

Coccolith-Calcite Concentration Validation
and Status... Understanding the error limits of
the two-band MODIS PIC algorithm

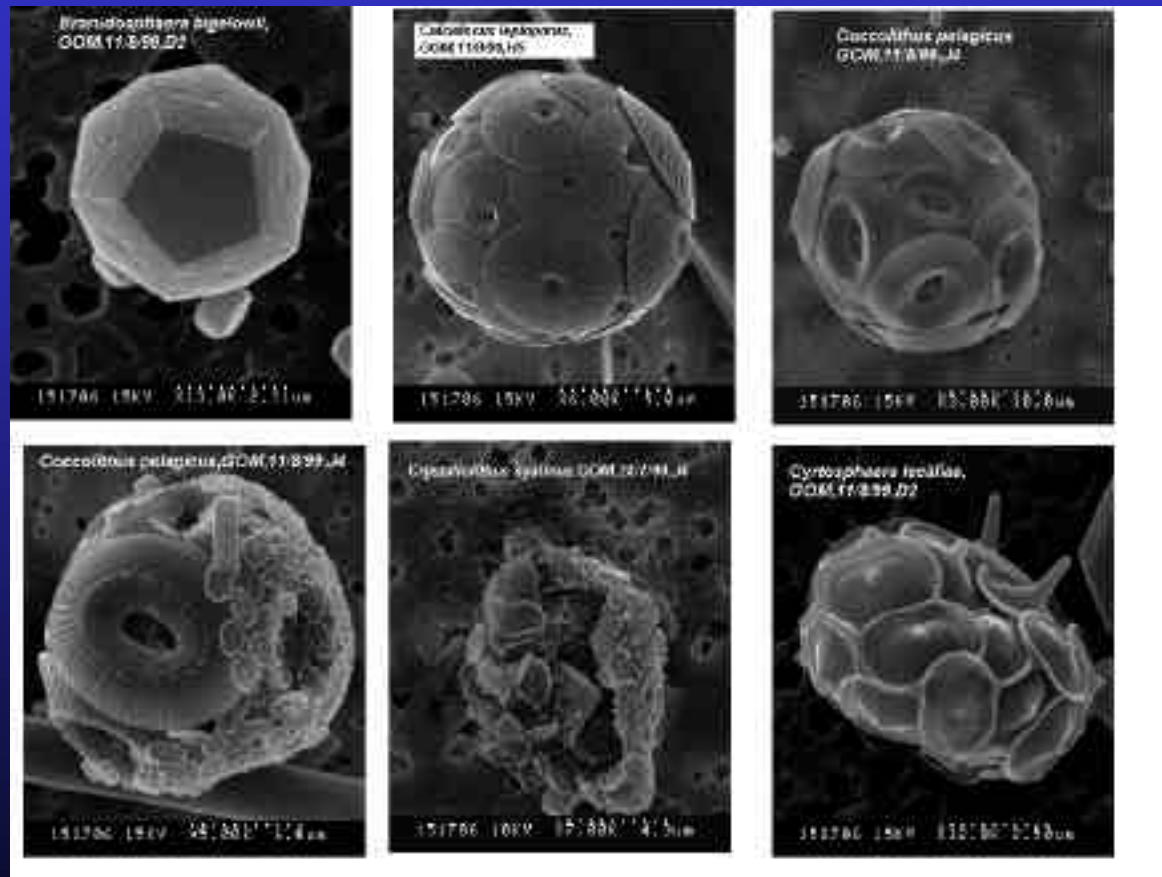
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Drapeau, Emily Booth, Joaquim Goes
Bigelow Laboratory for Ocean Sciences
W. Boothbay Harbor, ME

Howard Gordon and Katherine Kilpatrick
University of Miami, Miami, FL

Road Map

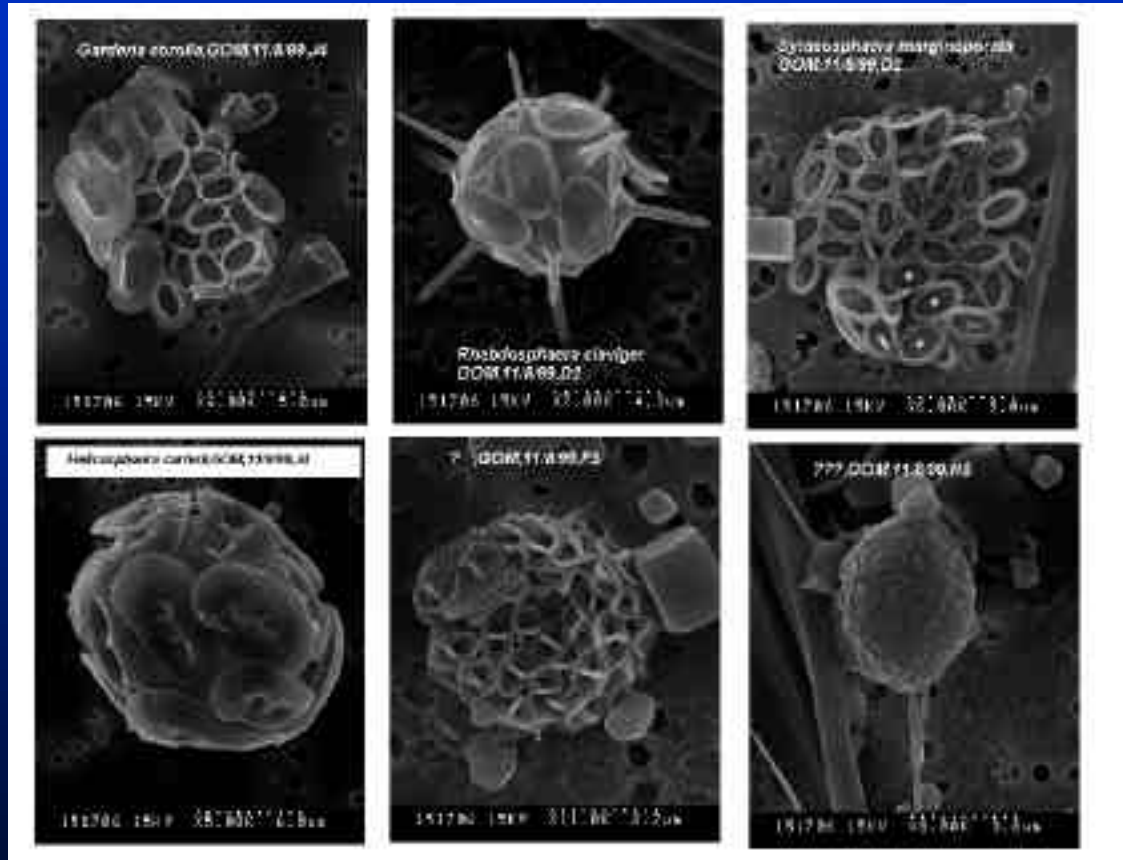
- What are coccoliths and coccolithophores?
- MODIS Products
 - Detached coccolith concentration [#21]
 - Particulate Inorganic Carbon (PIC) [#22]
 - Pigment concentration in coccolithophore blooms [#20]
- Basis of the Gordon two-band PIC algorithm
- Best-case scenario- ship measurements of PIC and backscattering
- Satellite validation of the PIC algorithm

Sources of scattering- various species of coccolithophores



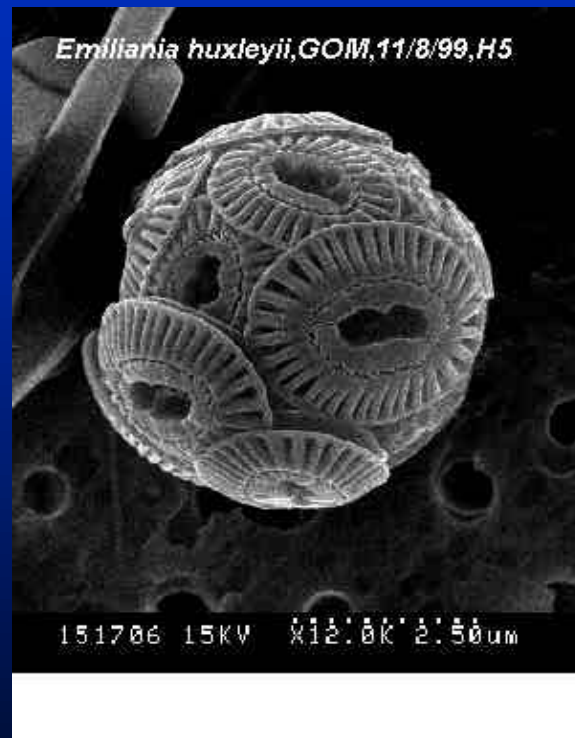
SEM's courtesy of Dr. Delors Blasco, Institute de Ciencias del Mar, Barcelona, Spain

Sources of scattering- various species of coccolithophores



SEM's courtesy of Dr. Delors Blasco, Institute de Ciències del Mar, Barcelona, Spain, 08039

Even *Emiliana huxleyi* has varieties with different shaped coccoliths



SEM's courtesy of Dr. Delors Blasco, Institute de Ciencias del Mar, Barcelona, Spain, 08039

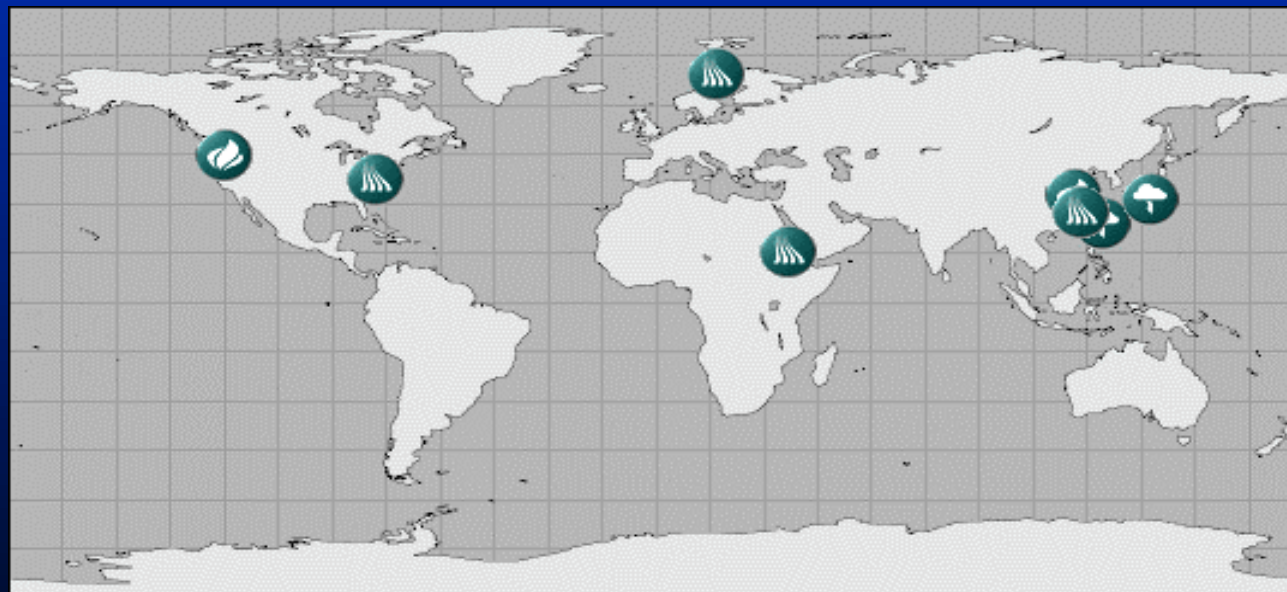
Coccolithophores appeared recently on NASA's Natural Hazards web site

earth observatory



home • data & images • features • news • reference • missions • experiments • search

NATURAL HAZARDS



 FIRES



Smoke from Canadian wildfires has crossed the Atlantic Ocean and arrived over the shores of Norway on July 12. See <http://earthobservatory.nasa.gov/NaturalHazards/>

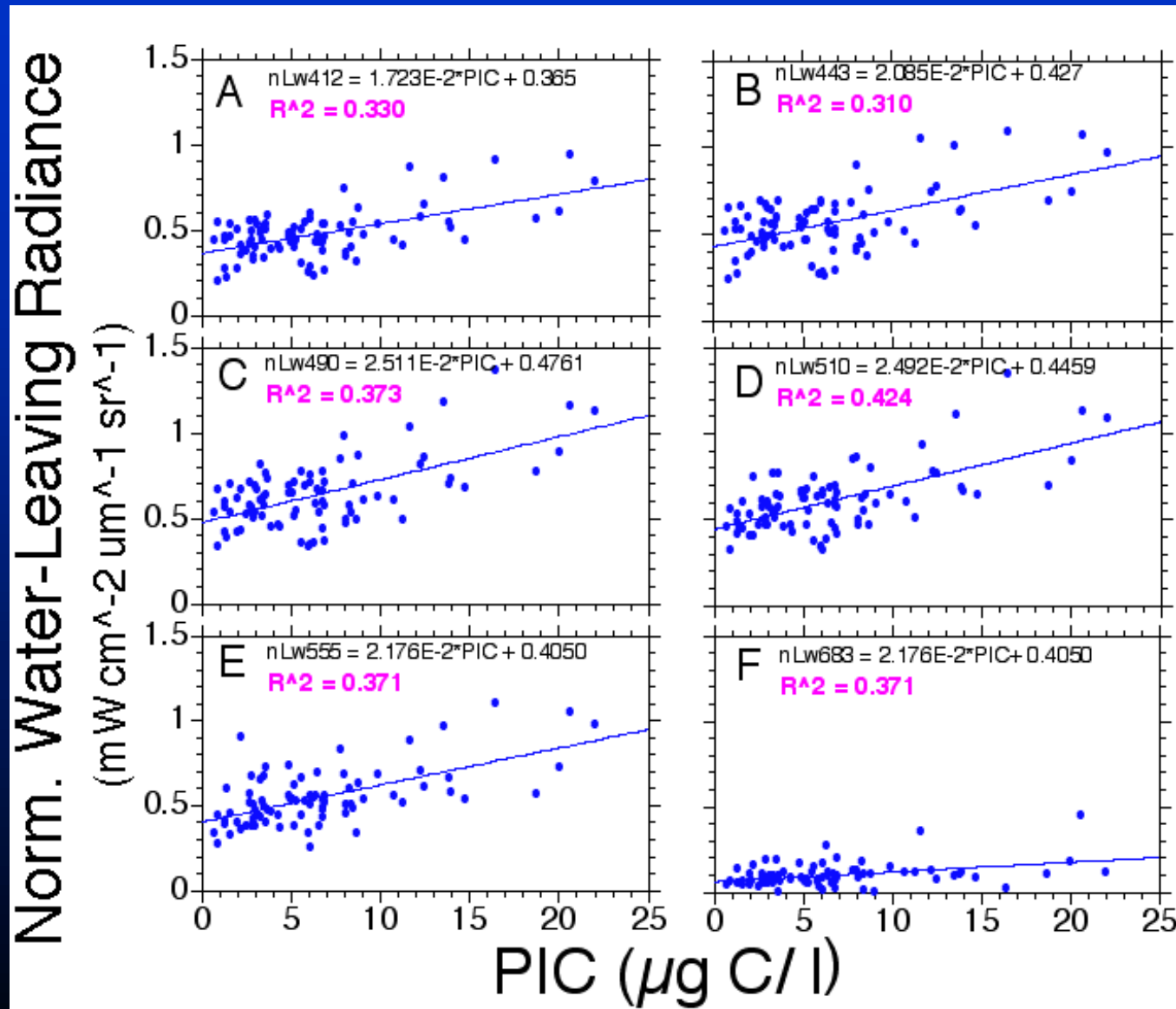
Canadian Smoke off Norway (plus coccolithophores)



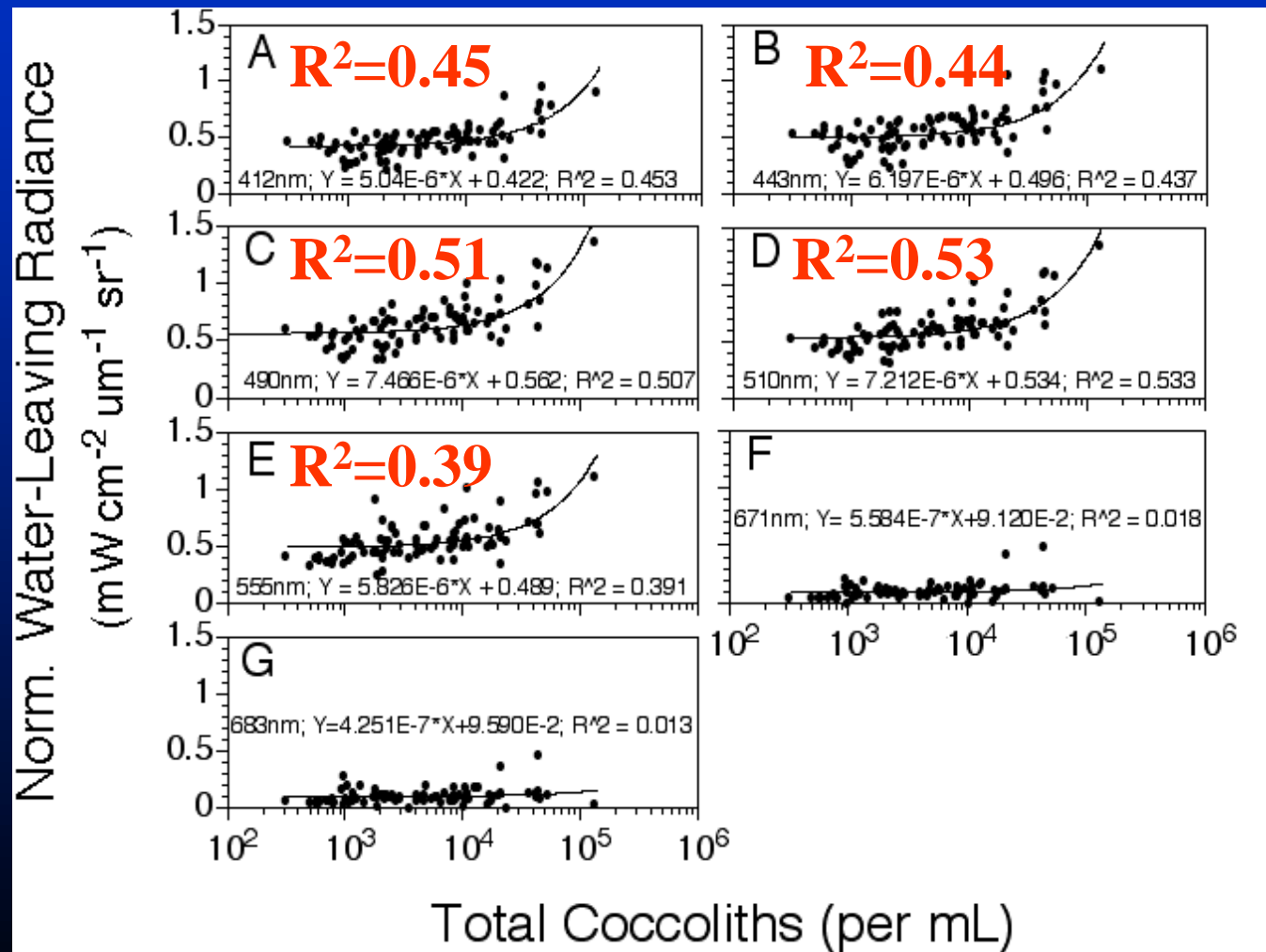
Smoke (greyish pixels) from the wildfires in Saskatchewan has crossed the Atlantic Ocean and arrived over the shores of Norway on July 12, 2002. The brighter, turquoise swirls in the otherwise dark waters of the Barents Sea indicate the presence of a large phytoplankton bloom. This true-color scene was acquired by the [Moderate Resolution Imaging Spectroradiometer](#), flying aboard NASA's [Terra](#) satellite.

Please note that the high-resolution scene provided here is 500 meters per pixel. For a copy of the scene at the sensor's fullest resolution, visit the [MODIS Rapid Response Image Gallery](#).
Image courtesy Jacques Descloitres, [MODIS Land Rapid Response Team](#) at [NASA GSFC](#)

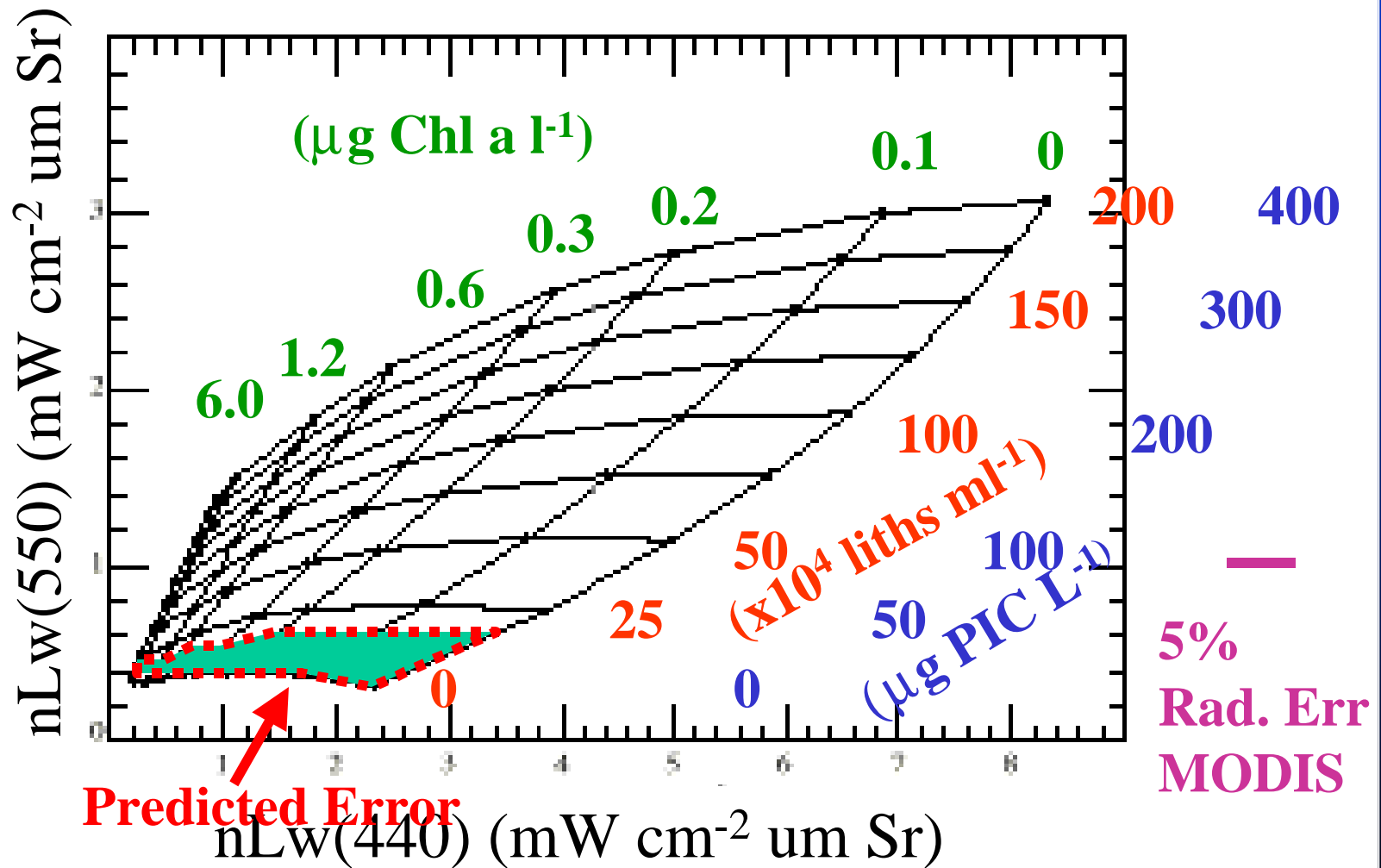
PIC can be a 1° determinant of nLw



Among all PIC, coccoliths likely play the major role in light scattering, especially at 412-550nm and when $>10,000 \text{ ml}^{-1}$.



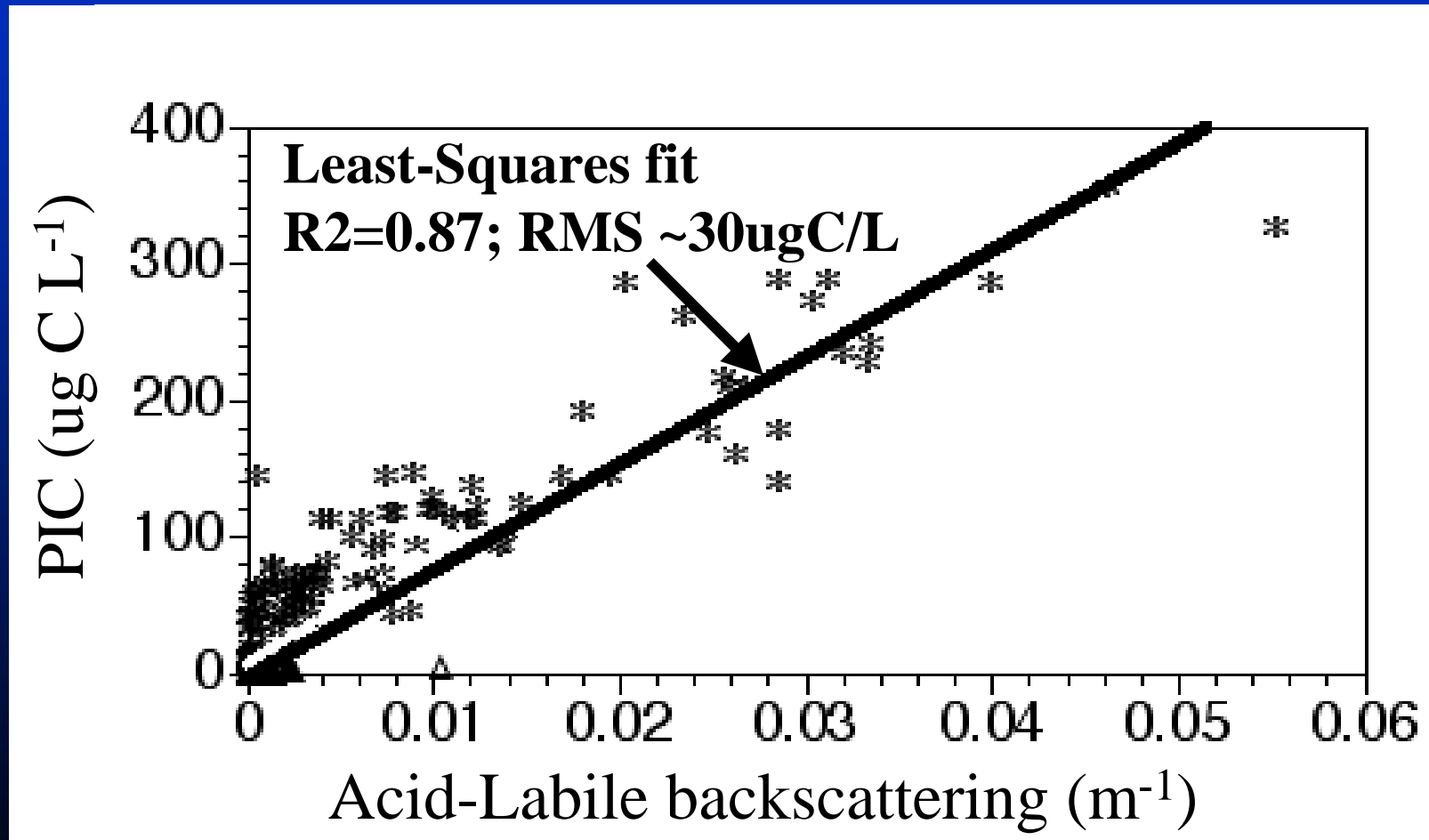
The 2-band PIC algorithm look-up table



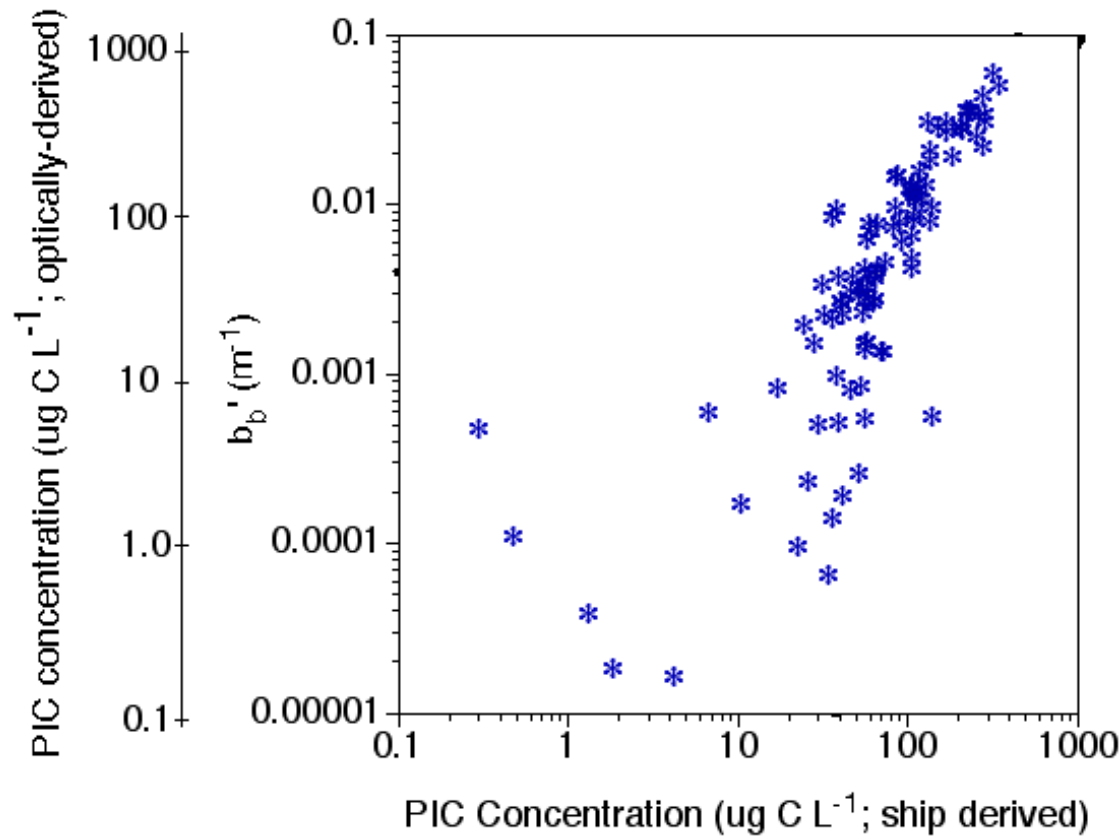
Measurements of CaCO_3 and b_b from ships

- Sources of error
- How much error can we expect?

Basis of the 2-band algorithm-
PIC vs bb relationship from the 1991 Iceland
coccolithophore bloom

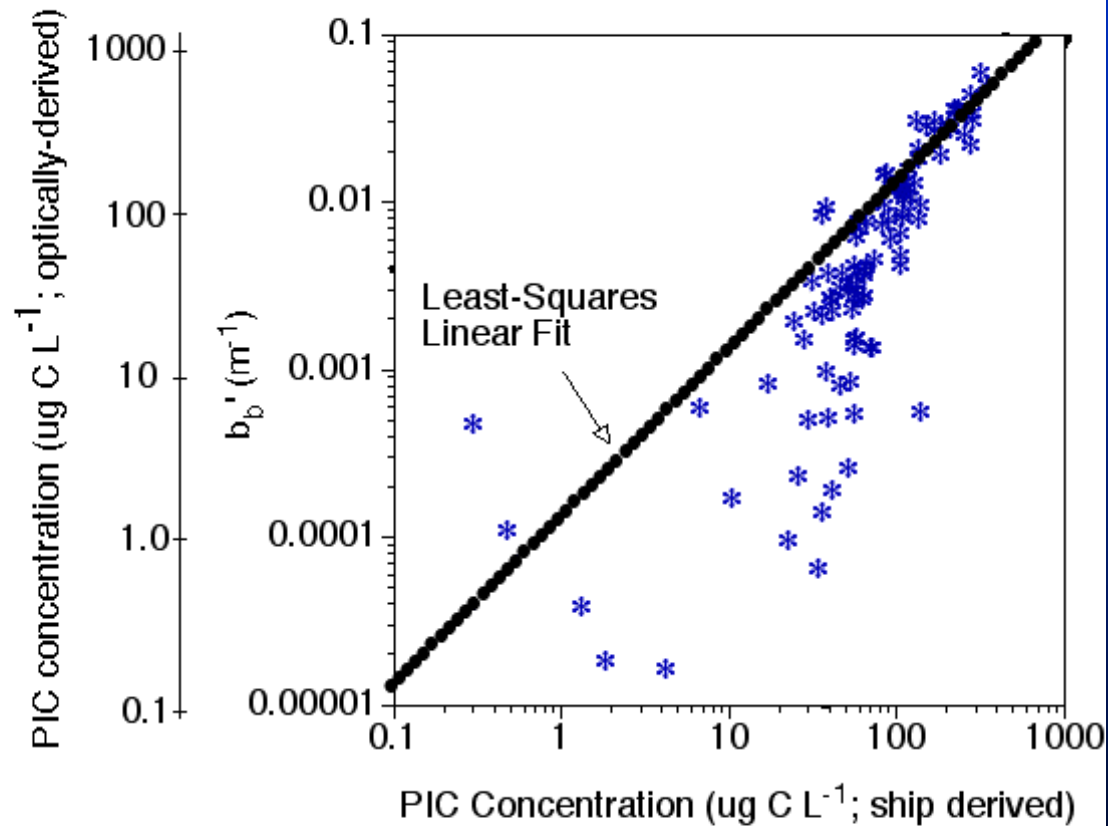


PIC vs bb relationship: the basis of the 2-band algorithm-1991 Iceland coccolithophore bloom



*=BOFS Cocco bloom '91;

PIC vs bb relationship: the basis of the 2-band algorithm-1991 Iceland coccolithophore bloom

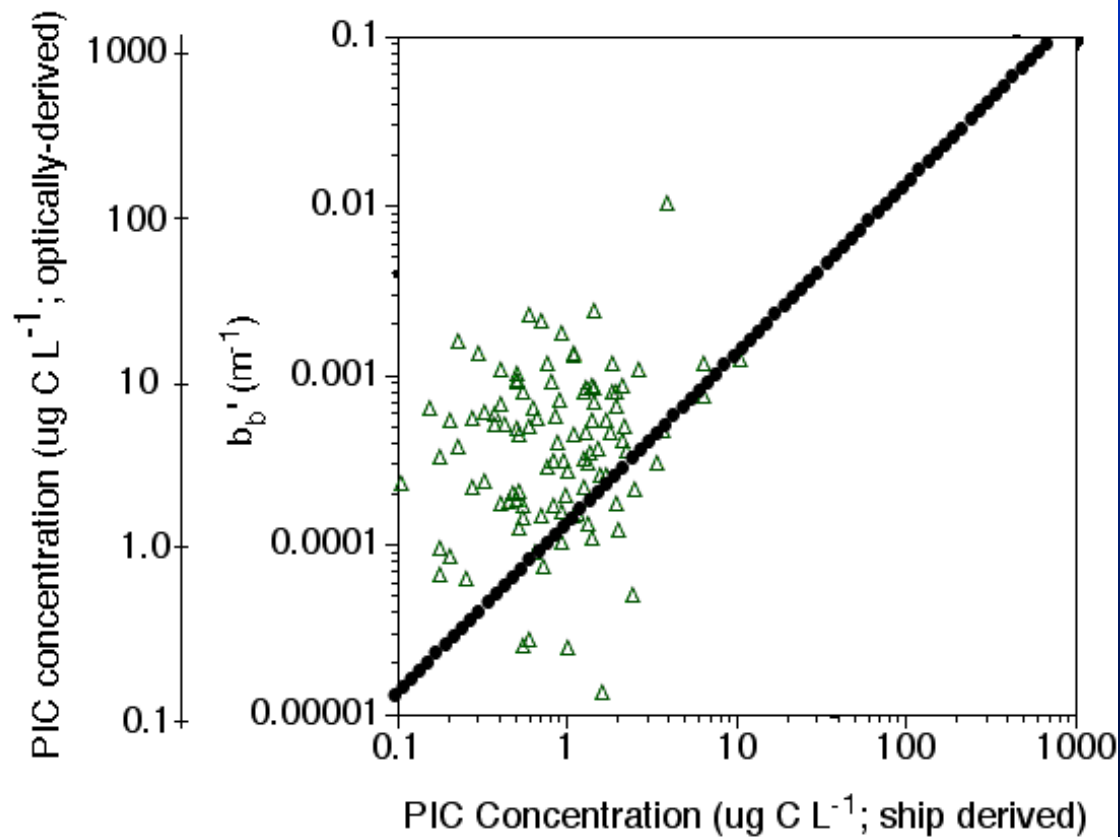


=BOFS Cocco bloom '91;

Conversion of b_b' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$



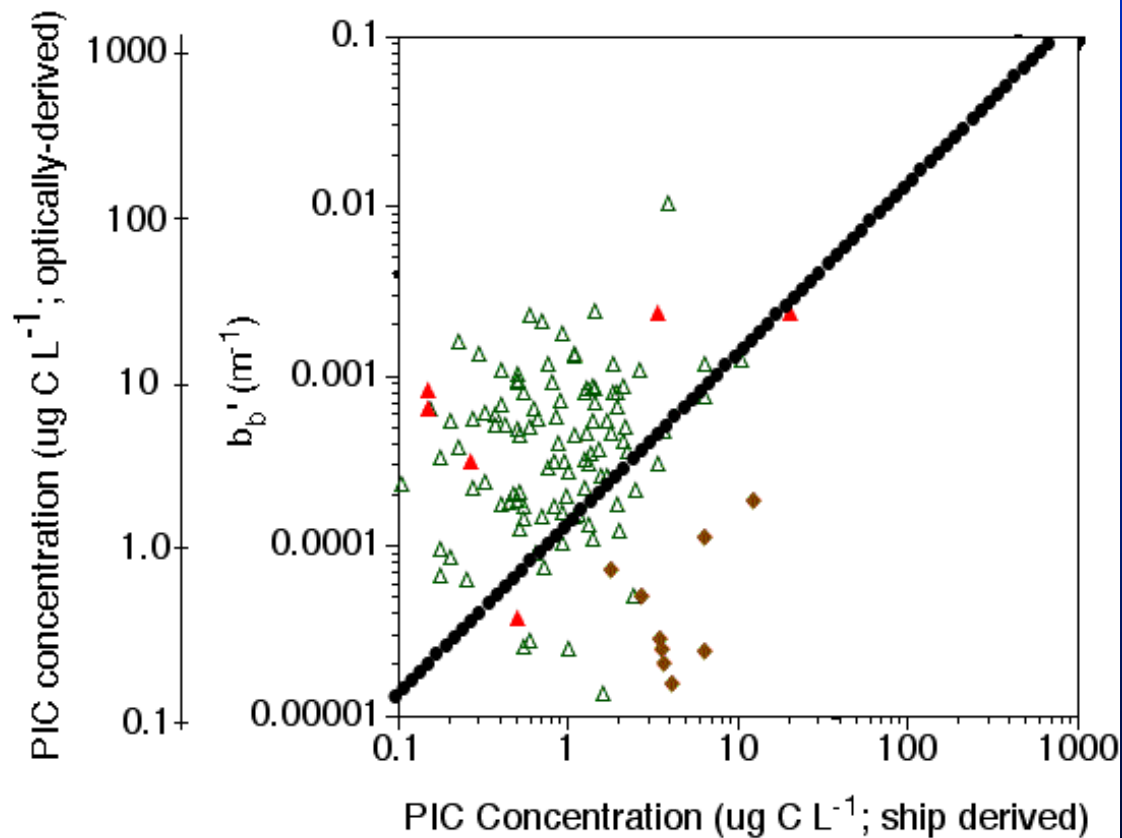
Adding more ship data to the PIC vs b_b relationship: Arabian Sea



Δ = Arabian Sea;

Conversion of b_b' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

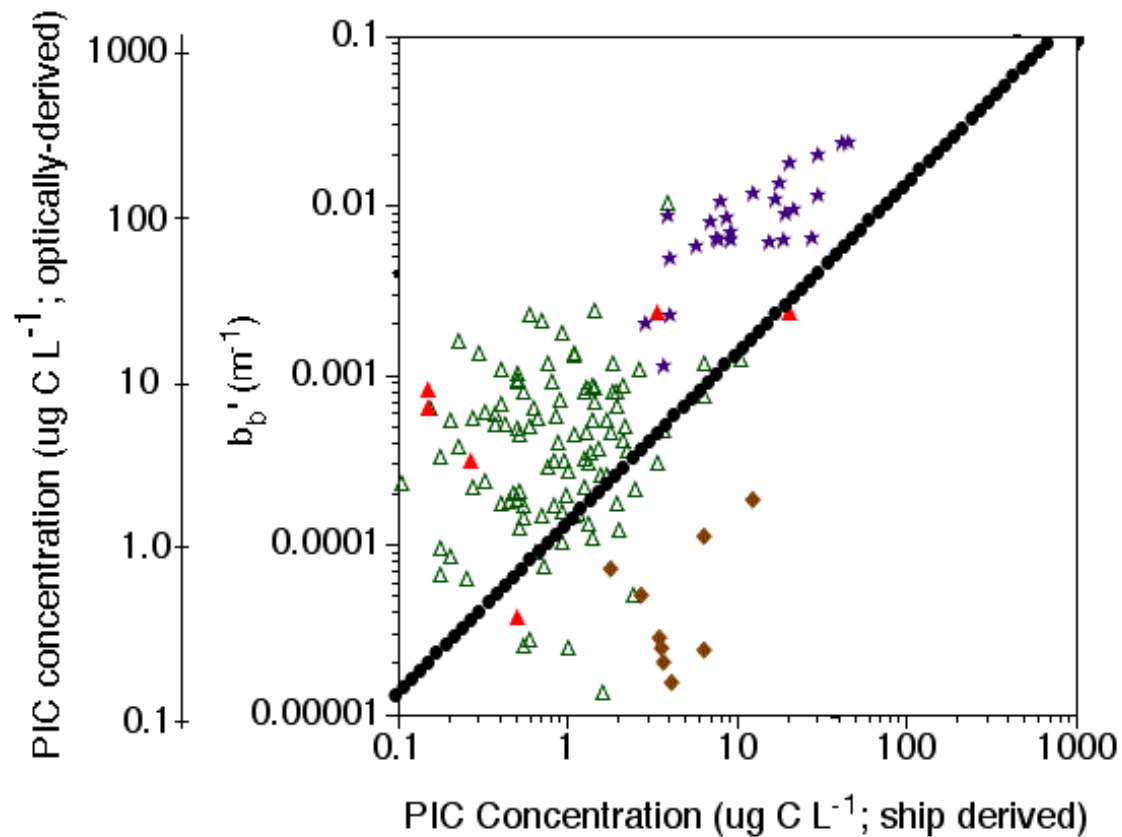
Adding more ship data to the PIC vs b_b relationship: Florida Straits



Δ = Arabian Sea \blacklozenge = Straits of FL'94; \blacktriangle = Straits of FL'95

Conversion of b_b to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

Adding more data to the PIC vs b_b relationship: Flow cytometer sorts of natural coccoliths

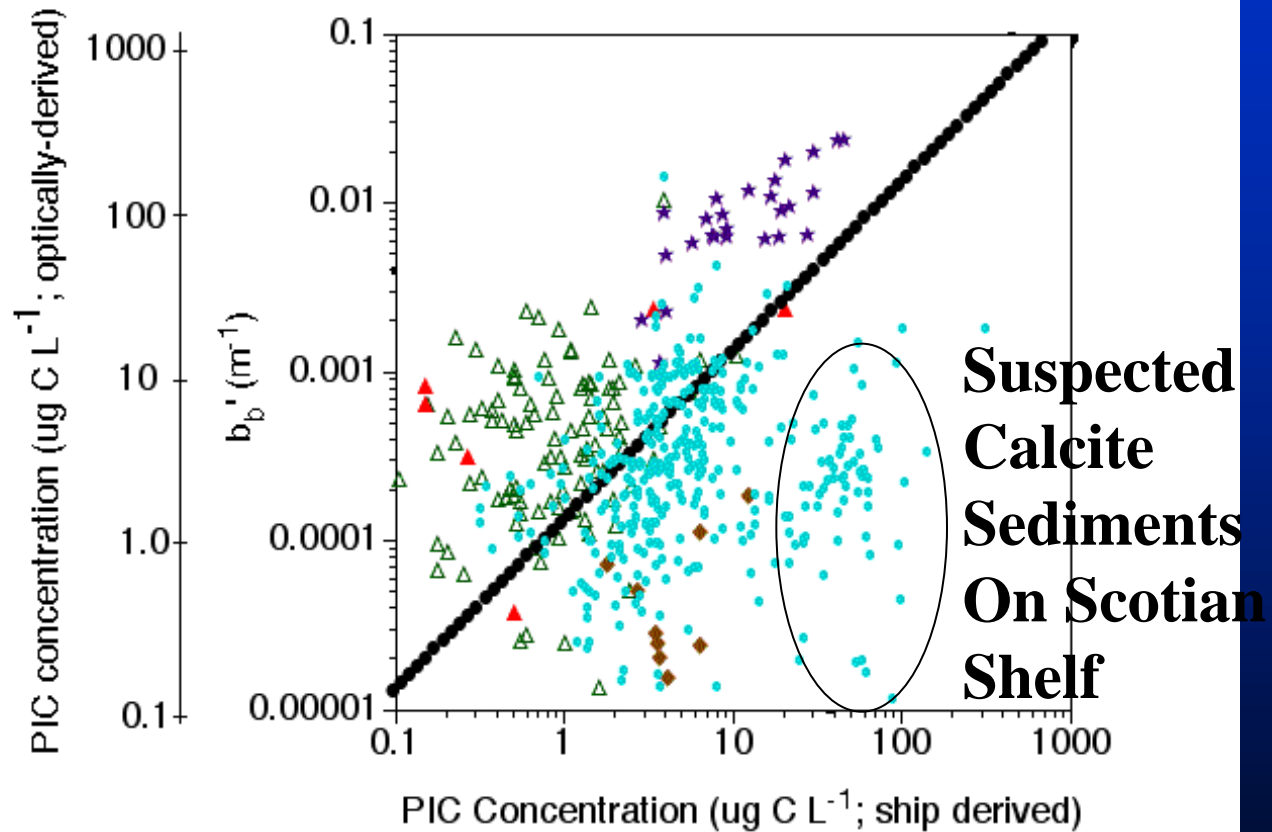


★=BOFS Cocco bloom '91; △ = Arabian Sea; ◆=Straits of FL'94; ▲=Straits of FL'95; ★= Flow Cytometer

analysis of sorted coccoliths;

Conversion of b_b to PIC assumes $1.37 \text{ m}^2/\text{mg}$ PIC= $1.14 \text{ m}^2/\text{mg}$ PIC

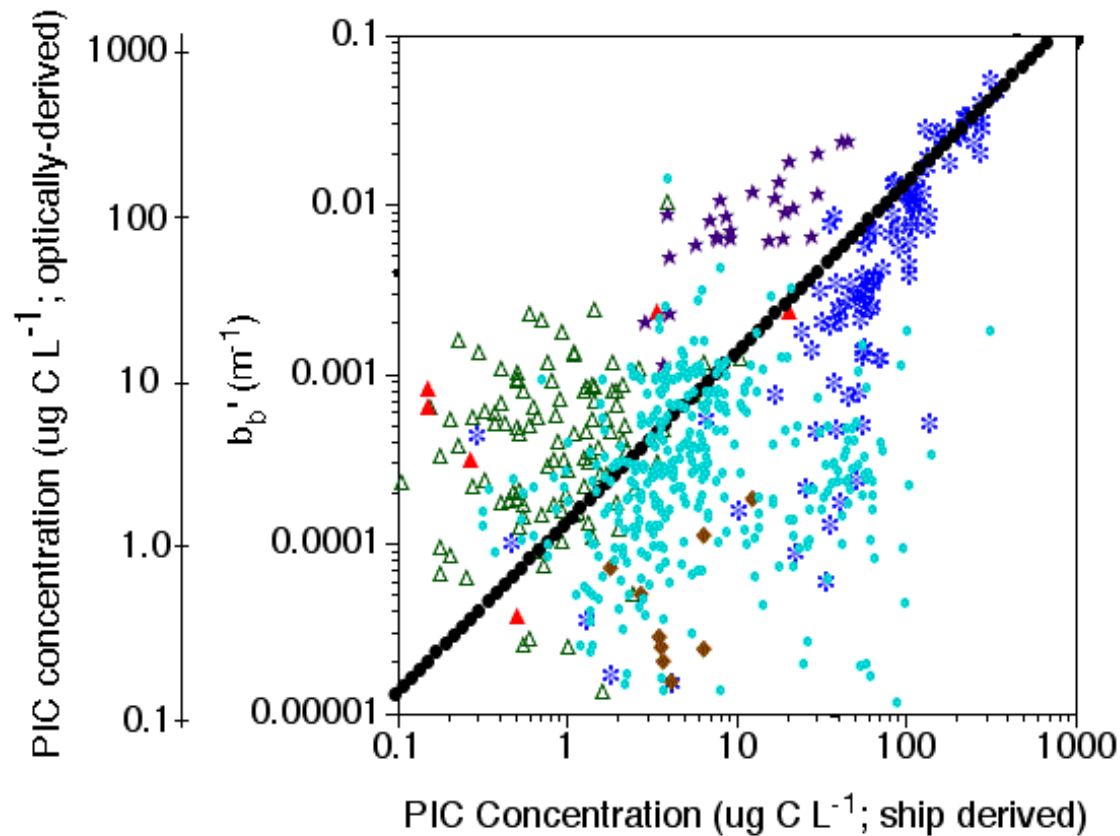
Adding more ship data to the PIC vs b_b relationship: Gulf of Maine 1998-2001



Δ = Arabian Sea; \blacklozenge = Straits of FL'94; \blacktriangle = Straits of FL'95; \star = Flow Cytometer

analysis of sorted coccoliths; \bullet = Gulf of Maine Ferry '98-01;
Conversion of b_b to PIC assumes $1.57 \text{ m}^2 \text{ Zimg PIC} = 1.14 \text{ m}^2 \text{ Zimg PIC}$

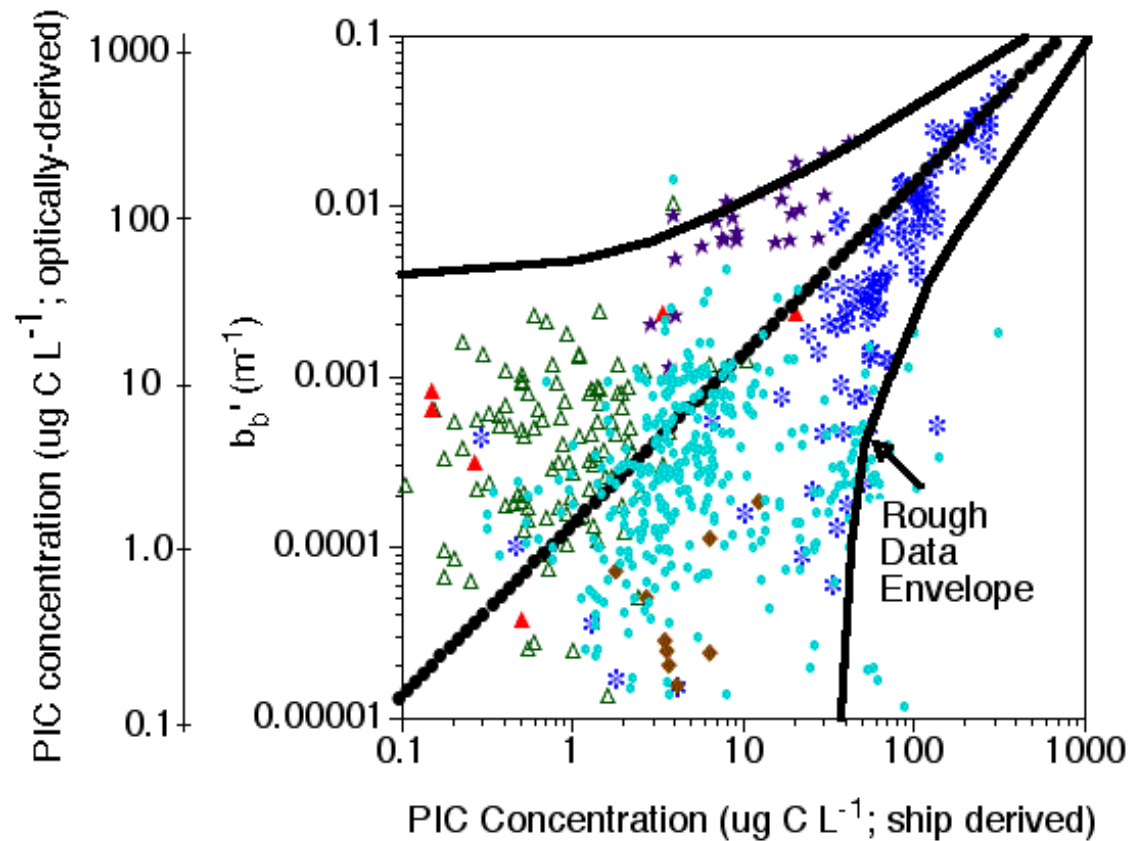
Combined with the original Iceland data showed high variance at low [PIC]



*=BCFS Cocco bloom '91; Δ = Arabian Sea; \blacklozenge =Straits of FL'94; \blacktriangle =Straits of FL'95; \star = Flow Cytometer

analysis of sorted coccoliths; \bullet =Gulf of Maine Ferry '98-01;
Conversion of b_b' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

The limits of the data suggested better accuracy at high [PIC]



*=BOFS Cocco bloom '91; Δ = Arabian Sea; \blacklozenge =Straits of FL'94; \blacktriangle =Straits of FL'95; \star = Flow Cytometer

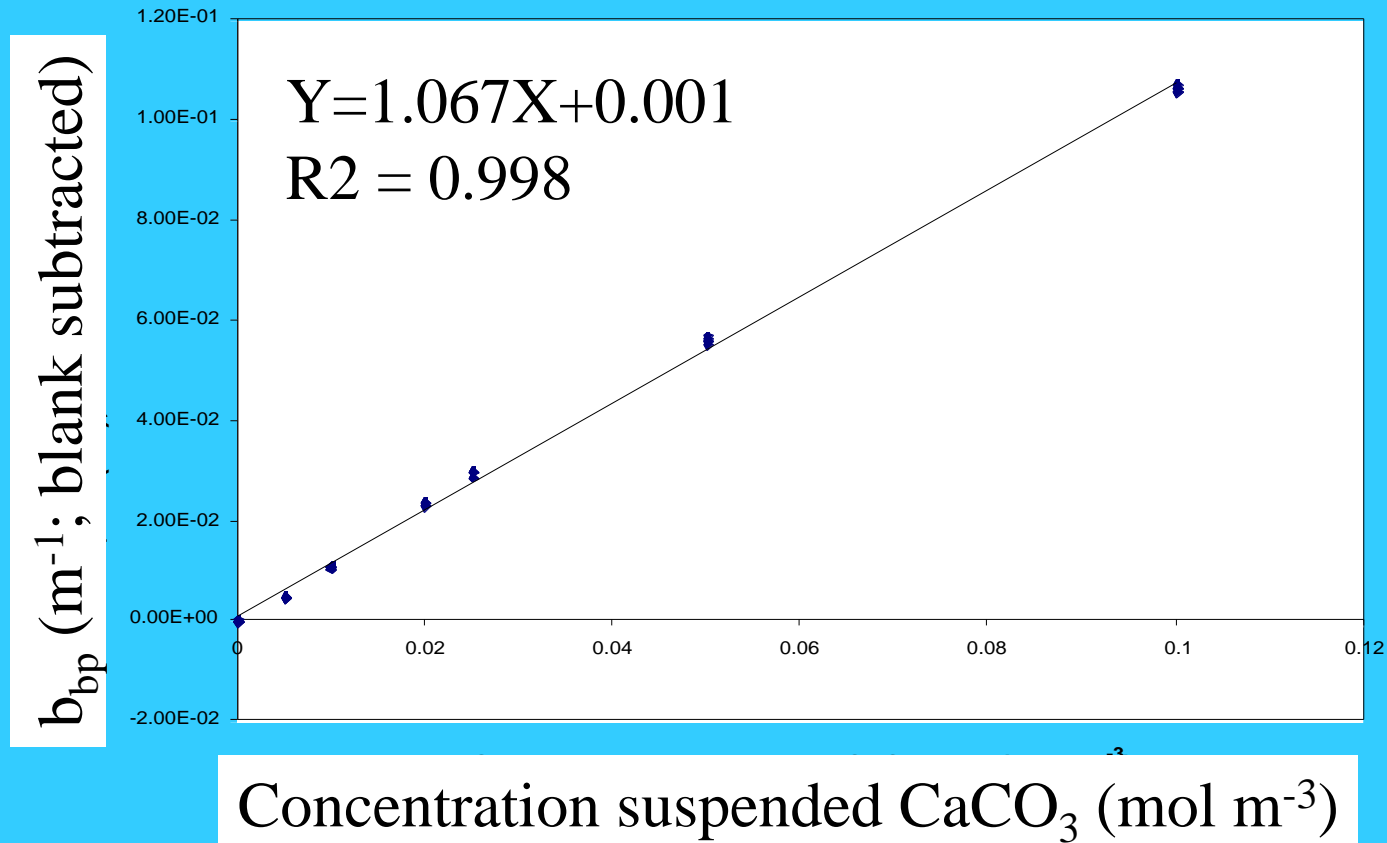
analysis of sorted coccoliths; \bullet =Gulf of Maine Ferry '98-01;
Conversion of bb' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

Still need some higher PIC concentrations: Chalk-ex

- “Do it yourself coccolithophore bloom”
- It doesn't take much coccolith chalk to make a patch visible from space (13T)
- _ of all marine sediments on earth are chalk so environmental impact is minimal
- Could time deployments to clear-sky days
- Gets over the problem of scheduling ships around rare bloom events!

Chalk concentration is highly correlated to its backscattering

SnoCal 90 Suspended in Filtered Sea Water @532nm



Loading Chalk In Portland, ME



Spreading
0500h-
0930h,
steaming
in an
expanding
ellipse, 1.5
x 0.5 km



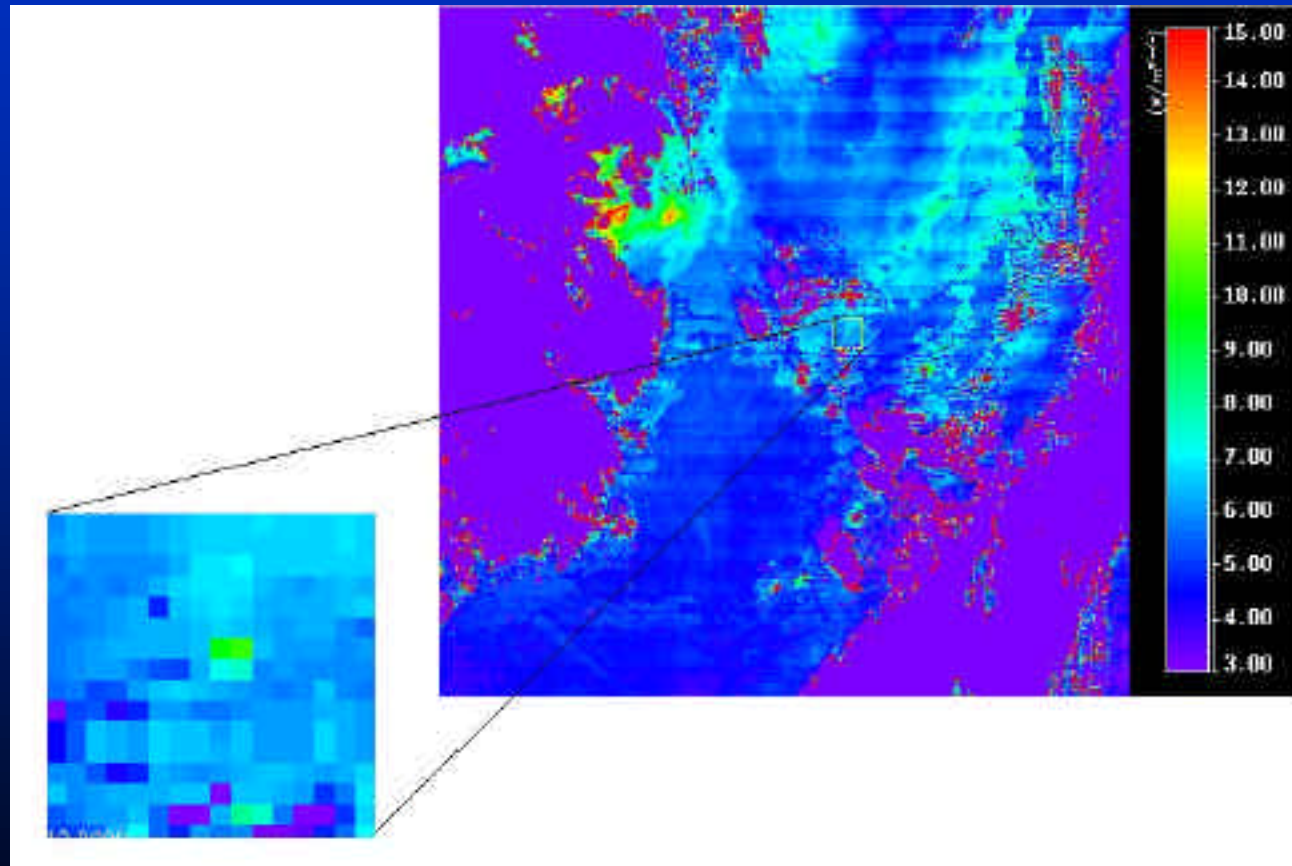
Southern patch (#2) complete



Aerial balloon images from patch#2

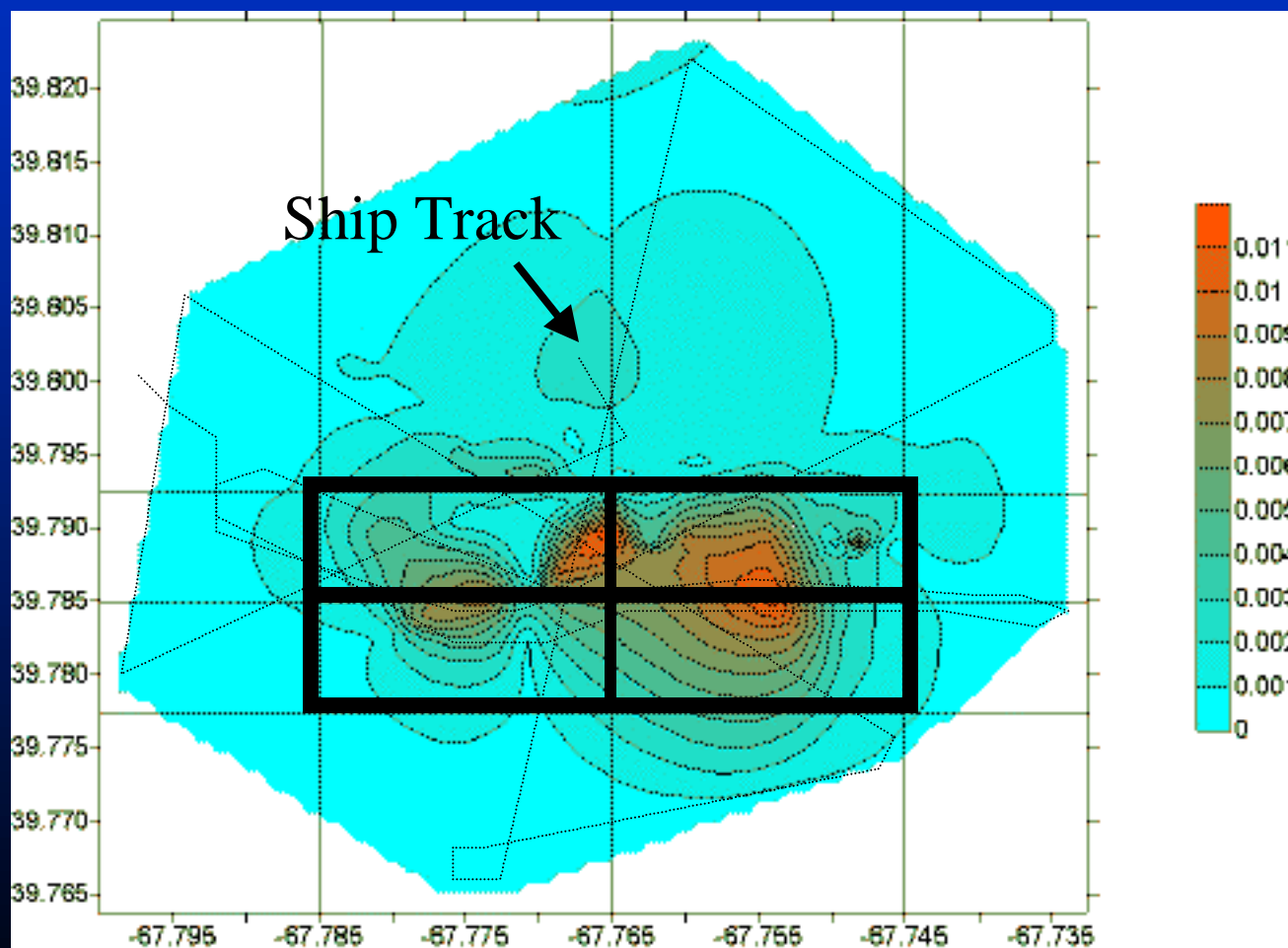


MODIS view of Chalk-Ex Patch #2: 551nm, 1Km data, 15 November 2001

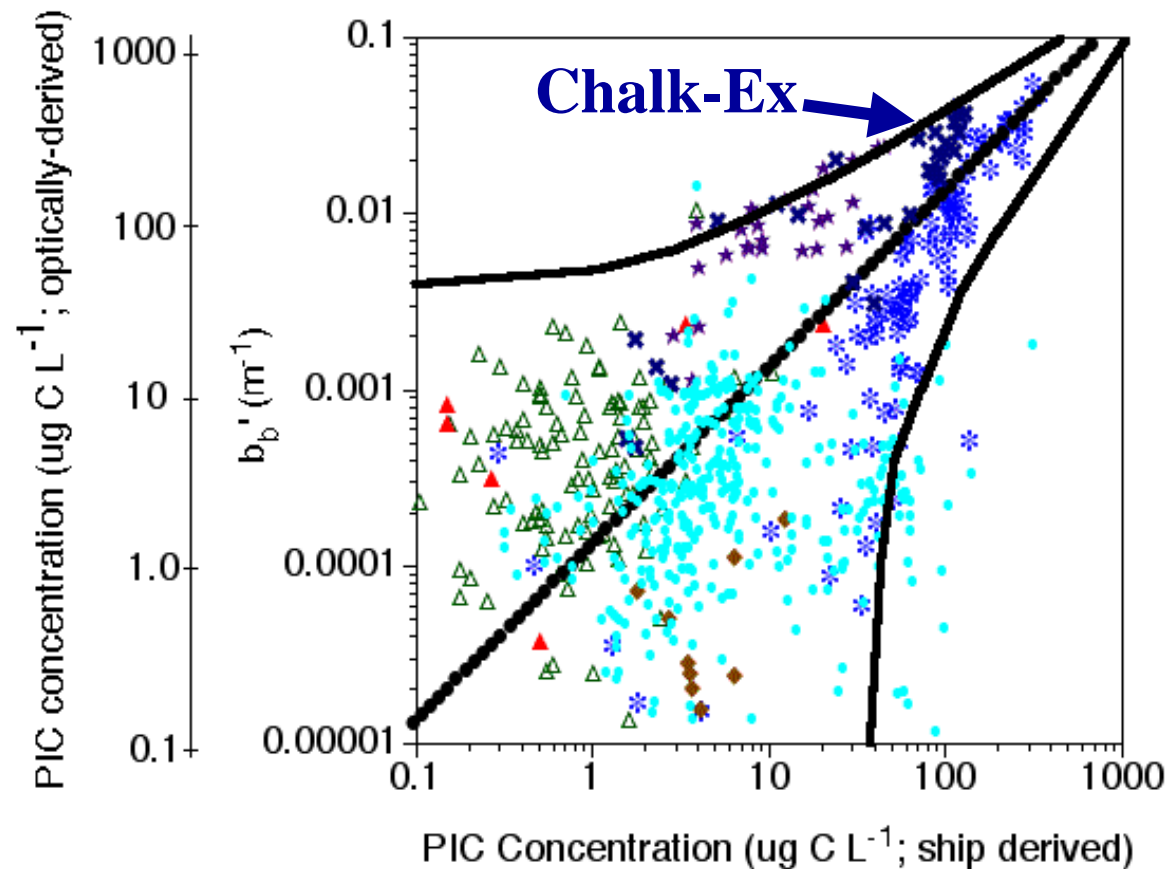


Two patch pixels: $39.81^{\circ}N \times 67.78^{\circ}W$ ($9.73 W m^{-2} um^{-1} sr^{-1}$)
 $39.80^{\circ}N \times 67.76^{\circ}W$ ($10.24 W m^{-2} um^{-1} sr^{-1}$)

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



Chalk-Ex ship results show consistently better accuracy of 2-band algorithm at high [PIC]



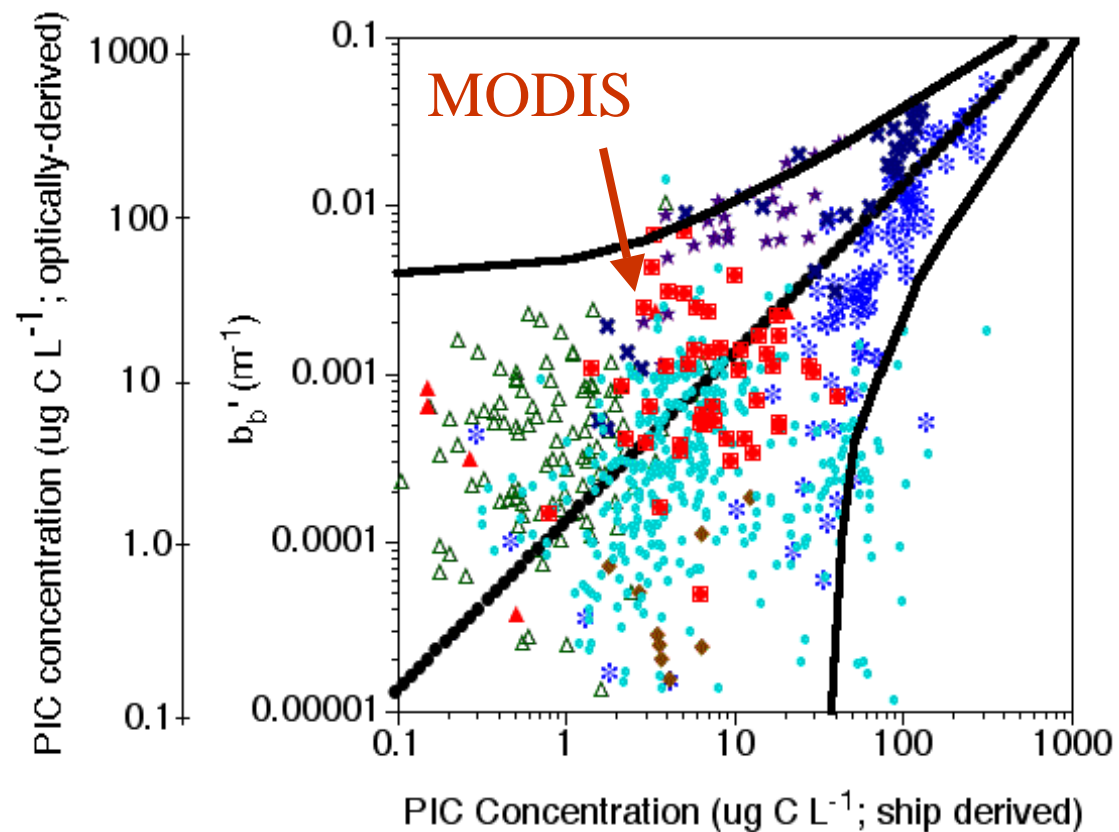
* = BOFS Cocco bloom '91; △ = Arabian Sea; ◆ = Straits of FL'94; ▲ = Straits of FL'95; ★ = Flow Cytometer

● = Gulf of Maine Ferry '98-01; * = Chalk-Ex

analysis of sorted coccoliths; Conversion of bb'_1 to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

How do satellite-derived estimates of PIC compare to the many ship measurements?

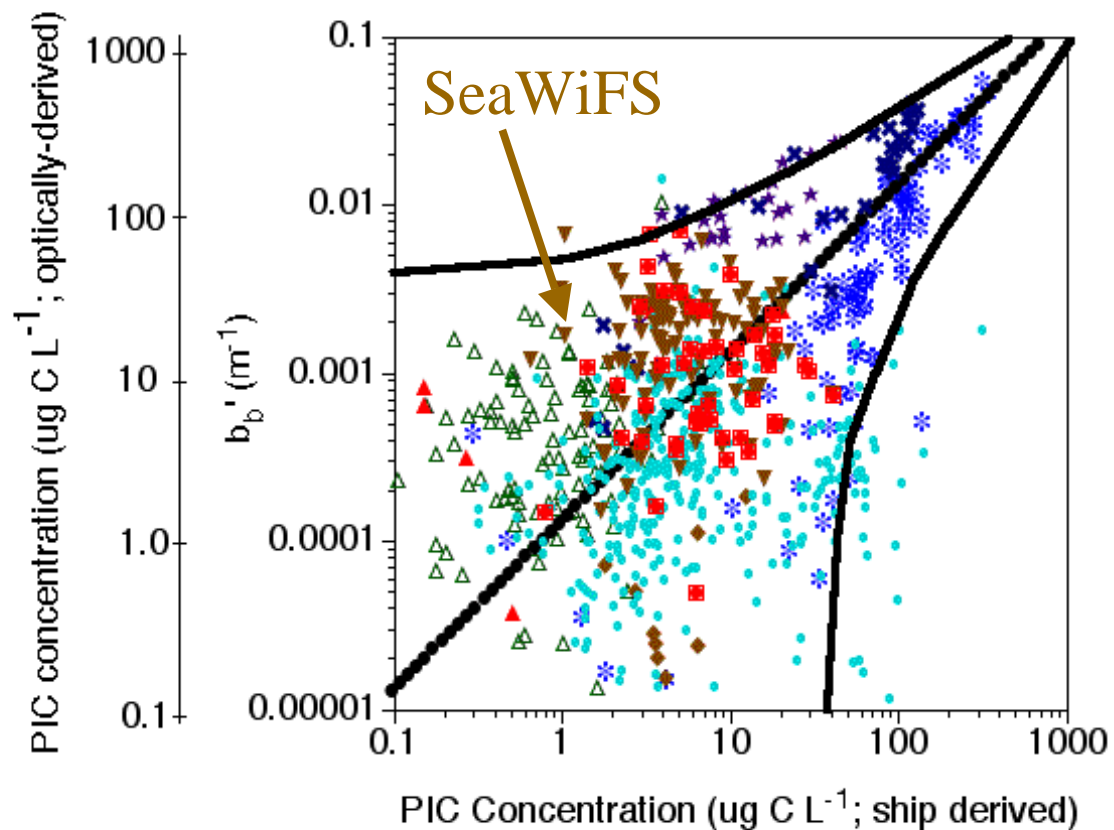
Superimposing MODIS data over ship data (level 0)



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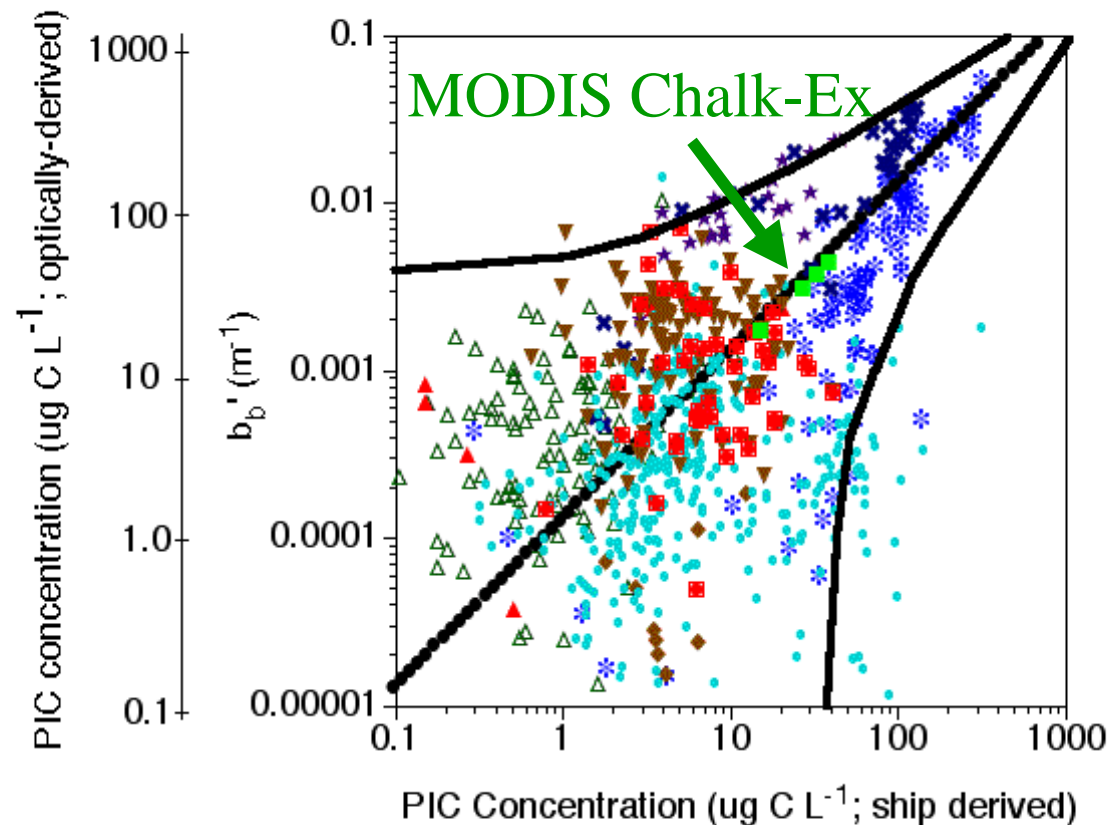
Conversion of b_b' to PIC assumes $1.37 \text{ m}^2/\text{mg}$ PIC = $1.14 \text{ m}^2/\text{mg}$ PIC

Are the MODIS data consistent with SeaWiFS estimates of PIC?



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 analysis of sorted coccoliths; \bullet = Gulf of Maine Ferry '98-01; \star = Chalk-Ex; \blacksquare = MODIS GOM; \blacktriangledown = SeaWiFS
 GOM;
 Conversion of b_b^1 to PIC assumes $1.37 \text{ m}^2/\text{mg}$ PIC = $1.14 \text{ m}^2/\text{mg}$ PIC

How about MODIS estimates of PIC from Chalk-Ex?



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 analysis of sorted coccoliths; \bullet = Gulf of Maine Ferry '98-01; \star = Chalk-Ex Ship; \blacksquare = MODIS GOM; \blacktriangledown =
 SeaWiFSGOM;
 Conversion of b_b ' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

\blacksquare = Chalk-Ex MODIS

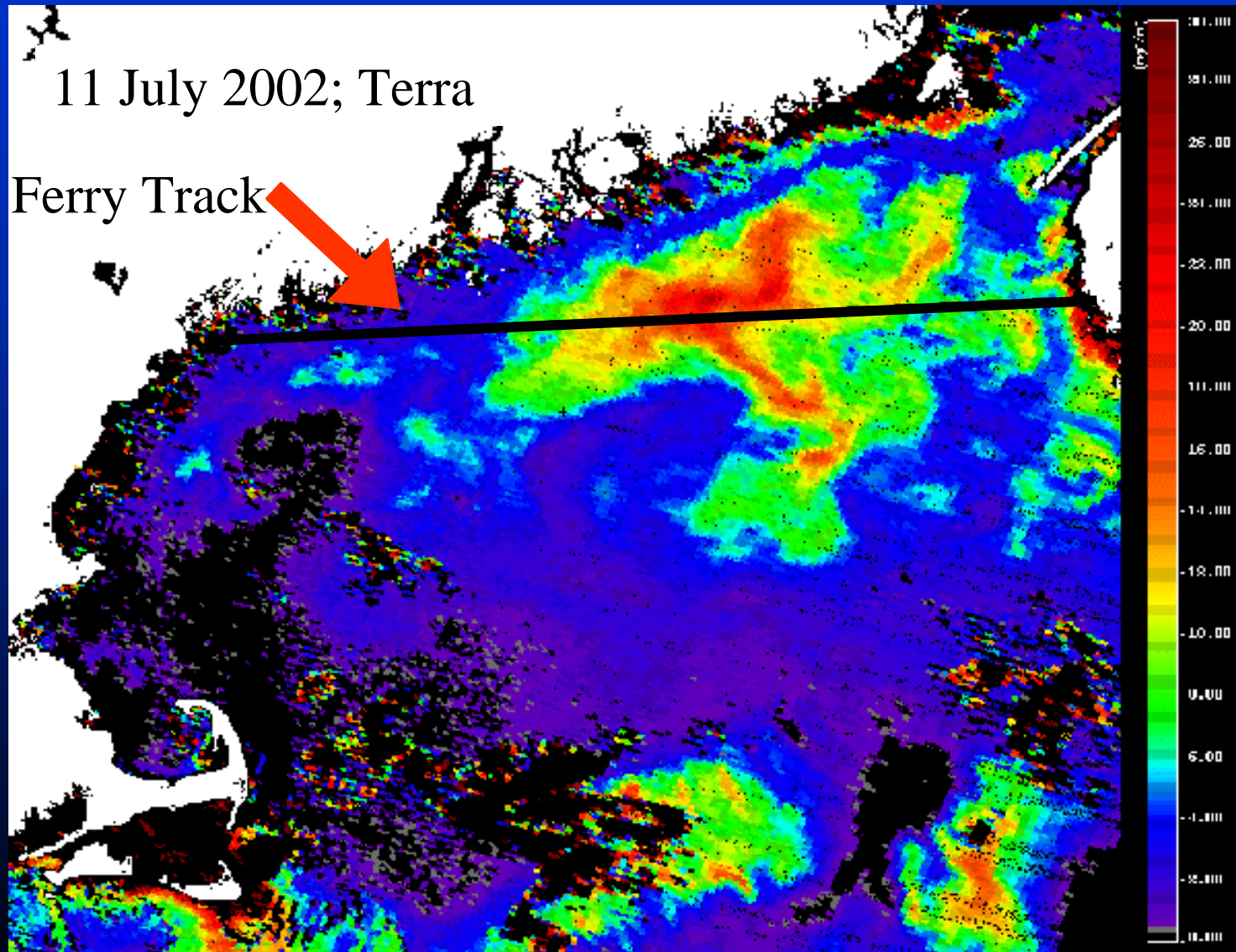
Ferry sea truth data (hot off the press):

- Above-water radiance measurements from ship used to derive two-band PIC then compare with ship-estimates
- MODIS-derived two-band PIC estimates compared to ship estimates

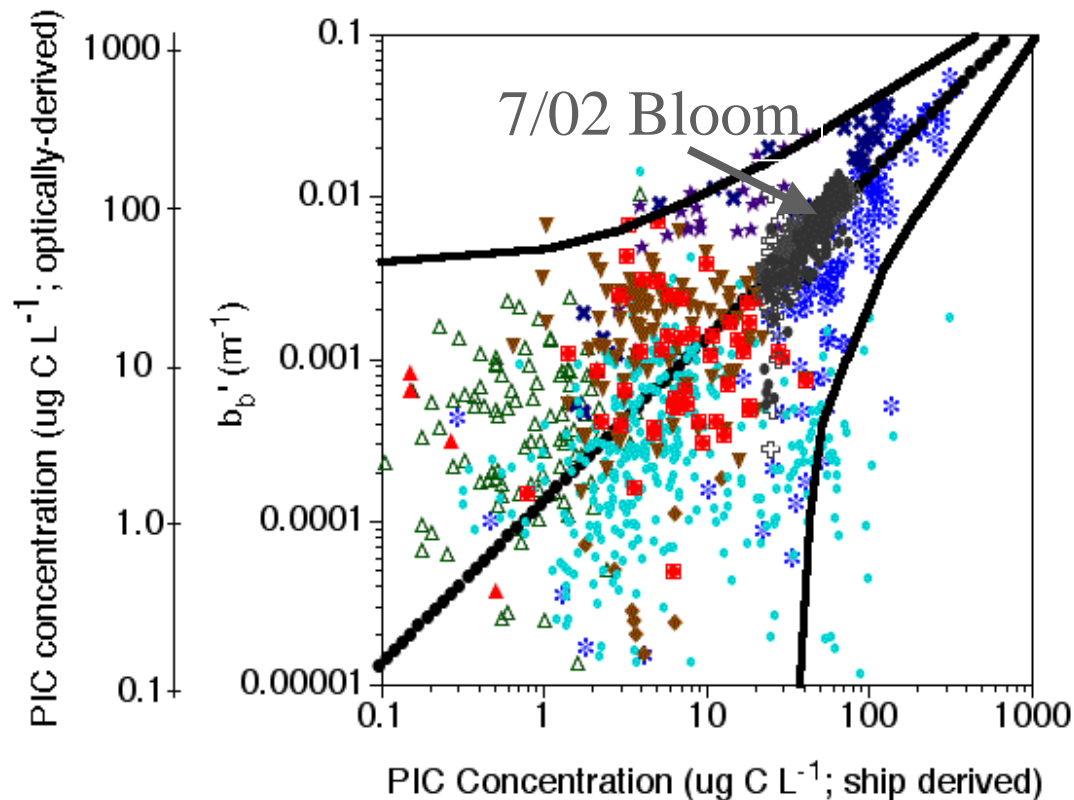
Mother nature pulls through with a _ to _ million ton “Chalk-ex” in July ’02!

- First hint on 6/24/02 SeaWiFS image
- Saw somewhat brighter patch under small clear spot of MODIS Terra image of 7/7/02
- Ship confirmation on 7/10/02 and 7/11/02 along with MODIS Terra imagery
- Bloom appears to be getting bigger. A cold front is slated to clear the air on Wednesday or Thursday...we are currently mobilizing for a validation trip.

Mother nature's "chalk-ex"

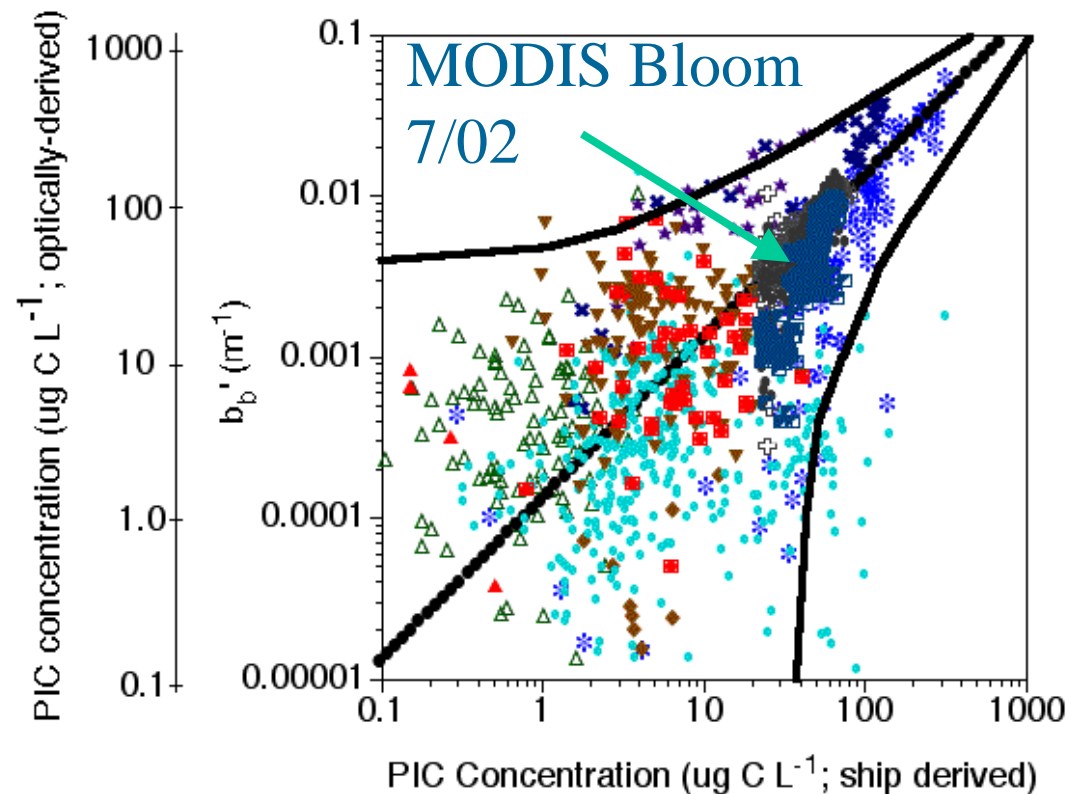


How do the bloom ship observations fit into the big picture of optical PIC estimates?



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 analysis of sorted coccoliths; \bullet = Gulf of Maine Ferry '98-01; \star = Chalk-Ex; \blacksquare = MODIS GOM; \blacktriangledown = SeaWiFS
 GOM; \bullet = GOM7/02 cocco bloom
 Conversion of b_b to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

How do the bloom MODIS observations fit into the big picture?

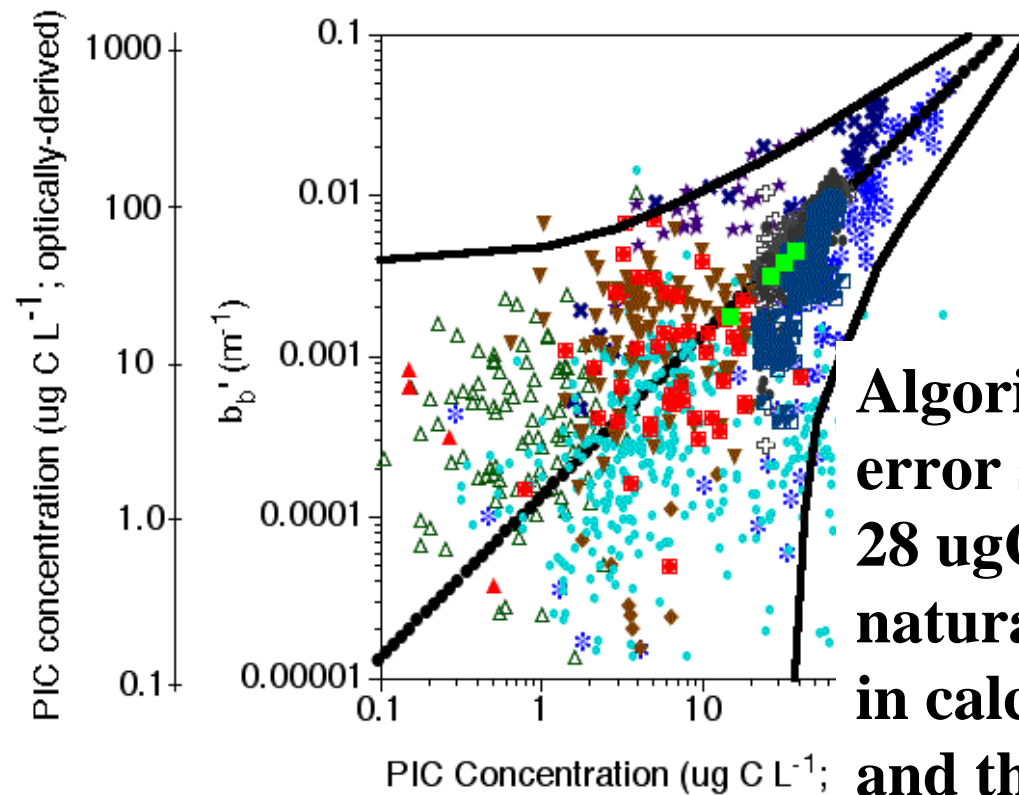


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analysis of sorted coccoliths; ● =Gulf of Maine Ferry '98-01; ✖=Chalk-Ex; ■=MODIS GOM; ▼= SeaWIFS GOM; ⊕ =GOM7/02 cocco bloom ship; ⊞= GOM 7/02 cocco bloom MODIS

Conversion of b_b to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

Putting all the data together (on log axes)...

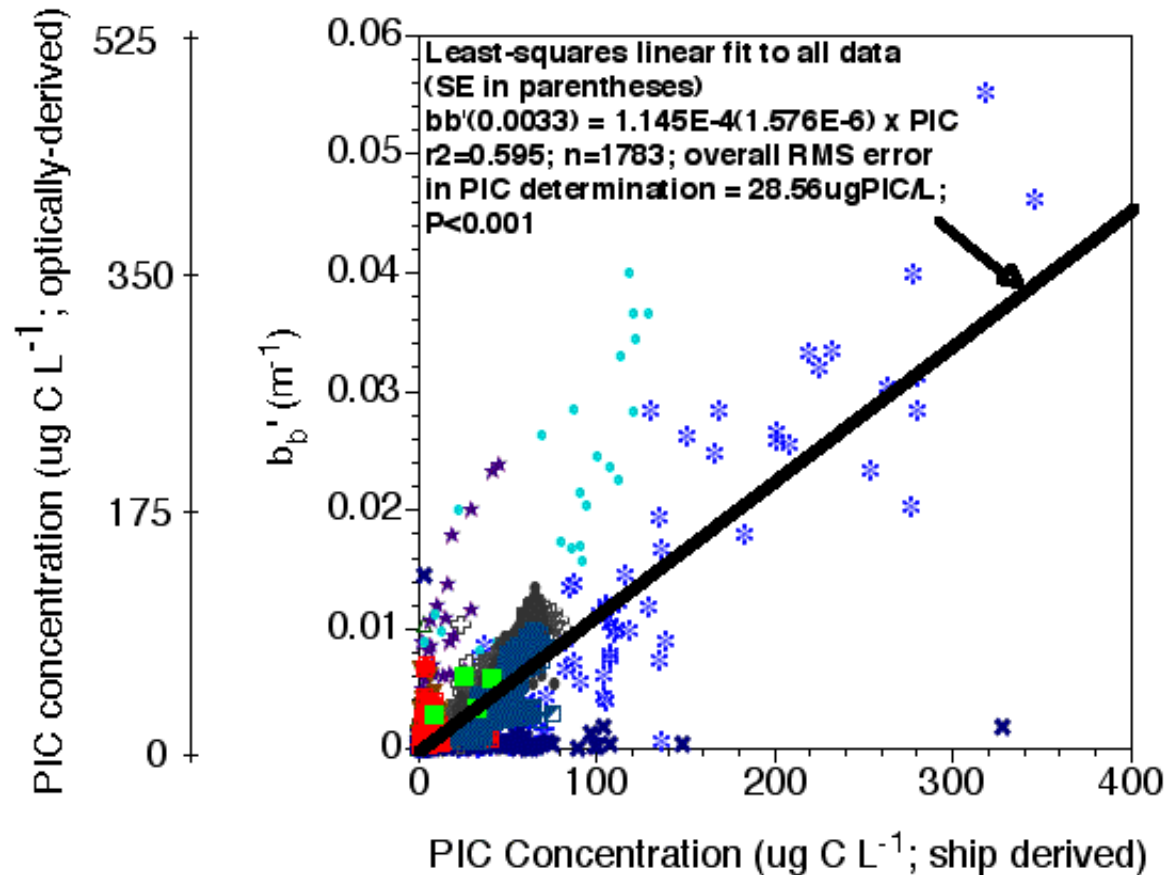


Algorithm RMS error still about 28 ugC/L due to natural variability in calcite particles and their b_b

★=BOFS Cocco bloom '91; △ = Arabian Sea; ◆=Straits of FL'94; ▲=Straits of FL'95; ★= Flow Cytometer

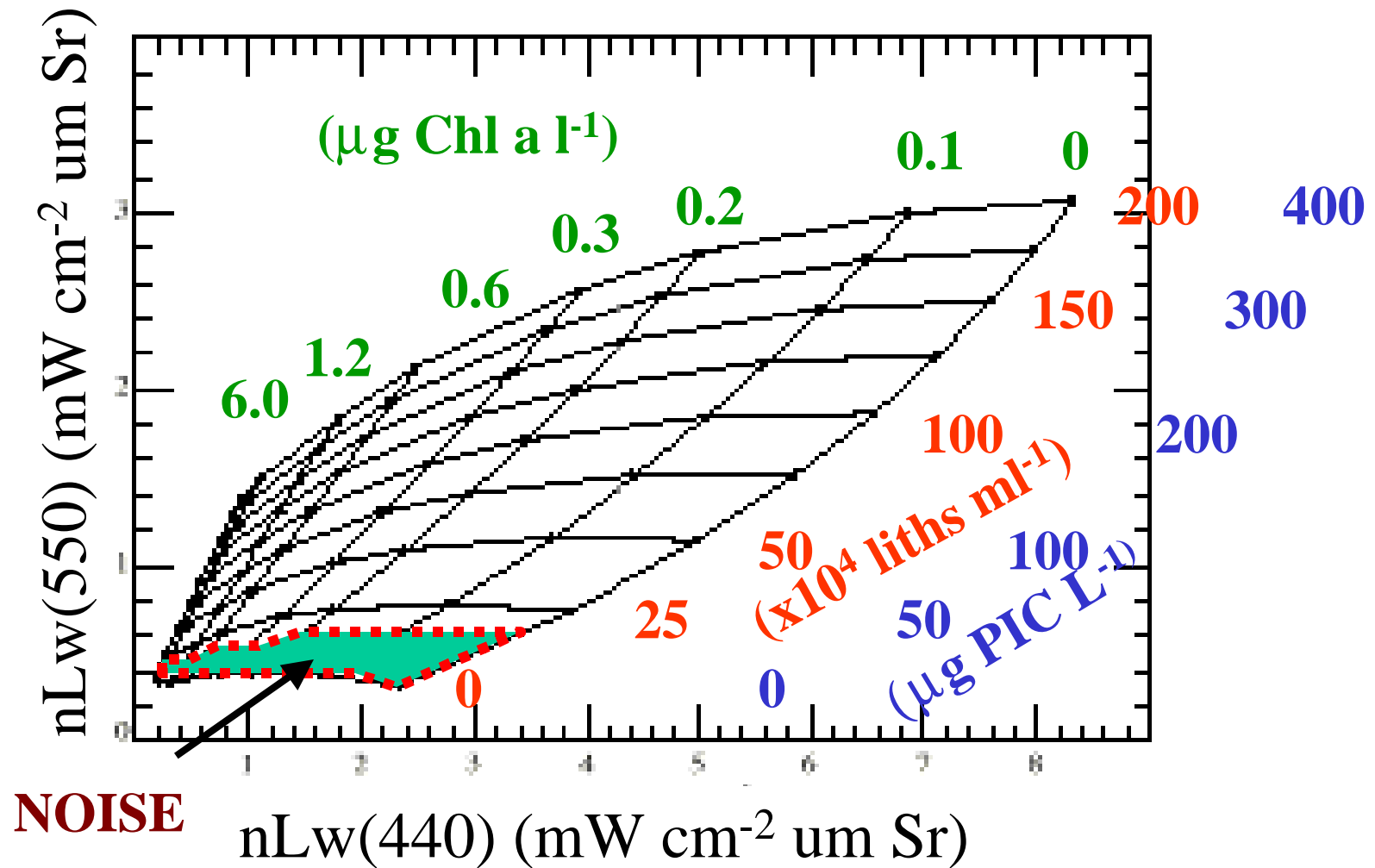
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Conversion of b_b' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC}=1.14 \text{ m}^2/\text{mg PIC}$

Putting all the data together (on linear axes)...



* = BOFS Cocco bloom '91; Δ = Arabian Sea; \blacklozenge = Straits of FL'94; \blacktriangle = Straits of FL'95; \star = Flow Cytometer
 analysis of sorted coccoliths; \bullet = Gulf of Maine Ferry '98-01; \times = Chalk-Ex Ship; \blacksquare = MODIS GOM; \blacktriangledown =
 SeaWiFS GOM; \oplus = GOM 7/02 cocco bloom ship; \blacksquare = GOM 7/02 cocco bloom MODIS; \blacksquare = Chalk-Ex MODIS
 Conversion of bb' to PIC assumes $1.37 \text{ m}^2/\text{mg PIC} = 1.14 \text{ m}^2/\text{mg PIC}$

The 2-band PIC algorithm look-up table



For monospecific features, the relative sensitivity of the PIC algorithm is quite good...

PIC (ug/L)

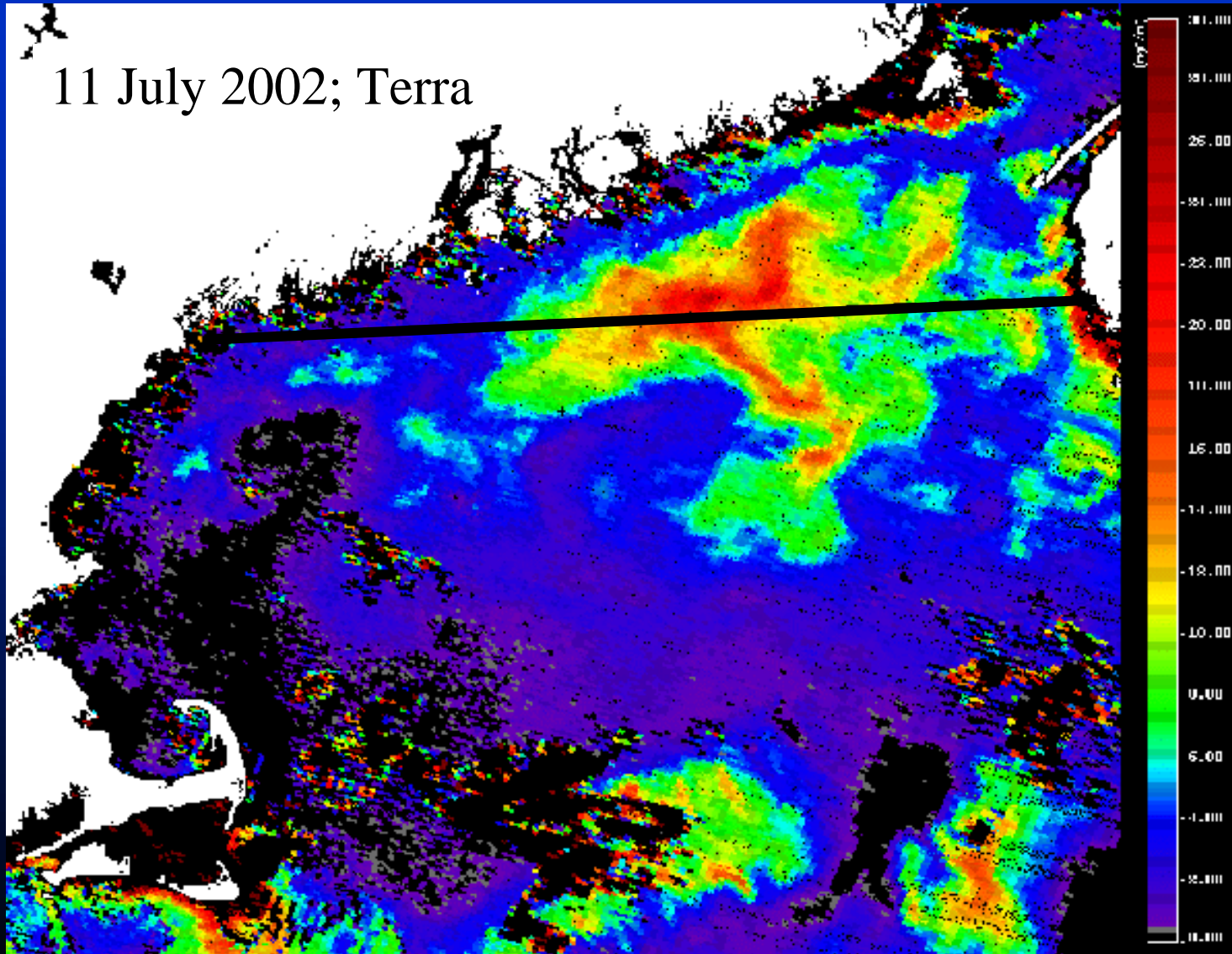
30

20

10

0

11 July 2002; Terra



Summary

- Is the algorithm, as defined using original Iceland coccolithophore bloom, working? Yes.
- Is PIC product validated?
 - The absolute RMS accuracy is +/- 30 μ g C/L for mixtures of unknown PIC particles.
 - The relative precision is much better in features with one type of particle. For example, Gulf of Maine bloom where algorithm detected relative variability of PIC at levels of 5 μ g PIC/L, or Chalk-Ex with uniform PIC particles.

Future

- Summer'03 Chalk-Ex in the Gulf of Maine (Joint ONR/NASA)
- Contribution of other particulate material to b_b (such as opal from diatom frustules)
- Validation work to define residual errors and improve accuracies of PIC retrievals below PIC concentrations of $30\mu\text{g C L}^{-1}$
- *Thank you!*



PIC vs bb relationship: Same for MODIS terra and ship data

