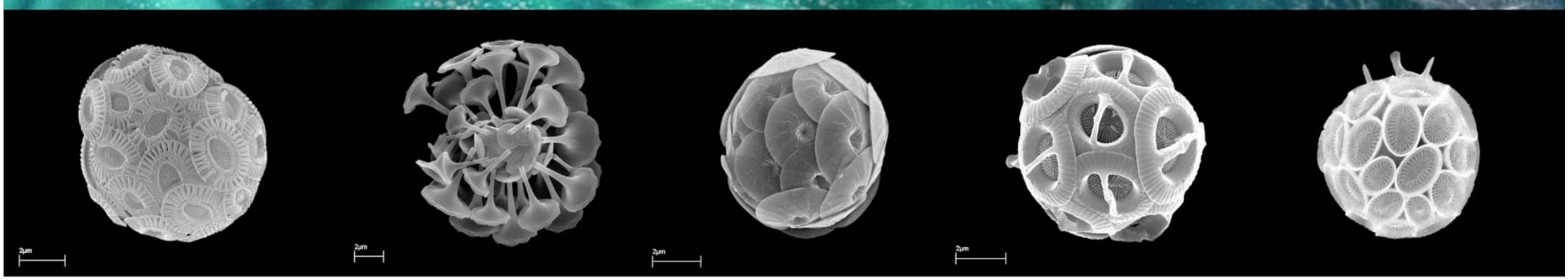
What's new with the PIC algorithm?

William Balch, Catherine Mitchell, David Drapeau, Bruce Bowler, Colin Fischer

Bigelow Laboratory for Ocean Sciences, East Boothbay, ME USA



The discovery of mesoscale blooms of coccolithophores…

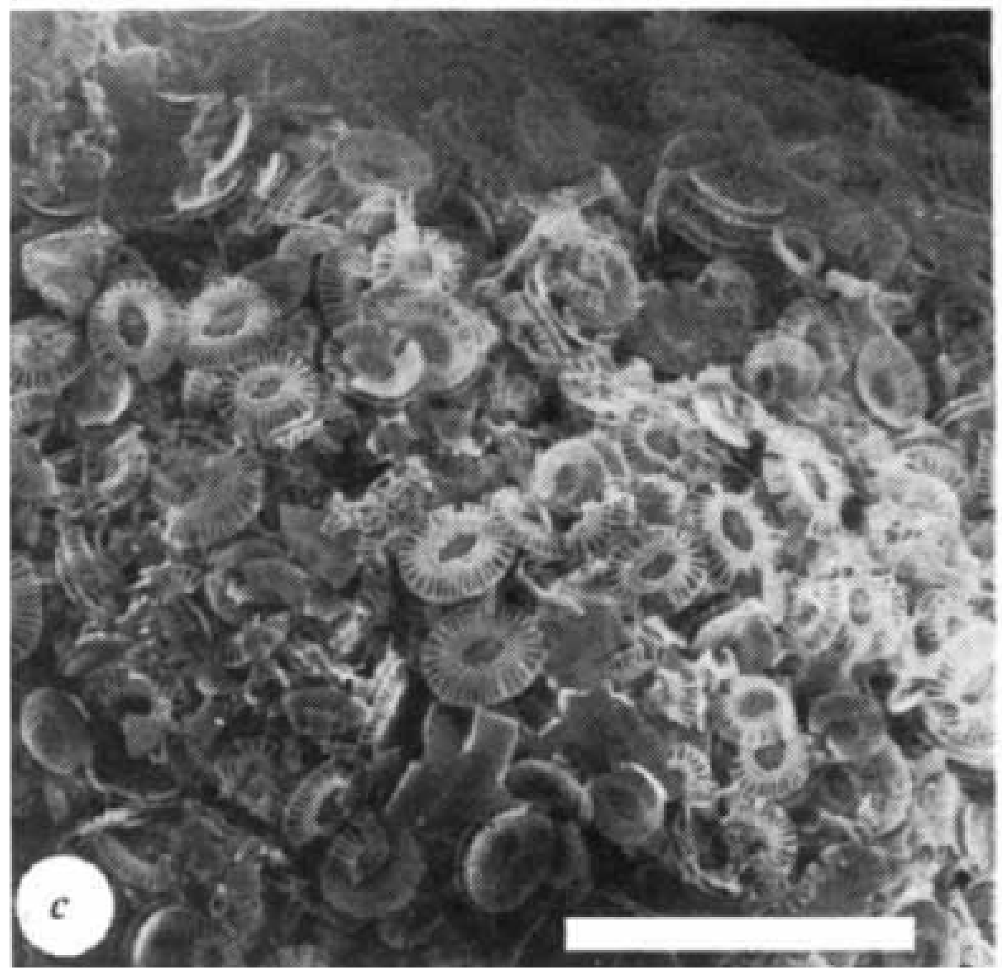
- The first observation o
  Holligan (1983)

Satellite and ship studies of coccolithophore production along a continental shelf edge

P. M. Holligan*, M. Viollier†||, D. S. Harbour*, P. Camus‡ & M. Champagne-Philippe§

* Marine Biological Association, Citadel Hill, Plymouth PL1 2PB, UK
† Joint Research Centre, Ispra Establishment, 21020 Ispra, Italy
‡ Institution Scientifique et Technique des Peches Maritimes, BP 1049, 44037 Nantes Cedex, France
§ Etablissement d'Etudes et de Recherches Meteorologiques, CMS, 22302 Lannion, France

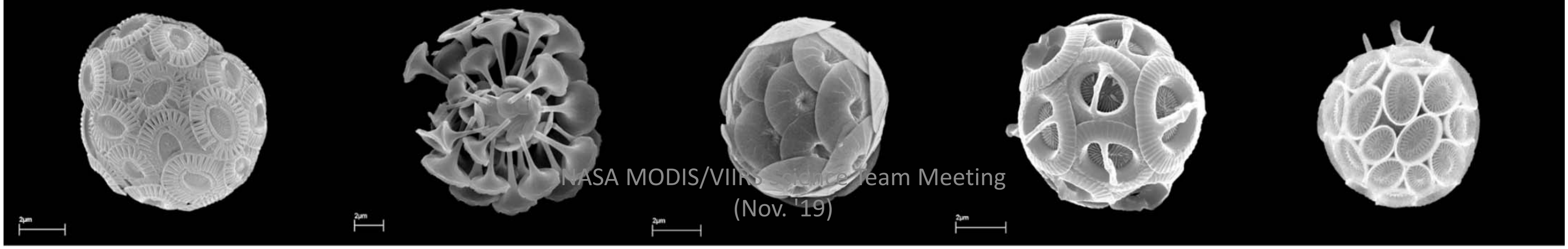
Nature, 1983, vol 304; pp 339-342



Loose coccoliths plus a coccolith-packed fecal pellet from bright water

The “known unknowns” about coccolithophores since the first observations, critical for algorithm development…

- Coccolithophore species?
- Surface concentrations of cells, coccoliths, PIC
- Vertical profiles of coccolithophores, PIC
- Inherent and apparent optical properties
- Phenology of blooms
- Statistics of all of the above for application to multiple sensors!

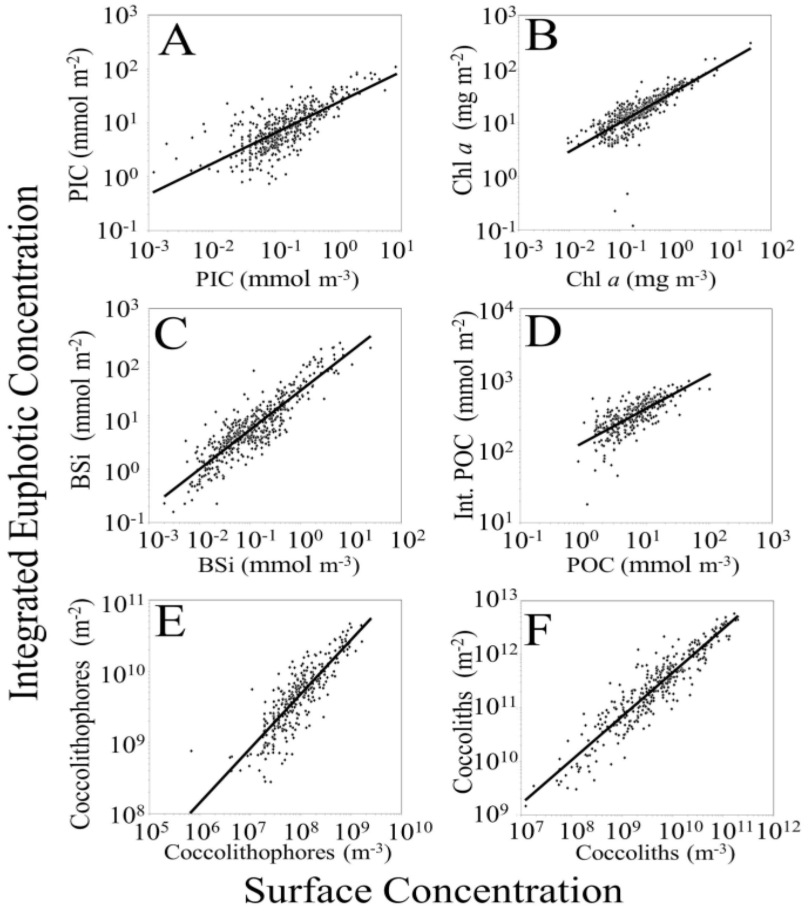


Vertical Distributions of Coccolithophores, PIC, POC, Biogenic Silica, and Chlorophyll *a* Throughout the Global Ocean.

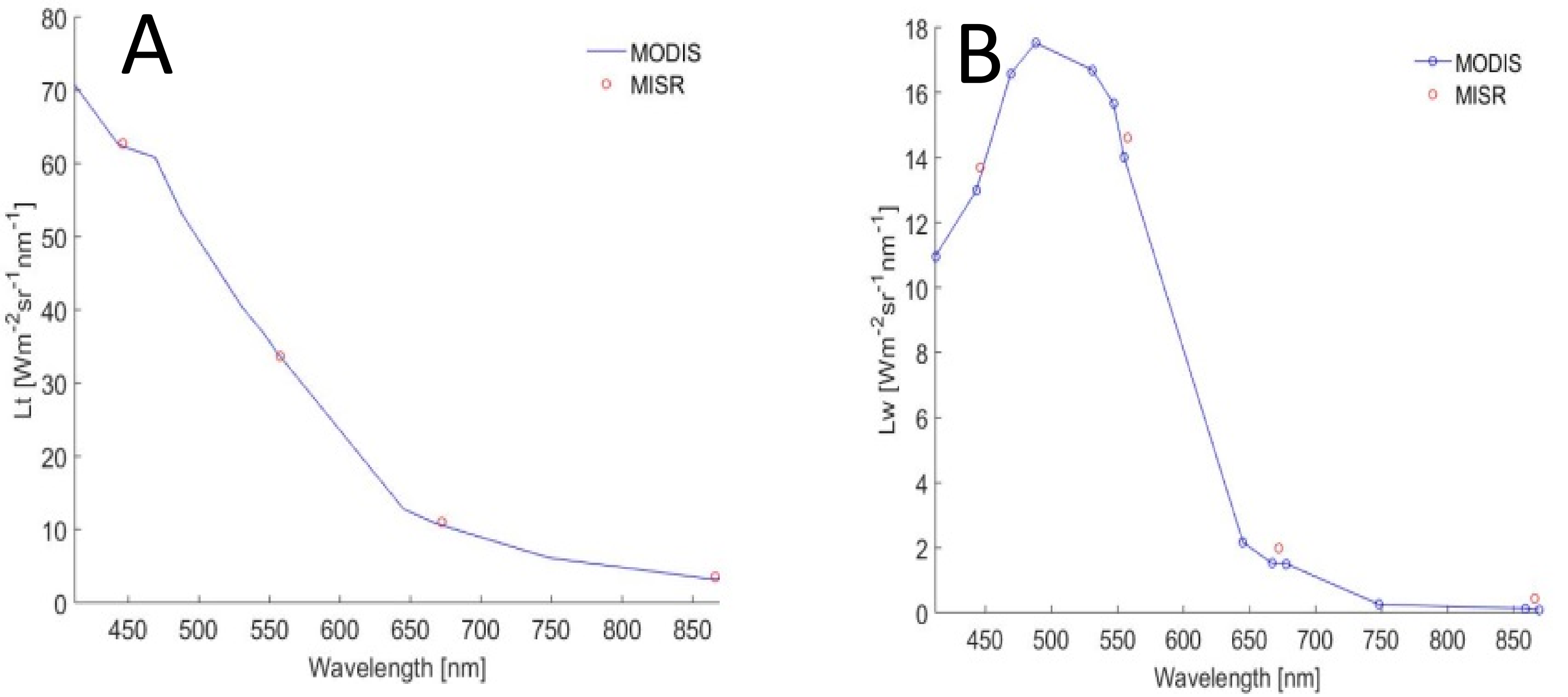
Balch, W.M., B.C.Bowler , D. T. Drapeau, L. C. Lubelczyk, and E. Lyczkowski (2018) Global Biogeochemical Cycles, p1-16, https://doi.org/10.1002/2016GB005614 Open access.

QUESTION: What are the relationships between surface- versus integrated-concentrations of six biogeochemically-relevant particles (coccolithophores, coccoliths, particulate inorganic carbon, particulate organic carbon, biogenic silica and chlorophyll *a*)?

- **Average vertical profiles of the different particle types are not the same as chlorophyll *a*.**
- **Coccolithophores, coccoliths, and PIC show highest integrated concentrations at moderate stratification levels at the base of the euphotic zone**

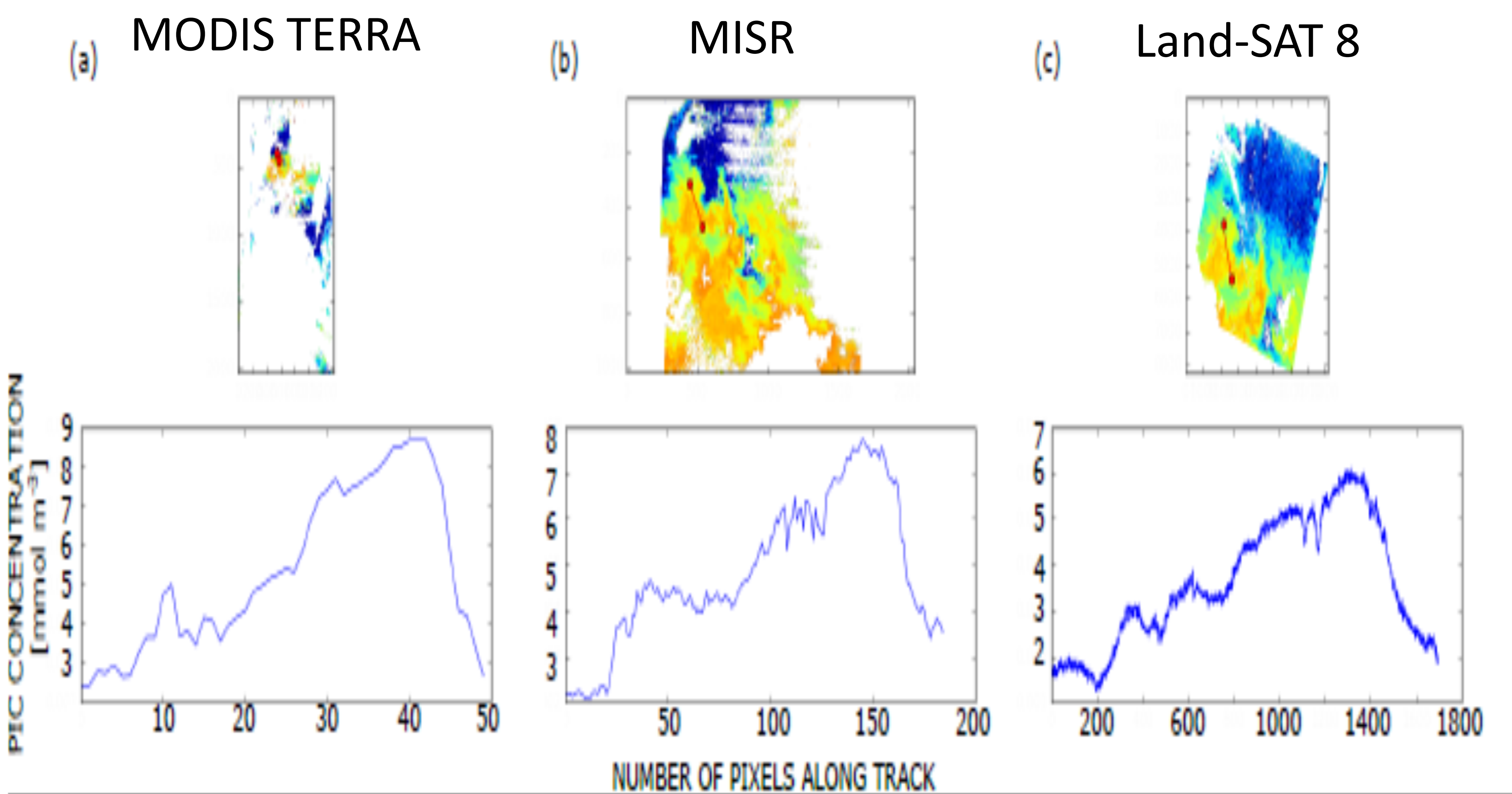


Using different sensors: Calibrating MISR nadir-viewing radiances with MODIS-Terra



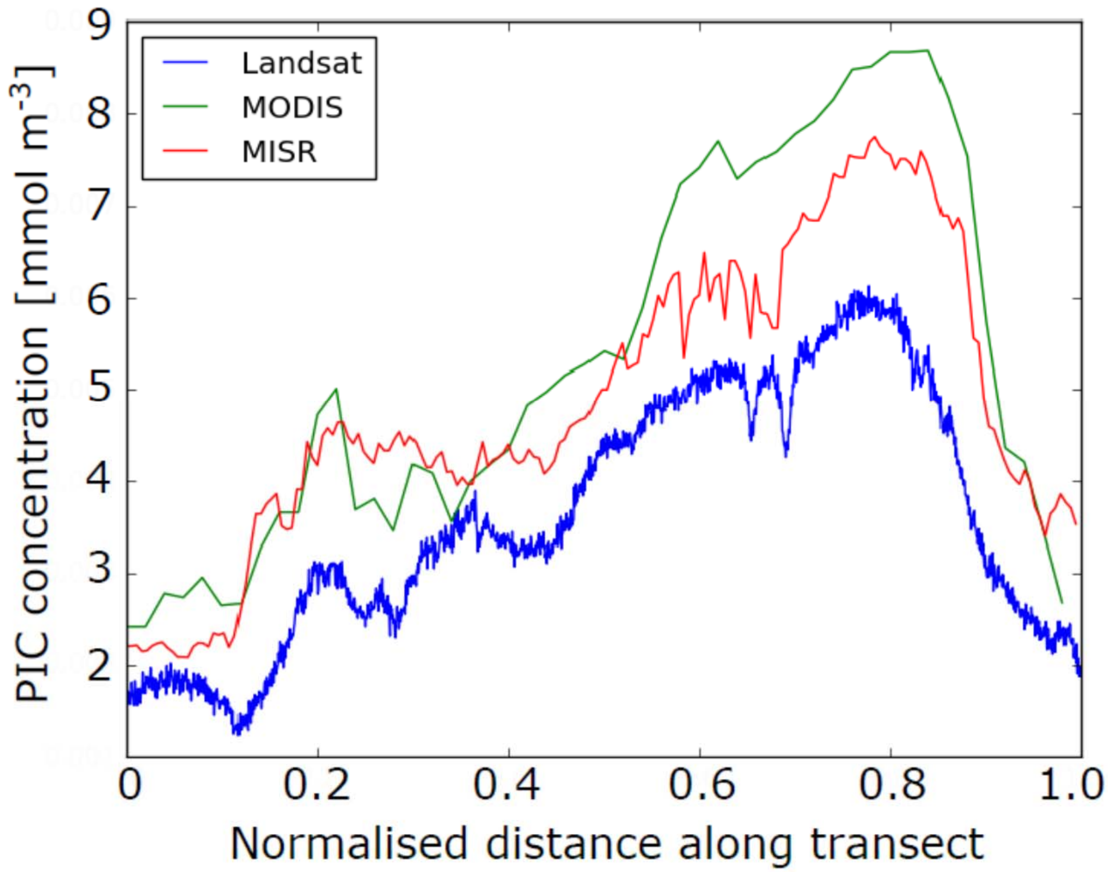
Hopkins & Balch, Bigelow Lab

Three transects through the same feature with three ocean color sensors:



Hopkins & Balch, Bigelow Lab

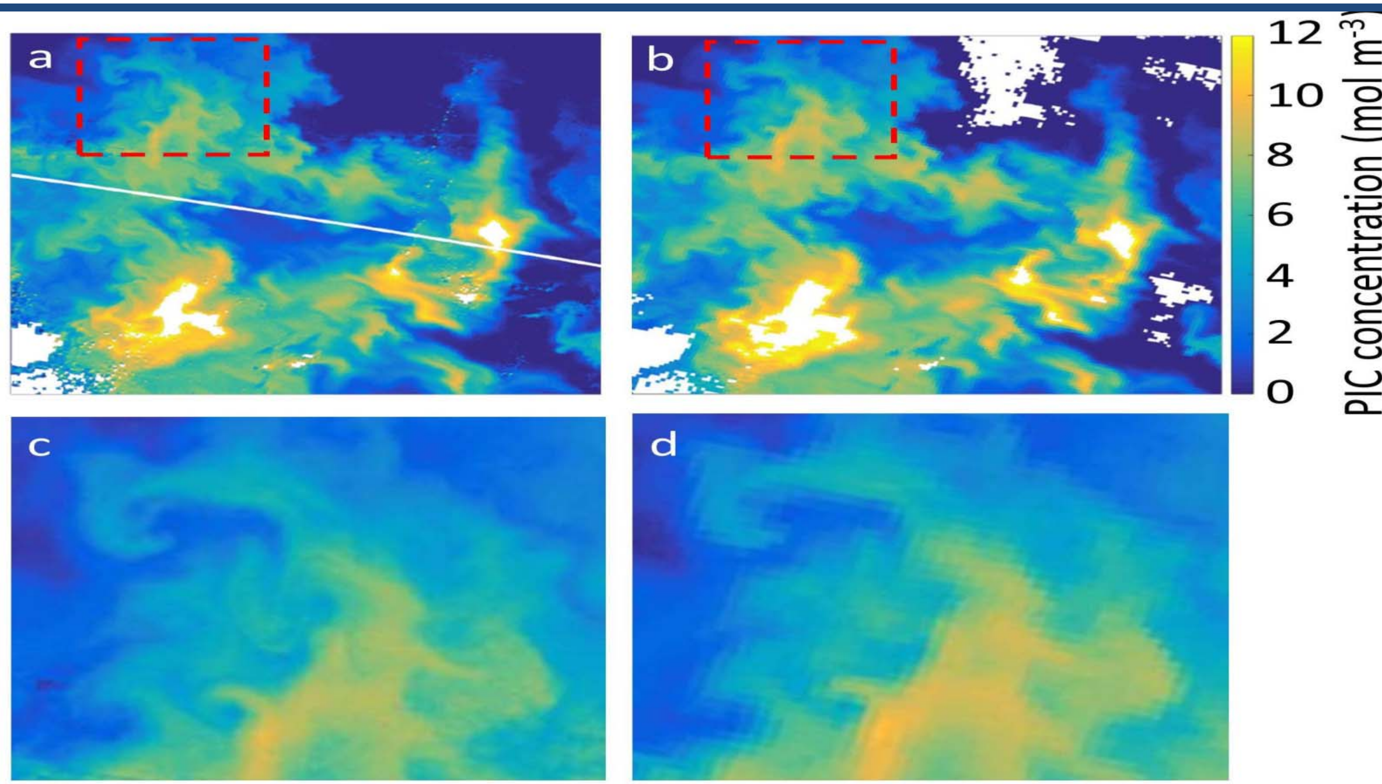
Superimpose all three PIC transects for different sensors…



Hopkins & Balch, Bigelow Lab

Using MISR and MODIS-Terra to estimate PIC concentration from coccolithophores

MISR-nadir MODIS-T



(a) MISR PIC data at 275 m resolution for Bering Sea coccolithophore bloom; (b) Equivalent scene for MODIS-Terra PIC product (merged 2-band/3-band). (c) Blow-up of region within dashed red square in panel a; (d) Blow-up of region within dashed red square in panel b .

Hopkins & Balch, Bigelow Lab

The state of PIC algorithms to measure phytoplankton remotely is improving…

- We are making more *in situ* measurements of coccolithophore species, optical properties, carbon content and their statistics
- New optical models are being formulated, advances in estimating backscattering cross-section of PIC, b_b^* (m^2 (mol PIC)$^{-1}$)

Cruise Track EN616; July 2018

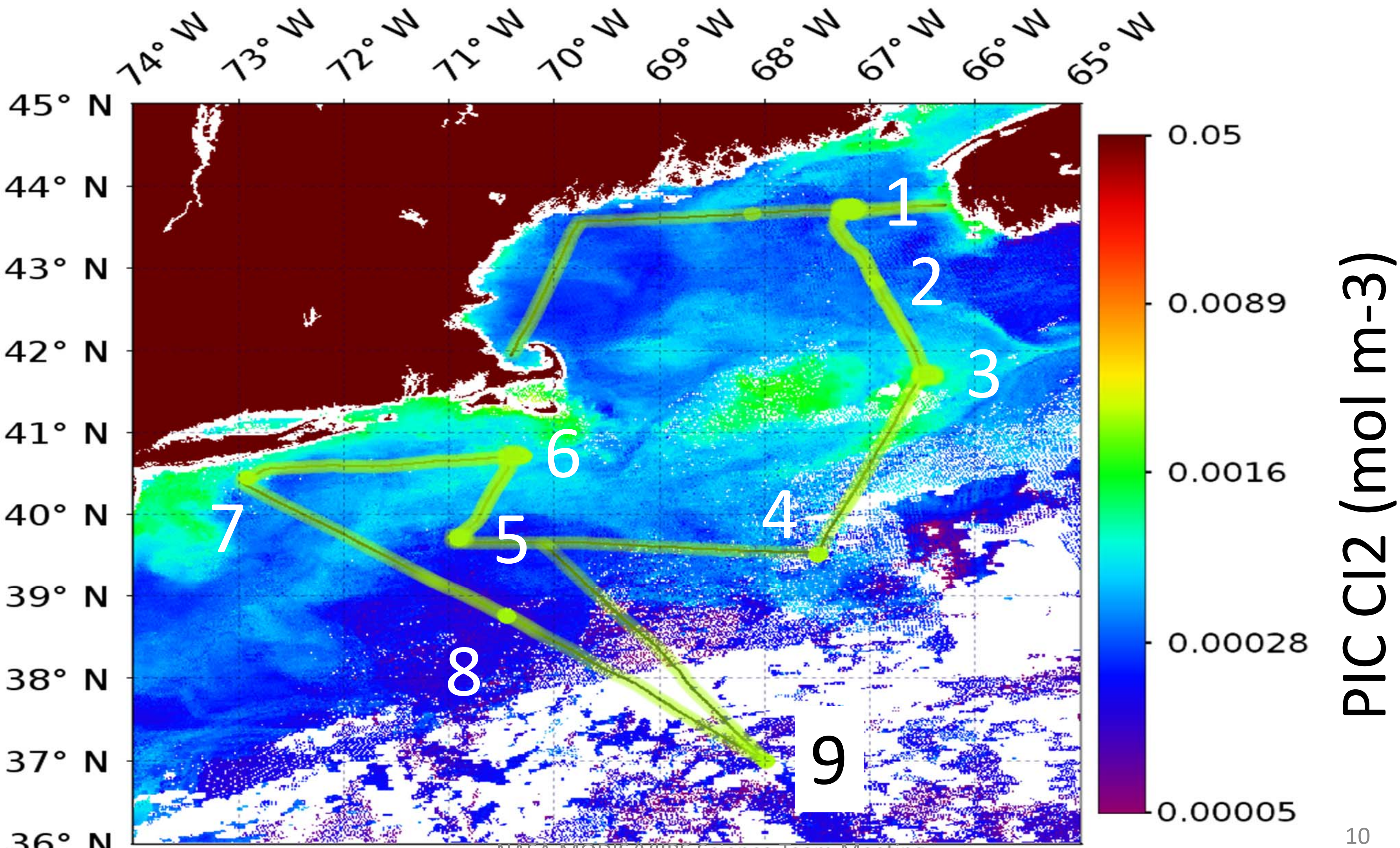
Journal of Geophysical Research: Oceans

RESEARCH ARTICLE
10.1002/2017JC013146

Estimating Particulate Inorganic Carbon Concentrations of the Global Ocean From Ocean Color Measurements Using a Reflectance Difference Approach

C. Mitchell[1], C. Hu[2], B. Bowler[1], D. Drapeau[1], and W. M. Balch[1]

[1]Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA, [2]College of Marine Science, University of South Florida, St. Petersburg, FL, USA



2018 Cruise *R/V Endeavor*

Remote Sensing of Environment 215 (2018) 85–96

Contents lists available at ScienceDirect

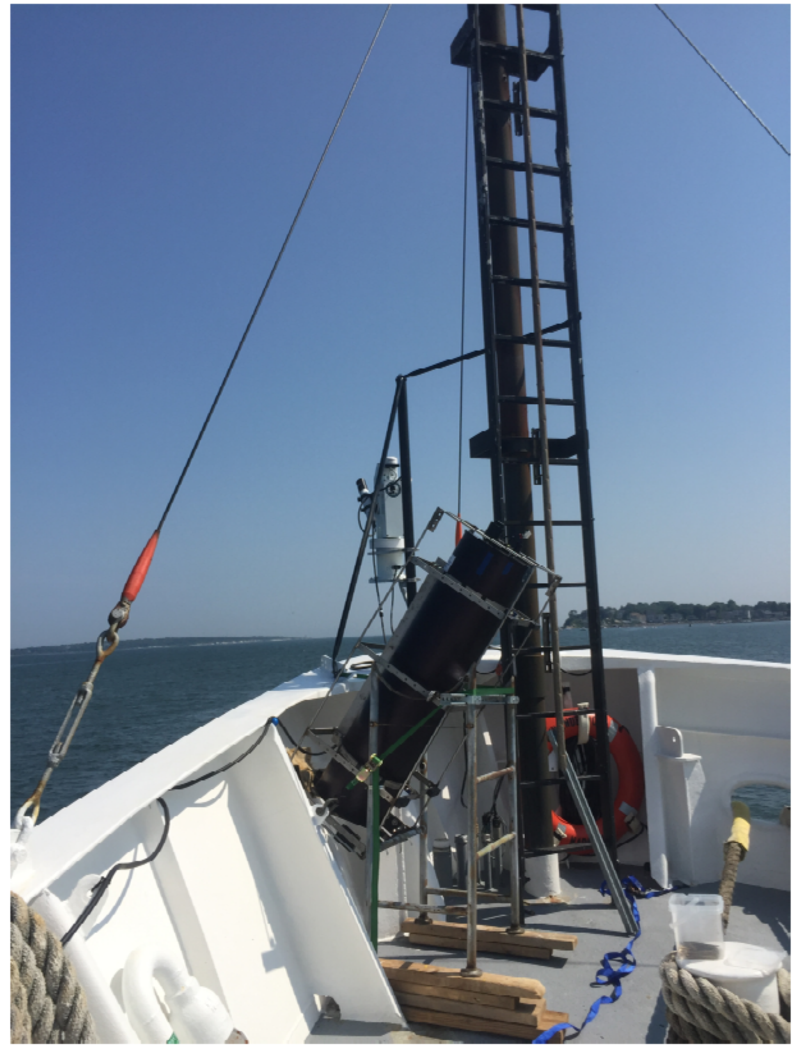
ELSEVIER

Remote Sensing of Environment

journal homepage: www.elsevier.com/locate/rse

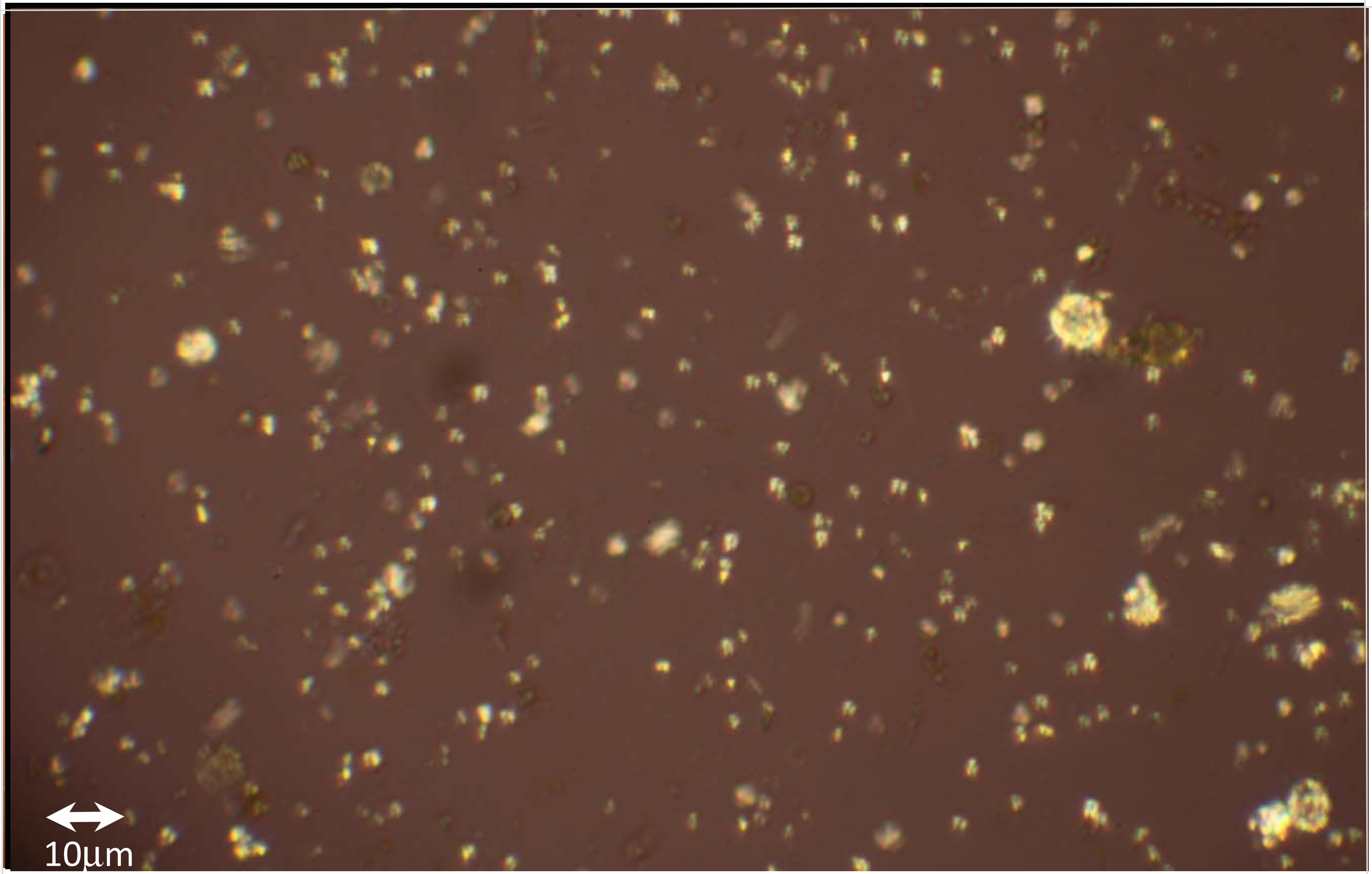
Remote sensing of optical characteristics and particle distributions of the upper ocean using shipboard lidar

Brian L. Collister[a,*], Richard C. Zimmerman[a], Charles I. Sukenik[b], Victoria J. Hill[a], William M. Balch[c]

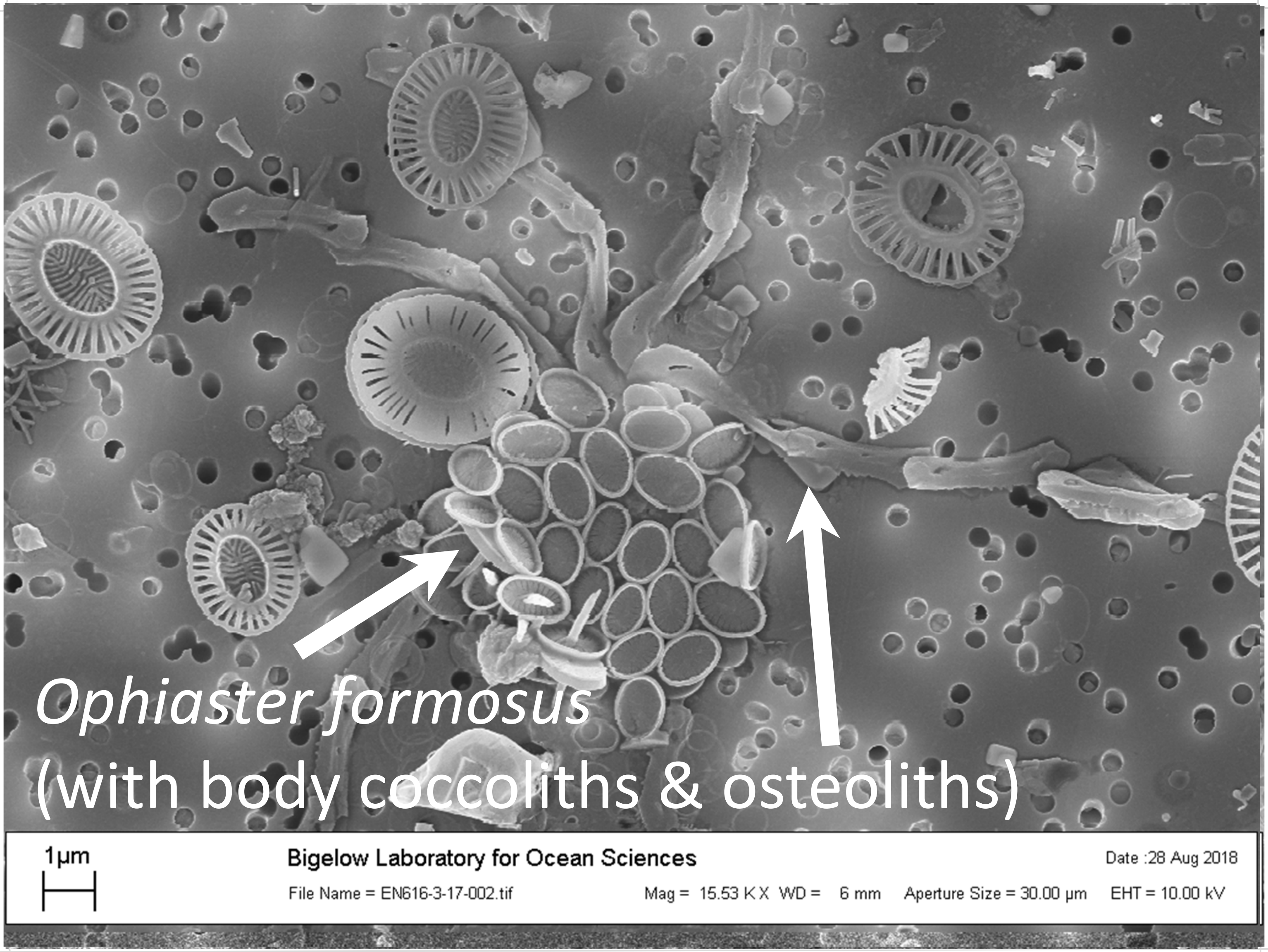


LiDAR and bow-mounted radiance sensors on bow

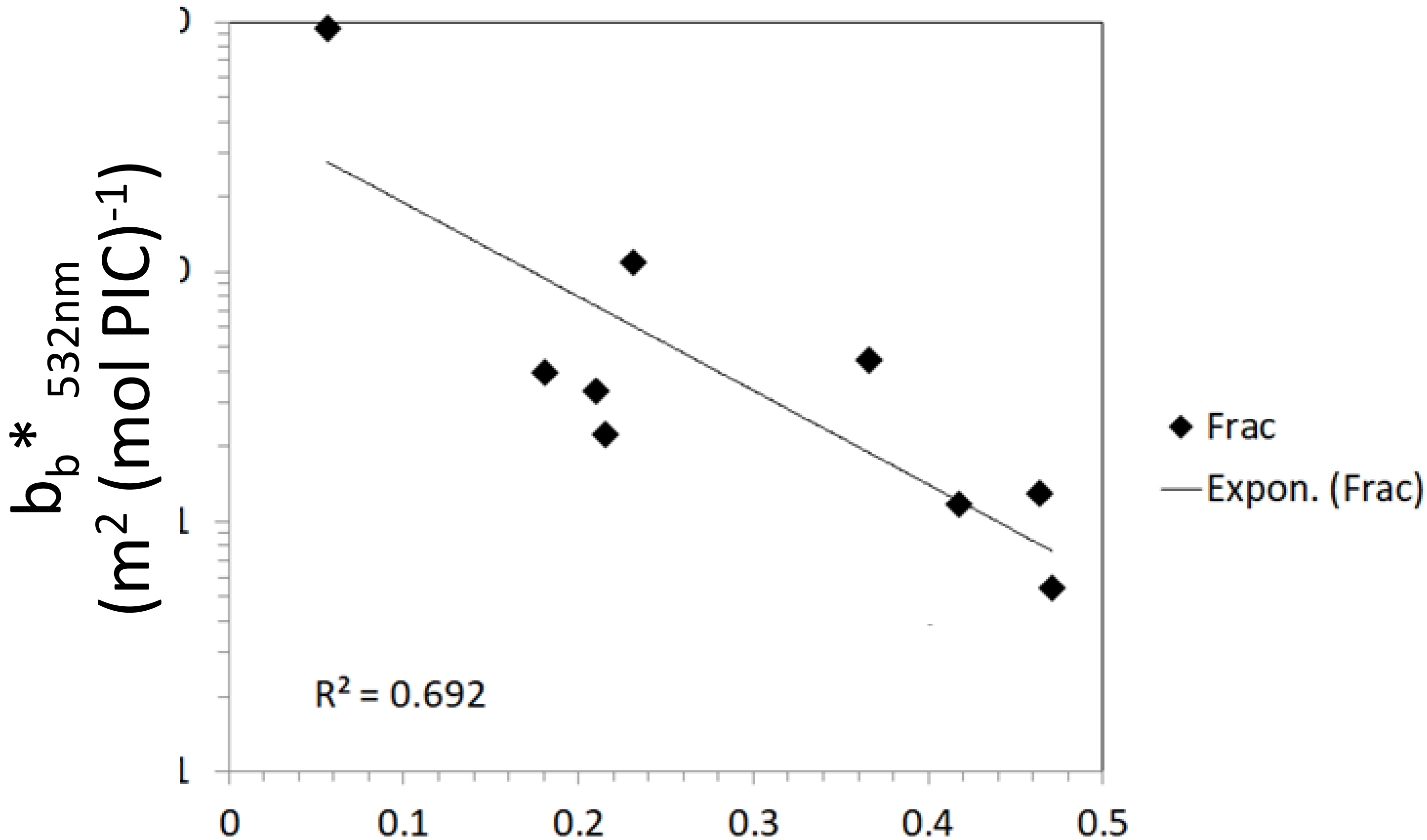
Alleged cocco bloom: What was in the water?



SEM is the only way to absolutely identify coccolithophore species. At the bloom center, was it all *E. huxleyi*?



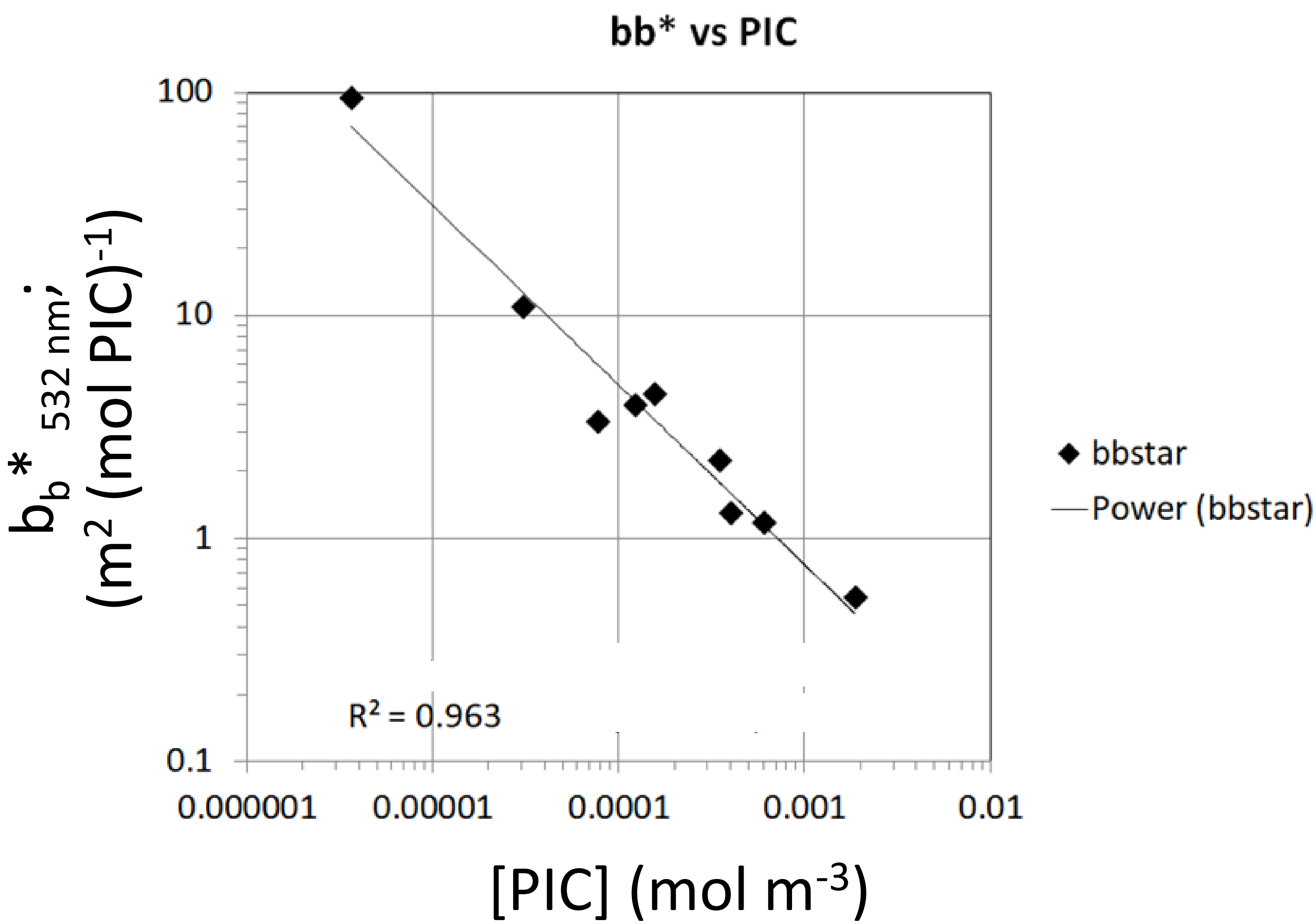
The b_b*of PIC is an inverse function of the fraction of *E.huxleyi* in the sample…



Avg. Fraction of coccolithophores and coccoliths as *E. huxleyi*

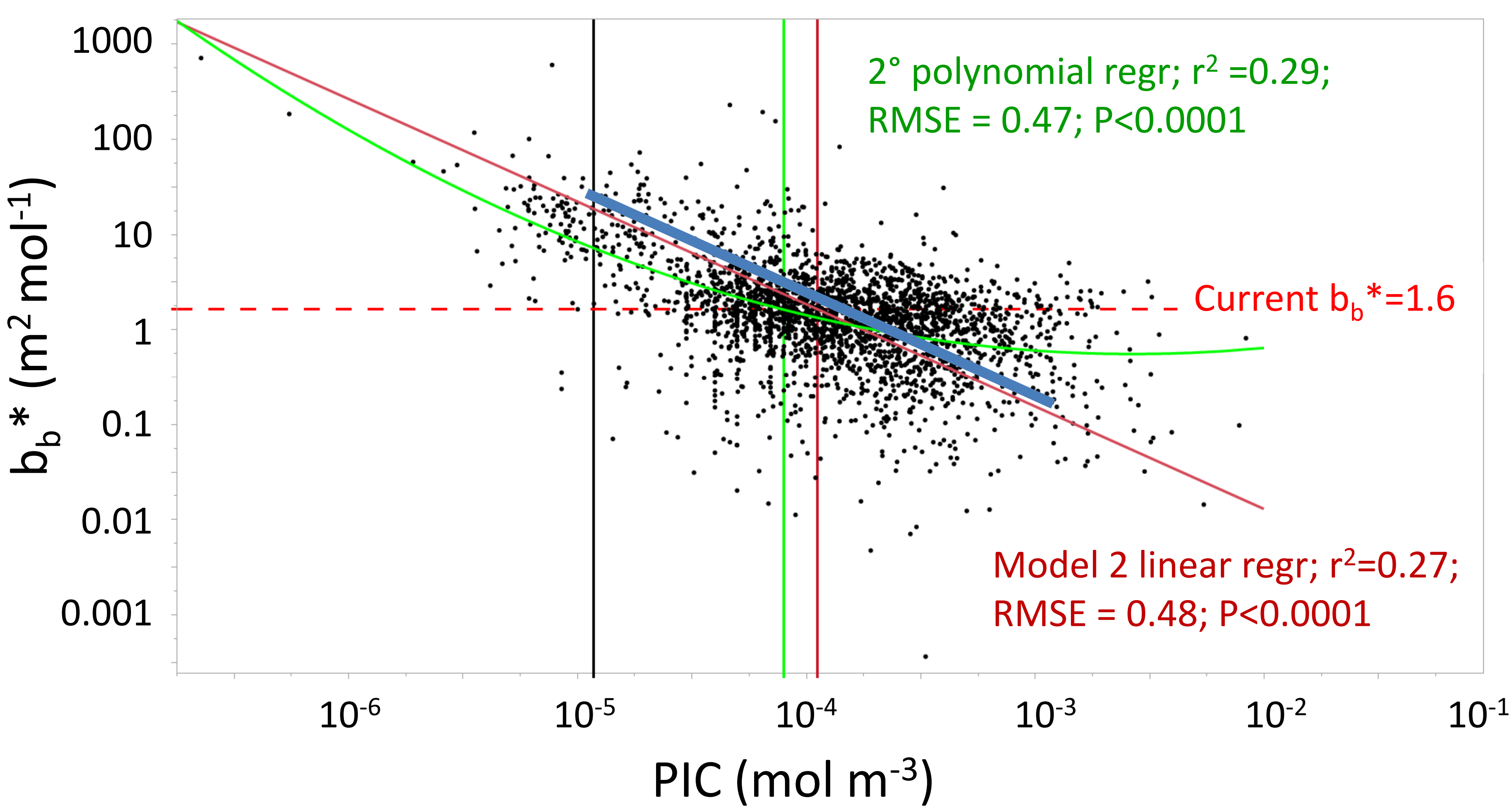
Balch et al., 2019; in prep

Lowest b_b*PIC at highest [PIC]

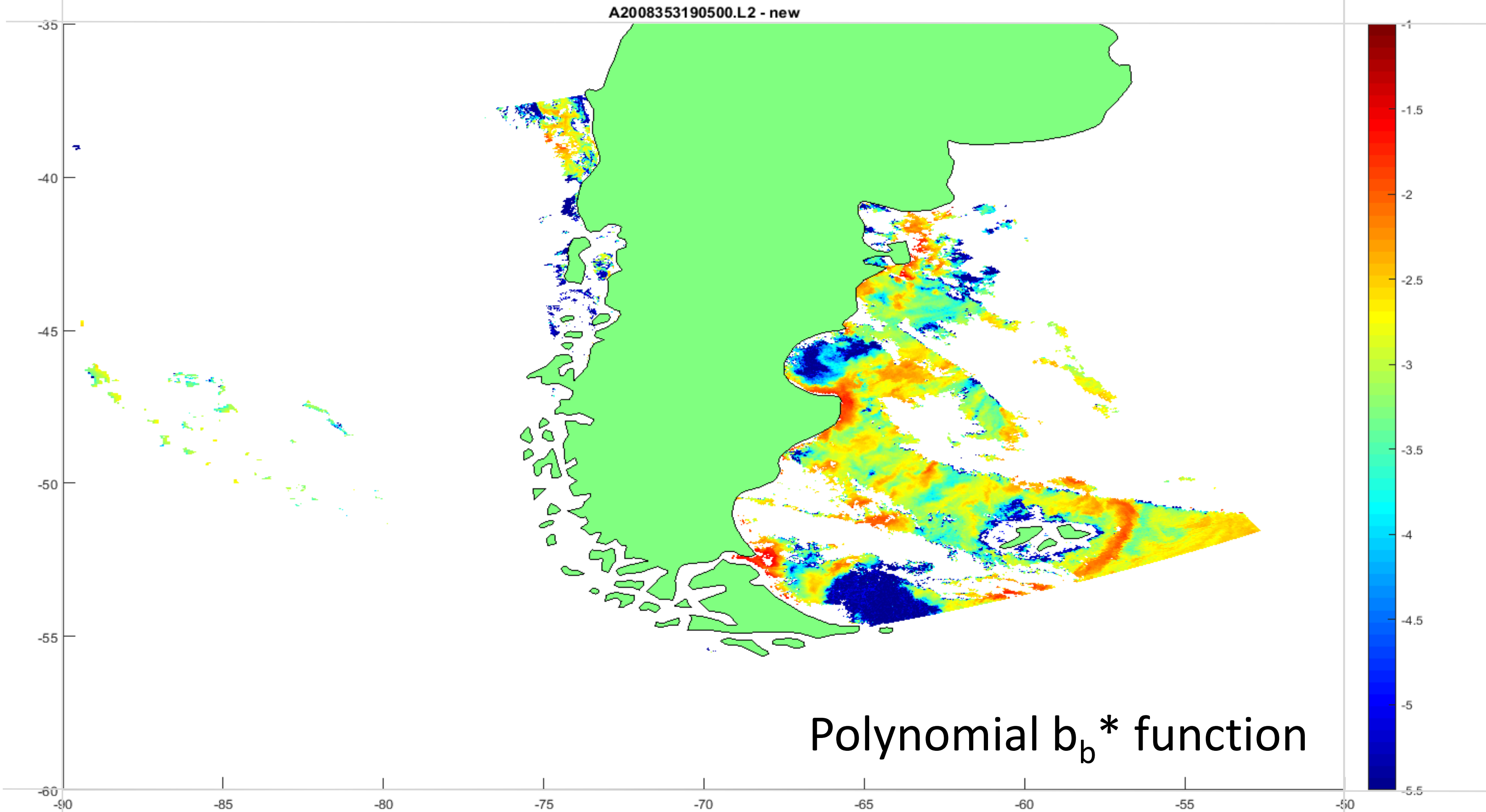


Balch et al., 2019; in prep

Compendium of all b_b* measurements based on 2609 bb' and ICPOES estimates of PIC

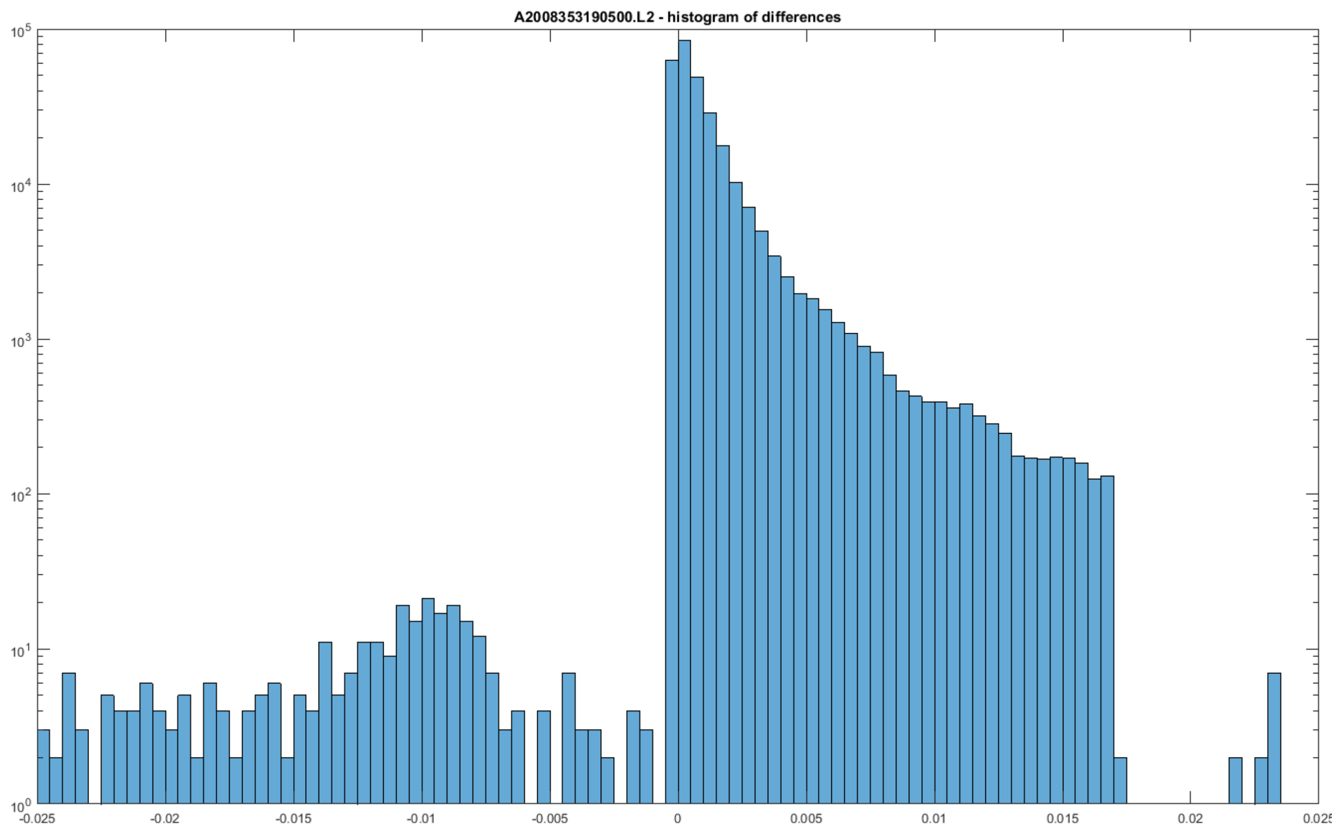


Aqua PIC "Bloom"

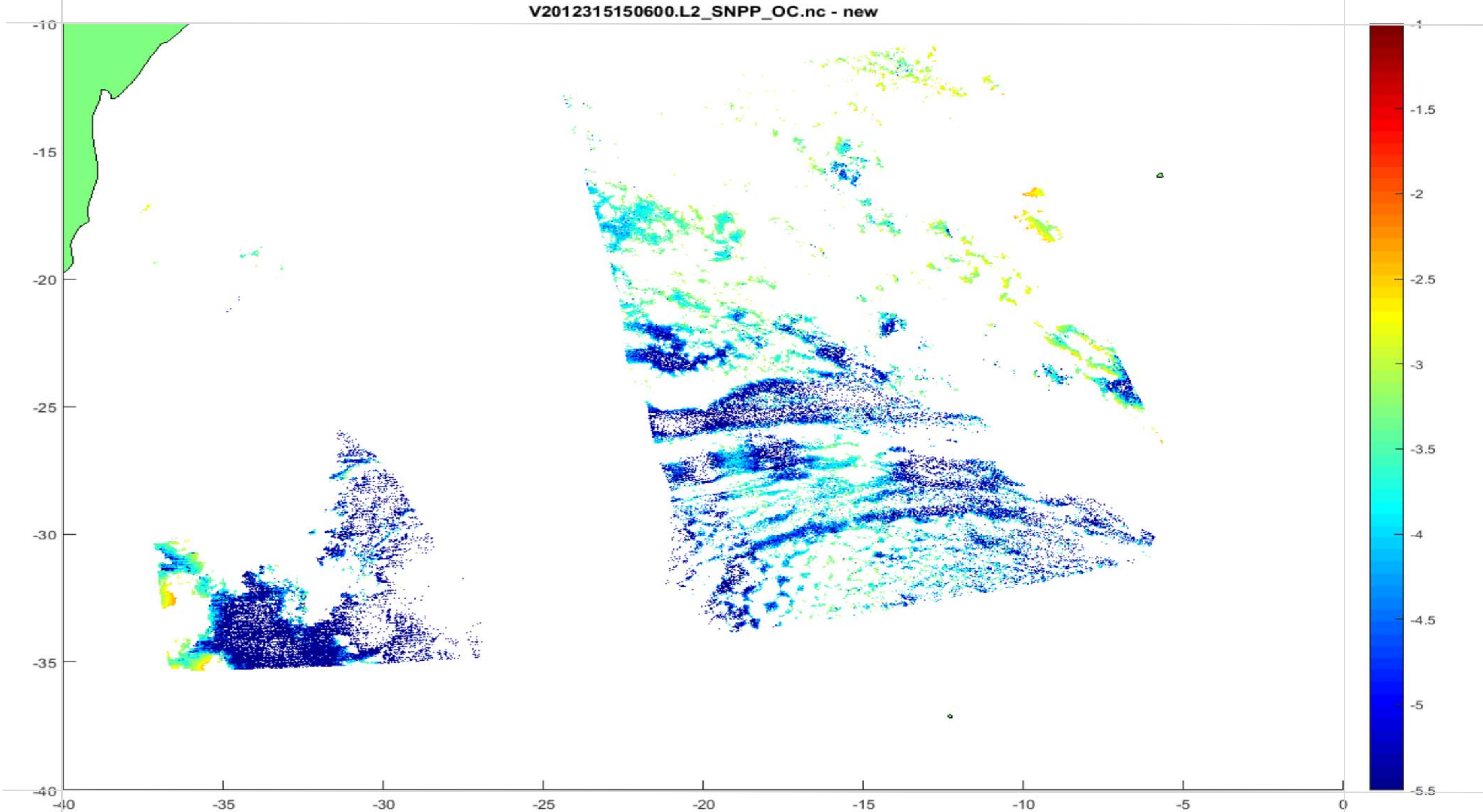


Polynomial b_b* function

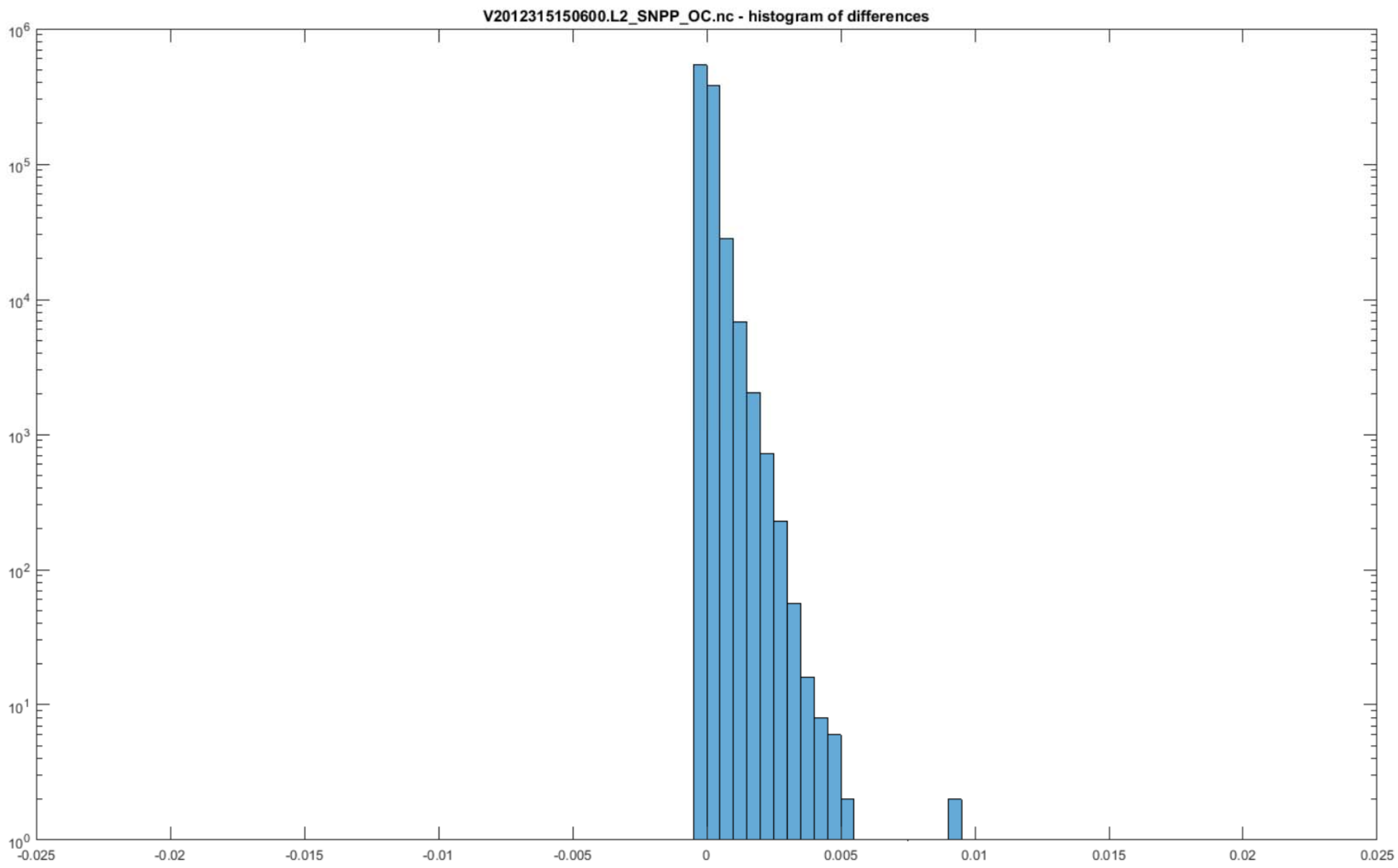
Aqua Histogram of differences (new-old)



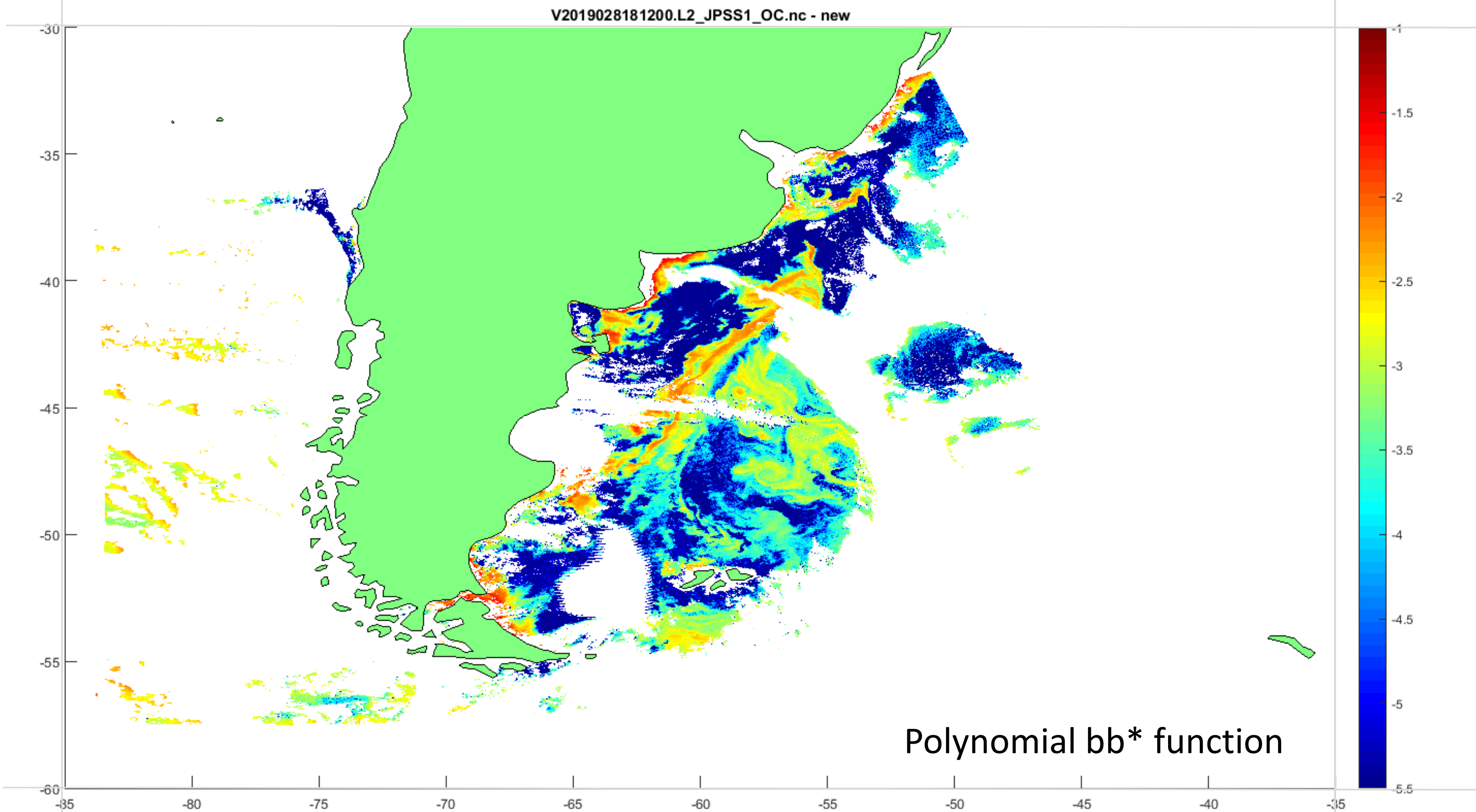
VIIRS S-NPP Low productivity



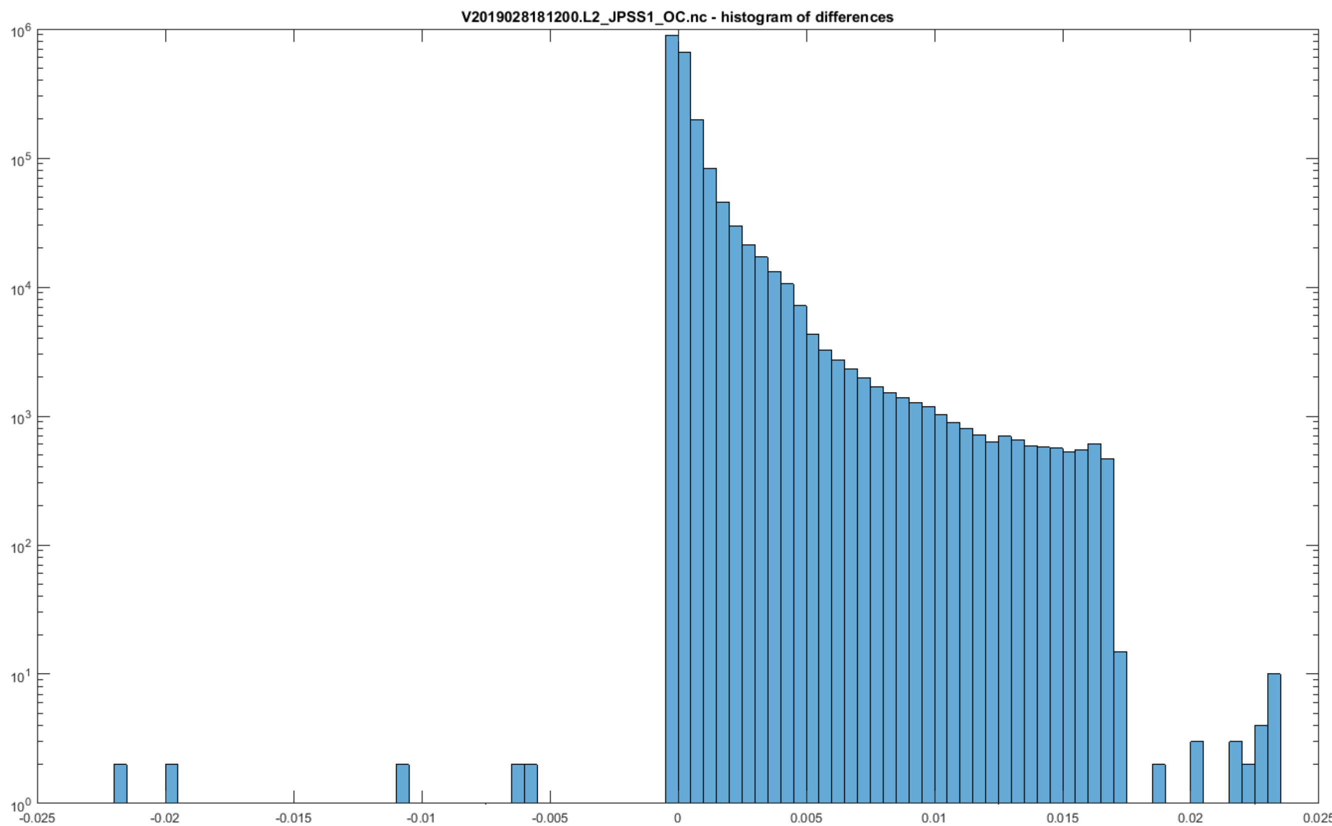
VIIRS S-NPP non bloom: Histogram of differences of PIC product (new-old); low productivity



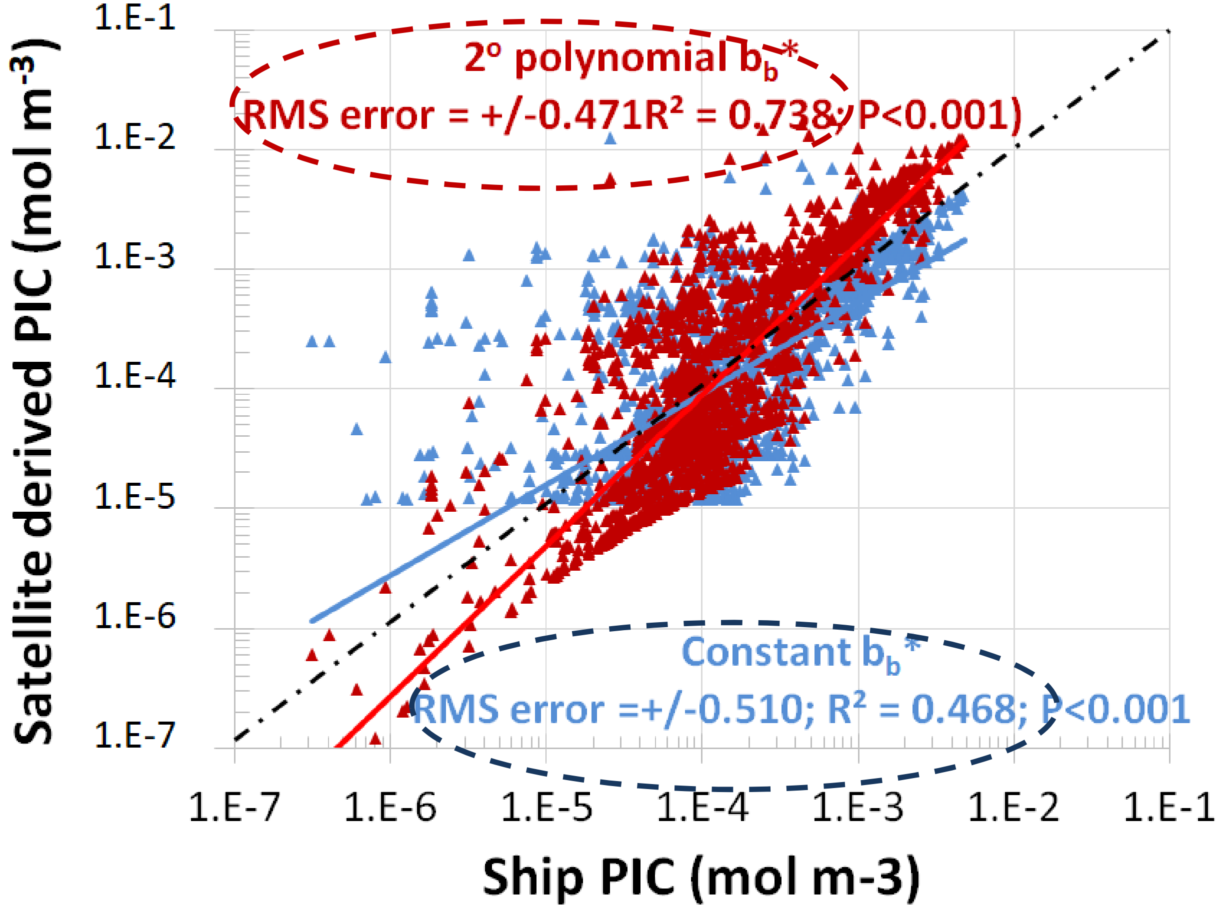
VIIRS-JPSS/NOAA-20 PIC "bloom"



VIIRS JPSS/NOAA 20 Histogram of differences (new-old)



With 2º polynomial b_b*, r^2 is increased and RMSE is reduced over the constant bb*



AGU PUBLICATIONS

Global Biogeochemical Cycles

RESEARCH ARTICLE

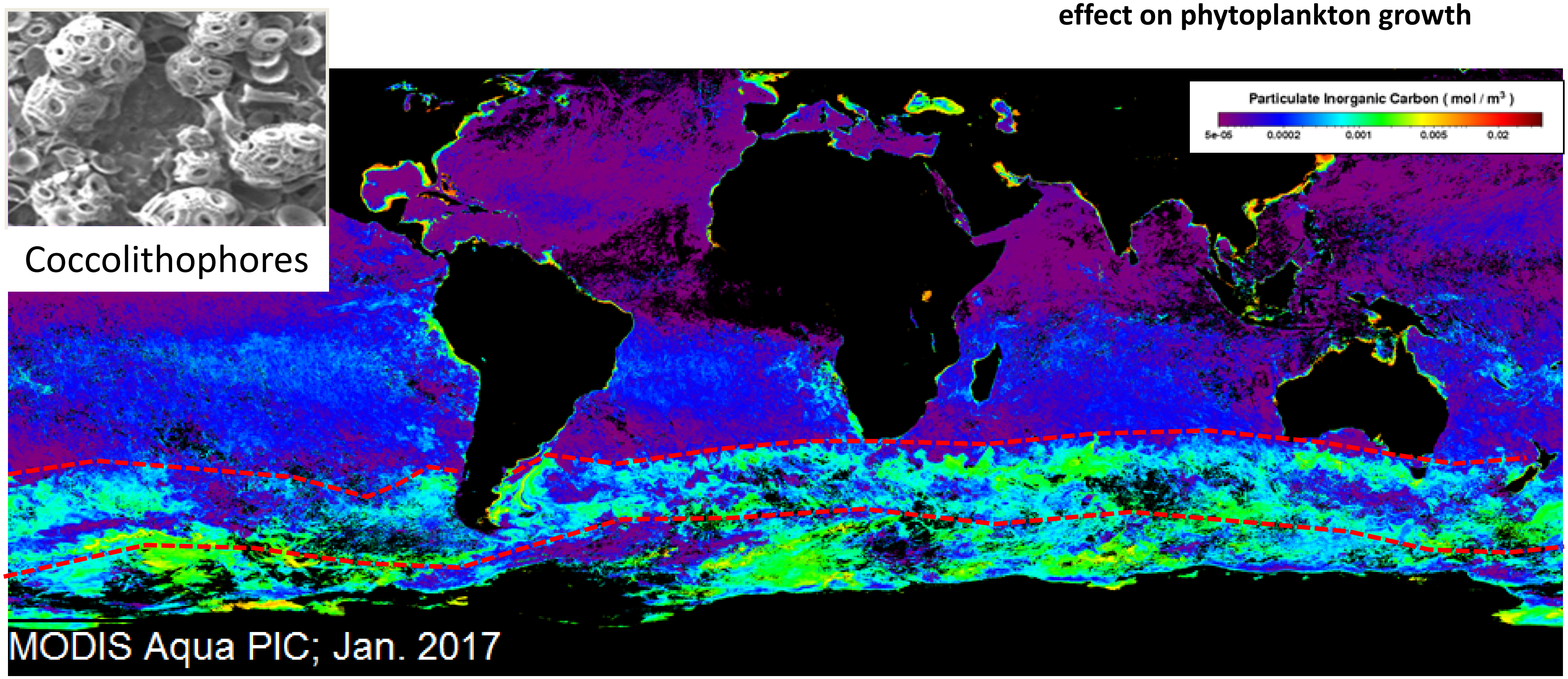
10.1002/2016GB005414

Factors regulating the Great Calcite Belt in the Southern Ocean and its biogeochemical significance

William M. Balch[1], Nicholas R. Bates[2,3], Phoebe J. Lam[4,5], Benjamin S. Twining[1], Sarah Z. Rosengard[4,6], Bruce C. Bowler[1], Dave T. Drapeau[1], Rebecca Garley[2], Laura C. Lubelczyk[1], Catherine Mitchell[1], and Sara Rauschenberg[1]

Key Points:

- The Southern Ocean Great Calcite Belt (GCB) results from high coccolithophore abundance
- The GCB enhances the ocean source of CO_2 and increases the efficiency of the biological pump
- The formation of the GCB is driven by nutrients and trace metals and their effect on phytoplankton growth



The Great Calcite Belt, the largest ocean color feature on Earth caused by a single type of phytoplankton (coccolithophores), covering 16% of the global ocean, was discovered because of the MODIS two-band/three-band PIC algorithm.

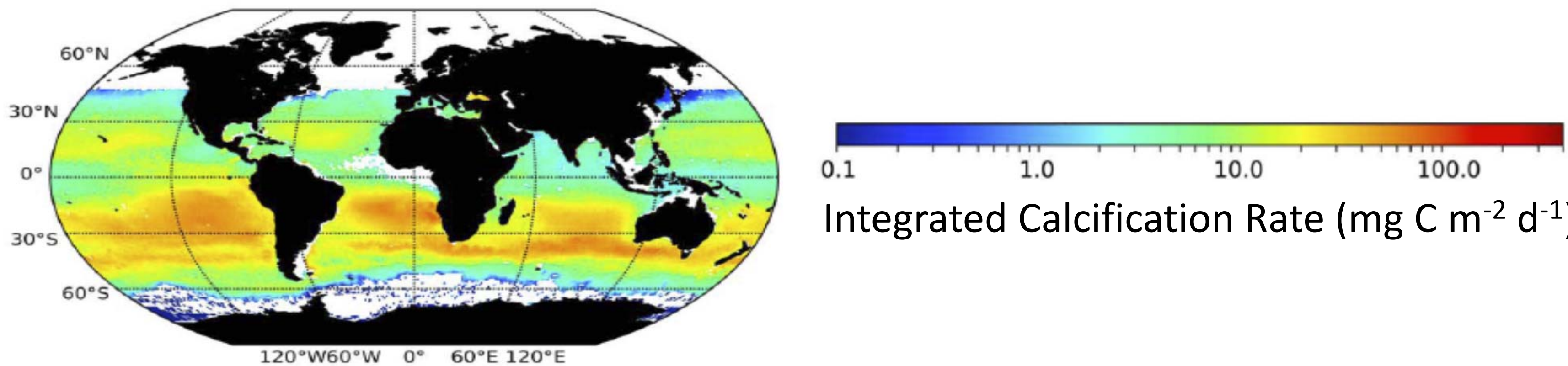
Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE
10.1002/2017JG004235

A New Approach to Estimating Coccolithophore Calcification Rates From Space

Jason Hopkins[1] and William M. Balch[1]

[1]Bigelow Laboratory for Ocean Sciences, East Boothbay, ME, USA



Key Points:

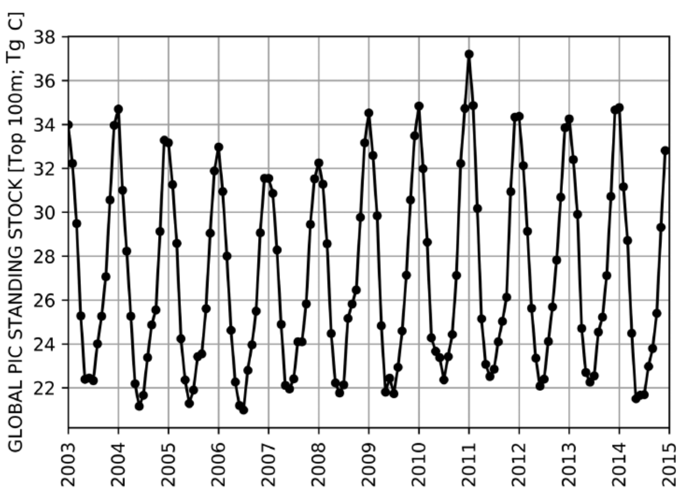
- Maximum global calcification rates seen in subtropical gyres and Great Calcite Belt
- Simple model parameterized with remotely sensed data used to estimate global calcification rates
- Global calcification rate: ~1.42 Pg C $(\text{year})^{-1}$, or ~1.5X C emitted biomass burning

Regional characteristics of the temporal variability in the global particulate inorganic carbon inventory

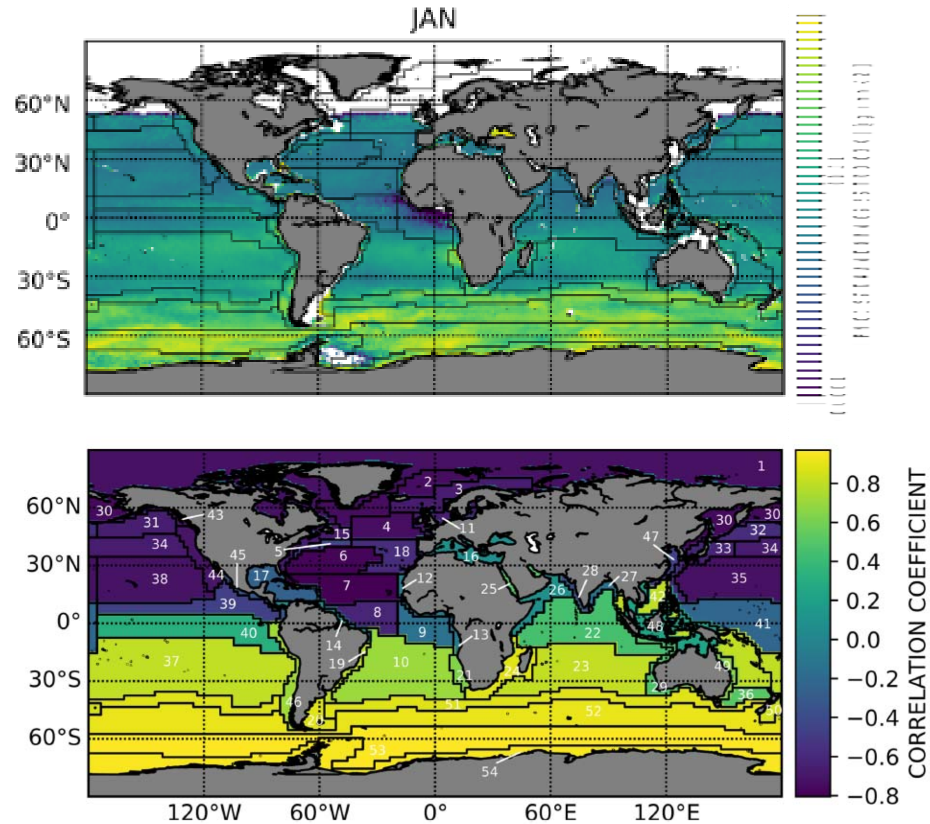
J. Hopkins, S.A. Henson, A.J. Poulton and W.M. Balch. 2019. Global Biogeochemical Cycles, 33.
https://doi. Org/10.1029/2019GB006300

Main Points:

- First interannually-resolved, global analysis of PIC standing stock.
- Avg global monthly PIC standing stock integrated over the top 100m is ~27.0Tg±0.233 log units)
- Average global PIC turnover time is ~7d
- Interannual variability in PIC standing stock is driven primarily by variability in the mid-latitude oceanic gyres and the Great Calcite Belt of the Southern Ocean.



⇧ **Figure 1.** Globally-integrated, monthly PIC standing stock time series (in teragrams of particulate inorganic carbon



⇧

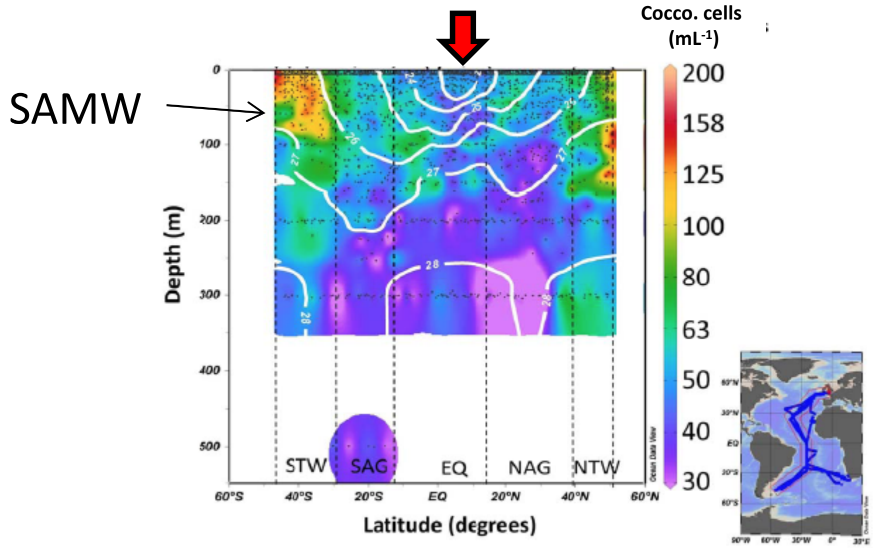
Figure 2- (A) Example of average monthly global PIC standing stock for January derived from MODIS Aqua (2003-2014) integrated to 100m. Boundaries represent Longhurst Provinces. (B) Correlation of Longhurst province PIC standing stock time series. Green to yellow represents a positive correlation coefficient; green to blue indicates a negative correlation coefficient.

Coccolithophore distributions of the North and South Atlantic Ocean

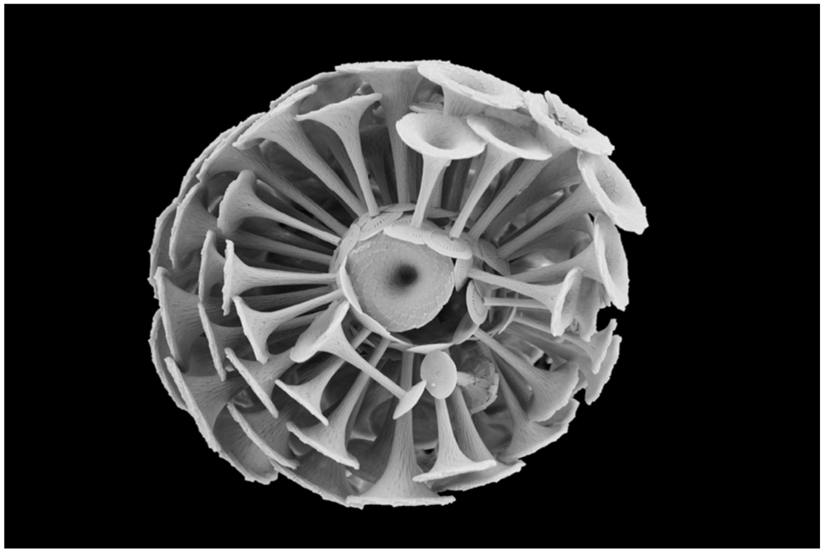
William M. Balch et al. ; Deep Sea Research 1; p 1-22; https://doi.org/10.1016/j.dsr.2019.06.012
Open access.

Main Points:

- Atlantic coccolithophores show a consistent abundance minimum in equatorial waters (see red arrow).
- Deep euphotic coccolithophores are associated with Sub-Antarctic Mode Water (SAMW).
- Maximum coccolithophore concentrations are found in north and south temperate waters.
- Molar concentrations of biogenic silica nonetheless exceed PIC in the Great Calcite Belt.
- Coccolithophore diversity is over double that for their detached coccoliths.



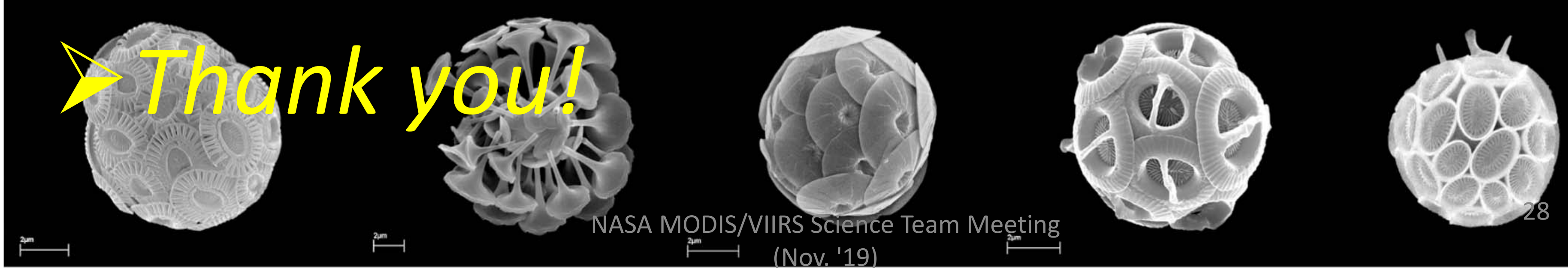
⇧ **Figure 1.** North-South mean section along AMT transects (showing cruises that ended in South America) of concentration of coccolithophore cells (mL-1). Isopleths of density anomaly (σ_θ) are shown in white. Sub-Antarctic Mode Water (SAMW) falls between σ_θ 26.5-27. Regional water masses designated across the bottom of the panel, and demarcated with vertical dashed lines (STW= South Temperate Water, SAG = South Atlantic Gyre; EQ = Equatorial waters; NAG = North Atlantic Gyre; NTW = North Temperate Water). Inset shows cruise tracks.



⇧ **Figure 2.** Coccolithophore *Discosphaera tubifera*, common coccolithophore species in subtropical gyres

Summary: What's new?

- New satellite sensors for PIC
- New PIC differencing algorithm
- New calcification algorithm
- New global estimates of cocco phenology, biomass
- Multispecies blooms now known (~15 spp in EN616, higher diversity of coccolithophores than detached coccoliths
- b_b* appears highly variable and is correlated to % of *E. huxleyi* and [PIC]; can now calculate a variable b_b*!
- ***Thank you!***



Acknowledgements

- MODIS project
- Funding NASA
- NSF shiptime