The Life and Times of Marine Particles: the JGOFS story

Ken O. Buesseler

Woods Hole Oceanographic Institution

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“separate biogeochemistry from physical oceanography”

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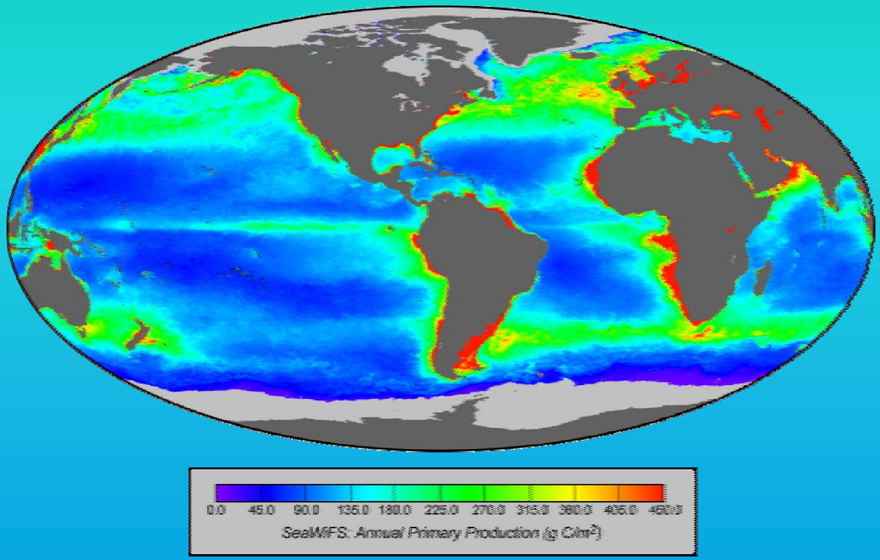
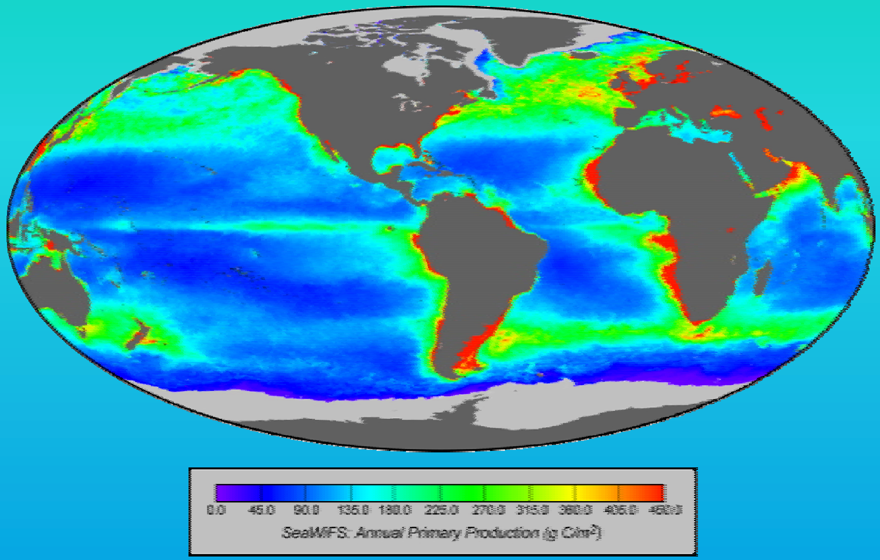


How do we get from here?

C uptake in surface ocean-
SeaWiFS global primary production
Behrenfeld & Falkowski, 1997

Marine Particles
"separate biogeochemistry from physical oceanography"



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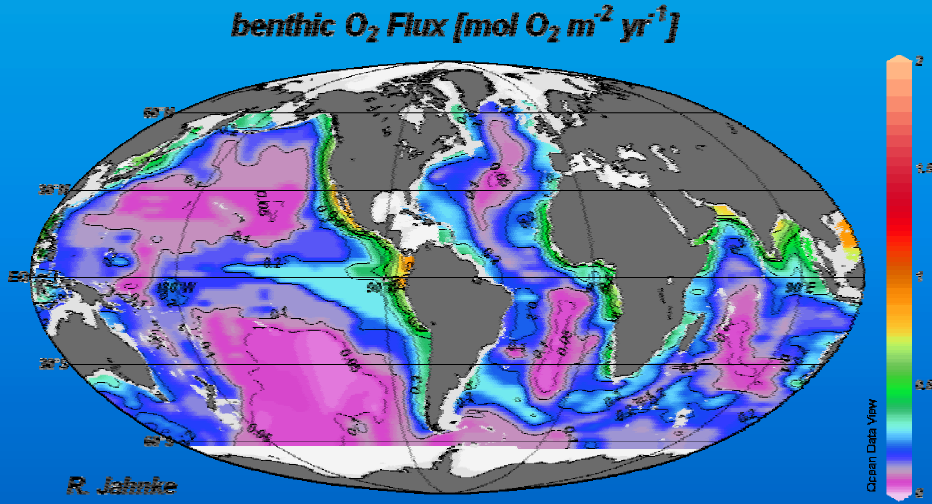


To here?

C flux to seafloor -
benthic O_2 demand
Jahnke, 1996

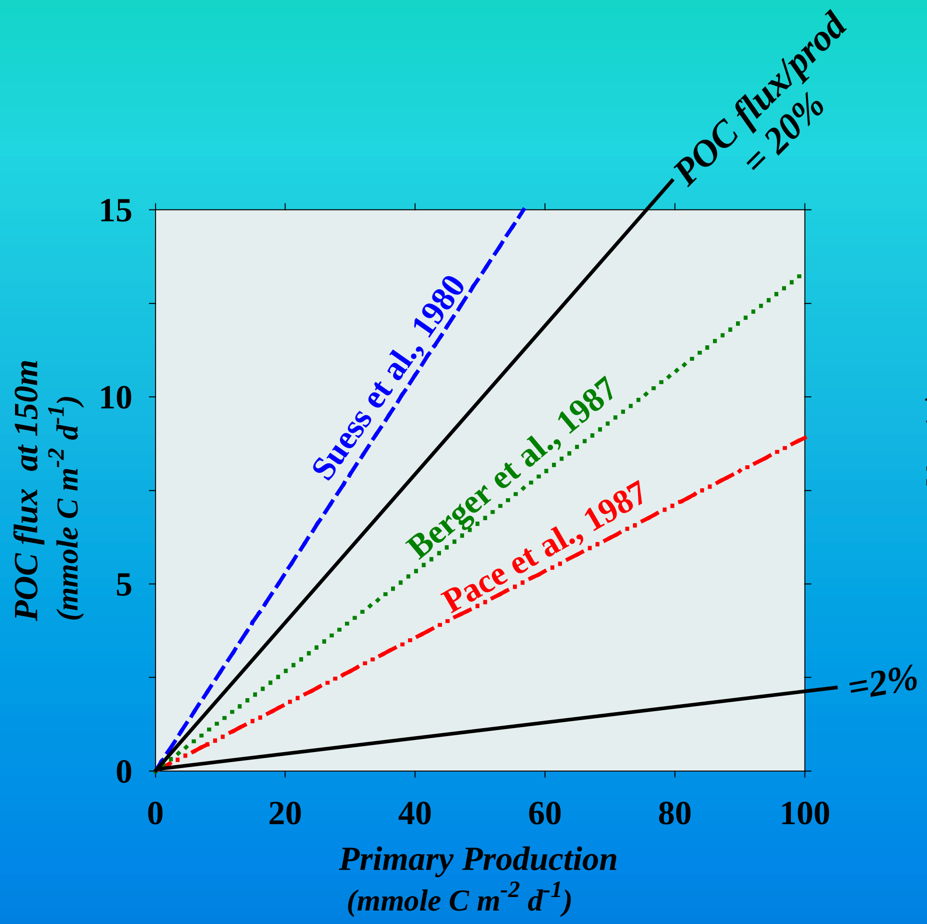
Outline

- pre-JGOFS world
- Basic Facts- marine particles
- Particle Export vs. Primary Production

  Rates and controls measured during JGOFS studies
- Predictions of POC Flux- global & regional

  Southern Ocean example
- What does the future hold

pre-JGOFS world: *Export ≈ βz ∗ Primary Production*



- **Important implications for export derived from satellite productivity**

How well do we understand rates and controls on POC export?

- the "F" in **JGO*F*S**

Marine Particles- basic facts

Methods classically define suspended vs. sinking particles

- **filtration**
- **sediment traps**

Methods matter!

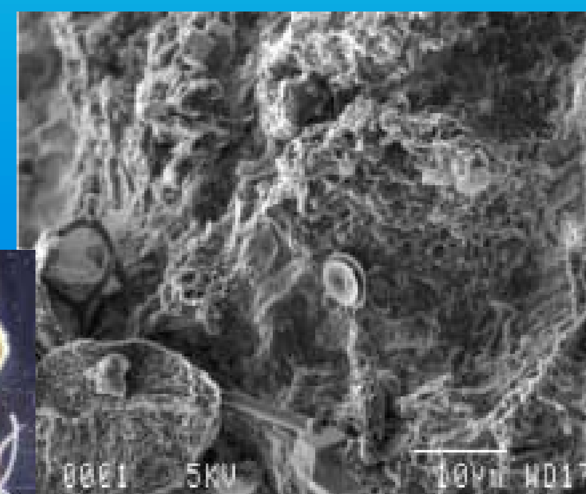
Marine Particles- basic facts

Settling velocity proportional to (radius)^2 & density difference

- **size matters**
- **and so does density (ballast; sinking speed)**
- **and so does chemistry (degradation; surface properties)**

Sources: biogenic material dominates surface open ocean vs. inorganic/detrital



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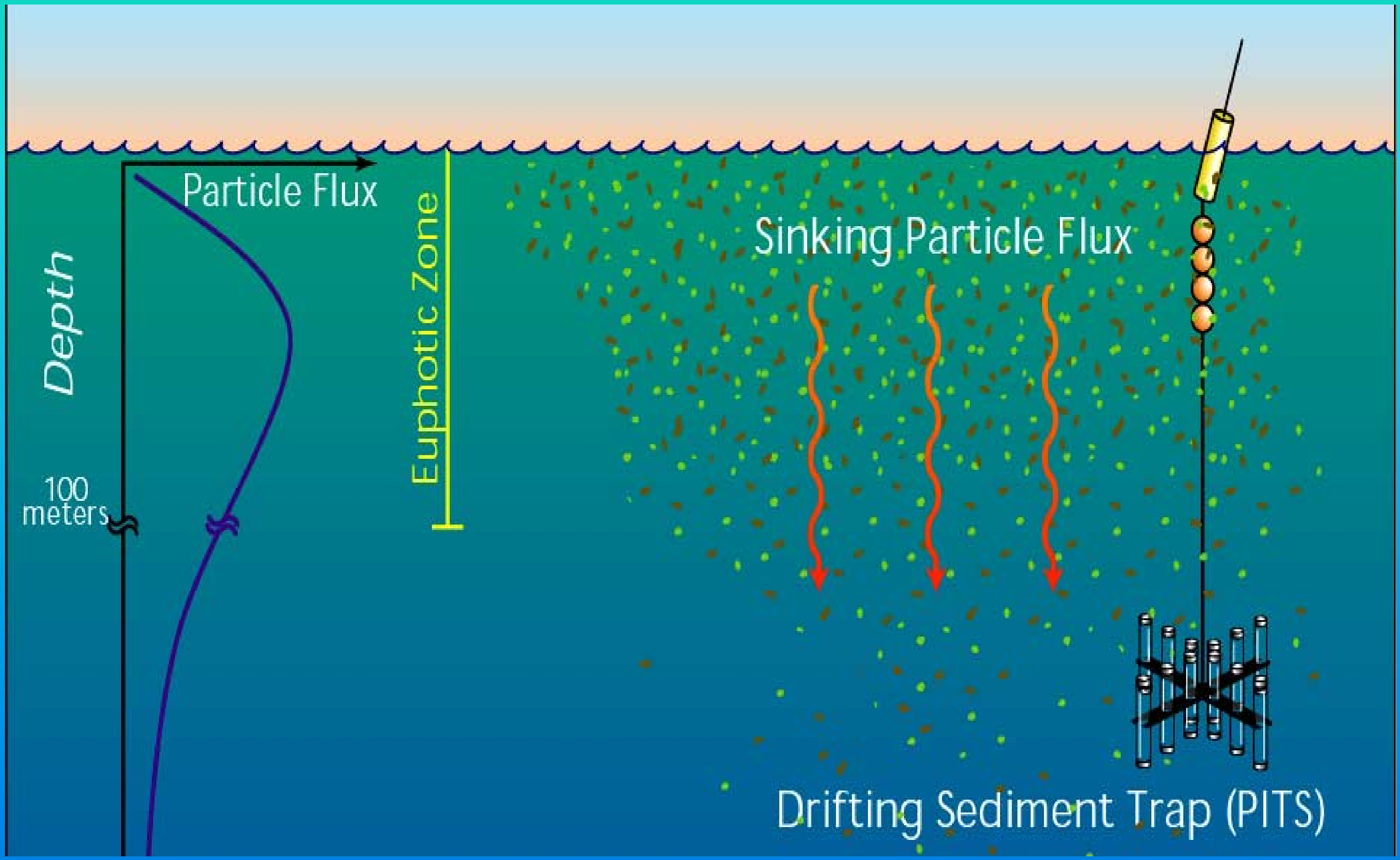

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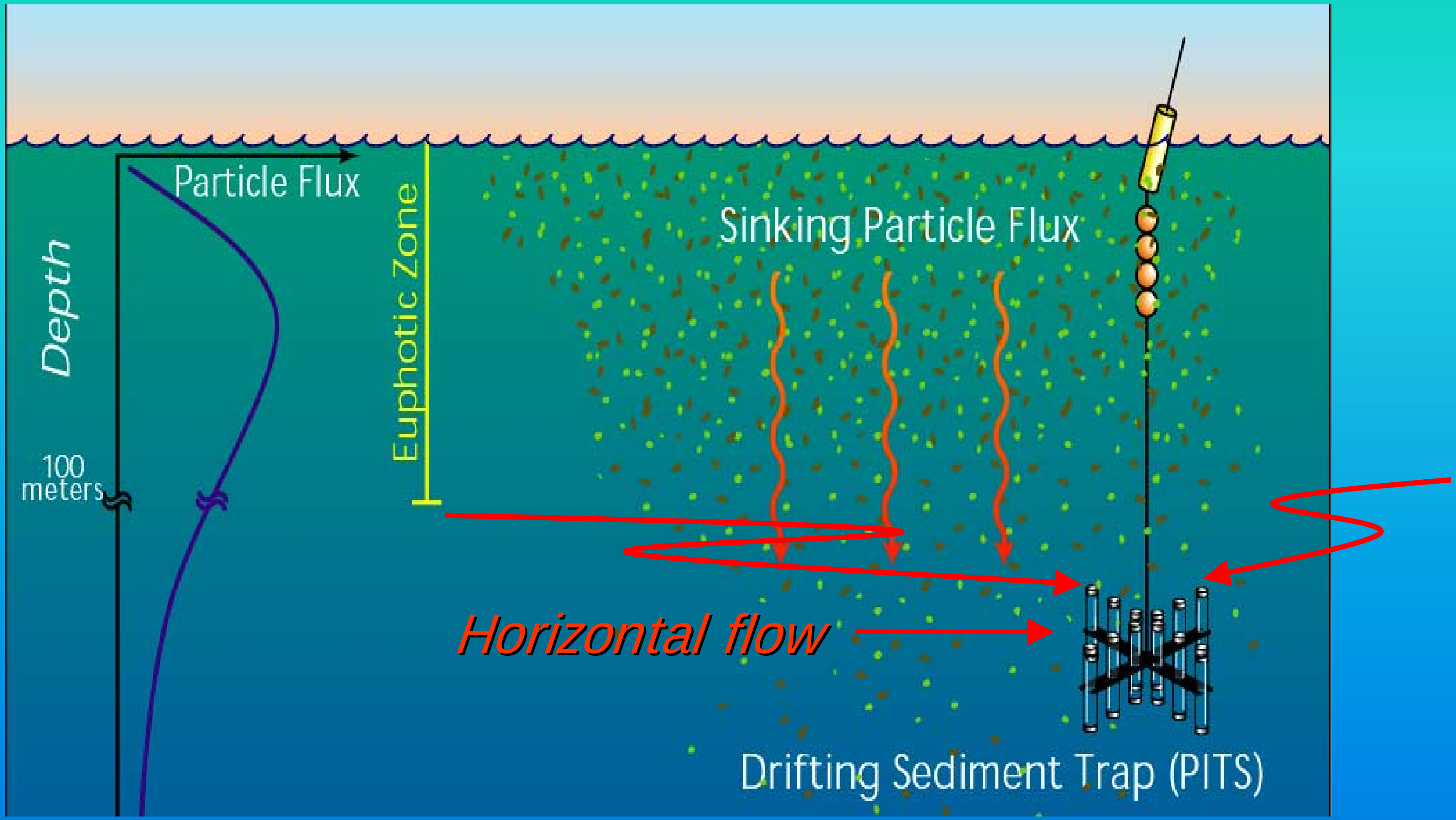


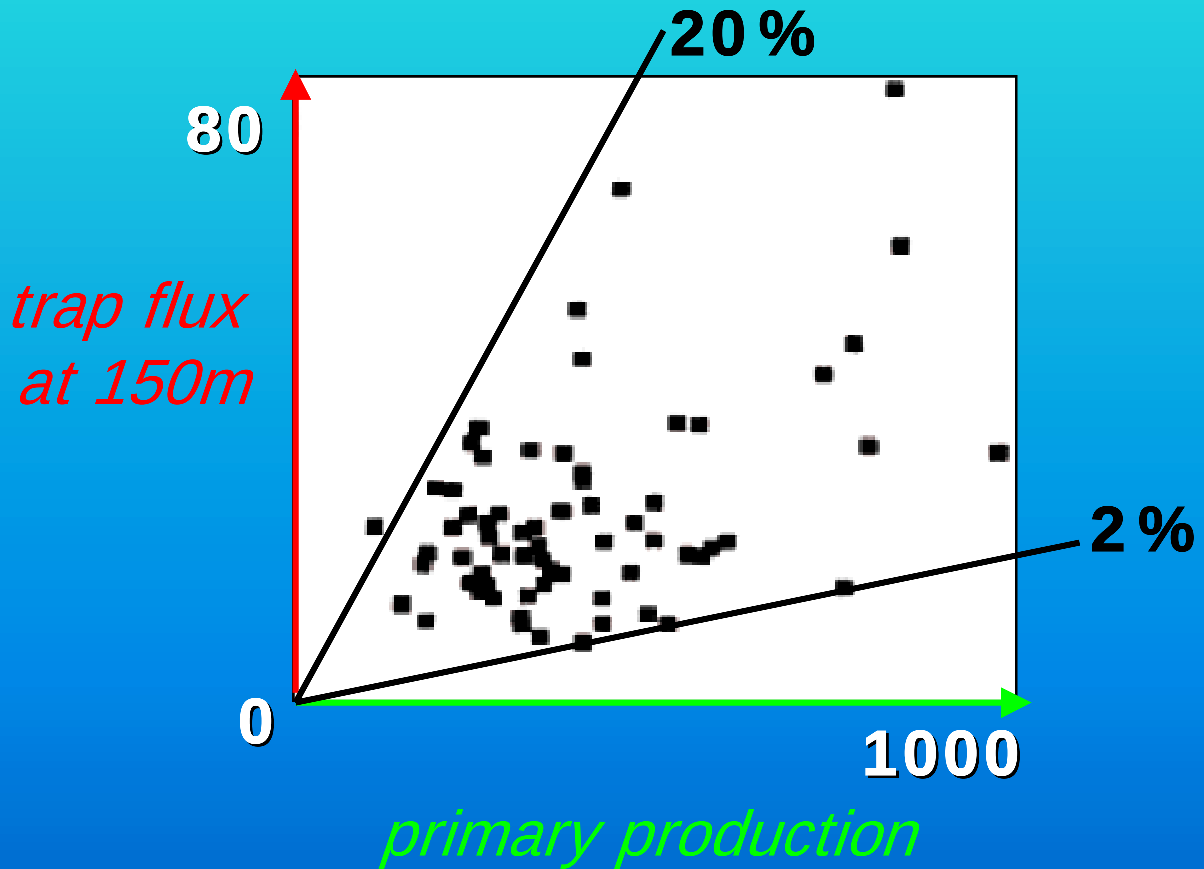
Sinking particles do not sink vertically

- **sinking velocity = 10's - >500 m/day**
- **horizontal velocity = few - 10's cm/sec**

(avg. "sinking" particle- 2 m drop & 270m trajectory during 30 min talk)

Particle export vs. primary production

Bermuda Atlantic Time-Series (BATS)



No simple relationship between production and export

(all units mg C m^{-2} d^{-1})

Michaels and Knap, 1996

What controls

Particle Export: Primary Production ratio?

- Ecology/Community Structure is important

- Timing is important

Decoupling of export:production

blooms & episodic pulses

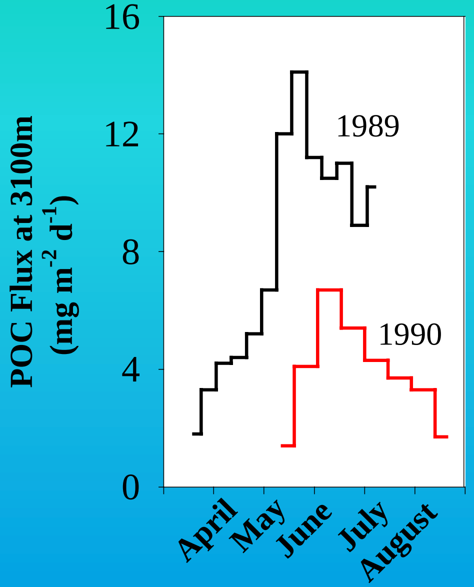
Seasonal dynamics can be large

difficulties with sampling

Impact of community structure on particle flux

North Atlantic Bloom Study

Boyd & Newton, 1995



1989 vs. 1990

Chlorophyll — **similar**

Prim. Production — **similar**

Dominant phytoplankton

1989 — **Large >200 µm diatoms**
(Chaetoceros spp.)

1990 — **Small 3-4 µm diatoms**
(Nanoneis hasleae spp.)
and autotrophic nanoflagellates

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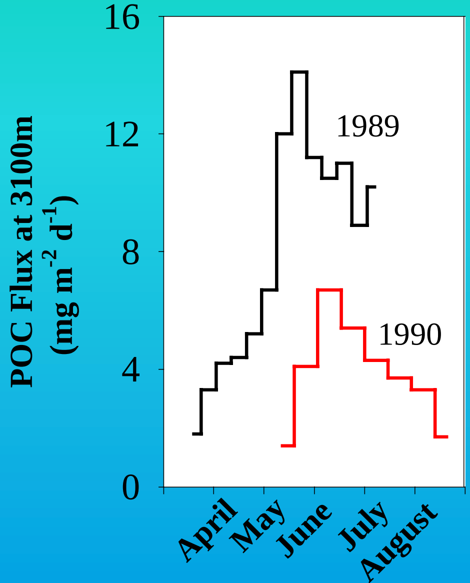

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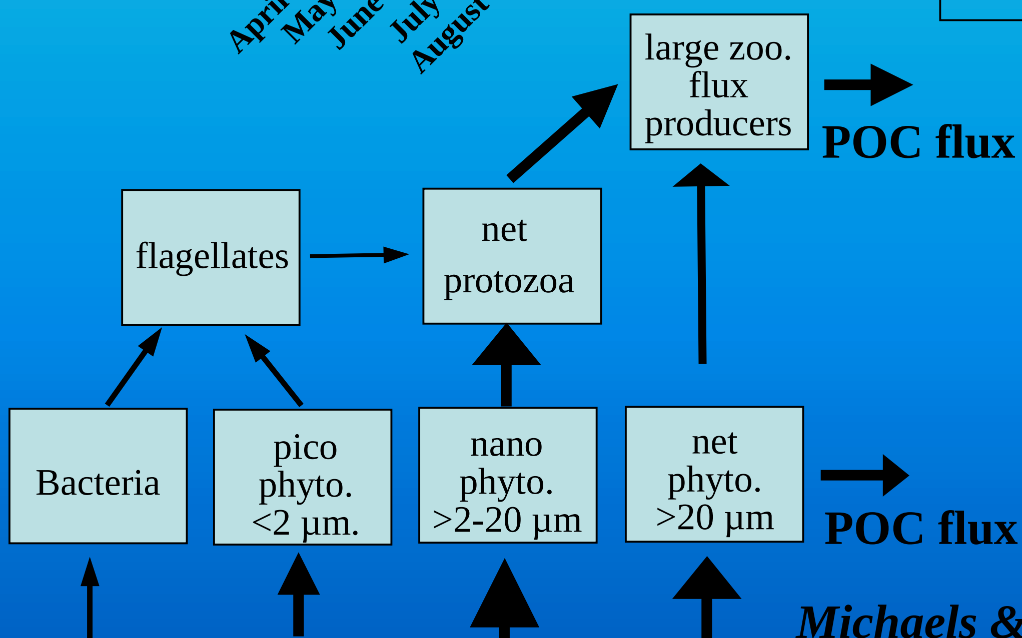
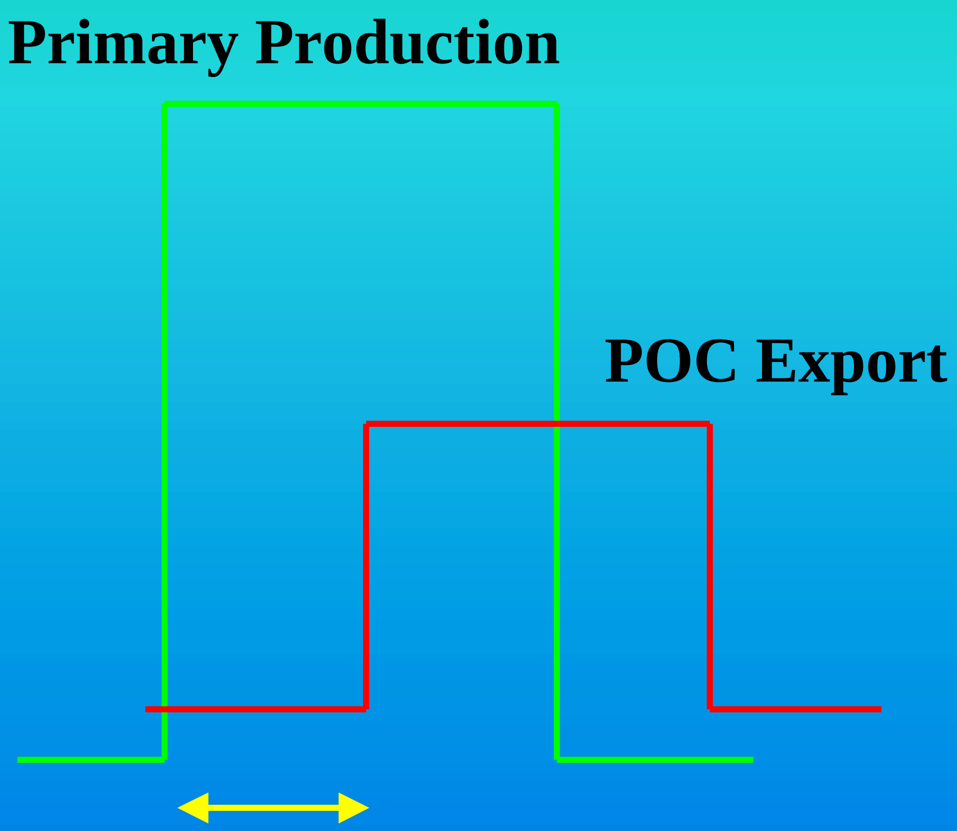


Conclusion:

Two fold change in deep POC flux due to different algal size distributions

Michaels & Silver, 1988

<u>POC Export:Production- *timing is important*</u>

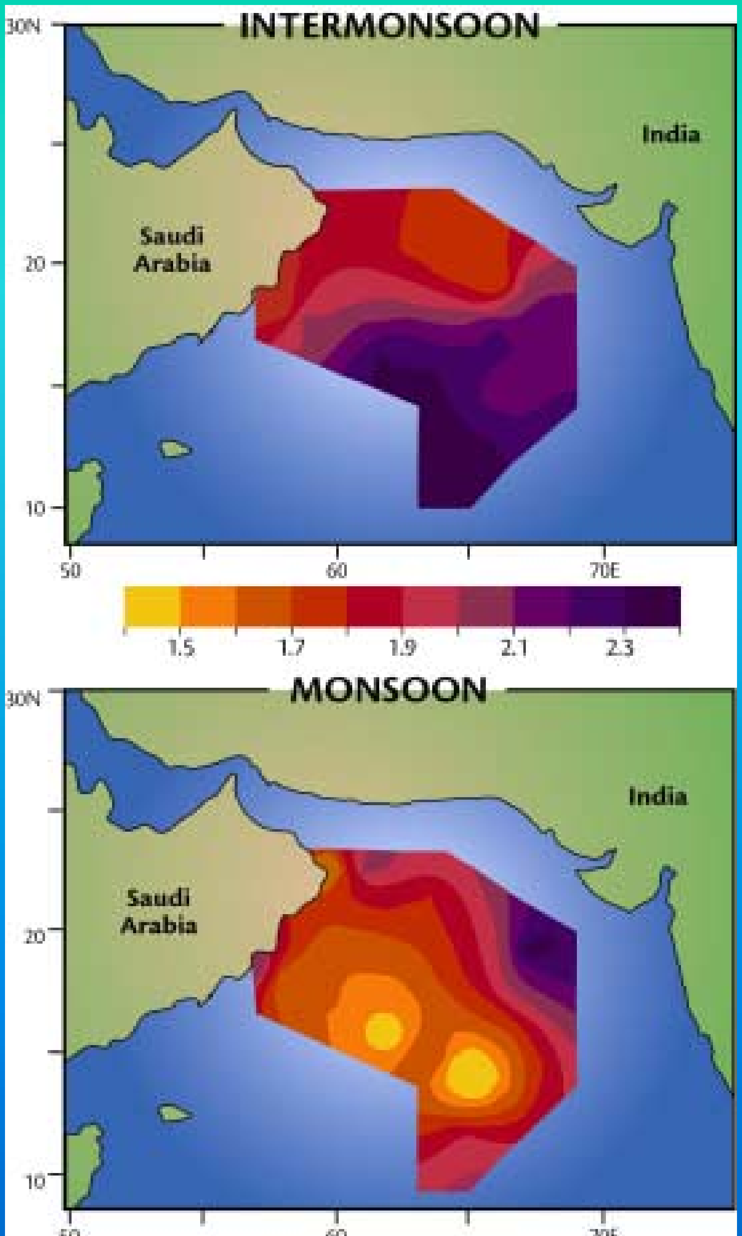


export/production ratio

- **varies within bloom**
- **varies between food webs**

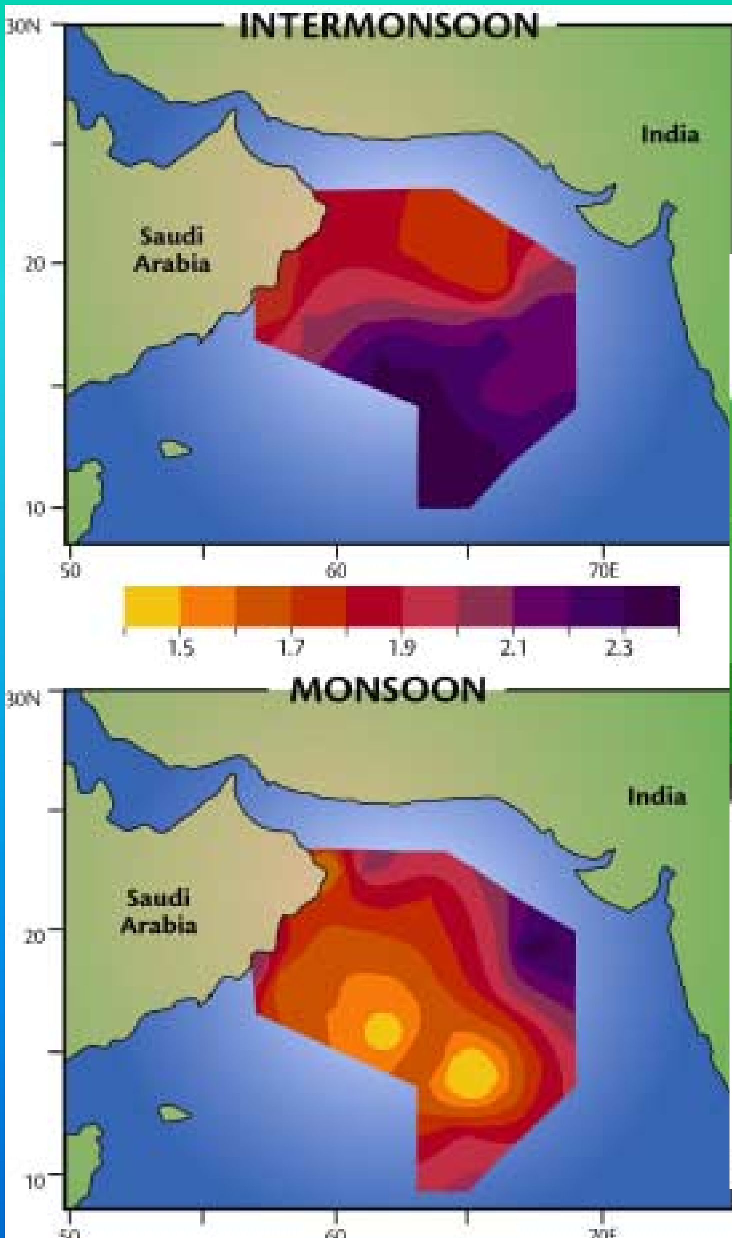
Time lag between onset of primary production and POC export

High C flux (low thorium-234) during SW Monsoon



Buesseler et al., 1998

High C flux (low thorium-234) during SW Monsoon associated with bloom of large diatoms



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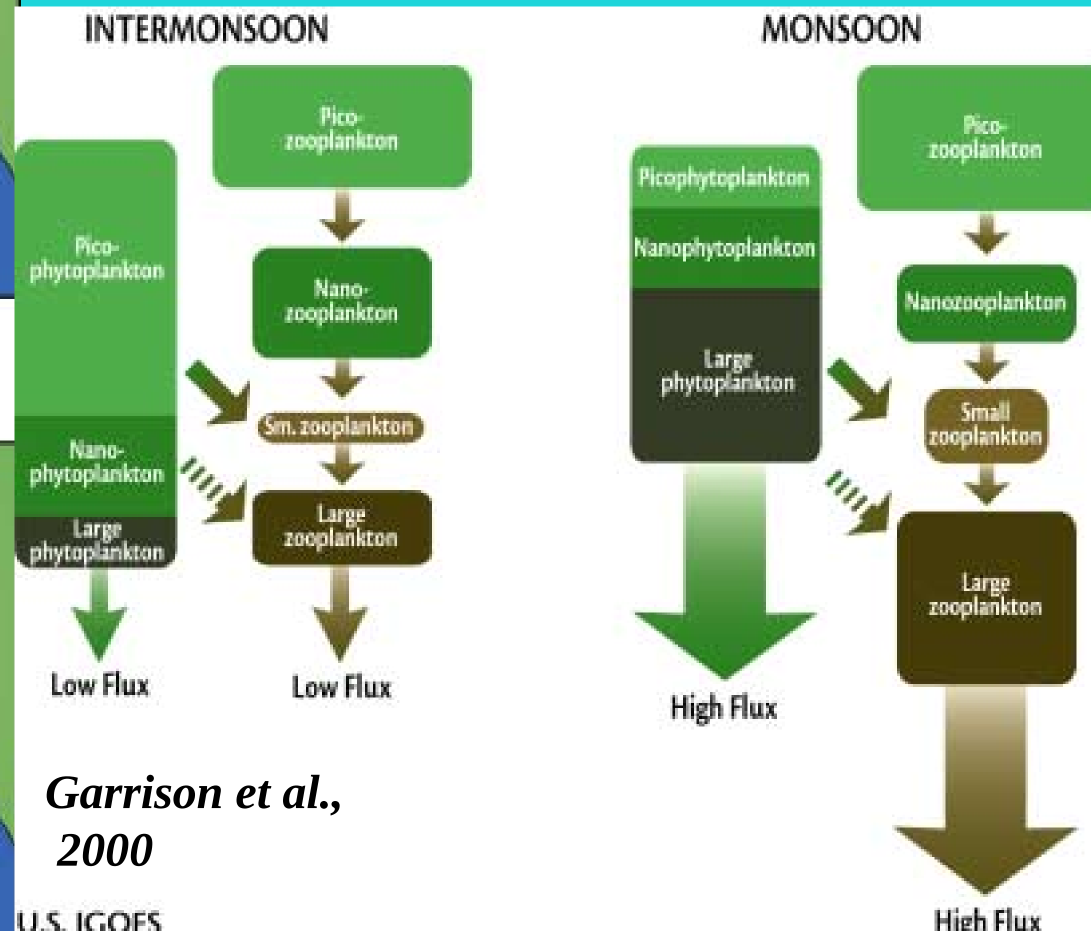
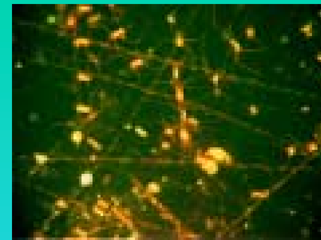
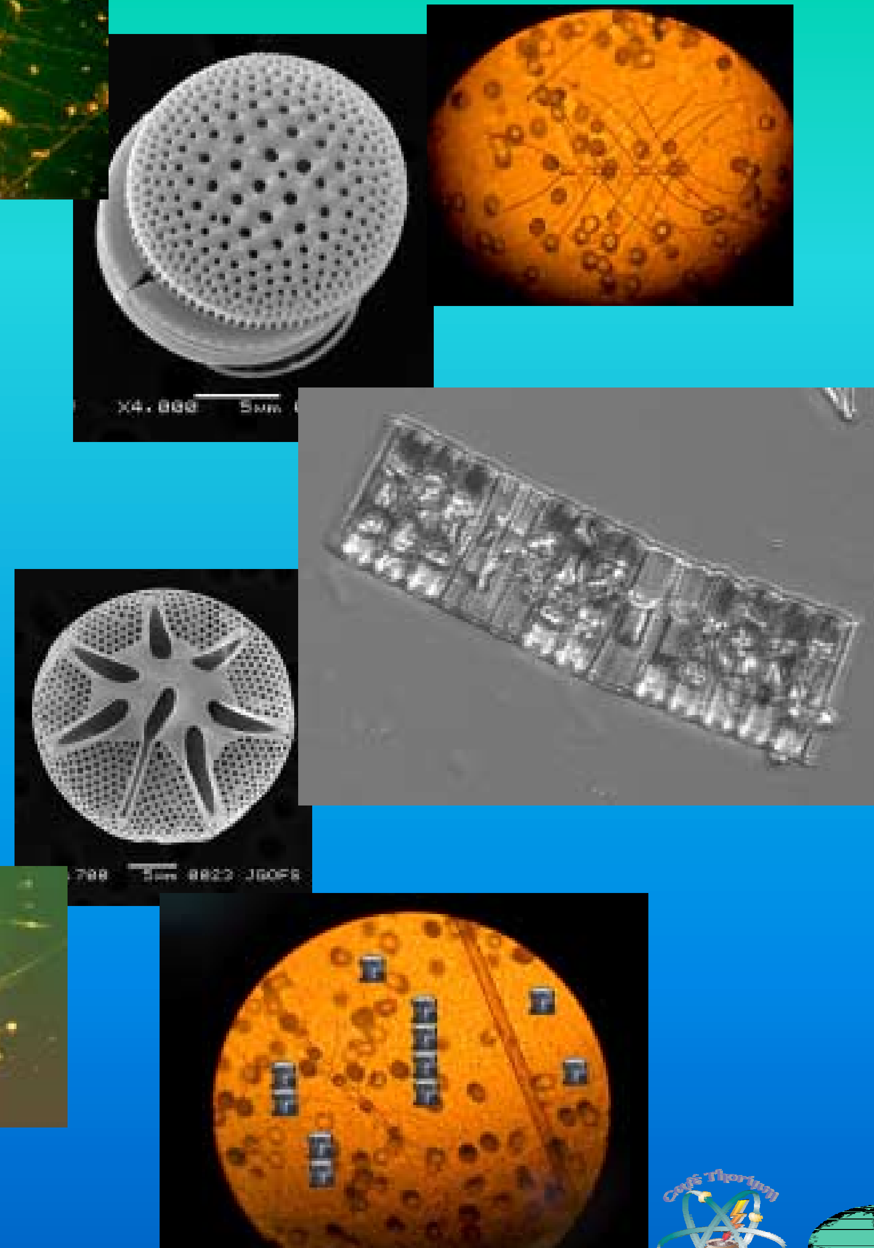


Garrison et al., 2000

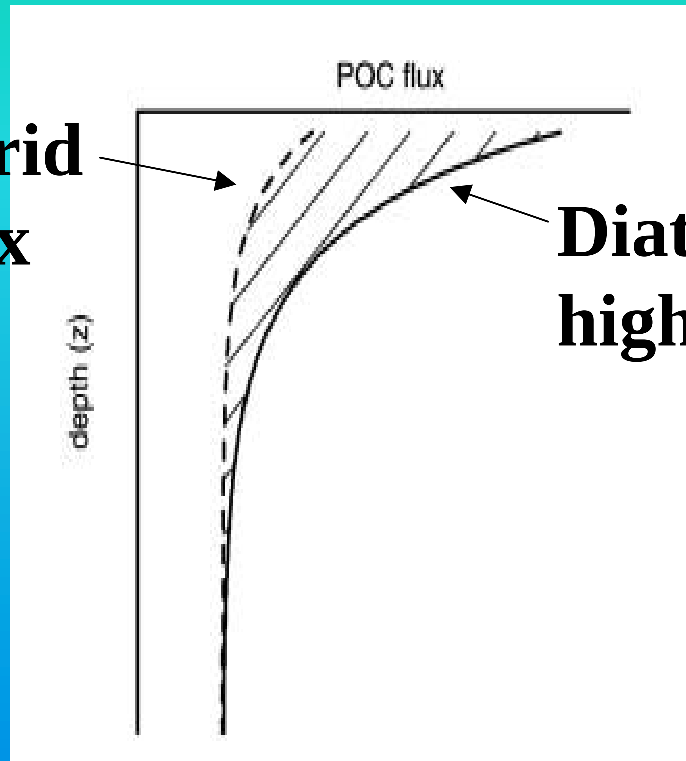




Diatoms rule!

(the upper ocean POC flux)

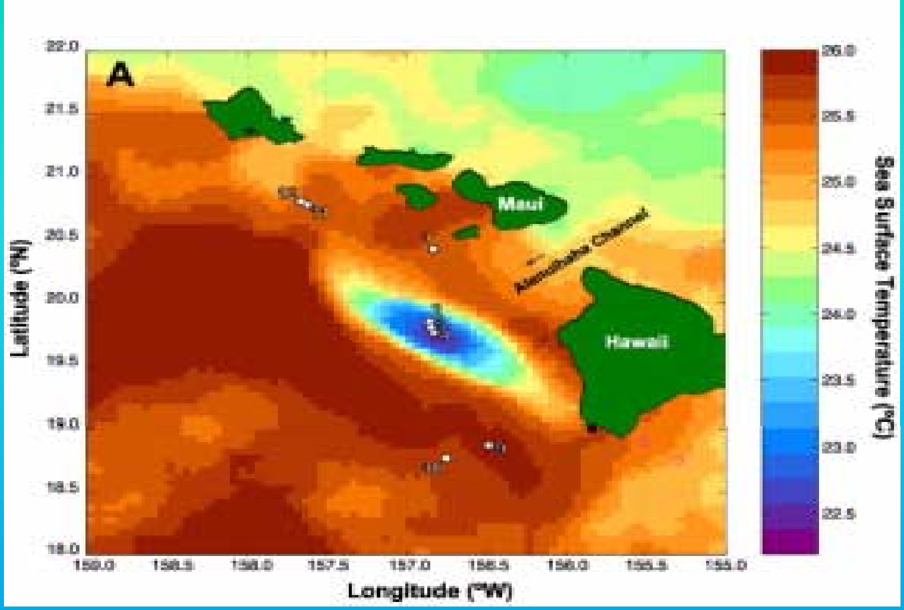
- large
- rapidly sinking
- bSi ballast
- bioprotection
- mass aggregation



Why can't diatoms control upper ocean export on regional or seasonal basis, while $CaCO_3$ materials show stronger association with deep flux?

Differences abound- in diatom types, sinking rates & bSi/C ratios

Variability in POC flux:production within mesoscale features



	In	Out
Primary Prod.	73	56
POC flux	2.6	1.0
(mmol C m^{-2} d^{-1})		
Export:Prod	3.6%	1.8%

Higher POC flux associated with larger >3μm phytoplankton

Bidigare et al., 2003

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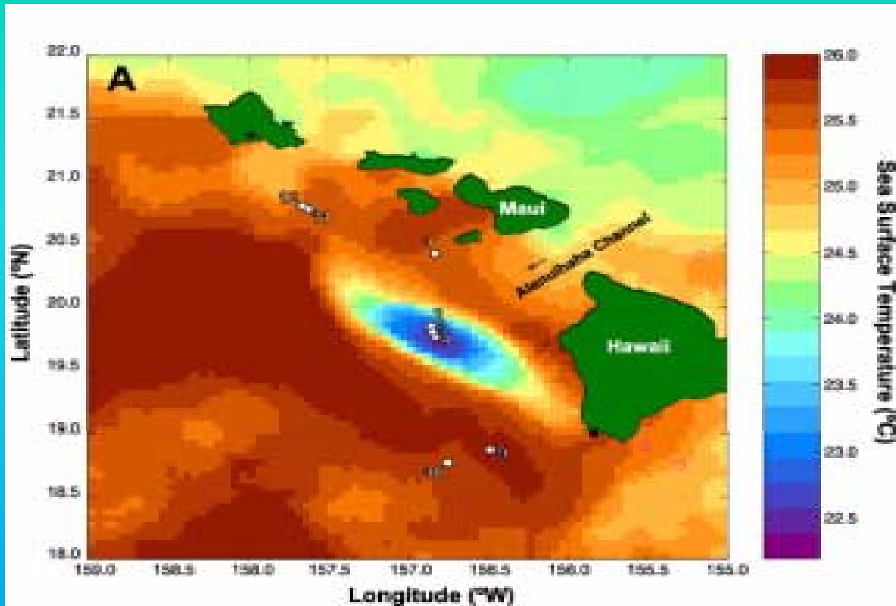

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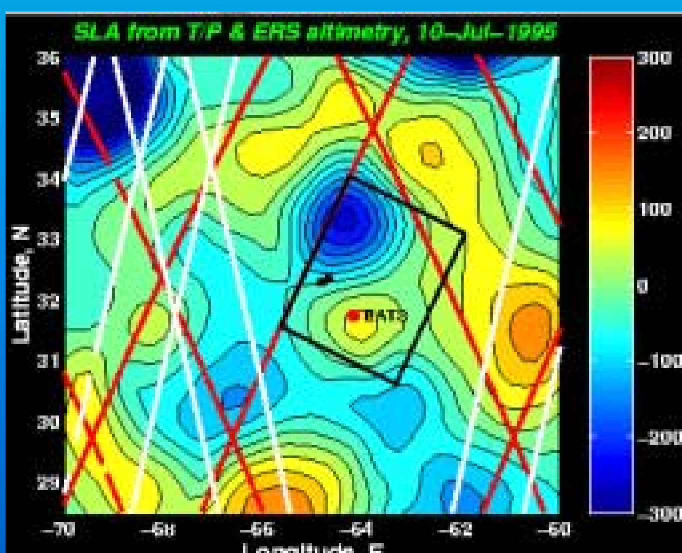


<u>BATS 1993-1995</u>

4 out of 6 high thorium-234 flux events associated with an eddy

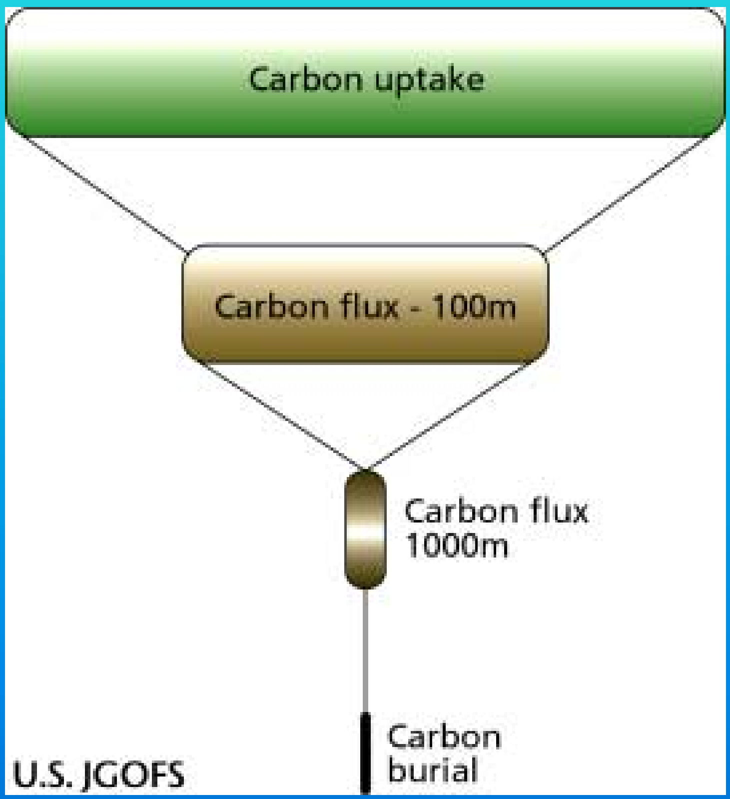
Age of the eddy matters

i.e. state of the bloom

Sweeney et al., 2003
in press

POC export efficiency

JGOFS examples



POC flux/Primary Production

(100m thorium-234 & ^{14}C methods)

North Atlantic bloom = <10-30%

Equatorial Pacific = 1-10%

Arabian Sea

- **late SW monsoon = 15-30%**
- **intermonsoon = 1-10%**

Southern Ocean = 25 - >50%

Hawaii = 4-10% (up to 22%)

Bermuda = <10% (up to 50%)

post-JGOFS view: *Life & Times of Marine Particles*

No simple relationship between particle export & production

Regional differences- export efficiency <5% to >50%

Efficiency of biological pump tied to foodweb

Diatoms rule the upper ocean (bSi ballast, bioprotection)

What about other flux producers

coccolithophores- rule the deep sea flux?

salps- massive blooms & large pellets

Seasonal & episodic variabilty important

What controls end of bloom?

grazing, nutrient limits, light/temp.

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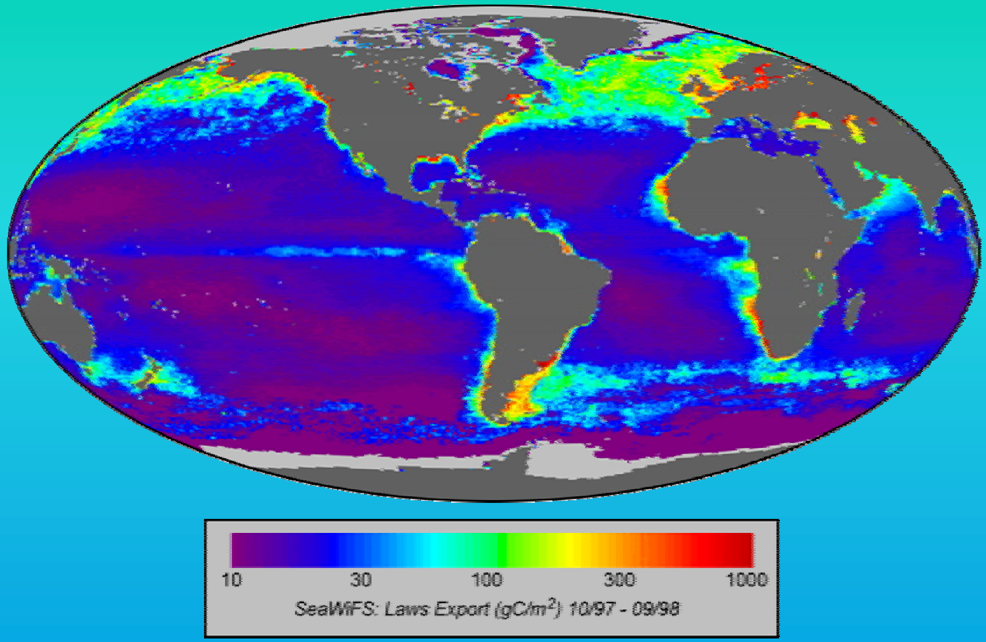
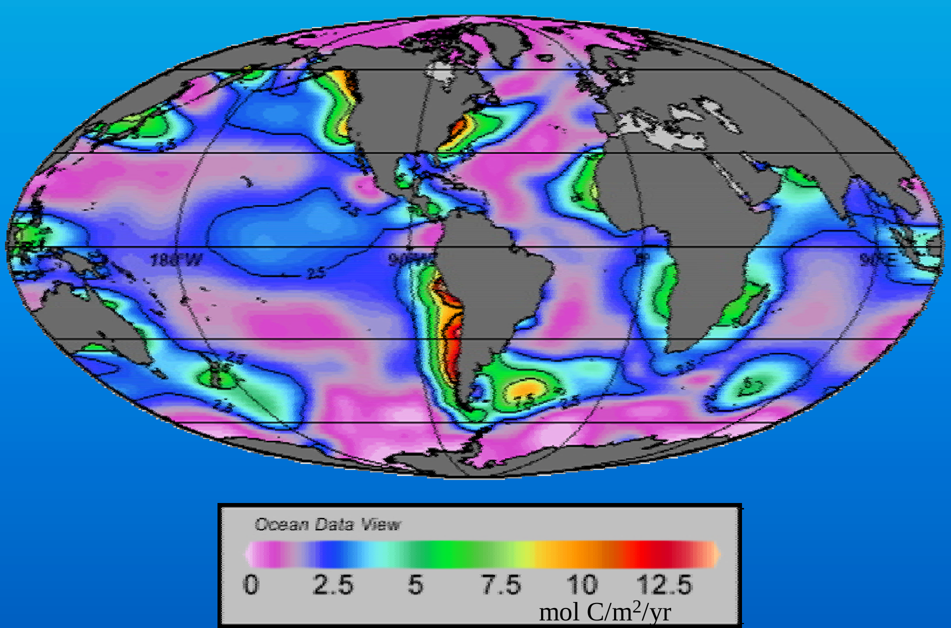
So where does this leave us with respect to models and JGOFS synthesis?

How well can we predict global POC export?



SeaWiFS PProd from Behrenfeld and temperature dependent food web model

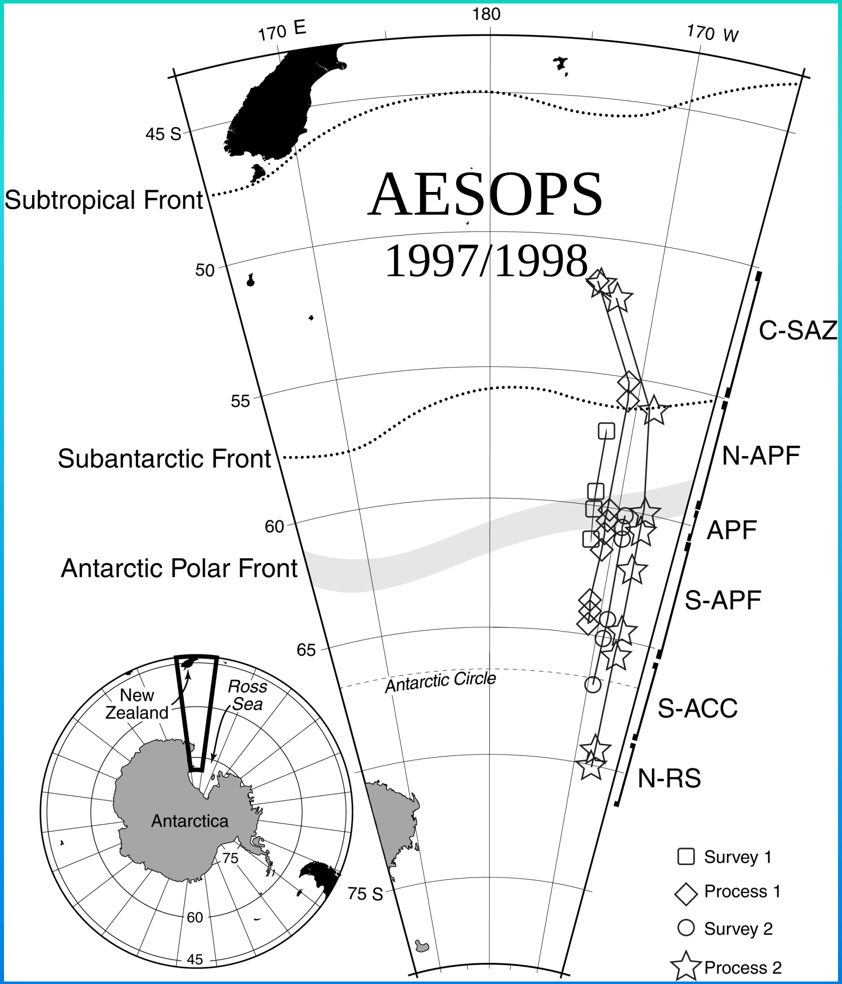
Laws et al., 2000



Inverse model used to calculate POC export flux

Schlitzer, 2002, 2003

Regional example: *Southern Ocean C cycle*



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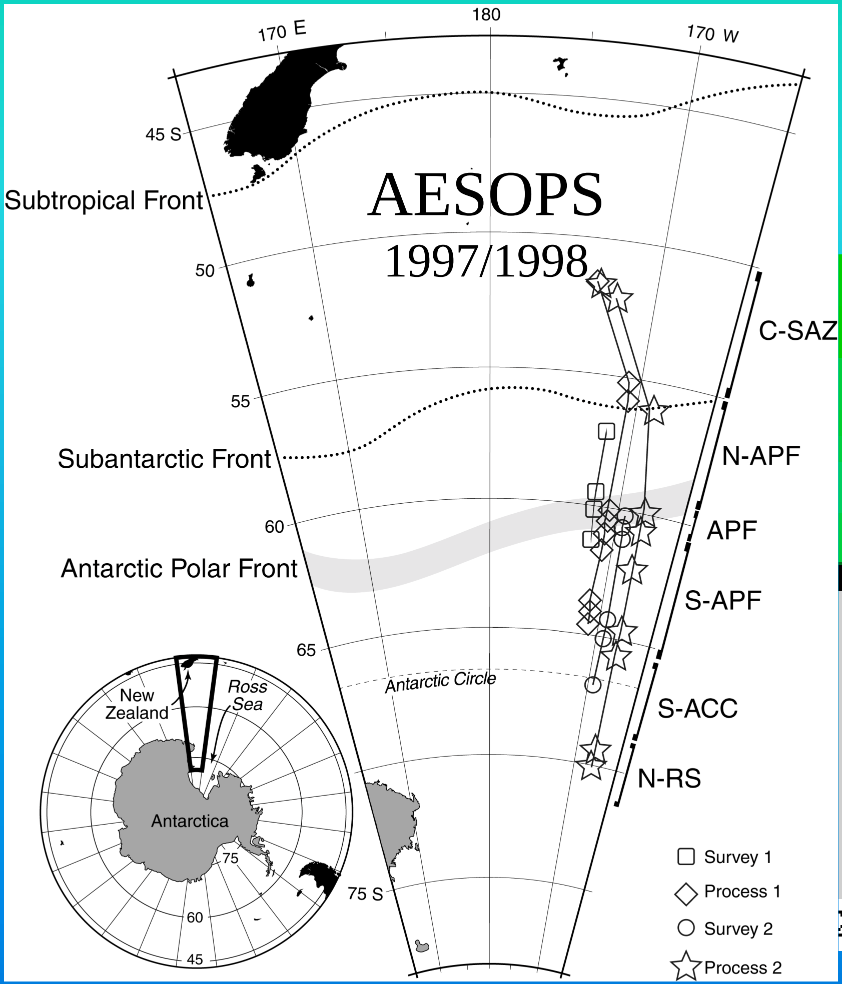
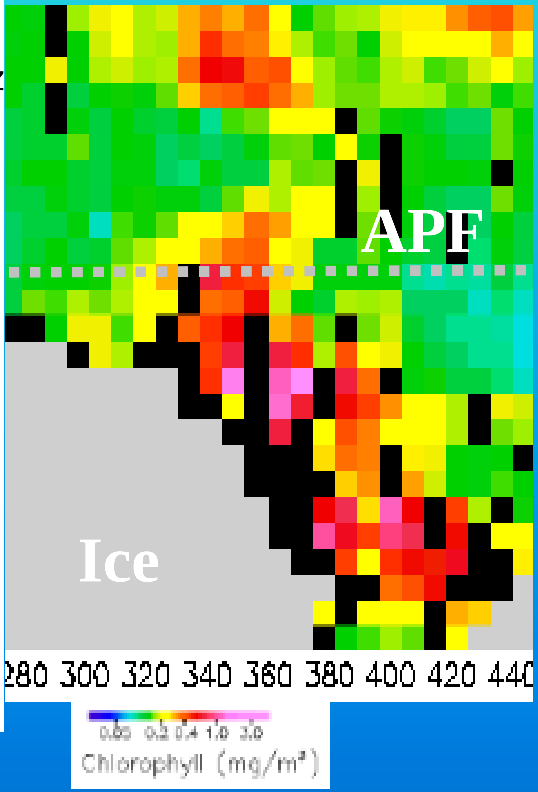


SeaWiFS Chl. vs. time



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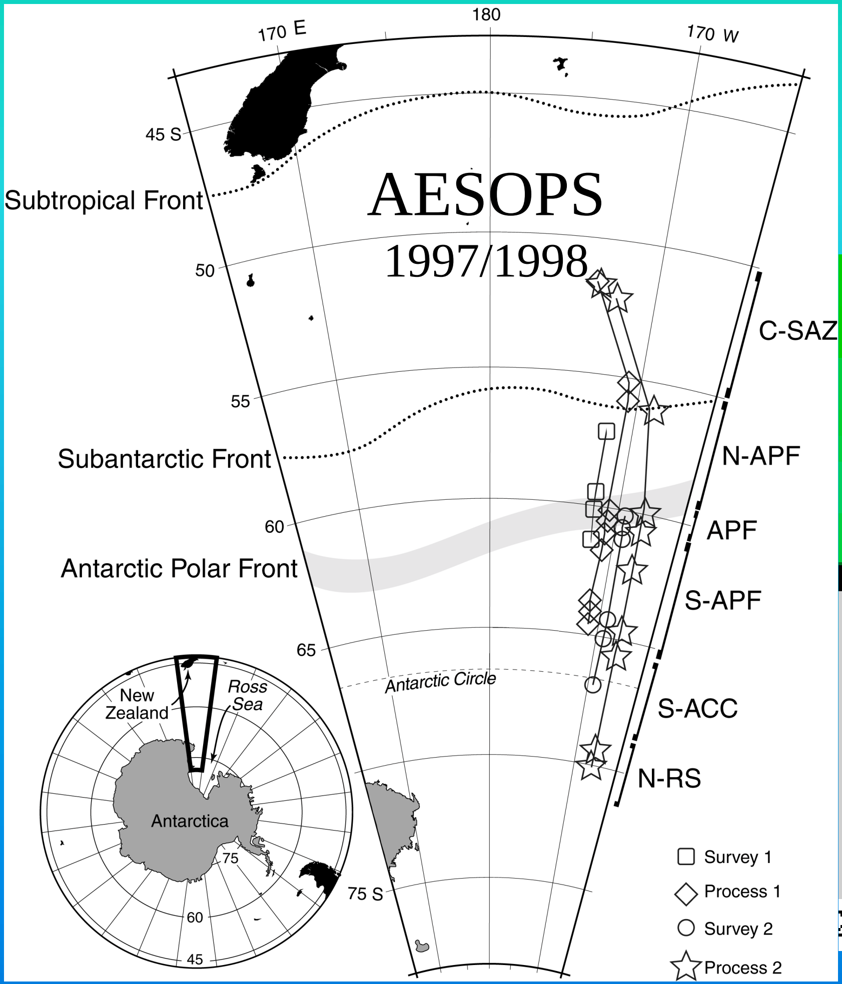

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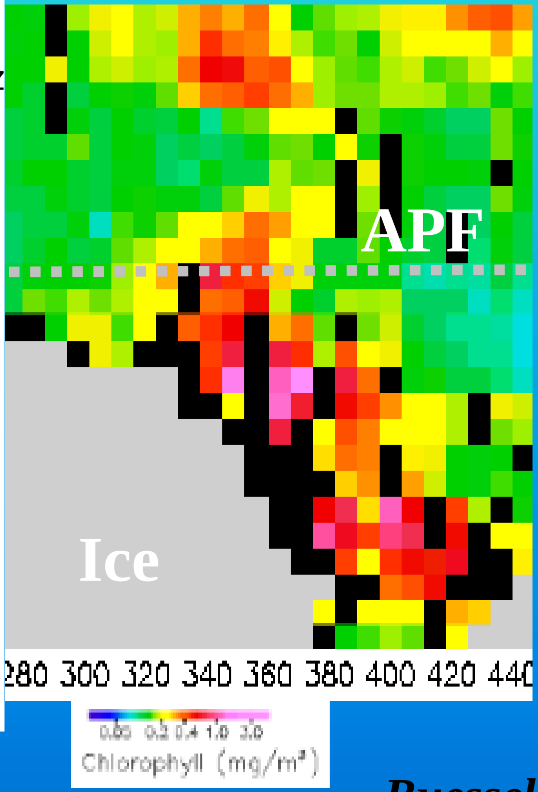

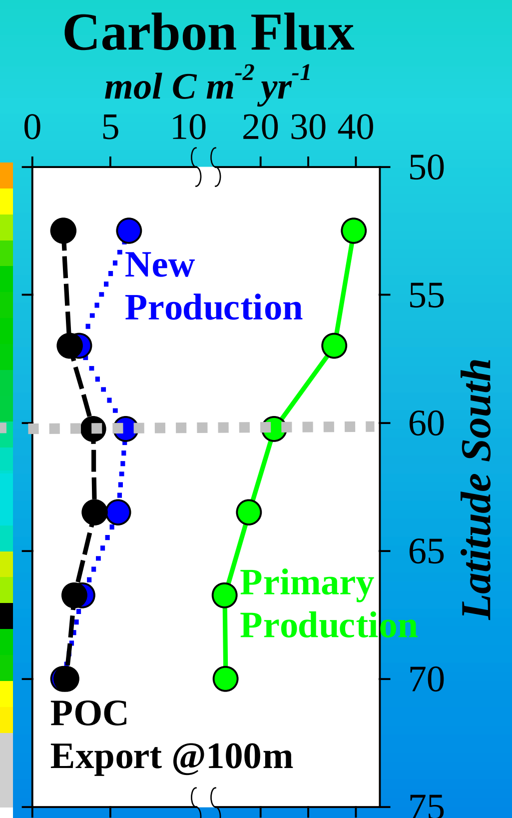

Buesseler et al., 2003

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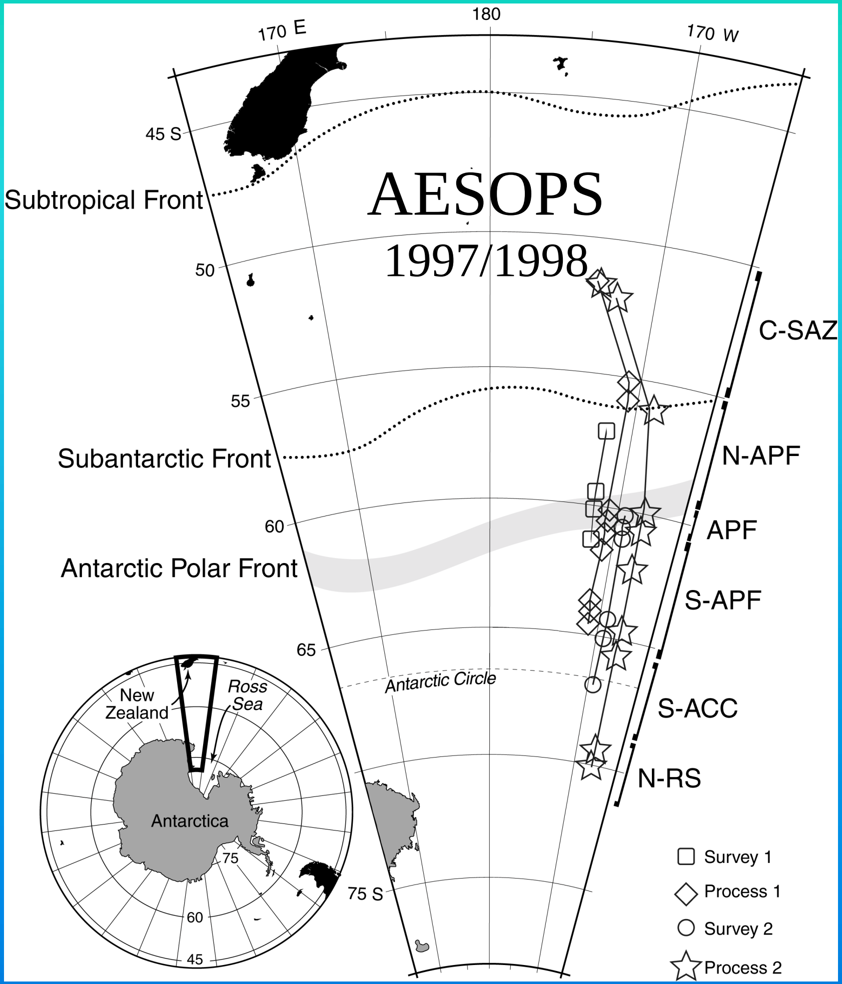


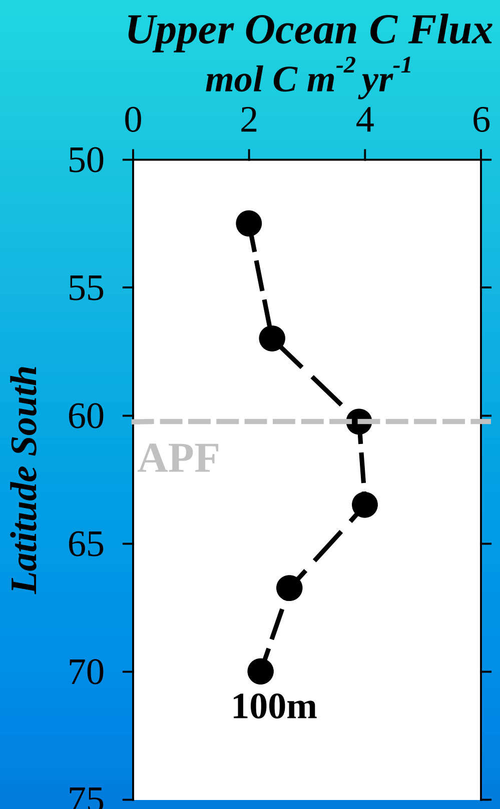
POC Flux/ Prim. Production	Seasonal Food Web & Biogeochemistry
North of APF 16-25%	Si limits to diatom growth; small phyto & microzoo grazing
APF and S-APF 35-40%	early *Phaeocystis* blooms w/retreat ice; large diatoms & aggregation w/Si depletion
S-ACC & N. Ross Sea >50-65%	*Phaeosystis* & small pennate diatoms; iron <0.2 nM; short growing season

R. Anderson, US JGOFS newsletter Apr. 2003

How well can we predict POC export?

Southern Ocean 170° W comparisons

Carbon Flux-
field estimates



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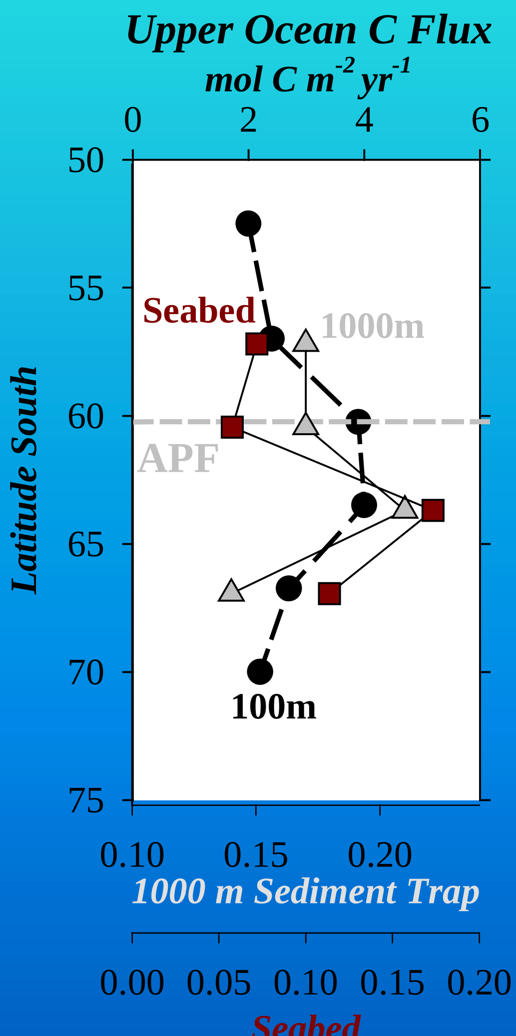

Nelson et al. 2002

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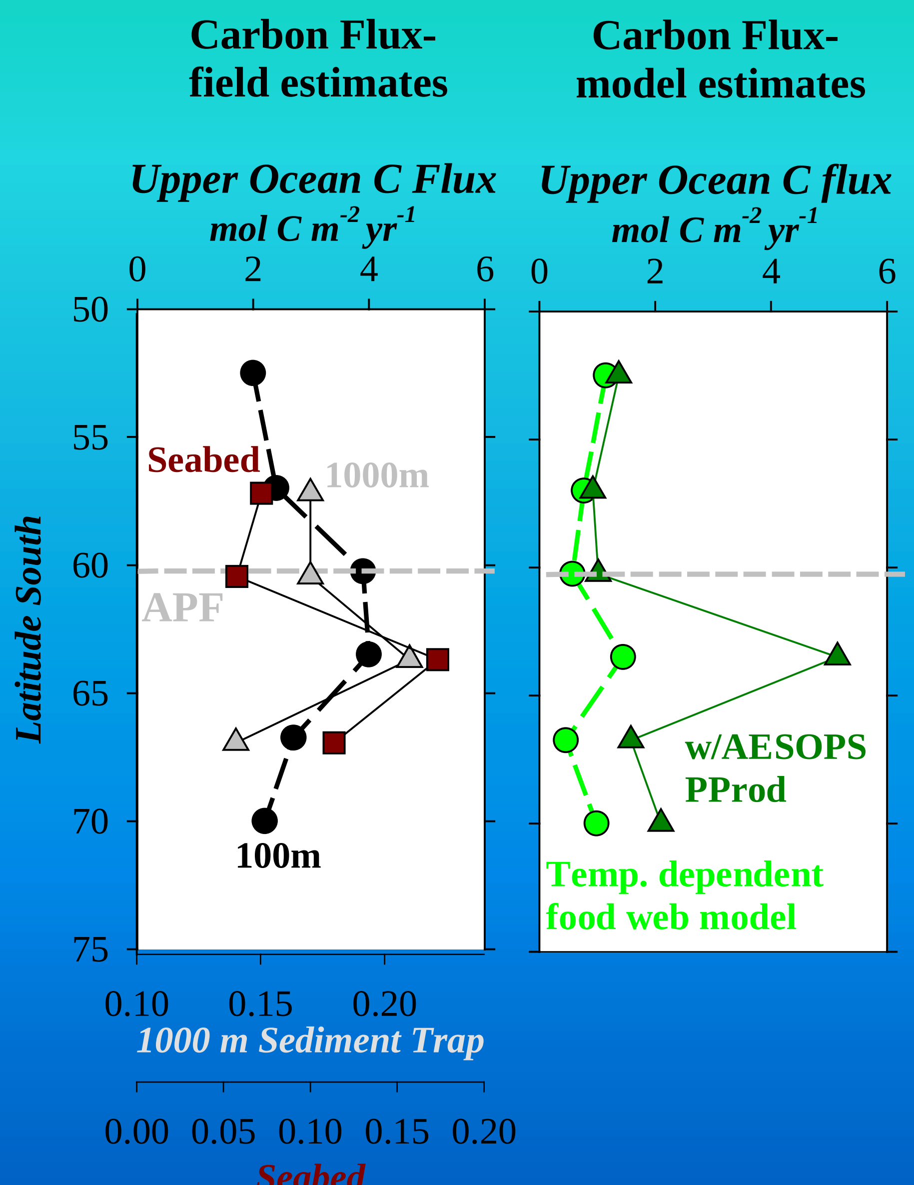

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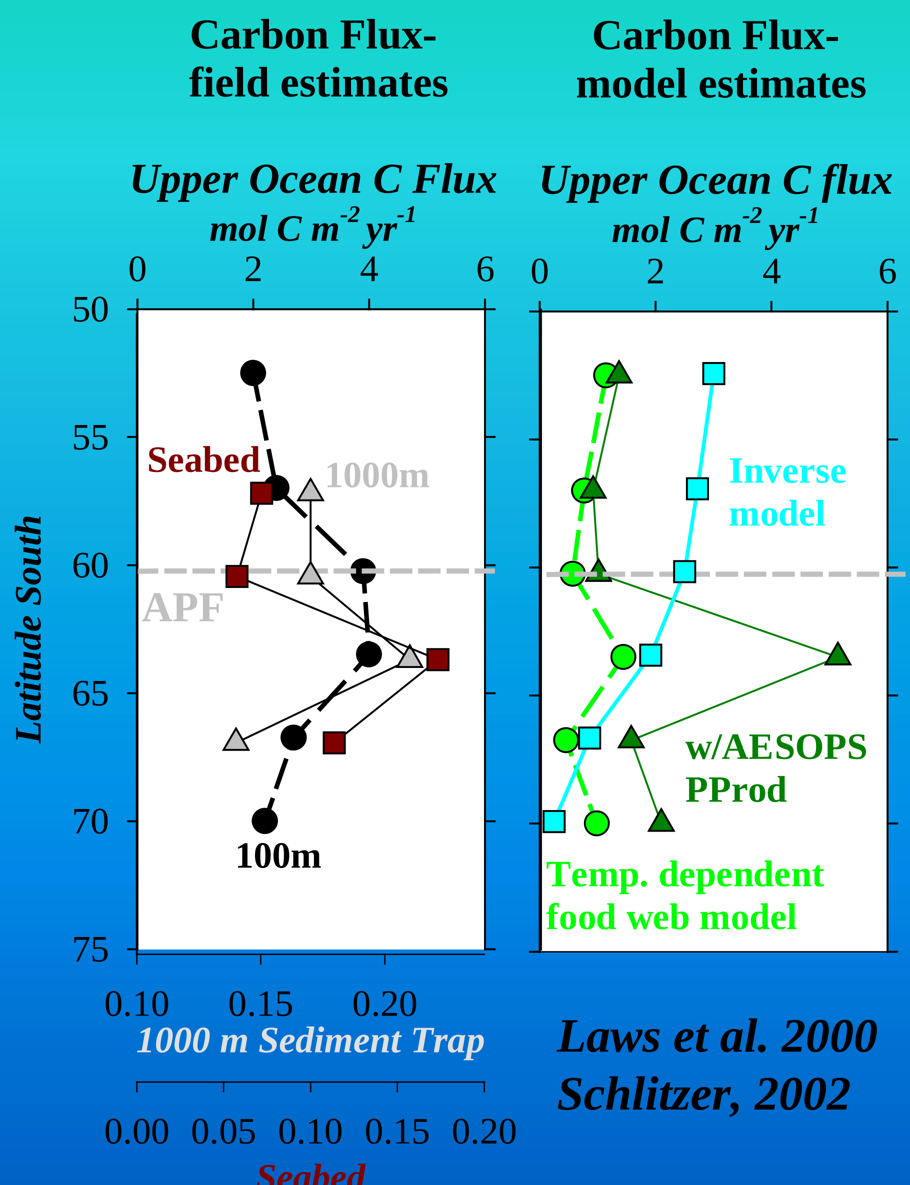

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Laws et al. 2000
Schlitzer, 2002

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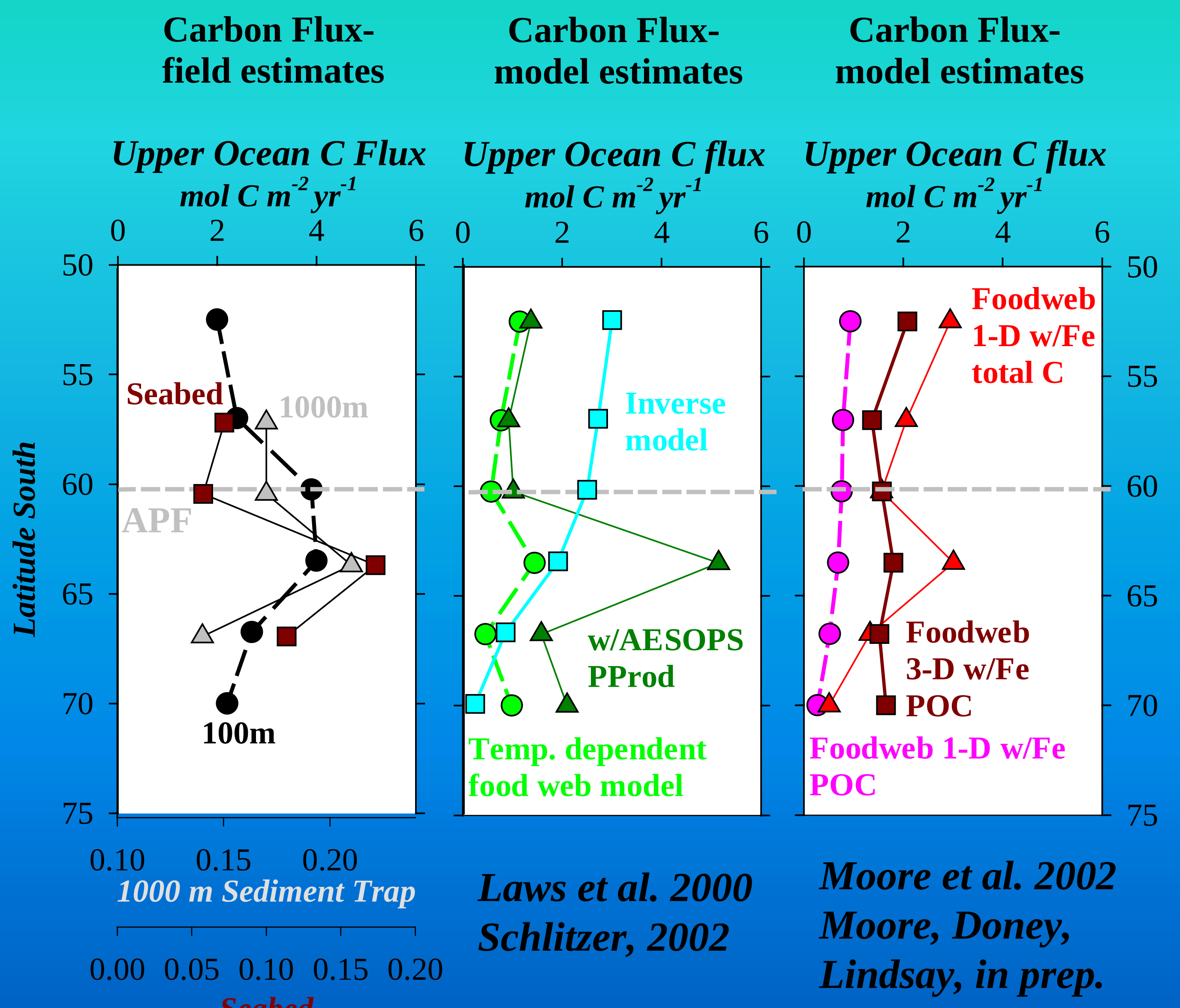

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Laws et al. 2000
Schlitzer, 2002

Moore et al. 2002
Moore, Doney, Lindsay, in prep.

Estimates of Shallow Export flux from Southern Ocean

Extrapolations to all waters >50 °S

Measured AESOPS- 1.6 Gt C yr^{-1}

one annual cycle along 170°W; peak at S. of APF

Laws- 0.6 Gt C yr^{-1}

>2x higher with new AESOPS Primary Productivity

Schlitzer- 1.0 Gt C yr^{-1}

no peak near Polar Front

Moore- ___

1-D vs. 3-D physics important; Fe and multi-limitations

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Model derived budgets of upper ocean C export are converging on global averages around 8-12 Gt C yr^{-1}, however-

- *Very few measurements on appropriate time/space scales*
- *Controls are poorly understood, so predictions with global change are unconstrained*
- *Models don't include seasonal/episodic events*

What does the future hold?

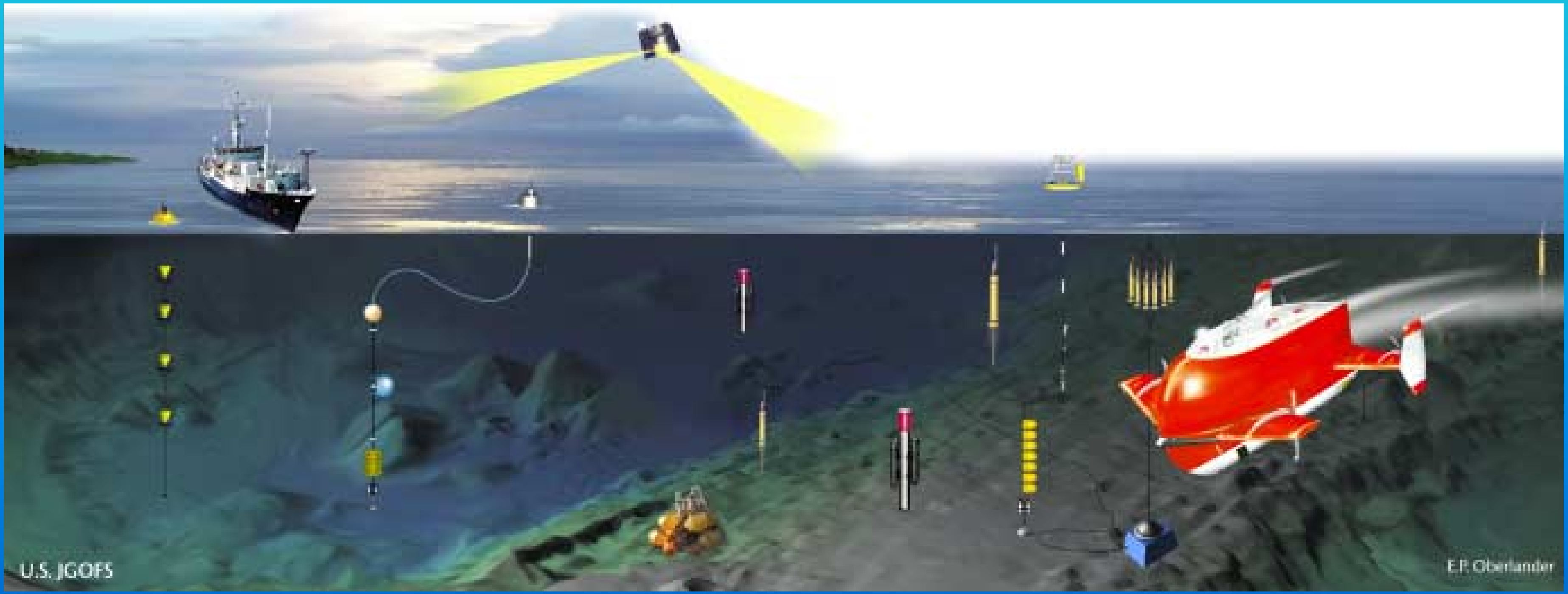
Methods Matter!

- **New developments in sampling POC & particle flux**

  Instrumented floats

  Neutrally buoyant sediment traps

  Satellite products- POC; food web info



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- **Particle geochemistry important**

- **Process studies needed to elucidate particle flux controls**

  Lagrangian time-series w/ecology & biogeochemistry

- **Biogeochemical models with improved functional ecology**

- **Inverse models for global balances**

- **Look deeper in the mesopelagic-** ***"Twilight Zone"***

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Too many to thank & credit for ideas, inspiration, challenges…