Biogeochemistry of coccolithophore blooms

William M. Balch,

Bigelow Laboratory for Ocean Sciences, East Boothbay, ME

bbalch@bigelow.org

Bigelow Laboratory for Ocean Sciences

Acknowledgments

- Team Effort-D. Drapeau, B. Bowler, L. Lubelczyk, E. Lyskowski, Amy Wyeth (Bigelow Laboratory), H. Smith & A. Poulton (NOC; for SEM images)
- Funding of Great Belt Cruises from NSF
- Our participation in AMT and other various cruises supported by NASA
- AMT cruises- NERC
- Captains and crew of: RRS Discovery, R/V Melville, R/V Revelle, R/V Ron Brown, RRS James Clark Ross, RRS James Cook, R/V Tangaroa
- Ocean Data View-Reiner Schlitzer, AWI

The Journey…

- History of coccolithophore blooms
- Coccolithophore distributions in non-bloom conditions
- Remote sensing of coccolithophores from space
- Great Calcite Belt description
- Taxonomic observations
- Relationships to hydrography
- Biogeochemistry

SARSIA 6

DISCOLORATION OF THE SEA DUE TO *COCCOLITHUS HUXLEYI* "BLOOM"[1]

By

GRIM BERGE

Directorate of Fisheries, Institute of Marine Research, Bergen

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.

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-

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

ANDREW MCINTYRE† and ALLAN W. H. BÉ†

Allan 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.

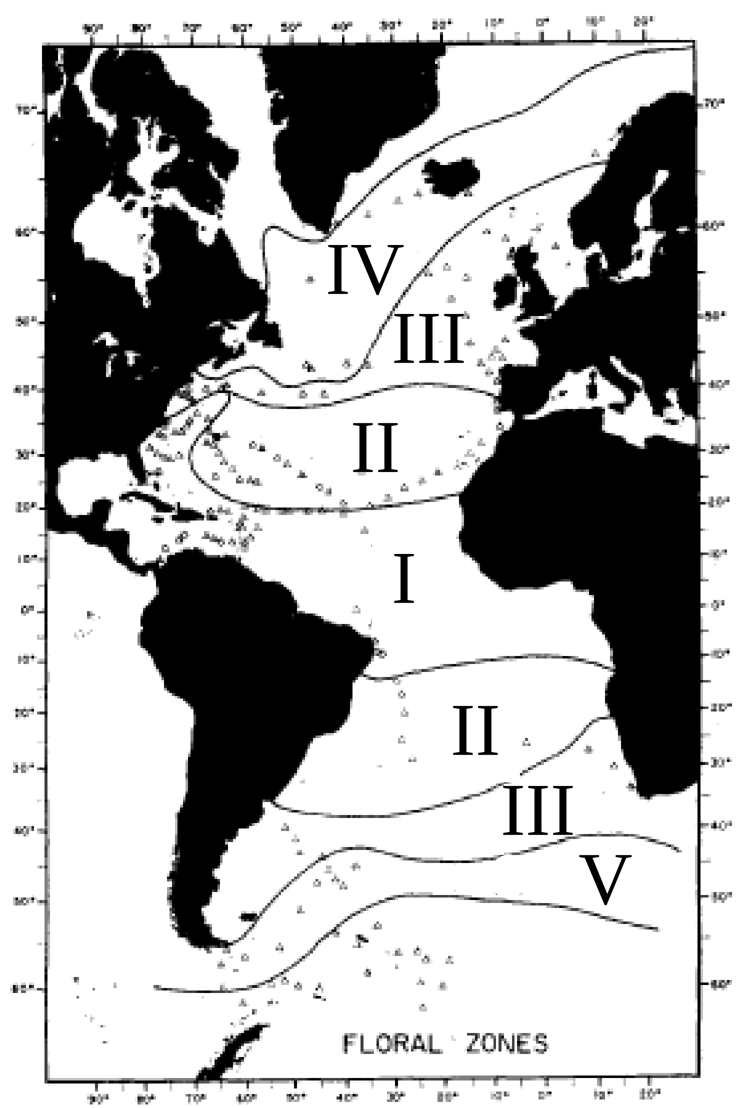


Fig. 17. The coccolithophorid floral zones of the Atlantic Ocean, I tropical, II subtropical, III transitional and IV subarctic–subantarctic.

Sub-Arctic

Transitional (STF)

Sub-Tropical

Tropical

Sub-Tropical

Transitional (STF)

Sub-Antarctic

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	II Subtropical
Umbellosphaera irregularis	*Umbellosphaera tenuis*
Cyclolithella annulus	*Rhabdosphaera stylifera*
Cyclococcolithus fragilis	*Discosphaera tubifera*
Umbellosphaera tenuis	*Cyclolithella annulus*
Discosphaera tubifera	*Gephyrocapsa oceanica*
Rhabdosphaera stylifera	*Umbilicosphaera mirabilis*
Helicosphaera carteri	*Helicosphaera carteri*
Gephyrocapsa oceanica	*Cyclococcolithus leptoporus*
Coccolithus huxleyi	*Cyclococcolithus fragilis*
Cyclococcolithus leptoporus	*Coccolithus huxleyi*
III Transitional	IV Subarctic
Coccolithus huxleyi	*Coccolithus pelagicus*
Cyclococcolithus leptoporus	*Coccolithus huxleyi*
Gephyrocapsa ericsonii	*Cyclococcolithus leptoporus*
Rhabdosphaera stylifera	
Gephyrocapsa oceanica	V Subantarctic
Umbellosphaera tenuis	*Coccolithus huxleyi*
Coccolithus pelagicus	*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 et al. (1983)

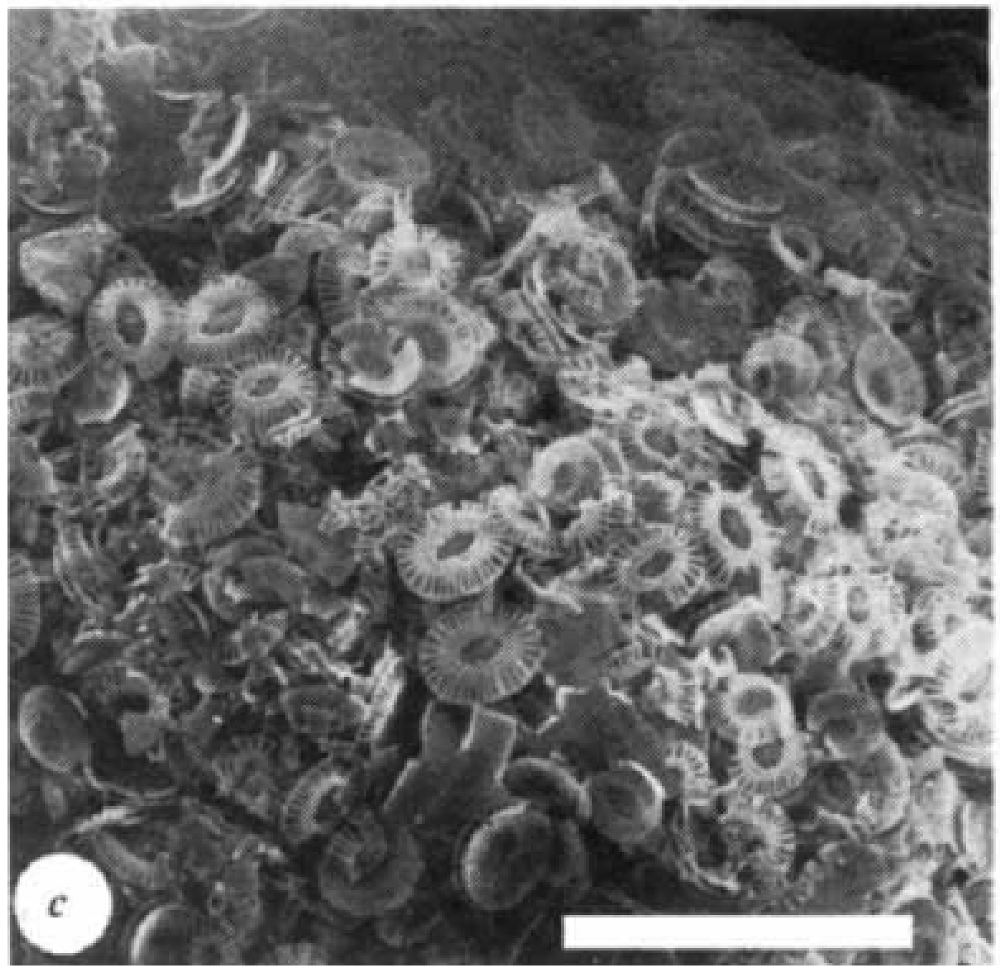
Satellite and ship studies of coccolithophore production along a continental shelf edge

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

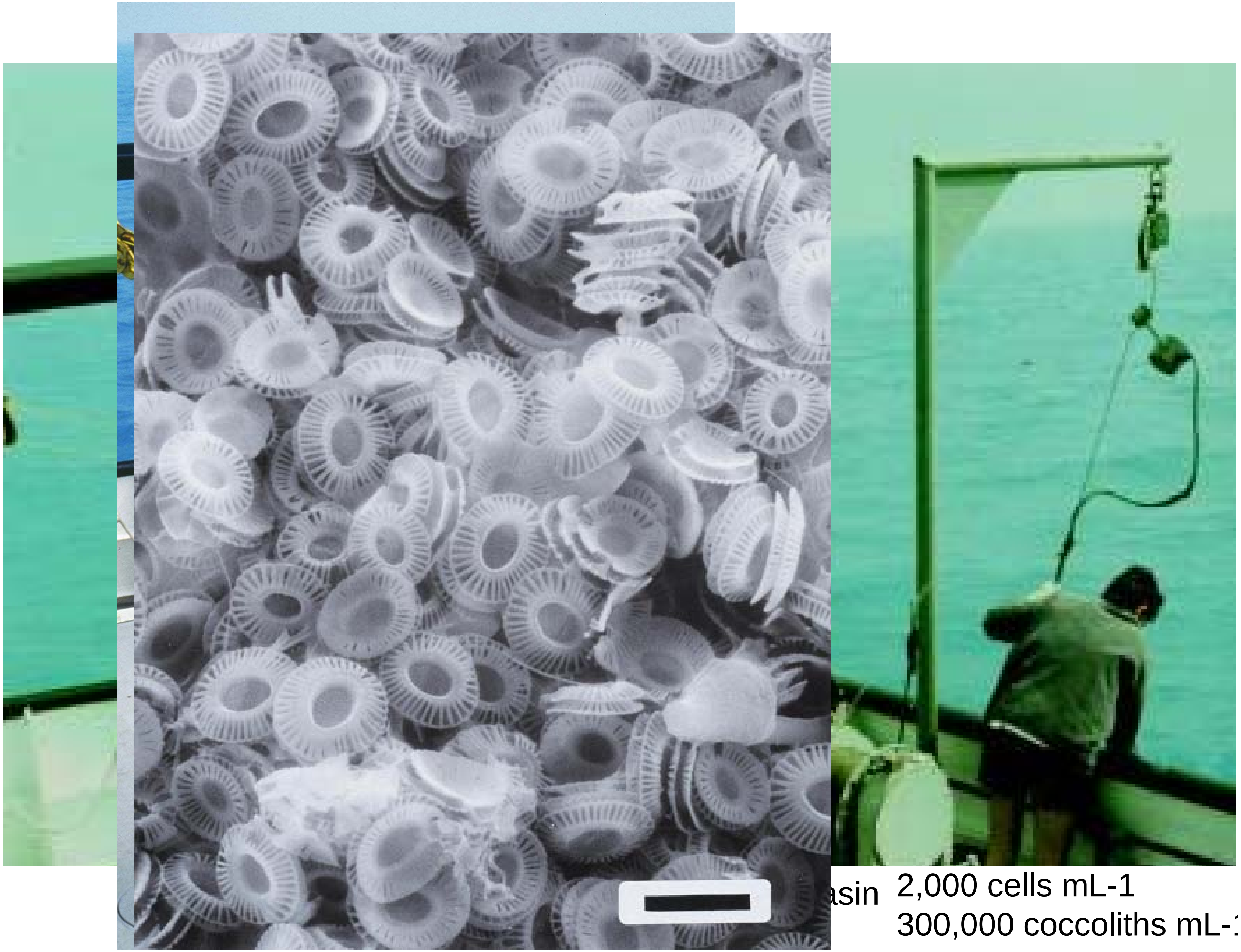
* Marine Biological Association, Citadel Hill, Plymouth PL1 2PB, UK
† Joint Research Centre, Ispra Establishment, 21020 Ispra, Italy
‡ Institution Scientifique et Technique des Peches Maritimes, BP 1049, 44037 Nantes Cedex, France
§ Etablissement d'Etudes et de Recherches Meteorologiques, CMS, 22302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

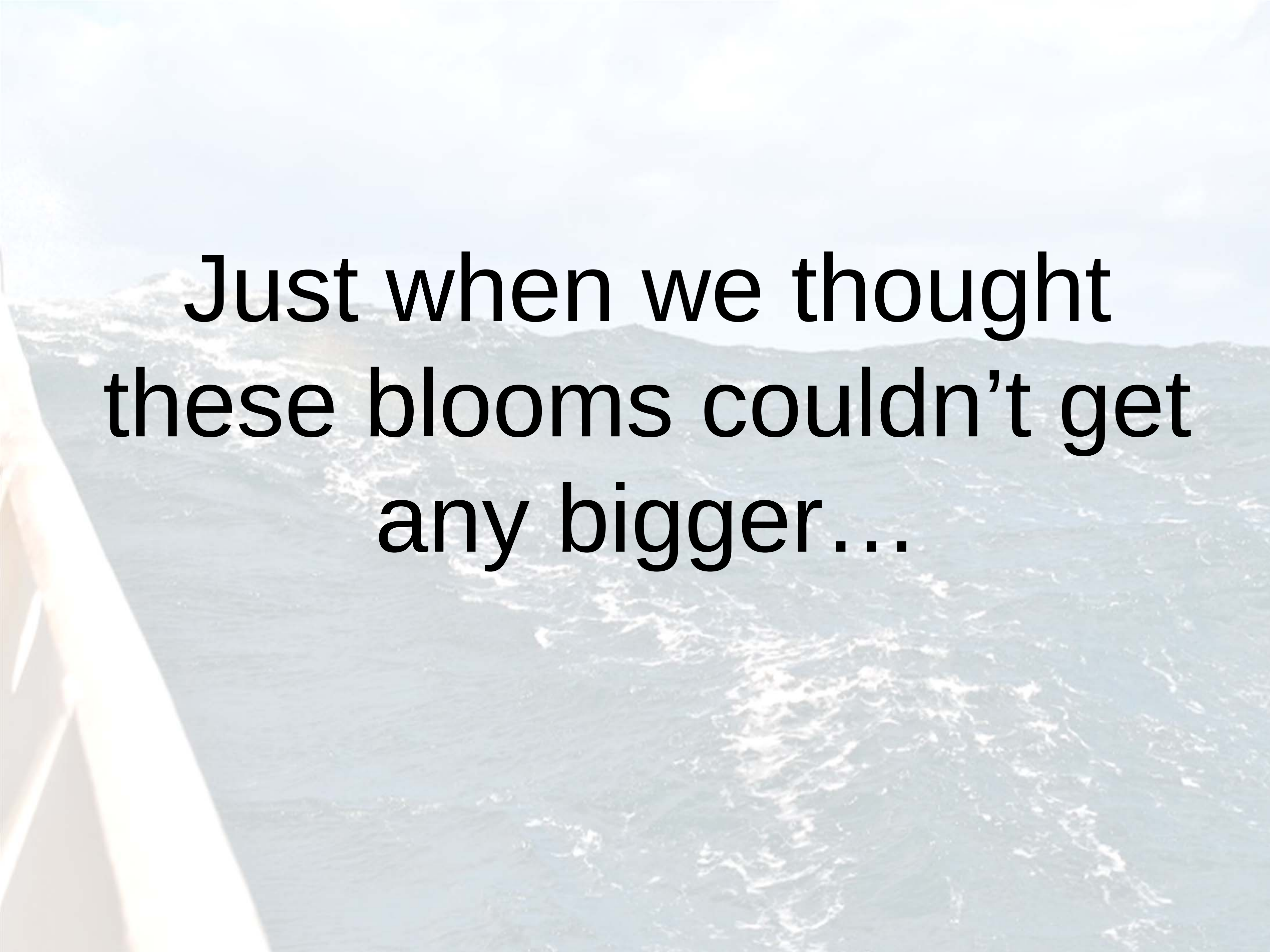
||Present address: Station Biologique, CNRS, 29211 Roscoff, France.



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



asin 2,000 cells mL-1
300,000 coccoliths mL-



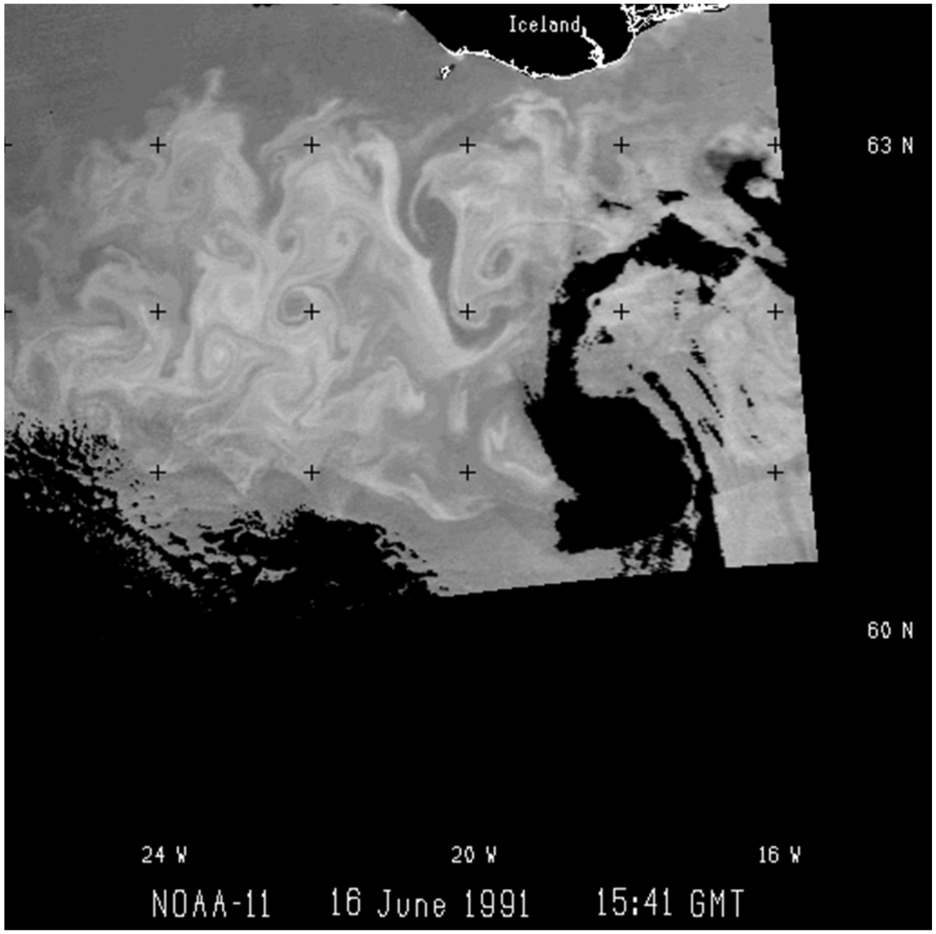
Just when we thought these blooms couldn't get any bigger…

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]



[Coccolithophores]= 10,000 mL-1
[Coccoliths] = 300,000 mL-1

Total area = 0.5 million km^2

South of Iceland, 1991

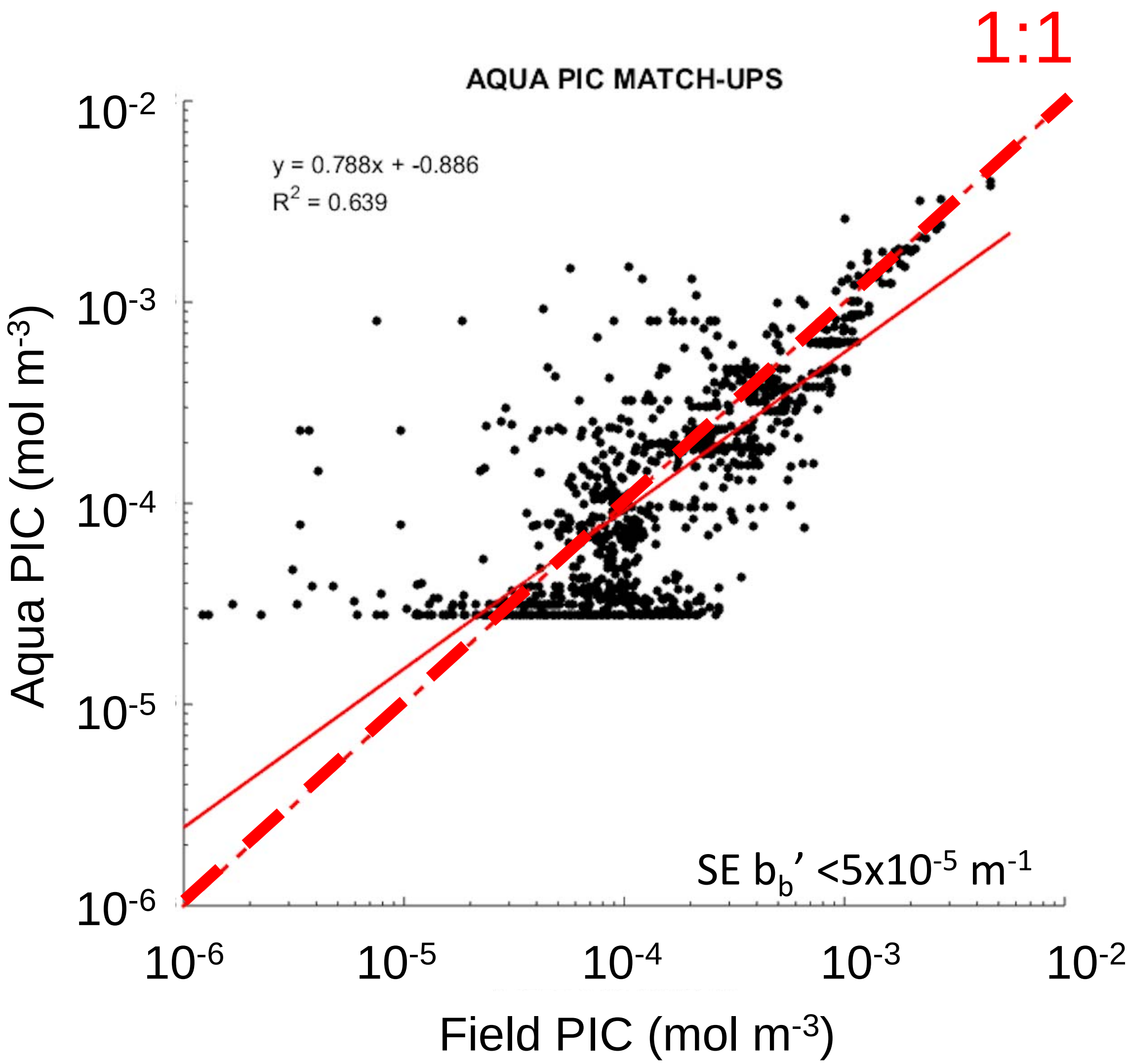
Outside Bloom

Constant “color chip” for comparison of water color

Inside Bloom

View from Lufthansa flight #423, 38,000 feet

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

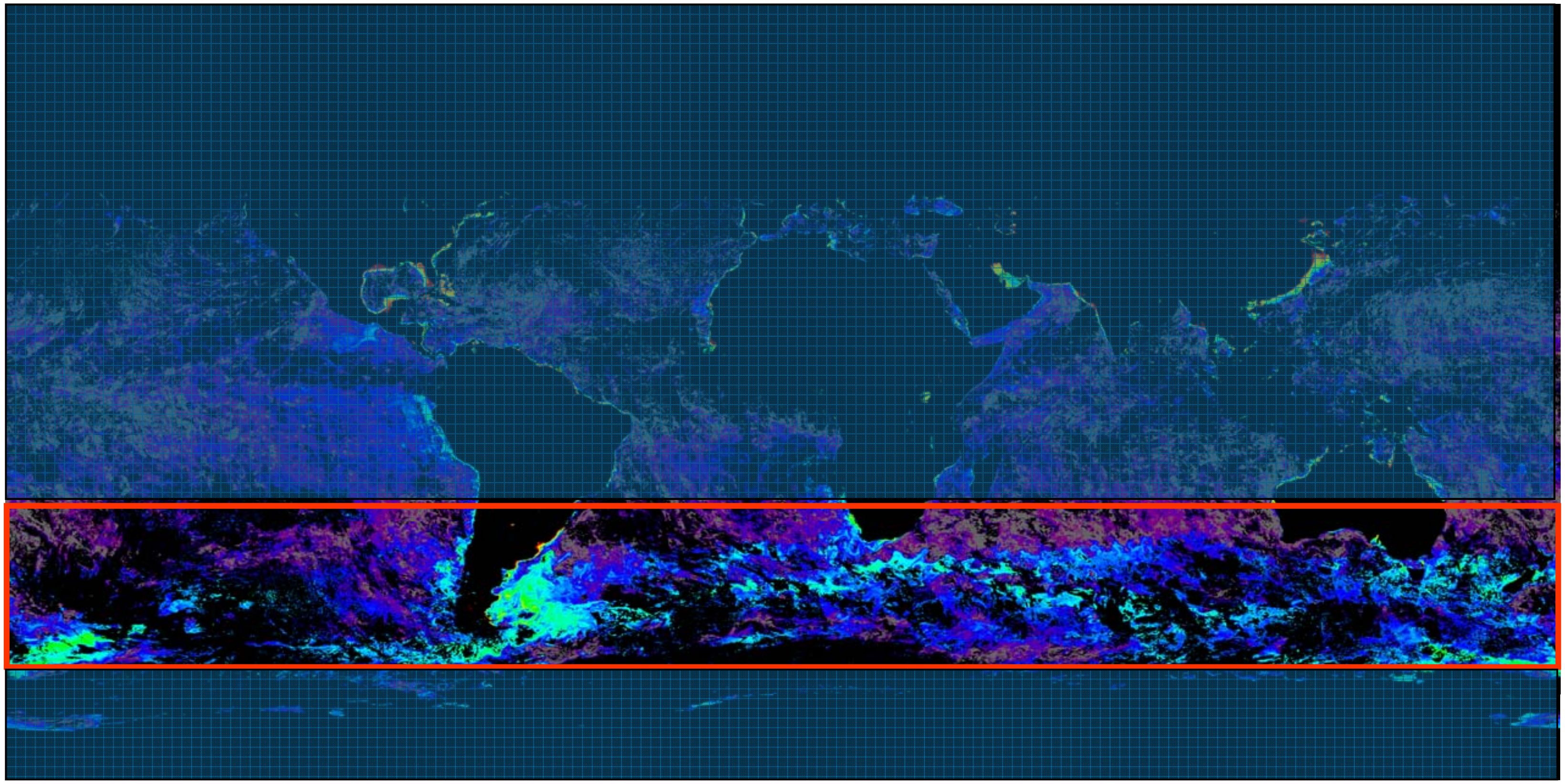


C. Mitchell/ J Hopkins; Bigelow Laboratory

Match-ups AQUA- Through May ‘15

The PIC algorithm regularly observed a high reflectance feature in the S. Ocean…**The great calcite belt**

- Appeared to contain 1/3 of the PIC in the global ocean



Great Calcite Belt description…

- Region of consistently high reflectance in the Southern Ocean (in ocean color remote sensing) Balch et al., 2011. *JGR Gas-Ex Special Issue*
- Observed annually by CZCS, SeaWiFS, MODIS Aqua, MODIS Terra, MERIS and VIIRS missions (1978-present)
- <u>52 million km^2</u> <u>(16% of the global ocean)</u>
- <u>Culprit…*Emiliania huxleyi but there are very few observations!*</u>

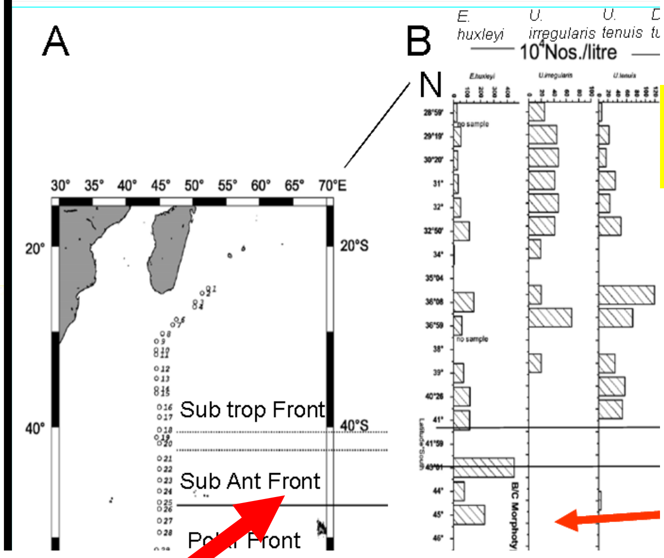
region…

Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Marine Micropaleontology 67 (2008) 30–45
MARINE MICROPALEONTOLOGY
www.elsevier.com/locate/marmicro

Published October 25

Ecology of coccolithophores in the Indian sector of the Southern Ocean

Rahul Mohan [a,*], Lina P. Mergulhao [c], M.V.S. Guptha [d], A
M. Thamban [a,1], N. AnilKumar [a,1], M. Sudhakar [a,1], Rasi



High abundance of E. huxleyi

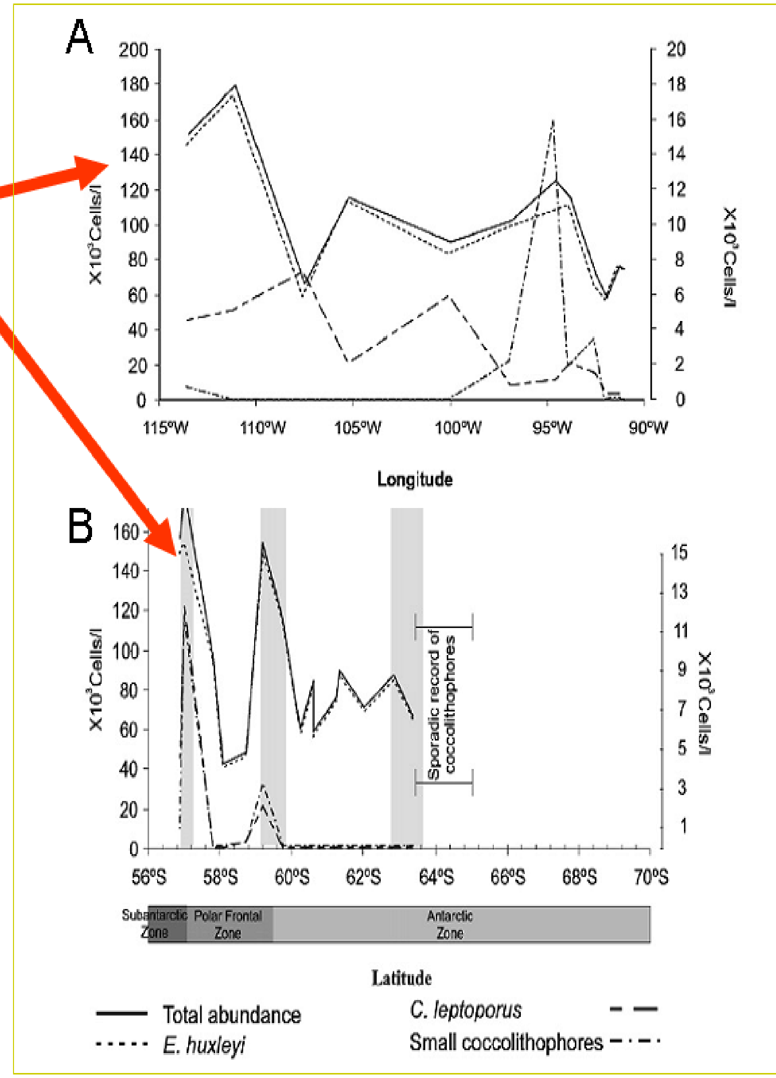
Marine Micropaleontology 69 (2008) 16–25

Contents lists available at ScienceDirect
ELSEVIER
Marine Micropaleontology
journal homepage: www.elsevier.com/locate/marmicro

Sea surface distribution of coccolithophores in the eastern Pacific sector of the Southern Ocean (Bellingshausen and Amundsen Seas) during the late austral summer of 2001

José M. Gravalosa [a,*], José-Abel Flores [a], Francisco J. Sierro [a], Rainer Gersonde [b]

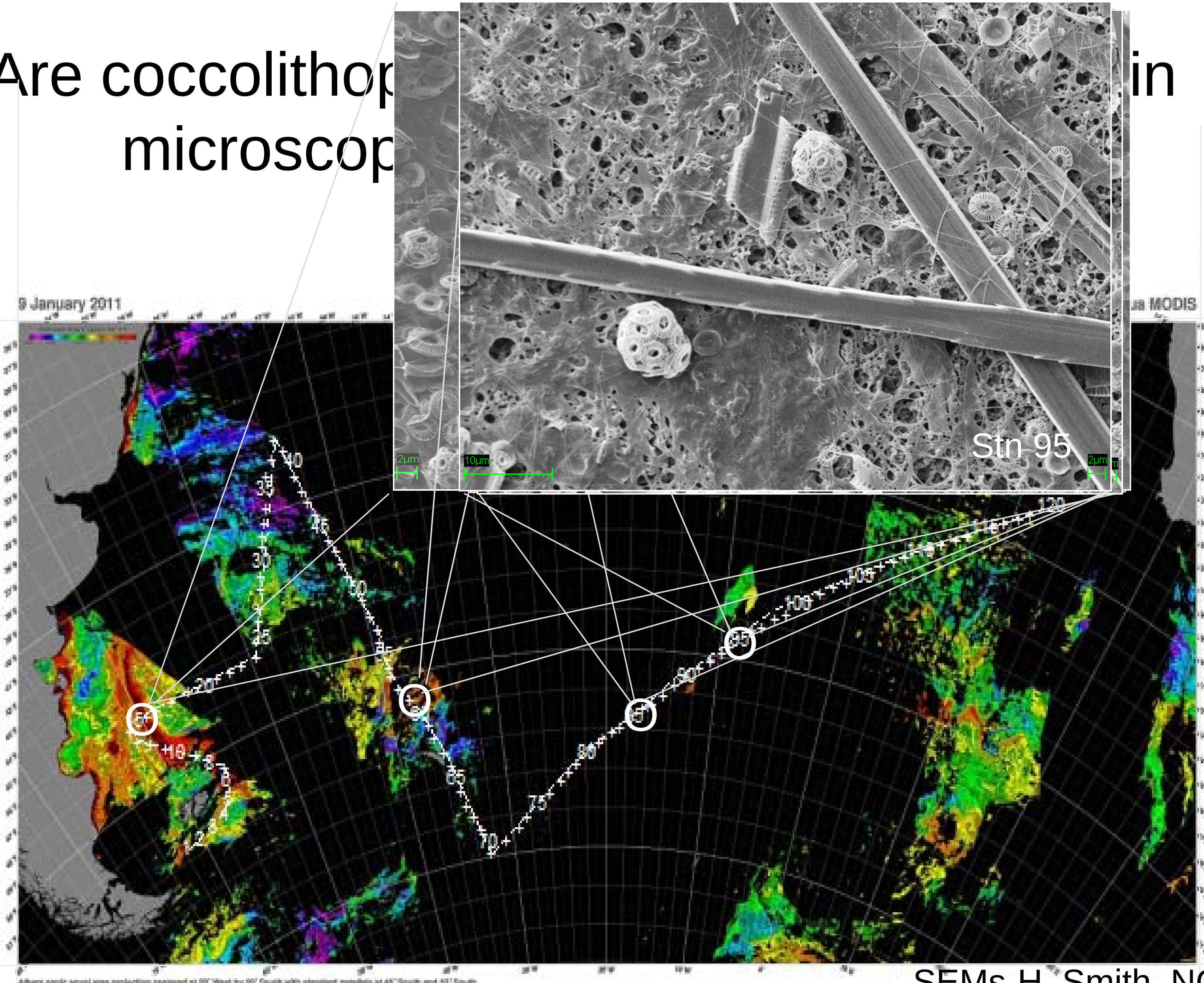
[a] Universidad de Salamanca, Departamento de Geología, 37008, Salamanca, Spain
[b] Alfred Wegener Institute for Polar and Marine Research, Postbox 120161, 27515 Bremerhaven, Germany



<u>13 research cruises</u> have crossed various parts of the Great Belt between Punta Arenas, Chile and Fremantle, Australia (half the Southern Ocean…

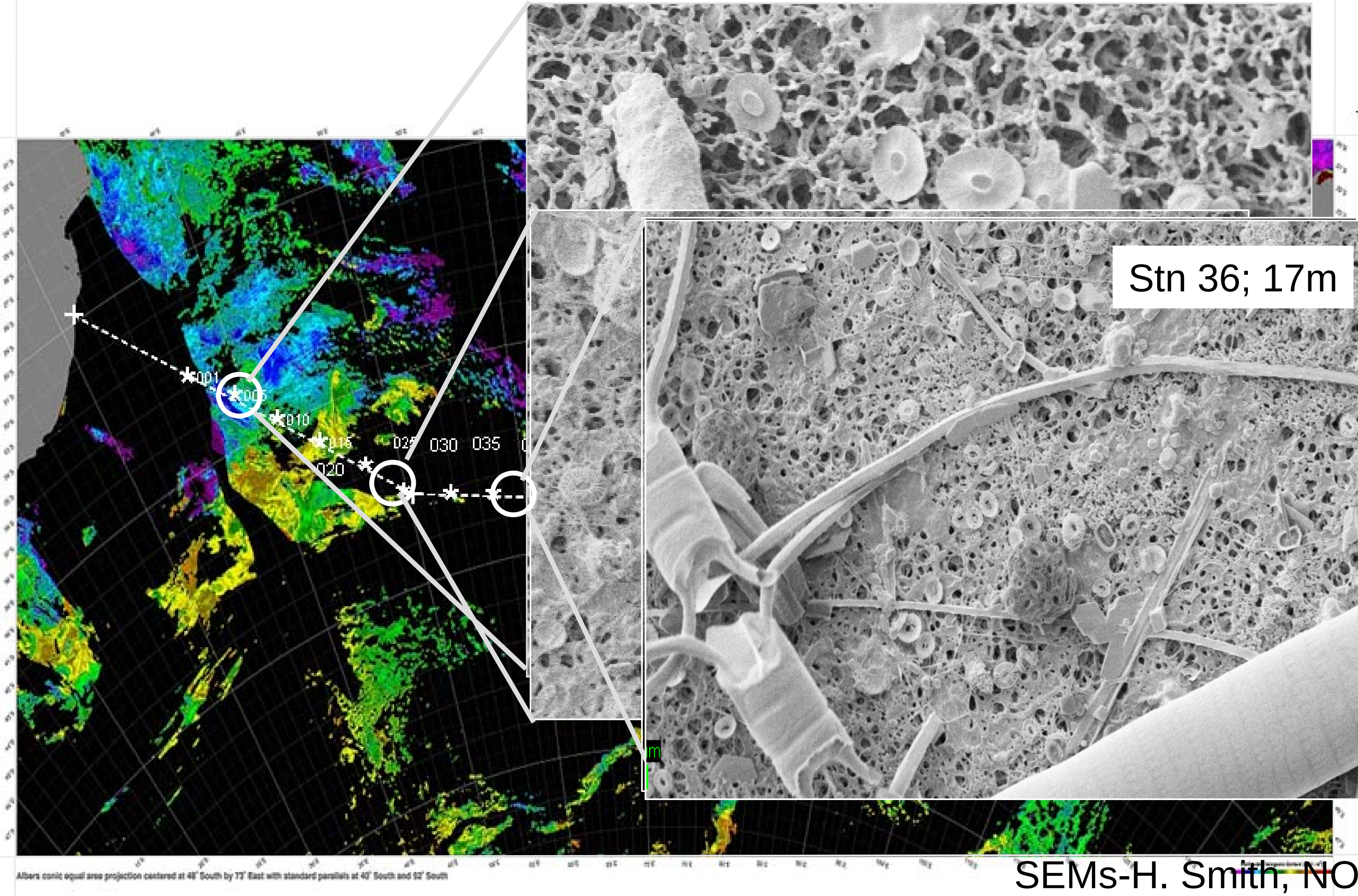
- AMT 15-22, 24 (southern end of each transect goes through the GCB)
- Southern Ocean Gas Ex
- COPAS ’08 (Patagonian Shelf)
- Great Belt I (Punta Arenas, Chile to Cape Town, S. Africa)
- Great Belt II (Durban, S.A. to Fremantle, Australia

Are coccolithop... in
microscop...



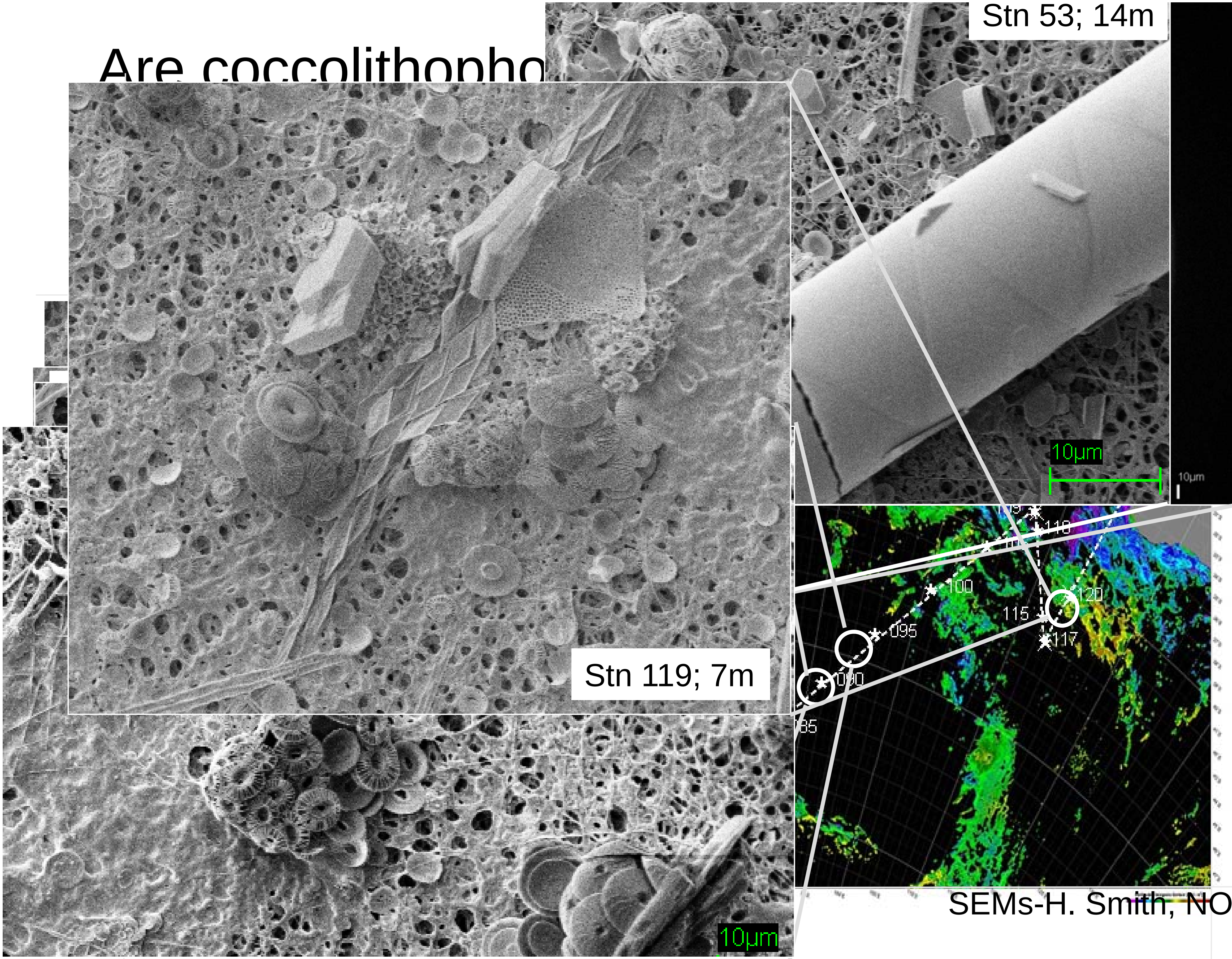
SEMs-H. Smith, NOC

Are coccolithophores actually observable in microscopy samples from GCB II?



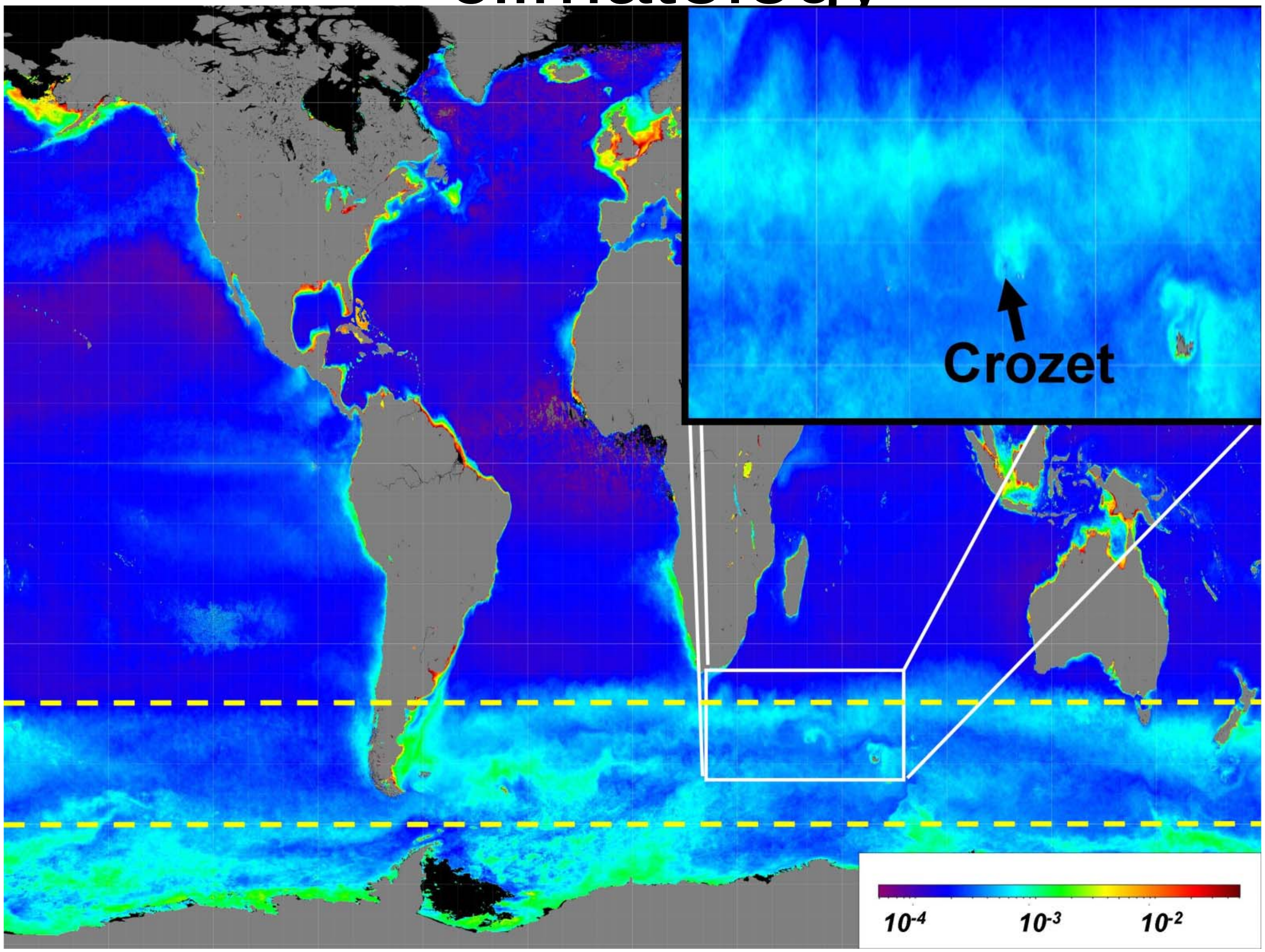
SEMs-H. Smith, NOC

Are coccolithopho

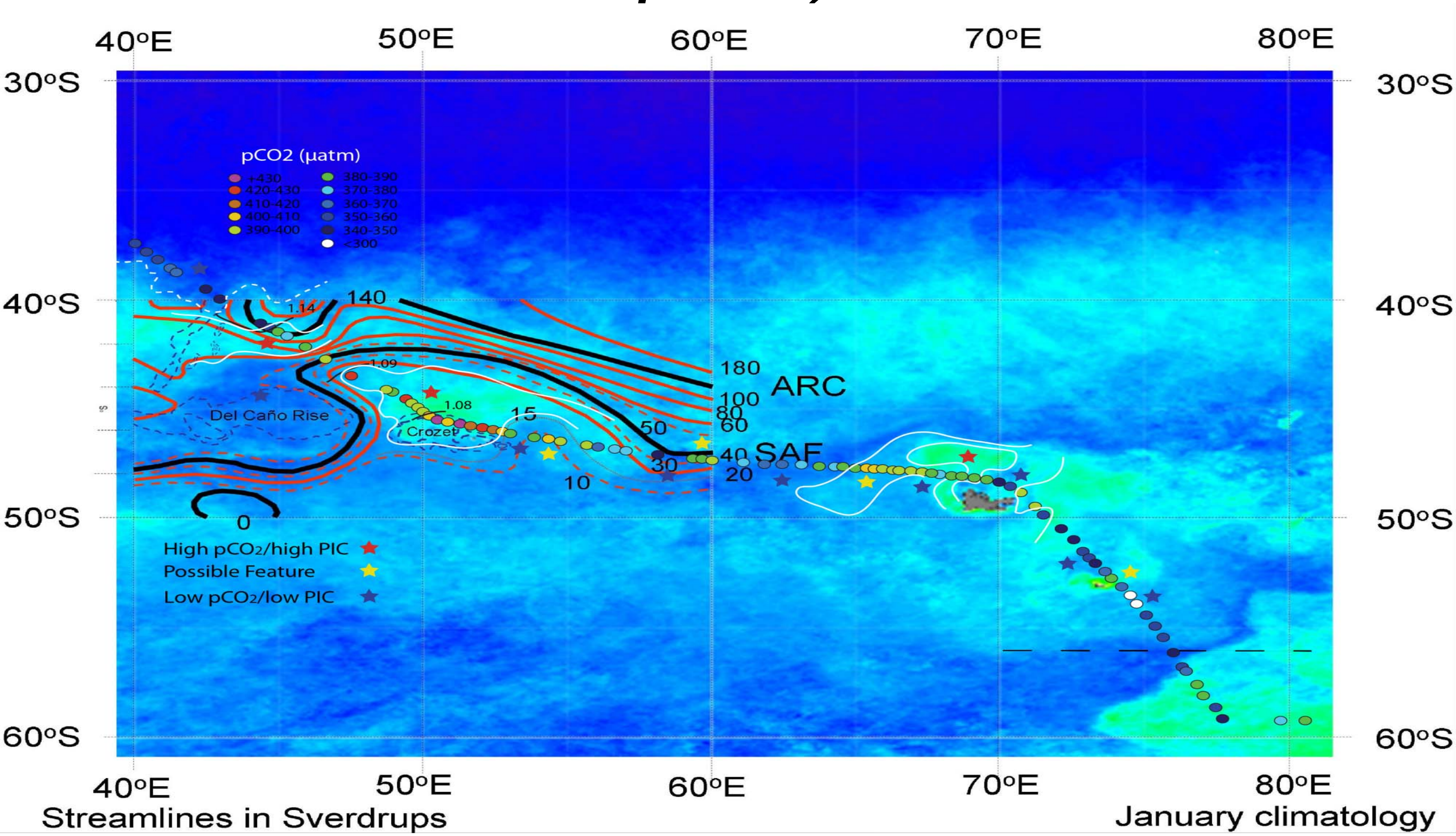


SEMs-H. Smith, NOC

There are consistantly "light and dark" parts of the GCB: 2002-2013 Aqua PIC climatology



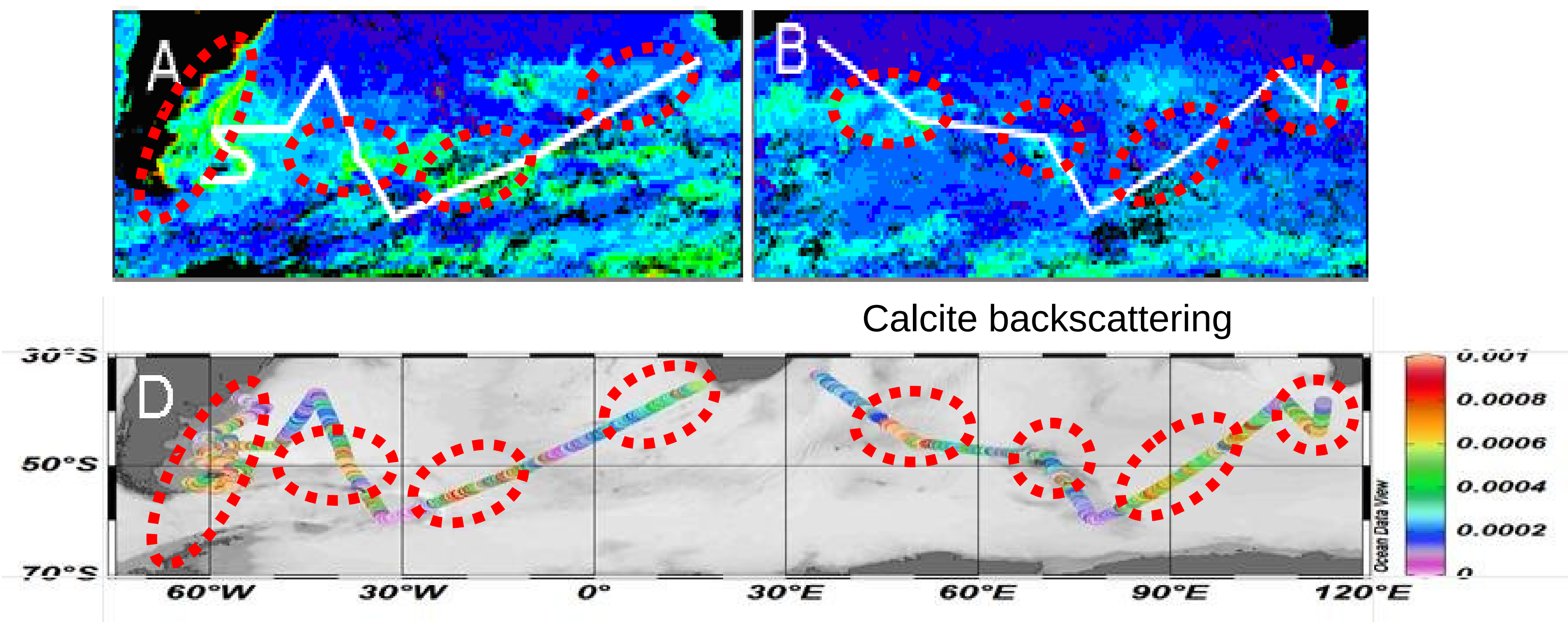
A close-up view of the belt…PIC & pCO$_2$



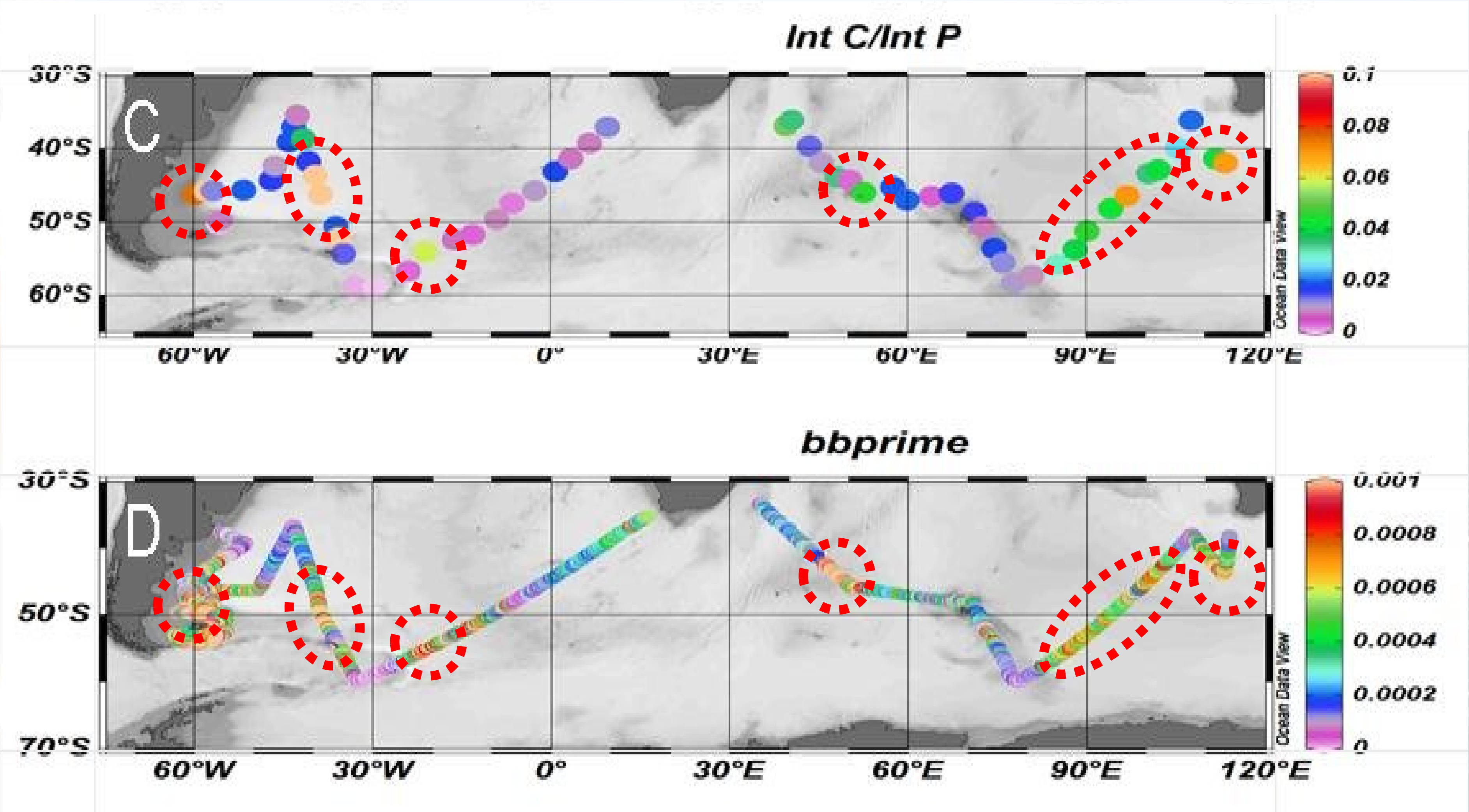
Bio-optical/hydrographic observations

- Do high reflectance waters of the GCB correspond to high scattering waters associated with PIC?
- Are these high reflectance waters associated with specific water masses?

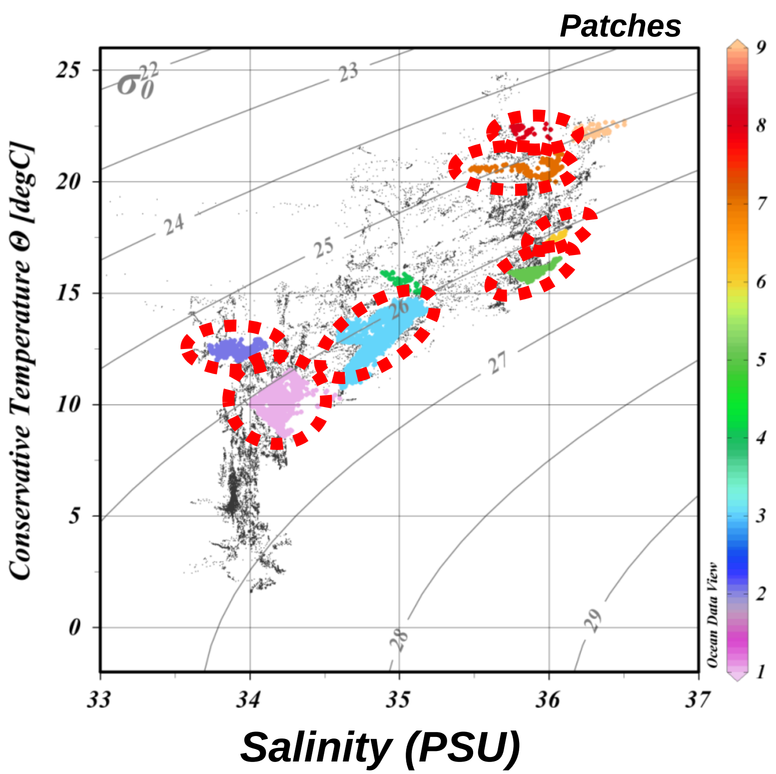
Patterns of satellite PIC [monthly binned] similar to ship-based optical estimates of PIC (sampled over 35d; b_b')

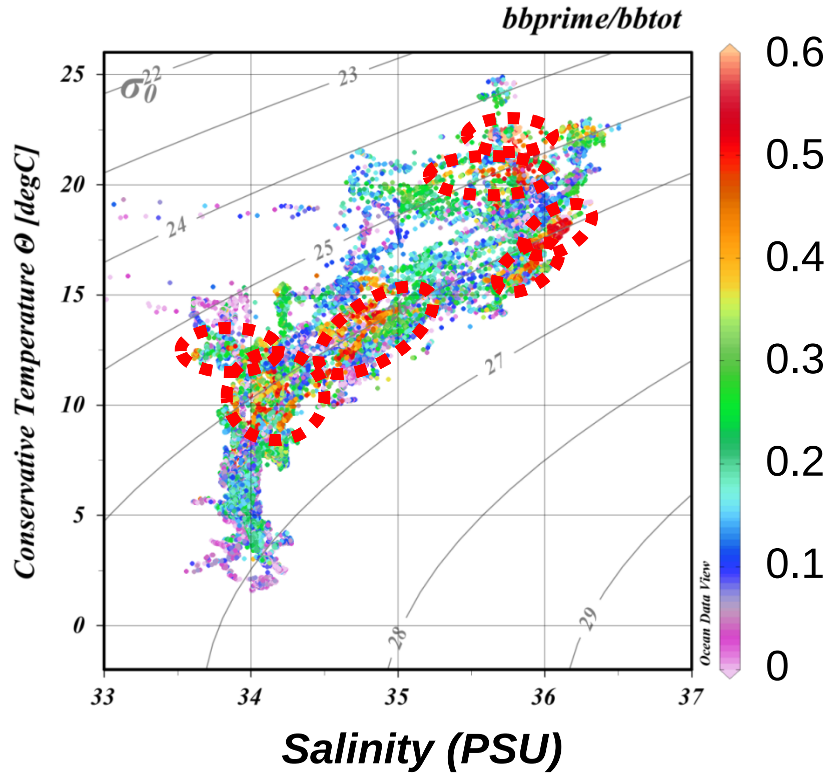


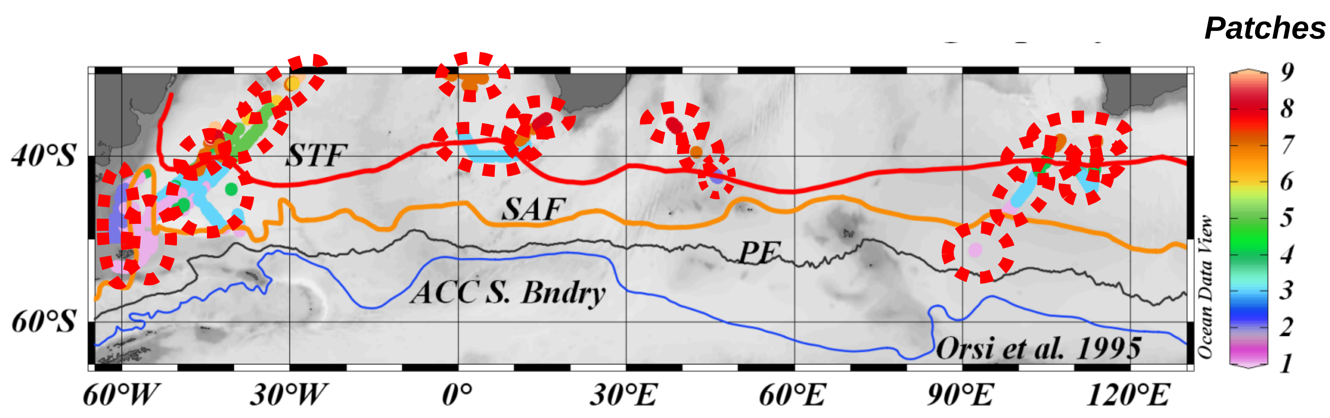
Ratio of Int calcification:photosynthesis roughly tracks standing stock of PIC (b_b')



T/S Plot with just patches of elevated b_b'/b_{bptot} defined







Highest PIC backscattering relative to total particle backscattering:

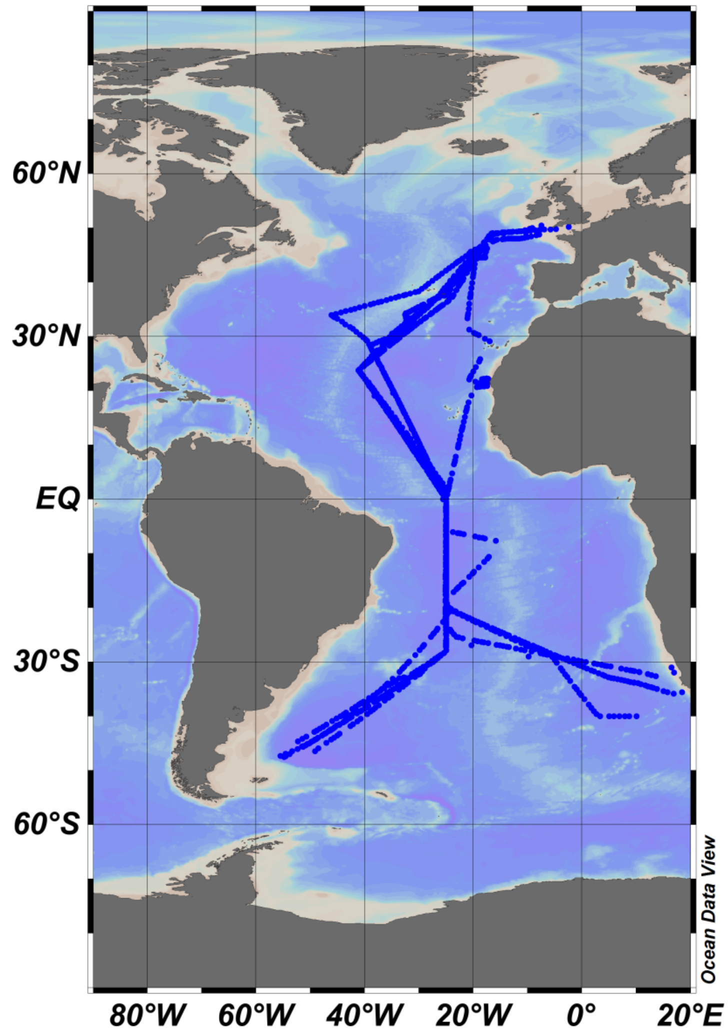
- Is not exactly at the climatological front positions but is close
- Greatest relative importance of PIC backscattering in the GCB is between the sub-antarctic front and the sub-tropical front

Latitudinal Sections through Atlantic

- How does the coccolithophore light scattering vary?
- How does coccolithophore concentration, PIC and BSi vary?

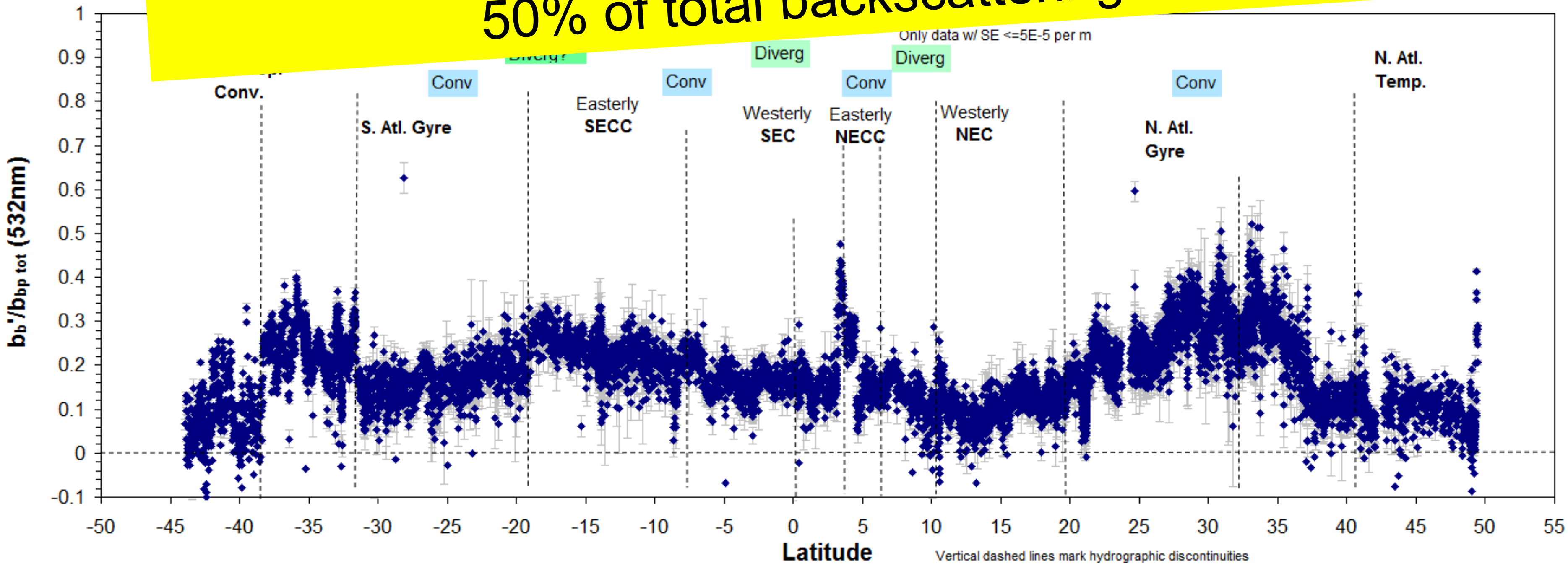
Integrated distributions of PIC, BSi and coccolithophores

AMT 15-22

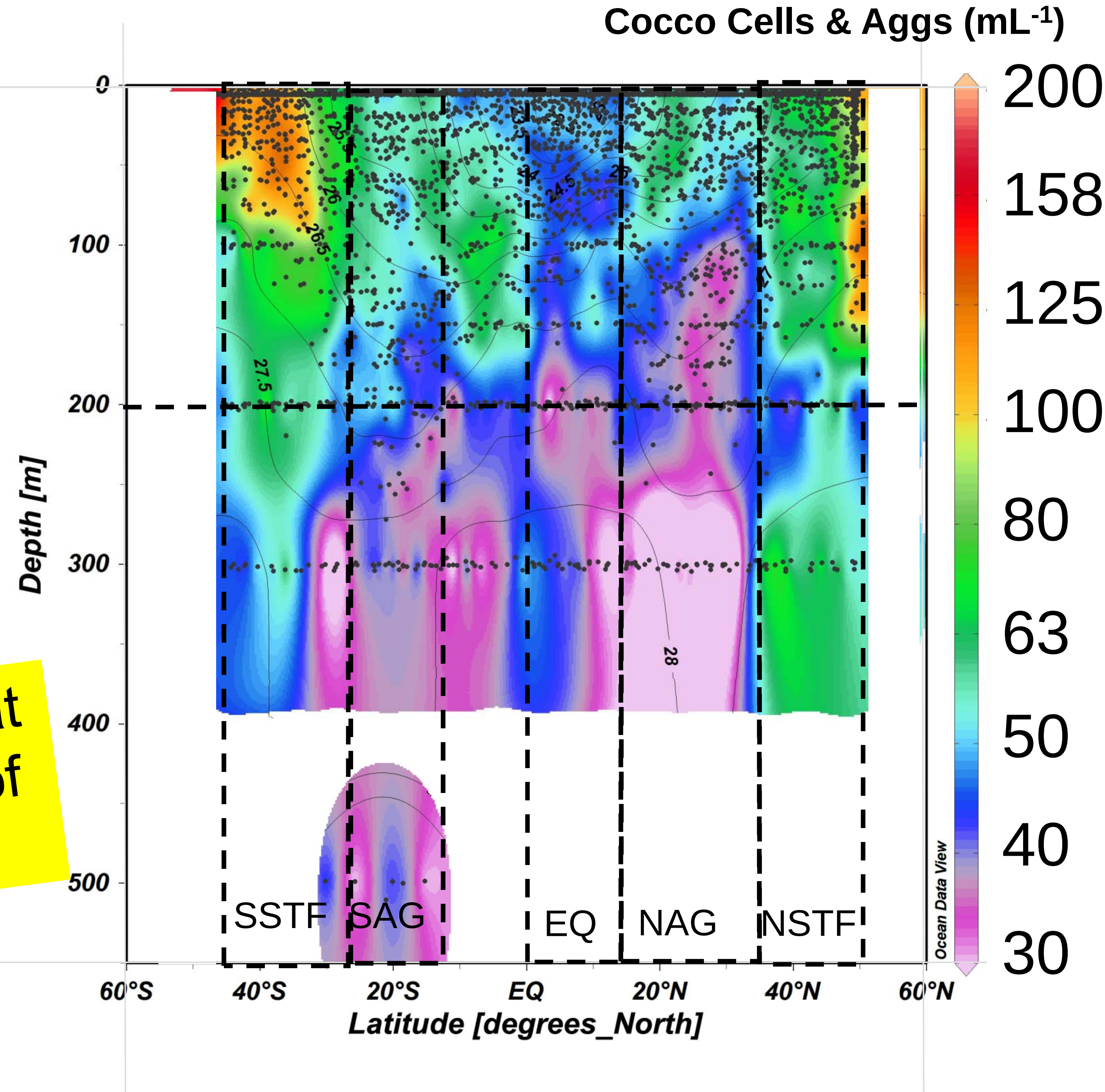


b_b' vs Lat; AMT19

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

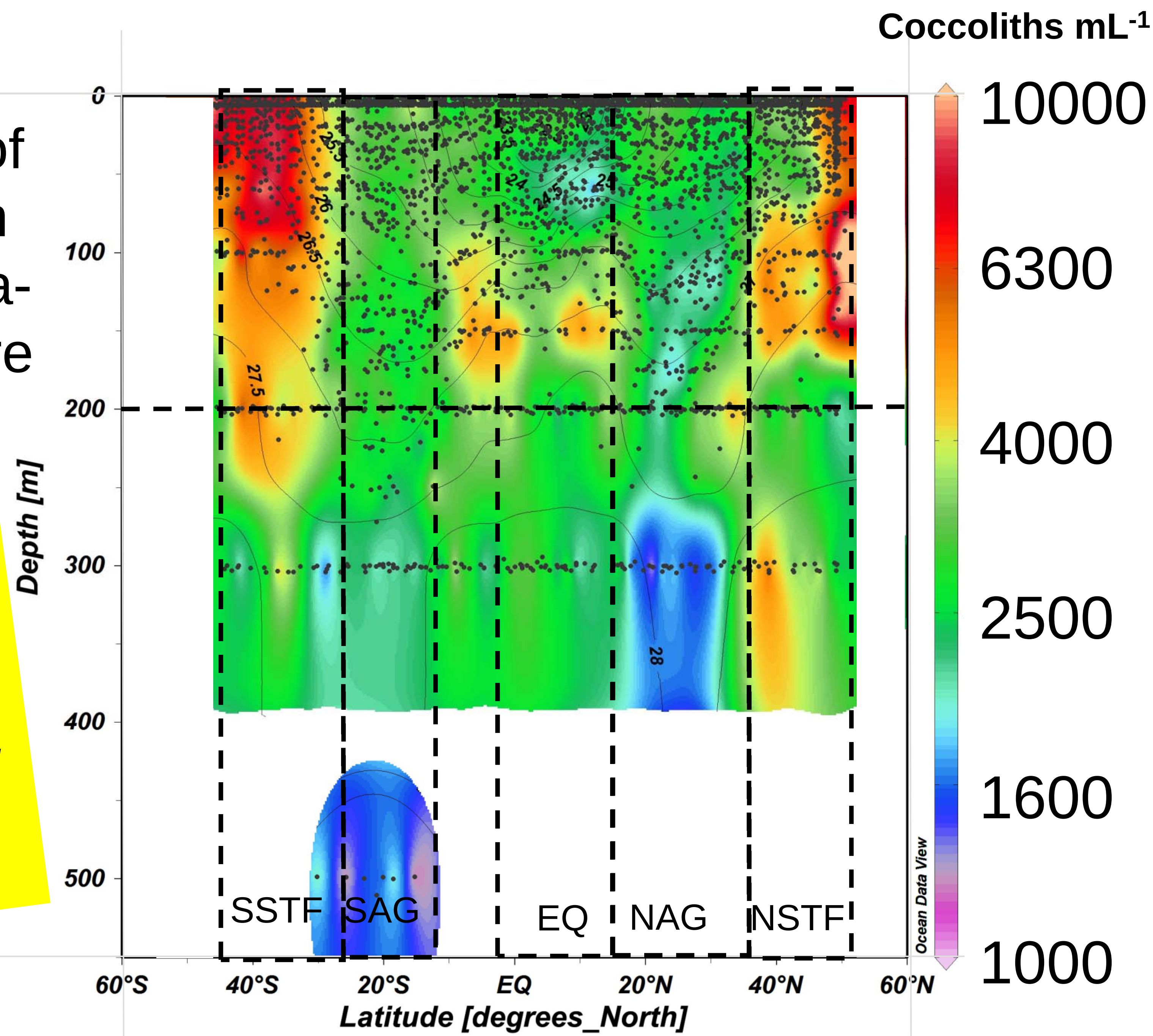


Mean Section of Cocco cells: Entire AMT



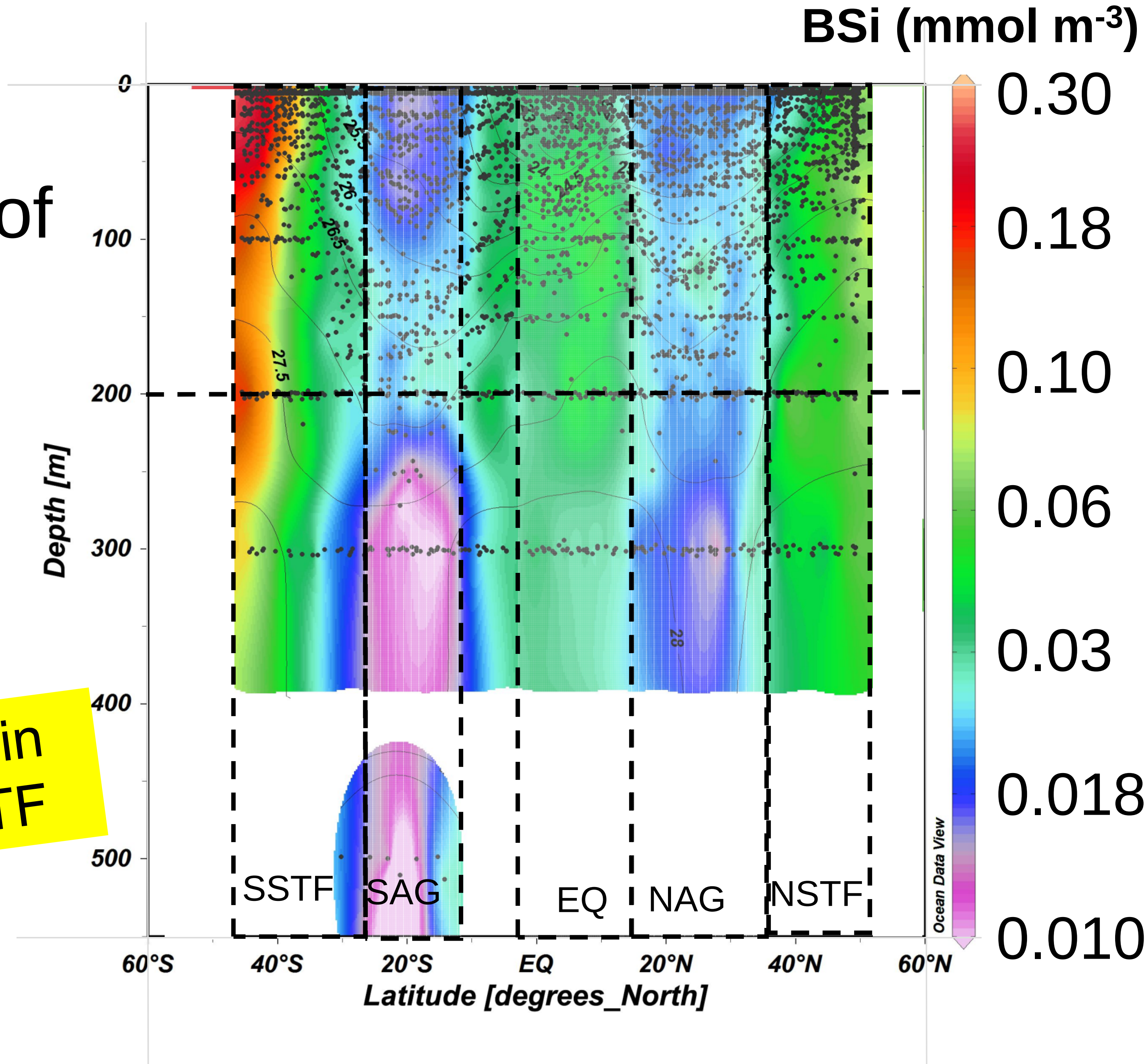
Elevated at both ends of transect

Mean Section of coccolith concentration: Entire AMT



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

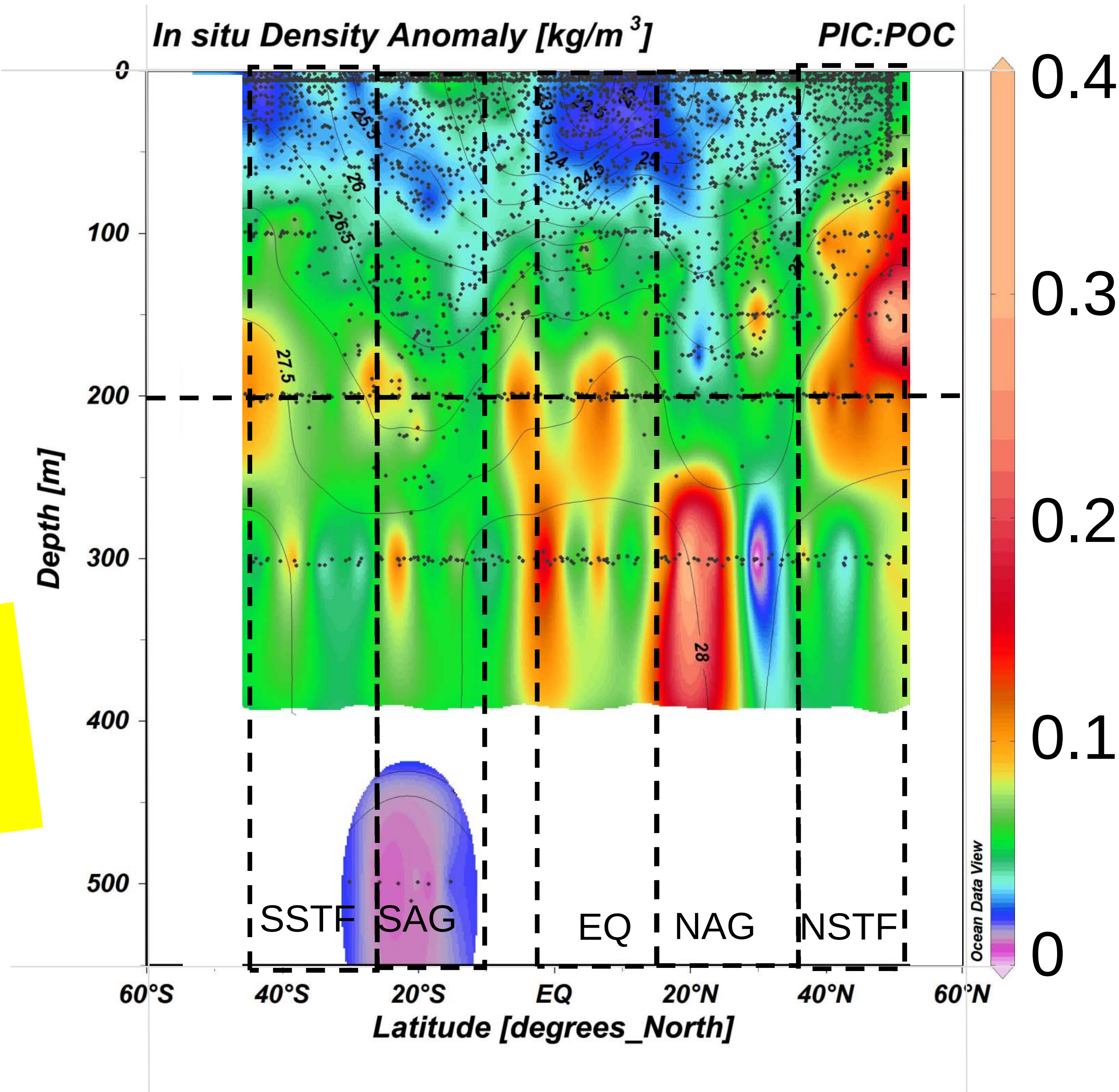
Mean Section of BSi: Entire AMT



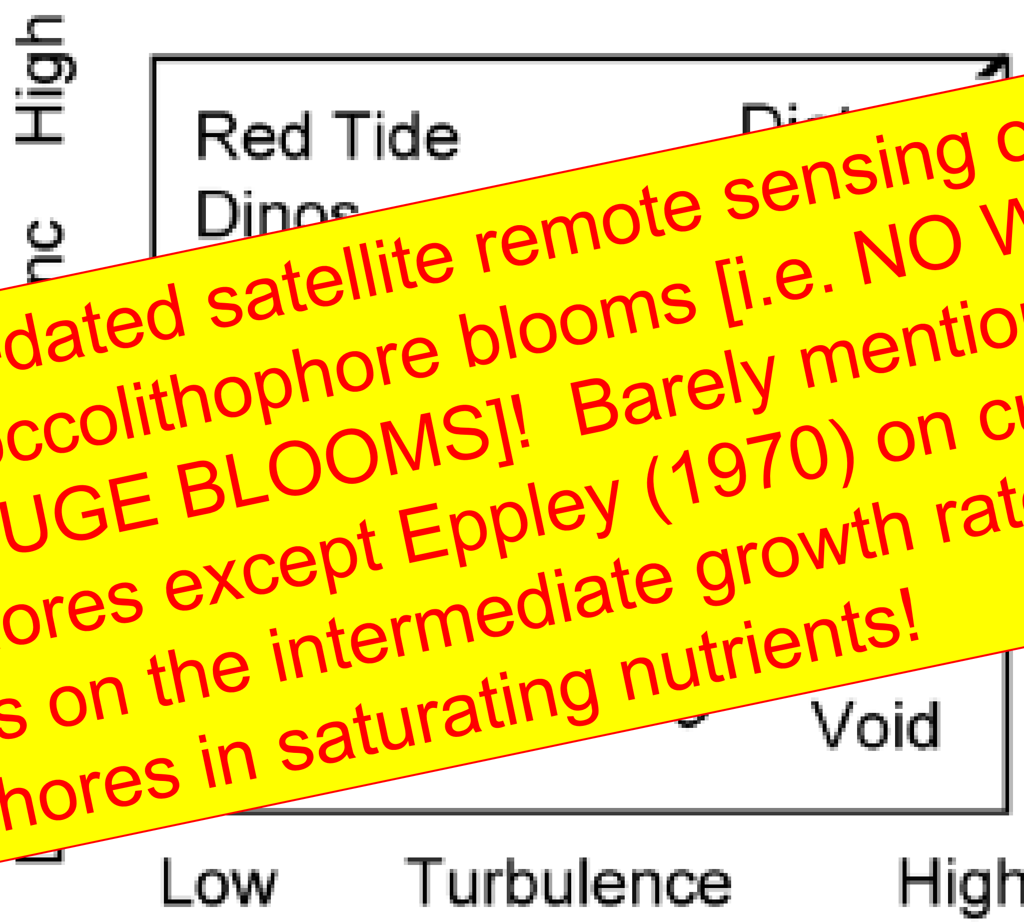
Greatest in South STF

Mean Section of PIC:POC Entire AMT

Note increases with depth



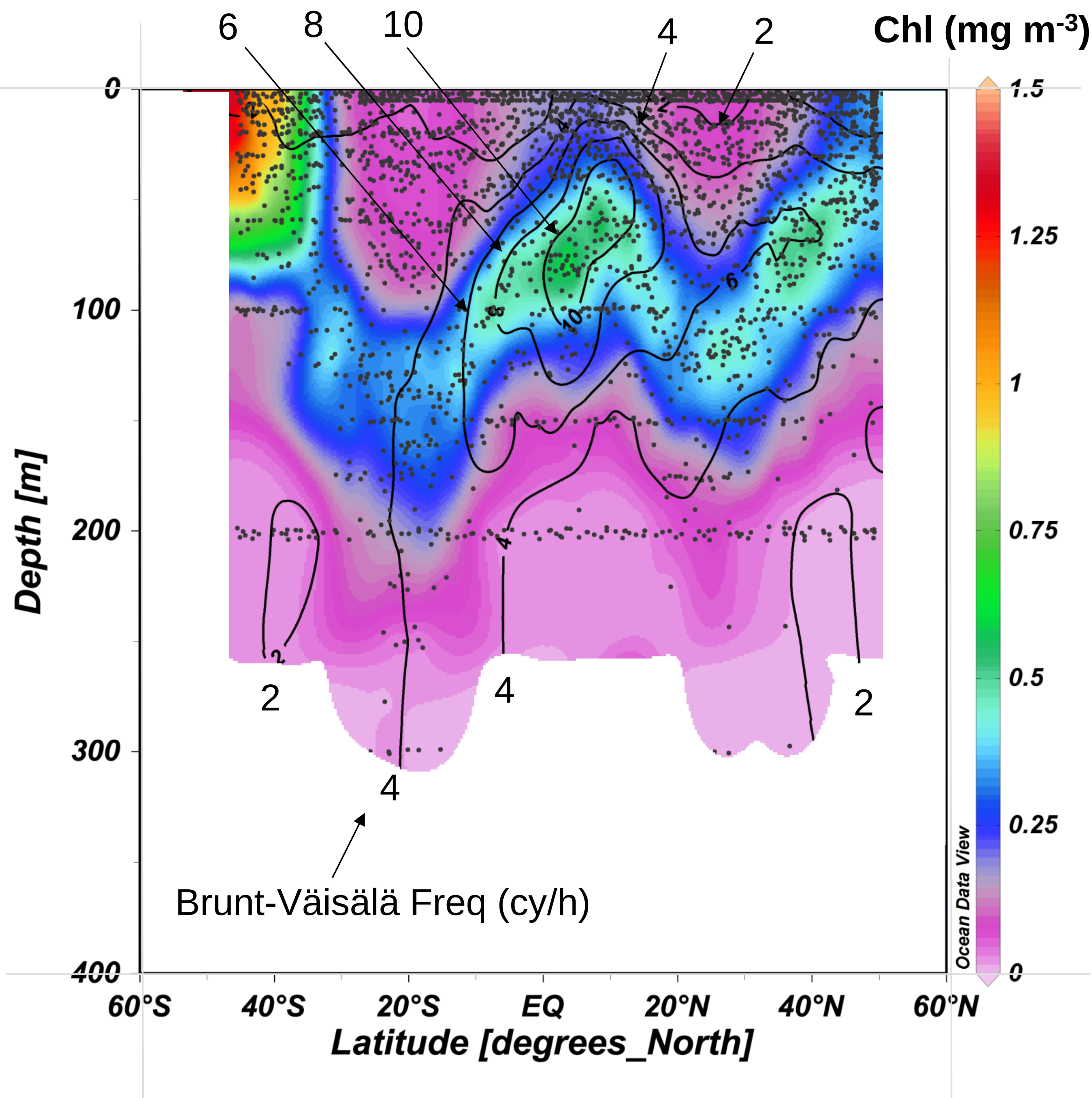
Classic mandala of phytoplankton succession (Margalef, 1978)…



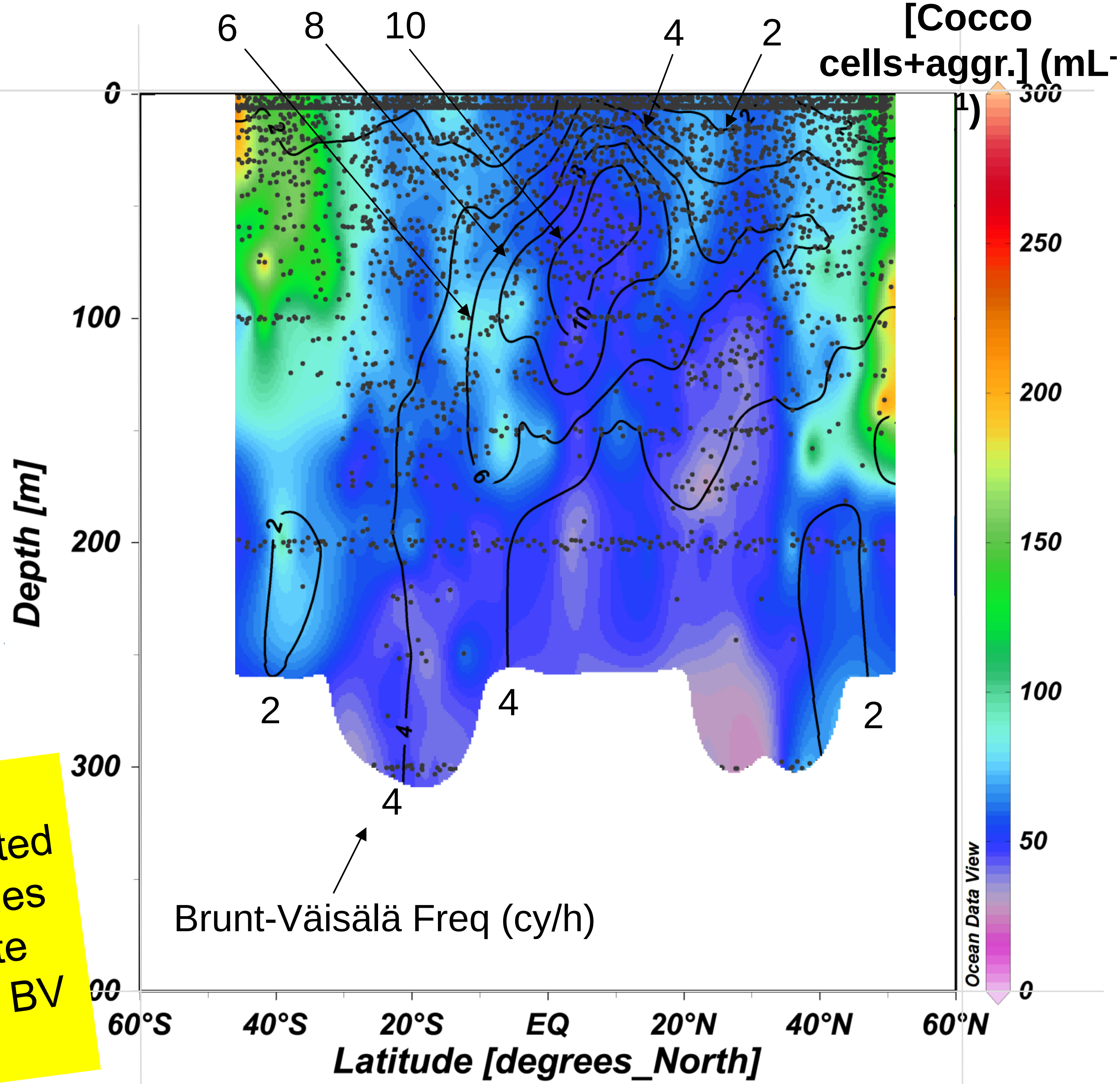
His paper pre-dated satellite remote sensing of mesoscale coccolithophore blooms [i.e. NO WAY TO OBSERVE HUGE BLOOMS]! Barely mentioned coccolithophores except Eppley (1970) on culture observations on the intermediate growth rates of coccolithophores in saturating nutrients!

Life-forms of phytoplankton as survival alternatives in an unstable environment. *Oceanologica Acta* 1: 493-509

Role of stability: Chl section shows strongest correspondence with BV frequency



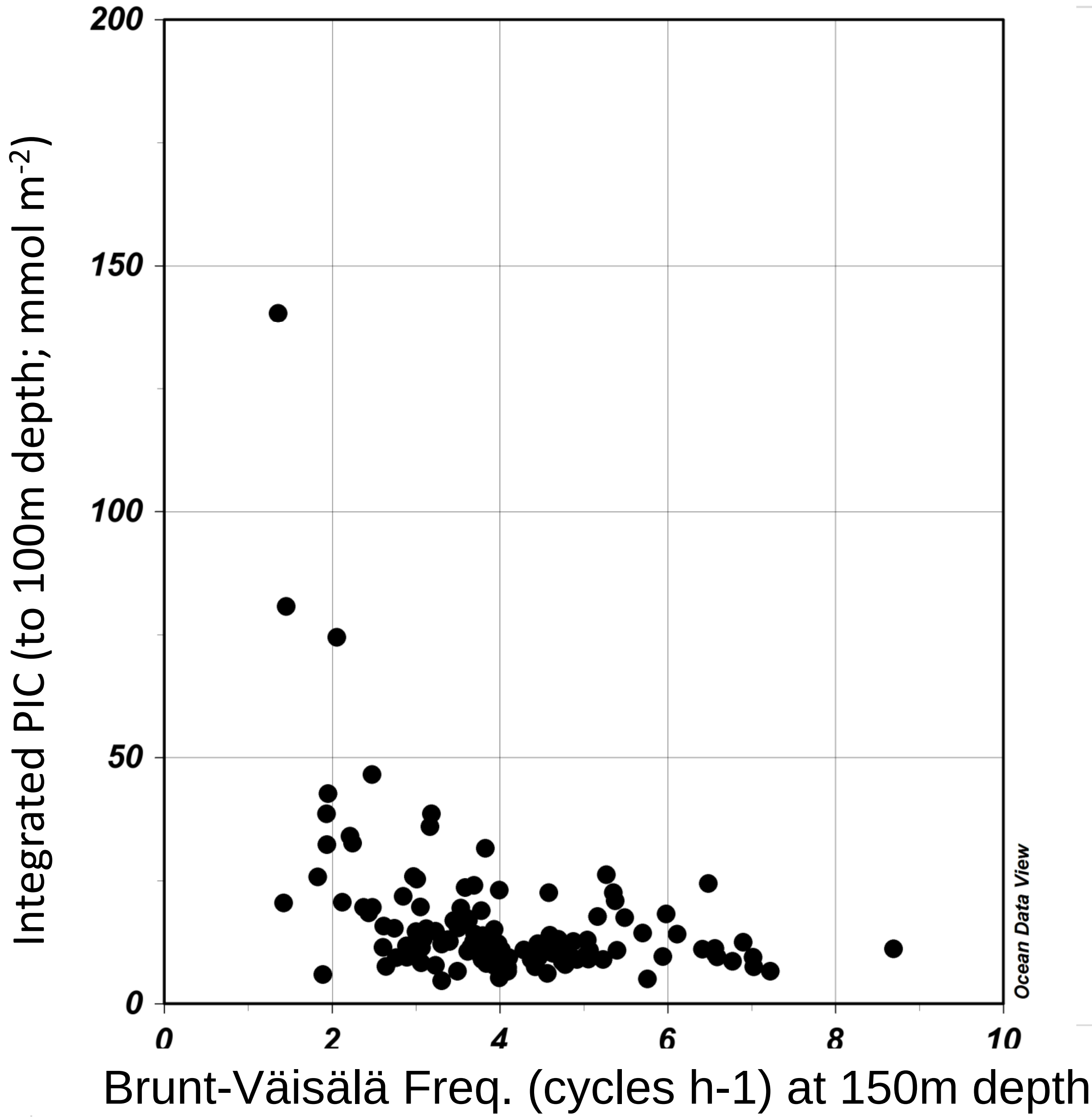
Section of cocco cells with BV frequency overlaid… less correspon-dence than with chlorophyll



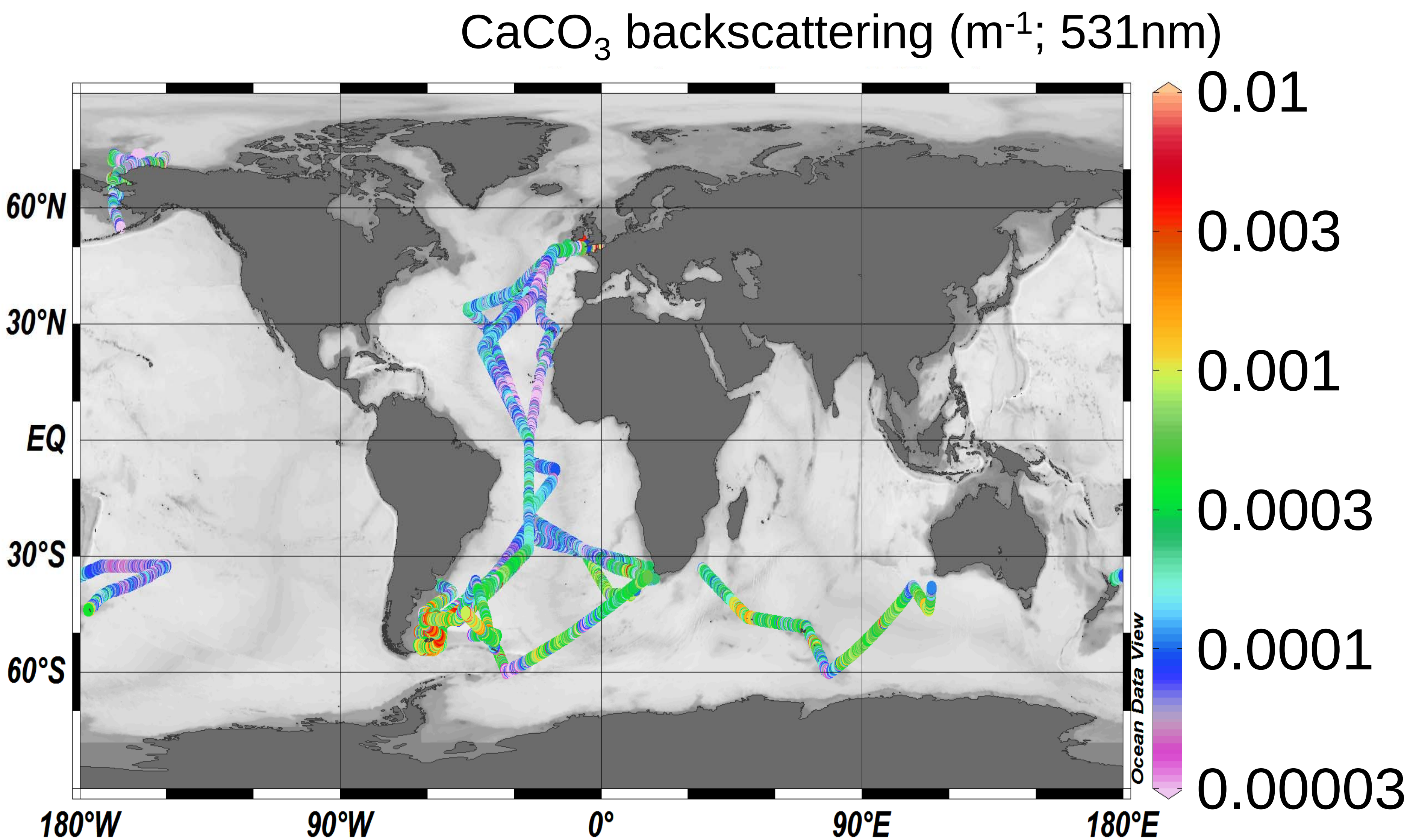
Highest conc of cocco cells associated with highest latitudes (e.g. Great Calcite Belt) with reduced BV freq

Int PIC highest at lowest Brunt-Vaisalla frequencies

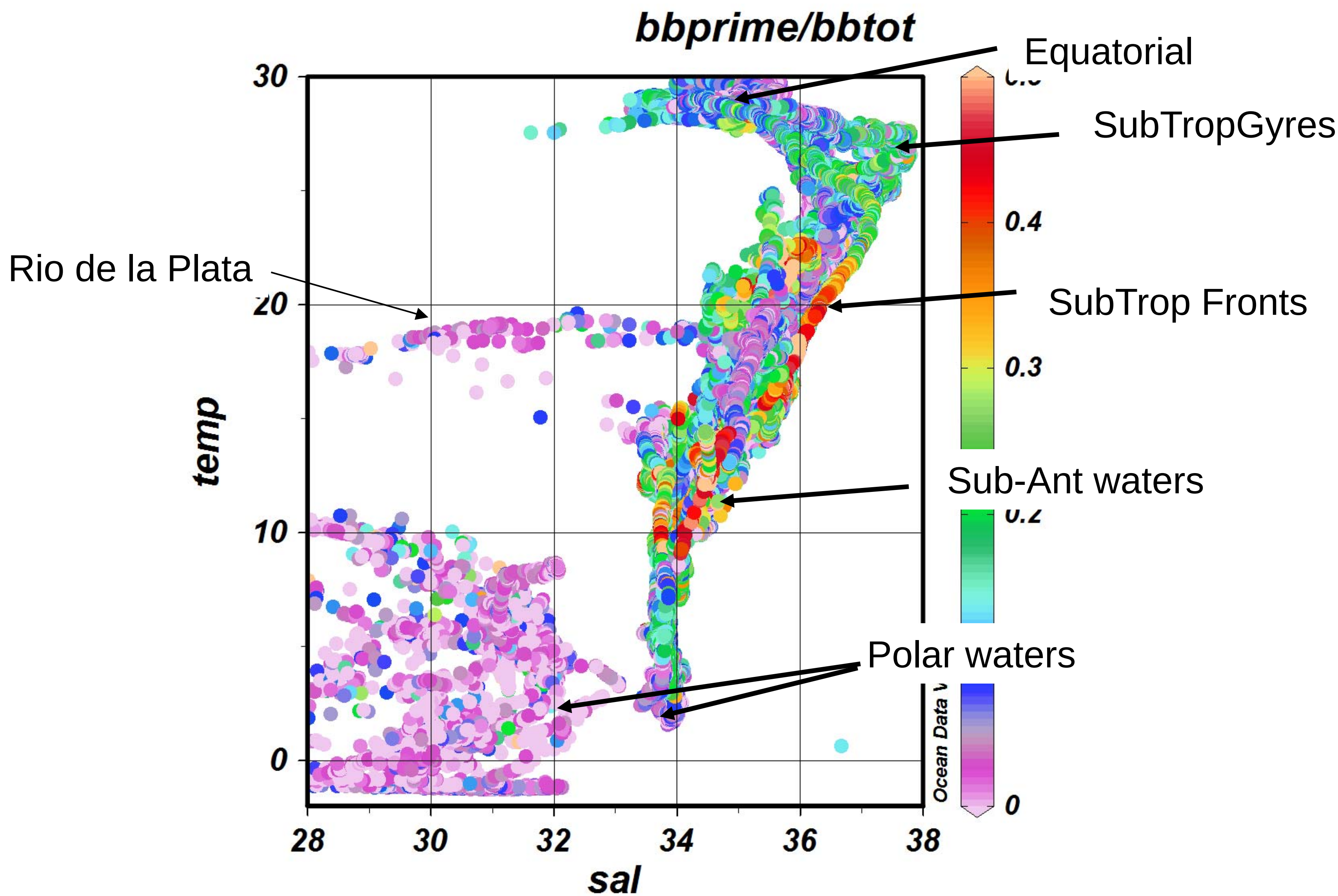
Results **not** consistent with Margalef's Mandala



Increasing the scale of observation…viewing all cruises

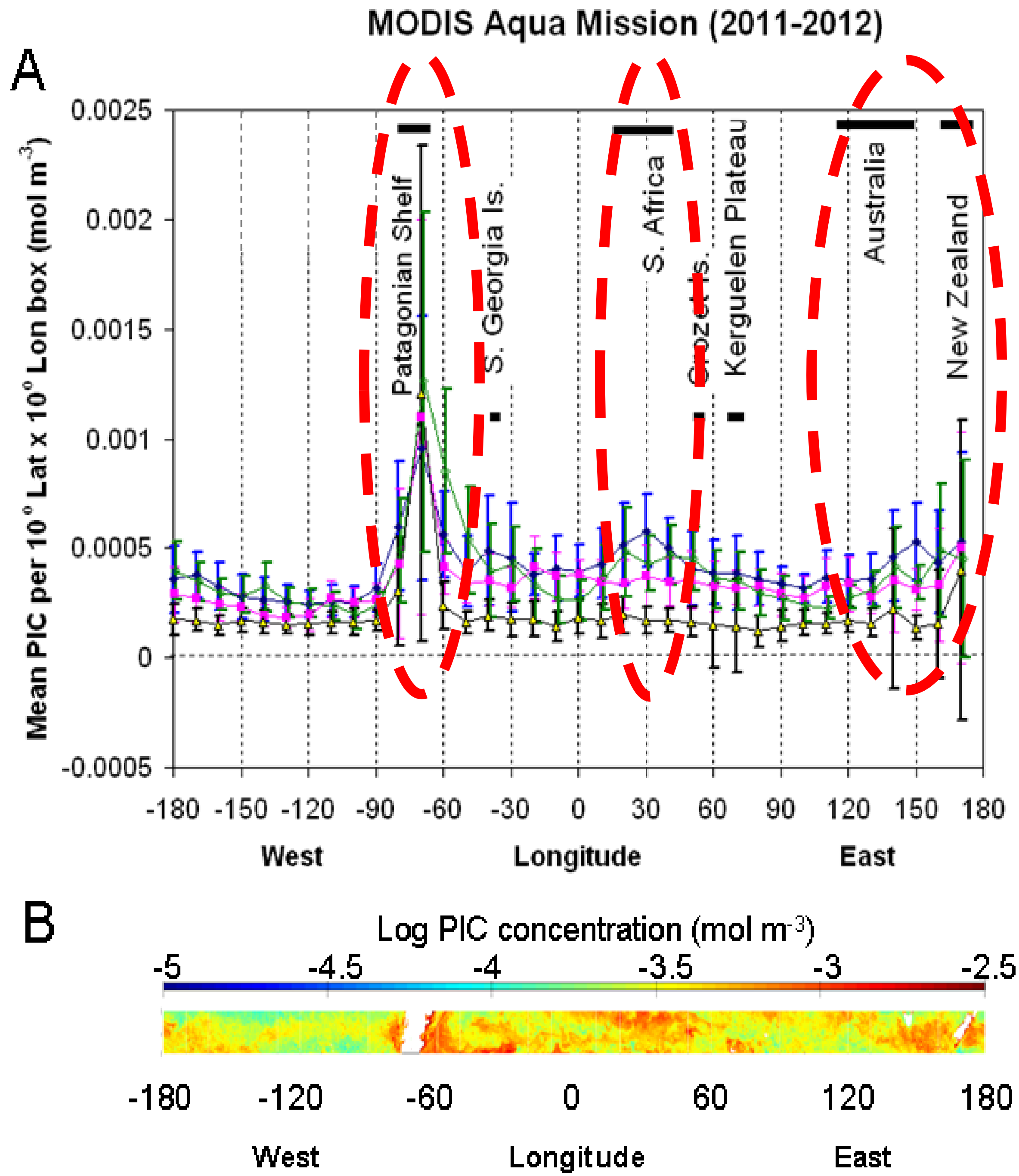


Putting all cruises together…



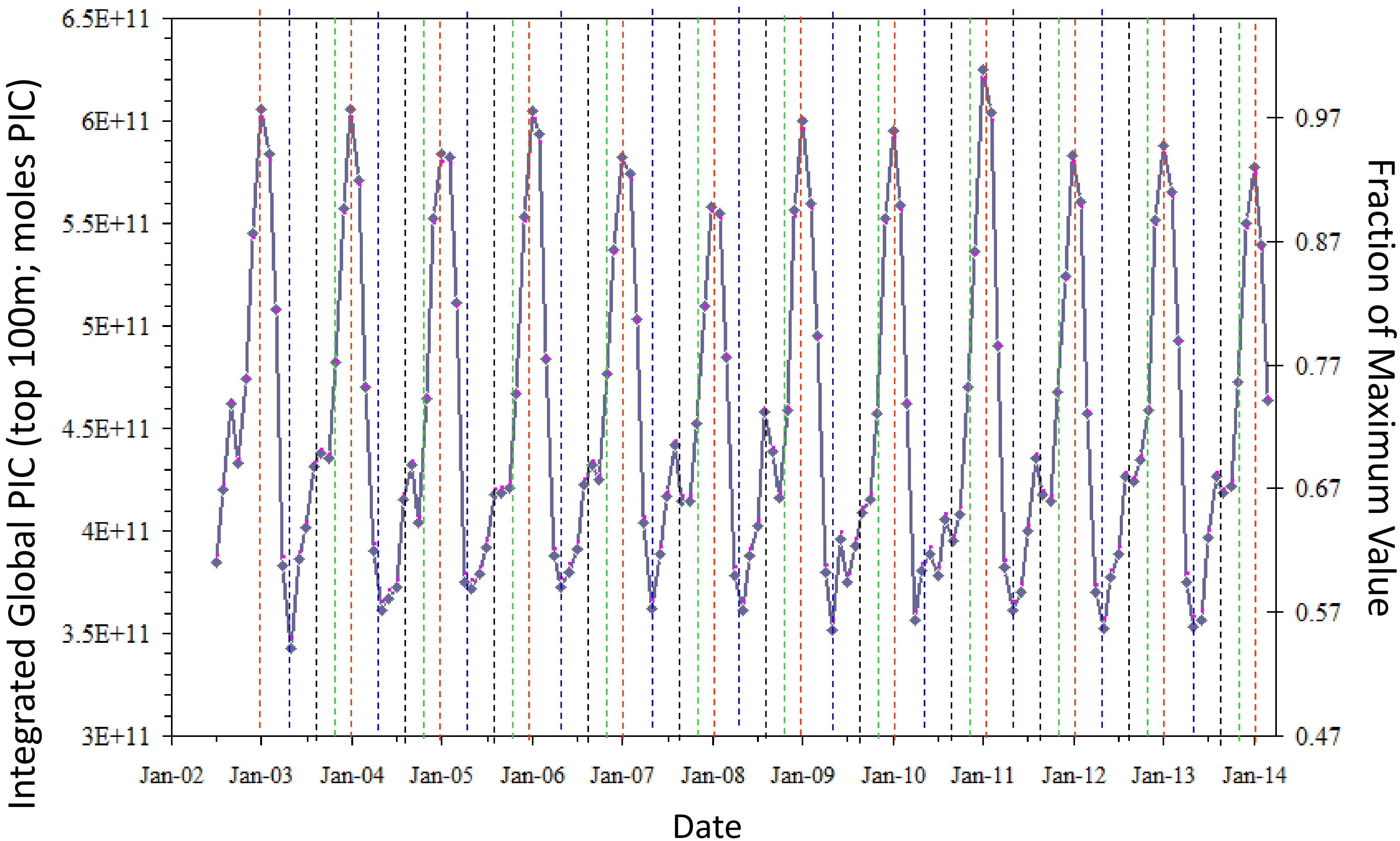
Biogeochemistry, global trends

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

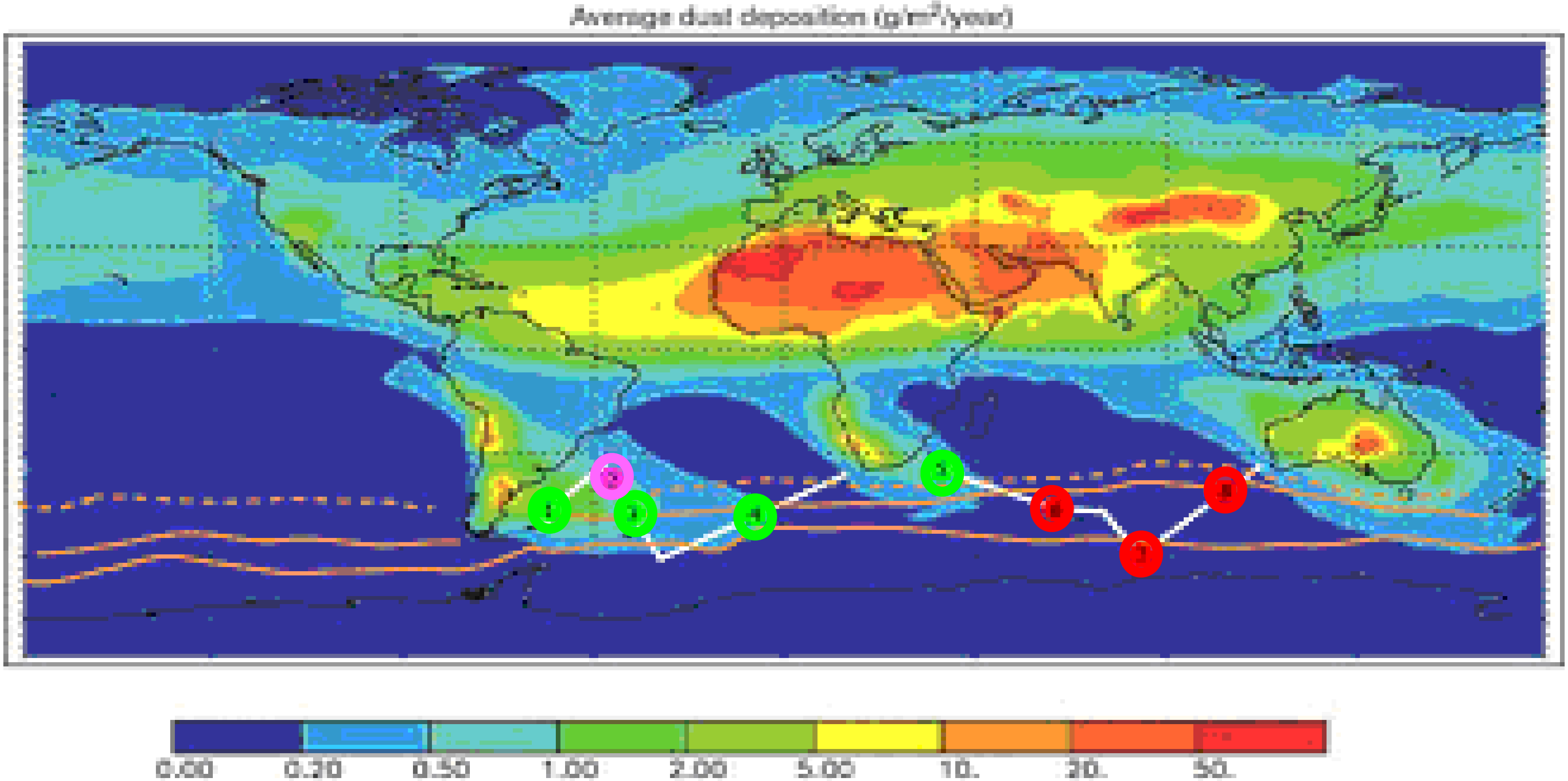


Austral summer
Austral Fall
Austral Winter
Austral Spring

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



Possible role of dust and metal limitation of phytoplankton…



=neither Zn, Fe or Co limited

= iron limited

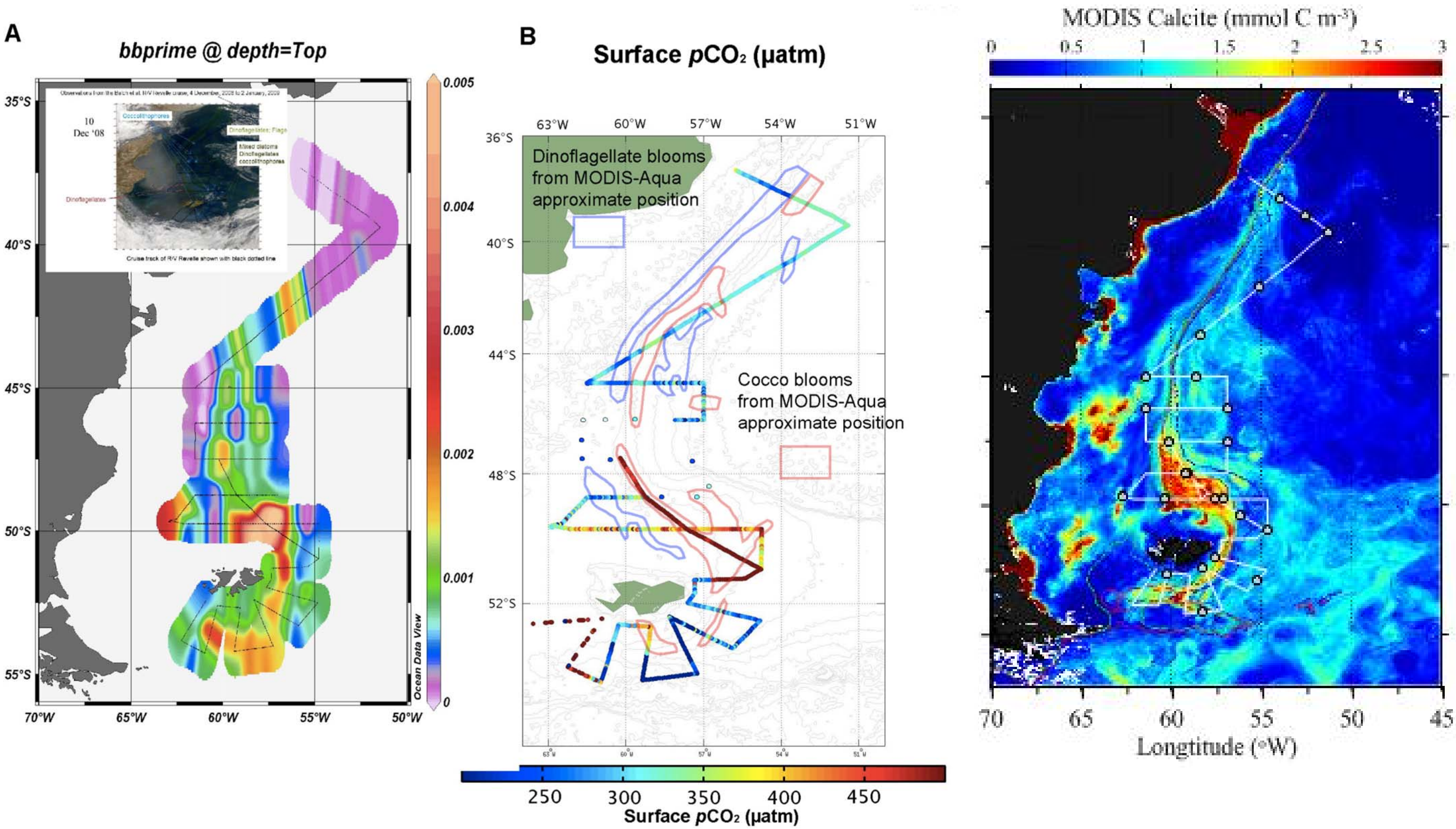
= Zn limited

Dust distribution of Jickells et al, 2005

Ben Twining, Bigelow Laboratory

Southern Ocean and *Great Belt* pCO_2

N. Bates, Bermuda Inst. Of Ocean Sciences

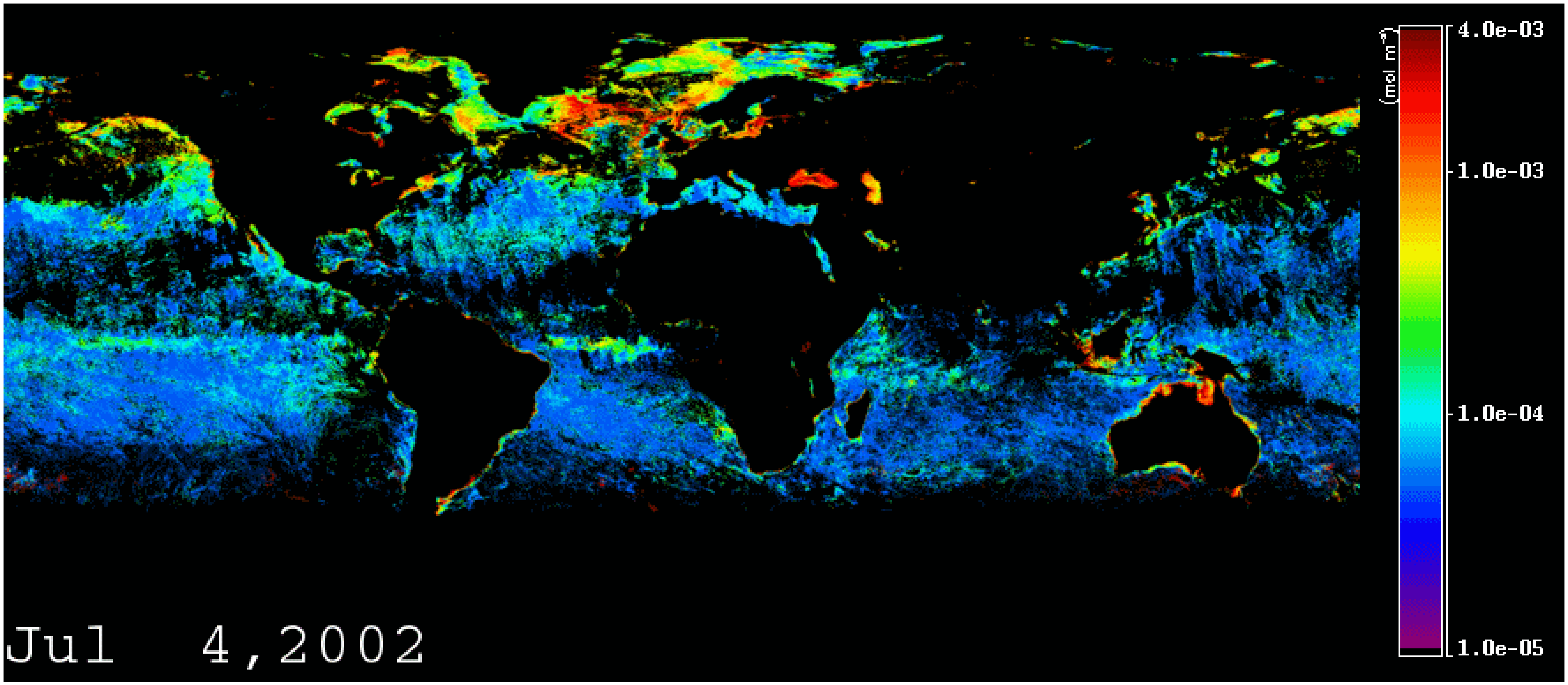


High surface pCO_2 in the region of high bb' and PIC biomass

Summary- Biogeochemistry of coccolithophore blooms…

- Highest coccolithophore density regions of GCB show enhanced pCO_2 (Iceland feature and GCB)
- Iceland and former GoM feature were real “blooms”
- Satellite-derived PIC estimates show enhancement near continents- possible role of dust/iron?
- Trace-metal limitation in GCB appears greatest in Indian Sector- consistent with dust deposition mechanism. Iron limitation also in N. Atlantic (Nielsdóttir et al, Global Biogeo. Cycles, 2009)
- Elevated abundance associated with low (AMT) to moderate stability (GCB).

Thank you!



The seasonal cycle of PIC as measured by NASA MODIS Aqua