Long-Term Research & Time-Series Observations: What Have we Learned?

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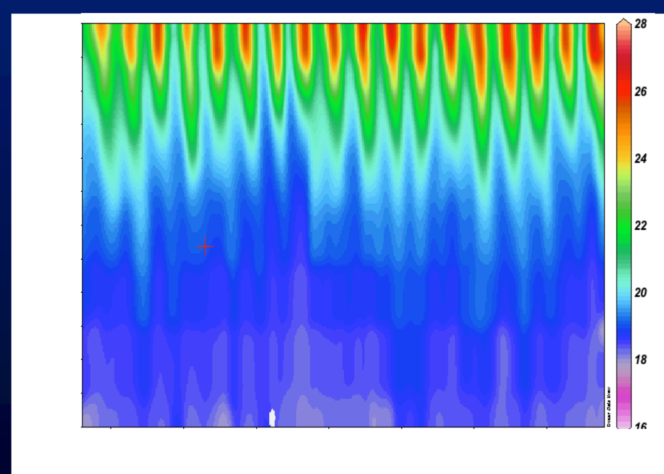
Hugh Ducklow (Marine Biological Laboratory)
Scott Doney (Woods Hole Oceanographic Institution)

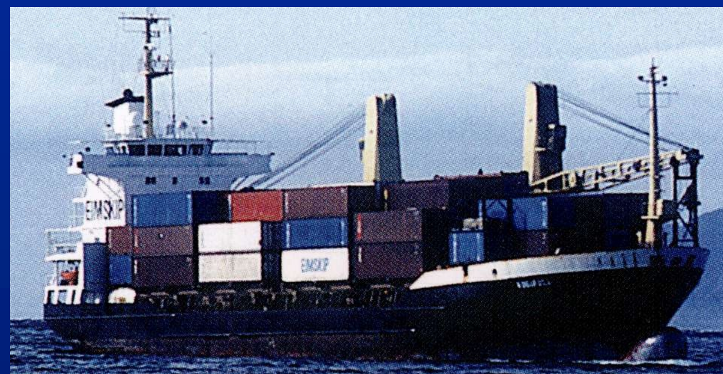
Ducklow, Doney, & Steinberg (submitted to inaugural issue of Annual Review of Marine Science- Jan 2009)

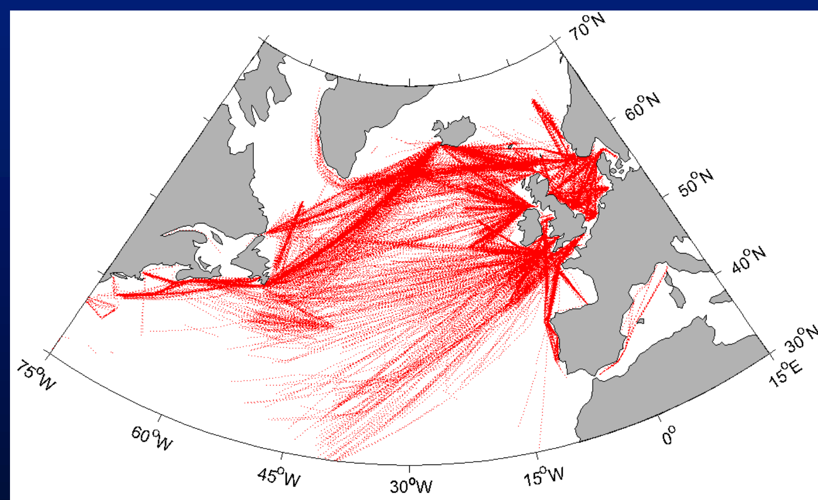


Time-series observations have been a core strategy in oceanography for >50 years

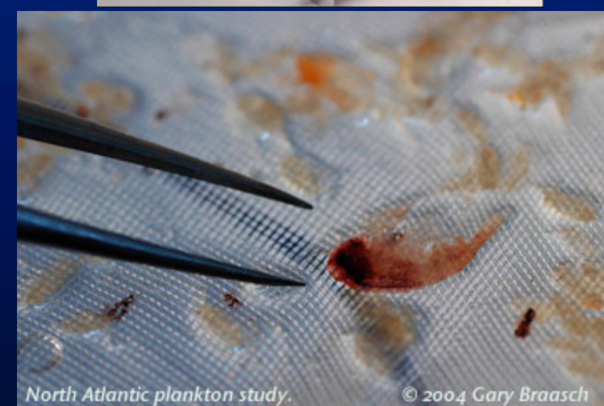
The Continous Plankton Recorder (CPR) Survey
1931-

Sir Alistair Hardy

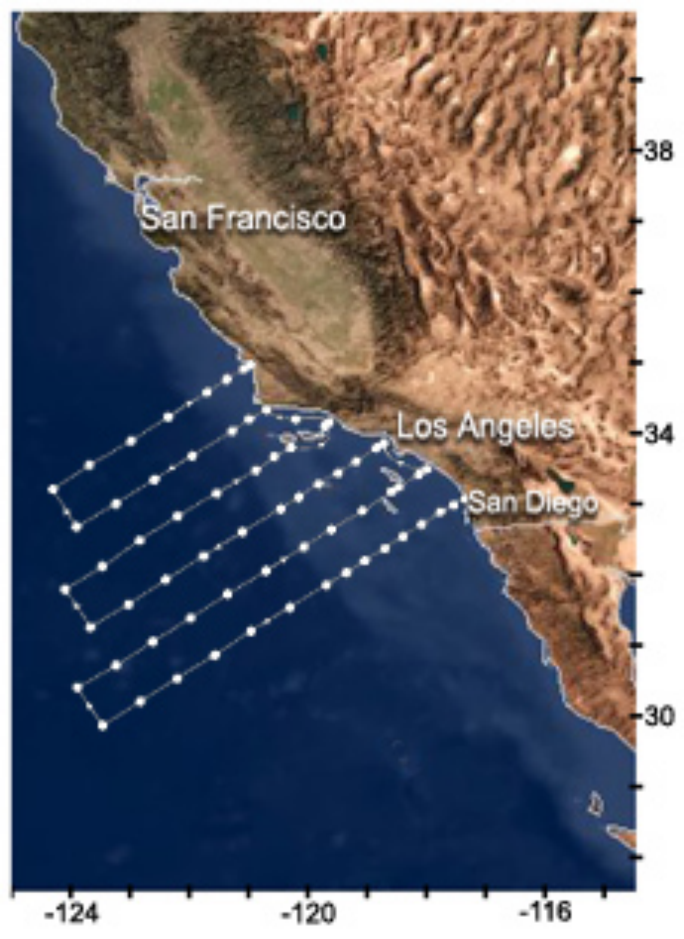




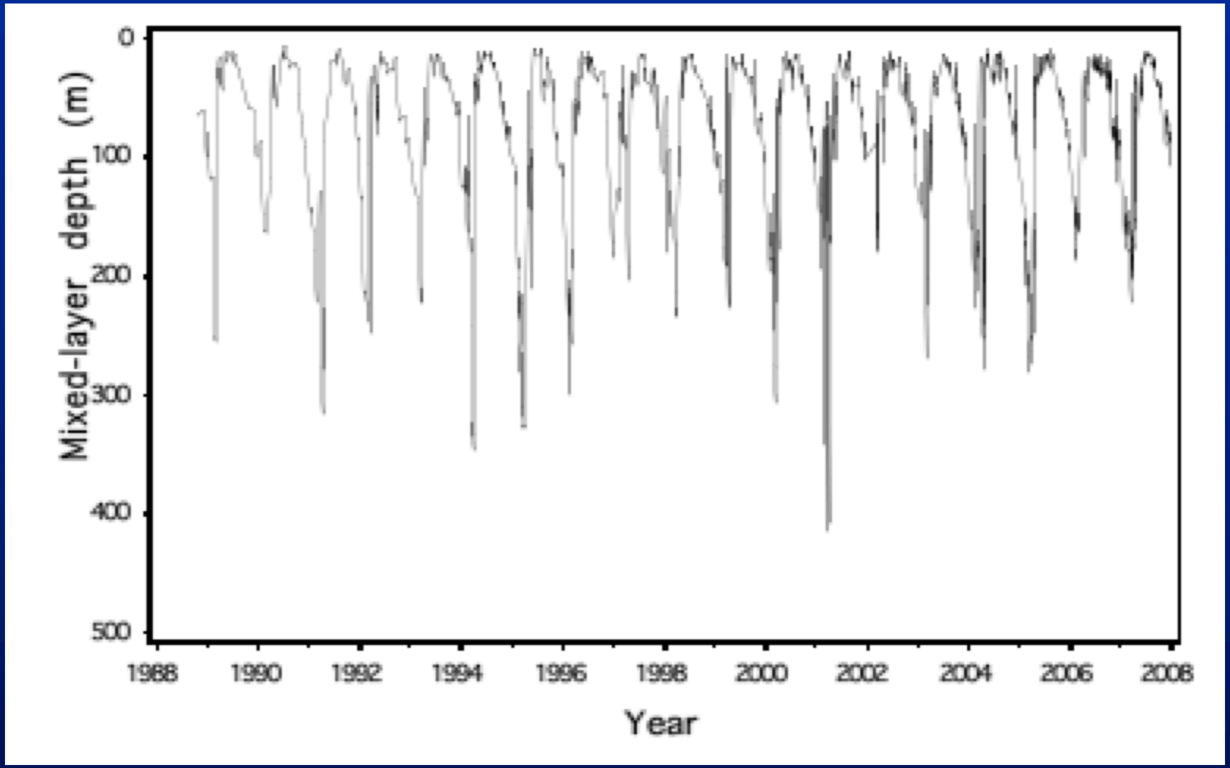
Spatial coverage of Atlantic survey



California Cooperative Fisheries Investigations (CalCOFI) 1949-

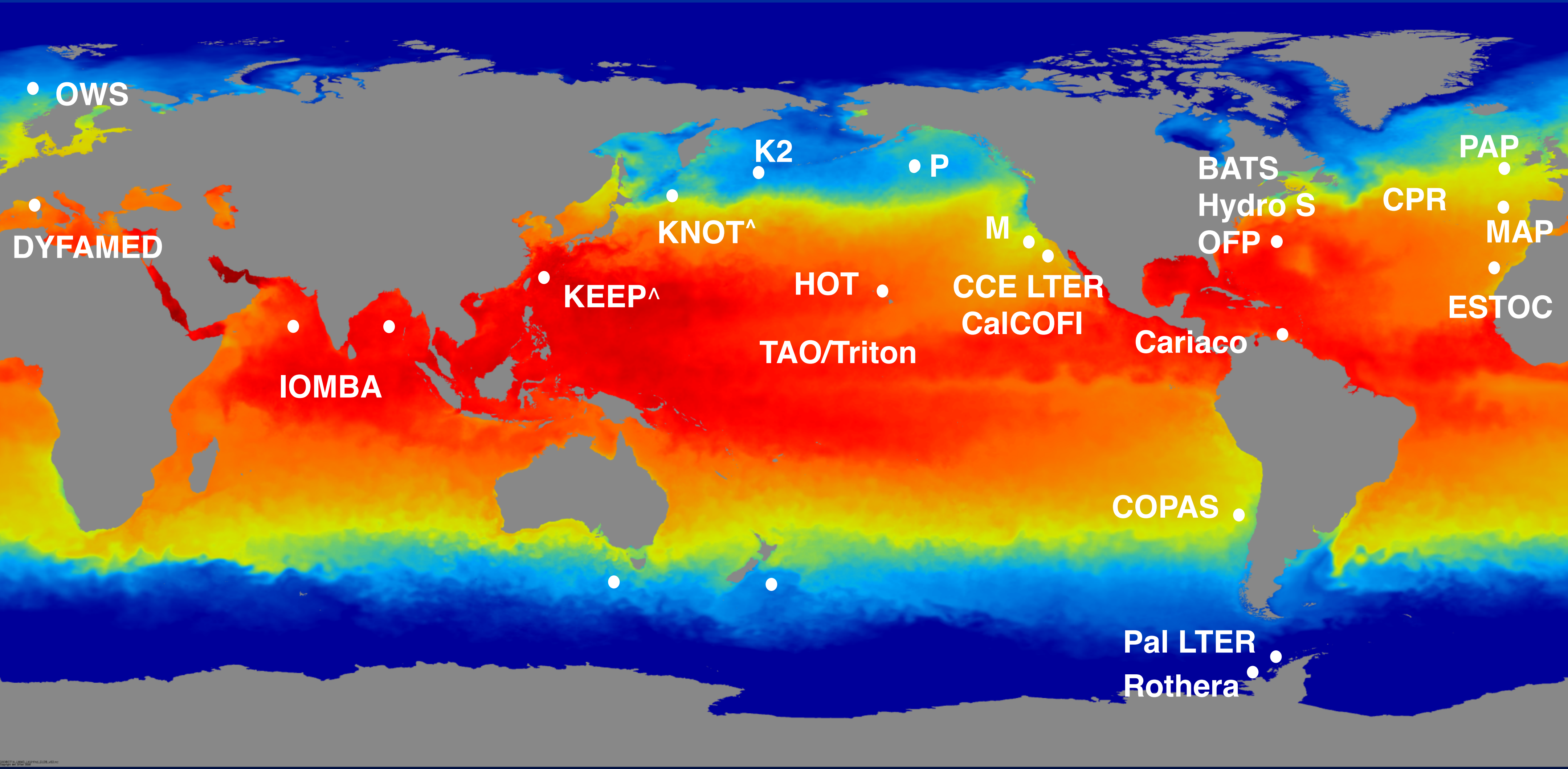


Hydrostation S 1955-



R. Johnson, BATS

Biogeochemical oceanographic time series & long-term ecological research sites (LTERs)



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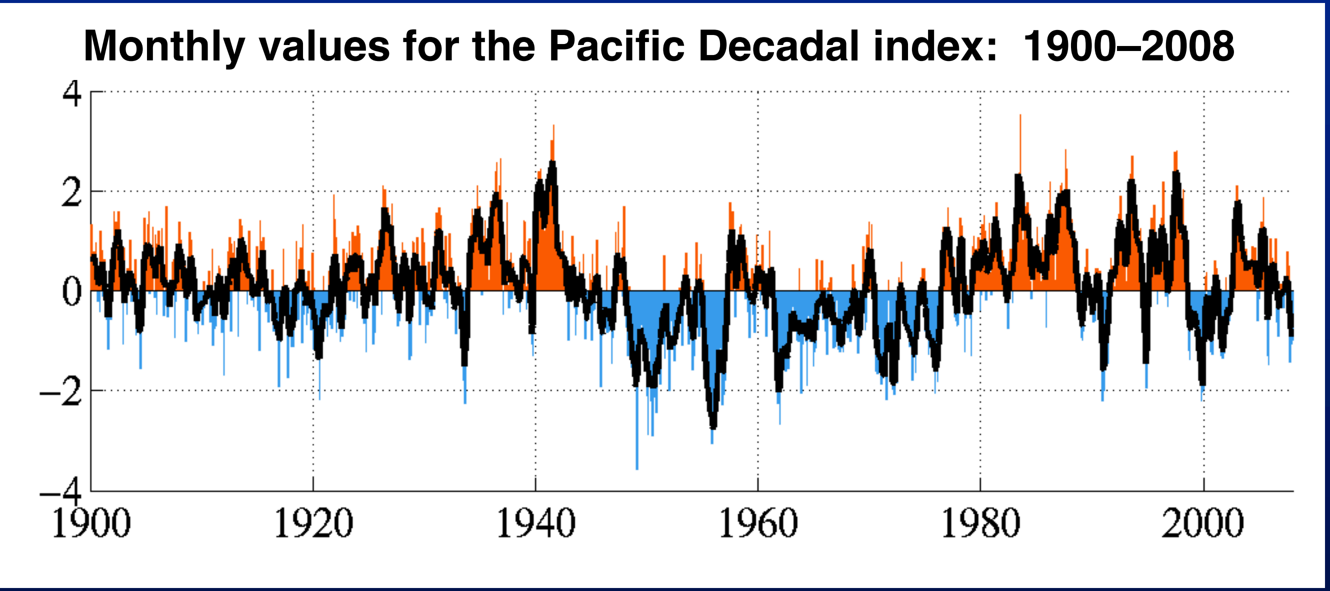
See www.oceansites.com for more complete map

Outline

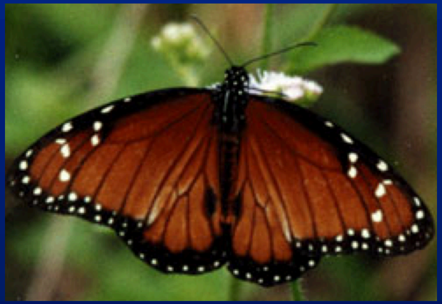
- Ecological responses to climate variability
- Biogeochemistry and the biological pump
- Informing models with observations

Ecological responses to climate variability

- Climate modes
- Regime change
- Anthropogenic warming



Terrestrial studies



Marine & FW

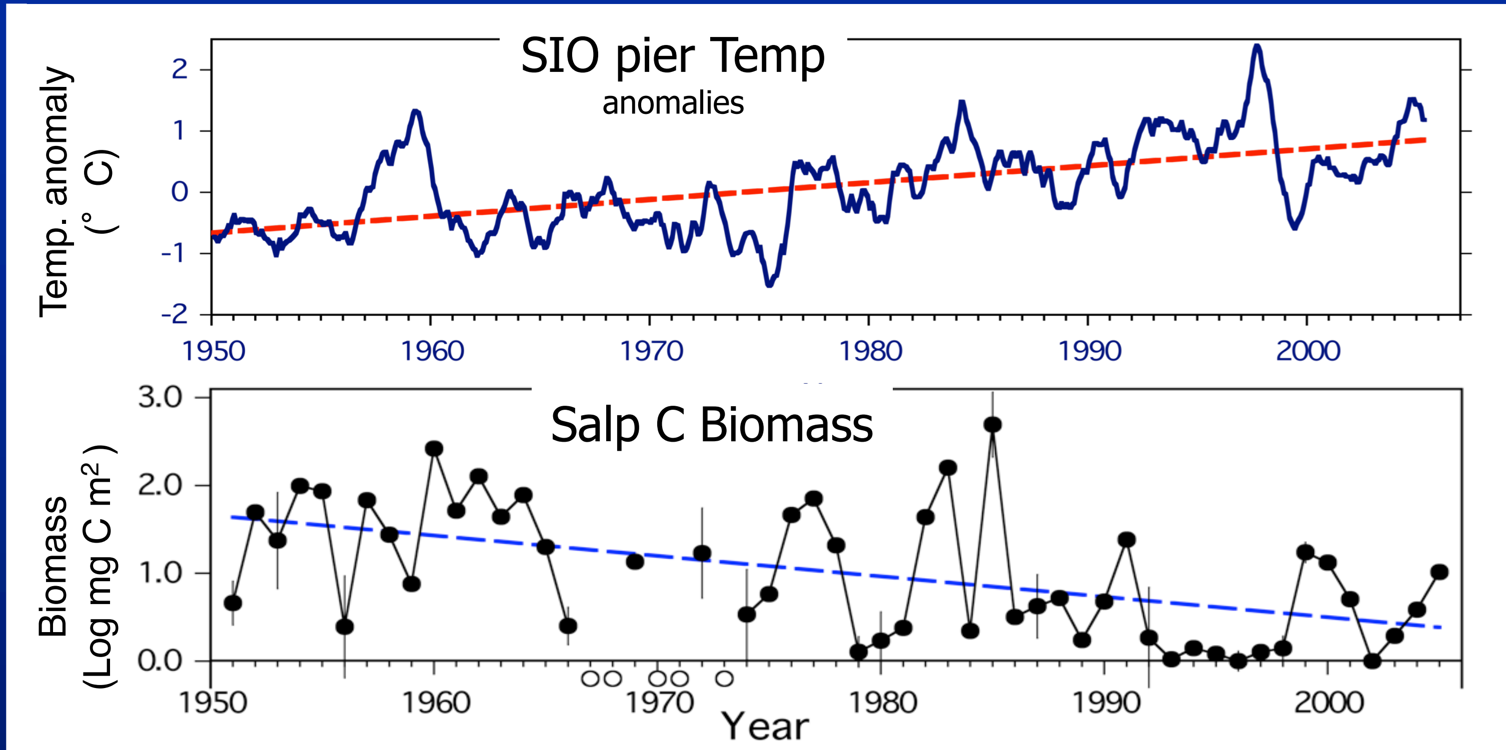
285,586 vs. 85

http://www.jisao.washington.edu/pdo/

(IPCC synthesis, Parry et al. 2007)

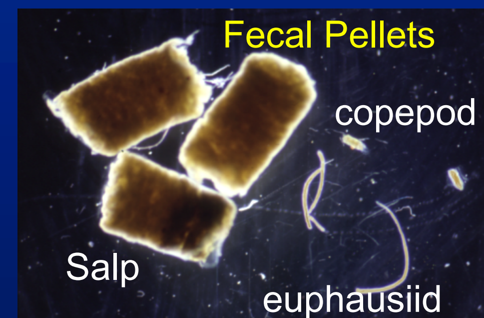
Decrease in pelagic tunicates (salps) in the California Current

(gelatinous zooplankton have a low C: biovolume ratio)



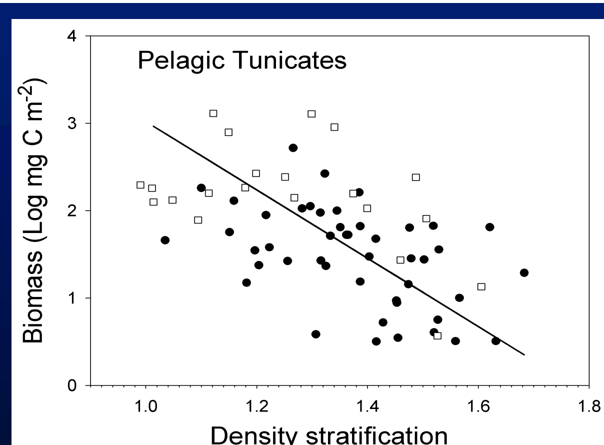
Salps

photo: D.Wrobel



D.Steinberg

Biomass of pelagic tunicates is inversely related to density stratification



● Southern CA
○ Central CA

CCE-LTER and CalCOFI

(Lavaniegos and Ohman 2007)

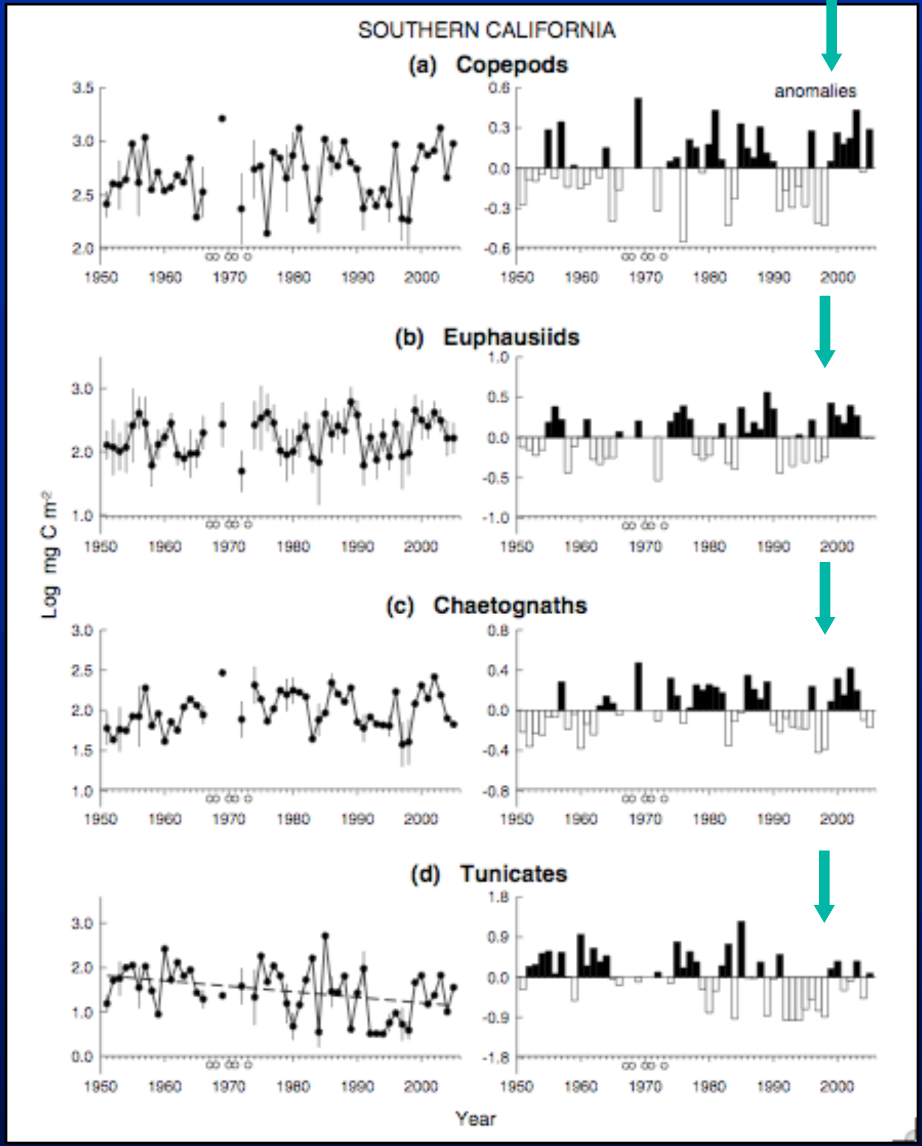
Multiple time-scales of change affect species composition

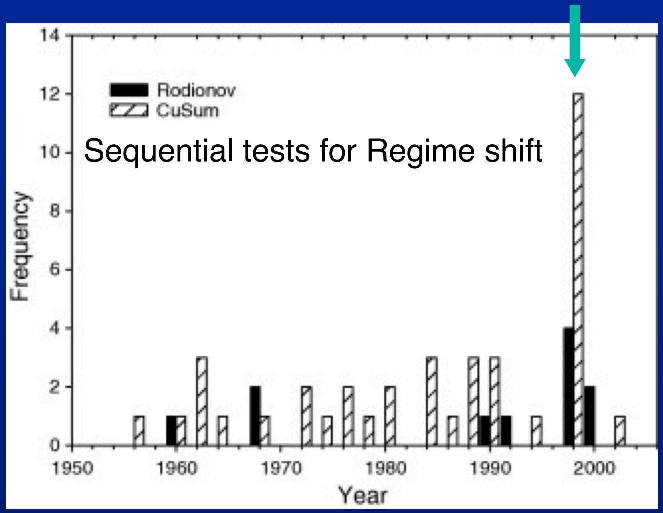
Long-term:
Decrease in pelagic tunicates

Multi-decadal (PDO):
1977- shift from cool to warm phase
(or NPGO)

ENSO:
Major El Niños have consistently depressed zooplankton biomass

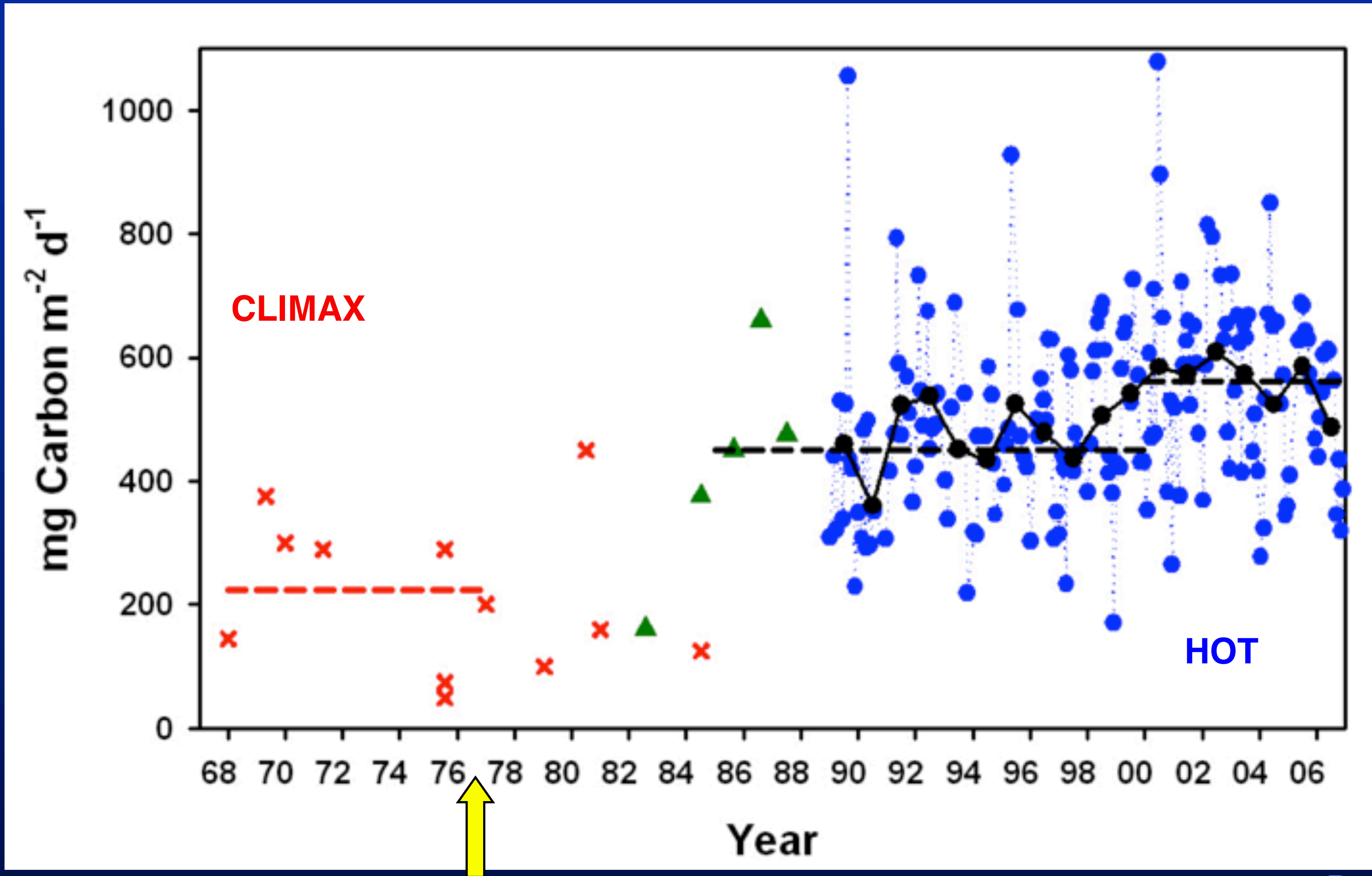
1999- strong La Niña strongest species shift





Lavaniegos & Ohman (2007)

Evidence of regime change
Primary production North Pacific Subtropical Gyre



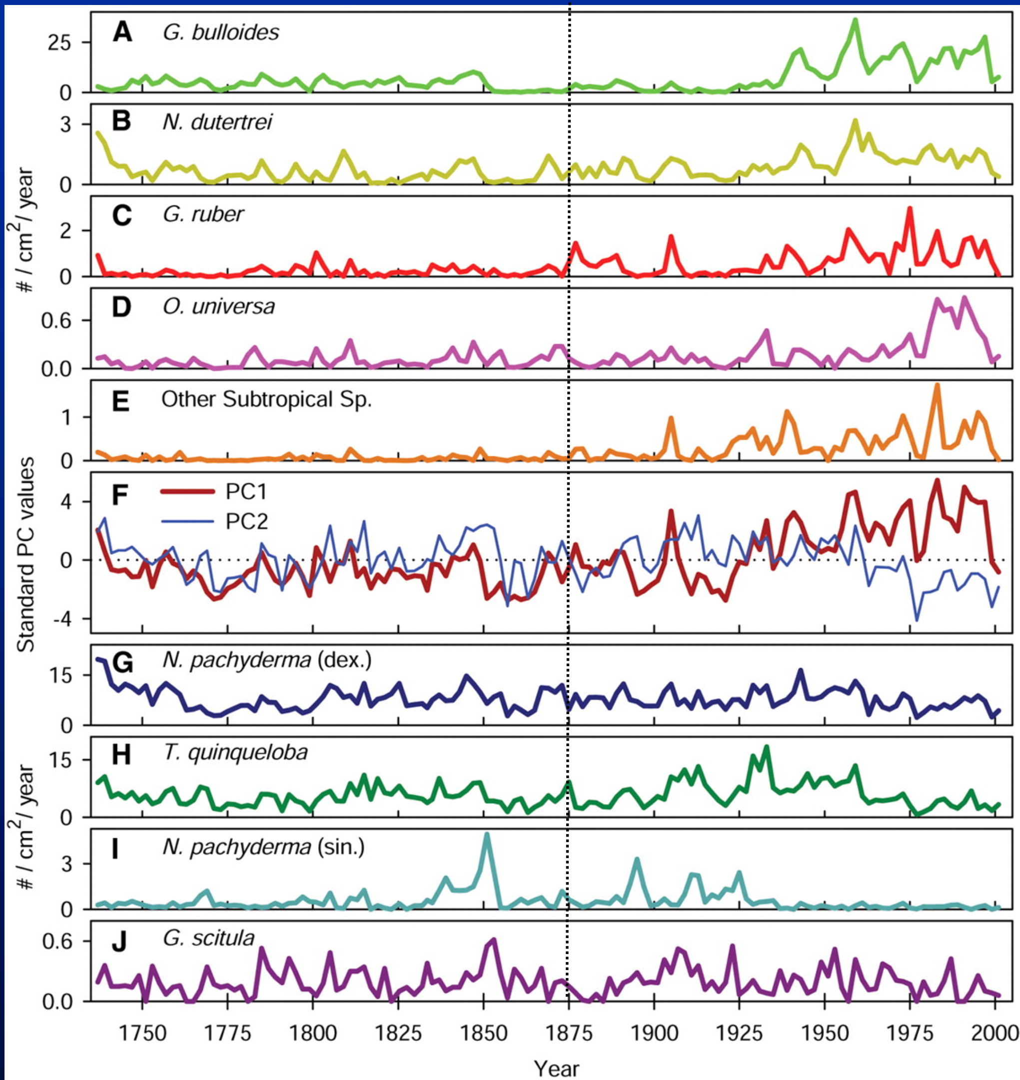
D. Karl, HOT

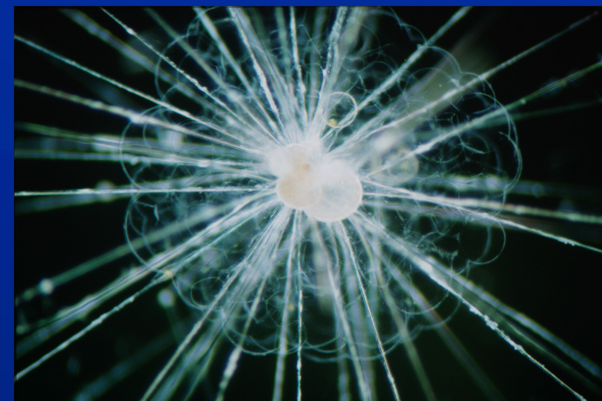
1977 PDO shift

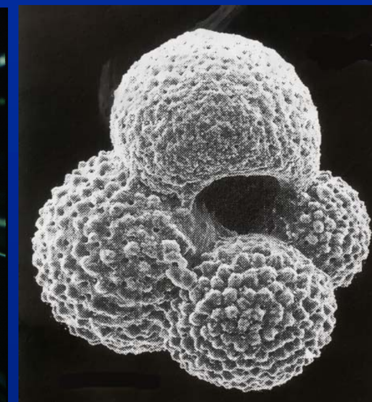
intensification of the Aleutian Low, increased westerly winds, deepening of the main thermocline, nutrient flux into the euphotic zone

Anthropogenic warming

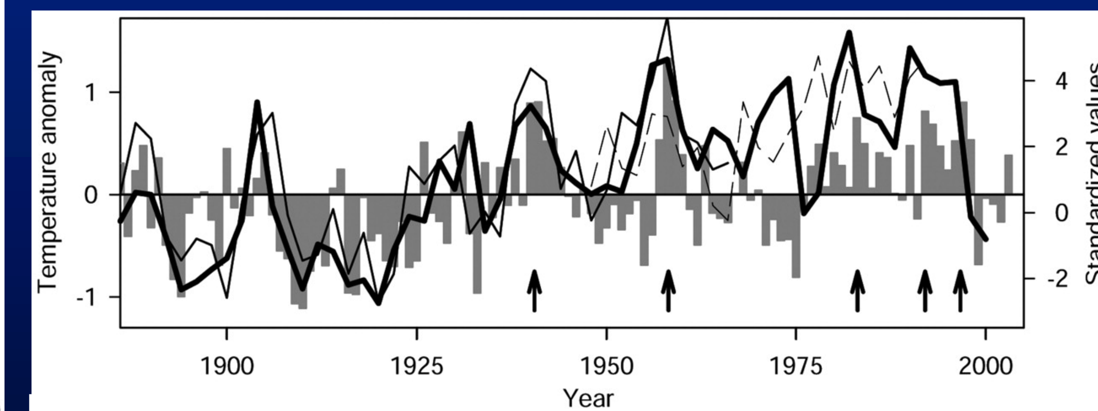
Species shifts in planktonic foraminifera in sediments off S. California







Coincident with 20th century warming



Arrows are strong El Niños

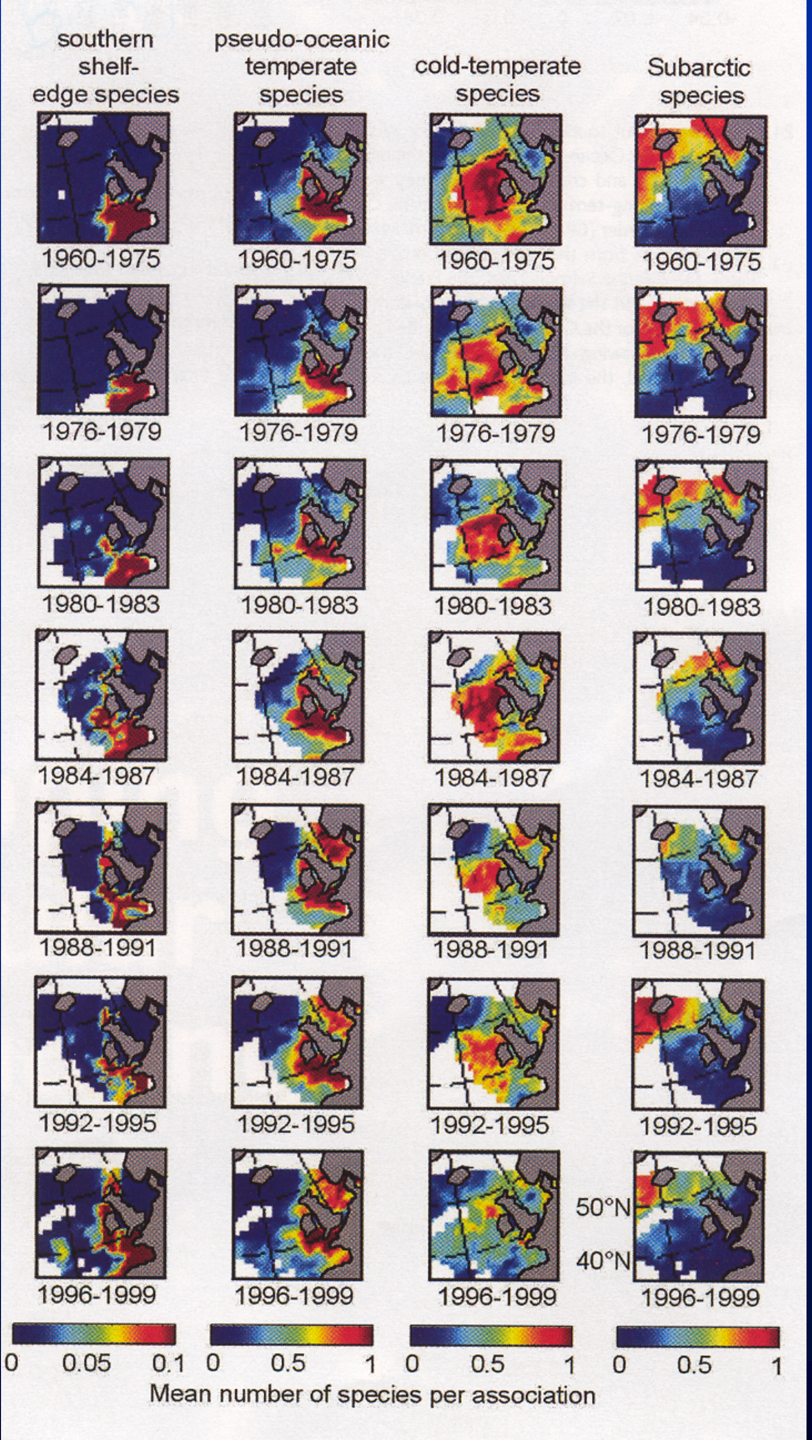
Field et al. 2006

North Atlantic copepods & warming

- Change in the biogeography of calanoid copepod species in N.Atlantic over period 1960-1999

- Northward extension of more than 10° latitude of warm water species, associated with decrease in cold water species.

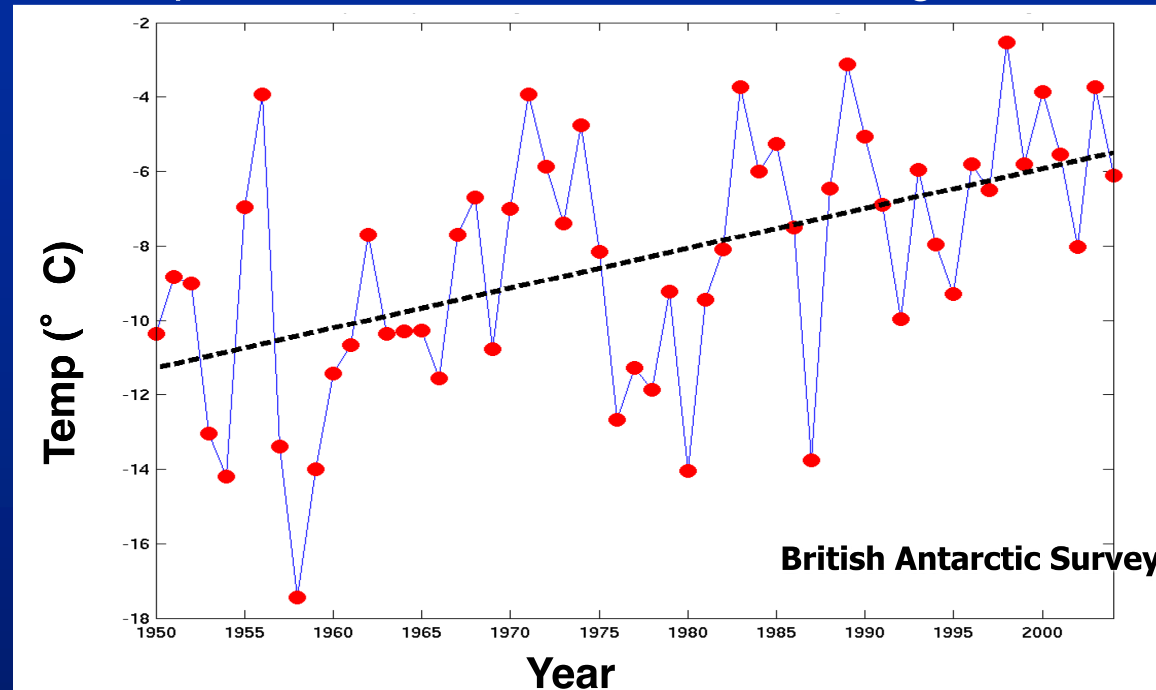
- Related to increasing trend in N. Hemisphere temp. and the NAO



(Beaugrand et al. 2002)

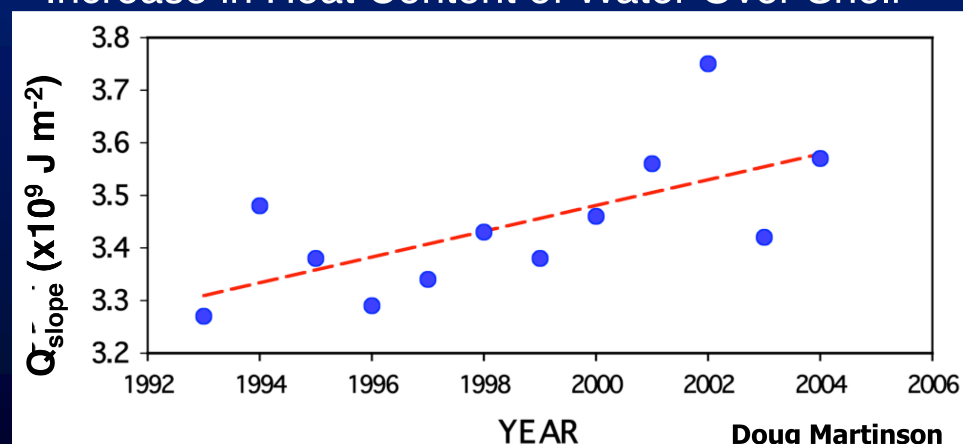
Warming in the Southern Ocean- Palmer Station LTER

Average winter (June-Aug.) temperature
+1.1°C per decade: 6°C since 1950: 5 x global ave.

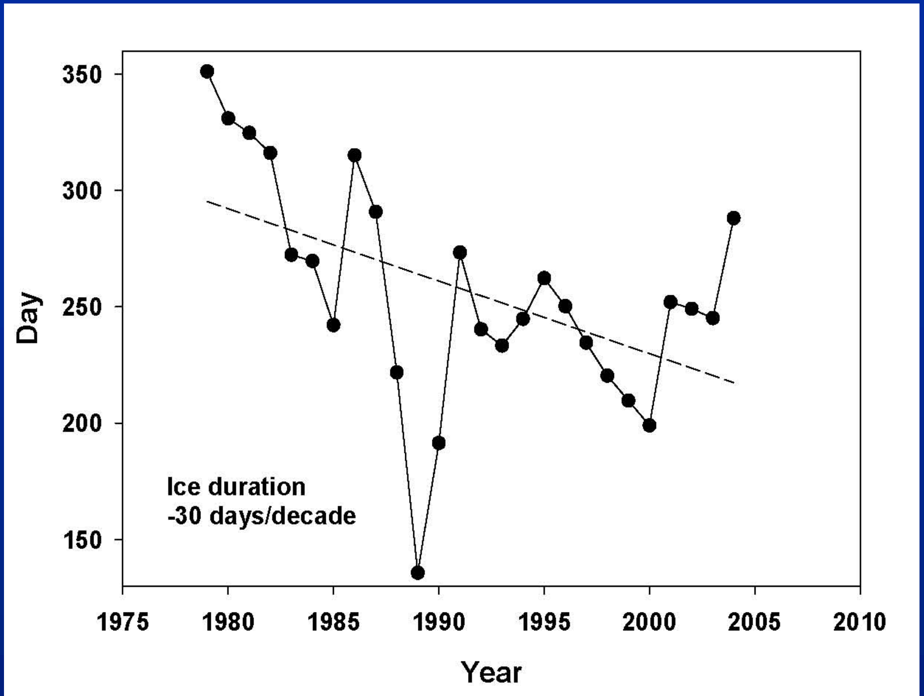


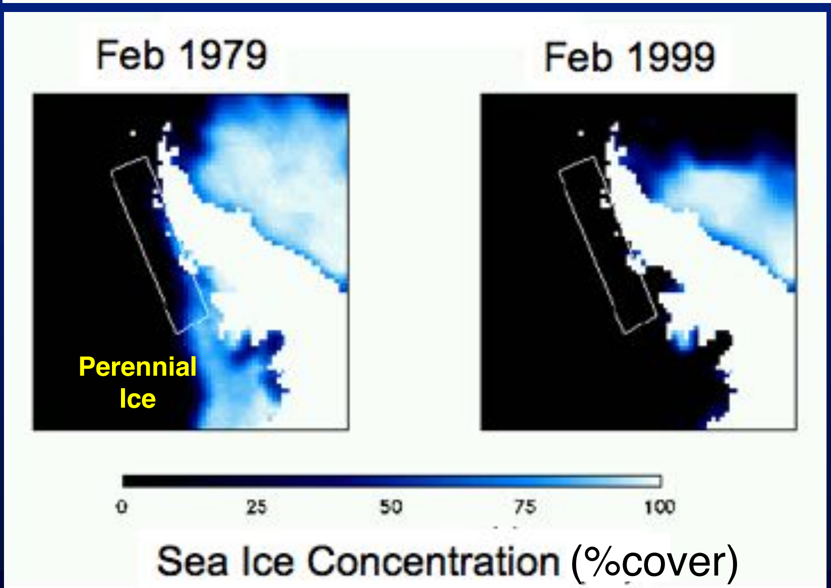
Adélie penguins near Palmer station

Increase in Heat Content of Water Over Shelf



Sea ice is declining

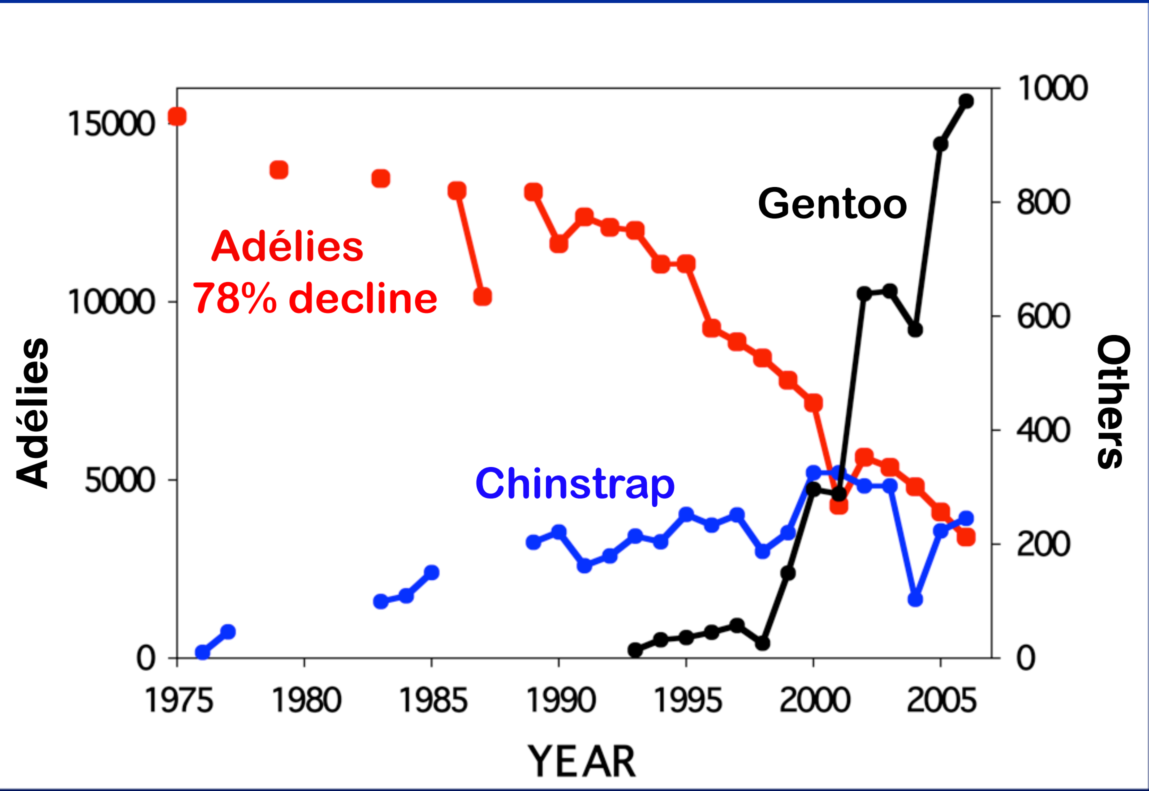




Sharon Stammerjohn

Penguin populations near Palmer Station

Adélies declining, other species invading & increasing

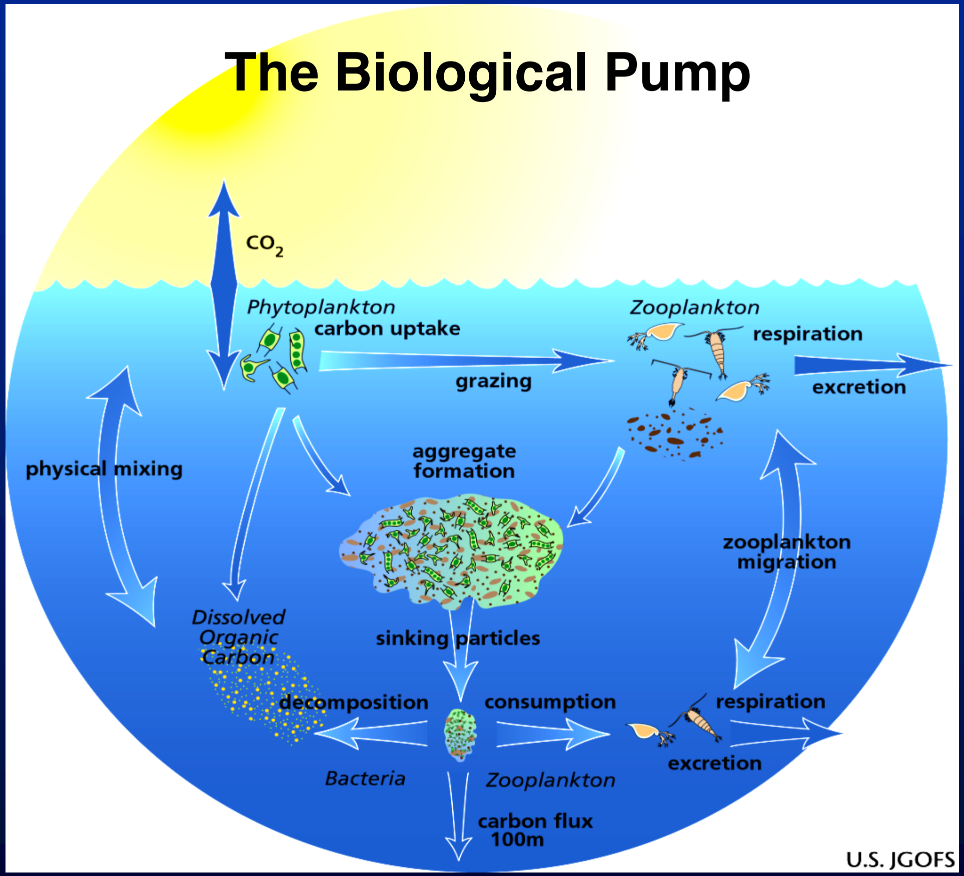


Biodiversity is increasing in response to climate warming

Bill Fraser, Ducklow et al. 2007

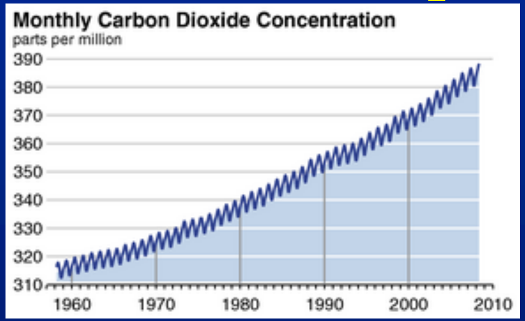
Biogeochemistry & the biological pump

- Increase in DIC in surface ocean
- Nutrient limitation of primary production & Redfield stoichiometry
- Particle flux to the deep ocean
- Other components of the biological pump

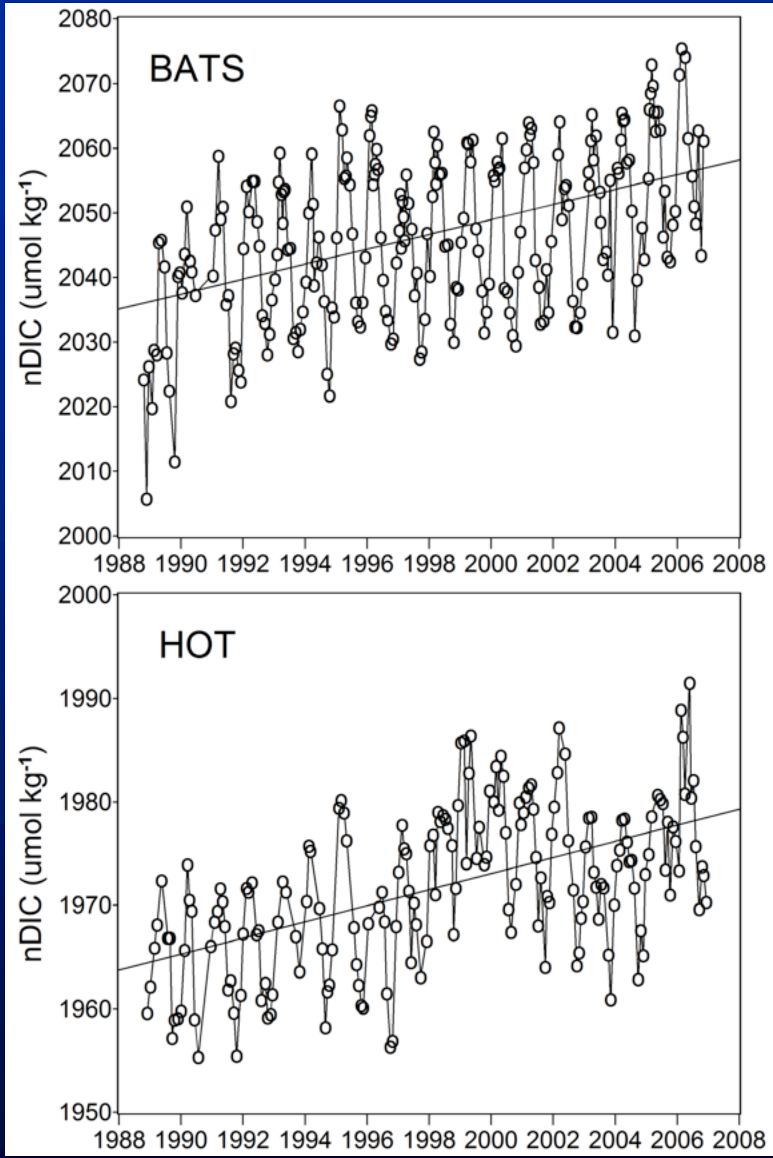


Long-term increase in surface-ocean dissolved inorganic carbon (DIC) at BATS and HOT

Atmospheric CO_2



D. Keeling



BATS:
Increasing at a rate in equilibrium with anthropogenic CO_2 increase in atmosphere

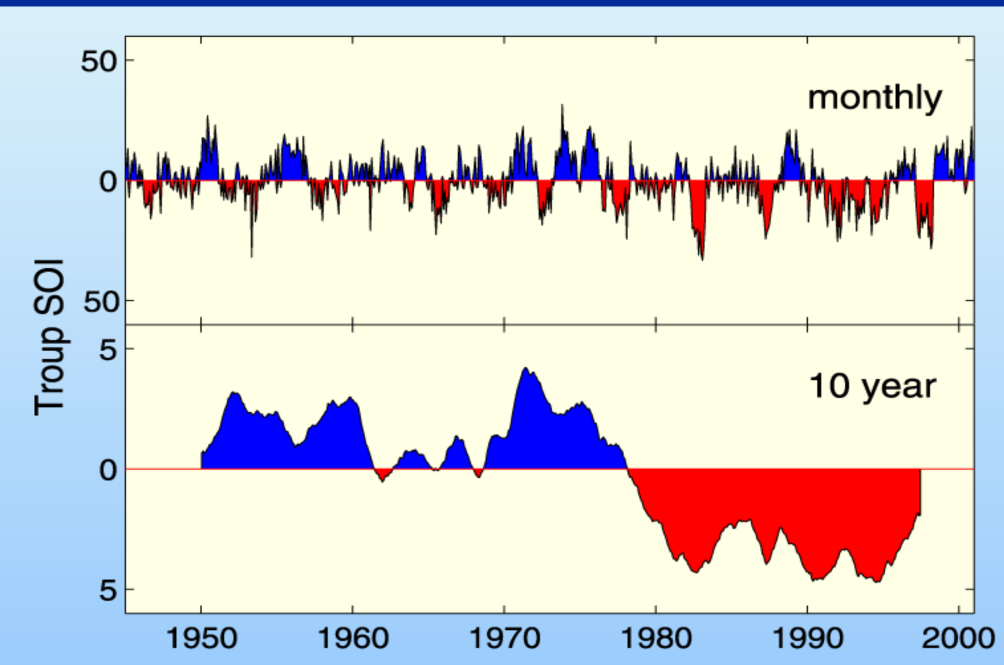
HOT:
Increasing at a rate slightly higher than expected oceanic equilibrium with anthropogenic CO_2 in atmosphere

Consequence:
increasing ocean acidity

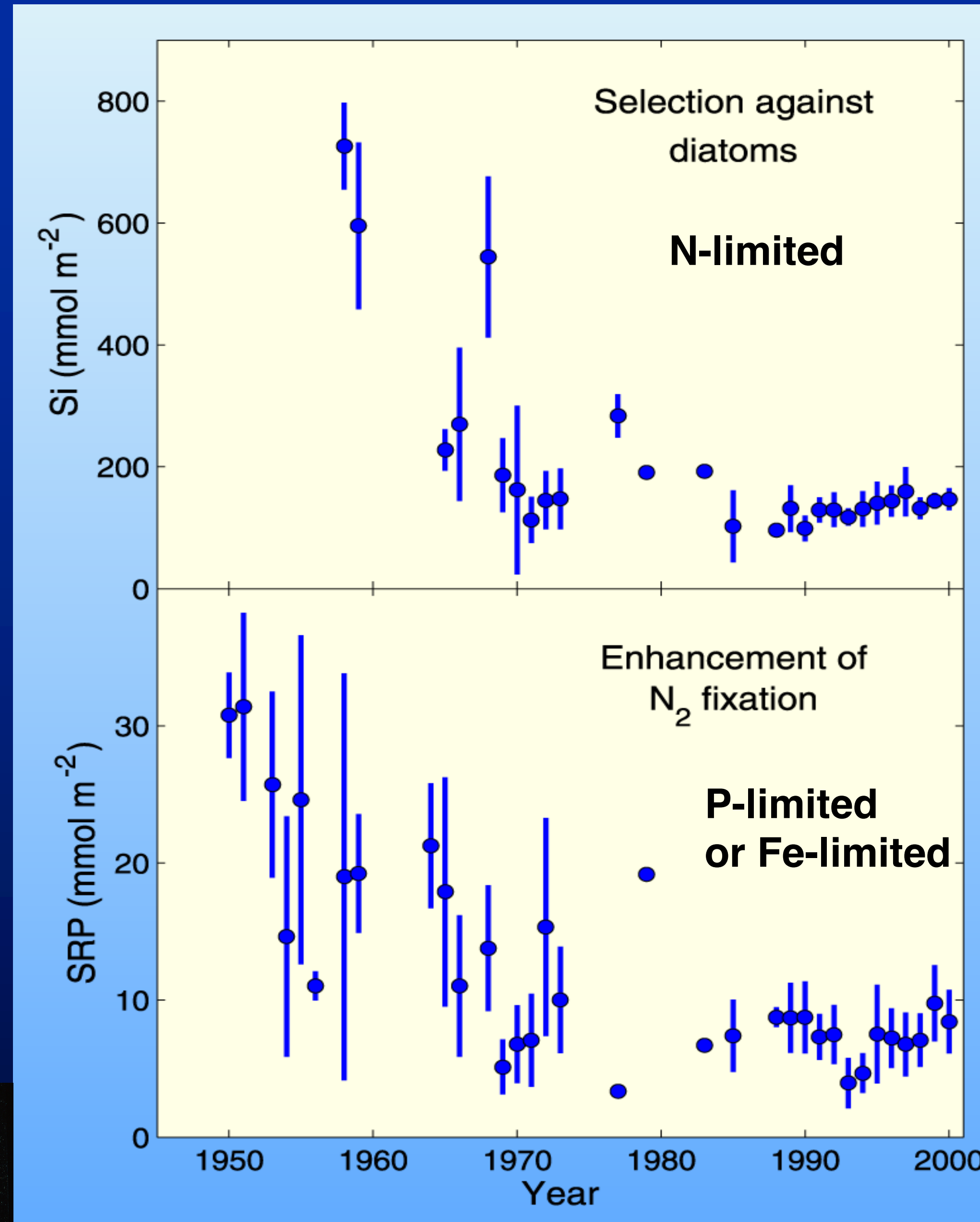
(courtesy of N. Bates, D. Karl; updated from Karl et al. 2001, Lomas et al. 2002)

Nutrient limitation of PP & Redfield stoichiometry

N. Pacific subtropical gyre



El Niño favorable

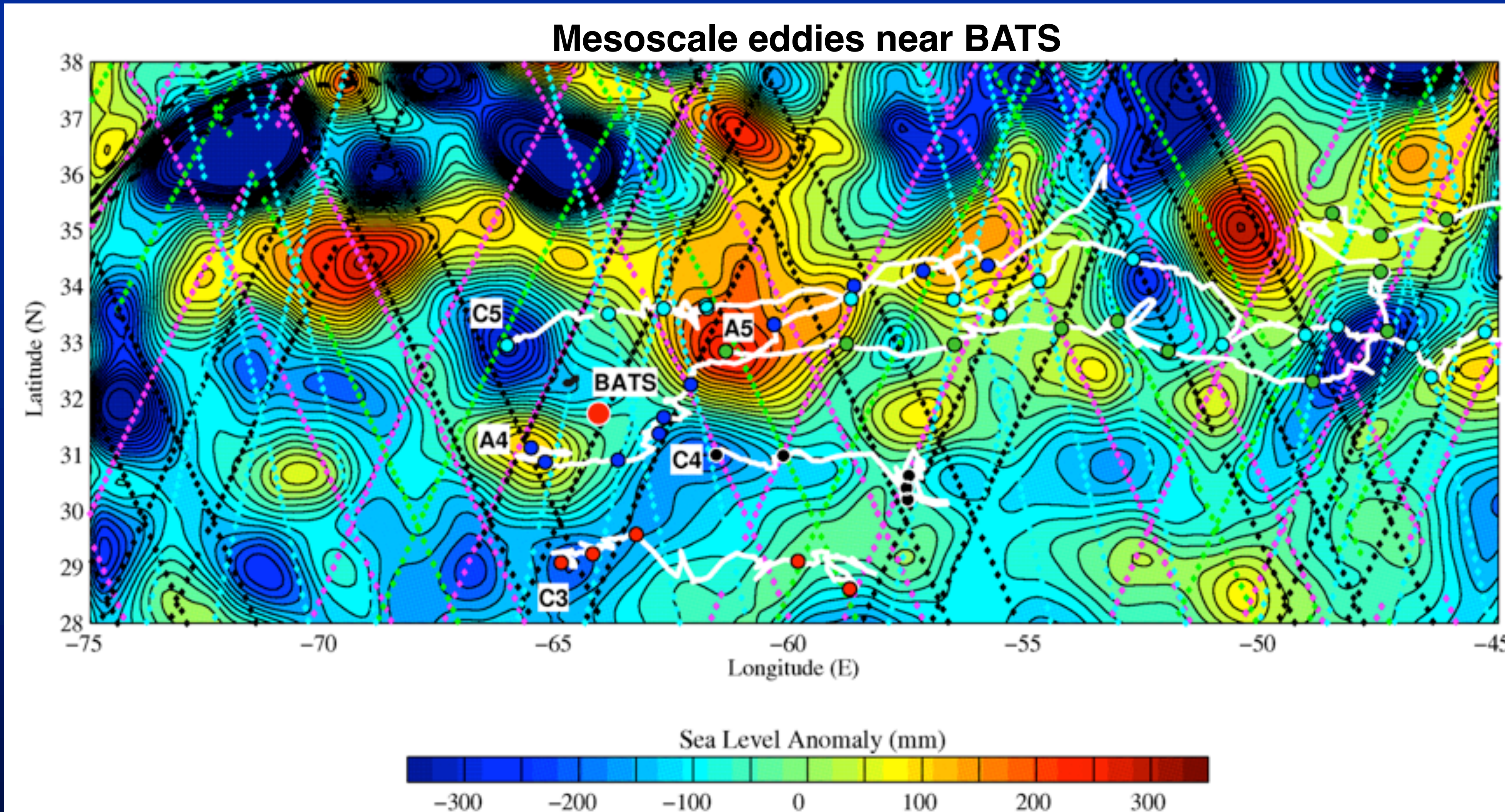


Favors increased stratification &
N-fixing cyanobacteria such as *Trichodesmium*

Leads to non-Redfield stoichiometry
in surface waters

D. Karl

Episodic nutrient supply and mesoscale eddies

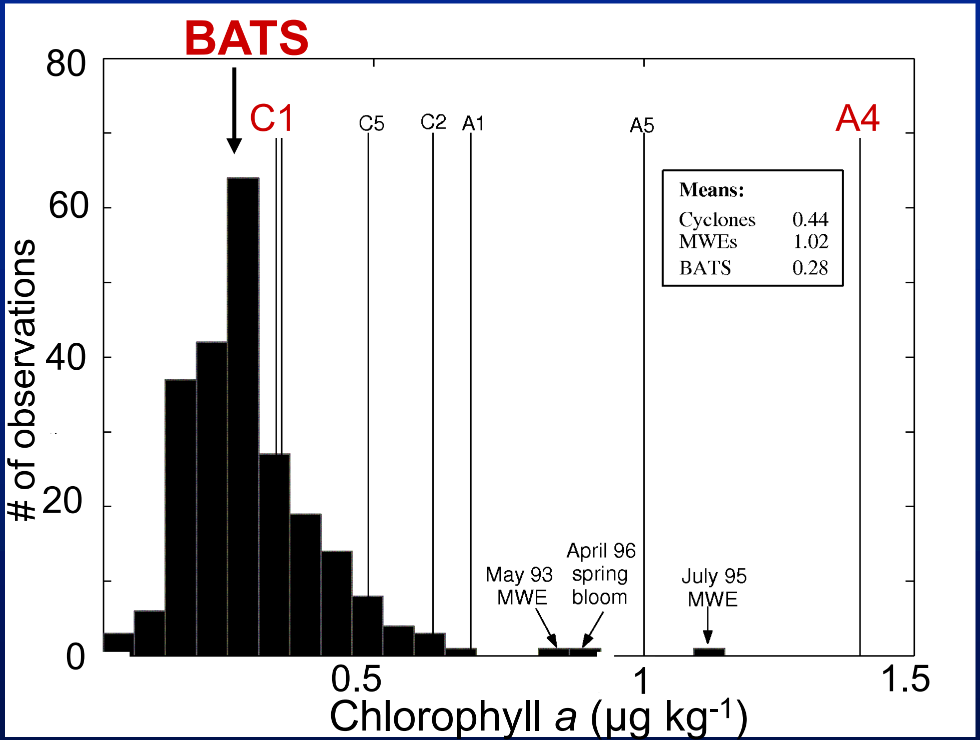


Understanding of mesoscale heterogeneity is key for Interpretation of time-series data, and visa versa.

McGillicuddy et al. (2007)

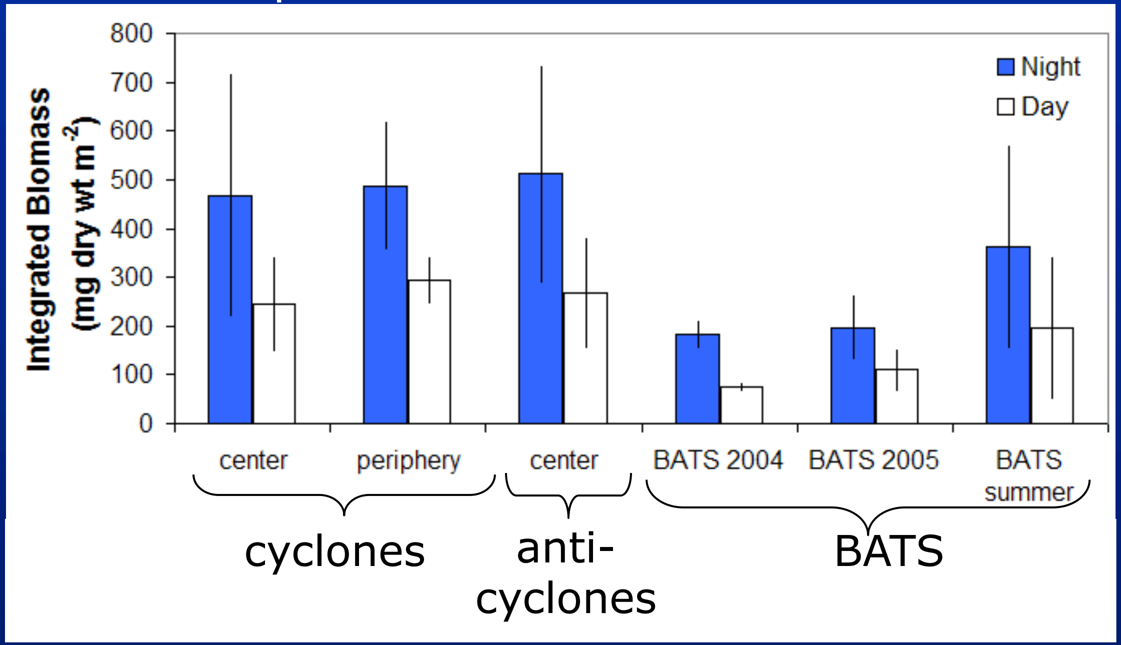
Eddy nutrient injection leads to increase in primary production, phytoplankton and zooplankton biomass at BATS (and HOT), and fecal pellet flux (BATS) compared to long-term records

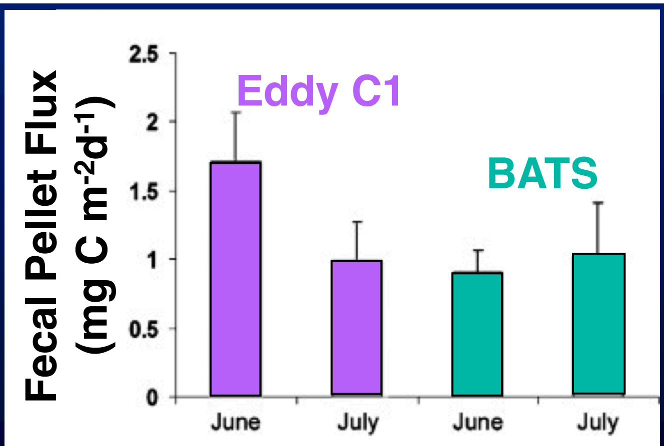
Subsurface Chl a maxima at BATS and in mesoscale eddies



McGillicuddy et al. (2007)

Mesozooplankton biomass in eddies vs. BATS





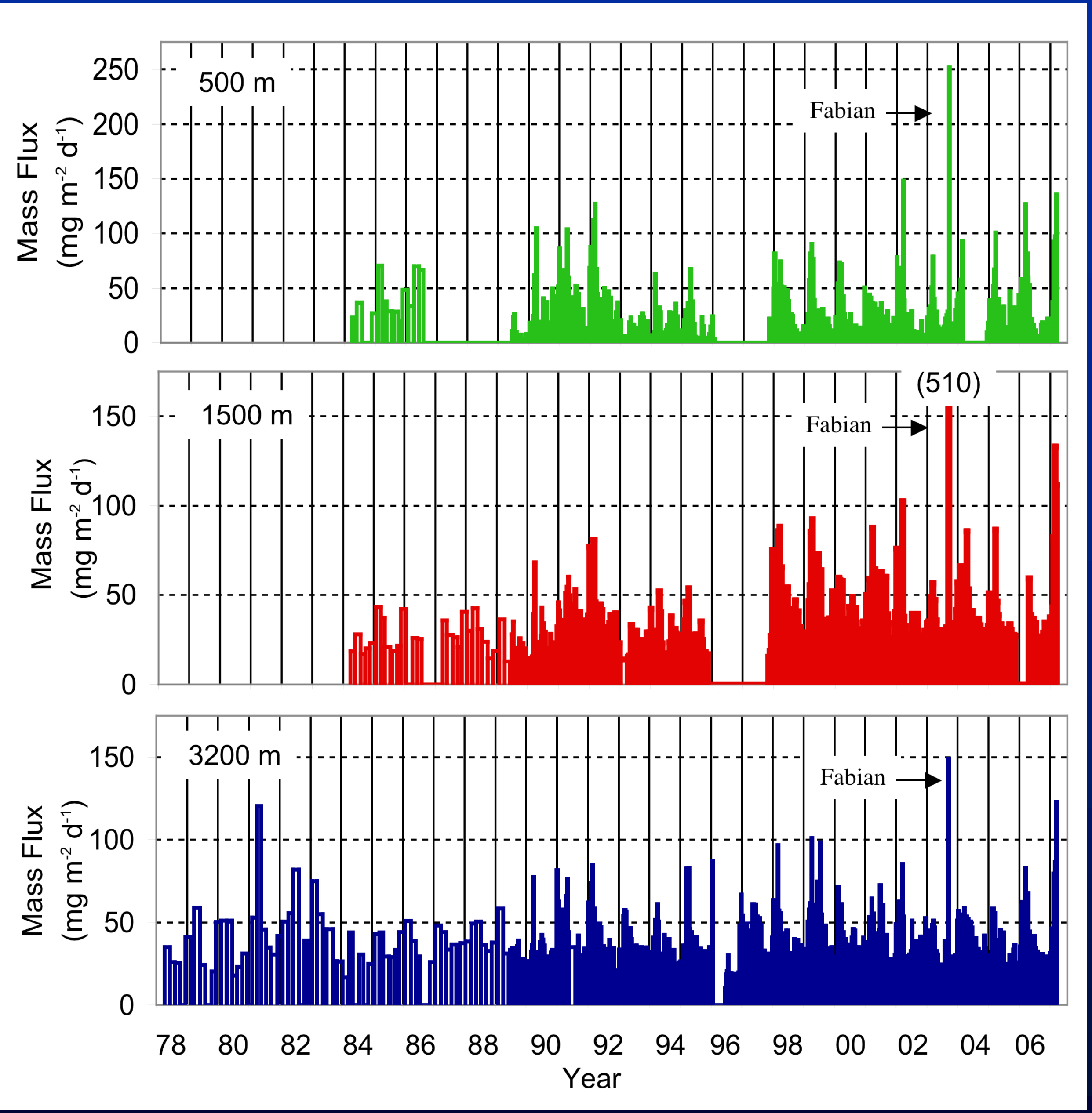
Goldthwait & Steinberg (2008)

Deep-ocean sediment trap flux in the Sargasso Sea

Oceanic Flux Program

Transformed the long-held view that the deep sea was a relatively stable, invariable environment

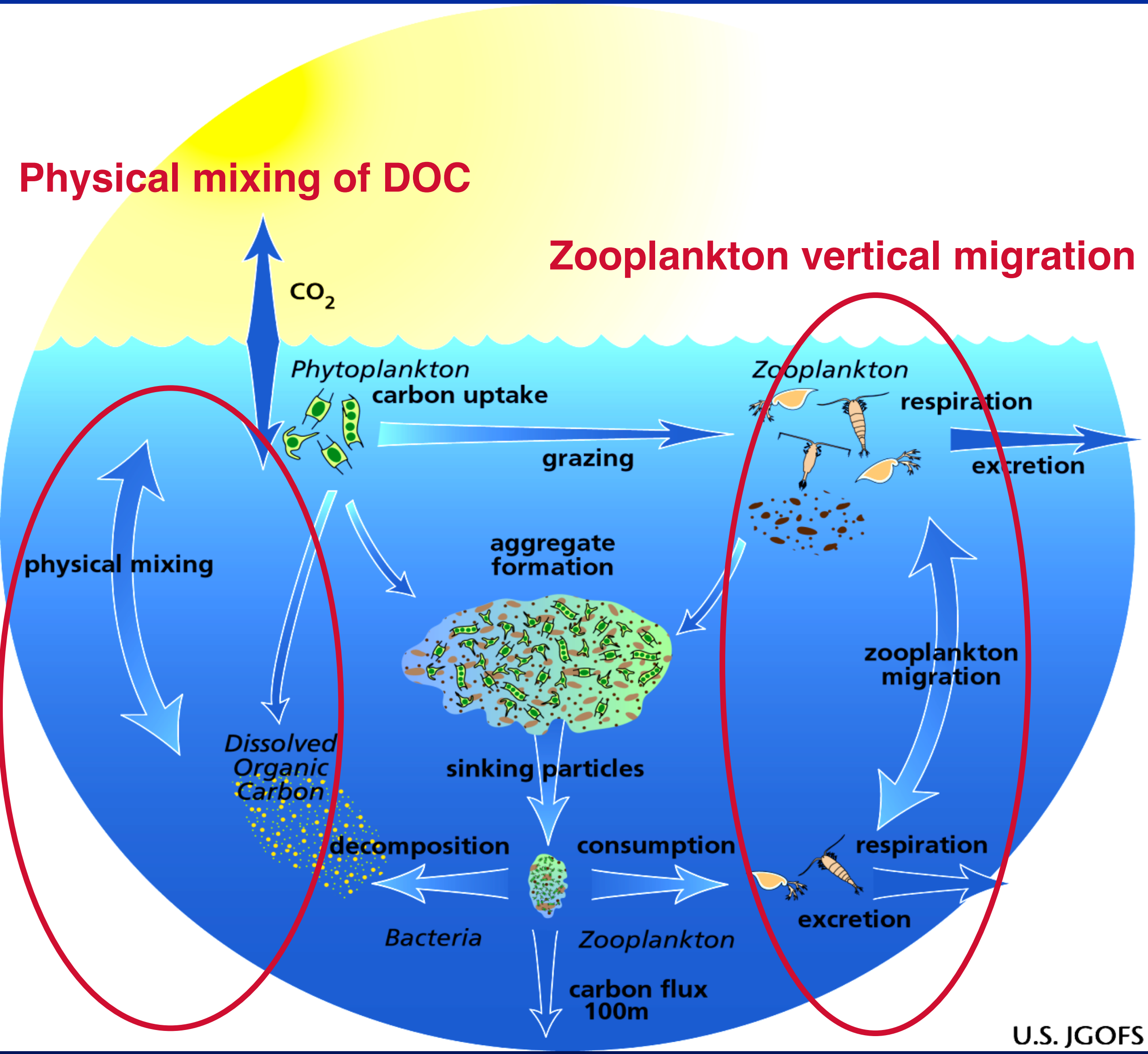
- Seasonality
- Also, short-lived episodic events



Extreme fluxes due to an advected plume of detrital carbonates during passage of Hurricane Fabian in Sep 2003.

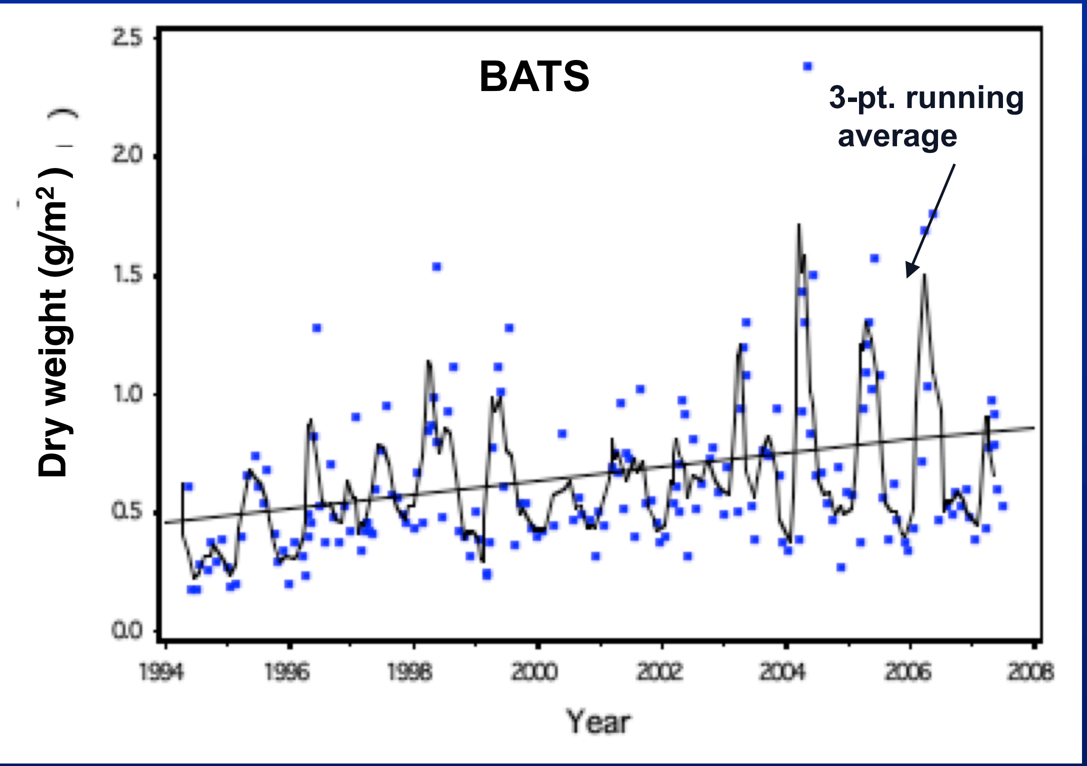
Conte and Weber (submitted)

Other components of the biological pump

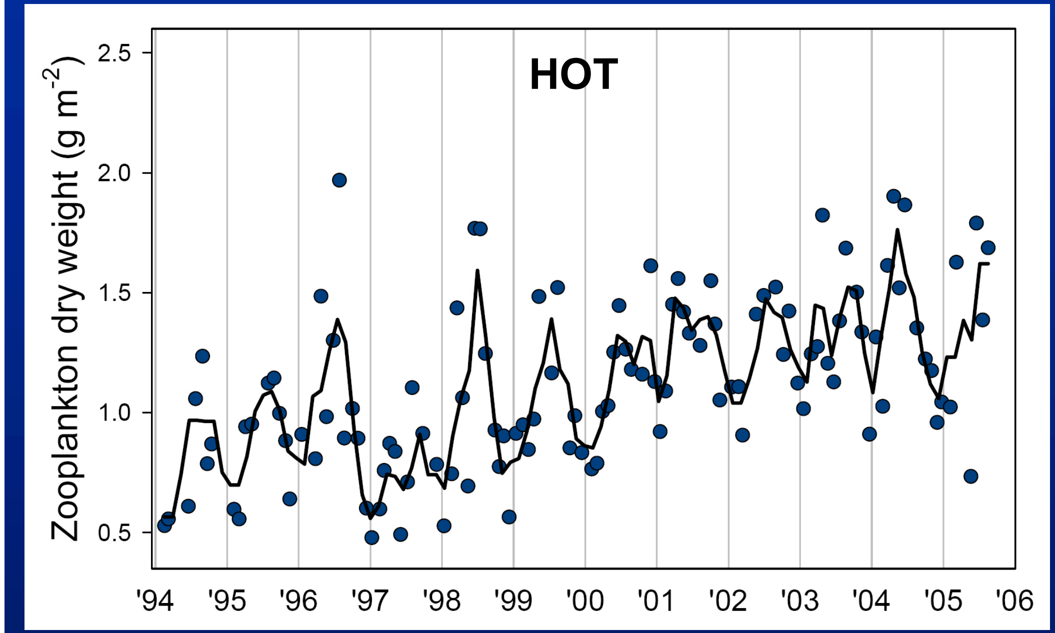


Common Vertical Migrators at BATS

Increase in epipelagic mesozooplankton biomass at BATS and HOT

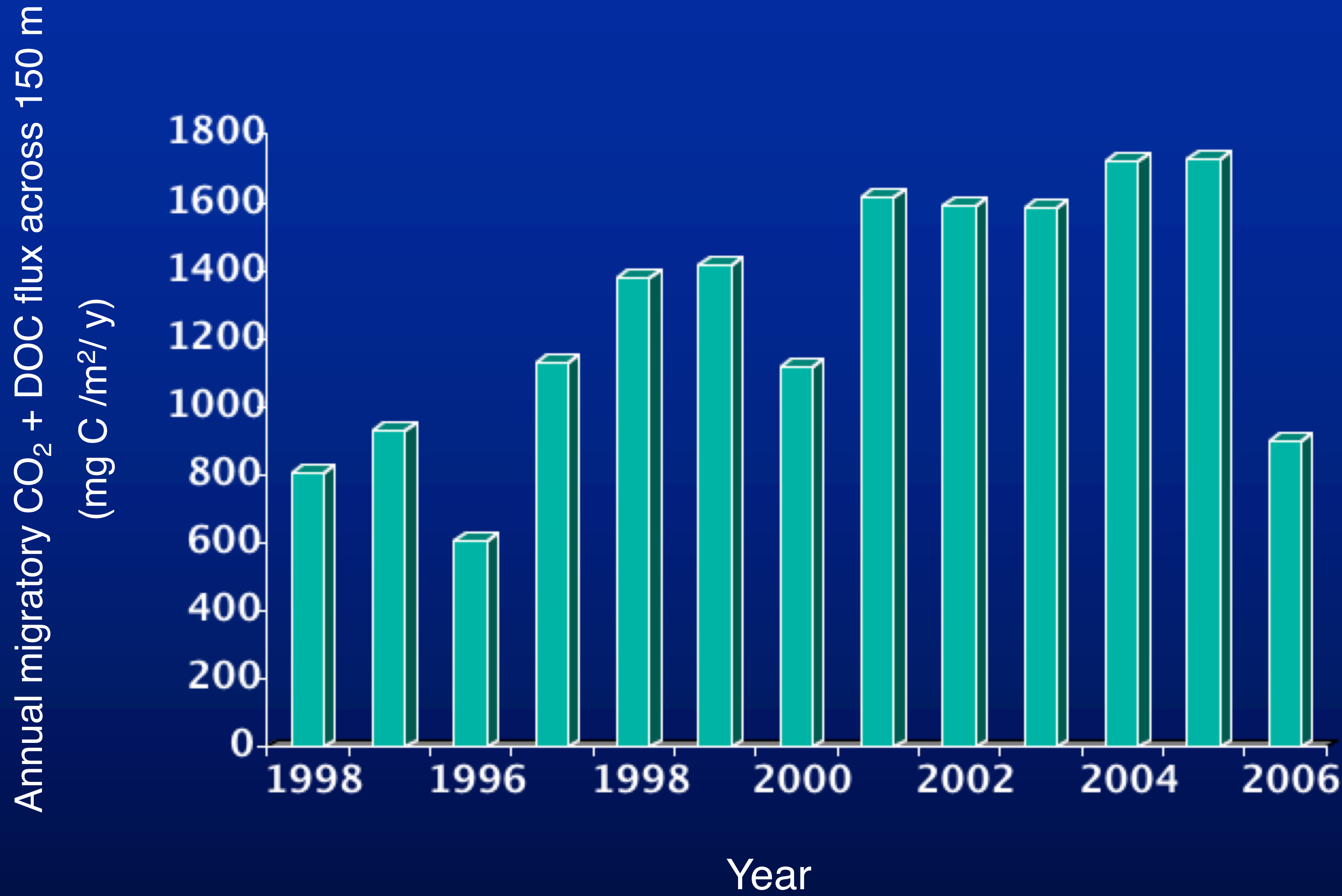


D. Steinberg



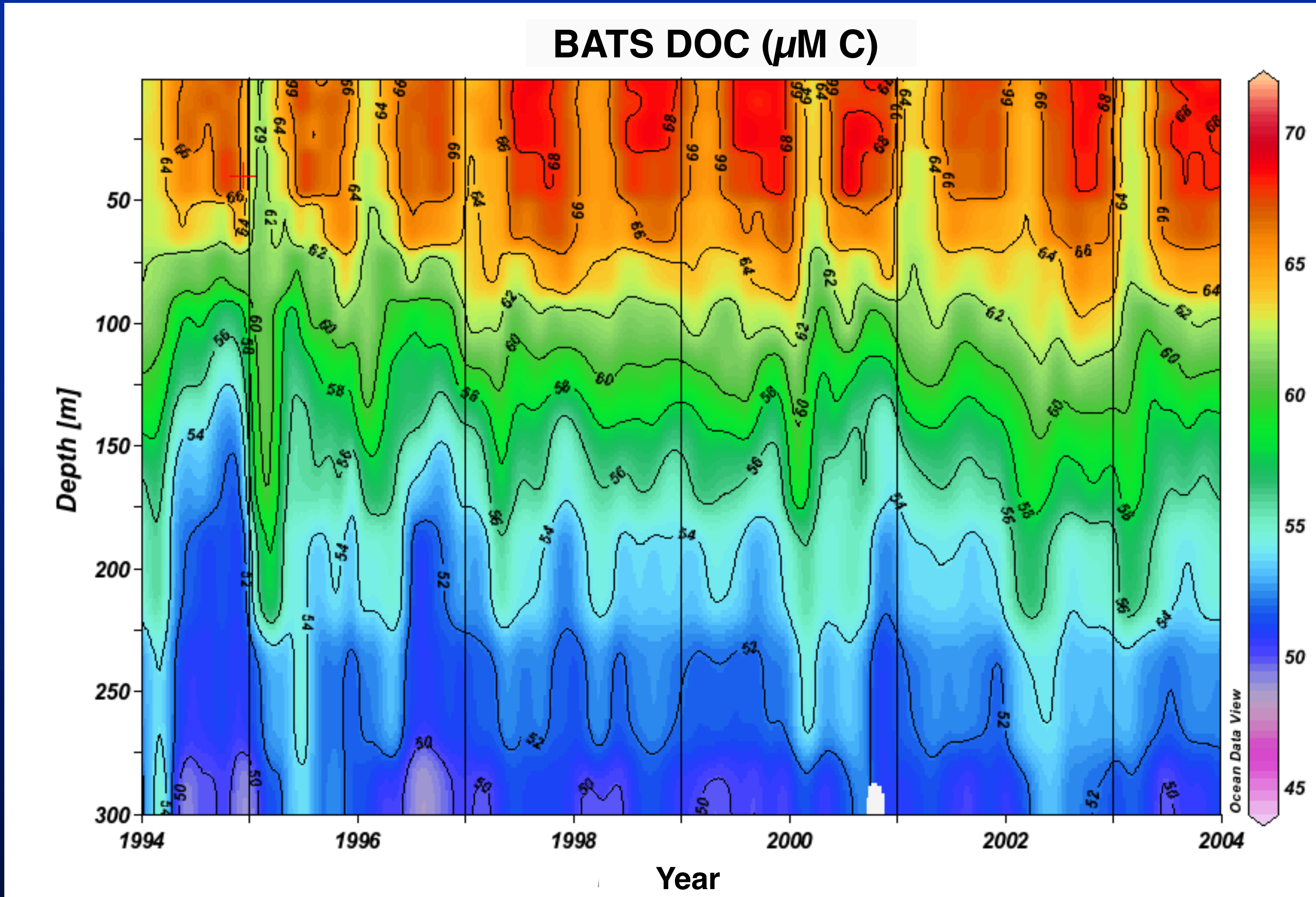
C. Sheridan,
updated from Sheridan & Landry (2004)

Increase in active transport by diel vertical migrators at BATS



Calculated as in Steinberg et al. (2000), Lomas et al. (2002)

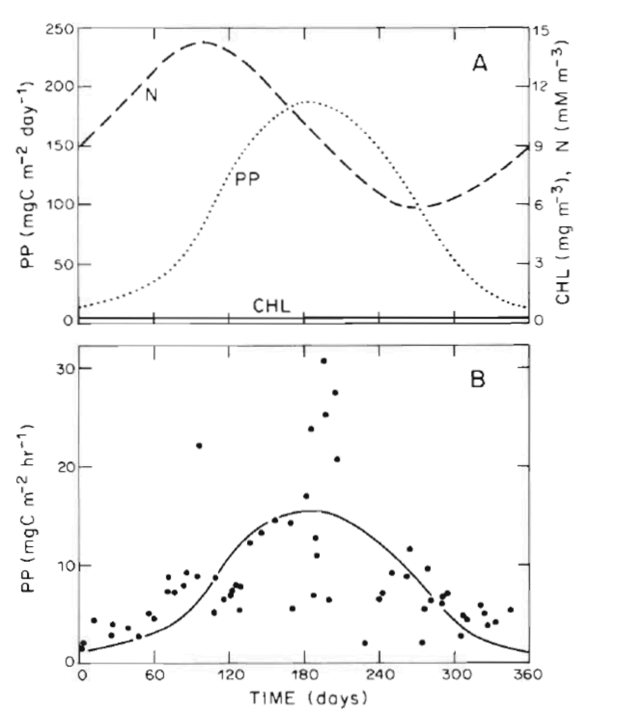
Vertical export of DOC via seasonal advective overturn



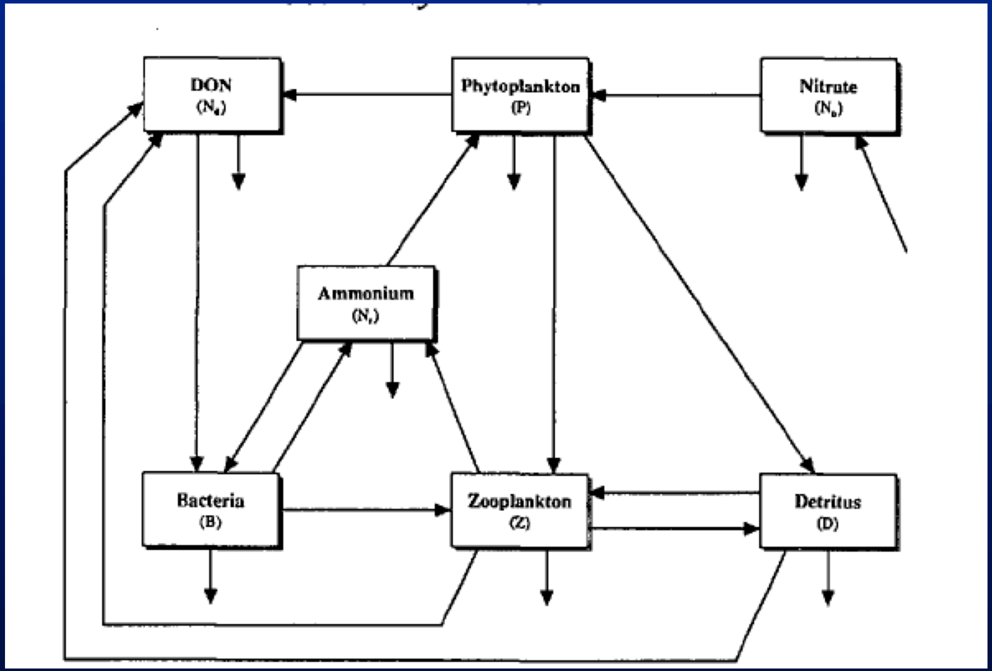
C. Carlson, updated from Hansell & Carlson 2001

Informing models with observations

- The synergy of time-series and models
- Simulating upper ocean physics
- Food-web and Biogeochemical complexity



Frost 1986- N-P-Z model w/ Station P data



Fasham, Ducklow, & McKelvie (1990)- Hydrostation S

The synergy of time-series and models

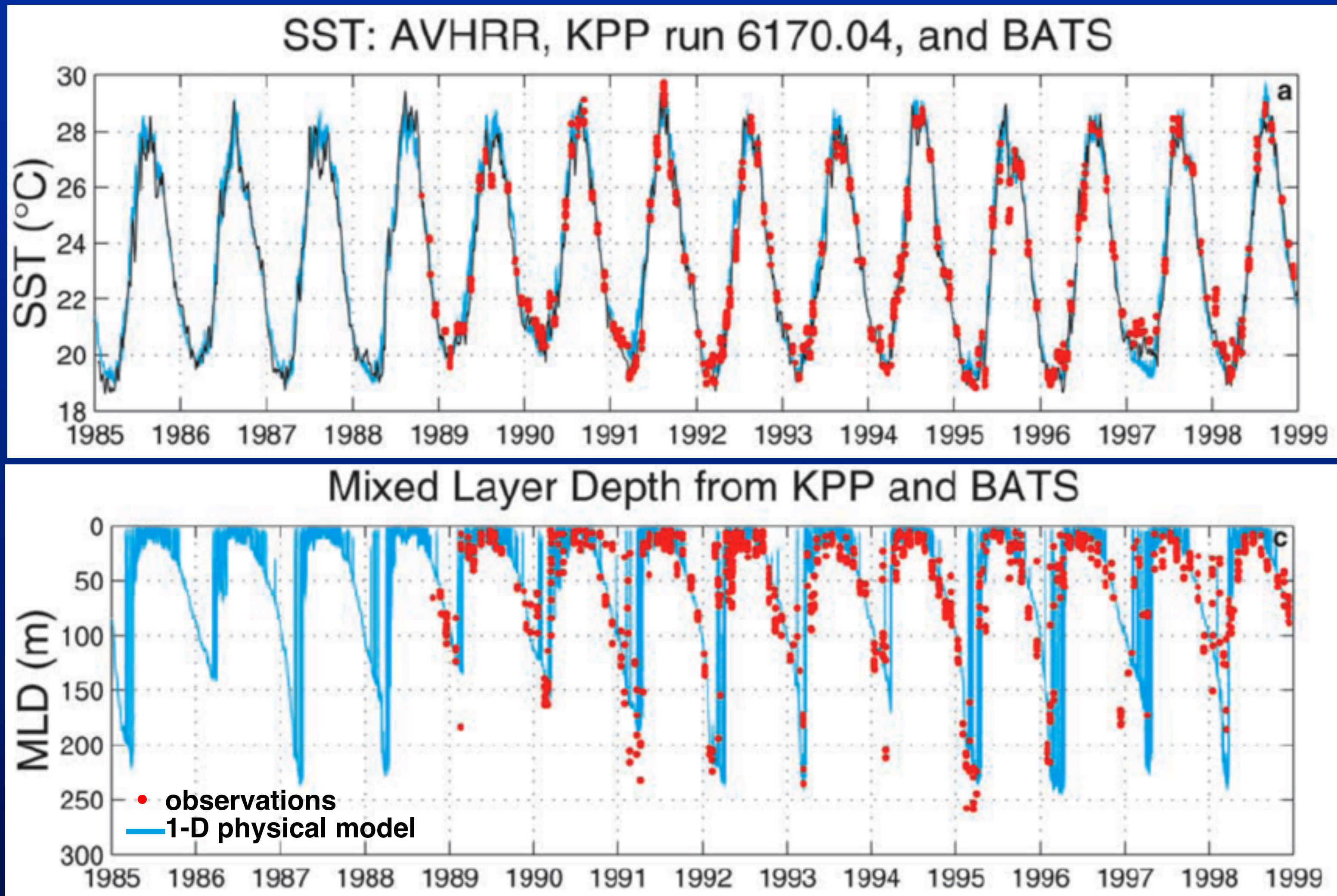
- Time-series are attractive- provide additional information on how system responds in time to perturbations (storms and dust deposition to seasonal cycle, ENSO, decadal variability, climate change)

- Biological modeling studies are inherently data limited. Observations are needed to test model parameterizations (e.g., for photosynthesis, grazing , respiration) and evaluate model skill.

- Model-data interaction is two-way, an integrated modeling component augments field programs. Simulations can help fill in data gaps.

Improved ocean physics

Seasonal & interannual variability in temperature & mixed layer depth at BATS



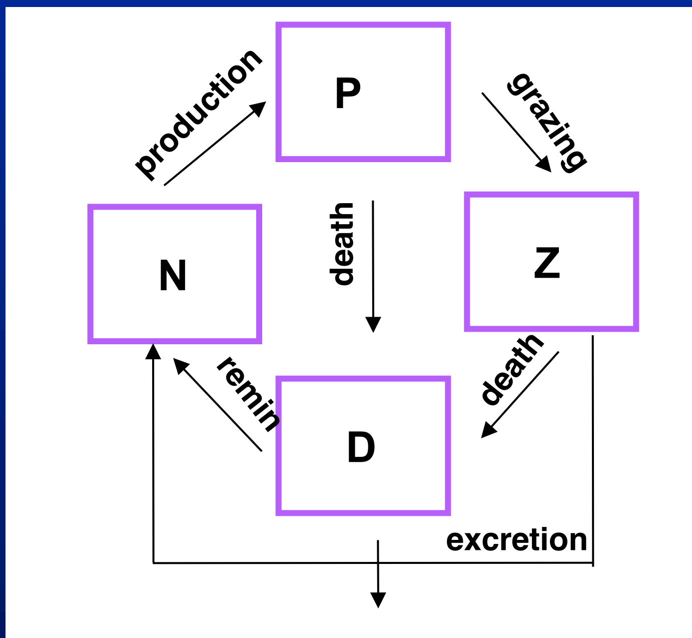
The ocean is a turbulent, moving fluid.

Realistic physics required for detailed model-data comparisons, climate variability and climate change studies.

Doney 1996, Glover et al. 2002, updated

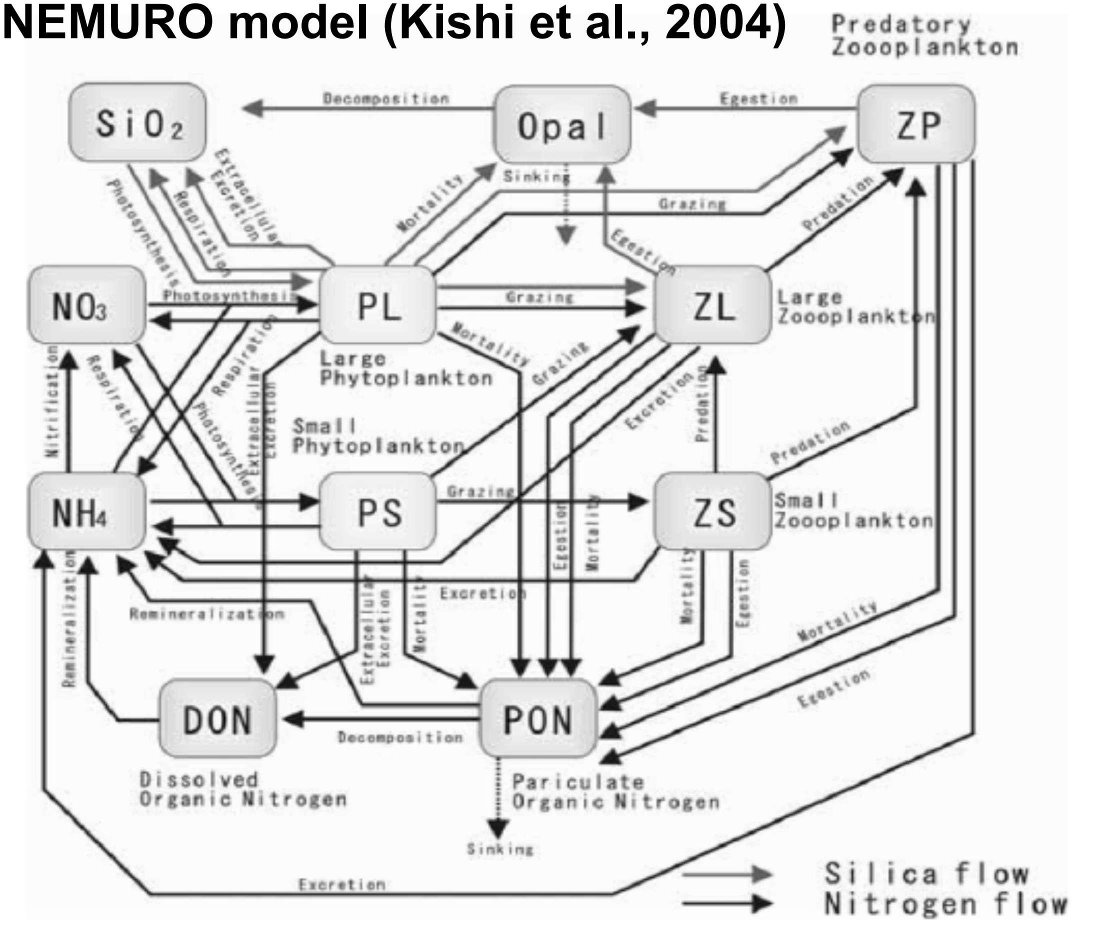
Food-web and biogeochemical complexity

The wealth of new time-series data demonstrated many flaws in model formulations (this is good!); in response ecosystem models have evolved in complexity.



Frost 1986 -like model

NEMURO model (Kishi et al., 2004)

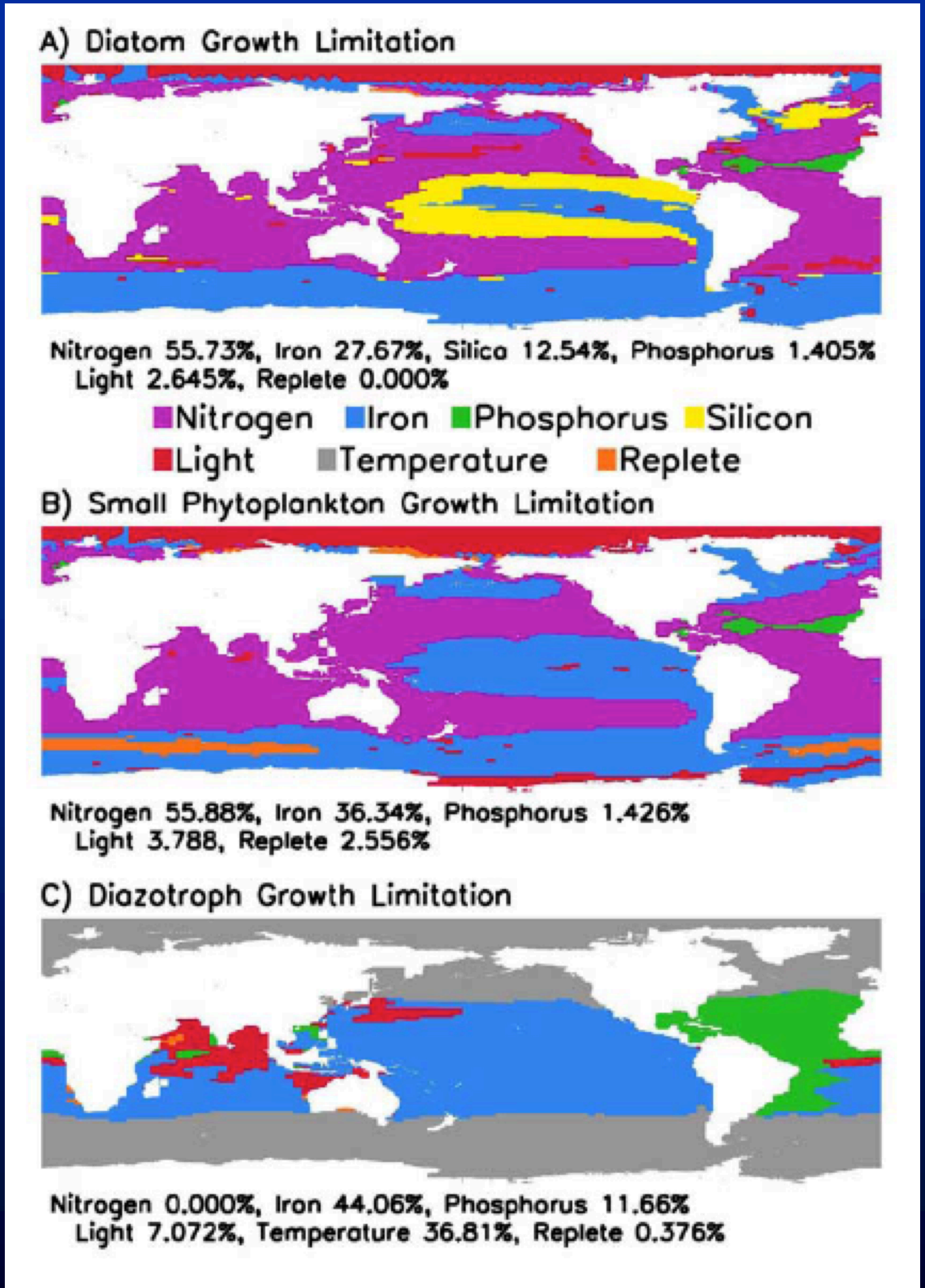


M. Friedrichs

Factors limiting phytoplankton growth

Global three-dimensional marine ecosystem model with:
• Several phytoplankton functional groups
• Multiple limiting nutrients
• Explicit iron cycling
• Mineral ballast/organic matter parameterization

Run with a global ocean circulation model



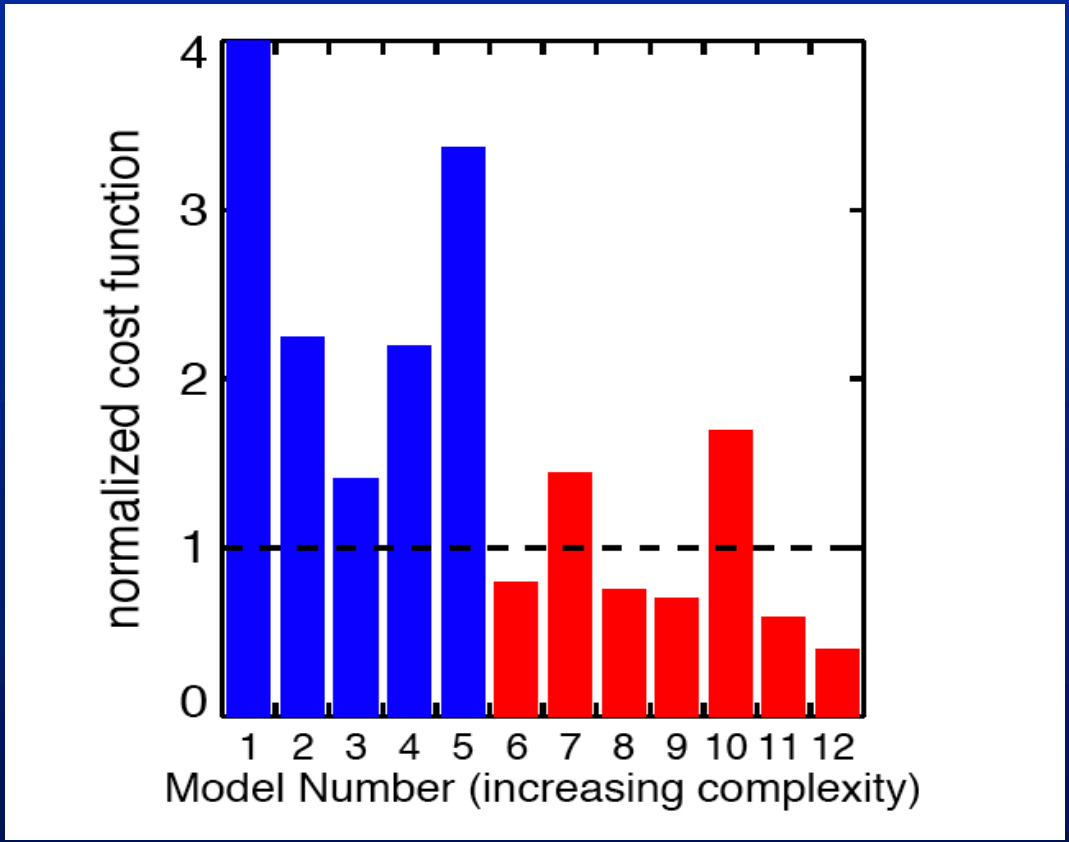
Moore et al. 2004

Cost function (model-data misfit) of single- and multi-phytoplankton functional groups

Cross validation experiment- data assimilated from one site, and optimal parameters used to generate simulation for the other site.

Worse than mean

Better than mean



Ecosystem Models (Arabian Sea & Eq Pac)

= single P

= multi-P

Models with multiple functional groups are more portable across marine biomes

Friedrichs et al. 2007

Conclusions

- Ocean time series have helped us build a better picture of lower-frequency ocean variability, the climate processes driving it, and its implications for food web dynamics, biogeochemical cycling, and C storage.

- Time series enlarge our understanding of ecological processes and are integral for improving models of physical-biogeochemical-ecological ocean dynamics.

Future issues

- How to enhance and maintain existing efforts and initiate new observation programs in critical, under-sampled ocean regions?

- To improve understanding of how ocean ecosystems will change in response to anthropogenic impacts, we need to better quantify high-frequency time and space variability around time-series sites, using autonomous moorings, gliders, and in-situ sensors

- We must develop integrated observing systems combining field data, satellite remote sensing, and data assimilation.

Thank you!

Especially to the dedicated multitude that forms the backbone of long-term oceanographic time series.
(Thank a time-series technician next time you talk to one!)

And, the funding agencies that support them.

Marjy Friedrichs, Craig Carlson, Dave Karl, Mark Ohman, Anthony Richardson, Gregory Beaugrand, and others who provided slides, help.