An Accurate Absorption-Based Net Primary Production Model for the Global Ocean

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Ocean Color Remote Sensing: Science & Challenges

Ocean Color \( (R_{RS}(\lambda)) \) \[\rightarrow\] Net Phytoplankton Production (NPP) Growth Rates (\( \mu \))

![Graph showing the relationship between Ocean Color and Net Phytoplankton Production](image-url)
NPP Models

- Most published NPP models use Chl $a$ as their central metric of phytoplankton biomass.
- Disparate changes in cellular Chl:C in response to light and nutrients confound a direct relationship between Chl $a$ and NPP.

NPP Models

- Spectral inversion algorithms now permit retrievals of Inherent Optical Properties (IOPs) from space (Lee et al. 2002; Maritorena et al. 2002; Werdell et al. 2013).

- The Carbon, Absorption, Fluorescence and Euphotic-Resolved (CAFE) model framework seeks to incorporate these products into a mechanistic model of NPP and μ.
Phytoplankton Absorption Coefficient \( (\alpha_\phi) \): The New Chlorophyll

- The phytoplankton absorption coefficient \( (\alpha_\phi) \) represents the sum of the product of all photosynthetic and non-photosynthetic pigments and the specific absorbance in-vivo.
Model Parameterization

Absorption Model: \( NPP = E(\lambda) \times a_{\phi}(\lambda) \times \phi_{\mu} \)

Carbon Model: \( NPP = C_{Phyto} \times \mu \)

Combined Eqs: \( \mu = E(\lambda) \times a_{\phi}(\lambda) \times \phi_{\mu} / C_{Phyto} \)

Where: \( E(\lambda) \) is spectral extrapolation of PAR

\( C_{Phyto} \) is derived from Graff et al. (2015)

\( a_{\phi}(\lambda), b_{bp}(\lambda) \) are from the GIOP-DC

\( \phi_{\mu} \) is the quantum efficiency of growth

Model Parameterization

\[ \phi_\mu = \phi_\mu^{\text{max}} \times \tanh\left(\frac{E_K}{E}\right) \]
Model Parameterization: $E_K$

Other absorption-based models:

- $E_K$ is globally constant at 116 mmol m\(^{-2}\) s\(^{-1}\) (Marra et al. (2007))
- $E_K$ varies with sea-surface temperature (SST) (Antione and Morel 1996; Smyth et al. 2005)

CAFE Model:

- $E_K$ varies with Growth Irradiance (Behrenfeld et al. 2015)
Model Parameterization - $E_K$

A) $E_K$ Annual Climatology

C) $E_K$ seasonality in select regions

Optical Model

SST Model

NPT  Optical Model  SST Model

NAT

NPG

NAG

SPG
Other absorption-based models:

- $\phi_{\mu}^{Max}$ is globally constant: 0.060 mol C (mol photons)$^{-1}$ (Smyth et al. 2005; Marra et al. 2007)
- $\phi_{\mu}^{Max}$ is globally variable: 0.058 ± 0.038 mol C (mol photons)$^{-1}$ (Antione and Morel 1996)
Model Parameterization: $\phi^\text{max}_\mu$

Other absorption-based models:

- $\phi^\text{Max}_\mu$ is globally constant: 0.060 mol C (mol photons)$^{-1}$ (Smyth et al. 2005; Marra et al. 2007)
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Model Parameterization: $\phi_{\mu}^{\text{max}}$

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Model Parameterization: $\phi^m_{\mu}$

Other absorption-based models:

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- $\phi^M_{\mu}$ is globally variable: 0.058 ± 0.038 mol C (mol photons)$^{-1}$ (Antione and Morel 1996)

Model Validation: $\phi_{\mu}^{\text{max}}$

Light-limited cultures

Nitrogen-limited cultures

Model Climatology

Global NPP estimated from MODIS monthly climatology is 53.8 Pg C year⁻¹
Model Validation – PPARR Approach

- CAFE NPP model results were tested against in-situ NPP measurements at 10 sites (n=1048)
- Data and methods follow PPARR4 (Saba et al. 2011)

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Model Validation – PPARR Approach

$$RMSD = \left( \frac{1}{n} \sum_{i=1}^{n} \Delta(\log_{10} NPP_{mod} - \log_{10} NPP_{obs})^2 \right)^{0.5}$$

$$Bias = \text{mean}(\log_{10} NPP_{mod}) - \text{mean}(\log_{10} NPP_{obs})$$
Model Validation – PPARR Approach

[Map and graphs showing validation results for different regions and models.]
Model Validation – Direct Satellite Measurements

Hawaii Ocean Time Series

- Measured
- CAFE Model

NPP (mg C m⁻² d⁻¹)

HOT 45 meters

HOT 100 meters

NPP (mg C m⁻³ d⁻¹)

Date

2006 2007 2008 2009 2010 2011 2012
Future Directions

• Most phytoplankton biomass is hidden from satellite measurements of ocean color.
• BIO-Argo profiles can help fill in this missing data
Future Directions

• Hyperspectral ocean color data (e.g. PACE) will provide improved derivation of IOPs, potentially allowing for taxonomic discrimination from space
Acknowledgements

NASA: The Science of Terra and Aqua

Questions?