Ocean Color Algorithms for the Southern Ocean – Constraining the Carbon cycle

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Antarctic Fronts:
South ACC Polar Front
SubAntarctic SubTropical Gyres (3)
e.g. Orsi et al. (1995)
Complexity of Southern Ocean waters

Talley (2011)
SO Carbon Cycle from space

• Remote sensing:
  – accurate reflectance spectrum at high solar angles

• Variables of interest:
  – Better interpretation of $b_{bp}$ signal
  – Phytoplankton biomass (chlorophyll a, carbon)
  – Phytoplankton Primary Production (NPP), growth
  – Net Community Production (NPP - Respiration)
  – Carbon Flux out of the Euphotic Zone/Mixed Layer
Phytoplankton Biomass

• First large-scale limitation is winter time (April to September) for which no ocean color data can be retrieved due to solar zenith angle being too large

1. Winter measurements:
   Lidar (e.g. MESACAL)
   Atmospheric correction (e.g. POLYMER)

2. Year-round field measurements:
   Profiling floats (BGC Argo)
   Optical sensors existing mooring (OI)
Discrepancies

Q1: Can we explain discrepancies between different investigations of Southern Ocean bio-optical algorithms based on time, sector, proximity to sea ice and continental shelves, temperature, latitude, and methodology?

Discrepancies among SO algorithms (NASA’s global and regional algorithms)
Southern Ocean Chl-a algorithm: Chl-SPGANT


Conclusion: NASA OC4v4 chlor_a underestimates 2-3 x at 0.2 < Chla < 3 mg m\(^{-3}\)

Version 4, Kahru & Mitchell (2010), included all stations in SeaBASS south of 55S: total of 1247 stations

Polynomial fits between log10 of Maximum Band Ratio (MBR) and Chla for SeaWiFS, MODISA, GLI, OCTS, MERIS
SOCCOM Results (biogeochemical floats)
Atmospheric Correction

• Q2: Can atmospheric corrections be improved to expand the time-space domain of ocean color data at higher solar zenith angles?
• Possibility of better correction with spherical geometry (or polynomial)
• White caps included as aerosols (winds >10 m/s) is not optimal for spectral correction
• Better cloud flag identification
SO Algorithm Development

- Q3: Do we have the data sets needed to calibrate/validate reflectance spectrum/fluorescence signals?
  - Summer data, subjective sampling, low data density compared to other oceanic domains
  - Optical sensors in GO_Ships
  - Optical variables with vertical resolution
  - Imaging flow cytometry (automated phytoplankton composition and size)
  - SIMBIOS-type optical van to take advantage of ships of opportunity
  - Above-water radiometry
  - Phytoplankton carbon (Cphyto)
  - Calcite estimation
  - Creation of a Southern Ocean database (SeaBASS-like)
Factors regulating the Great Calcite Belt in the Southern Ocean and its biogeochemical significance

William M. Balch¹, Nicholas R. Bates²,³, Phoebe J. Lam⁴,⁵, Benjamin S. Twining¹, Sarah Z. Rosengard⁴,⁶, Bruce C. Bowler¹, Dave T. Drapeau¹, Rebecca Garley², Laura C. Lubelczyk¹, Catherine Mitchell¹, and Sara Rauschenberg¹
Interrelationship among satellite NPP, PFTs and SST

Takao et al. (2012)
<table>
<thead>
<tr>
<th>Gap</th>
<th>Status</th>
<th>Medium-term action</th>
<th>Long-term action</th>
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<tbody>
<tr>
<td>Satellite Sensors</td>
<td>Multispectral sensors with limited PFT information</td>
<td>Develop AC for hyperspectral sensors</td>
<td>Exploit adding bands to multispectral (OLCI,...)</td>
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<td>Limited exploitation of hyperspectral:</td>
<td>Adapt hyperspectral PFT algorithms to current hyperspectral satellite data</td>
<td>Merge all sensors’ PFT data for long term coverage</td>
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<td>- SCIAMACHY PFT data but low coverage/resolution</td>
<td>Develop synergistic hyper&amp; multispectral PFT products</td>
<td>Launch hyperspectral OC sensors (PACE, ...)</td>
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<tr>
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<td>- AC failed to derive hyperspectral Lw, RRS data (HICO)</td>
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<tr>
<td>Uncertainties</td>
<td>Deficient theoretical background for inversions?</td>
<td>Optimize inversion (RTM)</td>
<td>Framework for clear traceability of errors</td>
</tr>
<tr>
<td></td>
<td>RTM lack PFT-info (esp. bb)</td>
<td>Round-Robins: PFT data format, method &amp; QC</td>
<td>Curate existing data sets</td>
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<tr>
<td></td>
<td>No appropriate in-situ</td>
<td>Exploit all in-situ PFT, auton.</td>
<td>Ensure complete PFT, hyperspectral IOP &amp; AOP acquisition</td>
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<td>HPLC-not really PFT, other PFT data require integration</td>
<td>Use complementary data to constrain algorithms</td>
<td></td>
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<tr>
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<td>Spectral IOPs (esp. bb) limited</td>
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4-D ocean

• Q4: How can we merge bio-optical-ARGO and satellite data for a better 4-D representation of plankton biomass and productivity for the SO?
• Full support for the BGC floats
• SO Modeling is essential for low-sampled region
Implications for models

The seasonal mismatch may result from the models assumption that all seasonal variability is simply due to acclimation by McKiver et al. (2015)

Models need to accommodate for variable chl-a:C$_{phyto}$ ratio that reflect phytoplankton adaptation to low light conditions in spring (low optimal chl-a:C$_{phyto}$ ratio) and higher optimal chl-a:C$_{phyto}$ ratios with species-specific increasing growth rates in summer.
Emerging Technologies

• Q5: What are emerging technologies that can improve the quality and number of observations in situ and airborne in the Southern Ocean needed to improve algorithms and models?

• LIDAR (space and on board ships)

• Automated optical sensors and species identification

• Hyper-spectral backscattering sensor
The Missing Iron Stress Signal

Fluorescence Quantum Yield

March–May

September–November

NIOQ corrected $F_{sat}$

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

0.00 0.01 0.02

0.00 0.01 0.02 0.03

0.00 0.01 0.02 0.03

0.00 0.01 0.02 0.03

Biogeoscience 6, 779–794
Westberry et al. 2013. Deep-Sea Research I, 73, 1–16

Model no iron stress

Model iron stress

High $\phi_{sat}$, model iron-limited

High $\phi_{sat}$, model other-limited


Westberry et al. 2013. Deep-Sea Research I, 73, 1–16
Field Campaigns

Q6: What are the plans in the international community for recent and future field campaigns to advance our understanding of Southern Ocean carbon cycle using satellite ocean color and other observations?

- ACE (2016-2017 Antarctic Circumpolar Experiment, International)
- Future ICESSOC (International Coordinated Experiment of the Southern Ocean Carbon Cycle, USA)
- Future SOOS (Southern Ocean Observing System, International)
- SOCLIM (2016 Kerguelen, France)
- CSIR cruises on board Agulhas (South Africa)
- SOCCOM (80 floats with bio-optics, NSF/NASA)
Project #1
“A bio-optical approach to understanding long term changes in phytoplankton abundance and composition in the Southern Ocean and their impact on the biological productivity”

A 3-month expedition, 3 main groups involved:

(Curtin Uni., Perth, Australia)
PI: D. Antoine

(CSIR, Cape Town, South Africa)
PI: S. Thomalla

(NASA, GSFC, USA)
PI: S. Hooker
Q7: How can we improve the understanding of the relationship between surface satellite observations and organic carbon export?

Modeling Improvements (Laws 2004)
Expected results from EXPORTS (SO version)
Summary

• C cycle in the Southern Ocean: why can’t we constrain it?
• Phytoplankton physiology: why can’t we detect iron limitation in SO?
• Usefulness of 2015 IOCCG report on high latitudes
• Creation of a SO ocean color community