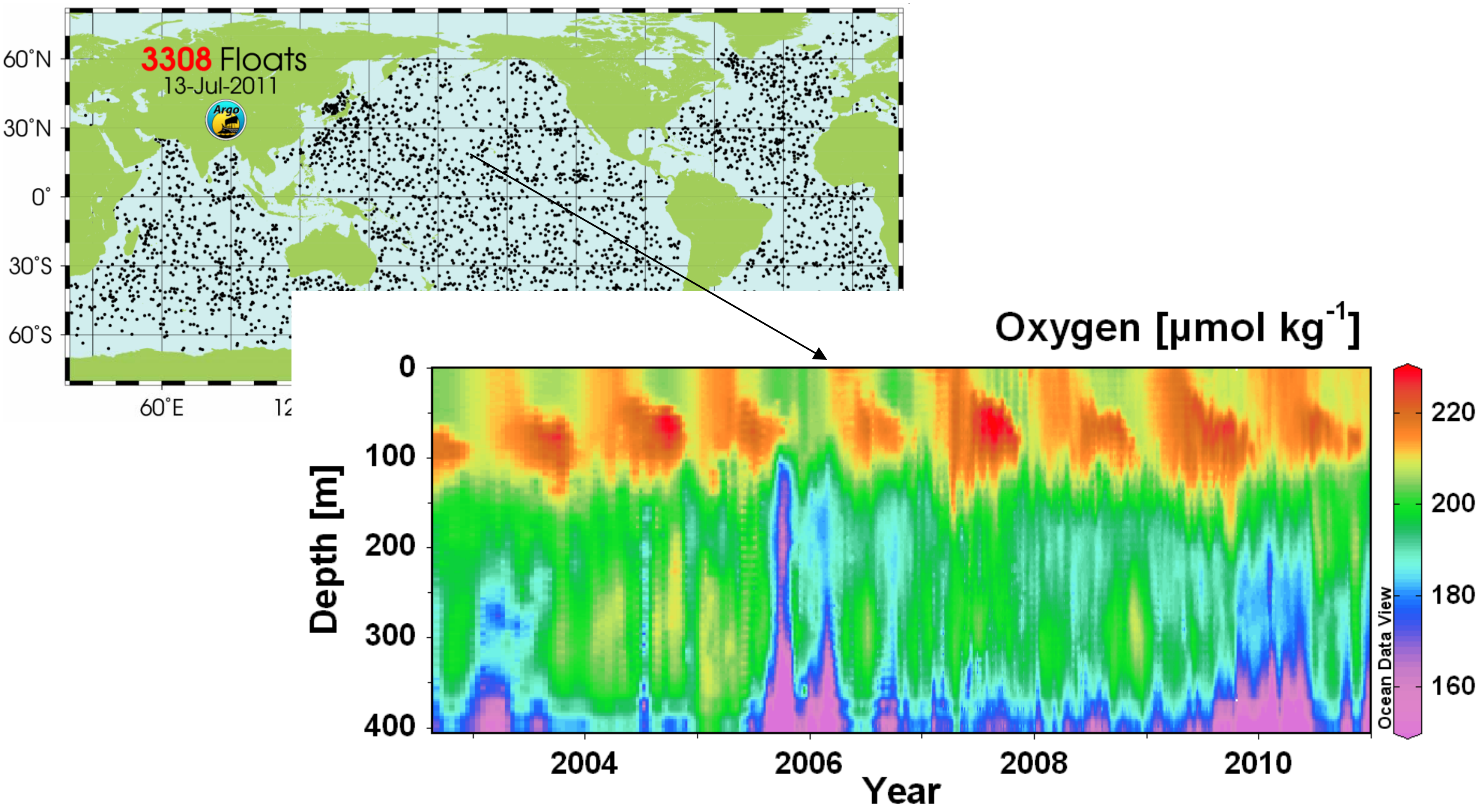
A vision for understanding the ocean with a global biogeochemical sensor network

Ken Johnson and the US Committee for GLOBE

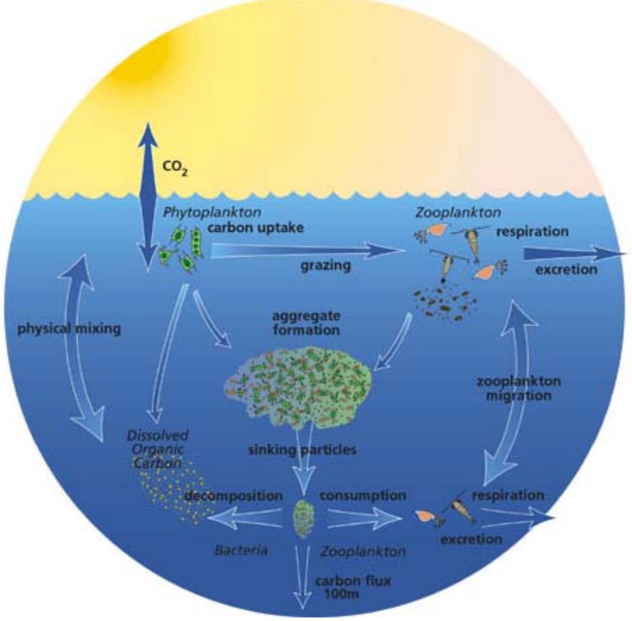


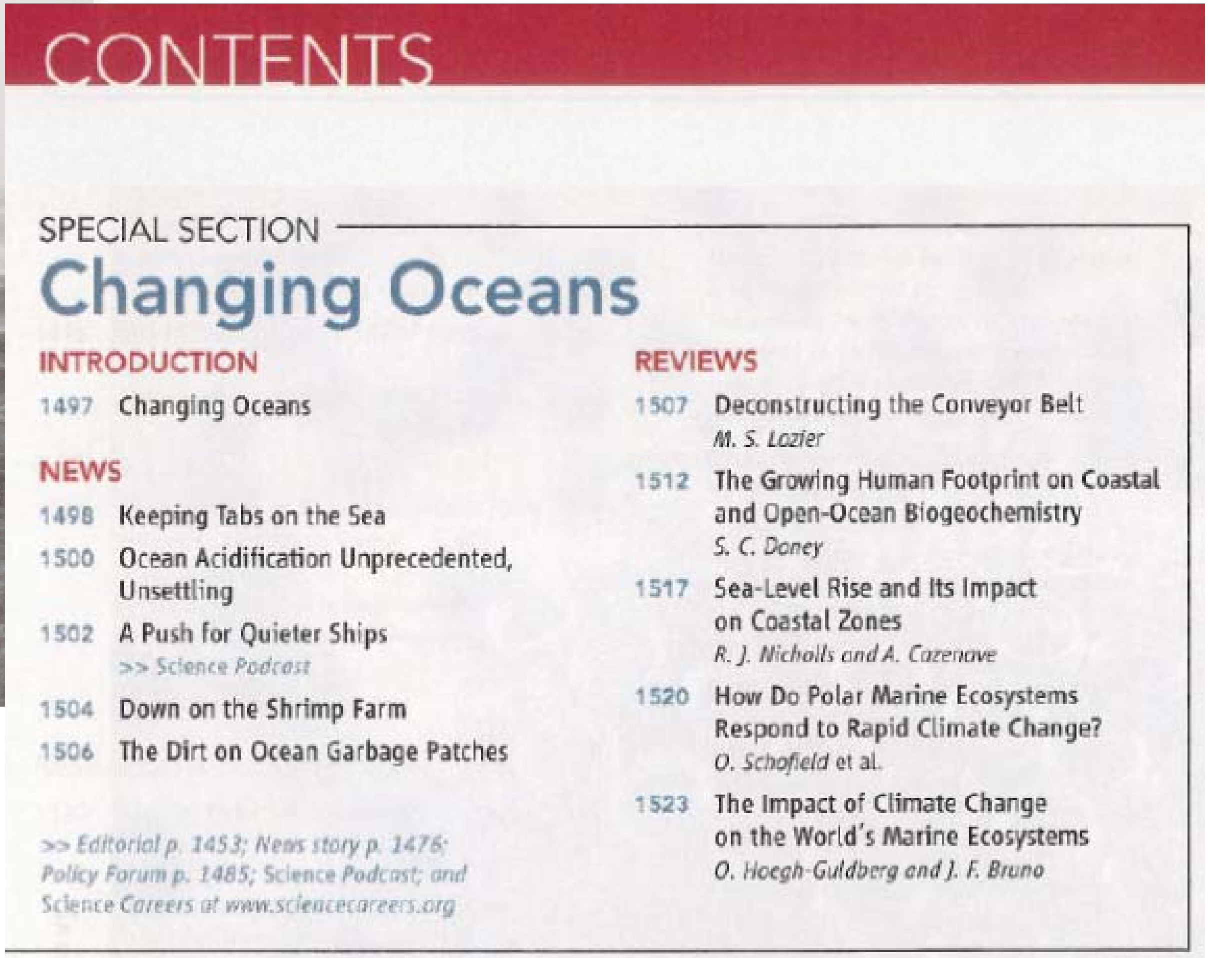
Grand challenges for ocean science:

1. Observe at a global scale how changing climate and ocean acidification interact with major portions of the ocean carbon, oxygen and nitrogen cycles.

2. Monitor the carbon, oxygen and nitrogen cycles with sufficient temporal resolution to identify perturbations as they might occur.

3. Provide reliable data that significantly improves global biogeochemical models.





CONTENTS

SPECIAL SECTION

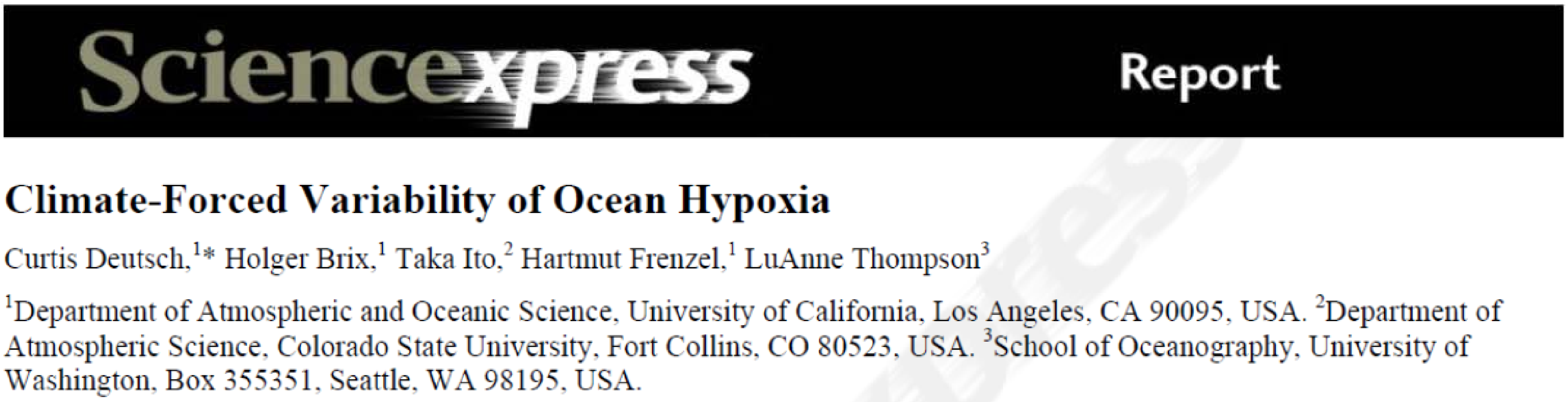
Changing Oceans

INTRODUCTION

NEWS

>> Editorial p. 1453; News story p. 1476; Policy Forum p. 1485; Science *Podcast; and* Science *Careers at www.sciencecareers.org*

REVIEWS



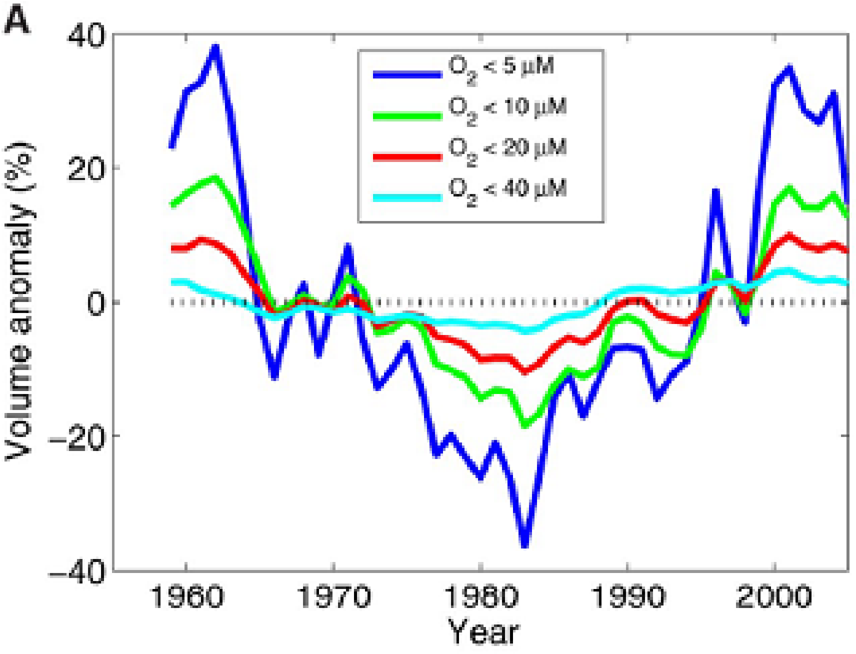
Sciencexpress Report

Climate-Forced Variability of Ocean Hypoxia

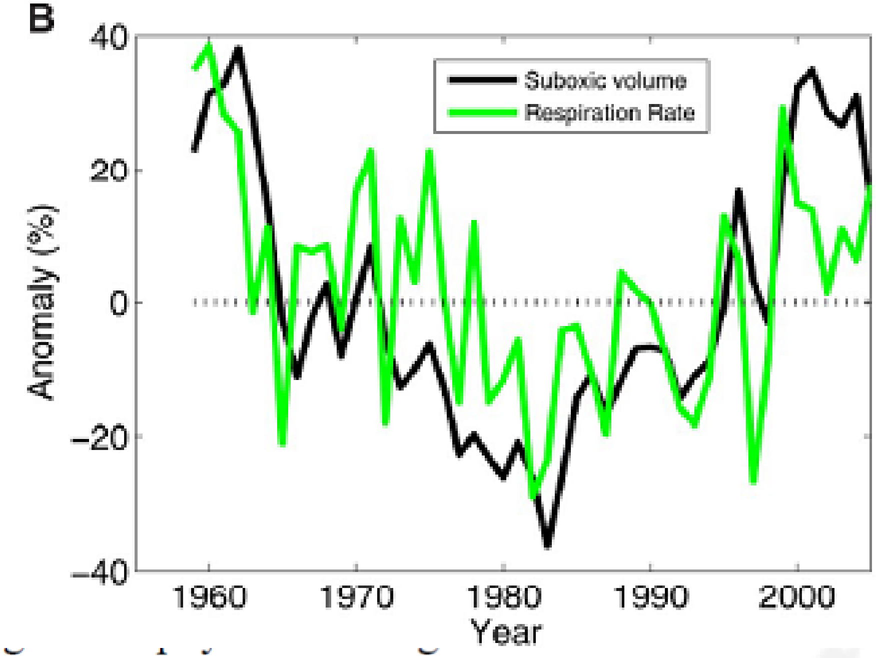
Curtis Deutsch,[1]* Holger Brix,[1] Taka Ito,[2] Hartmut Frenzel,[1] LuAnne Thompson[3]

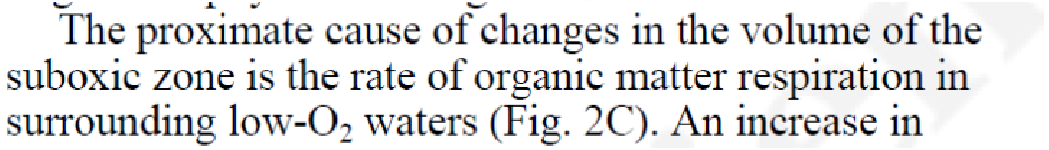
[1]Department of Atmospheric and Oceanic Science, University of California, Los Angeles, CA 90095, USA. [2]Department of Atmospheric Science, Colorado State University, Fort Collins, CO 80523, USA. [3]School of Oceanography, University of Washington, Box 355351, Seattle, WA 98195, USA.

Simulated change in global hypoxic volume



Observed change in hypoxic volume off So. California (CalCOFI time series)

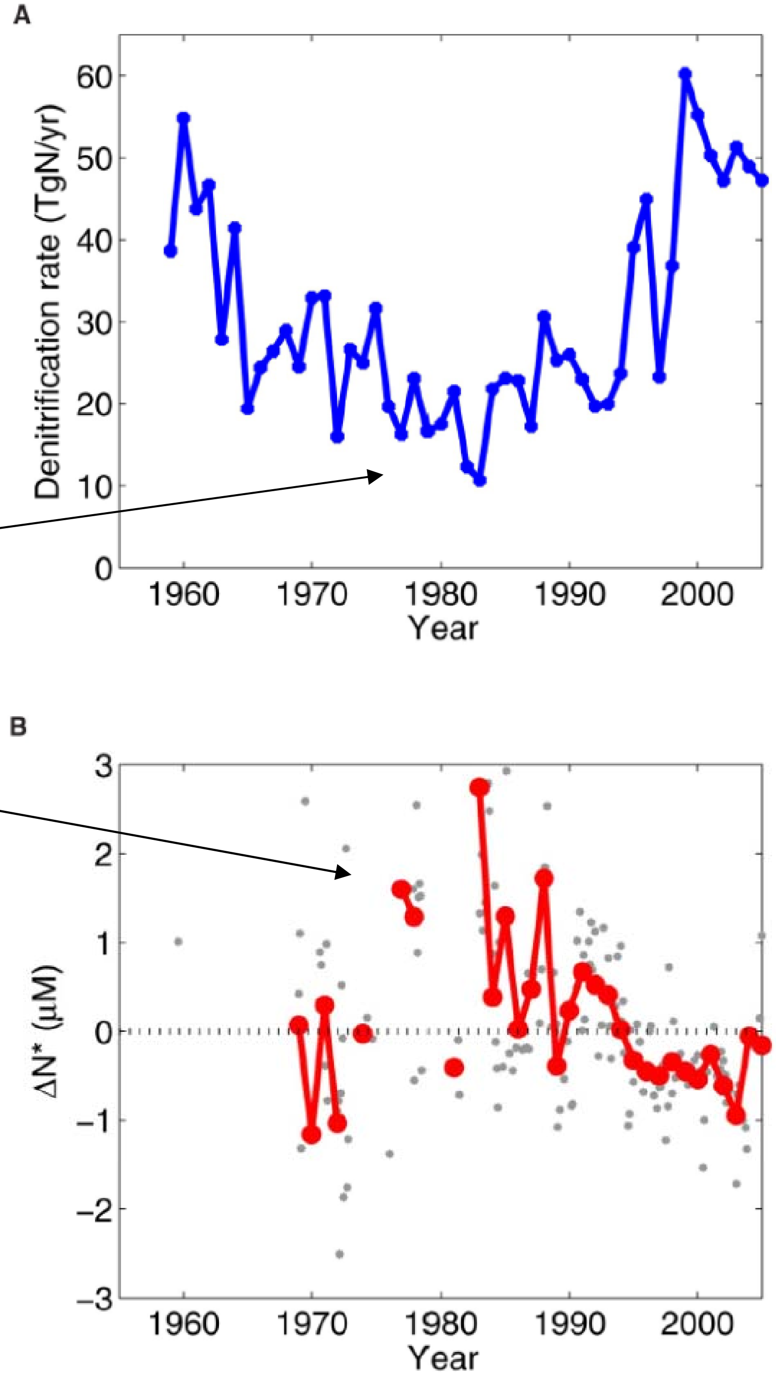




The proximate cause of changes in the volume of the suboxic zone is the rate of organic matter respiration in surrounding low-O_2 waters (Fig. 2C). An increase in

Biogeochemical cycles are coupled!

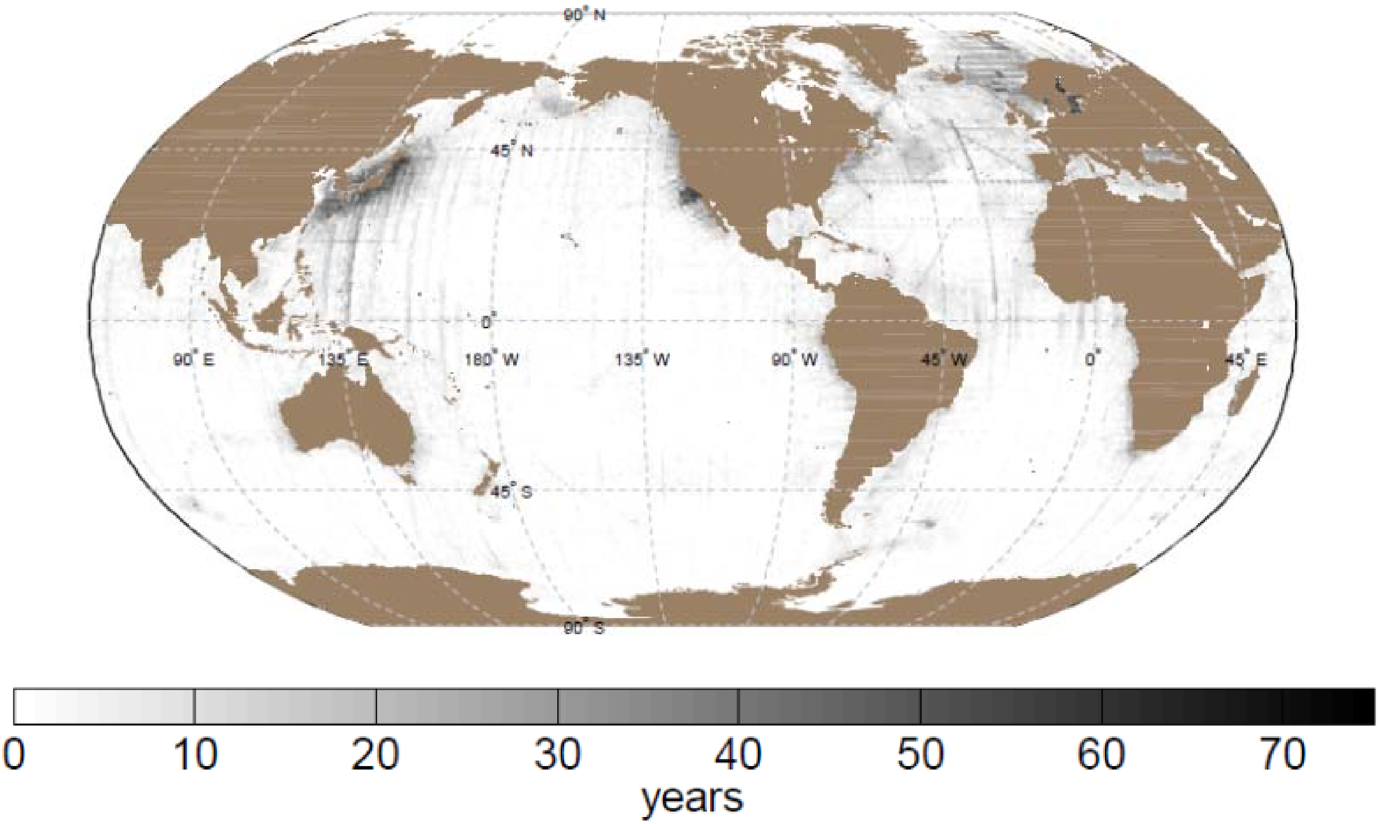
At times of low, modeled denitrification rate, there is an observed excess in NO_3^-, relative to PO_4^{3-} in the CalCOFI data. What happens globally?



Climate-Forced Variability of Ocean Hypoxia

Curtis Deutsch,[1]* Holger Brix,[1] Taka Ito,[2] Hartmut Frenzel,[1] LuAnne Thompson[3]

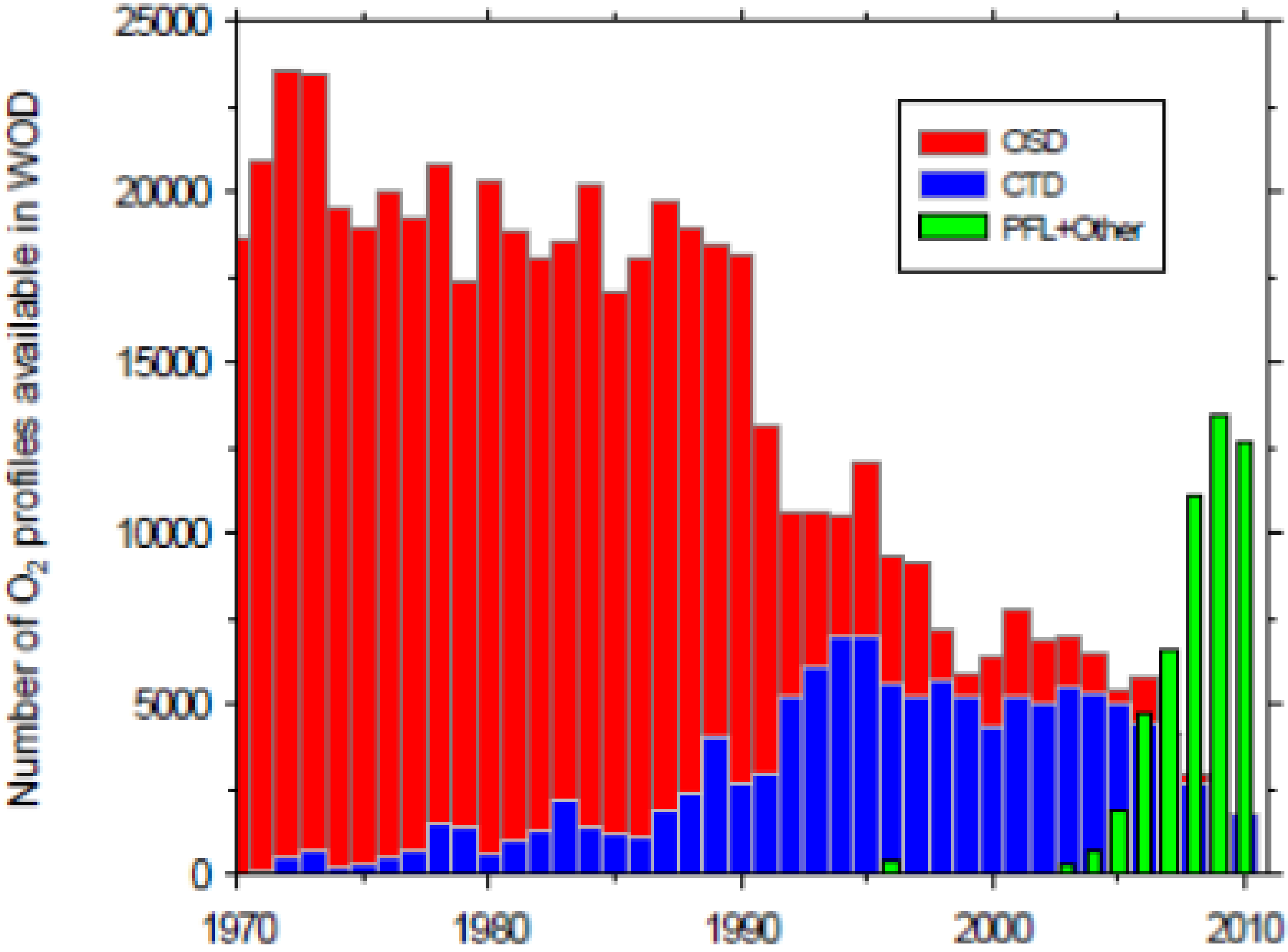
YEARS with O2 DATA, all depths


Number of years with oxygen data

Hernan Garcia (NODC, USA)
Tim Boyer (NODC, USA)
Denis Gilbert (DFO, Canada)

Argo-O2 workshop
IFREMER, Brest, France
May 25, 2011

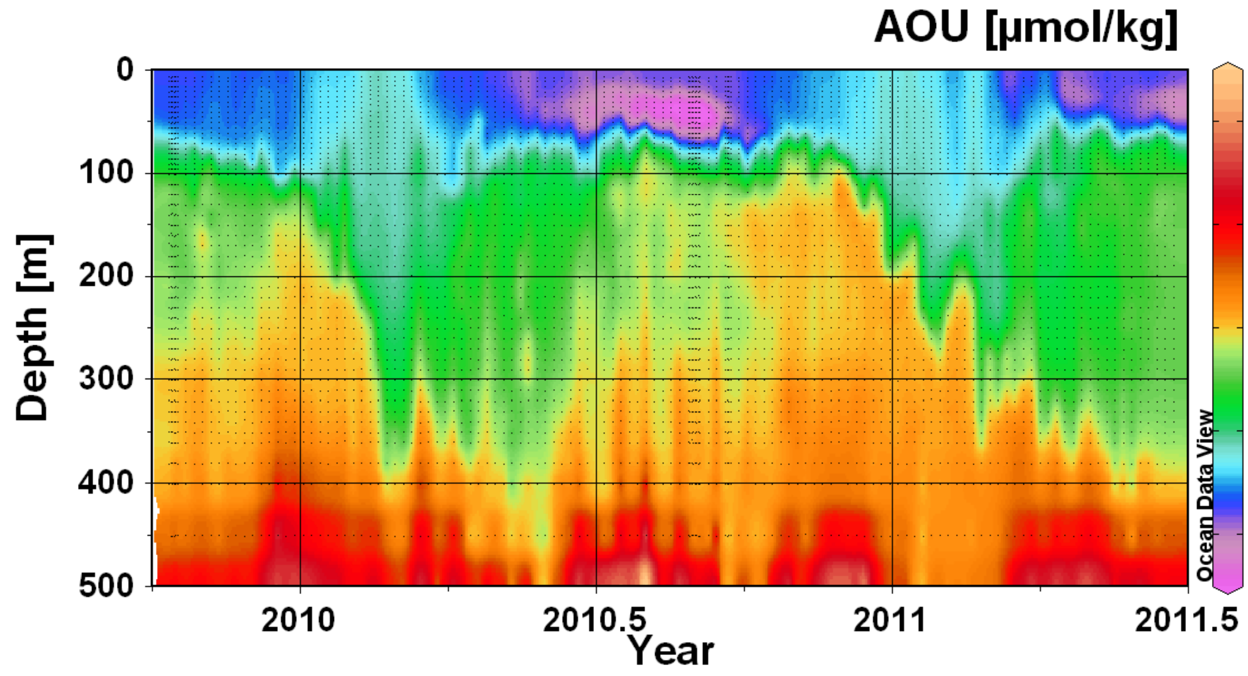
O2 profiles/year received at NODC

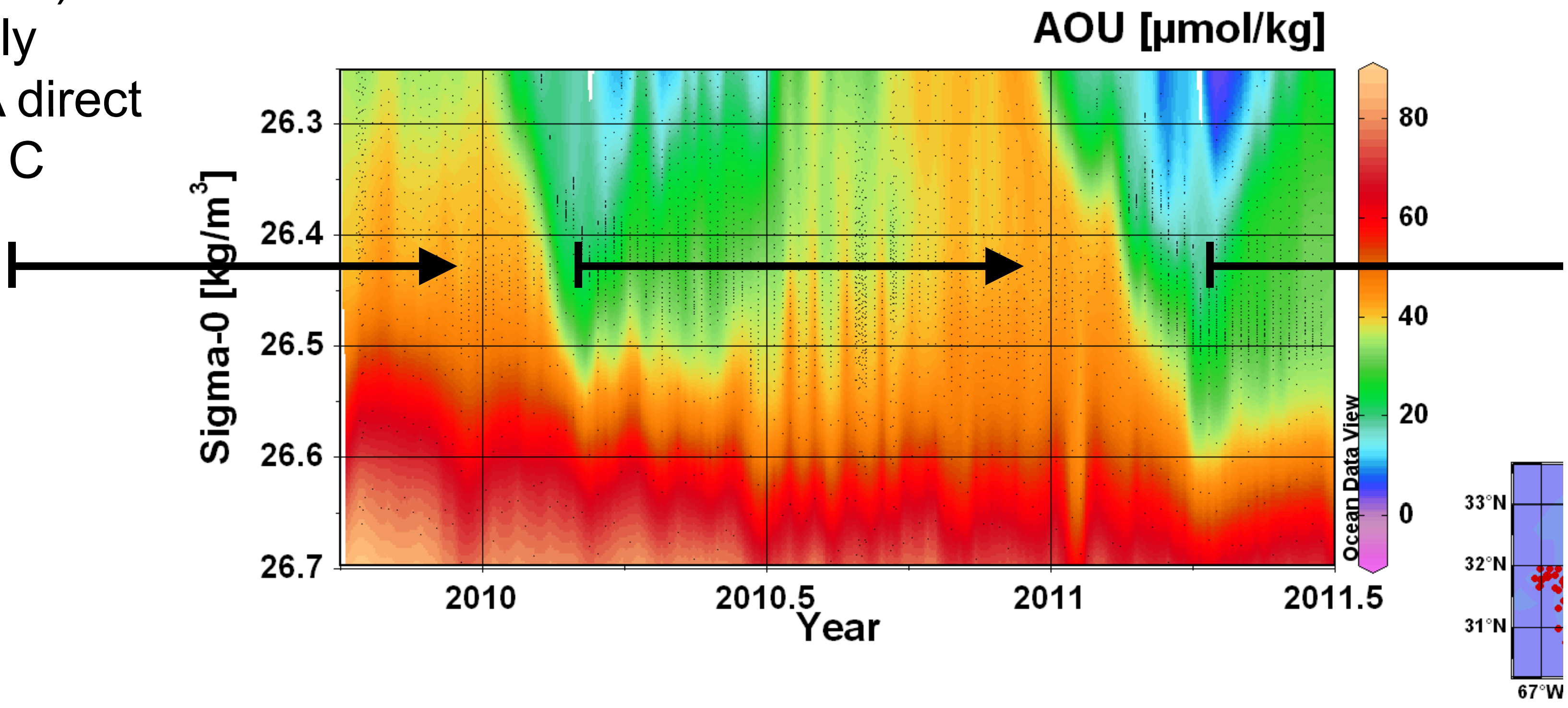


Hernan Garcia (NODC, USA)
Tim Boyer (NODC, USA)
Denis Gilbert (DFO, Canada)

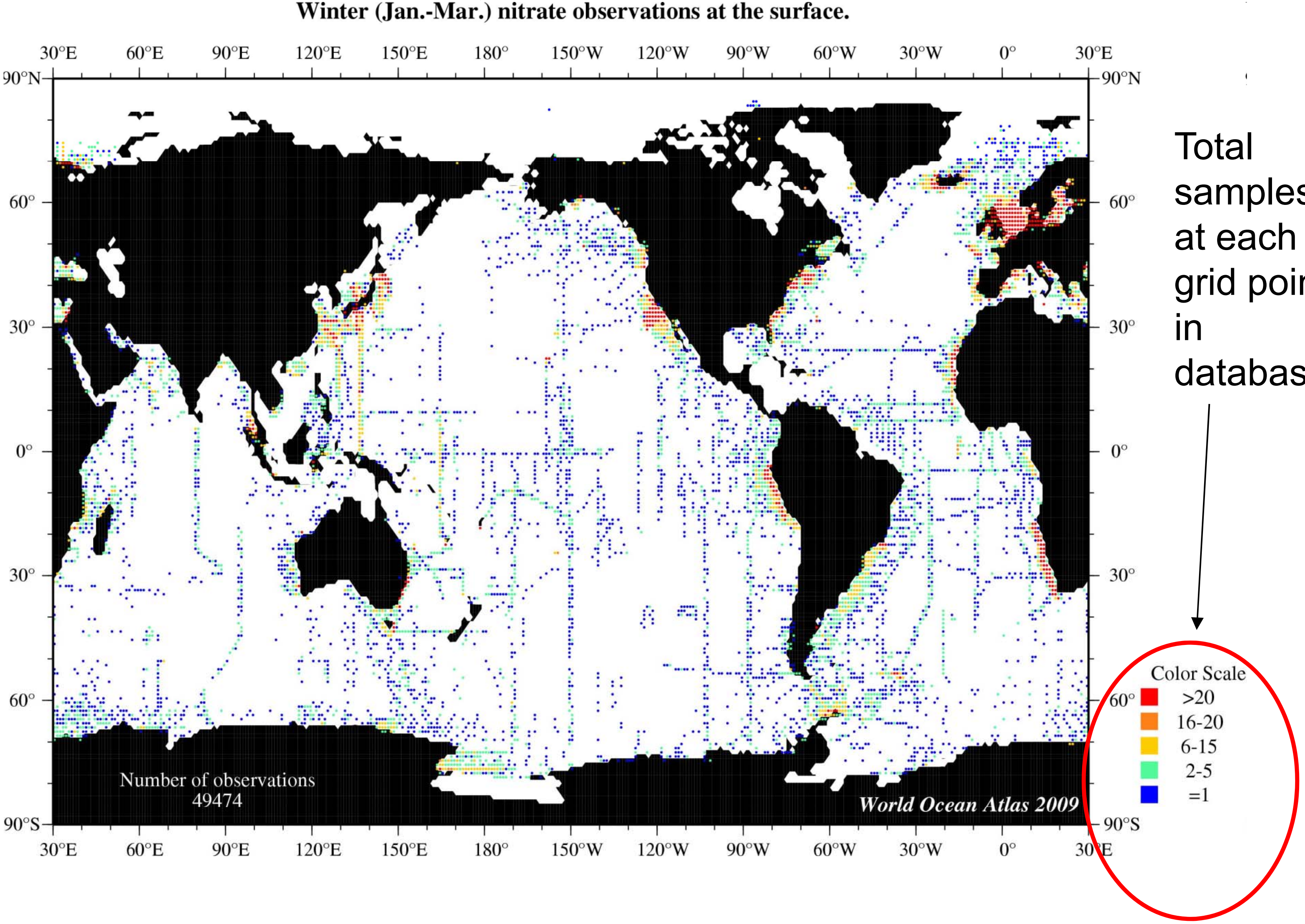
Profiling float deployed at BATS.

The seasonal cycle in mesopelagic O_2, first shown by Najjar and Keeling (1997) can be easily resolved. A direct measure of C export and respiration.





Number of nitrate observations at surface, January to March, in NODC data base.



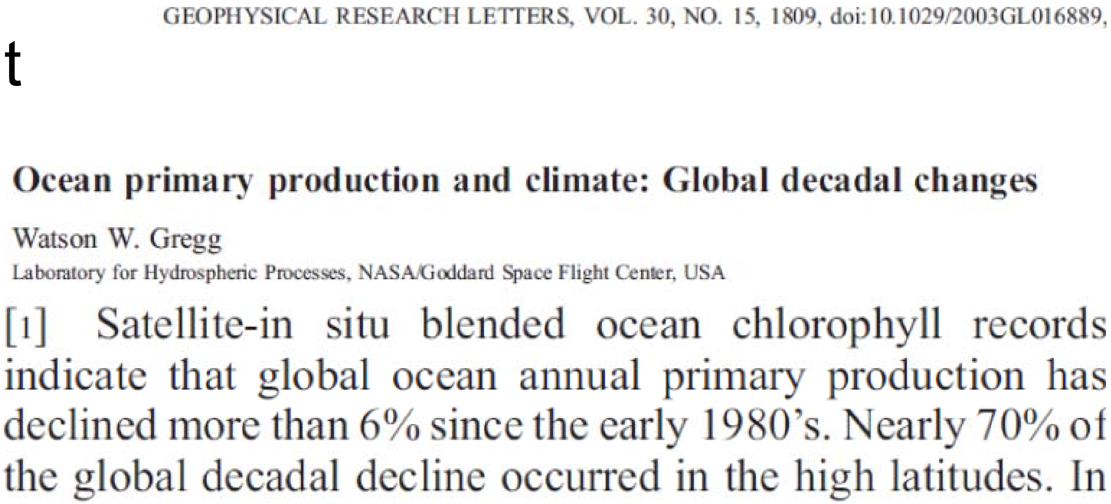
Total samples at each grid point in database

Numerous studies point to changing ocean phytoplankton/ productivity.

Results are often criticized because of problems in underlying data sets.

We need better data

- Global
- In Situ/Resolve Z
- DIrectly Linked To Pri. Prod./ Biomass



GEOPHYSICAL RESEARCH LETTERS, VOL. 30, NO. 15, 1809, doi:10.1029/2003GL016889,

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

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

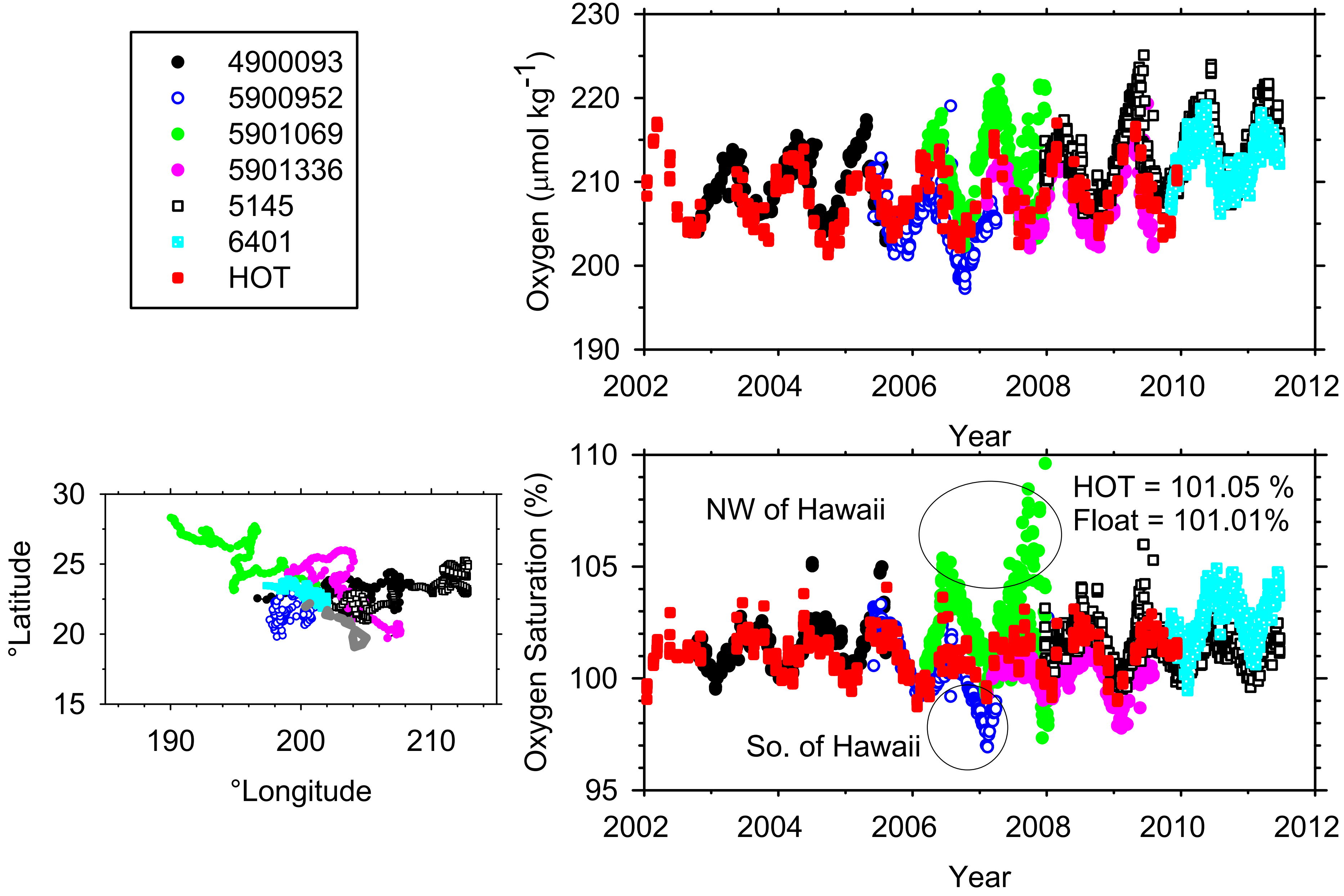
ARTICLES

Global phytoplankton decline over the past century

Daniel G. Boyce[1], Marlon R. Lewis[2] & Boris Worm[1]

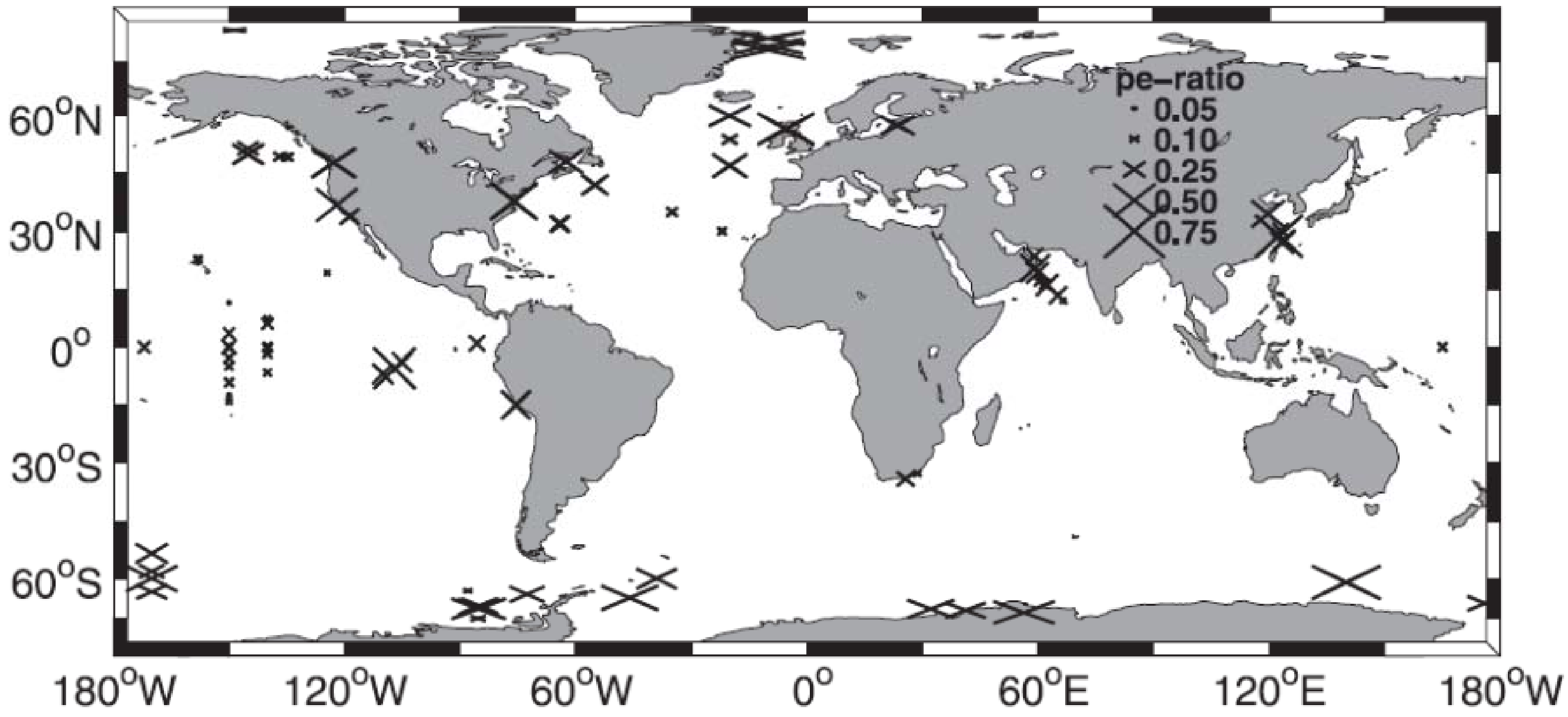
In the oceans, ubiquitous microscopic phototrophs (phytoplankton) account for approximately half the production of organic matter on Earth. Analyses of satellite-derived phytoplankton concentration (available since 1979) have suggested decadal-scale fluctuations linked to climate forcing, but the length 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

Autonomous platforms provides long-term records O2 good enough (±1 μmol/kg) to determine Net Community Prod.

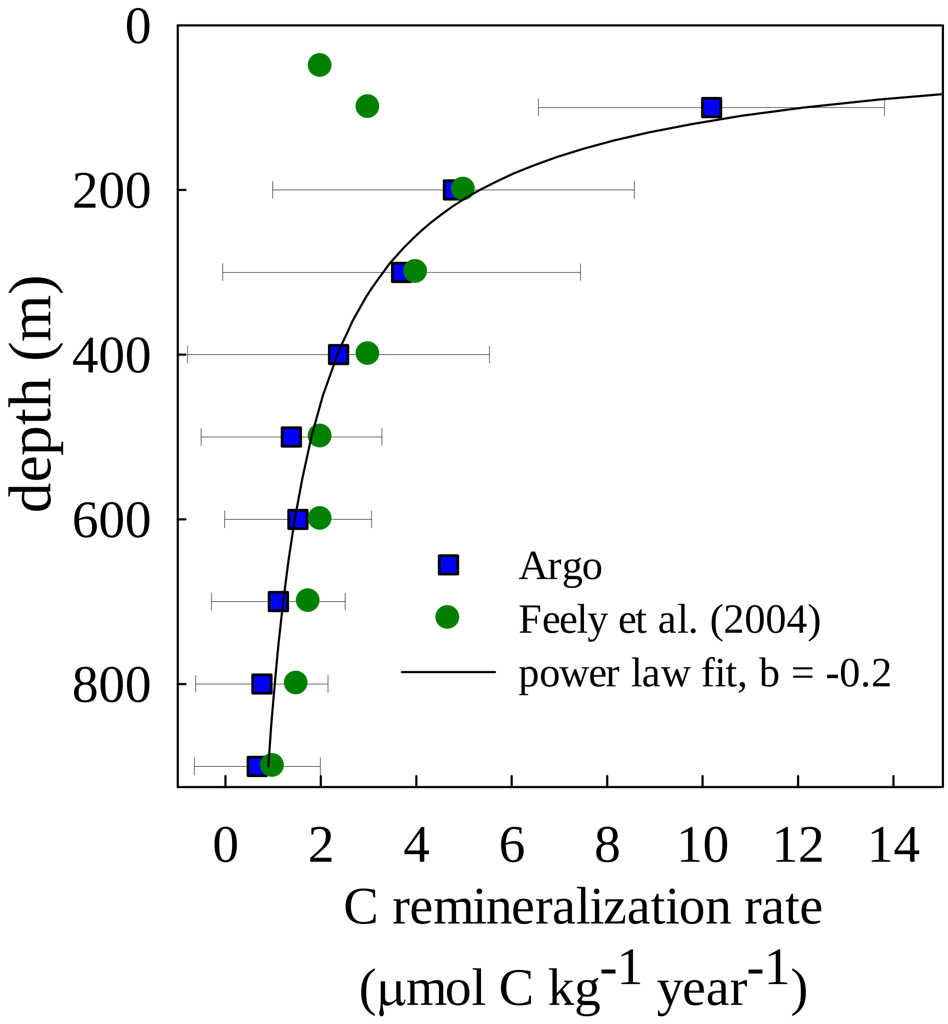


122 observations over 25 years of new production and carbon export. Ok to parameterize a model, but is it adequate to detect change in the ocean?

DUNNE ET AL.: MODELING THE PARTICLE EXPORT RATIO



Remineralization rates at 43ºS (Martz et al., 2008)



Derivative of the particle flux attenuation function

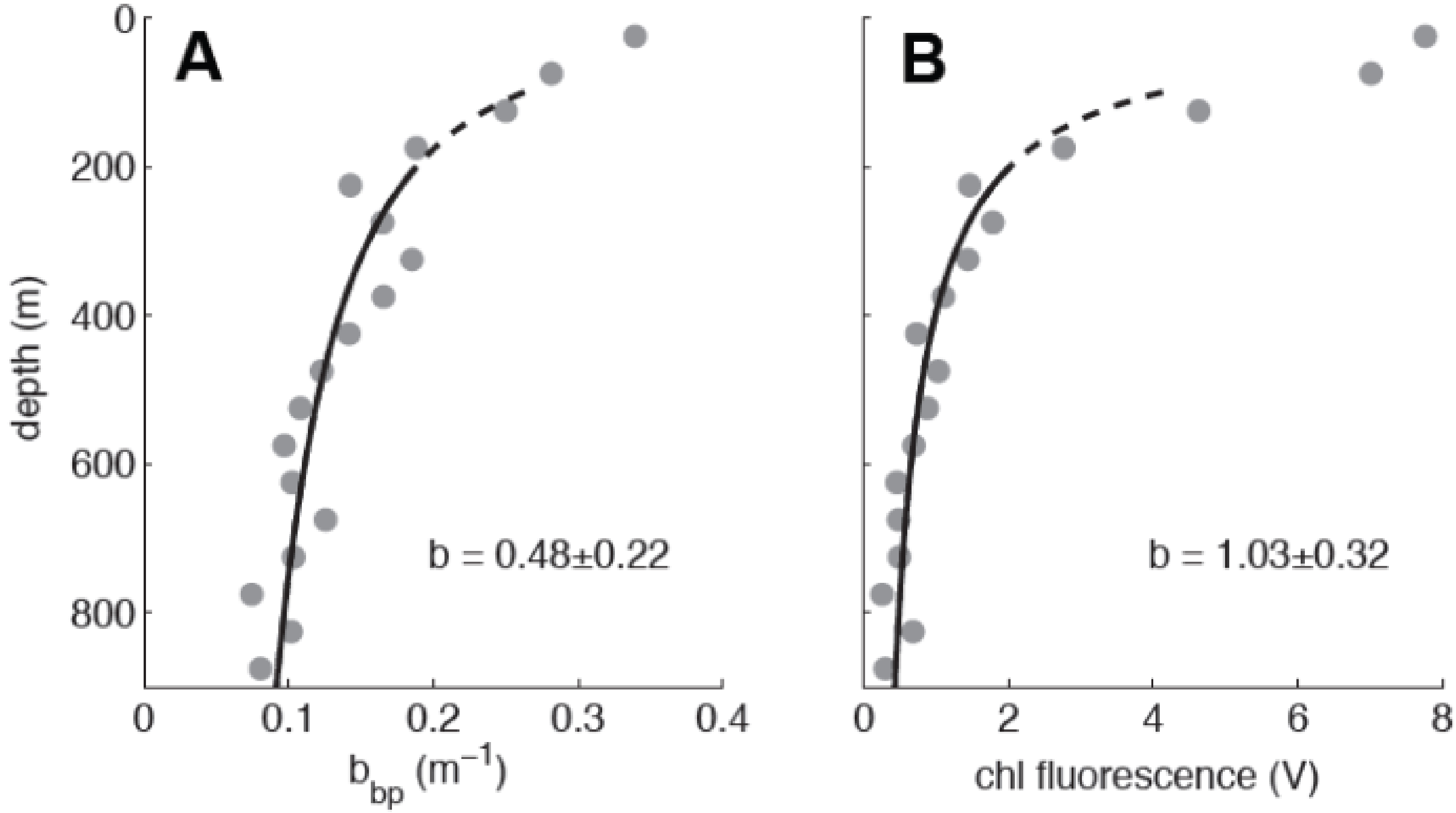
$$R_z \approx \frac{\partial F}{\partial z} = R_{100}\left(\frac{z}{100}\right)^{b-1}$$

Martin et al. (1987)

Martin 'b' exponent found using binned oxygen rates appears to be larger than trap-based values (usually -1.3 to -0.6).

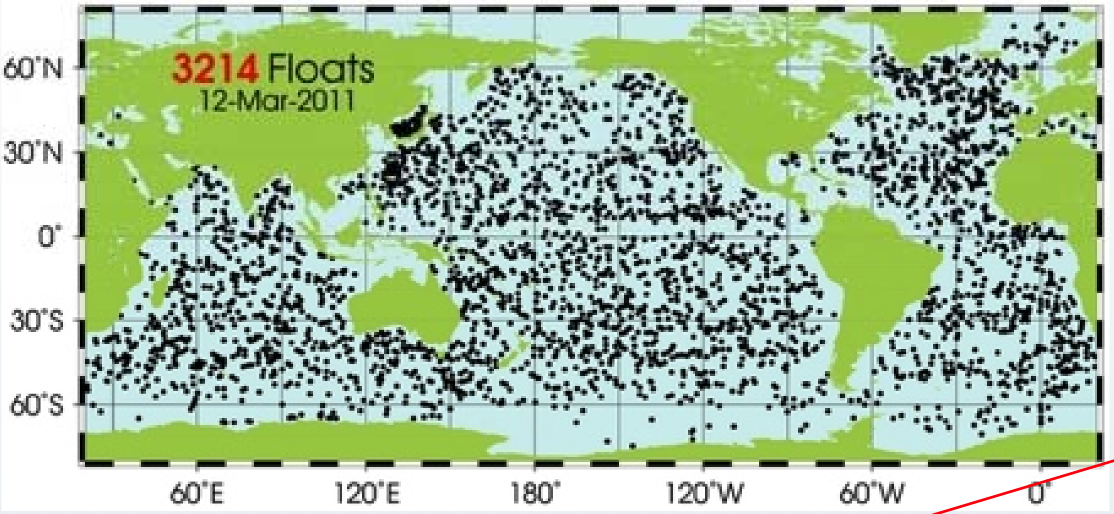
This can be reconciled by: oxygen gradients, trapping efficiency, active transport.

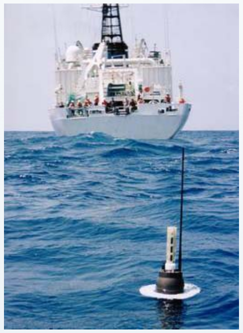
Briggs et al., in press, 2008 North Atlantic Bloom Experiment using gliders and biooptical sensors



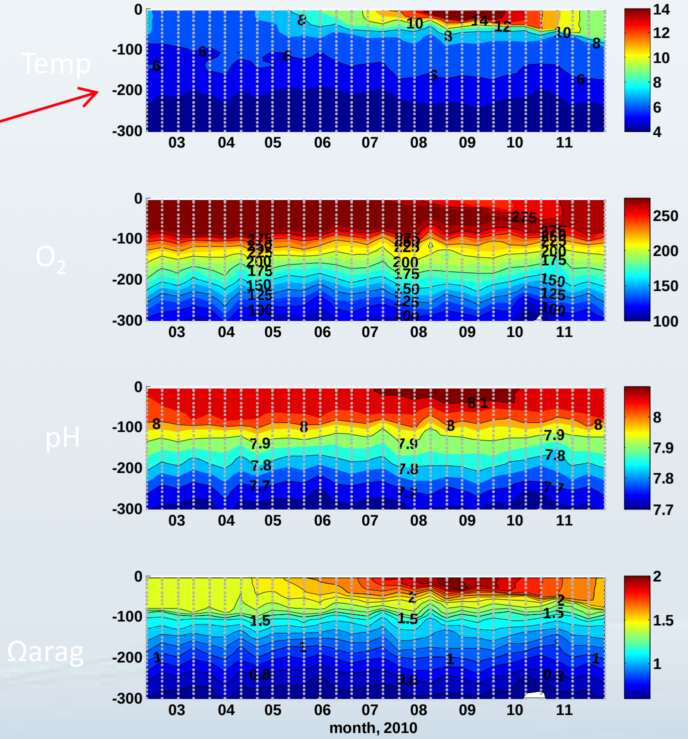
What existing resources can we use to monitor ocean acidification in the pelagic ocean?

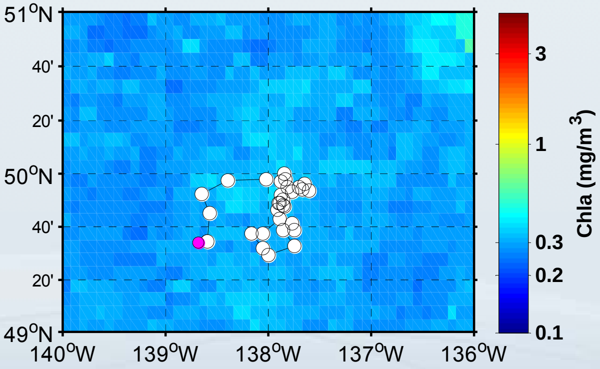
Argo – part integrated Global Observation Strategy





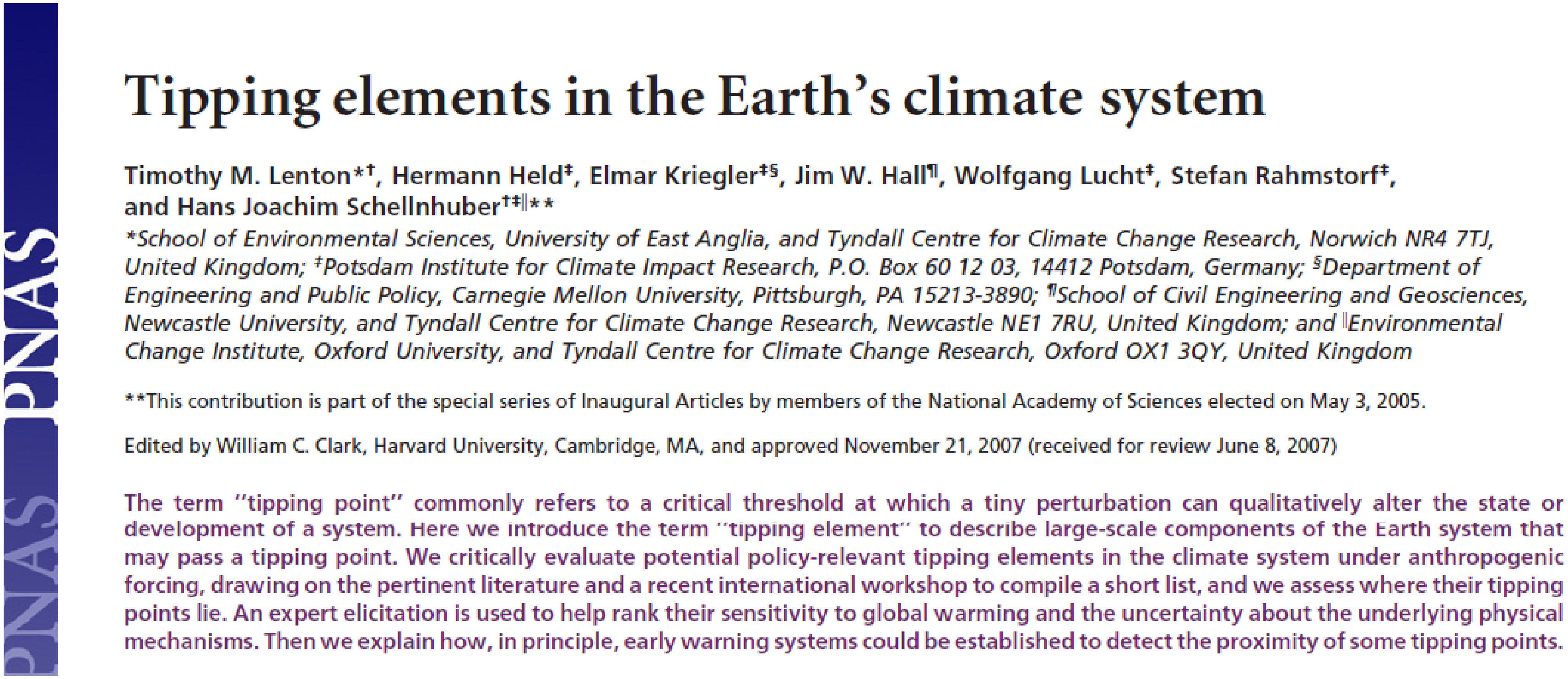
Juranek et al - Empirical algorithms to predict pH, Ω from hydrographic data





Allows low-cost monitoring of carbon system parameters in areas of interest from profiling floats and AUVs

Juranek et al., 2011, GRL, submitted



Tipping elements in the Earth's climate system

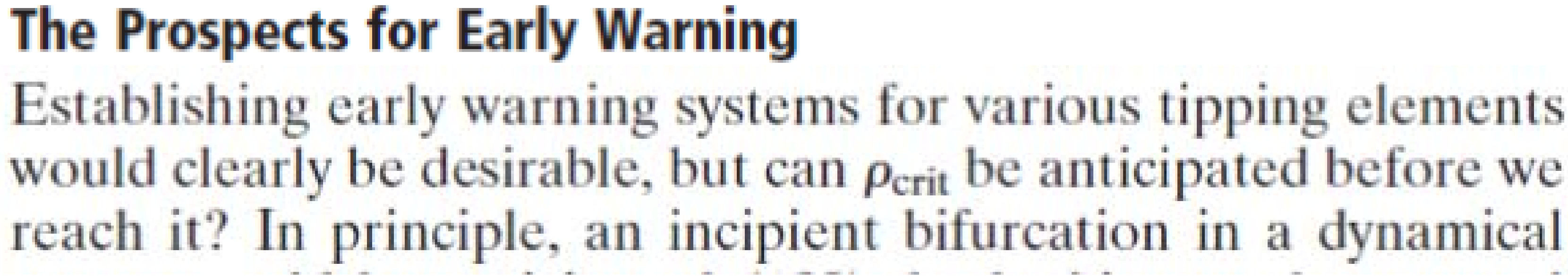
Timothy M. Lenton*[†], Hermann Held[‡], Elmar Kriegler[‡][§], Jim W. Hall[¶], Wolfgang Lucht[‡], Stefan Rahmstorf[‡], and Hans Joachim Schellnhuber[†][‡][‖]**

*School of Environmental Sciences, University of East Anglia, and Tyndall Centre for Climate Change Research, Norwich NR4 7TJ, United Kingdom; [‡]Potsdam Institute for Climate Impact Research, P.O. Box 60 12 03, 14412 Potsdam, Germany; [§]Department of Engineering and Public Policy, Carnegie Mellon University, Pittsburgh, PA 15213-3890; [¶]School of Civil Engineering and Geosciences, Newcastle University, and Tyndall Centre for Climate Change Research, Newcastle NE1 7RU, United Kingdom; and [‖]Environmental Change Institute, Oxford University, and Tyndall Centre for Climate Change Research, Oxford OX1 3QY, United Kingdom

**This contribution is part of the special series of Inaugural Articles by members of the National Academy of Sciences elected on May 3, 2005.

Edited by William C. Clark, Harvard University, Cambridge, MA, and approved November 21, 2007 (received for review June 8, 2007)

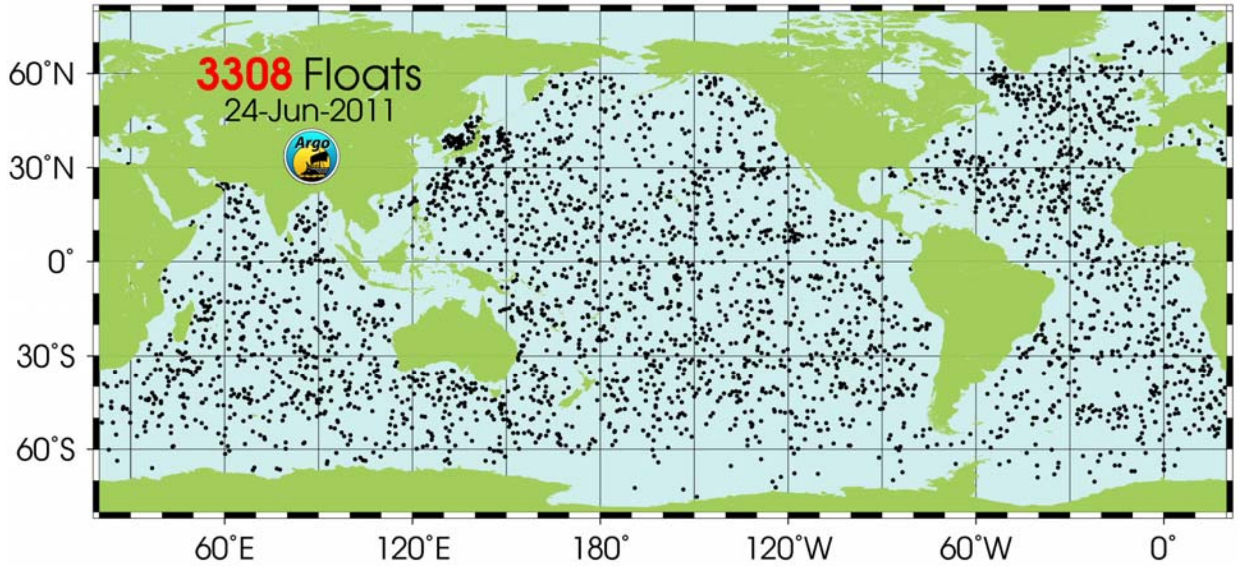
The term ''tipping point'' commonly refers to a critical threshold at which a tiny perturbation can qualitatively alter the state or development of a system. Here we introduce the term ''tipping element'' to describe large-scale components of the Earth system that may pass a tipping point. We critically evaluate potential policy-relevant tipping elements in the climate system under anthropogenic forcing, drawing on the pertinent literature and a recent international workshop to compile a short list, and we assess where their tipping points lie. An expert elicitation is used to help rank their sensitivity to global warming and the uncertainty about the underlying physical mechanisms. Then we explain how, in principle, early warning systems could be established to detect the proximity of some tipping points.

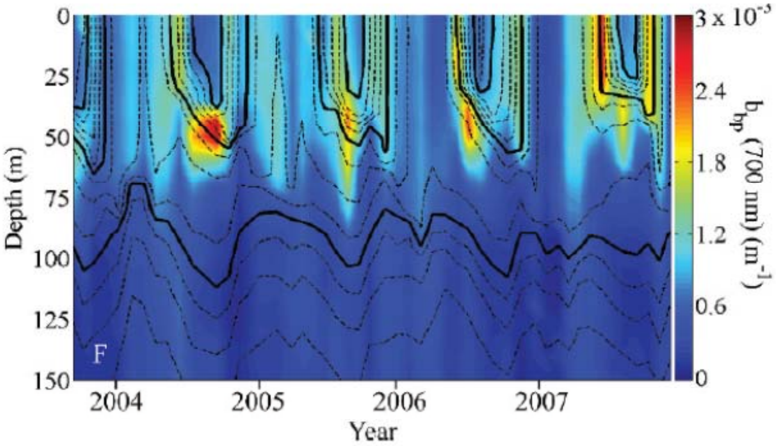


The Prospects for Early Warning

Establishing early warning systems for various tipping elements would clearly be desirable, but can ρ_{crit} be anticipated before we reach it? In principle, an incipient bifurcation in a dynamical

A global float/glider array: Argo as a model for a global biogeochemical observing system? Are we ready???





Perry et al., L&O, 2008

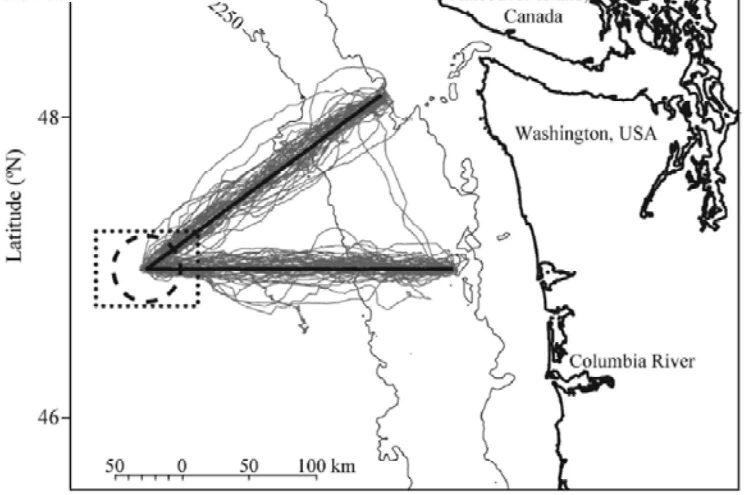
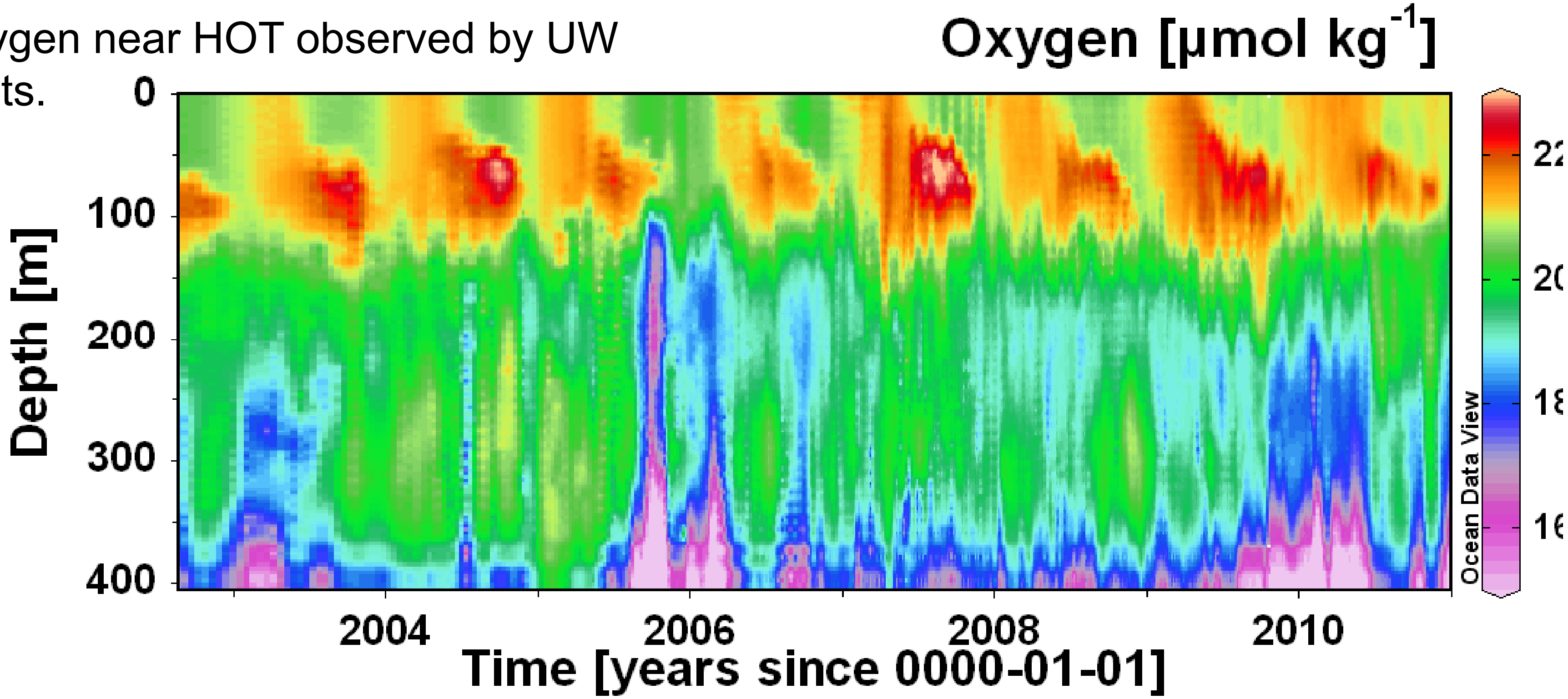


Fig. 1. Chart of Seaglider transects for all deployments between September 2002 and December 2007. Dashed circle highlights region analyzed in the text; dotted box represents area averaged for satellite data. Actual Seaglider transects (gray solid lines) deviated from the programmed flight path (black solid lines) because of variable currents.

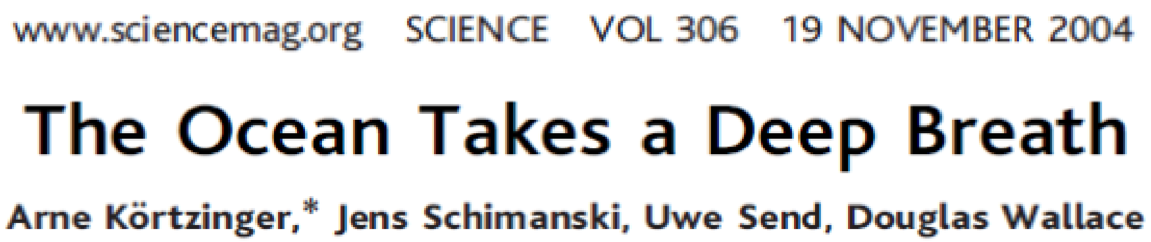
The platforms (floats/gliders) are proven, how about the sensors? Two classes:

- sensors proven by deployment on many floats/gliders over many years and strong peer-reviewed publications (O_2, basic biooptics, NO_3^-)
- sensors nearing operational status that will have high impact (e.g. pH, pCO2, Particulate Inorganic Carbon - PIC)

Oxygen near HOT observed by UW floats.

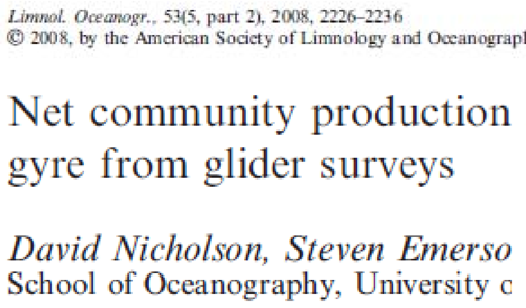


A subset of O_2 papers


www.sciencemag.org SCIENCE VOL 306 19 NOVEMBER 2004

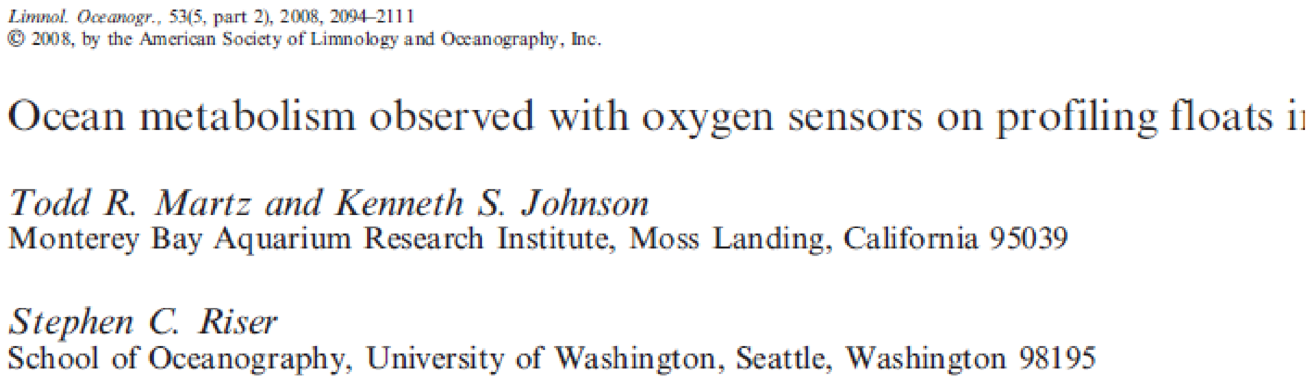
The Ocean Takes a Deep Breath

Arne Körtzinger,* Jens Schimanski, Uwe Send, Douglas Wallace


Limnol. Oceanogr., 53(5, part 2), 2008, 2226–2236
© 2008, by the American Society of Limnology and Oceanography, Inc.

Net community production in the deep euphotic zone of the subtropical North Pacific gyre from glider surveys

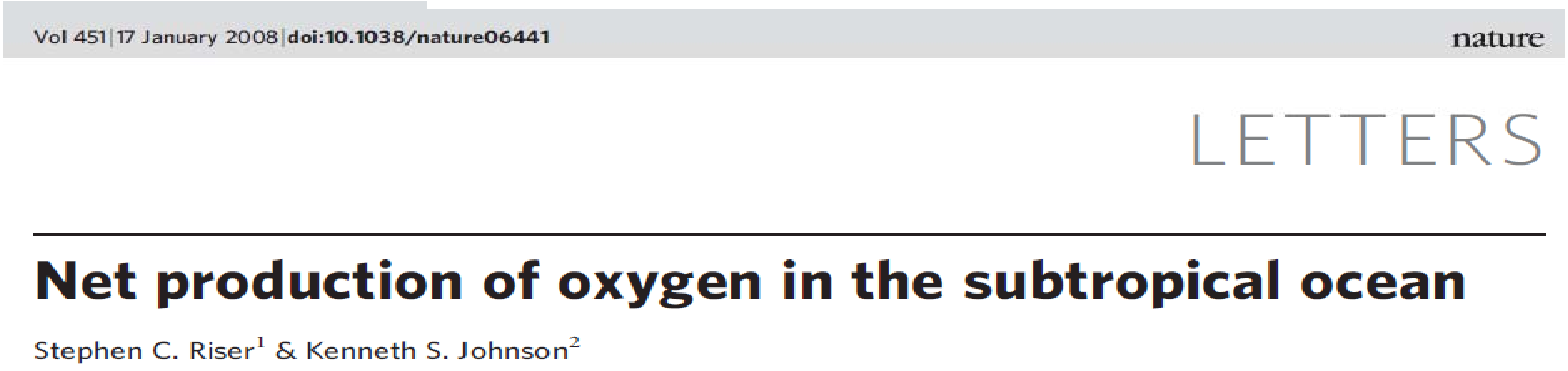
David Nicholson, Steven Emerso
School of Oceanography, University c


Limnol. Oceanogr., 53(5, part 2), 2008, 2094–2111
© 2008, by the American Society of Limnology and Oceanography, Inc.

Ocean metabolism observed with oxygen sensors on profiling floats i

Todd R. Martz and Kenneth S. Johnson
Monterey Bay Aquarium Research Institute, Moss Landing, California 95039

Stephen C. Riser
School of Oceanography, University of Washington, Seattle, Washington 98195


Vol 451 | 17 January 2008 | doi:10.1038/nature06441 nature

LETTERS

Net production of oxygen in the subtropical ocean

Stephen C. Riser[1] & Kenneth S. Johnson[2]

A subset of biooptics papers

Robotic Observations of Dust Storm Enhancement of Carbon Biomass in the North Pacific

James K. B. Bishop,[1]* Russ E. Davis,[2] Jeffrey T. Sherman[2]

www.sciencemag.org SCIENCE VOL 298 25 OCTOBER 2002

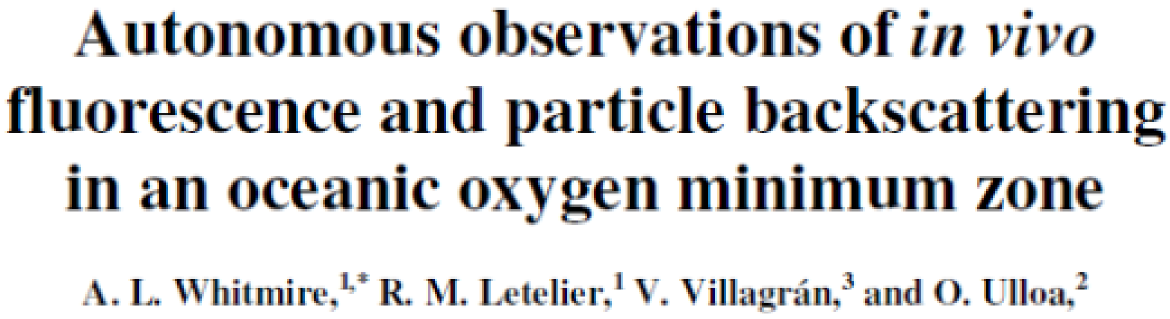
Limnol. Oceanogr., 53(5, part 2), 2008, 2169–2179

Seaglider observations of blooms and subsurface chlorophyll maxima off the Washington coast

M. J. Perry[1]
Ira C. Darling Marine Center and School of

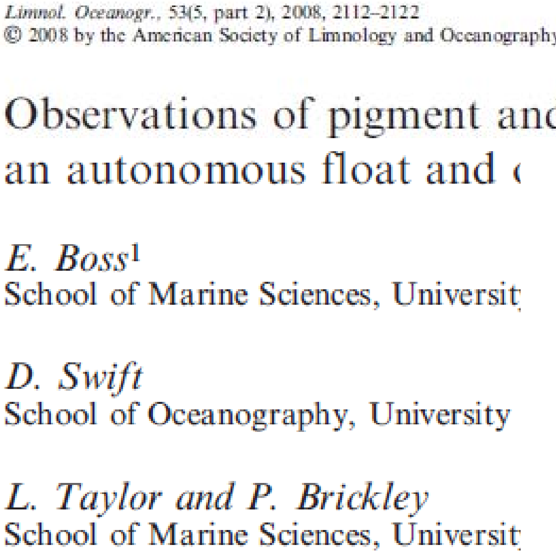
B. S. Sackmann
Monterey Bay Aquarium Research Institute,

C. C. Eriksen



Autonomous observations of *in vivo* fluorescence and particle backscattering in an oceanic oxygen minimum zone

A. L. Whitmire,[1,*] R. M. Letelier,[1] V. Villagrán,[3] and O. Ulloa,[2]



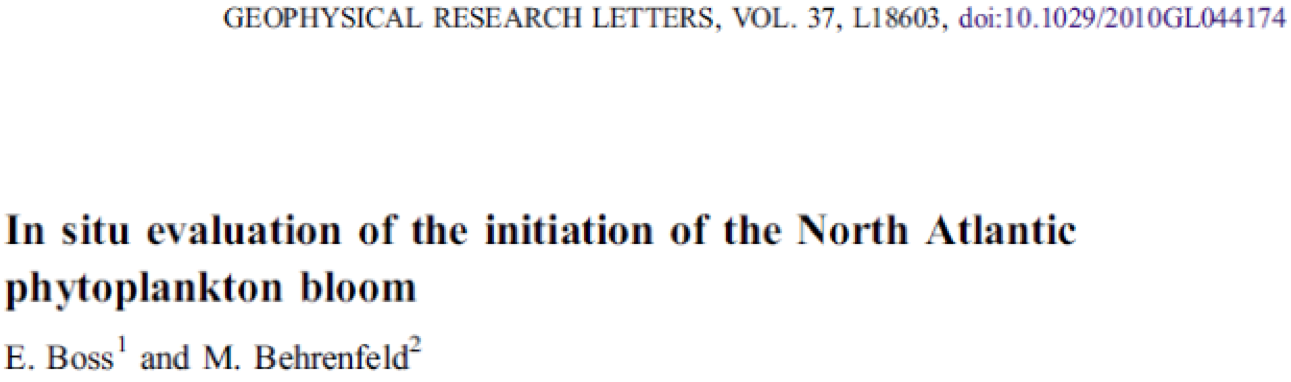
Limnol. Oceanogr., 53(5, part 2), 2008, 2112–2122

Observations of pigment and particle distributions in the western North Atlantic from an autonomous float and

E. Boss[1]
School of Marine Sciences, Universit

D. Swift
School of Oceanography, University

L. Taylor and P. Brickley
School of Marine Sciences, Universit



GEOPHYSICAL RESEARCH LETTERS, VOL. 37, L18603, doi:10.1029/2010GL044174

In situ evaluation of the initiation of the North Atlantic phytoplankton bloom

E. Boss[1] and M. Behrenfeld[2]

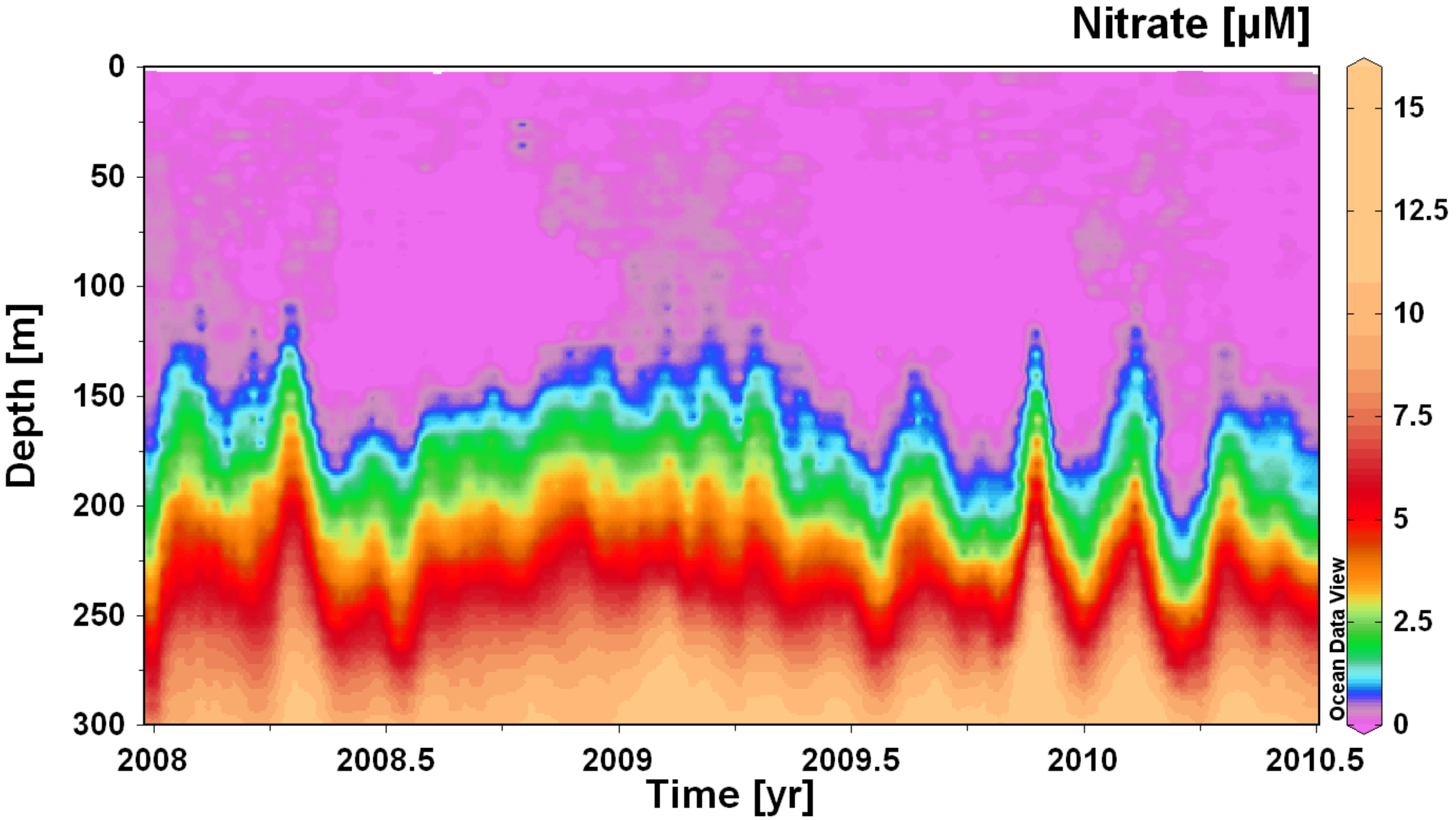
nature Vol 465|24 June 2010|doi:10.1038/nature09170

LETTERS

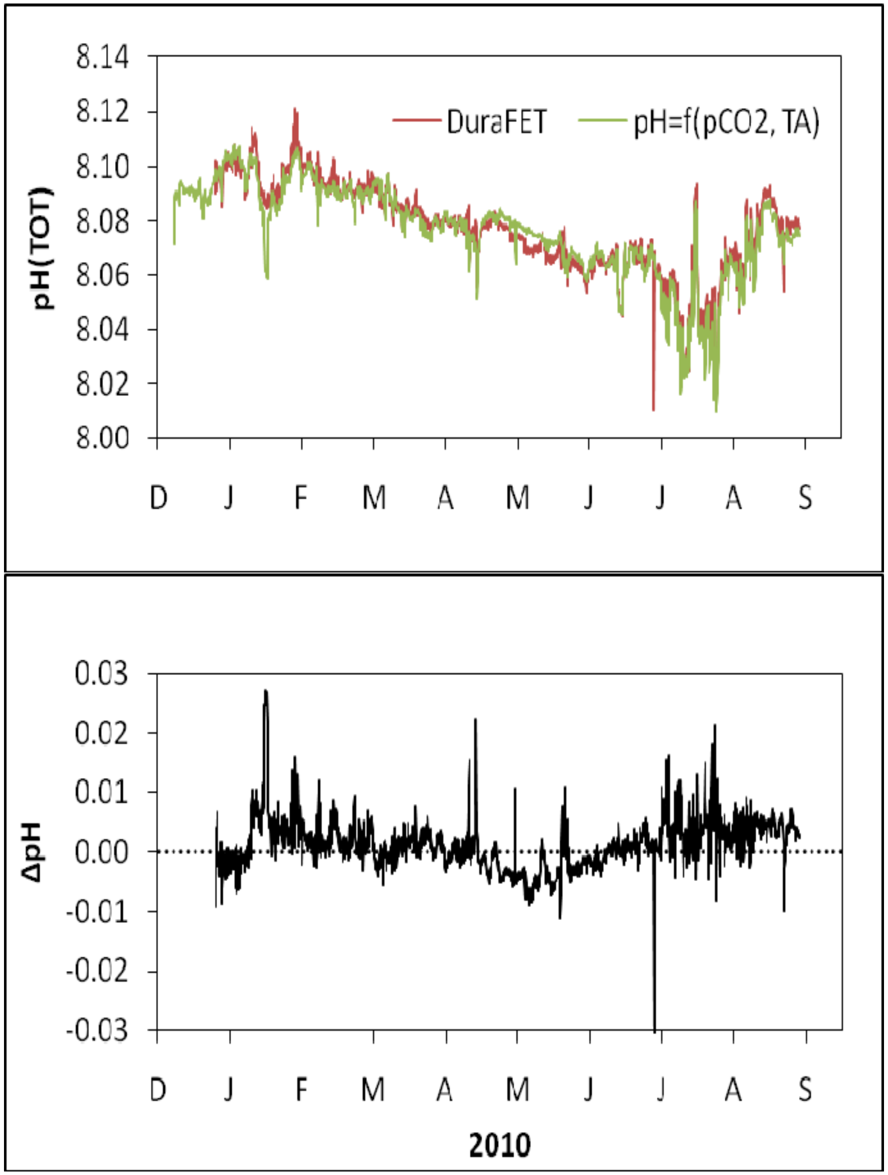
Nitrate supply from deep to near-surface waters of the North Pacific subtropical gyre

Kenneth S. Johnson[1], Stephen C. Riser[2] & David M. Karl[3]

Near Hawaii



pH to be deployed on floats this fall, proven by long deployments on surface moorings.



CCE-1 Mooring The ISFET pH sensor is very stable, relative to pH computed from pCO_2 (C. Sabine) and TA (estimated from salinity, T).

Ocean acidification signal is 0.002/y

Figure provided by T. Martz, U. Send and M. Ohman, SIO

Particulate Inorganic Carbon (PIC) Sensor

Univ. Cal., Berkeley

Jim Bishop (PI): OCE 0964888

WETLabs, Inc.; Scripps Inst Dev Group

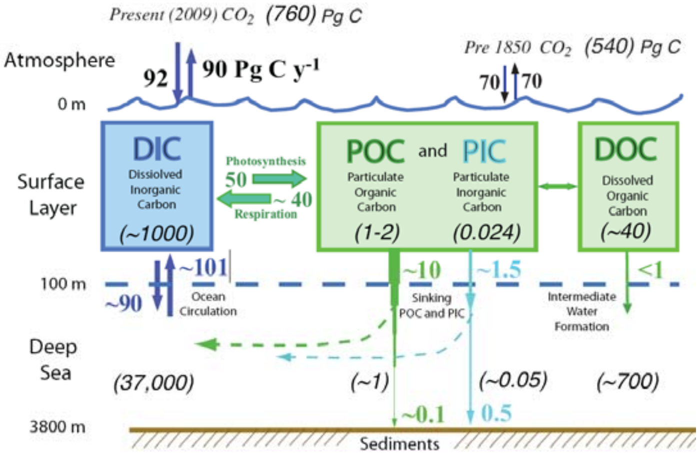
PIC concentration sensor for CTDs / ARGO floats. $CaCO_3$ dynamics.

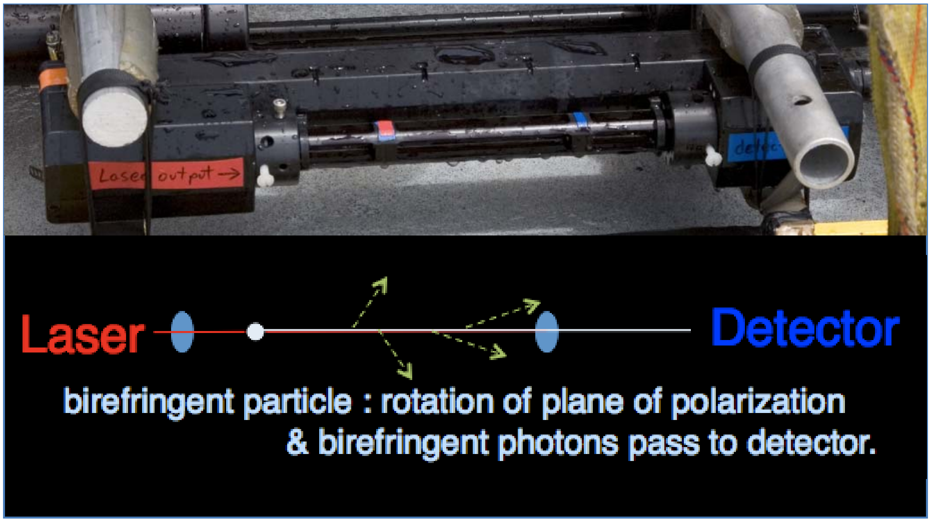
✓ Next Gen. Design: optics & electronics.

o Thermal/Pressure Testing (in progress)

o Ship CTD deployment calibration (May, July, Aug 2011 – in progress)

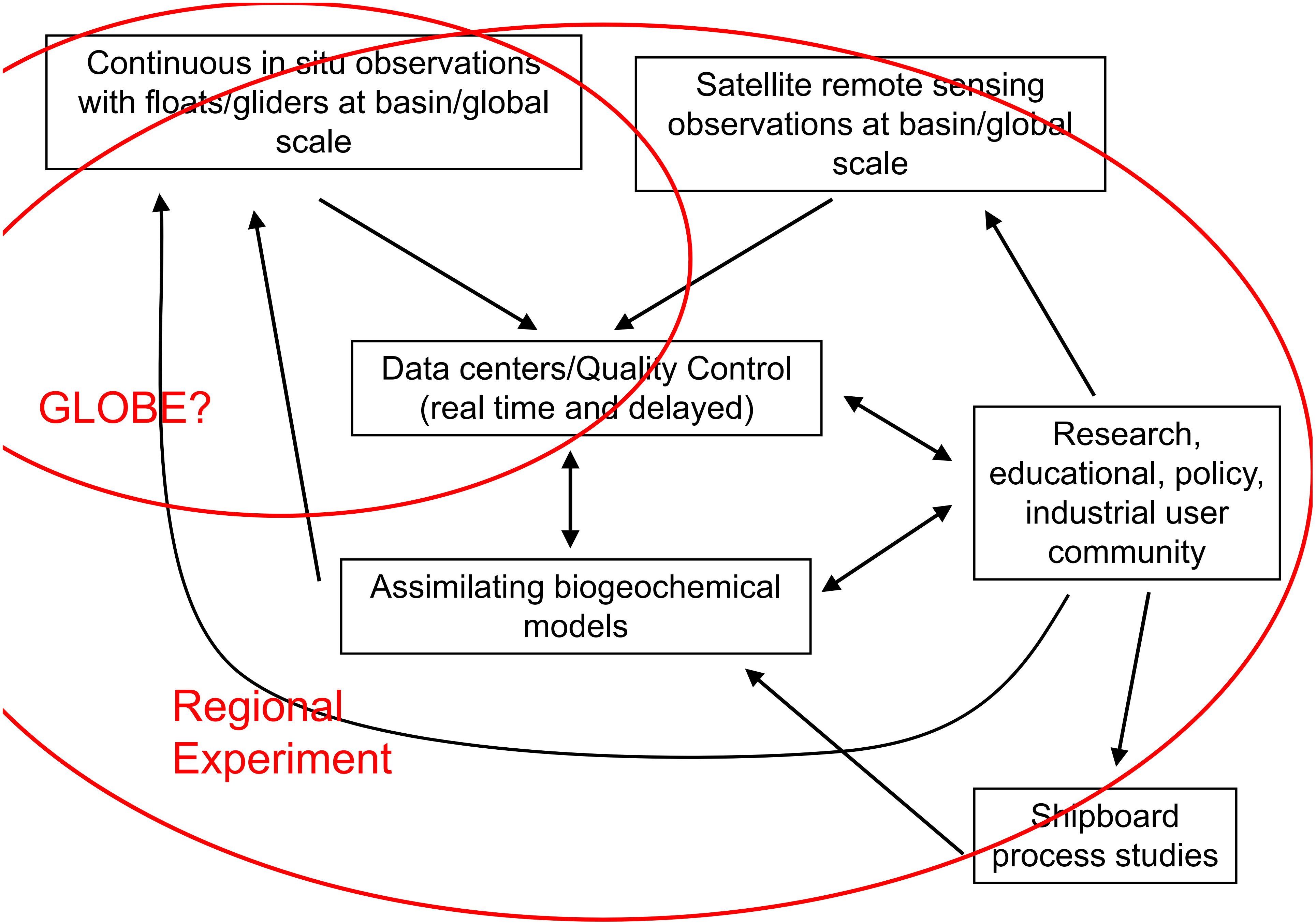
- Carbon Explorer Float deployment (2012) subarctic N Pacific.





birefringent particle : rotation of plane of polarization & birefringent photons pass to detector.

- Why a global observing system
  - major science needs
- Technology status
  - are we ready?
- Possible system designs
  - integration of in situ observations with satellite observations and numerical models
- Next steps
  - International partnerships
  - regional experiments
  - encouragement of new technology



Continuous in situ observations with floats/gliders at basin/global scale

Satellite remote sensing observations at basin/global scale

Data centers/Quality Control (real time and delayed)

Research, educational, policy, industrial user community

Assimilating biogeochemical models

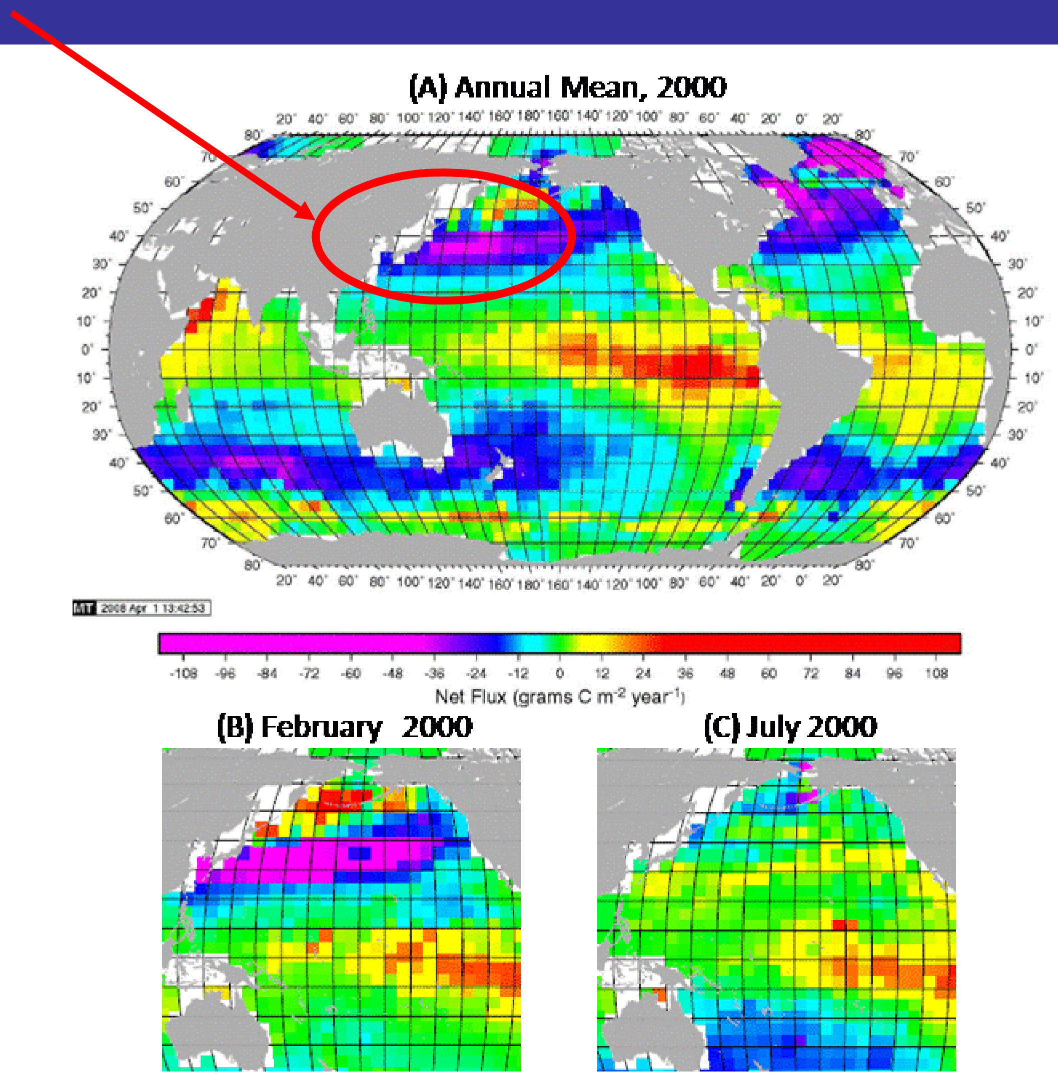
Shipboard process studies

GLOBE?

Regional Experiment

- Why a global observing system
  - Major science needs cannot be met with present observing systems
- Technology status
  - Are we ready?
- Possible system designs
  - Integration of in situ observations with satellite observations and numerical models
- Next steps
  - Receive community input
  - International partnerships
  - Regional experiments

Emerson/Riser regional project in NW Pacific – controls on seasonal CO_2 drawdown using O_2 floats



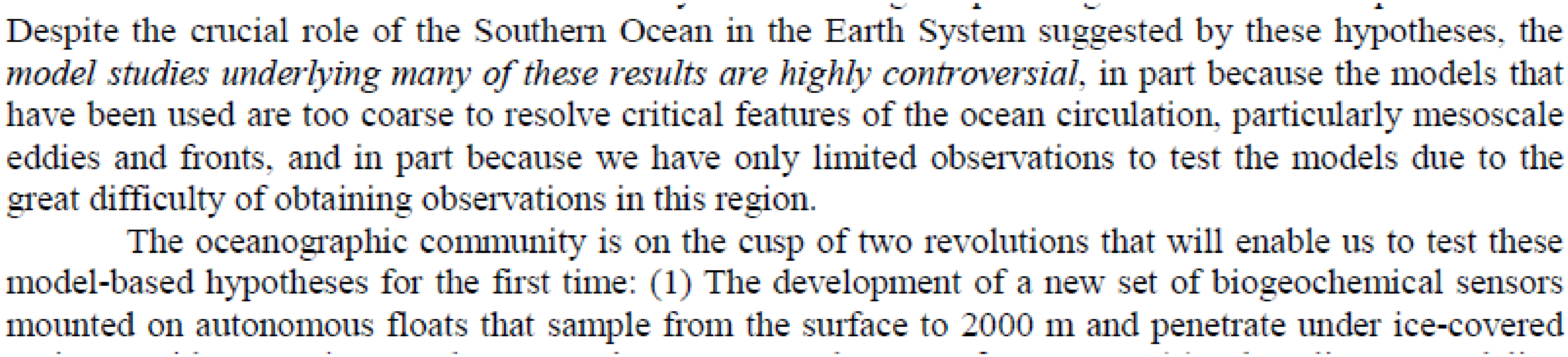
(A) Annual Mean, 2000

(B) February 2000

(C) July 2000

A proposal for a Southern Ocean observing system using profiling floats for long-term observations and gliders for process studies.

J. Sarmiento, L. Talley, J. Russell, H. Cullen, et al.



Despite the crucial role of the Southern Ocean in the Earth System suggested by these hypotheses, the *model studies underlying many of these results are highly controversial*, in part because the models that have been used are too coarse to resolve critical features of the ocean circulation, particularly mesoscale eddies and fronts, and in part because we have only limited observations to test the models due to the great difficulty of obtaining observations in this region.

The oceanographic community is on the cusp of two revolutions that will enable us to test these model-based hypotheses for the first time: (1) The development of a new set of biogeochemical sensors mounted on autonomous floats that sample from the surface to 2000 m and penetrate under ice-covered

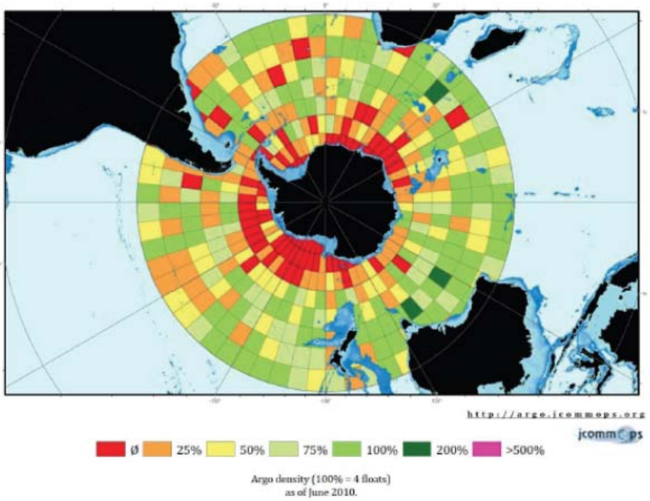


Figure 21: *The status of the Argo array in the Southern Ocean, as of July 2010. Blue colour indicates 0-2000 depth contour. Despite the progress in recent years, large regions of the high-latitude Southern Ocean remain poorly observed, especially close to the Antarctic continent. Courtesy of Mathieu Belbeoch, JCOMMOPS.*

Using Argo as an example, but there may be other models.

	US Share per year	Total Cost per year
Argo T/S array	$10 Million	$20 Million
Add O_2 to Argo (Gruber et al. 2007) $7070/float	$2.5 M (350 floats/y)	$5 M (700 floats/y)
Add Biooptics (sensor cost 1.75 x O_2)	$4.4 M	$8.8 M
Add Nitrate (sensor 3x O_2)	$7.5 M	$15 M
Add pH (1 x O_2)	$2.5 M	$5 M
Total cost	$27 Million	$54 Million

These numbers are completely scaleable.