Using AQUA MODIS PIC concentration to determine coccolithophore bloom phenology

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http://visibleearth.nasa.gov/
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Coccolithophore blooms from space

http://earthobservatory.nasa.gov/
http://visibleearth.nasa.gov/
Why are we interested in PIC?

Image adapted from de Vargas et al., 2007
The merged PIC algorithm

Balch et al., 2005 - Two-band algorithm. Uses LUT generated from forward modelling of the optical properties of chlorophyll-a and PIC. Good in relatively low PIC concentrations.

Gordon et al., 2001 - Three-band algorithm. Uses 3 NIR wavebands to estimate atmospheric effects and backscatter from coccolithophores. Good in relatively high PIC concentrations.
Global PIC

PIC Global Time Series (MODIS-Aqua)
Mission record- Highest PIC during austral summer
PIC Global Time Series (MODIS-Aqua)
Annual coccolithophore phenology
Relating surface to integrated PIC

Integrated PIC > expected if surface PIC homogenously dist.

Integrated PIC < expected if surface PIC homogenously dist.

Dashed line assumes homogenous distrib. throughout 100m water column

\[ y[\pm 0.233] = 40.555[\pm 2.520]x^{0.560[\pm 0.025]} \]

\[ R^2 = 0.482; \ DF = 550; \ Fstat = 512; \ P < 0.001 \]
Coccolithophore bloom phenology

North Atlantic

PIC (mmol m$^{-3}$)

- Bloom peak
- Bloom start
- Bloom end
- Start threshold
- End threshold

Hopkins et al., 2015, GBC
Bloom start date

Hopkins et al., 2015, GBC
Bloom peak concentration

Hopkins et al., 2015, GBC
Phytoplankton succession

Succession in peaks

![Graph showing species succession over time with peaks for chlorophyll and PIC concentrations.](image-url)
Co-occurrence of peaks

Species co-existence

- CHLOROPHYLL
- PIC

CONCENTRATION vs. TIME
PIC and chlorophyll time-series
Succession in peaks

TIME

CONCENTRATION

>24 DAYS

CHLOROPHYLL

PIC

INSET: PIC (mmol m$^{-3}$)

CHLOROPHYLL
Co-ocurrence of peaks

<16 DAYS

TIME

CONCENTRATION

CHLOROPHYLL

PIC
White bounded areas represent regions with low variability, persistent periods of missing data or water column depths <150 m.
Peaks that co-occur

White bounded areas represent regions with low variability, persistent periods of missing data or water column depths <150 m
Coccolithophores and diatoms

LARGE

Silicate

Relatively high Fe

SMALL

No silicate

Relatively low Fe
The case for Fe?

Timing gap between chlorophyll peak and PIC peak

Misumi et al., 2014 Biogeosciences
The case for Fe?

No timing gap between chlorophyll peak and PIC peak

Misumi et al., 2014 Biogeosciences
Coccolithophores and diatoms

**HIGH Fe**
Large diatoms dominate
Coccolithophores have to wait until diatom population has diminished

**LOW Fe**
Large diatoms unable to establish dominance in bloom
Coccolithophores can bloom with other phytoplankton taxa
Ongoing work
The merged PIC algorithm

Recent changes to PIC algorithm

- LUT modified to reflect data from increased number of in-situ acid labile $b_b$ measurements
- New $b_b^*$ implemented (now $1.628 \, \text{m}^2 \, \text{mol}^{-1}$)
Satellite PIC and in-situ PIC matchups – Terra MODIS

\[ y = 1.042x - 0.145 \]
\[ R^2 = 0.694 \]
Satellite PIC and in-situ PIC matchups – Aqua MODIS

\[ y = 0.7885x - 0.886 \]

\[ R^2 = 0.639 \]
Ongoing work - MISR

https://www-misr.jpl.nasa.gov/
Ongoing work – PIC at sub-kilometer resolution

http://earthobservatory.nasa.gov
Ongoing work – Edge detection algorithm

Density

T from MODIS
S from Aquarius

Edge Detection

Cayula & Cornillon, 1991
Thank you

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PIC and coccolithophores
Two band LUT

Adapted from Balch et al, 2005, *JGR*
Coccolithophores and chlorophyll

Bloom PIC content = 0.75 mmol m$^{-3}$

Bloom coccolith total = $0.75 \times 10^{-3} \div 0.016 \times 10^{-12} = 4.7 \times 10^{10}$ coccoliths m$^{-3}$ = 47000 ml$^{-1}$

Assuming 12 coccoliths per cell & 100 loose coccoliths per cell = 112 coccoliths for every cell

No. of cells in bloom = 420 cells ml$^{-1}$

Assuming chl content per cell = 0.1 pg [Stolte et al, 2000]

Chl contribution to bloom = 0.04 mg m$^{-3}$
PIC concentration seasonality

North Atlantic

MODIS PIC data; 8-day, 9km composites for 2003-2012