The prospects and rationale for a global biogeochemical Argo system (BGC Argo)

Kenneth S. Johnson, Monterey Bay Aquarium Research Institute, johnson@mbari.org

Jorge L. Sarmiento, Princeton University

Hervé Claustre, Laboratoire d'Océanographie de Villefranche

Outline

- The need for a global biogeochemical observing system.
- The Argo observing system.
- Are we ready?
- Planning for Biogeochemical-Argo.

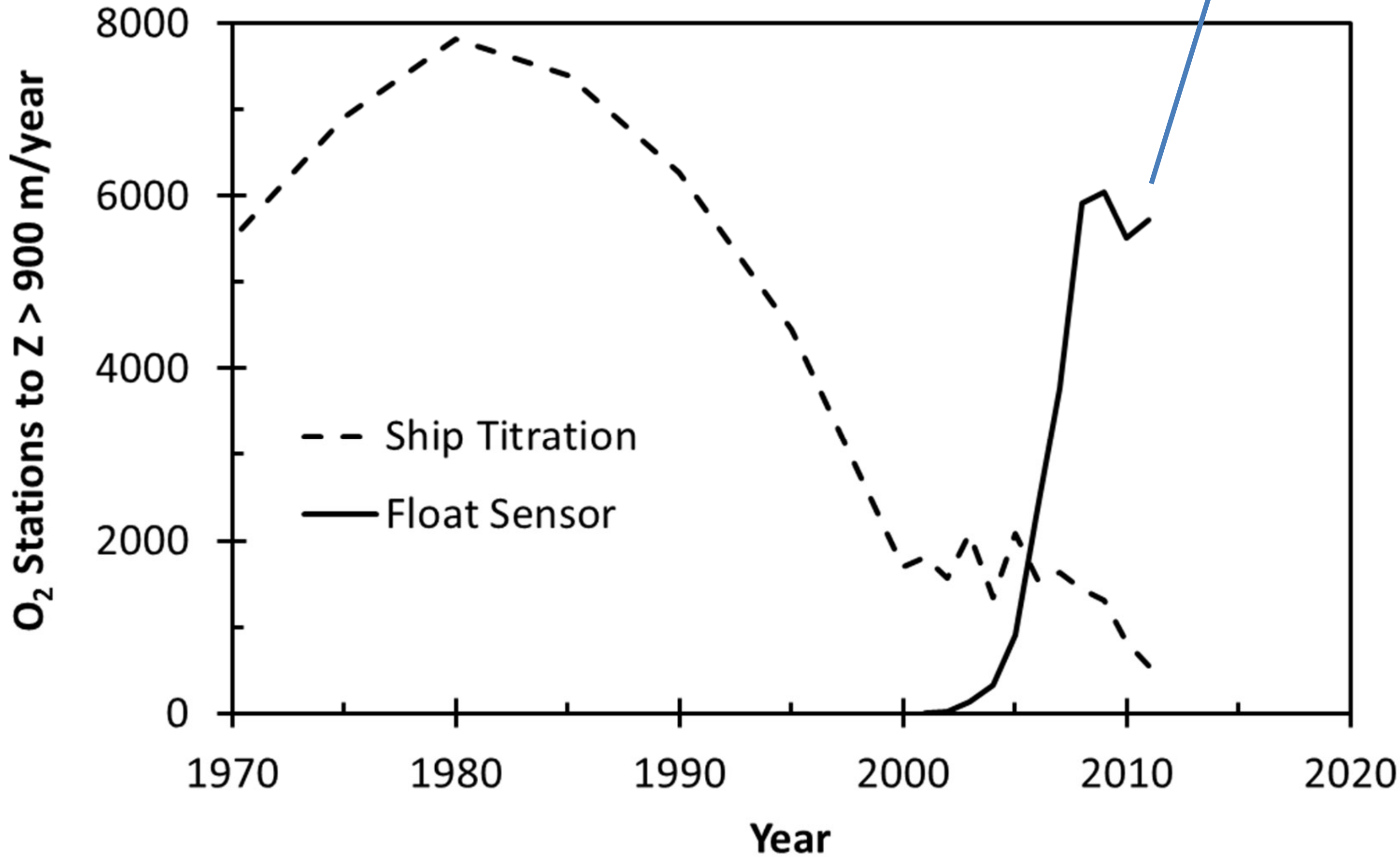
biogeochemical Argo

Oceans are undergoing remarkable stresses: warming, acidification, nutrient supply, melting ice, circulation changes….

Who's looking systematically?

Data from US National Ocean. Data Center

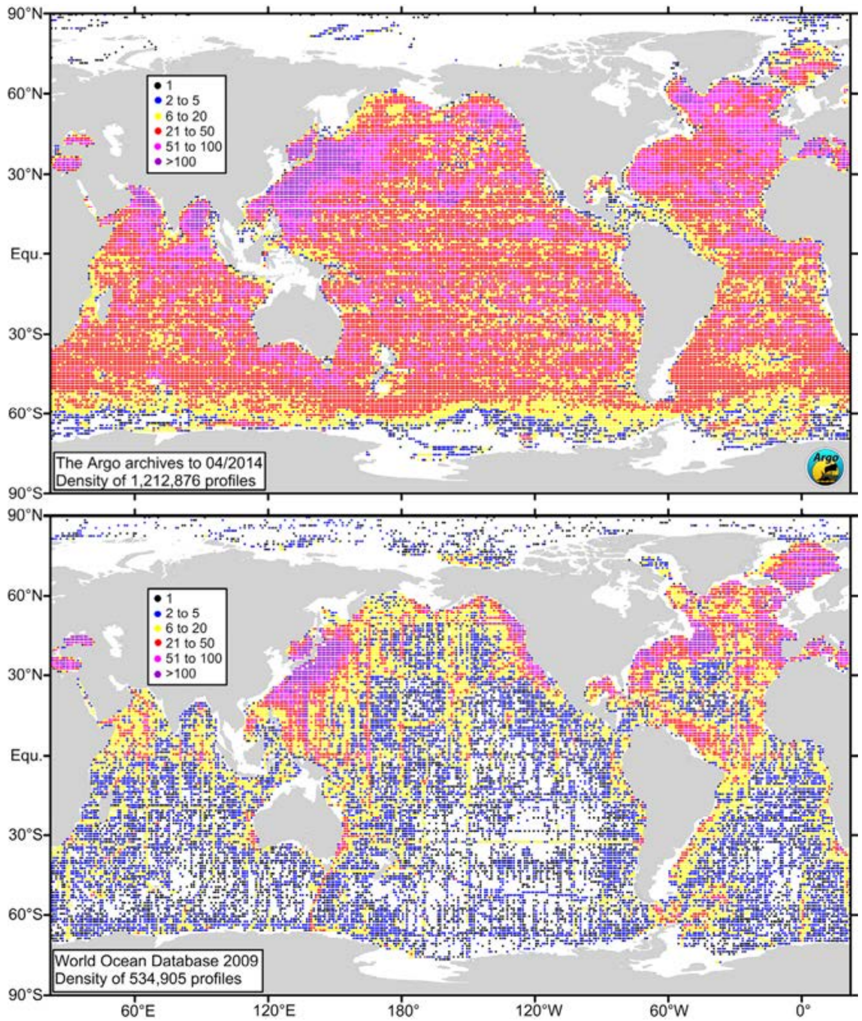
Close to 10,000 float O_2 profiles per year now (250 floats x 40 profiles/year)



Johnson et al., 2015, J. Atm. Oceanic Technol.

Argo transformed *global-scale* oceanography into *global* oceanography.

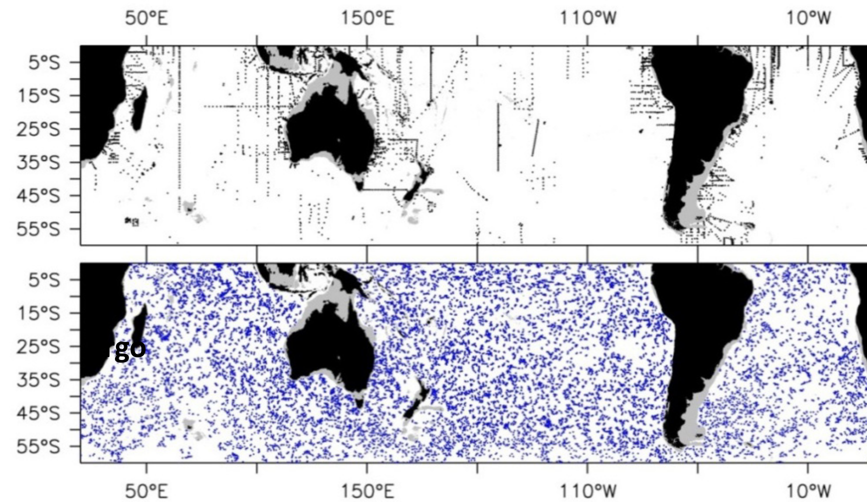
Argo: 1,000,000 T/S profiles milestone achieved in 2012.



20th Century: 500,000 T/S **profiles > 1000 m**

Argo Floats Do Not Mind Bad Weather

All August T/S profiles (> 1000 m, 1951 - 2000).



5 years of August Argo T/S profiles (2008-2012).

The World Ocean Circulation Experiment was a global survey of 8,000 T/S profiles in 7 years (1991-1997).

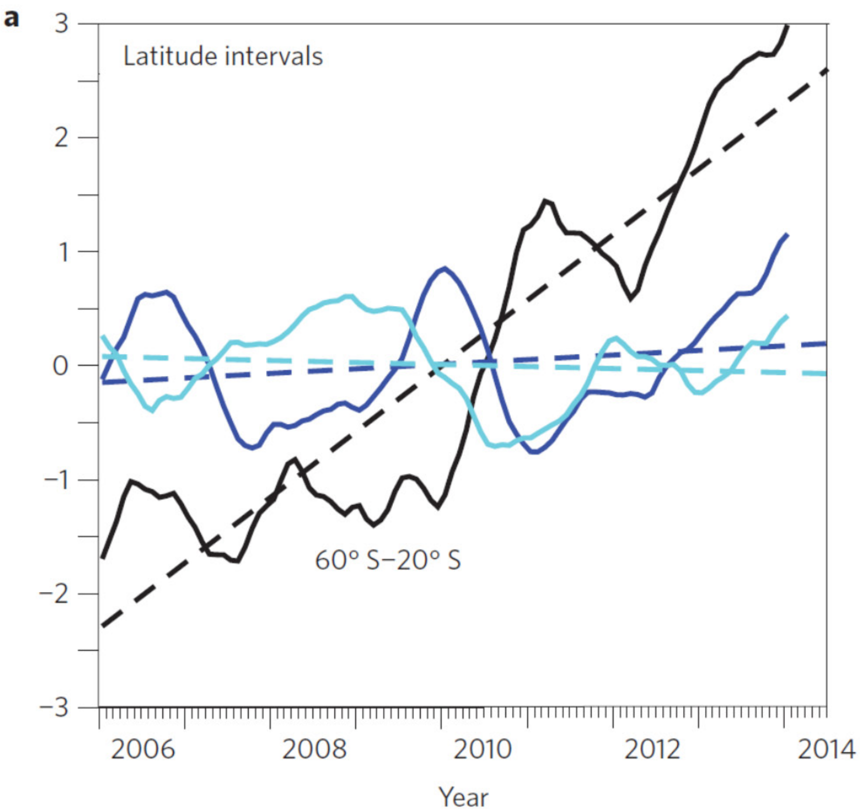
Argo is a global survey of 12,000 T/S profiles every month.

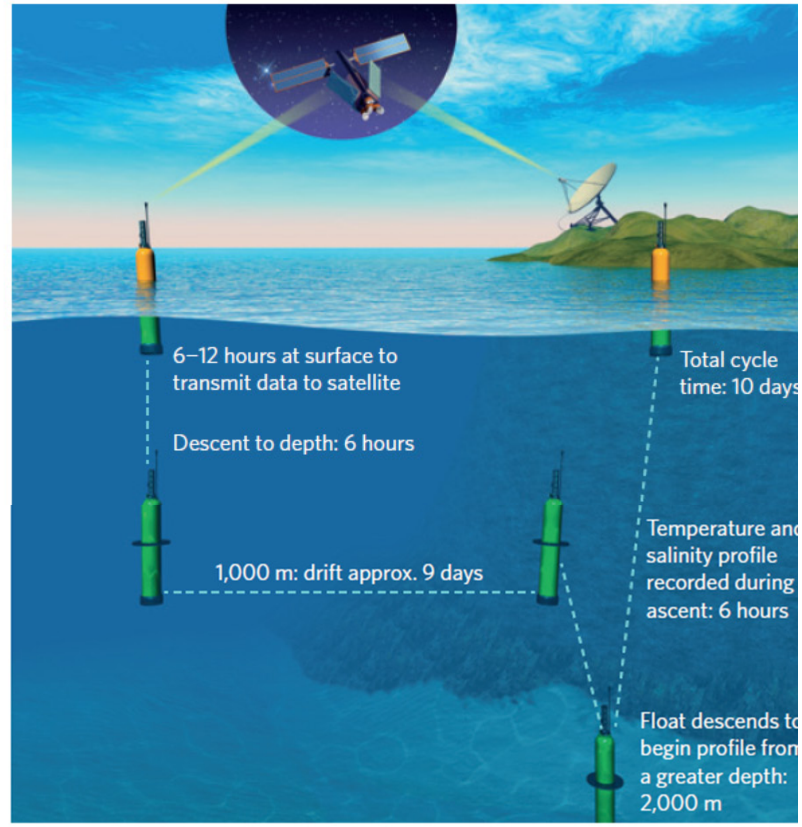
Courtesy S. Piotrowicz

nature climate change
REVIEW ARTICLE
PUBLISHED ONLINE: 27 JANUARY 2016 | DOI: 10.1038/NCLIMATE2872

Fifteen years of ocean observations with the global Argo array

Stephen C. Riser[1], Howard J. Freeland[2*], Dean Roemmich[3], Susan Wijffels[4], Ariel Troisi[5], Mathieu Belbéoch[6], Denis Gilbert[7], Jianping Xu[8], Sylvie Pouliquen[9], Ann Thresher[4], Pierre-Yves Le Traon[10], Guillaume Maze[9], Birgit Klein[11], M. Ravichandran[12], Fiona Grant[13], Pierre-Marie Poulain[14], Toshio Suga[15], Byunghwan Lim[16], Andreas Sterl[17], Philip Sutton[18], Kjell-Arne Mork[19], Pedro Joaquín Vélez-Belchí[20], Isabelle Ansorge[21], Brian King[22], Jon Turton[23], Molly Baringer[24] and Steven R. Jayne[25]



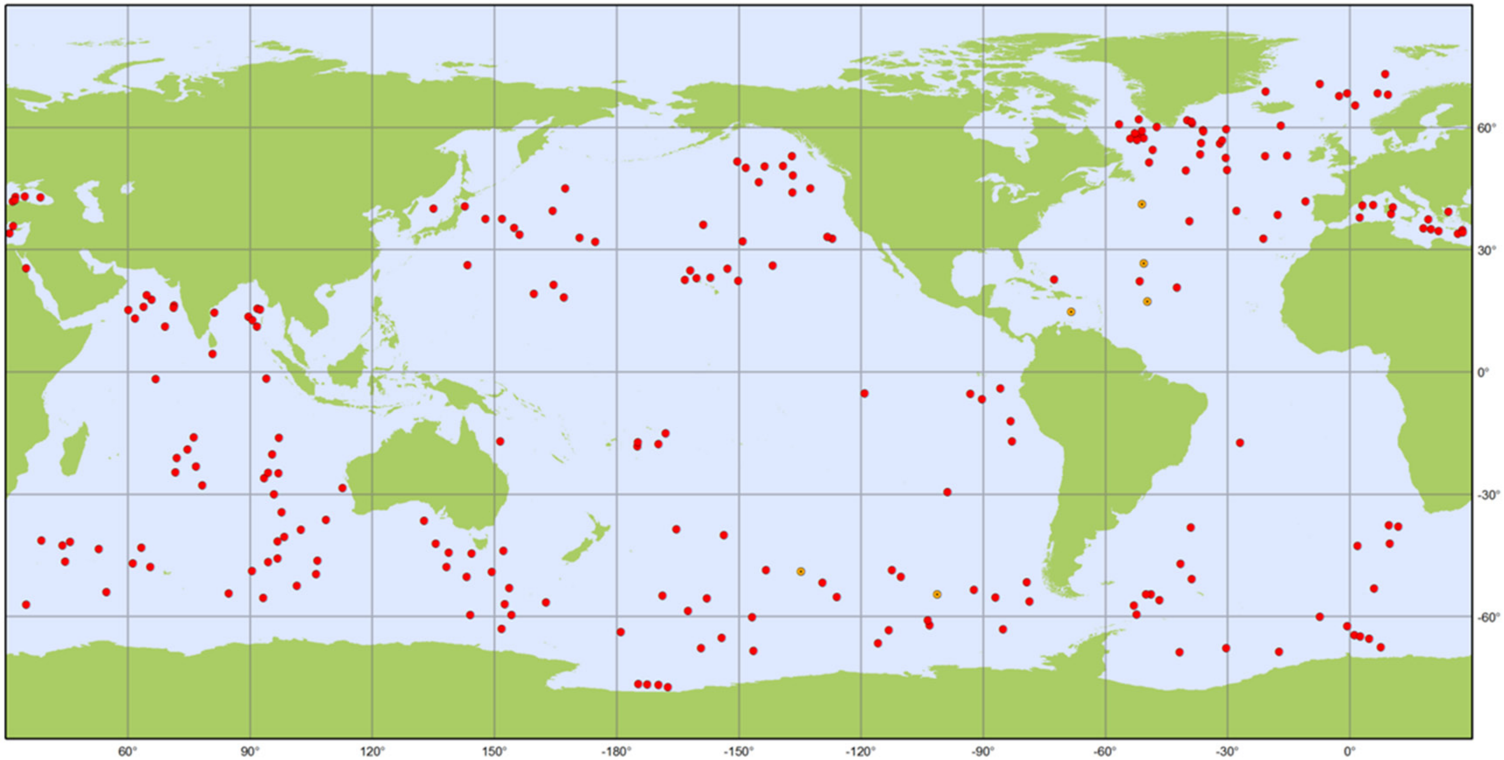


LETTERS
PUBLISHED ONLINE: 2 FEBRUARY 2015 | DOI: 10.1038/NCLIMATE2513
nature climate

Unabated planetary warming and its ocean structure since 2006

Dean Roemmich[1*], John Church[2], John Gilson[1], Didier Monselesan[2], Philip Sutton[3] and Susan Wijffels[2]

We can now do the same for biogeochemistry/ocean carbon cycling!



Argo **BioGeoChemical Argo - Oxygen** **May 2016**

Latest location of operational floats (data distributed within the last 30 days)

IDO_DOXY (6)

OPTODE_DOXY (234)

Generated by www.jcommops.org, 03/06/2016

308 2003 JOURNAL OF ATMOSPHERIC AND OCEANIC TECHNOLOGY VOLUME 20

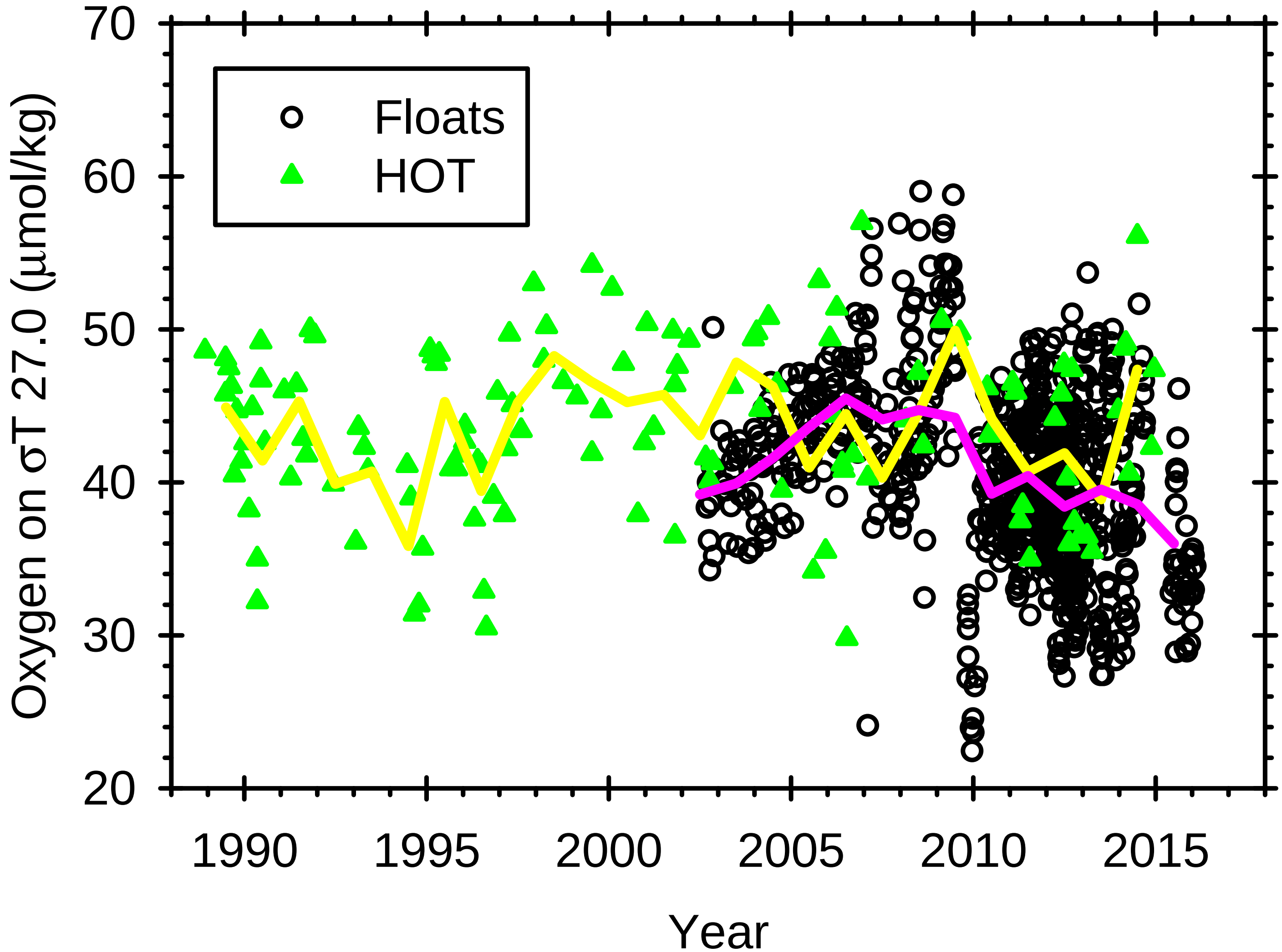
Delayed-Mode Calibration of Autonomous CTD Profiling Float Salinity Data by θ–S Climatology*

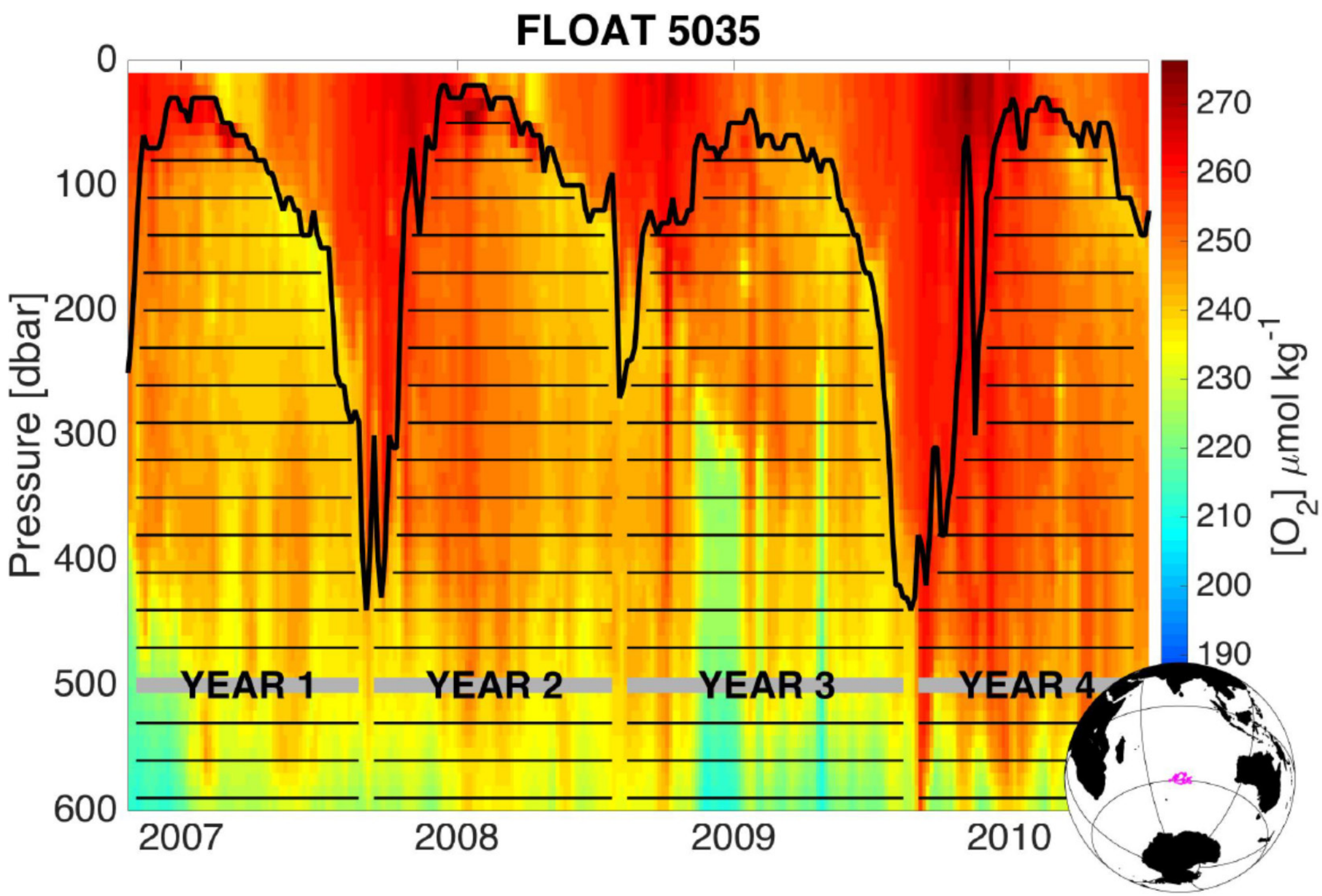
ANNIE P. S. WONG
GREGORY C. JOHNSON
W. BRECHNER OWENS

"These floats give good measurements of temperature and pressure, but salinity measurements may experience significant sensor drifts with time. The moving nature of these floats means that it is too expensive to retrieve them regularly for physical calibrations. Thus a system has been set up to correct the drift in these profiling float salinity data by using historical hydrographic data."

biogeochemical Argo

Oxygen measured with optodes. Re-calibration with air yields oxygen measurements consistent with shipboard measurements.





Hennon, Riser, Mecking, 2016, GBC, Profiling float-based observations of net respiration beneath the mixed layer.

A global assessment of respiration & C export.

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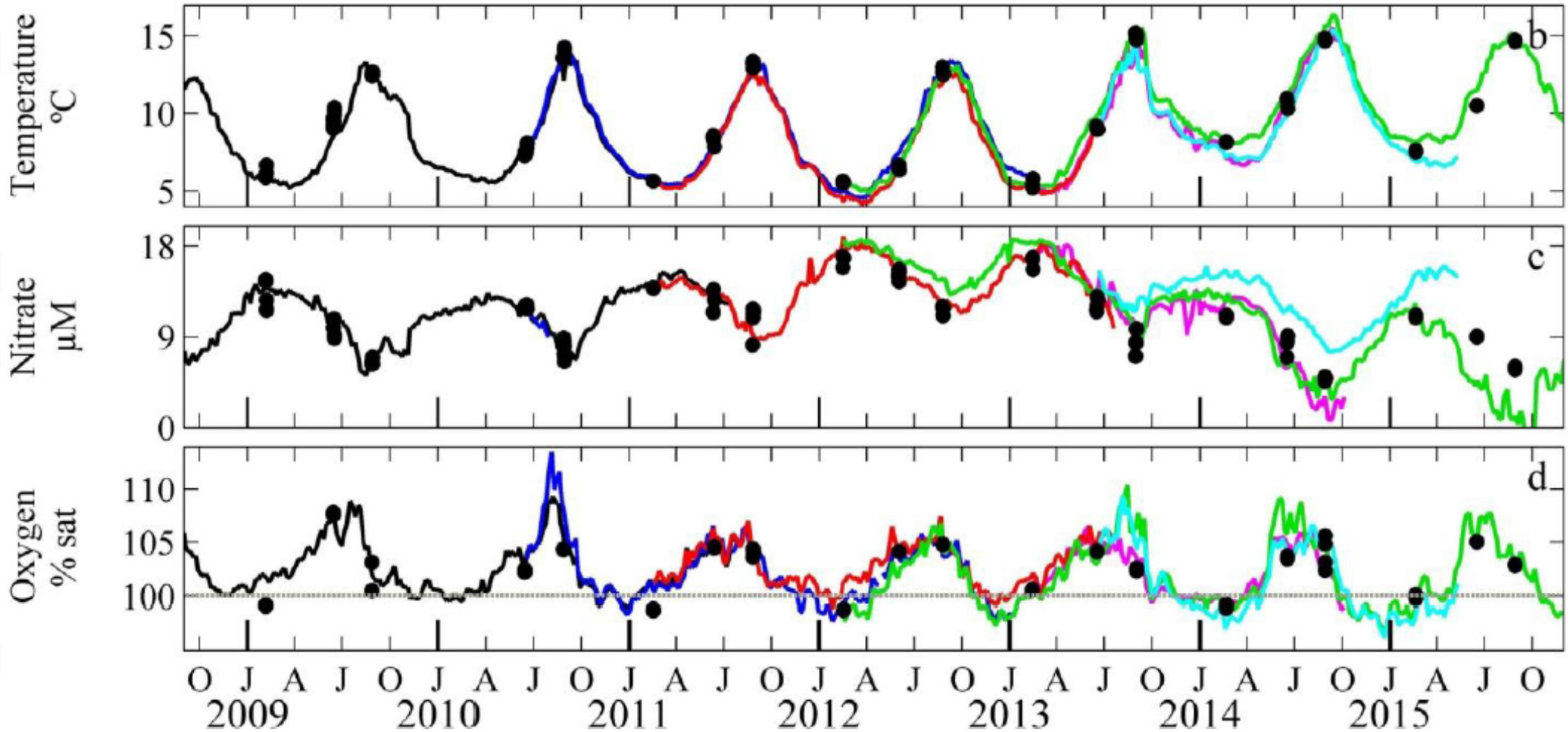
Nitrate measured with ISUS/SUNA UV optical sensors. 7 calendar years, 12 floats years of nitrate near Ocean Station Papa.



Plant, Johnson, et al., 2016, GBC, Net community production at Ocean Station Papa….

Nitrate data good enough to identify problems in bottle data. E.g., at Ocean Station P (Johnson et al. 2013):

> 3 yr. The 1000-m float measurements are about 2 μmol L^{-1} lower than the Line P data, which have a mean of 46.0 $\pm$0.6 μmol L^{-1} (1 SD) in the same period. This bias is most likely in the Line P data, as other nearby datasets

NOTE: July 2013: A correction has been applied to Nitrate_plus_Nitrite:Bottle and Phosphate:Bottle data from deep-water cruises analyzed at IOS between 2009 and 2012. For details see the report: Corrections_to_Nitrate_and_Phosphate_Data_2009-2012.pdf.

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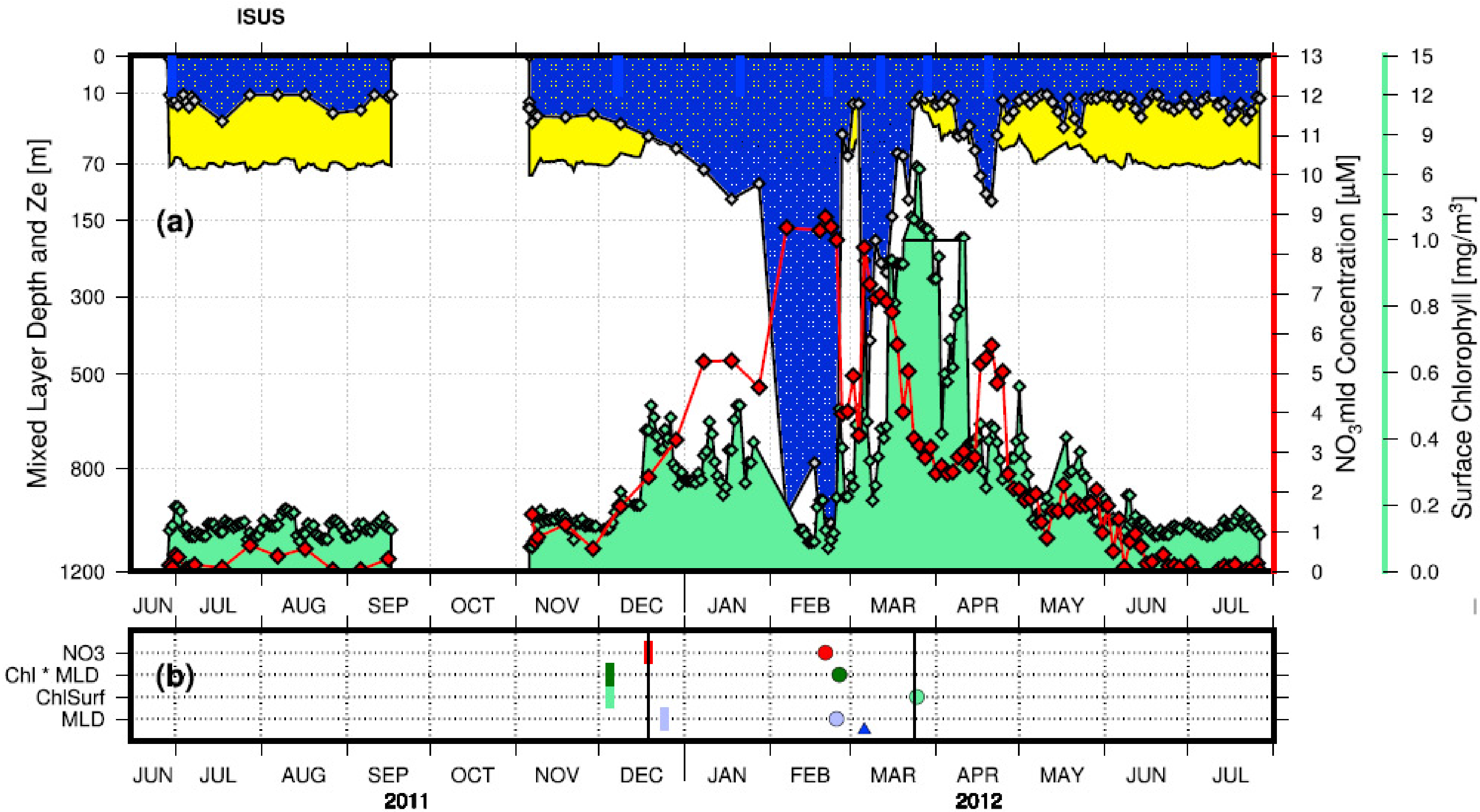
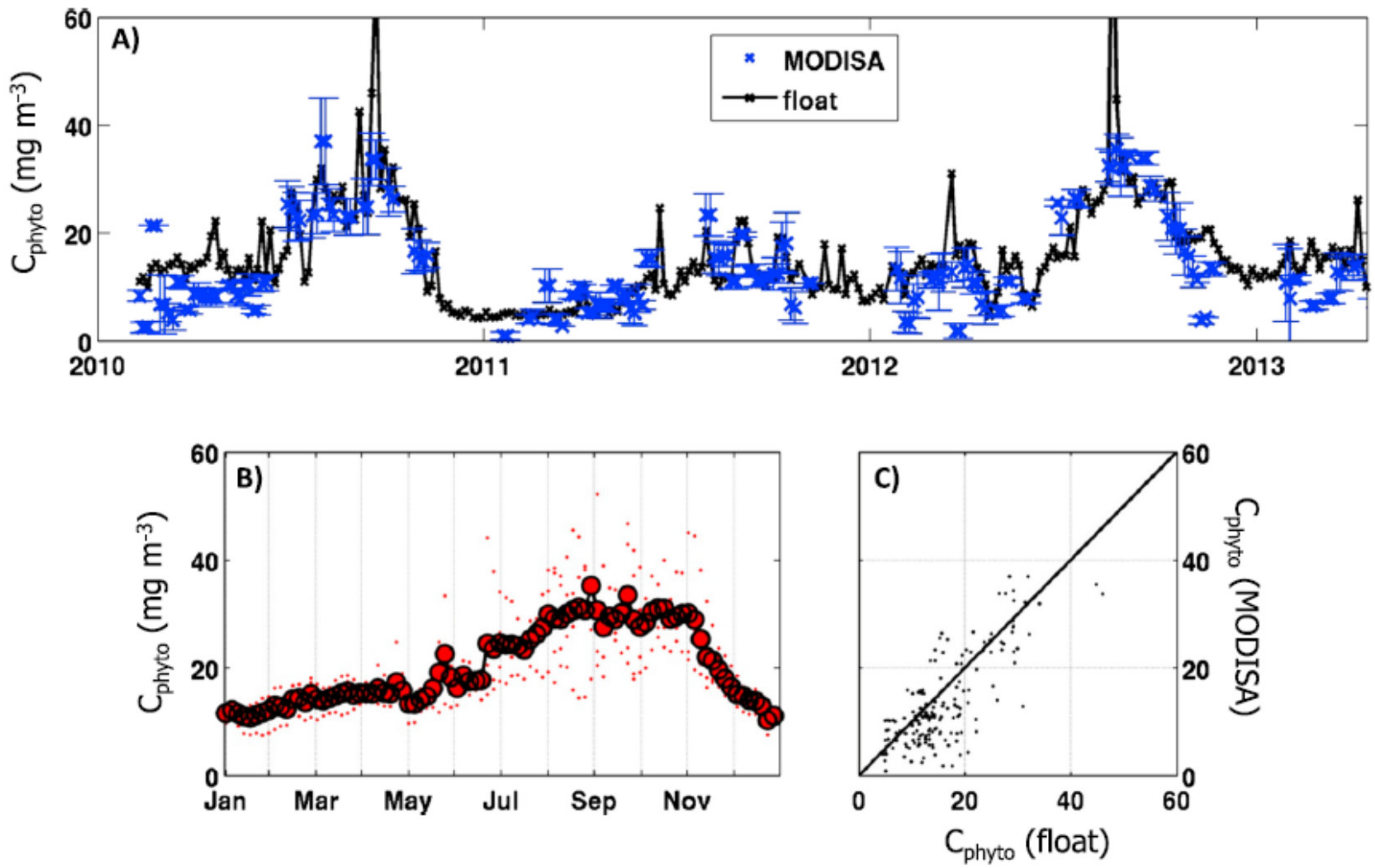
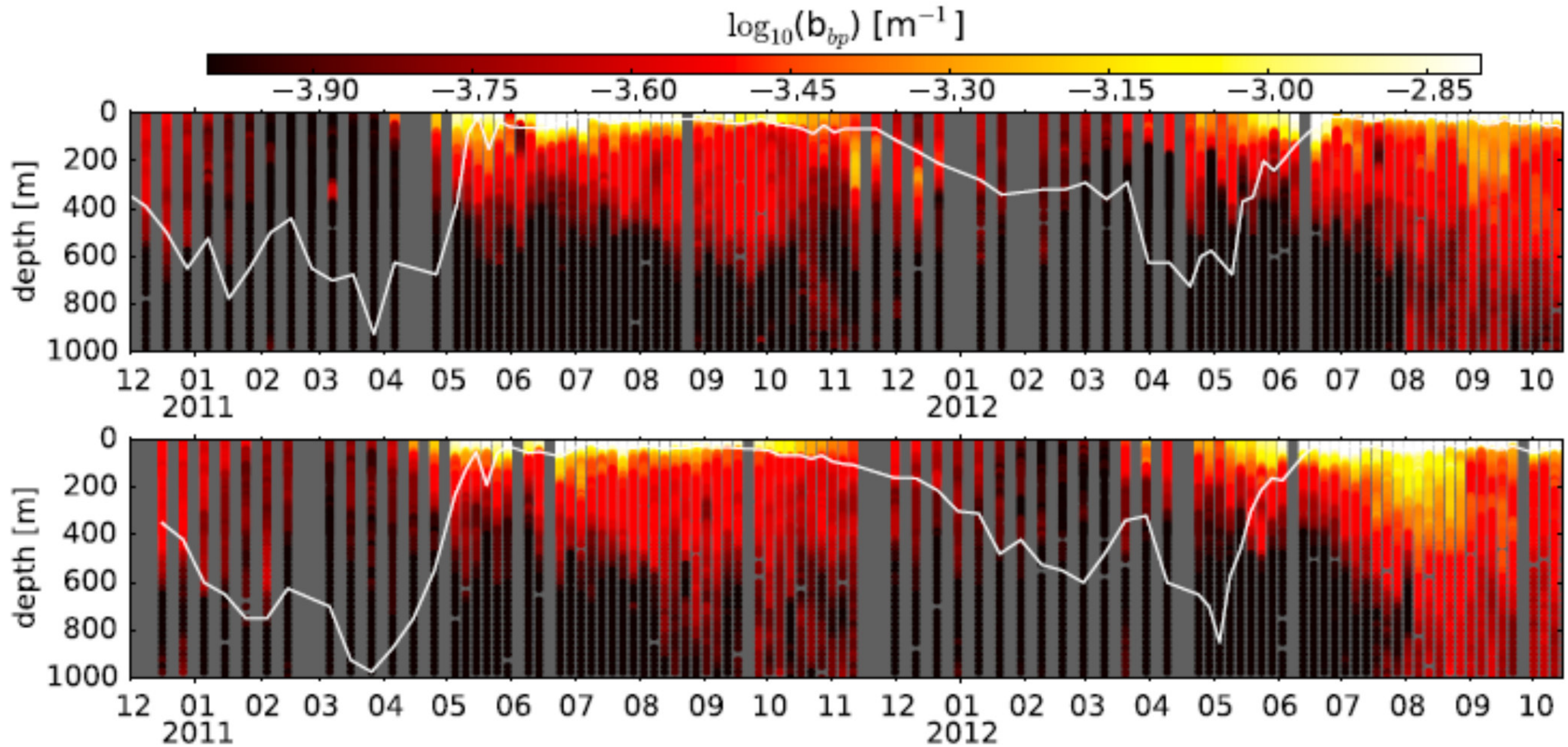


D'Ortenzio et al. 2014, GRL, Observing mixed layer depth, nitrate and chlorophyll in the northwestern Mediterranean: A combined satellite and NO3 profiling floats experiment.

Particulate carbon measured with backscatter sensors. Remarkable consistency with satellite observations.



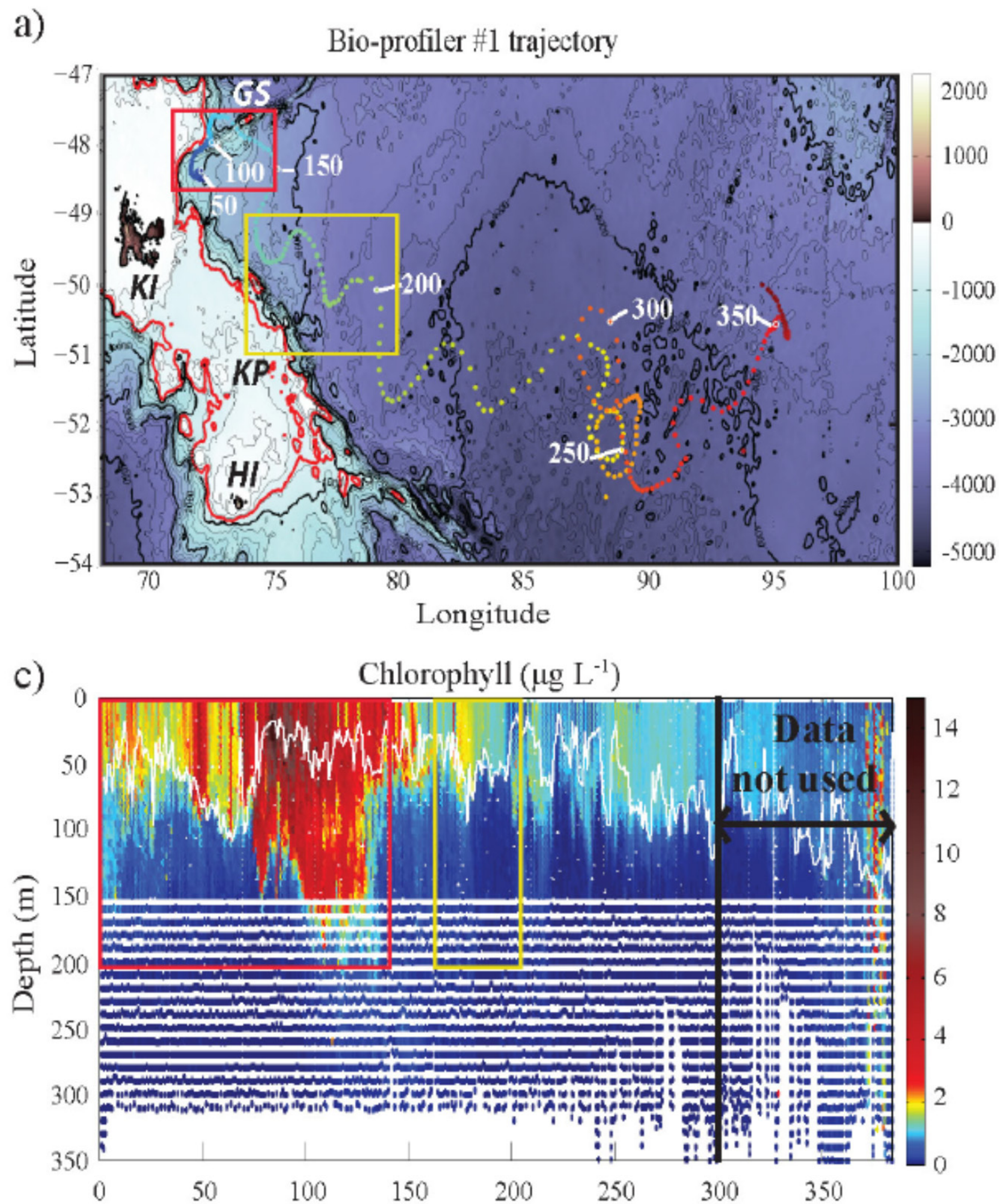
Westberry et al. 2015 GBC, Annual cycles of phytoplankton biomass in the subarctic Atlantic and Pacific Ocean.



Dall'Olmo and Mork, 2014, GRL, Carbon export by small particles in the Norwegian Sea.

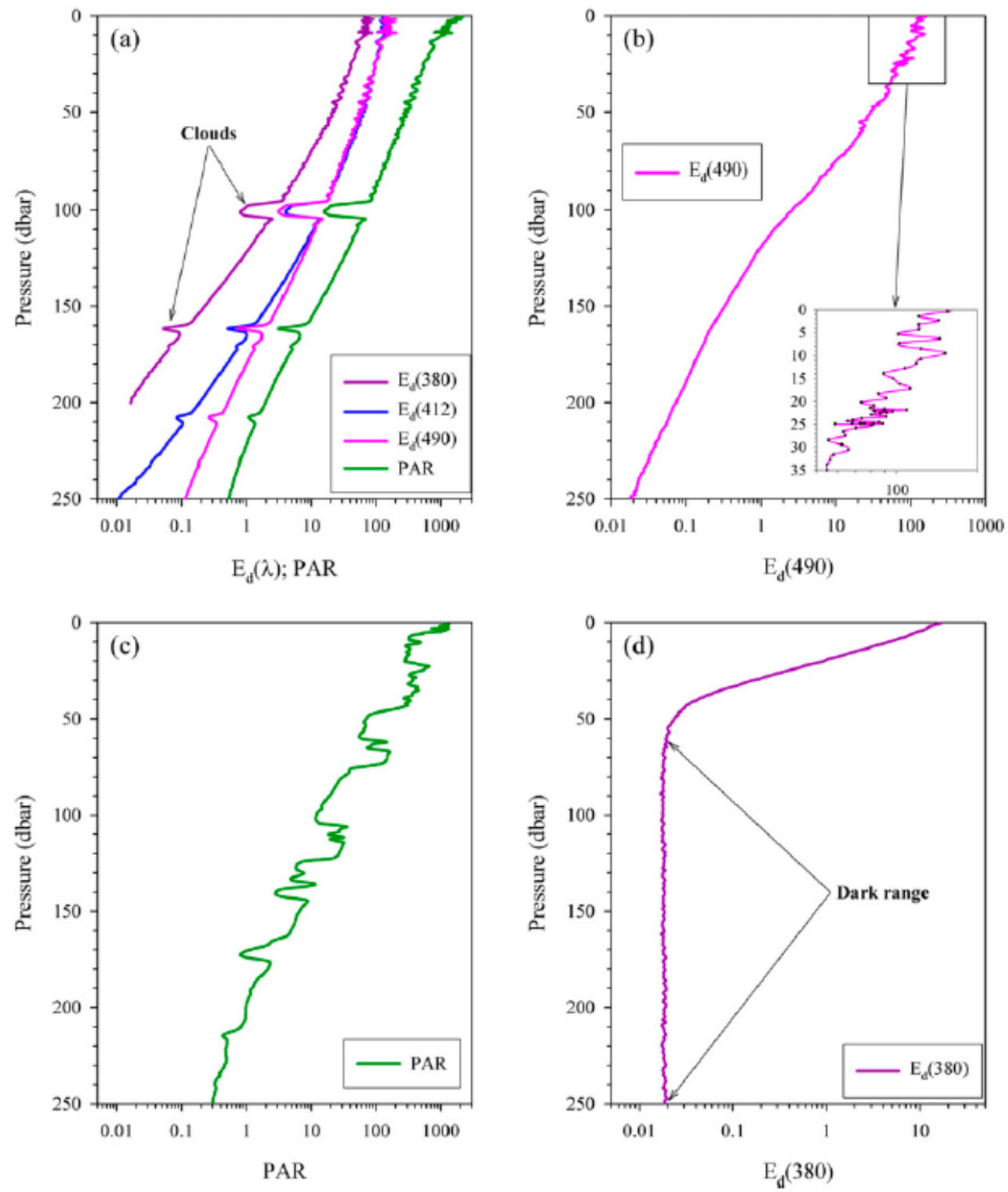
Chlorophyll by in situ fluorescence.

Grenier, Della Penna, Trull, 2015, Biogeosciences, Autonomous profiling float observations of the high-biomass plume downstream of the Kerguelen Plateau in the Southern Ocean

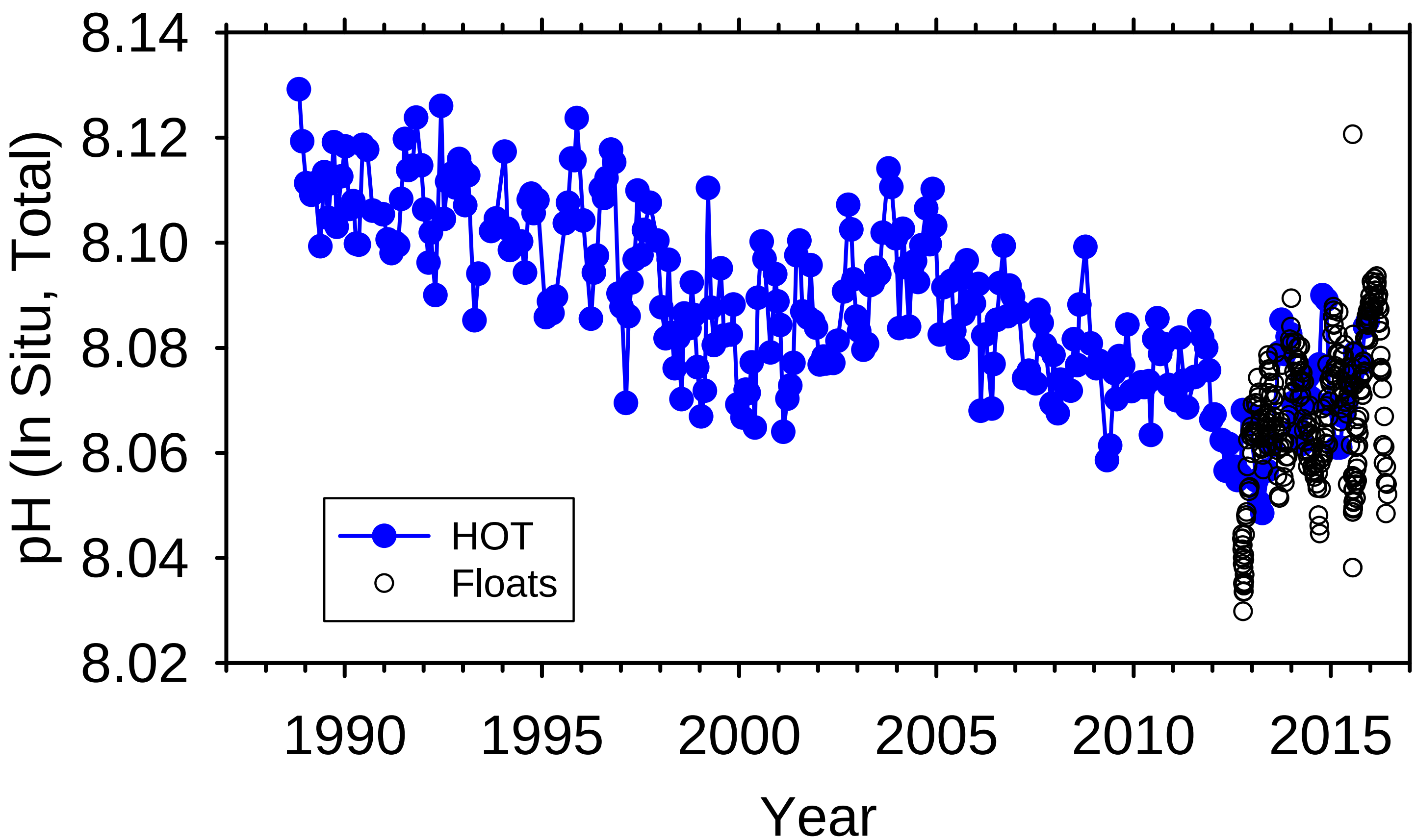


Wavelength resolved downwelling irradiance provides direct observations of light field, quantitative measure of chlorophyll.

Organelli, Claustre et al., 2016, JAOT, A novel near-real-time quality-control procedure for radiometric profiles
measured by Bio-Argo floats: protocols and performances



- pH is newest sensor.
- Measured with Deep-Sea Durafet ISFET sensors
- Like salinity, errors are correctable.
- Like salinity, performance is improving



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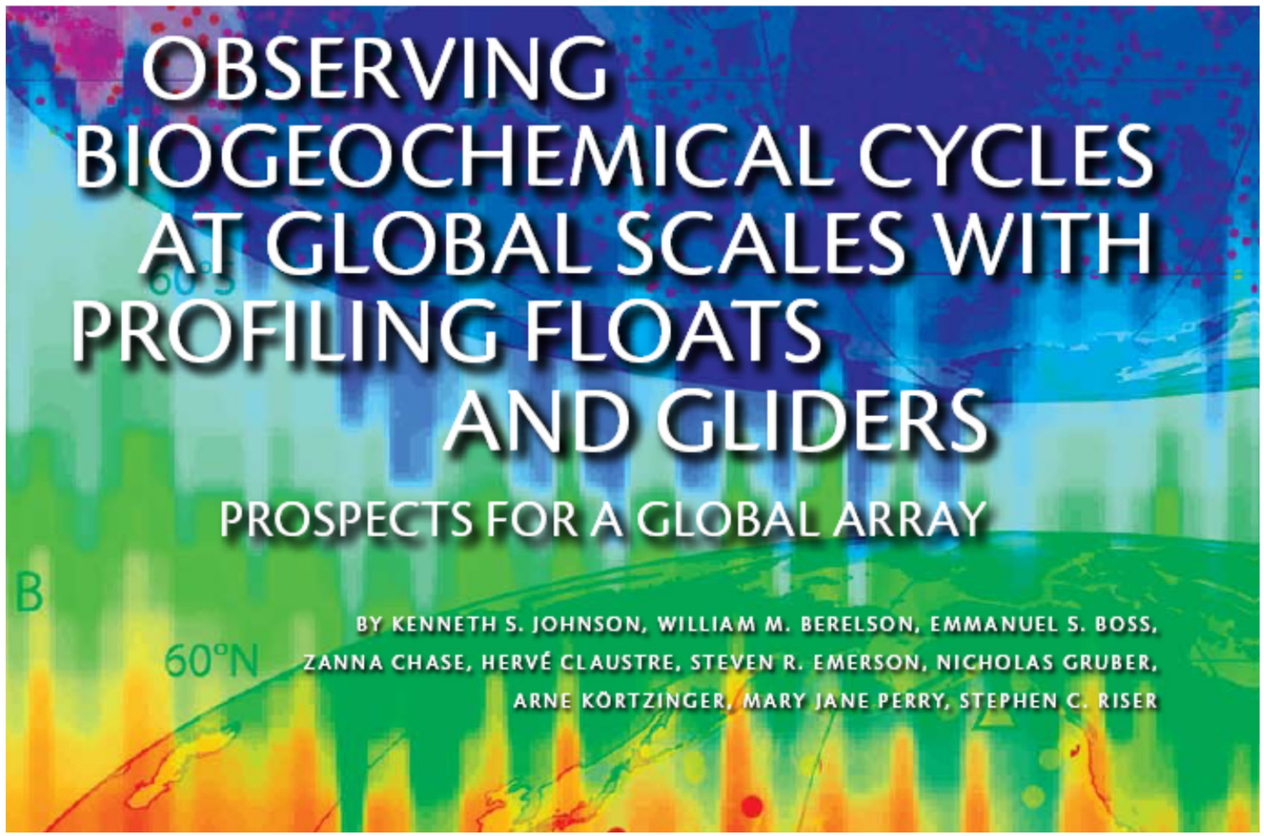
HOT data from Dore et al. (2009) and extended to 2015. Float data from Johnson et al. Anal. Chem. 2016 and extended to 2016.

US Ocean Carbon & Biogeochemistry Scoping Workshop

Observing biogeochemical cycles at global scales with floats and gliders

28-30 April 2009, Moss Landing, CA

http://www.whoi.edu/sites/OCBfloatsgliders



Sept. 2009 Issue of Oceanography

Home
Proceedings
Preface
Statement
Summary

Published in the
Proceedings of OceanObs'09: Sustained Ocean Observations and Information for Society

PLENARY PAPER

doi:10.5270/OceanObs09.pp.33

Integrating the Ocean Observing System: Mobile Platforms

ADDING OXYGEN TO ARGO: DEVELOPING A GLOBAL IN-SITU OBSERVATORY FOR OCEAN DEOXYGENATION AND BIOGEOCHEMISTRY

Nicolas Gruber [1], Scott C. Doney[2], Steven R. Emerson[3], Denis Gilbert[4], Taiyo Kobayashi[5], Arne Körtzinger[6], Gregory C. Johnson[7], Kenneth S. Johnson[8], Stephen C. Riser[3], and Osvaldo Ulloa[9]

[1] Institute of Biogeochemistry and Pollutant Dynamics, ETH Zurich, Zürich, Switzerland

BIO-OPTICAL PROFILING FLOATS AS NEW OBSERVATIONAL TOOLS FOR BIOGEOCHEMICAL AND ECOSYSTEM STUDIES: POTENTIAL SYNERGIES WITH OCEAN COLOR REMOTE SENSING.

Hervé Claustre[1], Jim Bishop[2], Emmanuel Boss[3], Stewart Bernard[4], Jean-François Berthon[5], Christine Coatanoan[6], Ken Johnson[7] Aneesh Lotiker[8], Osvaldo Ulloa[9], Marie Jane Perry[10], Fabrizio D'Ortenzio[11], Odile Hembise Fanton D'andon[12], Julia Uitz[13]

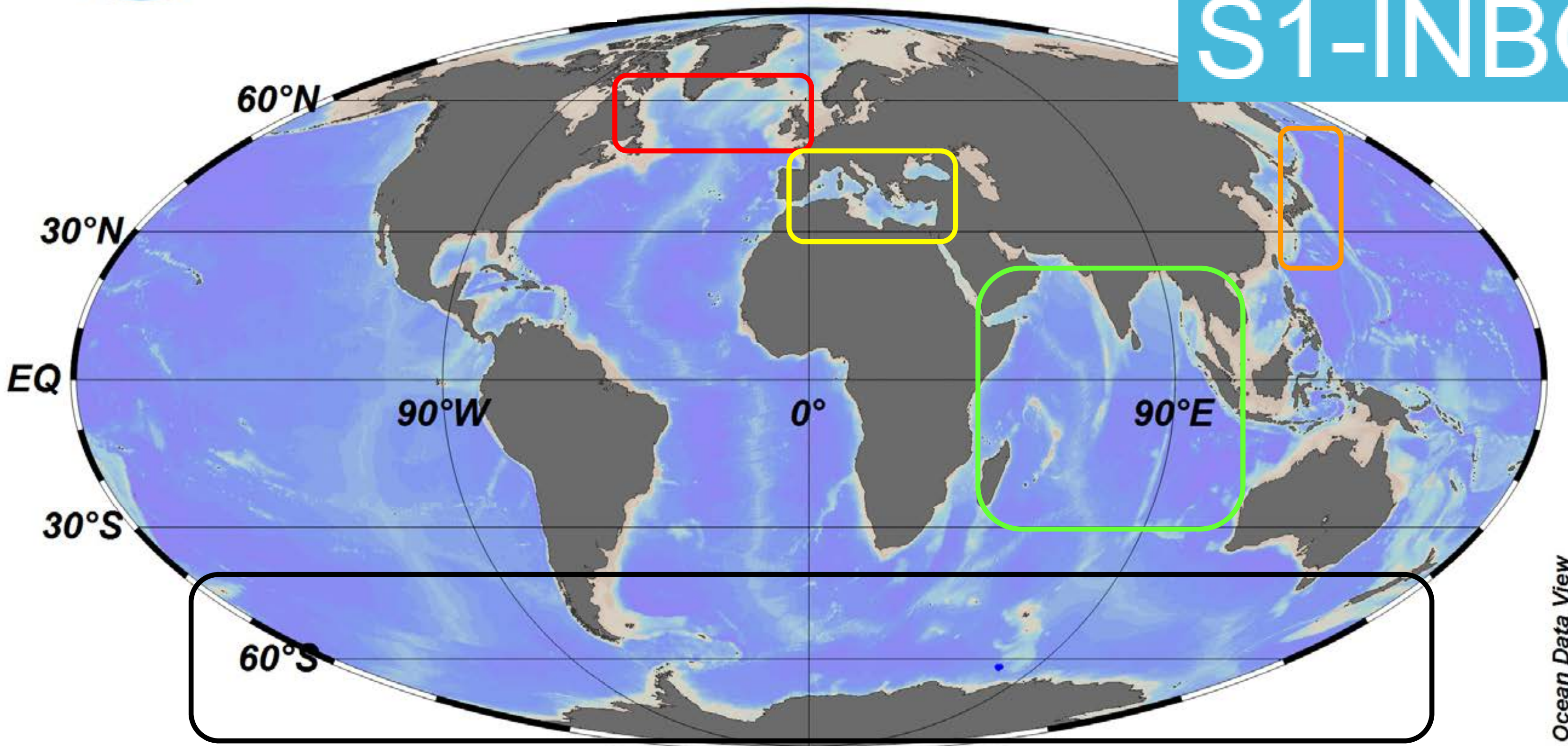
[1] CNRS and University P. & M. Curie, Laboratoire d'Océanographie de Villefranche, 06230 Villefranche-sur-mer, France, Email: claustre@obs-vlfr.fr

[2] Earth Sciences Division, Lawrence Berkeley National Laboratory, One Cyclotron Road, M/S 90-1116,

remOcean
Remotely-Sensed Biogeochemical Cycles in the Ocean

NAOS Project

S1-INBOX



SOCCOM

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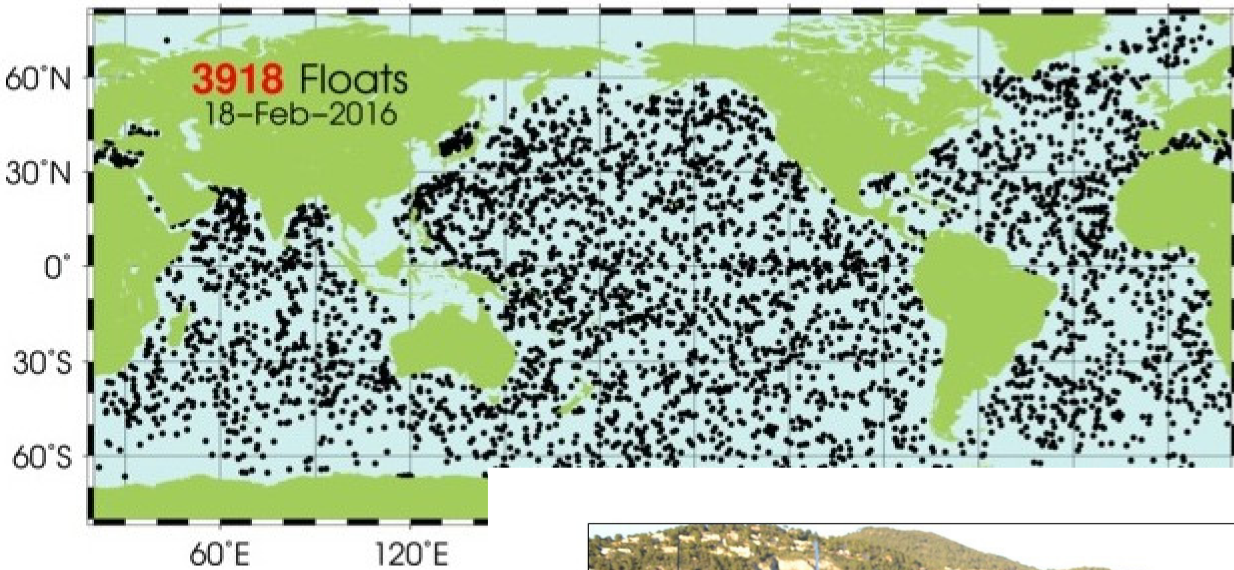
Australia-India Joint Indian Ocean Bio-Argo Project

"Characterising the changing Indian Ocean's biogeochemistry and ecology using revolutionary new robotic tools"



Planning for a global network has begun. First meeting in Villefranche-sur-Mer, 11-13 January 2016.

Draft implementation plan out for comment.

Biogeochemical-Argo Network - Group photo

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Attendees at Biogeochemical Argo meeting in Villefranche

Ken Johnson	USA	Pierre-Yves Le Traon	FR
Hervé Claustre	FR	Katja Fennel	CAN
Joellen Russell	USA	Marion Gehlen	FR
Pierre Brasseur	FR	Masao Ishii	JP
Steven Riser	USA	Shigeki Hosoda	JP
Jorge Sarmiento	USA	Toshimasa Doi	JP
Arne Kortzinger	GER	Tetsuichi Fujiki	JP
Emmanuel Boss	USA	Haili Wang	China
Giorgio D'alomo	UK	Michele Barbier	FR
Nick Hardman-Mountford	AUS	Alison Gray	USA
Fabrizio Dortenzio	FR	Mathieu Belbeoch	FR
Steve Piotrowicz	USA		

Invited, unable to attend: Brian King, Niki Gruber, John Dunne, Rik Wanninkhof, Dick Feely, Toshio Suga, Satya Prakash

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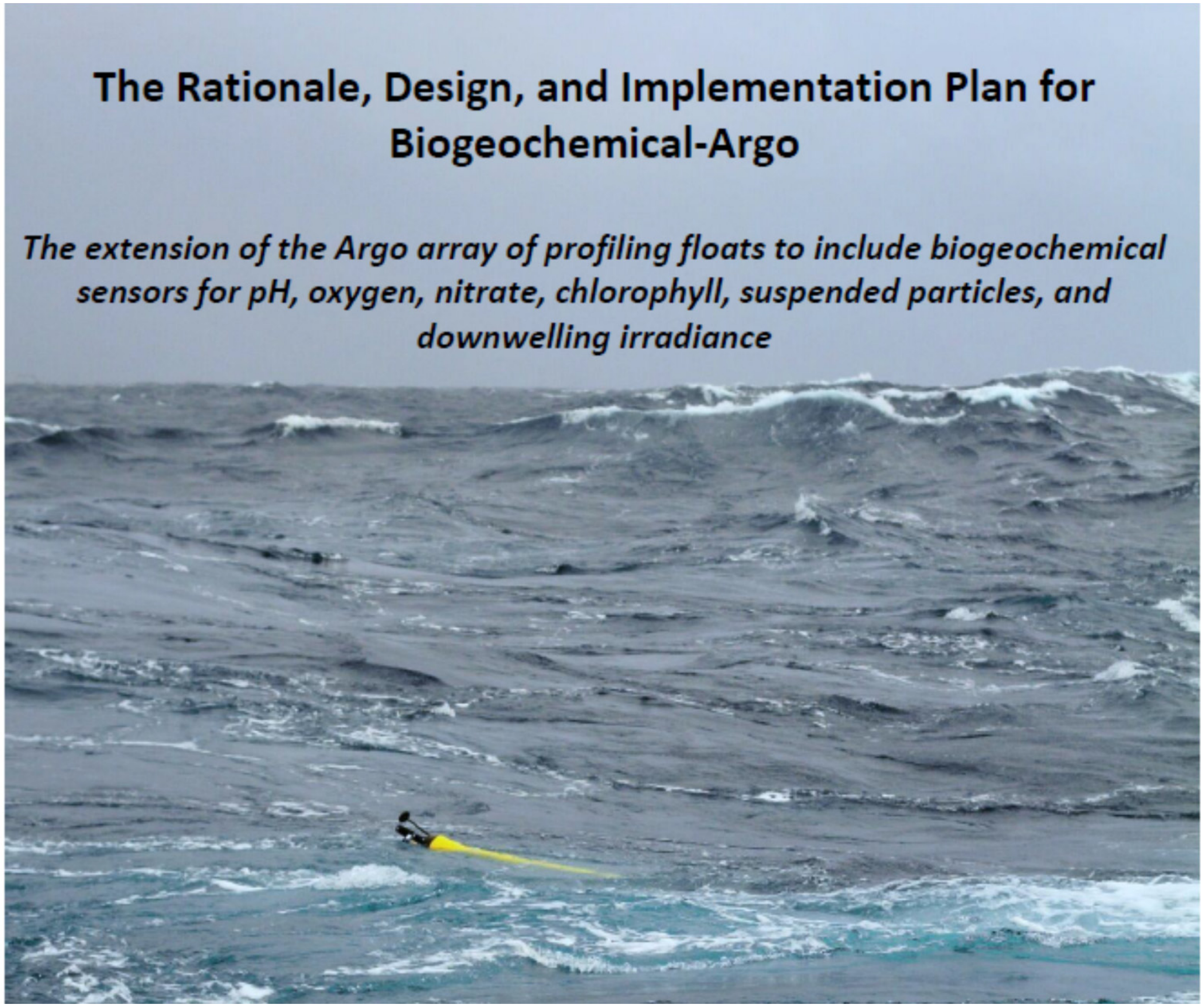
Comments to K. Johnson & H. Claustre by Aug. 15.



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http://www3.mbari.org/chemsensor/BGCArgoPlanJune21.pdf

johnson@mbari.org, claustre@obs-vlfr.fr

Biogeochemical-Argo data is freely available, in real-time, without restriction!

In particular, this provides a means for early career scientists to do good, imaginative work without implementing large, costly research programs.

Overarching questions and research priorities for program

- Basic/Climate Research/Grand Challenge Questions
  - Ocean carbon cycle (carbon uptake, NCP, C export…), linkage to ocean color sensing (chlorophyll, NPP, functional groups), and link to climate models
  - Ocean oxygen/deoxygenation and linkage to nitrogen cycle
  - Ocean acidification and linkage to carbon cycle and ecosystem processes

- Applied research
  - Improving ocean carbon budget to understand terrestrial changes
  - Living marine resources/ocean forecasting
    - Ecosystem/fishery models

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Assessment	Global Array Size
Southern Ocean OSSE extrapolated to global scale	700
Global OSSE of air-sea CO2 flux	1000
Satellite chlorophyll reconstruction	1000
pCO_2/nutrient decorrelation length scales	1800
Mean of all assessments	1000

Sustaining a 1000 float array will require ~250 floats/year

Table 2. Biogeochemical-Argo system costs*		
Item	Capital cost	Total cost (capital + data transmission + data processing and QC).
Core Argo T/S float	\$22,000	\$33,000
Add O_2 to Argo	\$7,000	\$10,200
Add nitrate	\$24,000	\$31,000
Add biooptics (Chl, BB, Ed)	\$17,000	\$20,200
Add pH	\$10,000	\$13,200
Cost per float	\$80,000	\$107,600
	Floats/year	Program Cost/year
US share (1/2)	125	\$13,450,000
Complete array	250	\$26,900,000

* Capital costs of components are estimates of current market price. Total cost for a core Argo float was estimated as US Argo budget of \$10,000,000/year/300 floats/year. Operating costs for additional sensors were estimated from Gruber et al. (2007) for O_2, and a similar cost was applied to biooptics and pH. Nitrate is more complex and its operating cost was doubled, relative to oxygen.

Other facility costs*:

- US Deep-Sea Drilling Program order of $58 million/year.
- Academic research fleet $83 million/year at NSF.
- One Global Class ship order of $40,000/d x 250 days/y = $10 million/year.
- Ocean Observatory Initiative (OOI) $386 million capital and ~$45 million/year to operate.

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*Compiled from NRC Sea Change report and NSF response.

We, the Science and Technology Ministers of Canada, France, Germany, Italy, Japan, the United Kingdom, the United States, and the European Commissioner for Research, Science and Innovation, met in Tsukuba City, Ibaraki Prefecture from May 15 to 17, 2016.

…we support taking the following actions:

i. Support the development of an initiative for enhanced global sea and ocean observation …..e.g. through the Global Argo Network and other observation platforms, while fully sustaining and coordinating with ongoing observation;

This should include but not be limited to:

- Increasing the capability of the global Argo network to include more biological and biogeochemical observation and observation of the deep sea;

Global Biogeochemical Argo is the glue that brings these programs together

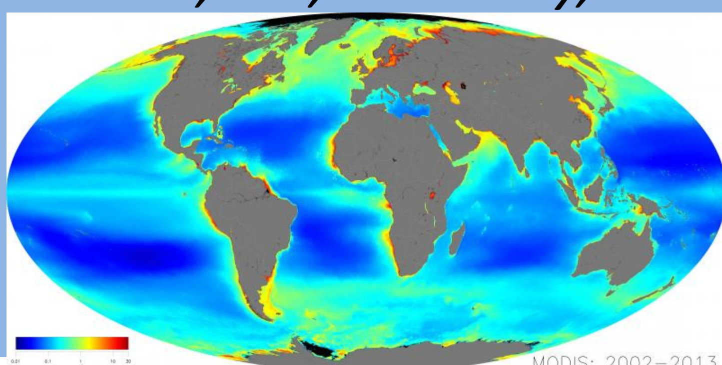
GO - SHIP

TOWARDS A SUSTAINED GLOBAL SURVEY OF THE OCEAN INTERIOR

GO-SHIP brings together scientists with interests in physical oceanography, the carbon cycle, marine biogeochemistry and ecosystems, and other users and collectors of hydrographic data to develop a globally coordinated network of sustained hydrographic sections as part of the global ocean/climate observing system.

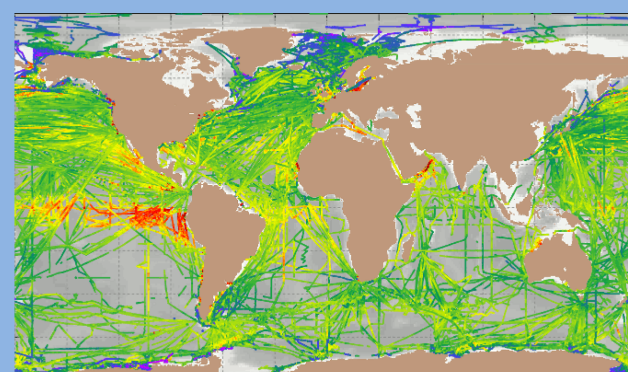
GO-SHIP is a major contributor to WCRP's Climate Variability and Predictability Experiment (CLIVAR) and International Ocean Carbon Coordination Project. GO-SHIP is part of the Global Climate Observing System / Global Ocean Observing System (GCOS / GOOS).

Ocean color, SST, Altimetry, LIDAR



SOCAT

- SURFACE OCEAN CO_2 ATLAS -



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The time to implement a global observing system for ocean biogeochemistry management and research is now!

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future tense ASU | NEW AMERICA | SLATE

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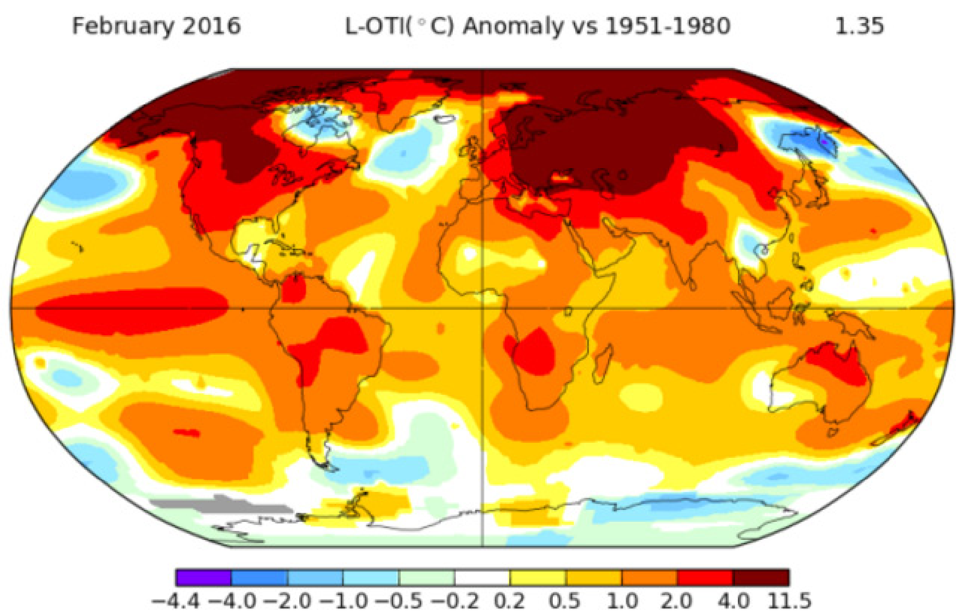
future tense THE CITIZEN'S GUIDE TO THE FUTURE | MARCH 12 2016 1:27 PM

Our Planet's Temperature Just Reached a Terrifying Milestone

By Eric Holthaus

68.1k 13.8k 926



NASA has confirmed that our planet's temperature surged in February 2016—past a major milestone.

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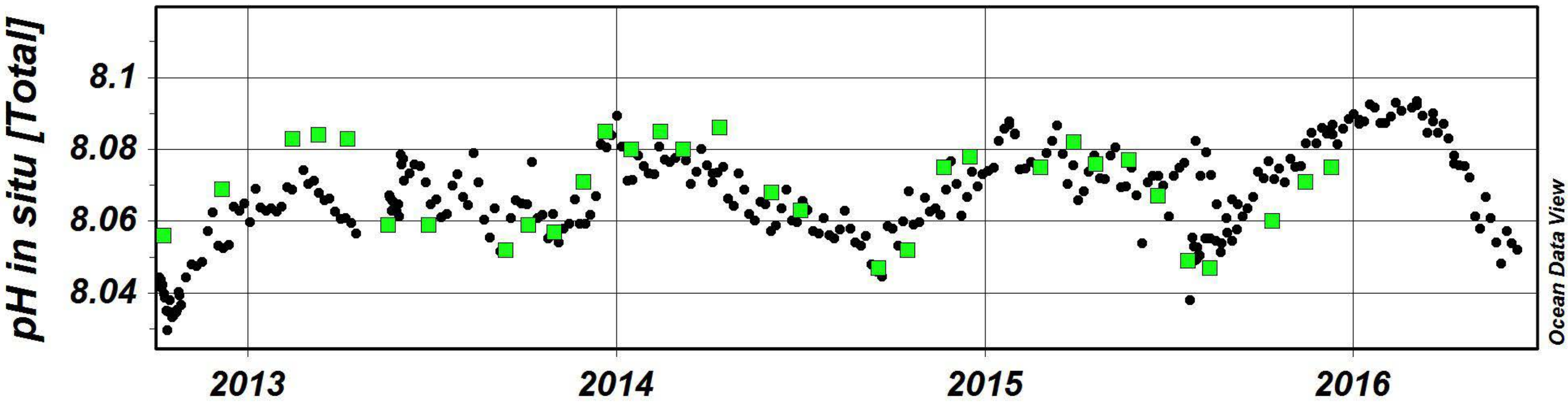
Float population that results with 250 floats deployed per year, 250 profile battery capacity, 90% survival each year and a 6 day cycle time.

Cycle Time	6	days per cycle						
Survival Rate	0.90	fraction surviving each year						
Total Cycles/float	250							
Lifetime	4.1	years						
Project Year		0	1	2	3	4	5	6
Floats left in year class	0	250	225	202	181	162	0	0
Floats left in year class	1		250	225	202	181	162	0
Floats left in year class	2			250	225	202	181	162
Floats left in year class	3				250	225	202	181
Floats left in year class	4					250	225	202
Floats left in year class	5						250	225
Floats left in year class	6							250
total running/year		250	475	677	858	1020	1020	1020
Cumm. Total Built		250	500	750	1000	1250	1500	1750



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- Numerous studies point to climate and decreasing ocean phytoplankton/ productivity links.

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]

8 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 dependence of phytoplankton biomass at local, regional and global scales since 1899. We observe declines in eight out of ten ocean regions, and estimate a global rate of decline of ~1% of the global median per year. Our analyses further reveal interannual to decadal phytoplankton fluctuations superimposed on long-term trends. These fluctuations are strongly correlated with basin-scale climate indices, whereas long-term declining trends are related to increasing sea surface temperatures. We conclude that global phytoplankton concentration has declined over the past century; this decline will

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nature climate change

ARTICLES

PUBLISHED ONLINE: 26 OCTOBER 2015 | DOI: 10.1038/NCLIMATE2838

Revaluating ocean warming impacts on global phytoplankton

Michael J. Behrenfeld[1]*, Robert T. O'Malley[1], Emmanuel S. Boss[2], Toby K. Westberry[1], Jason R. Graff[1], Kimberly H. Halsey[3], Allen J. Milligan[1], David A. Siegel[4] and Matthew B. Brown[1]

Is the satellite ocean color signal a reflection of physiological adaptation by phytoplankton to a warmer ocean, and not a change in biomass?

Unambiguous answers to such questions require an in situ observing system.

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