Coccolithophores: Their biogeochemical and optical properties

Barney Balch

Bigelow Laboratory for Ocean Sciences

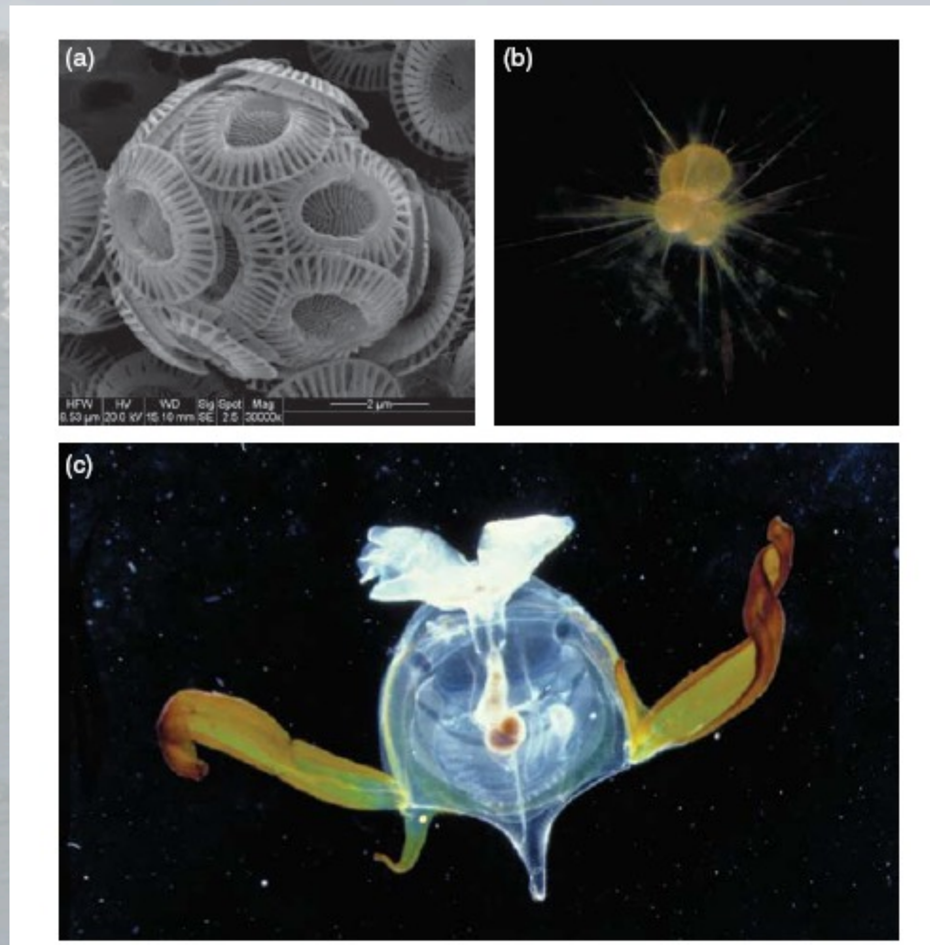
E. Boothbay, ME

Outline

- What are coccolithophores?
  - Taxonomy
  - Blooms
  - Physiology
- Who cares about coccolithophores?
  - Biogeochemistry
  - Ballast
  - Impact on the carbon cycle
- Optical properties
  - Scattering
  - Absorption
  - Reflectance
  - Birefringence
  - Ways to measure them

Marine planktonic calcifiers…

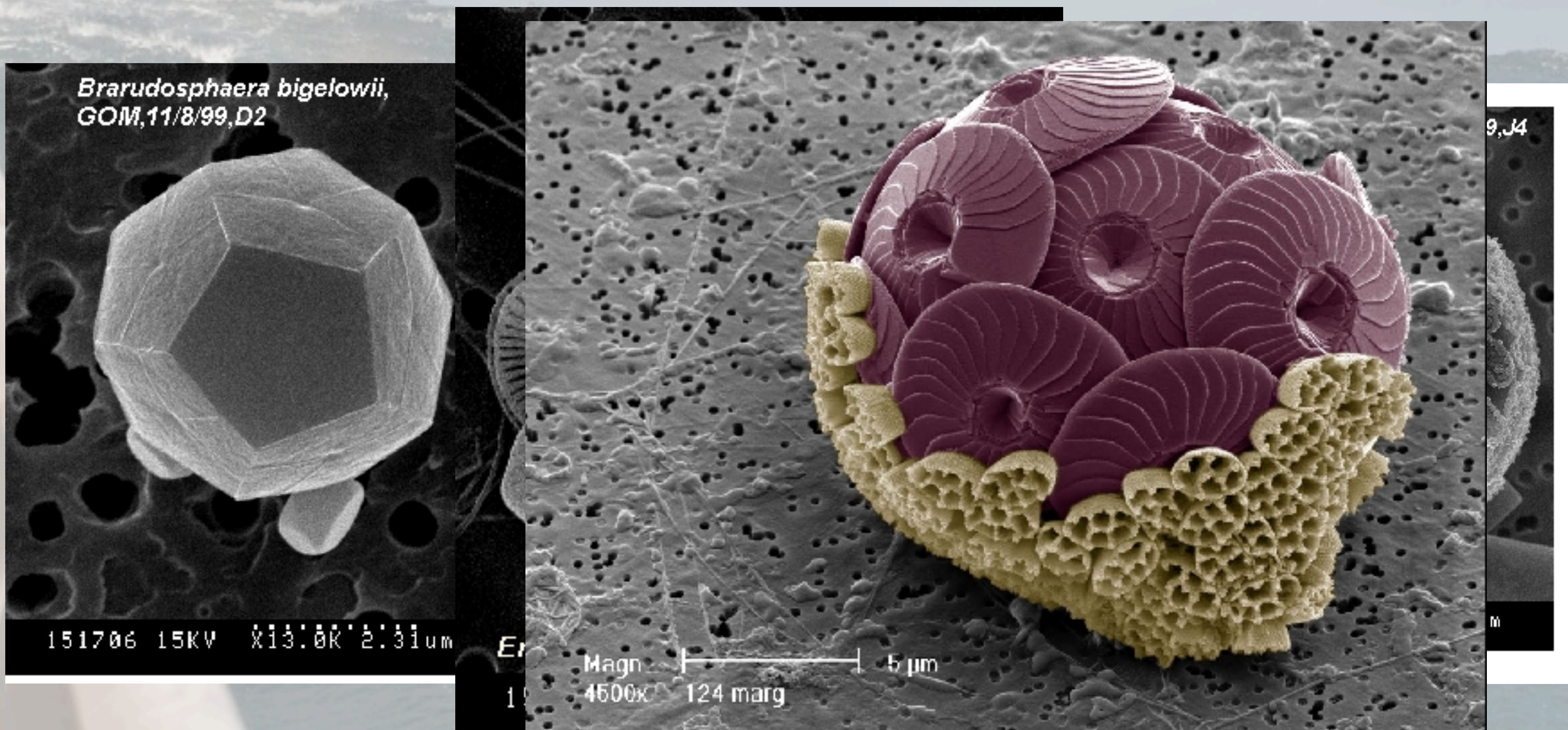
Coccolithophores (unicellular plants; 5-30um)



Foraminifera (Protozoa; 50-500um)

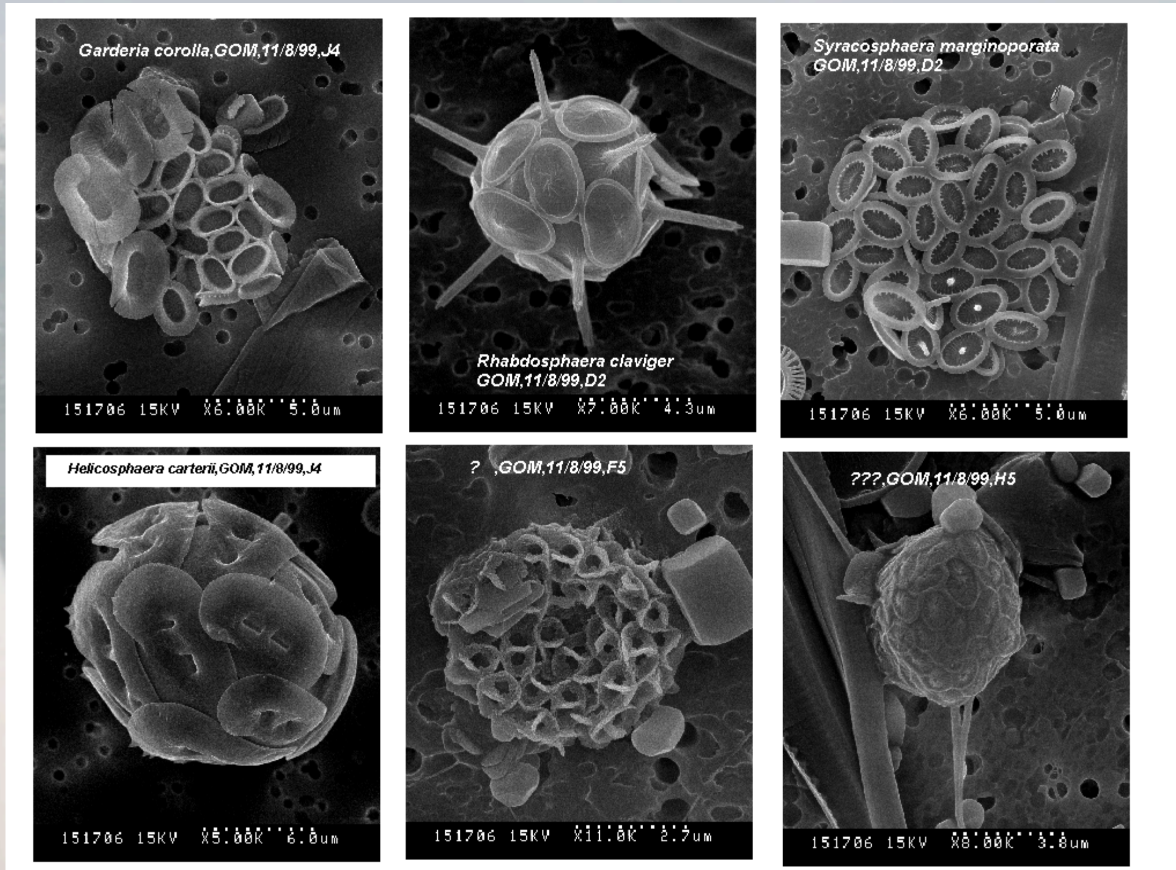
Pteropods (Mollusca; 5mm-1cm)

One of the most important biocalcifiers in the ocean: coccolithophores (Class Prymnesiophycea, family Haptophyta); unicellular, evolutionarily young (<2.5MYBP)



SEMs courtesy of Dr. Delors Blasco, Institute de Ciencias del Mar, Barcelona, Spain; Markus Geisen, Alfred Wegener Inst for Polar and Marine Res.

They come in a wide assortment of shapes and sizes with exquisite architecture…



They drop their coccoliths constantly, producing an **oceanic "dandruff"**, which can discolor the water

SEMs courtesy of Dr. Delors Blasco, Institute de Ciencias del Mar, Barcelona, Spain

More scientific observations of

- Co

SARSIA 6

DISCOLORATION OF THE SEA DUE TO *COCCOLITHUS*

INTRODUCTION

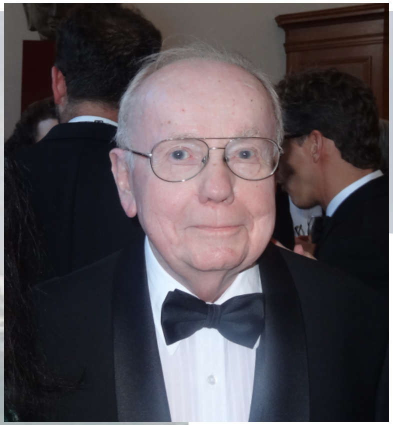
In June 1955 a conspicuous discoloration of the coastal waters and the fjord systems was reported from the surroundings of Haugesund, South-West Norway. According to the report the sea water had acquired an unusual milky-green colour, a condition noticed both by fishermen and other inhabitants in the area. Preserved surface samples were sent to the Institute and microscopical examination revealed enormous concentrations of the calcareous flagellate *Coccolithus huxleyi* (LOHM.) KAMPTNER. The phenomenon was evidently caused by this organism, which was recorded in numbers up to 115 million cells per litre of surface water, the situation being similar to that reported by BRAARUD (1937 and 1945) from the Oslofjord and (1940) from the Grønsfjord.

composition.

INTRODUCTION

In June 1955 a conspicuous discoloration of the coastal waters and the fjord systems was reported from the surroundings of Haugesund, South-West Norway. According to the report the sea water had acquired an unusual milky-green colour, a condition noticed both by fishermen and other inhabitants in the area.

Deep-Sea Research, 1967, Vol. 14, pp. 561 to 597. Pergamon Press Ltd.



Andy McIntyre-

Allan Bé

Modern Coccolithophoridae of the Atlantic Ocean—I. Placoliths and Cyrtoliths*

ANDREW McINTYRE† and ALLAN W. H. BÉ†

(*Received* 21 *June* 1967)

Abstract—Although there are more than 70 species of Coccolithophoridae living in the Atlantic only about 16 of these have adequate fossil records, mainly placoliths and to a lesser extent cyrtoliths.

Biogeographic ranges determined from surface sediment and plankton samples show that living species have slightly broader distributional ranges than those preserved in oceanic sediments. This is attributed to rapid warming of the Atlantic since the last glacial age. Species distributions have been delineated by maximum position poleward of the limiting isotherm for warm-water species and maximum equatorward position of the limiting isotherm for cold water species. Dispersion beyond their present boundaries by ocean currents after death is negligible.

Temperature studies based on cruise data and bimonthly sampling off Bermuda enabled the authors to determine maximum and optimum temperature ranges for each species. The majority are subtropical forms. A few are stenothermal, such as *Umbellosphaera irregularis* (21°–28°C) and *Coccolithus pelagicus* (7°–14°C) and they have proved useful in paleoecology.

The species are grouped into five climatic assemblages: tropical, subtropical, transitional, subarctic, and subantarctic.

Deep-Sea Research, 1967, Vol. 14, pp. 561 to 597. Pergamon Press Ltd.

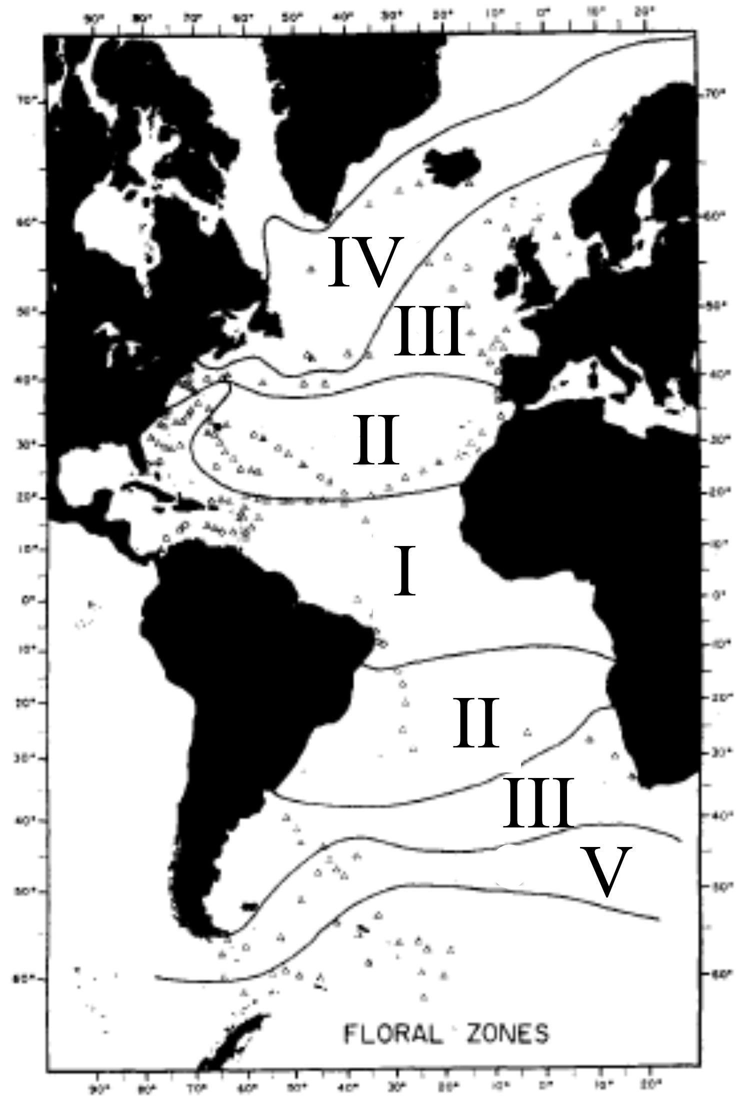


Fig. 17. The coccolithophorid floral zones of the Atlantic Ocean, I tropical, II subtropical, III transitional and IV subarctic–subantarctic.

Deep-Sea Research, 1967, Vol. 14, pp. 561 to 597. Pergamon Press Ltd.

Table 10. Species of the Atlantic coccolithophorid floral assemblages arranged in descending order of importance within each group.

I Tropical
Umbellosphaera irregularis
Cyclolithella annulus
Cyclococcolithus fragilis
Umbellosphaera tenuis
Discosphaera tubifera
Rhabdosphaera stylifera
Helicosphaera carteri
Gephyrocapsa oceanica
Coccolithus huxleyi
Cyclococcolithus leptoporus

II Subtropical
Umbellosphaera tenuis
Rhabdosphaera stylifera
Discosphaera tubifera
Cyclolithella annulus
Gephyrocapsa oceanica
Umbilicosphaera mirabilis
Helicosphaera carteri
Cyclococcolithus leptoporus
Cyclococcolithus fragilis
Coccolithus huxleyi

III Transitional
Coccolithus huxleyi
Cyclococcolithus leptoporus
Gephyrocapsa ericsonii
Rhabdosphaera stylifera
Gephyrocapsa oceanica
Umbellosphaera tenuis
Coccolithus pelagicus

IV Subarctic
Coccolithus pelagicus
Coccolithus huxleyi
Cyclococcolithus leptoporus

V Subantarctic
Coccolithus huxleyi
Cyclococcolithus leptoporus

Coccolithophore diversity decreases towards the poles

What is a coccolithophore bloom?

- Holligan et al. (1983) observed 8500 cells per mL and 78,000 coccoliths per mL
- But note, chlorophyll can be ~1 mg m^{-3}
- But it represents a significant discoloration

The discovery of mesoscale blooms of coccolithophores…

- The first observation Holligan (1983)

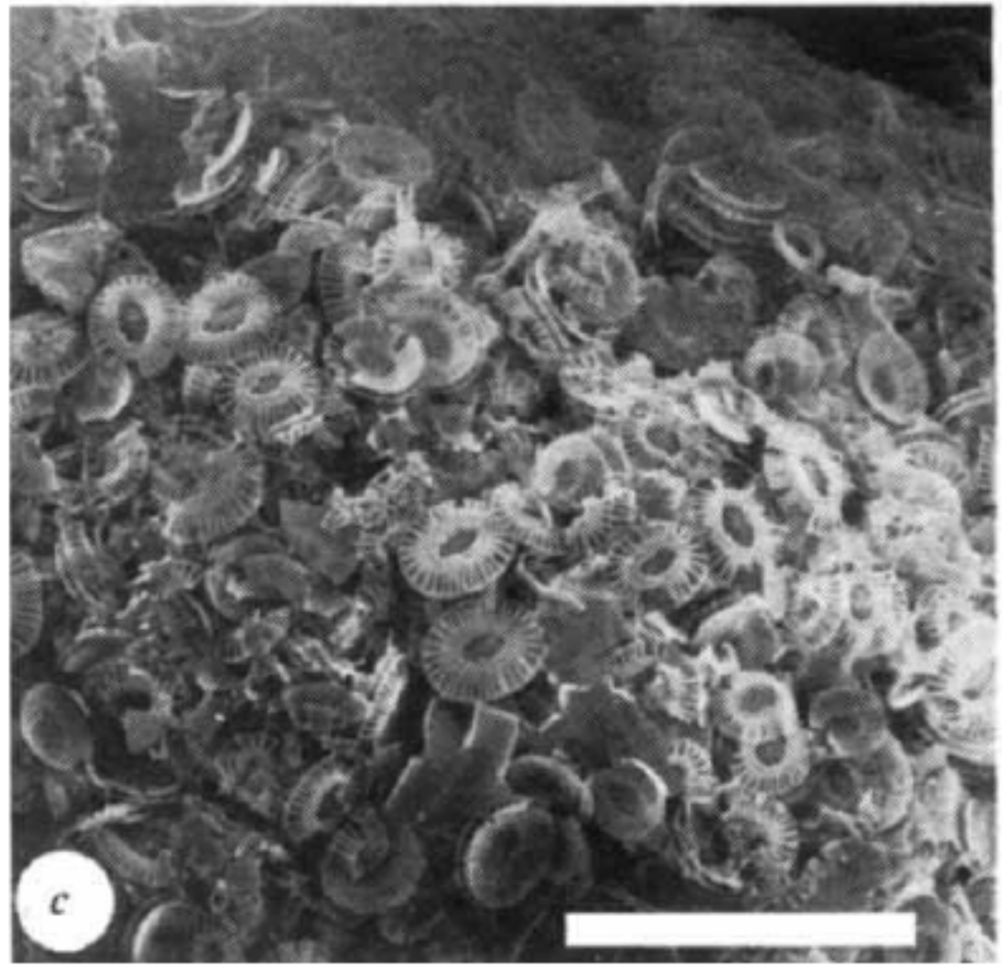
Satellite and ship studies of coccolithophore production along a continental shelf edge

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

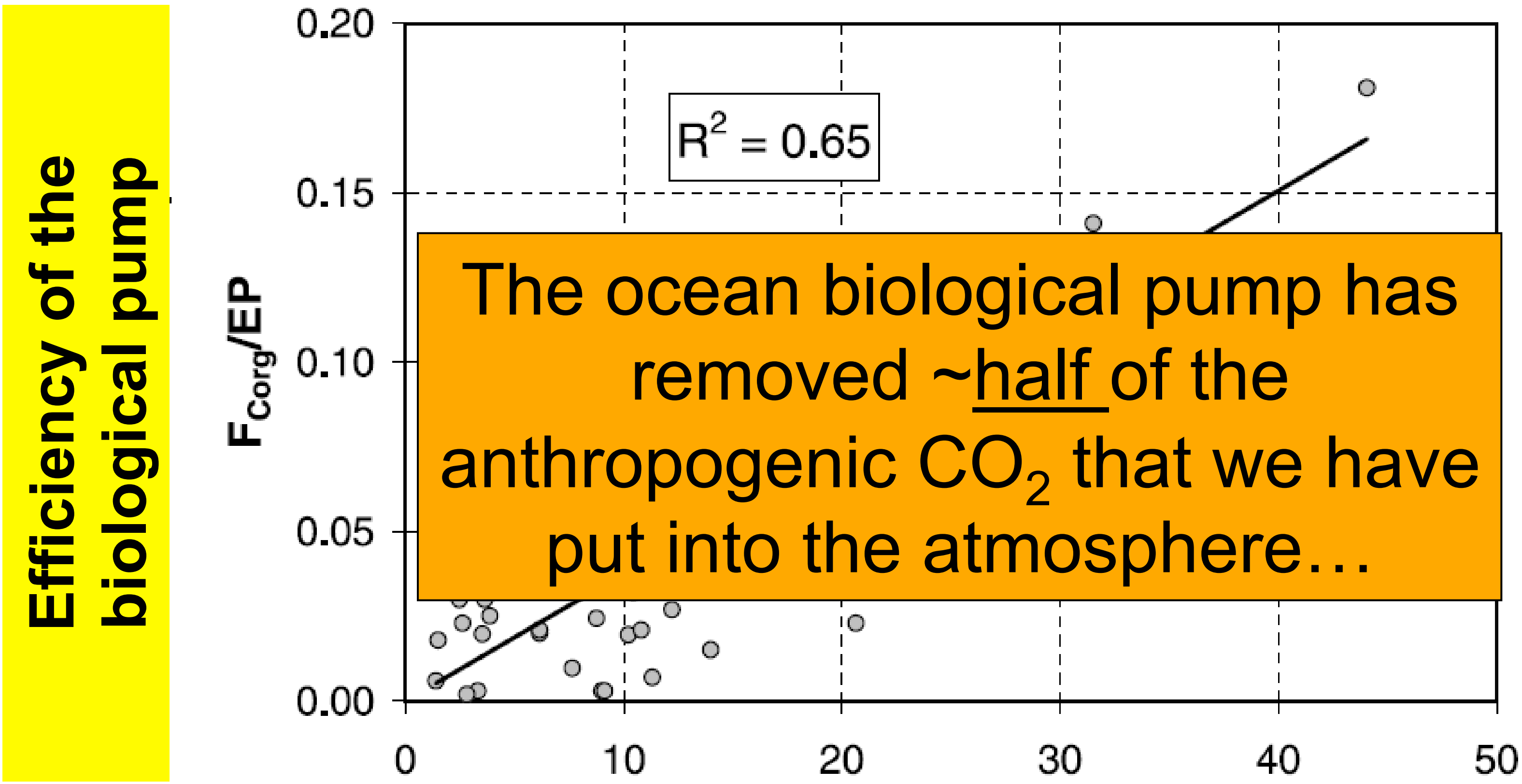
Each year since the Coastal Zone Color Scanner (CZCS)[1] was launched on the Nimbus 7 satellite in November 1978, extensive patches of water giving strong reflectance of visible light have been observed during the early summer along the outer margin of the north-west European continental shelf between 45 and 60° N (refs 2, 3). Various hypotheses including coccolithophores, phytoplankton with external calcified plates or coccoliths, were suggested to explain a comparable feature on Landsat images for July 1977[4]. To test these, we report here observations made from French and UK research vessels in 1982, using unprocessed CZCS images supplied by the University of Dundee and Centre de Meteorologie Spatiale in Lannion to locate suitable sampling areas immediately before and during the cruise, and atmospherically corrected data from the European Space Agency for subsequent analysis and calibration of the reflectance signals. The high reflectance was found to be

||Present address: Station Biologique, CNRS, 29211 Roscoff, France.



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

Influence of carbonate flux on the transfer efficiency of organic matter to the deep sea



Flux of $CaCO_3$ (gC m^{-2} y^{-1})

Francois (2002)

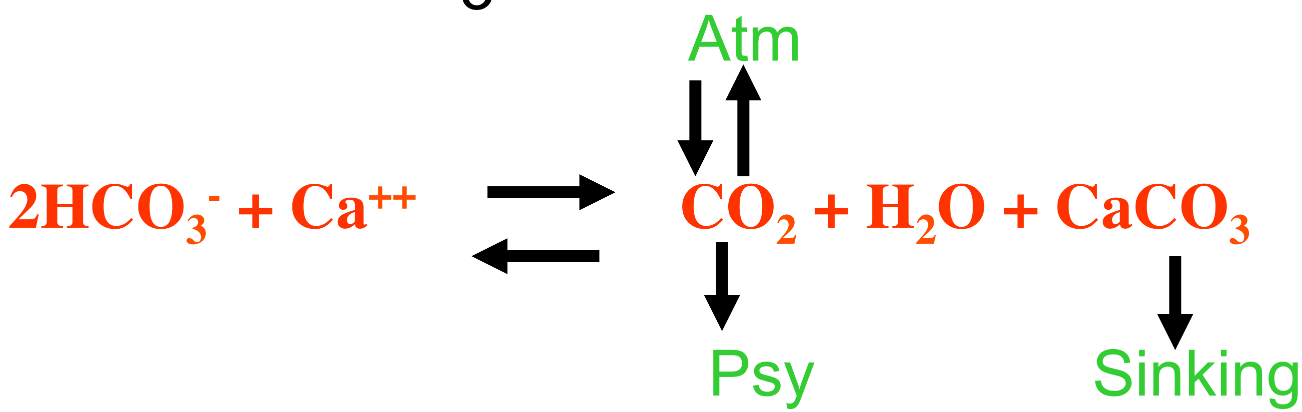
Calcium Carbonate and Global Carbon Pools

- Calcium carbonate (PIC) is one of the **major particulate carbon pools** on earth, 1/4 of all marine sediments are $CaCO_3$.
- Biosphere has many calcifiers but the small ones play a **disproportionately large role in the carbon cycle**

Pool	*GT C*
PIC (sediments)	$5.7\text{x } 10^6$
DOC (ocean)	1000
POC (sediments)	$0.8 \text{ x } 10^6$
Atmospheric C	700

Stoichiometry and biogeochemistry of $CaCO_3$ biomineralization:

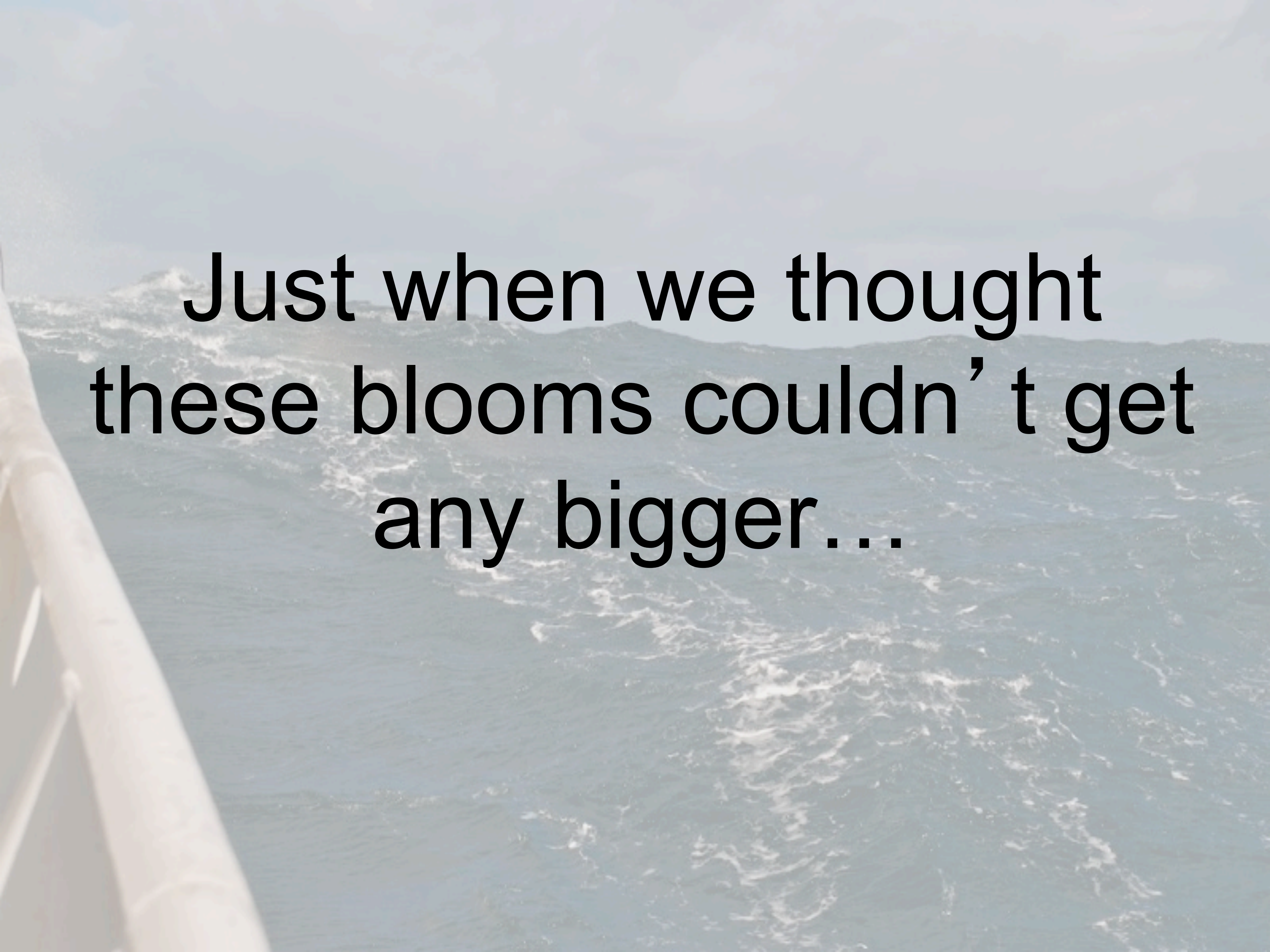
- $2HCO_3^- + Ca^{++} \rightleftharpoons CO_2 + H_2O + CaCO_3$



- In top kilometer of ocean, reaction strongly driven to right, but pressure, temperature and pH affect equilibrium
- Marine calcification thought to be about 1-1.5GT per year (~1/5 fossil fuel CO_2 generation or ~equivalent to CO_2 production associated with deforestation and agricultural tilling of soils)

[Intergovernmental Panel on Carbon Climate]

asin

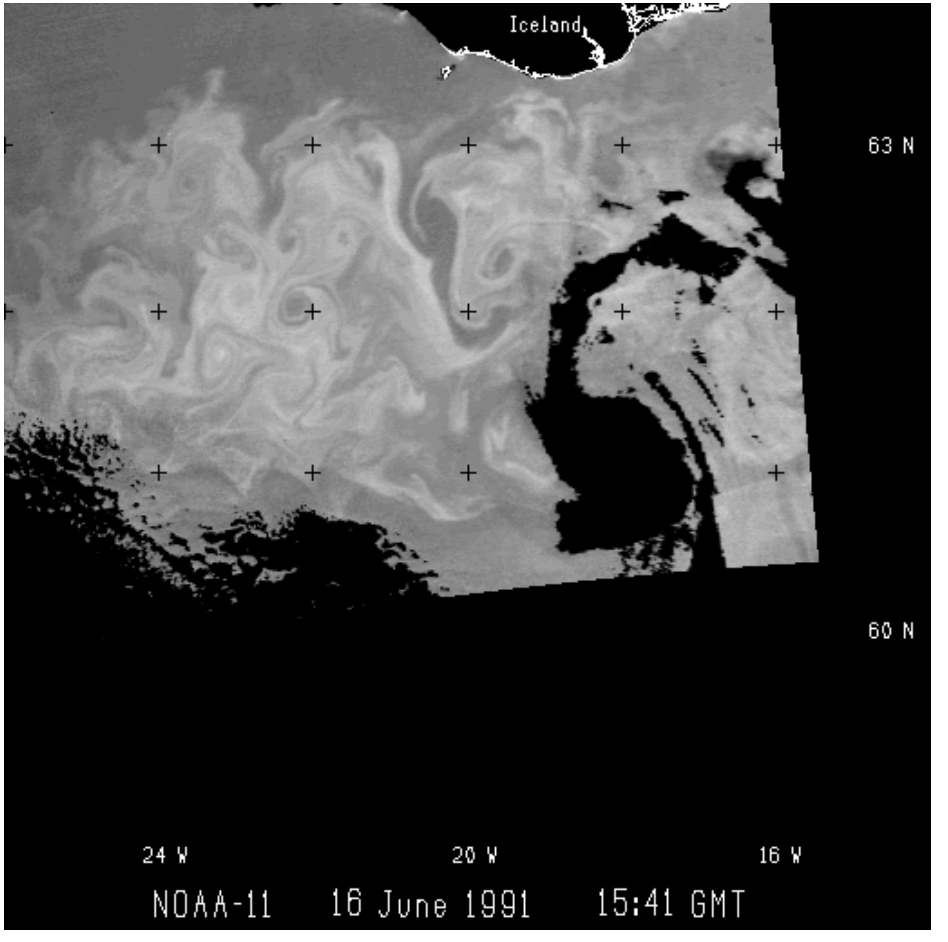

Just when we thought these blooms couldn’t get any bigger…

AVHRR- June 18, 29 and July 1, 1991 composite

GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 7, NO. 4, PAGES 879-900, DECEMBER 1993

A BIOGEOCHEMICAL STUDY OF THE COCCOLITHOPHORE, *Emiliania huxleyi*, IN THE NORTH ATLANTIC

Patrick M. Holligan,[1] Emilio Fernández,[1] James Aiken,[1] William M. Balch,[2] Philip Boyd,[3] Peter H. Burkill,[1] Miles Finch,[4] Stephen B. Groom,[5] Gillian Malin,[6] Kerstin Muller,[7] Duncan A. Purdie,[4] Carol Robinson,[7] Charles C. Trees,[8] Suzanne M. Turner,[6] and Paul van der Wal[9]



Total area = 0.5 million km^2

A “sea of milk”, Iceland-style

Outside Bloom

Constant color chip for comparison of water color

Inside Inside

View from Lufthansa flight #423, 38,000 feet

Effects of coccolithophores on optical properties in a bloom- Tyrell, 1991

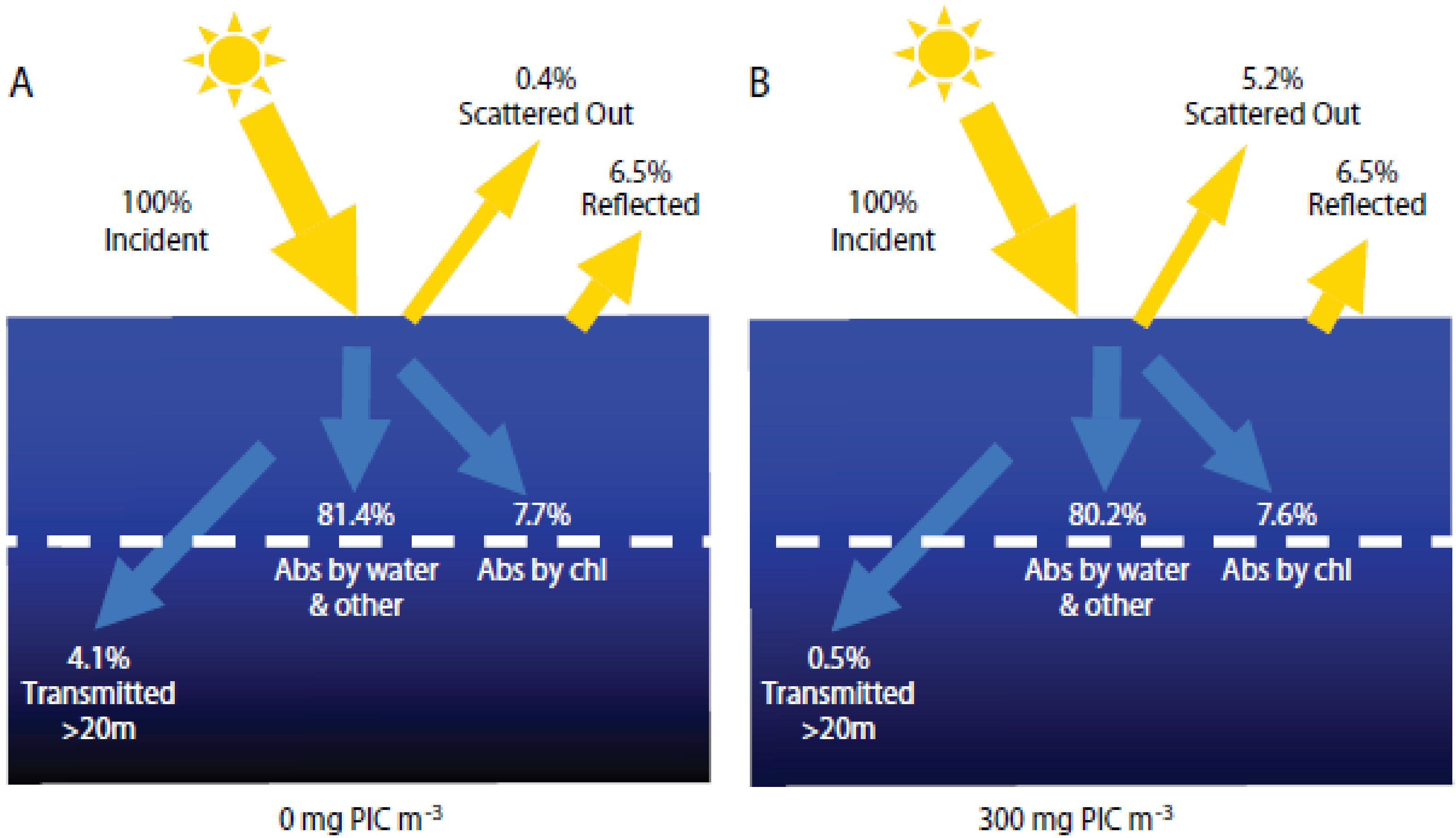
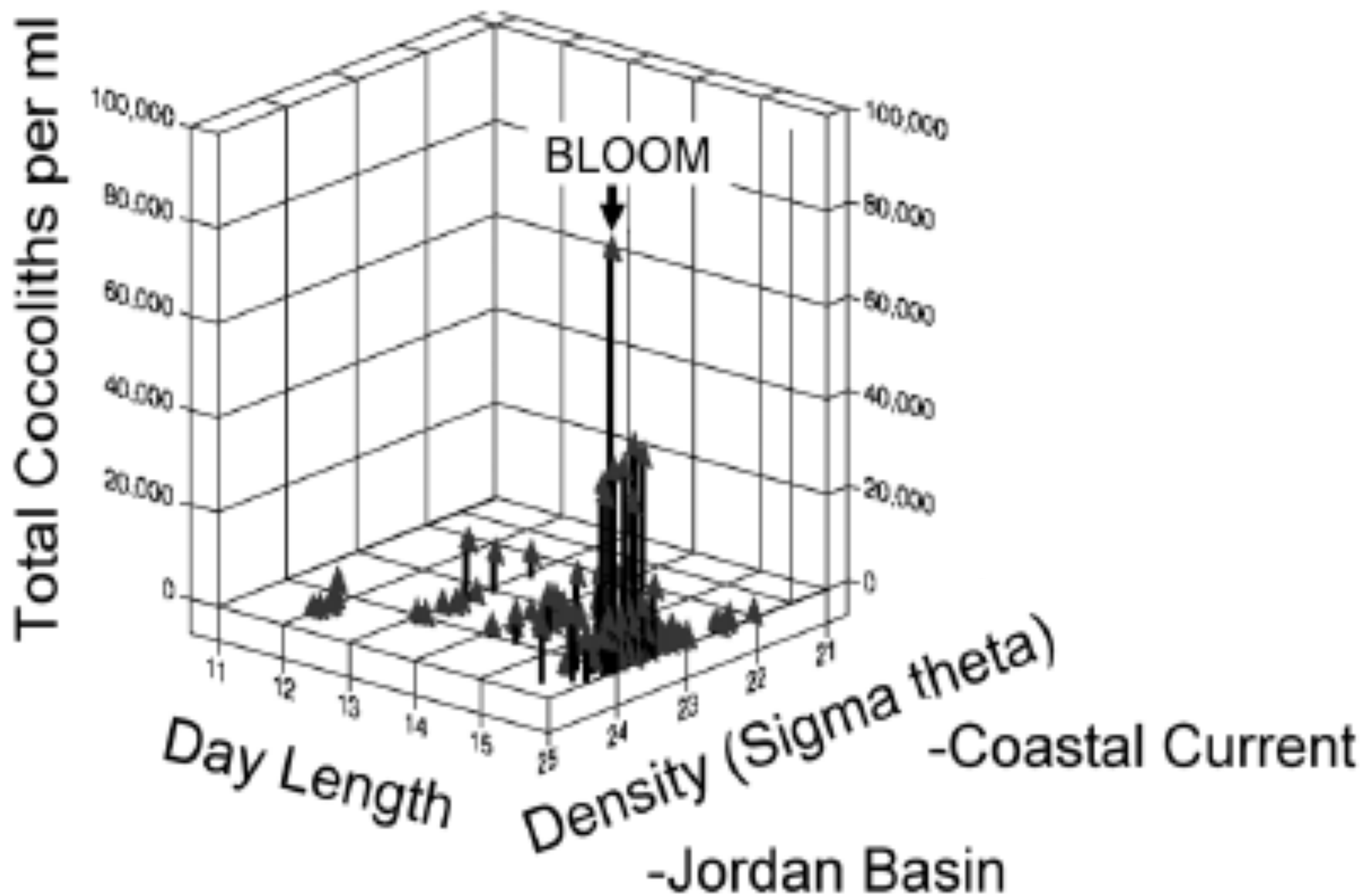


Figure 2. Photon budgets for water with (A) no particulate inorganic carbon (PIC) vs. (B) 300 µgPIC L^{-1}. Values are based on incoming irradiance of 1100 µEin m^{-2} s^{-1}, wind speed = 5 m s^{-1}, cloud cover = 25%, chl = 0.75 µg L^{-1}, and solar zenith angle = 45°. 1 Einstein = 1 mole of photons (or Avogadro's number of photons: 6.02×10^{23}). *Optical modeling results redrawn from Tyrell et al. (1999)*

In the Gulf of Maine, blooms begin in moderately stratified water near the summer solstice…



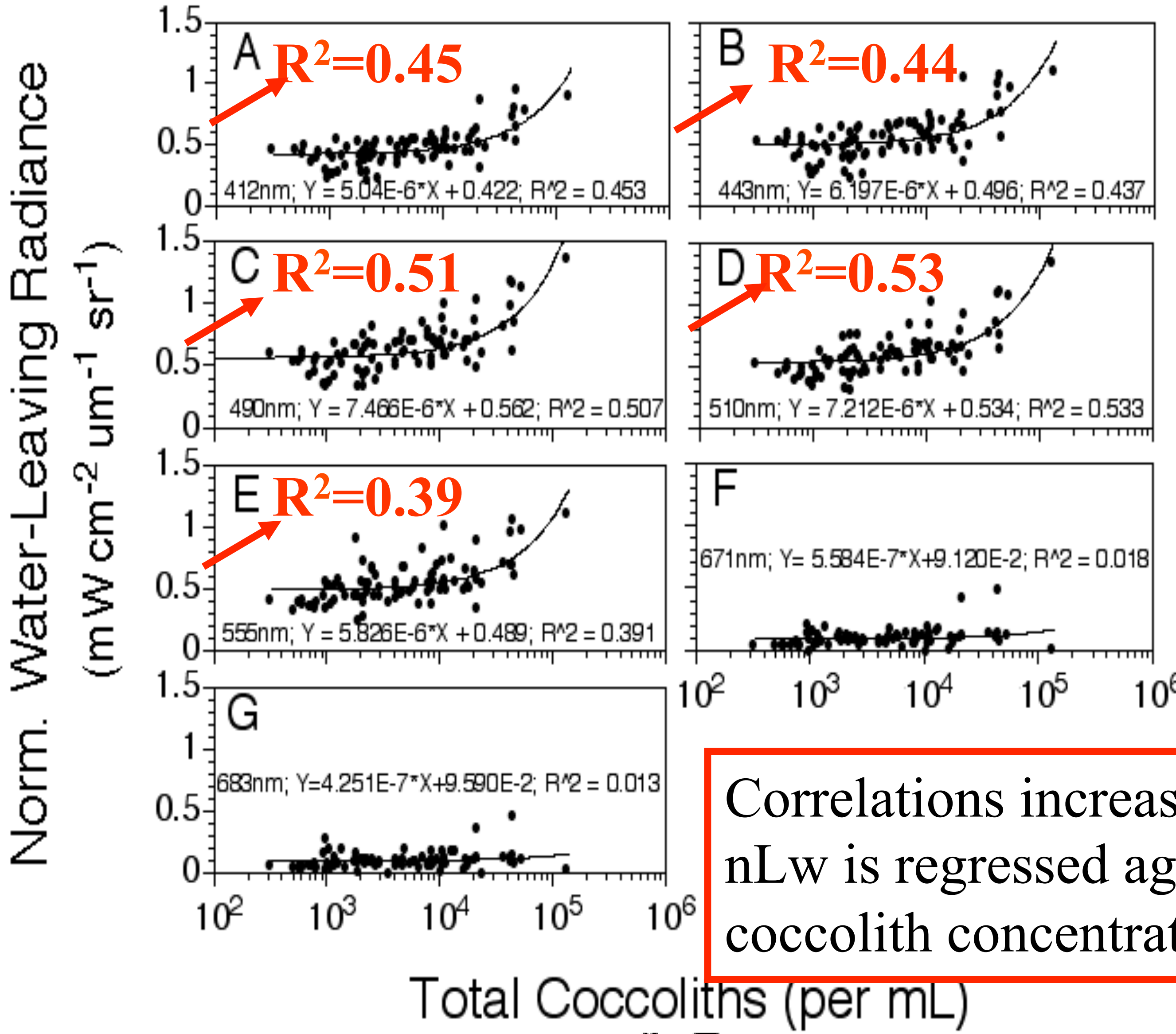
Optical properties

- Absorption
- Scattering
- Reflectance
- Birefringence
- Remote Sensing
- Acid-Labile Backscattering

Optical properties of PIC

- PIC relative refractive index = 1.19 (POC rel. refractive index = 1.05; BSi rel. refractive index biogenic silica = 1.07 (Costello, 1995), thus PIC is highly scattering.
- Dense ocean suspensions of coccoliths can have a high albedo (0.35)
- PIC is birefringent, rotates the plane of linearly polarized light by 90^o
- Low absorbance
- Mass and shape of coccoliths varies by species, hence the scattering cross section is variable with values ranging from 1 to 8 m^2 $mole^{-1}$
- Coccoliths can be a primary determinant of nLw…

PIC can be a 1° determinant of nLw



Correlations increase when nLw is regressed against coccolith concentration!

Gulf of Maine

Absorption of coccoliths

Limnol. Oceanogr., 36(4), 1991, 629–643

Biological and optical properties of mesoscale coccolithophore blooms in the Gulf of Maine

William M. Balch
Division of Marine Biology and Fisheries, Rosenstiel School for Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149-1098

Patrick M. Holligan
Plymouth Marine Laboratory, West Hoe, Plymouth PL1 3DH, United Kingdom

Steven G. Ackleson[1]
Bigelow Laboratory for Ocean Sciences, McKown Point, West Boothbay Harbor, Maine 04575

Kenneth J. Voss
Department of Physics, University of Miami, Coral Gables, Florida 33124

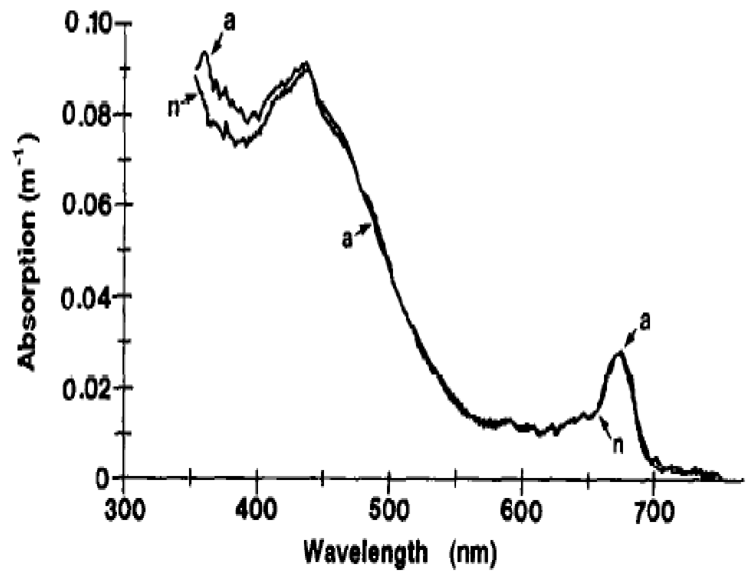


Fig. 9. Particulate absorption spectrum (m^{-1}) from station 8 at 5 m. Data represent two scans, one of a glass-fiber filter through which raw coccolithophore bloom water was passed (curve n) and an identical filter through which bloom water was passed following dissolution of coccoliths (curve a).

- Used filter-pad technique
- Absorption is negligible
- Carbonates do absorb organics, surprising there isn’t more absorption in the UV

Size dependence of the scattering cross-section

Limnol. Oceanogr., 41(8), 1996, 1684–1696

The 1991 coccolithophore bloom in the central North Atlantic.
2. Relating optics to coccolith concentration

William M. Balch
Bigelow Laboratory for Ocean Sciences, McKown Point, W. Boothbay Harbor, Maine 04575

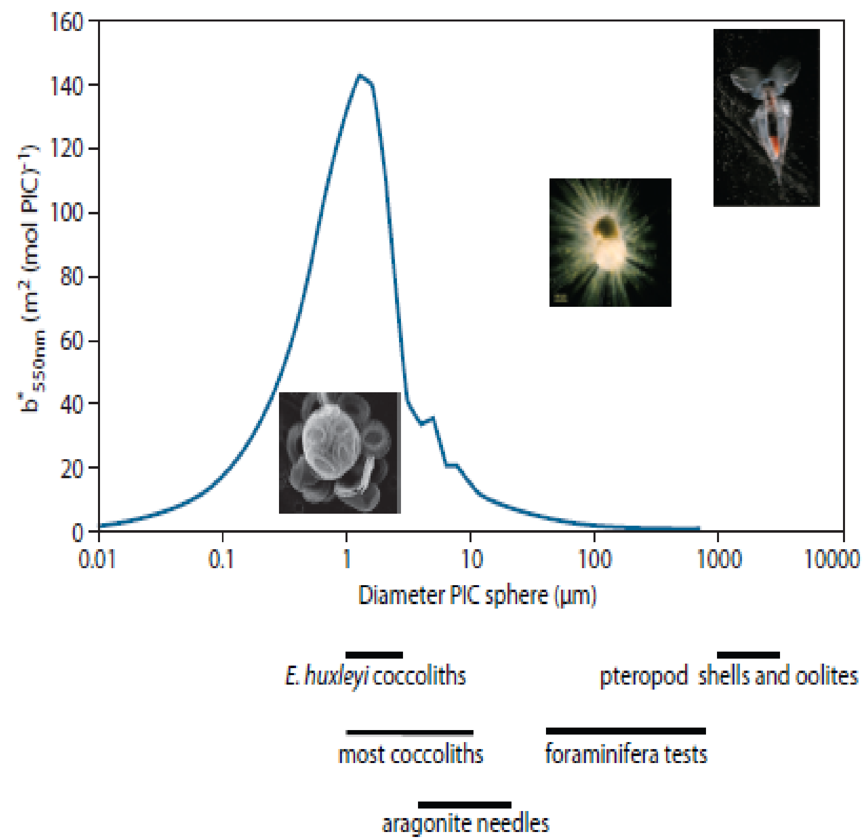
Katherine A. Kilpatrick
Division of Meterology and Physical Oceanography, Rosenstiel School for Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149-1098

Patrick Holligan
Dept. of Oceanography, University of Southampton Highfield, Southampton, S017 1BJ, United Kingdom

Derek Harbour
Plymouth Marine Laboratory, West Hoe, Plymouth, United Kingdom

Emilio Fernandez
Depto. Recursos Naturais e Medio Ambiente, Facultad de Ciencias del Mar, Campus Lagoas-Marcosende, Universidade de Vigo, E-36200, Vigo, Spain

- Anomalous diffraction theory for non-absorbing spheres (Van de Hulst, 1981)
- Relative refractive index of PIC =1.19
- Density = 2.71E6 g/m3
- Micron-sized coccoliths have highest b* (m2/mg PIC)



VSF flattens in backward direction…

Limnol. Oceanogr., 43(5), 1998, 870–876

Scattering and attenuation properties of *Emiliania huxleyi* cells and their detached coccoliths

Kenneth J. Voss
Department of Physics, University of Miami, Coral Gables, Florida 33124

William M. Balch
Bigelow Laboratory for Ocean Sciences, McKown Point, West Boothbay Harbor, Maine 04575

Katherine A. Kilpatrick
Division of Meteorology and Physical Oceanography, Rosenstiel School for Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149

- General Angle Scattering Meter suspended in barrel of coccolithophore culture
- VSF is relatively flat in the backwards direction compared to typical Petzold VSFs

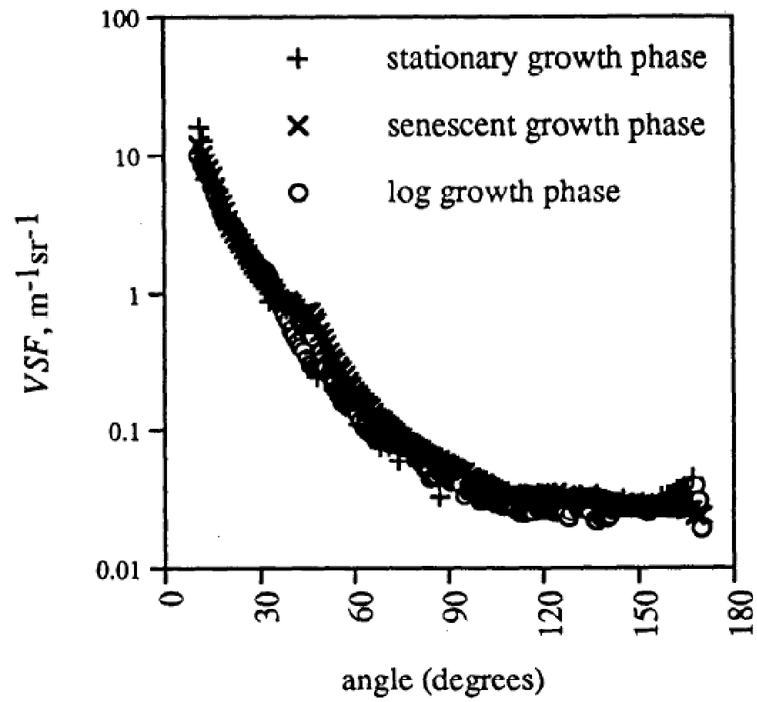


Fig. 4. Example VSF (490 nm) for each growth phase (stationary, log, and senescent).

Wavelength dependence of b_b*

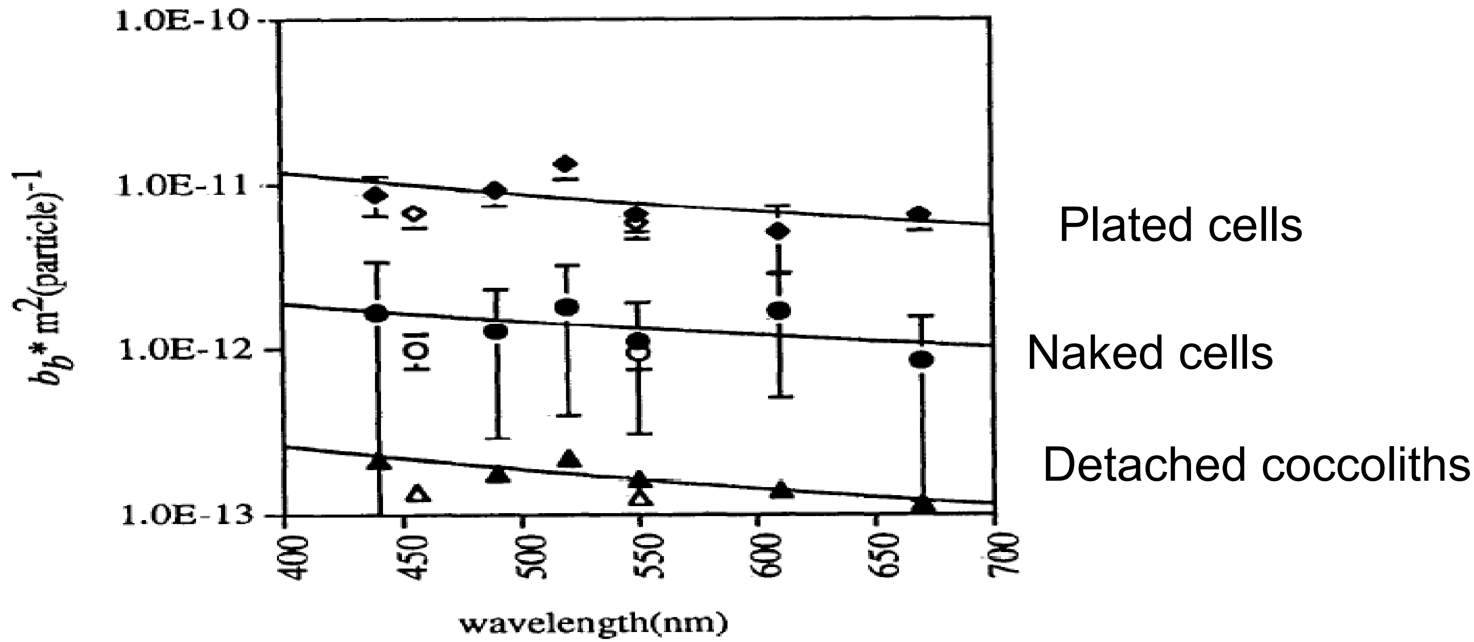


Fig. 6. Specific b_b coefficients (b_b*) as a function of wavelength for both the BP-derived and GASM-derived measurements. Open symbols are the GASM-derived coefficients; filled symbols are the BP-derived coefficients. Triangles correspond to coccoliths, diamonds to plated cells, and circles to naked cells. Also shown is the power law fit to each component (as discussed in the text). The exponent found for each component was −1.4, −1.2 and −1.0 for coccoliths, plated cells, and naked cells, respectively.

Voss et al., 1998; L&O v43; p.874

Some historical context:

Previous direct measurements of b_b* in support of the two-band PIC algorithm. Just like a*, b_b* shows natural variability…

JOURNAL OF GEOPHYSICAL RESEARCH, VOL. 104, NO. C1, PAGES 1541–1558, JANUARY 15, 1999

Optical backscattering by calcifying algae: Separating the contribution of particulate inorganic and organic carbon fractions

William M. Balch, David T. Drapeau, Terry L. Cucci, and Robert D. Vaillancourt

Bigelow Laboratory for Ocean Sciences, West Boothbay Harbor, Maine

Katherine A. Kilpatrick

Division of Meteorology and Physical Oceanography, Rosenstiel School for Marine and Atmospheric Science, University of Miami, Miami, Florida

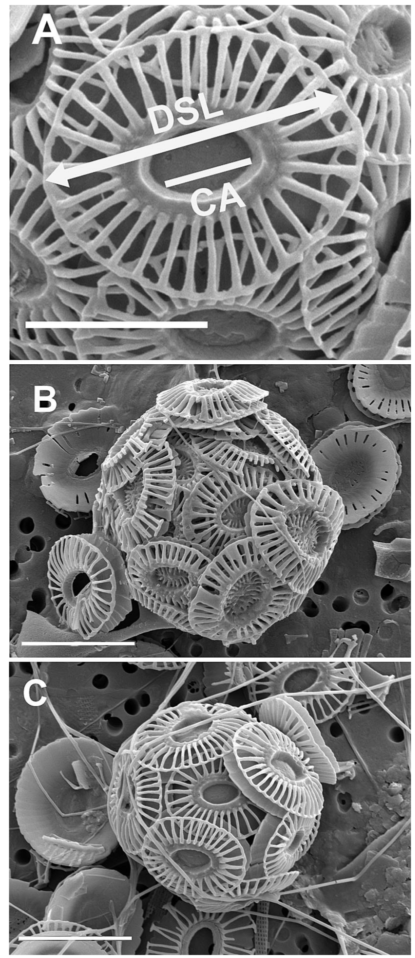
Jennifer J. Fritz

Smithsonian Environmental Research Center, Edgewater, Maryland

All *E. huxleyi* coccoliths are not the alike!

Common morphotypes referred to as A, B, C and R (e.g. Young et al. 2003) or as distinct *E. huxleyi* varieties (var. *huxleyi*, var. *pujosae*, var. *kleijniae*; Medlin et al. 1996).

A fifth morphotype, B/C is observed in the southern hemisphere (Cubillos et al. 2007, Holligan et al. 2010, Cook et al. 2011) and subpolar waters (Hagino et al. 2005).



Type A coccoliths- common

Type B/C coccoliths

Poulton et al., 2011 MEPS

Biometry of E. huxleyi coccoliths

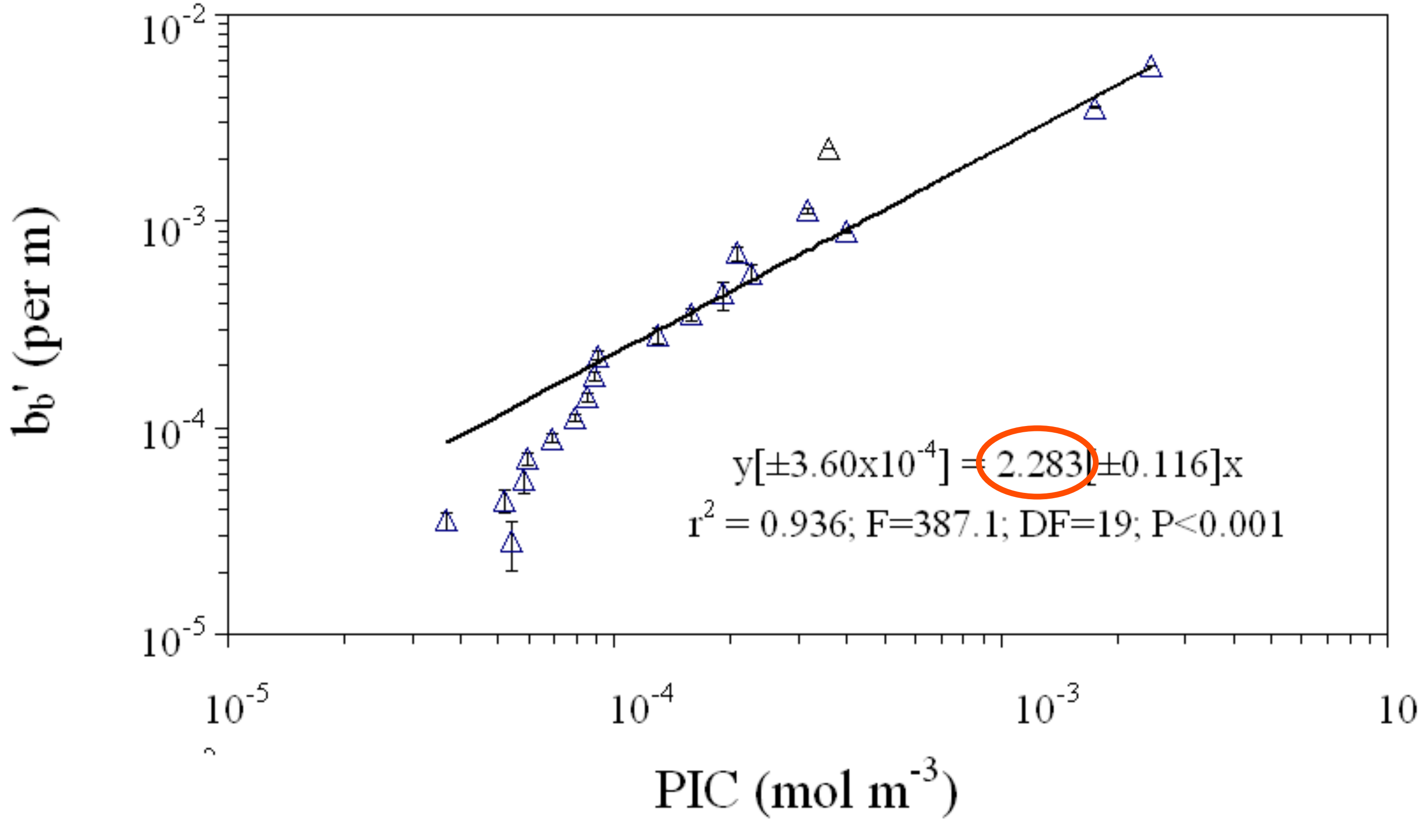
Coccolith Morphology	*Distal length (μm; diam*		*ol C/lith*
A (N. Atl. Cocc Blooms)		ments st; DS>PS	0.015-0.035 Medium size
B		Distal elements delicate; DS<PS	0.023-0.068 Largest; 53-94% bigger than type A
B/C	2-4	Distal elements delicate; DS=PS	0.011-0.026 Smallest 73% smaller than type A

Could these differences lead to differences in the backscattering cross-section of the coccoliths?

Poulton et al., 2011 MEPS

Reconcile this with AMT cruises (between the UK and S. Africa; multi-species of coccolithophores) we found:

average b_b^* = 2.283+/-0.116 m^2 (mol PIC)$^{-1}$



Reconcile this with the North Atlantic coccolithophore bloom (*E. huxleyi*), we found b_b^* =

avg b_b^*= 1.632+/-0.063 m^2 (mol PIC)$^{-1}$

Limnol. Oceanogr., 41(8), 1996, 1684–1696

The 1991 coccolithophore bloom in the central North Atlantic.
2. Relating optics to coccolith concentration

William M. Balch
Bigelow Laboratory for Ocean Sciences, McKown Point, W. Boothbay Harbor, Maine 04575

Katherine A. Kilpatrick
Division of Meterology and Physical Oceanography, Rosenstiel School for Marine and Atmospheric Science, University of Miami, 4600 Rickenbacker Causeway, Miami, Florida 33149-1098

Patrick Holligan
Dept. of Oceanography, University of Southampton Highfield, Southampton, S017 1BJ, United Kingdom

Derek Harbour
Plymouth Marine Laboratory, West Hoe, Plymouth, United Kingdom

Emilio Fernandez
Depto. Recursos Naturais e Medio Ambiente, Facultad de Ciencias del Mar, Campus Lagoas-Marcosende, Universidade de Vigo, E-36200, Vigo, Spain

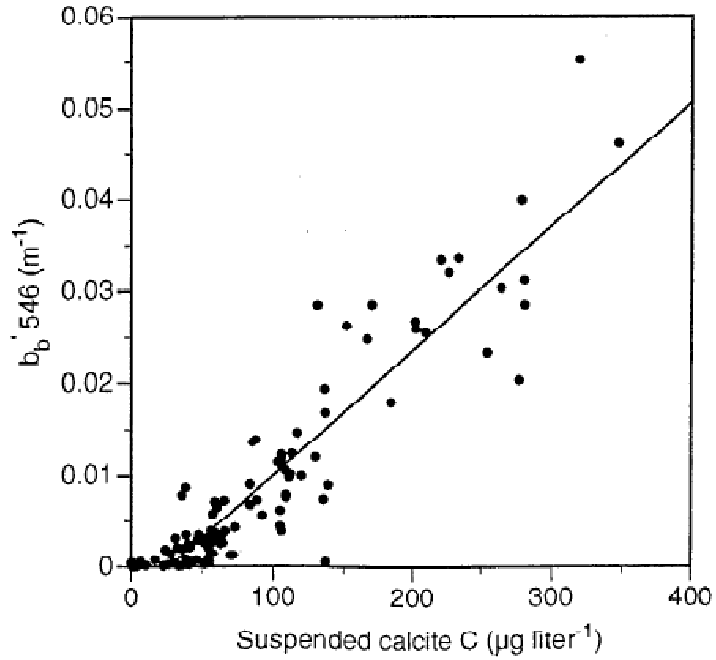
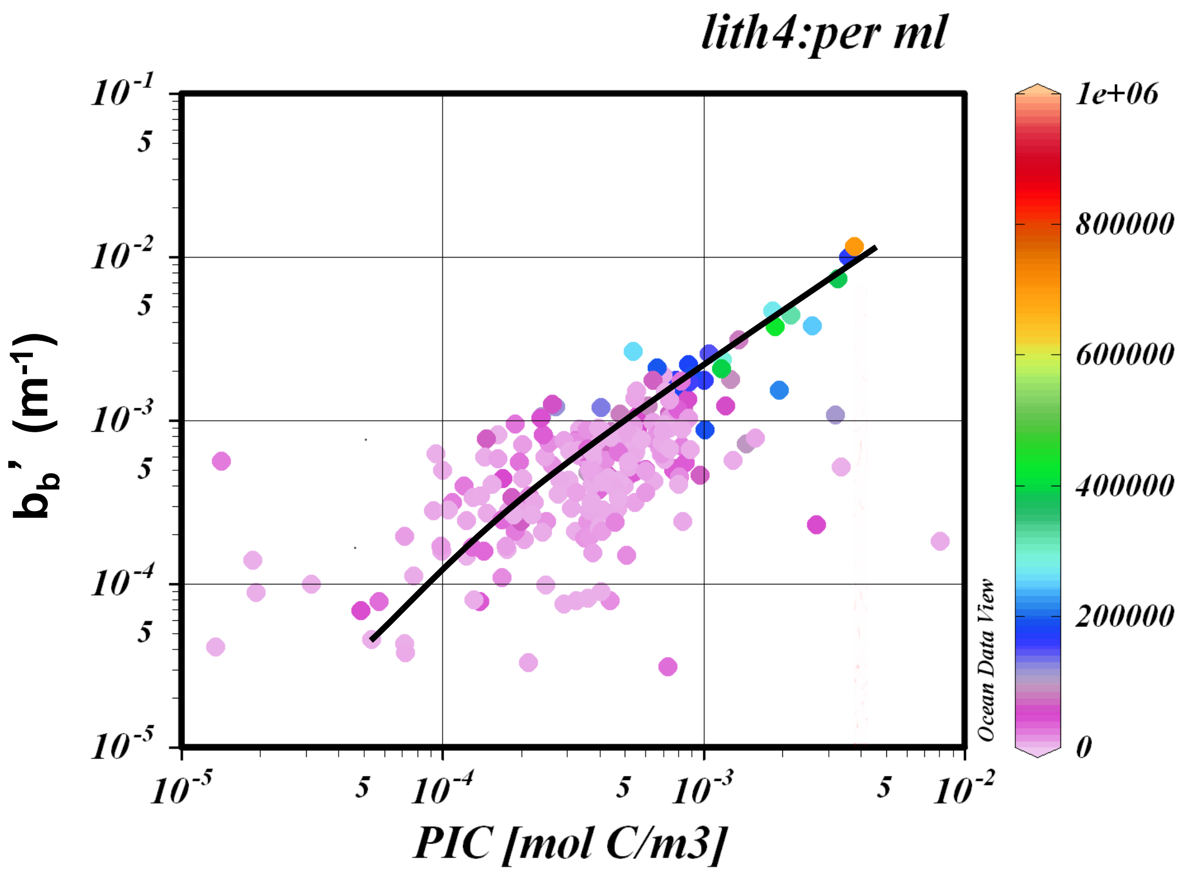


Fig. 2. Calcite-specific backscattering at 436 nm and 546 nm as a function of concentration of suspended calcite. Lines are least-squares fits to the data. (Equations given in Table 1.)

PIC-specific backscattering cross-section in the GCBis lowest of all

avg $b_b^* = 1.553[\pm 0.089]\ m^2\ (mol\ PIC)^{-1}$)



$y[\pm 8.07e\text{-}4] = 1.553[\pm 0.089]x - 4E\text{-}05[\pm 7.08e\text{-}5]$

$r2 = 0.553$; $F = 302$; $DF=244$; $P<0.001$

Optical ways to measure PIC… useful over scales of meters to 1000’s of km’s

- Birefringence
- Acid-labile backscattering
- Satellite PIC algorithms

Birefringence

- Canada Balsam technique (e.g. Haidar AT, Thierstein HR, Deuser WG (2000) Calcareous phytoplankton standing stocks, fluxes and accumulation in Holocene sediments off Bermuda (N. Atlantic). Deep Sea Research 47:1907-1938)
- In situ birefringence (Guay CKH, Bishop JKB (2002) A rapid birefingence method for measuring suspended $CaCO_3$ concentration in seawater. Deep-Sea Res I 49:197–210).

PERGAMON

Deep-Sea Research I 49 (2002) 197–210

DEEP-SEA RESEARCH
PART I

www.elsevier.com/locate/dsr

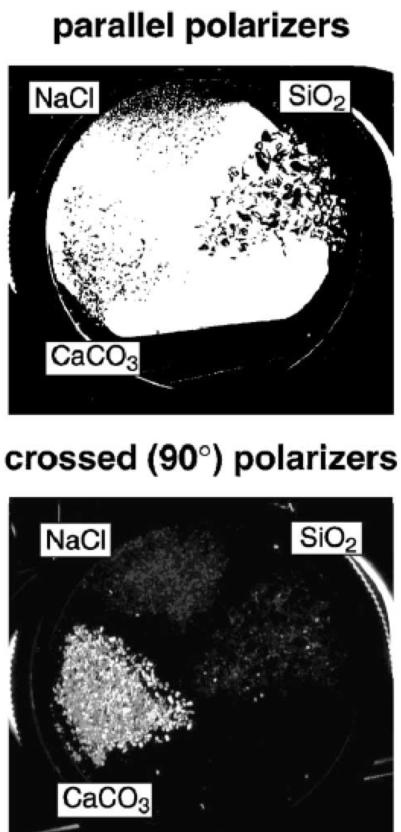
Instruments and methods

A rapid birefringence method for measuring suspended $CaCO_3$ concentrations in seawater

Christopher K.H. Guay*, James K.B. Bishop

Earth Sciences Division, Lawrence Berkeley National Laboratory, One Cyclotron Road, Berkeley, CA 94720, USA

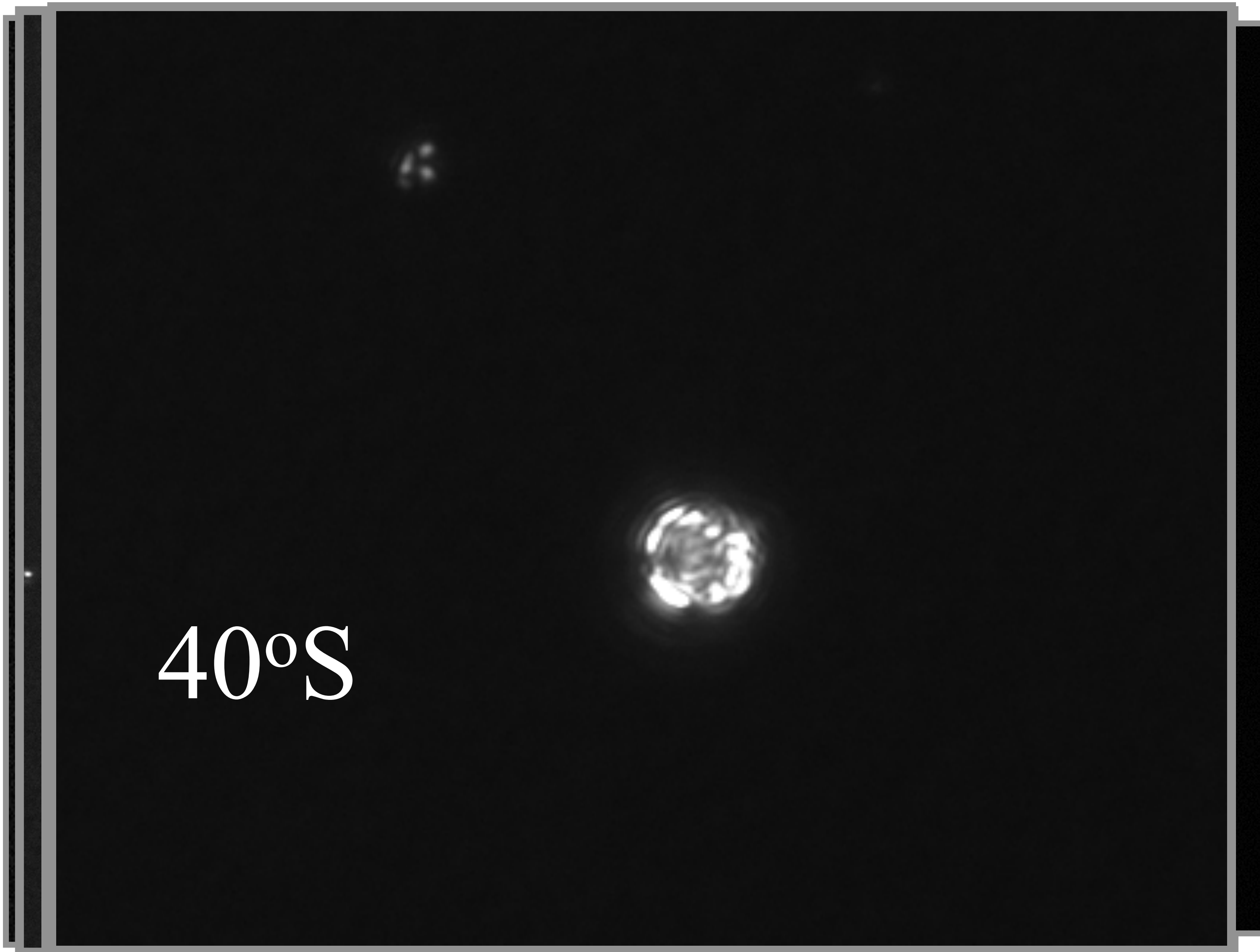
Received 31 August 2000; received in revised form 31 May 2001; accepted 17 August 2001



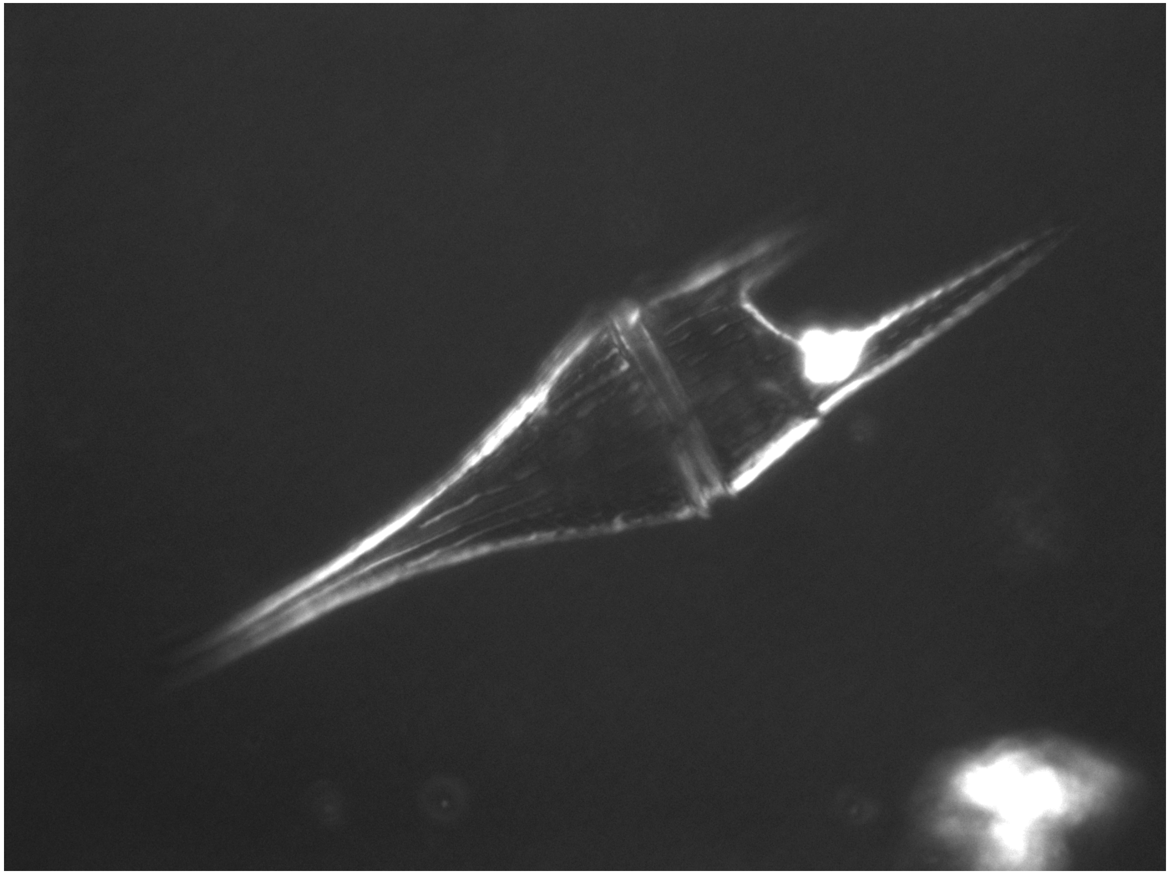
Technique can be put on autonomous vehicles like the “Carbon Explorer”

-Must be calibrated with natural PIC suspensions because of the presence of non-calcareous, birefringent material

Examples of birefringence coccolithophores from AMT 15…

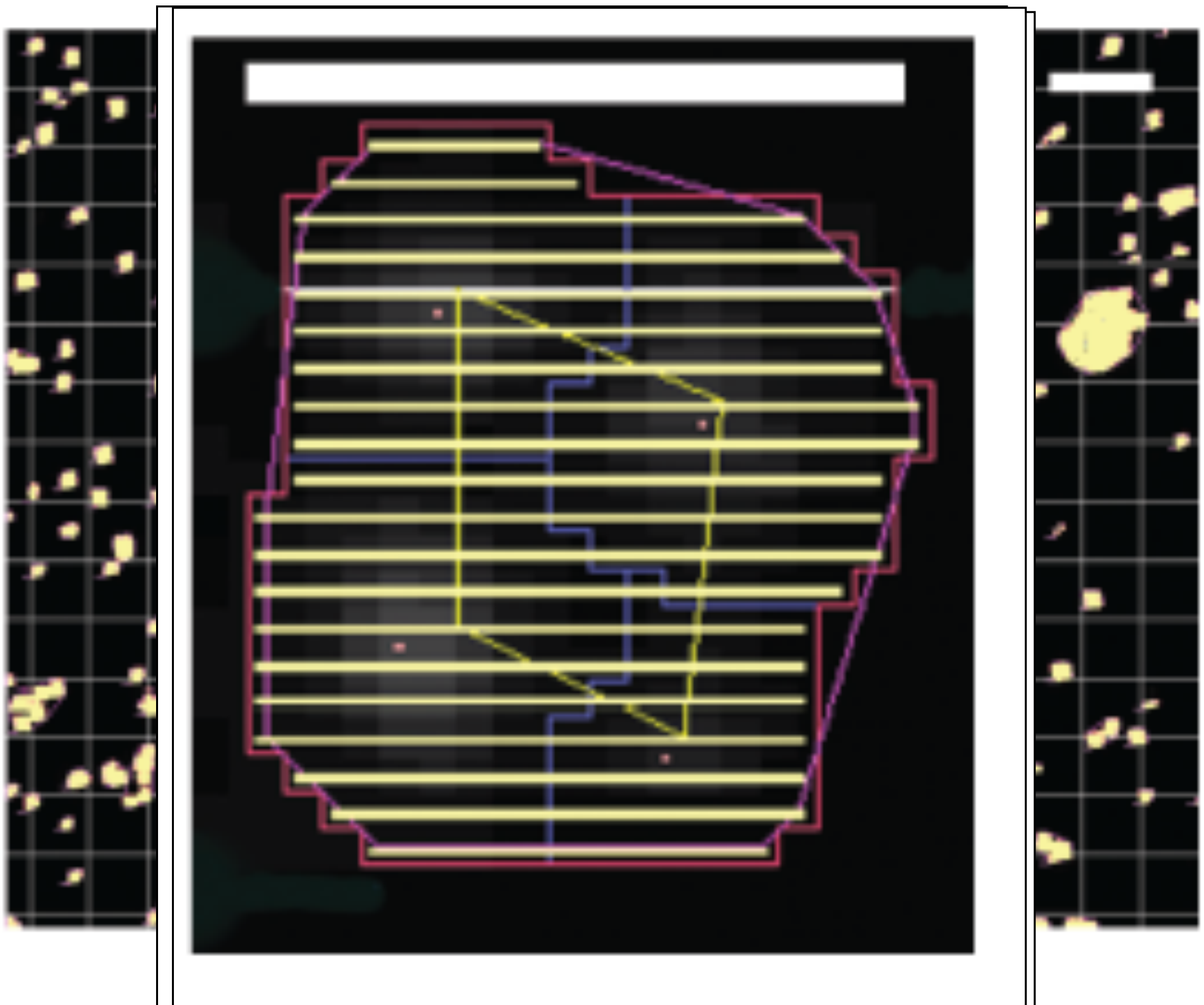


Limitation of quantitative birefringent approach: Calcium carbonate is not the only birefringent material in the sea…zooplankton carapaces, lipid droplets, detritus, even some dinoflagellates…



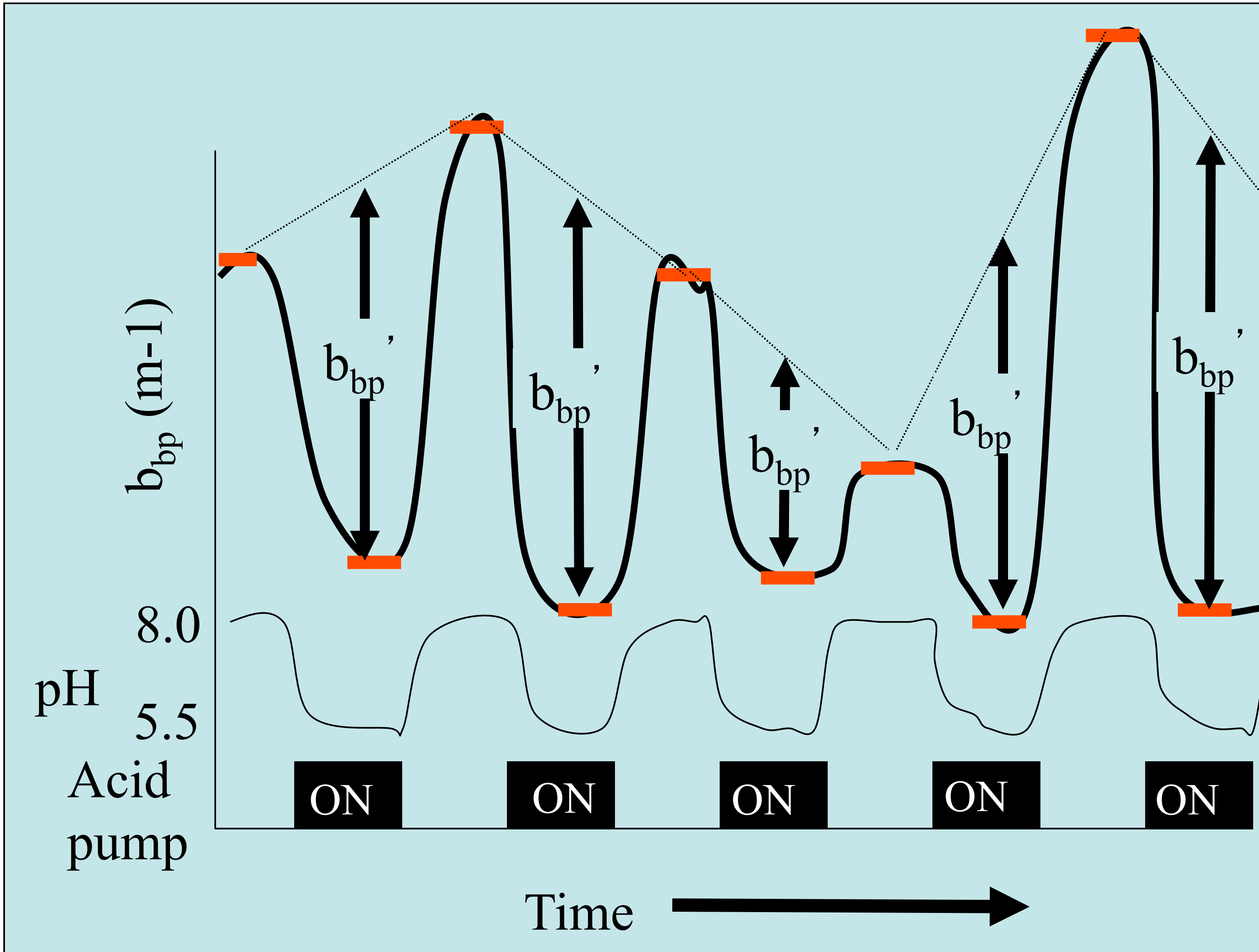
Balch & Fabry
MEPS
2008

Birefringence can be unambiguously dealt with using image analysis…



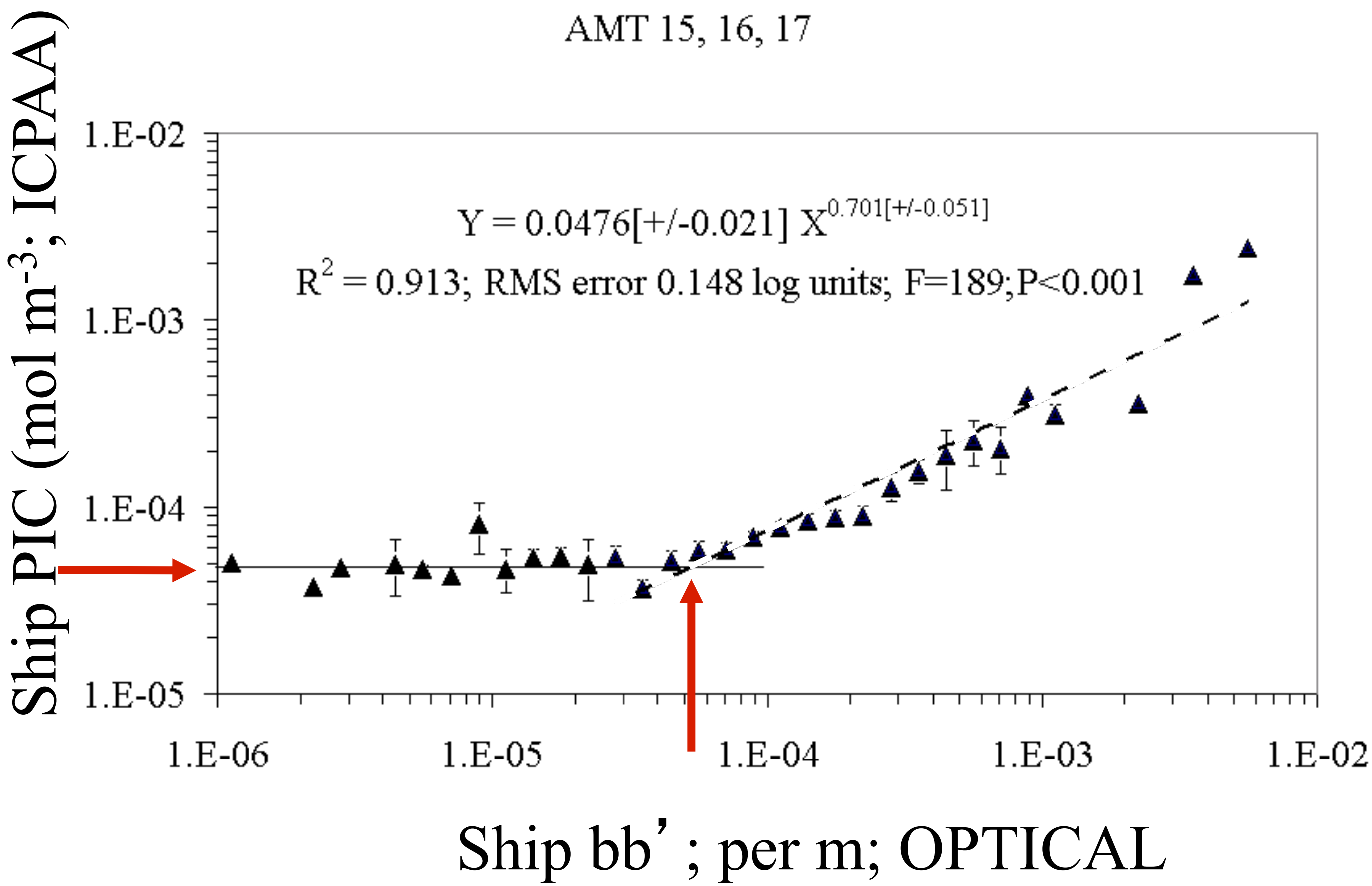
Balch & Utgoff,Oceanography 2009

Acid-labile backscattering?



Balch DSRI, 2001

Acid labile b_{bp}' vs ICPAA PIC (binned)…



Lowest obs Values $5x10^{-5}$ mol m^{-3} PIC

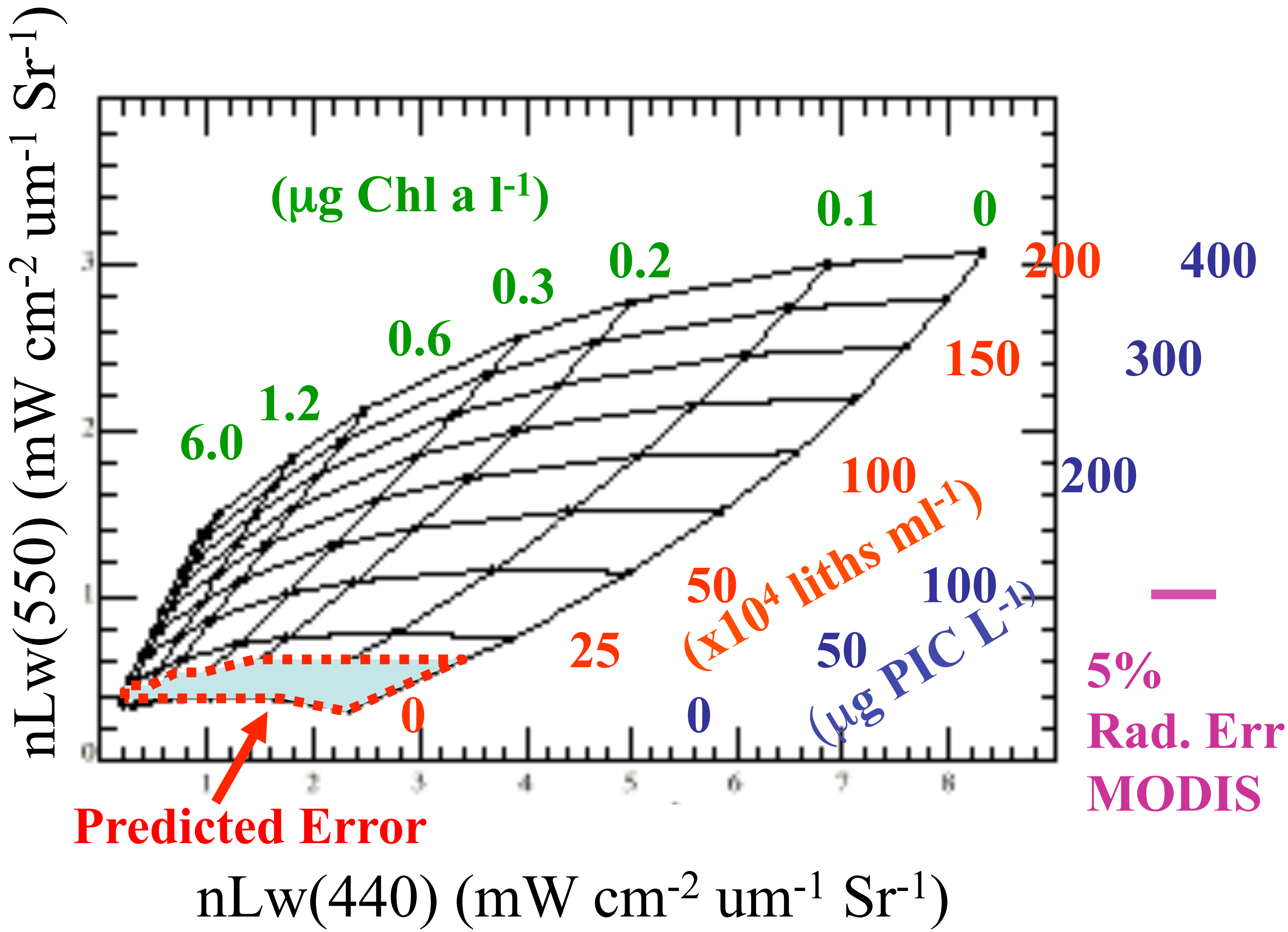
Optical technique linear down to bb' = $5x10^{-5}$ m^{-1}

REMOTE SENSING
Two PIC algorithms exist

- Two band algorithm (based on nLw440 and nLw550); Balch et al. (2005 Calcium Carbonate Measurements in the Surface Global Ocean based on MODIS Data. *JGR-Oceans **110**, C07001 doi:10.1029/2004JC002560*)

- Three-band algorithm (based on 670, 765, and 865nm bands; Gordon et al. (2001. Retrieval of coccolithophore calcite concentration from SeaWiFS imagery, *Geochemical Research Letters*, *28* (8), 1587-1590.)

The 2-band PIC algorithm is based on a look-up table



3-Band Algorithm

- At 670nm, 765, and 865nm, we assume absorption is mainly due to water (a_w):

$$R = \sim b_b / [3(b_b + a_w)]$$

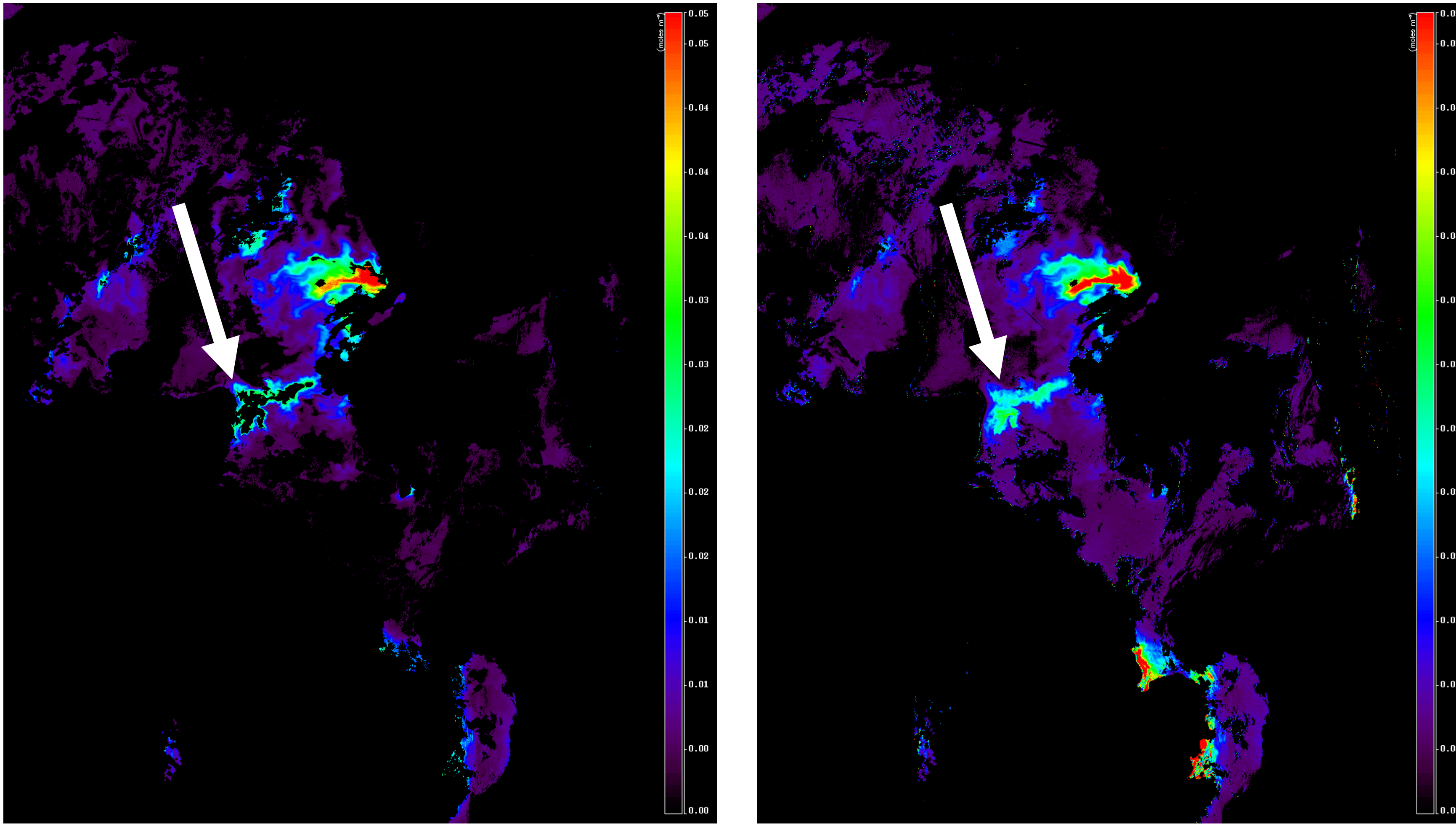
Measure $R(\lambda)$, use published $a_w(\lambda)$, estimate $b_b(\lambda)$.

- Also assume that: $b_b(\lambda) = b_b(550) * (550/\lambda)^n$

where n~1.35 based on empirical results

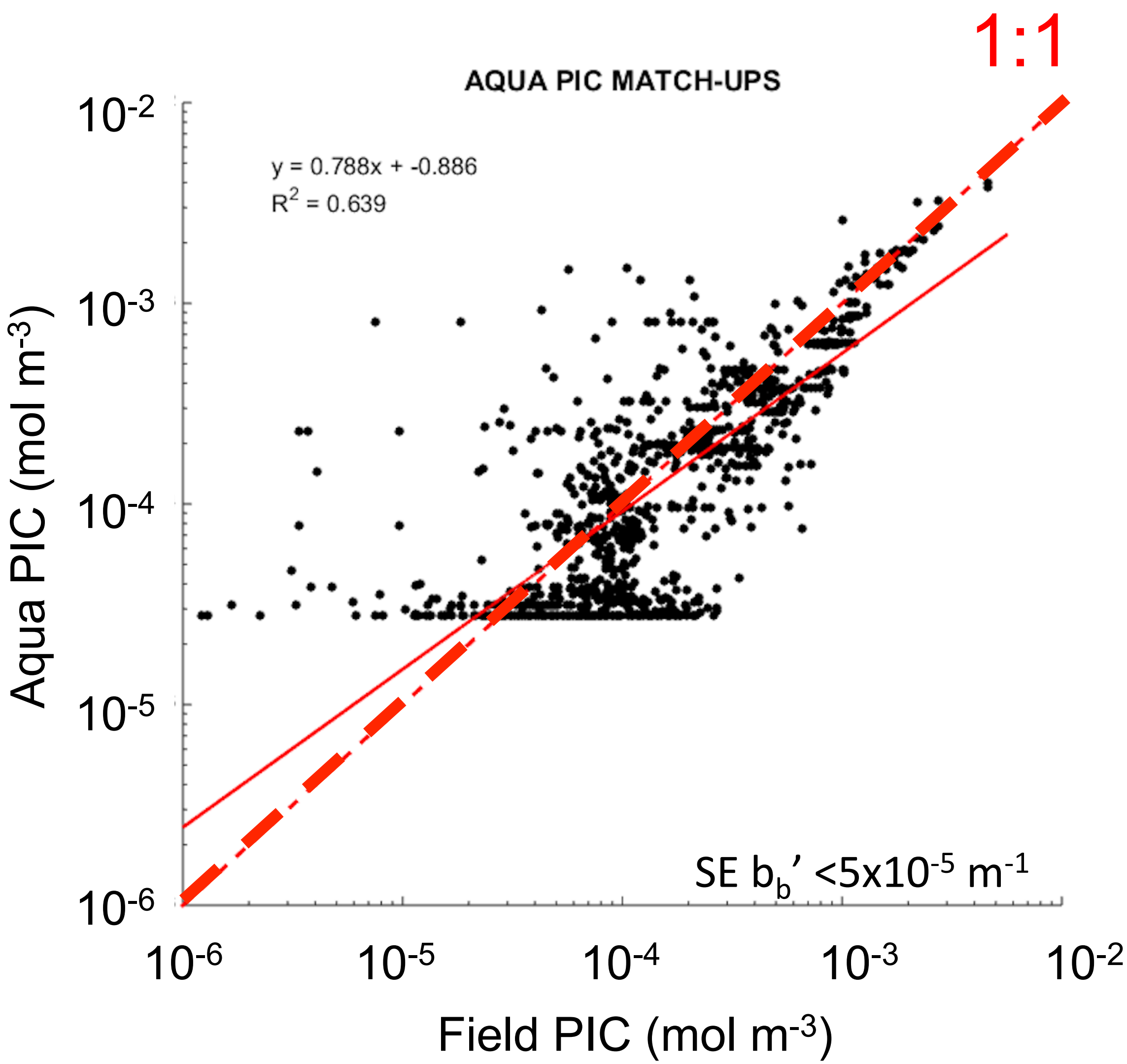
- These assumptions allow estimation of b_b at other wavelengths
- Works best in turbid waters

2 Band   3 Band



SeaWiFS scene S2003147125430 of a coccolithophore bloom in the North Sea on May 27 2003. Comparison between 2-band PIC algorithm and 3-band PIC algorithm. Color scales range from 0-0.05 moles PIC m-3. Images by Sean Bailey and Brian Franz.

Performance of the PIC 2-band/3-band algorithm



C. Mitchell/ J Hopkins; Bigelow Laboratory

Match-ups AQUA- Through May '15

Global views: Important caveats

- The 2-band or 3-band PIC algorithm can be "fooled" by other scattering materials (e.g. error from scattering by suspended sediments or diatom frustules).
- Expected standard error for mean satellite-derived b_b is ~14.9 ug PIC $L^{-1}/(n^{1/2})$ based on 1km daily data.

SE of time/space binned PIC averages (ug C L^{-1})

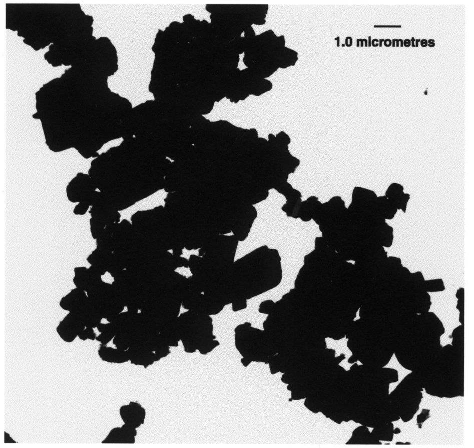
Spatial res (km)	1	4.63	36	111.2
Time bins (d)				
1	14.900	3.218	0.414	0.134
7	5.632	1.216	0.156	0.051
30	2.720	0.588	0.076	0.024
365	0.780	0.168	0.022	0.007

Still need some higher PIC concentrations: Chalk-ex

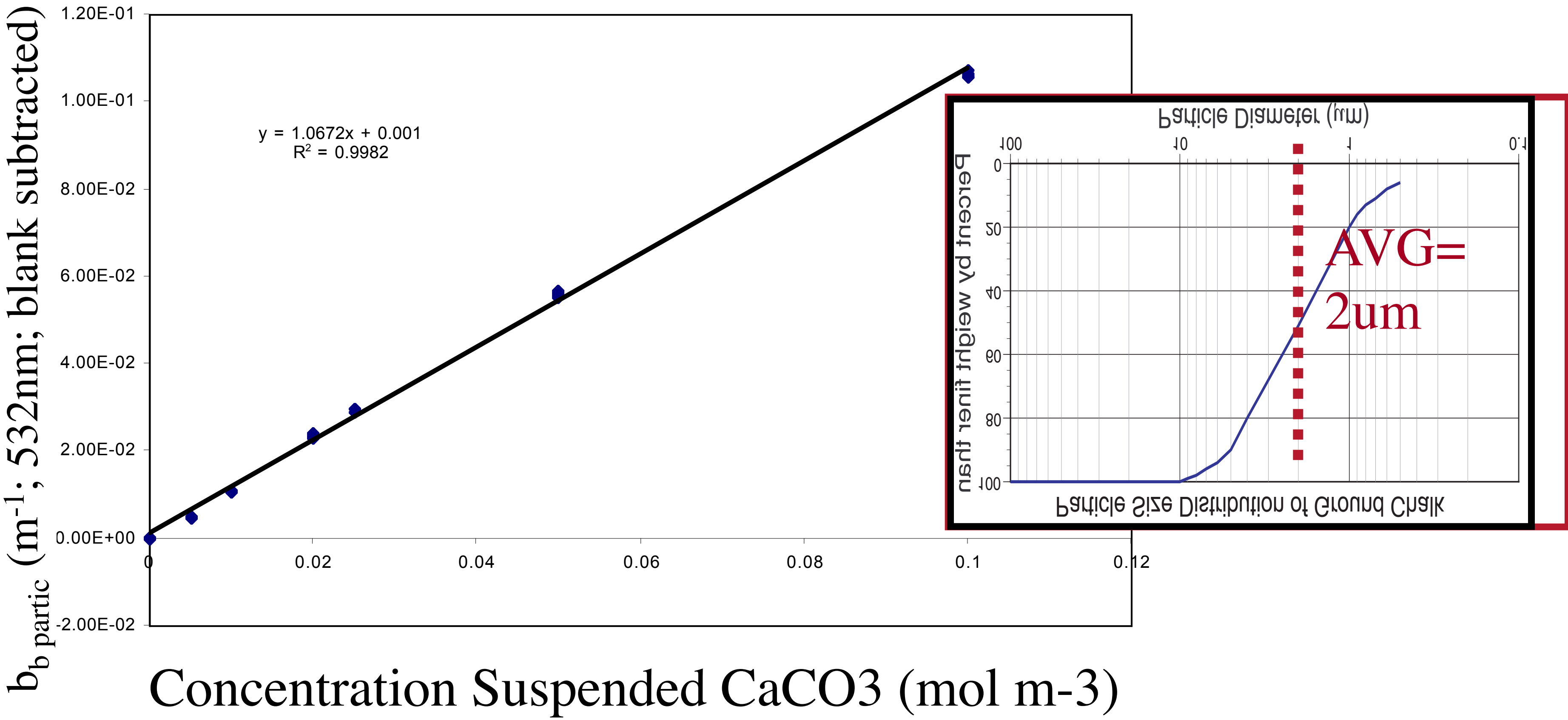
- Blooms are relatively rare events
- “Do it yourself coccolithophore bloom”
- It doesn’t take much coccolith chalk to make a patch visible from space (13T)
- Could time deployments to clear-sky days… also gets over the problem of scheduling ships around rare bloom events!
- Essential for the EPA and Coast Guard environmental impact process that ¼ of all marine sediments on earth are chalk… we did deployments in regions of known cocco blooms as well as chalk-dominated sediments

Chalk concentration is highly correlated to its backscattering

Cretaceous chalk suspended in Filtered Sea Water



negative 2824



Loading Chalk In Portland, ME

Chalk spreading; steaming in an expanding ellipse, 1.5 x 0.5 km over 4h

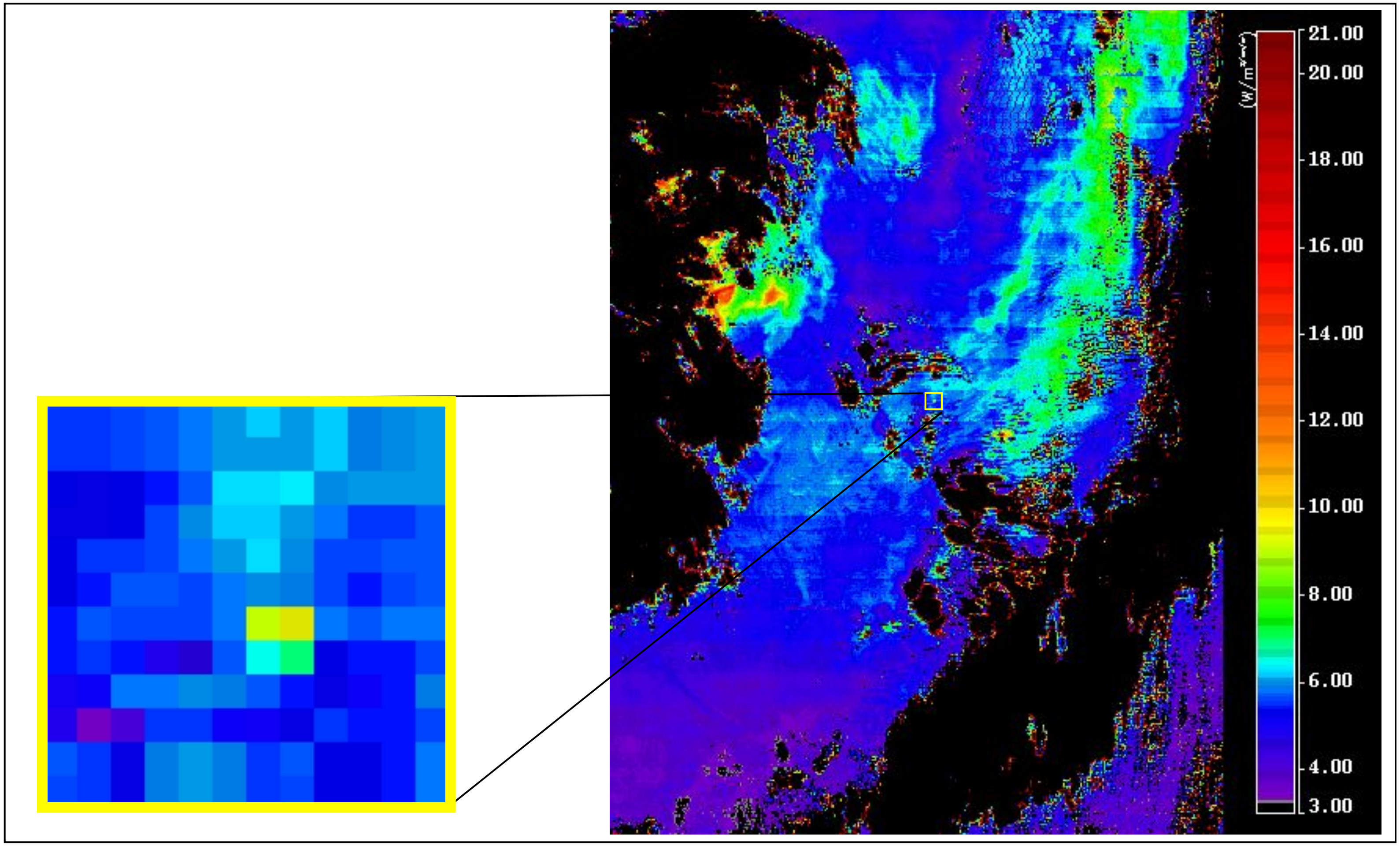
Completed patch

Satlantic radiometers on *R/V Endeavor*

Ed (λ) sensor

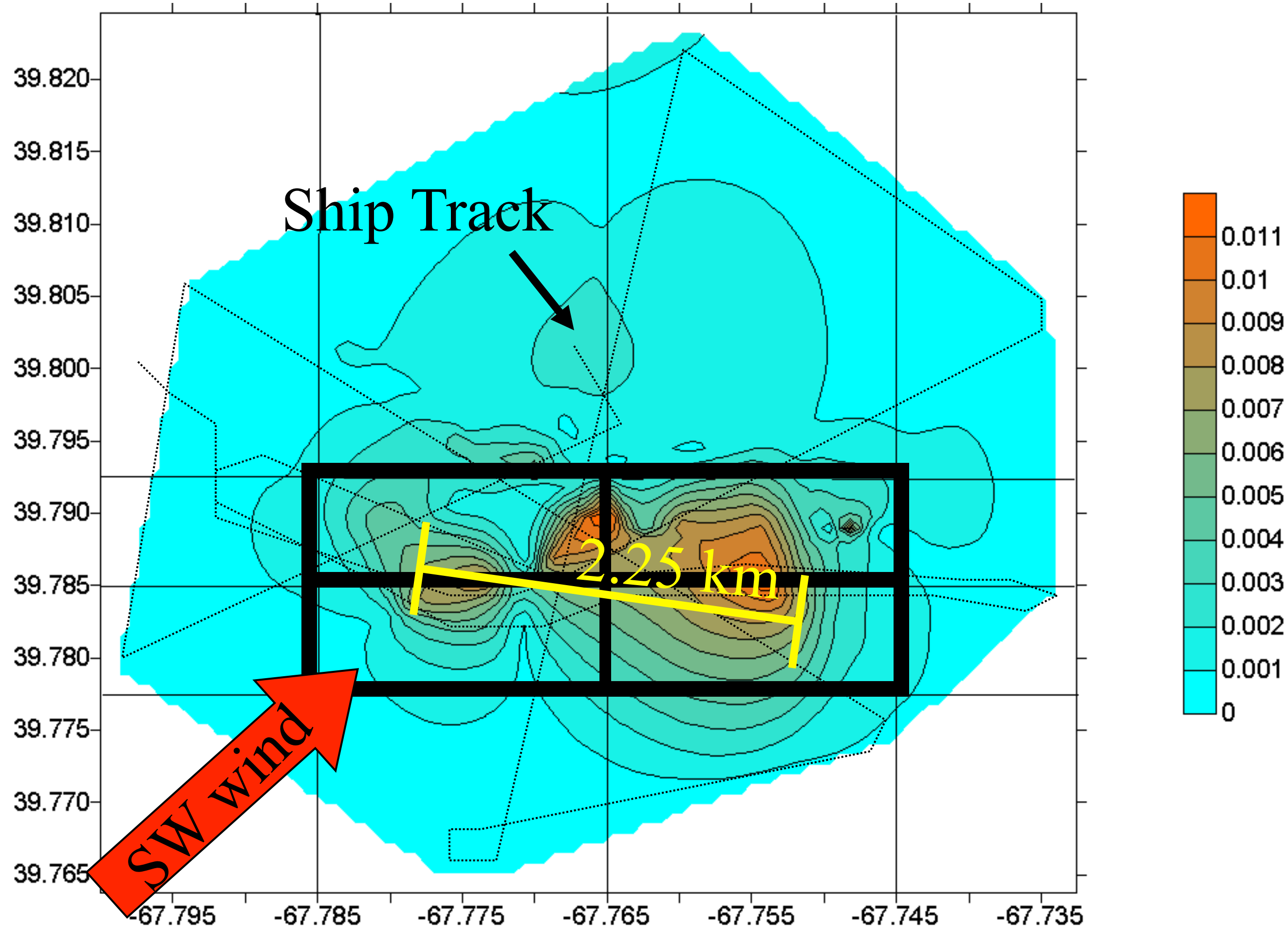
Lu(λ) and Lsky (λ) sensors

MODIS view of Chalk-Ex Patch #2: 551nm, 1Km data, 15 November 2001

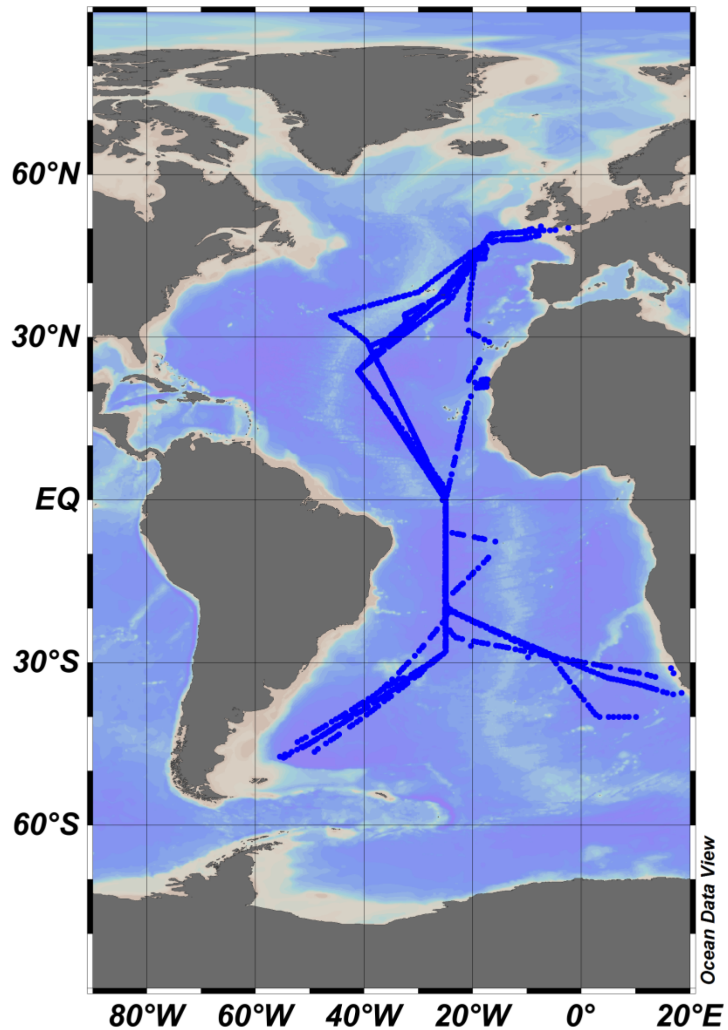


Two highest nLw pixels: 39.81°N x 67.78°W (9.04 W m^{-2} um^{-1} sr^{-1})
39.80°N x 67.76°W (9.47 W m^{-2} um^{-1} sr^{-1})

Ship-measured/contoured surface b_b showing four most intense MODIS pixels

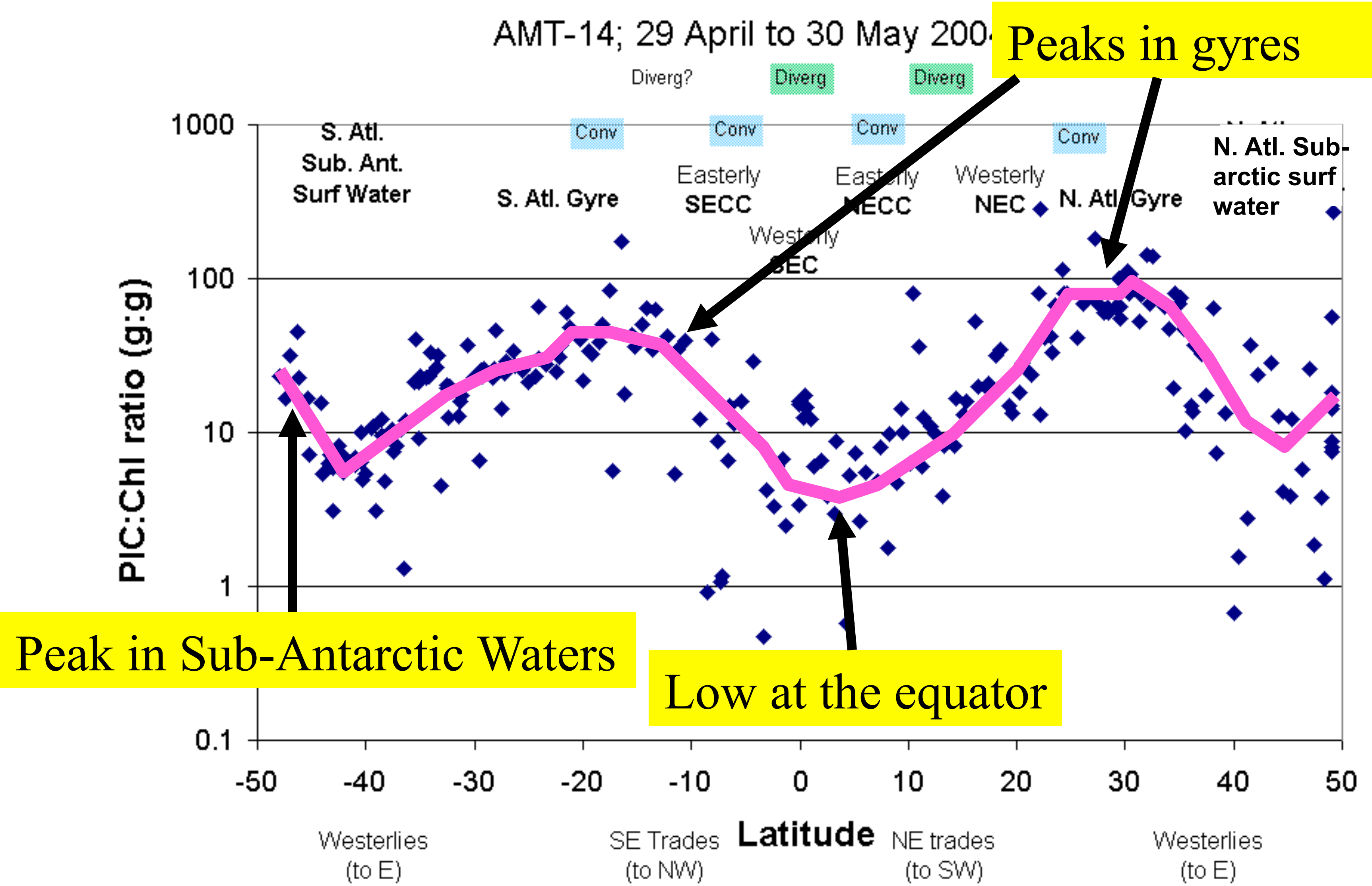


Integrated distributions of PIC, BSi and coccolithophores



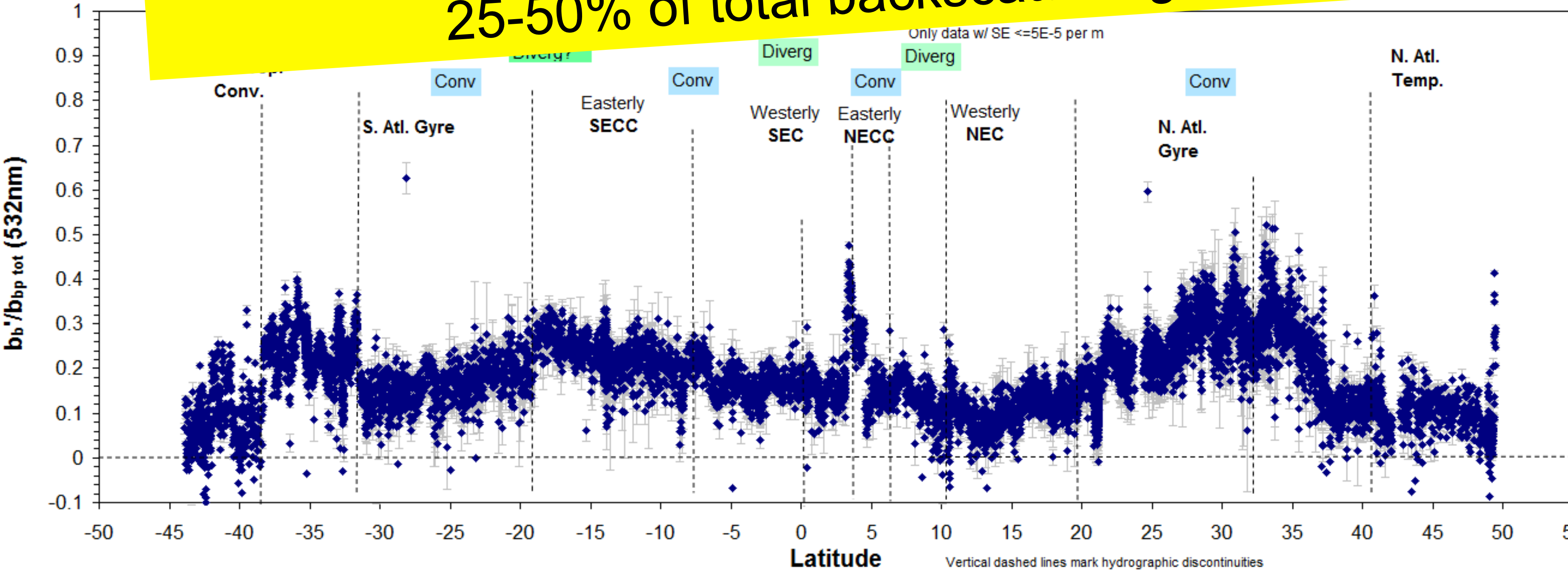
AMT 15-22

Note the ratio of the two optically-active molecules, chlorophyll and PIC, here plotted on a log scale…

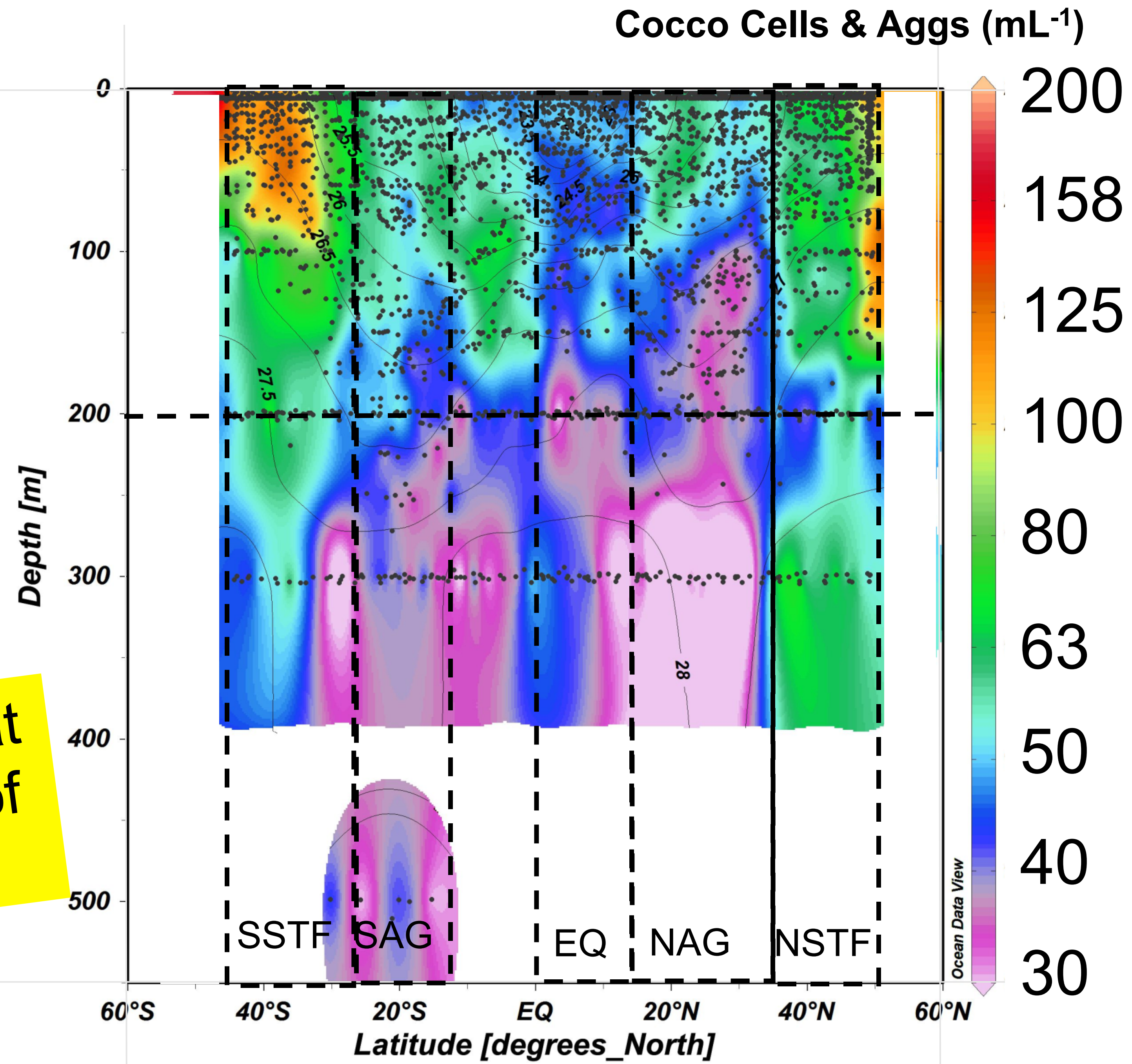


b_b’ vs Lat; AMT19

In NACG, Equatorial region, SACG and Southern Sub-Tropical Convergence, CaCO3 accounts for 25-50% of total backscattering

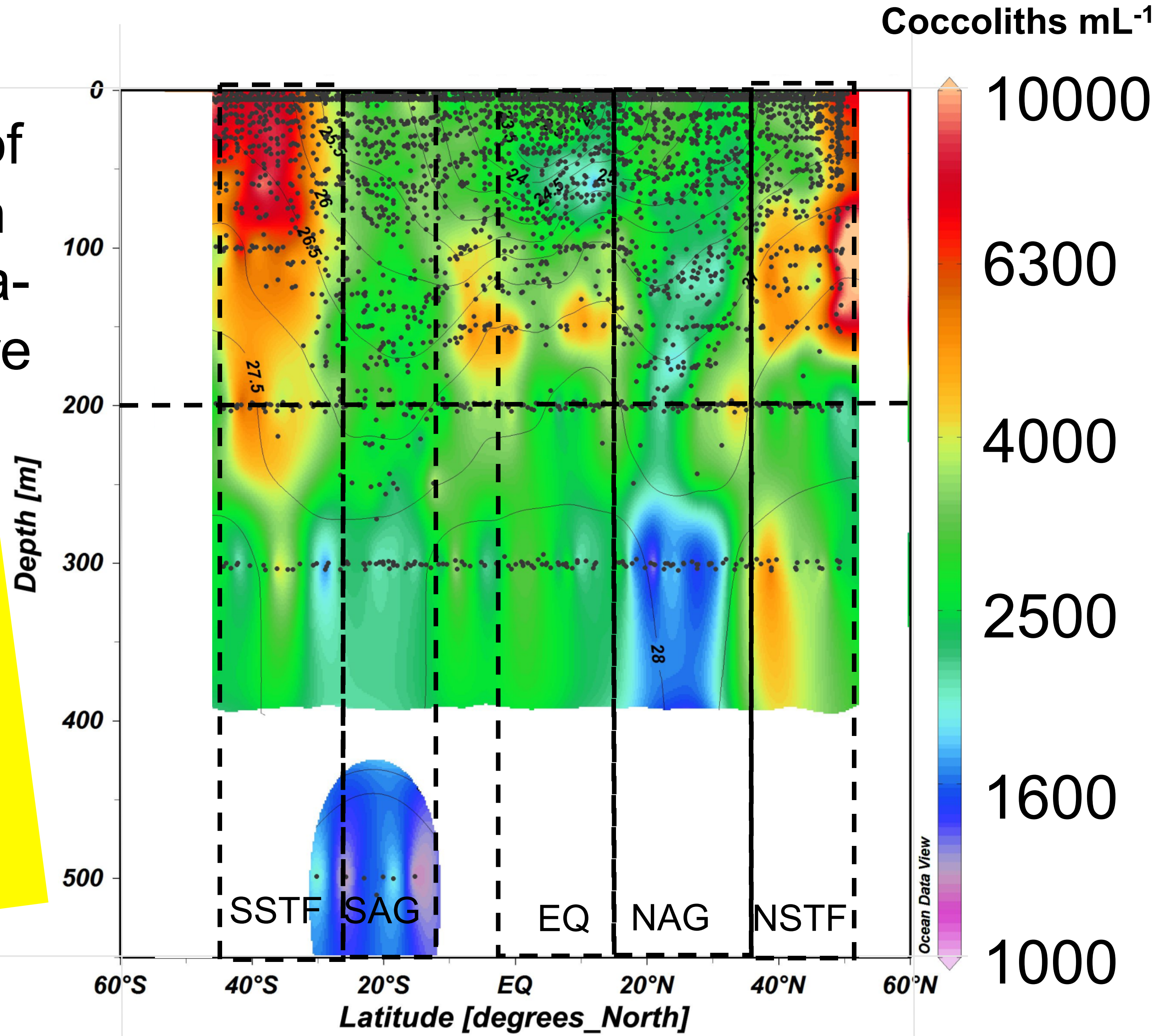


Mean Section of Cocco cells: Entire AMT



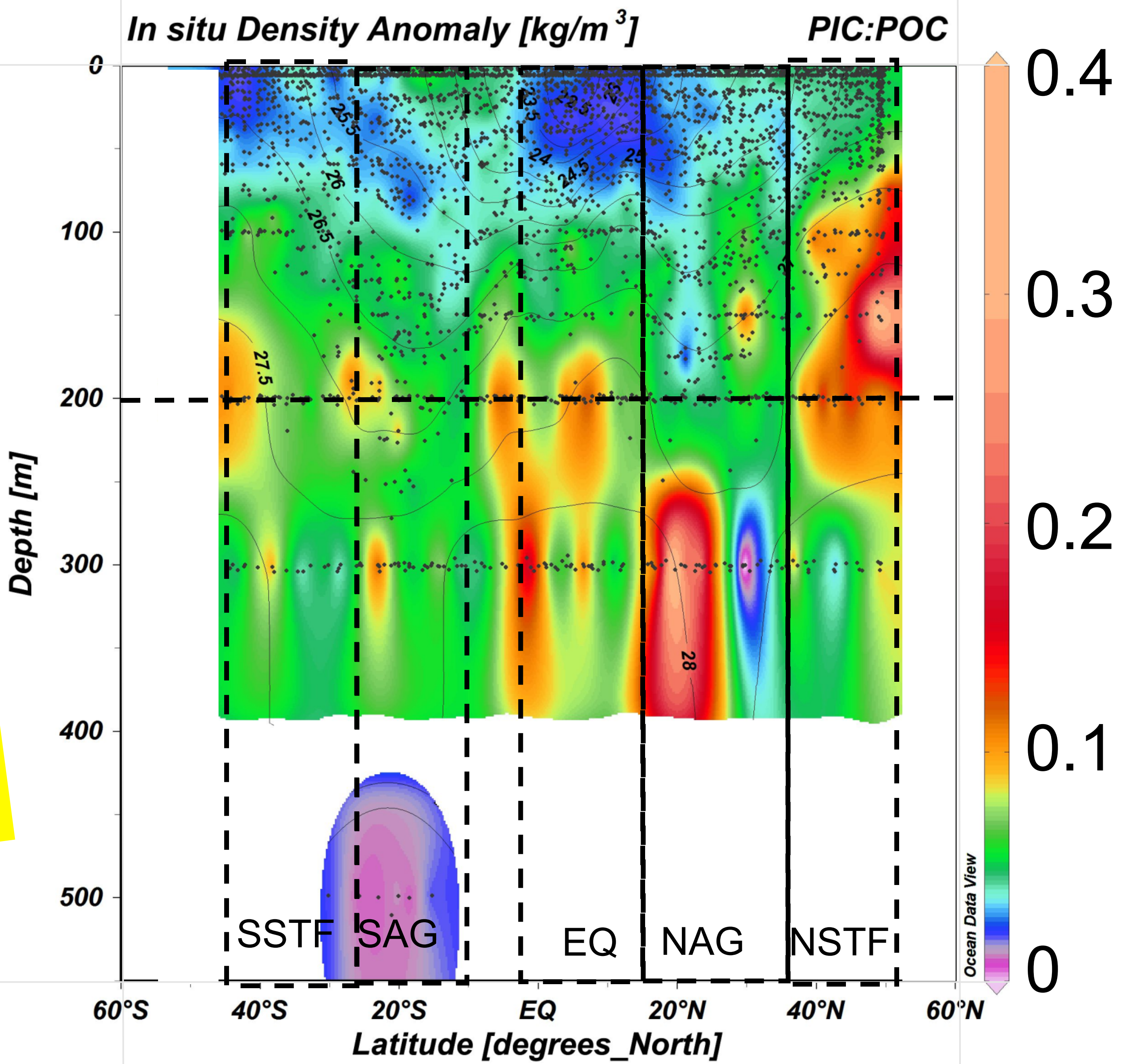
Elevated at both ends of transect

Mean Section of coccolith concentration: Entire AMT



Elevated at both ends of transect w/ sub-surf peak below equatorial region

Mean Section of PIC:POC Entire AMT

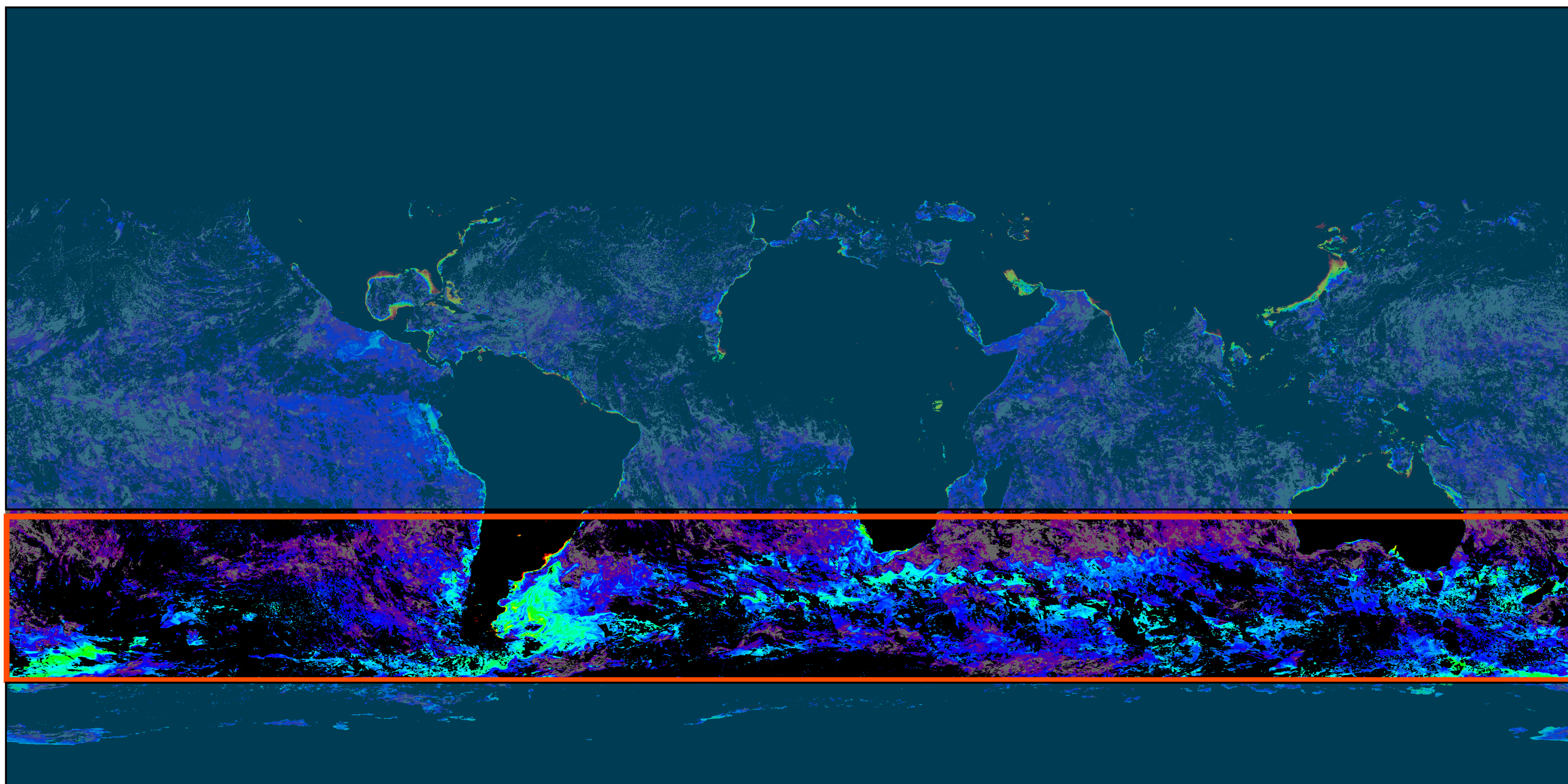


Note increases with depth

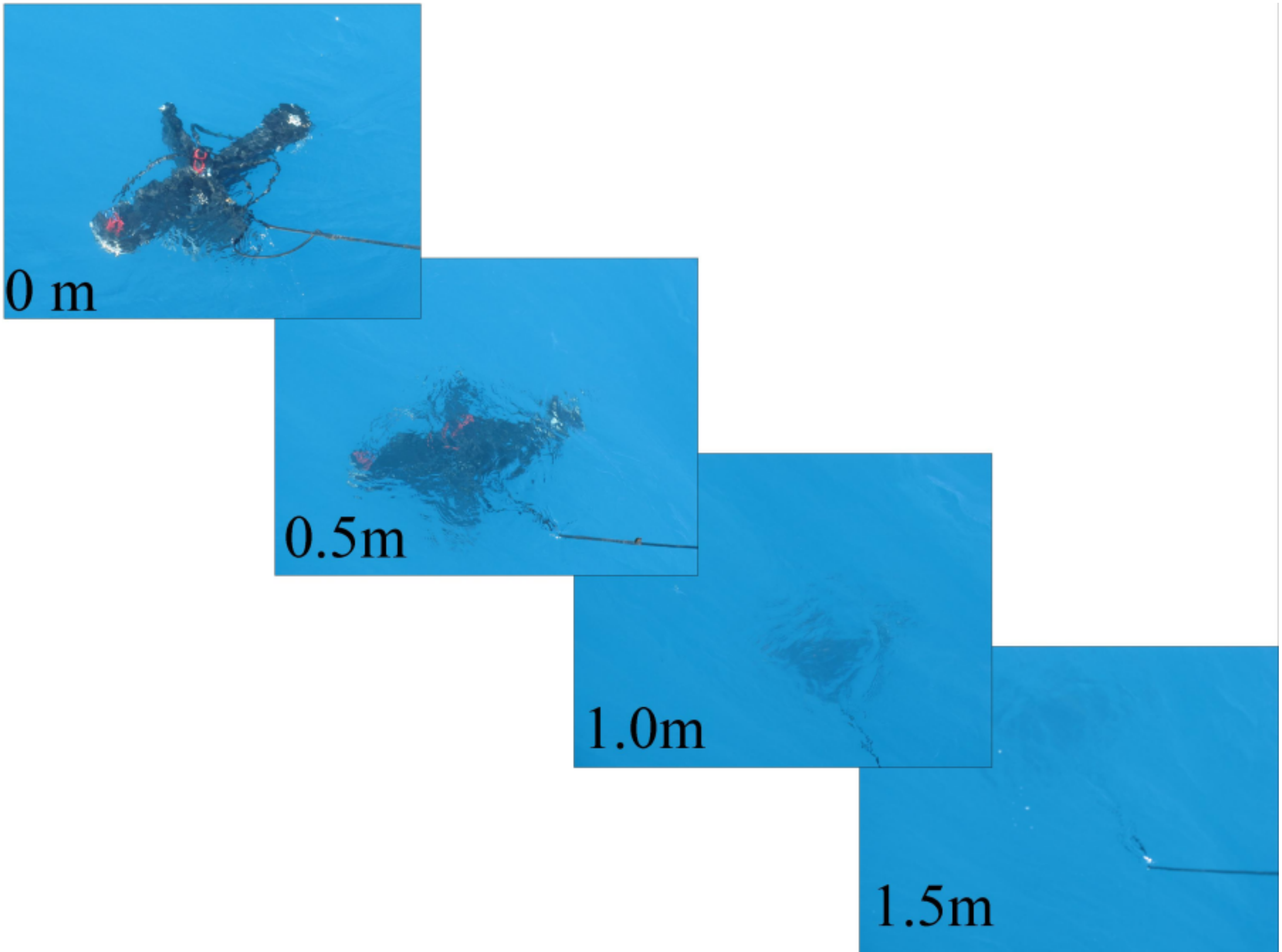
Viewing at the global scale:

The great calcite belt

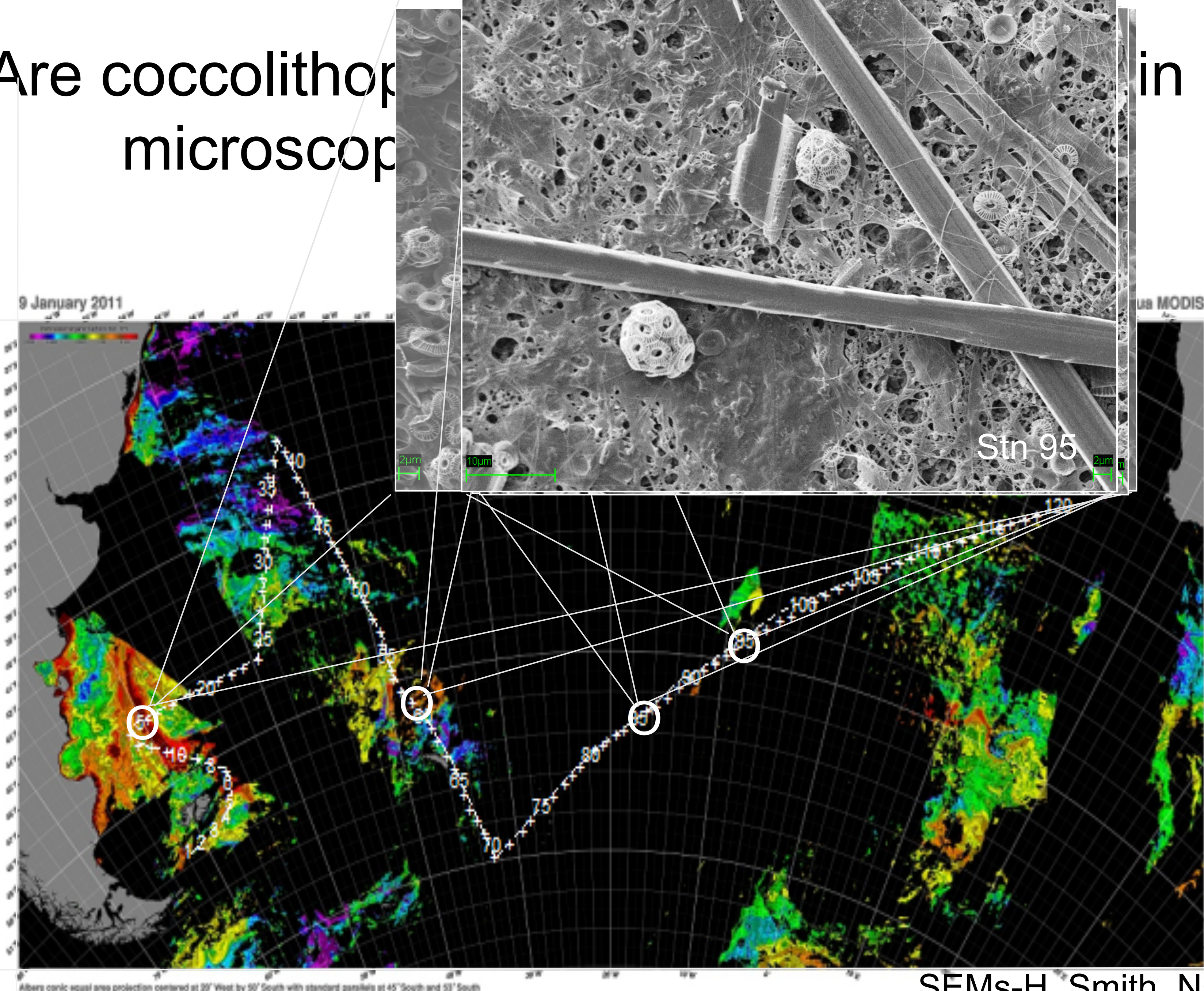
- 52 million square kilometers
- ~16% of the global ocean
- Contains over 1/3 of the PIC in the ocean



PIC shoals the euphotic zone

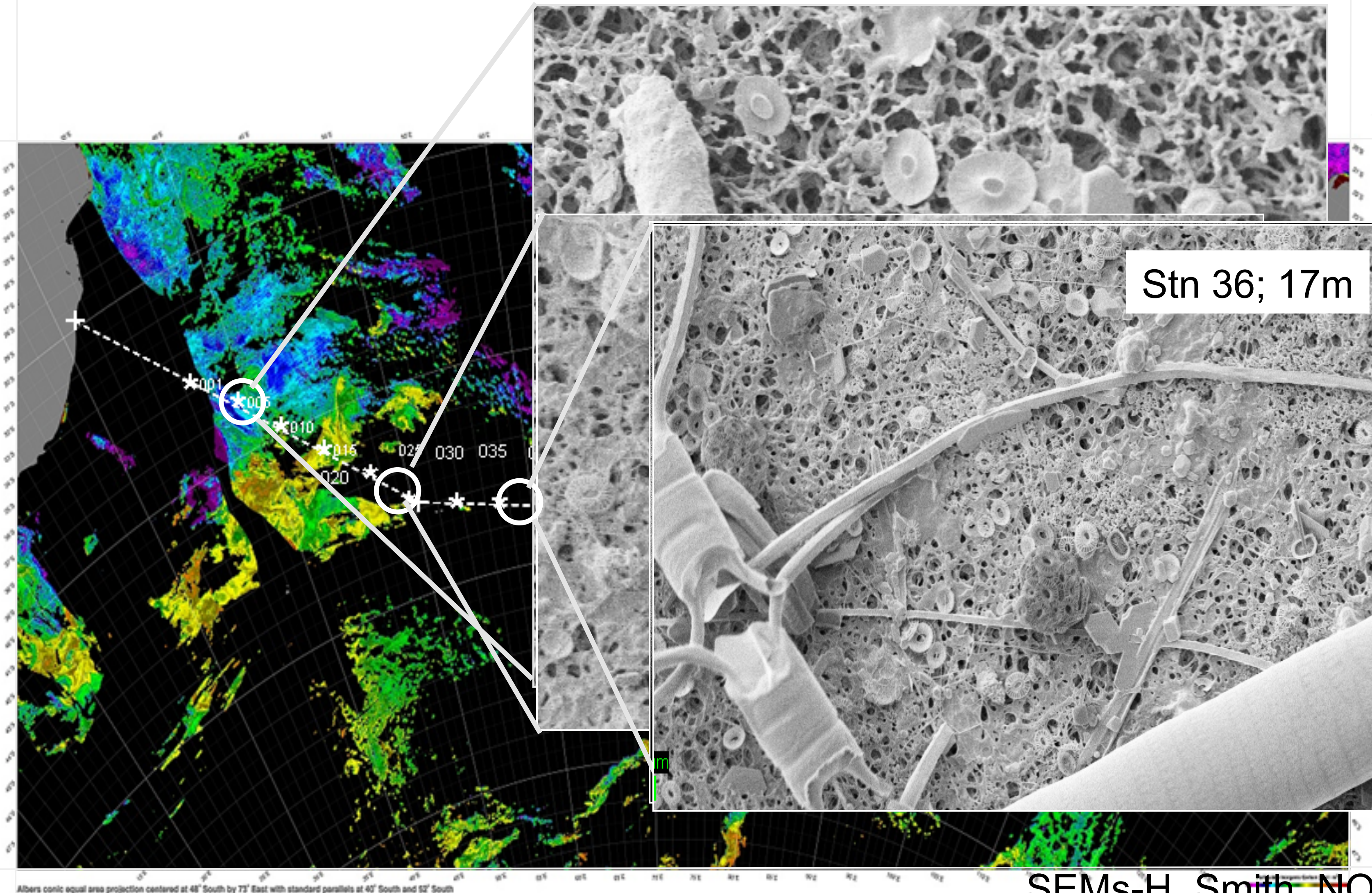


Are coccolithop… in microscop…



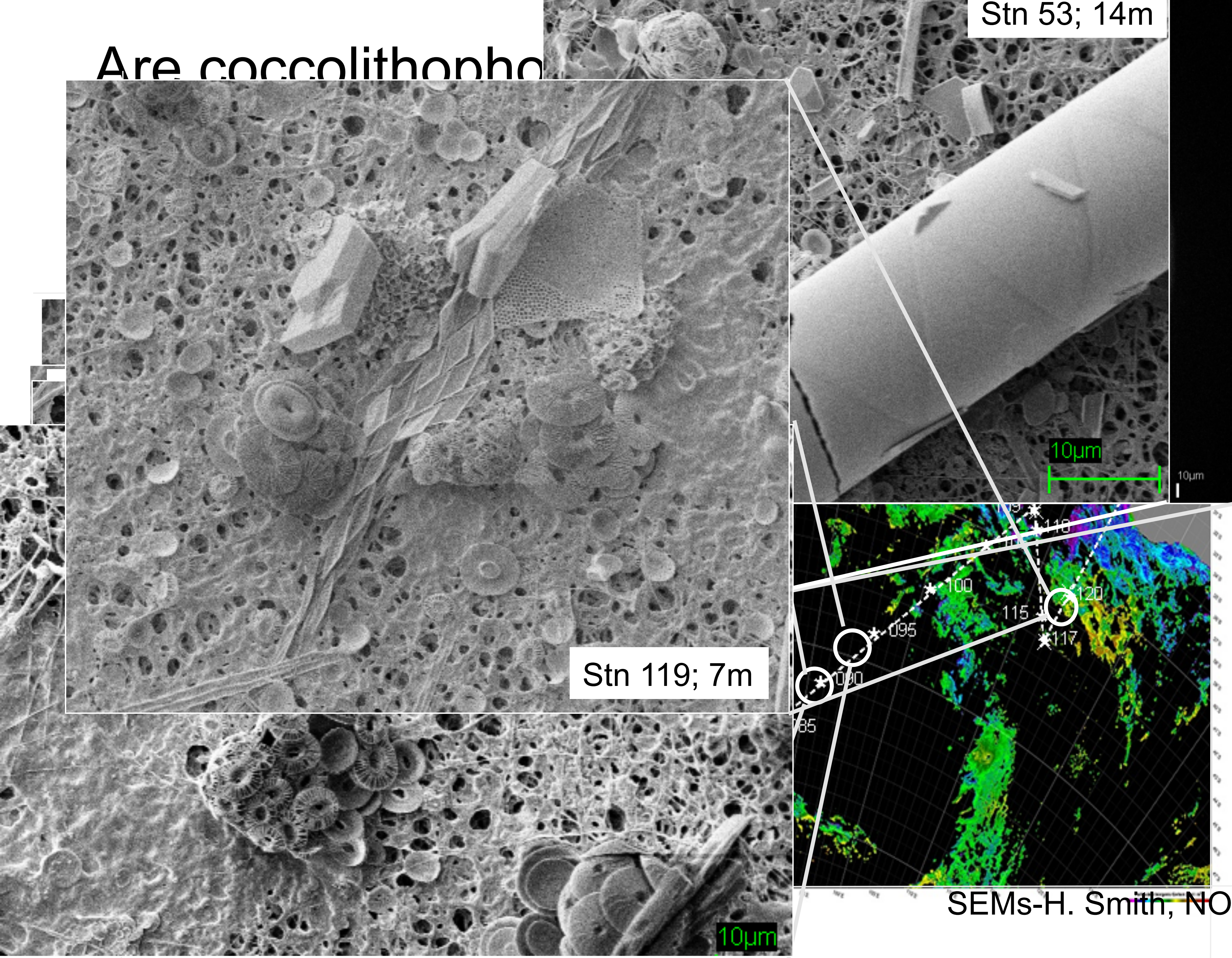
SEMs-H. Smith, NOC

Are coccolithophores actually observable in microscopy samples from GCB II?



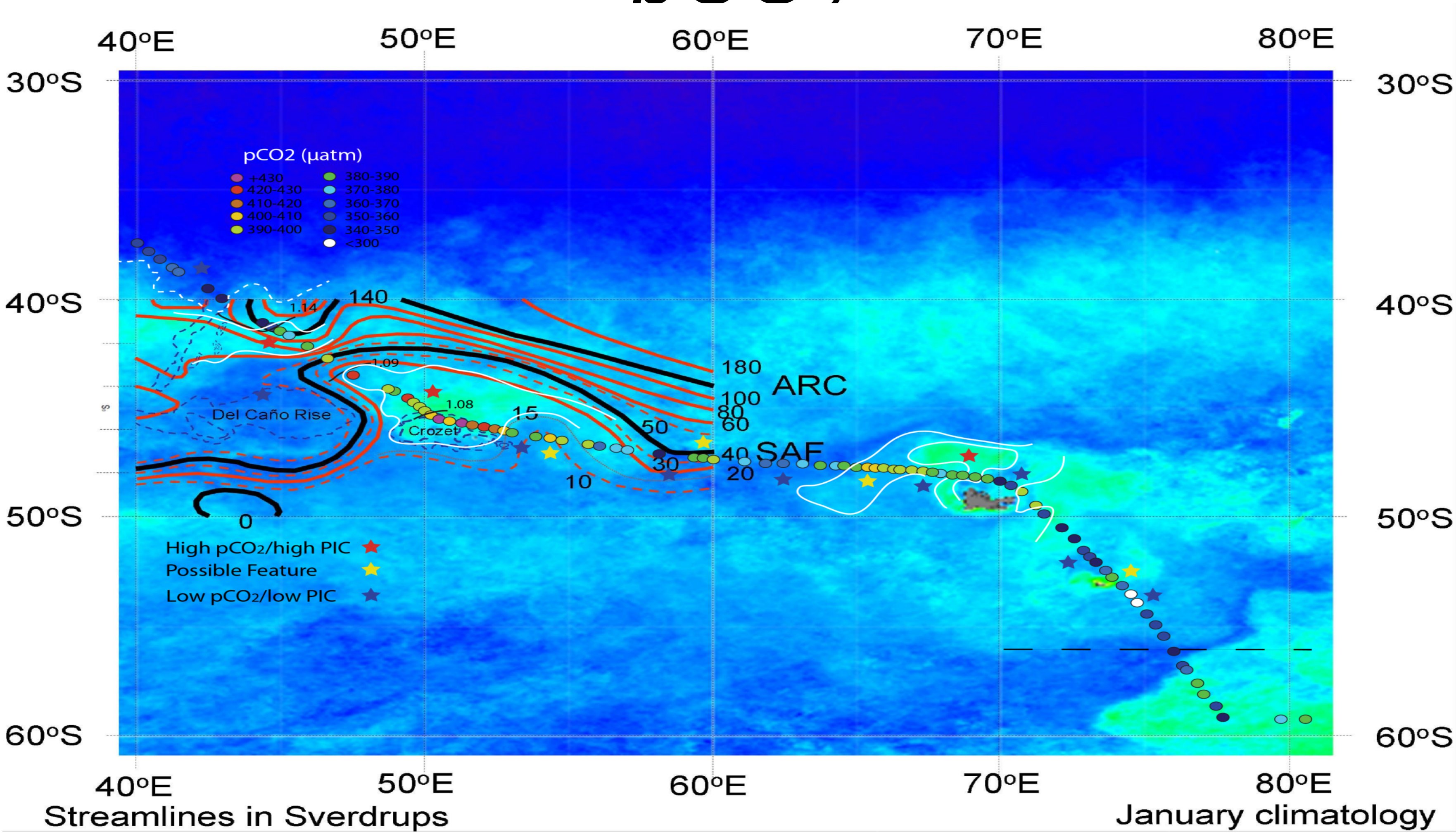
SEMs-H. Smith, NOC

Are coccolithopho

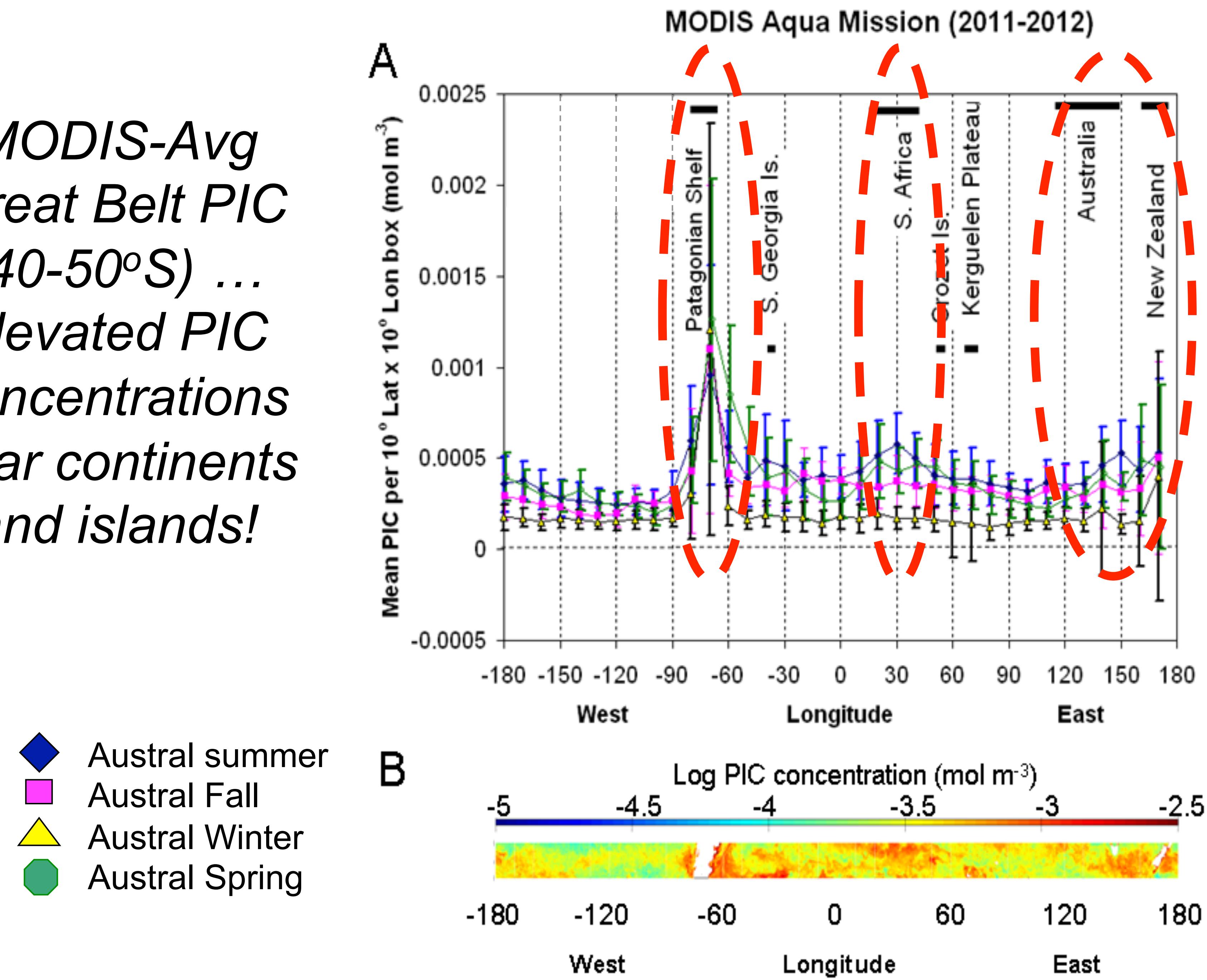


SEMs-H. Smith, NOC

A close-up view of the belt…PIC & pCO$_2$



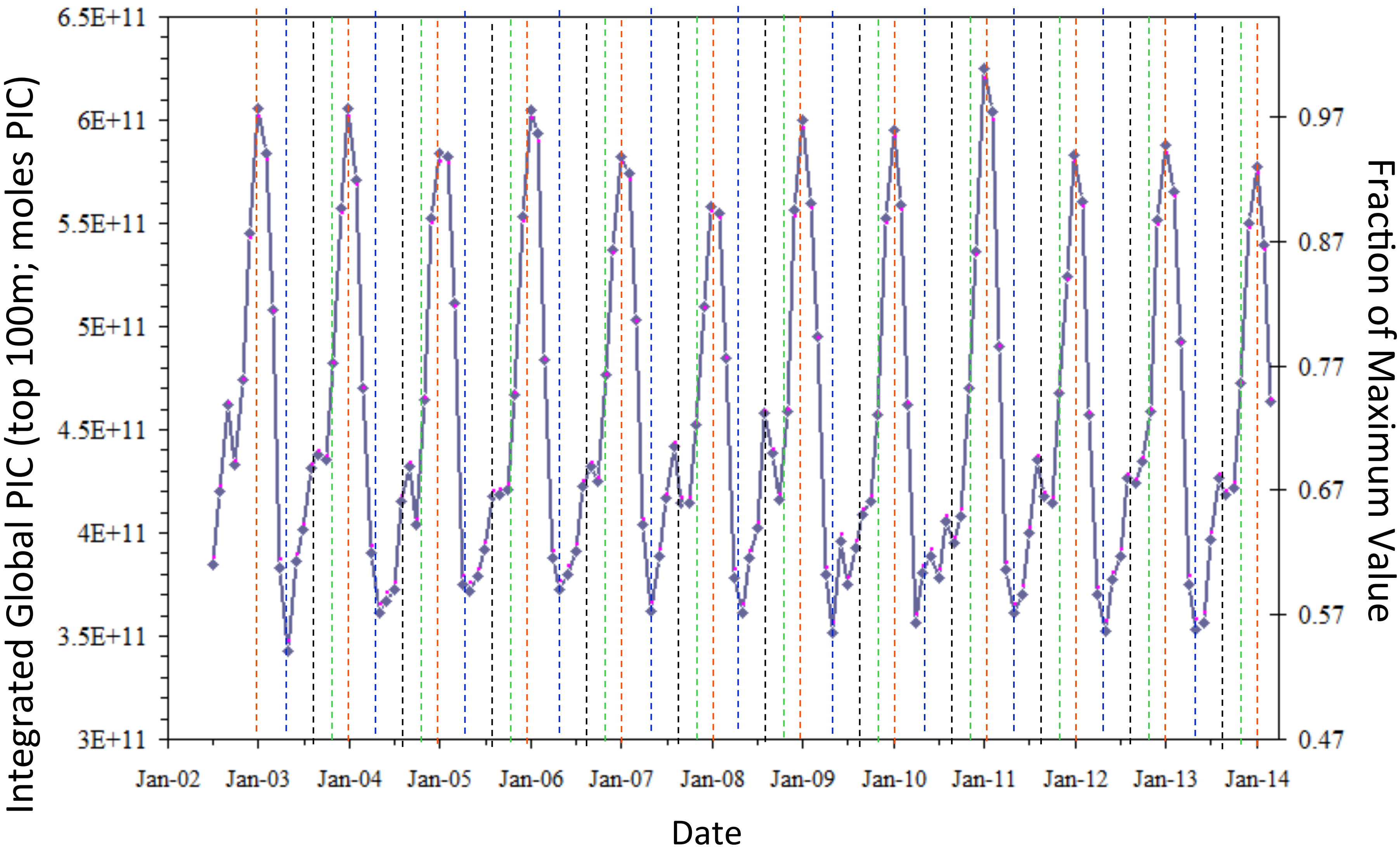
MODIS-Avg Great Belt PIC (40-50^{o}S) … elevated PIC concentrations near continents and islands!



Climate Change effects on coccolithophores…

- Ocean acidification
- More acidic water, harder to calcify (-)
- First waters to be subsaturating to calcite will be high latitude, polar waters
- Coccolithophores favored by warming polar waters…advancing north? (+) increasing high latitude biological pump
- Coccolithophores could be between a rock and a hard place forced by temperature and acidification

PIC Global Time Series (MODIS-Aqua) Mission record- Highest PIC during austral summer->**95% non-bloom**



Optical properties Summary

- Absorption- minimal
- Scattering- high…
- can be a first-order contributor to water-leaving radiance
- Scattering cross-sections variable, likely species dependent
- Birefringence- strong, but beware of non-calcite birefringent particles
- Mesoscale high reflectance blooms are immense and are found mostly at high latitudes

Why should you care about coccolithophores?

- Coccolithophores serve as the **primary ballast material** for driving the biological pump (responsible for ultimately removing CO_2 from the atmosphere on long time scales). This pump has removed **half** of the anthropogenic CO_2 that we humans have produced.
- On short time scales, coccolithophores actually act as a significant **source of CO_2.**

Why should you care about coccolithophores?

- Suspended coccoliths found throughout the ocean **increase the ocean albedo** but also the **warming** rate ($0.06^{o}C\ d^{-1}$ higher inside a bloom than outside)
- **Warming/stratification** will likely enhance coccolithophore growth **(+)**
- Coccolithophores <u>may</u> be **sensitive to ocean acidity (-)**, which in the changing Arctic may limit their advance poleward.

Importance of satellite remote sensing of coccolithophores…

- **Satellite record is not yet long enough** to see any trends in the abundance of coccolithophores, as predicted by models

- **Continued satellite ocean color remote sensing** will be the best way to synoptically follow the fate of these plants through time as the planet warms and the oceans acidify.

The seasonal cycle of PIC taken by MODIS Aqua…Thank you!