Ocean Biology, Food Webs and Climate
The Role of Surprise

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Roadmap

- Do food-webs matter for biogeochemistry?
- What do ocean food-webs look like?
- What biological processes influence air-sea partitioning of carbon dioxide?
  - HNLC regions
  - Particulate Inorganic Carbon
  - Nitrogen Fixation
  - Remineralization length-scales
- How might food-webs surprise us?
- The challenge of scale in ocean biology

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Tension and Balance

- Biologist's love of the details of life
- Biogeochemist's need to simplify in order to model global dynamics

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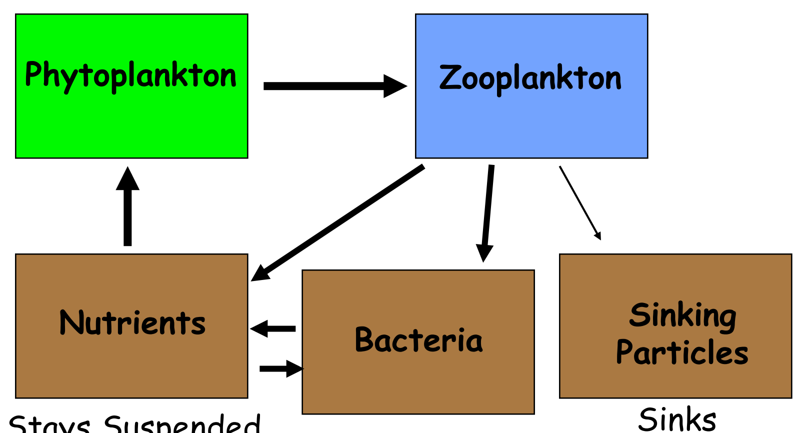
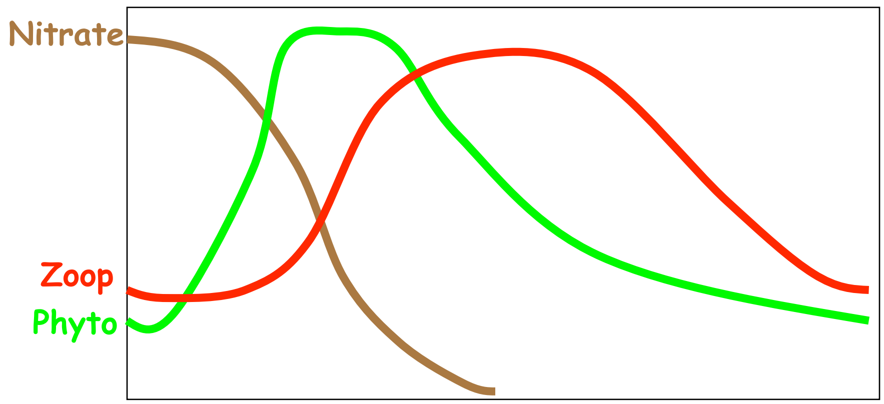
What do we need to get a food web?



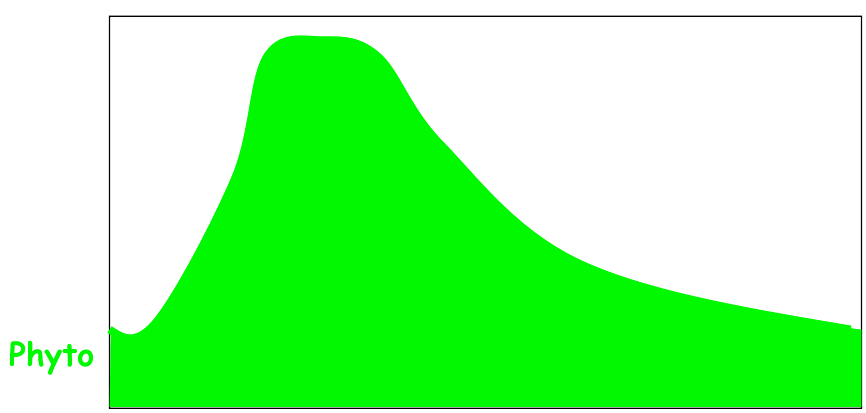
(Fasham et al., 1990)

P-Z-N Dynamics: Populations Change through Time

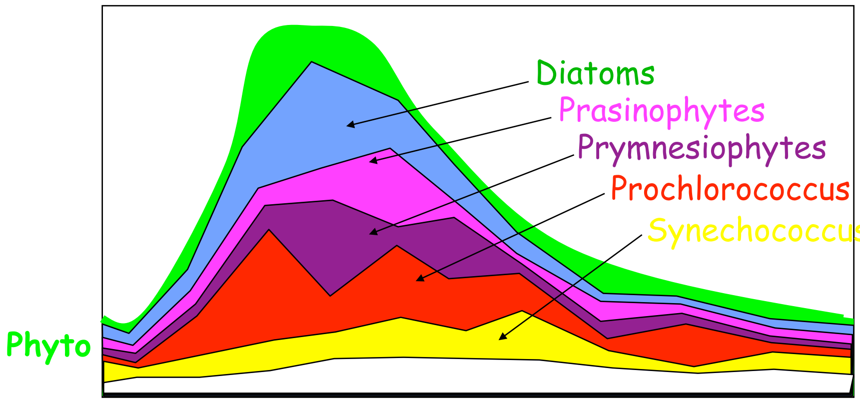


So, what are we **really** asking?

Real Question:
Does it matter what biology is hidden within each box?



Is this level of details necessary to understand the carbon cycle?



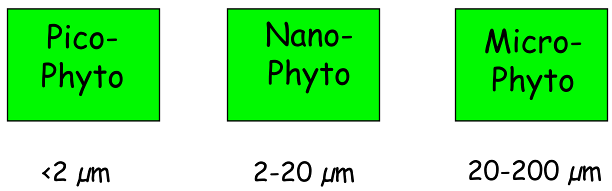
Rephrase the Question

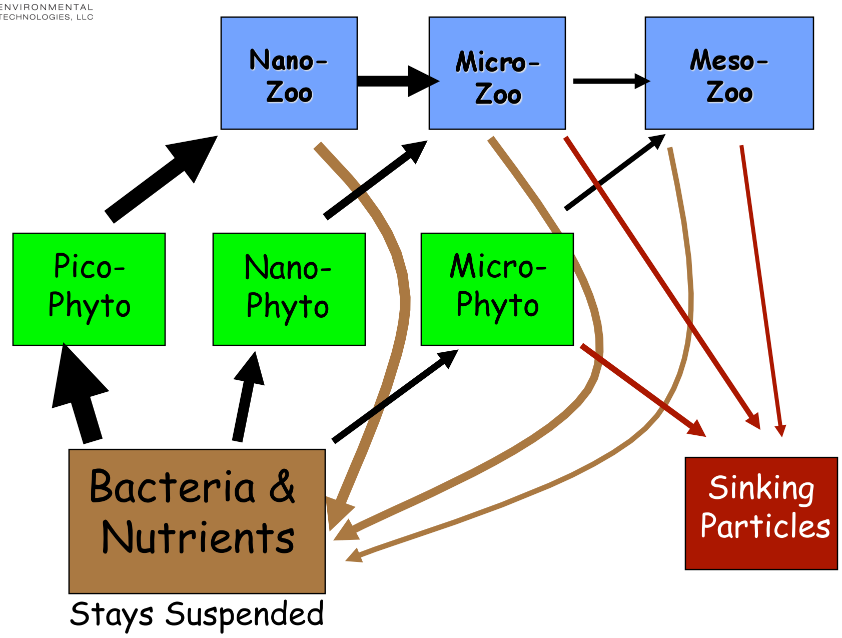
Do we need more structure than P-Z-N-B to capture the important carbon dynamics for *global* scales and for the partitioning of carbon between ocean and atmosphere?

(*e.g.,* more phytoplankton, more zooplankton, viruses, marine snow, etc.)

Community Structure and Flux: Circa 1988

Start with big size range of plants





Foodwebs and Flux - 1988

- Focus on f-ratio and the amount of export from surface waters
- “Ryther-esque” outcome (# trophic steps, transfer efficiency)
- Implication that the removal of carbon from the surface is directly related to CO_2 exchange with atmosphere

Nature’s Food Webs

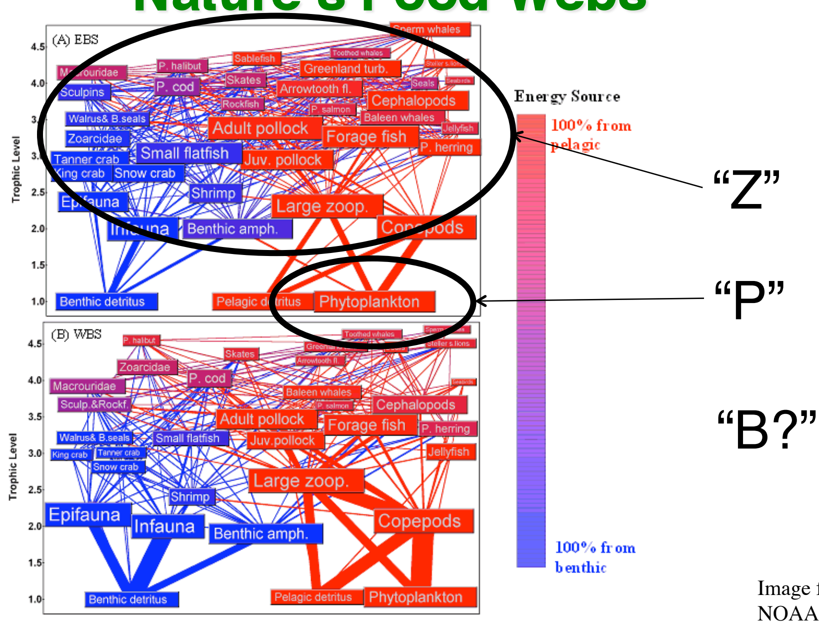
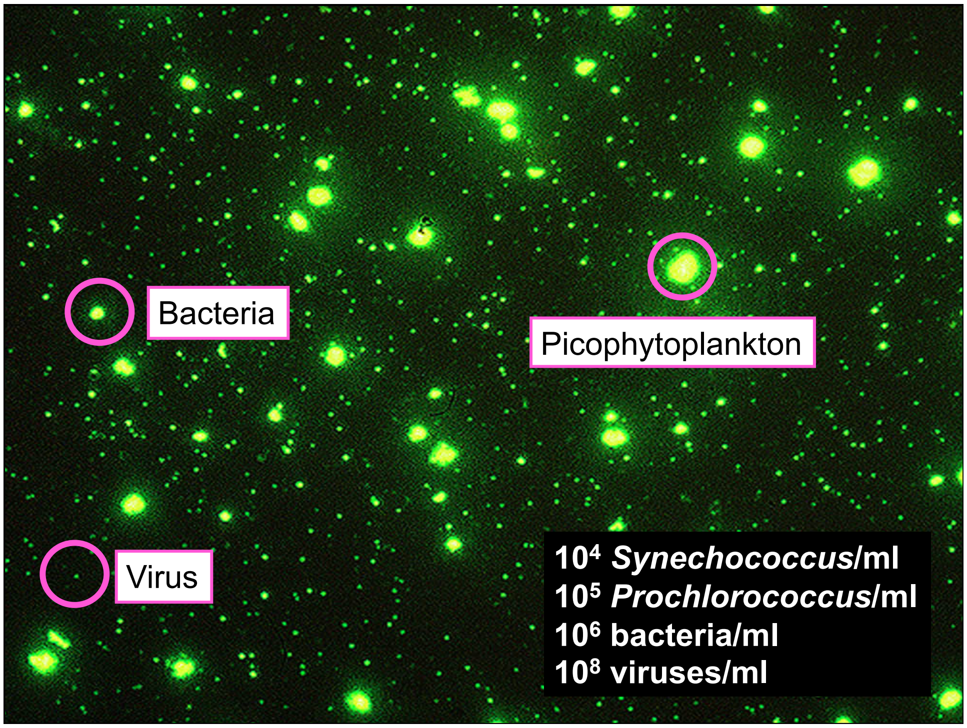


Image from NOAA



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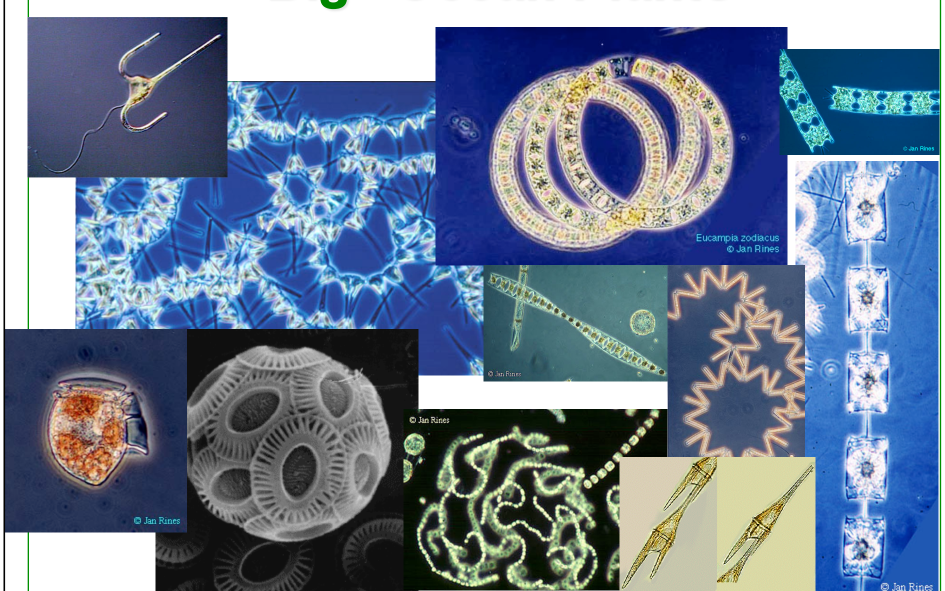
“Big” Ocean Plants



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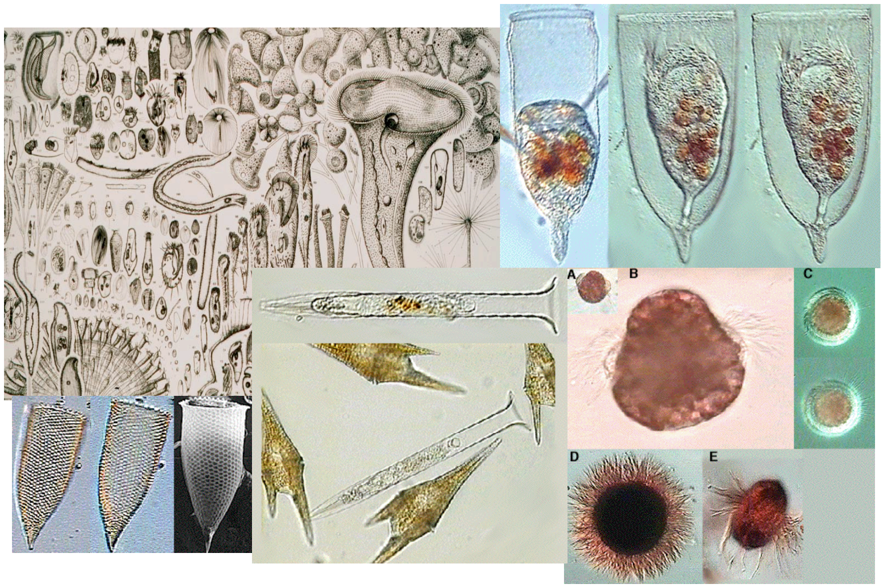
Protozoa



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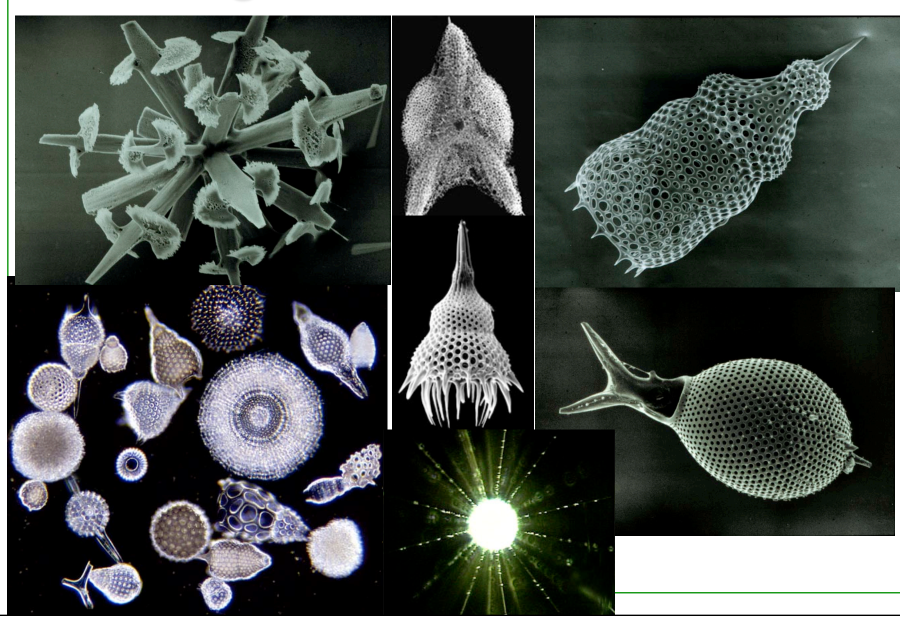
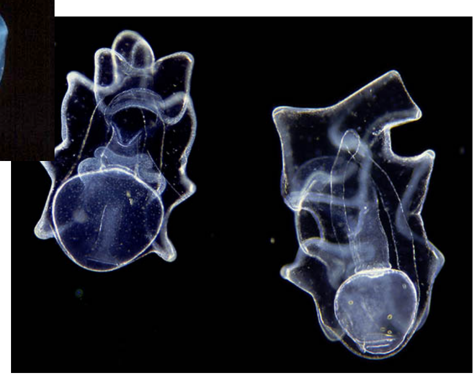
“Big” Animals - Protozoa



Crustaceans

Salps, Jellyfish and Larvae



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Fishes
The Epi-phenomenon We Eat

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But, but, but …

Does all that "structure" matter for the carbon cycle?

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What Biological Processes Can Affect Air-Sea Partitioning of Carbon Dioxide?

1. Incomplete Nutrient Utilization (HNLC)
2. Particulate Inorganic Carbon:Organic Carbon Ratio
3. Changes in Nitrogen fixation:Denitrification balance (LNLC)
4. Changes in Remineralization Length-scales

Do food webs matter for any of these?

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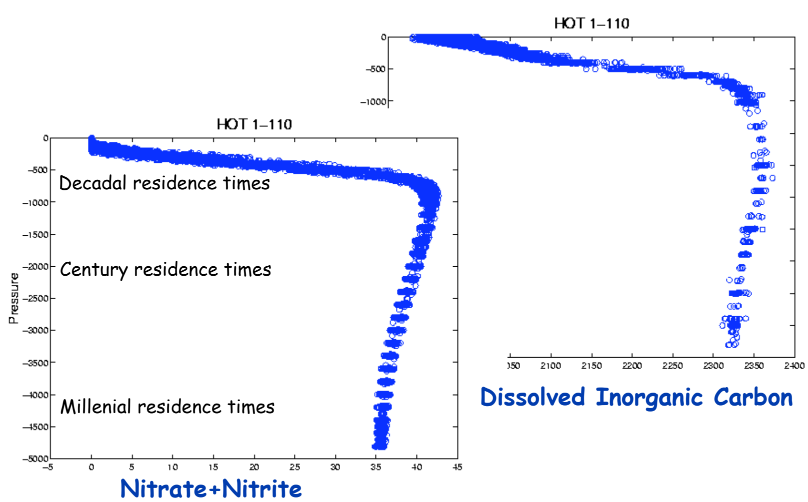
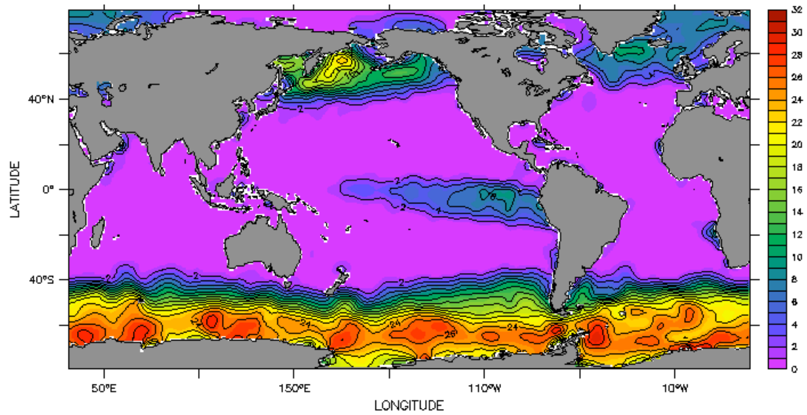
Ocean biology maintains a vertical DIC gradient - ocean biology is limited by the supply of nutrients:



Most of the ocean shows near-complete nutrient utilization



Surface Nitrate (μmoles/kg)

Low Nutrient Areas

If nutrient levels stay near detection and
if C:N:P stoichiometry is constant,

then P-Z-N should be good enough for the global carbon models

- Those are some big "**if**s"
- There is more of interest on this planet than just global carbon

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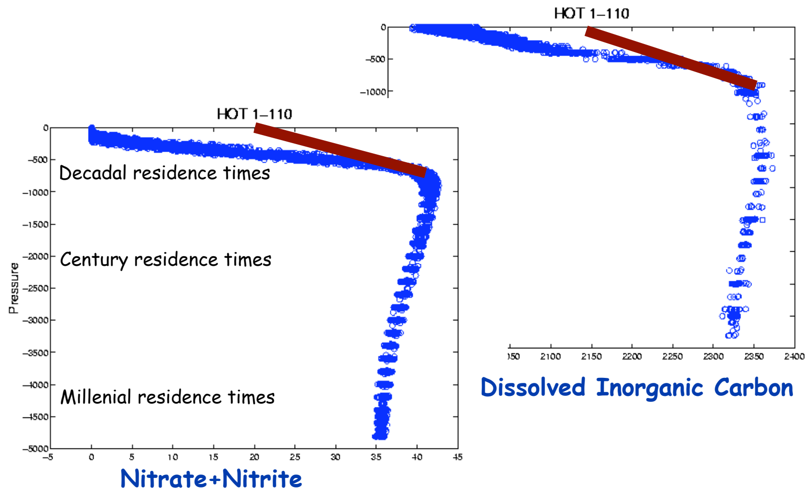
1. Incomplete Nutrient Utilization in the Surface Waters (HNLC)



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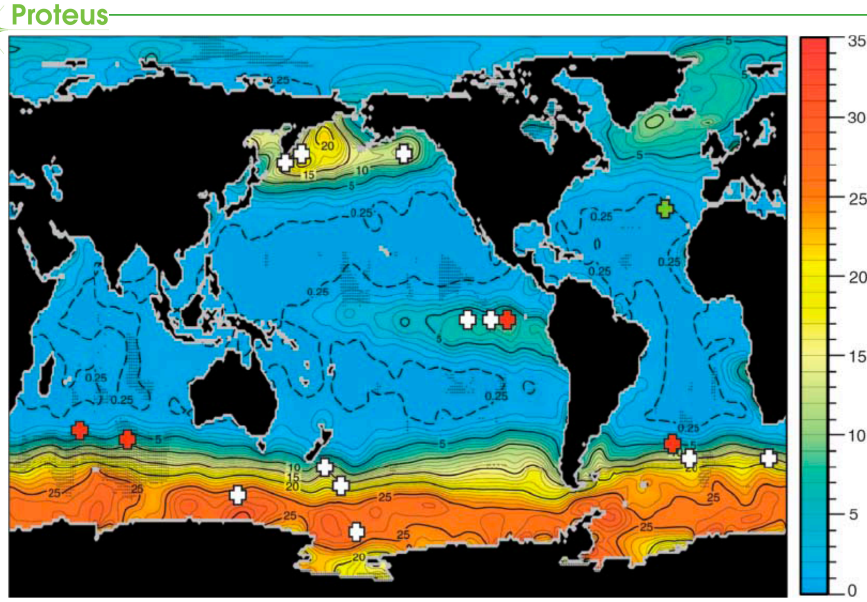
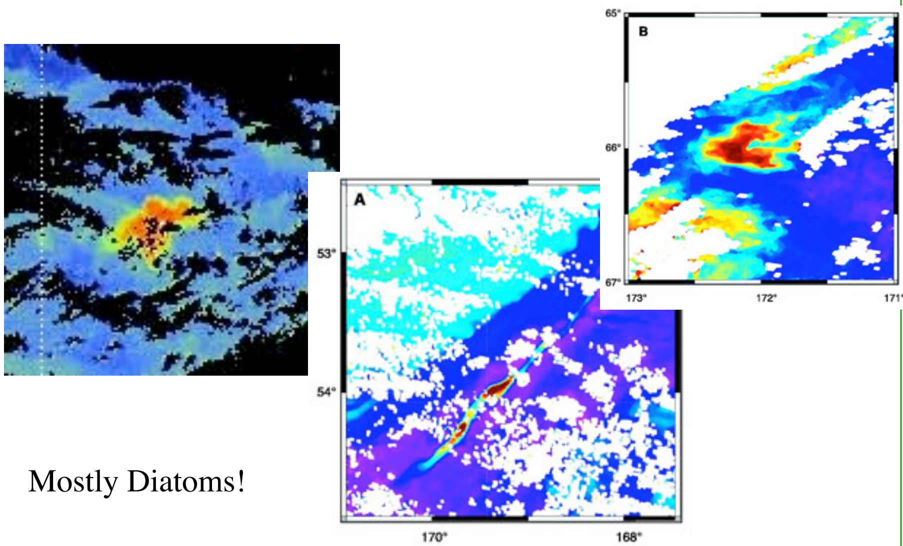


Boyd et al., 2007

Fe induced blooms



Mostly Diatoms!

Property	IronEX I (6)	IronEX II (30)	SOIREE (49)	EisenEx (56)	SEEDS I (57)	SOFEX-S (54, 58)	SOFEX-N (58)	EIFEX (46)	SERIES (17)	SEEDS II (59)	SAGE (59)	FeeP (59)
Fe added (kg)	450	450	1750	2350	350	1300	1700	2820	490	480	1100	1840
Temperature (°C)	23	25	2	3 to 4	11	−1	5	4 to 5	13	9 to 12	11.8	21
Season	Fall	Summer	Summer	Spring	Summer	Summer	Summer	Summer	Summer	Summer	Fall	Spring
Light climate (μmol quanta m^{-2} s^{-1})	254 (max) to 230 (min)	216 to 108	59 to 33	82 to 40	178 to 39	103 to 62	125 to 74		173 to 73		59 to 52	
Dilution rate (day^{-1})	0.27	0.18	0.07	0.04 to 0.43	0.05	0.08	0.1		0.07 to 0.16			0.4
Chlorophyll, $t = 0$ (mg m^{-3})	0.2	0.2	0.2	0.5	0.9	0.2	0.3	0.6	0.4	0.8	0.6	0.04
Chlorophyll, maximum (mg m^{-3})	0.6	3.3	2.3	2.8	23.0	2.5	2.4	3.0	5.5	2.4	1.3	0.07
MLD (m)	35	40*	65*	80*	13	35	45	100	30*	30	70*	30*
Bloom phase (duration, days)	Evolving (5) subducted	Decline (17)	Evolving (13)	Evolving (21)	Evolving (10)	Evolving (28)	Evolving (27) subducted	Partial decline, evolving	Decline (25)	Evolving (25)	No bloom (17)	No bloom (7)
delDIC	6	26	17	14	58	21	13	36		nc	<1	
δDMS (μmol m^{-3})	0.8	1.8	2.9	1.3, then to 0†	nc	nc	Increased		8.5, then to −5.7†	nc	nc	nc
Dominant phytoplankton	Mixed	Diatom	Diatom	Diatom	Diatom	Diatom	Mixed	Diatom	Diatom	Mixed	Mixed	*Cyanobacteria Prochlorococcus*
Export	nc	increase	nc	nc	nc	Increase	Increase§	Increase	Increase	nc	nc	
Mesozooplankton stocks	Increase‡	Increase	nc	nc	nc	nc	nc	Increase	Increase	Increase	nc	nc
Primary production (max/min ratio)	4	6	9	4	4	6	10	2	10		2	1.7

*Changes in MLD were observed during the study; the maximum MLD is shown (for initial MLD, see table S1). †An initial increase in DMS concentration followed by a decline by the end of the study. ‡Based on anecdotal evidence. §Increased export was mainly associated with a subduction event.

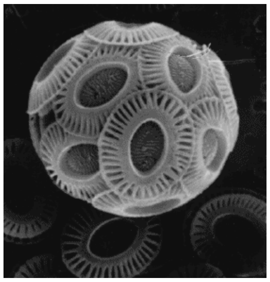
Boyd et al., 2007

2. Changes in Particulate Inorganic Carbon Flux

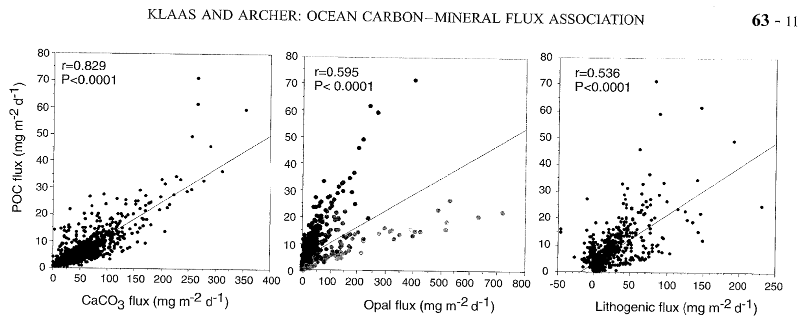
- Archer and Maier-Reimer, 1994
- Skeletons of coccolithophorids, foraminifera and pteropods
- Alkalinity change! Increase in PIC flux -> increase in pCO_2
- Net effect on atmosphere depends on PIC:POC ratio
- Community structure effects analogous to remineralization length scale

They Change Alkalinity!

- Three main taxa:
  - Coccolithophorids
  - Foraminifera
  - Pteropods

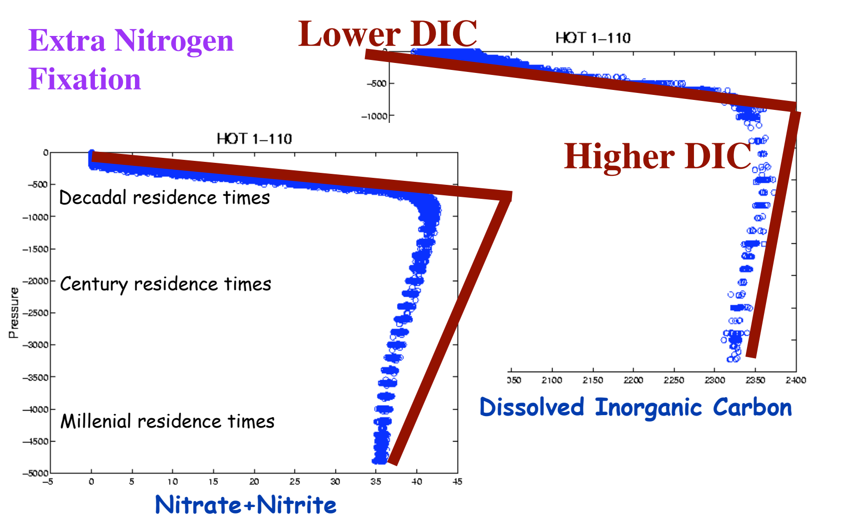


Carbonate Flux Linked to Organic Carbon Flux via Ballasting (a la Armstrong et al, 2002)



(Klaas and Archer, 2002)

3. Changes in Nitrogen Fixation - Denitrification Balance



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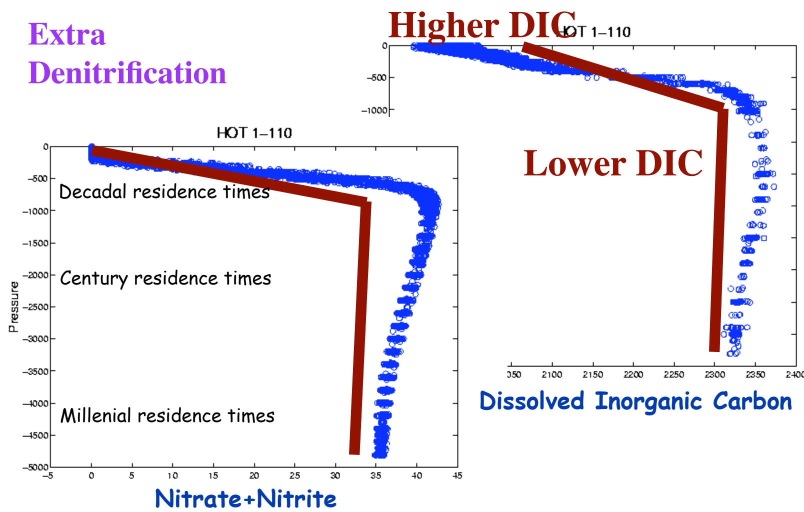

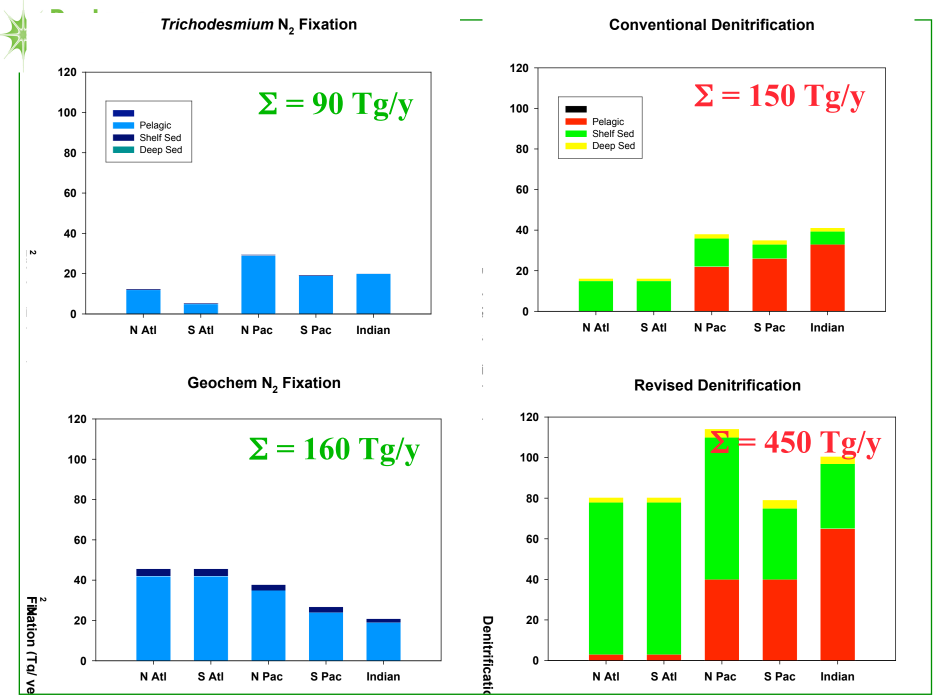

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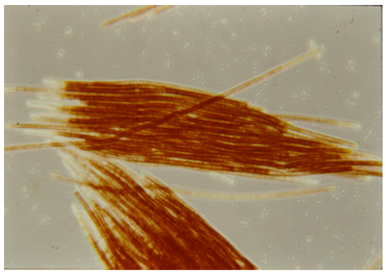
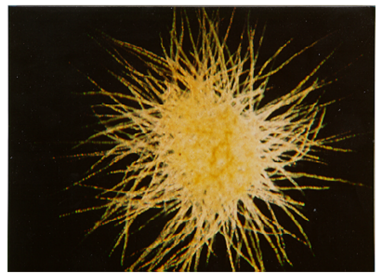
Trichodesmium spp.

Best Known Planktonic Diazotroph





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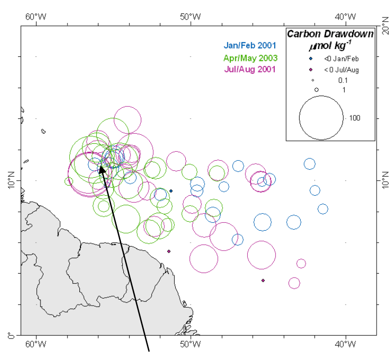
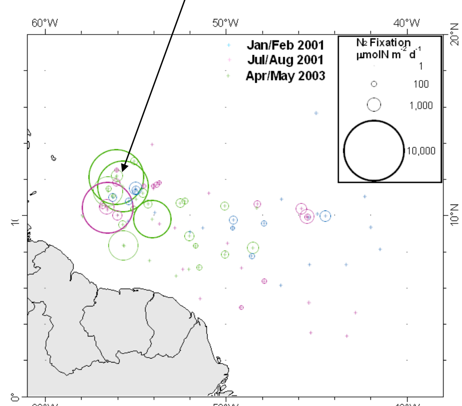
Amazon Plume Data (Cooley et al)



N-fixation blooms in
Amazon plume



Highest carbon
Drawdown in center
Of N-fixation blooms

Amazon Plume Data (Cooley et al)

Range of
DIC uptake
Is similar to
HNLC
results

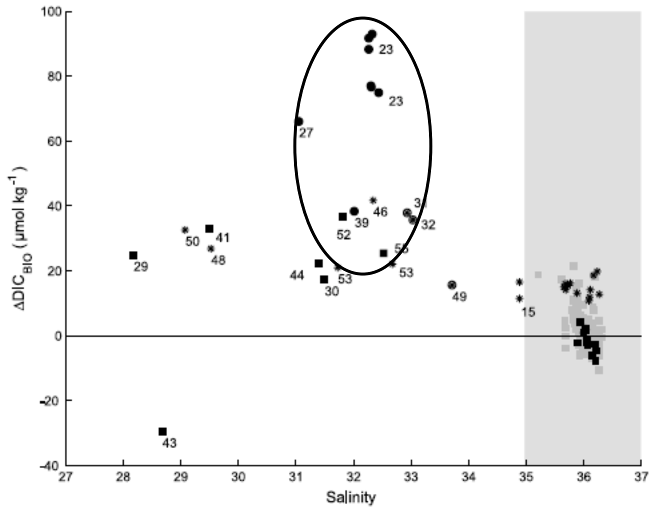
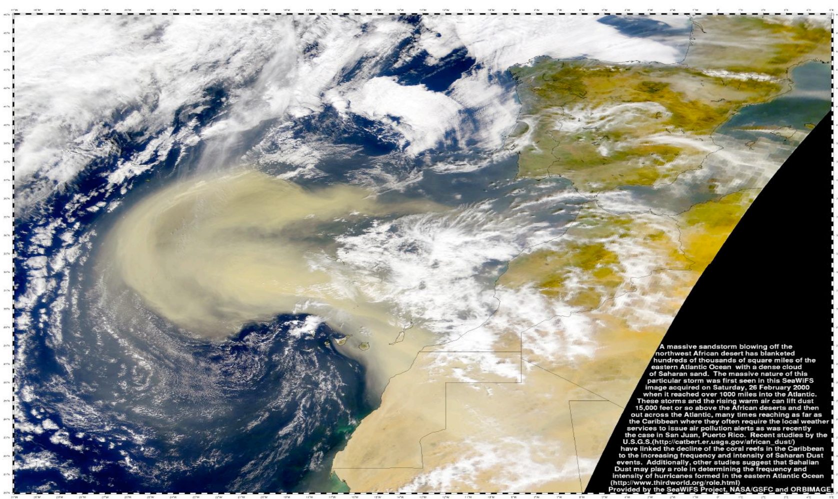
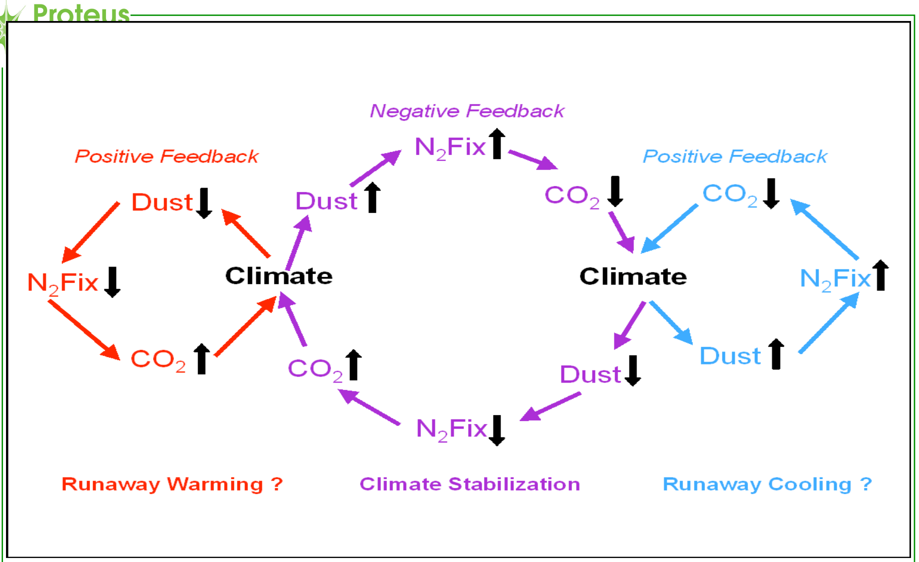


Figure 6. Community impact on DIC (ΔDIC_{BIO}), calculated with the mixing model, plotted against

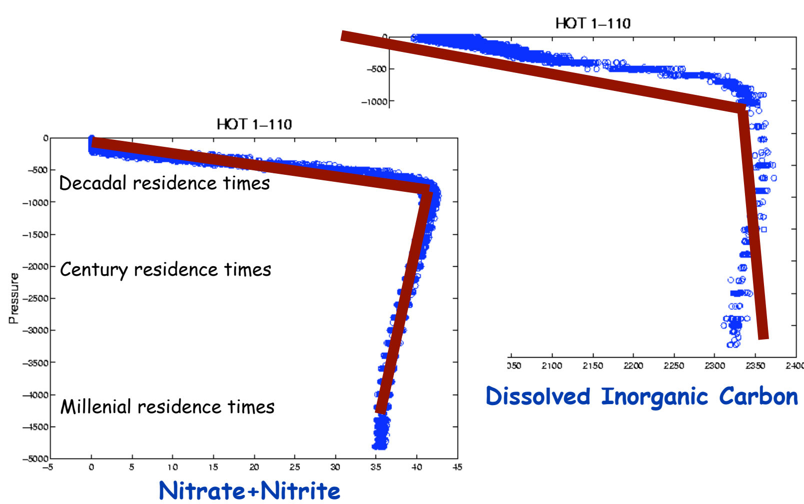


For most of the oligotrophic ocean
Fe source is dust



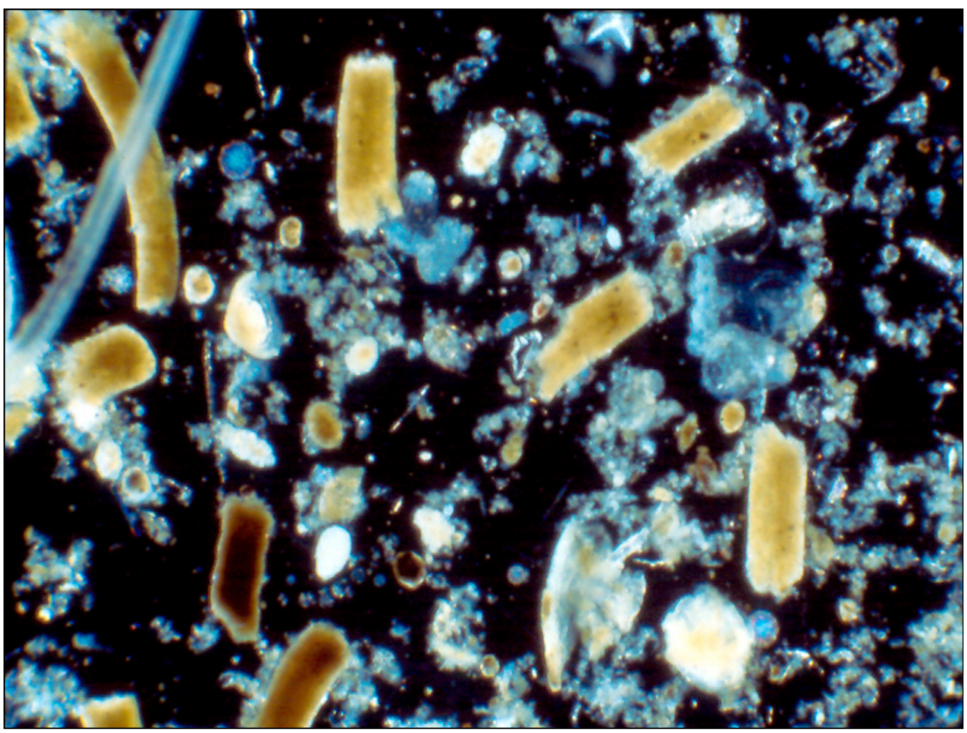
Nitrogen Fixation Feedback Cycle Hypothesis
(as an example)

4. Changes in remineralization length-scales and C-N-P stoichiometry

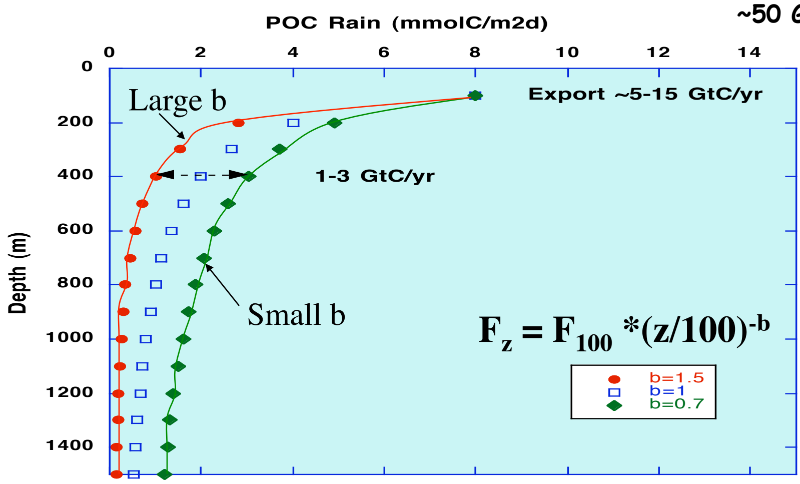


Changes in remineralization length-scales

- Depends on the depth horizon and ventilation time-scale:
  - Annual: 10-20 Gt C/y
  - Multi-annual (>200 m): 5-10 Gt C/y
  - Multi-Decadal: 2-4 Gt C/y
  - > Centennial: ~1-2 Gt C/y



Global PP
~50 GtC/yr



Larger b value, more POC is recycled in upper ocean
Smaller b value, more POC gets to deep ocean

Where's the Surprise?

Surface bloom of *Trichodesmium* in Capricorn Channel of the Coral Sea/ Great Barrier Reef Area near Australia

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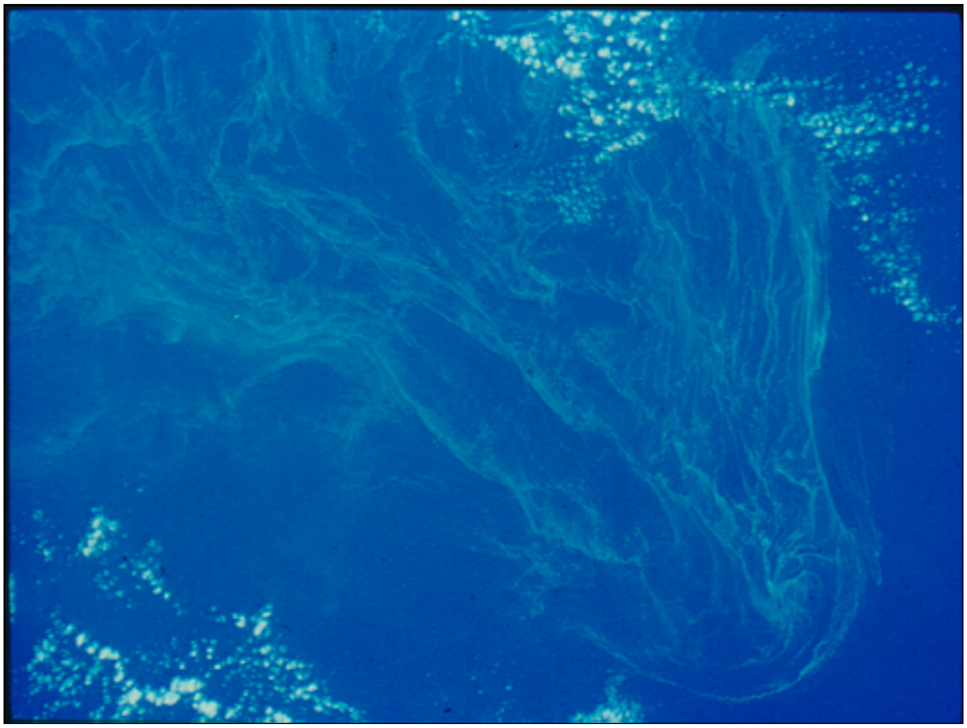
Where's the Surprise?

Plankton Blooms



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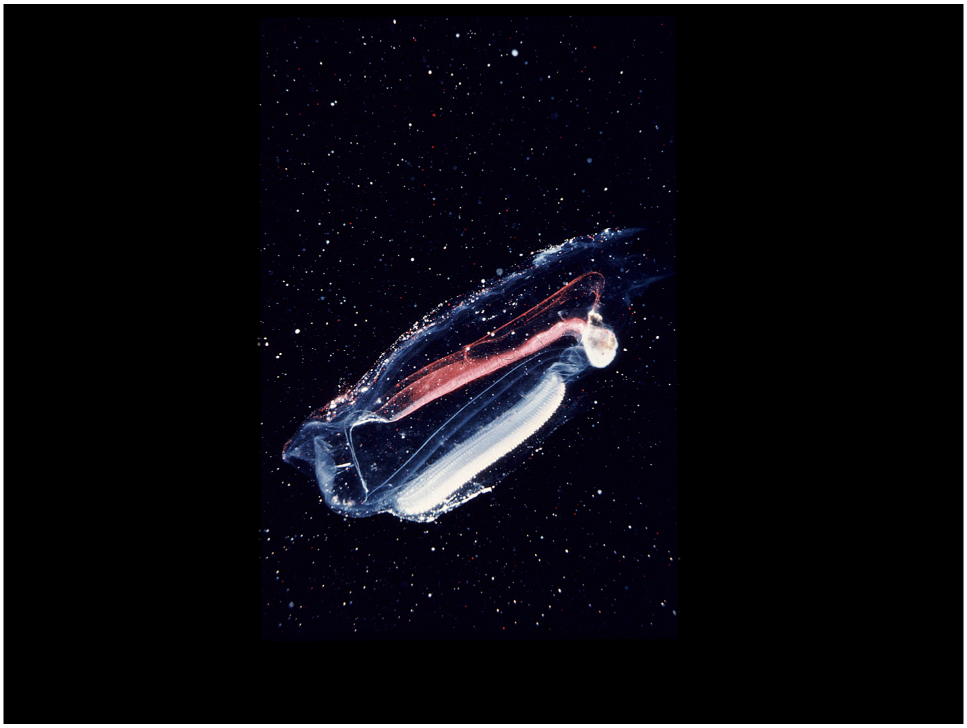
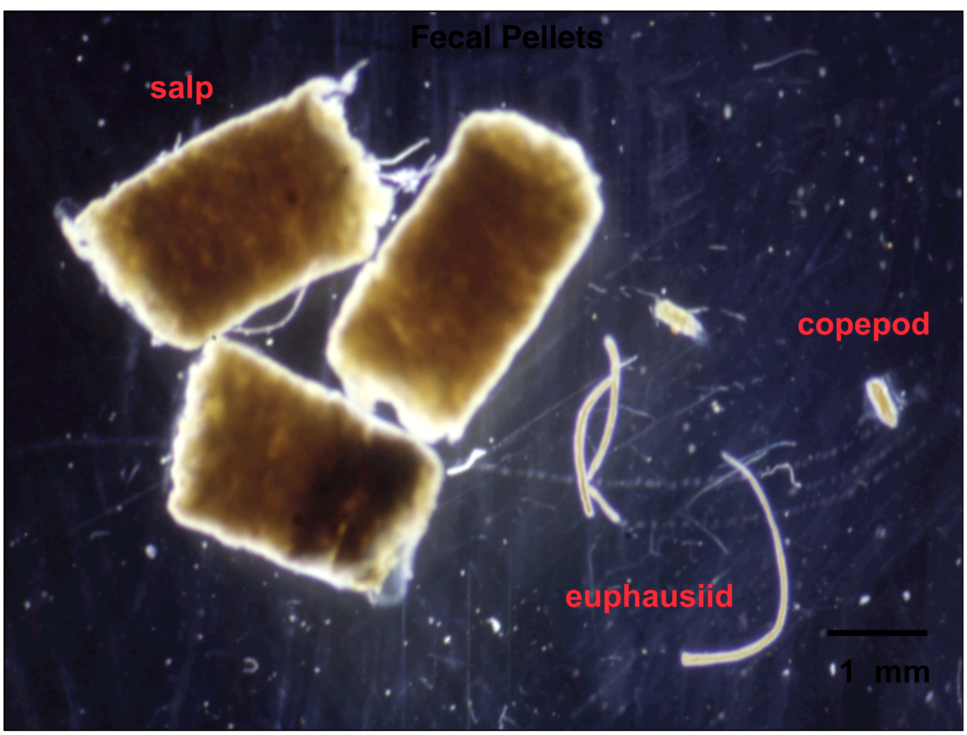
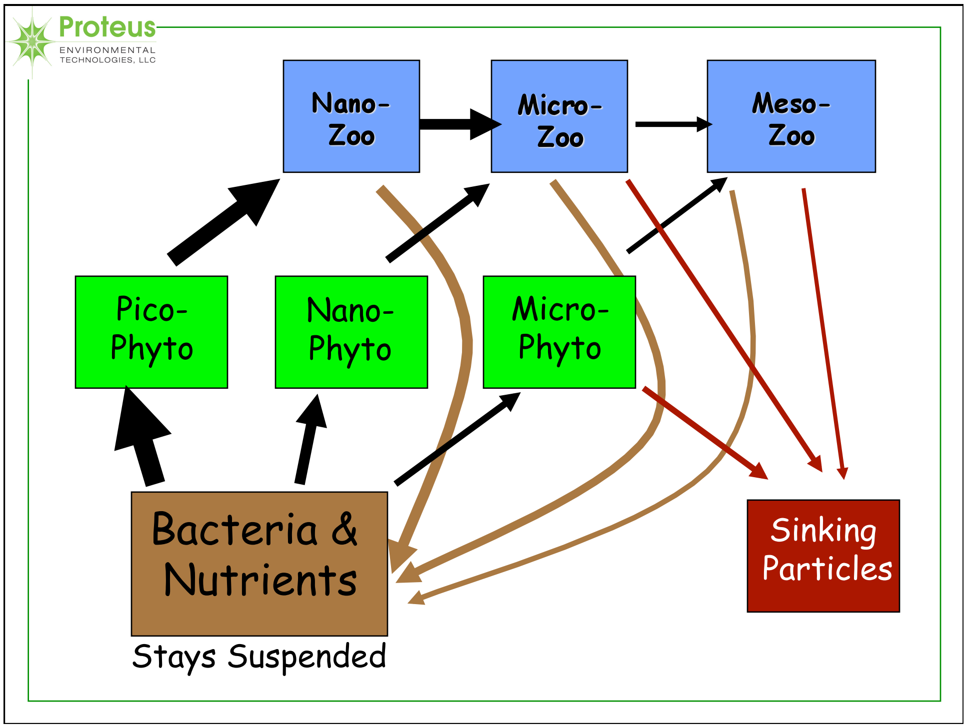
Do Plankton Blooms Matter?

- Rare burst of intense activity
- Overwhelm background system
- Really hard to study!




Fecal Pellets
salp
copepod
euphausiid
1 mm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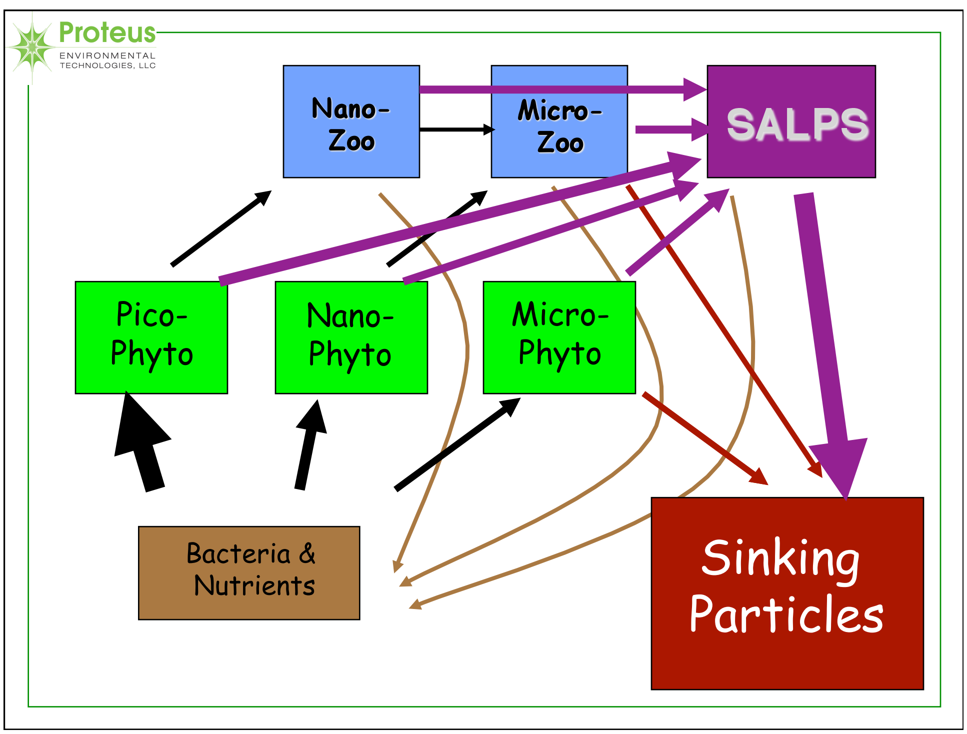
Nano-Zoo
Micro-Zoo
Meso-Zoo
Pico-Phyto
Nano-Phyto
Micro-Phyto
Bacteria & Nutrients
Sinking Particles
Stays Suspended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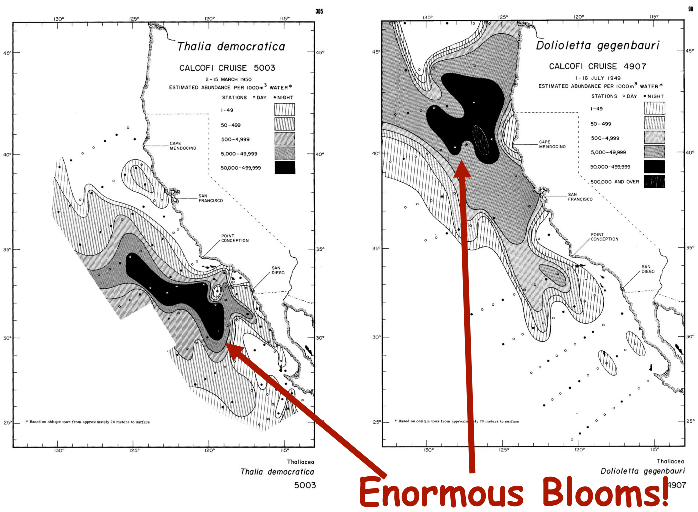
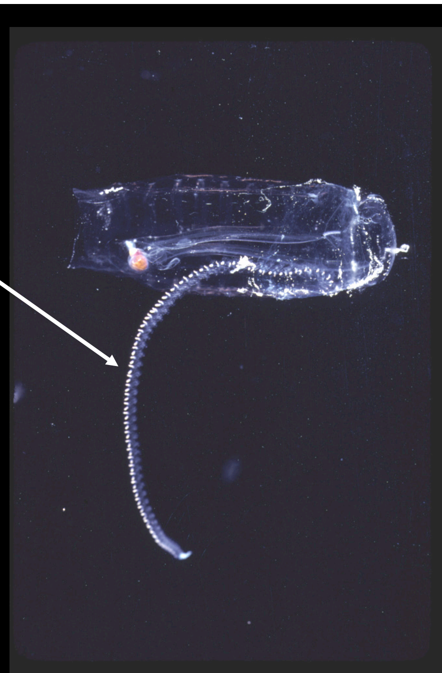
Nano-Zoo
Micro-Zoo
SALPS
Pico-Phyto
Nano-Phyto
Micro-Phyto
Bacteria & Nutrients
Sinking Particles

Twice in a decade!



Asexual reproduction by budding



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Ecosystems and Plankton Blooms

- Ecosystems are complex-dynamical systems
- Bloom dynamics are poorly understood and hard to study
- Top-down vs bottom-up, a debate that is sorely lacking in ocean science
- Blooms created and controlled by internal dynamics of ecosystem, rarely bounded by external controls like nutrients

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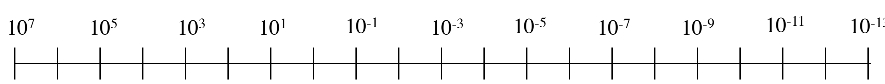
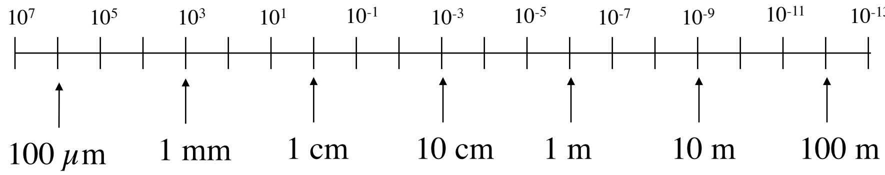
Cells per milliliter



Caution: A real scale conundrum

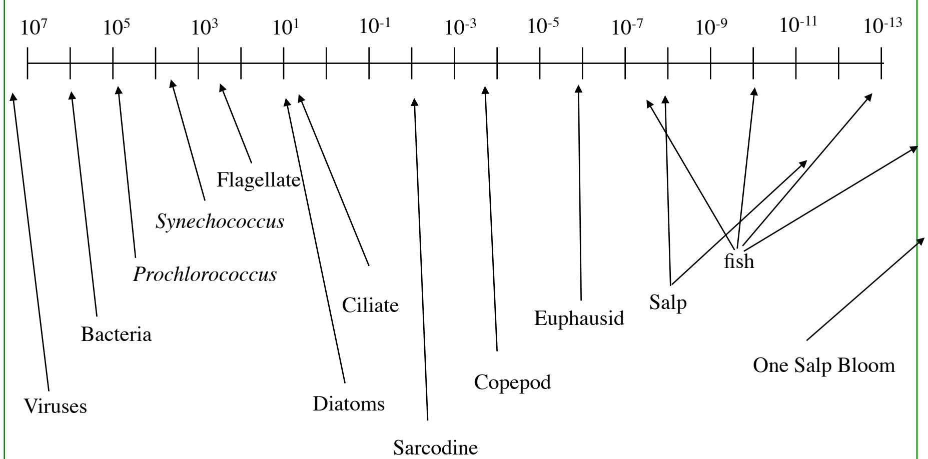
Cells per milliliter



Comparison to length-scales

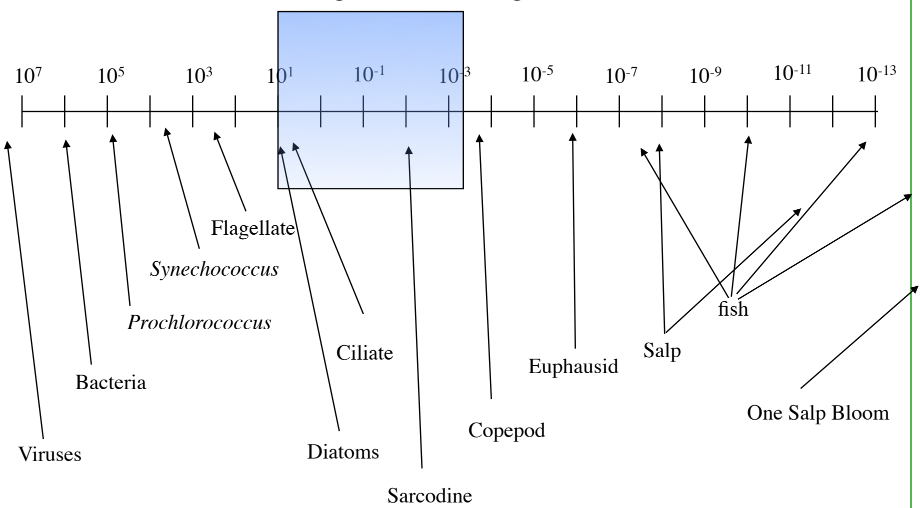
(average spacing)

Cells per milliliter

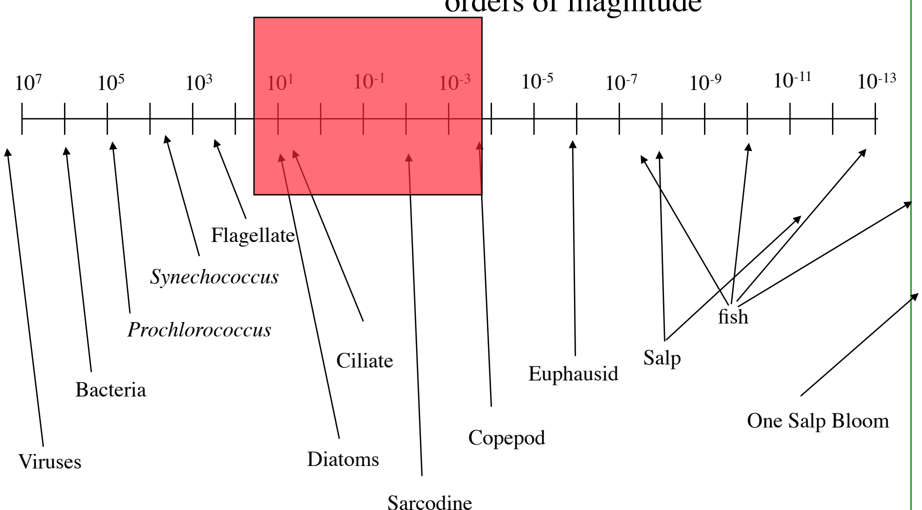


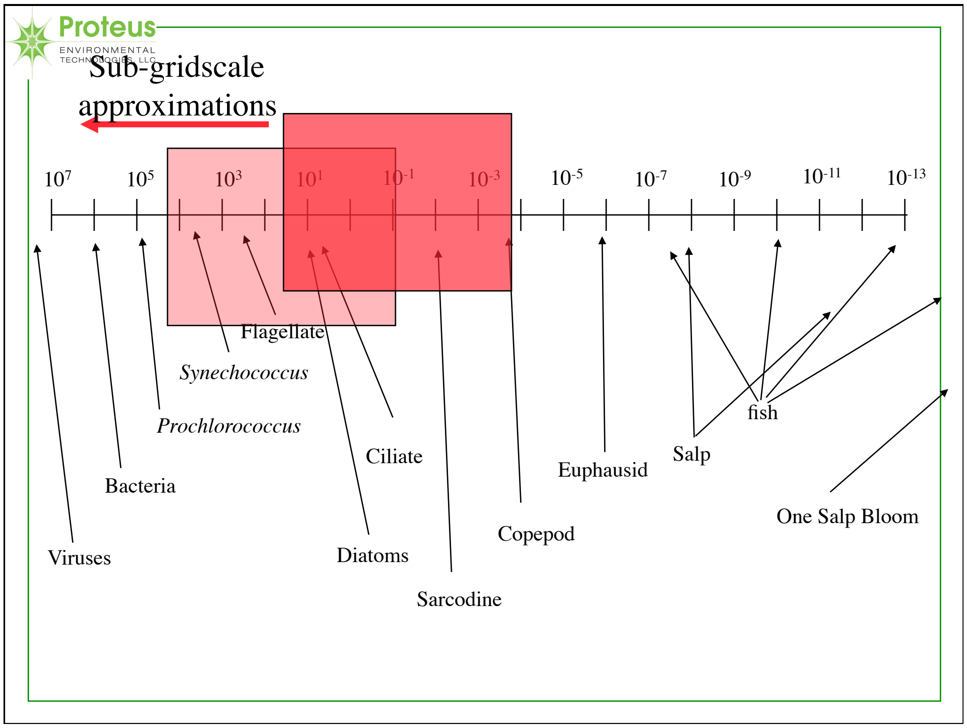
Average spacing of 100-1000 body lengths

Today - best models fully resolve 3 orders of magnitude of lengthscale and 4-5 for abundance



In a decade - it may improve by 1-2 orders of magnitude

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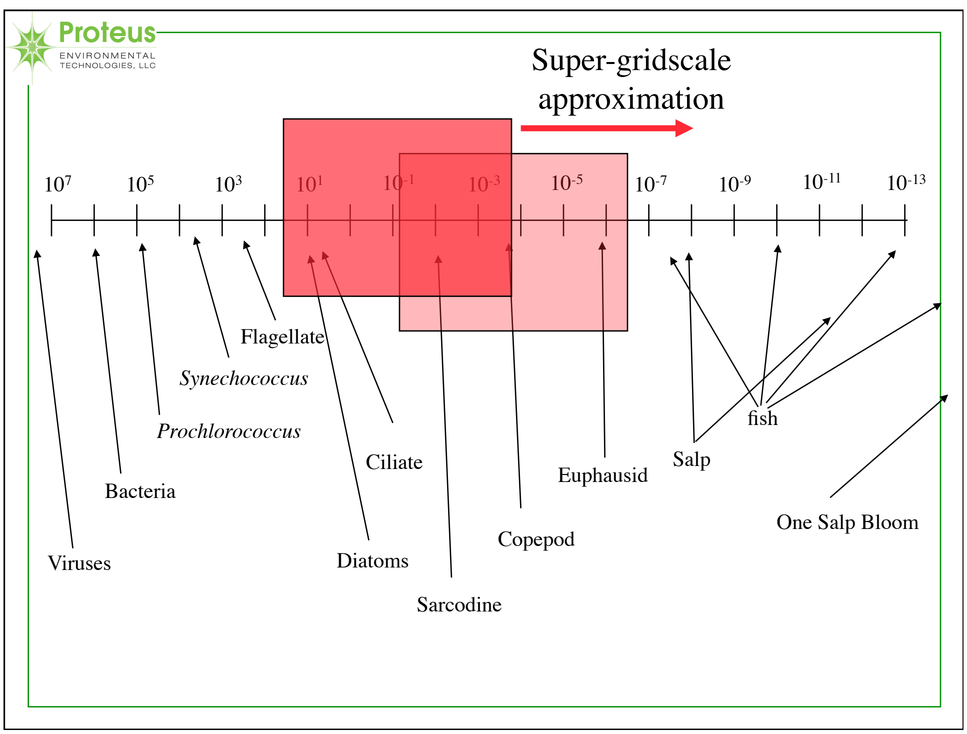
Sub-gridscale approximations
10^7
10^5
10^3
10^1
10^-1
10^-3
10^-5
10^-7
10^-9
10^-11
10^-13
Flagellate
Synechococcus
Prochlorococcus
Ciliate
Bacteria
Euphausid
Salp
fish
One Salp Bloom
Copepod
Viruses
Diatoms
Sarcodine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Super-gridscale approximation
10^7
10^5
10^3
10^1
10^-1
10^-3
10^-5
10^-7
10^-9
10^-11
10^-13
Flagellate
Synechococcus
Prochlorococcus
Ciliate
Bacteria
Euphausid
Salp
fish
One Salp Bloom
Copepod
Viruses
Diatoms
Sarcodine

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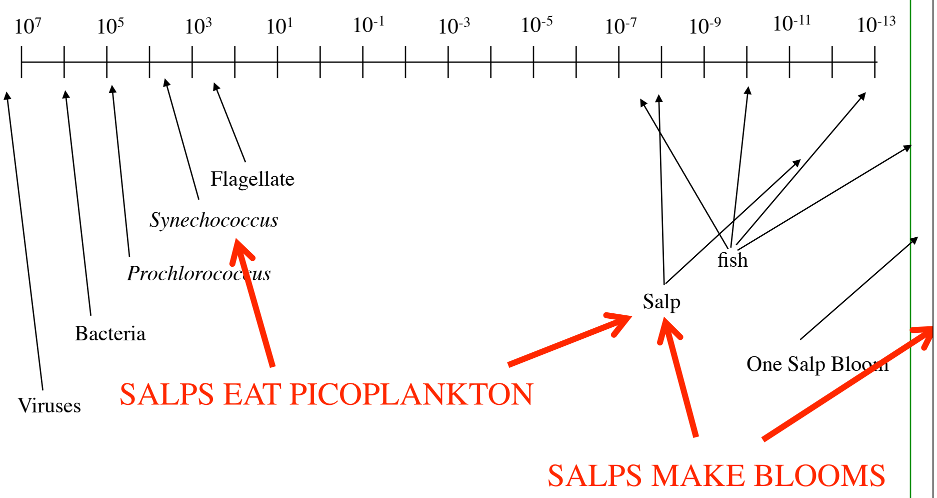

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Conclusions

- Community structure matters for the partitioning of carbon between ocean and atmosphere
- Influence is through specific mechanisms that are controlled by a tiny subset of biological processes operating on a very large scale
  - Nitrogen Fixation
  - Particle Export from Blooms
- When community structure is important, the outcome often emerges from internal dynamics
- Rare blooms and scale are a big challenge