New & Export Production in the North Pacific: Lessons from The Hawaii Ocean Time-series

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and many others

FUNDING : Primarely NSF

OUTLINE

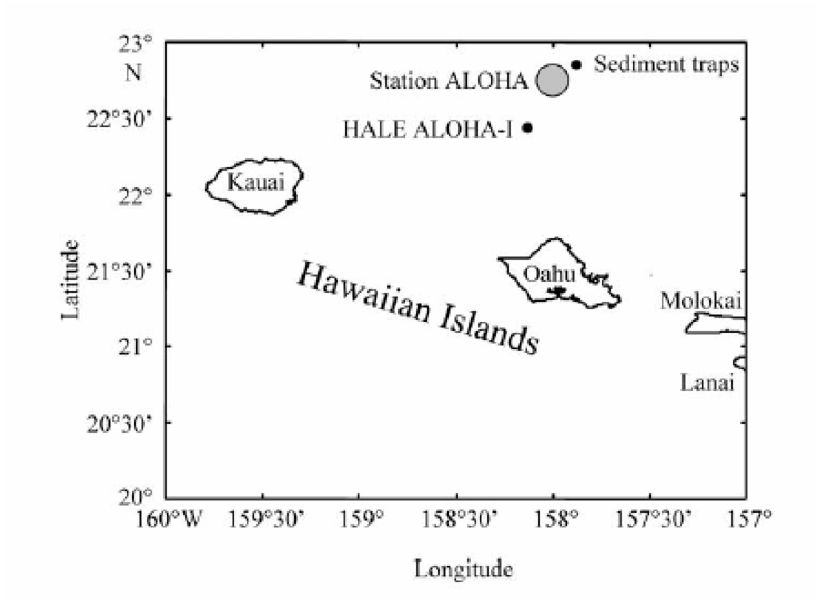
1) The Hawaii Ocean Time-series (HOT) program

2) Potential mechanisms to explain the observed seasonal patterns of Particulate Export Production

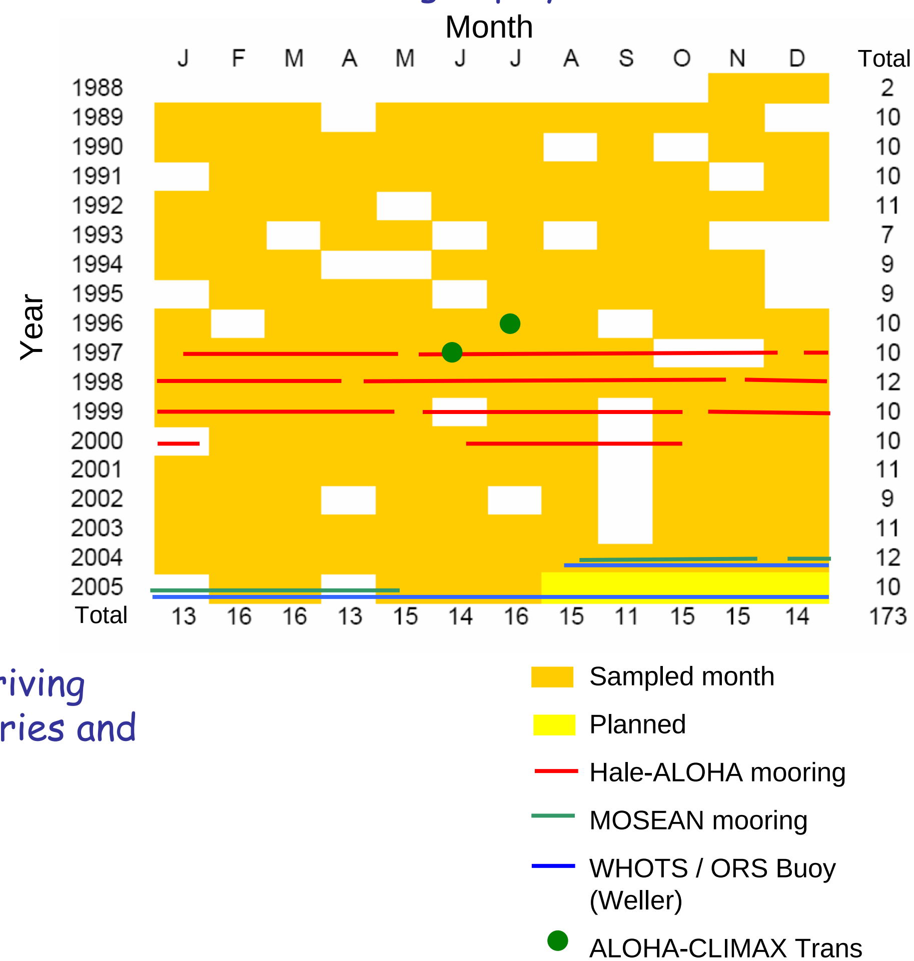
3) Changes in long-term forcing

4) Future Challenges

Map of Station ALOHA



Cruise & mooring deployment schedule



Initial objectives under JGOFS

- Identify & characterize the mechanisms driving the temporal variability in C,N, and P inventories and fluxes

Some numbers

- # of cruises to date = 171 (~5 day cruises)
- # of participants = >350
  (PI = 10, Scientists = 59, Technicians = 77, Students = 180, Others = 4)
- # of Collaborating institutions = 23
- # Publications using HOT observations = > 175

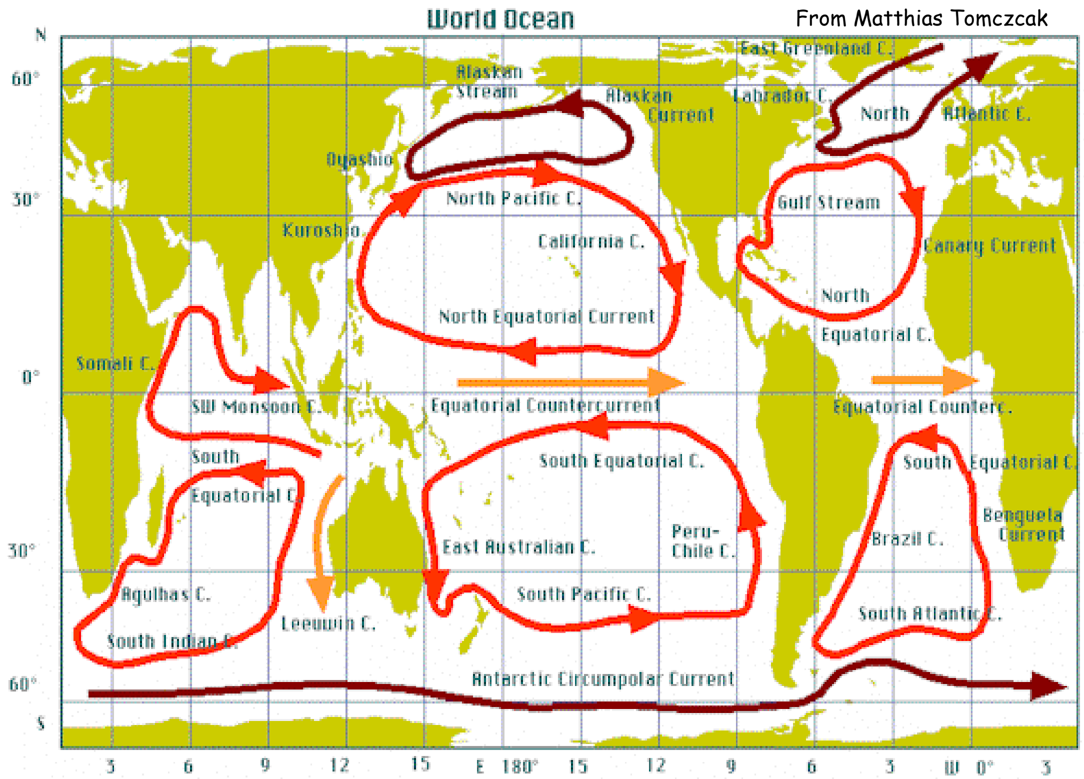
Human & Infrastructure Support Lessons

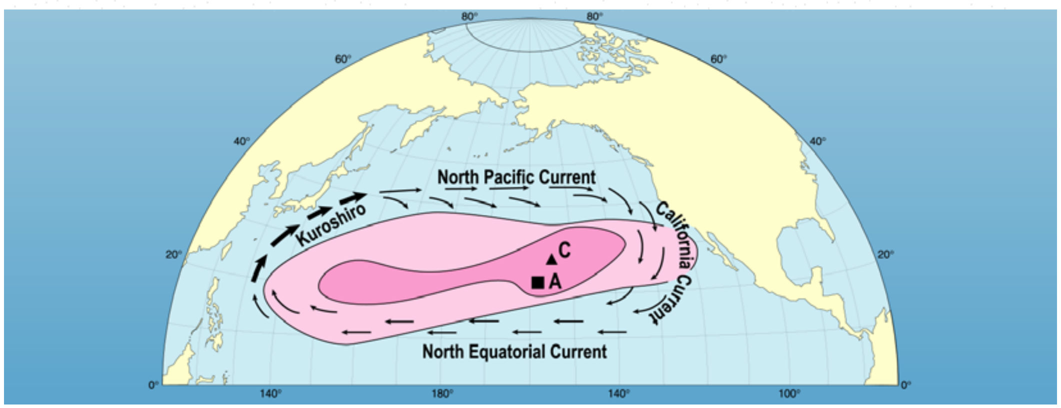
1) HOT is the result of the effort, leadership, commitment & collaboration of two PIs (Karl & Lukas) and their colleagues.
2) The long-term involvement of technicians & the contribution of students are a fundamental component of this effort.
3) Long-term funding and advanced cruise schedule facilitates the synergistic collaborations with other research teams

Some basic challenges inherent to T/S research

1) Maintaining the scientific interest & motivation of the core program team
2) Maintaining the coherence of the T/S core measurements while being flexible in adopting new technologies, facing personal and expertise replacement, and addressing new science questions.

From Matthias Tomczcak





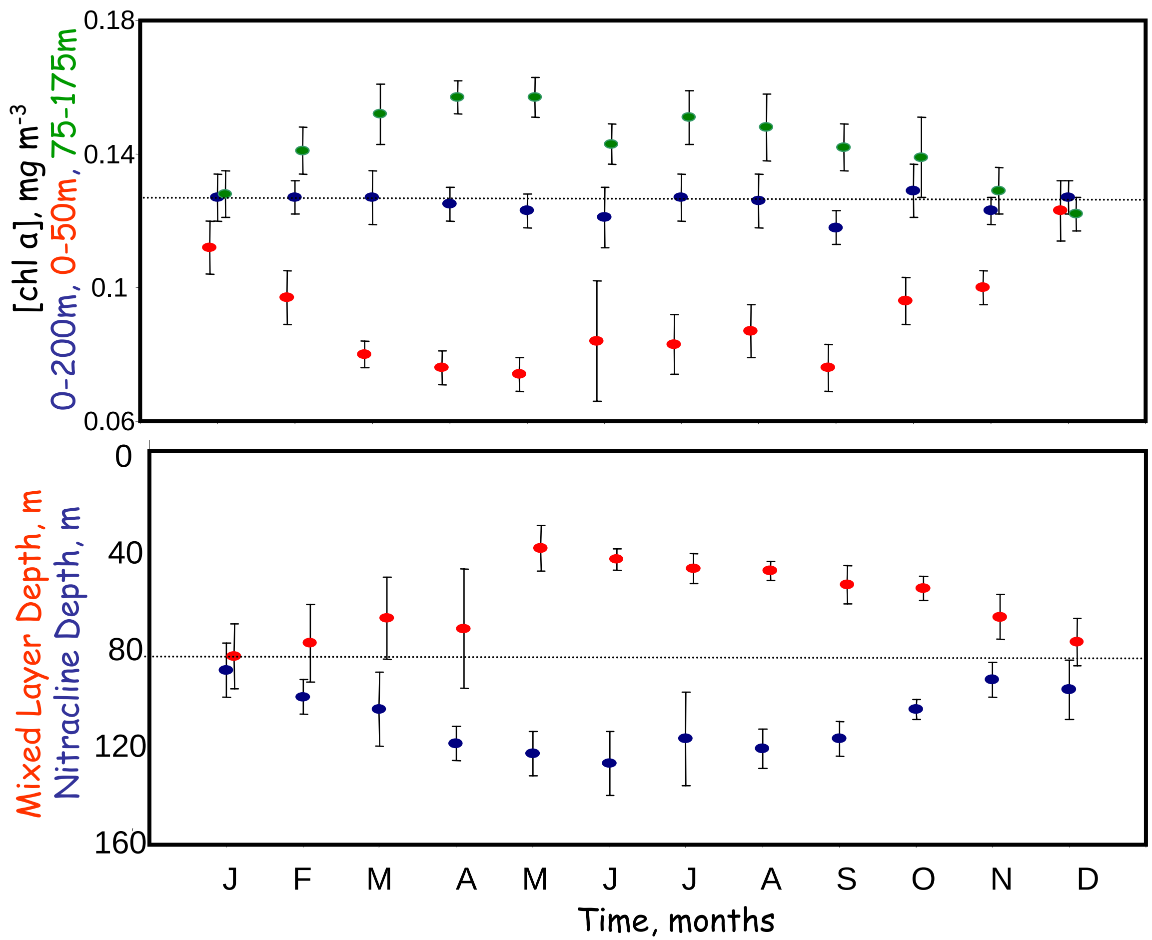
Karl (1999) redrawn from McGowan (1974)

- Approximately 60% of the surface of the ocean is occupied by subtropical gyres.
- These gyres support very old, low biomass, and apparently stable ecosystems
- Turnover rates of organic matter is very rapid in surface waters (strong coupling of microbial activity)

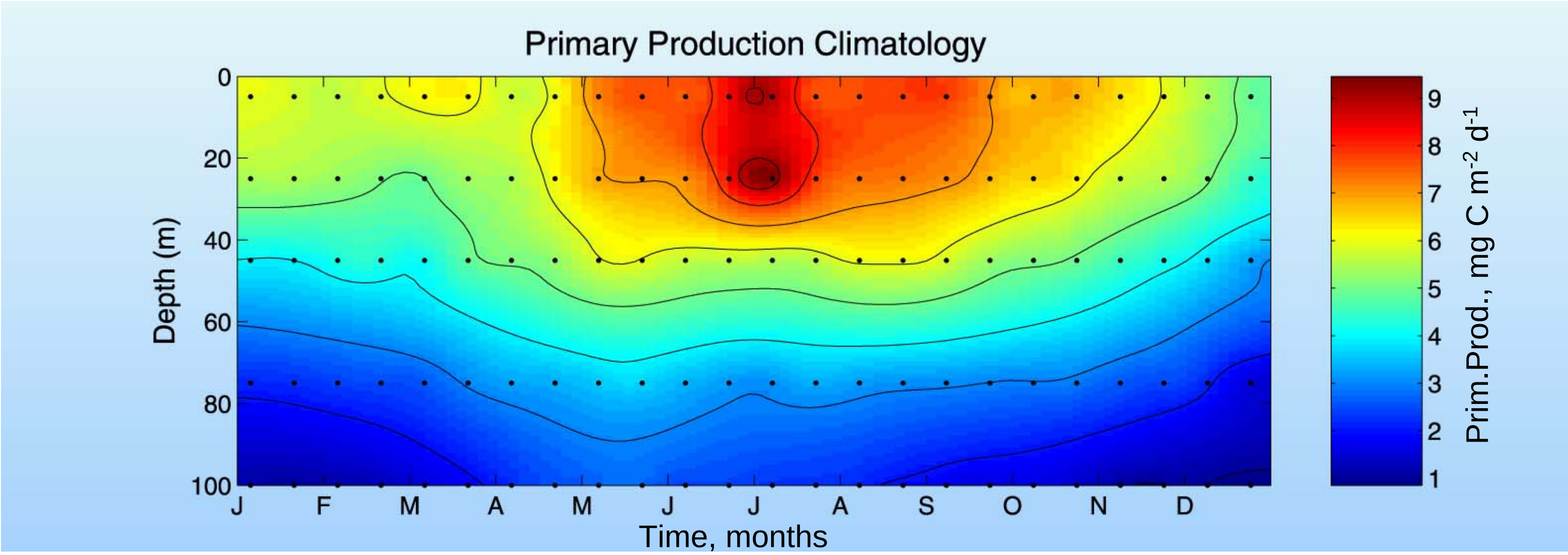
Generalized cycle of chlorophyll, mixed-layer depth and top of the nitracline using 1989-2004 data

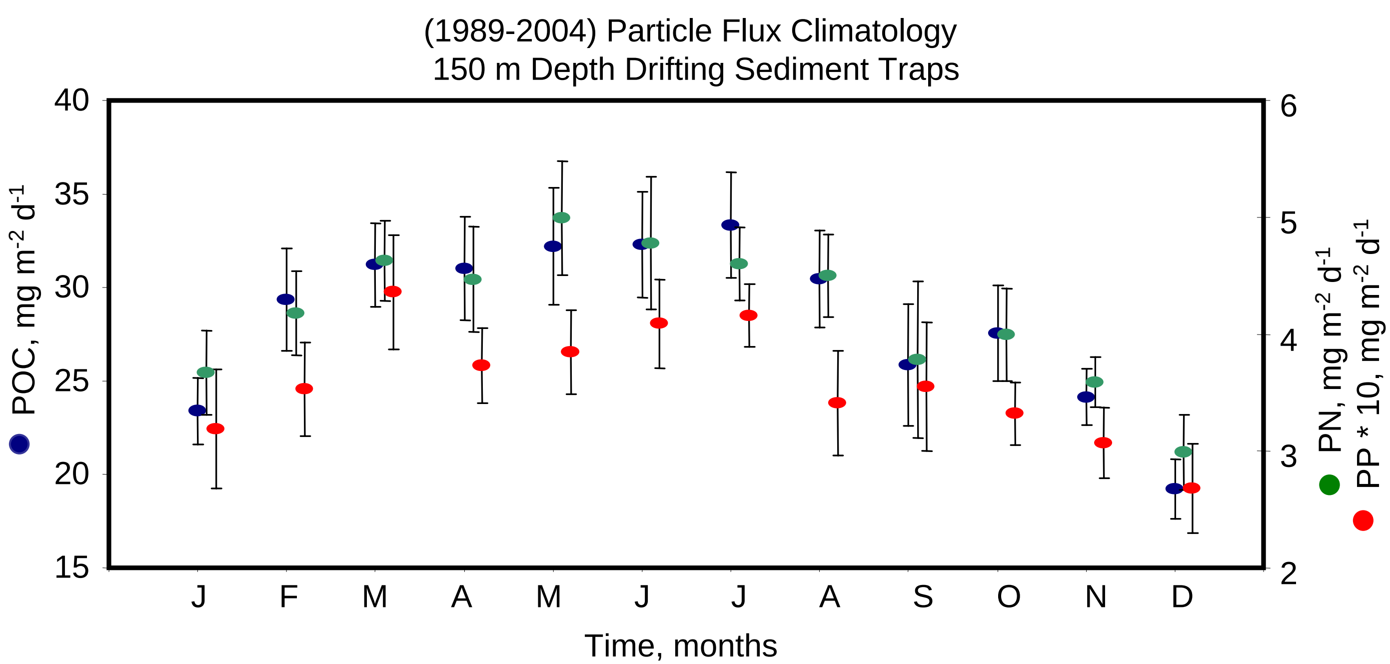
- No seasonal cycle in the 0-200 m integrated but an oposite seasonal cycle in the mixed-layer and the DCML
- While the chl a mixed-layer cycle is due to photoadaptation, the DCML is the result of changes in biomass -(Winn et al. 1995)

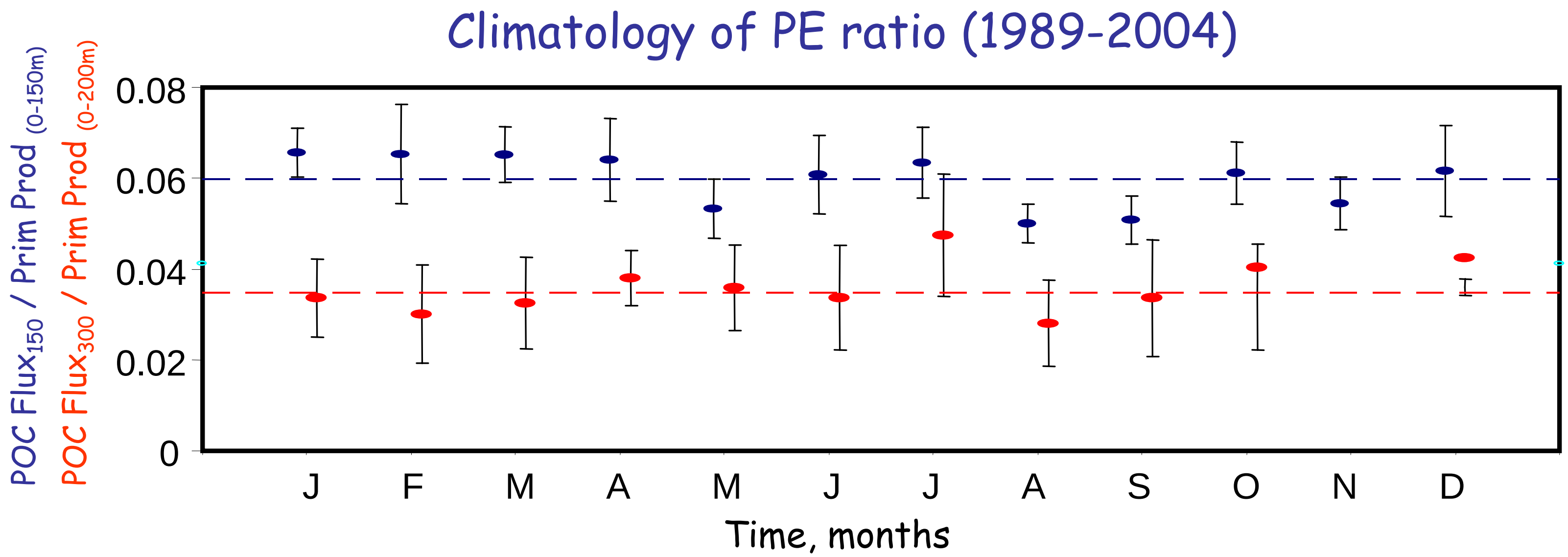
- The mixed layer deepens in winter reaching in some years the top of the nutricline.
- The position of the upper nutricline deepens in summer.

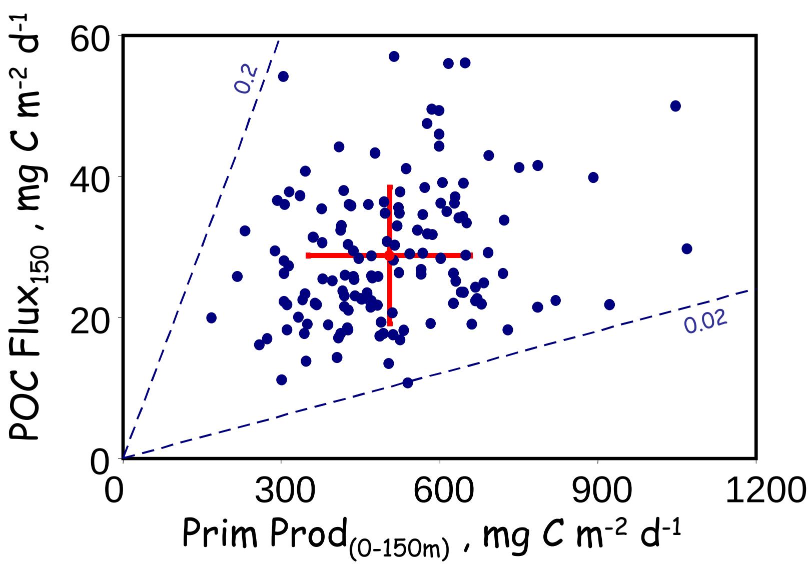


New & Export Production at HOT





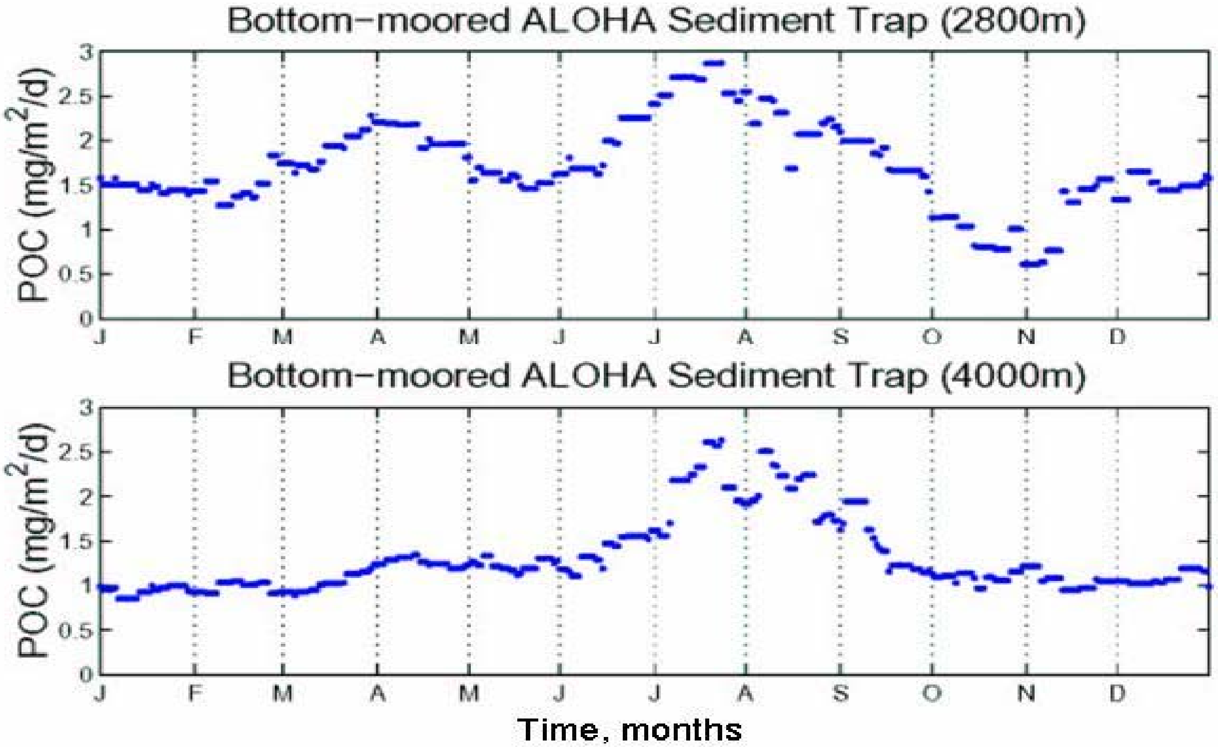


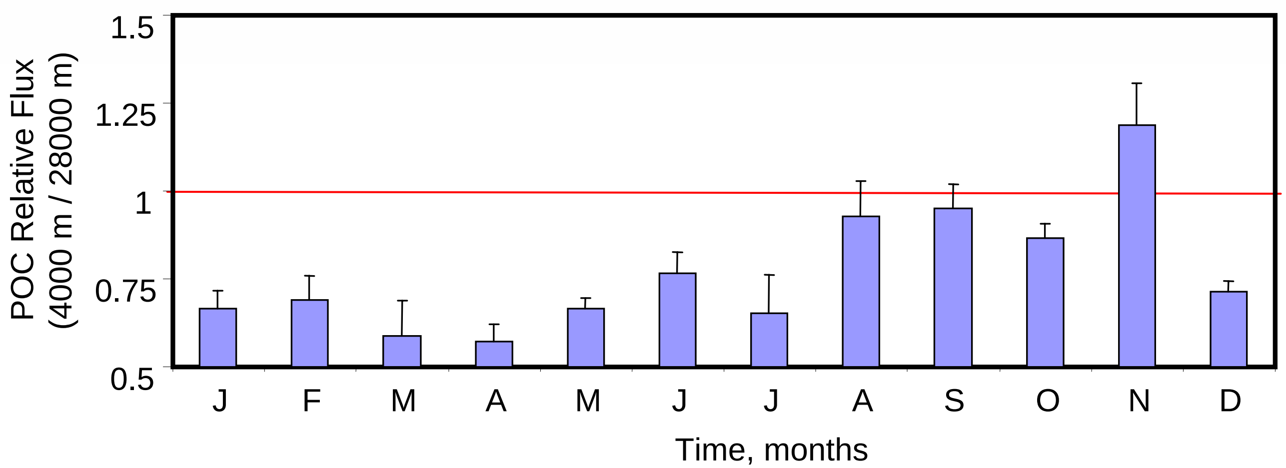


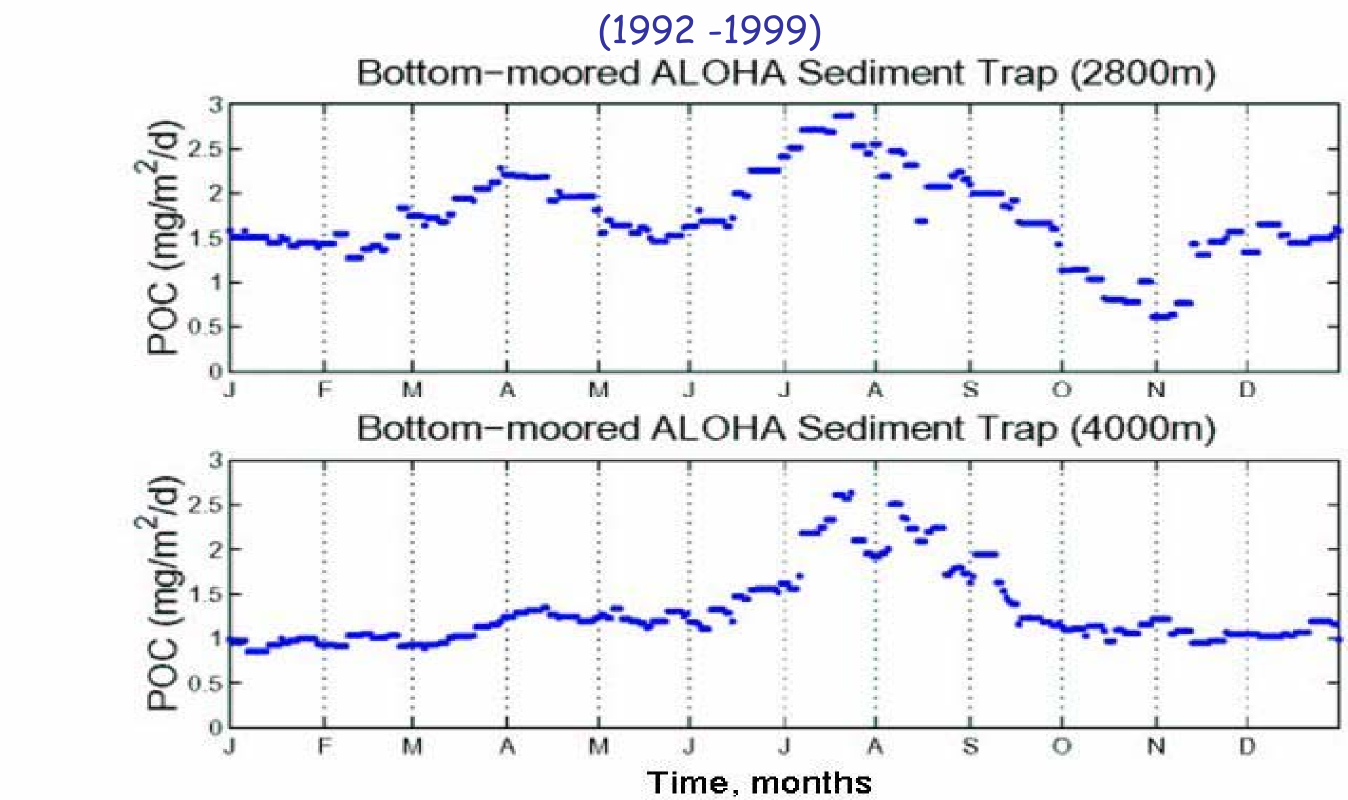
- There is no clear seasonal pattern in PE ratio derived from the particulate flux measured the sediments traps

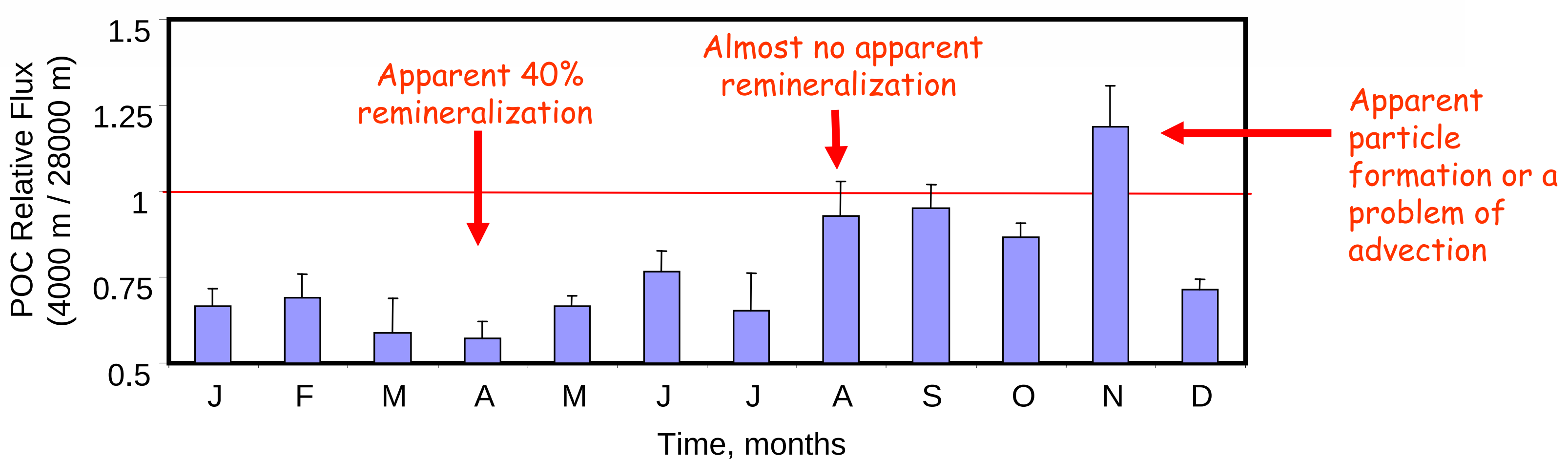
New & Export Production at HOT

(1992 -1999)



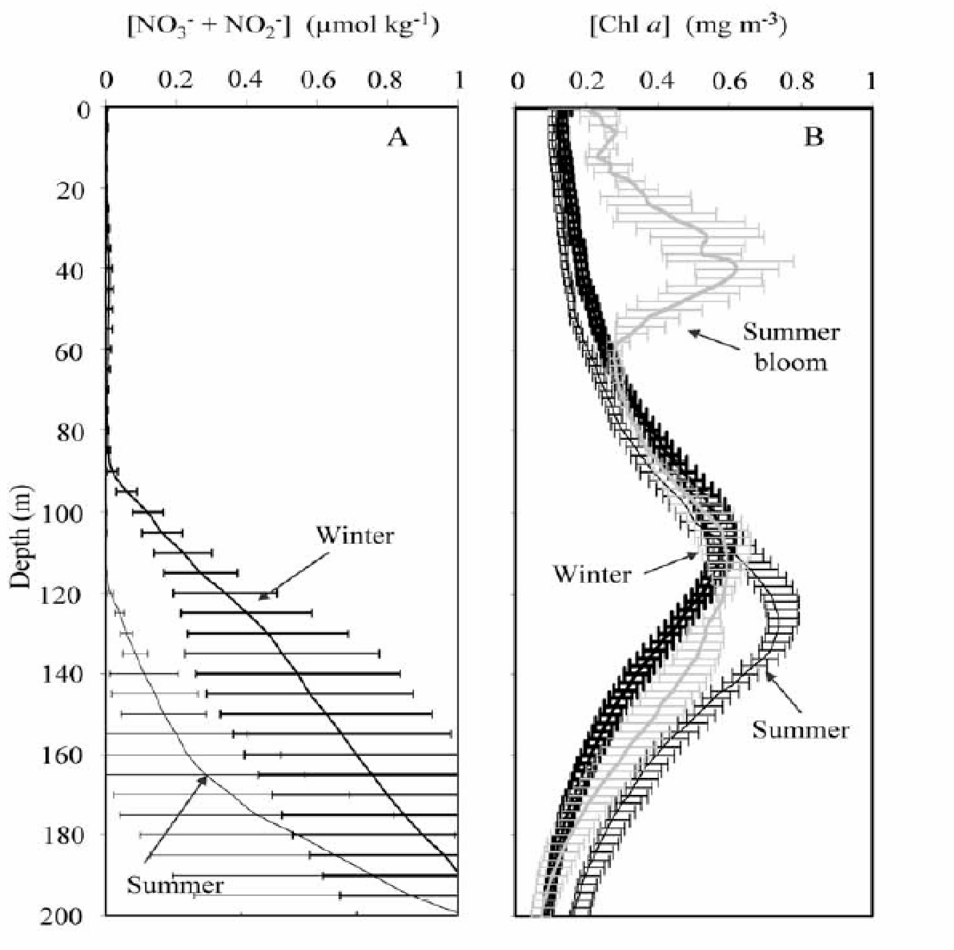



(1992 -1999)
Bottom−moored ALOHA Sediment Trap (2800m)
POC (mg/m²/d)
0
0.5
1
1.5
2
2.5
3
J F M A M J J A S O N D
Bottom−moored ALOHA Sediment Trap (4000m)
POC (mg/m²/d)
0
0.5
1
1.5
2
2.5
3
J F M A M J J A S O N D
Time, months

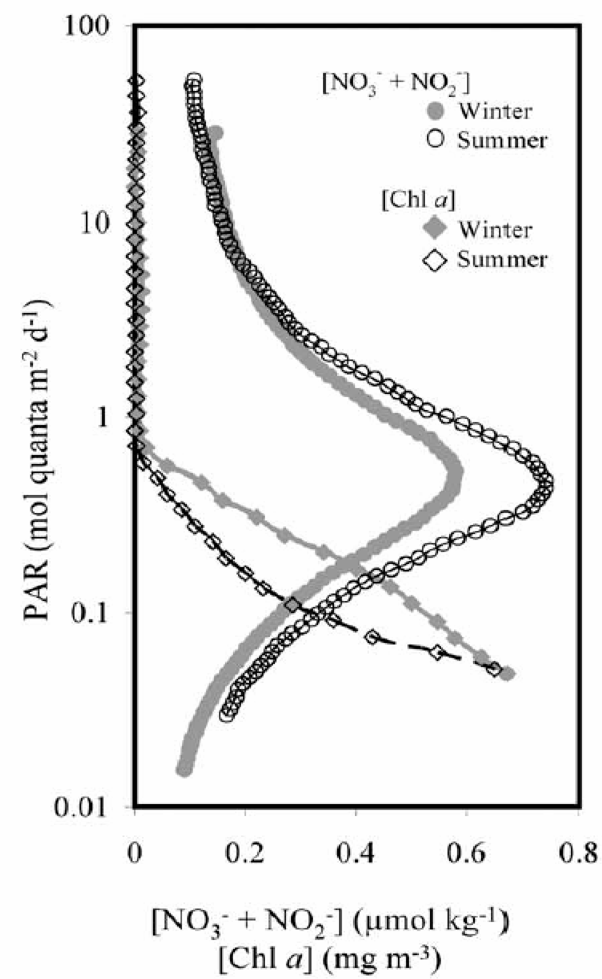

POC Relative Flux
(4000 m / 28000 m)
0.5
0.75
1
1.25
1.5
Apparent 40% remineralization
Almost no apparent remineralization
Apparent particle formation or a problem of advection
J F M A M J J A S O N D
Time, months

Seasonal displacement of the DCML and nitracline

Relative to depth (2 db avg. profile)



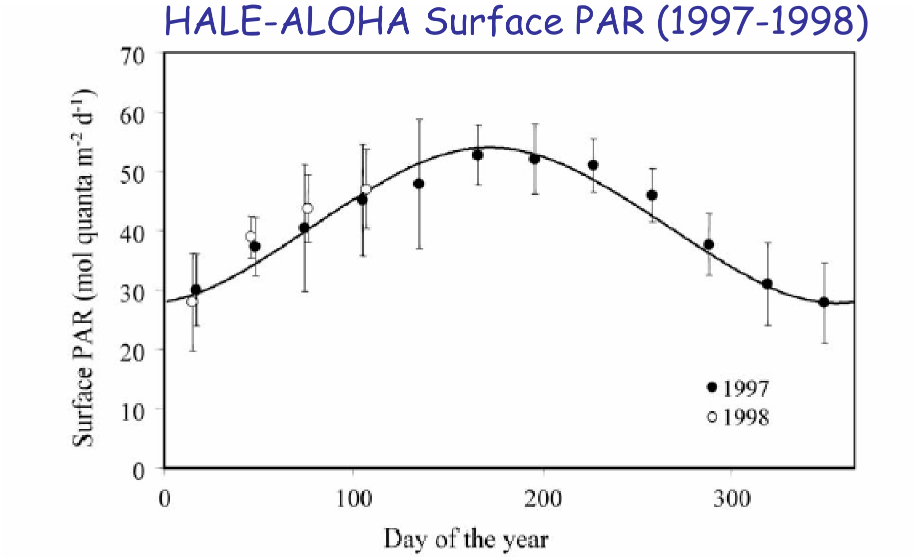
Relative to PAR



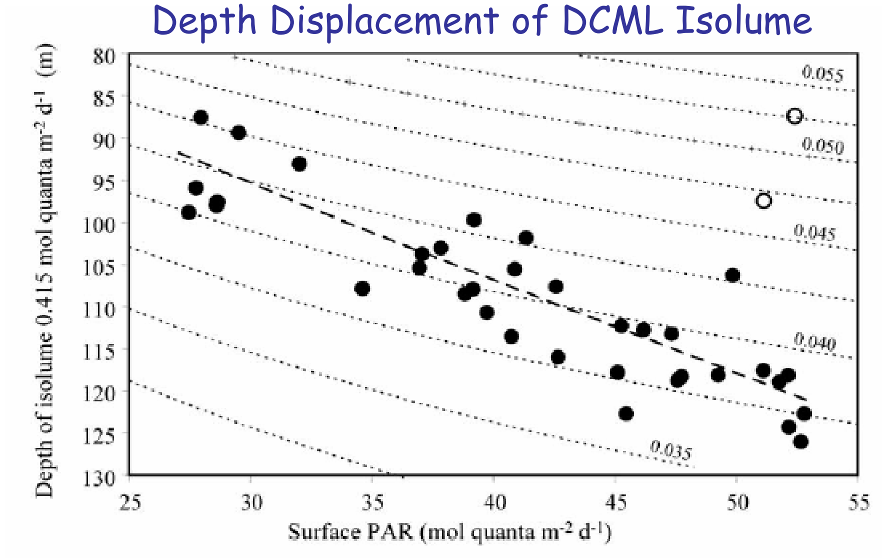
From Letelier et al. (2004)

New & Export Production at HOT

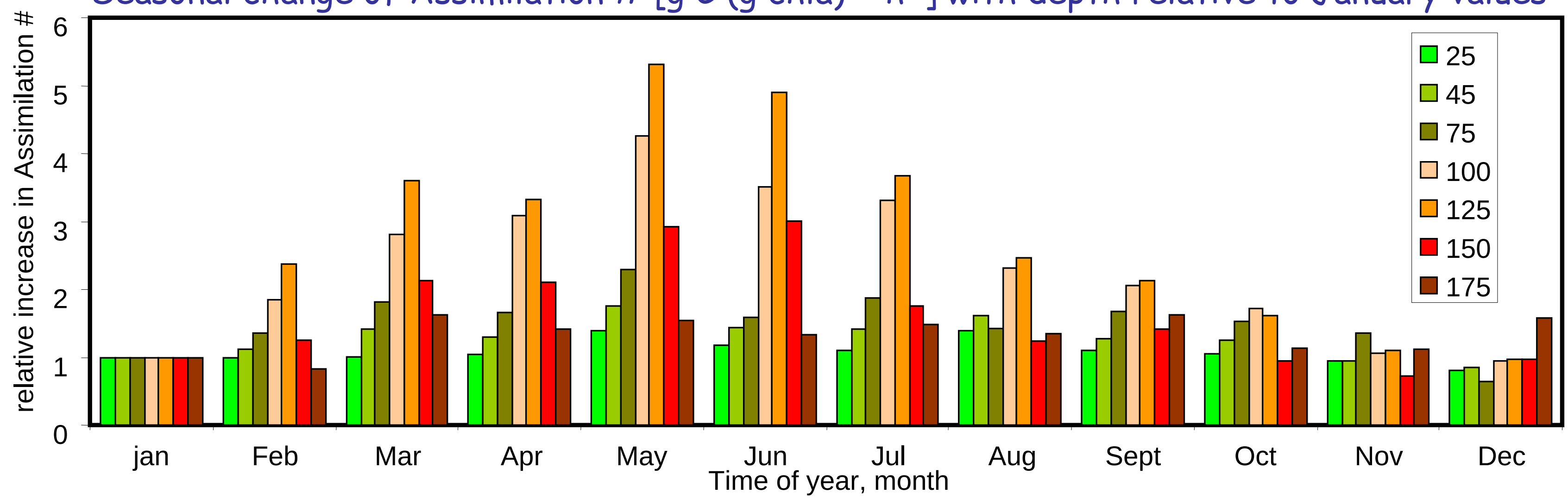
HALE-ALOHA Surface PAR (1997-1998)



Depth Displacement of DCML Isolume



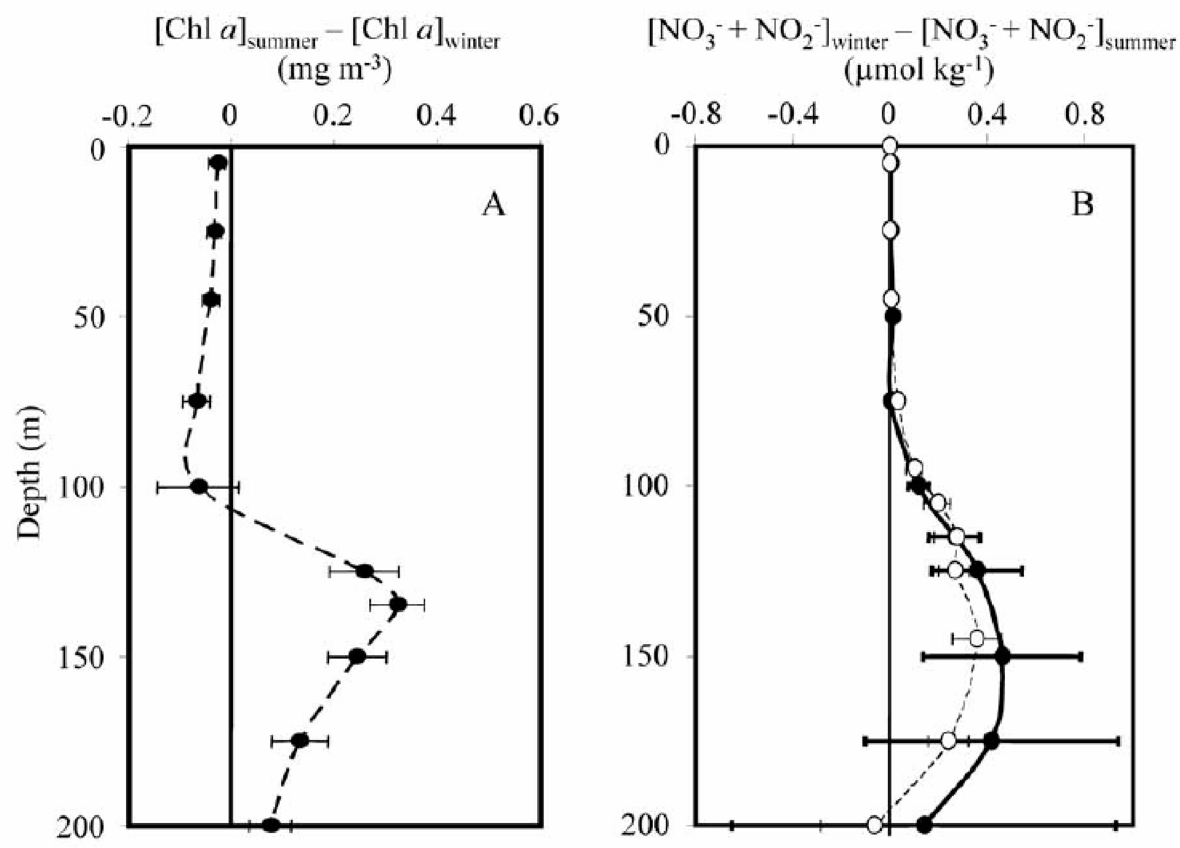
Seasonal change of Assimilation # [g C (g chla) $^{-1}$ h^{-1}] with depth relative to January values



Nitrogen summer deficit

Chl a spring increase

N spring decrease



-The integrated deficit in $[NO_3 + NO_2]$ generated during spring between 75 m and 200 m is approx. 36 mmol N m^{-2}.

-The N equivalent to the chl a increase in this depth range is approx. 5 mmol m^{-2}.
→ Production transferred to higher trophic levels or lost through sedimentation.

- The mean annual Export flux measured at 150 m is approx. 106 mmol N m^{-2}.

- Assuming a "Martin Curve" parameterization as derived by Karl

$$N\ Flux_{(z)} = N\ flux_{(150m)} * (z/150)^{-0.82}$$

$$N\ Flux_{(200m)} = 84\ mmol\ N\ m^{-2}.$$

→ N summer deficit = 42% of N $Flux_{(200)}$

Lower Euphotic Zone seasonal nitrate depletion

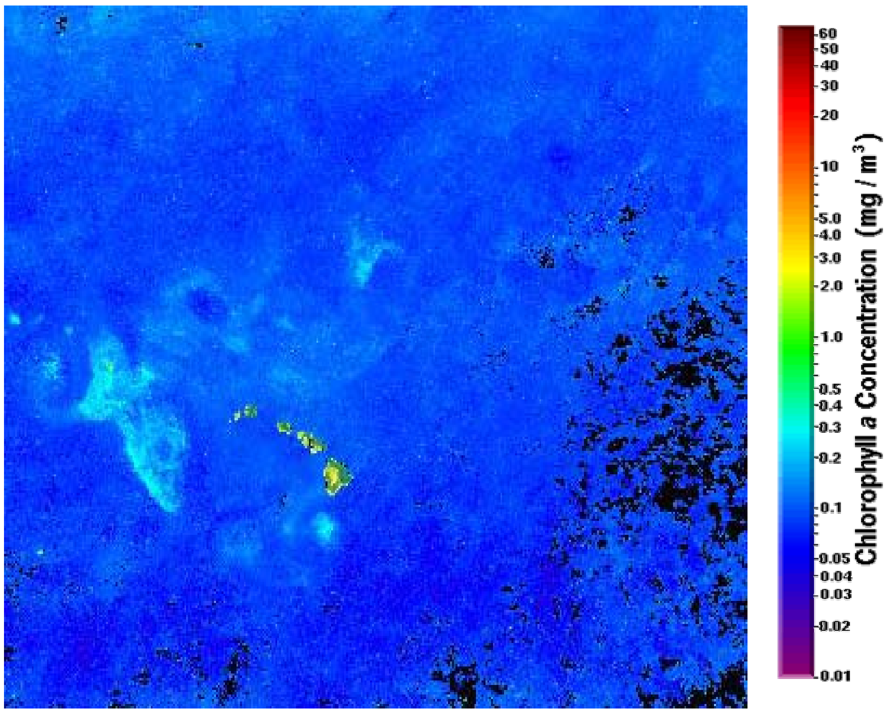
1) Depth position of the DCML and the upper nutricline appear to be driven primarily by light.
2) The seasonal nutrient depletion of (NO_3 + NO_2) in the 100-200m depth range is equivalent to approximately 40% of the annual PON flux derived for the 200 m horizon
3) The seasonal increase in the DCML magnitude suggests an uncoupling between photoautotrophy and heterotrophy in spring → Lower euphotic zone "spring bloom".

Known unknowns

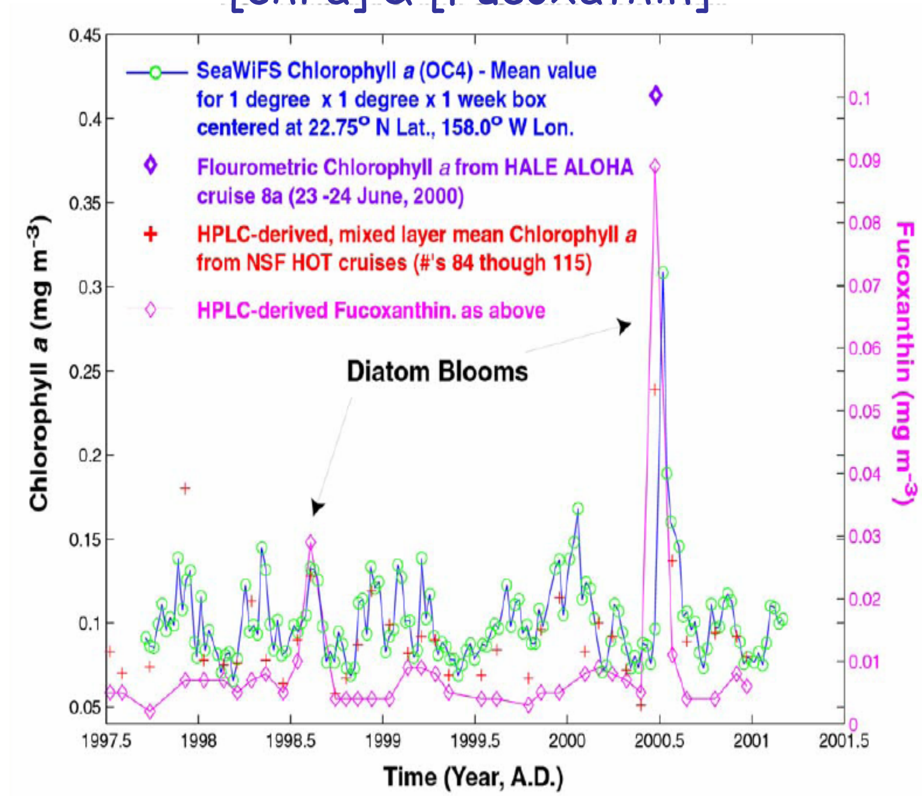
1) What is the fate of the seasonal PON produced in the lower euphotic zone?
2) How much DON versus PON is generated?
3) Are there seasonal succession patterns in the DCM assemblage?

Upper water column pigment dynamics

SeaWiFS image July August 1998



Time-series of Sea Surface [chl a] & [Fucoxathin]



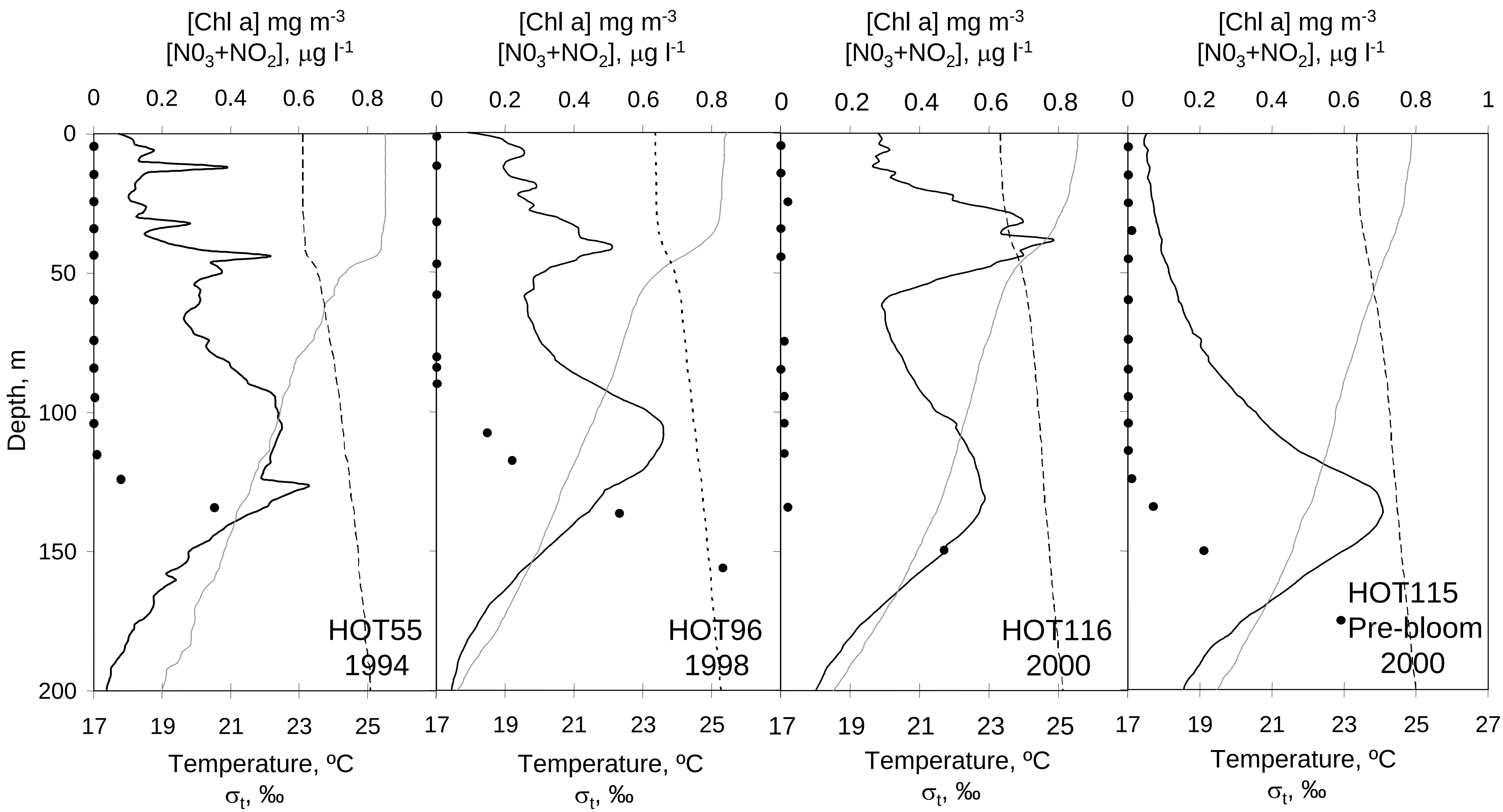
SeaWiFS data courtesy of Orbimage Inc. and NASA|GSFC DAAC
HOT HPLC pigment data courtesy of Bidigare (UH Oceanography)
HALE-ALOHA cruise flourometric data courtesy of Karl (UH Oceanography)
Additional processing and assembly at Hawaii CoastWatch (UH JIMAR & NOAA|NMFS)

Evidence of Summer Blooms at Station ALOHA

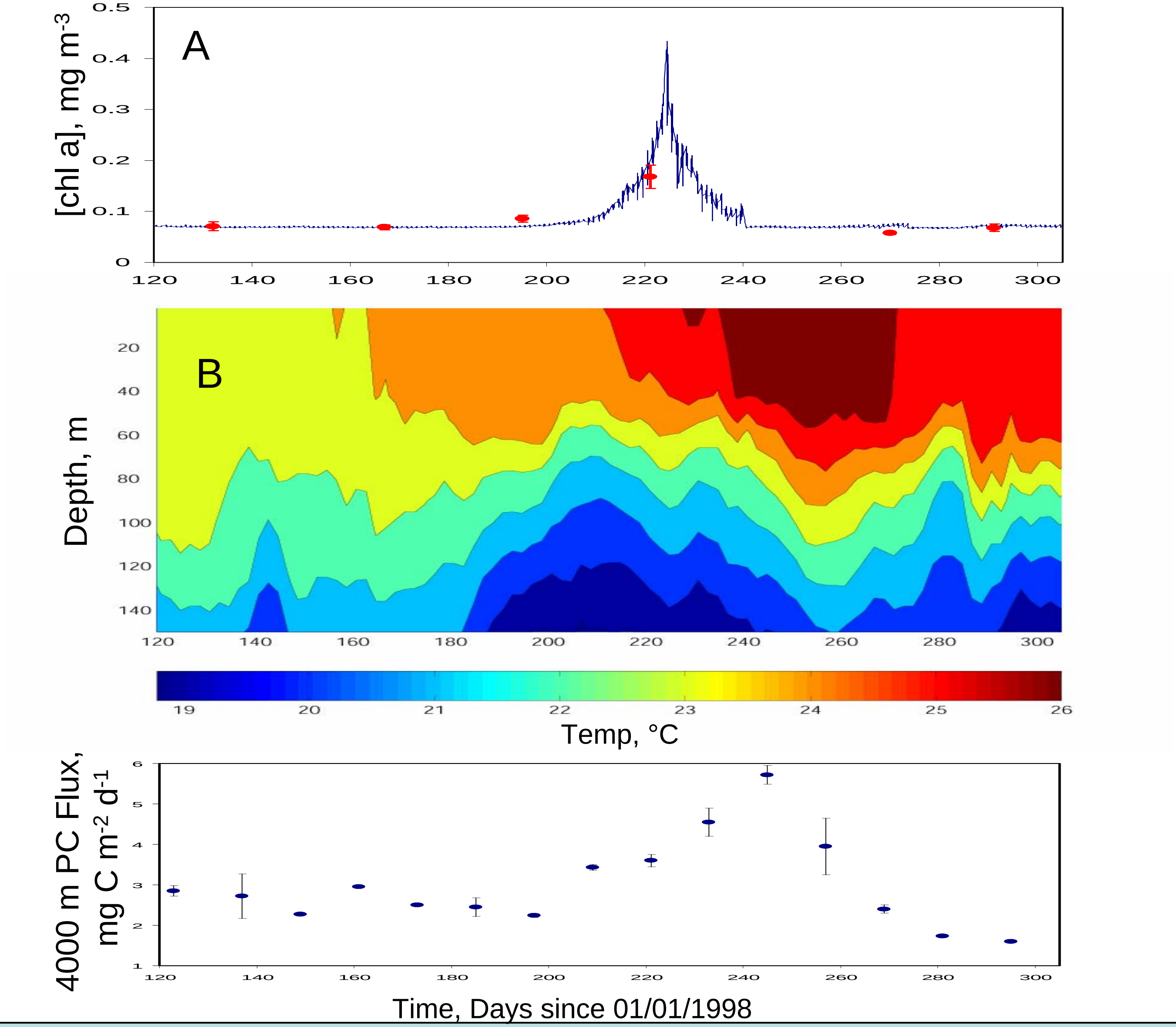
Month & Year	Detection techniques	Reference
August 1989	Ship based	Karl et al., 1992
July 1992	Ship based and moored sediment traps	Scharek et al, 1999a
July 1994	Ship based and moored Sediment Traps	Scharek et al., 1999b
July 1996	Ship based observations	Brezinski et al., 1998
Sept 1997	Remote Sensing	Unpublished
August 1998	Moored, Remote sensing, and Ship based Observations	Sakamoto et al., 2004; Unpublished
July 2000	Remote sensing and ship based observations	Unpublished
July 2002	Ship based observations	Unpublished
July 2005	Remote sensing, and Ship based Observations	Unpublished

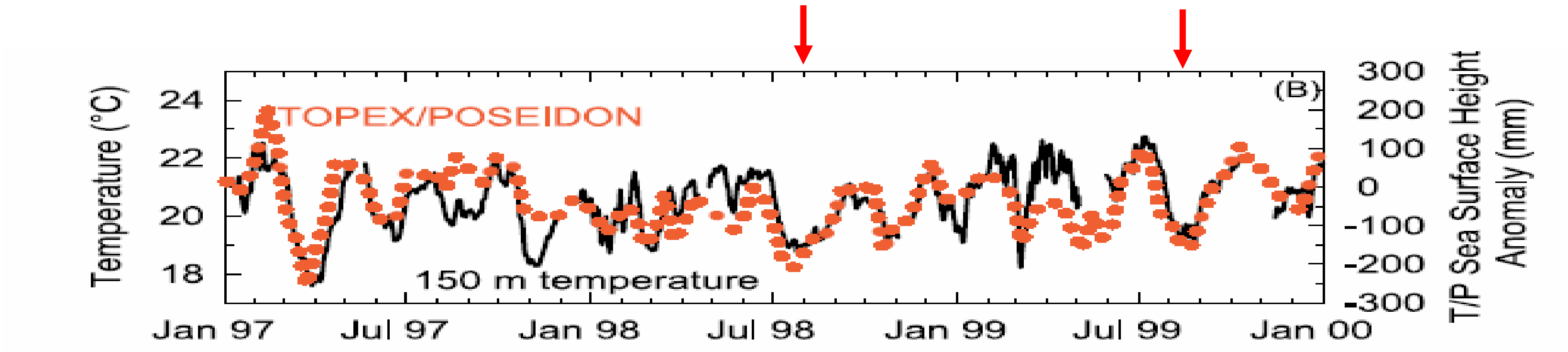
Dominated by large photoautotrophs that have N_2-fixing and density control capabilities

Depth Distribution of chl a Fluorescence during summer blooms

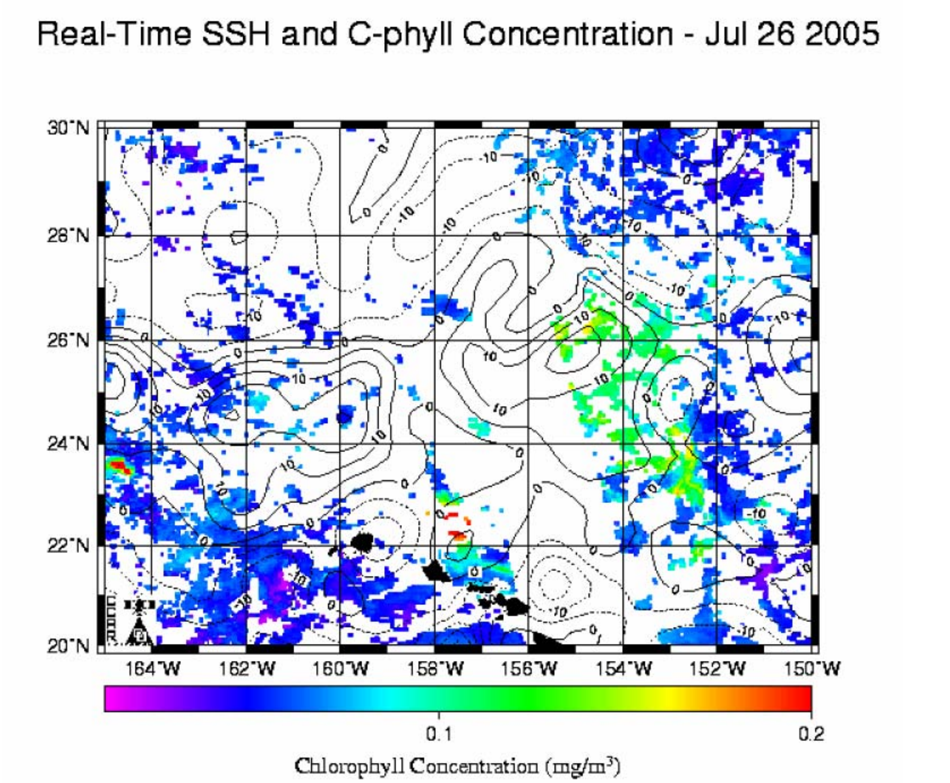


1998 Summer cyclonic eddy at Station ALOHA (22° 45'N, 158° W)





From Sakamoto et al. (2004)
See also Wilson (2003)



From the Colorado Center for Astrodynamic Research (CCAR)

-Summer blooms often have a geographical extent that is much larger than a Rossby radius.

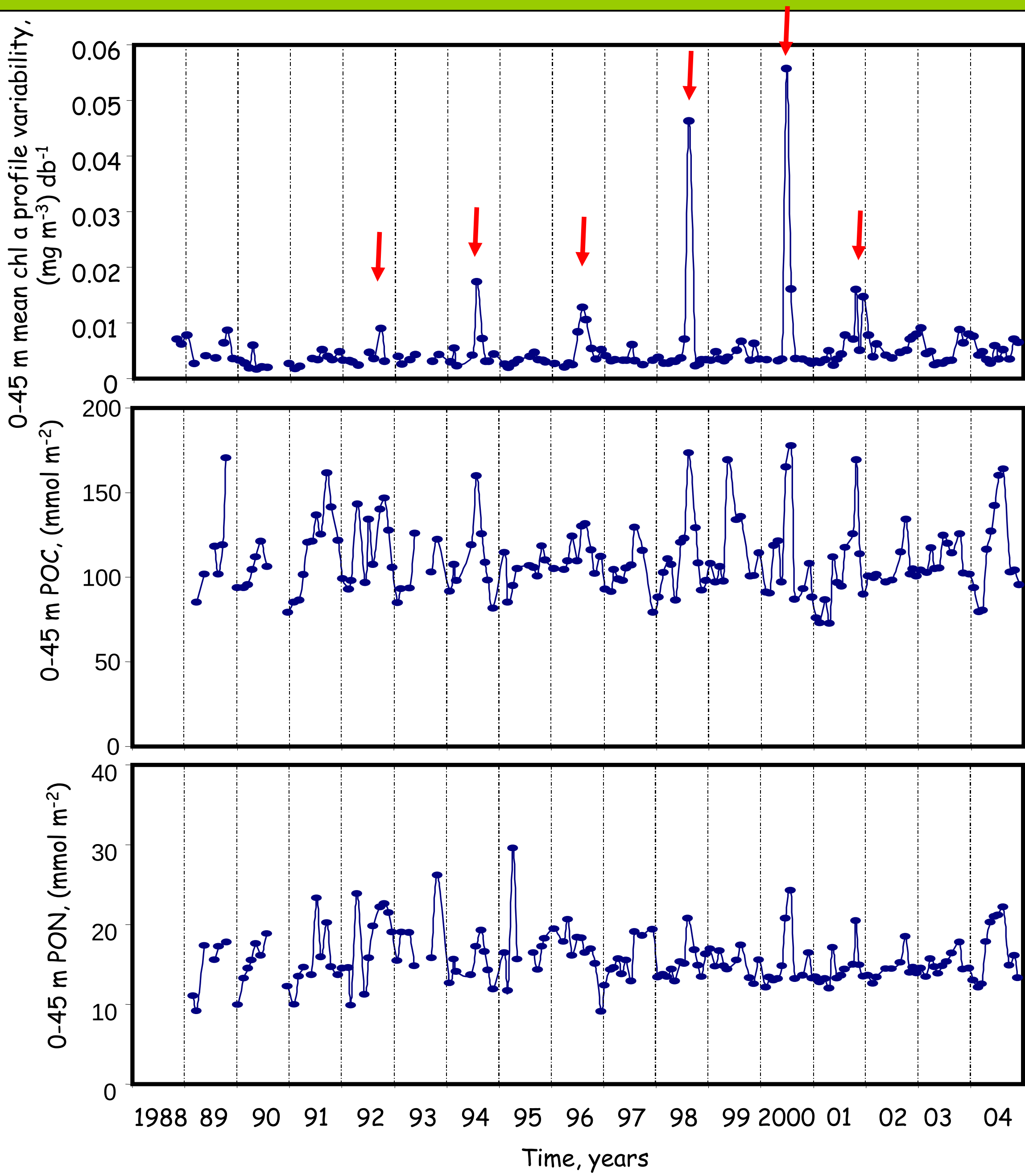
-Sometimes, like this last week, they appear associated to an anticyclonic circulation system.

New & Export Production at HOT

Upper watercolumn fluorescence trace "roughness"

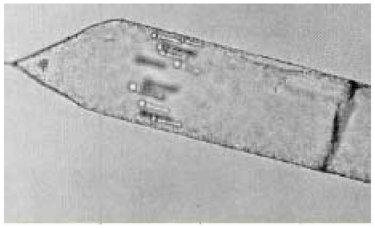
Particulate Carbon

Particulate Nitrogen

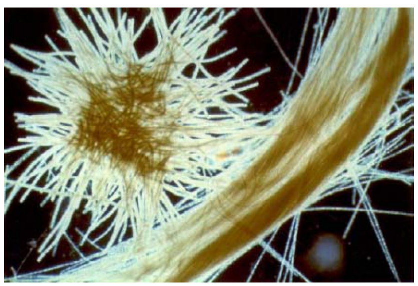


New & Export Production at HOT

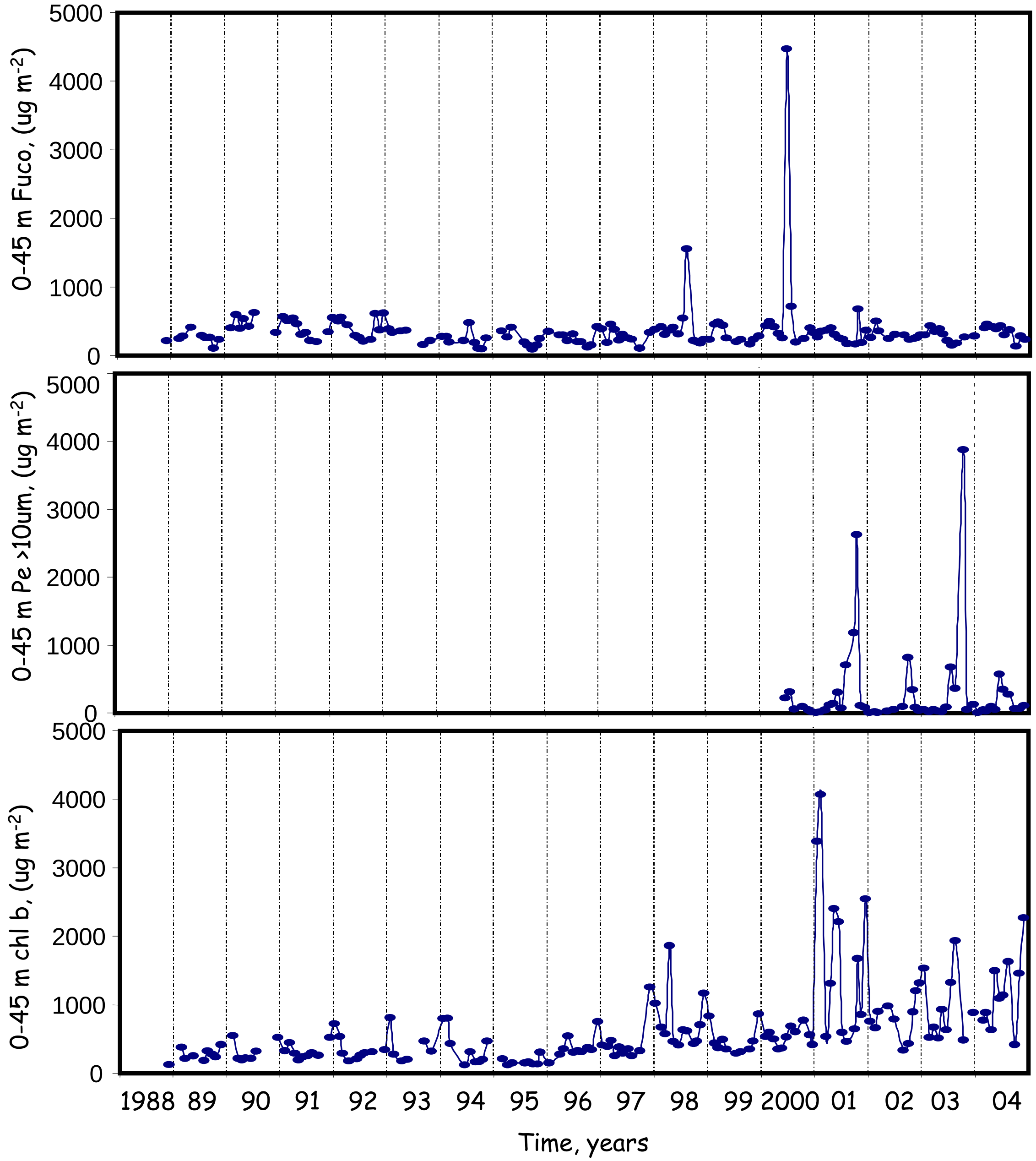
Diatoms



Trichodesmium spp.



Prochlorococcus spp.



Summer blooms observations

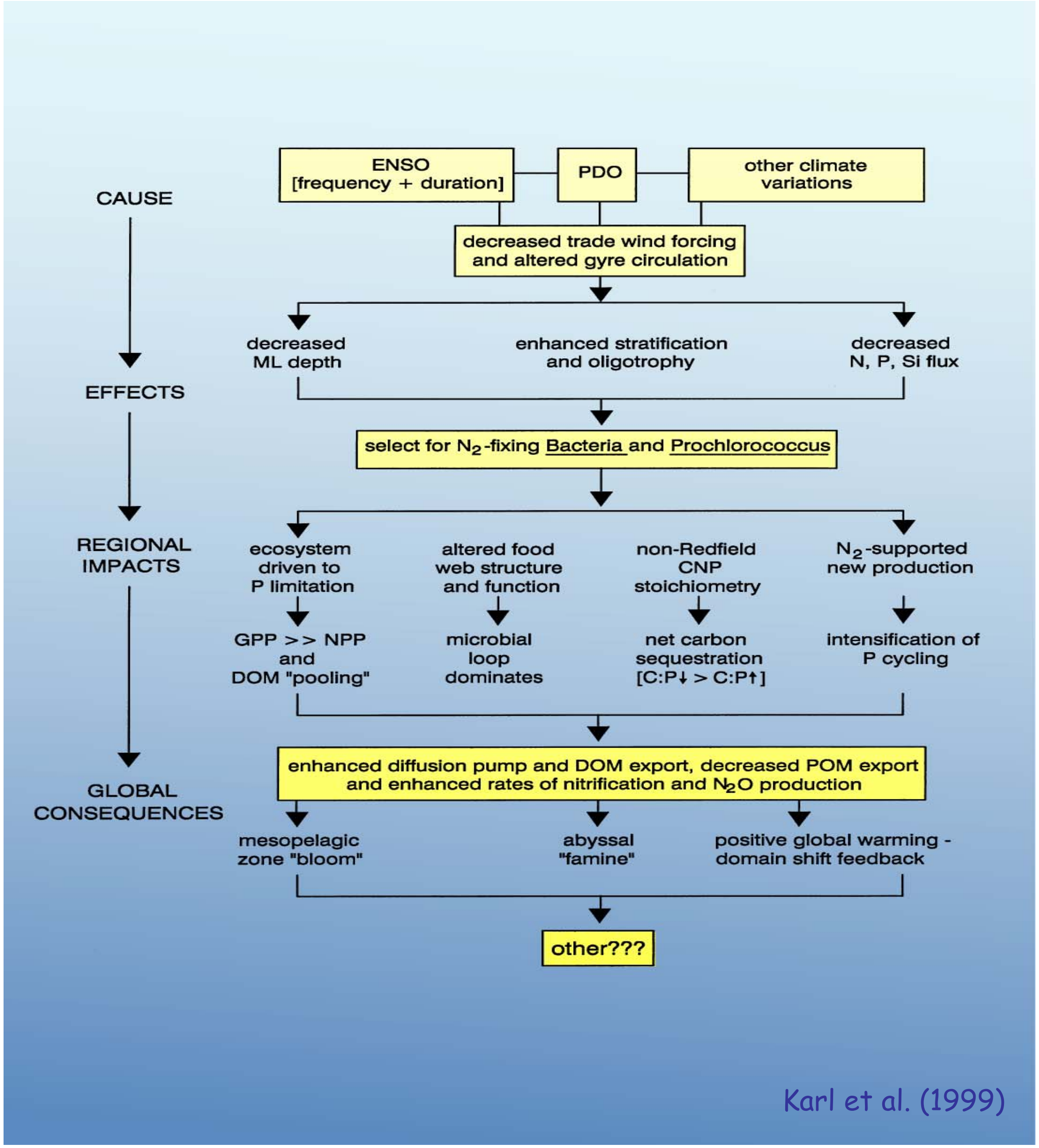
1) They are frequently observed at Station ALOHA, although not always sampled.
2) Require a well stratified water column for an extended period of time
3) Are dominated by microphytoplankton species that have two characteristics:
   - Buoyancy control
   - N_2-fixation
4) Bloom biomass maximum is often, if not always, found centered at the based of the mixed-layer → may not be observed by satellites
5) Summer blooms appear to be triggered or enhanced by eddies or Rossby waves.
6) They have a large ballasting effect transporting rapidly fresh organic matter to the benthic environment once the blooms starts to senesce.

Known unknowns

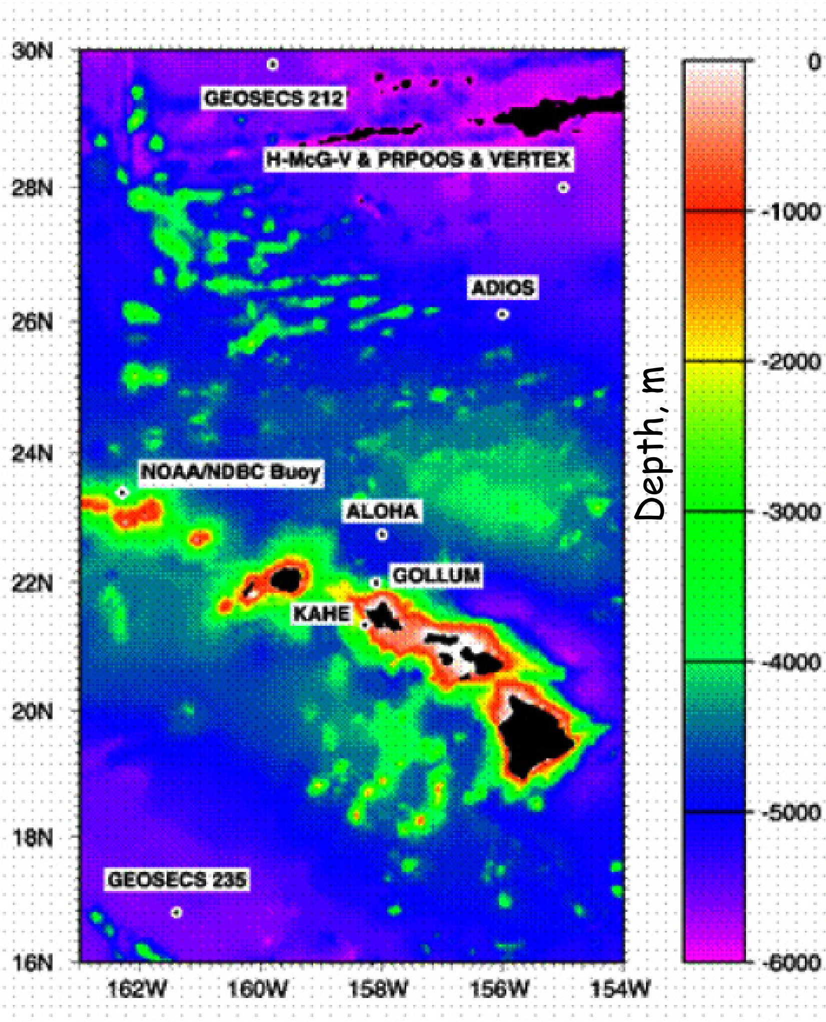
1) We still do not understand how these blooms develop (Deep seeding population versus vertical migrating P-shuttle?)
2) What causes a bloom to be dominated by diatoms versus cyanobacteria?
3) How do they affect the coupling of elemental cycles in the upper water-column?
4) How will the relative importance of these export events change if the gyres expand?

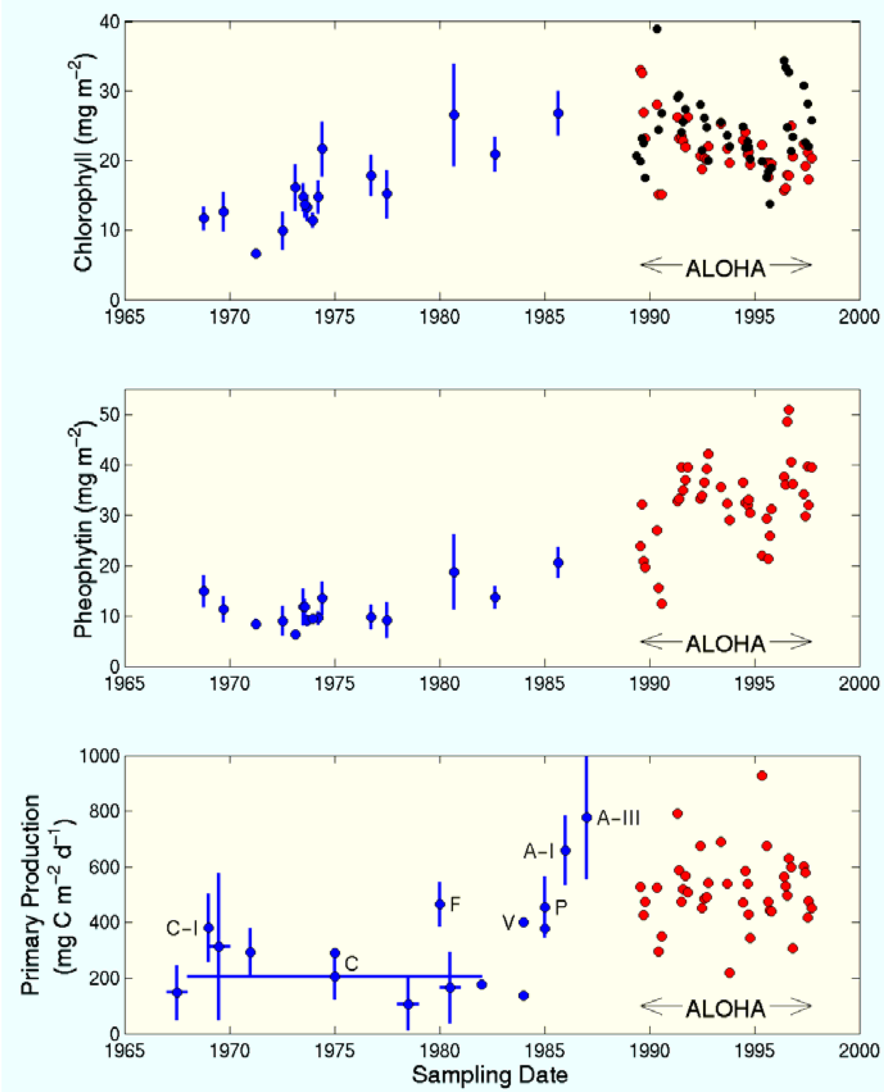
What have we learned about the variability in ecosystem structure at longer time-scales?

- A general hypothesis regarding how ocean biology responds to changes in large scale physical forcing.

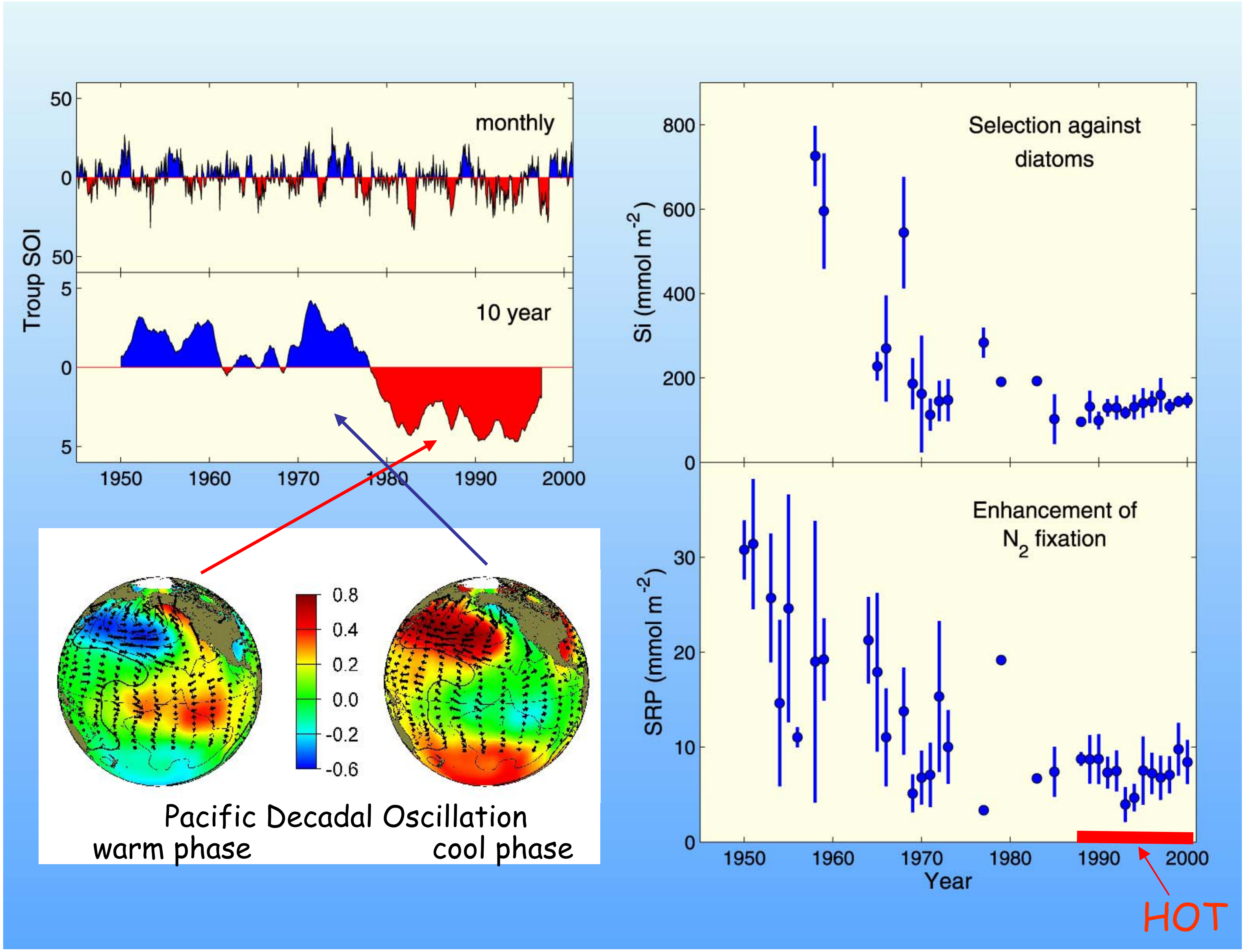


- A long-term record in the NPSG suggests a significant and persistent increase in chlorophyll concentrations in the late 1970's.



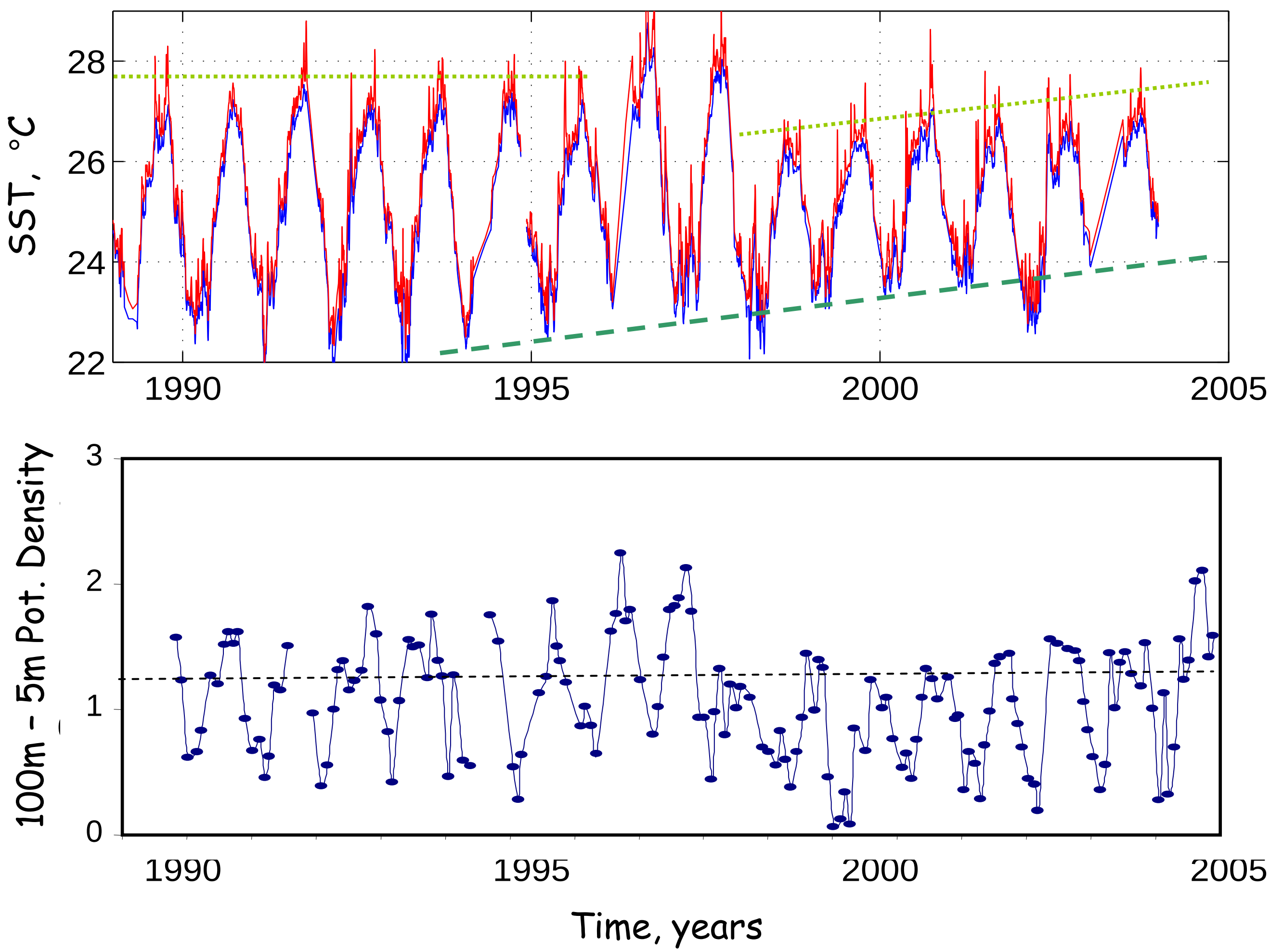


Karl et al. (2001)

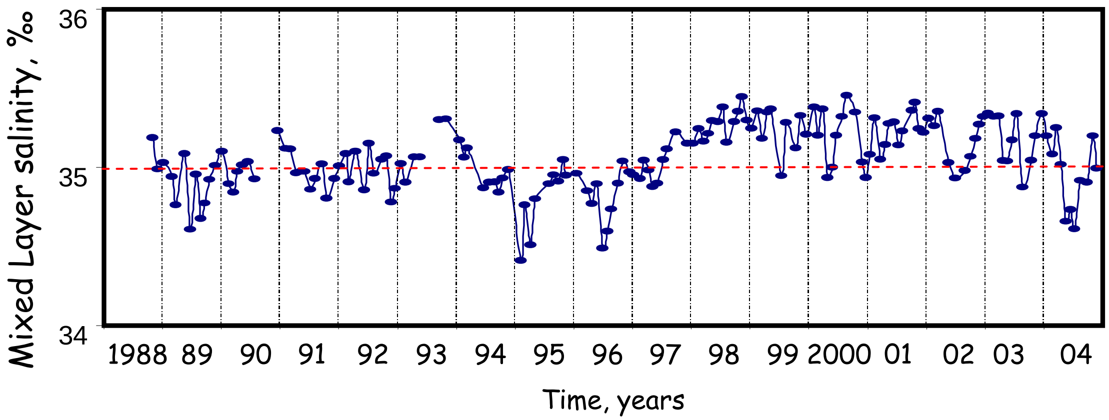


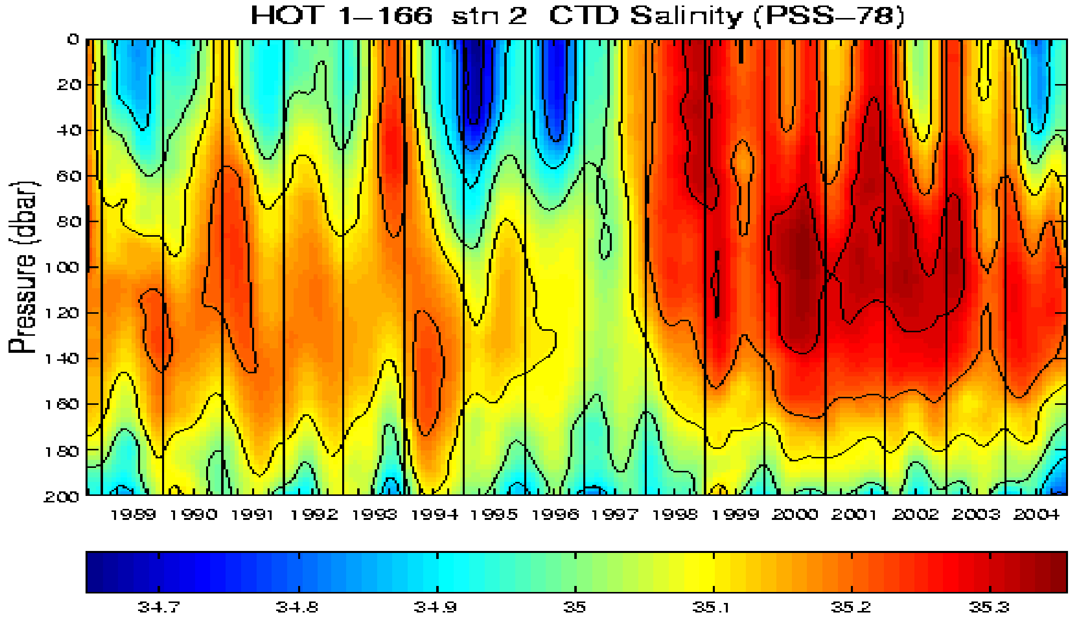
Karl et al. (2001)

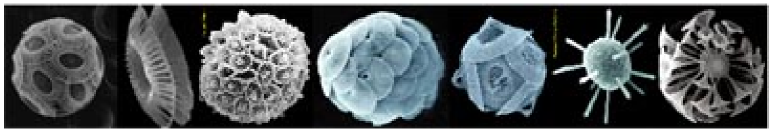
Interannual changes and trends in sea surface temperature



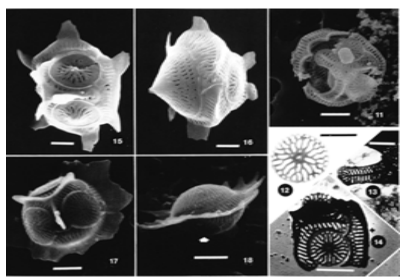
Station ALOHA salinity record (1989-2004)

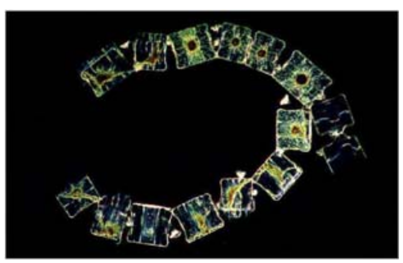


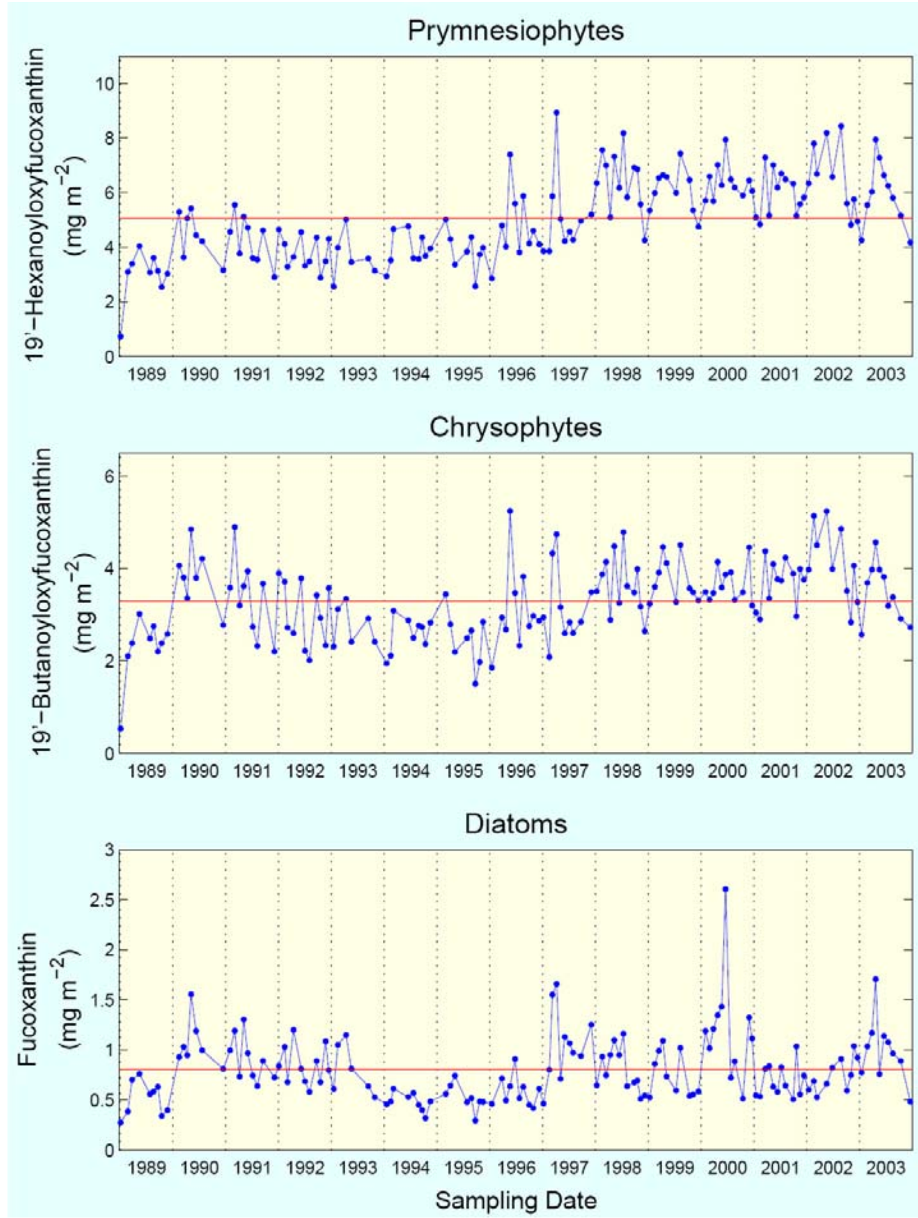




- Phytoplankton taxa display distinct long term patterns of variability

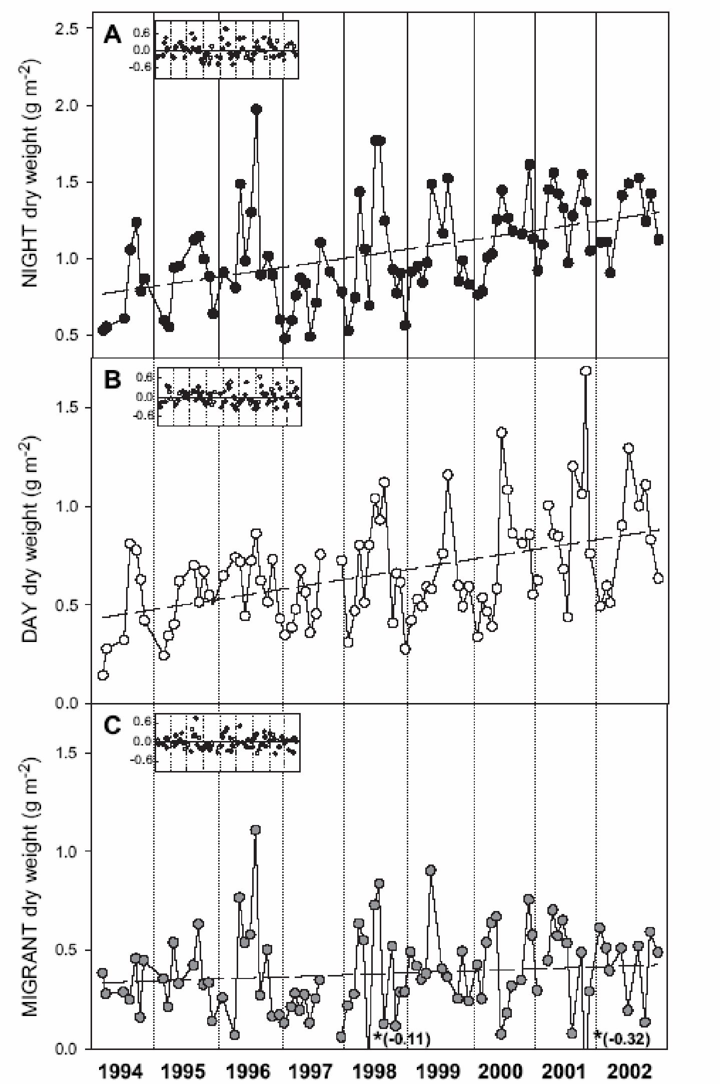






Mesozooplankton trends

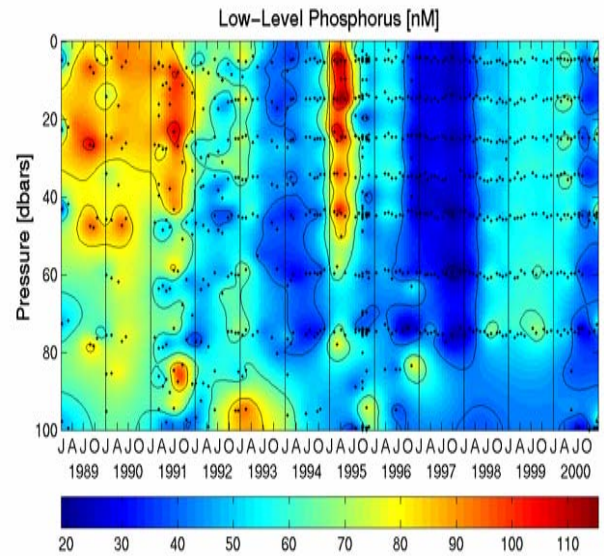
Oblique tows from 160m to surface with 200 μmnesh size

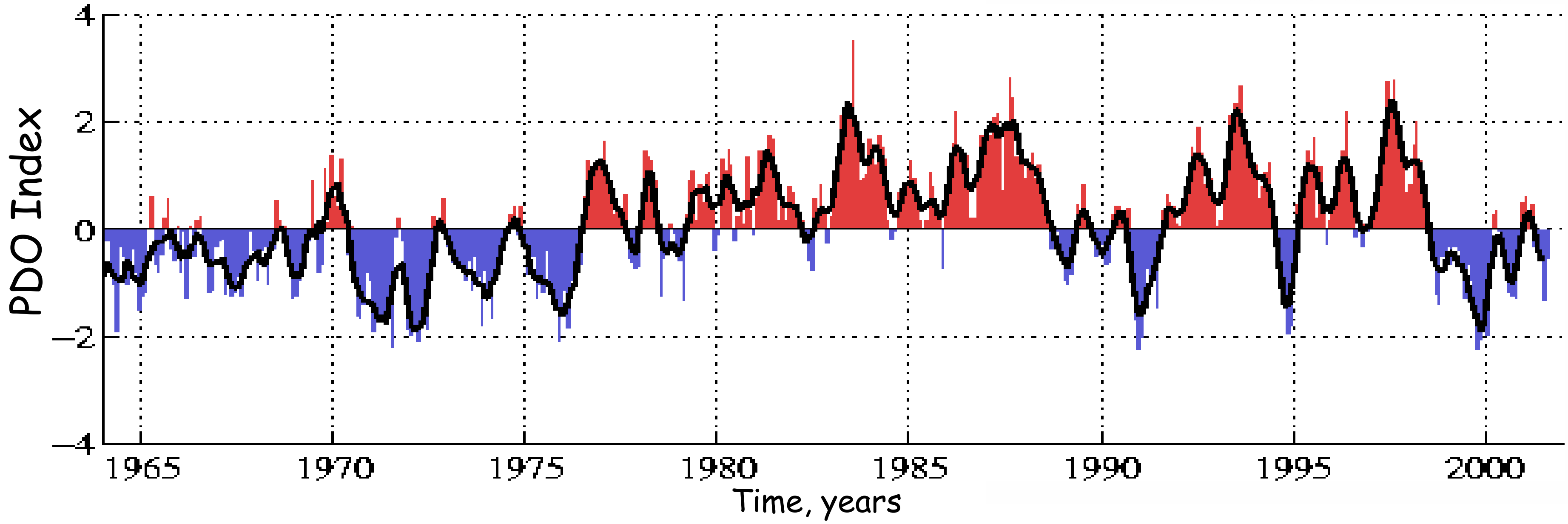


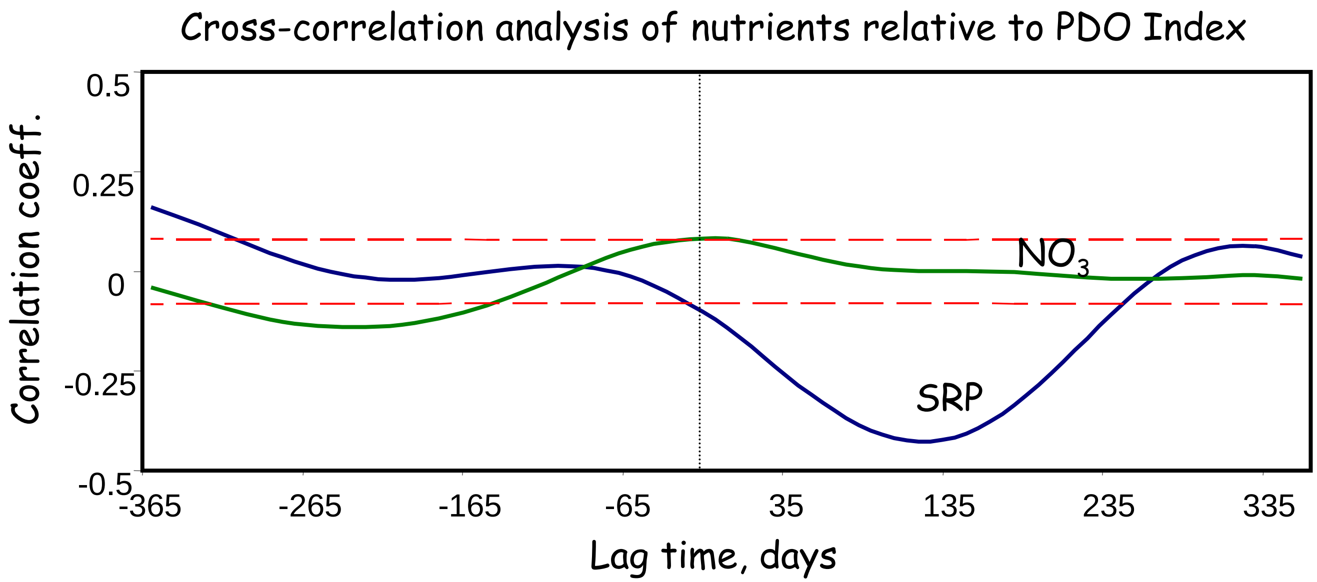
From Sheridan & Landry 2004

Pacific Decadal Oscillation & P availability

- Gyre-wide circulation patterns may also modulate the availability of specific nutrients in ways that we do not yet understand but seem consistent with Karl's hypothesis.







- The long-term patterns of variability in low level soluble reactive phosphorus (SRP) suggest that the phosphorus affinity, or efficiency of phosphorus removal, of phytoplankton assemblages varies with time.

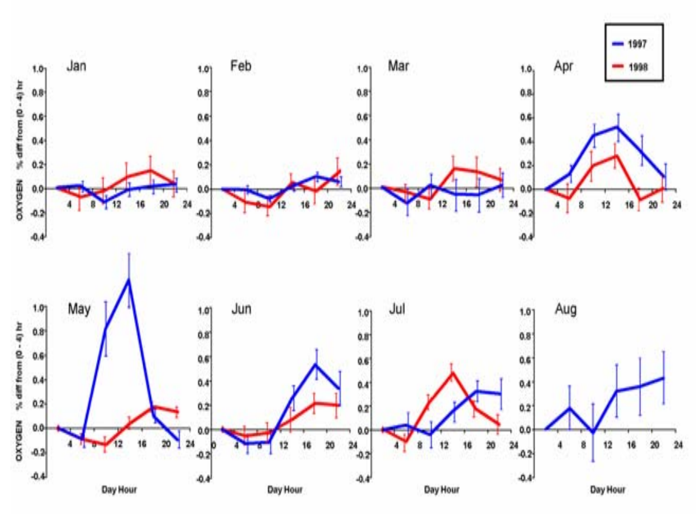
- Are these patterns the results of changes in the limiting nutrient, or are they due to variability in the composition of the phytoplankton assemblage? What is the role of the dissolved organic phosphorus pool?

→ We now know, or believe to know, that the input of different nutrients in rhese oligotrophic regions are modulated by different environmental forcing?

A few future challenges:

1) The issue of undersampling (time, region, depth, community diversity and functionality)
   - Moorings (Dickey, Weeler, Karl)
   - Tracers (Emerson, Quay)
   - Remote sensing, AUVs (Flament in the past, Karl)
   - Vertical profilers (proposed by Howe)
   - Molecular approaches (DeLong, Zehr, Rappe, and others)
   - Modeling efforts (Spitz, Chai, and others)

   → Different approaches require different expertise → collaborations

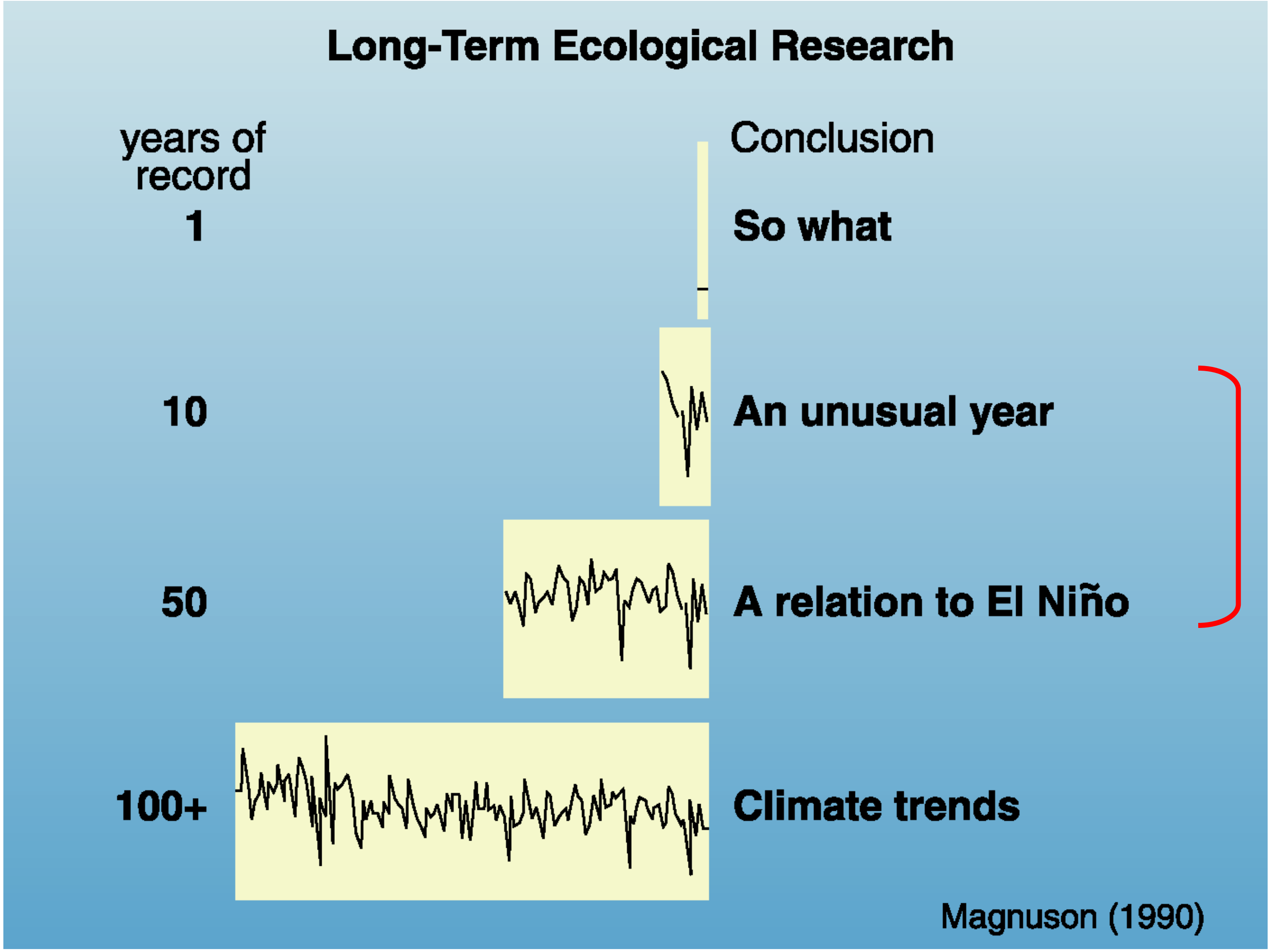


From Steve Emerson

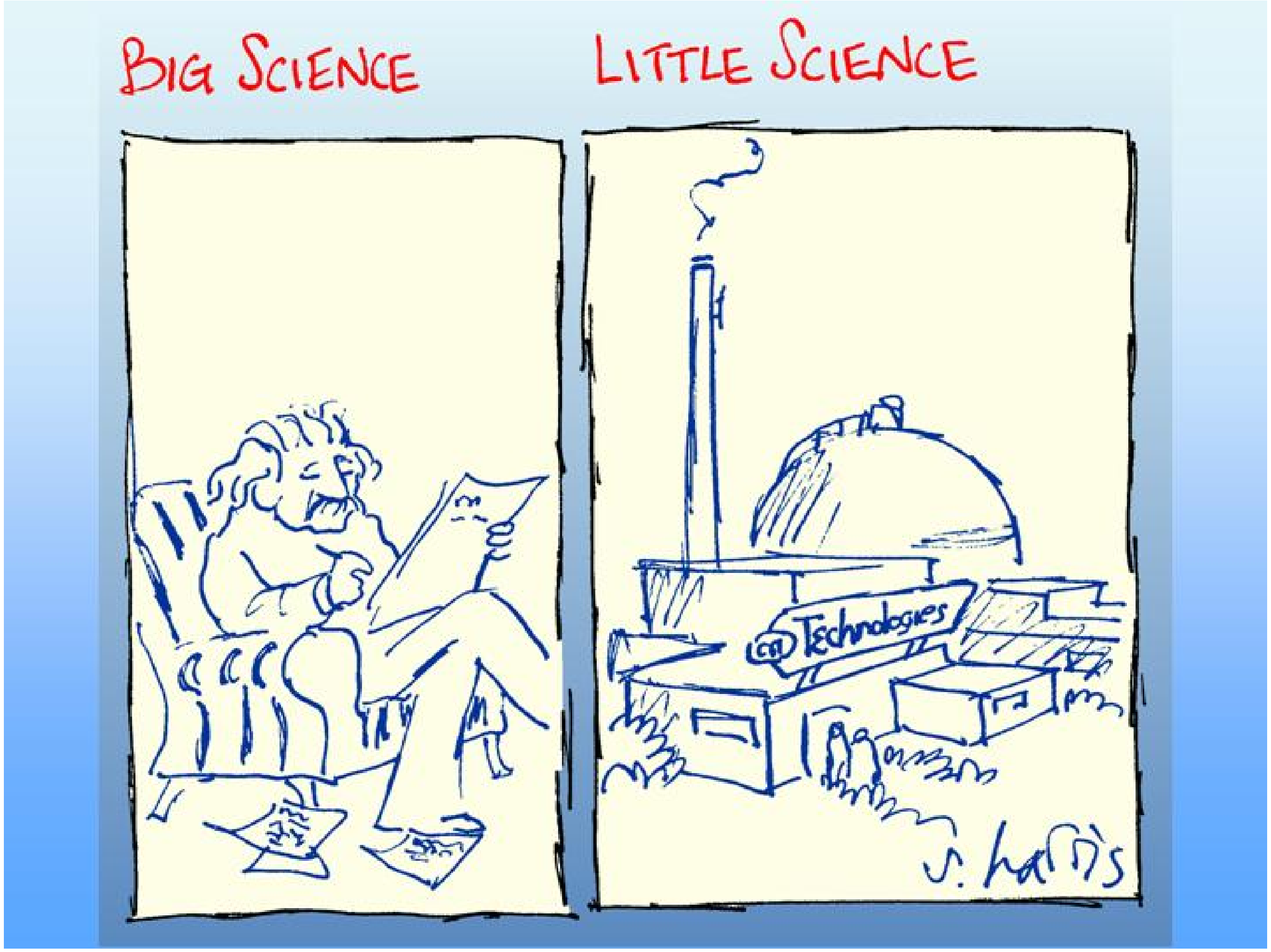
2) How do we constrain the uncertainties in our methods?
   - Comparative approaches

3) Coherence of methods across Time-series efforts
   - Comparative studies and models
   - Standardization of methods (i.e. Sharp with TIN and TDN)

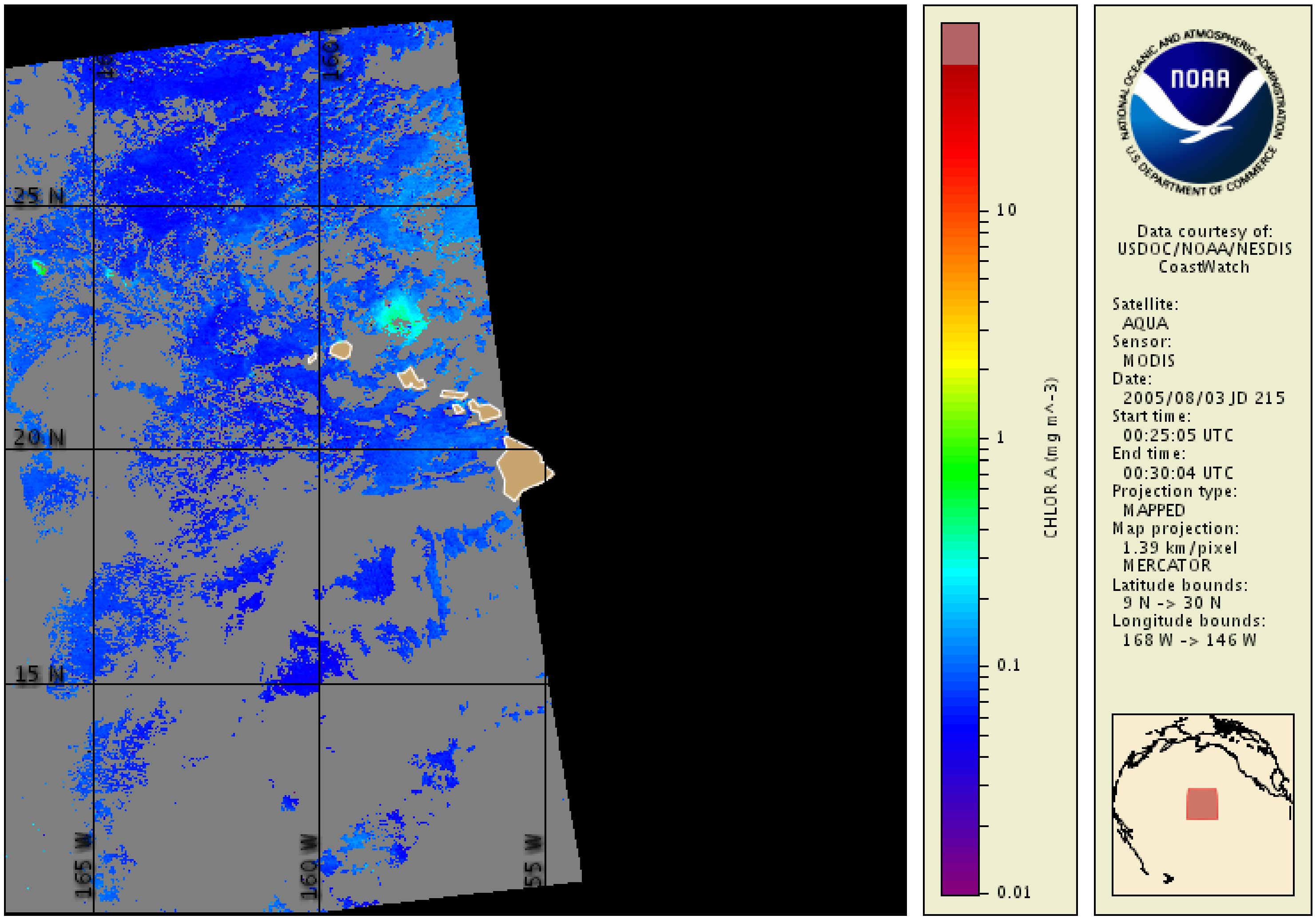
4) How do we maintain the integrity of the Time-series records while remaining flexible to integrate new technologies and address new emerging questions?



We are somewhere within this bracket


BIG SCIENCE
LITTLE SCIENCE
Technologies
S. Harris

Thanks



Today's MODIS Aqua [chl a] image from the HOT region