

BATS and HOT, 25 years of incredible productivity! CARIACO 18 years!

What should we focus on for the next 25 years?

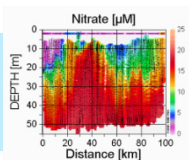
Ken Johnson

Monterey Bay Aquarium Research Institute

Net community production, carbon export and nutrient supply at ocean time series sites. Should we expect consensus? Should fluxes agree?

Ken Johnson

Monterey Bay Aquarium Research Institute



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Overarching goal – convince OCB community that we need a systematic assessment of major carbon fluxes (NCP, Export, ...) at time series station (HOT, BATS, CARIACO, ESTOC, Papa).

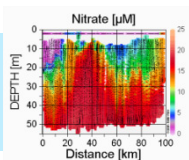
- Perhaps an OCB working group?
- How do methods compare?

I'll argue that time series stations need to make quantitative observations of major carbon fluxes over time.

- Are sediment traps at 150 m good enough?
- Methods should be intercomparable.
- Time series stations should serve as a benchmark for more expandable systems.

Ultimately we need global, carbon observing systems.

But first a little time series history!



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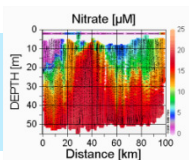
HOT-1 Cruise Report  
R/V Moana Wave  
29 Oct. - 3 Nov. 1988

Narrative:

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HOT-1 was the shakedown cruise of the HOT program, much of the equipment had never been used, and there were some equipment failures. One conductivity cell and the General Oceanics rosette pylon failed. In addition, there were problems with the winch level-wind mechanism, and with the slip-rings. The Kahe Point station was abandoned because of these problems.

The sediment traps were tracked using ARGOS for two days after deployment, but we lost contact with them a few hours before they were due to be retrieved, and despite a 16-hour search, they were not found.



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*Bermuda Biological Station For Research, Inc.*  
*U.S. JGOFS Bermuda Atlantic Time-series Study*

## **Cruise Report, BATS 1**

Cruise dates: October 20, 1988 - October 21, 1988

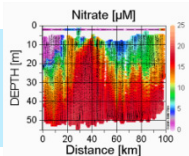
Personnel: A.H. Knap, R.L. Sherriff-Dow, P. Wassmann, R. Johnson.  
R.V. Weatherbird

**Cast 1** on deck at 0200.

Wire kinked. Decide not to put CTD back down.

Lat: 31.160 N; Long: 64.500 W

Nominal depths: 2000,2200,2400,2600,2800,3000,3200,3400,3600,3800,4000,  
4200 m.



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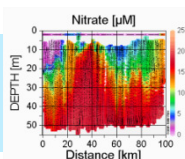
# HOT-253: Chief Scientist Report

## Chief Scientist: Susan Curless

### R/V Kilo Moana

### June 24-28, 2013

HOT-253: Chief Scientist Report																																																																																						
Chief Scientist: Susan Curless R/V Kilo Moana June 24-28, 2013																																																																																						
<p>Cruise ID: KML2013 Departed: June 24, 2013 at 0600 (IST) Returned: June 28, 2013 at 0700 (IST) Vessel: R/V Kilo Moana, University of Hawaii Master of the Vessel: Captain Rick Meyer Chief Scientist: Susan Curless, University of Hawaii OTD Marine Technicians: Trevor Goodman and David Haskins</p>																																																																																						
<p>1. SCIENTIFIC OBJECTIVES</p> <p>The objective of the cruise was to maintain a collection of hydrographic and biogeochemical data at the Hawaii Ocean Time-series (HOT) station. Four stations were to be occupied during the cruise, in the following order:</p> <ol style="list-style-type: none"> <li>Station 1, referred to as Station Kilo, is located at 21° 20.6'N, 159° 38.4'W and was to be occupied on June 26th for about 3 hours.</li> <li>Station 2, referred to as Station ALOHA, is defined as a circle with a 6 nautical mile radius centered at 22° 49'N, 159° W. This is the main HOT station and was to be occupied June 26th, 26th, and 27th.</li> <li>Station 3B, the site of WHEIS-9 Mooring (mooring position 22° 46.07'N 157° 53.95'W) was to be occupied on June 27th for about one hour.</li> <li>Station 4, referred to as Station Kama, is located off Kama Point at 21° 30.8'N, 159° 21.8'W and was to be occupied on June 27th for approximately 3 hours.</li> </ol> <p>Upon arrival at Station Kilo, a 1300 lb. weight-haul cast to 500 m, one CTD cast to 1000 m, a Hyperspyr cast, and a 20 m radius cast were to be conducted on the afternoon of June 26th. The weight-haul cast was to be conducted to collect continuous profiles of various physical and chemical parameters. Water samples were to be collected at discrete depths for biogeochemical measurements. After these operations were satisfactorily completed, the ship was to proceed to Station ALOHA.</p> <p>Upon arrival at Station ALOHA, the free-drifting sediment trap array was to be deployed. The sediment trap array was to stay in the water for about 12 hours. This was to be followed by one 200 m CTD cast to prepare incubation experiments and 1000 m CTD cast for preparation of the Primary Productivity Array. This cast was to be followed by the deployment of the free-drifting Primary Productivity Array to incubate inside for 12 hours. A full-depth (&gt;4500 m) CTD cast was to be conducted after the deployment of the Primary Productivity Array, followed by 1000 m CTD casts at 15 minute intervals for at least 30 hours for continuous and discrete data collection, ending with another full-depth CTD cast at 2300 m on June 26th.</p> <p>Another free-drifting array (One Array) was to be deployed for 24 hours for incubation experiments on June 26th. The One Array was to be recovered on June 27th.</p> <p>A platform net was to be towed between 1000-1400, and 2200-0200 for 30 minute intervals on June 27th and 28th at Station ALOHA.</p> <p>A haul net tow was to be deployed for approximately 15 minutes on the afternoon of June 26th.</p> <p>The Hyperspyr was to be deployed for a half-hour period near noon time on June 26th, 27th, and 28th.</p> <p>HOT-253 Chief Scientist Report</p>																																																																																						
<p>A package including a Wet Lab ACS, a Chl-a Fluorometer (F800), a SeaBec 9000, and a LISST-100X particle size and distribution analyzer was to be used to profile the upper 200 m at Station ALOHA in the early morning and around noon on June 27th.</p> <p>A three meter line sample was to be collected by the ATU sampler on June 26th.</p> <p>After the 36 hour burst period of CTD work at Station ALOHA was accomplished, the ship was to transit to recover the floating sediment trap array and the One Array on the morning of June 27th.</p> <p>After recovering both arrays, the ship was to transit back to Station ALOHA to conduct an ACSACFLOWEST cast, and a Hyperspyr cast. Once the option profile was complete, the ship was to transit to Station 3B to conduct a one-hour 200 m CTD pre-cast.</p> <p>Once operations at Station 3B were complete, the ship was to transit to Station 4, referred to as Station Kama where a near-bottom CTD cast (&lt;200 m) was to be conducted to collect salinity and chlorophyll samples for calibration.</p> <p>After Station Kama operations were complete, the ship was to transit back to Hong Harbor.</p> <p>The following instruments were to collect data throughout the cruise: shipboard ADCP, thermosalinograph, underway fluorometer, pCO<sub>2</sub> system, and the meteorological package.</p>																																																																																						
<p>2. SCIENCE PERSONNEL</p> <table> <thead> <tr> <th>Participant</th><th>Title</th><th>Affiliation</th></tr> </thead> <tbody> <tr><td>Susan Curless</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Don Sadler</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Shawn Goldberg</td><td>Postdoctoral Researcher</td><td>UHI</td></tr> <tr><td>Doreen O'Neil</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Adriana Telford</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Loren Truesdale</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Doreen O'Neil</td><td>Graduate Student</td><td>UHI</td></tr> <tr><td>Sara Thomas</td><td>Graduate Student</td><td>UHI</td></tr> <tr><td>Shane Wallace</td><td>Graduate Student</td><td>UHI</td></tr> <tr><td>Christopher Schvartz</td><td>Marine Engineer</td><td>UHI</td></tr> <tr><td>Jeffrey Snyder</td><td>Marine Technician</td><td>UHI</td></tr> <tr><td>Forrestal Jennings-Henderson</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Caroline Foster</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Donald McKay</td><td>Research Associate</td><td>UHI</td></tr> <tr><td>Carly Goodman</td><td>Undergraduate Student</td><td>UHI</td></tr> <tr><td>Carly Goodman</td><td>Undergraduate Student</td><td>UHI</td></tr> <tr><td>Mika Ormen</td><td>Graduate Student</td><td>UHI</td></tr> <tr><td>Erica Goetze</td><td>Postdoctoral Researcher</td><td>UCSC</td></tr> <tr><td>Henderson Carter</td><td>Research Specialist</td><td>UCSC</td></tr> <tr><td>Elizabeth Kolber</td><td>Scientist</td><td>UCSC</td></tr> <tr><td>Mark Mills</td><td>Research Specialist</td><td>Stanford</td></tr> <tr><td>Jim Foley</td><td>Marine Librarian</td><td>UHI</td></tr> <tr><td>Matthew Casamento</td><td>STARS Participant</td><td>Kilauea IBI and Intermediate</td></tr> <tr><td>Katherine Lake-Rosenberg</td><td>STARS Participant</td><td>Kilauea IBI and Intermediate</td></tr> <tr><td>Deborah LaRue-Ara</td><td>STARS Participant</td><td>Kilauea IBI and Intermediate</td></tr> <tr><td>Trevor Goodman</td><td>Marine Technician</td><td>OTD</td></tr> <tr><td>Doreen Haskins</td><td>Marine Technician</td><td>OTD</td></tr> </tbody> </table> <p>HOT-253 Chief Scientist Report</p>			Participant	Title	Affiliation	Susan Curless	Research Associate	UHI	Don Sadler	Research Associate	UHI	Shawn Goldberg	Postdoctoral Researcher	UHI	Doreen O'Neil	Research Associate	UHI	Adriana Telford	Research Associate	UHI	Loren Truesdale	Research Associate	UHI	Doreen O'Neil	Graduate Student	UHI	Sara Thomas	Graduate Student	UHI	Shane Wallace	Graduate Student	UHI	Christopher Schvartz	Marine Engineer	UHI	Jeffrey Snyder	Marine Technician	UHI	Forrestal Jennings-Henderson	Research Associate	UHI	Caroline Foster	Research Associate	UHI	Donald McKay	Research Associate	UHI	Carly Goodman	Undergraduate Student	UHI	Carly Goodman	Undergraduate Student	UHI	Mika Ormen	Graduate Student	UHI	Erica Goetze	Postdoctoral Researcher	UCSC	Henderson Carter	Research Specialist	UCSC	Elizabeth Kolber	Scientist	UCSC	Mark Mills	Research Specialist	Stanford	Jim Foley	Marine Librarian	UHI	Matthew Casamento	STARS Participant	Kilauea IBI and Intermediate	Katherine Lake-Rosenberg	STARS Participant	Kilauea IBI and Intermediate	Deborah LaRue-Ara	STARS Participant	Kilauea IBI and Intermediate	Trevor Goodman	Marine Technician	OTD	Doreen Haskins	Marine Technician	OTD
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<p>3. GENERAL SUMMARY</p> <p>Operations at Station ALOHA were conducted as planned. One 1000 m CTD cast and one 20 m radius cast were completed at Station Kilo. Two near bottom CTD casts, one 200 m CTD cast and</p>																																																																																						



## MBARI Chemical Sensor Lab

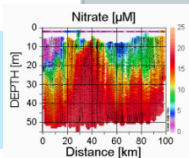
The Honomu was deployed and recovered successfully three times near noon.

Investigator	Project	Institution
Matt Church Dave Karl Bob Bidigare	Core Biogeochemistry	UH
John Dore	Biogeochemistry QA/QC	MSU
Roger Lukas	Hydrography	UH
Mike Landry	Zooplankton dynamics	SIO
Ricardo Letelier	Optical measurements	OSU
Ancillary programs: Andrew Dickson	CO <sub>2</sub> dynamics and intercalibration	SIO
Paul Quay	DI <sup>13</sup> C	UW
Matt Church & Ricardo Letelier	Diversity and activities of nitrogen-fixing microorganisms	UH
Sam Wilson	Reduced gases in the upper ocean: The cycling of methane, sulfide and nitrous oxide	UH
Donn Viviani	Bacterial production and EOC at Station ALOHA	UH
Sara Thomas	Chemolithoautotroph experiment	UH
Adina Paytan	O <sup>18</sup> natural abundance	UCSC
Christopher Schvartz	Viral Dynamics at Station ALOHA and surface water collection for virus and phytoplankton culturing	UH
Erica Goetze	Temporal stability of copepod populations at Station ALOHA	UH
Irina Shilova, Brandon Carter, Matt Mills, and Zbigniew Kolber	Phytoplankton responses to different nitrogen sources in the North Pacific Subtropical Gyre	UCSC Stanford
Scott Turn	Storage Stability of Next Generation Biofuels	HNEI/UH
Stu Goldberg	Nutrient and DOC cycling experiment	UH

# What's HOT?

## Program objectives:

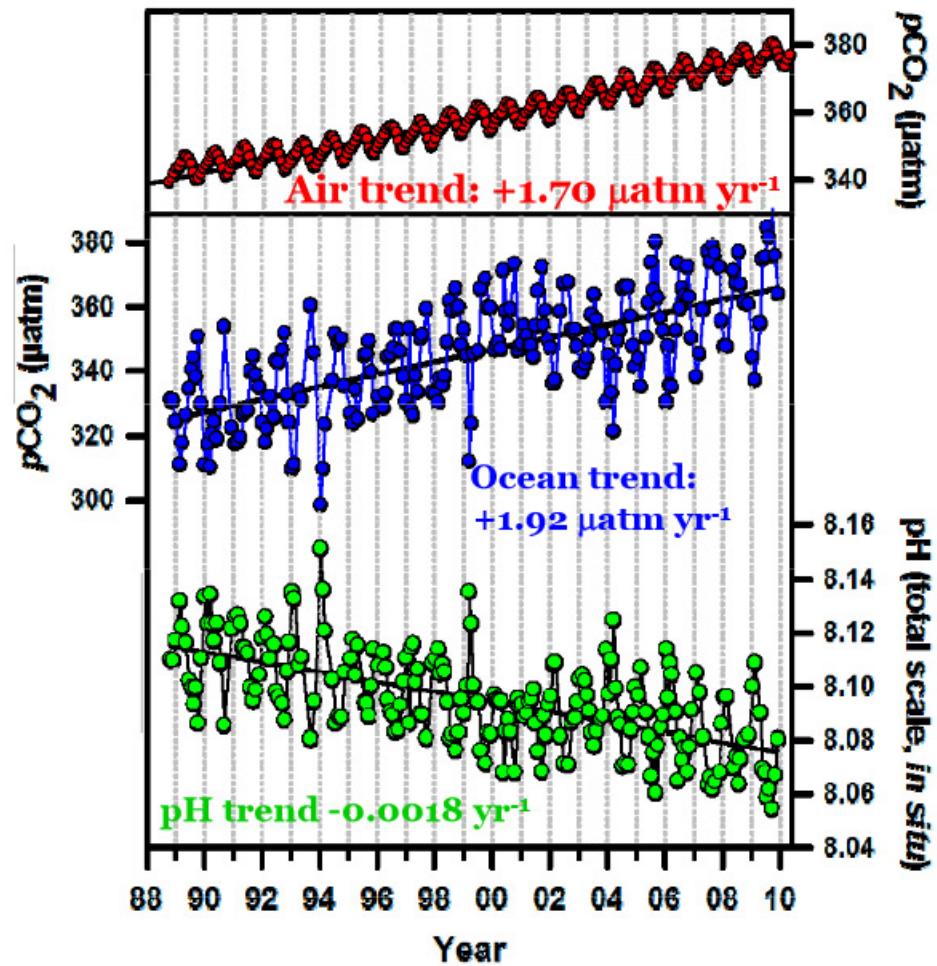
- Quantify time-dependent variability in key physical, biogeochemical, and ecological properties and processes
- Define relationships between plankton community structure and biogeochemical dynamics
- Quantify physical and biological processes controlling oceanic carbon uptake, transformation, and sequestration



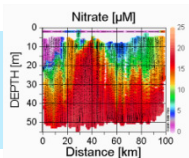
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# HOT –Dore et al., PNAS 2009

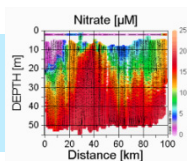
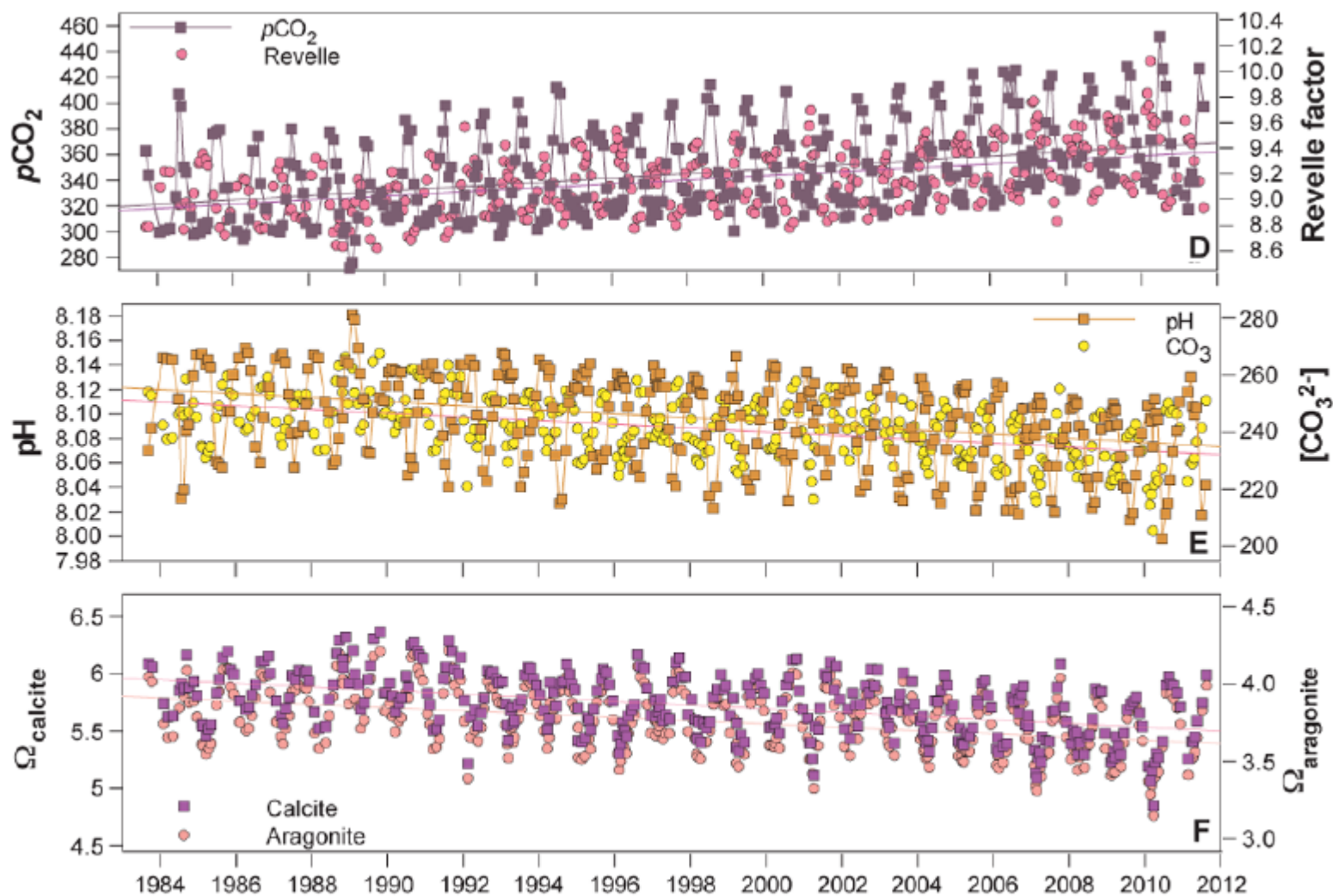
**Rising  
CO<sub>2</sub>,  
Falling pH**



Dore et al. (2009)

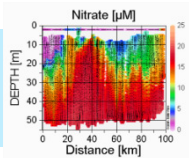
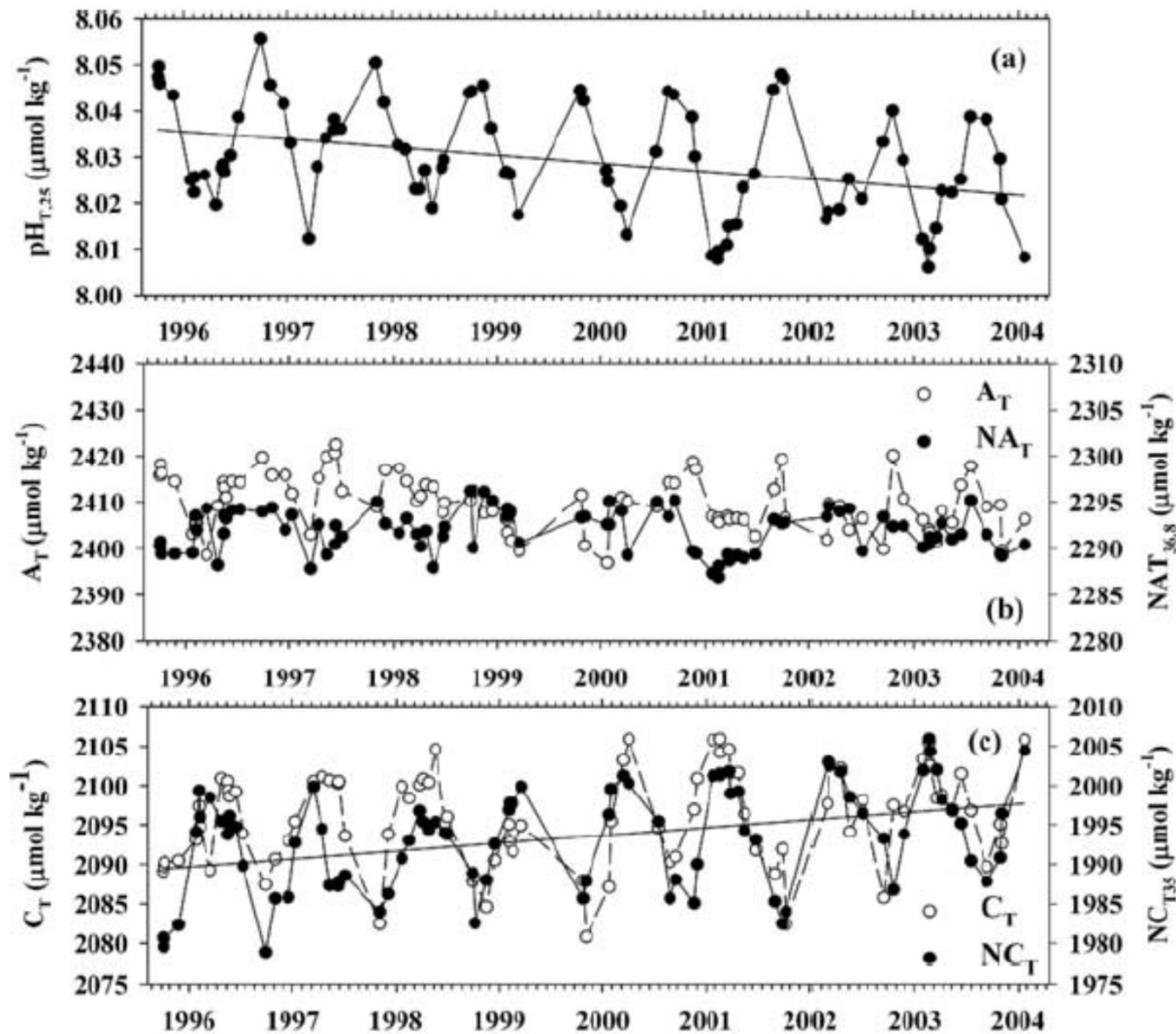


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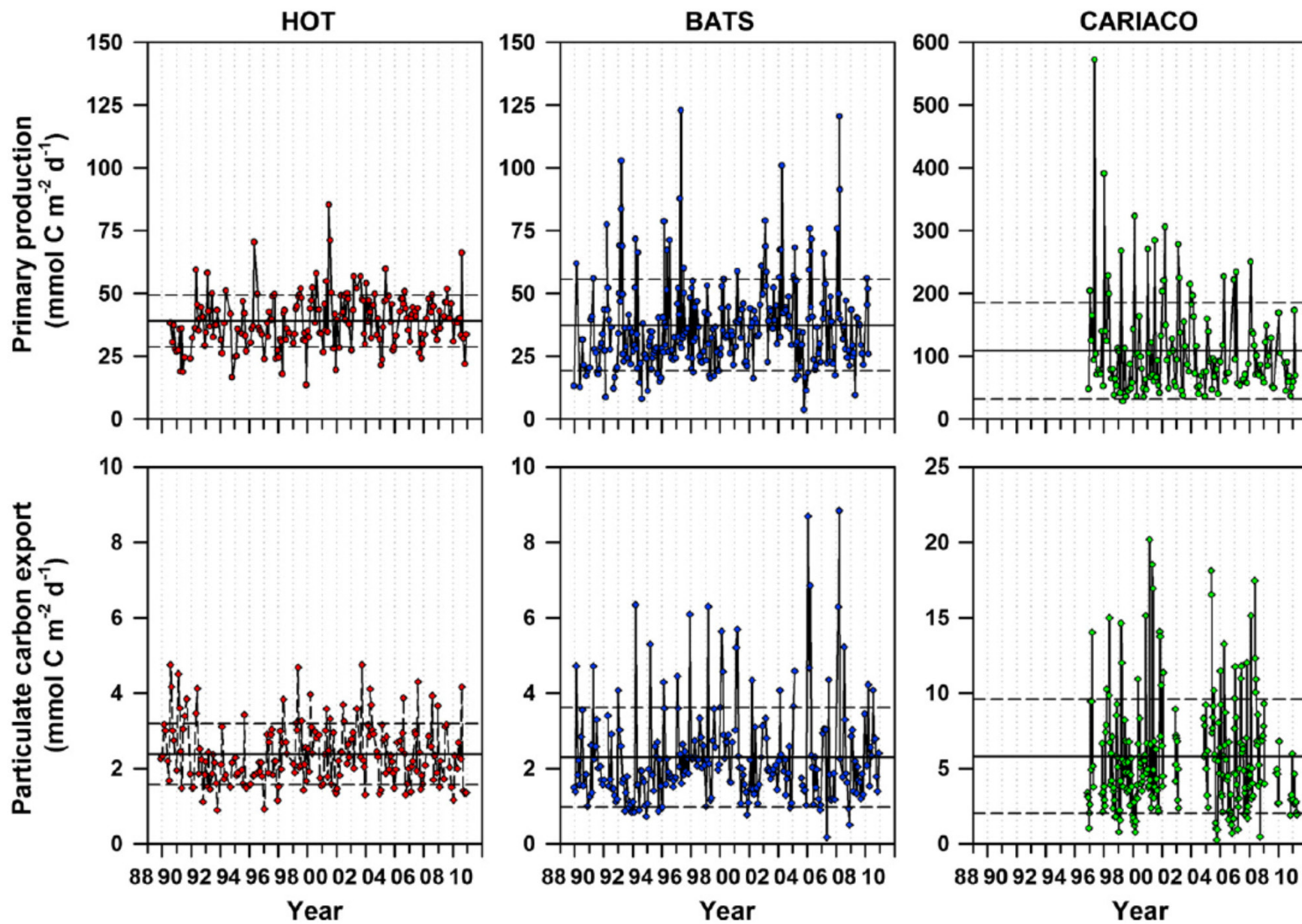




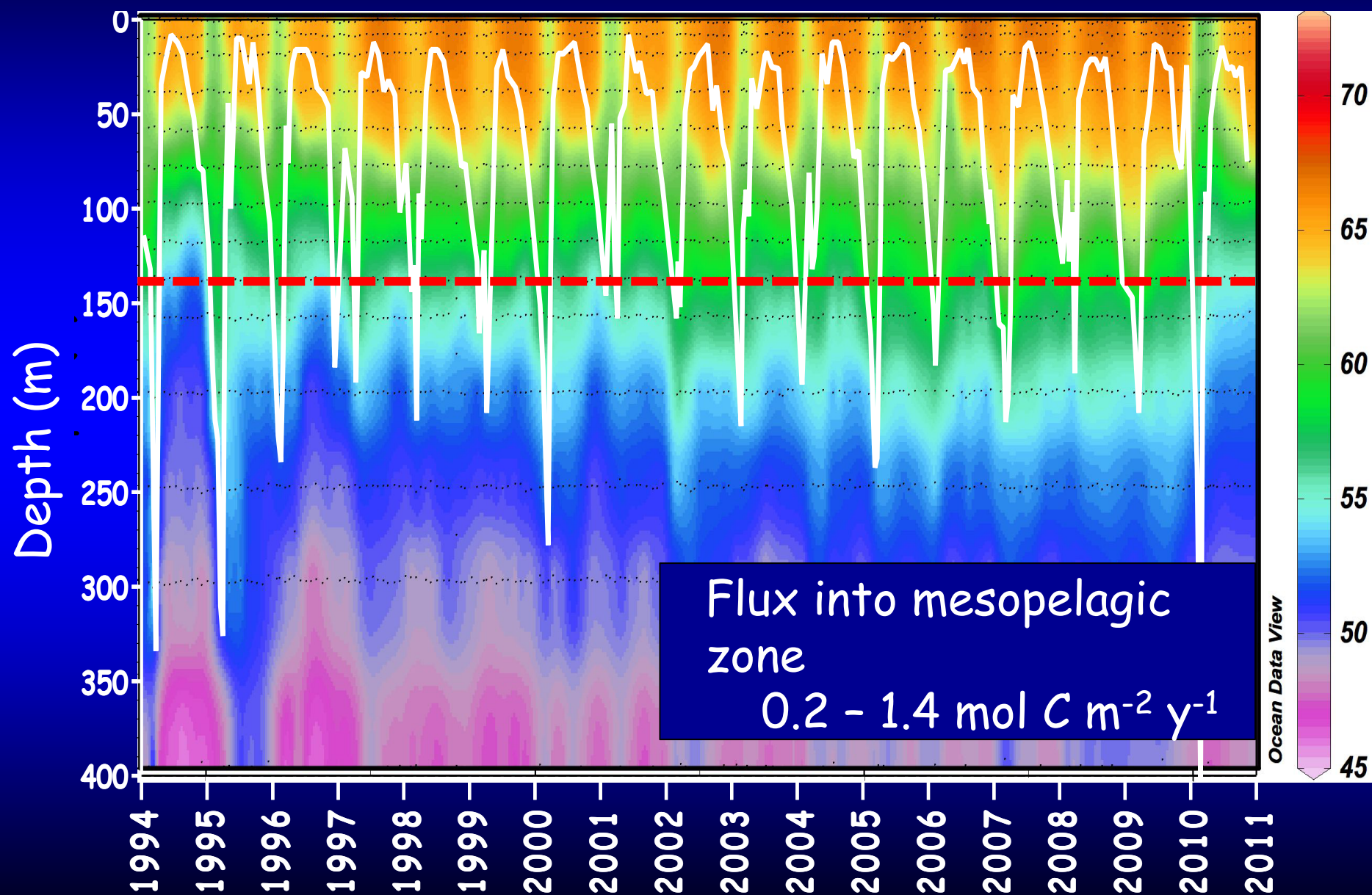
# SANTANA-CASIANO ET AL.: CO<sub>2</sub> VARIABILITY AT THE ESTOC SITE



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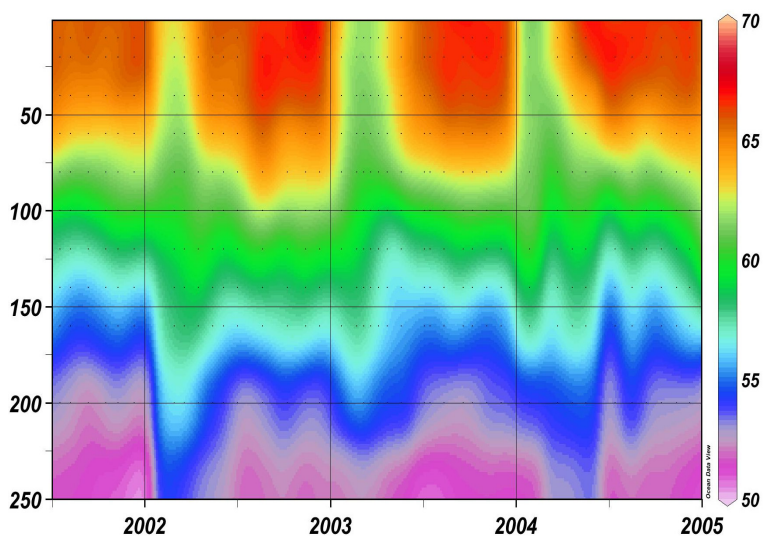
# DOC ( $\mu\text{mol kg}^{-1}$ ) dynamics at BATS (Carlson & Hansell)



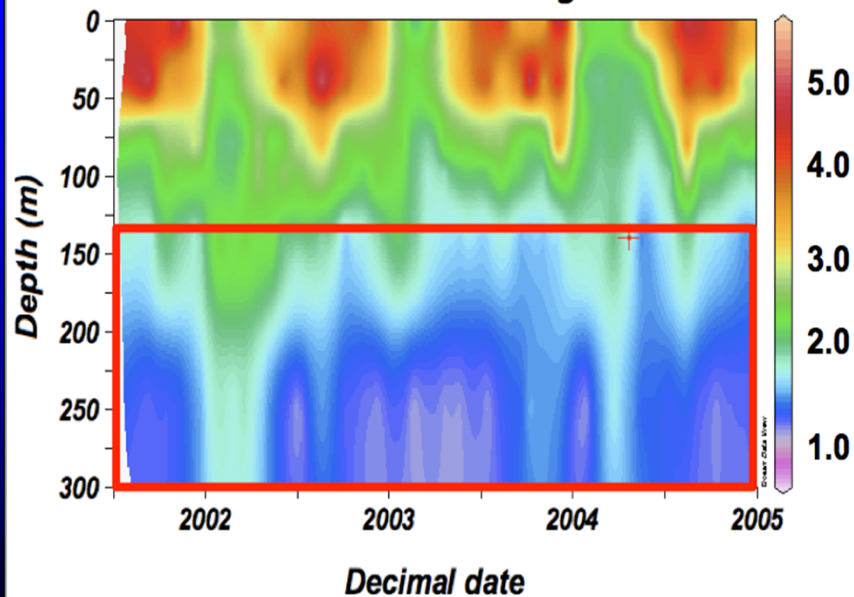


# DOC Dynamics at BATS

DOC ( $\mu\text{M}$ )

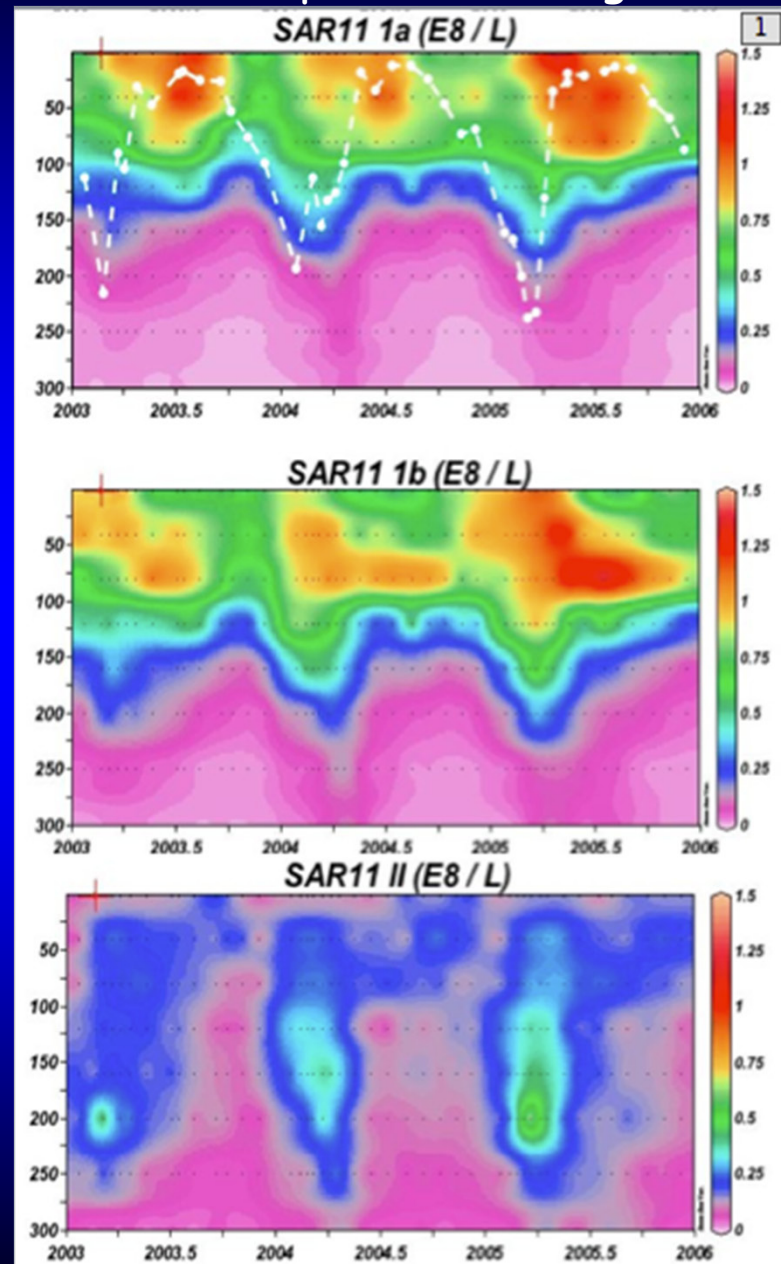


Dissolved Combined Neutral Sugars % of DOC



Goldberg et al. 2009

# Response of specific bacterioplankton lineages



Carlson et al. 2009

## BATS/ Original Motivation and Objectives/

The Bermuda Atlantic Time-series Study (BATS) was initiated under the JGOFS umbrella with the overall motivation...

*“ To determine and understand the **time-varying fluxes** of carbon and associated biogenic elements in the ocean and to evaluate the related **exchanges with the atmosphere, sea floor and continental boundaries** .” (SCOR, 1987)*

Original Objectives:

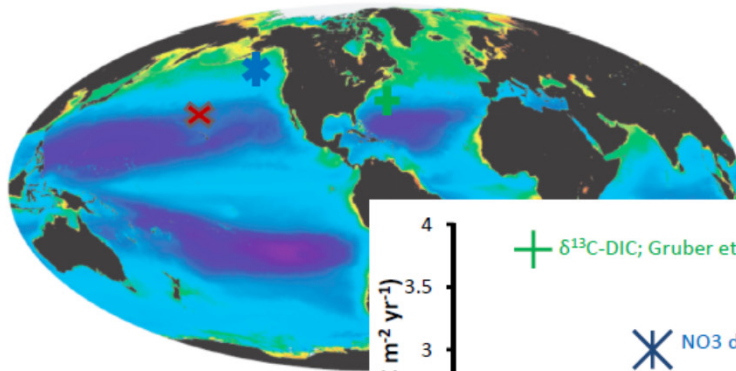
- To understand the seasonal and interannual variations in ocean physics, chemistry and biology
- To understand the processes that control surface  $p\text{CO}_2$
- To understand the physical controls on biological rate processes
- To provide a test-bed for the validation of new methods and technologies



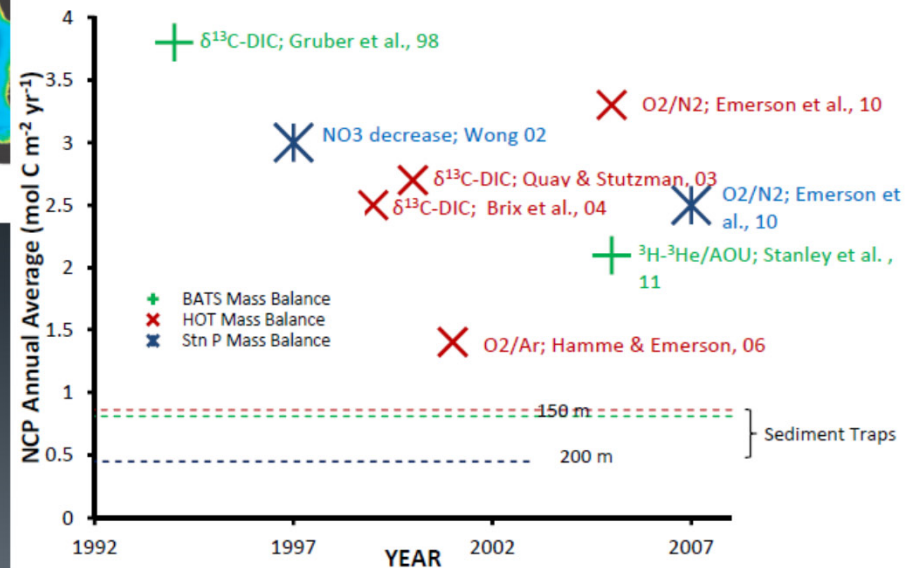
# Steve Emerson, 2012 OCB Summer Workshop

## HOW WELL DO WE KNOW THE ANNUALLY-AVERAGED NET COMMUNITY PRODUCTION?

Measurements at Time-Series Locations



Can You Explain the  
The Mass Balance-  
Sediment Trap  
Difference by DOC  
Export and Trap  
Depth?



Net Community Production (NCP) = Primary Prod. – Respiration at all trophic levels (Net production of C = C export on an annual basis)

NCP estimates near HOT to base of euphotic zone

Method	NCP (mol C m <sup>-2</sup> y <sup>-1</sup> )	Ref.
POC Flux	1.1±0.3	Karl et al. 1995
DI <sup>13</sup> C mass balance	1.6±0.9	Emerson et al. 1997
Sum of C fluxes	2.0±0.9	Emerson et al. 1997
O <sub>2</sub> utilization rates	2.2±0.5	Sonnerup et al. 1999
O <sub>2</sub> , Ar, N <sub>2</sub> mass balance	2.7±1.7	Emerson et al. 1997
<sup>234</sup> Th C flux	2.7±0.9	Benitez-Nelson et al. 1995
DIC, DI <sup>13</sup> C & model	2.7±1.3	Quay & Stutsman 2003
DIC & model	2.8±0.8	Keeling et al., 2004
Moored O <sub>2</sub> sensor	4.0±2.0	Emerson et al., 2008
O <sub>2</sub> /Ar	5.0±1.0	Quay et al., 2010
<b>MEAN</b>	<b>2.7±0.6 (90% CI)</b>	
<b>19 Years of Prof. Float O<sub>2</sub></b>	<b>3.4±0.4 (90% CI)</b>	



Matt Church, OCB Time Series Workshop

## Net Community Production at Station ALOHA

Method	Rate mol C m <sup>-2</sup> yr <sup>-1</sup>	Period of measurements	References
Mixed Layer O <sub>2</sub> + 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 <sup>13</sup> C budgets	2.7 - 2.8 (± 1.4)	1988–2002	Quay and Stutsman (2003); Keeling et al. (2004)
Mooring O <sub>2</sub>	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
<i>In vitro</i> O <sub>2</sub> 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 Is the Metabolic State of the Oligotrophic Ocean? A Debate

Hugh W. Ducklow<sup>1</sup> and Scott C. Doney<sup>2</sup>

<sup>1</sup>The Ecosystems Center, A  
email: hducklow@mbl.edu

<sup>2</sup>Department of Marine Ch  
Woods Hole, Massachusett

## The Oligotrophic Ocean Is Autotrophic\*

Peter J. le B. Williams,<sup>1</sup> Paul D. Quay,<sup>2</sup>  
Toby K. Westberry,<sup>3</sup> and Michael J. Behrenfeld<sup>3</sup>

<sup>1</sup>School of Ocean Sciences, Bangor University, Menai  
United Kingdom; email: pjlw@bangor.ac.uk

<sup>2</sup>School of Oceanography, University of Washington,

<sup>3</sup>Department of Botany and Plant Pathology, Oregon  
Oregon 97331-2902

## The Oligotrophic Ocean Is Heterotrophic\*

Carlos M. Duarte,<sup>1,2</sup> Aurore Regaudie-de-Gioux,<sup>1,4</sup>  
Jesús M. Arrieta,<sup>1</sup> Antonio Delgado-Huertas,<sup>5</sup>  
and Susana Agustí<sup>1,2,3</sup>

<sup>1</sup>Department of Global Change Research, Mediterranean Institute of Advanced Studies,  
CSIC-UIB, 07190 Esporles, Spain; email: carlosduarte@imedea.uib-csic.es

<sup>2</sup>Oceans Institute and <sup>3</sup>School of Plant Biology, University of Western Australia,  
Crawley 6009, Australia

<sup>4</sup>Spanish Oceanographic Institute, 33213 Gijón, Spain

<sup>5</sup>Instituto Andaluz de Ciencias de la Tierra, CSIC-UGR, 18100 Armilla, Spain

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## IMPLICATIONS AND UNRESOLVED ISSUES

There are two key implications of our conclusions.

- A bias toward net heterotrophy in the *in vitro* O<sub>2</sub>-based measurements calls into question whether the same issues exist for other *in vitro* measurements (i.e., <sup>14</sup>C and <sup>15</sup>N measurements)
- Net autotrophy....raises issues regarding sources of nutrients supporting positive NCP.

The Oligotrophic Ocean  
Is Autotrophic\*

Peter J. le B. Williams,<sup>1</sup> Paul D. Quay,<sup>2</sup>  
Toby K. Westberry,<sup>3</sup> and Michael J. Behrenfeld<sup>3</sup>

## Temperature effects on export production in the open ocean

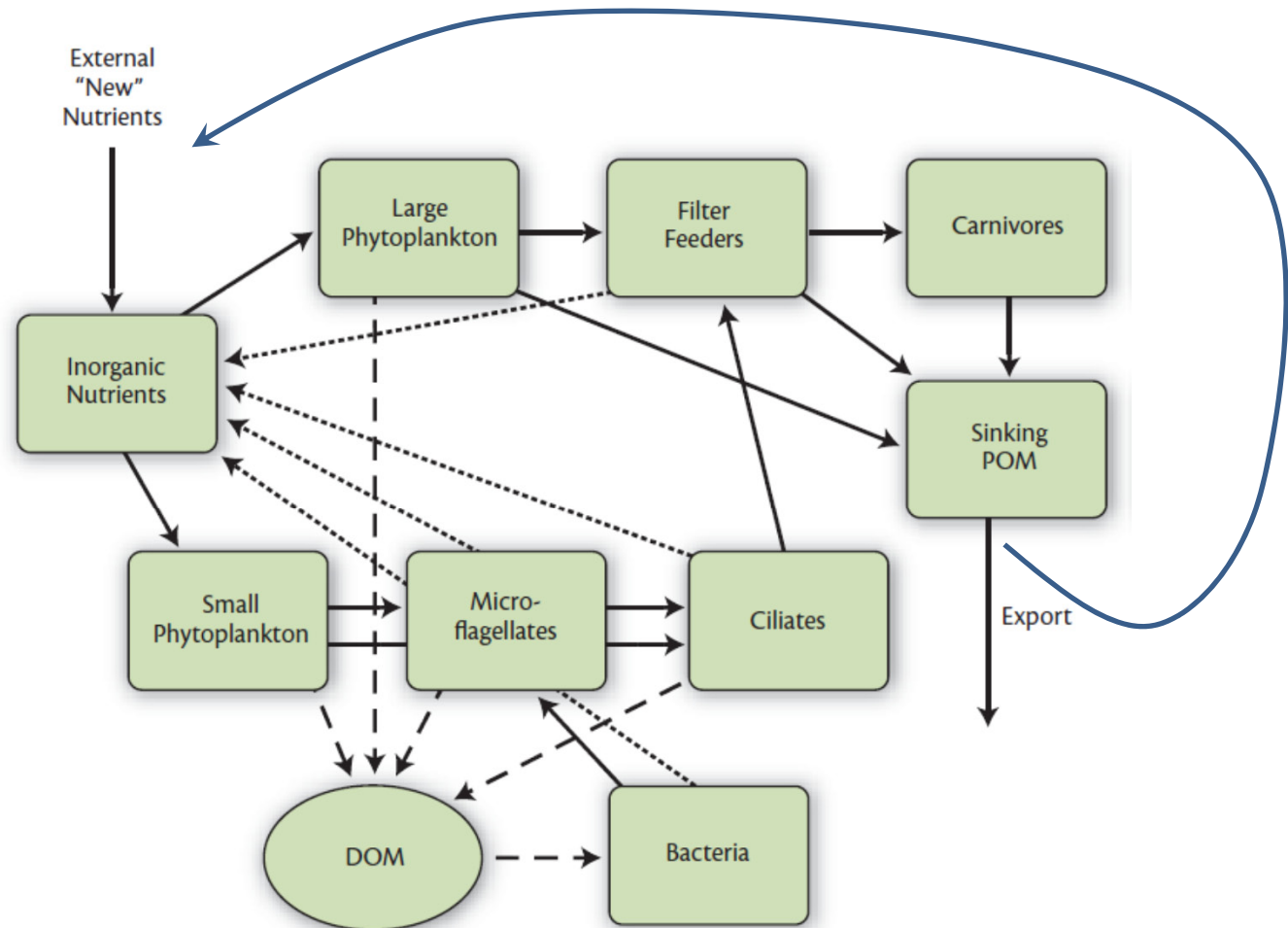
Edward A. Laws,<sup>1</sup> Paul G. Falkowski,<sup>2</sup> Walker O. Smith Jr.,<sup>3</sup> Hugh Ducklow,<sup>3</sup>  
and James J. McCarthy<sup>4</sup>

New nutrient  
input =

Net  
Community  
Production =

Export =

New nutrient  
input





## Carbon-cycle imbalances in the Sargasso Sea

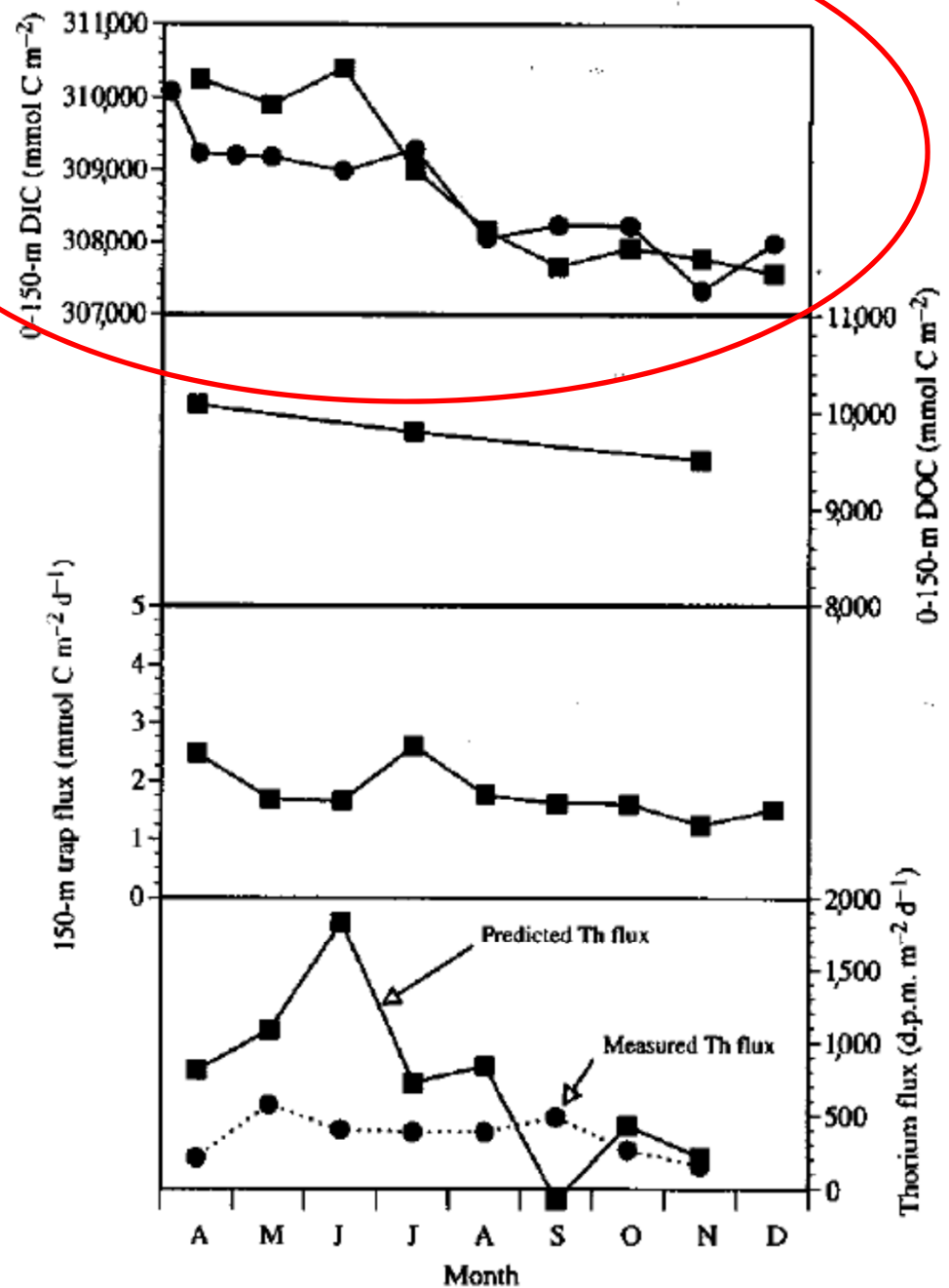
**Anthony F. Michaels\***, **Nicholas R. Bates\***,  
**Ken O. Buesseler†**, **Craig A. Carlson‡**  
& **Anthony H. Knap\***

\* Bermuda Biological Station for Research, Ferry Reach GE01, Bermuda

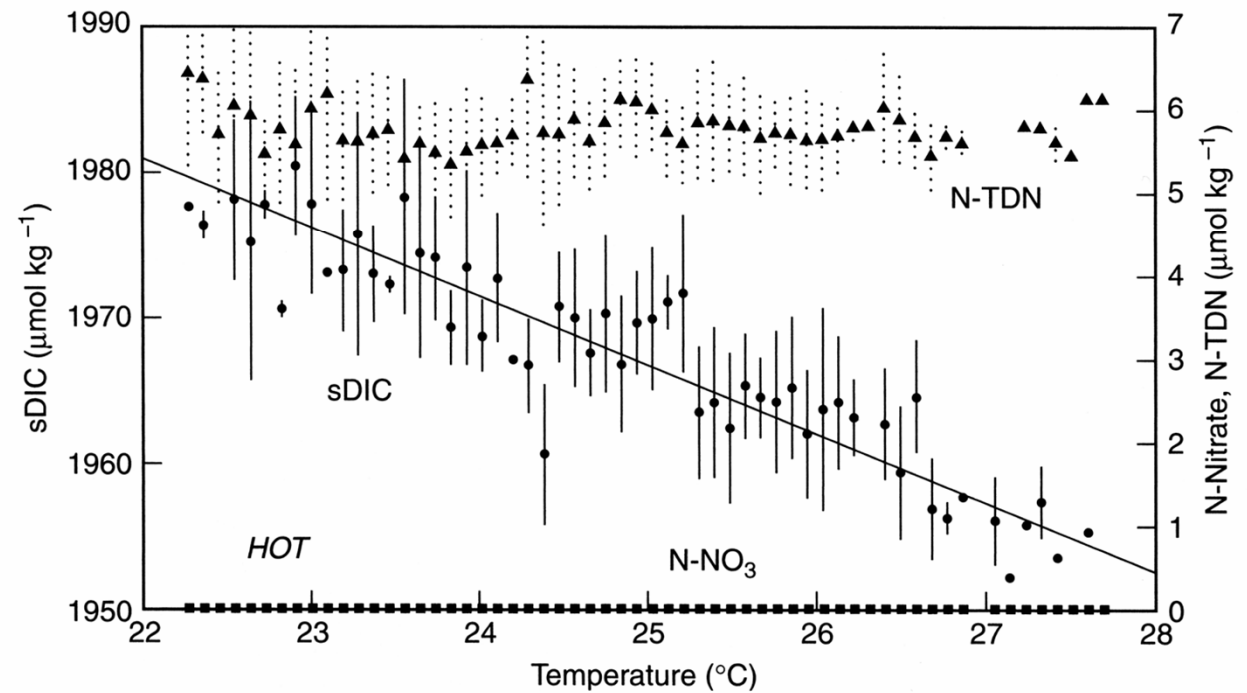
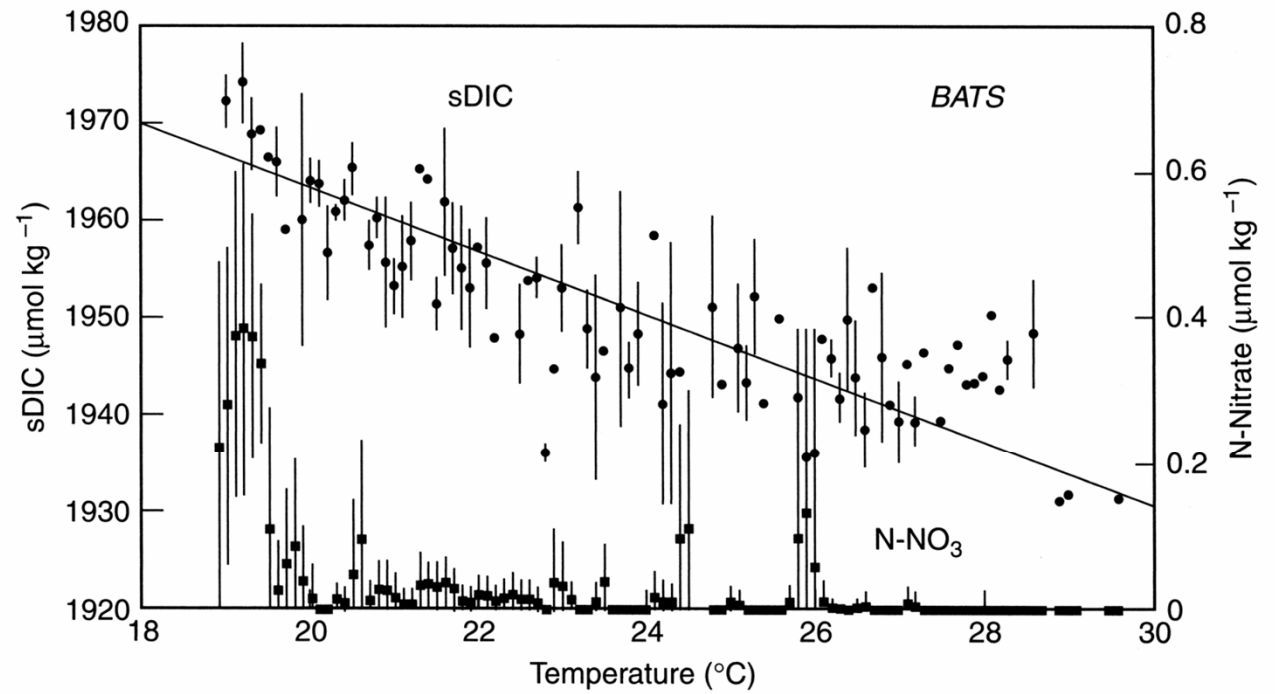
† Woods Hole Oceanographic Institution, Woods Hole, Massachusetts 02543, USA

‡ Horn Point Environmental Laboratory, University of Maryland, Cambridge, Maryland 21613, USA

DIC decreases each year, but there is no nitrate present!



from Karl et al.  
Chap. 10 in  
Fasham, "Ocean  
Biogeochemistry"



## 10.5.2 Case Study 2:

### A 'Bermuda Triangle' Carbon Mystery with Global Implications

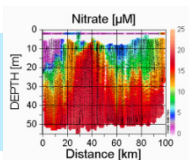
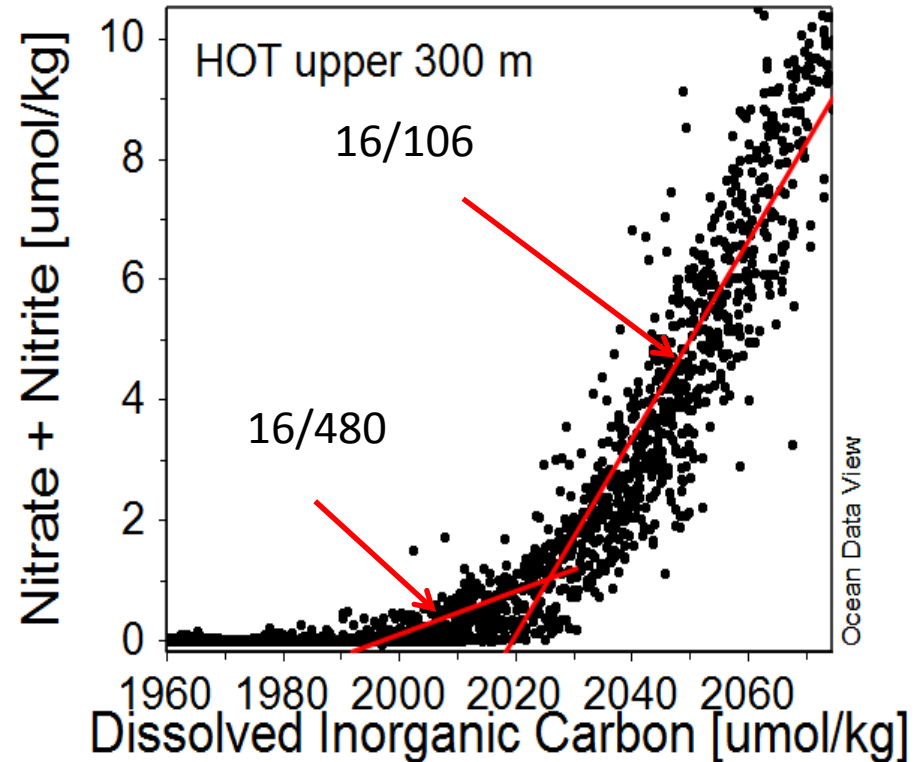
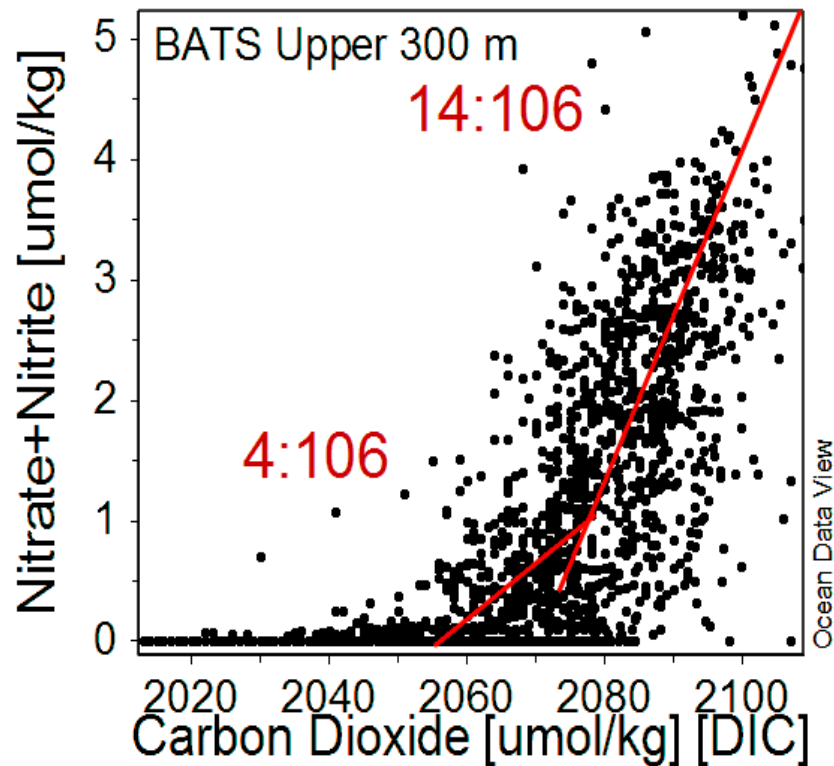
The continued disappearance of salinity normalized dissolved inorganic carbon (N-DIC) in the absence of nitrate was first reported by Michaels et al. (1994). They reasoned that if nitrate was added by episodic wind mixing or mesoscale eddy motions, the nitrate would be delivered along with DIC, so simple enhancements of nitrate-supported new and export production could not be responsible for the repeatable summertime N-DIC

- from Karl et al. Chap. 10 in Fasham, "Ocean Biogeochemistry"

Siegel et al., JGR 104, 1999

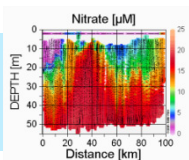
	Annual Flux mol N m <sup>-2</sup> y <sup>-1</sup>	Annual Flux mol C m <sup>-2</sup> y <sup>-1</sup>
NCP	0.50	3.3
Total N Flux	0.51	3.4
Eddy pumping	0.18	1.2
Winter Convection	0.17	1.1
Isopycnal Diffusion	0.03	0.2
Large-scale Ekman pumping	0.03	0.2
Atmospheric Dep.	0.03	0.2
Diapycnal Diffusion	0.015	0.1

Carbon is at or above Redfield, relative to nitrate, at the base of the euphotic zone. Upward transport of sufficient nitrate also brings carbon and there is no annual drawdown



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Why do we care about getting C and nutrient fluxes right???



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- Numerous studies point to climate and changing ocean phytoplankton/productivity links.
- Trend detection based primarily on remote sensing and results can be opposite to in situ time series observations
- Need bio-chemical sensors to directly sense change in carbon cycle.

## Ocean primary production and climate: Global decadal changes

Watson W. Gregg

Laboratory for Hydrospheric Processes, NASA/Goddard Space Flight Center, USA

[1] Satellite-in situ blended ocean chlorophyll records indicate that global ocean annual primary production has declined more than 6% since the early 1980's. Nearly 70% of the global decadal decline occurred in the high latitudes. In

nature

Vol 444 | 7 December 2006 | doi:10.1038/nature05317

## LETTERS

### Climate-driven trends in contemporary ocean productivity

Michael J. Behrenfeld<sup>1</sup>, Robert T. O'Malley<sup>1</sup>, David A. Siegel<sup>3</sup>, Charles R. McClain<sup>4</sup>, Jorge L. Sarmiento<sup>5</sup>, Gene C. Feldman<sup>4</sup>, Allen J. Milligan<sup>1</sup>, Paul G. Falkowski<sup>6</sup>, Ricardo M. Letelier<sup>2</sup> & Emmanuel S. Boss<sup>7</sup>

Vol 466 | 29 July 2010 | doi:10.1038/nature09268

nature

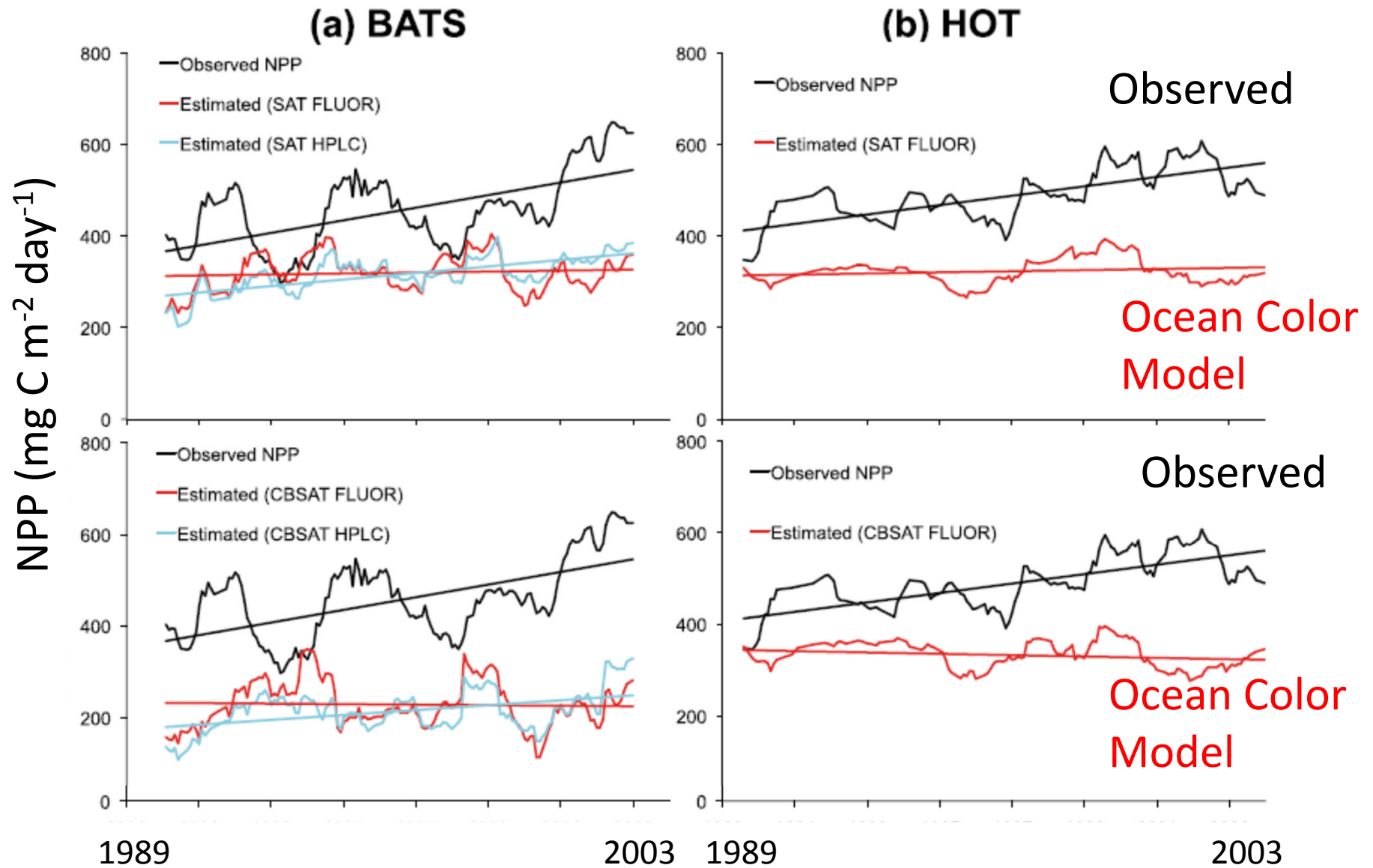
## ARTICLES

### Global phytoplankton decline over the past century

Daniel G. Boyce<sup>1</sup>, Marlon R. Lewis<sup>2</sup> & Boris Worm<sup>1</sup>

In the oceans, ubiquitous microscopic phototrophs (phytoplankton) account for approximately half the production of organic matter on Earth. Analyses of satellite-derived phytoplankton concentration (available since 1979) have suggested decadal-scale fluctuations linked to climate forcing, but the length of this record is insufficient to resolve longer-term trends. Here we combine available ocean transparency measurements and in situ chlorophyll observations to estimate the time

# SABA ET AL.: MODELING MARINE PRIMARY PRODUCTIVITY

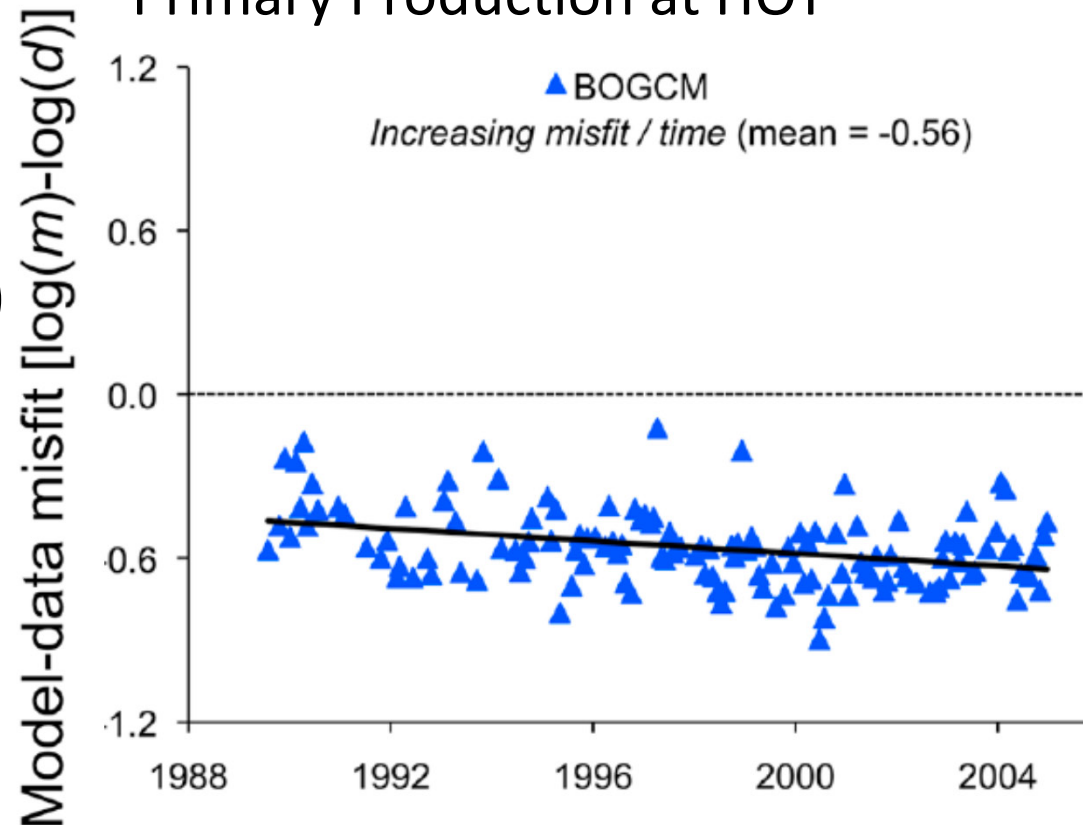




## Mean 3D Biogeochemical model error for estimates of Net Primary Production at HOT

$$= \log (\text{Model NPP} / \text{Obsd. NPP})$$

$$10^{-0.56} = 0.27$$



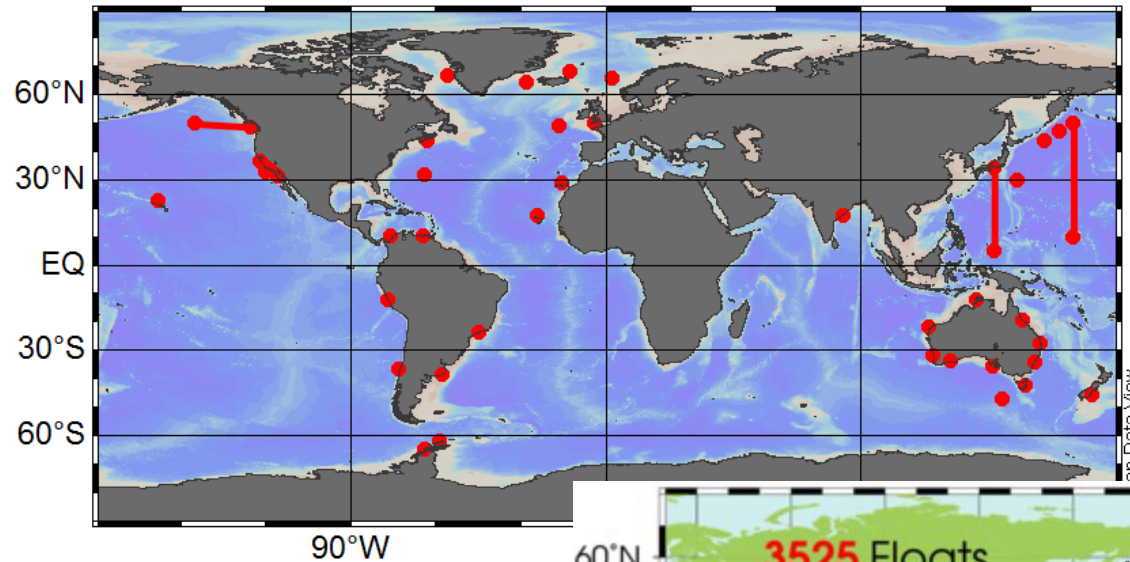
GLOBAL BIOGEOCHEMICAL CYCLES, VOL. 24, GB3020, doi:10.1029/2009GB003655, 2010

### Challenges of modeling depth-integrated marine primary productivity over multiple decades: A case study at BATS and HOT

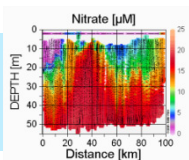
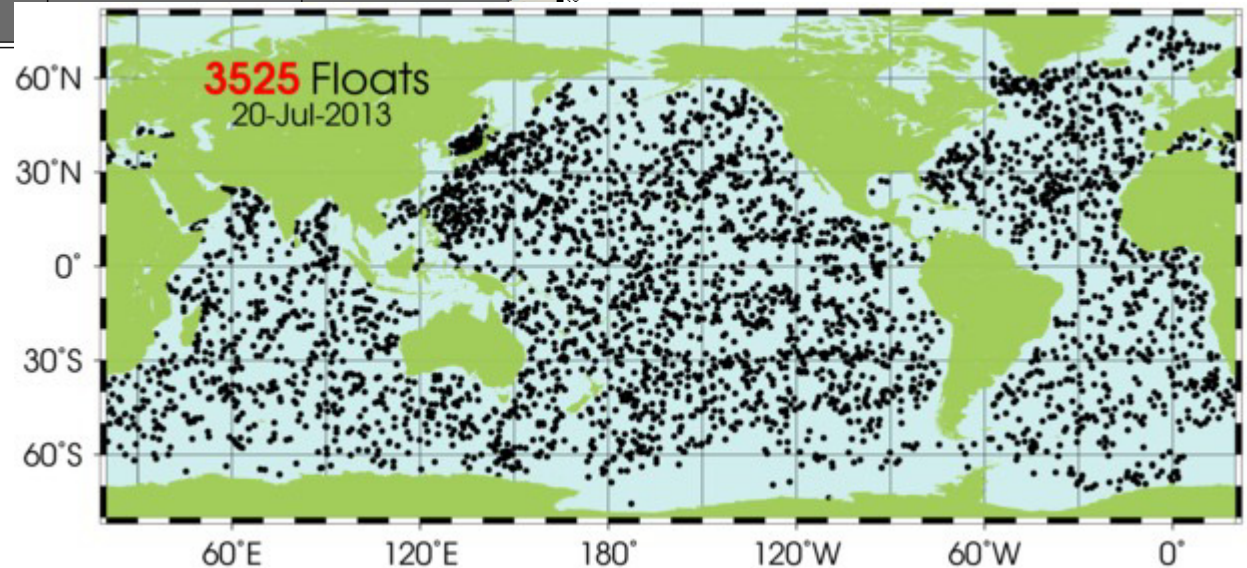
Vincent S. Saba,<sup>1,2</sup> Marjorie A. M. Friedrichs,<sup>1</sup> Mary-Elena Carr,<sup>3</sup> David Antoine,<sup>4</sup> & 39 others

# Time Series Represented at OCB

## Time Series Workshop Nov. 2012

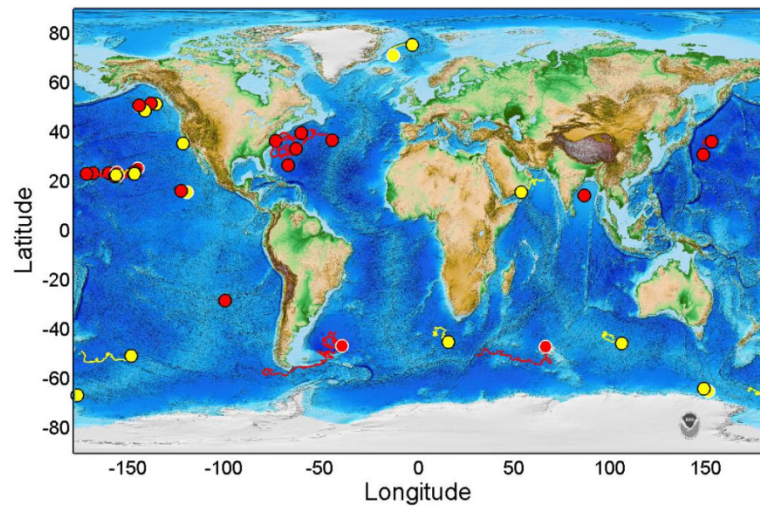


Observing  
system  
needed to get  
heat content

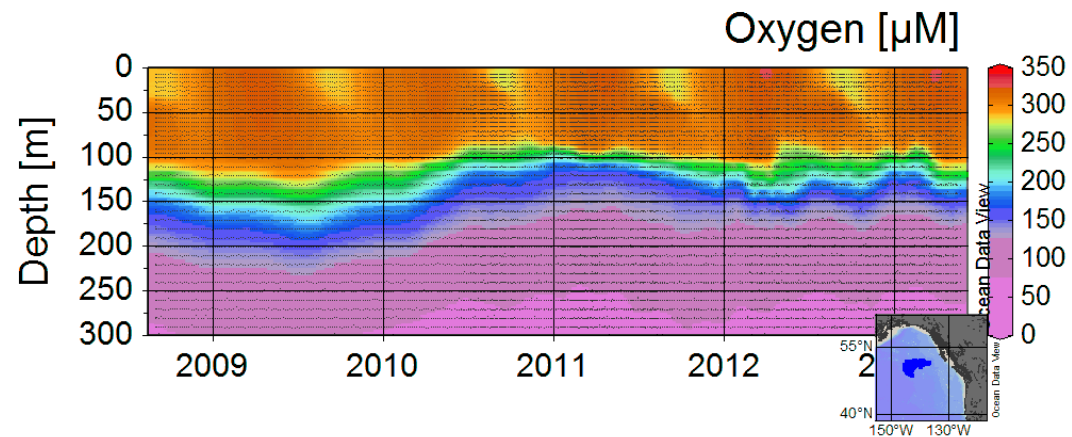
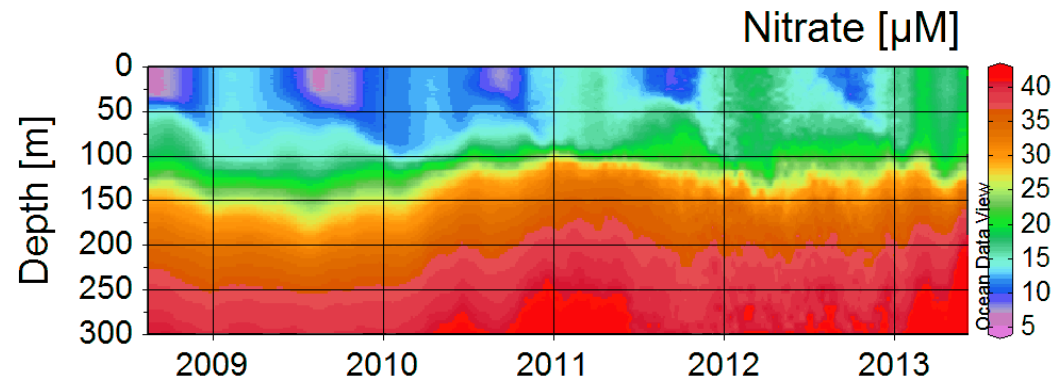


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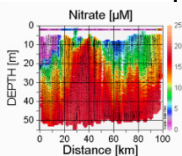
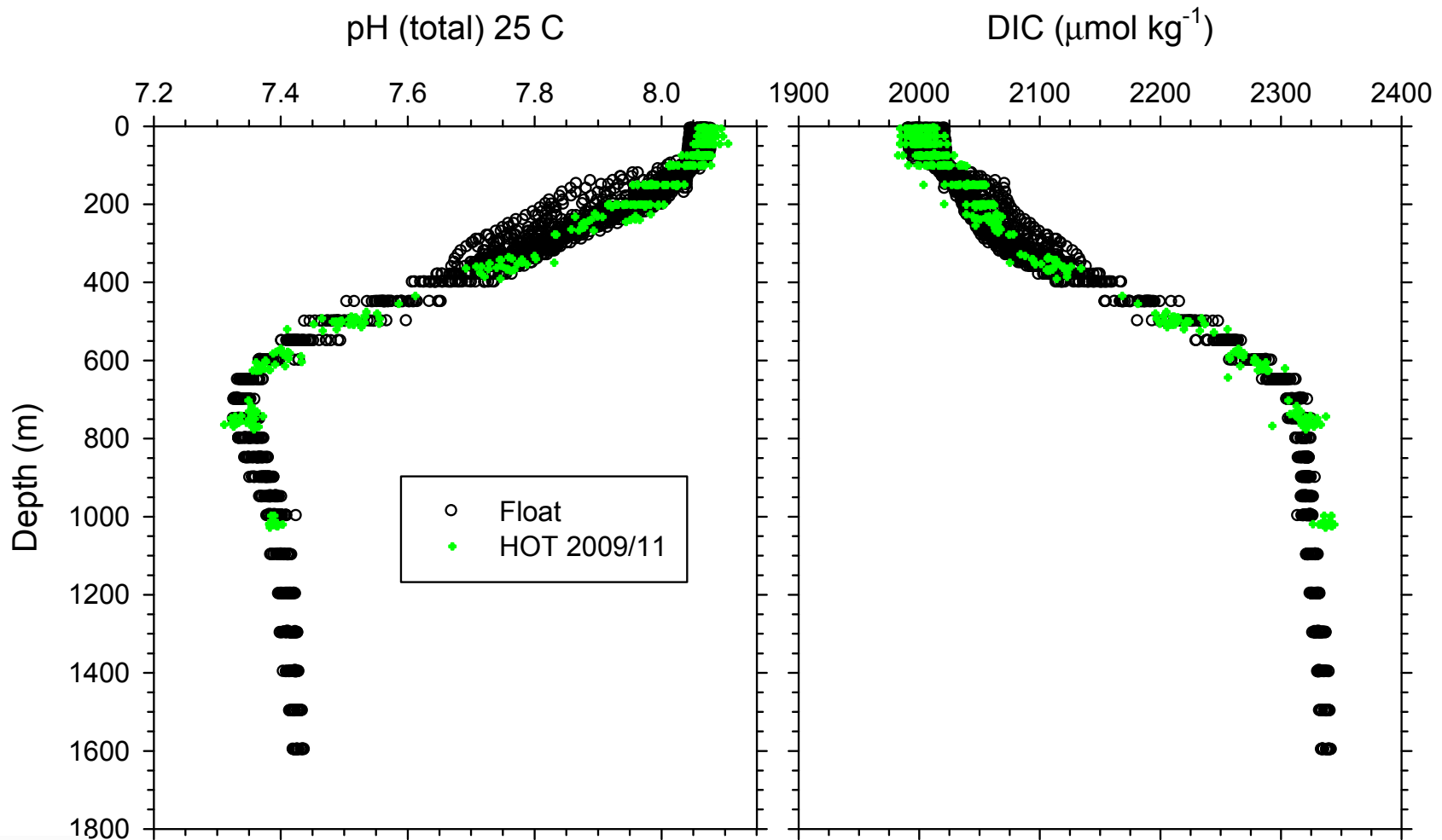
40 floats  
24-May-2013



Nitrate  
Oxygen  
pH  
Chl. Fluorescence  
Optical Backscatter  
60 obs. from 1000 m  
300 profiles (4.5 y at 5 d/cycle)



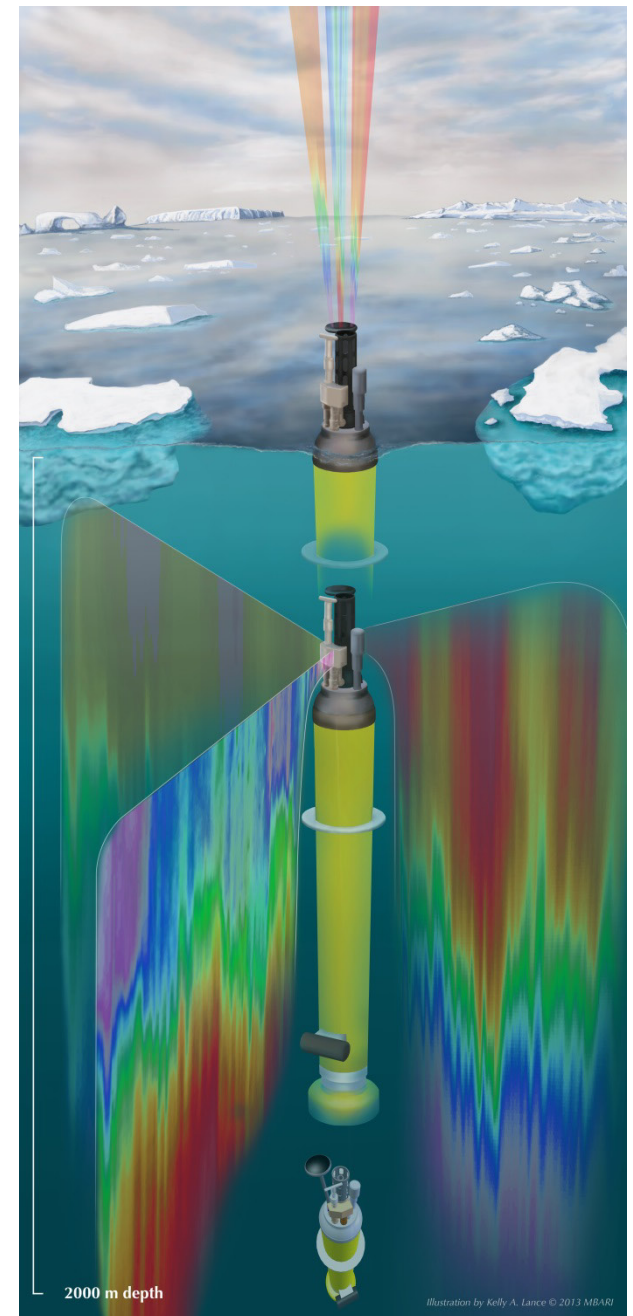
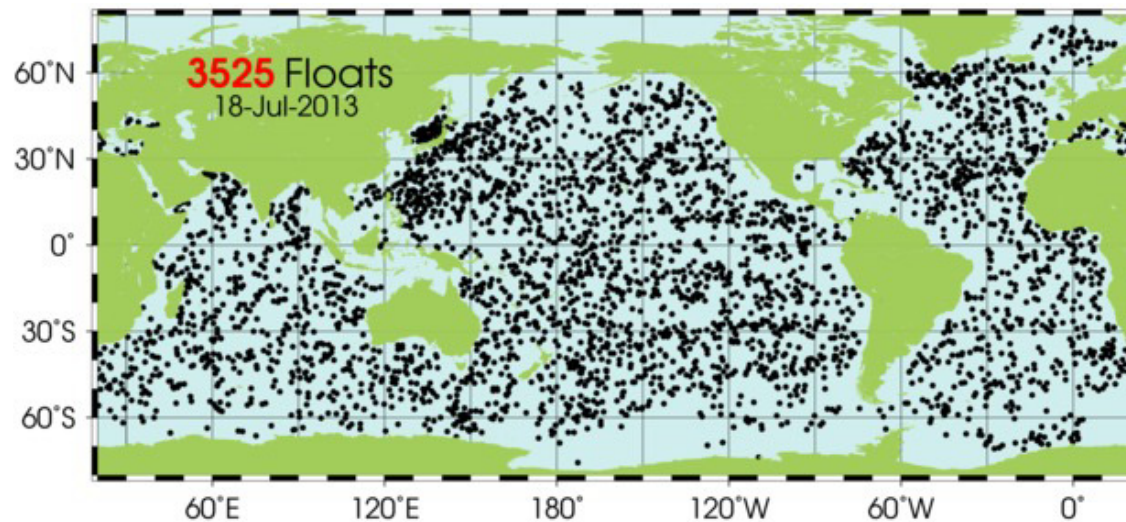
pH can be measured robustly using Ion Sensitive Field Effect Transistors (Martz et al., L&O Methods, 2010). If you have pH, Dissolved Inorganic Carbon can be estimated to about  $8 \mu\text{mol/kg}$



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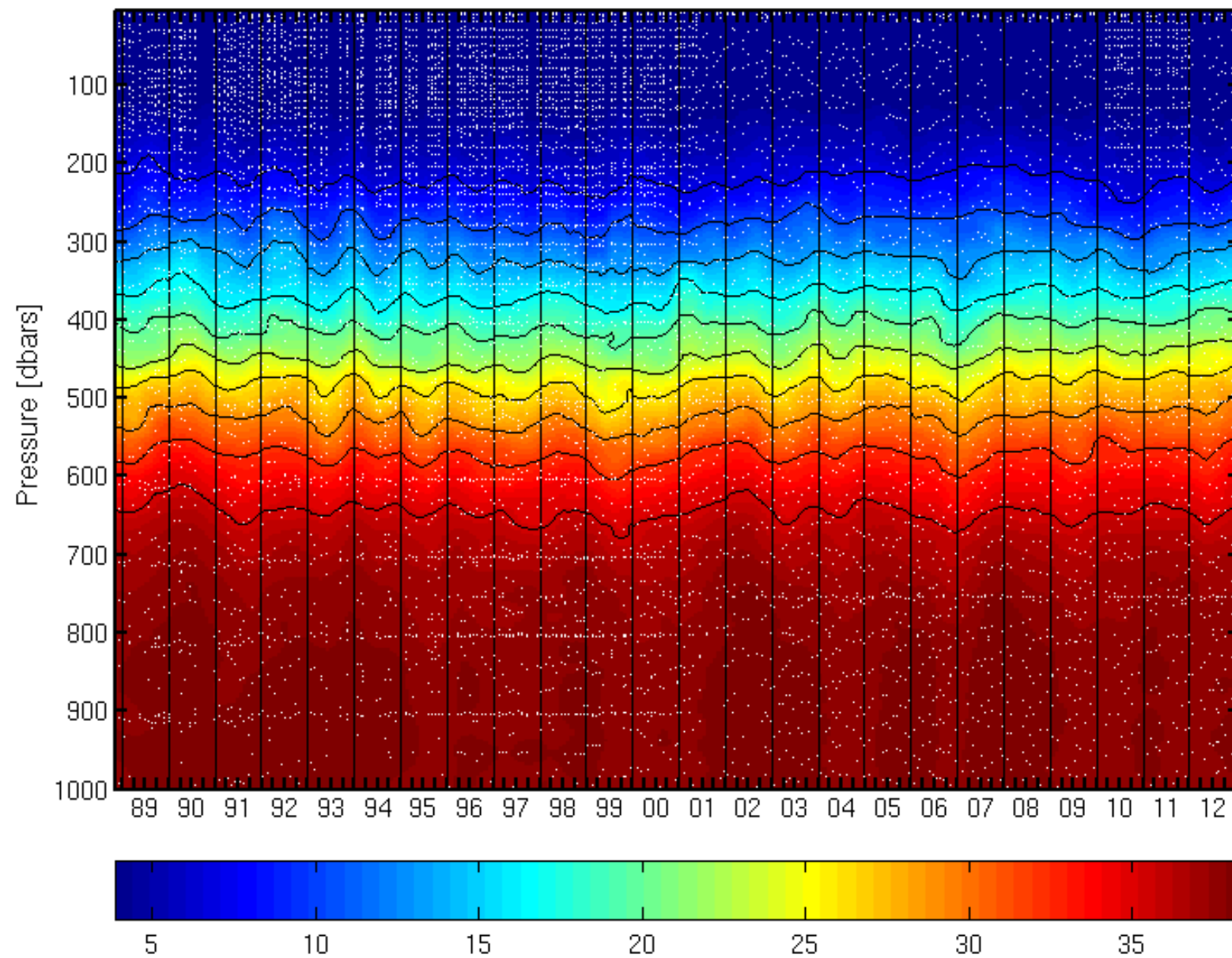


1. We need global scale, quantitative, autonomous observing systems for carbon.
2. We need to know time varying carbon flux at Time Series sites to ensure calibration of a global system carbon observing system.





HOT 1-248 Nitrate + Nitrite [ $\mu\text{mol kg}^{-1}$ ]



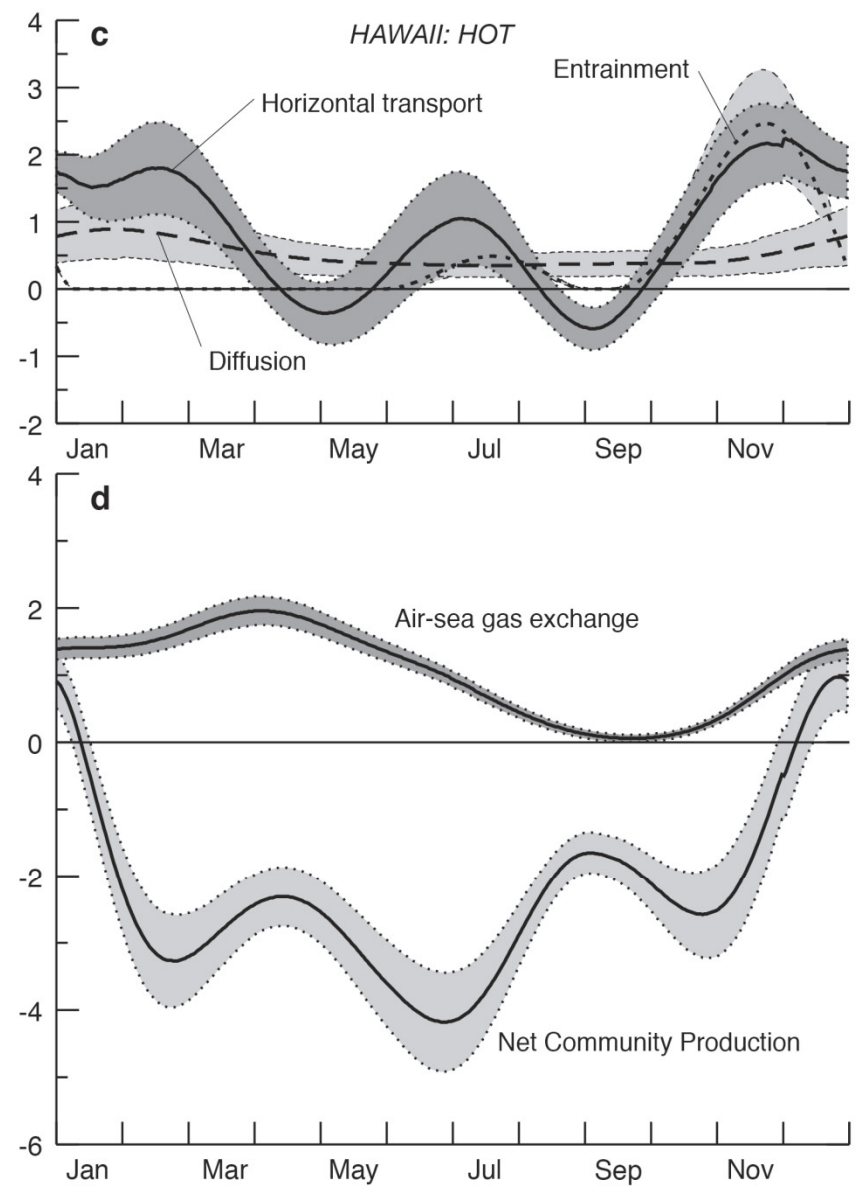
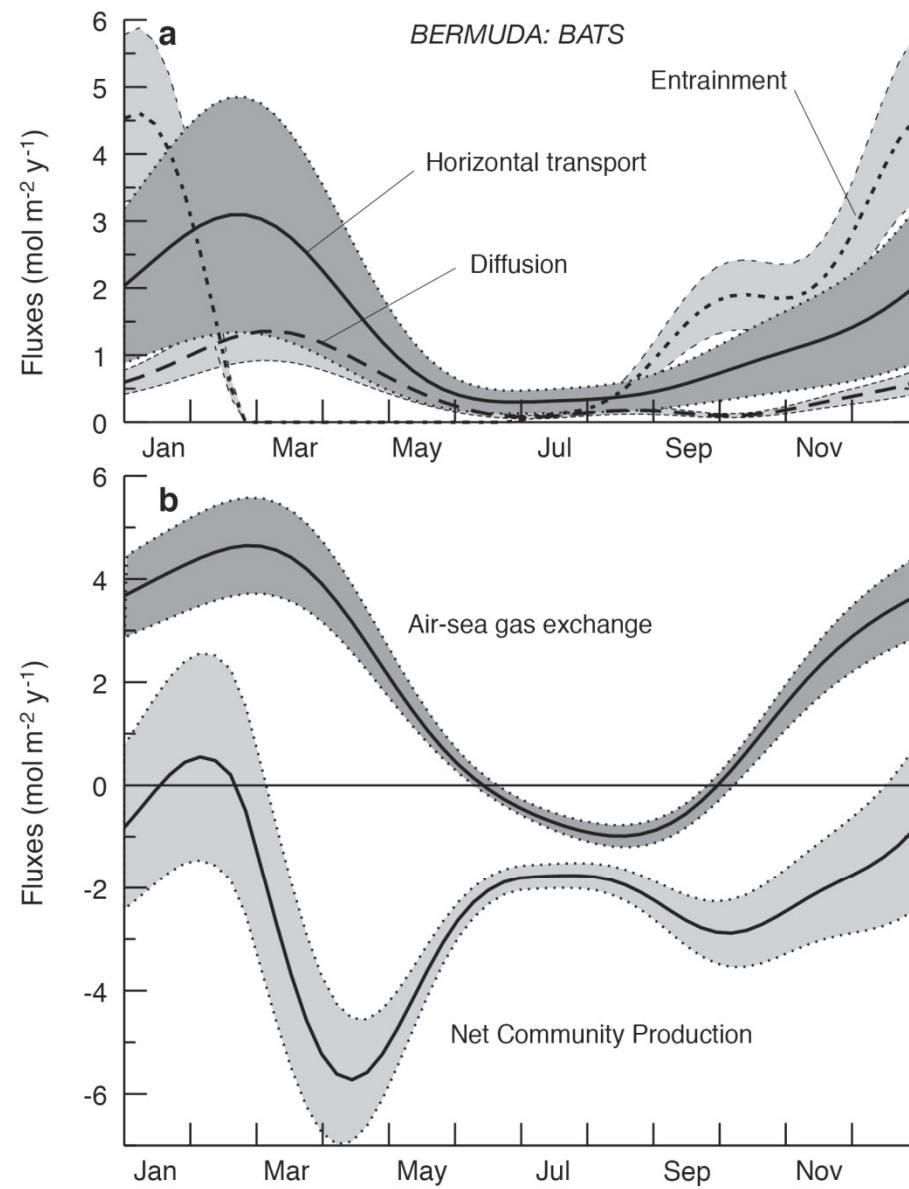
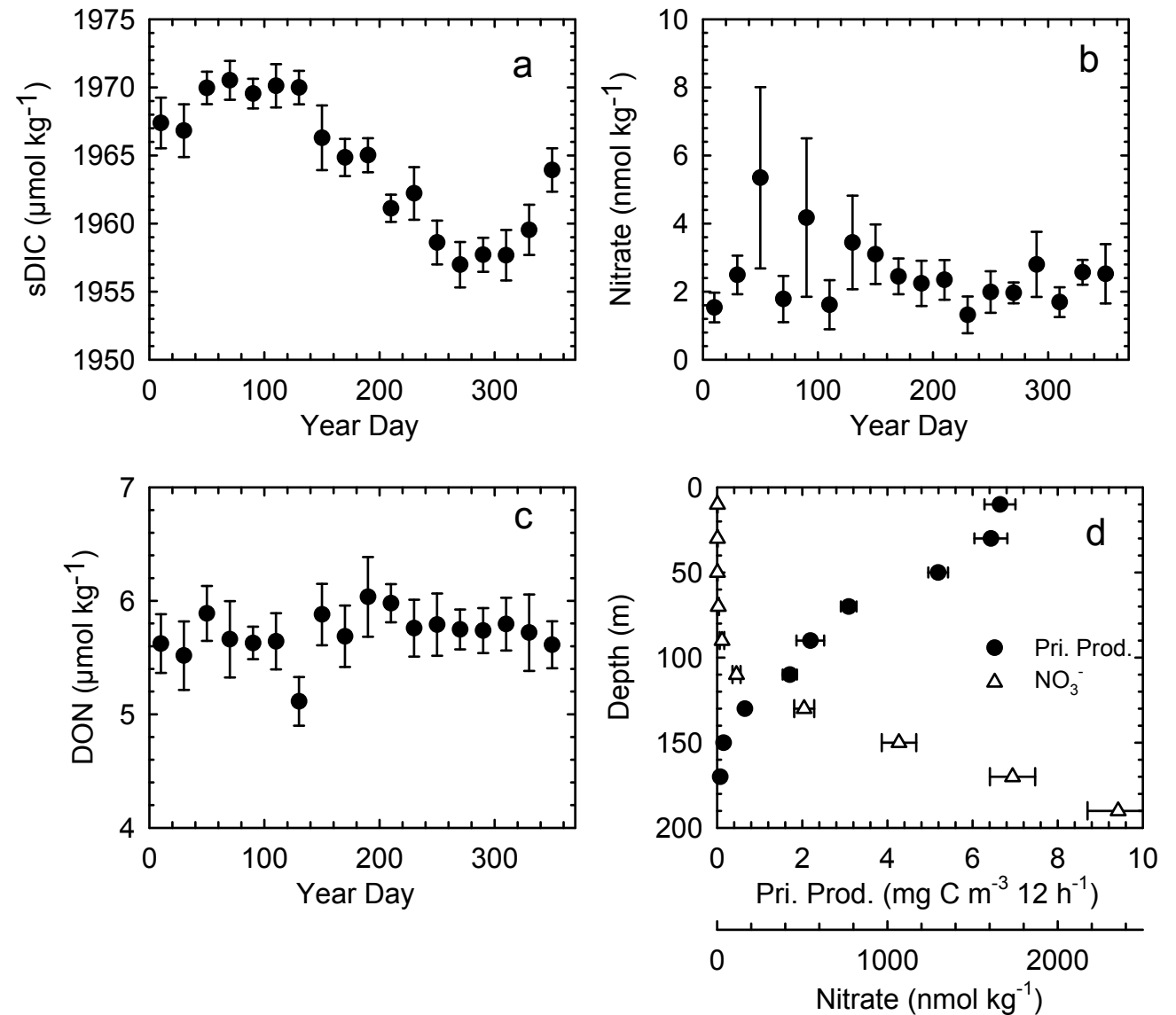


Fig. 8.3.11 Sarmiento & Gruber



The real question is, how do phytoplankton manage positive net growth with no apparent N in the system. Redfield requires C/N of  $106/16 = 6.6$



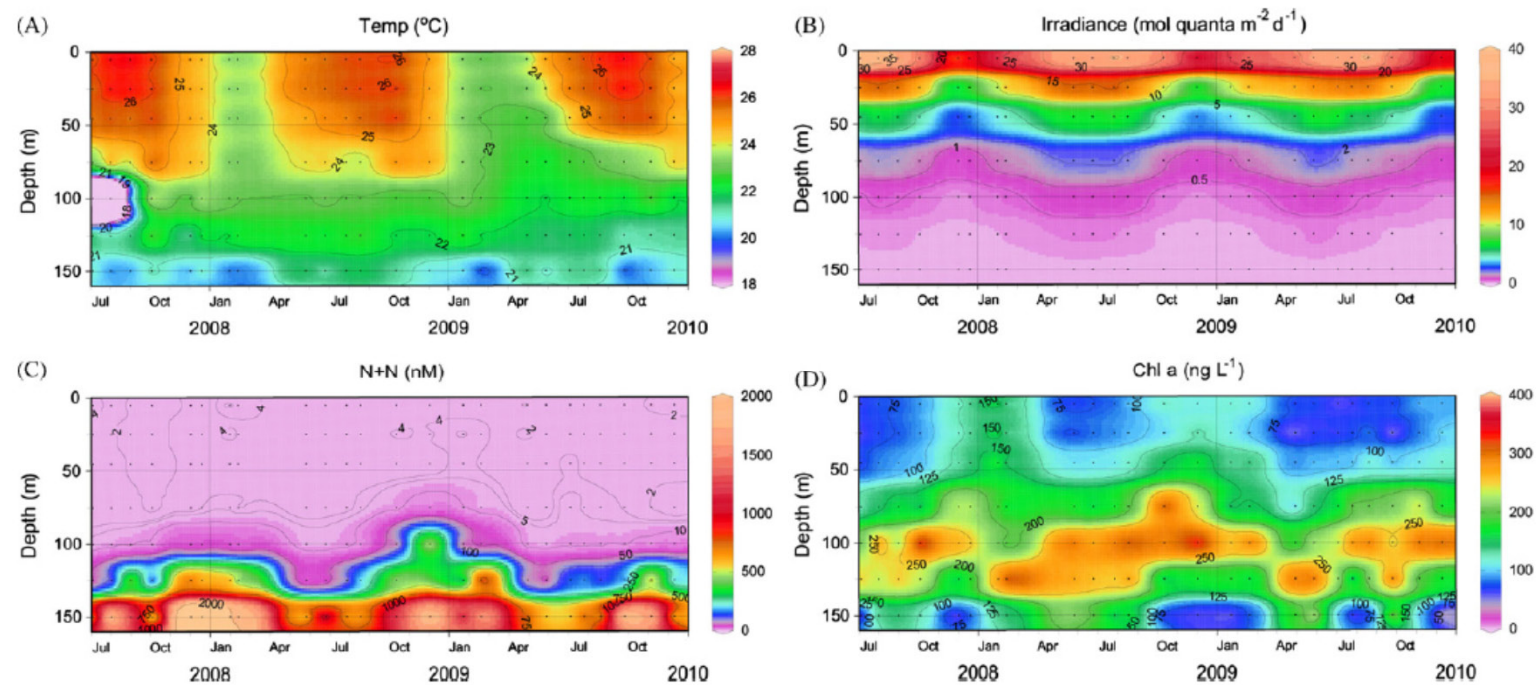


Fig. 2. Contour plots of temperature (A), photosynthetically active radiation (PAR) (B), nitrate+nitrite (N+N) concentrations (C), and Chl a (D) in the upper 150 m at Station ALOHA during this study (October 2007–December 2009).

## Variability of chromophytic phytoplankton in the North Pacific Subtropical Gyre

Binglin Li<sup>a</sup>, David M. Karl<sup>a</sup>, Ricardo M. Letelier<sup>b</sup>, Robert R. Bidigare<sup>c</sup>, Matthew J. Church<sup>a,\*</sup>

HOT – nutrient supply Church

BATS – C drawdown mechanisms – Lomas

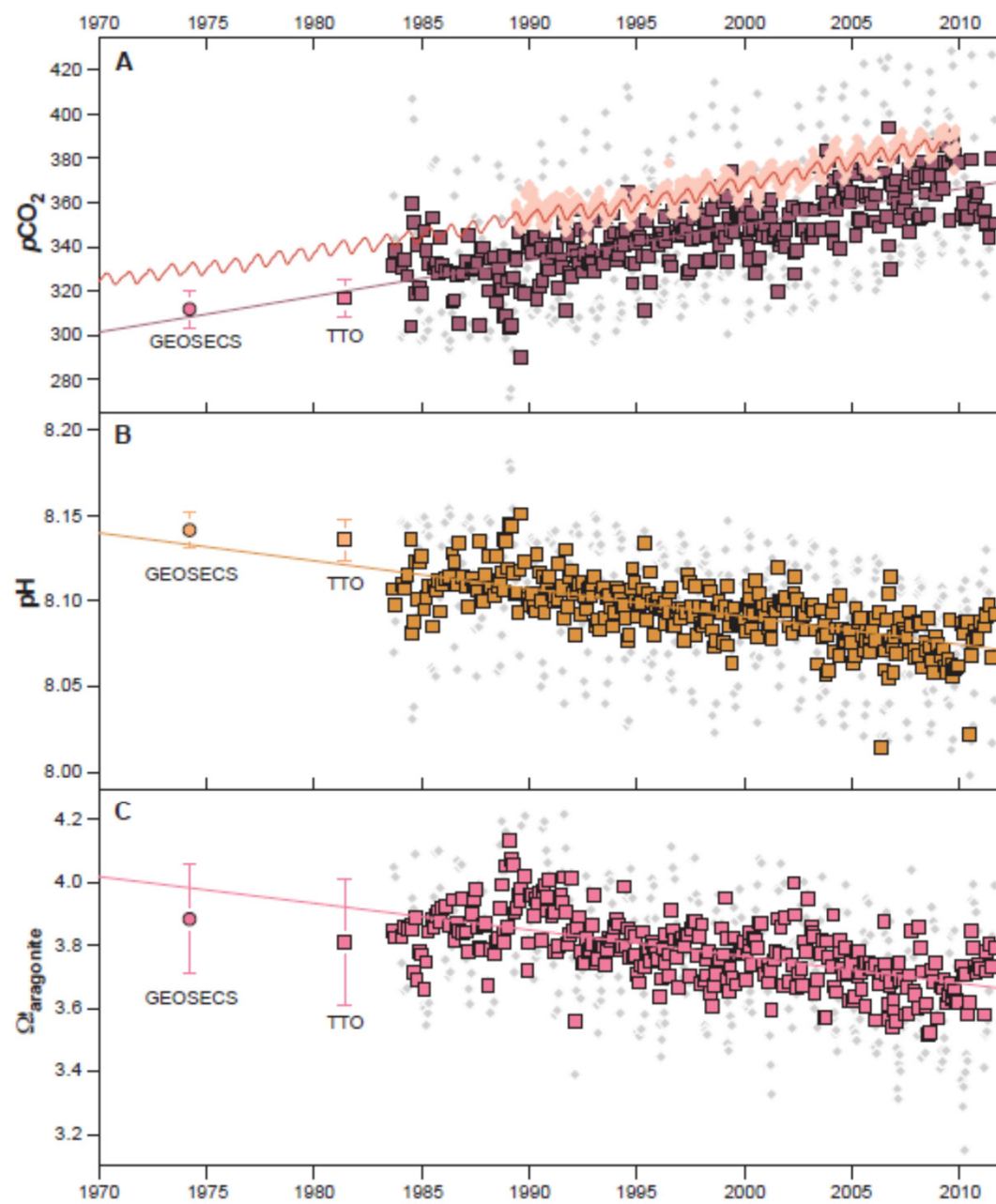
Bats – DOC/link to microbiology.....

The objectives of HOT specific to the JGOFS program are to:

- document and understand seasonal and interannual variability in the rates of primary production, new production and particle export from the surface ocean;
- determine the mechanisms and rates of nutrient input and recycling, especially for N and P in the upper 200 m of the water column;
- measure the time-varying concentrations of carbon dioxide in the upper water column and estimate the annual air-to-sea gas flux.

## Lomas et al (2013)

- Document the seasonal, interannual and decadal scale variability in carbon and macronutrient cycle parameters and processes.
- Including, for example, an understanding of the controls on the coupling/decoupling (relative to the Redfield ratio) of elemental cycles.
- Document variability in planktonic community structure and function, and its impact on the ocean's carbon cycle (including new and export production) and coupling with other macronutrient cycles.

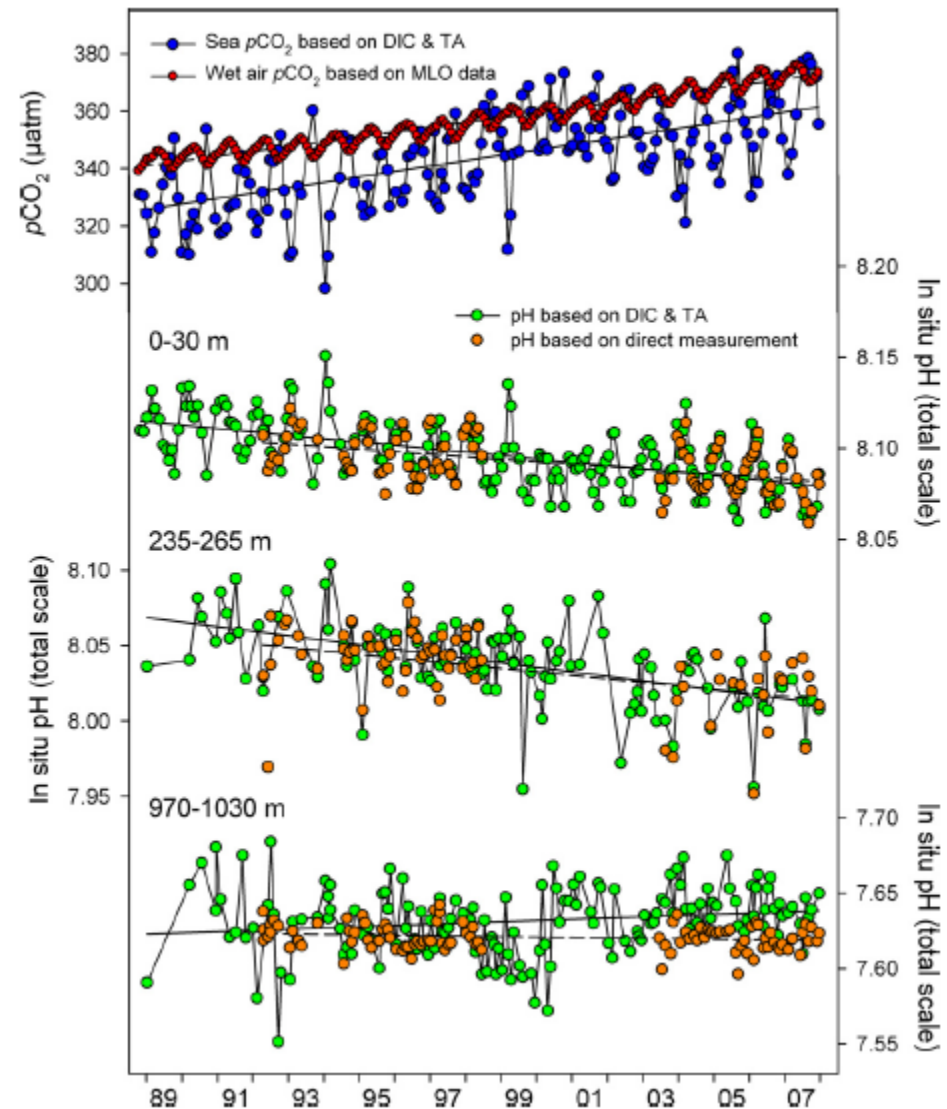


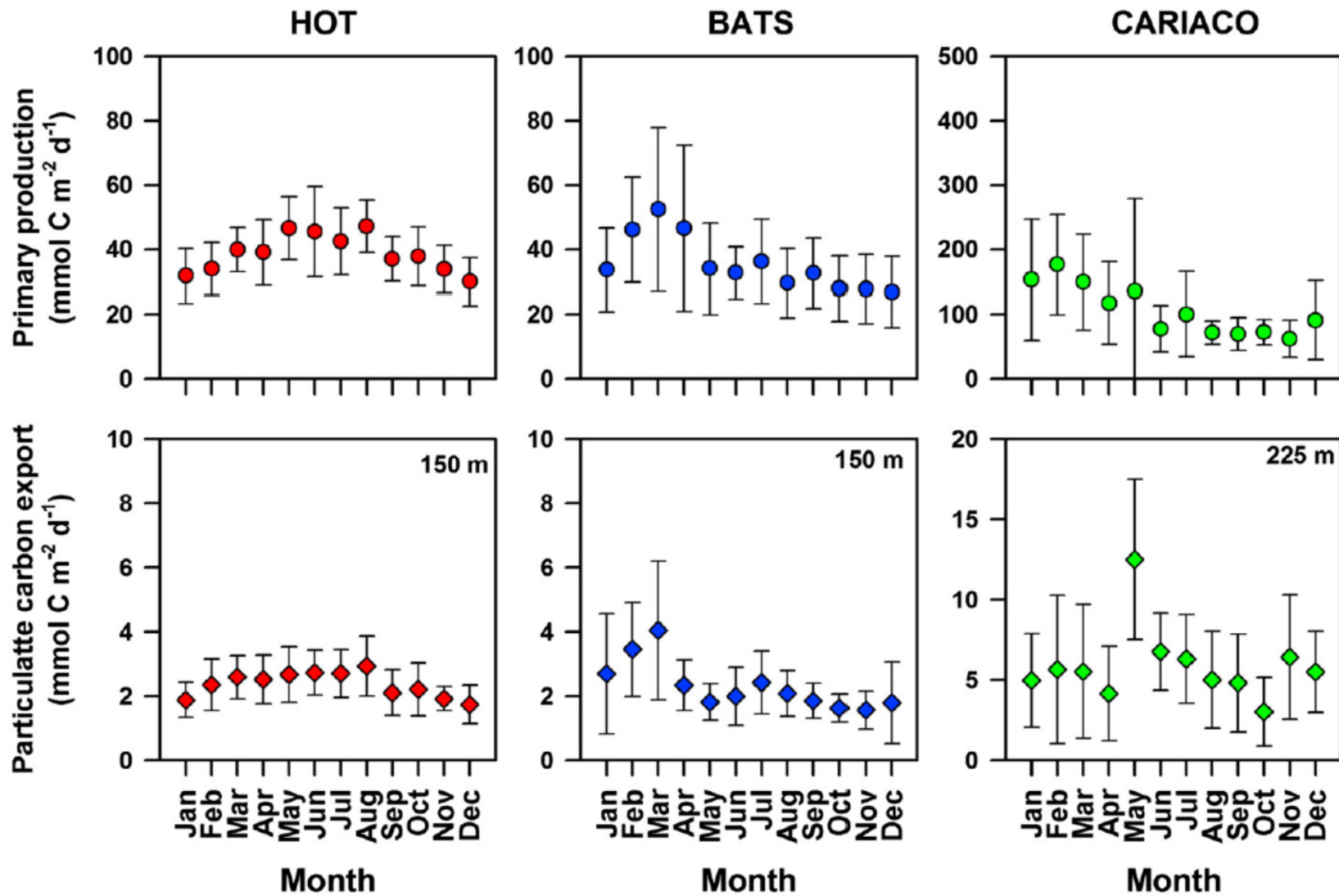
# Physical and biogeochemical modulation of ocean acidification in the central North Pacific

John E. Dore<sup>a,1</sup>, Roger Lukas<sup>b</sup>, Daniel W. Sadler<sup>b</sup>, Matthew J. Church<sup>b</sup>, and David M. Karl<sup>b,1</sup>

Acidification signal =  
-0.0017 pH/year

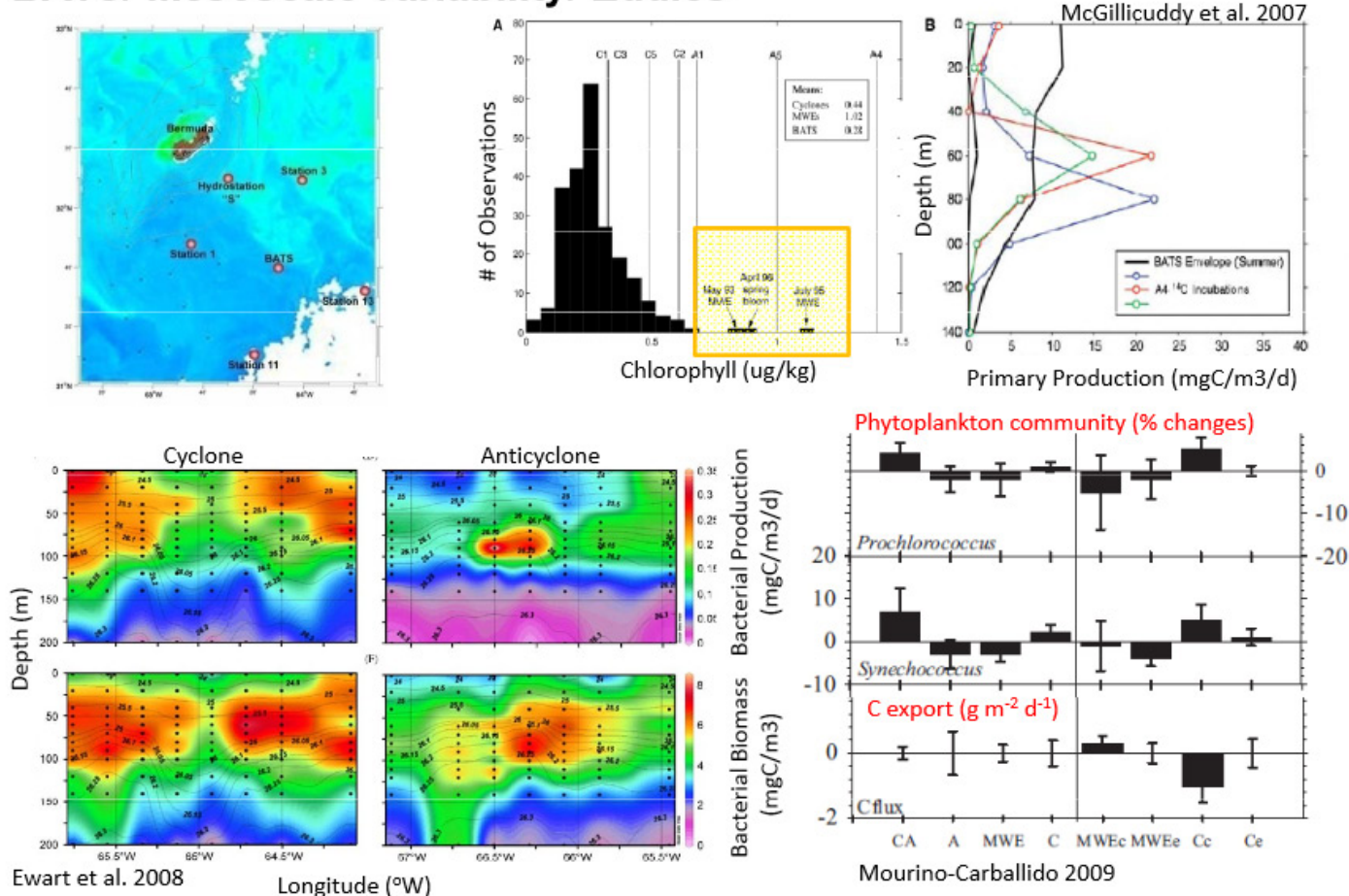
Production/Respiration  
signal = 0.03 pH/year





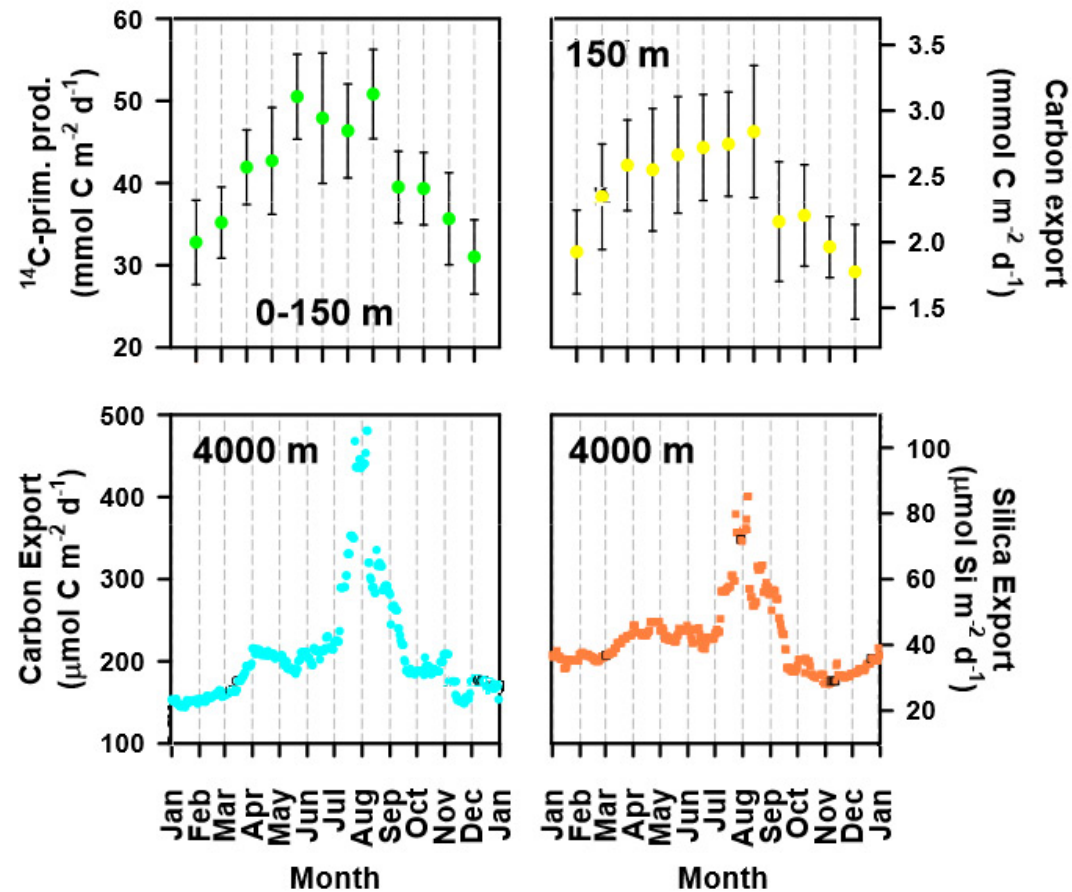


## BATS/ Mesoscale variability/ Eddies

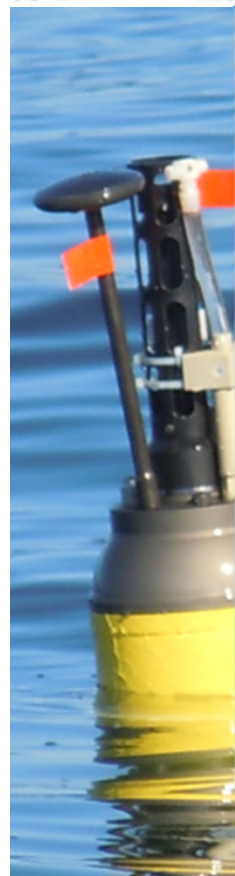


On an annual scale, eddies appear to 'average out' their impact on biogeochemistry.

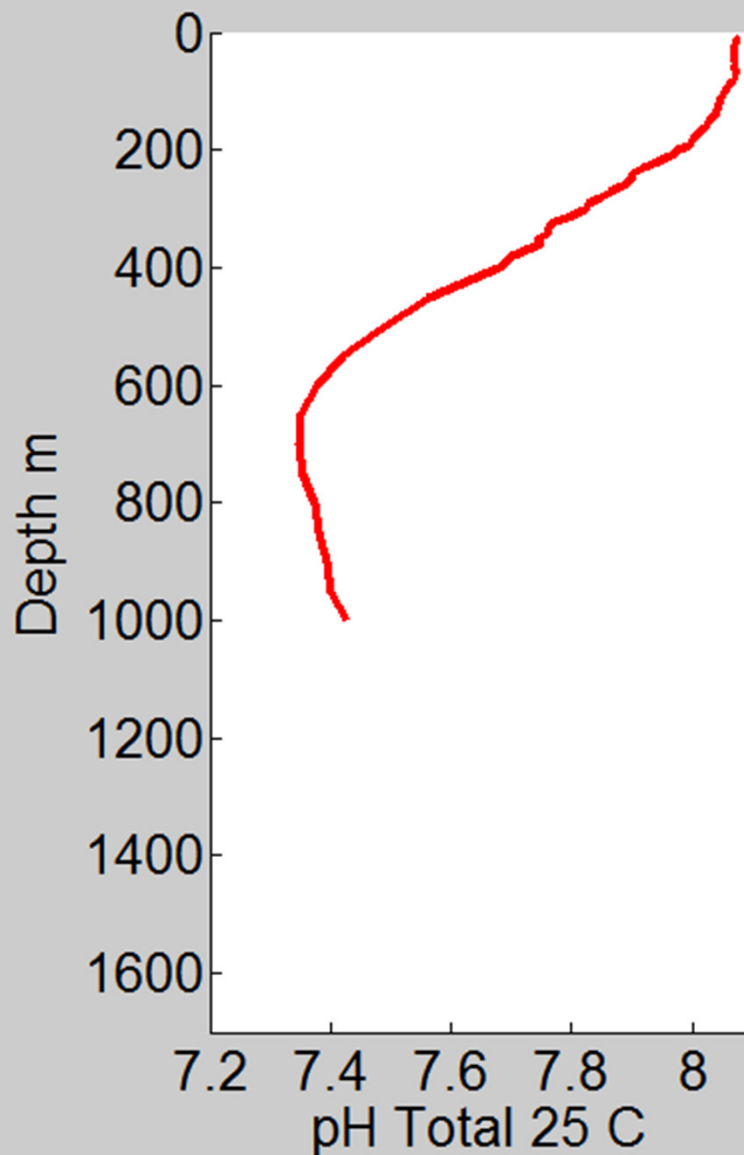
## Annual cycle of productivity and export



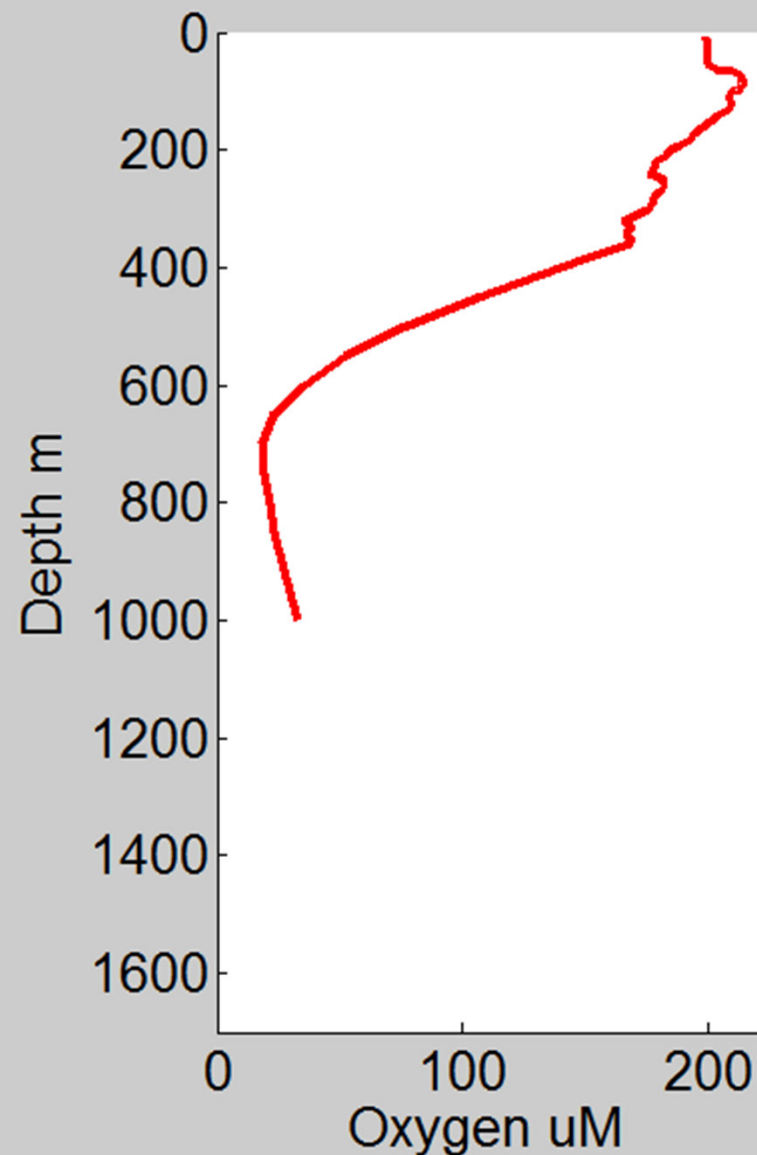
Plankton community structure plays a key role in carbon flux to the deep sea



10/03/2012



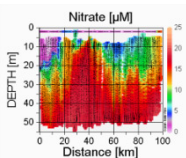
10/03/2012



# OCB time series success is a reflection of open data access policy

Time Series	Publ. Interval	Number
HOT	1990-2012	549
BATS	1988-2012	480
CARIACO	1996-2012	89*
Total		1118

\*Publications by CARIACO PI's only.



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Matt Church, OCB Time Series Workshop

## Net Community Production at Station ALOHA

Method	Rate mol C m <sup>-2</sup> yr <sup>-1</sup>	Period of measurements	References
Mixed Layer O <sub>2</sub> + 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 <sup>13</sup> C budgets	2.7 - 2.8 (± 1.4)	1988–2002	Quay and Stutsman (2003); Keeling et al. (2004)
Mooring O <sub>2</sub>	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
<i>In vitro</i> O <sub>2</sub> 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**