PIC Algorithms

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PIC=Particulate Inorganic Carbon (coccoliths, calcium carbonate)

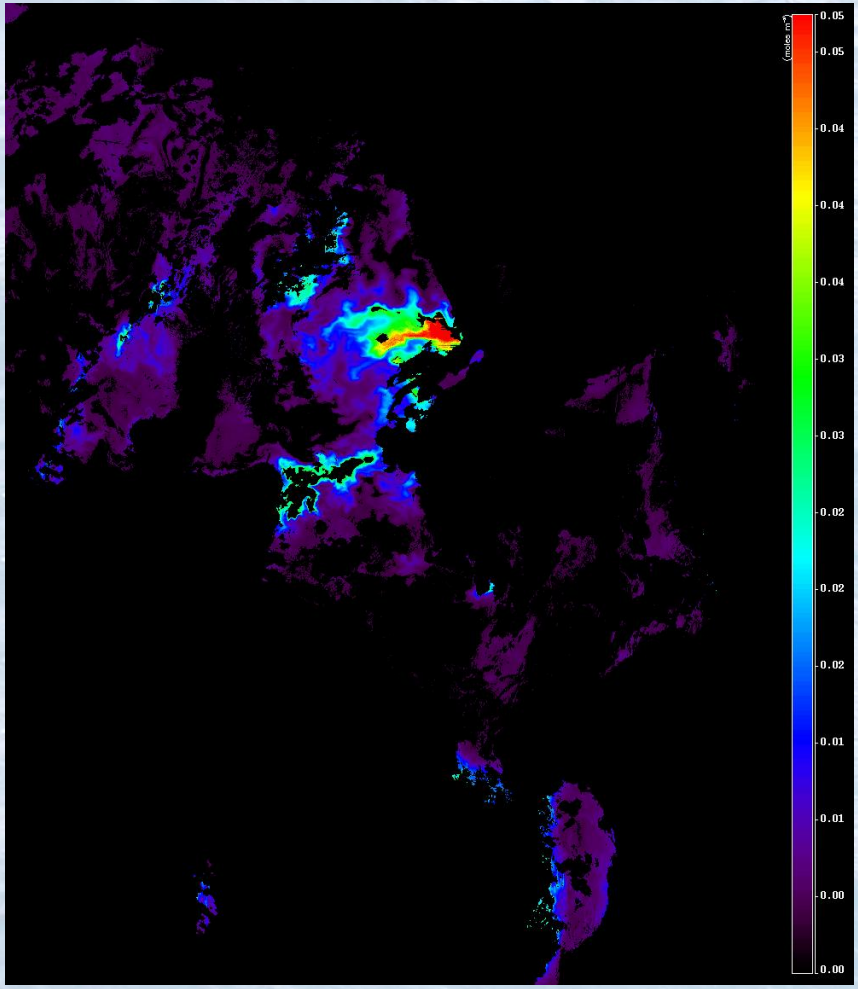
- Major biogeochemical significance
- They represent one of the larger radiometric signals in the blue ocean, available to ocean color sensors

Two PIC algorithms exist

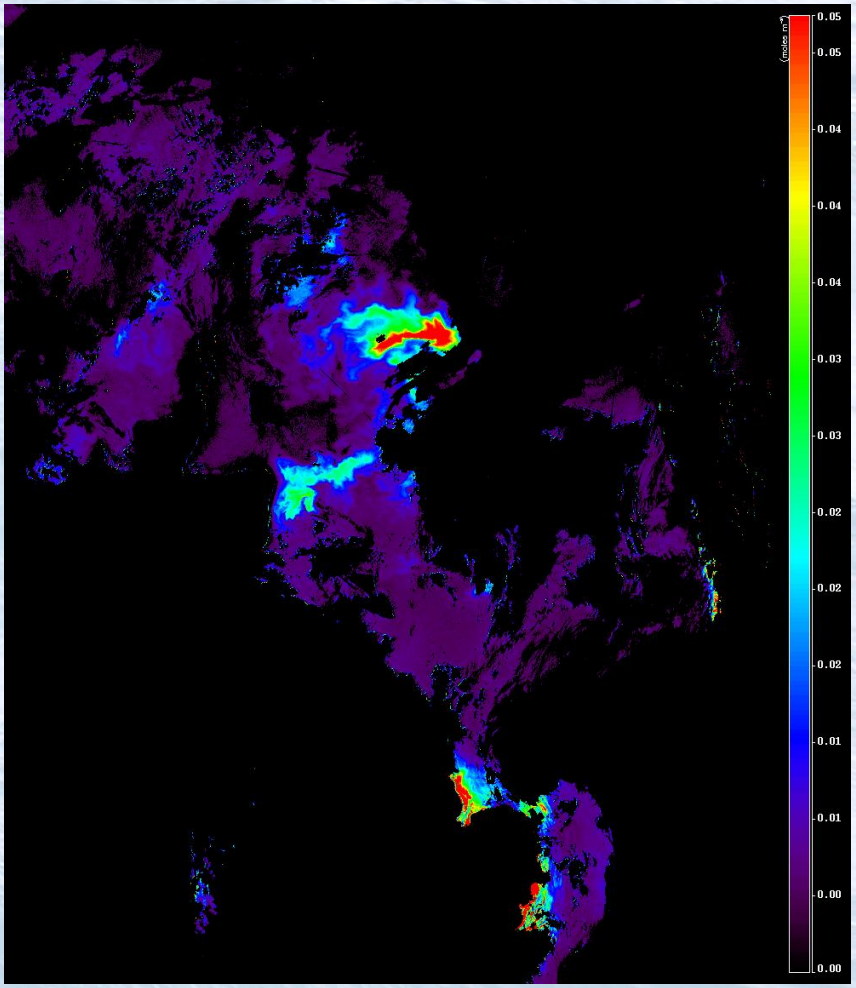
- Two band algorithm (based on nLw440 and nLw550) Citation: Balch et al. 2005 Calcium Carbonate Measurements in the Surface Global Ocean based on MODIS Data. In press *JGR-Oceans*)

- 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, 2001.)

2 Band



3 Band

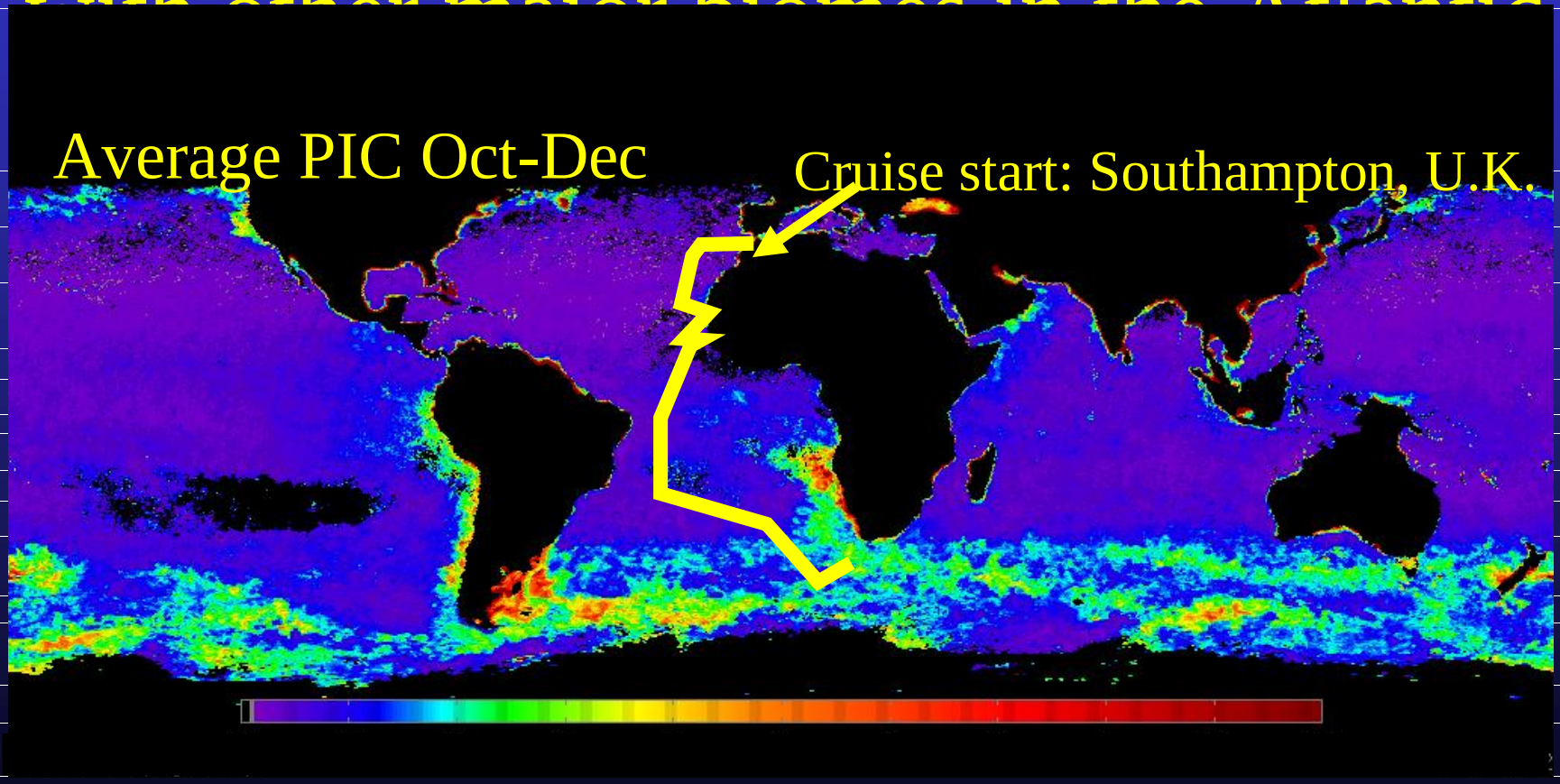


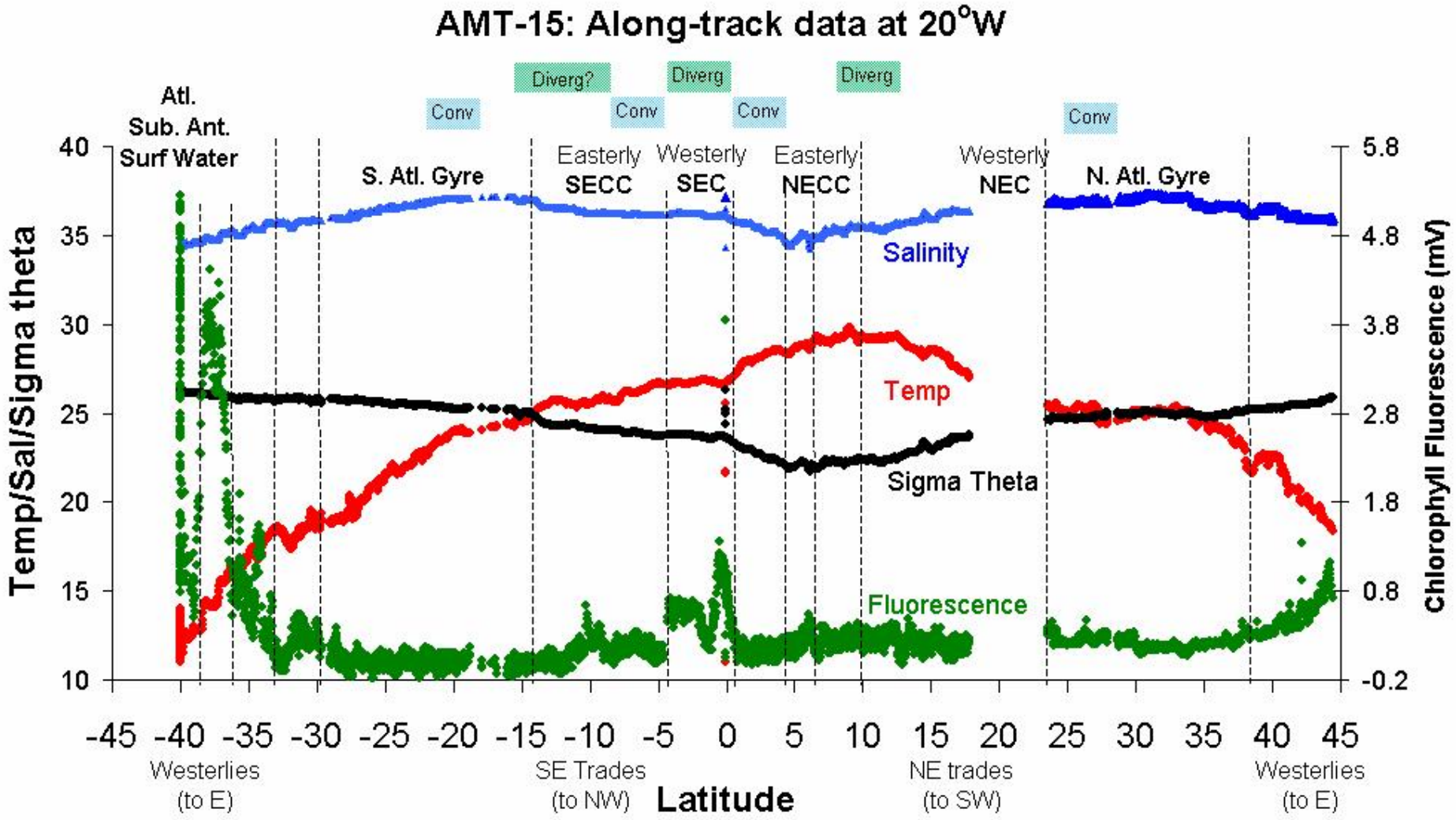
SeaWiFS scene S2003147125430 of a coccolithophore bloom in the North Sea on May 27 2003. Comparison between 2-band PIC algorithm and 3-band PIC algorithm. Color scales range from 0-0.05 moles PIC m-3. Images by Sean Bailey and Brian Franz.

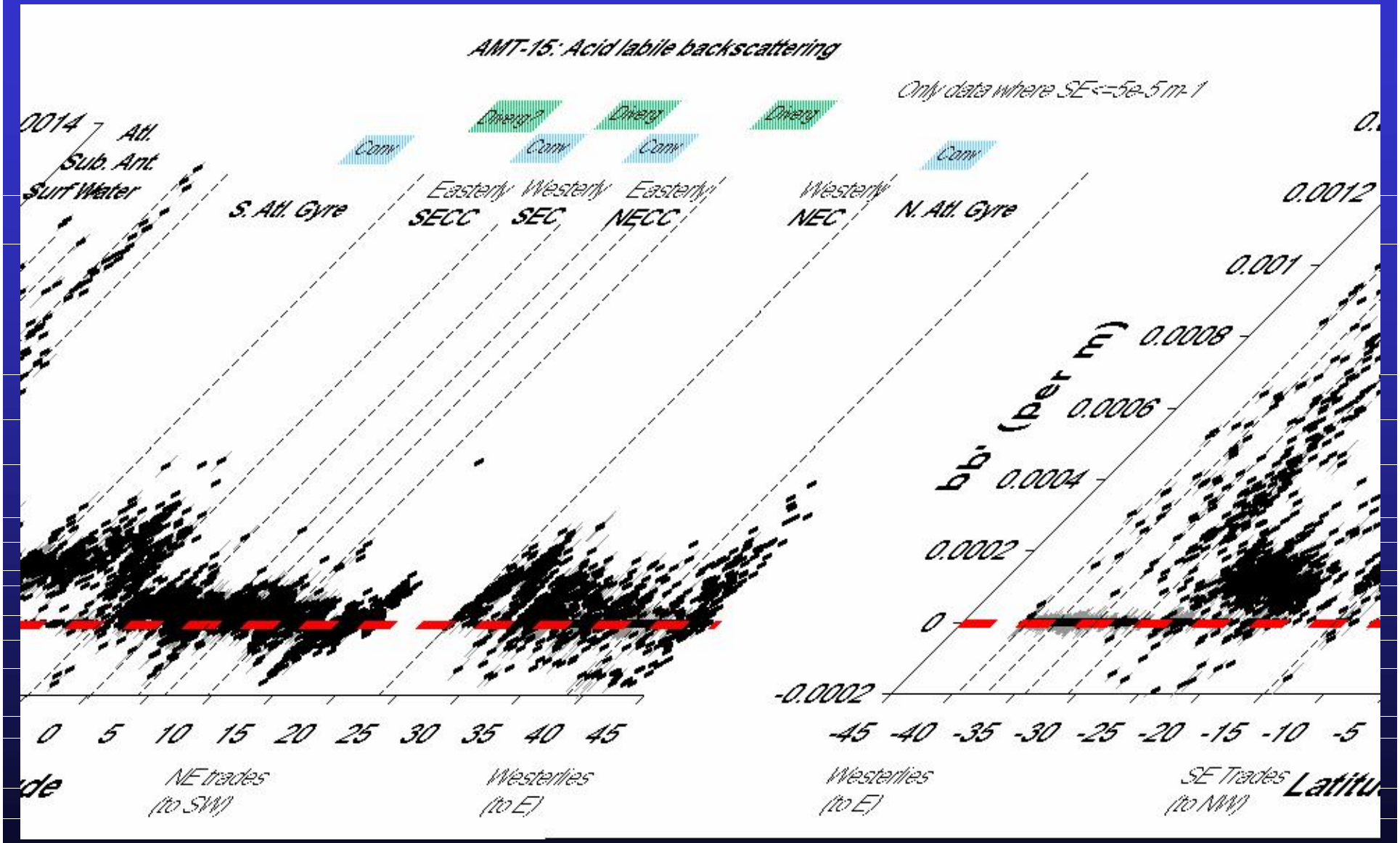
A geographically-large ship-satellite data set is needed with which to objectively compare the two PIC algorithms

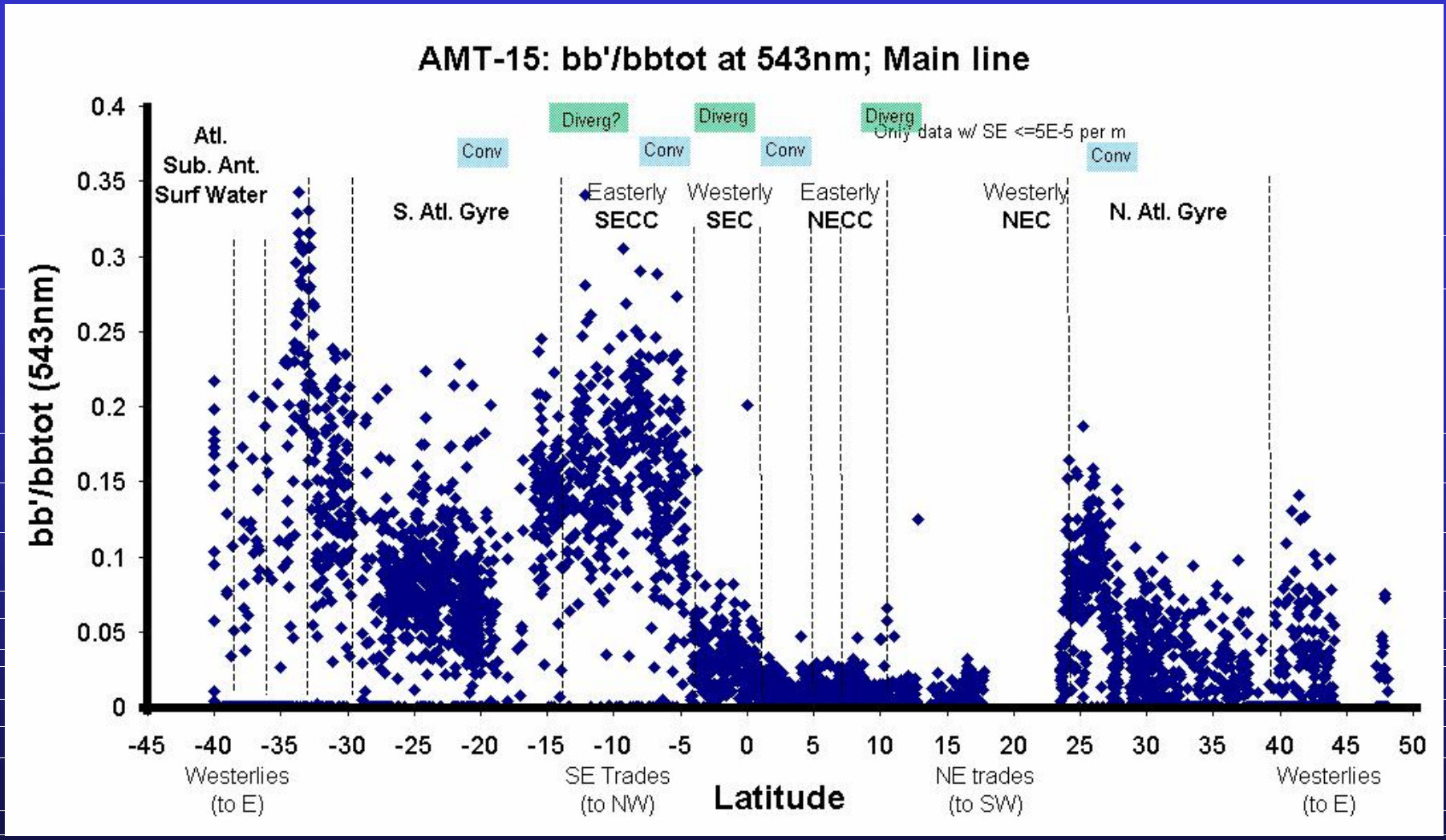
- We've been participating in U.K. AMT cruises between England and South Africa to collect data for PIC, biogenic silica, POC, chlorophyll plus underway IOP's (a, c, b_b) and AOP's (above-water radiometry).
- We continue to collect these data associated with the Gulf of Maine ferry program aboard the M/S Scotia Prince.
- We also participated in an equatorial Pacific cruise from December '04- January '05.

Bands of high PIC near sub-antarctic front have been observed by MODIS. AMT-15 provided us the means to sample it (along with other major biomes in the Atlantic

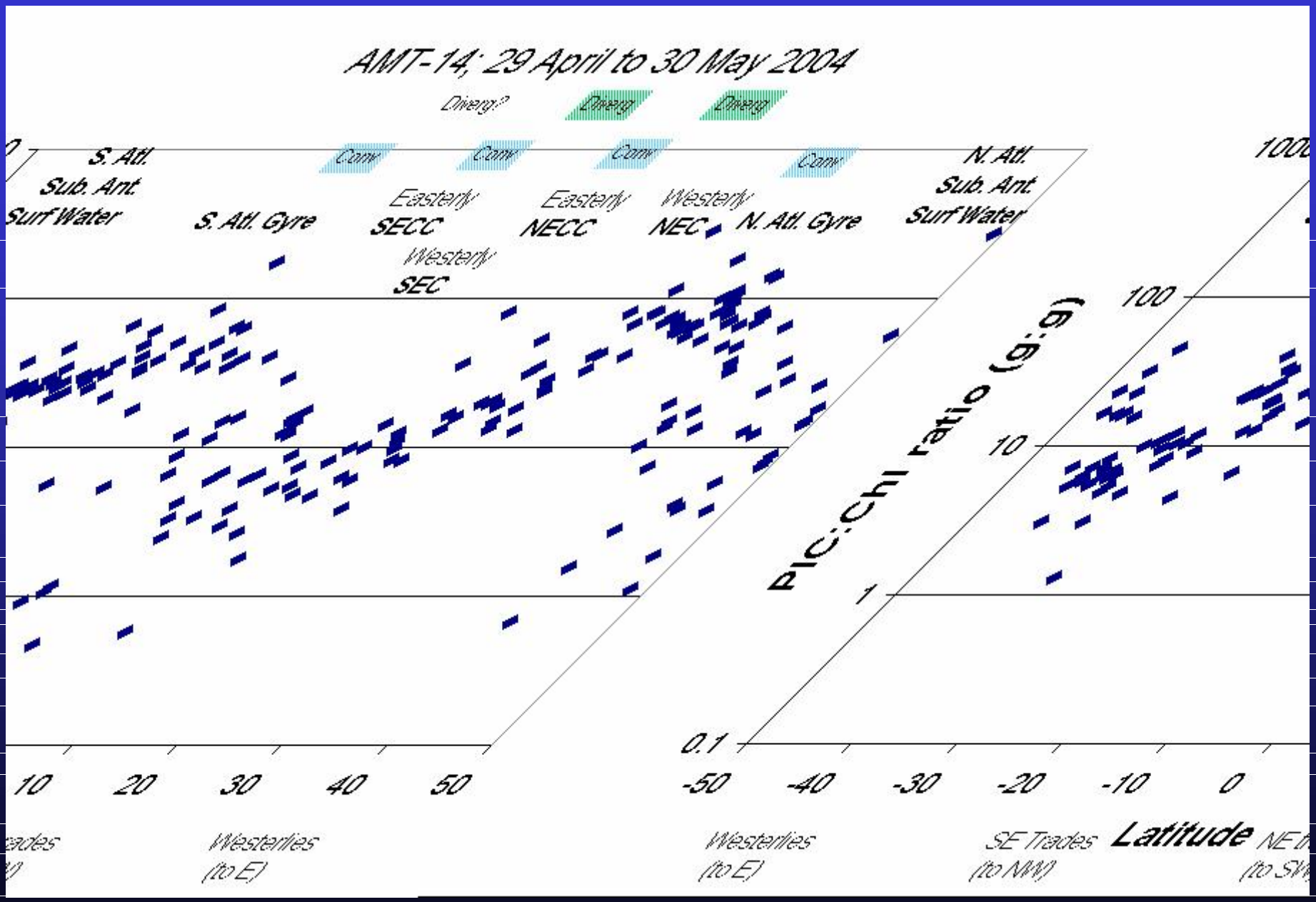



AMT-15: Along-track data at 20°W
Atl.
Sub. Ant.
Surf Water
S. Atl. Gyre
Conv
Diverg?
Conv
Diverg
Conv
Diverg
Conv
Easterly
SECC
Westerly
SEC
Easterly
NECC
Westerly
NEC
N. Atl. Gyre
Salinity
Temp
Sigma Theta
Fluorescence
Temp/Sal/Sigma theta
Chlorophyll Fluorescence (mV)
40
35
30
25
20
15
10
5.8
4.8
3.8
2.8
1.8
0.8
-0.2
-45 -40 -35 -30 -25 -20 -15 -10 -5 0 5 10 15 20 25 30 35 40 45
Westerlies
(to E)
SE Trades
(to NW)
Latitude
NE trades
(to SW)
Westerlies
(to E)


AMT-15: Acid labile backscattering
Only data where bbp<=5e-5 m-1
0014
Atl.
Sub. Ant.
Surf Water
S. Atl. Gyre
Eastern
SECC
Western
SEC
Eastern
NECC
Western
NEC
N. Atl. Gyre
Conv
Divg
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
-0.0002
0 5 10 15 20 25 30 35 40 45
-45 -40 -35 -30 -25 -20 -15 -10 -5
NE trades
(to SW)
Westerlies
(to E)
Westerlies
(to E)
SE Trades
(to NW)
Latitu

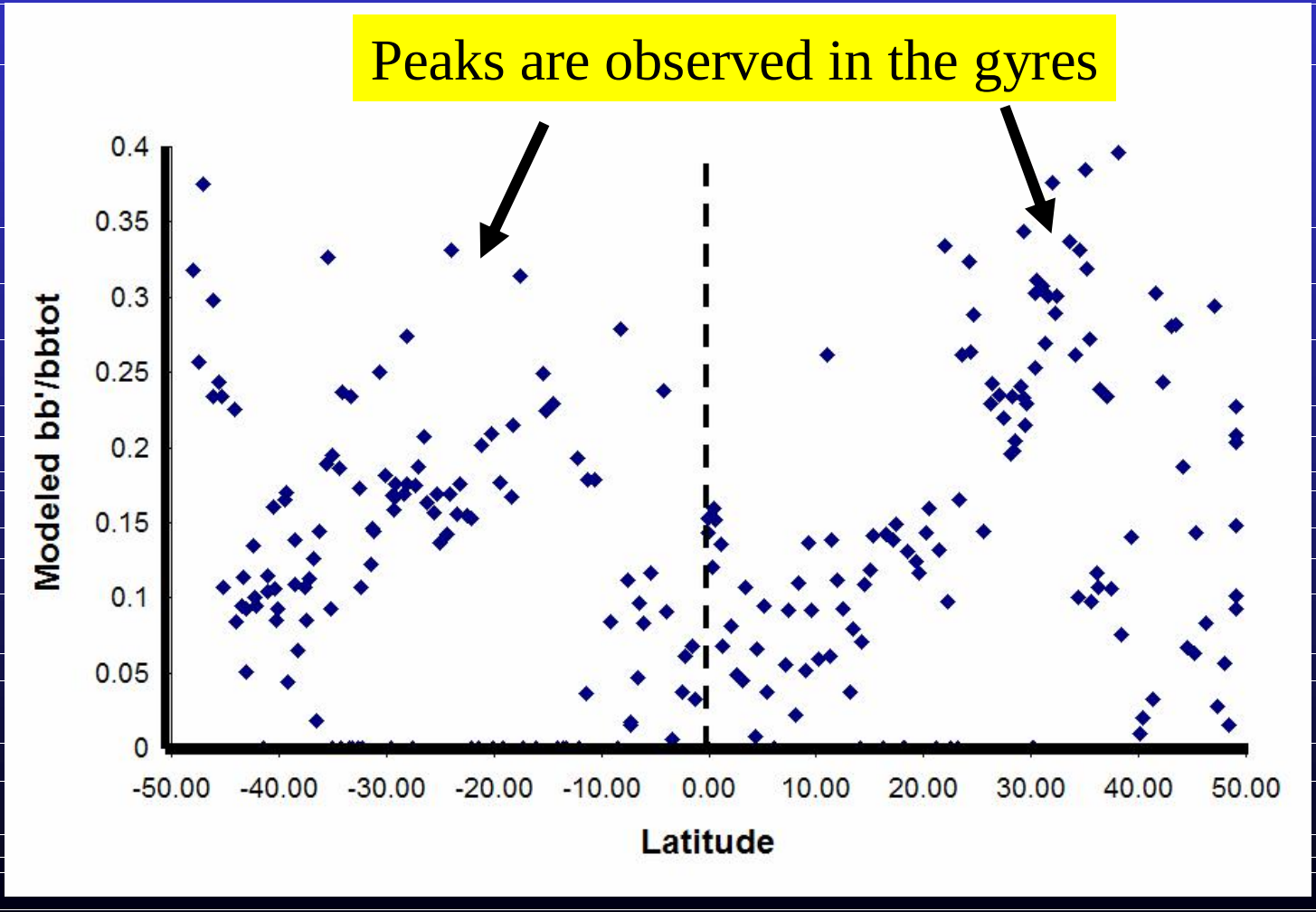


We are still processing the discrete PIC samples
from AMT-15 to absolutely verify that these peaks were calcite…


AMT-14; 29 April to 30 May 2004
Diverg.?
Diverg.
Diverg.
Conv.
Conv.
Conv.
Conv.
S. Atl.
Sub. Ant.
Surf Water
S. Atl. Gyre
Easterly
SECC
Westerly
SEC
Easterly
NECC
Westerly
NEC
N. Atl. Gyre
N. Atl.
Sub. Ant.
Surf Water
Chl a (mg m-3)
1000
100
10
1
0.1
10
20
30
40
50
-50
-40
-30
-20
-10
0
Latitude
Westerlies
(to E)
Westerlies
(to E)
SE Trades
(to NW)

Consistency of AMT-14 and AMT-15 results:

Using b_b*(546) for calcite, silica, phytoplankton POC (via chl) plus b_{bw}(546), what values of b_b'/$b_{b\ tot}$ would we expect?

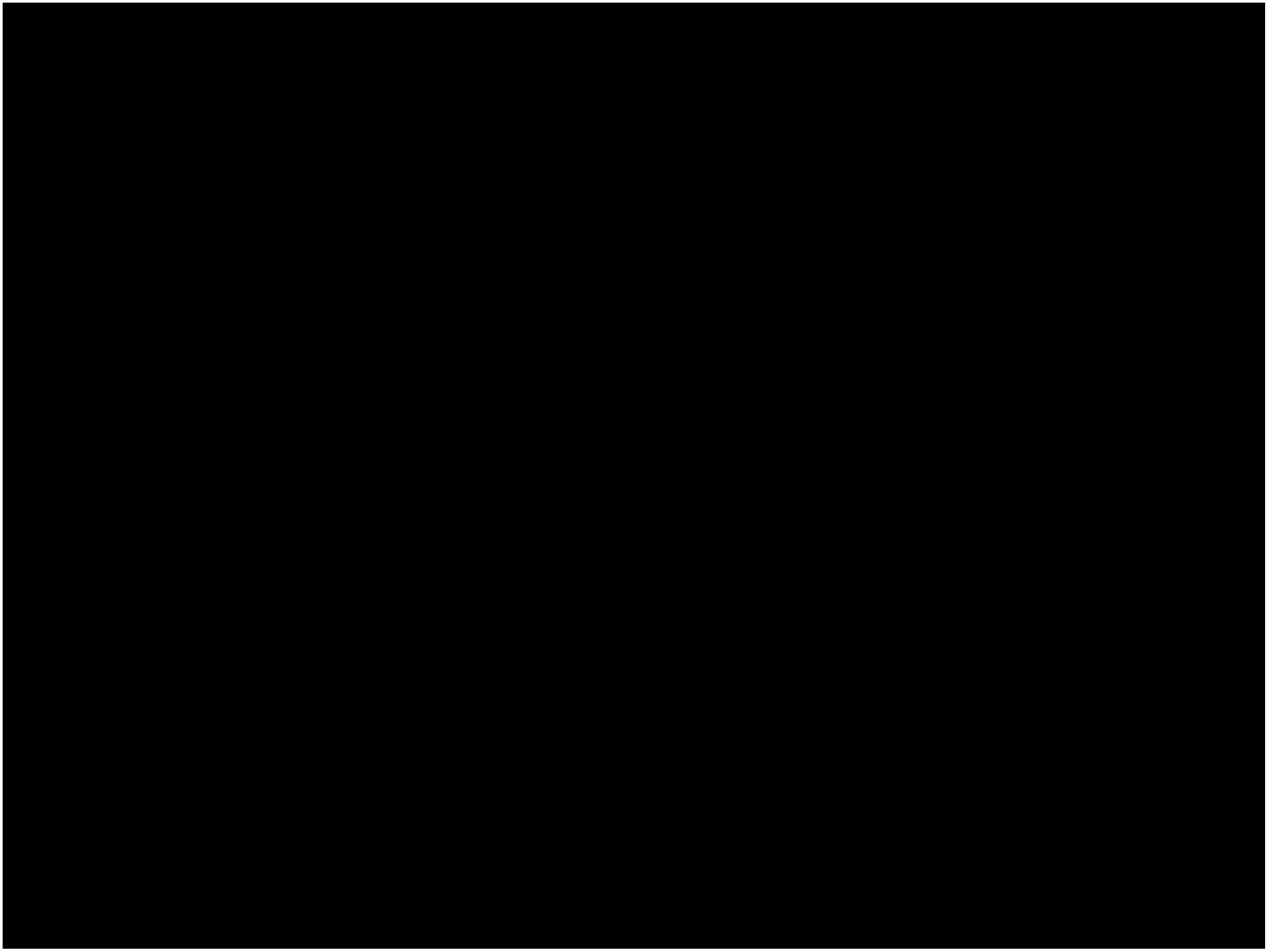


Summary-our focus is on major field campaigns to collect globally-significant data sets for comparison of two PIC algorithms

- Both algorithm descriptions now published
- AMT-14 discrete samples now processed. They show high PIC/Chl ratios in both Atlantic subtropical gyres.
- Discrete, and along-track IOP and AOP data still being processed for AMT 15 (ended Nov'04). These suggest relatively high calcite scattering in gyres. Heretofore not appreciated.
- Results consistent with AMT-14 expected $b_b'/b_{b\ tot}$ estimates

Summary (continued)

- Also collecting samples from other regions such as Gulf of Maine ferry and two equatorial Pacific cruises between 110^{o}W and 140^{o}W
- Preparing for AMT-16, which departs mid May ’05 and AMT-17 which departs mid September ’05
- Future algorithm improvements: Need geographically-diverse estimates of the average calcite per coccolith for central ocean coccolithophores
- Need to check assumptions on wavelength dependence of calcite in the NIR (accumulating evidence that the power law is a poor approximation of $b_b(\lambda)$.



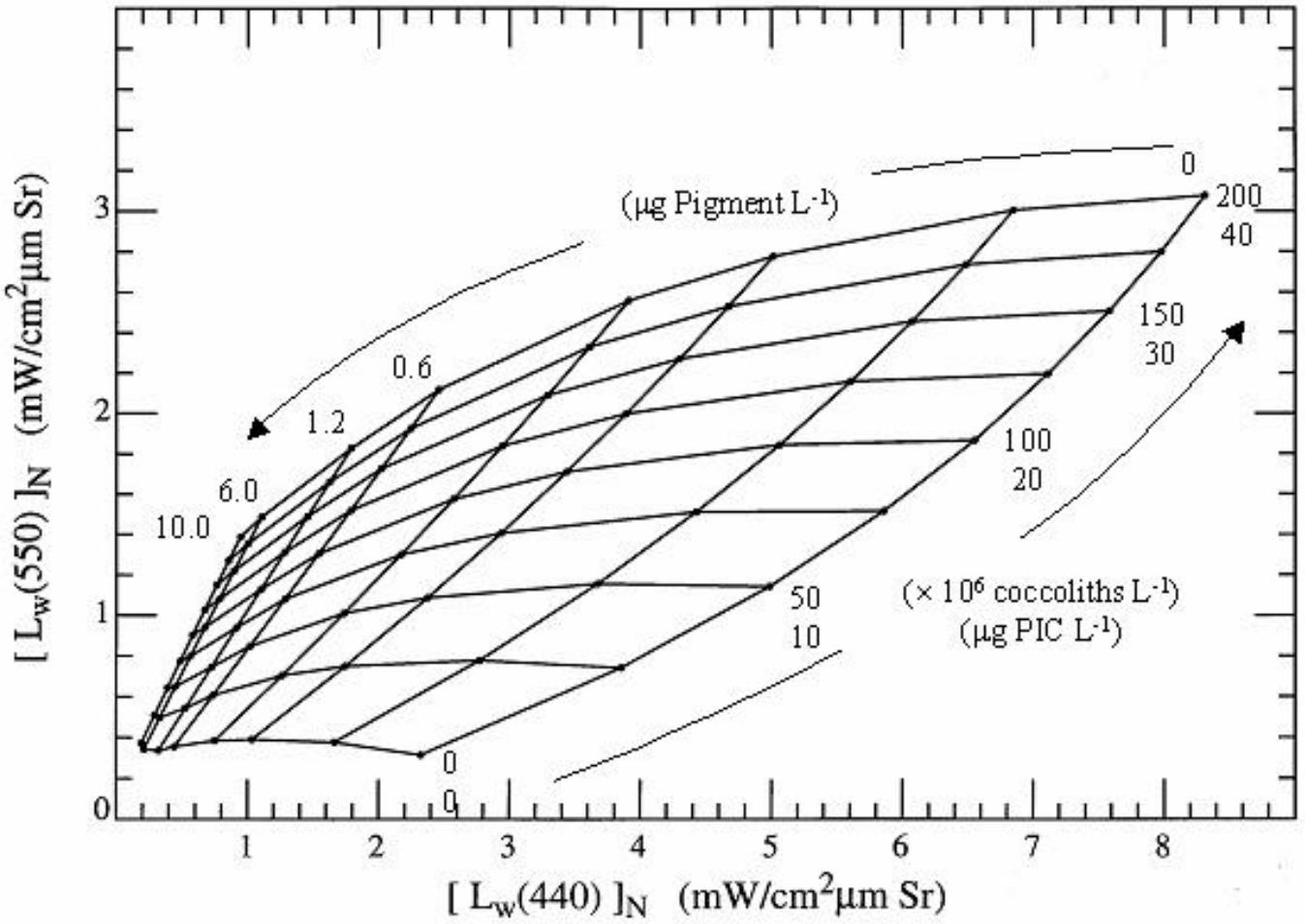
Two-band algorithm

- Based on Gordon et al. (1988) and dependence of water-leaving radiance on concentration of various constituents in Case 1 waters
- nLw related to a and b_b of the phytoplankton and associated detritus.
- Introduce coccoliths and coccolithophores by including their contribution to backscattering
- Iteratively solves for chlorophyll and calcite concentration, first using a standard ratio algorithm (to estimate chlorophyll) then absolute nLw's to estimate chlorophyll and PIC, iterating again with the ratio algorithm, etc.

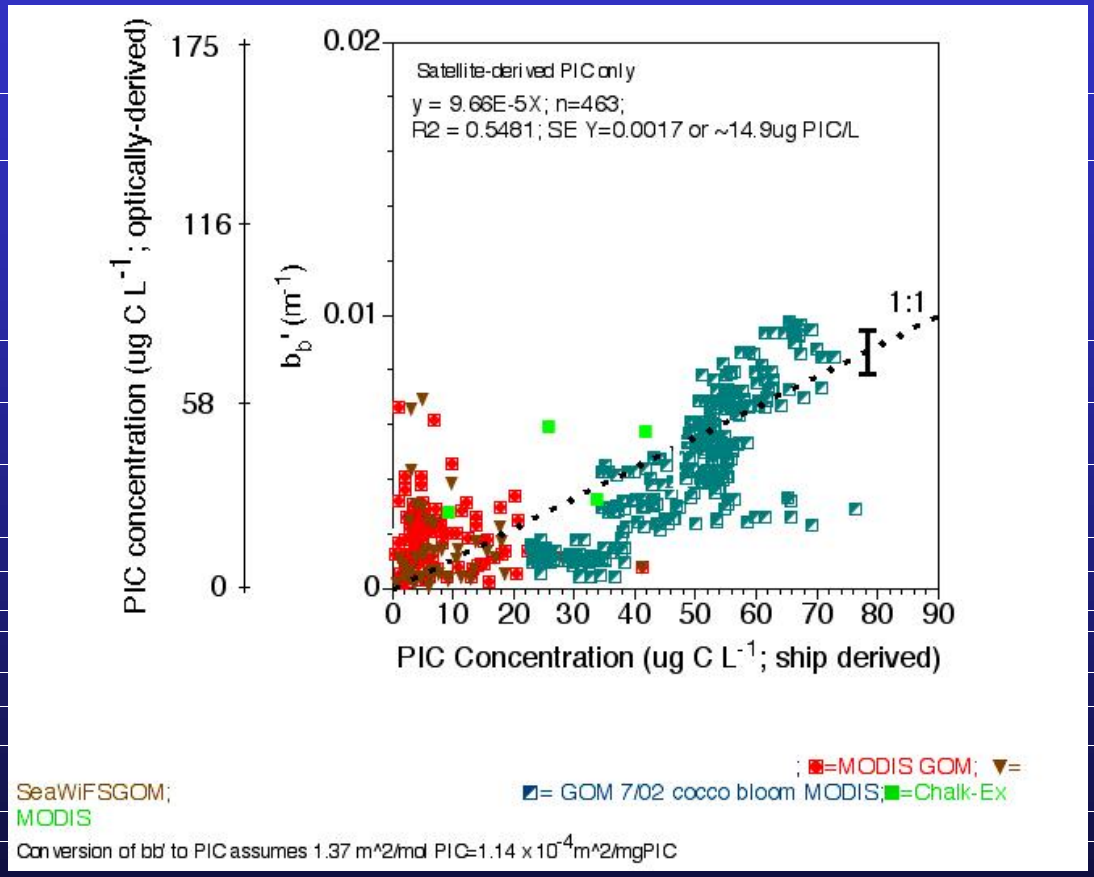
Pros and Cons of the 2-band algorithm

- **Pros**
  - Provides quantitative estimate of chlorophyll and PIC in waters where pigment retrievals have traditionally been problematic
- **Cons**
  - Two bands are in spectral regions influenced by chlorophyll and cDOM.
  - Atmospheric correction within these bands is significant, especially for absolute nLw.
  - Potential confusion from other suspended minerals?

Two-band look-up table



Ship-Satellite Comparisons with 2-band algorithm



Using 1km daily data, the RMS error is ~14.9ug C L^{-1}

Using 4km, 8d data, the RMS error is 1.2 ug C L^{-1}

3-Band Algorithm

- Basically, with three bands and knowledge of the spectral dependence of coccolith backscattering, the algorithm estimates three unknowns:
  a) $b_{b\,546}$
  b) $_{A}$ -spectral reflectance contribution from scattering by aerosols in absence of air but including Rayleigh aerosol interactions
  c)“a” -constant used in the estimate of $_{A}$

3-Band Algorithm

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

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

- 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

Pros and Cons of the 3-band algorithm

- **Pros**
  - Absorption coefficient of water is so high in red and near IR that added phytoplankton and cDOM absorption is negligible.
  - Bands less likely to saturate
  - Less extrapolation for atmospheric correction
- **Cons**
  - Assumption of background b_b
  - Presumably affected by other suspended minerals like biogenic silica