The Hawaii Ocean Time-series (HOT): Highlights and perspectives from two decades of ocean observations

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OCB SCOPING WORKSHOP
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A Dedicated HOT Team

What’s HOT?

Program objectives:

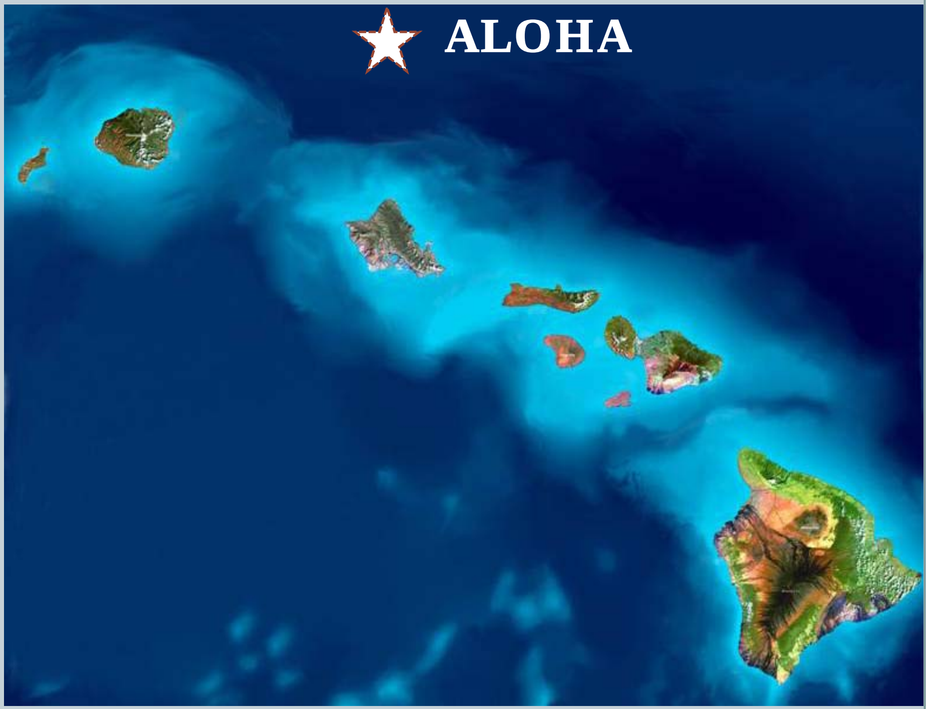
- Quantify time-dependent variability in key physical, biogeochemical, and ecological properties and processes
- Define relationships between plankton community structure and biogeochemical dynamics
- Quantify physical and biological processes controlling oceanic carbon uptake, transformation, and sequestration

The Hawaii Ocean Time-series (HOT)

- **Near monthly cruises to Station ALOHA since October 1988**
- **Deep ocean (~4800 m) observatory**
- **Shipboard and remote measurements of ocean biogeochemistry, physics, and plankton ecology**
- **4-day cruises, intensive sampling to 1000 m**

Time, water, and change

- The value of HOT observations continues to increase with time.
- HOT provides some of the best and only records of biogeochemical and physical variability in the open ocean waters of the Pacific across multiple time scales: episodic, seasonal, interannual, and multi-decadal.
- Knowledge gained from HOT furthers our understanding of global-scale ocean change.



Ongoing projects supported by HOT:

If you build it, they will come…

- **Ocean Carbon System Variability,** NSF; A. Dickson (P.I.), 1988-present
- **WHOI Hawaii Ocean Time Series Station (WHOTS),** NOAA-NSF; R. Weller (P.I.), 2004-present
- **CFC and SF_6 Water Mass Tracers,** NOAA; J. Bullister (P.I.), 2004-present
- **Microbial Oceanography: Genomes to Biomes – Summer training course,** NSF-Agouron Institute-Gordon and Betty Moore Foundation; D. Karl (P.I.), 2006-present
- **Marine Microbiology Initiative,** Gordon and Betty Moore Foundation; D. Karl (P.I.), 2005-present
- **Center for Microbial Oceanography: Research and Education (C-MORE),** NSF; D. Karl (P.I.), 2006-present
- **Si Cycling and Dynamics,** NSF; M. Brzezinski (P.I.), 2007-present
- **ALOHA Cabled Observatory,** NSF; B. Howe (P.I.), 2007-present
- **Diazotrophy in a High CO_2 World,** NSF; M. Church (P.I.),2009-present
- **Profiling Floats for Ocean Biogeochemistry,** NSF-NOPP; K. Johnson, 2007-present
- **Subsurface Moored Profiler,** NSF; M. Alford (P.I.), 2009-present
- **Taxon-specific Variability of Organic Matter Production and Remineralization,** NSF; A. White (P.I.), 2009-present
- **Primary Productivity as a Function of Absorption, Pigment-based Phytoplankton Diversity, and Particle Size Distributions,** NASA; A. White (P.I.), 2009-present

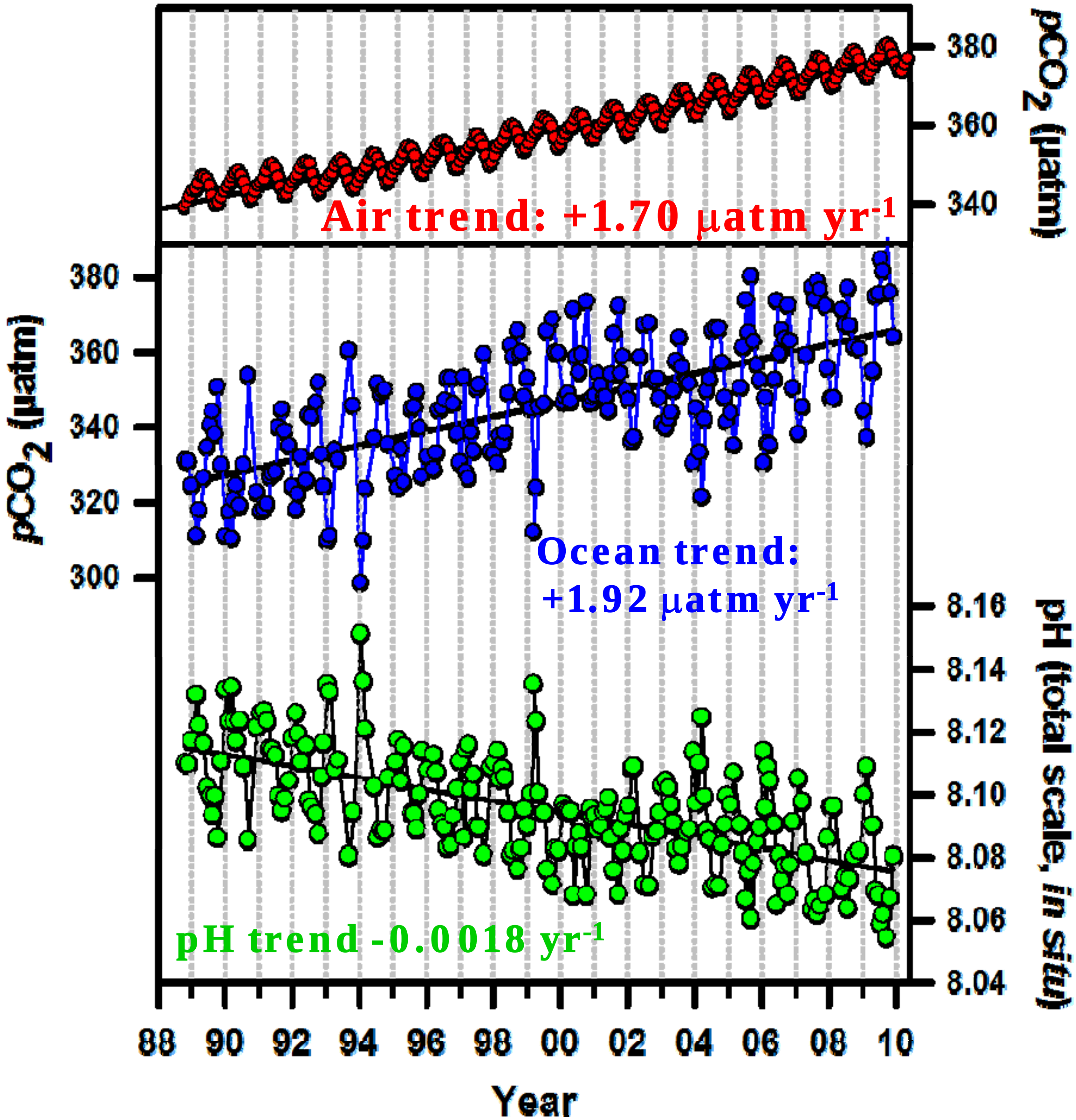
From the Predictable to the Unexpected: Highlights on 3 interlinked themes in ocean biogeochemistry

- **Ocean carbon cycling**
- **Plankton productivity and the importance of community structure**
- **New production and export**

HOT carbon reservoirs and fluxes

- **Carbon reservoirs:**
  - Carbonate system: DIC, total alkalinity, pH, pCO_2
    - Coulometry (DIC), potentiometric titration (total alkalinity), spectrophotometric (pH), shipboard (KM) pCO_2 equilibrator (SOEST), and moored pCO_2 sensor (C. Sabine-PMEL)
  - Total organic carbon (TOC)
    - High temperature combustion
  - Particulate carbon (POC and PIC)
    - High temperature combustion (POC); acidification/ IR detection (PIC)
- **Carbon fluxes:**
  - Biological carbon production (POC and DOC)
    - ^{14}C-bicarbonate assimilation (primary production), changes in carbon and oxygen
  - Particulate carbon export
    - Sediment trap particle collections

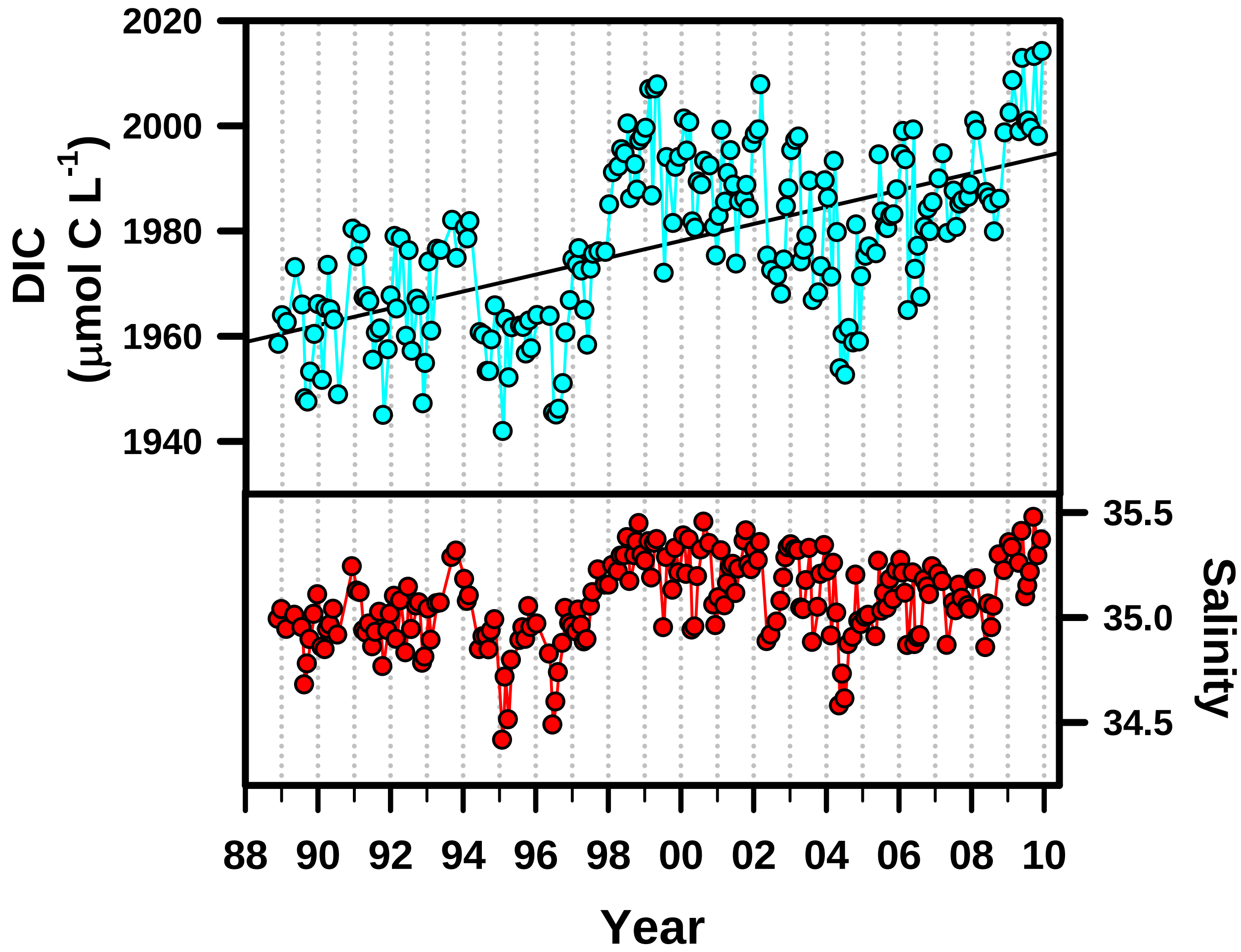
Rising CO_2, Falling pH



Dore et al. (2009)

Temporal variability in mixed layer inorganic carbon

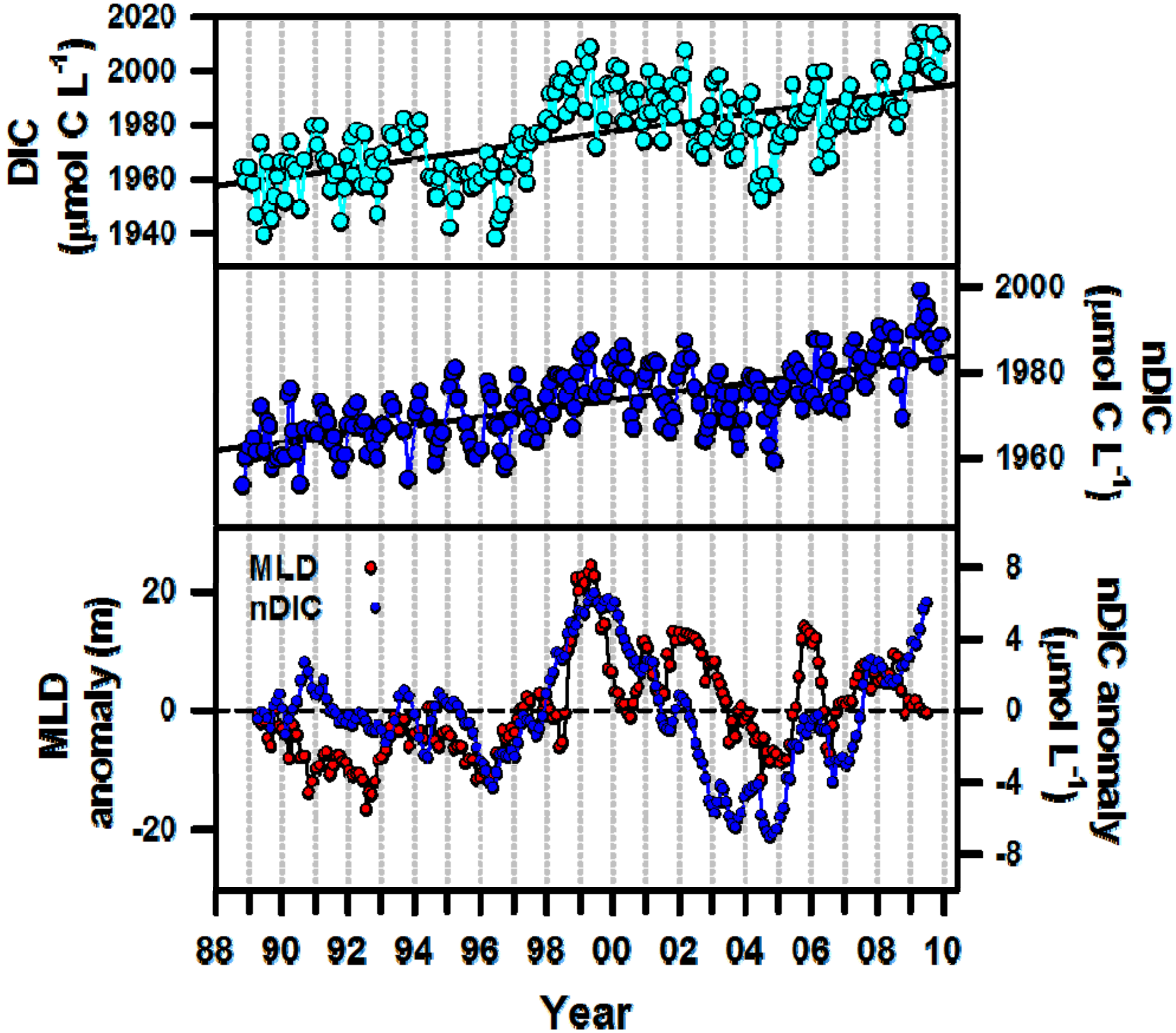
Interannual variations in DIC concentrations closely coincident with changes to upper ocean salinity.



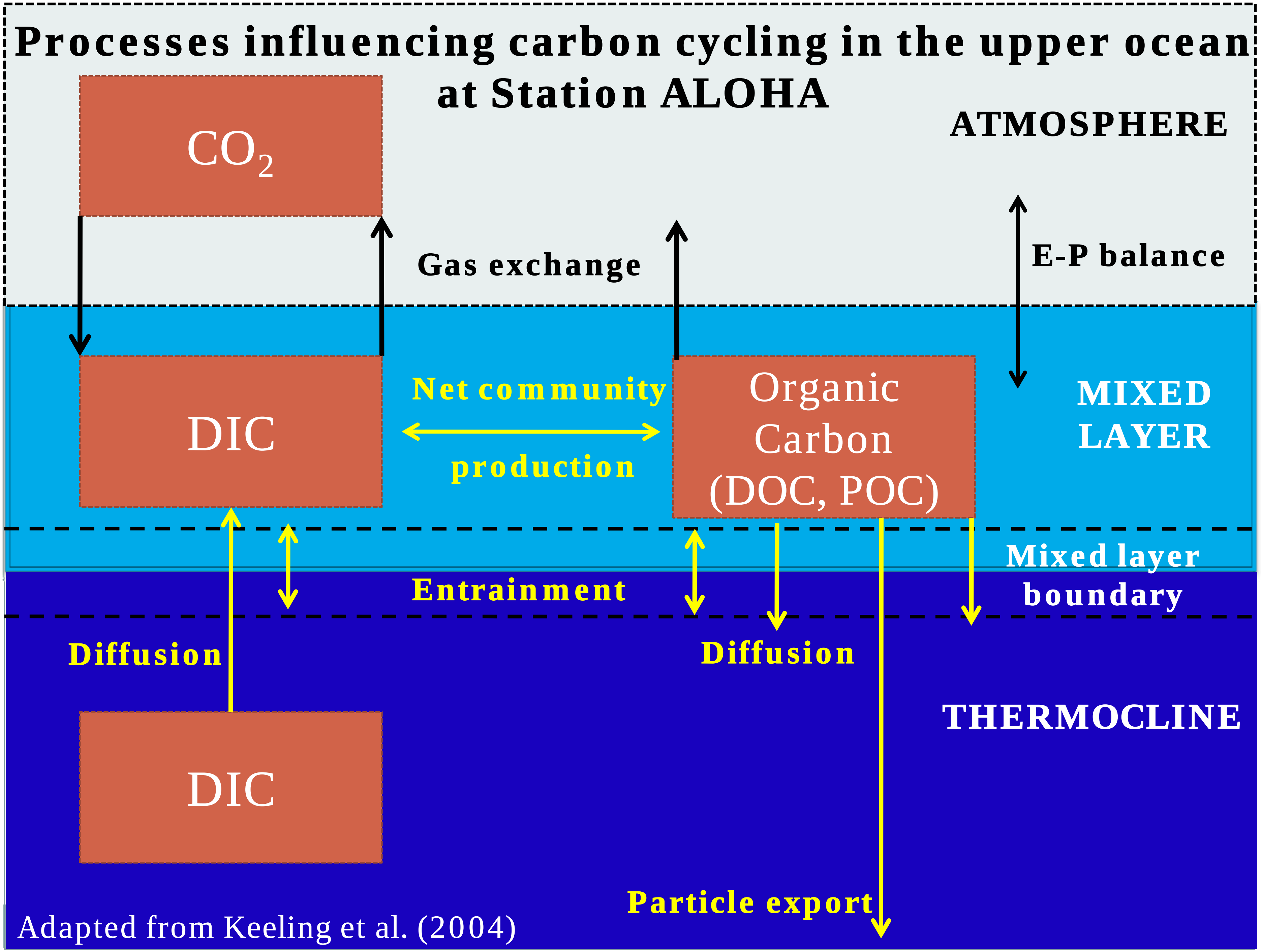
Dore et al. (2003)

Interannual variability in inorganic carbon pools

- Annual accumulation (0-150 m) of nDIC ~ 0.1 mol C m^{-2} yr^{-1}
- Interannual variations in the E-P balance and mixing important controls on carbon inventories



Winn et al. 1994, Dore et al. 2003, 2009

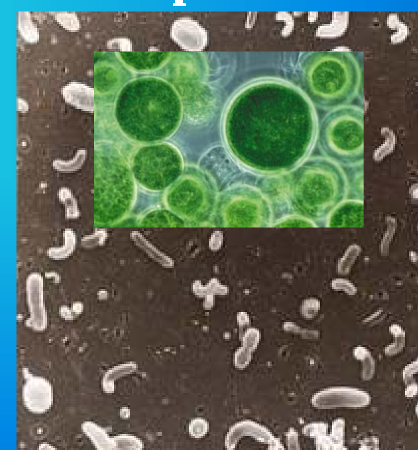

Processes influencing carbon cycling in the upper ocean at Station ALOHA
CO_2
ATMOSPHERE
Gas exchange
E-P balance
DIC
Net community
production
Organic Carbon (DOC, POC)
MIXED LAYER
Mixed layer boundary
Entrainment
Diffusion
Diffusion
THERMOCLINE
DIC
Particle export
Adapted from Keeling et al. (2004)

What is the biological contribution to ocean carbon flux at ALOHA?

Photosynthesis

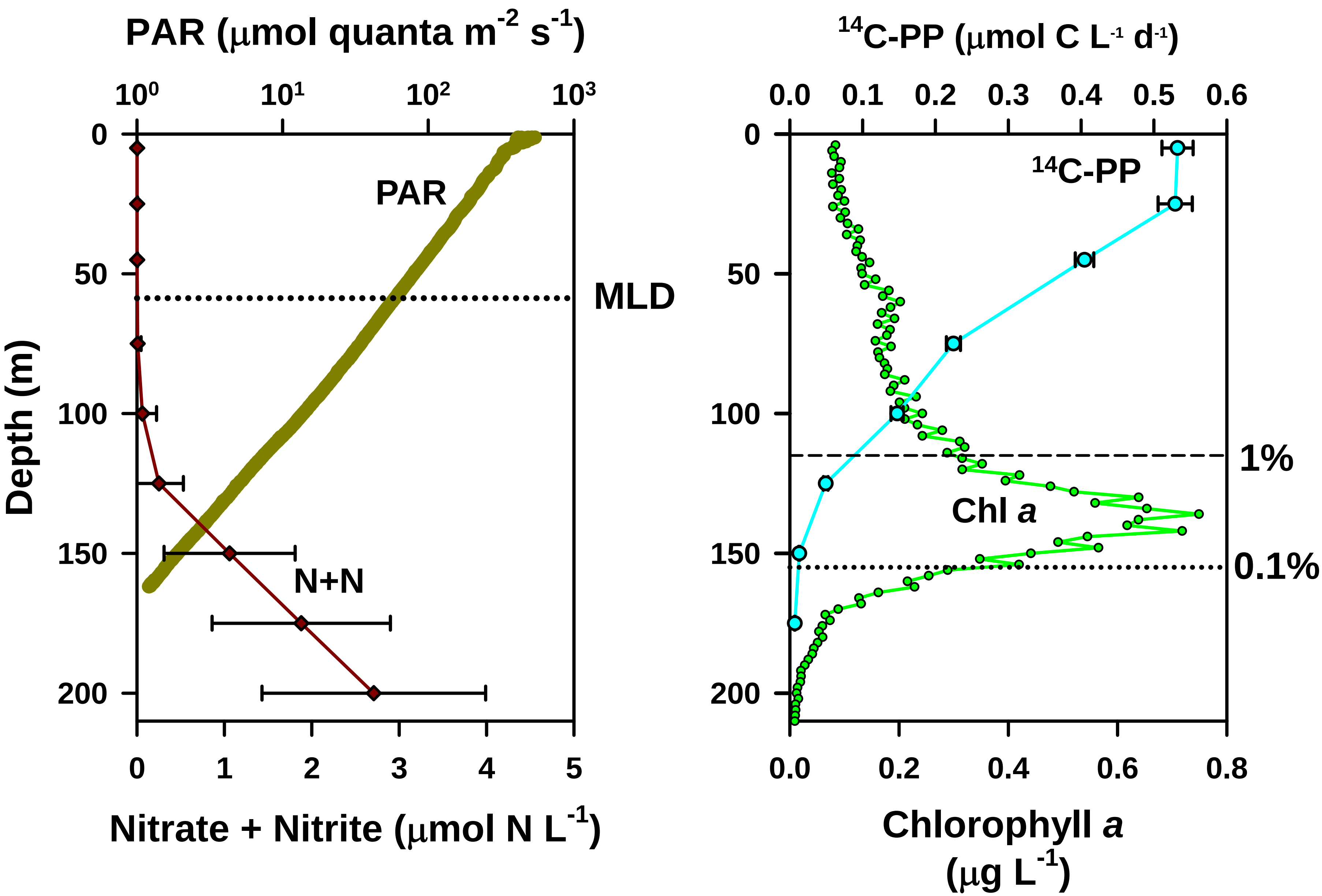
+ O_2,
- CO_2

Respiration



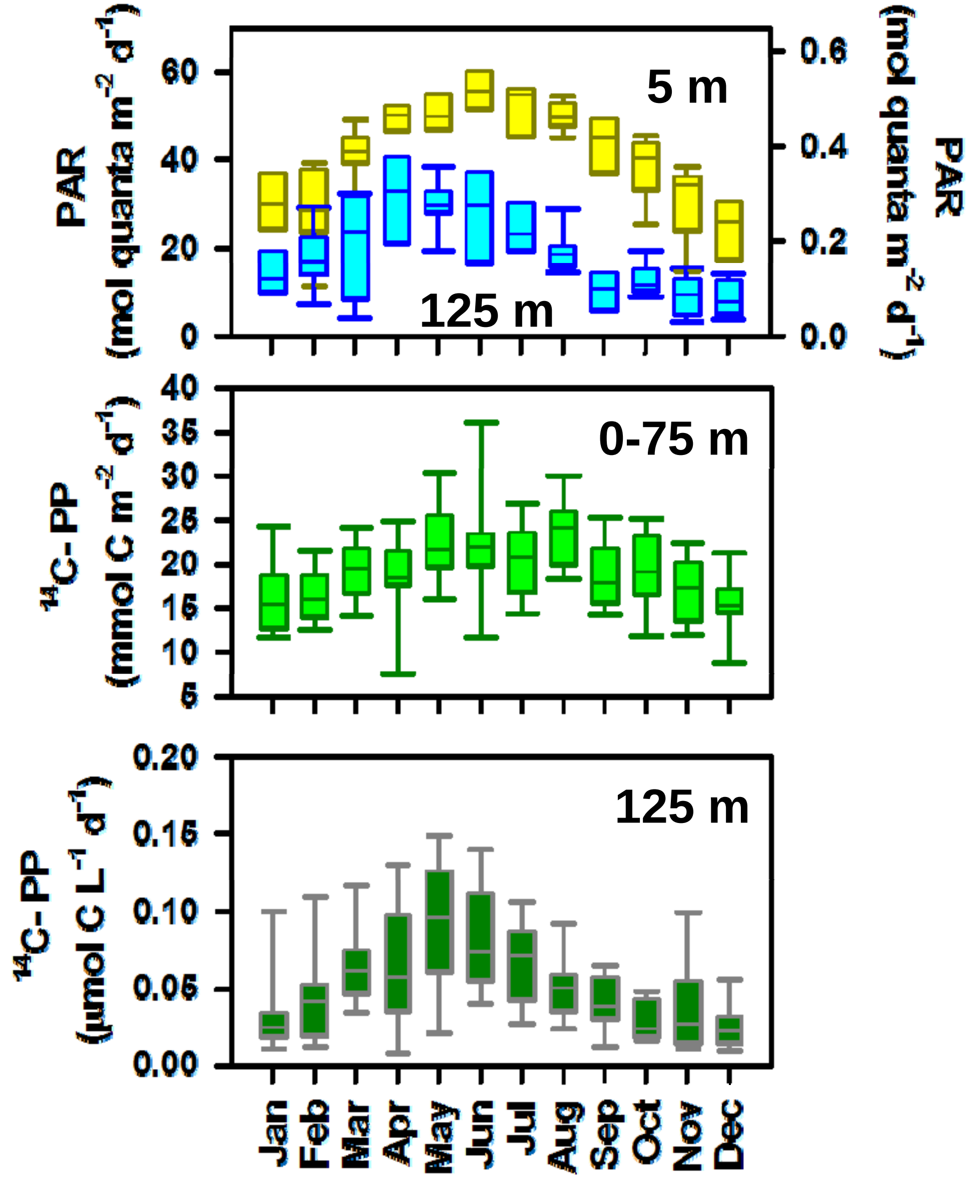
-O_2 ,
+ CO_2

The upper ocean habitat

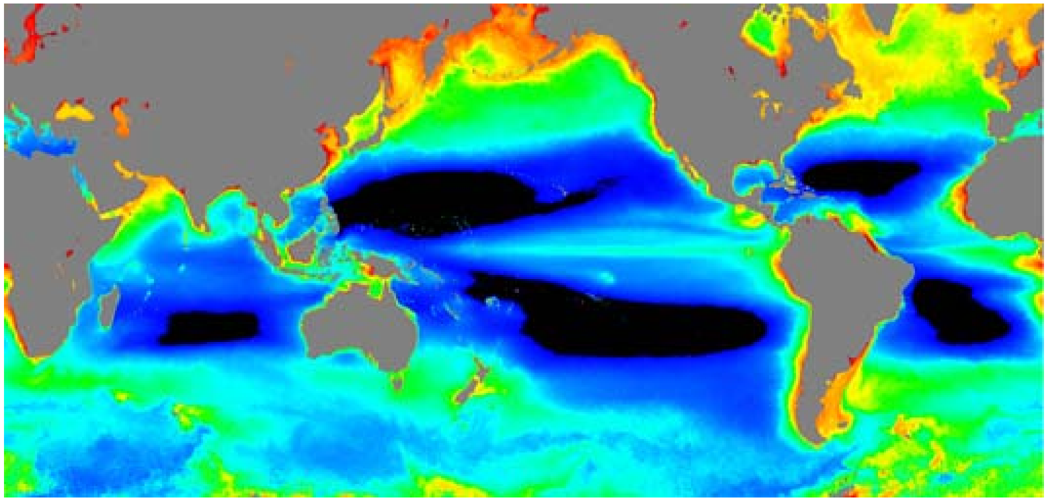


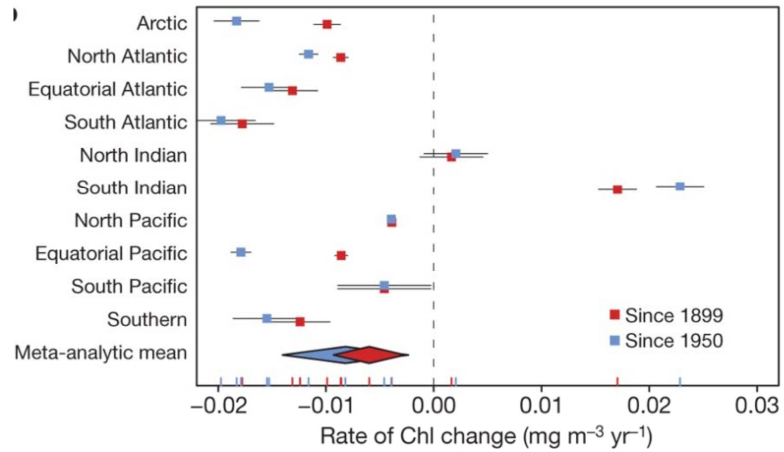
Light is an important habitat control

Seasonal changes in light appear to drive productivity in both the near surface waters and deep chlorophyll maximum

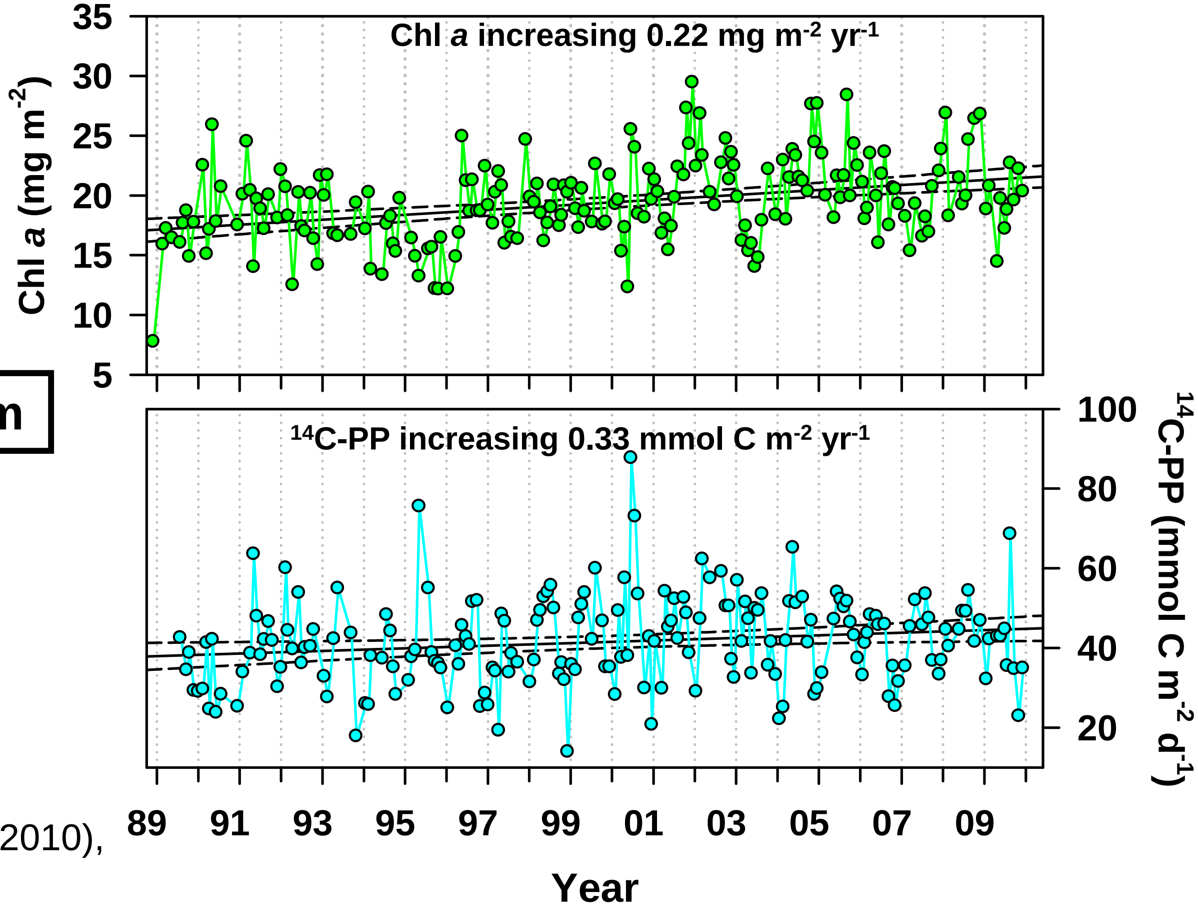


Polovina et al. (2008)





Boyce *et al.* (2010)

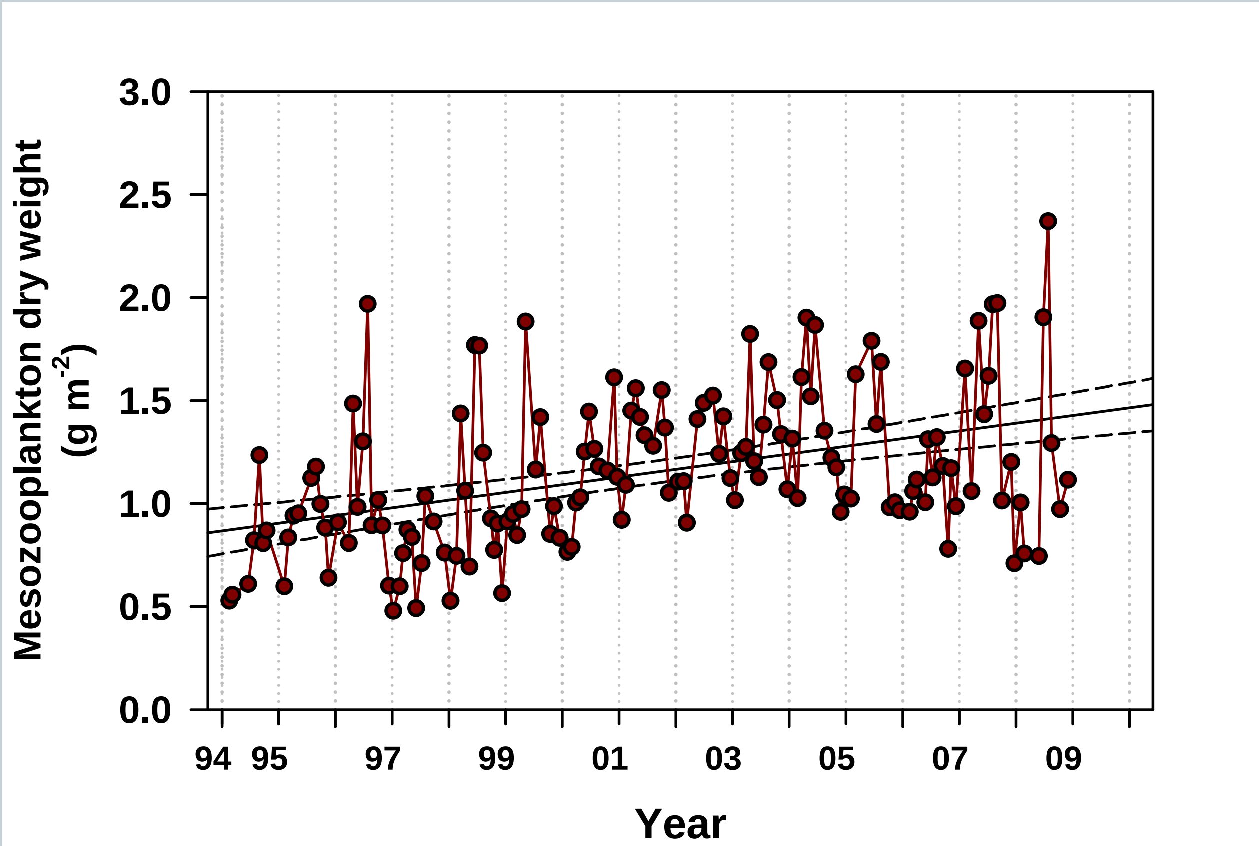


0-125 m

Corno et al. (2007),
Saba et al. (2010),
Luo et al.

HOT observations indicate both chlorophyll and primary production are increasing. Prominent increases occurring below the depth of satellite detection.

Material transfer through the food web

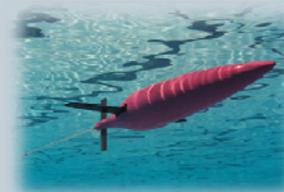
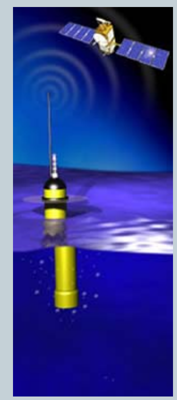
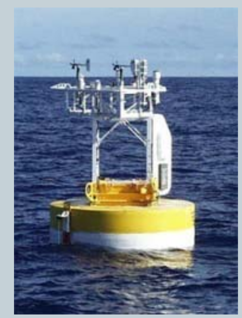


Zooplankton dry weight (0-150 m) increasing at 37 mg m^{-2} per year

Sheridan and Landry (2004)

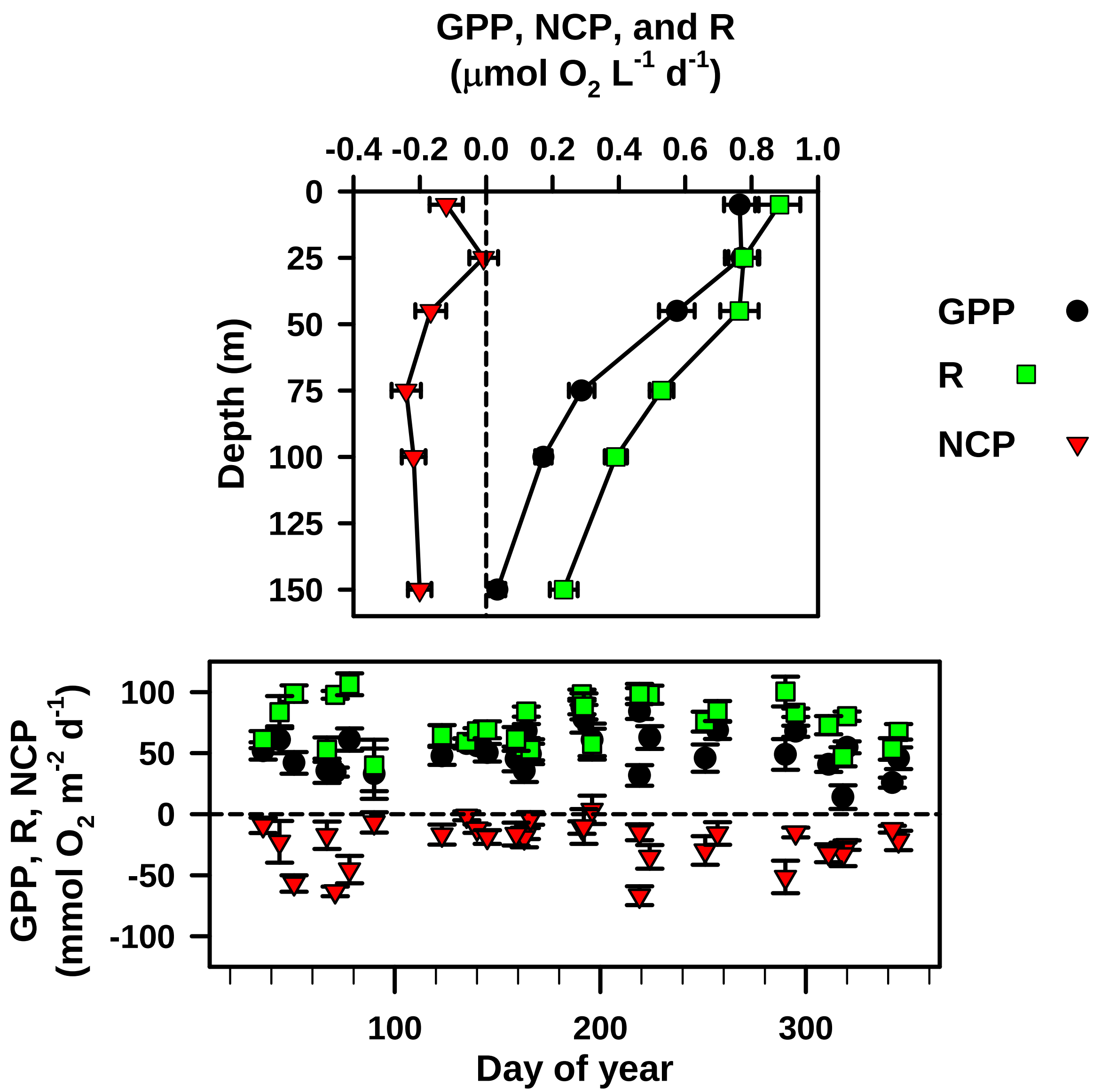
Measurements and models of primary production at Station ALOHA

- **Carbon production**
  - ^{14}C-bicarbonate assimilation (daylight incubation period ~12 hours)
  - DIC, TOC, and PC variability
- **Oxygen production**
  - In vitro O_2 bottle incubations
  - In situ O_2 dynamics: gliders, floats, moorings, and ships
  - $^{18}O_2$ production from $H_2{}^{18}O$
  - ^{16}O, ^{17}O, ^{18}O Triple O_2 isotopes
- **Bio-optics and satellites**
  - Bio-optical approaches
  - Satellite remote sensing

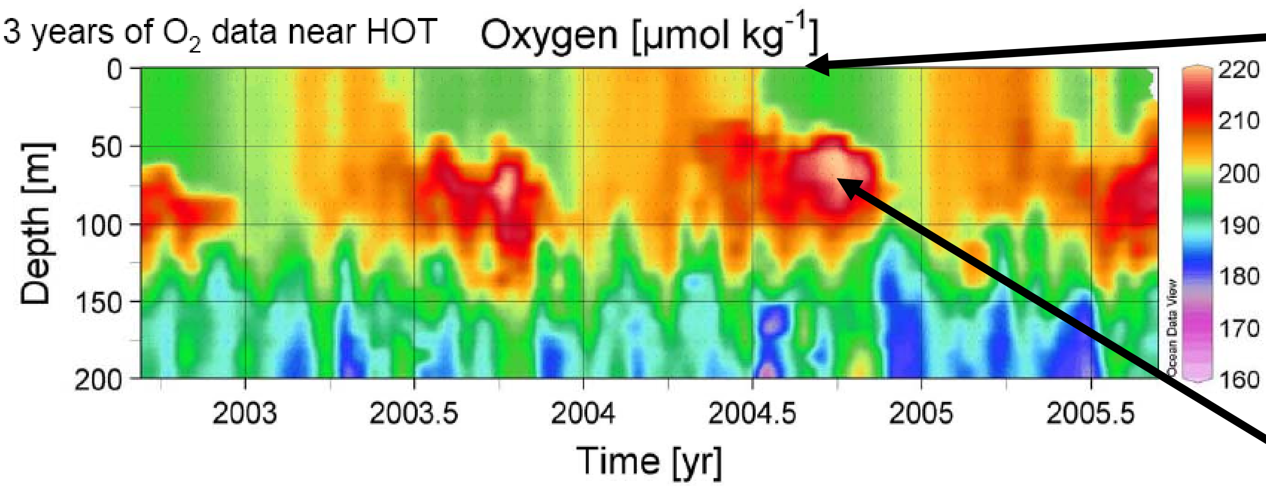





In vitro O_2 dynamics at Station ALOHA

- 4 years of measurements (2001, 2005-2007)
- Net Community Production: -4.2 to -7.4 mol C m^{-2} yr^{-1}
- Gross Primary Production: 11.9-14.0 mol C m^{-2} yr^{-1}
- Respiration: 17-21 mol C m^{-2} yr^{-1}
- Conclusion: Net heterotrophy due to incubation conditions and/or under sampling

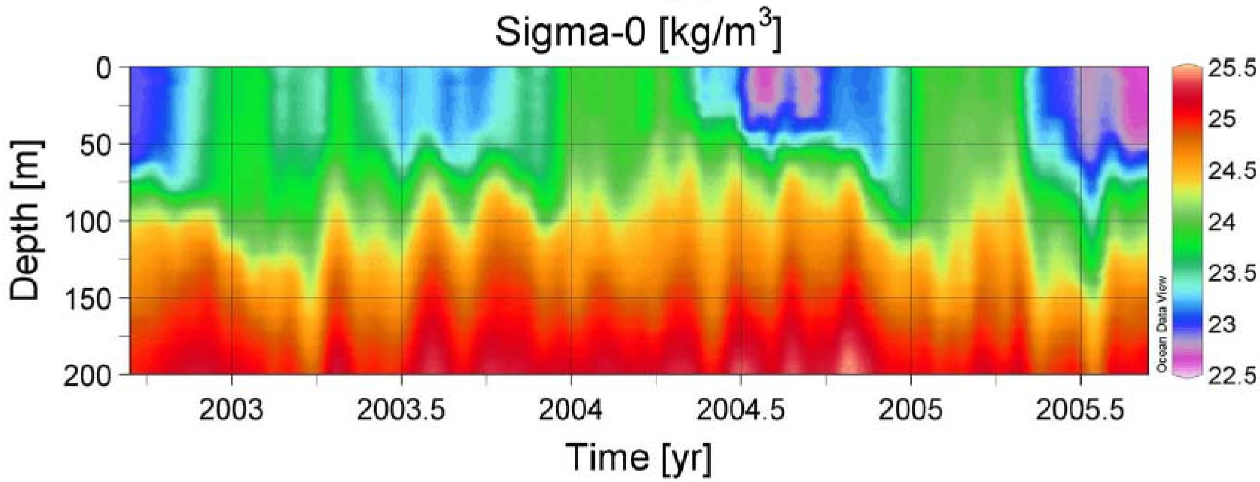


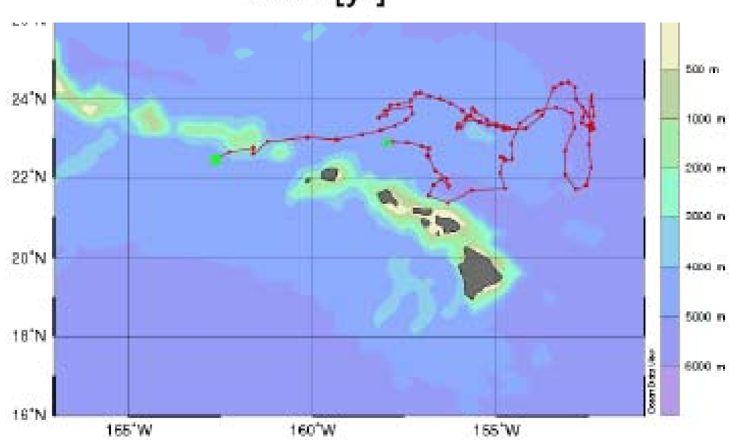
e.g. Williams et al. (2004)

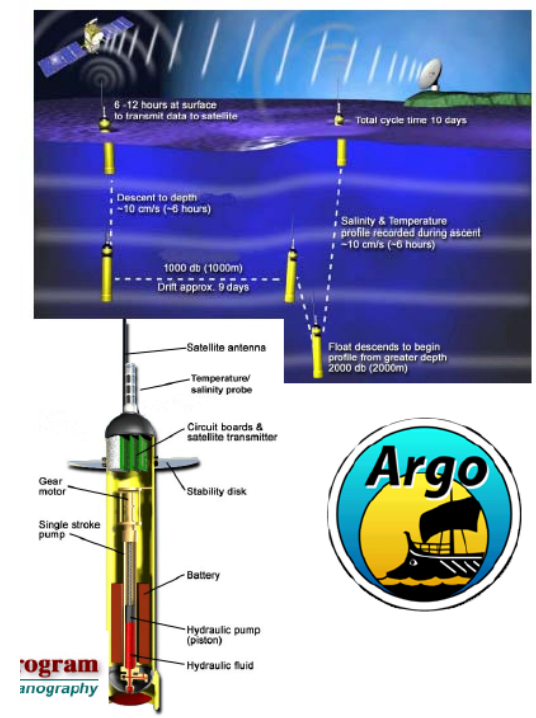


Mixed layer O_2 is in equilibrium with the atmosphere

Rate of subsurface O_2 accumulation provides information on NCP



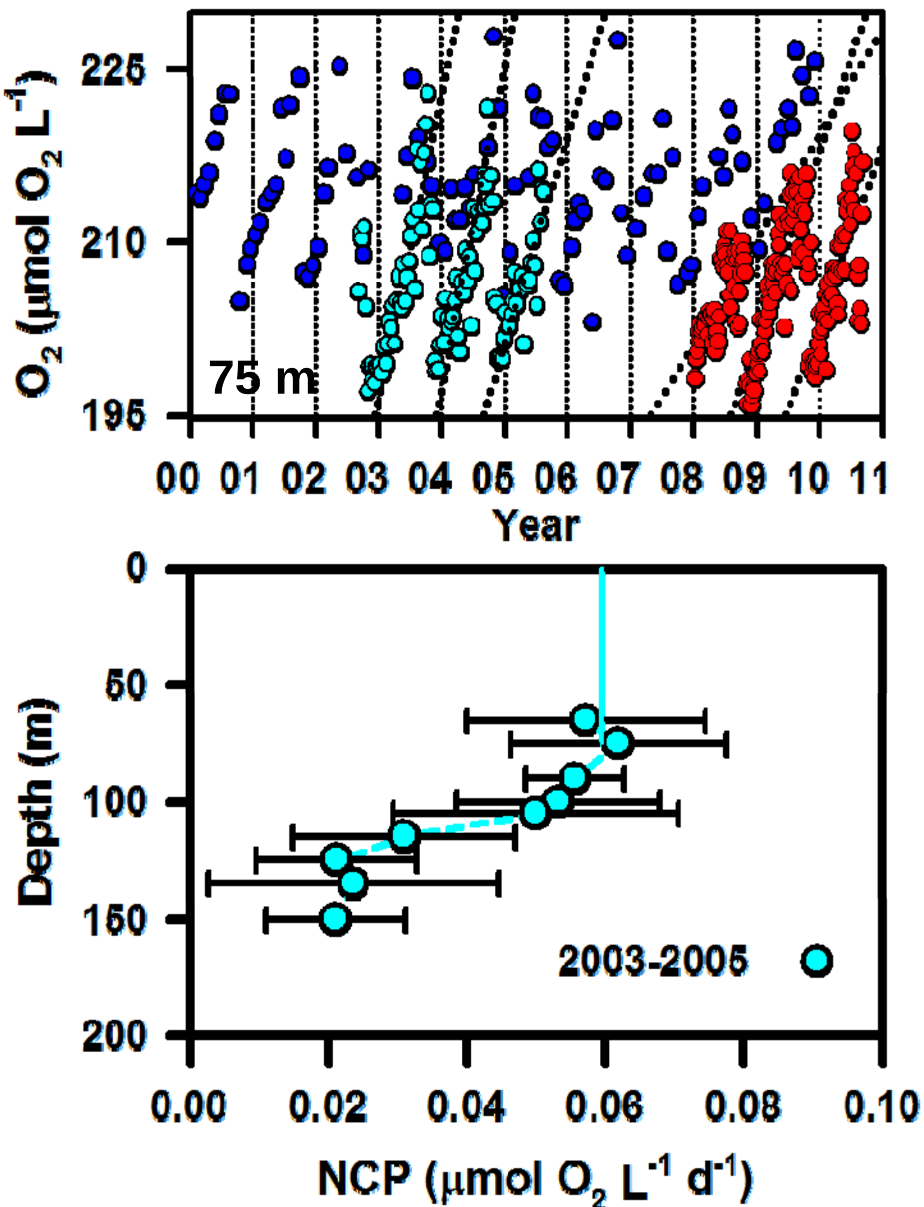




Argo

In situ O_2 dynamics at Station ALOHA

- >6+ years of *in situ* measurements (2003-05, 2008-present)
- Net Community Production: 1.1-1.7 mol C m^{-2} yr^{-1}



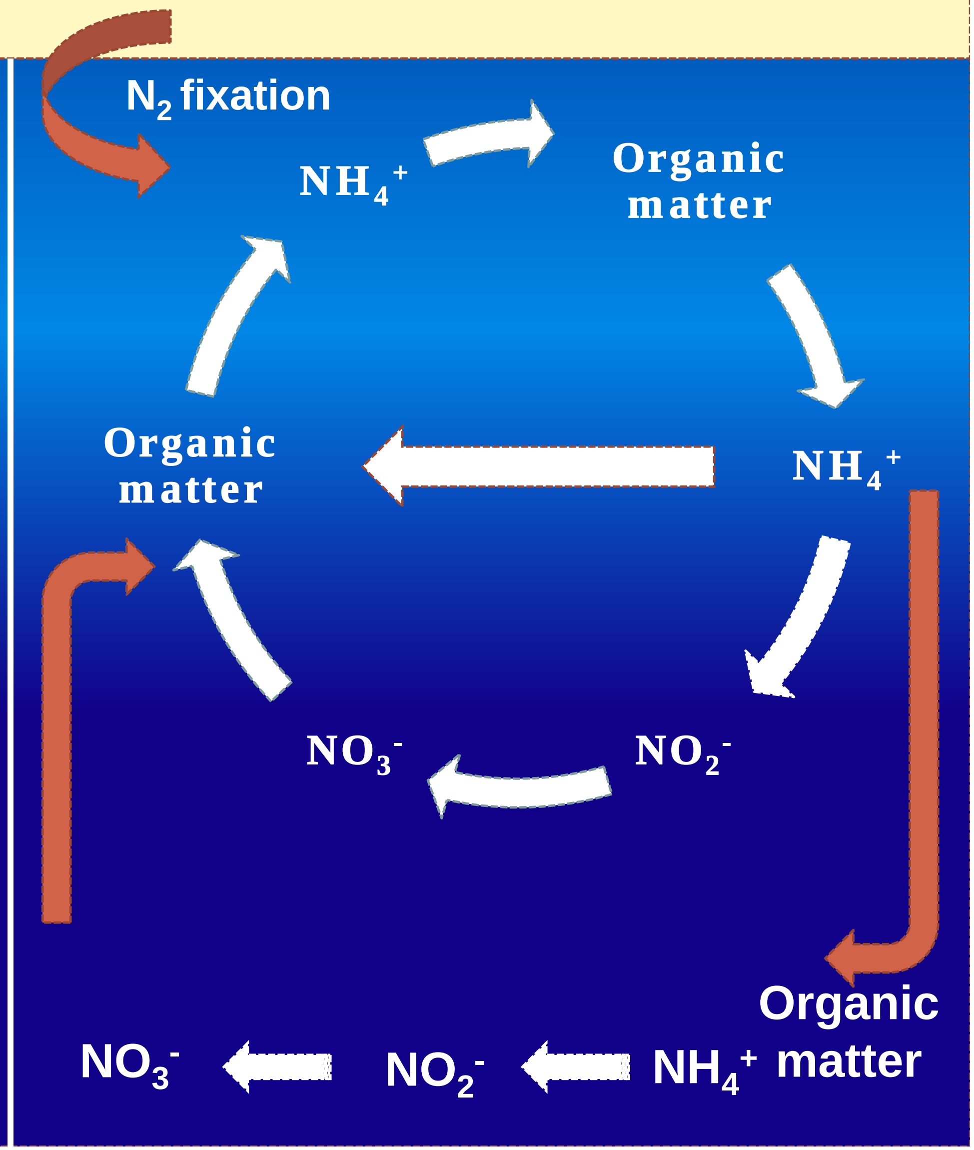
Riser and Johnson (2008)

Net Community Production at Station ALOHA

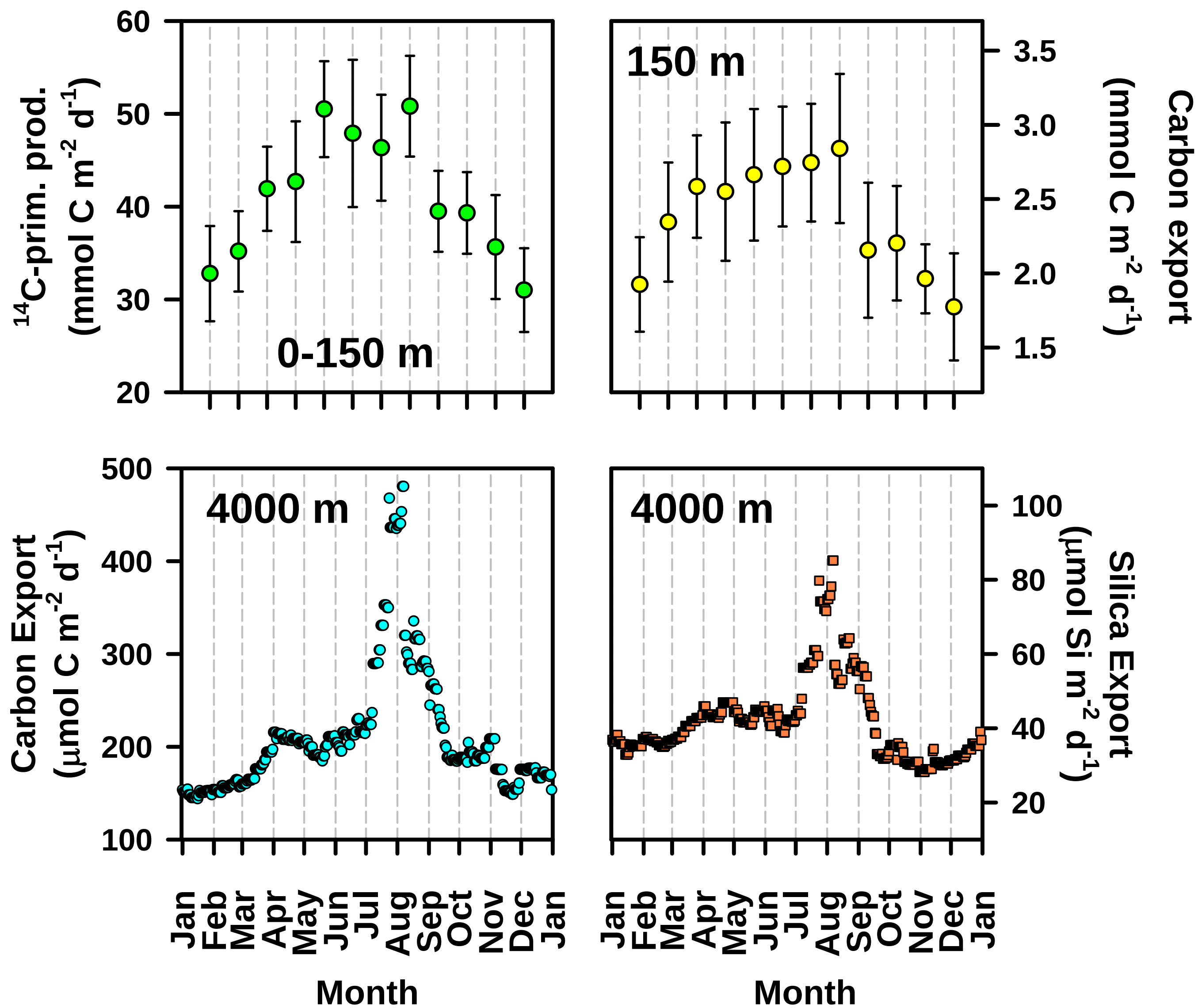
Method	Rate mol C m^{-2} yr^{-1}	Period of measurements	References
Mixed Layer O_2 + Ar budgets	1.4 - 3.7 (± 1.0)	1992–2008	Emerson et al. (1997); Hamme and Emerson (2006); Juanek and Quay (2005); Quay et al. (2010)
DIC + $DI^{13}C$ budgets	2.7 - 2.8 (± 1.4)	1988–2002	Quay and Stutsman (2003); Keeling et al. (2004)
Mooring O_2	4.1 (± 1.8)	2005	Emerson et al. (2008)
Sub-mixed layer float profiles	1.1 - 1.7 (±0.2)	2003-2010	Riser and Johnson (2008)
Sub-mixed layer glider surveys	0.9 (± 0.1)	2005	Nicholson et al. (2008)
Sediment traps	0.9 (± 0.3)	1989–2009	HOT core data
In vitro O_2 incubations	-6.1 (± 4.6)	2001, 2005-2007	Williams et al. (2004)

NCP appears constrained to ~2-fold variability
GPP estimated ~20-fold greater than NCP

What controls variability in nutrient supply supporting net community production?



Annual cycle of productivity and export



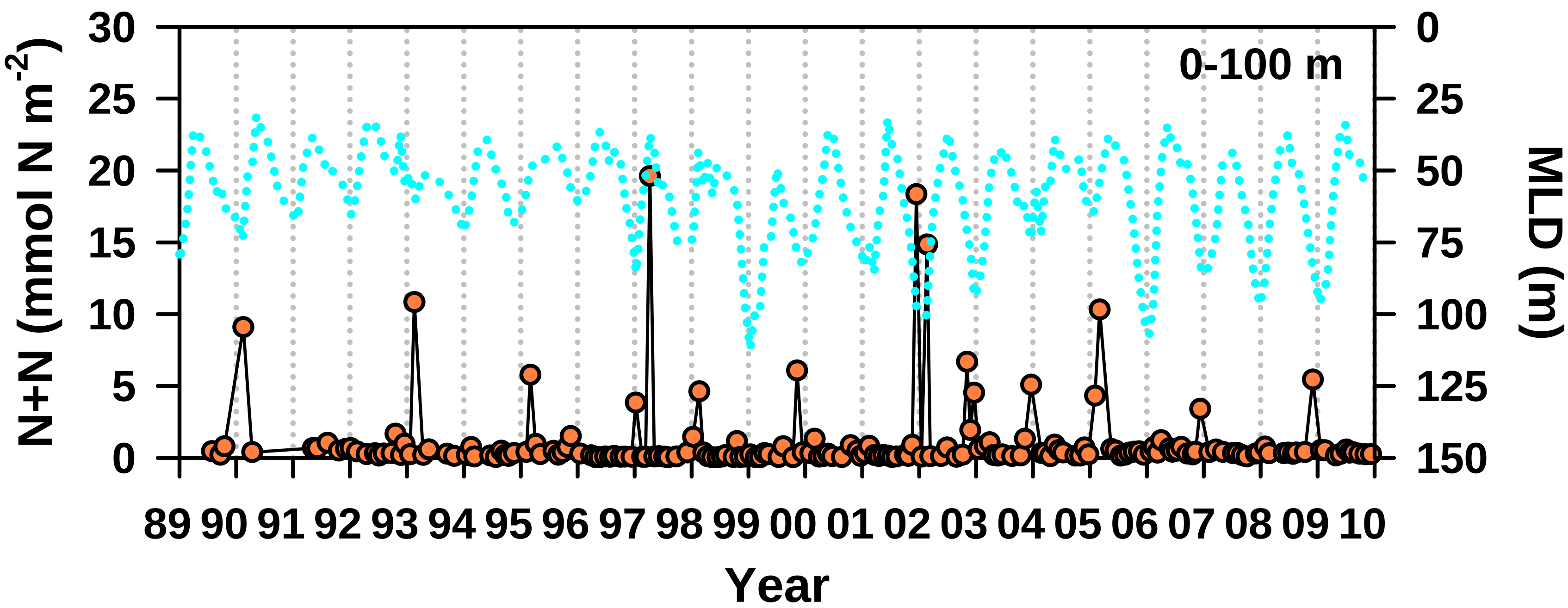
Plankton community structure plays a key role in carbon flux to the deep sea

Controls on nitrogen supply to the upper ocean

- **Physical:**
  - **Mixing, upwelling, diffusion, advection**
    - **NO_3^- supported new production**

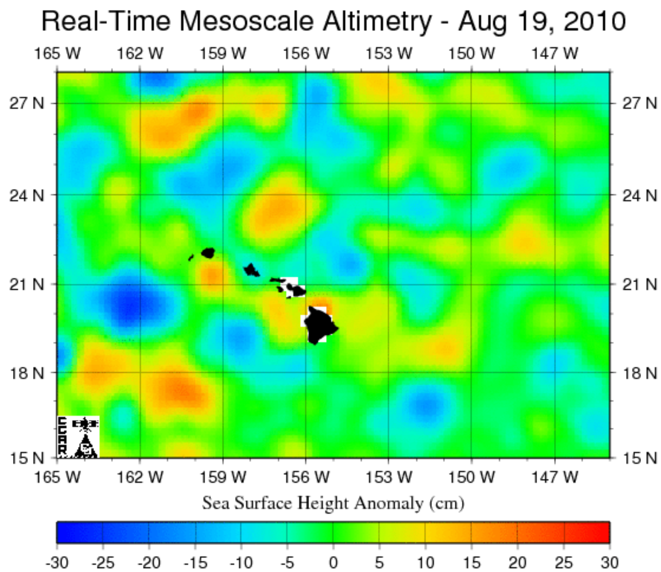
- **Biological:**
  - **N_2 fixation ($N_2 \rightarrow NH_3$)**
    - **N_2 supported new production**

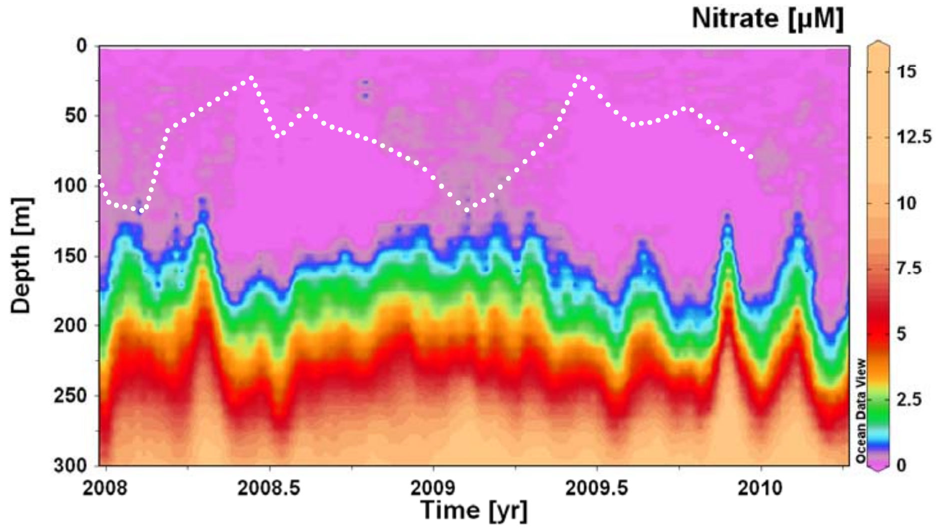
Physical supply of nutrients: Mixing

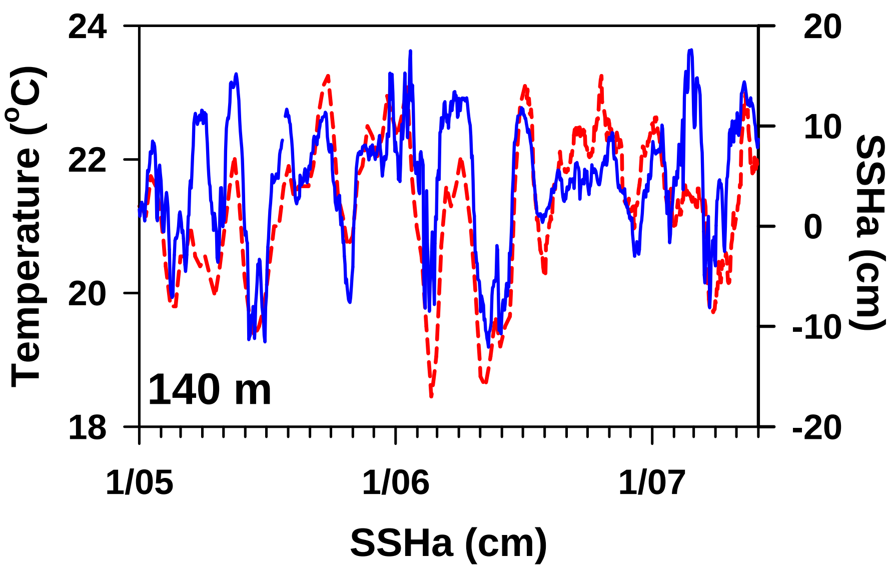


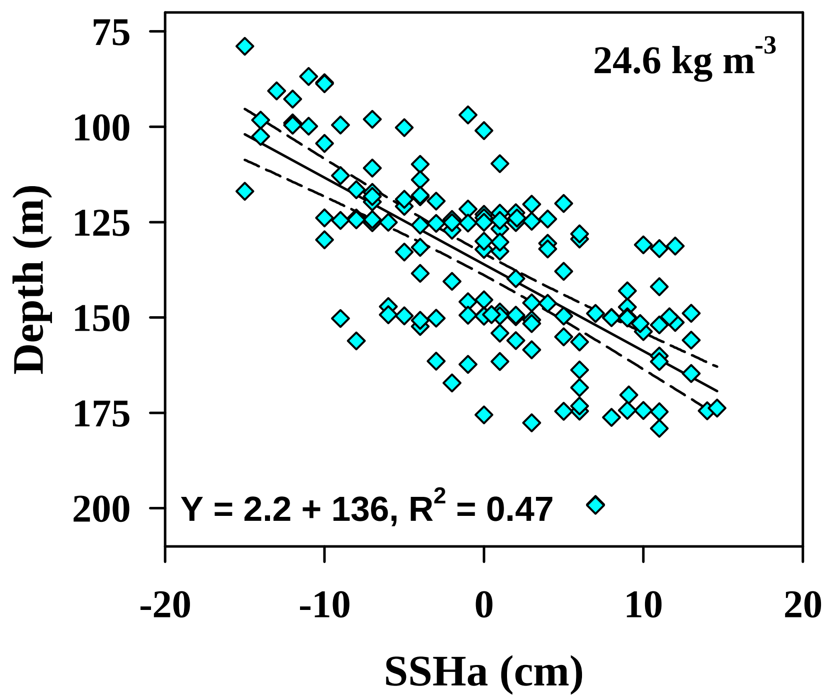
Winter mixing “increases” upper ocean nitrate concentrations

Mesoscale variability at Station ALOHA

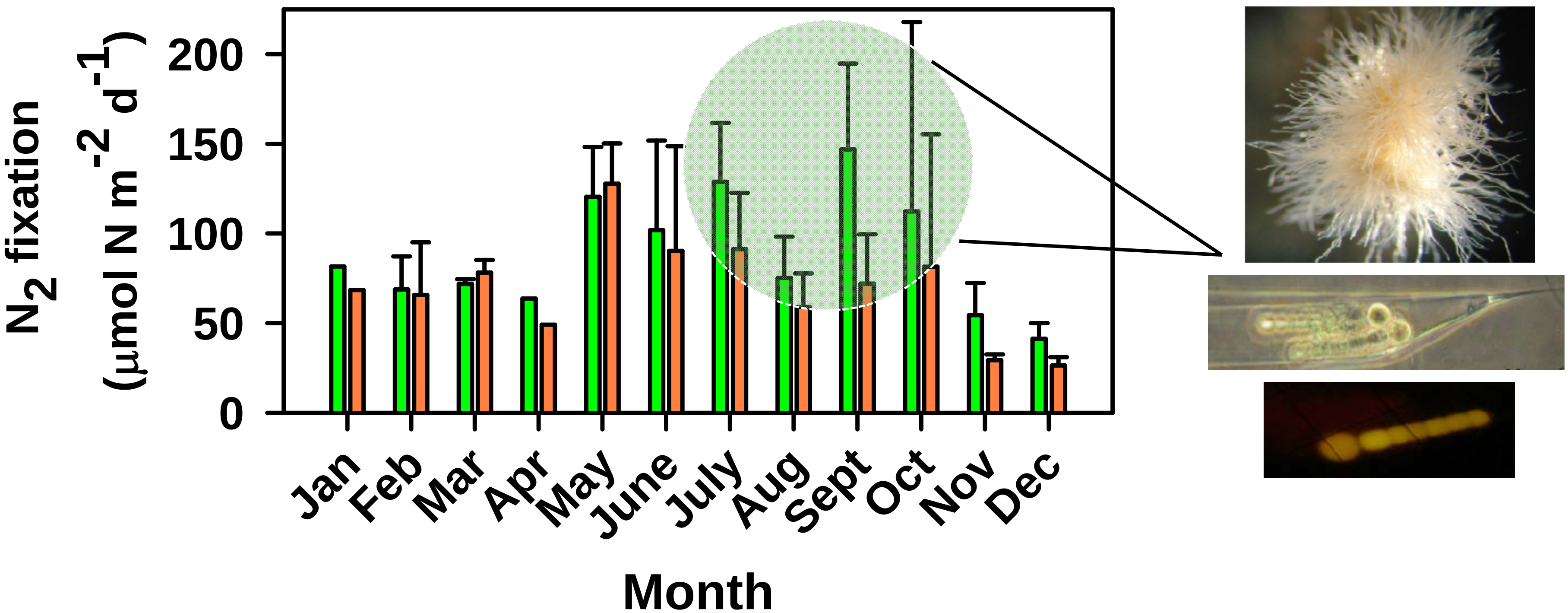




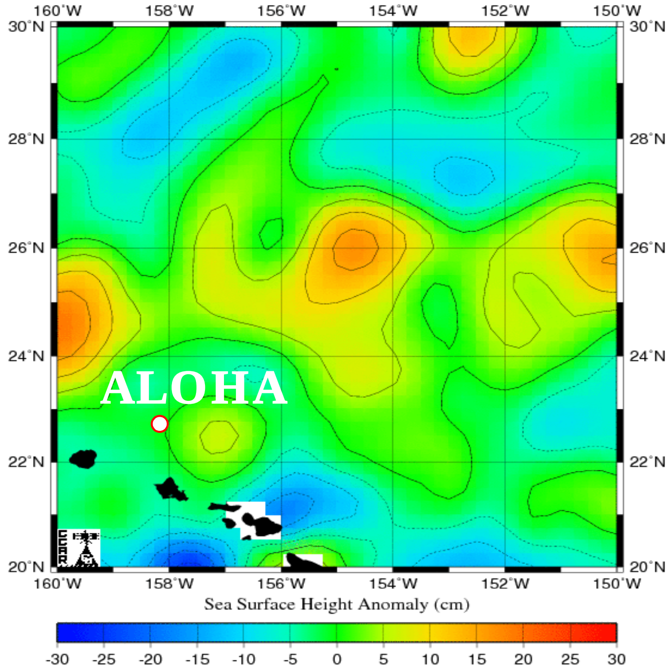




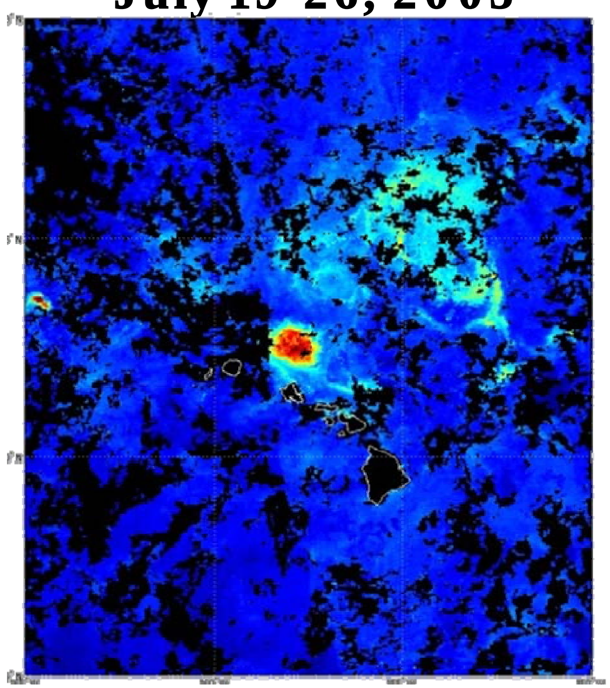
Biological supply of nutrients: N_2 fixation

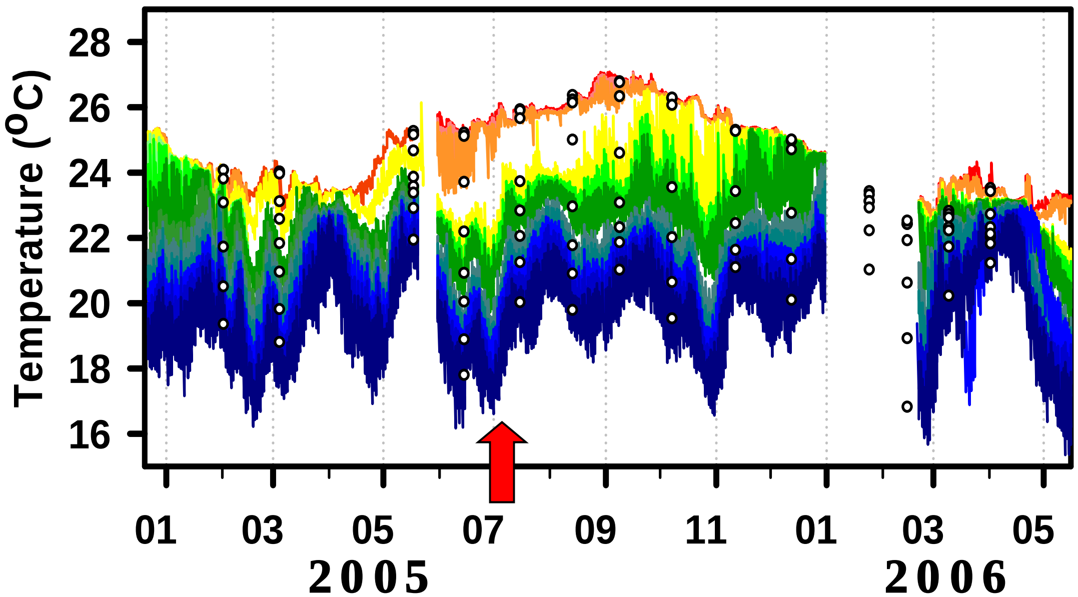


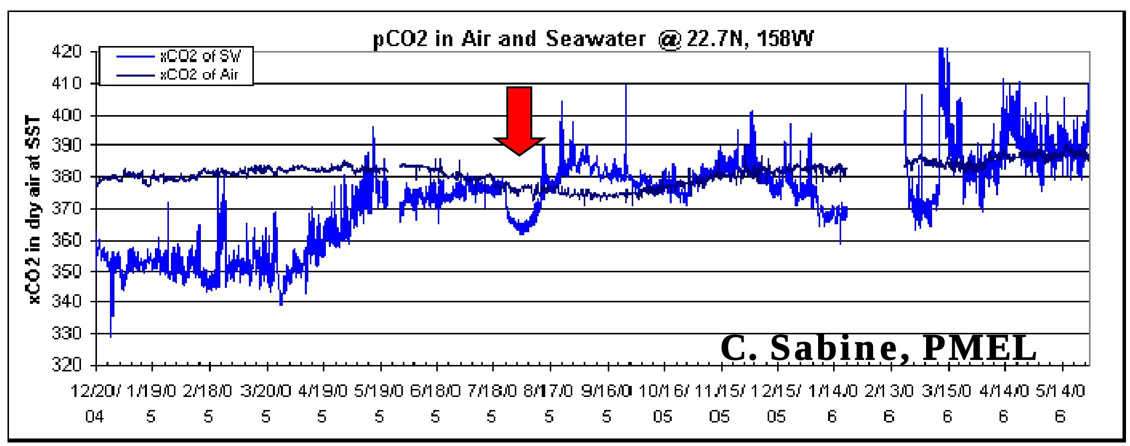
Rates of N_2 fixation are variable, but generally increase in the spring and summer

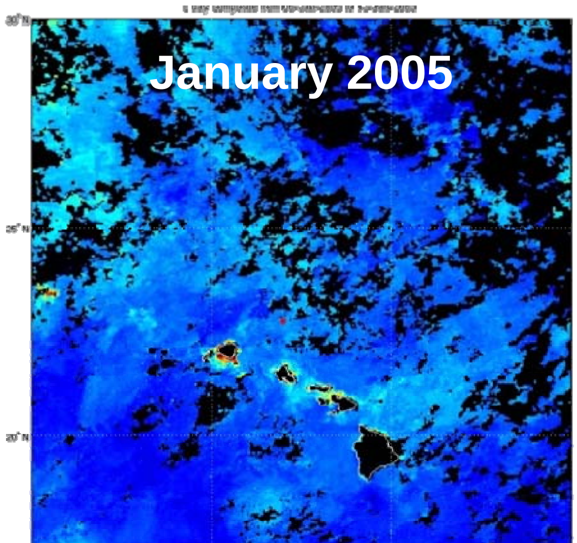


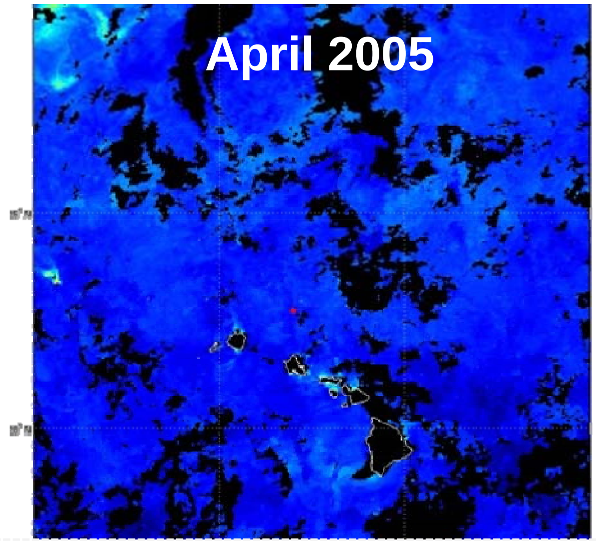
July 19-26, 2005

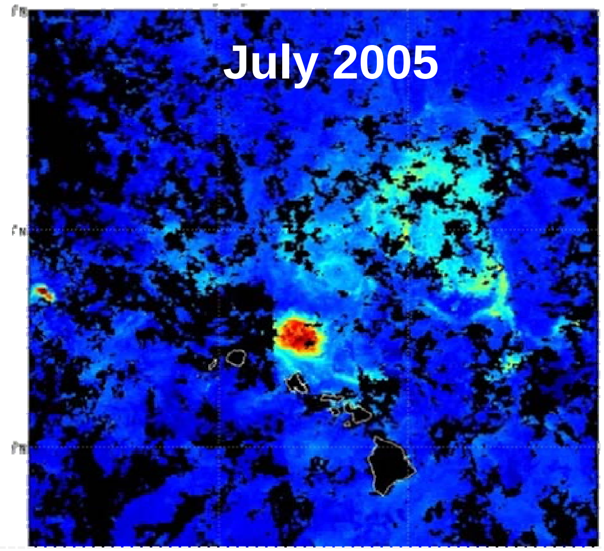


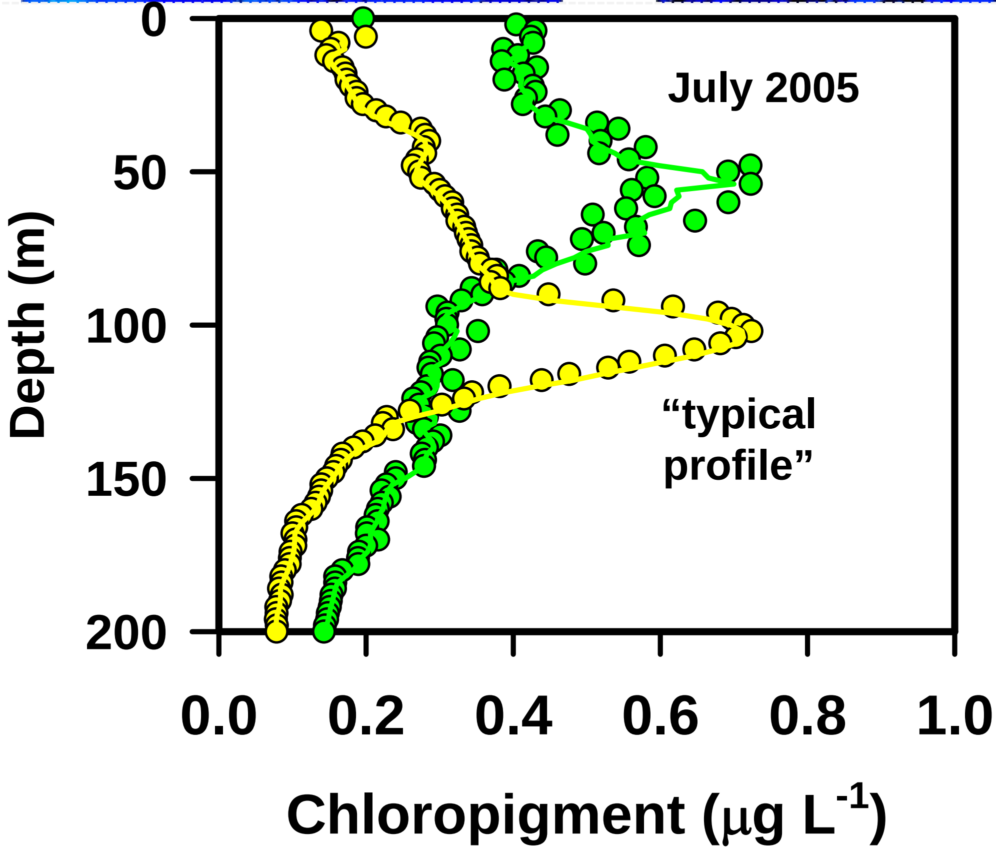


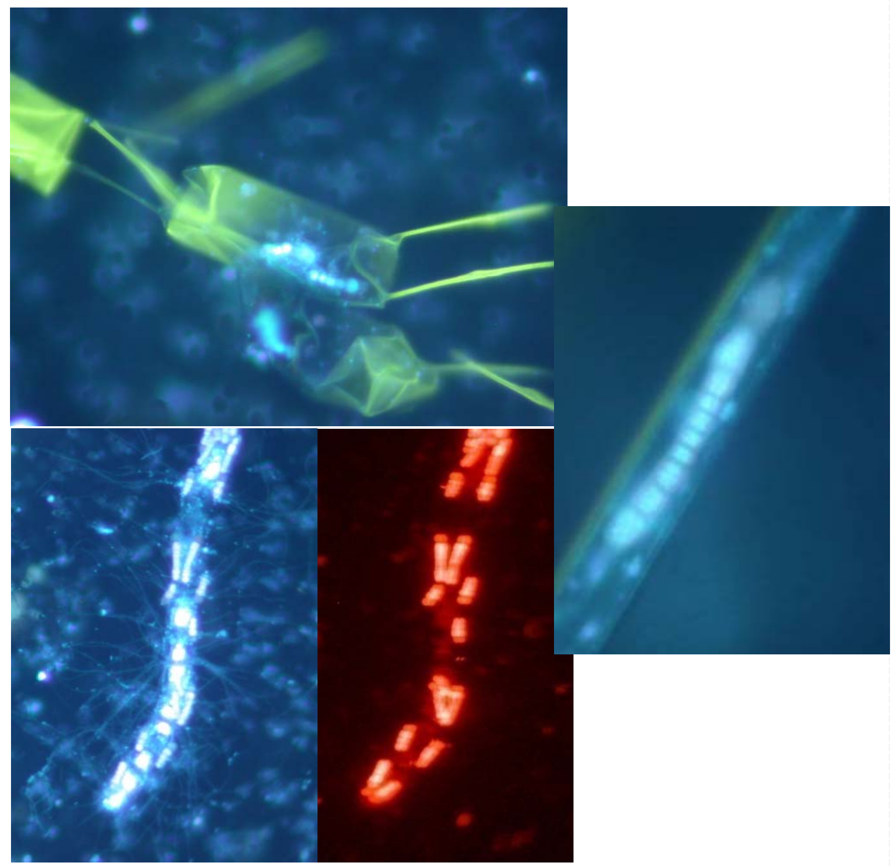








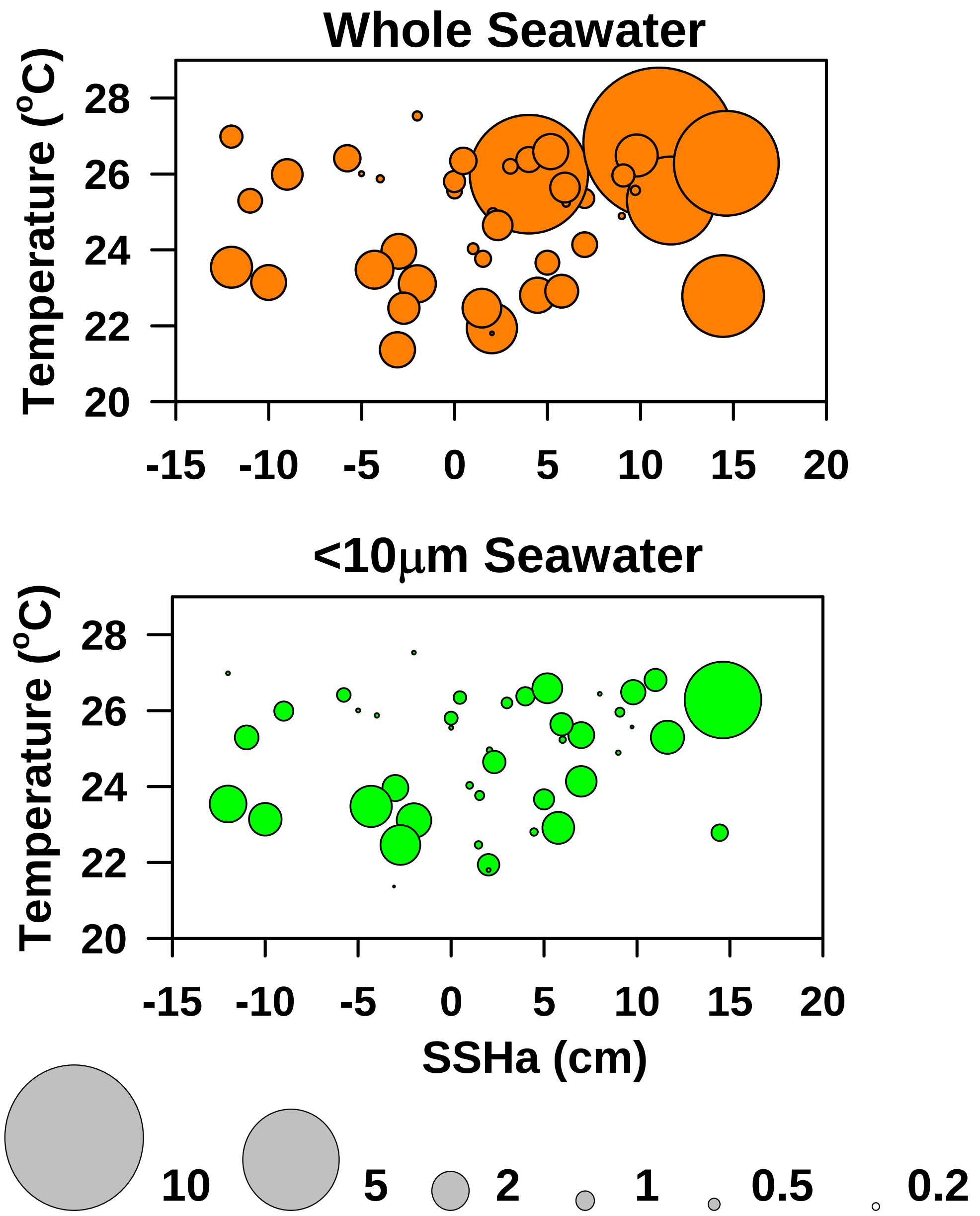




Fong et al. (2007)

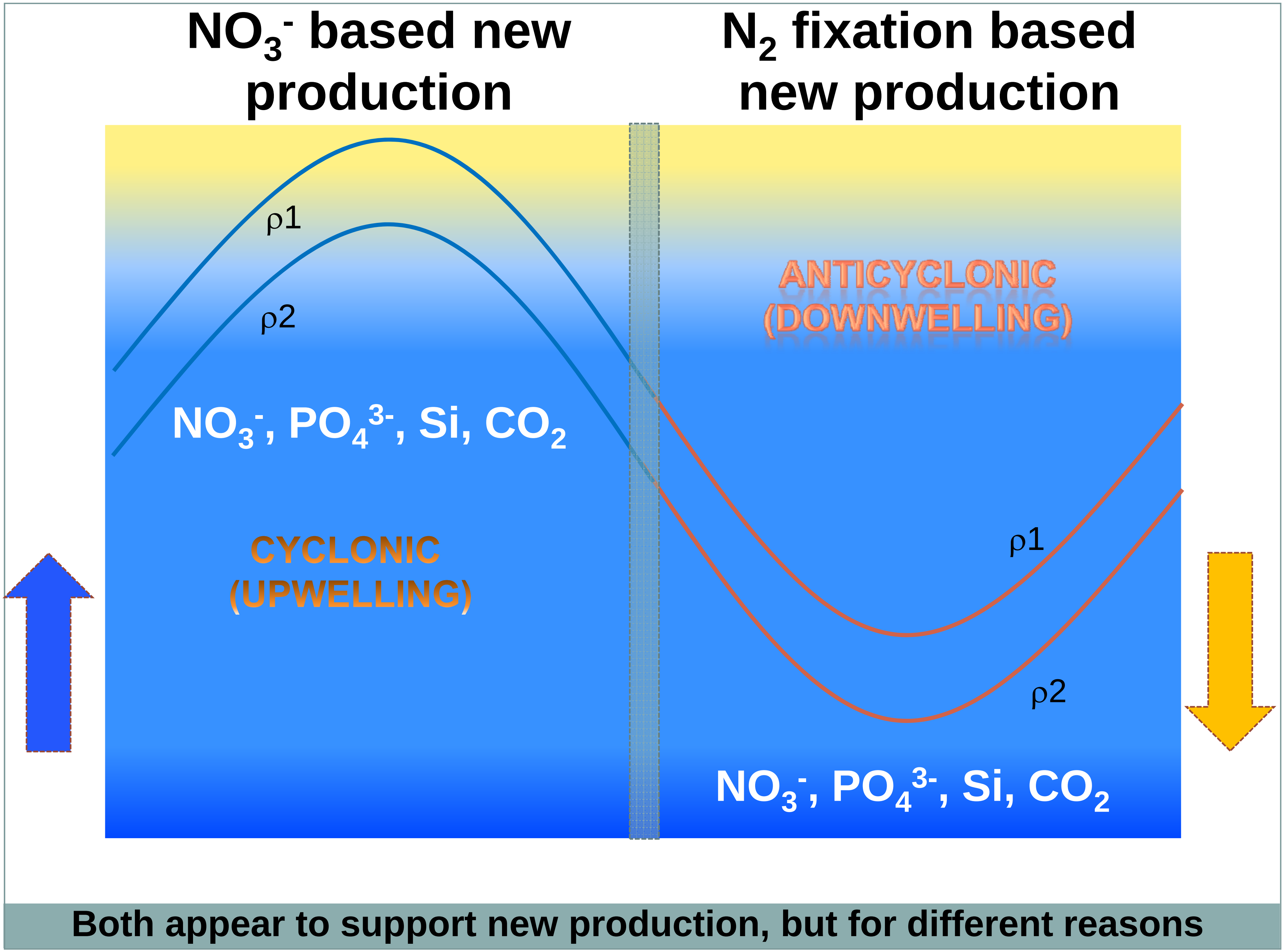
Time series measurements of near-surface ocean N_2 fixation at Station ALOHA

Episodic increases in N_2 fixation by diazotrophs >10 μm appear associated with mesoscale (anticyclonic) eddies.



Church et al. (2009)

nmol N L^{-1} d^{-1}



NO_3^- based new production
N_2 fixation based new production
ρ1
ρ2
ANTICYCLONIC (DOWNWELLING)
NO_3^-, PO_4^{3-}, Si, CO_2
CYCLONIC (UPWELLING)
ρ1
ρ2
NO_3^-, PO_4^{3-}, Si, CO_2
Both appear to support new production, but for different reasons

HOT insights

- Biological and physical processes interact to control time-variability in ocean carbon inventories and fluxes.
- The complexity of ocean ecosystem change demands interdisciplinary studies.
- HOT measurements indicate we need to study carbon cycle processes at a range of scales, from decadal to seasonal to episodic.
- The value of HOT continues to increase with time.

Facing Future

- The complexity of ecosystem dynamics, even in this "stable" ecosystem, demands sustained observations.

- The shipboard time series program continues to enrich our understanding of the NPSG, and help direct application of remote and autonomous sensing technologies.

- These multi-decadal time series programs are some of our best (and only) barometers of ocean ecosystem change.