path to carbon biomass & growth rate from space

The problems with this approach are….

1. We don’t measure phytoplankton C in the field
2. We rarely measure phytoplankton growth rates
3. Scattering is not a unique property of algae

Carbon-based ocean productivity and phytoplankton physiology from space

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 19, GB1006, doi:10.1029/2004GB002299, 2005

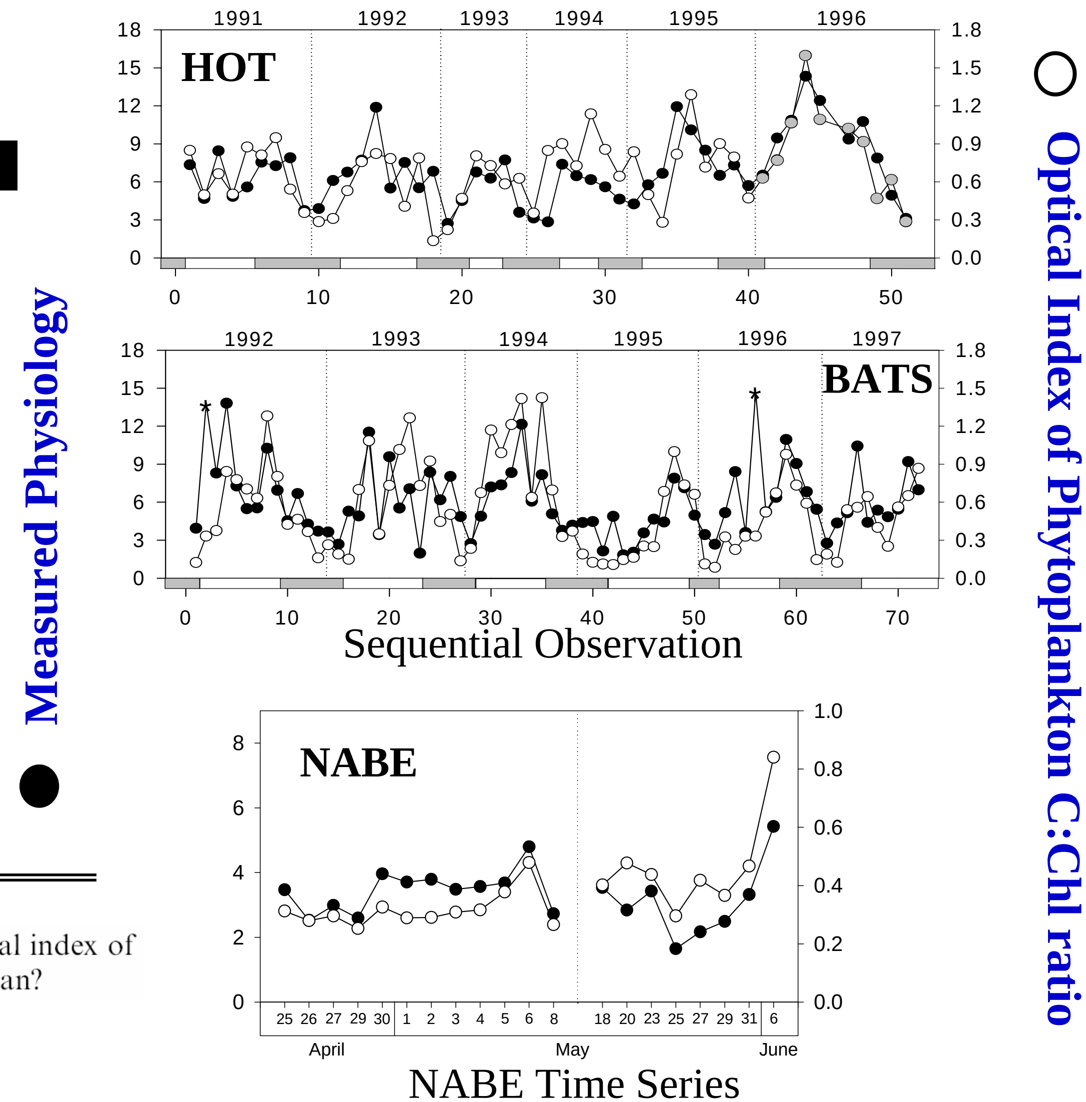
Can optics yield physiology? …

Beam attenuation is the most common measure of particle scattering in the field and its variability is dominated by changes in phytoplankton.

Does the ratio of attenuation:scattering provide information on physiology?

The beam attenuation to chlorophyll ratio: an optical index of phytoplankton physiology in the surface ocean?

DEEP-SEA RESEARCH
PART I

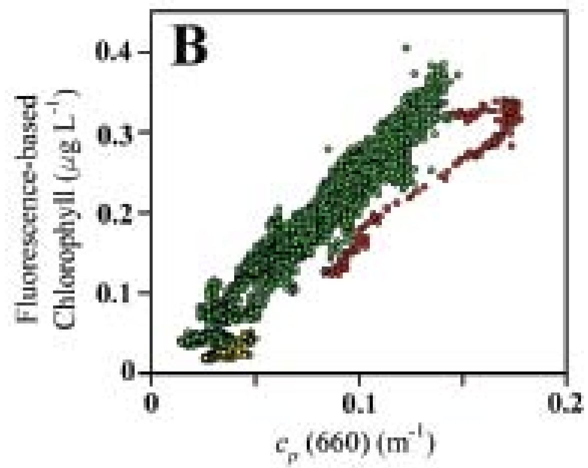


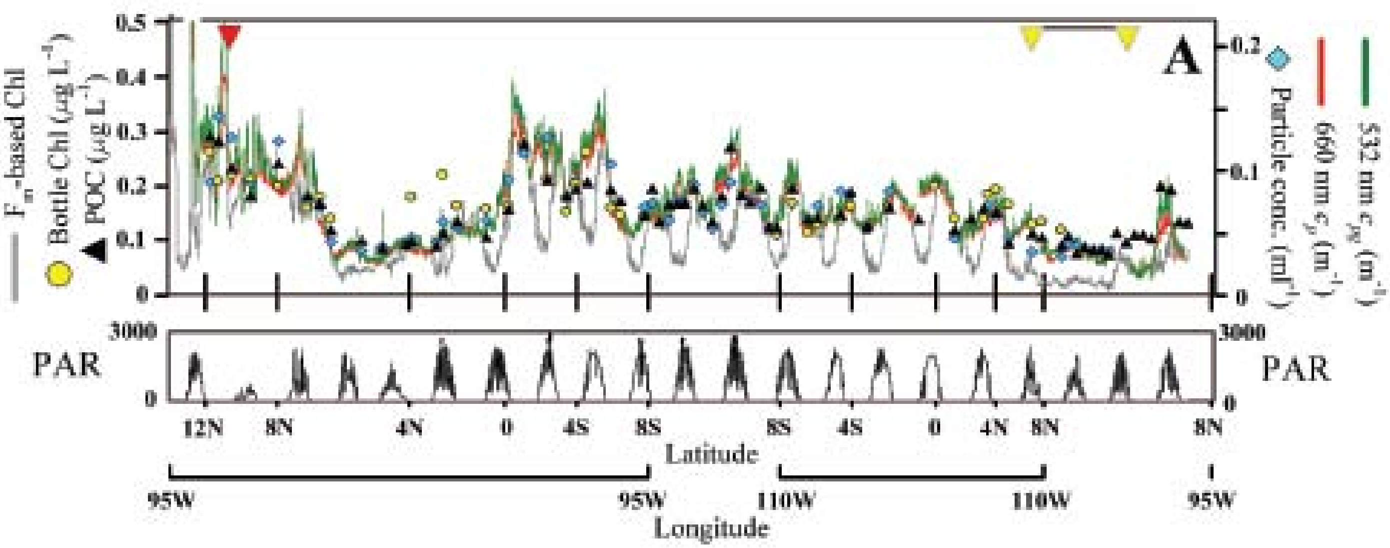
Optics and phytoplankton carbon

Another approach is to look in areas that do not exhibit much variability in growth conditions

Beam attenuation and chlorophyll concentration as alternative optical indices of phytoplankton biomass

Journal of Marine Research, 64, 431–451, 2006





Optics and phytoplankton carbon

- The new inversion algorithms provide estimates of **particulate backscatter coefficients**, not beam attenuation

- According to Mie Theory, backscatter is dominated by particles less than 1 µm – i.e., generally *not* phytoplankton.

- Can backscattering be used as an index of phytoplankton carbon?

•Yes #1: If the particle size spectrum slope is conserved

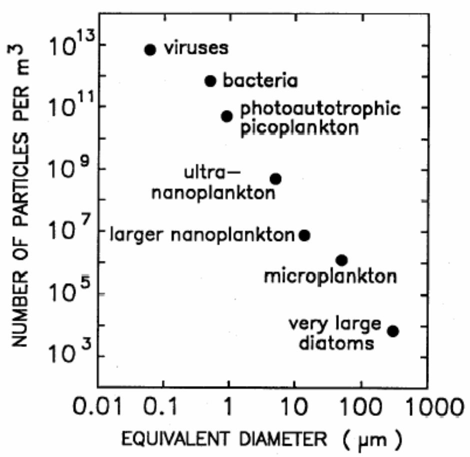
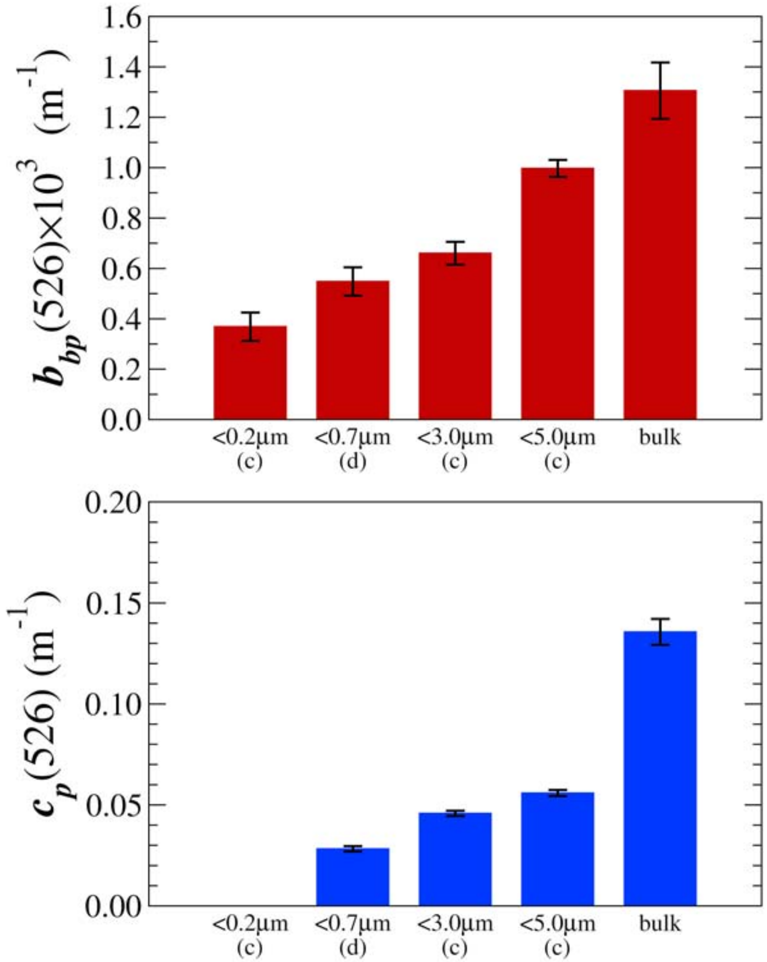


FIG.1. A logarithmic plot of the approximate abundances of major groups of microorganisms in the open ocean. On the scale of abscissa, the circles correspond to midpoints of size classes of the specified microbial components (the class width varies between components which is not graphed).

Optics and phytoplankton carbon

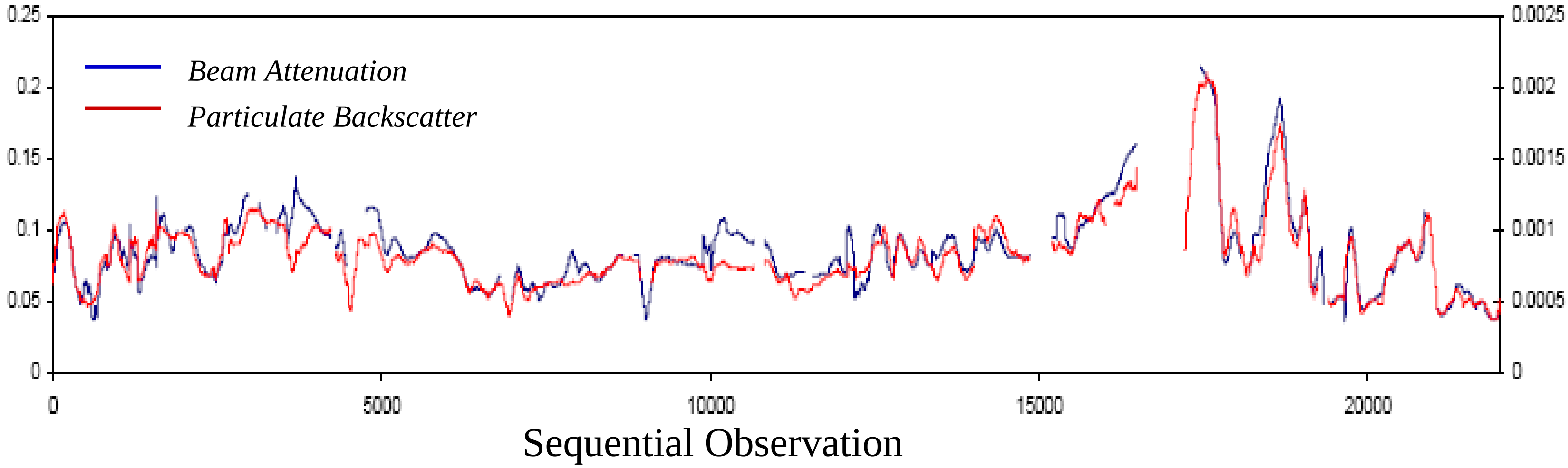


- Yes #2: If phytoplankton contribute more to backscatter than Mie predicts

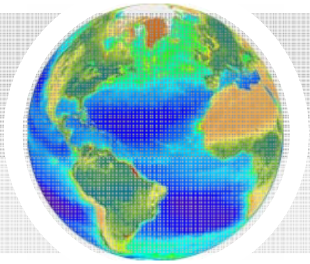
Dall'Olmo et al. 2007 (in prep)

Optics and phytoplankton carbon

Tropical Pacific 2007

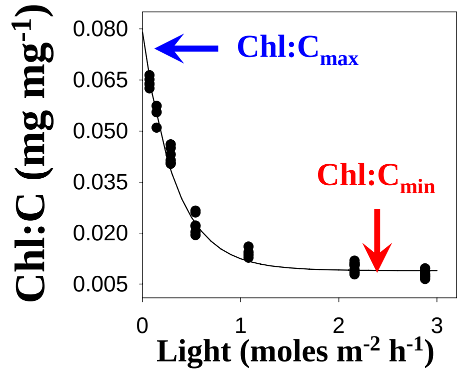


Dall'Olmo et al. 2007 (in prep)



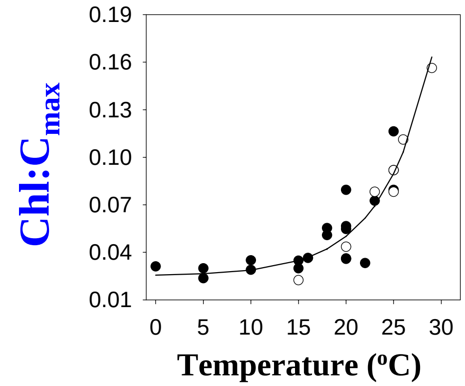
Phytoplankton carbon from Space

3 primary factors



Light

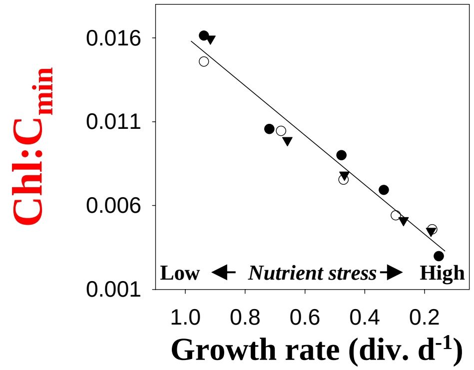
Dunaliella tertiolecta
20 ºC
Replete nutrients
Exponential growth phase



Temperature

Geider (1987) *New Phytol*. **106**: 1-34

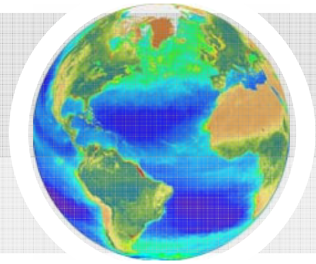
16 species
● = Diatoms
○ = all other species



Nutrients

Laws & Bannister (1980)
Limnol. Oceanogr. **25**: 457-473

Thalassiosira fluviatilis
● = NO_3 limited cultures
○ = NH_4 limited cultures
▼ = PO_4 limited cultures



Phytoplankton carbon from Space

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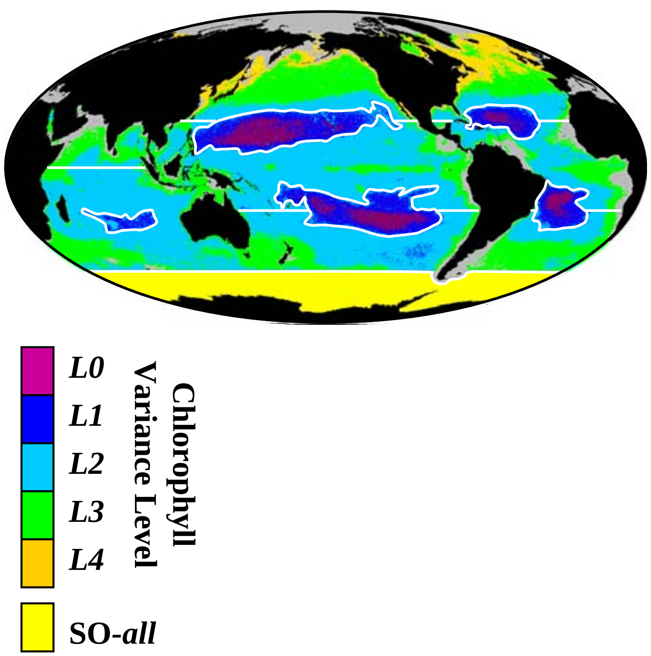
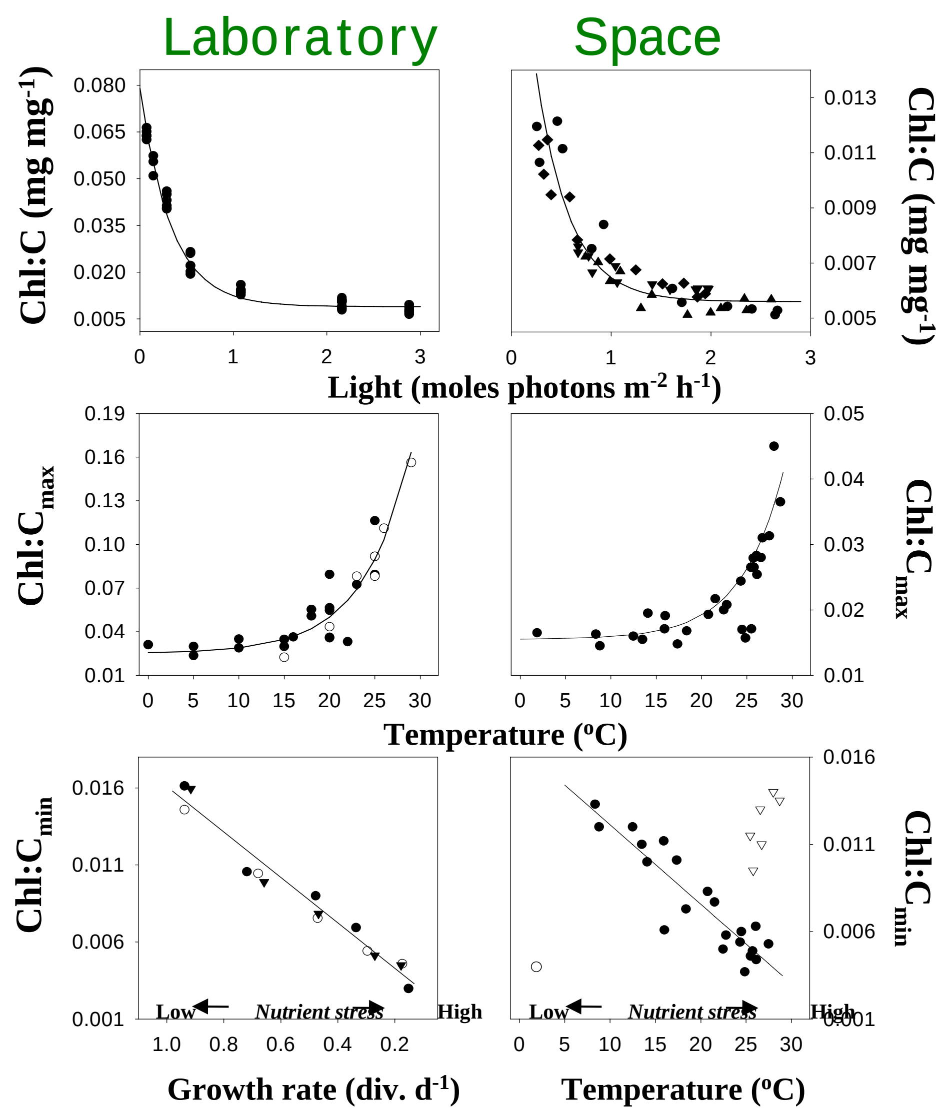
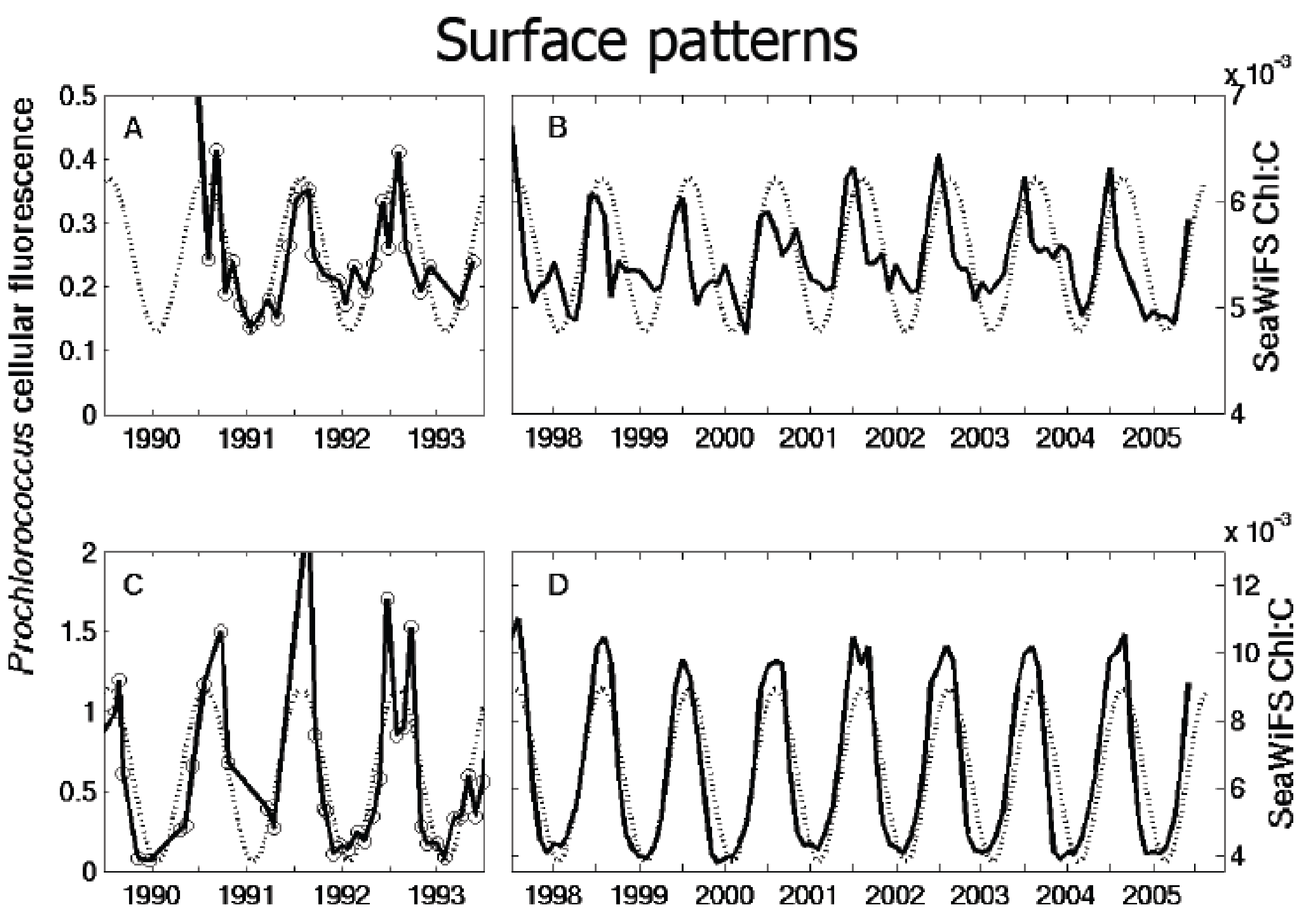


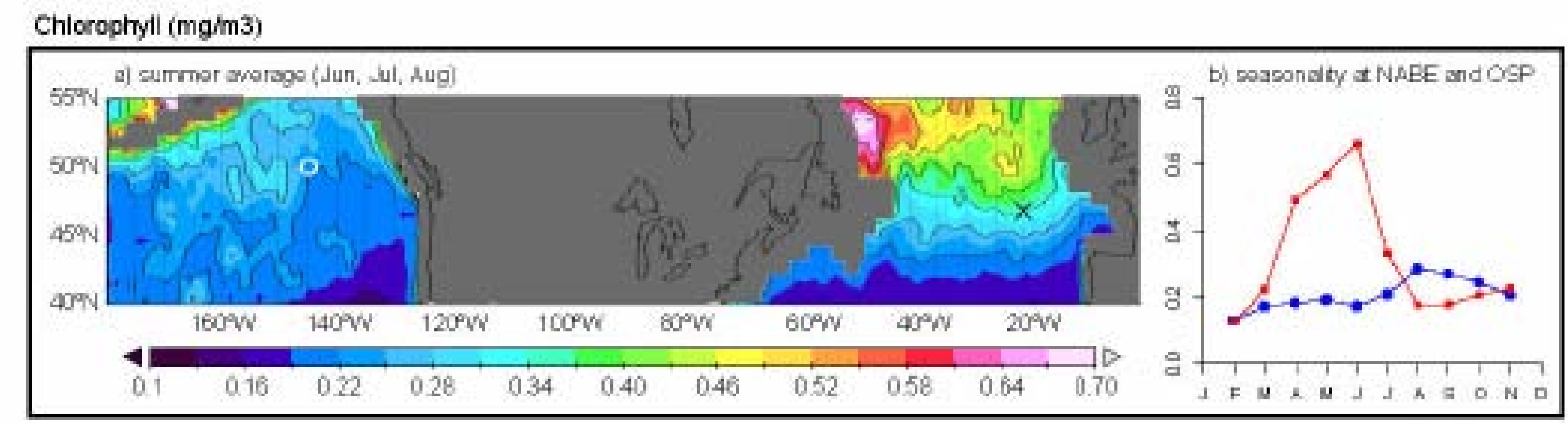


Phytoplankton carbon from Space



Westberry et al. 2007 Global Biogeochem. Cycles (submitted)

The Northern Subarctic



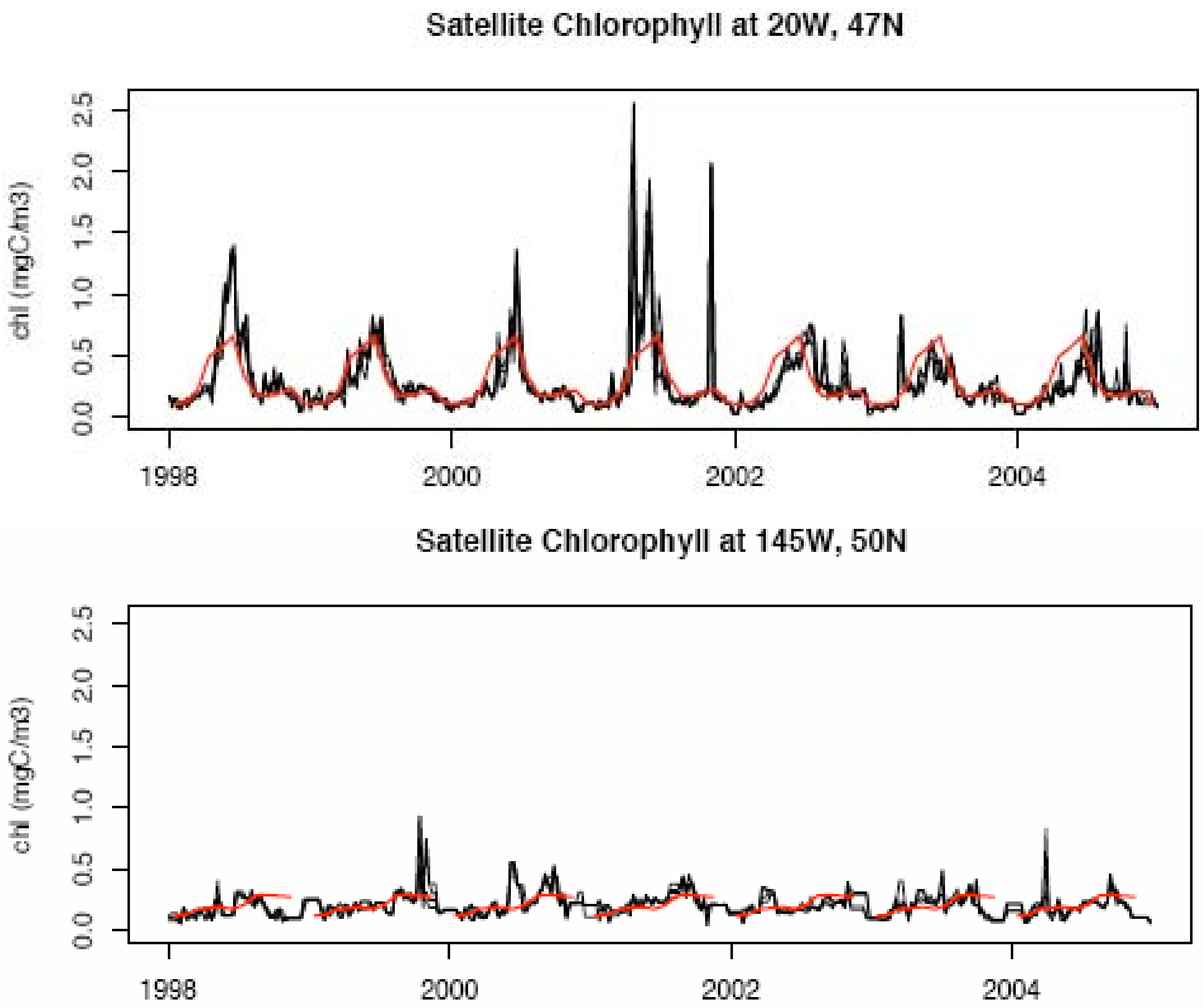
Current Explanation:

North Atlantic – deep winter mixing, slow growth rate, nutrient-charged surface layer ➛ spring stratification, diatom bloom, large grazers can't keep up (lifecycle issues) ➛ summer nitrate depletion bloom demise

North Pacific – shallower winter mixing, phytoplankton continue to grow, support microbial loop ➛ iron limitation of larger phytoplankton, microbial loop limitation of small phytoplankton, no spring/summer bloom

Schultz et al. 2007 (submitted)

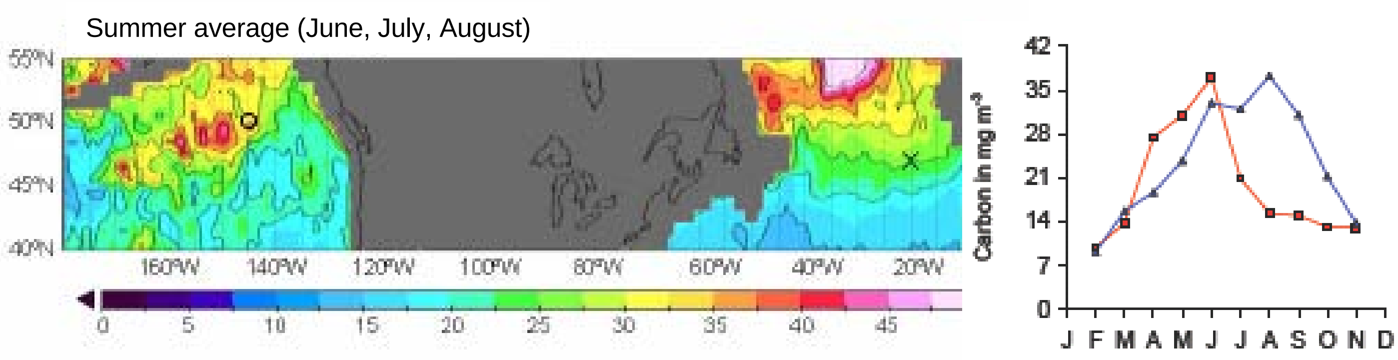
The Northern Subarctic



Schultz et al. 2007 (submitted)

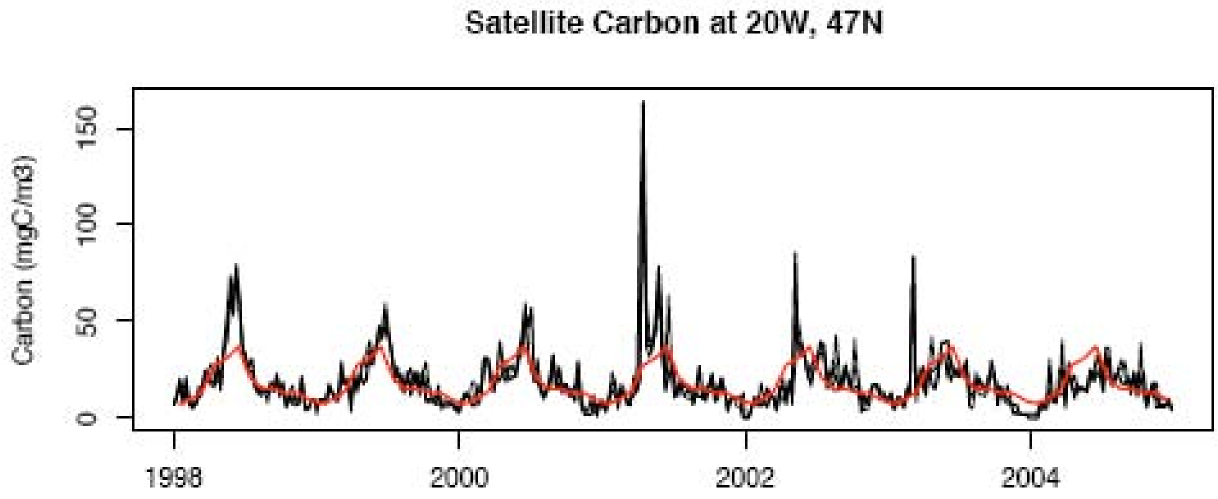
The Northern Subarctic

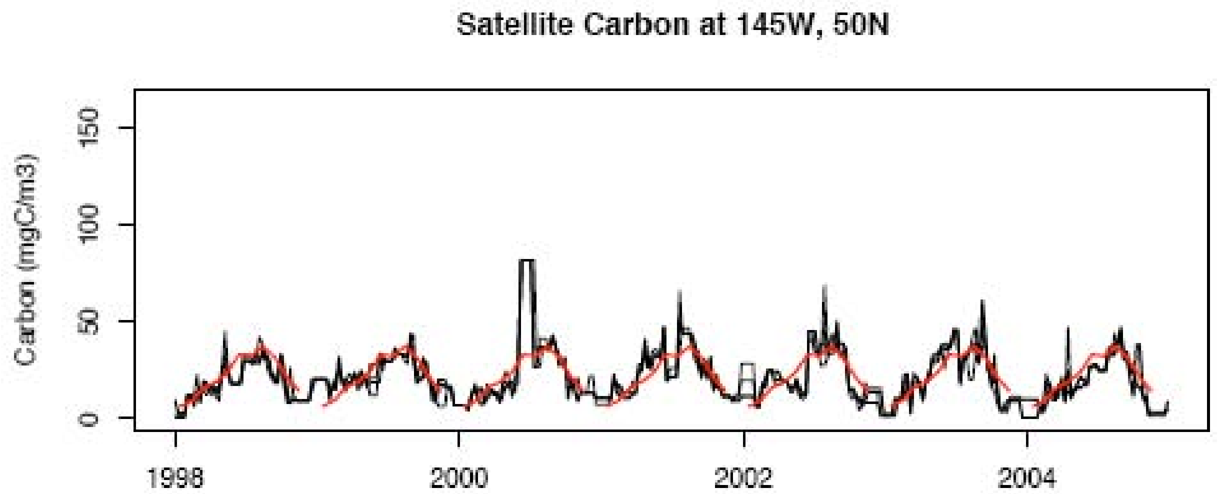
Phytoplankton carbon (mg/m3)



Schultz et al. 2007 (submitted)

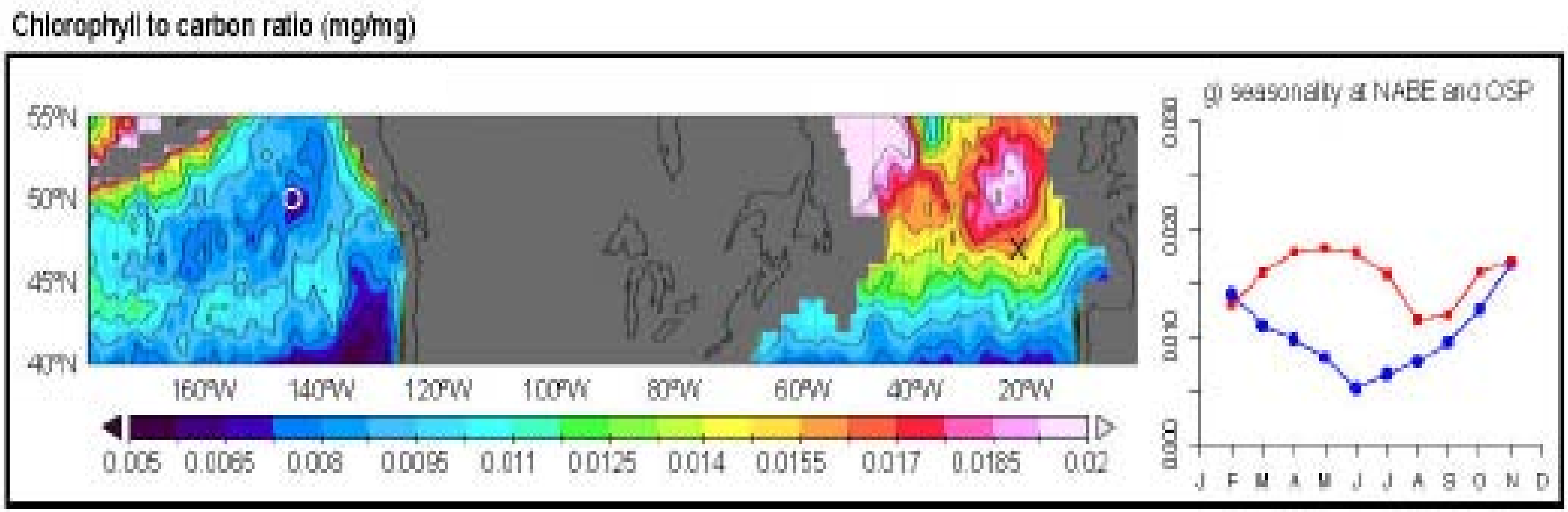
The Northern Subarctic





Schultz et al. 2007 (submitted)

The Northern Subarctic

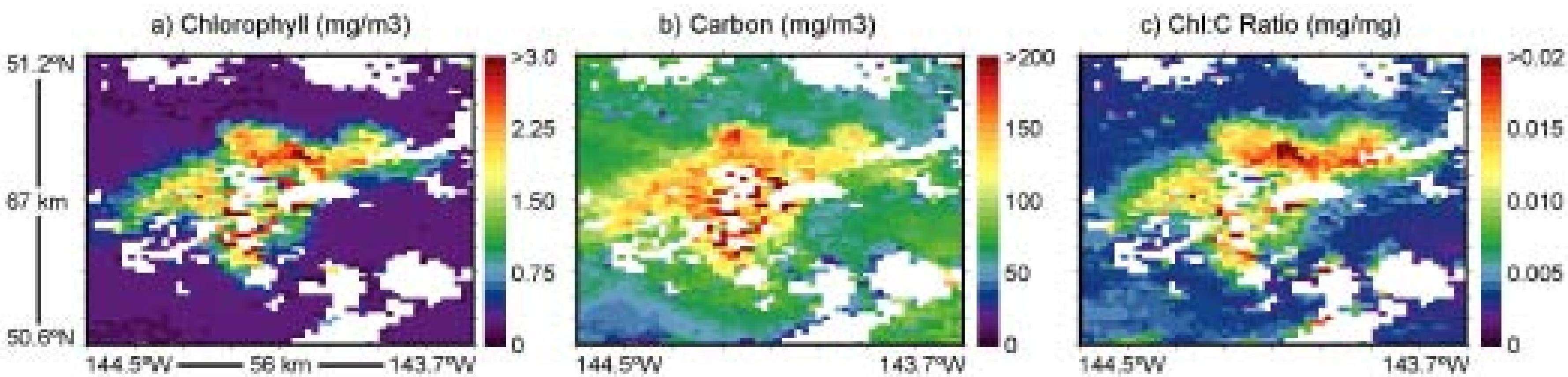


…physiology, physiology, physiology…

Schultz et al. 2007 (submitted)

The Northern Subarctic

SERIES Iron Enrichment Experiment
(subarctic north Pacific)



Schultz et al. 2007 (submitted)

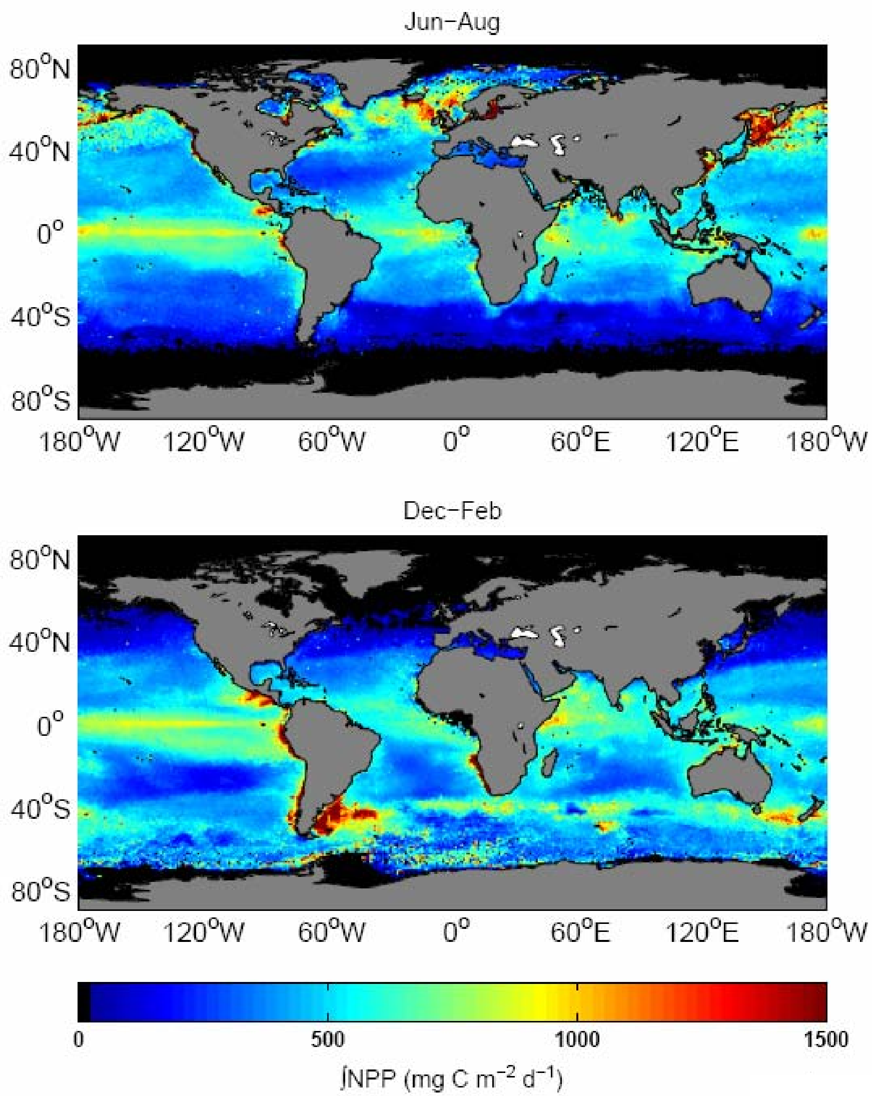
From Chl & C to Primary Production

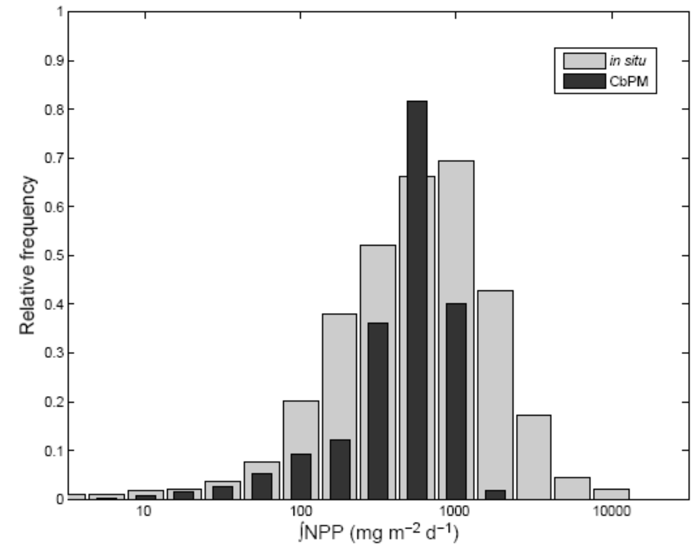
Net Primary Production (NPP) = $\mu \times C_{phyto}$

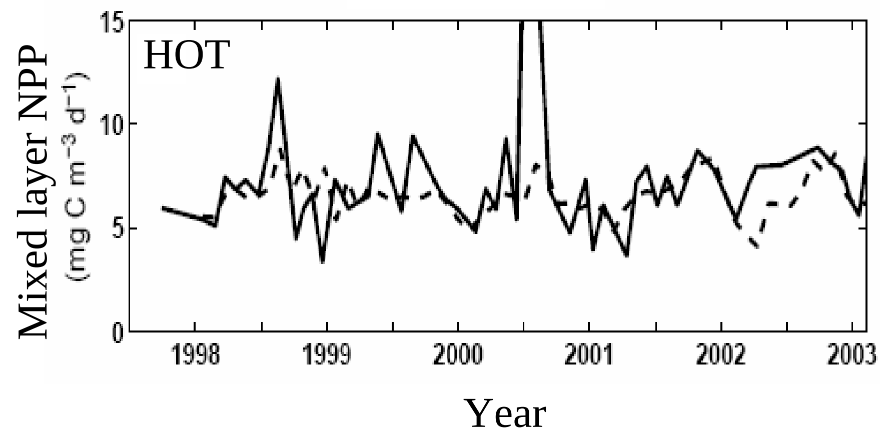
Growth rate (μ) = f (nuts, temp) $\times$ g (light)

$$f(\text{nuts, temp}) \leftarrow \frac{\text{Chl:Csat}}{(\text{Chl:C}_{N,T\text{-max}})_{\text{Light}}} \qquad g(\text{light}) \leftarrow 1 - \exp^{-3\text{light}}$$

From Chl & C to Primary Production

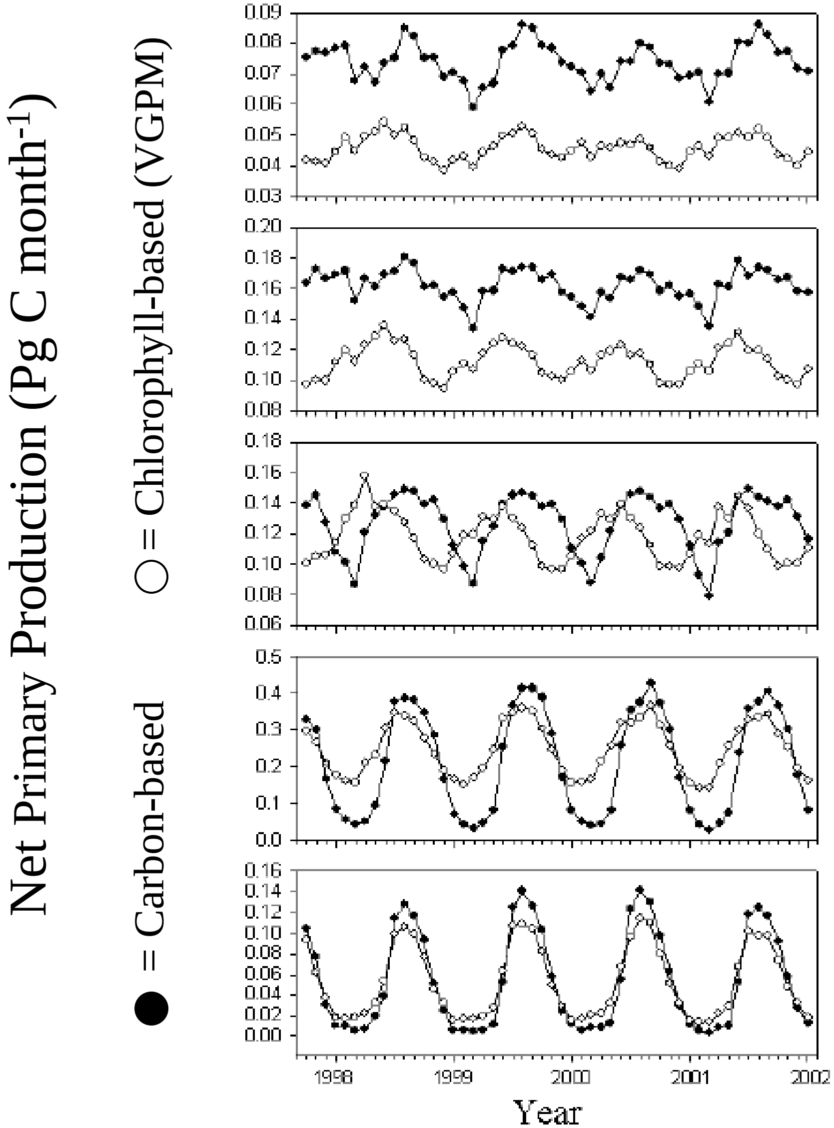






Westberry et al. 2007 Global Biogeochem. Cycles (submitted)

NPP of the North Pacific



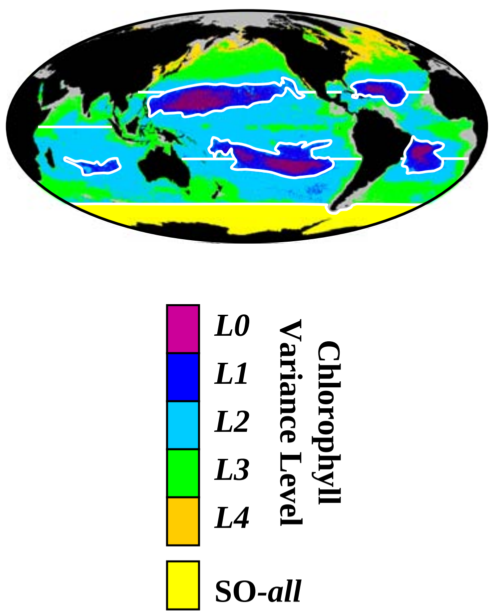
Variance Level 0

Variance Level 1

Variance Level 2

Variance Level 3

Variance Level 4



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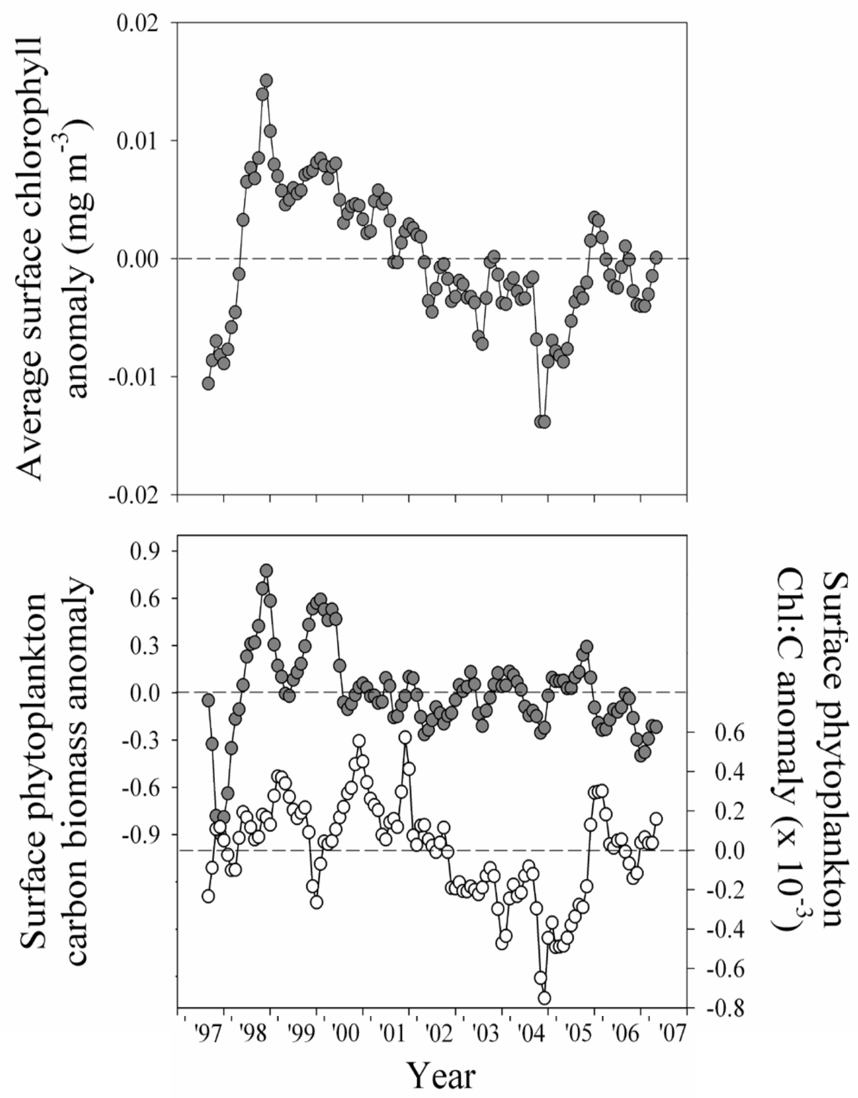
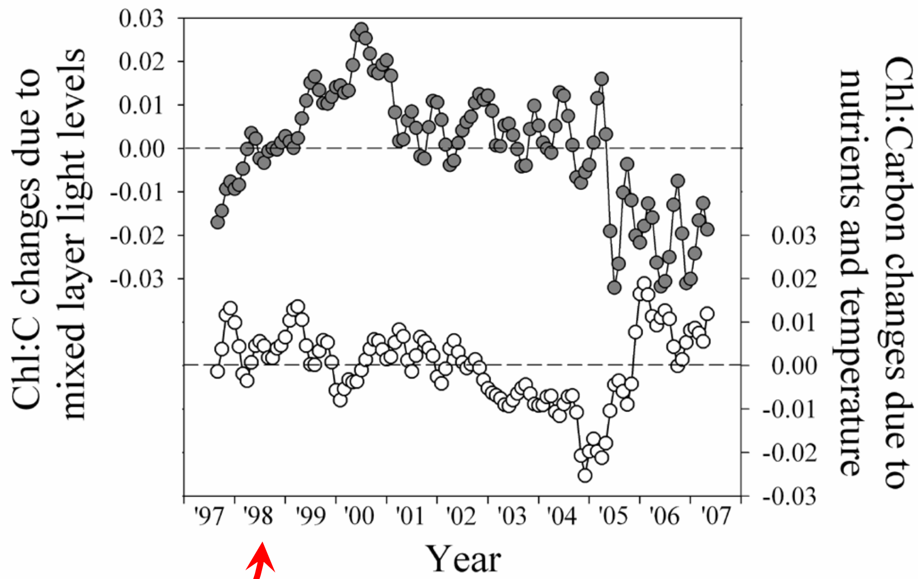
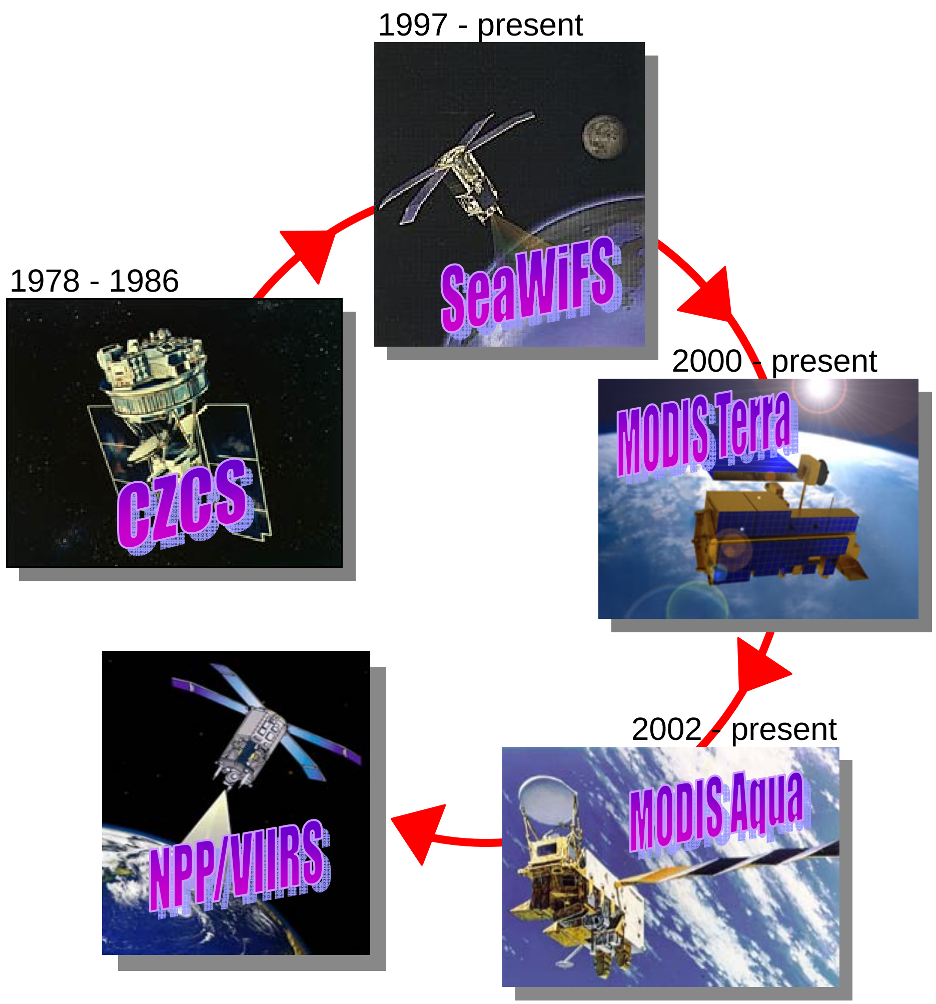
Decomposing chlorophyll trends

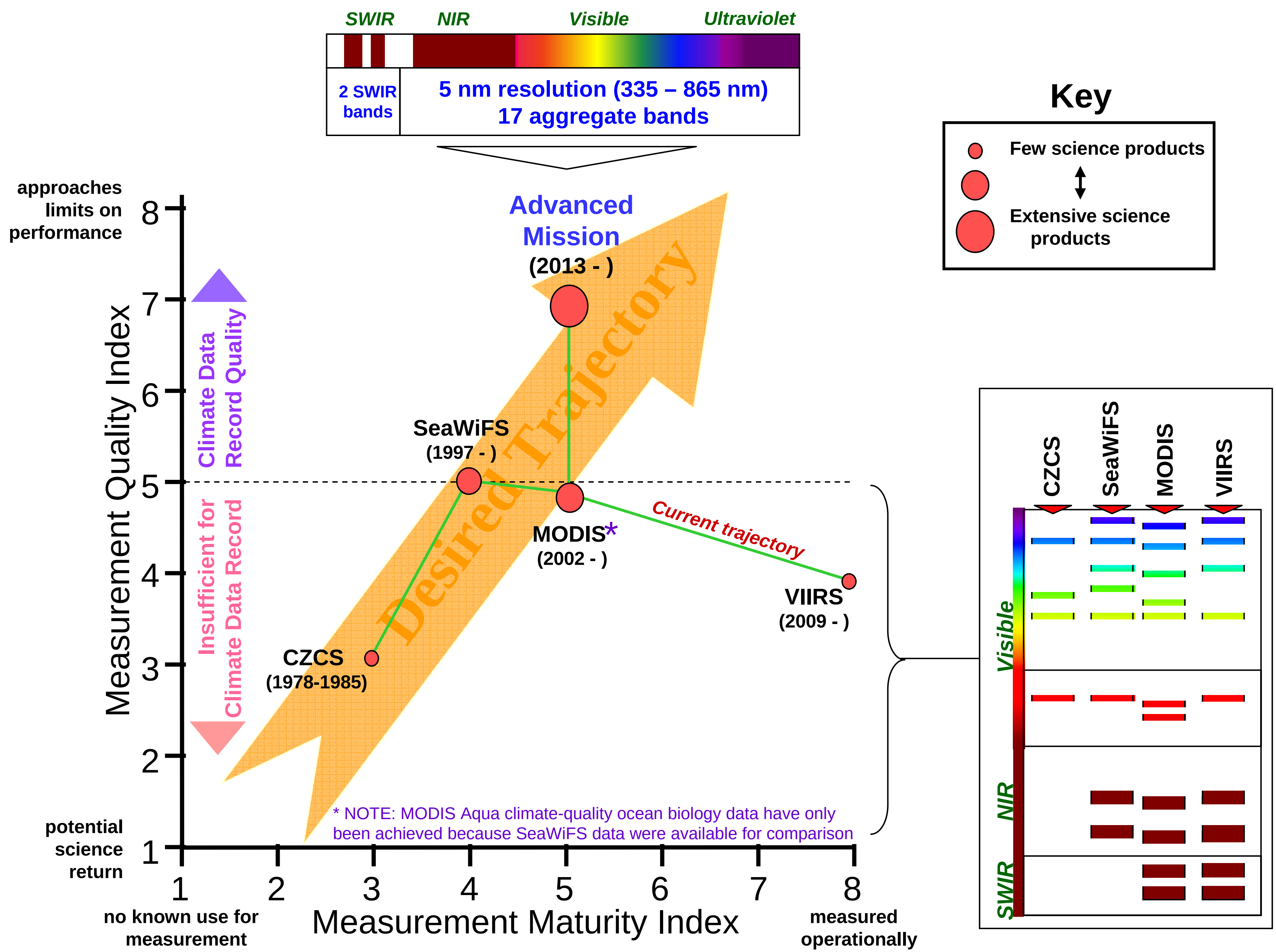




Click here if out of time

Heritage Ocean Color Sensors




SWIR
NIR
Visible
Ultraviolet
2 SWIR bands
5 nm resolution (335 – 865 nm)
17 aggregate bands
Key
Few science products
Extensive science products
approaches limits on performance
potential science return
Measurement Quality Index
Climate Data Record Quality
Insufficient for Climate Data Record
Advanced Mission
(2013 -)
Desired Trajectory
SeaWiFS
(1997 -)
MODIS*
(2002 -)
Current trajectory
VIIRS
(2009 -)
CZCS
(1978-1985)
* NOTE: MODIS Aqua climate-quality ocean biology data have only been achieved because SeaWiFS data were available for comparison
1
2
3
4
5
6
7
8
no known use for measurement
Measurement Maturity Index
measured operationally
CZCS
SeaWiFS
MODIS
VIIRS
Visible
NIR
SWIR

The End

http://web.science.oregonstate.edu/ocean.productivity/

Acknowledgements

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Dave Siegel
Emmanuel Boss
Chuck McClain
Jorge Sarmiento