Refinement of global MODIS chlorophyll fluorescence quantum yields

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ABSTRACT
Chlorophyll fluorescence is the only remotely sensed property uniquely attributable to phytoplankton, and therefore conveys a wealth of information related to standing stocks, rates of photosynthesis, and important physiological processes.

The overarching goal of this proposal is to better characterize non-photochemical quenching (NPQ) processes that affect observed satellite fluorescence. Successful removal of the NPQ signal will result in satellite fluorescence products that provide a clearer picture of phytoplankton physiology over the entire surface ocean.

The research project proposed here seeks to merge a mechanistic cellular level understanding of NPQ with MODIS satellite data through 4 complimentary efforts:

1. Extrapolation of laboratory findings on NPQ to satellite estimates of photoacclimation
2. Establishment of constraints on NPQ dynamics observed in natural phytoplankton populations using an existing database of active fluorescence and passive radiometry
3. Evaluation of NPQ behavior over the course of the daily irradiance cycle from a geostationary ocean color satellite (Korean GOCI)
4. Use of MODIS fluorescence data at high latitudes where overlapping swaths provide multiple views on a given day

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MODIS chlorophyll fluorescence

- CHL fluorescence can be measured from passive ocean color measurements in the red-nearIR
- The “efficiency” of fluorescence is given by the quantum yield (ϕ):

\[ FLH = \frac{n_L(678) - \frac{n}{\text{m}^2} n_L(667) - \frac{n}{\text{m}^2} n_L(748)}{n_L(678)} \]

- \[ \phi = \frac{E_\mu(0^*, 678) FLH}{\int_0^\infty \frac{1}{K_c K_s(\lambda)} a_{\mu \lambda} E_\mu(0^*, \lambda) d\lambda} \]

Non-photochemical quenching in MODIS fluorescence measurements

- NPQ often dominates FLH and \( \phi \) variability
- It obscures other forms of interesting physiology contained in satellite fluorescence measurements

MODIS fluorescence and iron stress

- Fluorescence is a well-known diagnostic of iron (Fe) stress
- This relationship presents a link between satellite fluorescence and climate

How can we remove non-photochemical quenching (NPQ) effects from MODIS fluorescence measurements?

1. NPQ in Fast Repetition Rate fluorometry (FRRf) data

- Continuous measurements of active fluorometry displays NPQ behavior
- We have >500 sampling days worth of these data to characterize variability in NPQ

2. Analysis of geostationary ocean color data

- Geostationary satellite observations can resolve NPQ in hourly measurements of chlorophyll fluorescence
- We can use data from the Korean Geostationary Ocean Color Imager (GOCI)
- The NASA Ocean Biology Processing Group will soon be receiving, processing, and archiving GOCI data

3. MODIS data at high latitudes

- High latitude environments can be imaged by MODIS on several (3-5) orbits per day
- The range of light levels corresponding to these granules should allow us to resolve NPQ for a given day or set of consecutive days (e.g., during the winter MODIS Aqua will image the same pixel cycling through 50-100% of its daily maximal irradiance

4. Evaluation of NPQ behavior from laboratory and field measurements

- NPQ can be characterized in a laboratory setting
- We can extrapolate results from past experiments

Figure 1. Relationship between incident light, absorption, and fluorescence. Absorbed light is a linear function of incident light, while fluoresced light saturates. At high light levels, the fluorescence yield closely approximates an inverse (1/iPAR) function of light (red line). As phytoplankton acclimate to different growth irradiances (Ia), their saturation point (Ia) changes causing NPQ to be engaged at different times. For example, phytoplankton acclimated to low light have a low Ia, and thus NPQ is engaged sooner, resulting in a more rapid reduction in \( \phi \).

Figure 2. Non-photochemical quenching (NPQ) in MODIS chlorophyll fluorescence data. (Left) MODIS Level-3 FLH from June 2011 for discrete CHL bins averaged over the North and South Pacific and Atlantic Subtropical Gyres. For a given CHL concentration, FLH in the summertime hemisphere (red and green lines are N. Pacific and N. Atlantic, respectively) is significantly lower than in the low light, wintertime hemisphere (black and blue lines are S. Pacific and S. Atlantic, respectively). (Right) Five years of monthly, global MODIS Level-3 data binned regionally. Red line is scaled 1/iPAR relationship, which is the basis for the existing NPQ correction.

Figure 3. MODIS Terra daily composite imagery (July 29, 2002) around the SERIES experiment in Subarctic Northeast Pacific Ocean. The Fe-enriched patch is outlined in black and is >1000 km².

Figure 4. Global average \( \phi \) during Spring 2004. \( \phi >1.4\% \) are shown in a shade of red to highlight areas of generally elevated fluorescence. Red boxes outline canonical Fe-limited regions. Only Equatorial Pacific (B) shows widespread elevated \( \phi \), while Subarctic Pacific (A) and Southern Ocean (C) do not.

Figure 5. Relative fluorescence yield (~\( \phi \)) as a function of iPAR for high and low light-acclimated cultures of Thalassiosira weissflogii. Theoretical curves from Behrenfeld et al. (2009). Reprinted with permission from Milligan et al. (2012).