The Bermuda Atlantic Time-series Study (BATS): A Broadened Array of Sustained Observations and Process Understanding of the North Atlantic Ocean

Prof. Nicholas R. Bates

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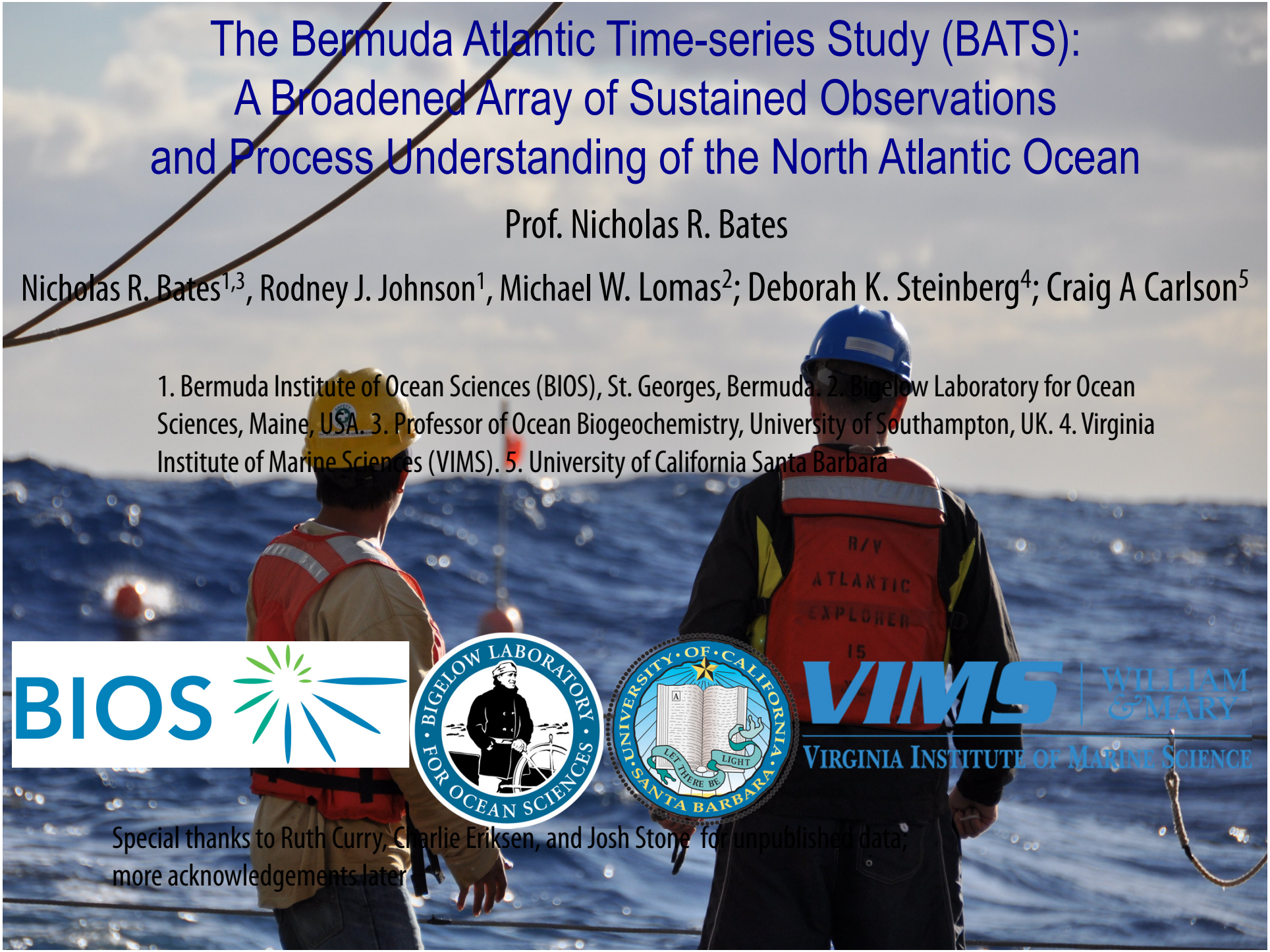
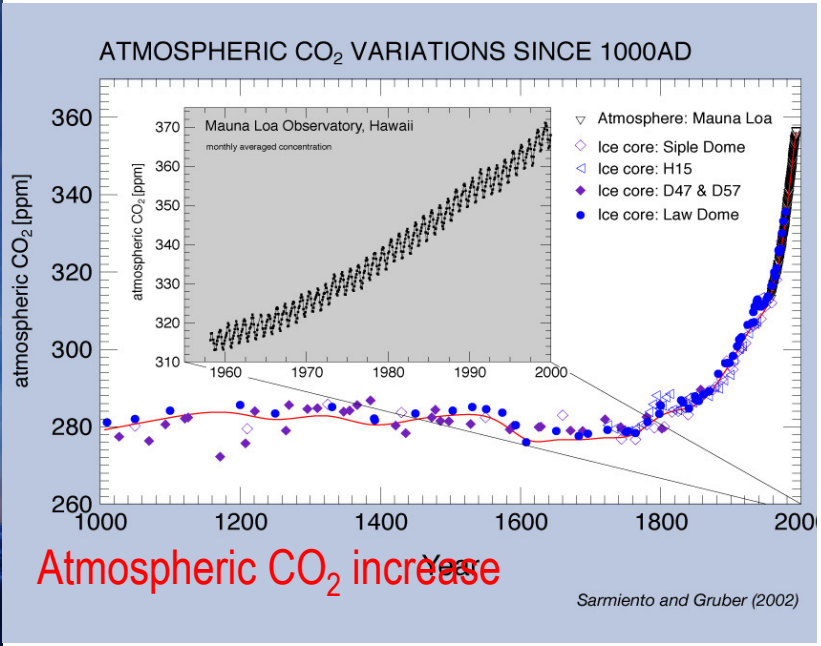


Special thanks to Ruth Curry, Charlie Eriksen, and Josh Stone for unpublished data; more acknowledgements later

Two Iconic Time-series: Mauna Loa and BATS

- Rising carbon dioxide (CO_2) in the atmosphere
- Climate impacts

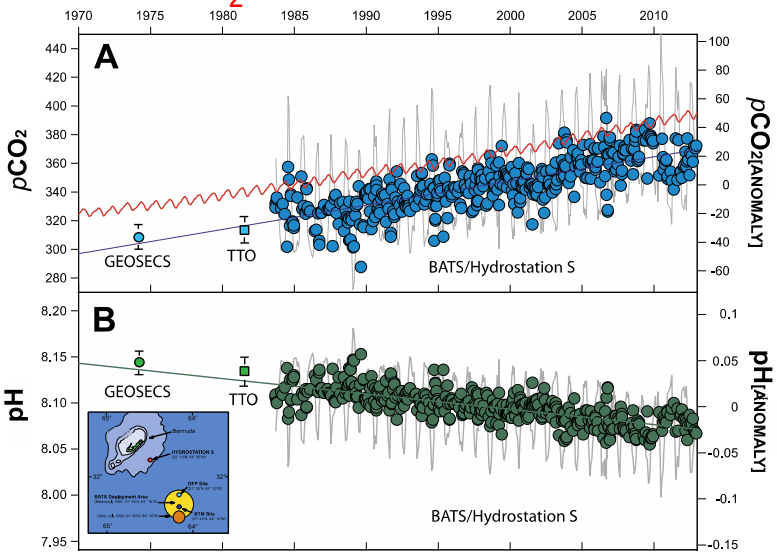
- Rising CO_2 in the ocean
- Changing ocean chemistry
- Ocean acidification
- Changes in marine ecosystems



Atmospheric CO_2 increase

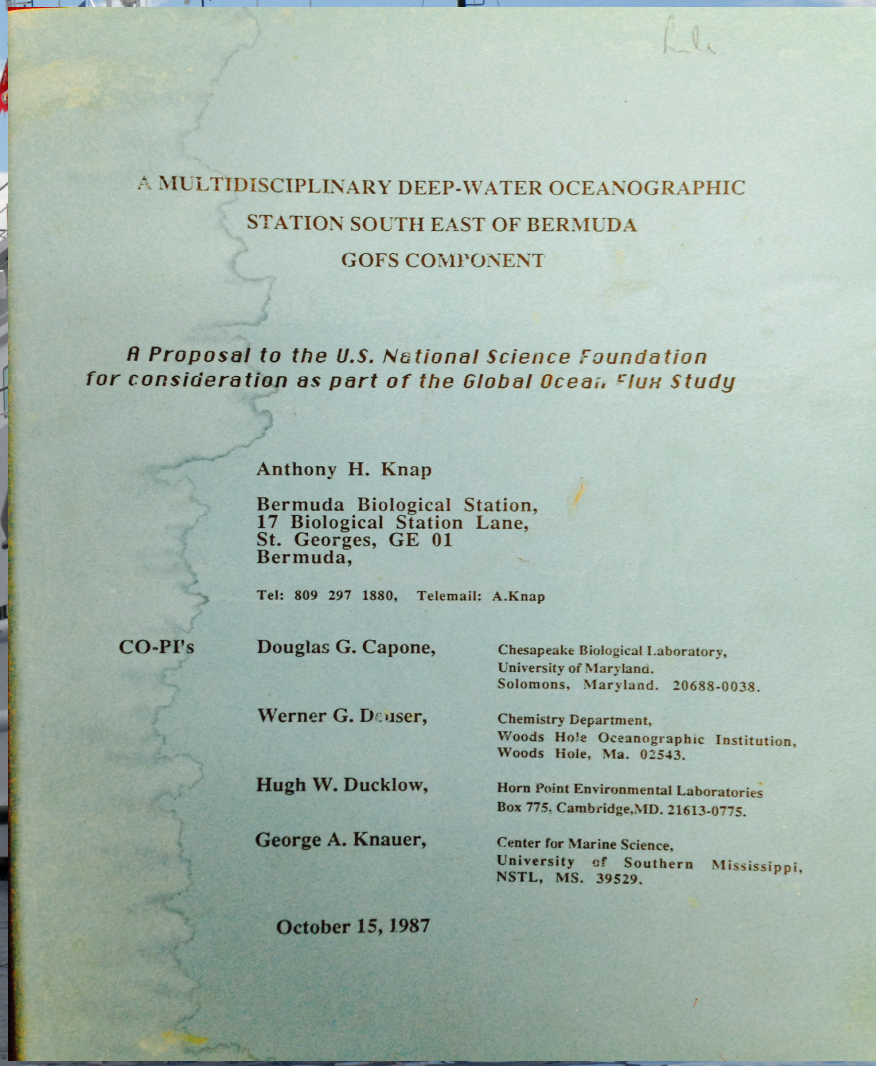
Sarmiento and Gruber (2002)

Oceanic CO_2 increase



The Original and Continuing Science Focus of the BATS Program

The focus of the BATS program has been, and continues to be, improving our understanding of the "time-varying" components of the ocean carbon cycle, related biogenic elements of interest (e.g., nitrogen, phosphorus, silica), and identifying the relevant physical, chemical and ecosystem properties responsible for this variability.



A MULTIDISCIPLINARY DEEP-WATER OCEANOGRAPHIC
STATION SOUTH EAST OF BERMUDA
GOFS COMPONENT

A Proposal to the U.S. National Science Foundation
for consideration as part of the Global Ocean Flux Study

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Hugh W. Ducklow, Horn Point Environmental Laboratories Box 775, Cambridge,MD. 21613-0775.

George A. Knauer, Center for Marine Science, University of Southern Mississippi, NSTL, MS. 39529.

October 15, 1987

"Understanding How the Ocean Works"

- In it's Natural State
- In the Era of Environmental and Climate Change

Past and Present BATS Principal Investigators


Nick Bates


Rod Johnson


Mike Lomas


Tony Knap


Tony Michaels


Debbie Steinberg


Dennis Hansell

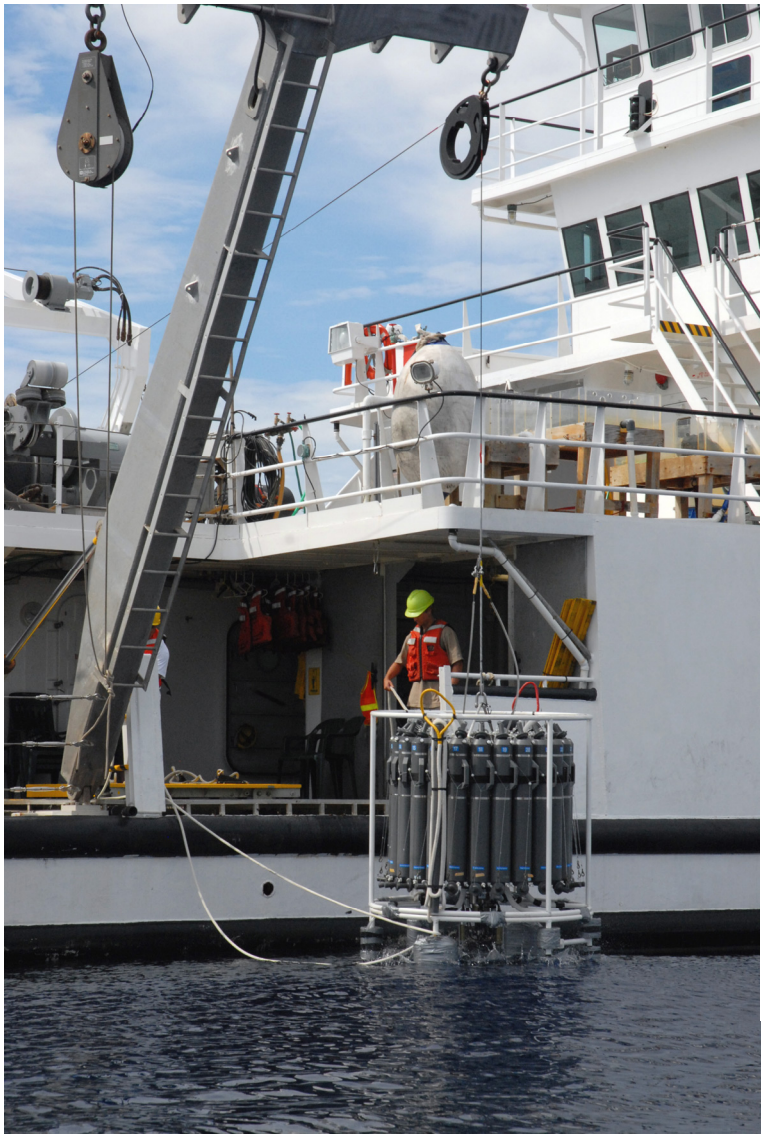

Craig Carlson

The Core BATS Program

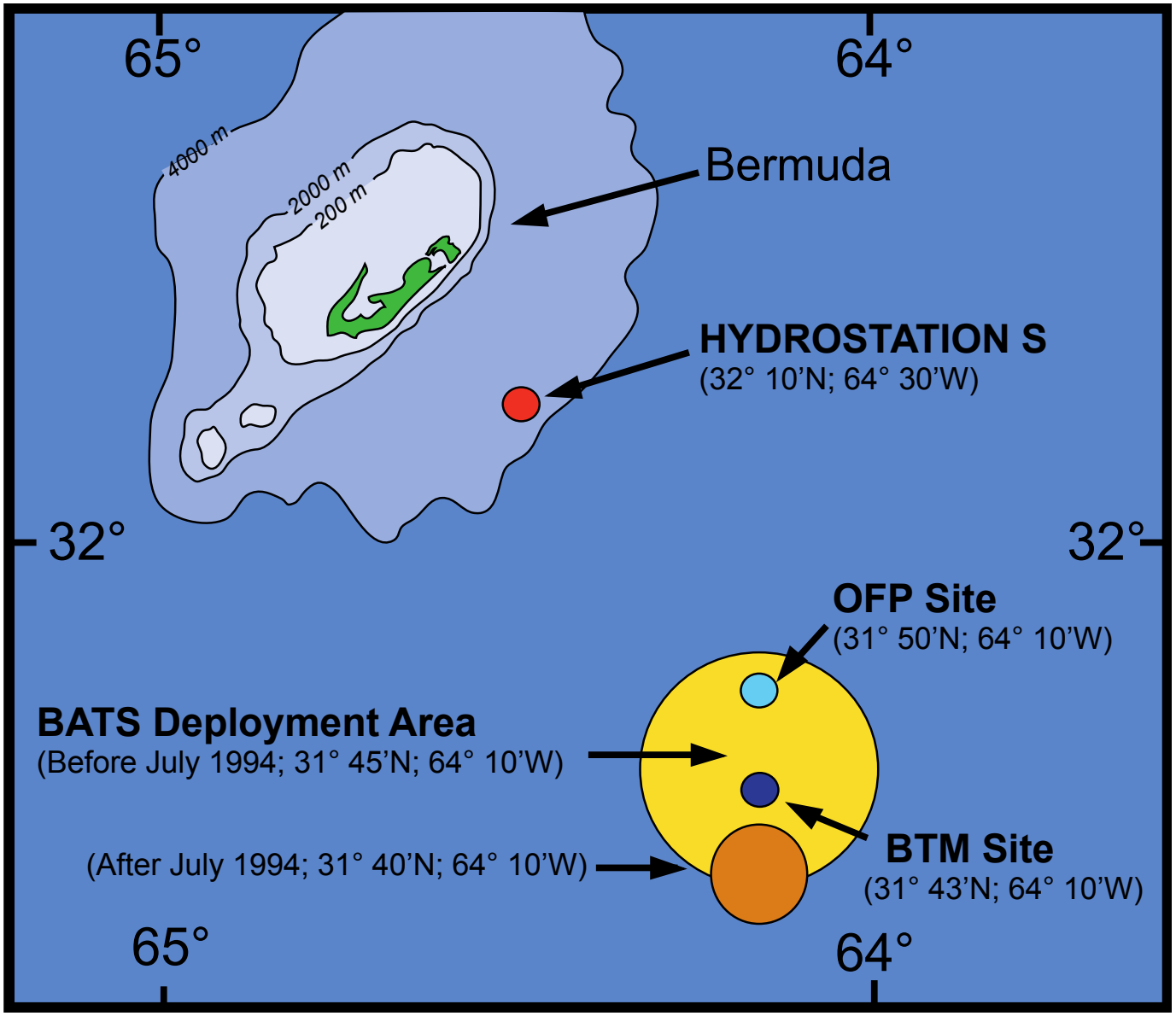
BATS Core Measurements

Parameter	Depth Range (m)	Method/Instrument
	Continuous electronic measurements	
Temperature	0 - 4200	Dual SBE-03f sensors
Conductivity	0 - 4200	Dual SBE04 sensors
Pressure	0 - 4200	SeaBird Digiquartz
Dissolved Oxygen	0 - 4200	SBE43 polarographic membrane sensors
Fluorescence	0 - 4200	Chelsea Instruments
	Discrete Samples	
Salinity	0 - 4200	Guildline Autosal 8400B
Dissolved Oxygen	0 - 4200	Winkler Titration, UV endpoint
Total CO_2	0 - 500	Automated coulometric analysis
Alkalinity	0 - 500	High precision titration
Nitrate, Nitrite	0 - 4200	CFA colorometric using Technicon-2
Phosphate	0 - 4200	CFA colorometric using Technicon-2
Silicate	0 - 4200	CFA colorometric using Technicon-2
Dissolved Organic Carbon	0 - 4200	High temperature catalytic oxidation
Dissolved Organic Nitrogen	0 - 4200	UV oxidation
Particulate Organic Carbon	0 - 1000	High temperature combustion CHN analyzer
Particulate Organic Nitrogen	0 - 1000	High temperature combustion CHN analyzer
Particulate Silicate	0 - 1000	Chemical digestion, colorometric analysis
Phytoplankton Pigments	0 - 250	HPLC
Fluorometric Chlorophyll a	0 - 250	Turner fluorometer
Bacteria Enumeration	0 - 4000	DAPI stained, fluorescence microscopy
	Rate Measurements	
Primary Production	0 - 140	in-situ incubation , 14C uptake
Bacterial activity	0 - 300	Thymidine incorporation
Particle Fluxes	150, 200, 300	Free drifting surface tethered MultiPITs
Mass flux		Gravimetric analysis
Total Carbon flux		Swimmer removal, CHN analysis
Organic carbon flux		Swimmer removal, acidification , CHN
Organic nitrogen flux		Swimmer removal, CHN analysis

15 to 16 BATS cruises each year



Sustained Ocean Observations off Bermuda

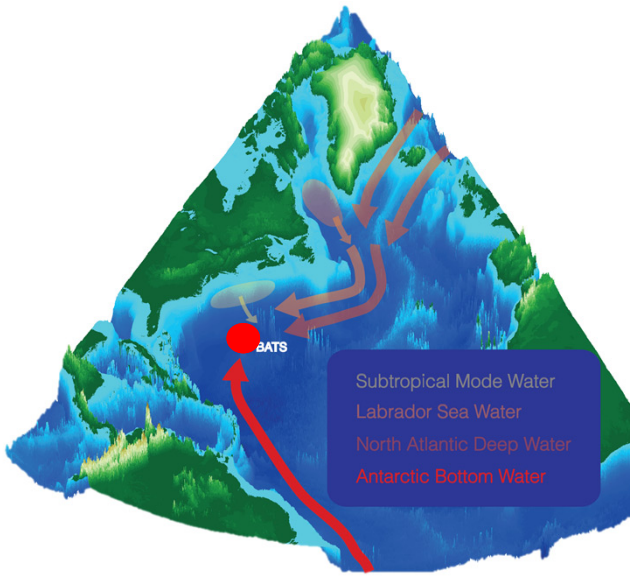


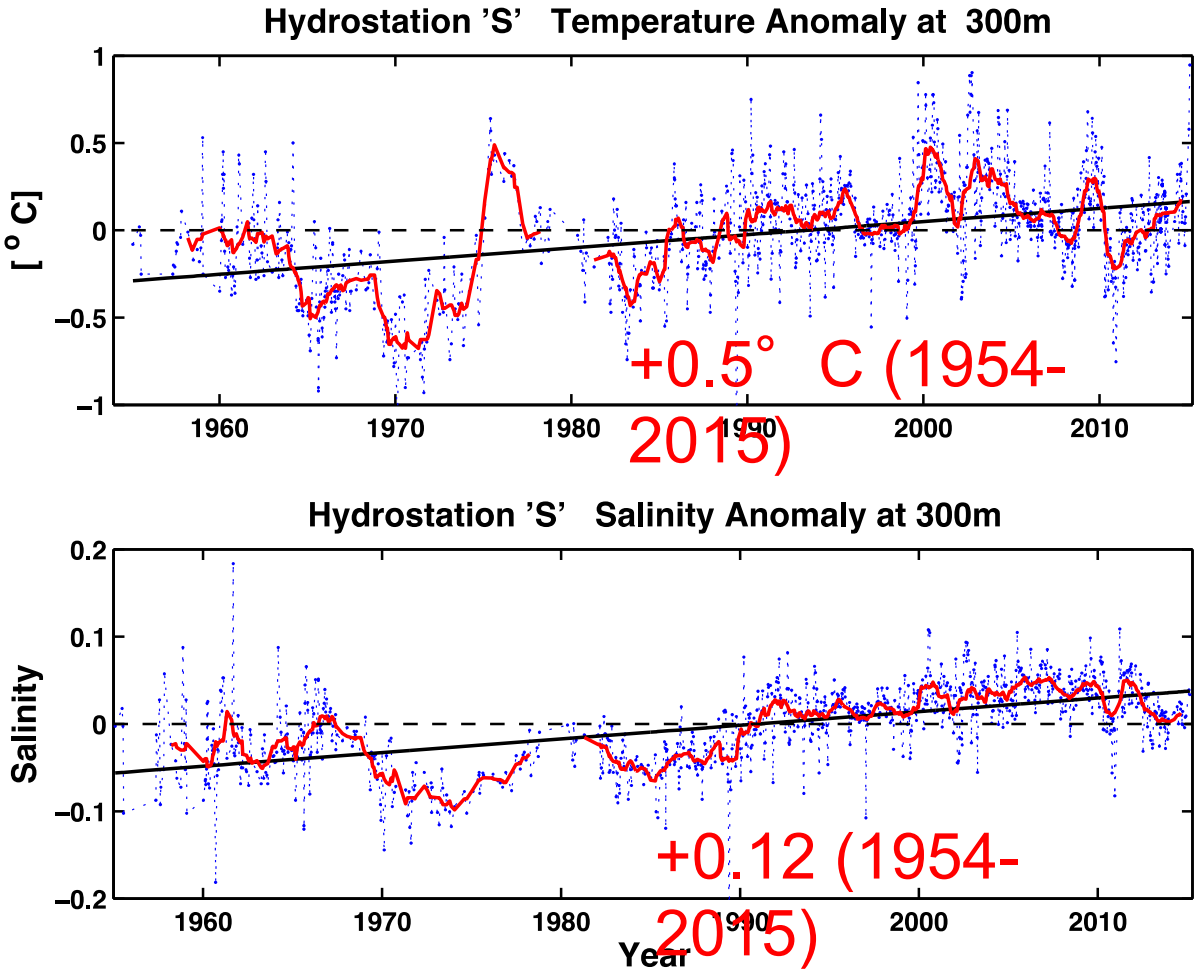
Ocean warming and salinification in shallow water mass

Hydrostation S (1954-) and the Bermuda Atlantic Time-series Study sites (1988-)

Long-term trends: ~0.08˚ C per decade and 0.02 per decade salinity

Subtropical mode water



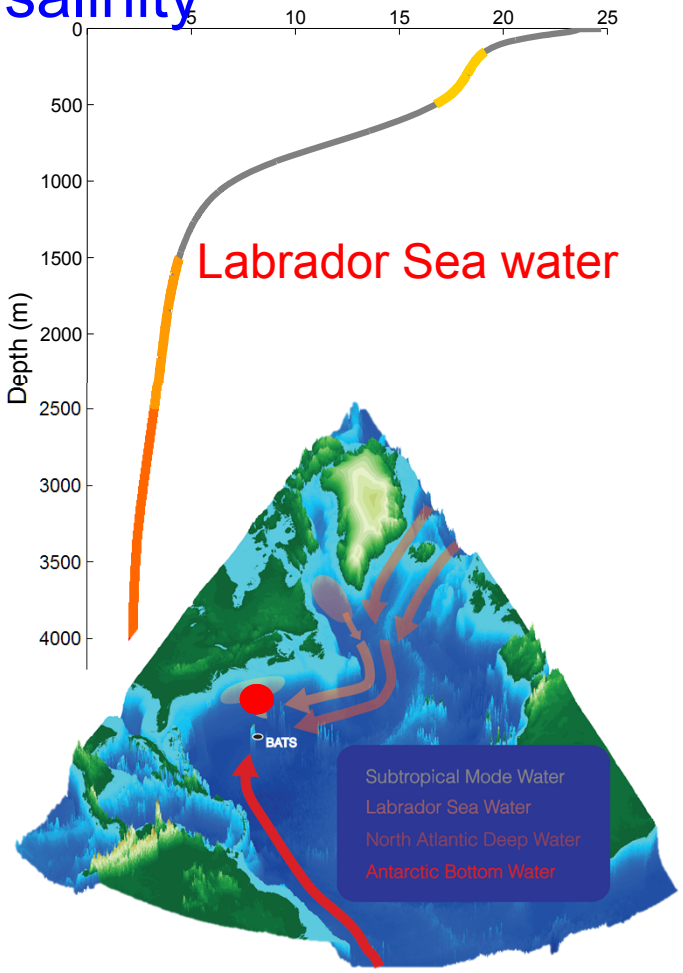


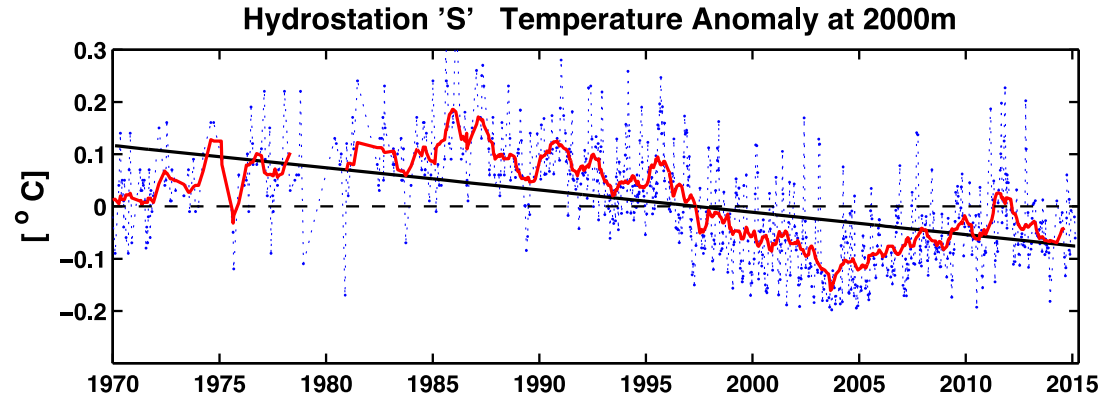
R.J. Johnson and N.R. Bates (Hydrostation S; unpubl. data)

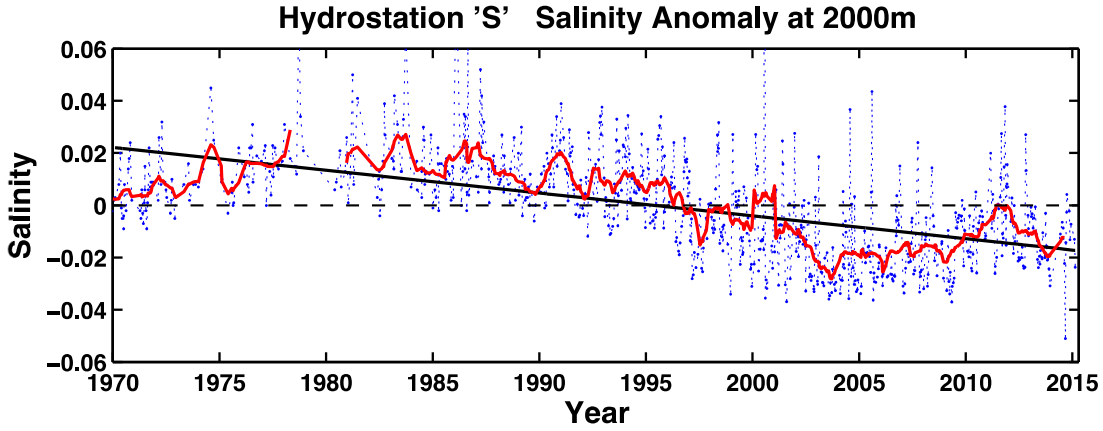
Cooling in deeper water masses

Hydrostation S (1954-) and the Bermuda Atlantic Time-series Study sites (1988-)

Long-term trends: ~0.04° C per decade and 0.01 per decade in salinity



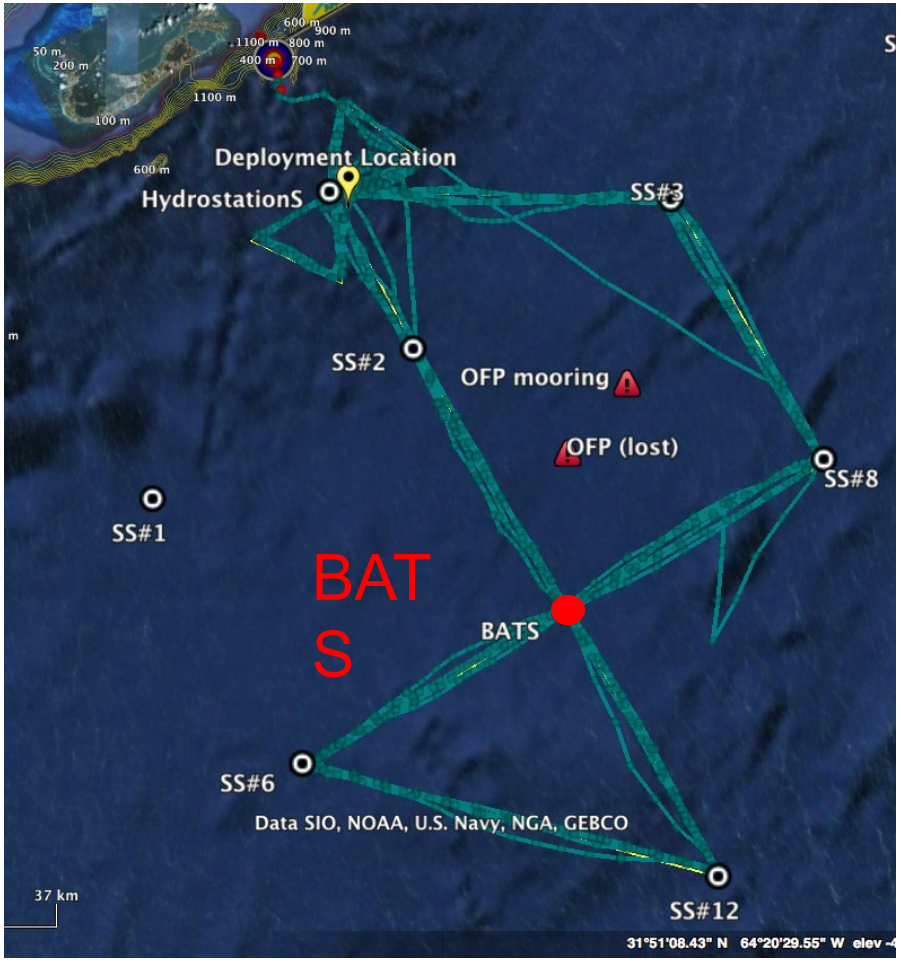




New surface ocean physics studies

Courtesy of Ruth Curry (WHOI/BIOS)

Slocum Glider Operations off Bermuda



Mission #1 in 2014

"Learning"

Duration: 100 days; Distance: 2204 km

766 dives, 1532 profiles

T, S, O_2, Chlorophyll, CDOM, velocity

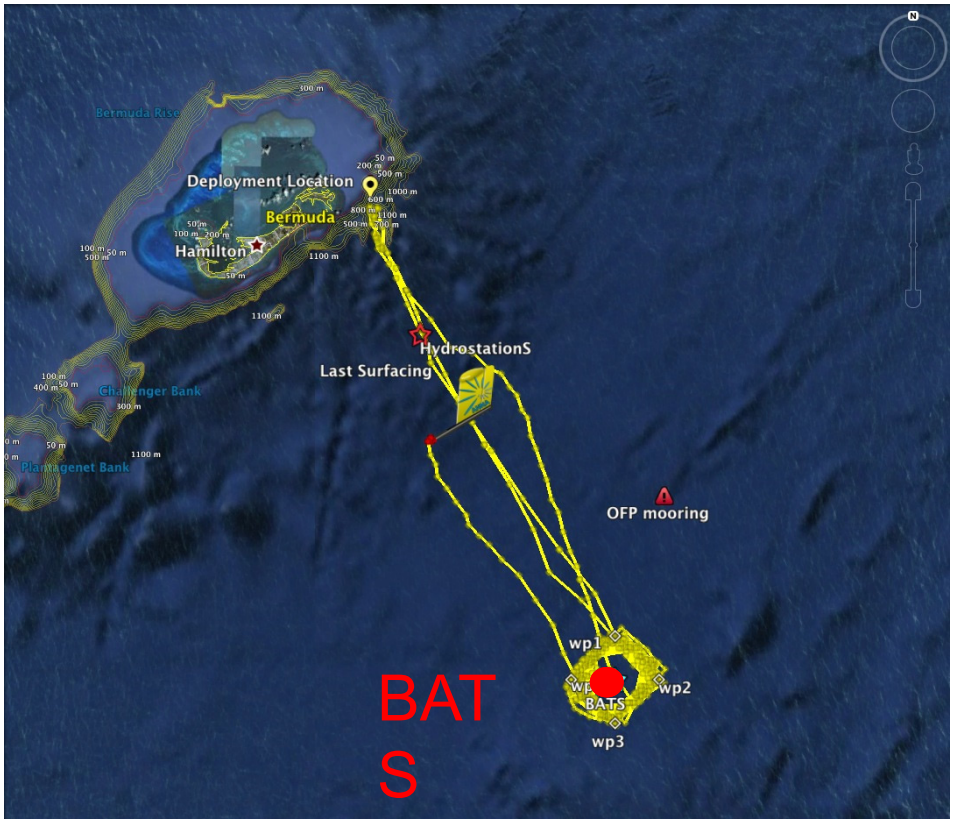
Data courtesy of Ruth Curry (WHOI); slide modified by NR Bates

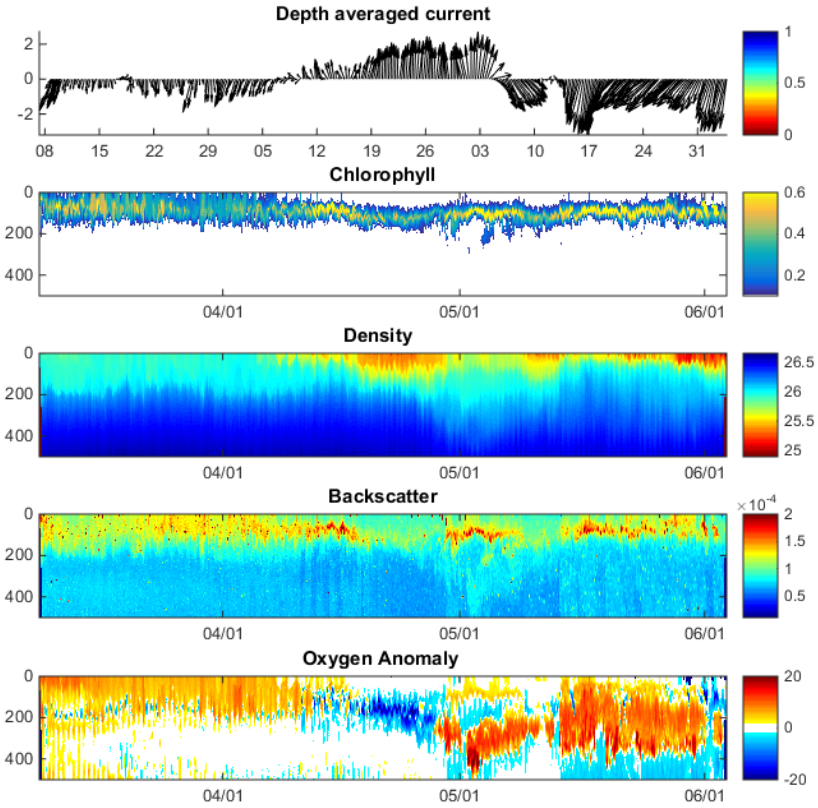
Bates et al, 2015 OCB

New surface ocean physics studies

Courtesy of Ruth Curry (WHOI/BIOS)

Slocum Glider Operations off Bermuda





Spring Bloom Mission (#4)

8 Mar – 3 Jun 2015

Duration: 87 days; 1532 profiles

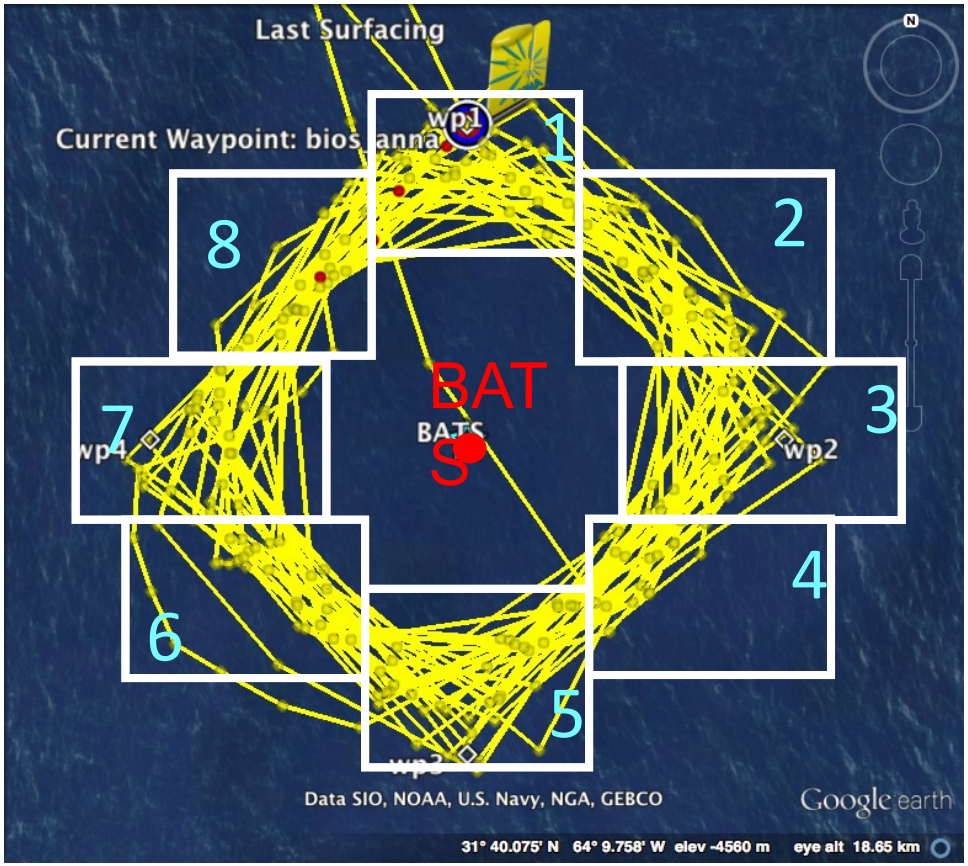
T, S, O_2, Chlorophyll, CDOM, velocity

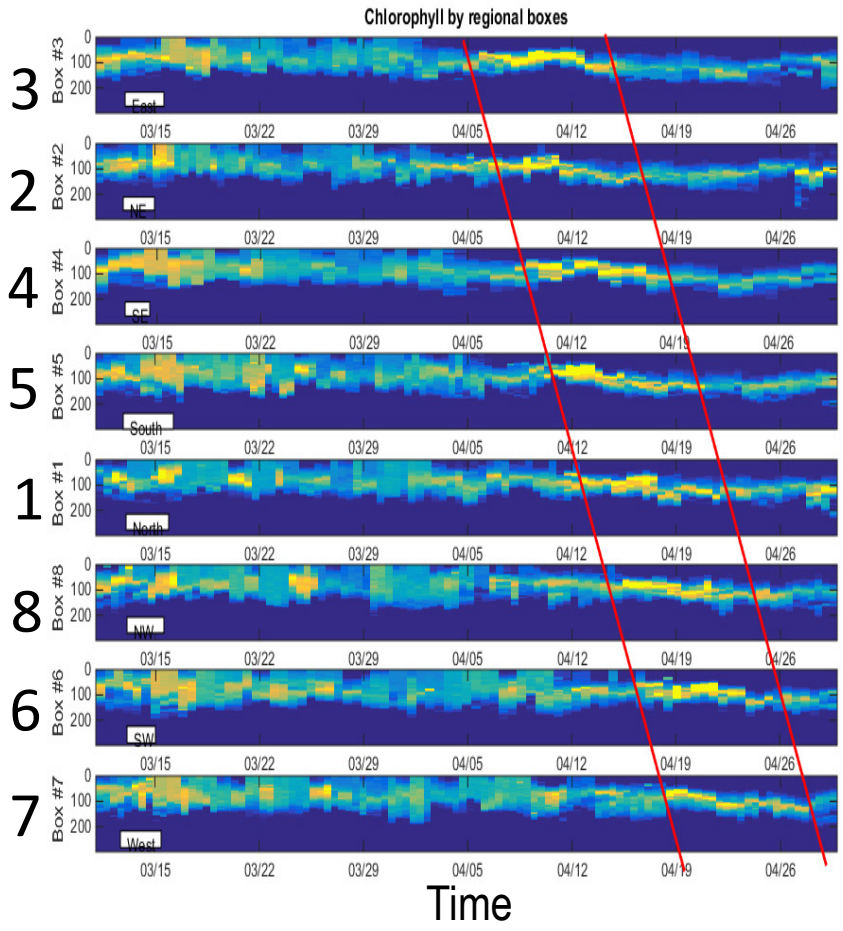
Data courtesy of Ruth Curry (WHOI); slide modified by NR Bates

New surface ocean physics studies

Courtesy of Ruth Curry (WHOI)

Slocum Glider Operations off Bermuda





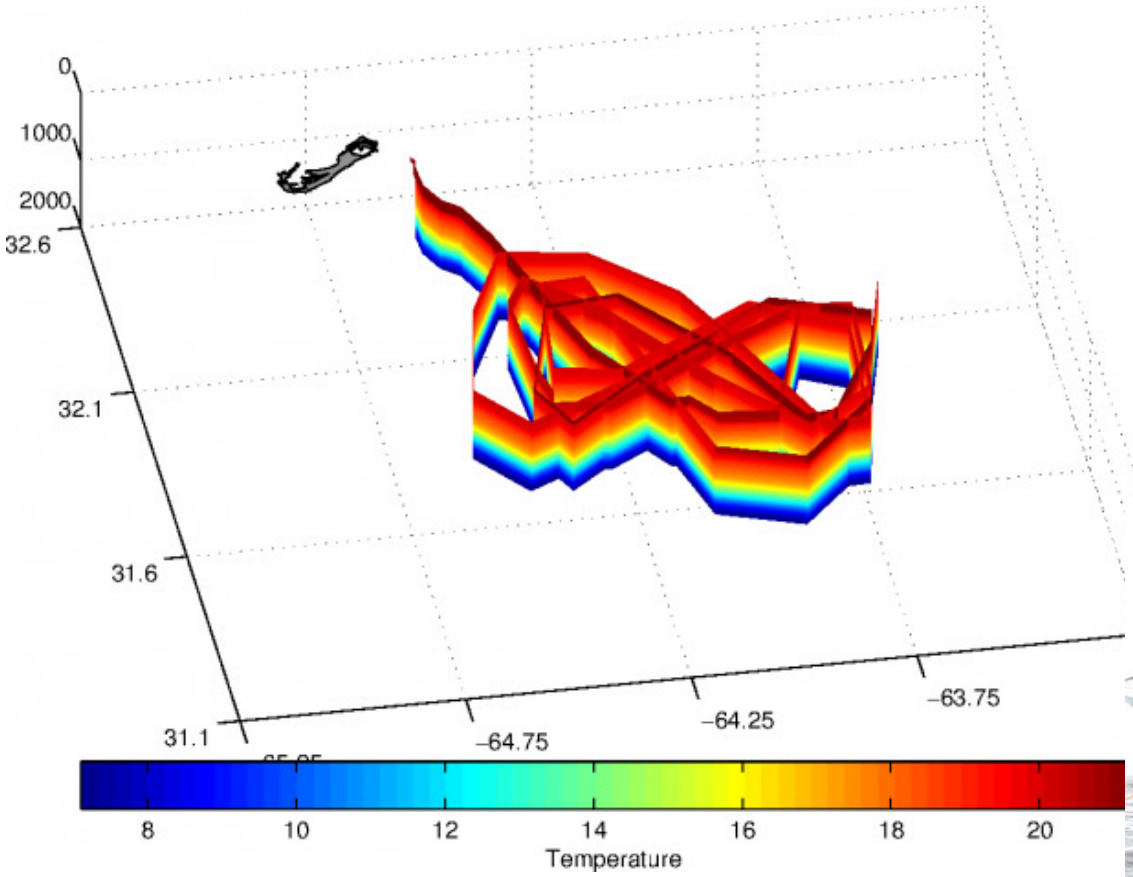
Propagation of eddy feature (chlorophyll) to west

Data courtesy of Ruth Curry (WHOI); slide modified by NR Bates

New deep ocean physics studies

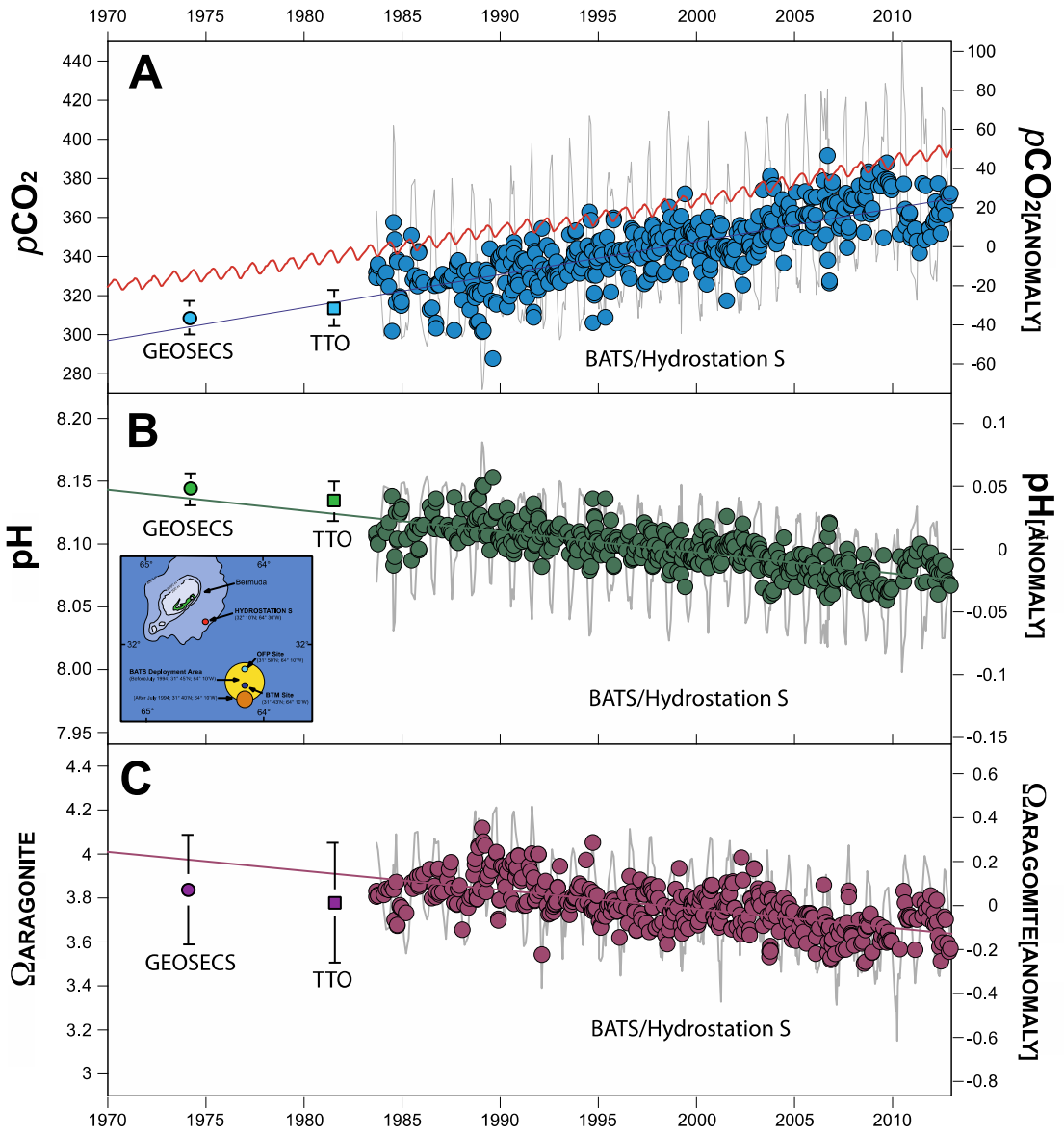
Courtesy of Charlie Eriksen (University of Washington)

DeepGlider Operations off Bermuda



- DG35 (deepGlider) deployed January 2015
- Full ocean depth profiles (T,S,O_2) 0-6000 m
- Survey grid 80 km with BATS at center of grid
- One cycle of grid ~ each week.
- Monthly side-by-side calibrations with BATS
- Proposed recovery June 2016.

Long-term ocean acidification at BATS



Seawater pCO_2 changes = +1.8 µatm year^{-1}

or about 5% increase per decade

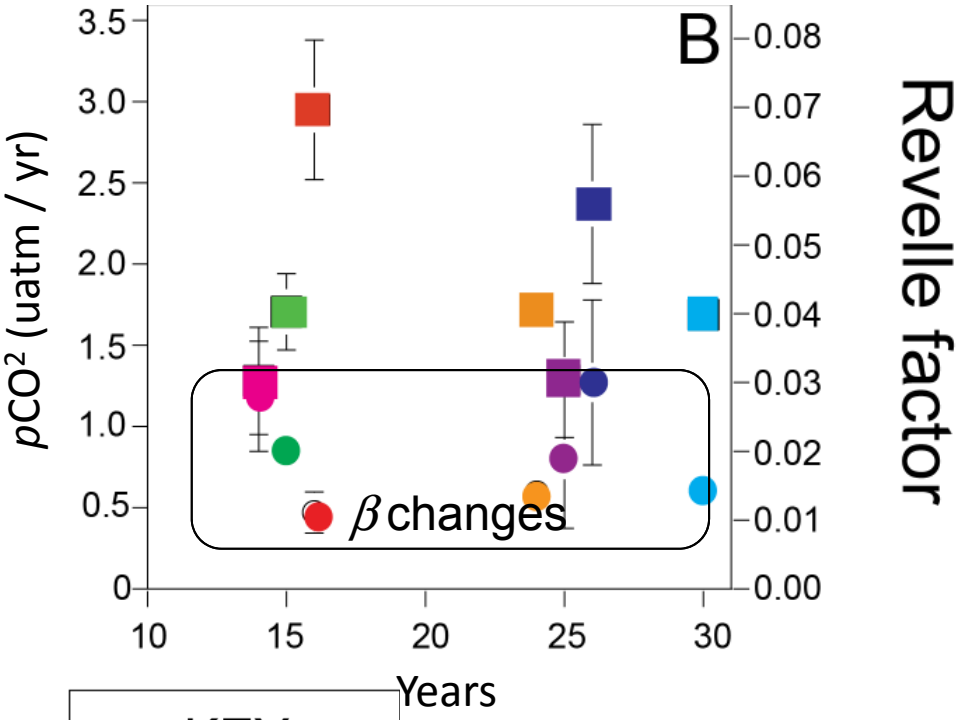
Seawater pH changes = -0.0017 year^{-1}
or about 25% to 30% increase in acidity (H^+) of seawater in the past forty years

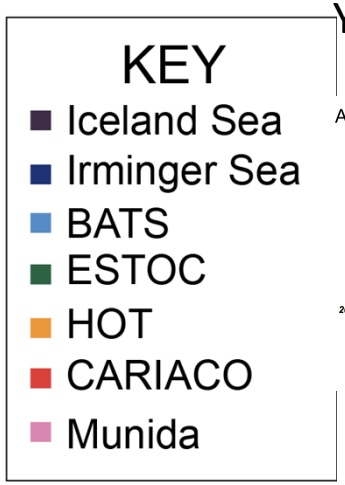
Ω_{CaCO3} changes = -0.01 year^{-1}

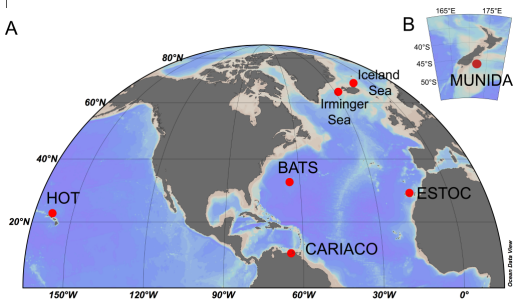
Bates et al., 2014

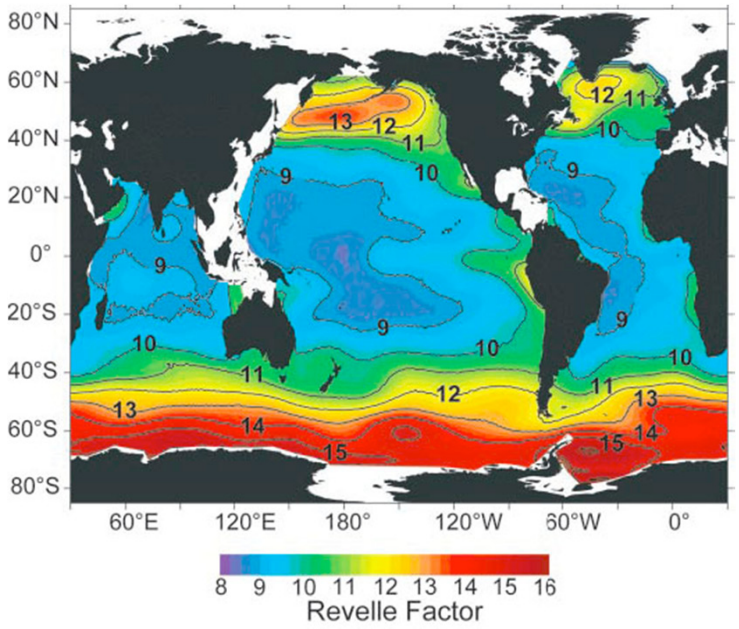
Ocean Buffer Capacity Changes

Bates et al., 2014









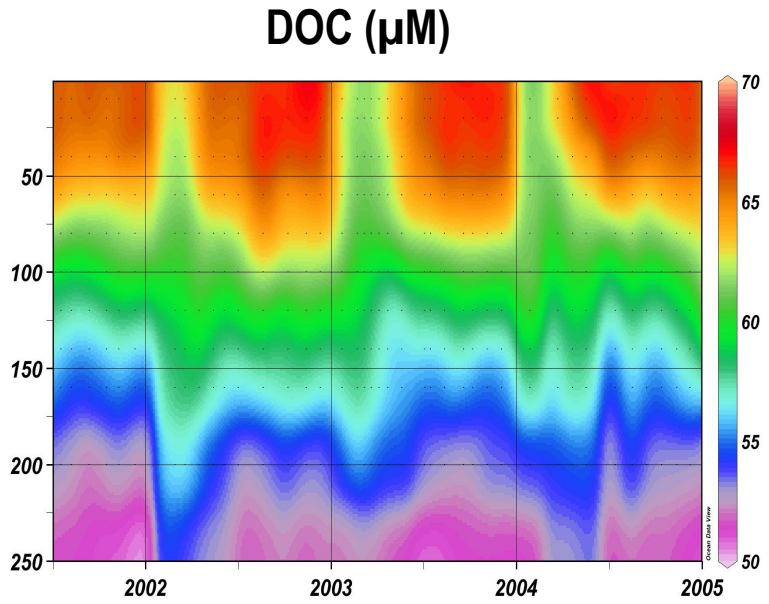
Revelle factor (β) changes = +0.011 to +0.030 year^{-1}

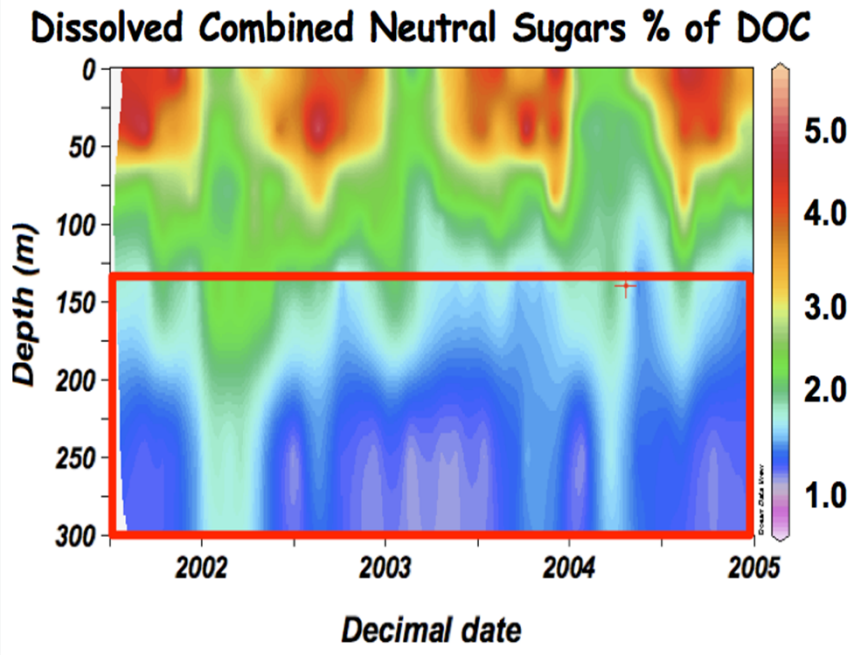
or about 0.4 to 0.9% per decade

Global ocean capacity to absorb Anthropogenic CO_2 will decrease with time in the future

Bates et al., 2014

DOC Dynamics and Variability in its Diagenetic Alteration at BATS

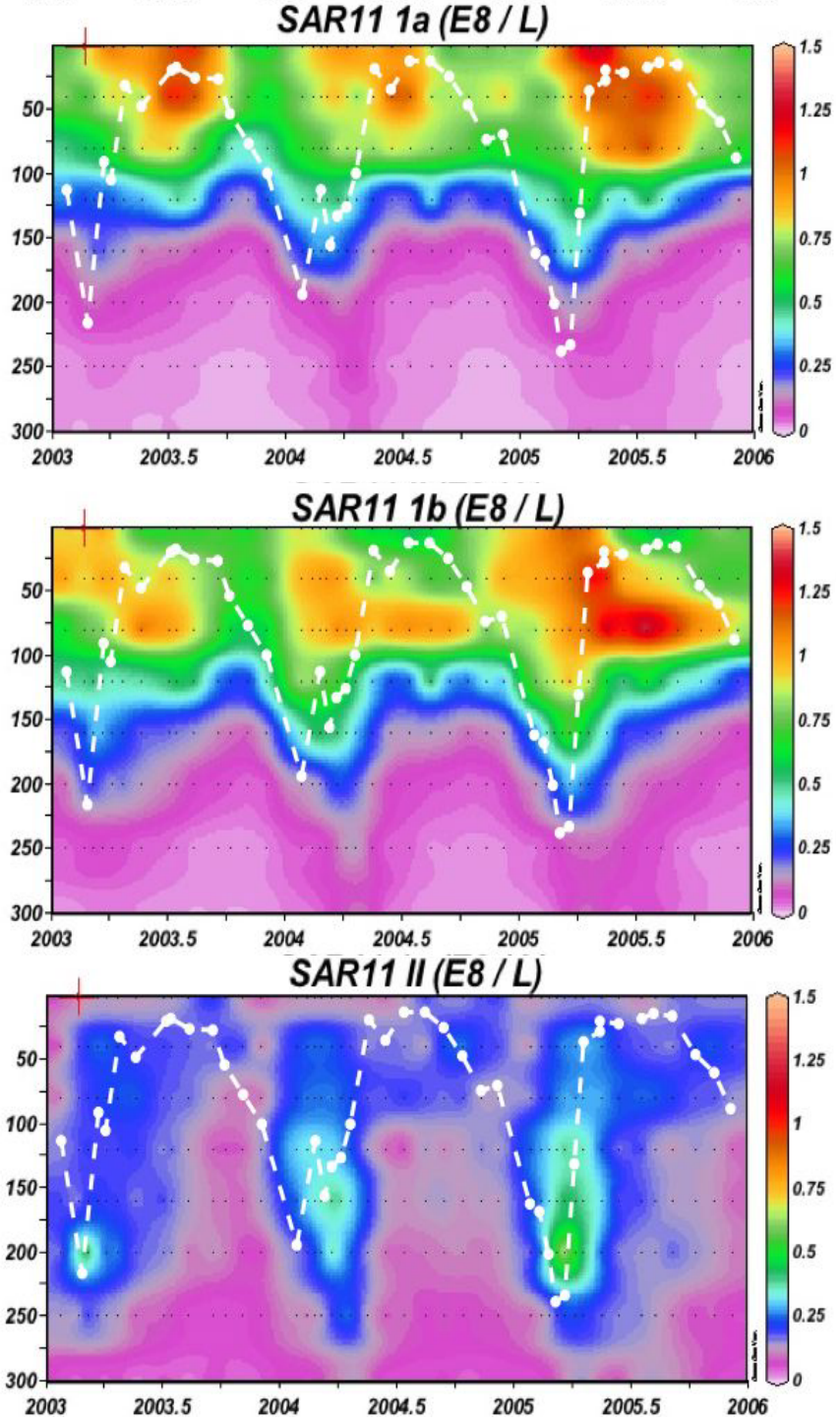




Courtesy of Craig Carlson (UCSB);
Goldberg et al., 2009

- DOC in surface water is diagenetically "fresher" than in the upper mesopelagic zone during stratified periods

- Decrease in DCNS Yield in mesopelagic after stratification indicates DOC is diagenetically altered *after* export



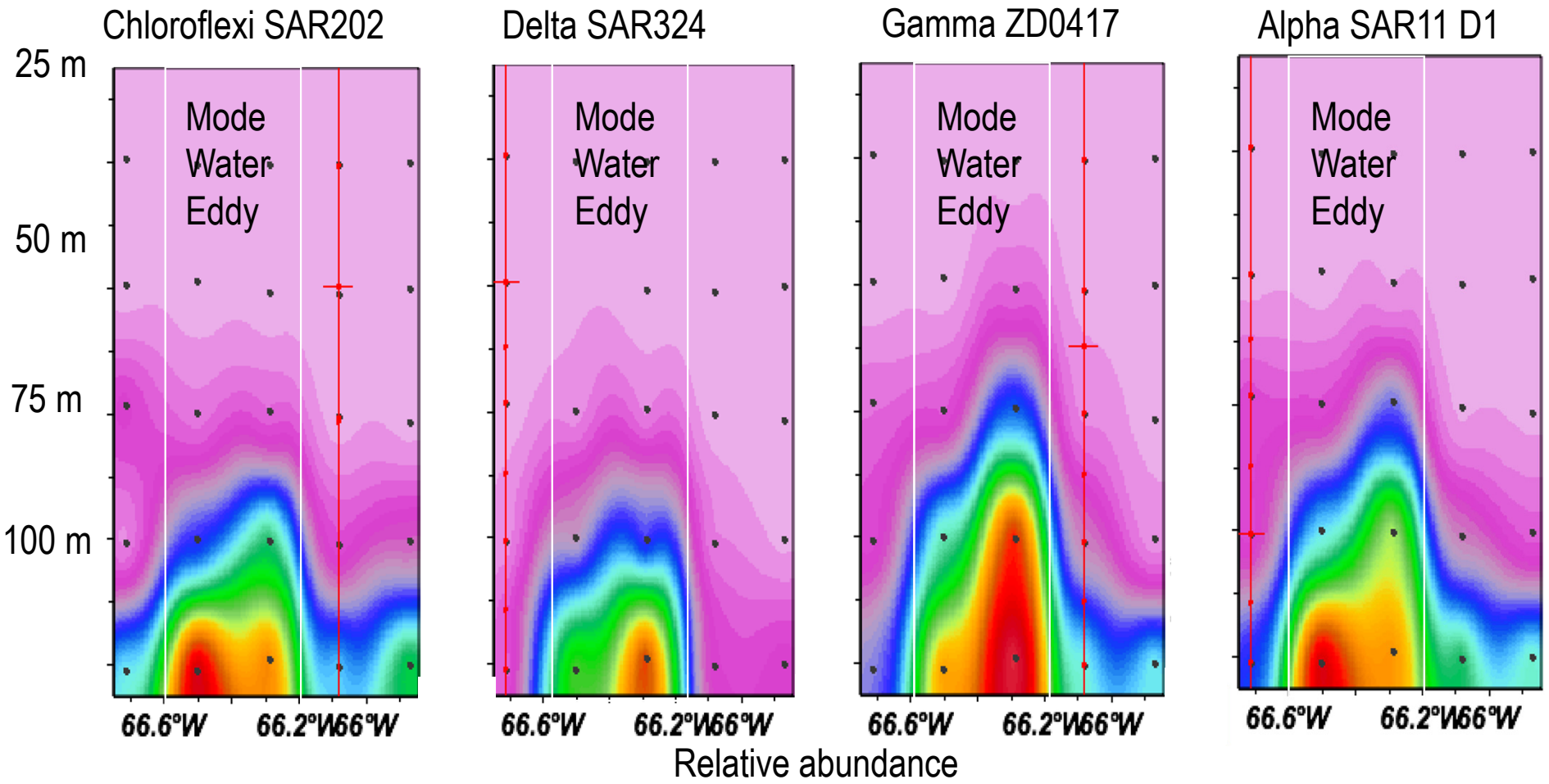
Seasonal Dynamics of SAR-11 Ecotypes (Pelagibacterales)

Data courtesy of Craig Carlson (UCSB); Carlson et al., 2009

- Contours of SAR11 Ecotypes Determined from FISH counts and relative contribution of SAR11 OTUs in T-RFLP fingerprints

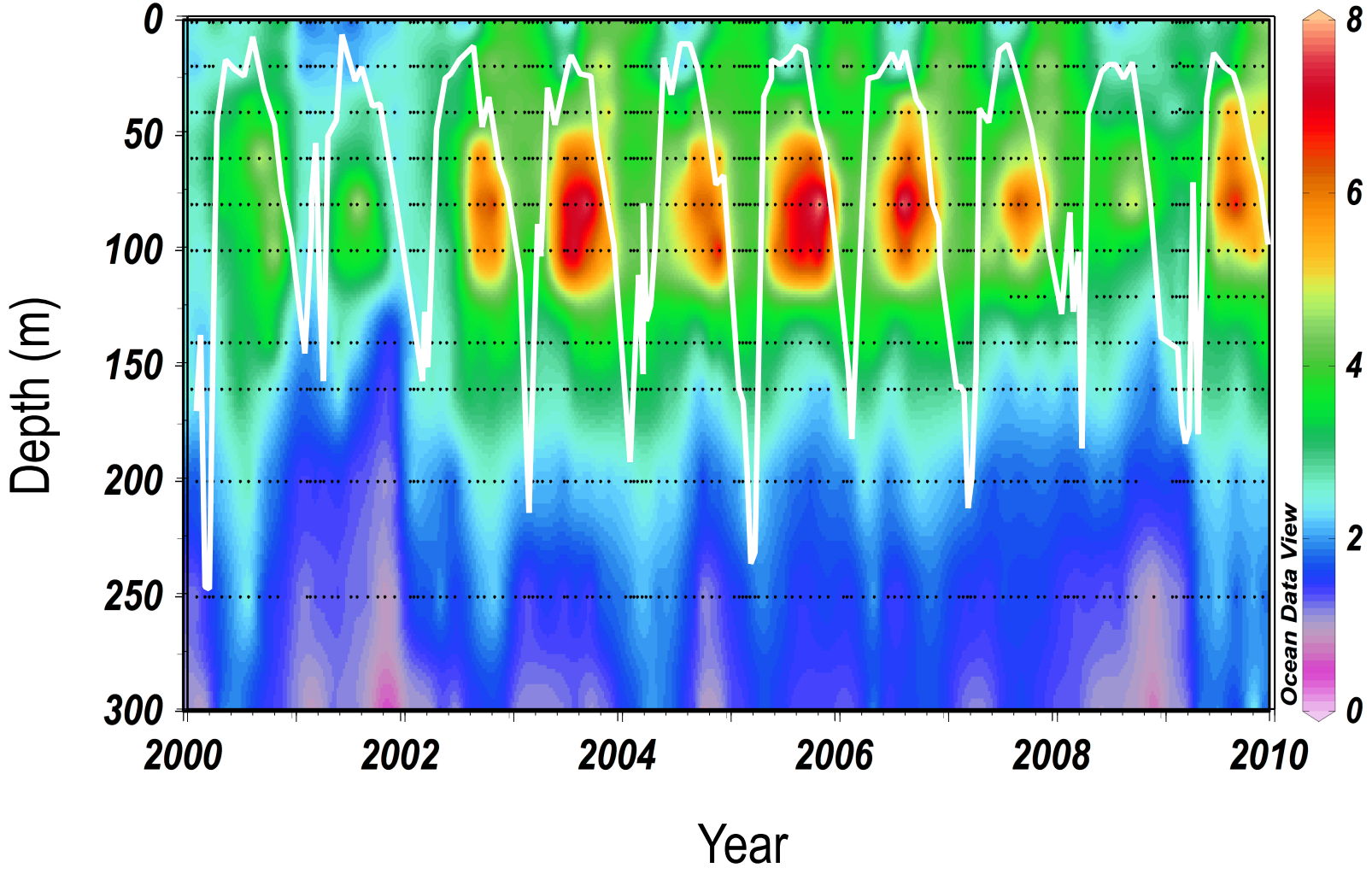
- Distinct Ecotypes of SAR 11 including a mesopelagic subgroup who's growth is cued to delivery of organic matter

Heterotrophic bacterioplankton taxa that appear to be physically introduced to the euphotic zone during Isopycnal uplift of a mode water eddy near BATS



Courtesy of Craig Carlson (UCSB); Nelson et al., 2013

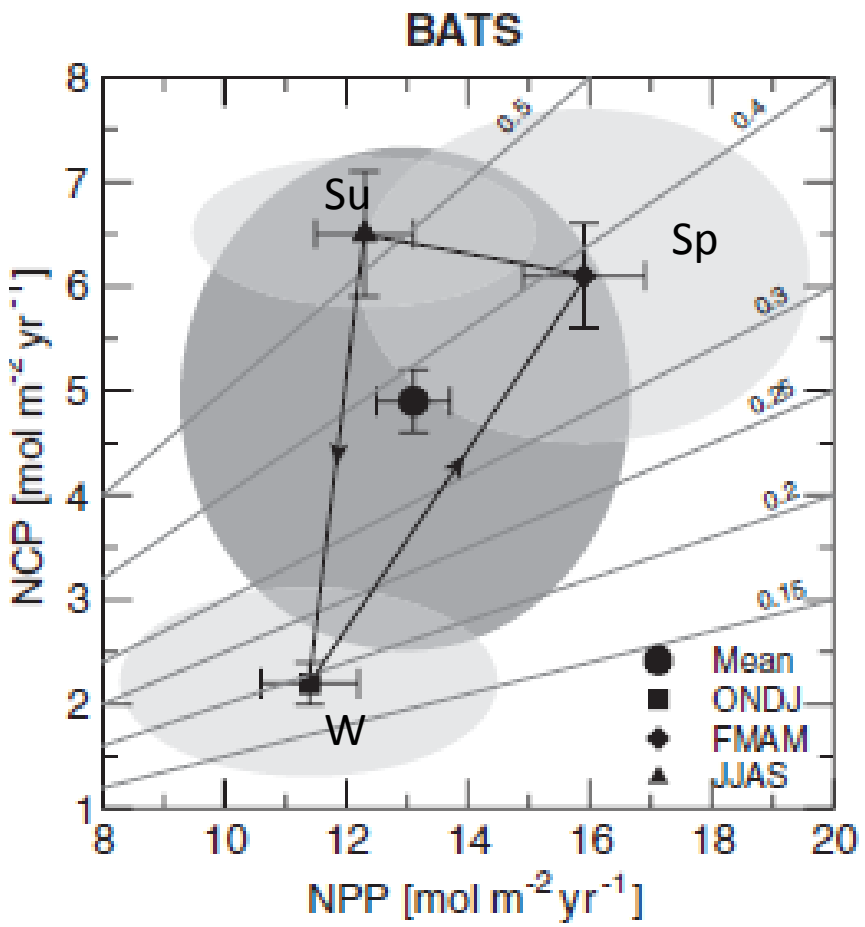
Viroplankton Dynamics in the Sargasso Sea



Courtesy of Craig Carlson (UCSB);
Parsons et al., 2012

Reconciling Net community Production in the Sargasso Sea

Complete explanation of the seasonal drawdown in salinity normalized DIC (nDIC) remains elusive.



Past biogeochemical observations

Net C removal is uncoupled from N, P cycles, with highest C drawdown at lowest N, P availability.
NCP:NPP = 0.38

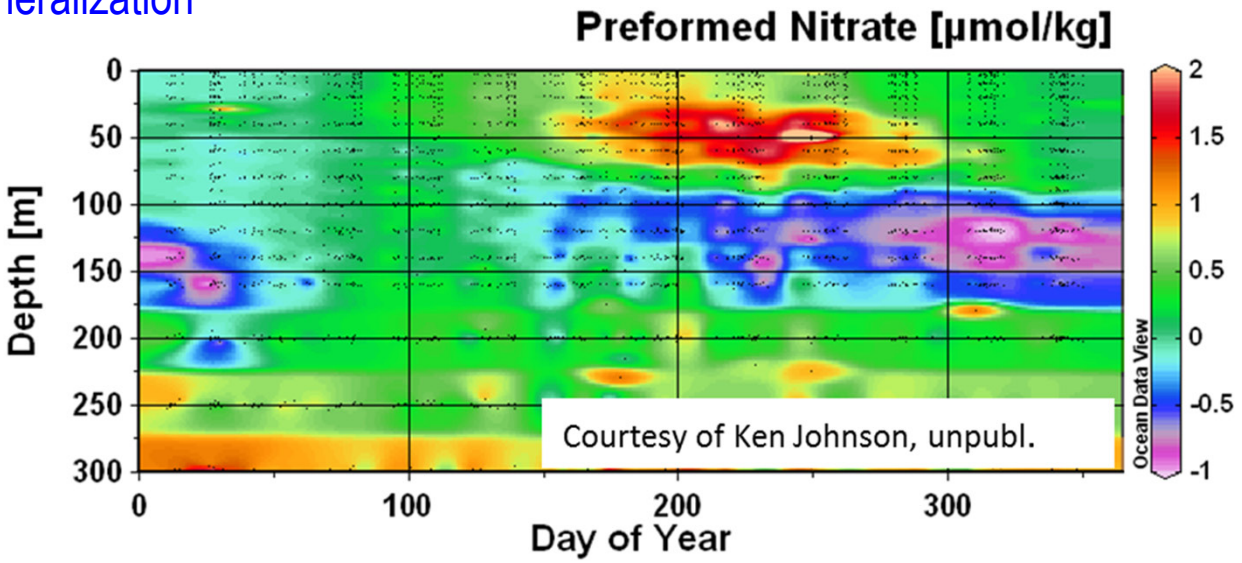
Traps are not catching C (**F_{POC} : NPP = 0.08**), so missing a mechanism(s) of carbon export.

Brix et al. 2006

Summertime Primary Production in the Sargasso Sea?

Unpublished data courtesy of Ken Johnson (MBARI)

Coupling of oxygen and nitrogen: red = 'to small a deficit in N' to support production; blue = 'not enough N arising from remineralization'

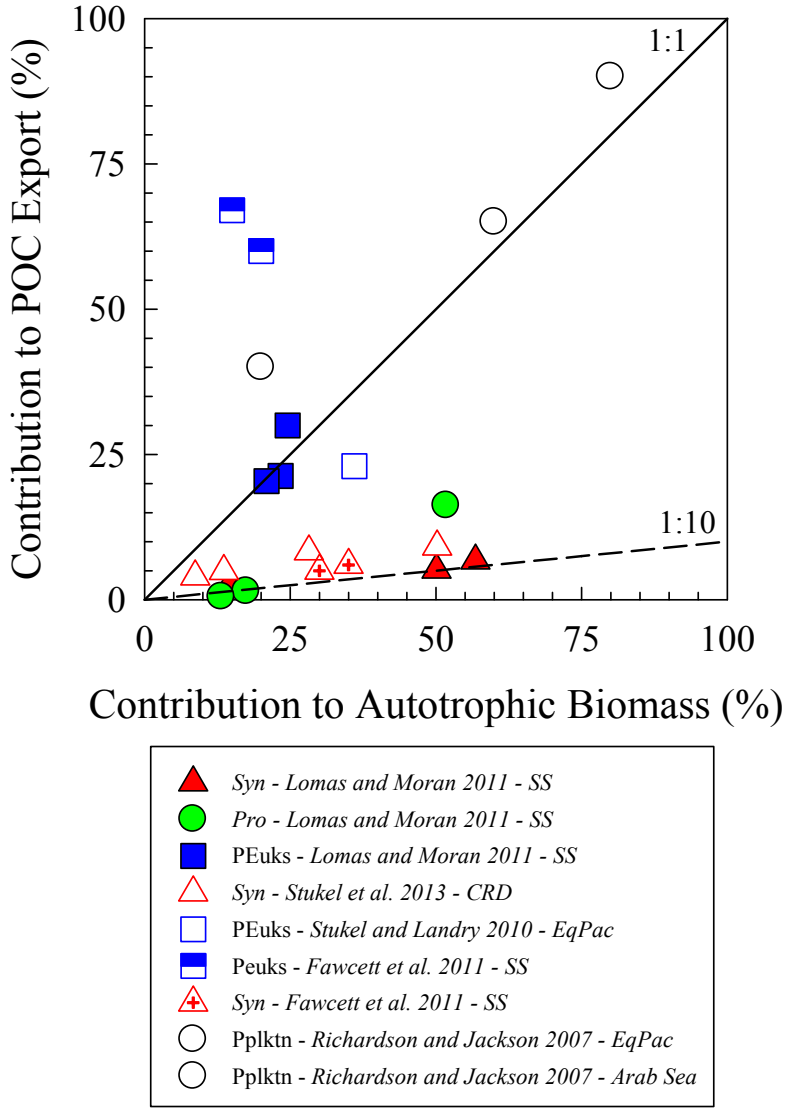


• Nutrient data from BioFloats suggest that in the Sargasso Sea there is consumption of N below the euphotic zone that leads to production in the euphotic zone.

• Apparently not due to mixing through the mixed layer depth, but could be due to vertical migration of small phytoplankton, 'restriction' on nitrification.

Johnson et al., unpubl. data

Summertime Primary Production in the Sargasso Sea?



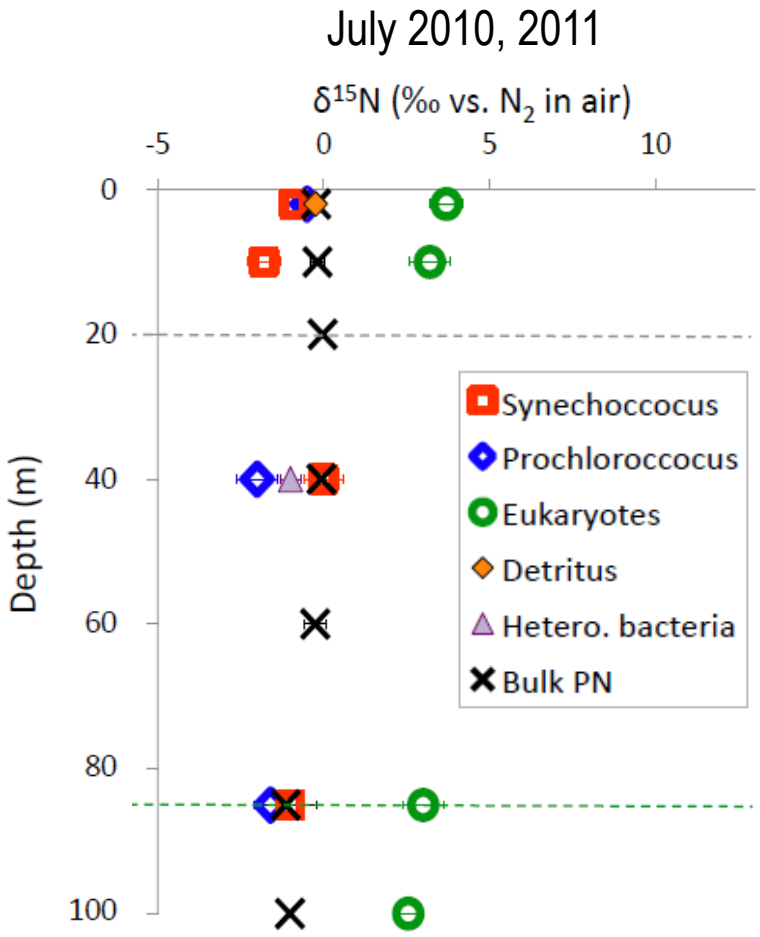
Courtesy of Mike Lomas (BLOS)

Cell size and carbon export - revisited

There is a growing body of literature, from diverse regions, that shows pico- and nanoplankton groups can make significant contributions to organic matter export, in comparison to their contribution to biomass.

What nitrogen sources support phytoplankton in the Sargasso Sea?

Courtesy of Mike Lomas (BLOS)
Fawcett et al., 2011



What nitrogen sources support phytoplankton in the Sargasso Sea?

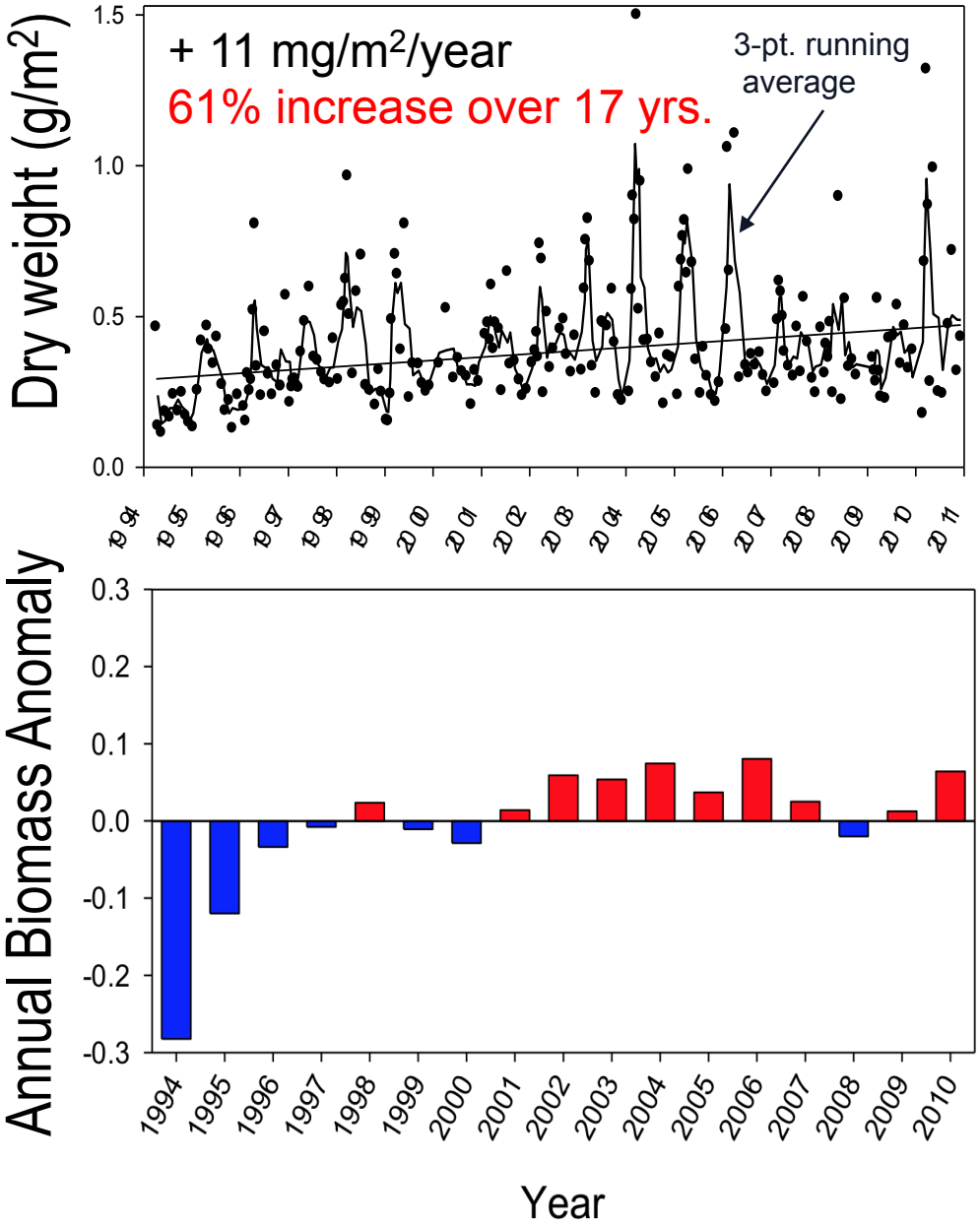
During summer, strongest stratification, eukaryotes are isotopically heavy (high del15N), but not cyanobacteria.

This isotopic signature can only come from growth on deep nitrate which has a high del15N, and is not related to uptake fractionation.

From this data, we can estimate a community f-ratio based upon isotopic signature and contributions to biomass. That value is: **0.15-0.23, similar to geochemical estimates of export, and much higher than sediment trap estimates of export production.**

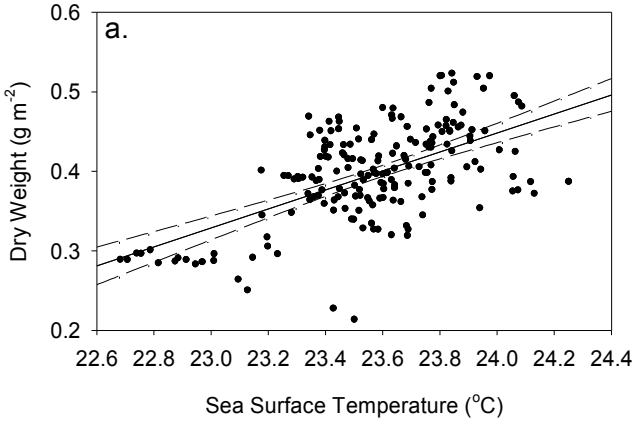
Increase in mesozooplankton biomass at BATS

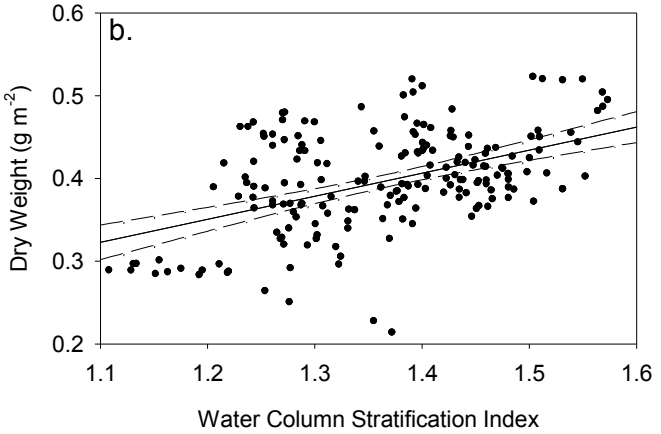
Steinberg et al., 2012



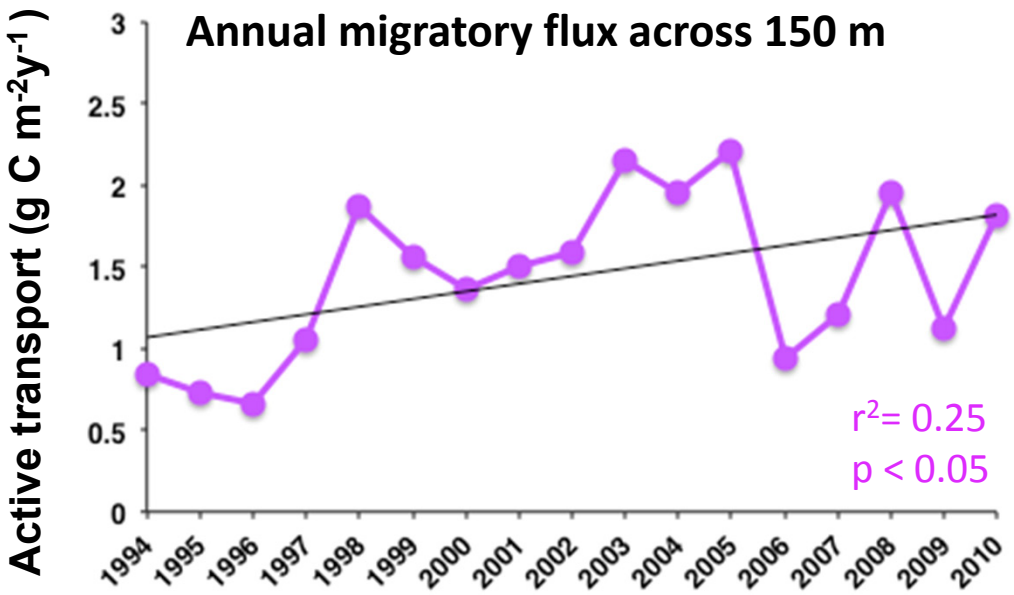
Why?

Increase with warming of ~0.5° C and increased stratification



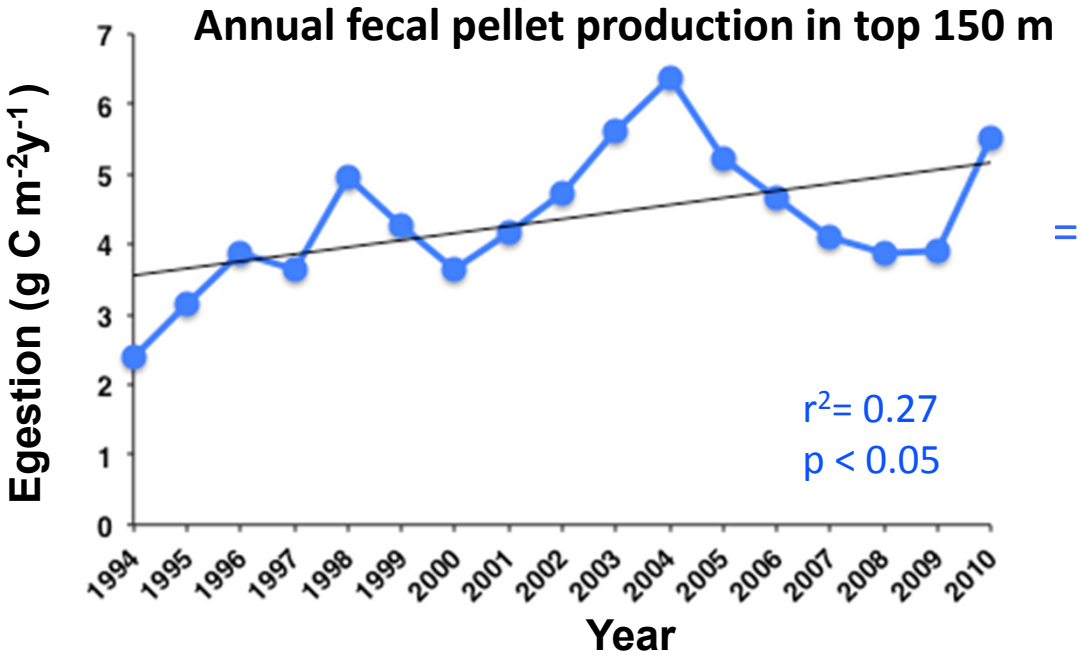


Consequence of biomass increase for biogeochemical cycling



Steinberg et al., 2012

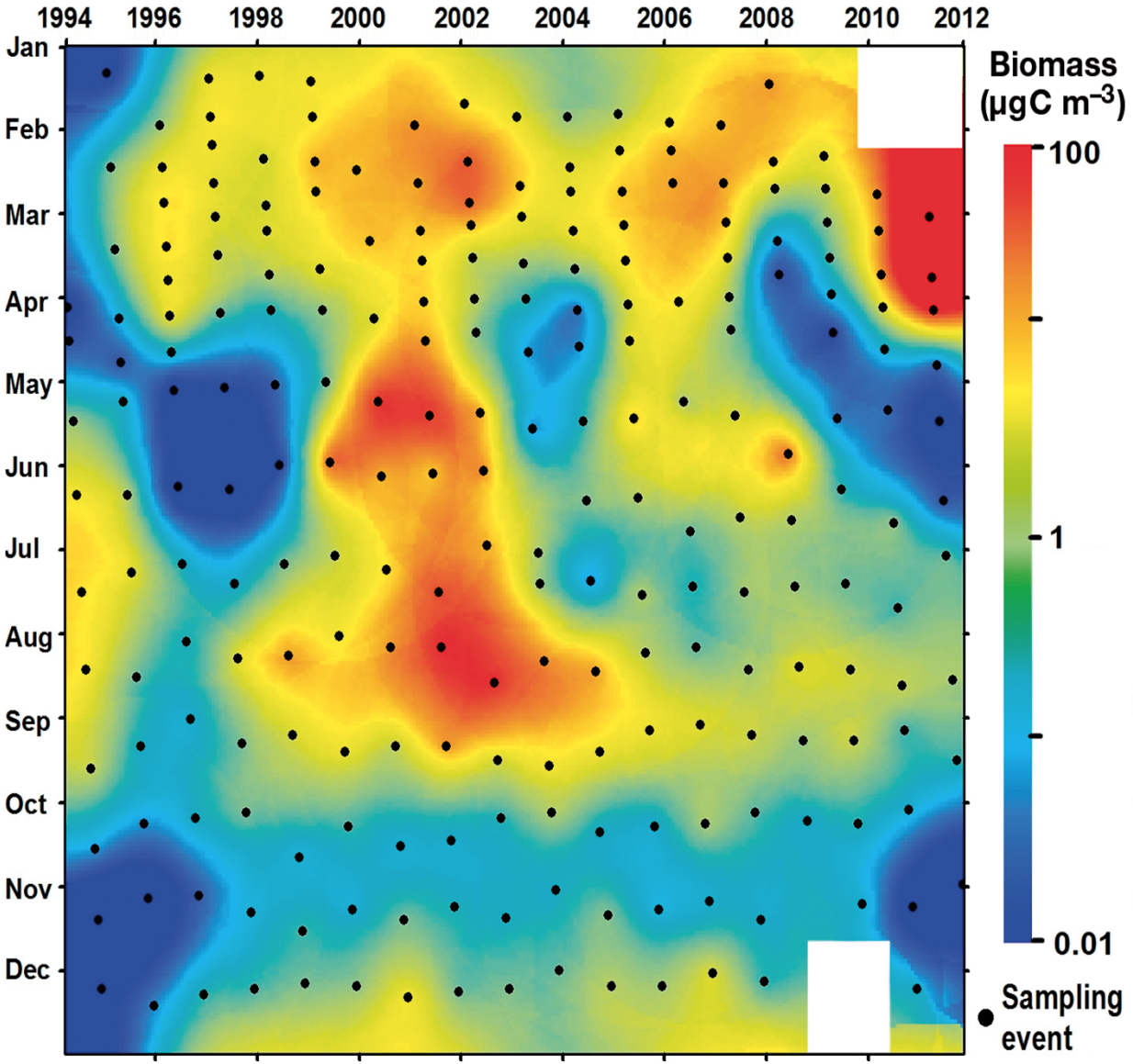
= 5-33% of POC flux



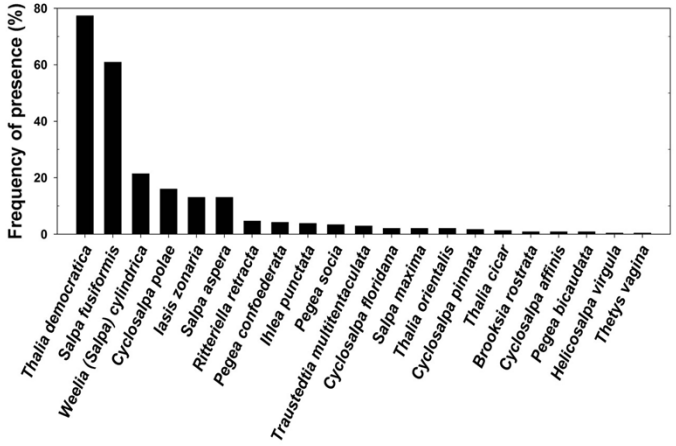
= 28-89% of POC flux

Seasonal and Interannual Salp Biomass

Stone and Steinberg 2014

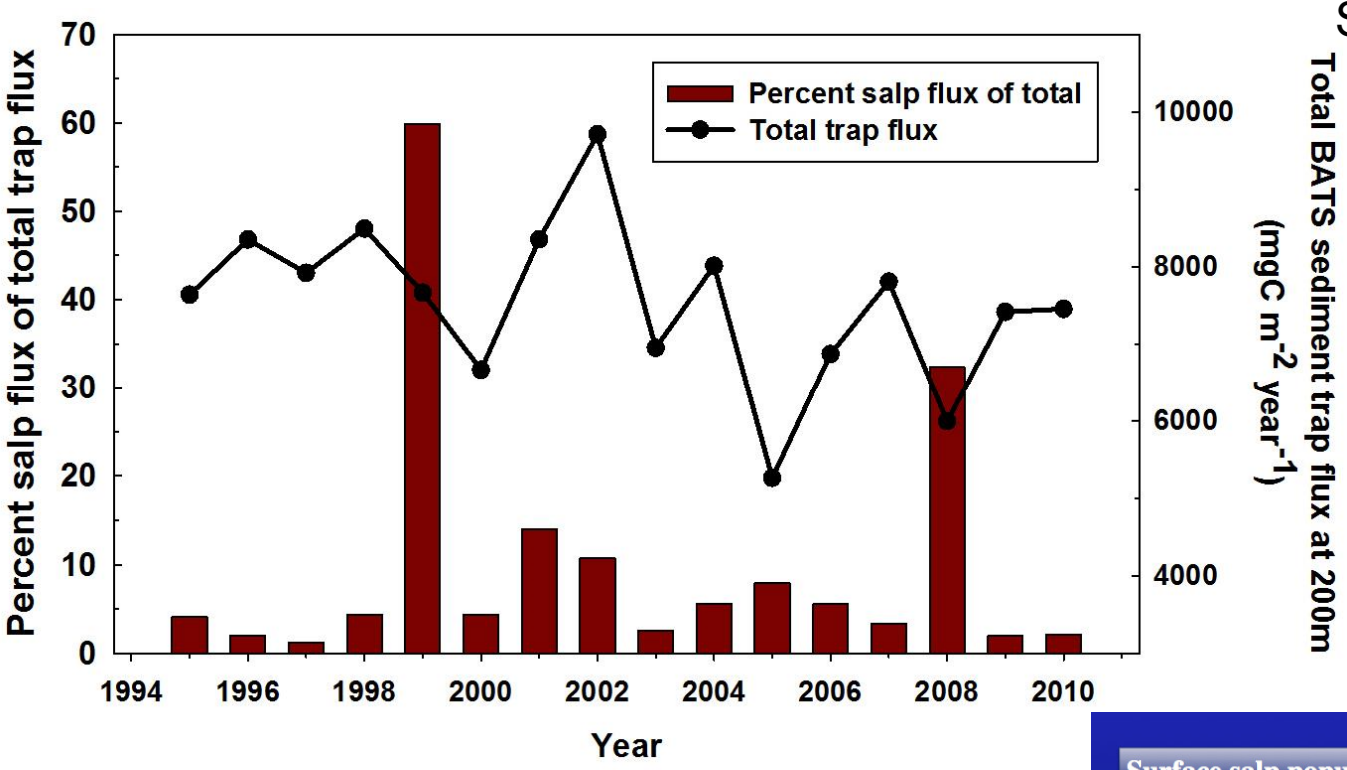


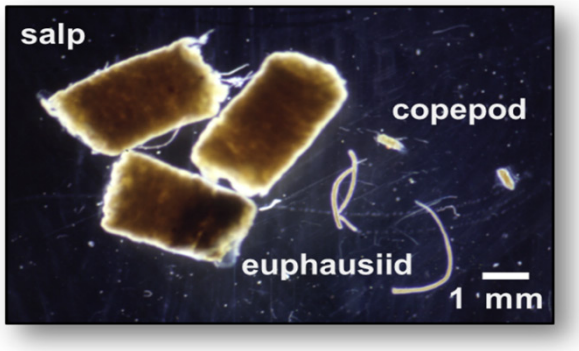
Thalia democratica and Salpa fusiformis dominant

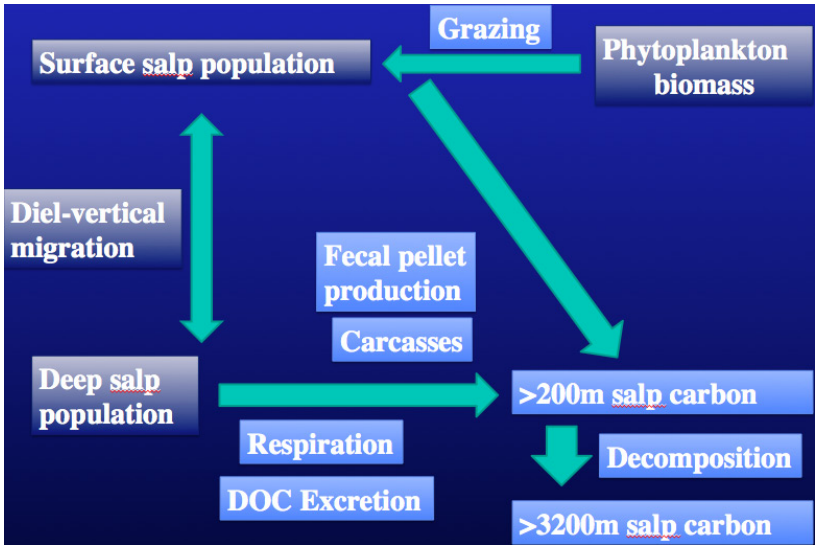


Salp Contribution to Annual Carbon Export at BATS

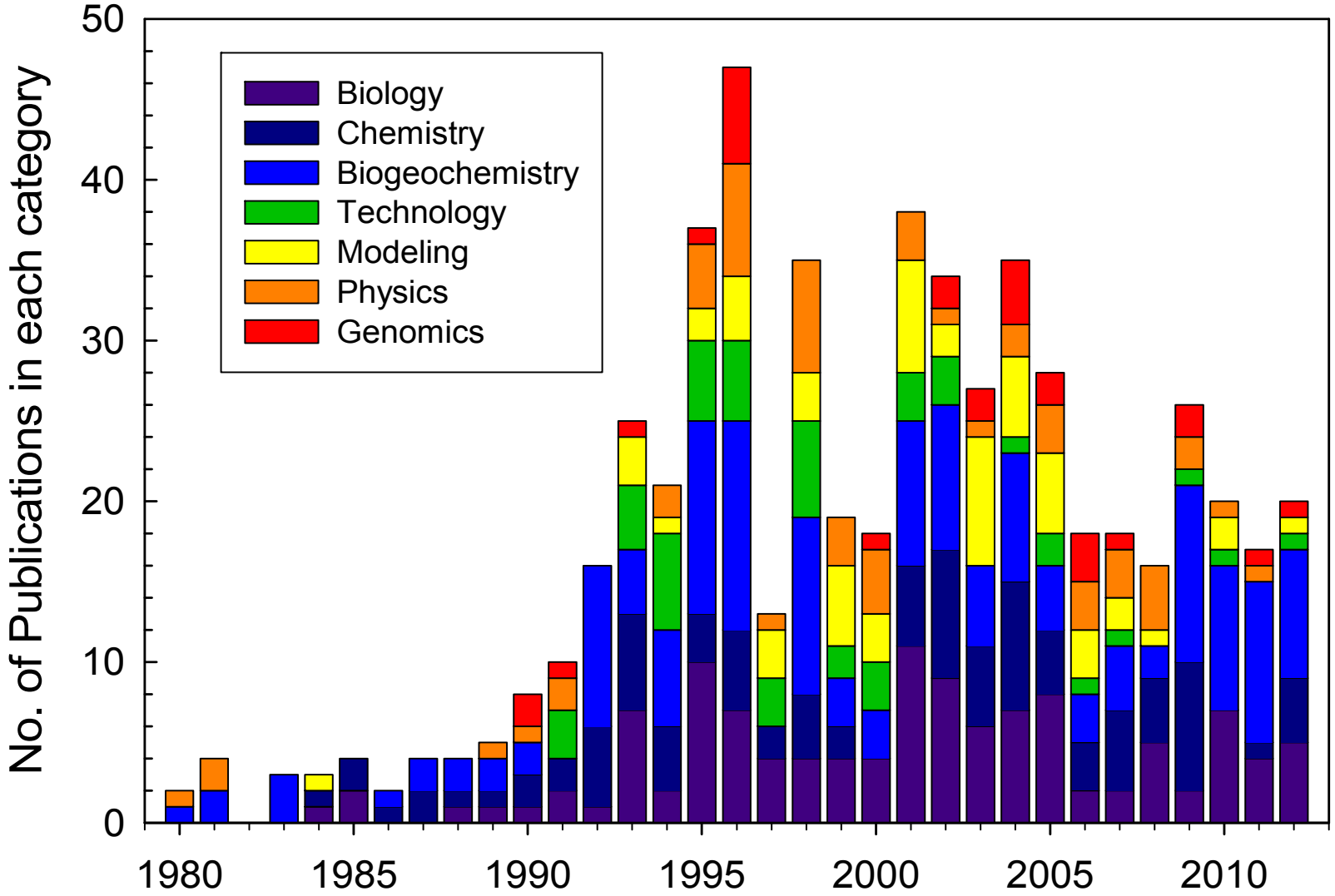
Stone & Steinberg *in prep*







Sustainable Diversity of Collaborative Research Around BATS



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Thanks to NSF program officers
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Neil Anderson; Don Rice;
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National Science Foundation
WHERE DISCOVERIES BEGIN

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BIOS

Past, Current and Associated BATS technicians

55 Research Technicians and Specialists in total over past 27 years

Fred Bahr; Nick Bates; Steve Bell; Margaret Best; Nathan Buck; Liz Caporelli; Ann Close Kevin Clouter; Peter Countway; Debra Clougherty; Alice Doyle; Rachael Dow (Gosling); Matthew Enright; Dafydd Evans; Rebecca Garley; Sarah Goldthwait; Alfonso Goncalves; Kjell Gundersen; Melodie Hammer; Frances Howse; Pat Hyder; Lilia Jackman; Rod Johnson; Joanna Jones; Rhonda Kelly; Paul Lethaby; Kevin Lew; Rebecca Little; Vivienne Lochhead; Julia Mathesen; Natasha McDonald; Julian Mitchell; Sam Monk; Keven Neely; Karen Orcutt; Mark Otero; Richard Owen; Violetta Paba; Rachel Parsons; Sybille Pluvinage; Cathy Rathburn; Nicholas Record; Megan Roadman; James Sadler; Marta Sanderson; Jens Sorensen; Sam Stevens; Shannon Stone; Matt Tiahlo; Chrissy Van Hilst; Elise Van Meerssche; Tye Waterhouse; Jonathan Whitefield

Recent BATS Collaborations (2005-present)

A growing list of ancillary projects that use the opportunity to sample on BATS cruises!

SCOPE Investigator	Member, National Academy of Sciences	Fellow, American Geophysical Union	Moore Foundation Microbiology Fellow

Note: MBARI: Monterey Bay Aquarium and Research Institute; NOC: National Oceanography Centre (UK); WHOI: Woods Hole Oceanographic Institution

Principal Investigator	Institute	Time Period	Project
Andreas Andersson	UC, San Diego	2005-present	Seawater geochemistry and coral reef metabolism and linkages with ocean acidification.
Mark Altabet	UMass Dartmouth	2011-2014	Microbial ecology of nitrogen fixation, particularly by unicellular and heterotrophic organisms.
Barbara Campbell	U. Delaware	2008-2010	Genomic samples and manipulation experiments to study relationships between abundance of specific bacterial clades and metabolic activity.
Max Berkelhammer	U. Illinois	2014-present	Carbonyl sulphide in the marine- atmosphere boundary layer as a gaseous tracer for phytoplankton productivity.
Tom Bibby	NOC (UK)	2005-present	Phytoplankton ecology using in-situ instrumentation such as Fast Rate Repetition Fluorometry and molecular techniques with an emphasis on protein catalysts.
Alexander Bochdansky	Old Dominion U.	2015-present	Development of a deep-sea particle collector to better understand the sinking flux and transformation of particles in the deep ocean.
Ed Boyle	MIT	2005-2014	Trace metal concentrations in the upper ocean using an automated trace element sampler.
Mya Breitbart	U. South Florida	2008-2010	Microbial interactions and processes, specifically viral diversity and function in the Sargasso Sea.
Kristen Buck	U. South Florida	2011-2014	Trace metal dynamics in the upper ocean at and Hydrostation and BATS.
Ken Buesseler	WHOI	2005-present	Ocean particle flux estimates using geochemical approaches (^{234}Th inventories) and novel instrumentation such as Neutrally Buoyant Sediment Traps, Twilight Zone Explorer and profiling bio-optical floats.
Craig Carlson	UC, Santa Barbara	2005-present 2005-2013 2005-2013 2005-2011	Microbial processes in upper ocean focusing on bacteria communities and bacteria production rates. Assessment of bacteria communities from bacteria DNA and Fluorescent In-situ Hybridization measurements. Seasonal cycling of dissolved sugar in the upper ocean. Oceanic virioplankton variability at BATS.
Penny Chisholm	MIT	2005-2012	*Prochlorococcus* ecotype diversity and *Prochlorococcus* phages with the objective to generate a time-series record of variability in the abundance of specific type-examples of the two broad *Prochlorococcus* ecotypes (high-light, and low-light) in the Sargasso Sea.
Tom Church	U. Delaware	2007-2009	Trace metals in the marine and atmospheric boundary layer with a focus on wet deposition of these elements to the ocean.

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Maureen Coleman	U. Chicago	2014-present	Nutrient-virus interactions and their impact on marine biogeochemistry based on samples for viral and microbial metagenomes to look at trace metal and phosphate impacts on viral infection of cyanobacteria and picoeukaryotes.
Maureen Conte	Marine Biological Laboratory/BIOS	2005-present	Ocean Flux Program (OFP), which is closely coupled with the BATS program in quantifying the elemental flux of particles from the upper ocean to the deep ocean.
Andrew Dickson	UC, San Diego	2005-present	Time-series of surface CO_2 measurements initiated by Dave Keeling which is the longest continuous ocean time-series of CO_2.
Solange Duhamel	Lamont Doherty Earth Observatory	2015-present	Factors controlling marine Synechococcus distribution, functions, genetic and taxonomic diversity at BATS with a focus on molecular probing of nutrient stresses.
Sonya Dhyrman	Columbia U.	2006-2008	Protein mapping in the marine diazatroph *Trichodesmium.*
Steve Emerson	U. Washington	2011-2012	Global assessment of noble gases in the deep ocean.
Margaret Estapa	Skidmore College	2011-present	Application of autonomous devices (e.g., Neutrally Buoyant Sediment Traps) to collect more spatial and higher temporal information on vertical carbon fluxes in the Sargasso Sea. Co-developed a profiling bio-optical proxy for both slow and rapid flux events.
Charles Eriksen	U. Washington	2014-present	Development of deep (0-6000m) ocean gliders and use for defining 3-dimensional variability. BATS has been test site for past 2 years and is currently only location globally with an operational deep glider. Anticipate three operational units in Sargasso Sea for 2015-2016.
Sarah Fawcett	Princeton U.	2009-2014	Quantifying the natural ^{15}N isotopic abundance in flow cytometrically sorted autotroph and bacterial populations to determine the relative importance of deep NO_3 and nitrogen derived from nitrogen fixation as nitrogen sources for growth
Frank Ferarri	Smithsonian Institution	2005-2012	Deep zooplankton tows to document copeped abundance and copepod sex ratios.
Gavin Foster	NOC (UK)	2014-present	Boron isotope measurements in coral as a proxy for ocean pH over the last hundred years
Steve Giovannoni	Oregon State U.	2005-present	Bacteria community analysis from DNA extractions and proteomics analysis of samples from BATS at 200m to further characterize the SAR11 metagenome.
Sharon Grim	U. Delaware	2008-2010	Genomic samples and manipulation experiments to study relationships between abundance of specific bacterial clades and metabolic activity, as well as which metabolic genes are most abundantly expressed.
Dennis Hansell	U. Miami	2005-present	Dissolved organic carbon and nitrogen measurements at BATS.
Gideon Henderson	Oxford University	2011-present	Estimation of dust and iron fluxes to the surface ocean using ocean measurements of ^{234}Th.
Patrick Hyder	UK Meteorological Office	2005-present	Validation of hindcast and operational numerical models using hindcast and forecast models for observational validation.

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Seth John	U. South Carolina	2014-present 2013-2014	Nutrient-virus interactions and their impact on marine biogeochemistry based on samples for viral and microbial metagenomes to look at trace metal and phosphate impacts on viral infection of cyanobacteria and picoeukaryotes. Trace elements in the deep ocean benthic layer.
Ken Johnson	MBARI	2009-2012	Upper ocean productivity using profiling CTD floats equipped with nitrate, fluorometry and oxygen sensors.
Dave Kadko	U. Miami	2010-2014	Determination of the cosmogenic produced radionuclide Be^{7} as a tracer of vertical and horizontal mixing processes in the Sargasso Sea to help quantify nutrient fluxes and new production.
Ron Keane	U. South Alabama	2011-2013	Upper ocean sulphur dynamics with a focus on DMS production and emission to the atmosphere
David Kirchman	U. Delaware	2008-2010	Genomic samples and manipulation experiments to study relationships between abundance of specific bacterial clades and metabolic activity, as well as which metabolic genes are most abundantly expressed.
Jeff Krause	U. South Alabama	2005-present	Characterization of lithogenic and biogenic sillica in the upper ocean at BATS.
Karl Lamborg	WHOI	2007-2013	Mercury cycling in the upper ocean with emphasis on methylated species.
Richard Lampitt	NOC (UK)	2014-present	Coordination of research efforts at sustained ocean time-series and mooring as part of the EU FixO3 project
Mario Lebrato	IFM GEOMAR (Germany)	2012-2013	Global inventory of trace elements in particular Mg/Ca ratios for investigating coccolithophore abundance.
Adam Martiny	U. Southern California	2010-2013	Microbial and genomic investigation of Prochlorococcus and its contribution to new production in the Sargasso Sea.
Matt McCarthy	UC, Santa Cruz	2015-present	The Microbial Nitrogen pump: coupling ^{14}C and compound-specific amino acids to understand the role of microbial transformations in the ocean's refractory DON pool.
Dennis McGillicuddy	WHOI	2005-present	Mesoscale eddy dynamics and their role in modulating biogeochemcial cycles in the Sargasso Sea using satellite altimetry and numerical modeling. Provides near-real-time eddy maps for all BATS related cruises.
Brad Moran	U. Rhode Island	2006-2008	Particle flux estimates in upper ocean using inventories of naturally occurring radionuclides ^{234}Th and ^{210}Po.
Julio Morell	U. Puerto Rico	2005-present	Hydrography of the Sargasso Sea (BATS Validation sections from Bermuda to Puerto Rico) with emphasis on physical forcing of the biological system.
Pia Moisander	UMass Dartmouth	2011-2014	Microbial ecology of nitrogen fixation, particularly by unicellular and heterotrophic organisms.
Suzanne Neuer	Arizona State U.	2008-2011	Genomic analysis of sediment trap material.

Recent BATS Collaborations (2005-present)

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Norm Nelson	UC, Santa Barbara	2005-present	NASA funded Bermuda Bio-Optical Project at BIOS which works closely with BATS and seeks to quantify (i) downwelling & upwelling solar irradiance and (ii) inherent optical seawater properties.
Monica Orellana	Institute for Systems Biology	2010-2012	Dynamics of oceanic polymer gels and their production by phytoplankton as an export source of DOM.
Kim Poppendorf	Lamont Doherty Earth Observatory	2015-present	Factors controlling marine Synechococcus distribution, functions, genetic and taxonomic diversity at BATS with a focus on molecular probing of nutrient stresses.
Steve Riser	U. Washington	2005-2009	Deployment and recovery of ARGO and APEX floats to assess mesopelagic variability in Sargasso Sea.
Mak Saito	WHOI	2015-present	Application of a new nutrient stress protein biomarker method 'targeted metaproteomics', to discern nutrient (nitrogen, phosphate, iron, etc.) stress in high-light Prochlorococcus and associated seasonal variability.
Peter Sedwick	Old Dominion U.	2007-2013	Assessment of iron input to the ocean through wet deposition and dust events and consequential influence on phytoplankton production.
Dave Siegel	UC, Santa Barbara	2011-2013	Mesoscale eddy dynamics and role of Lagrangian Coherent events in creating enhanced export production.
Danny Sigman	Princeton U.	2011-2014	Sources and supply rates of nitrogen to phytoplankton in the Sargasso Sea through isotopic analyses.
Frederik Simons	Princeton U.	2014-present	Development of a novel free drifting passive sonobuoy 'Son-of-Mermaid' to provide better global coverage for seismic tomography studies investigating wave speeds in Earth's interior following earthquakes.
Rachel Stanley	WHOI	2005-2008	Analysis of noble gases and the triple isotopic signature of oxygen in the upper ocean to help physically constrain oxygen budgets and better quantify net community production.
Hans Christian Steen-Larson	Laboratoire des Sciences du Climat et de l'Environnement (Paris, France)	2013-present	Analysis of the isotopic ratio of ^{18}O:^{16}O as conservative tracer to (i) estimate rates of evaporation (ii) 'finger print' local evaporative flux to estimate long range atmospheric transport and (iii) estimate origin of deep water masses.
Matt Sullivan	U. Arizona	2014-present	Nutrient-virus interactions and their impact on marine biogeochemistry based on samples for viral and microbial metagenomes to look at trace metal and phosphate impacts on viral infection of cyanobacteria and picoeukaryotes.
Ben Twinning	Bigelow Laboratory for Ocean Sciences	2007-2013	Role of metal species in particular iron on phytoplankton growth in the Sargasso Sea with a focus on elemental accumulation in phytoplankton cells using synchrotron x-ray fluorescence microscopy.
Simon Ussher	U. Plymouth (UK)	2007-2011	Role of dissolved iron on phytoplankton productivity.

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Ben Van Mooy	WHOI	2008-2010 2014-present	Phospho- and sulfo-lipids substitutions in the microbial membranes under phosphorus-stress in the Sargasso Sea. Oceanic phosphorous redox cycles as revealed by rates of chemical phosphate reduction by plankton.
Kevin Vergin	Oregon State U.	2005-2013	Characterization of the microbial diversity at BATS using a new bioinformatics pipeline (Phyloassigner) and resulted in the discovery of four new *Peligibacterales* ecotypes at BATS.
Harold Vincent	U. Rhode Island	2014-present	Development of a novel free drifting passive sonobuoy 'Son-of-Mermaid' to provide better global coverage for seismic tomography studies investigating wave speeds in Earth's interior following earthquakes.
Jake Waldbauer	U. Chicago	2014-present	Nutrient-virus interactions and their impact on marine biogeochemistry based on samples for viral and microbial metagenomes to look at trace metal and phosphate impacts on viral infection of cyanobacteria and picoeukaryotes.
Bess Ward	Princeton U.	2011	Phytoplankton carbon and nitrogen utilization rates using stable isotopes.
Alexandra Worden	MBARI	2014-present	Nutrient-virus interactions and their impact on marine biogeochemistry based on samples for viral and microbial metagenomes to look at trace metal and phosphate impacts on viral infection of cyanobacteria and picoeukaryotes.