Phytoplankton physiology diagnosed from MODIS chlorophyll fluorescence

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What is Chlorophyll fluorescence?

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

• Chlorophyll-a (Chl) is a ubiquitous plant pigment
• It dissipates some of its absorbed energy as photons (i.e., fluorescence)
• Fluorescent even under natural sunlight
• Fluoresced radiation is discernable in upwelled radiant flux

A typical ocean reflectance spectra

![Graph showing reflectance spectra vs wavelength (nm)]
MODIS Fluorescence Line Height (FLH)

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

- Alternative & independent measure of chlorophyll (particularly in coastal environments)
- Improved NPP estimates
- Index of phytoplankton physiology
  - Pigment Packaging
  - Non-photochemical quenching
  - Nutrient stress effects
  - Photoacclimation
Fluorescence Basics

Three primary factors regulate global phytoplankton fluorescence distributions:

(1) pigment concentrations


(3) a photoprotective response aimed at preventing high-light damage (i.e., “nonphotochemical quenching”, NPQ)
Derivation of $\phi$ (Fluorescence quantum yield)

Absorbed energy

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

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

\[ \varphi_{\text{sat}} = \frac{4\pi n^2 \beta C_f}{t E_0(678)} \frac{E_d(0^+, 678) F_{\text{sat}}}{\int_{400}^{700} \frac{\lambda}{hc} \frac{1}{K(\lambda) + k_L(678)} a_{ph}(\lambda) E_0(0^-, \lambda) d\lambda} \]

full spectral fluorescence emission relative to 683 nm

air-sea interface

Isotropiic emission

TOA irradiance

attenuation of downwelling radiation

attenuation of upwelling fluorescence

phytoplankton absorption

spectral irradiance

incident scalar PAR

FLH
Results
Global MODIS FLH

Chlorophyll (mg m\(^{-3}\))

FLH (mW cm\(^{-2}\) um\(^{-1}\) sr\(^{-1}\))
Global MODIS FLH

- Compute averages within bins of similar Chl $\sigma^2$
- 2003 – 2009 Monthly MODIS OC3 Chl
- 43 regional bins
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Pigment Packaging

Non-photochemical quenching (NPQ)

iPAR (µmol photon m\(^{-2}\) s\(^{-1}\))

MODIS observations
Remaining variability in $\text{FLH}_{\text{corrected}}$
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. $\phi$ increases with PSII:PSI ratio

#2: Photoacclimation
- Low light = enhanced NPQ at any given $iPAR$
  $\rightarrow$ lower $\phi$
Fluorescence Quantum Yields ($\varphi$, or FQY)

Spring 2004

Soluble Fe deposition
(ng m$^{-2}$ s$^{-1}$)

$\varphi_{\text{sat}}$ (%)

Spring 2004

0.001
0.01
0.1
1

0%
0.5%
1.0%
1.5%
2.0%
Fluorescence Quantum Yields ($\phi$, or FQY)

- High $\phi_{sat}$, model iron-limited
- High $\phi_{sat}$, model other-limited
Indian Ocean FQY
North Atlantic FQY

new satellite findings

new field results

Iron limitation of the postbloom phytoplankton communities in the Iceland Basin
Maria C. Nielsdóttir, Christopher Mark Moore, Richard Sanders, Daria J. Hinz, and Eric P. Achterberg
Fluorescence and Fe enrichment experiments

- Example from SERIES
- July 2002 at Station Papa (50°N, 145°W)
Conclusions and Future Directions

1. Ironically, it is the global ocean that is easy, not productive waters

2. Hierarchy: \([\text{Chl}] > \frac{1}{i\text{PAR}_{\text{NPQ}}} > \text{packaging} > \begin{cases} \text{Fe stress} \\ E_k \end{cases}\)

3. Solve \(E_k\) to expand iron diagnostic

4. Solve iron stress to derive \(E_k\) – then apply to Chl:C!

5. New tool for evaluating (i) \(\text{Chl}_{\text{sat}}\), (ii) climate models, (iii) responses to natural and purposeful iron enrichments

6. Opportunity to view physiological changes over time
Thank you!

References:


