What have we learned from MODIS chlorophyll fluorescence?

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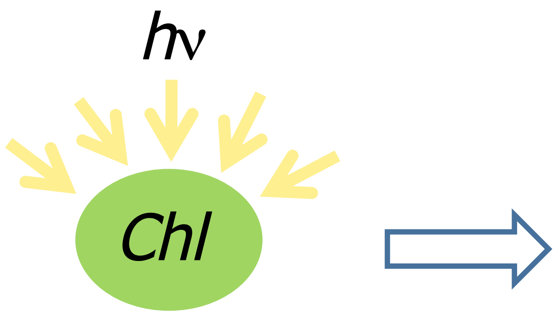
Others: Emmanuel Boss, Dave Siegel, Scott Doney, Ivan Lima, Jerry Wiggert, Natalie Mahowald

What is Chlorophyll fluorescence?

- Chlorophyll-a (Chl) is a ubiquitous plant pigment
- Chl dissipates some of its absorbed energy as photons (i.e., fluorescence)



1. Photochemistry
2. Heat (non-photochemical quenching)
3. Fluorescence

- Fluorescence occurs under natural sunlight
- Fluoresced radiation is discernable in upwelled radiant flux

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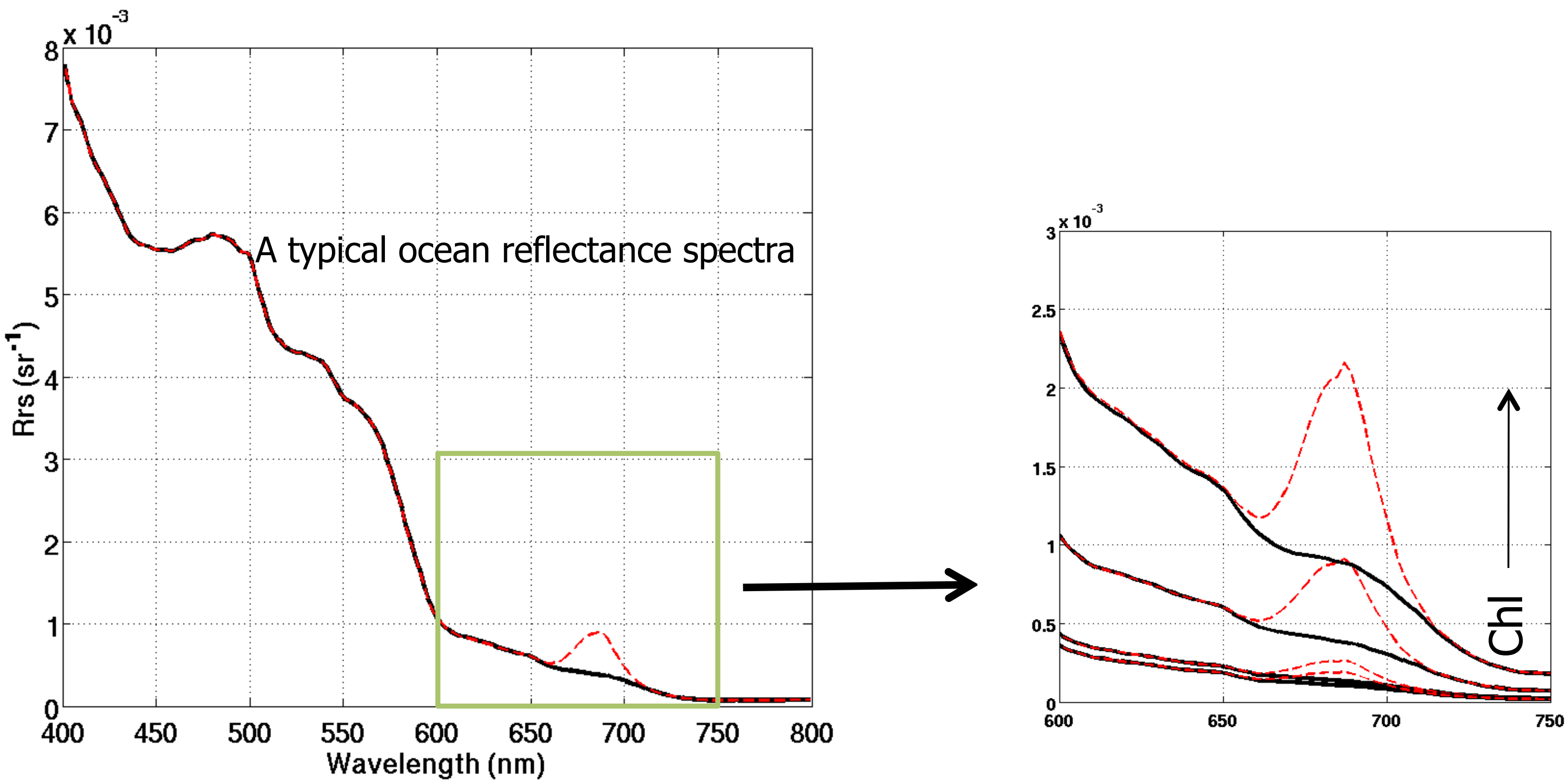
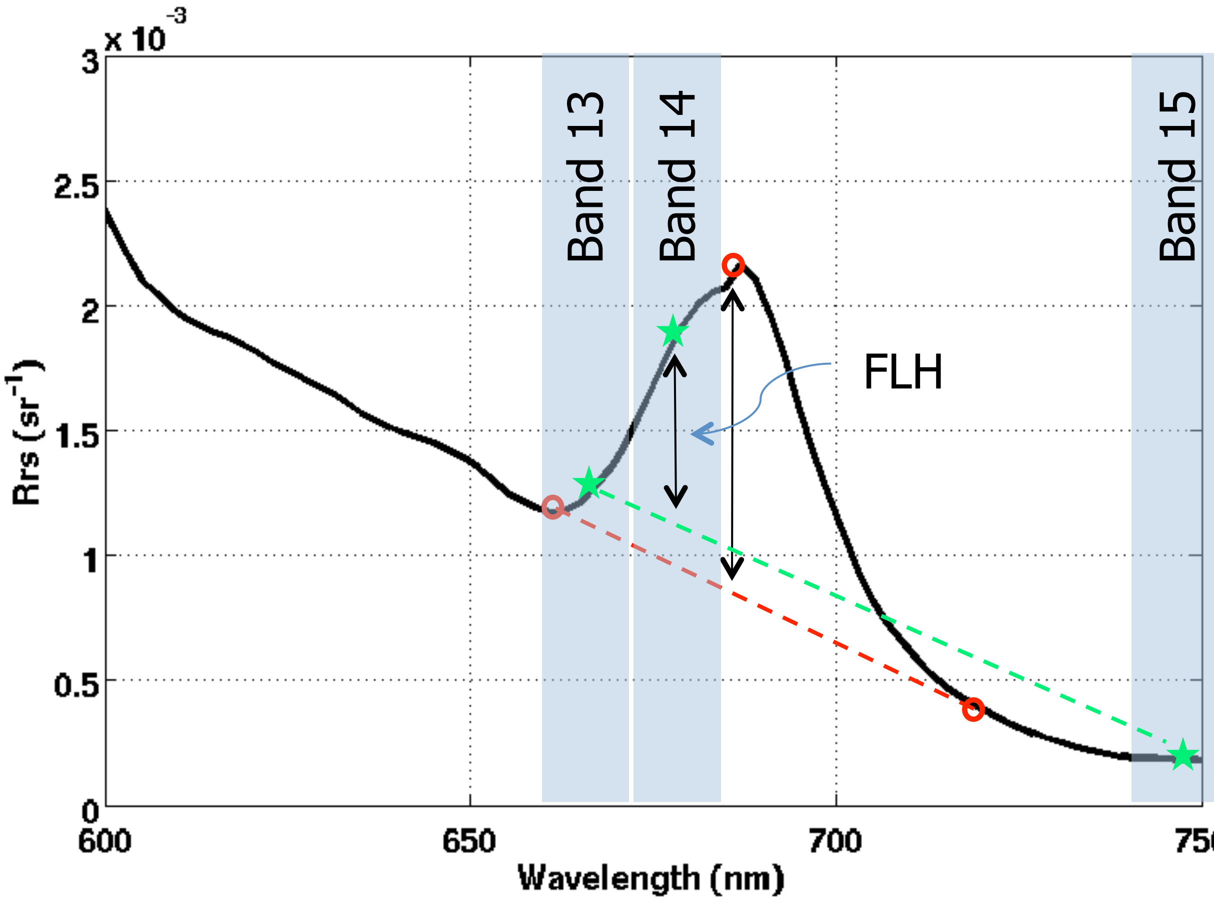


MODIS Fluorescence Line Height (FLH)

- A geometric definition
- Can be related to total fluoresced flux (e.g., Huot et al., 2005)



<u>Why MODIS FLH?</u>

- Alternative & independent measure of chlorophyll (particularly in coastal environments)
- Improved NPP estimates

OLD

- Index of phytoplankton physiology
  - Pigment Packaging
  - Non-photochemical quenching
  - Nutrient stress effects
  - Photoacclimation

NEW

Derivation of φ (Fluorescence quantum yield)

Absorbed energy

$$FLH = Chl_{sat} \times \langle a_{ph}^{*} \rangle \times PAR \times \varphi \times \mathbf{S}$$

- Chl_{sat}: satellite chlorophyll
- $\langle a_{ph}^{*} \rangle$: chlorophyll-specific absorption
- φ: fluorescence quantum yield

- subtract small *FLH* value of 0.001 mW cm^{-2} μm^{-1} sr^{-1} to satisfy requirement that *FLH* = 0 when Chl = 0

Derivation of ϕ (Fluorescence quantum yield)

$$\varphi_{\mathrm{sat}} = \frac{4\pi n_w^2 C_f}{t\,F_0(678)}\;\frac{E_d(0^+, 678)\,F_{\mathrm{sat}}}{\int_{400}^{700} \frac{\lambda}{hc}\,\frac{1}{K(\lambda)+k_L(678)}\,a_{ph}(\lambda)\,E_0(0^-, \lambda)\,d\lambda}$$

Isotropic emmission (4π)

air-sea interface (n_w^2)

full spectral fluorescence emission relative to 683 nm (C_f)

TOA irradiance ($F_0(678)$)

incident scalar PAR ($E_d(0^+, 678)$)

FLH (F_{sat})

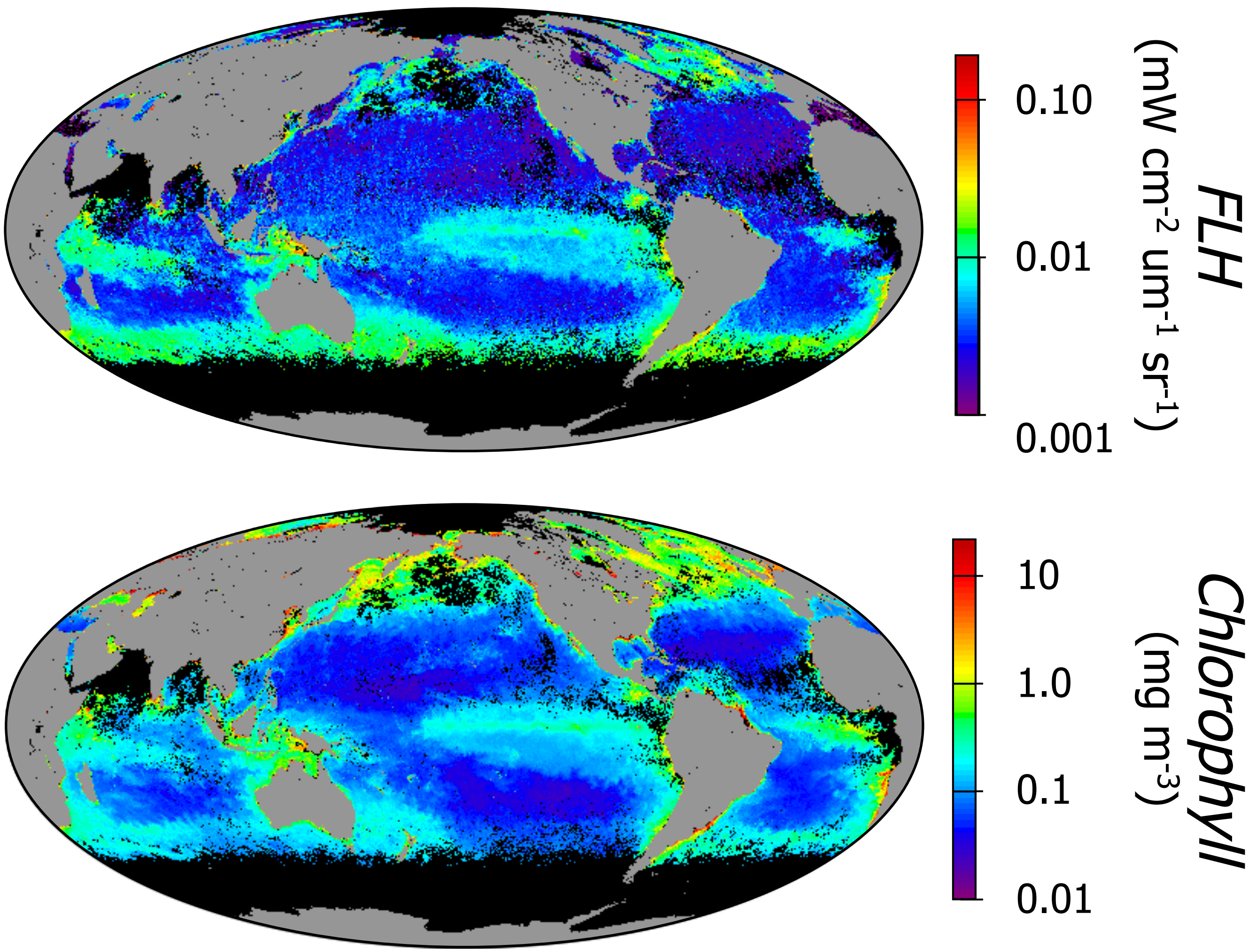
attenuation of downwelling radiation ($K(\lambda)$)

attenuation of upwelling fluorescence ($k_L(678)$)

phytoplankton absorption ($a_{ph}(\lambda)$)

spectral irradiance ($E_0(0^-, \lambda)$)

Results - Global MODIS FLH



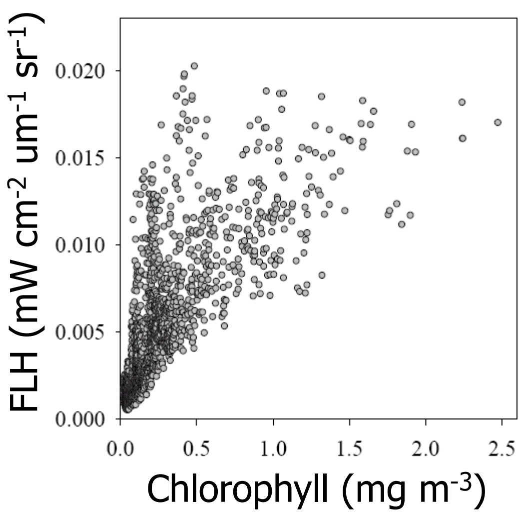
Results - Global MODIS FLH

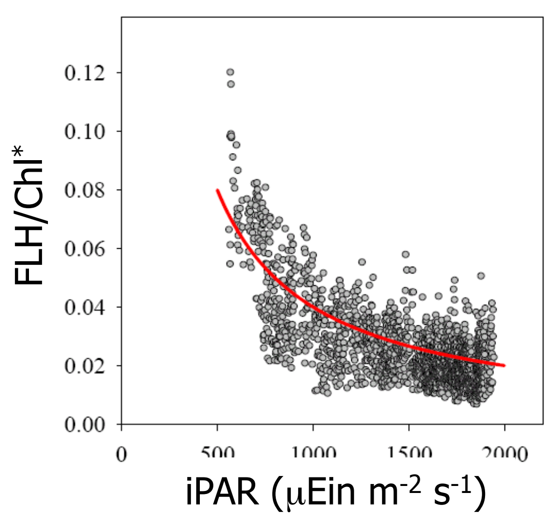
Three primary factors regulate global phytoplankton fluorescence distributions:

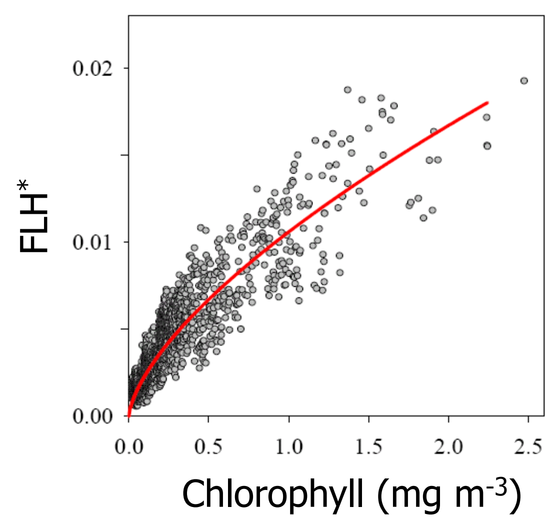
#1. Pigment concentrations (Chl)

#2. Light (non-photochemical quenching)

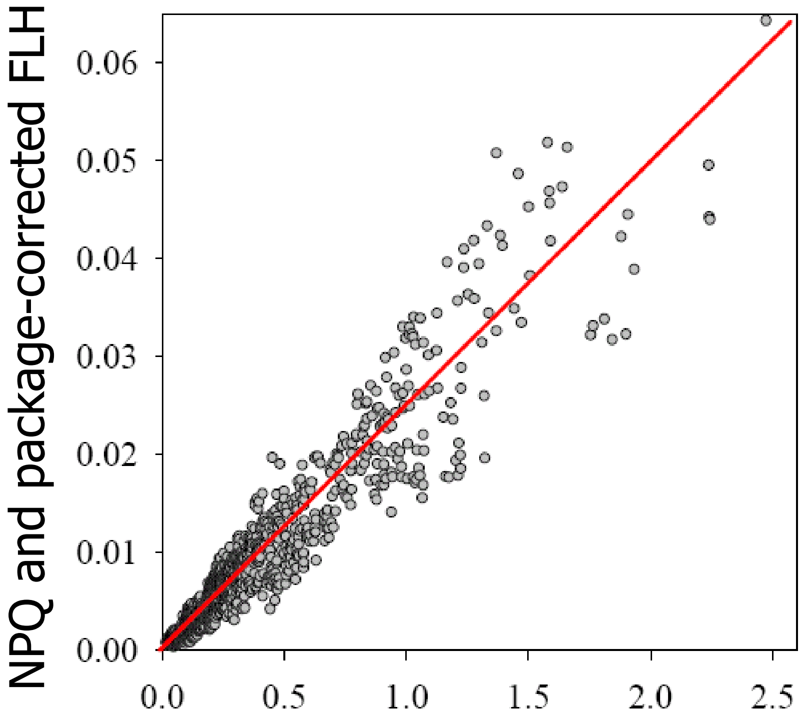
#3. “Pigment packaging”



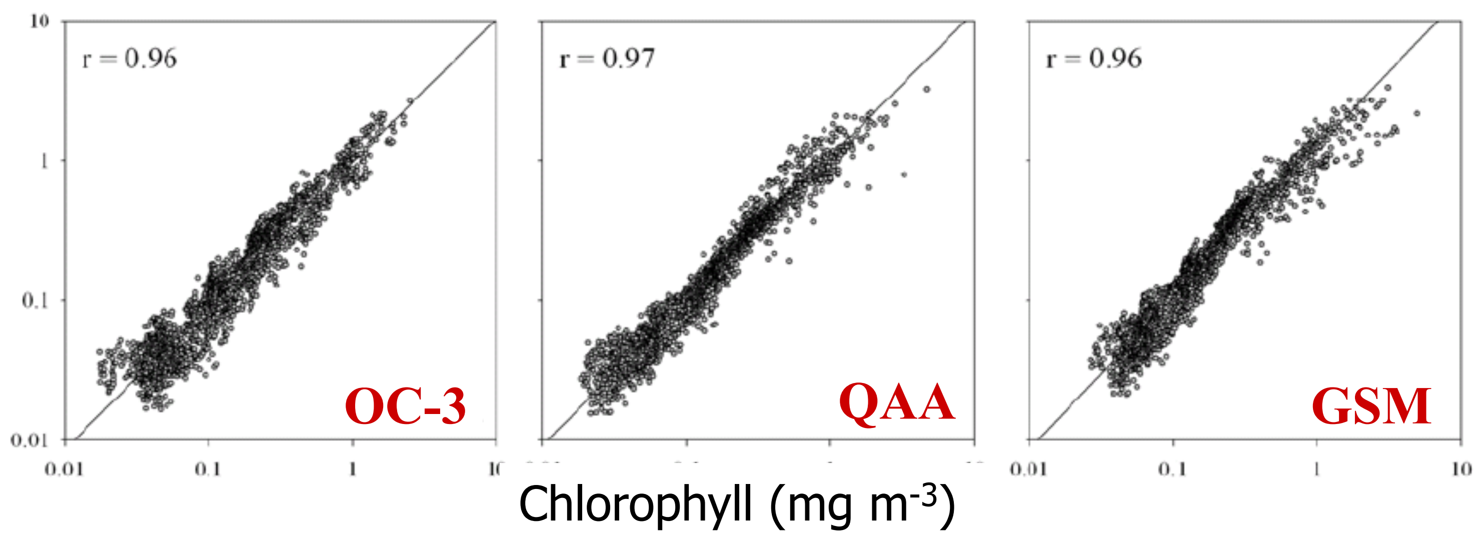




Results - Global MODIS FLH



- After correction for NPQ and pigment packaging
- **What do we expect in the remaining variability?**

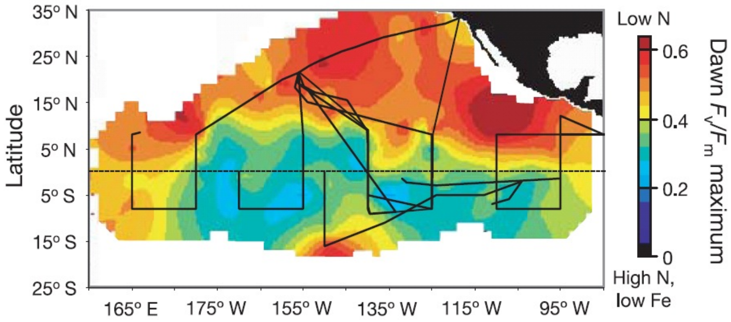


What do we expect in remaining variability?

#1. Unique consequences of iron stress

- Over-expression of pigment complexes
- Increases in PSII:PSI ratio

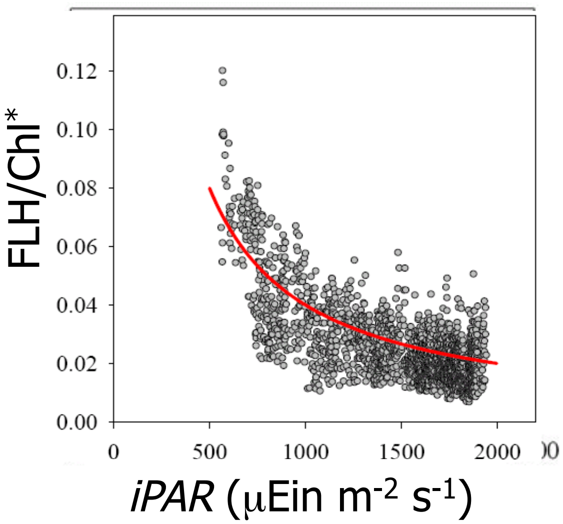
1. Chlorophyll = PSII & PSI
2. Fluorescence = PSII
3. φ increases with PSII:PSI ratio



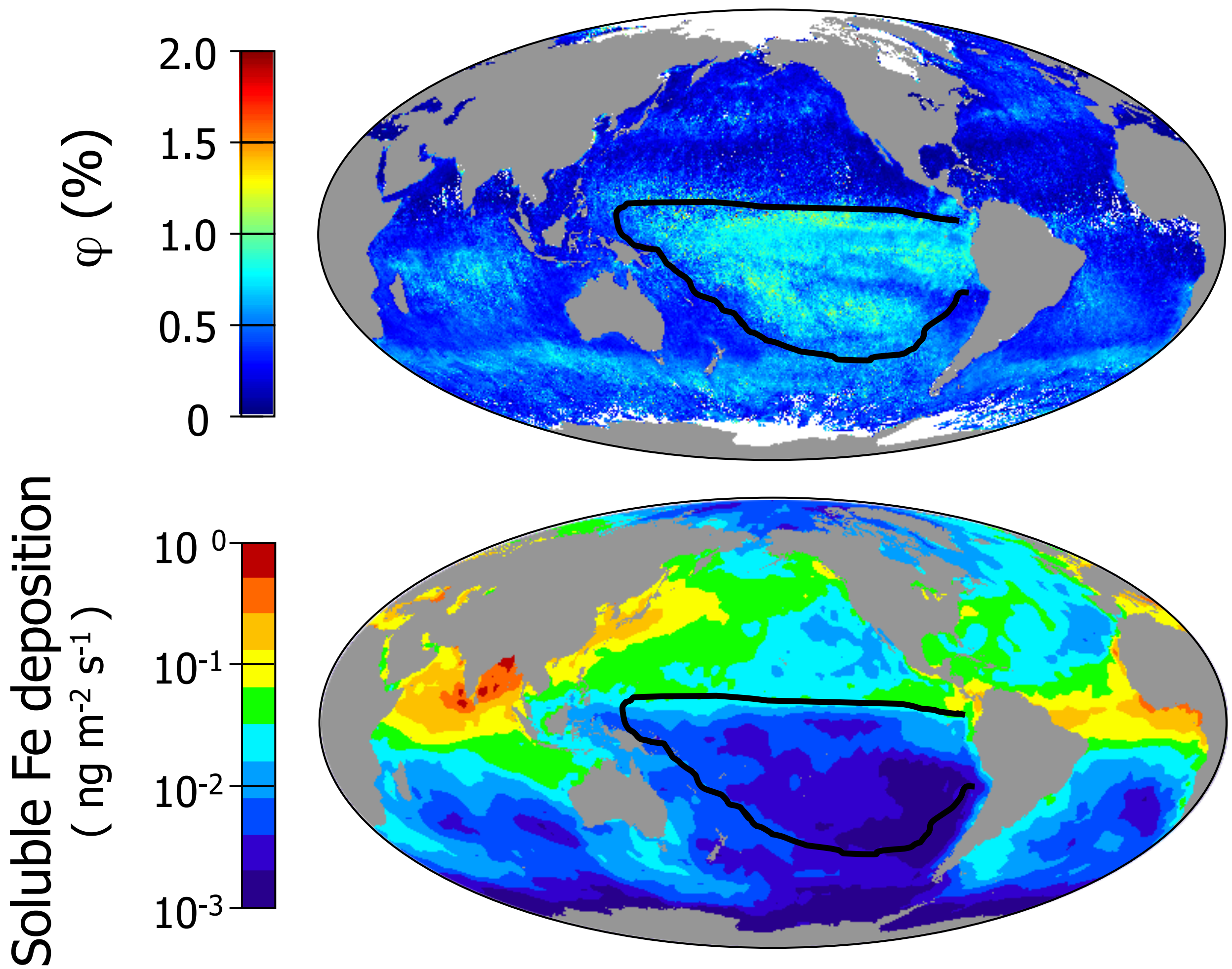
#2. Photoacclimation

- Low light = enhanced NPQ at any given *iPAR*

→ lower φ



Fluorescence Quantum Yields (φ)



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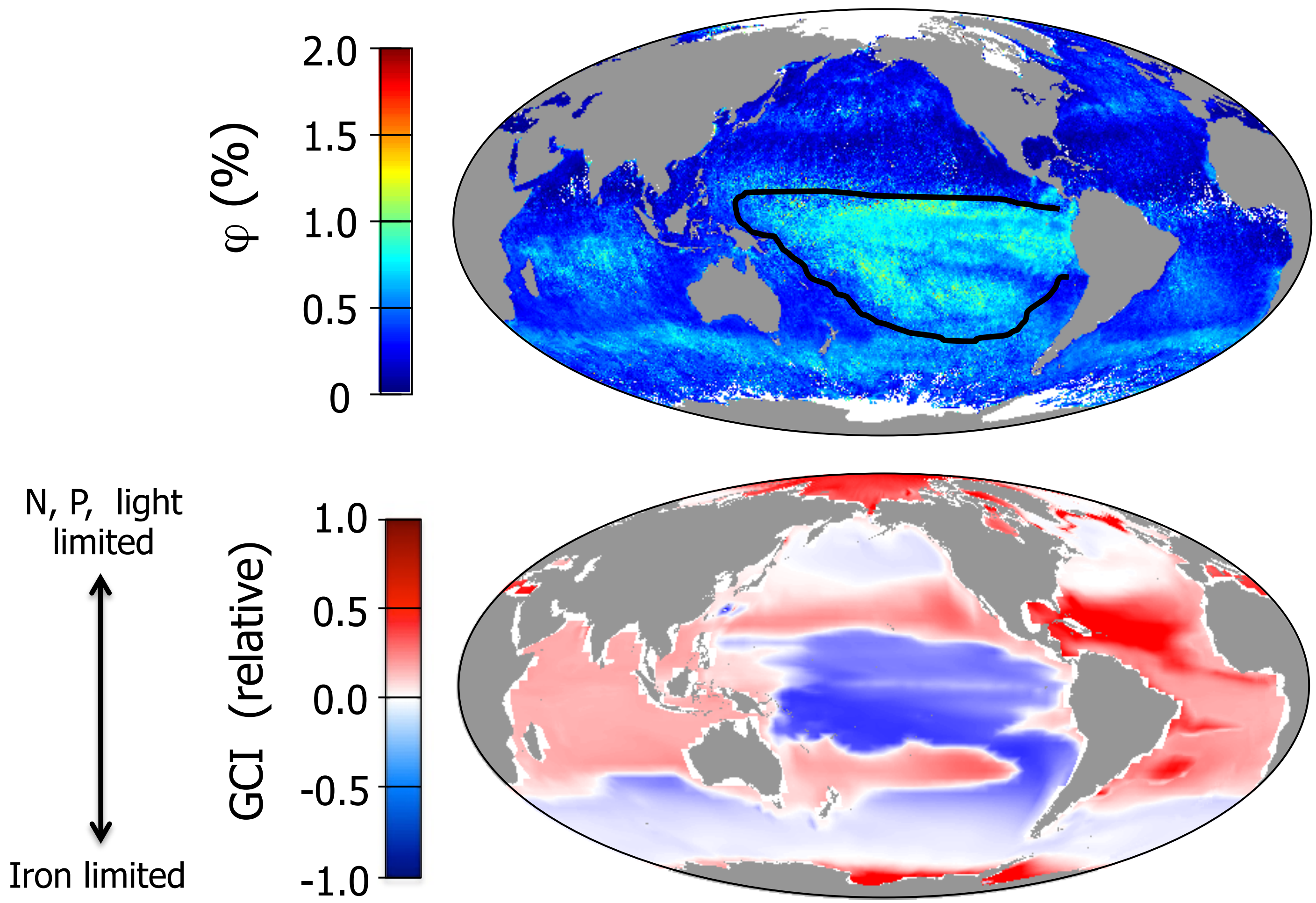
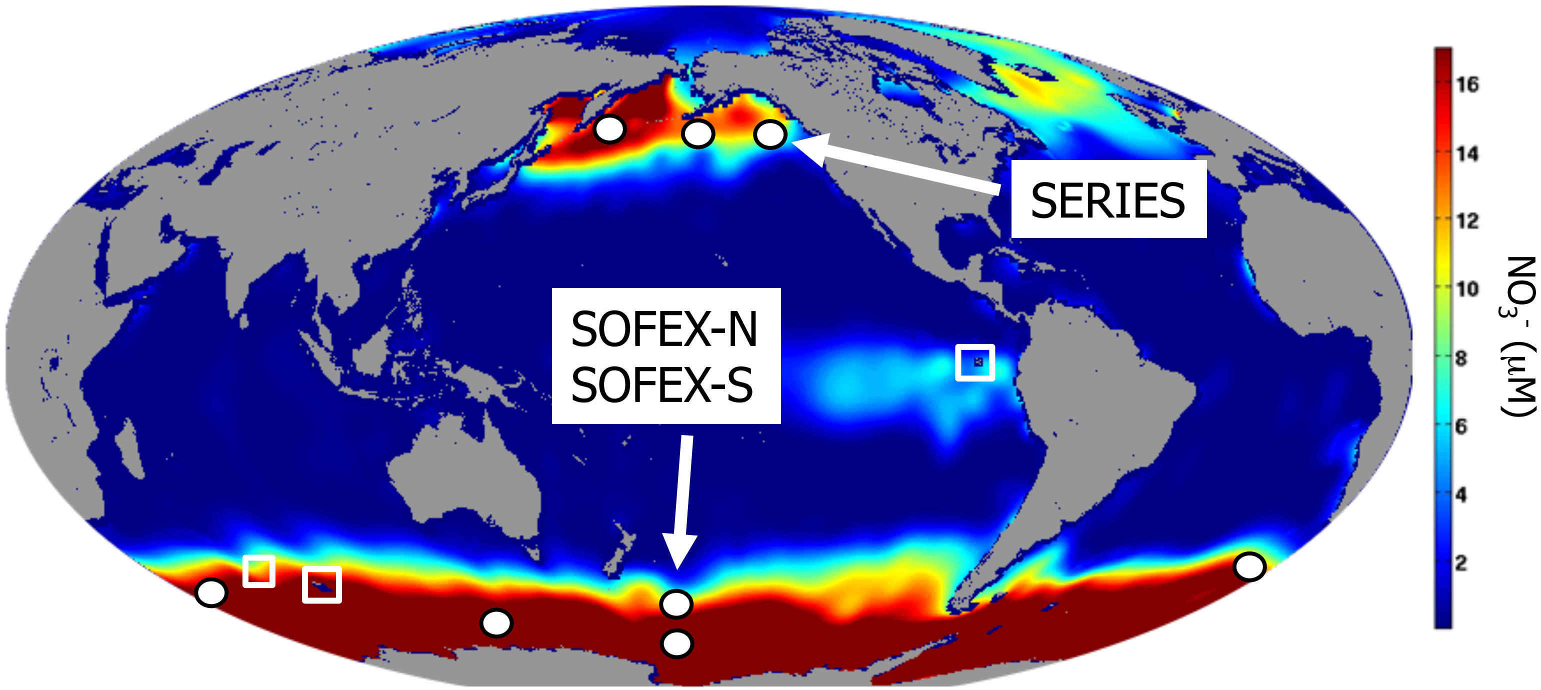


Fluorescence Quantum Yields (φ) and iron

- Broadscale correspondence between fluorescence and degree of Fe stress
  - ↑ φ when Fe is low
  - ↓ φ when Fe is high
- Is this causal? How can we test? What might we expect?

Fluorescence and Fe enrichment experiments

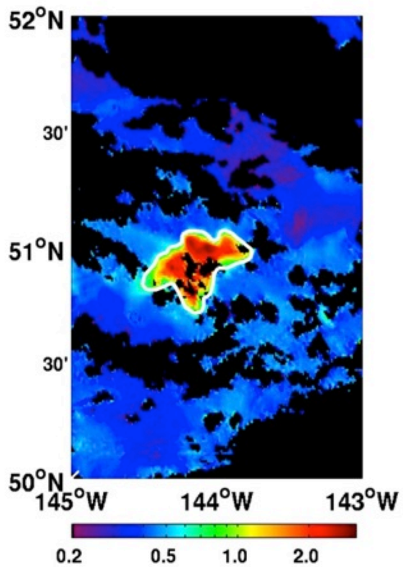


- SERIES – (Subarctic Ecosystem Response to Iron Enrichment Study), Jul/Aug 2002

- SOFeX - (Southern Ocean Iron (Fe) Experiment), Jan/Feb 2002

Fluorescence and Fe enrichment experiments -SERIES

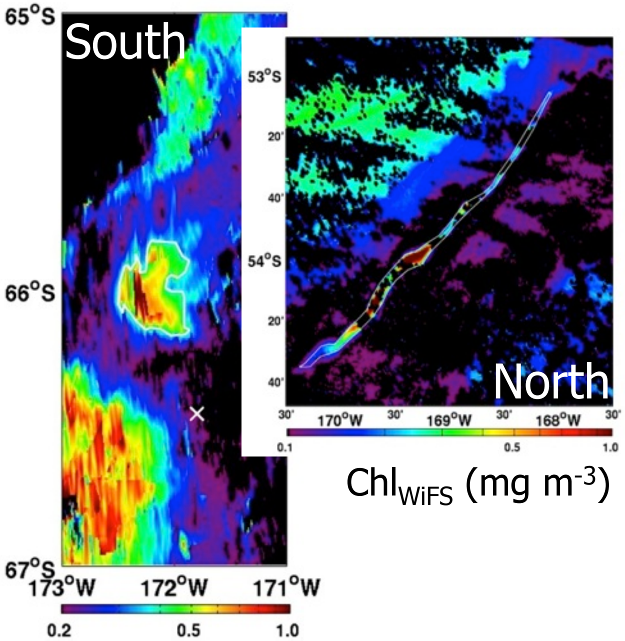
SeaWiFS
29 Jul 2002



Chl (mg m^{-3})

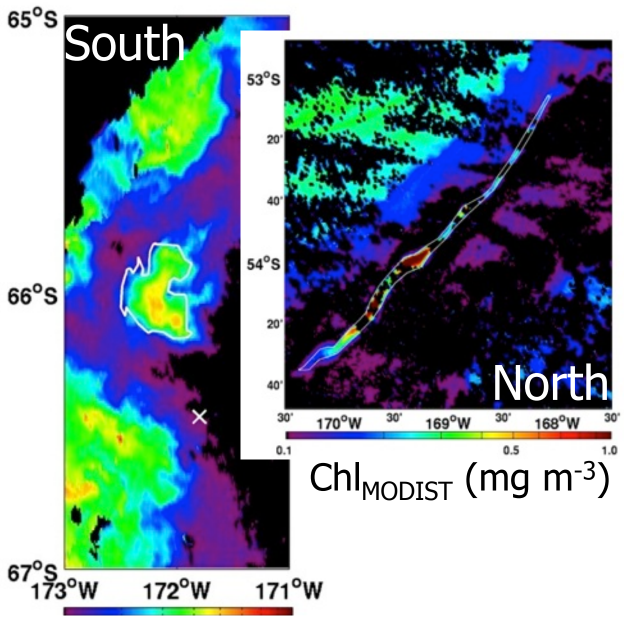
- Coverage is an issue (very cloudy!)
- MODIST consistent with SeaWiFS
- Chl increases, FLH increases, but FLH:Chl decreases!

Fluorescence and Fe enrichment experiments -SOFeX

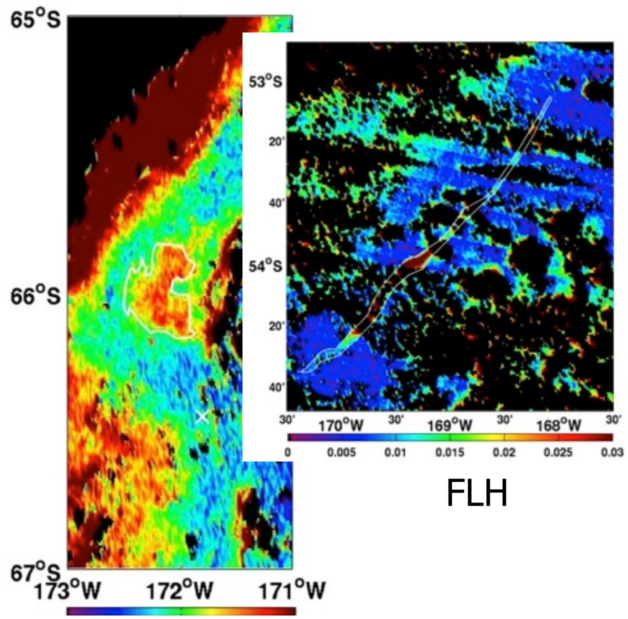


Chl_{WiFS} (mg m^{-3})

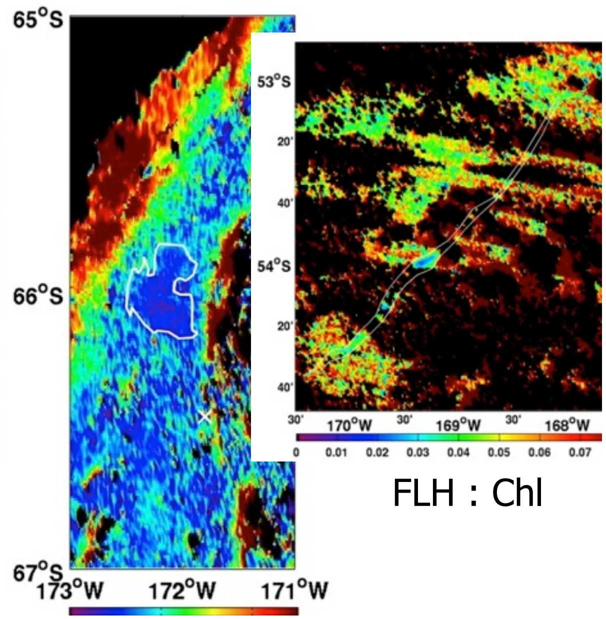
- North = SeaWiFS and MODIST from 12-13 Feb 2002
  South = SeaWiFS and MODIST from 5 Feb 2002
- MODIST consistent with SeaWiFS
- Chl increases, FLH increases, but FLH:Chl decreases!



Chl_{MODIST} (mg m^{-3})

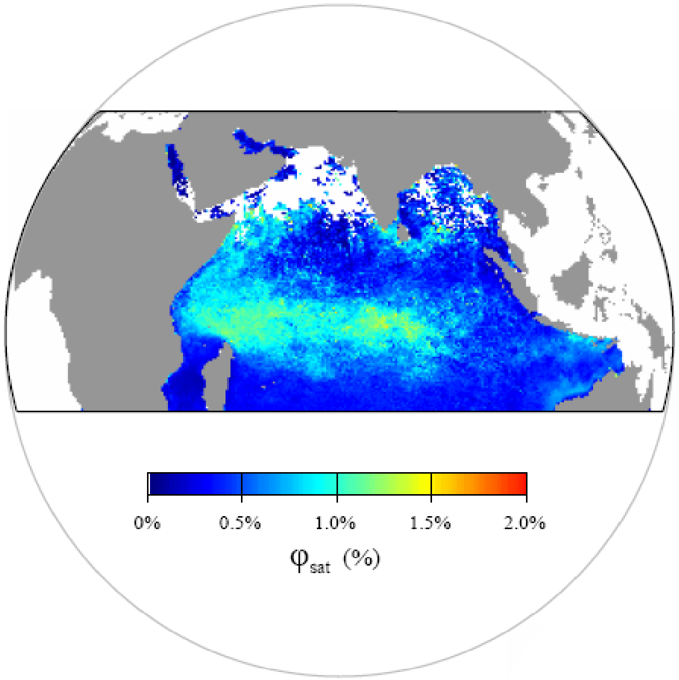


FLH



FLH : Chl

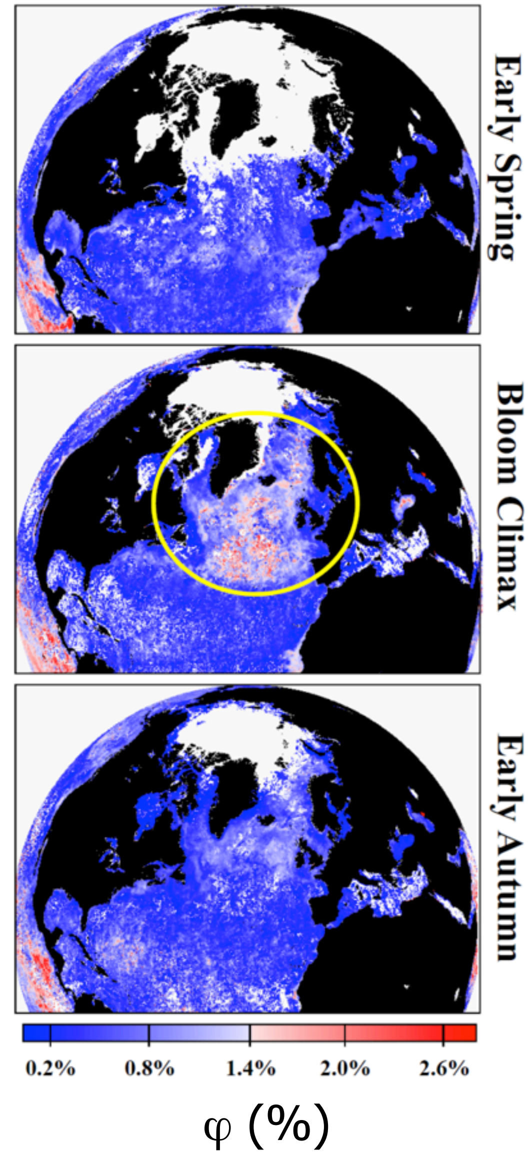
Indian Ocean Fluorescence Quantum Yields (φ)



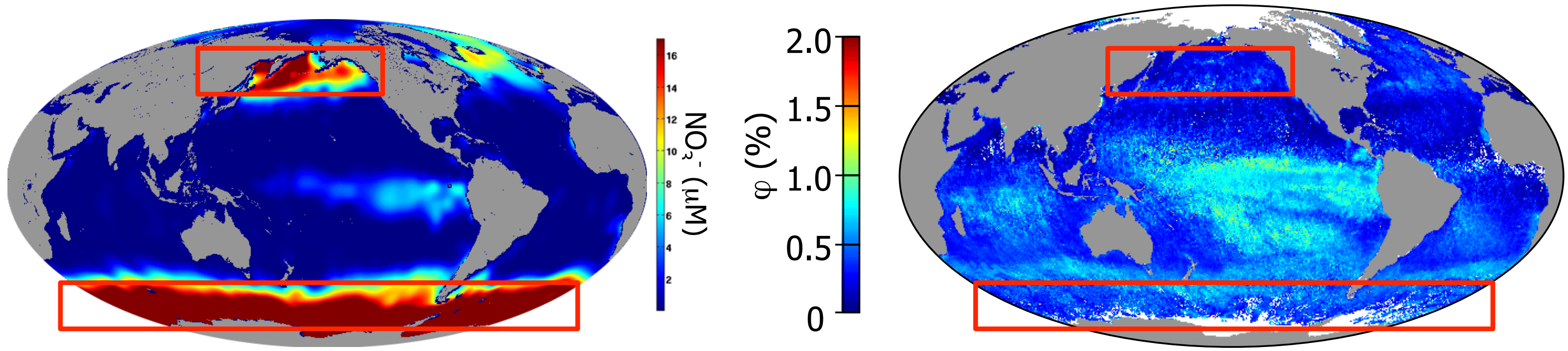
- Seasonally elevated fluorescence over south-central Indian Ocean
- Regionally tuned ecosystem model indicates Fe stress

North Atlantic Ocean φ

- Not generally thought of as being Fe-limited
- In some years, NO_3^- doesn't get drawn down all the way
- Recent field studies have demonstrated Fe-limitation of post-bloom phytoplankton communities (Nielsdotter et al., 2009; Ryan-Keough et al., 2013)

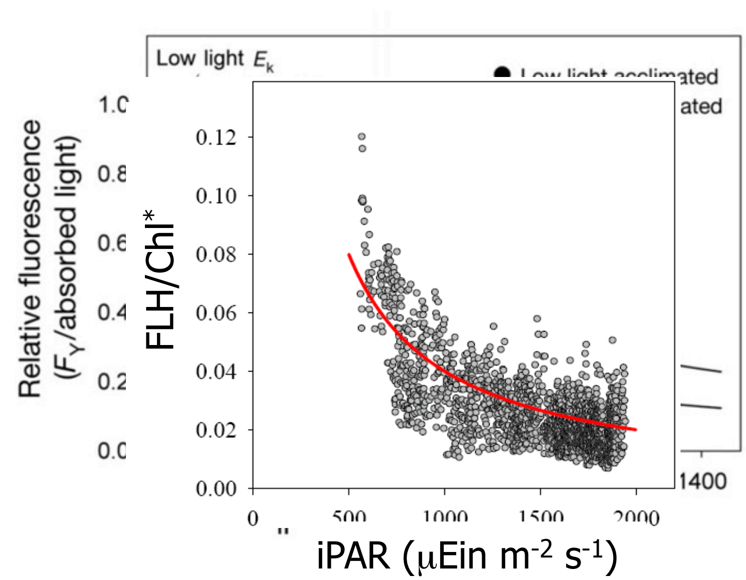


Photoacclimation, NPQ, and φ



- What about Fe-limited areas that do not show elevated fluorescence?

- Related to photoacclimation-dependent NPQ response



Conclusions

- Three major factors influcence FLH and φ :
  [Chl] > NPQ > packaging
- Remaining variability can be related to iron nutrition and photoacclimation
- Demonstrated response to active iron enrichment
- We understand how photoacclimation affects φ in the lab and field, but how do we incorporate that information into satellite studies?

Parting Thoughts

- Tool to map new areas of iron stress
  Examine physiological changes over time
- Inclusion of FLH data into primary production modeling.
  CAFÉ model
- Fluorescence capabilities for future missions?

Thank you!

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