Particulate organic carbon and phytoplankton carbon: algorithm comparisons

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IOCS 2017, Lisbon
Outline

- Particulate carbon pools
- Why and how - POC, PIC, $C_{phy}$
- What do users want?
- \textit{In situ} measurements
- Algorithm validation
- Theoretical considerations
- Recommendations and points for discussion
Particulate Carbon Pools

\[ pCO_{2\text{atm}} \]

\[ pCO_{2\text{water}} \]

Air-sea flux \( (FCO_2) \)

\[ \text{Dissolved Inorganic Carbon} \]
- \( \text{CO}_2 \)
- \( \text{HCO}_3^- \)
- \( \text{H}_2\text{CO}_3 \)
- \( \text{CO}_3^{2-} \)

\[ \text{Dissolved Organic Carbon} \]
- Non-colored component
- CDOM

Primary production

Respiration

\[ \text{Particulate Organic Carbon} \]
- Particulate Organic Carbon
- Total Carbon phytoplankton
- Total chlorophyll \( a \)
- Phytoplankton groups (Chlorophyll \( a \))
- Phytoplankton groups (Carbon)
- Zooplankton & bacteria
- Detritus

\[ \text{Coccolithophores} \]

Export

Production

Riverine input

LAND

Figure courtesy of C.S. Rousseaux & W.W. Gregg
POC and phytoplankton carbon

- POC – multiple ways to detect from satellite as [POC] linked to optics in a variety of ways:
  - Phytoplankton contribute, therefore some link with [Chl]
  - POC is particulate, therefore linked with absorption and scattering.
- Phytoplankton carbon – as above [Chl], $a_{ph}$, $b_{bp}$. 
PIC

- PIC in the ocean is dominantly from calcifying organisms such as coccolithophores and foraminifera.
- Interesting due to role in carbonate system and ecosystem role.
- Detectable from space due to high scattering, algorithms based on $R_{rs}$ ratios, $b_{bp}$ etc.

See work by Gordon, Balch, Shutler and others...
What do users want?

- Users surveyed:
  - Interest for model validation
  - POC and $C_{\text{phy}}$
  - Uncertainties are important
    - Range of 10-25% = good. More also acceptable for some users.
Validation

• POCO project recently undertook an algorithm intercomparison exercise for both POC and $C_{\text{phy}}$ algorithms.

• Collation of large *in situ* databases for POC and $C_{\text{phy}}$
  
  – Uncertainties in this, particularly for $C_{\text{phy}}$:
    
    • Blanks for POC (see Cetinic *et al.*, 2012)
    
    • Proxies (with challenging assumptions – discussed by Heidi)
    
    • More direct methods (e.g. Casey *et al.*, 2013; Graff *et al.*, 2015)

• Matchups extracted from OC-CCI version 2.

• Algorithms applied:
  
  – POC: Stramski *et al.*, 2008, $R_{\text{rs}}$ (A), Stramski *et al.*, 2008, $b_{\text{bp}}$ (B), Loisel *et al*. 2002, $b_{\text{bp}}$ and [Chl] (C), Gardner *et al.*, 2006, $K_d(490)$ (D), Konstadinov *et al.*, 2016, $b_{\text{bp}}$ to derive PSD (E)
  
  – $C_{\text{phy}}$: Sathyendranath *et al.*, 2009, [Chl] (A), Maranon *et al.*, 2014, [Chl] (B), Behrenfeld *et al.*, 2005, $b_{\text{bp}}$ (443) (C), Martinez-Vicente *et al.*, 2013, $b_{\text{bp}}$(470) (D), Kostadinov *et al.*, 2016, $b_{\text{bp}}$ PSD (E), Roy *et al.*, 2017, [Chl], $a_{\text{ph}}$(676).
Validation - POC

~63000 points, 3891 matchups, biased towards Atlantic (AMT)
Validation - $C_{\text{phy}}$

$C_{\text{phy}}$ (mg m$^{-3}$)

~50000 points, 593 matchups, biased towards Atlantic (AMT)
Algorithm intercomparison - POC

Stramski $R_{rs}$

Stramski $b_{bp}$

Loisel, $b_{bp}$ [Chl]

Gardner $K_d$

Kostadinov, $b_{bp}$ PSD

$\text{Algorithm A-POC}$

$\text{Algorithm B-POC}$

$\text{Algorithm C-POC}$

$\text{Algorithm D-POC}$

$\text{Algorithm E-POC}$

$r = 0.80$

$r = 0.73$

$r = 0.79$

$r = 0.80$

$\varphi = 0.29$

$\varphi = 0.33$

$\varphi = 0.33$

$\varphi = 0.32$

$\Delta = 0.04$

$\Delta = 0.03$

$\Delta = 0.13$

$\Delta = 0.13$

$\delta = 0.93$

$\delta = 0.84$

$\delta = 1.00$

$\delta = 0.63$

$I = 0.14$

$I = 0.76$

$I = 0.13$

$I = 0.62$

$A$

$B$

$C$

$D$

$E$

$F$

$G$

$H$

$\text{POC (mg m}^{-3}\text{)}$

$\text{POC (mg m}^{-3}\text{)}$

$\text{POC (mg m}^{-3}\text{)}$

$\text{POC (mg m}^{-3}\text{)}$

$\text{in situ POC (mg m}^{-3}\text{)}$

$\text{POC (mg m}^{-3}\text{)}$

$\text{POC (mg m}^{-3}\text{)}$

$\text{POC (mg m}^{-3}\text{)}$

$\text{in situ POC (mg m}^{-3}\text{)}$

$\text{in situ POC (mg m}^{-3}\text{)}$
Algorithm intercomparison - $C_{phy}$

**Algorithm A**
Sathyendranath [Chl]

**Algorithm B**
Maranon [Chl]

**Algorithm C**
Behrenfeld $b_{bp}$

**Algorithm D**
Martinez-Vicente $b_{bp}$

**Algorithm E**
Kostadinov $b_{bp}$

**Algorithm F**
Roy [Chl] $a_{ph}$
Algorithm intercomparison - $C_{phy}$
Theoretical considerations, C:Chl

- Scatter between in situ POC and satellite [Chl].
- Algorithms should be able to capture this variability.
Product maturity

- Validation of POC for optical waterclasses as per OC-CCI
- Errors per waterclass assigned to each pixel.
- Weighted sum when there is multiple membership.
- Errors close to user requirements.
Outstanding theoretical questions?

• Beyond empirical to understand the scatter we see in relationships:
  – What causes this?
  – We have lots of ideas – size/particle structures/PFTs/photosynthesis/irradiance parameters, growth rates?
  – How do we quantify these routinely and evolve understanding towards new algorithms?
  – Semi-analytical/models probably necessary for this.

• Assumptions invoked to interpret optical data also influence algorithm design/choice of validation data
  – e.g. phytoplankton carbon from cell counts (what size range?)
  – Backscattering…
  – Assumptions – consistent between in situ data and algorithm?
Discussion points

• Where are the critical shortcomings and needs?
• What is ready for operational agencies to pick up
• Algorithms development and validation: what actions are needed?
• What is needed from *in situ* observations?
• What are the priority directions, evolution of needs?
Discussion points

• Where are the critical shortcomings and needs?
  – Lack of *in situ* phytoplankton carbon data
    • Lots from indirect, fewer from more direct methods.
    • Lots of uncertainties and assumptions.
Discussion points

- Algorithms development and validation: what actions are needed?
  - Improving semi-analytical algorithms to account for factors that affect POC/C_{phy}
  - Cell size and other parameters
  - Testing routinely against open databases – as we have for other OC parameters historically.
  - Metrics for selection – discussed in other sessions too…
    - Which statistics to use? How to combine?
Discussion points

• What is ready for operational agencies to pick up
  – Can derive POC to reasonable error in global open ocean with empirical relationships.
  – OC-CCI type methodology can be applied for carbon errors, and potentially used for blending where justified.
Discussion points

- What is needed from *in situ* observations?
  - More *in situ* data collection – community data bases (e.g. from modellers) have been very useful, but need work to improve accuracy and detail for satellite validation.
    - Community to derive a list of parameters
    - Community to develop best practice protocols as have been done for other variables. (keep in mind uncertainty calculations)
      - e.g counts to carbon
Discussion points

- What are the priority directions, evolution of needs?
  - Multiple, varied, lines of development for $C_{phy}$ algorithms, necessary for improvement.
  - Continued work with modelling community – lots to be gained on this i.e. wrt C:Chl dynamics and physiology.
  - Community building in terms of \textit{in situ} measurements (suggested by Heidi this morning)
Discussion points

• Where are the critical shortcomings and needs?
• What is ready for operational agencies to pick up
• Algorithms development and validation: what actions are needed?
• What is needed from *in situ* observations?
• What are the priority directions, evolution of needs?

Thanks to all co-authors, algorithm providers, contributors to CLEO session on carbon, ESA (funding and management of POCO).