Prospects for Biogeochemical-Argo (BGC-Argo)

Todd Martz (Scripps) Presenting slides on behalf of:
Kenneth S. Johnson, Monterey Bay Aquarium Research Institute
Jorge L. Sarmiento, Princeton University
Hervé Claustre, Laboratoire d'Océanographie de Villefranche

NOAA Ocean Observing and Monitoring Division
10th OOMD Community Workshop
NOAA Science Center, Silver Spring, MD
9-11 May 2017

Ken Johnson
Co-Chairman - USA

Hervé Claustre
Co-Chairman - FRANCE

Emmanuel Boss
USA

Paulo Calil
BRAZIL

Catherine Schmechtig
FRANCE

Arne Körtzinger
GERMANY

Giorgio Dall'Olmo
UNITED KINGDOM

Nick Hardman-Mountford
AUSTRALIA

Sandy Thomalla
SOUTH AFRICA

Haily Wang
CHINA

Tetsuichi Fujiki
JAPAN

Katja Fennel
CANADA

Satya Prakash
INDIA

International Biogeochemical-Argo Steering Committee

US Biogeochemical-Argo Subcommittee

Emmanuel Boss - Univ. of Maine (co-chair)

Brendan Carter - NOAA/PMEL

Scott Doney - Woods Hole Oceanographic Inst.

John Dunne - NOAA/GFDL

Steve Emerson - Univ. of Washington

Meg Estapa - Skidmore College

Alison Gray - Princeton Univ.

Ken Johnson - Monterey Bay Research Inst. (co-chair)

Todd Martz - Scripps Inst. Oceanography

Matt Mazloff - Scripps Inst. Oceanography

Melissa Omand - Univ. Rhode Island

Steve Riser - Univ. of Washington

Joellen Russell - Univ. of Arizona

Jorge Sarmiento - Princeton Univ.

Megan Scanderbeg - Scripps Inst. Oceanography, Ex-officio for Argo Data Management Team

Yui Takeshita - Monterey Bay Research Inst.

Lynne Talley - Scripps Inst. Oceanography, Ex-officio for GO-SHIP

Toby Westberry - Oregon State Univ.

Cara Wilson - NOAA/PFEL

Meeting May 23/24
Princeton, NJ

biogeochemical Argo

Outline

- The need for a global observing system
- Present state of technology
- Forward looking: Planning for BGC-Argo

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

Who's looking systematically?

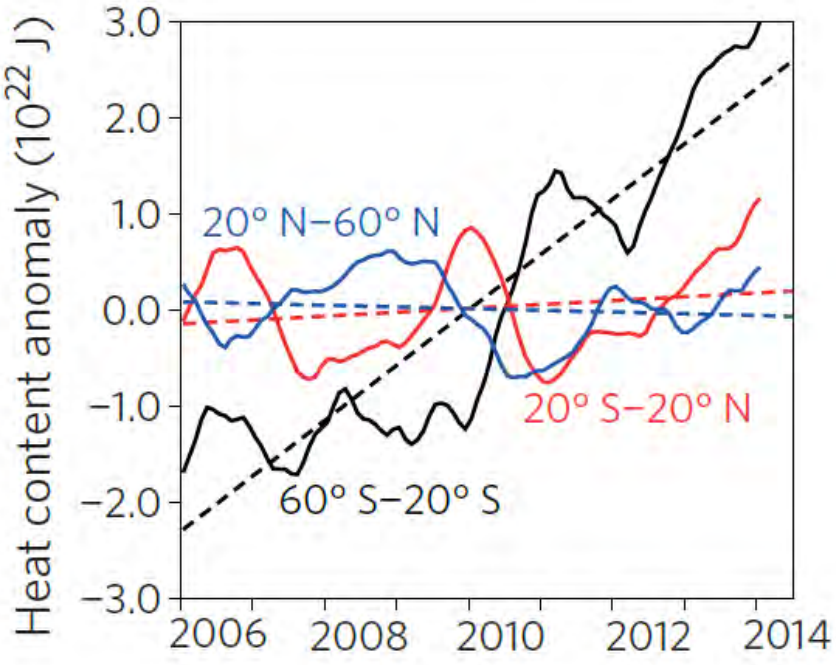
nature climate change

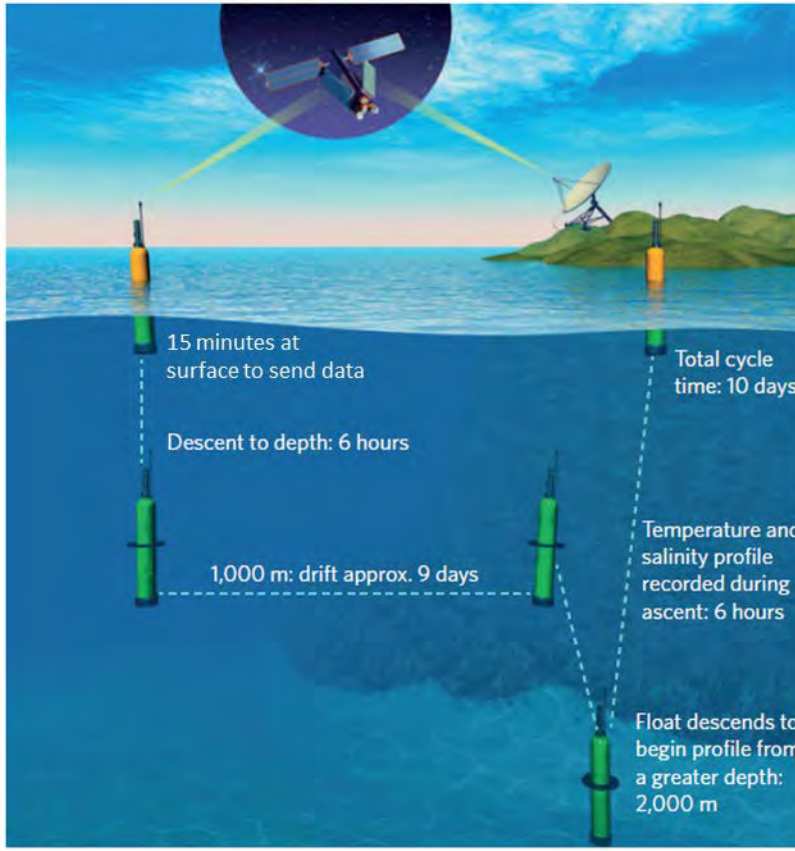
REVIEW ARTICLE

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

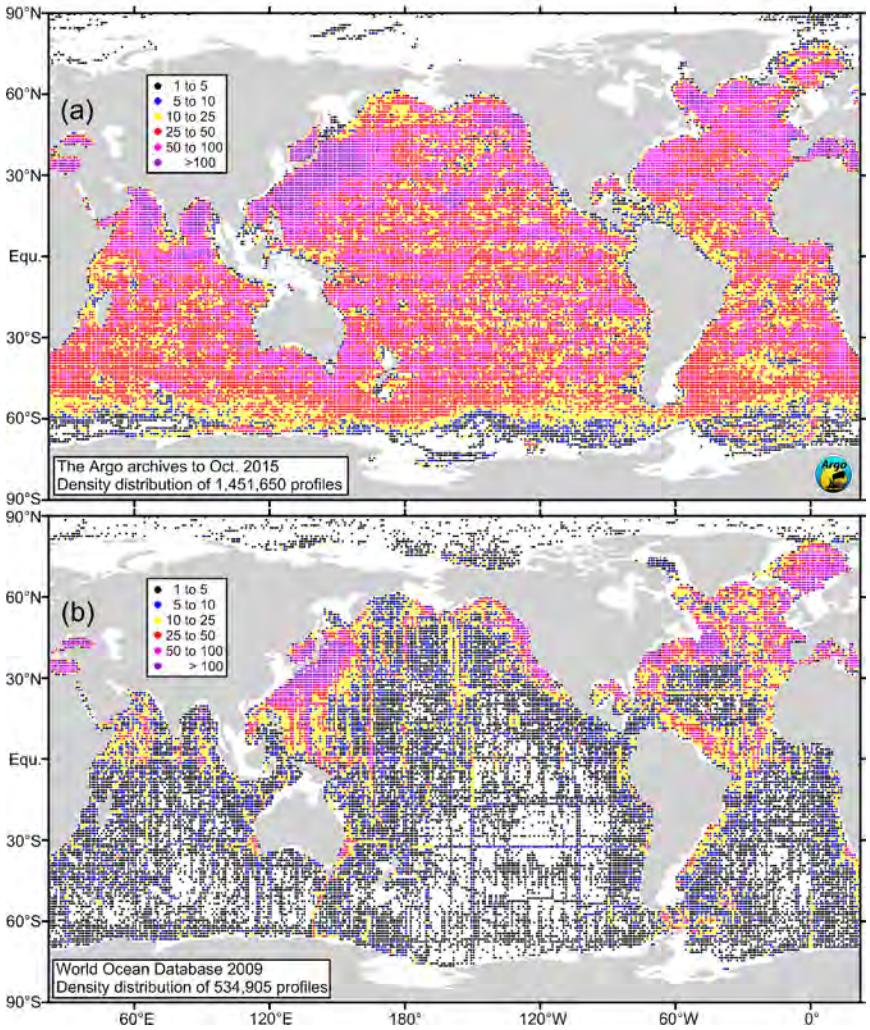
nature climate

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]

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

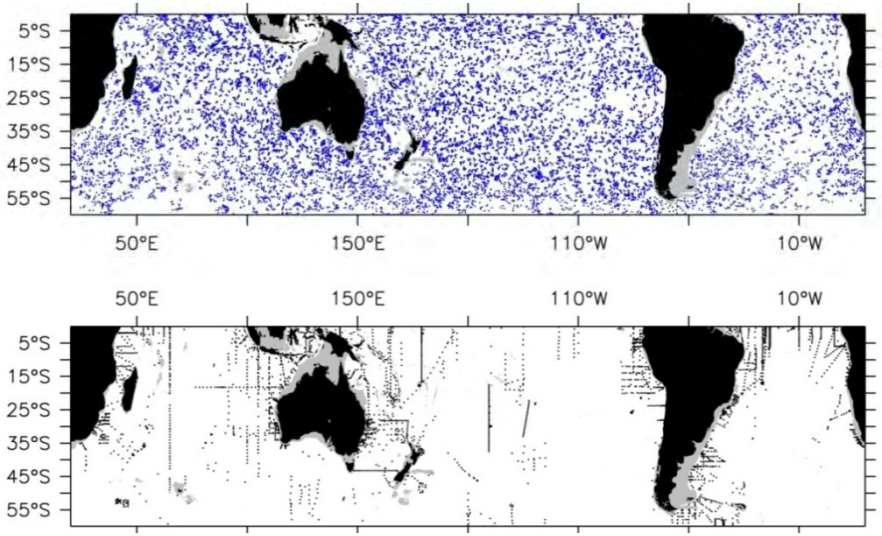
Argo: 1,450,000 T/S profiles 1999 to 2015.



~140 years of ship obs.: 530,000 T/S profiles > 1000 m

Argo Floats Do Not Mind Bad Weather

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

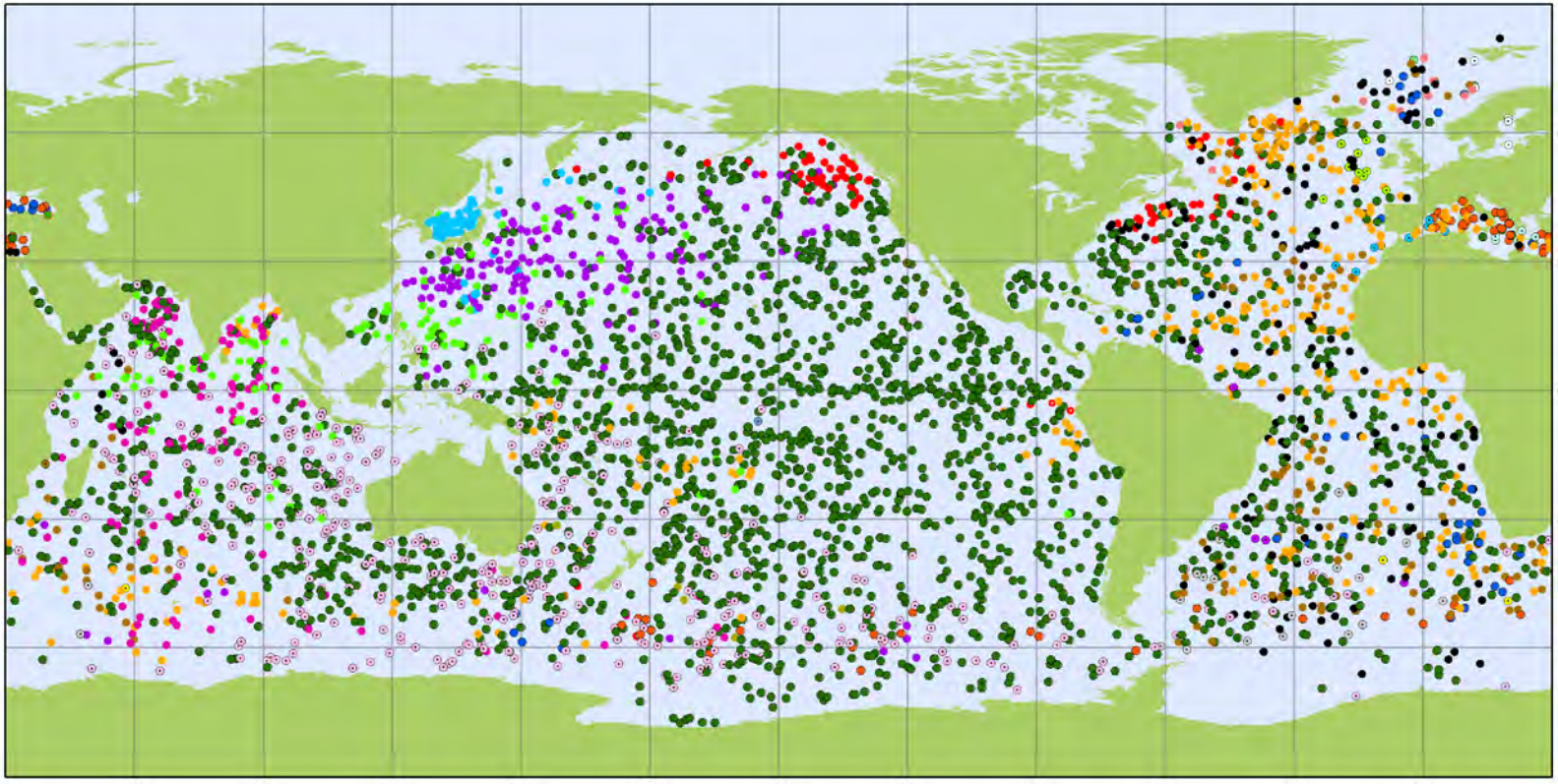


All August T/S profiles (> 1000 m, 1951 - 2000).

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 H. Freeland



Argo

National contributions - 3936 Operational Floats

March 2017

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

ARGENTINA (3)	CHINA (117)	GERMANY (145)	JAPAN (165)	NEW ZEALAND (7)	SPAIN (7)
AUSTRALIA (380)	ECUADOR (1)	GREECE (5)	KENYA (1)	NORWAY (10)	UK (145)
BRAZIL (6)	EUROPE (50)	INDIA (112)	MAURITIUS (1)	PERU (3)	USA (2210)
BULGARIA (1)	FINLAND (6)	IRELAND (11)	MEXICO (2)	POLAND (2)	
CANADA (72)	FRANCE (322)	ITALY (68)	NETHERLANDS (22)	KOREA, REPUBLIC OF (62)	

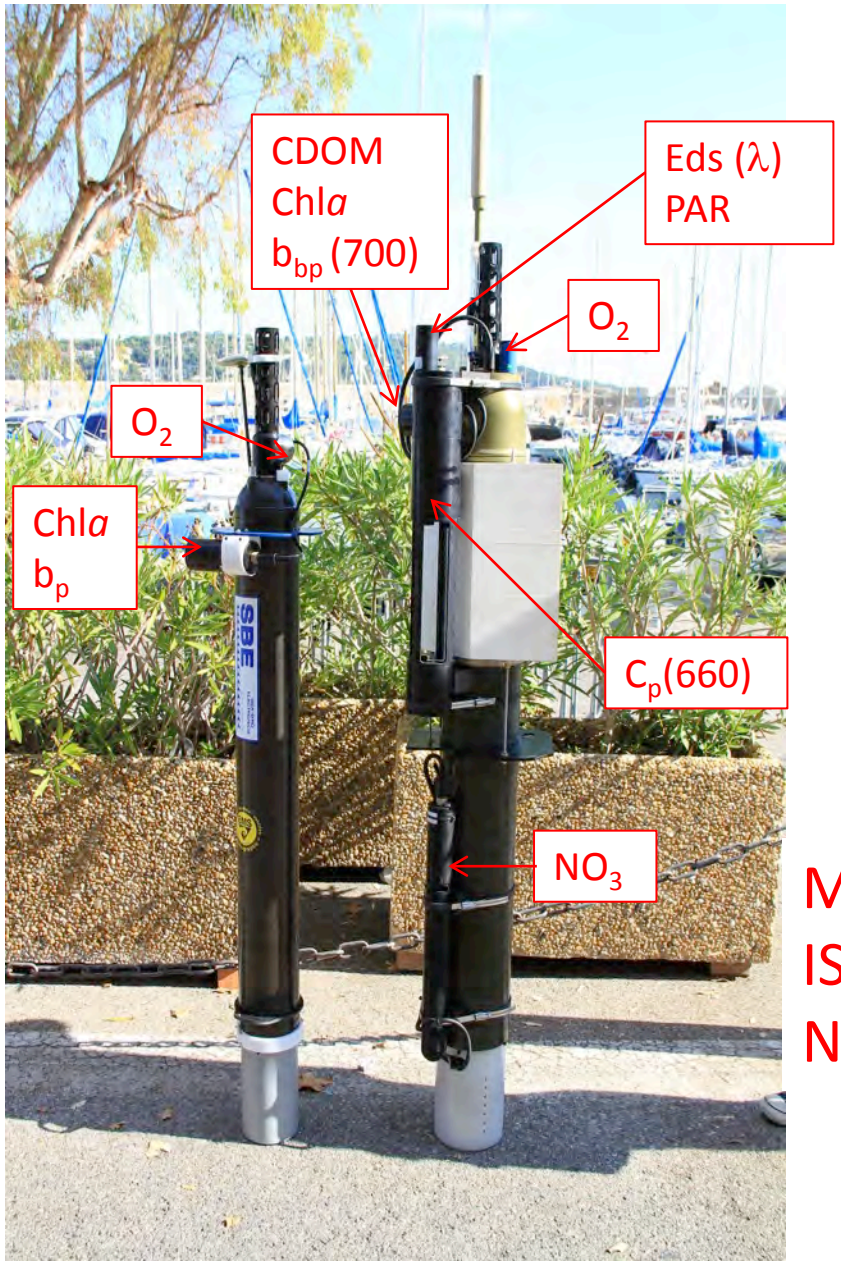
Generated by www.jcommops.org, 10/04/2017

Biogeochemical-Argo is the extension of the Argo array to include floats with biogeochemical sensors for:

- pH,
- oxygen,
- nitrate,
- chlorophyll,
- suspended particles,
- and downwelling irradiance.

There is real-time, public data access.
BGC-Argo floats generally follow the Argo mission: 1000 m park depth, 5 to 10 day cycle time, profile from ~2000 m.

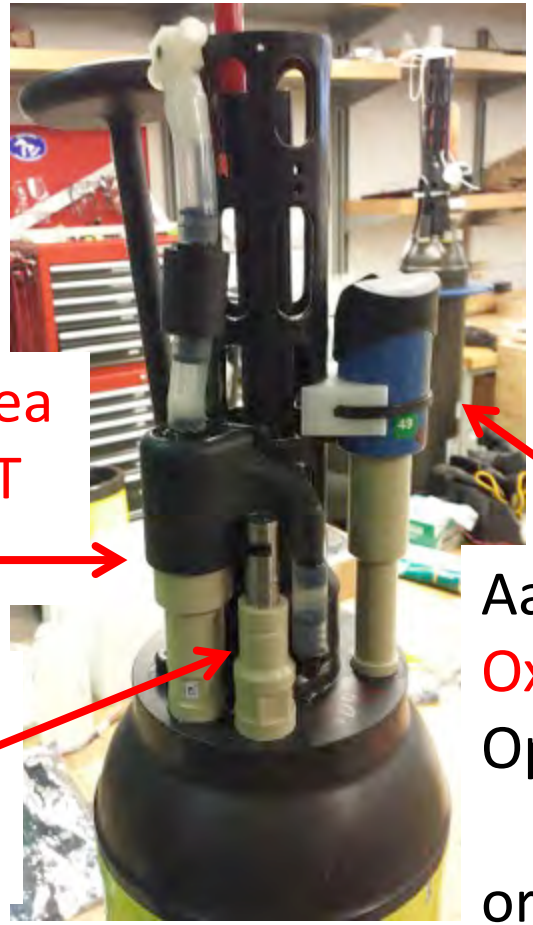
Biogeochemical sensors now available.



NAVIS PROVOR

Deep-Sea
DuraFET
pH

MBARI
ISUS
Nitrate

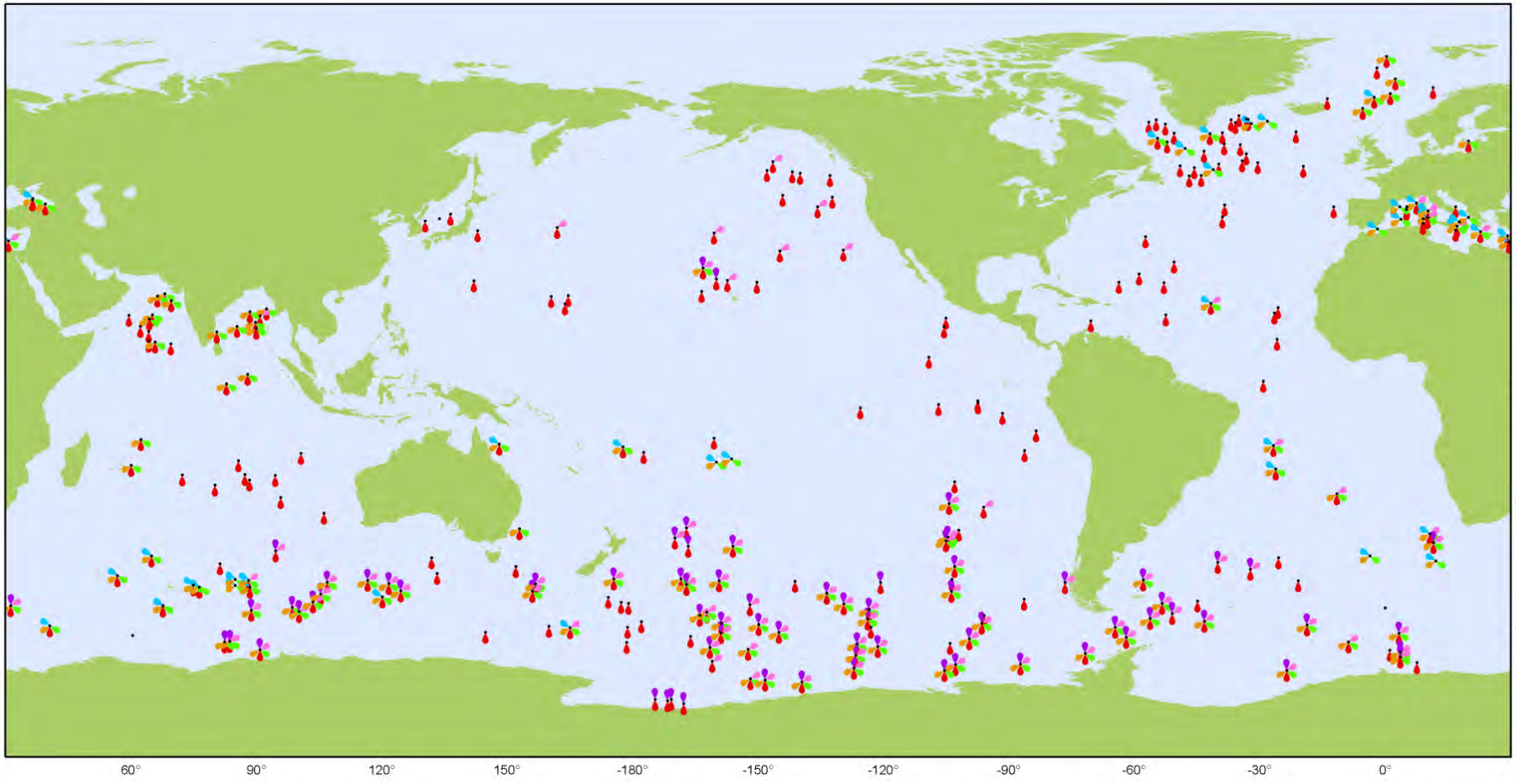


Aanderaa
Oxygen
Optode

or SBE 63
Oxygen

APEX

15 nations deploying BGC floats



Biogeochemical Argo

Sensor Types

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

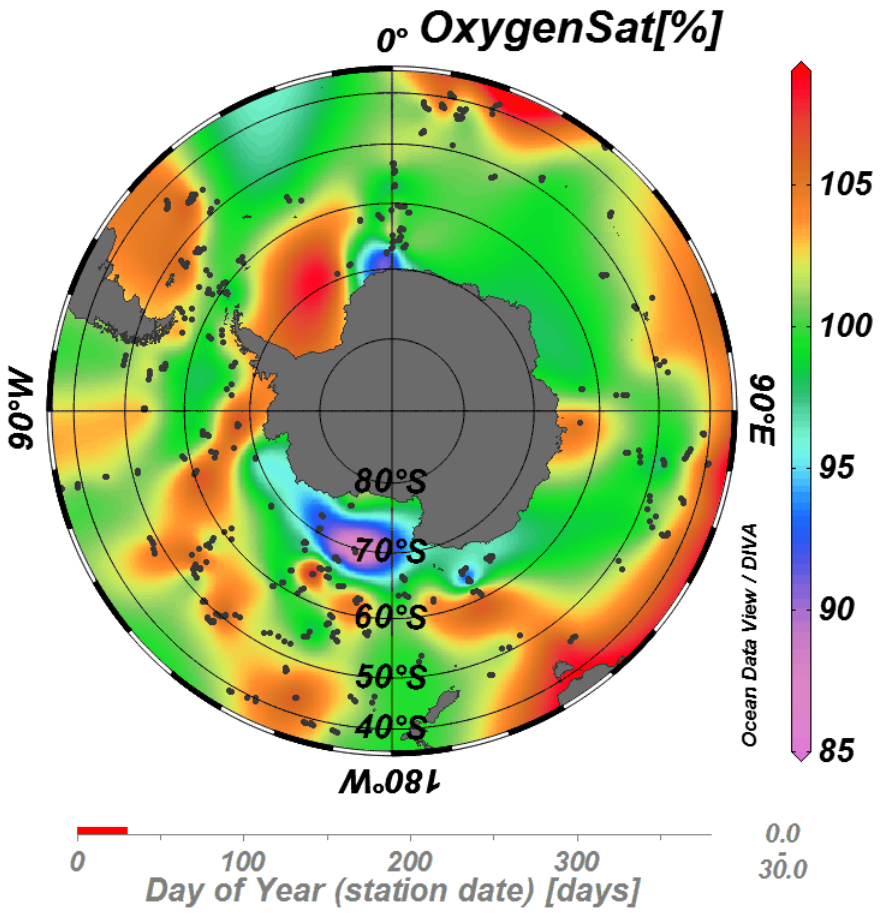
March 2017

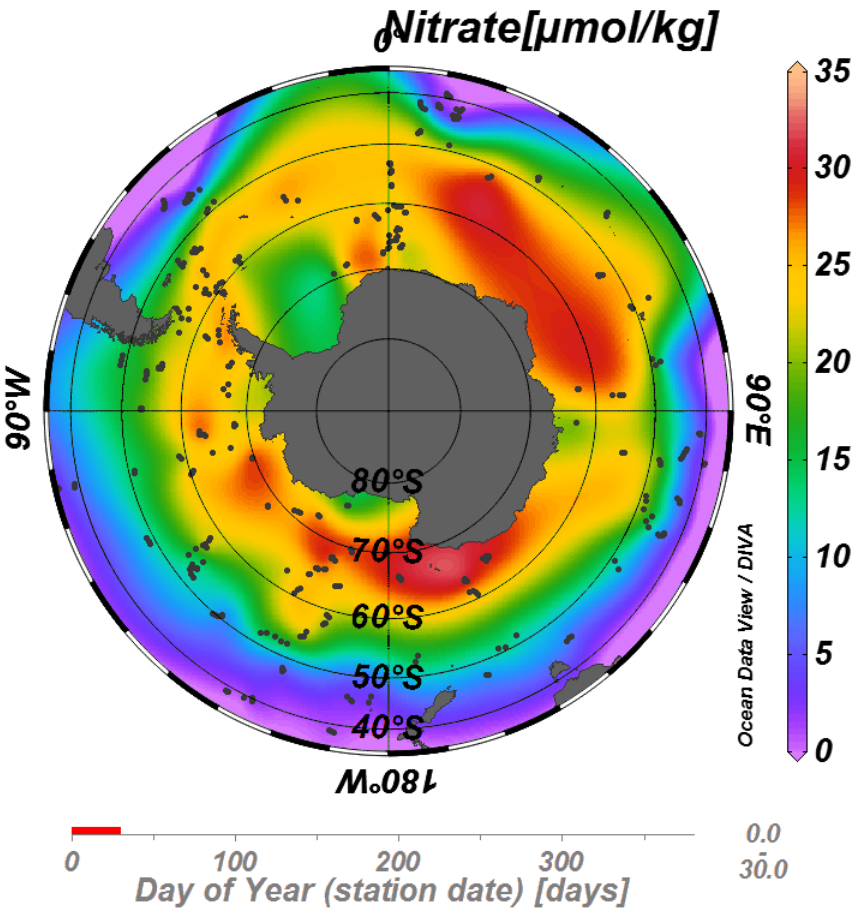
Operational Floats (275)
Suspended particles (132)
Downwelling irradiance (44)
pH (75)
Nitrate (96)
Chlorophyll a (132)
Oxygen (257)

Generated by www.jcommops.org, 10/04/2017


remOcean
Remotely-Sensed Biogeochemical Cycles in the Ocean
NAOS
NAOS Project
S1-INBOX
Project finished, see J. Mar. Res. 2016 papers
Australia-India Joint Indian Ocean Bio-Argo Project
"Characterising the changing Indian Ocean's biogeochemistry and ecology using revolutionary new robotic tools"
SOCCOM
60°
30°
0°
-30°
-60°
-180°
-150°
-120°
-90°
-60°
-30°
0°

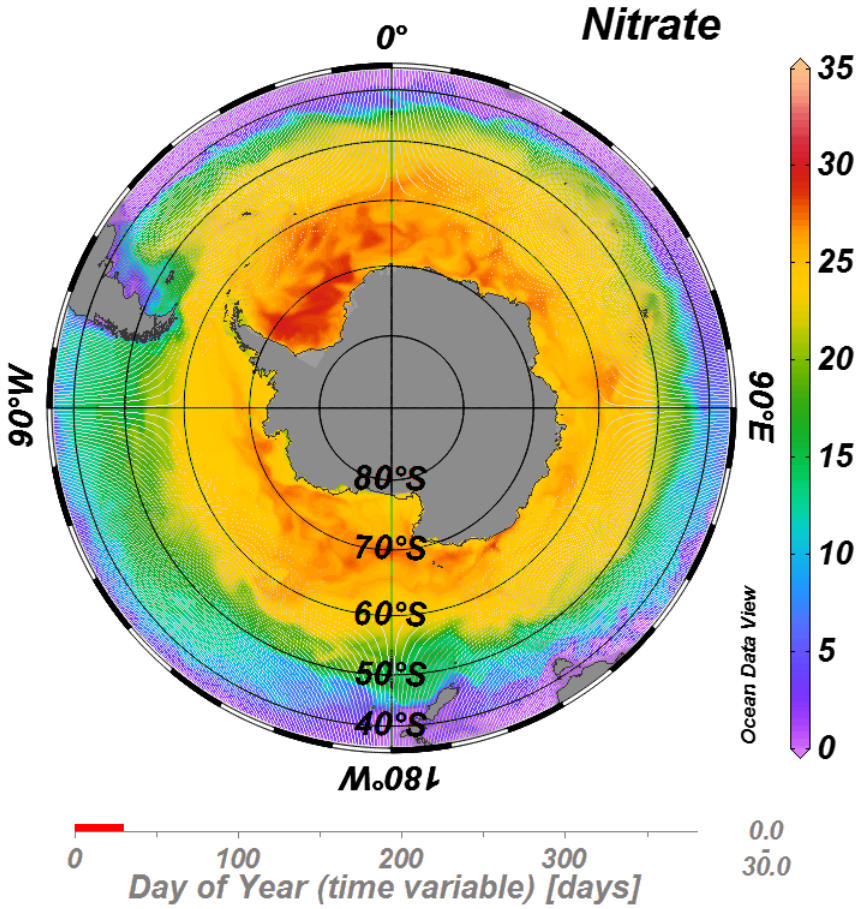
SOCCOM Floats (surface data)



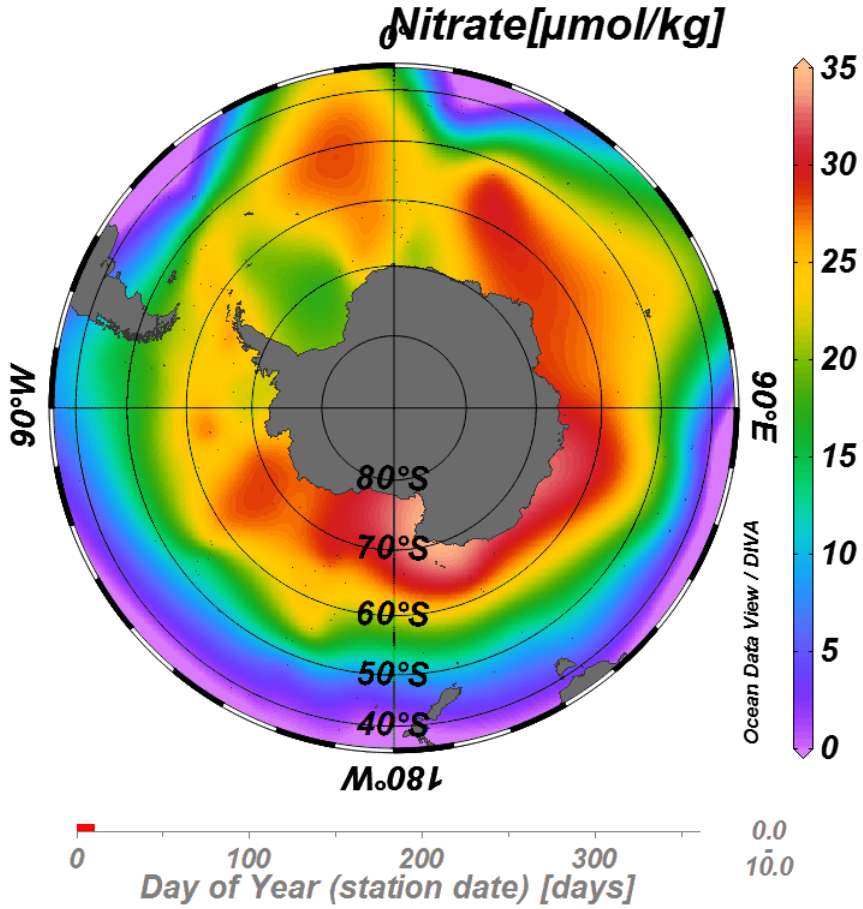


- 76 floats in the water, 11 more this season
- ~100 more over next 3 years

SOSE



SOCCOM Floats



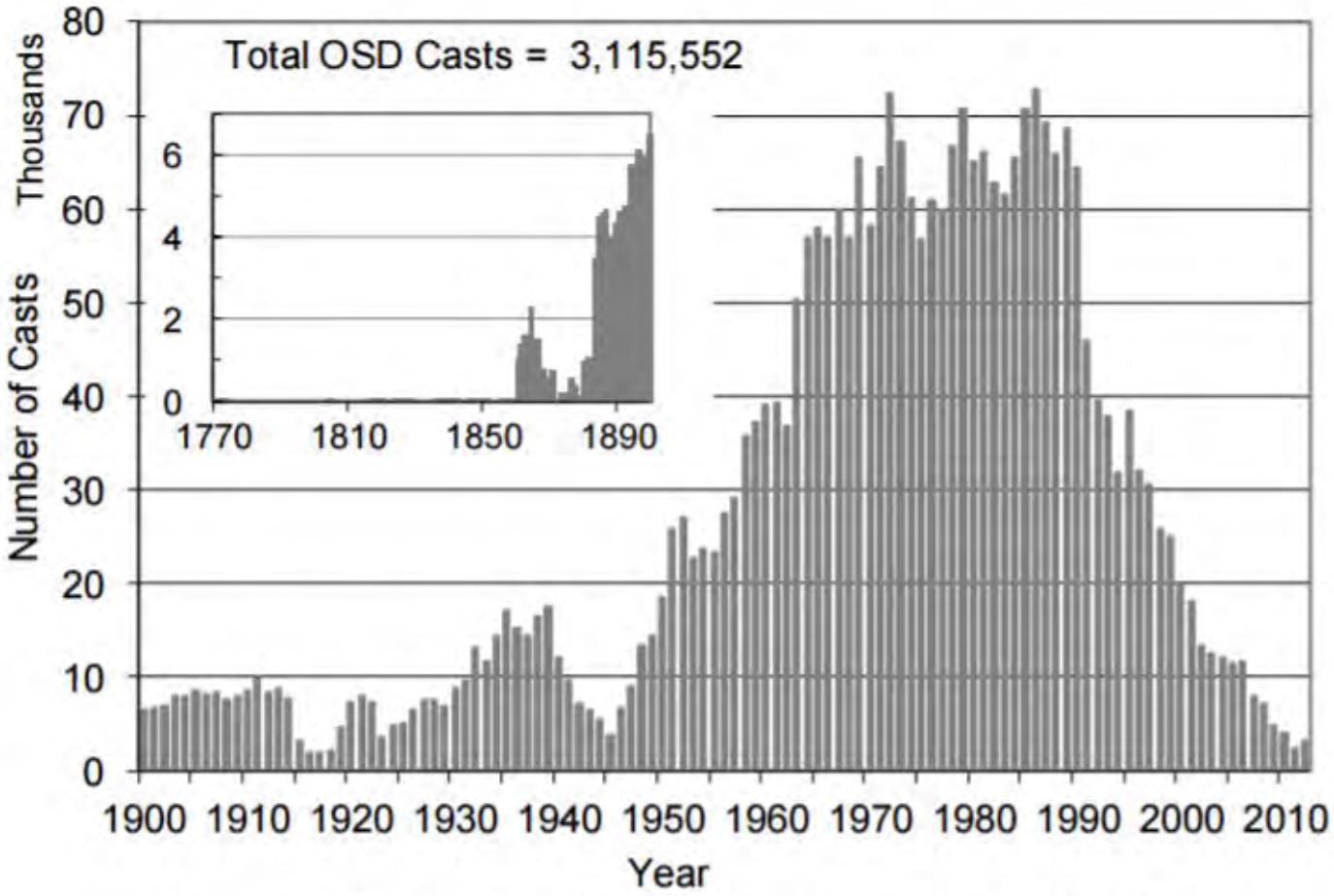


Figure 2.1. Time series of the number of OSD casts in WOD13

World Ocean Database 2013

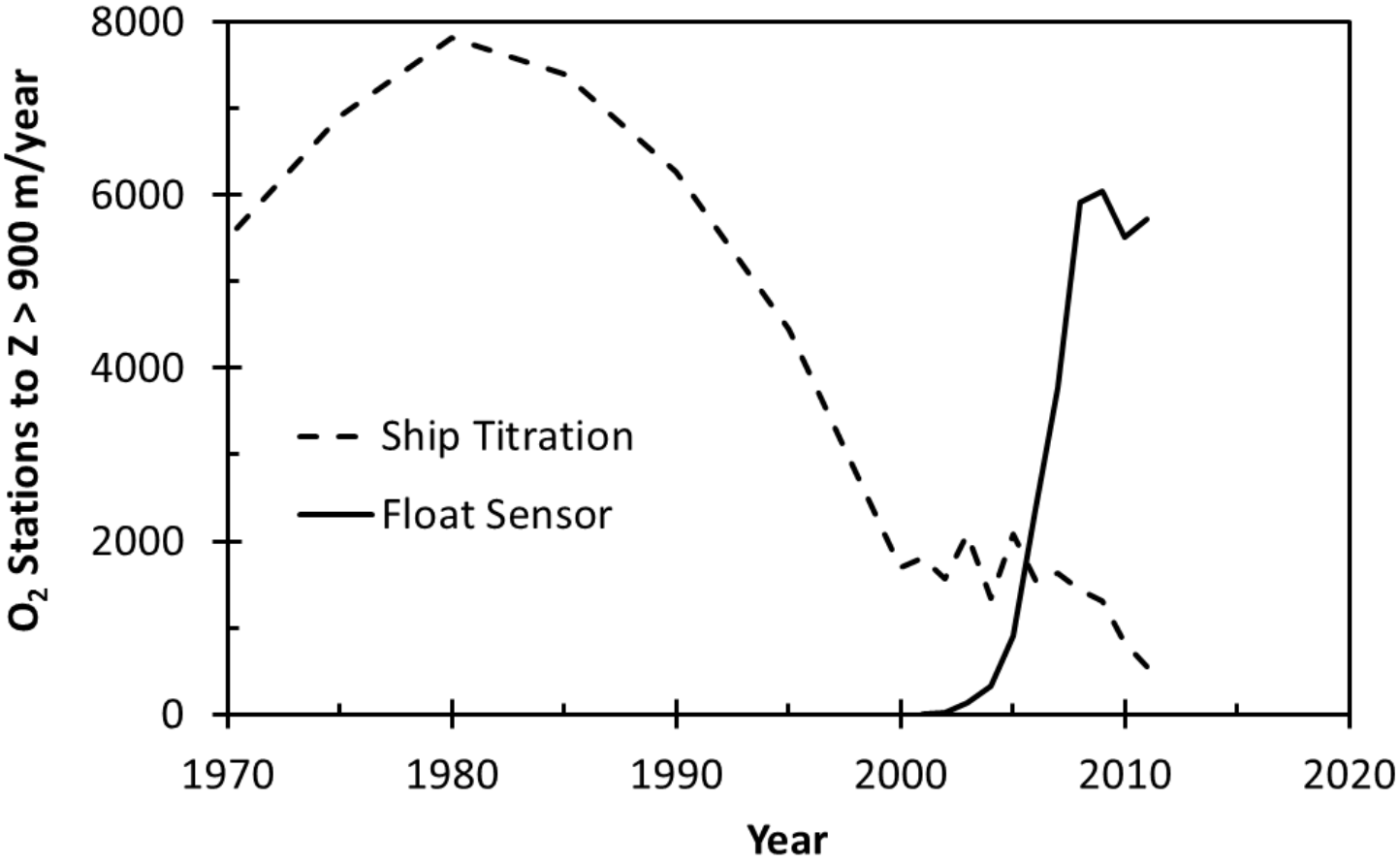
OSD = Ship-based profiles

NOAA Atlas NESDIS 72

WORLD OCEAN DATABASE 2013

Timothy P. Boyer, John I. Antonov, Olga K. Baranova,
Carla Coleman, Hernan E. Garcia, Alexandra Grodsky,
Daphne R. Johnson, Ricardo A. Locarnini,
Alexey V. Mishonov, Todd D. O'Brien, Christopher R. Paver,
James R. Reagan, Dan Seidov, Igor V. Smolyar, Melissa M. Zweng

Data from US National Ocean. Data Center



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

BGC-Argo has become the dominant source of deep ocean biogeochemical data!

Table 1. Profiles to depth > 900 m.

Parameter	Ship Profiles per year (2001-2010)	BGC-Argo Profiles per year (2016)	BGC-Argo /Ship
Oxygen	1730	11332	6.5
Nitrate	1231	3835	3.1
pH direct	460	1862	4.0
pH (TA/DIC)	540		3.4
Source	US NODC	Argo GDAC	

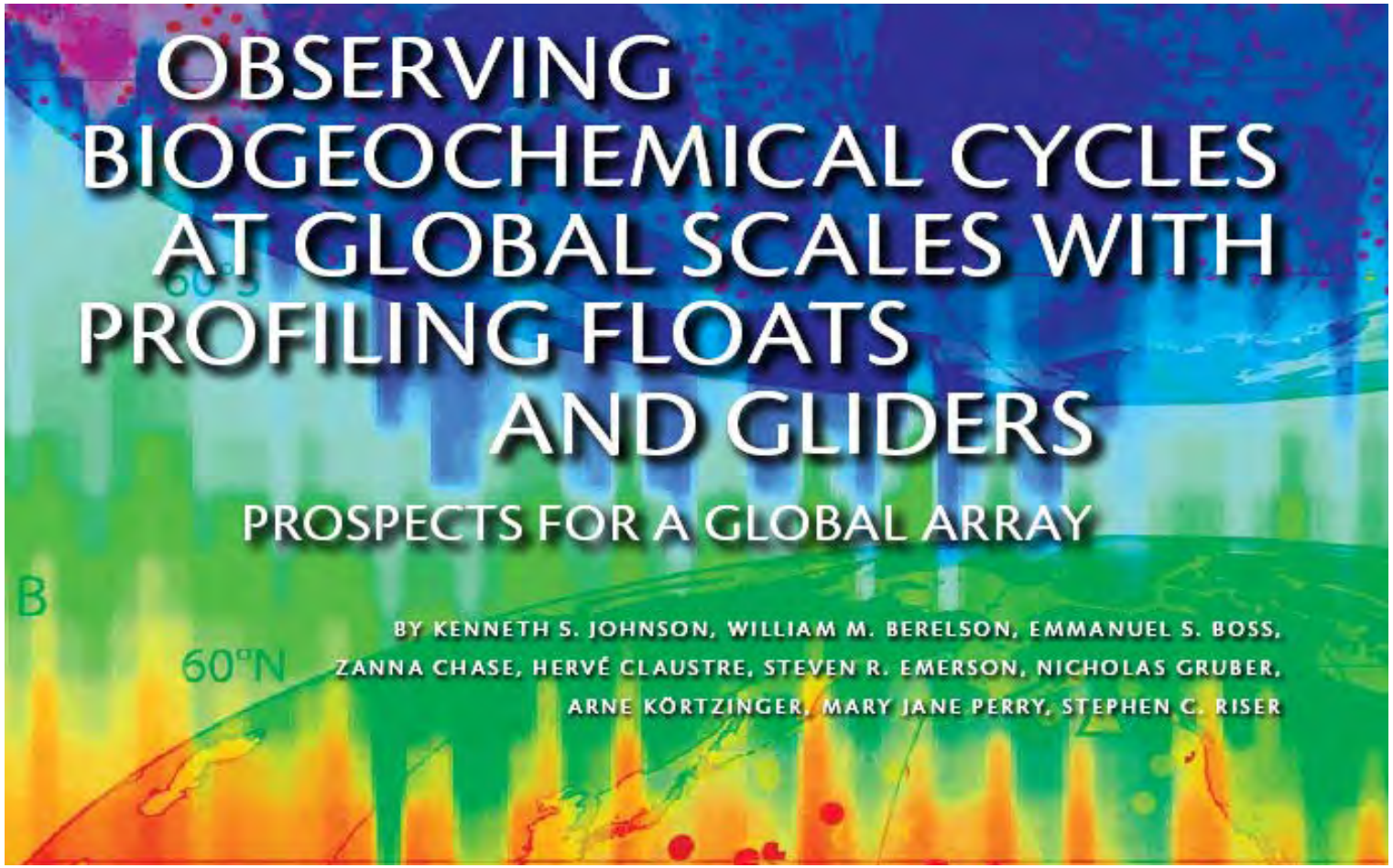
Outcome of Argo Steering Team Mtg. 15: The BGC-Argo Task Team Term of references

Within the Argo program, the BGC-Argo task team acts as a scientific committee of BGC-Argo national representatives, which provide recommendations and guidance for the **progressive development and implementation of a BGC-Argo program**. More specifically, its terms of reference are to:

- Develop and update the BGC-Argo **science plan** with respect to regional **pilot projects** and to a **global network**.
- Coordinate the **implementation plan**, in particular to optimize the various national efforts.
- Interact with other task teams (e.g. “marginal Seas”, “polar areas”).

US Ocean Carbon & Biogeochemistry Scoping Workshop

28-30 April 2009, Moss Landing, USA



IOCCG sponsored working group

Various community white papers

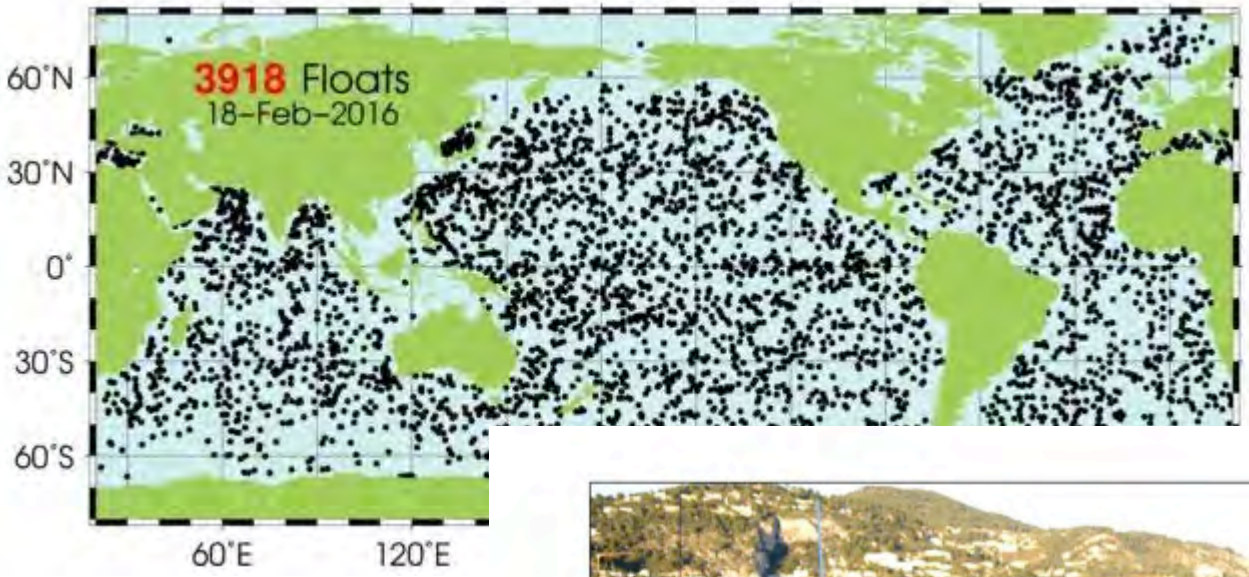
ADDING OXYGEN TO ARGO: DEVELOPING A GLOBAL IN-SITU OBSERVATORY FOR OCEAN DEOXYGENATION AND BIOGEOCHEMISTRY

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

International Council for Science
SCOR
Scientific Committee on Oceanic Research

WG 142 Quality Control Procedures for Oxygen and Other Biogeochemical Sensors on Floats and Gliders

Planning for a global network
Meeting in Villefranche-sur-Mer, 11-13 January 2016.



8 Nations represented

Science plan and implementation discussion

Biogeochemical-Argo Network - Group photo

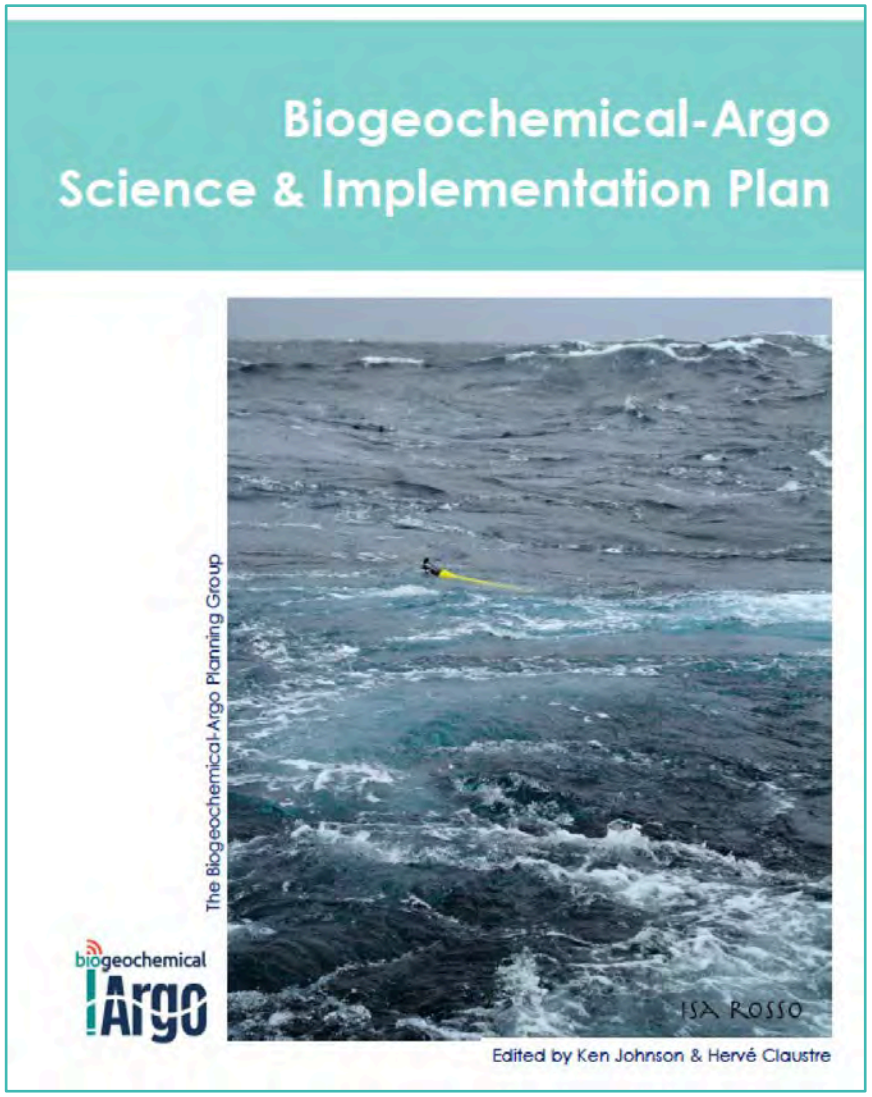
Biogeochemical-Argo topics

Research topics

- Carbon uptake
- OMZs and nitrate cycling
- Acidification
- Biological carbon pump
- Phytoplankton communities

Management topics

- Living marine resources
- Carbon budget verification

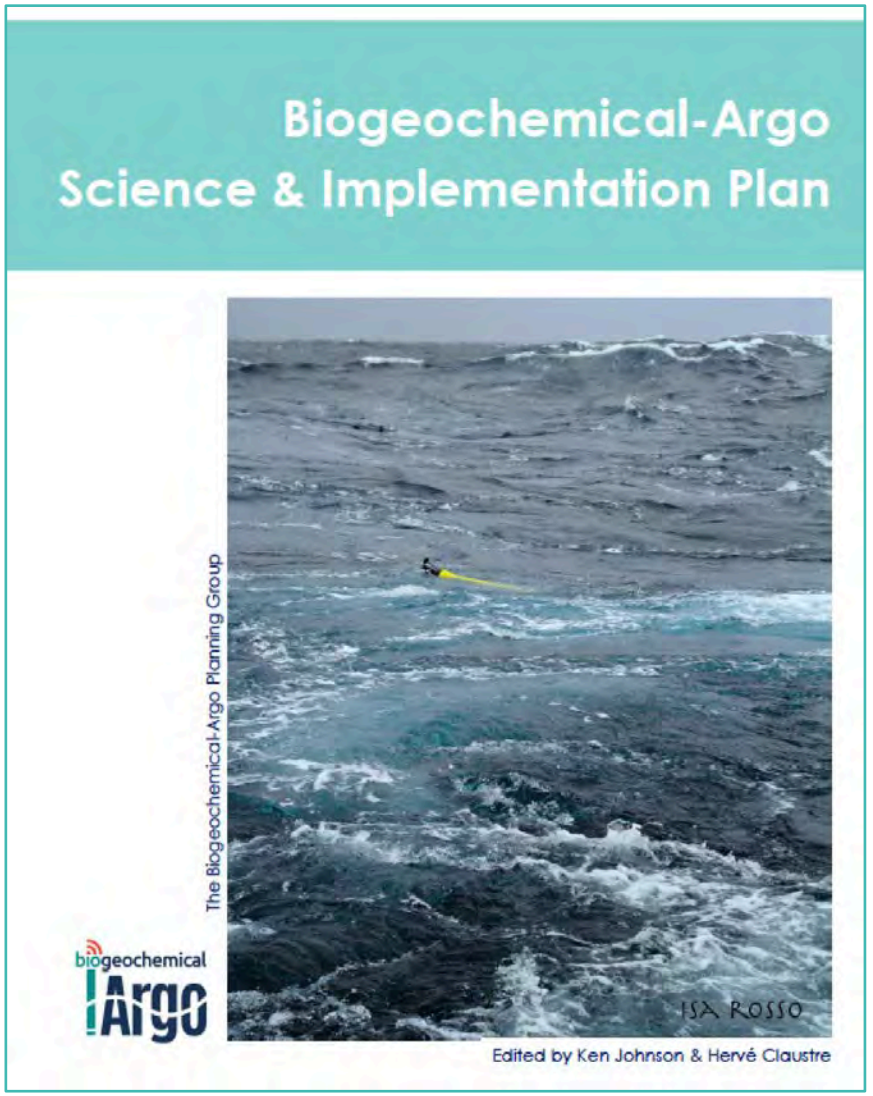


http://biogeochemical-argo.org

Biogeochemical-Argo core variables

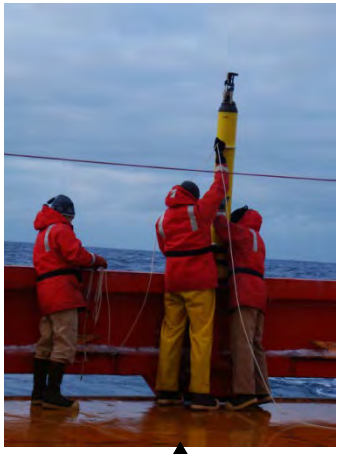
- O_2
- NO_3
- pH
- Chl*a*
- Suspended particles
- Downwelling irradiance

Sensors well tested and understood.



http://biogeochemical-argo.org

Biogeochemical-Argo is at the cross-roads of ocean observing. It will enable a transformation in ocean understanding.



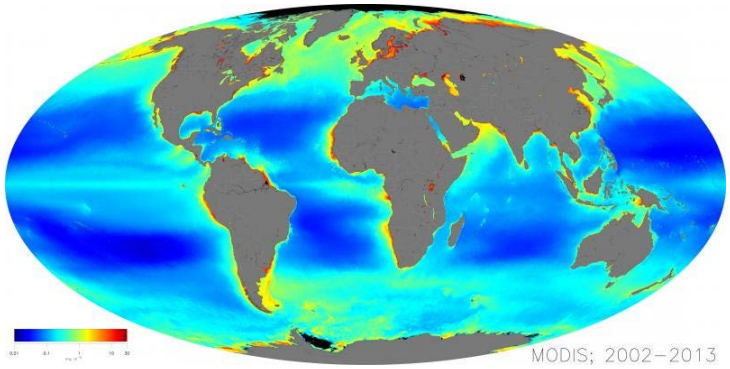
GO-SHIP

TOWARDS A SUSTAINED GLOBAL SURVEY OF THE OCEAN INTERIOR

Global Ocean Ship-based Hydrographic Investigations Program

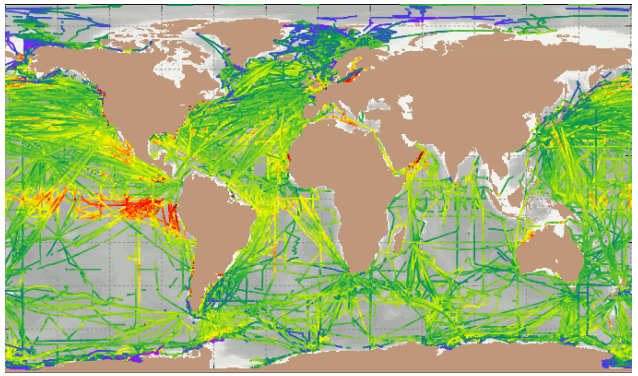
GO-SHIP is a major contributor to WCRP's Climate Variability and Predictability Experiment (CLIVAR) and International Ocean Carbon Coordination Project. GO-SHIP is part of the Global Climate Observing System / Global Ocean Observing System (GCOS / GOOS).

Ocean color, SST, Altimetry, LIDAR



SOCAT

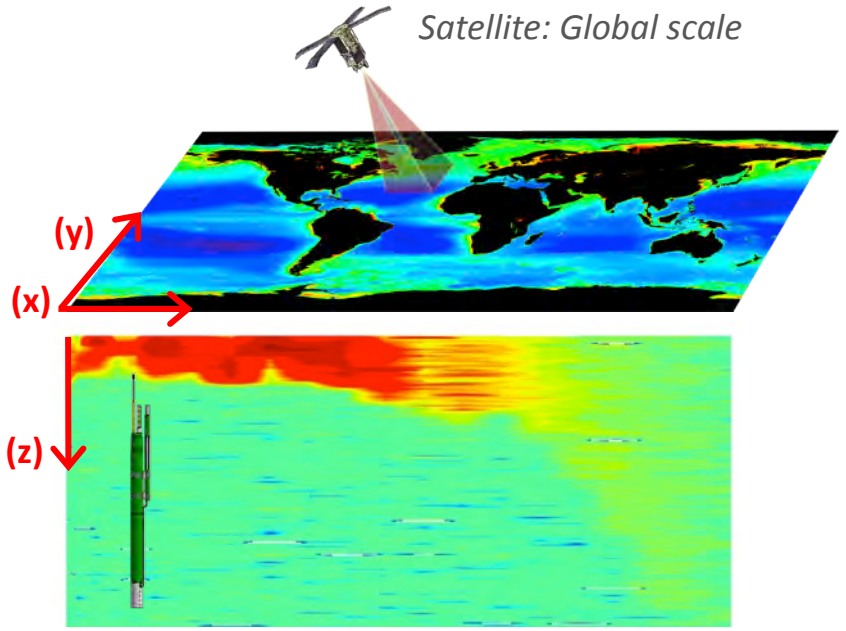
SURFACE OCEAN CO2 ATLAS



BGC-Argo must work in synergy with other components of the global observing system

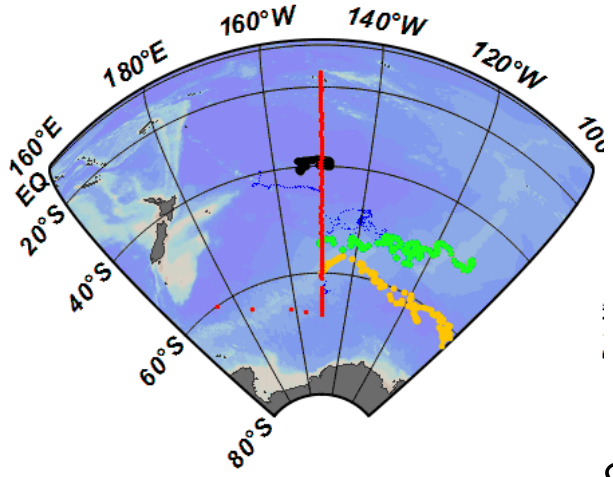
- **Floats and ocean color share key biogeochemical variables (matchups & validation):**
  - ✓ Chla
  - ✓ b_{bp} (POC)
  - ✓ Kd
  - ✓ CDOM

- **Benefits of a coupled approach:**
  - ✓ OC satellites "see" only the 1/5 of the euphotic layer => Profiling floats bring vertical dimension
  - ✓ Profiling floats bring observations under cloud cover or no light conditions
  - ✓ Remote sensing provides extrapolation to the global ocean



BGC-Argo profiling float: Vertical dimension

→ **3D/4D OCEAN BIOGEOCHEMISTRY**



Float 9254

Float 9095

Float 9092

BGC-Argo dependent on GO-SHIP for high quality data used to assess calibration

Global Biogeochemical Cycles

RESEARCH ARTICLE
10.1002/2016GB005541

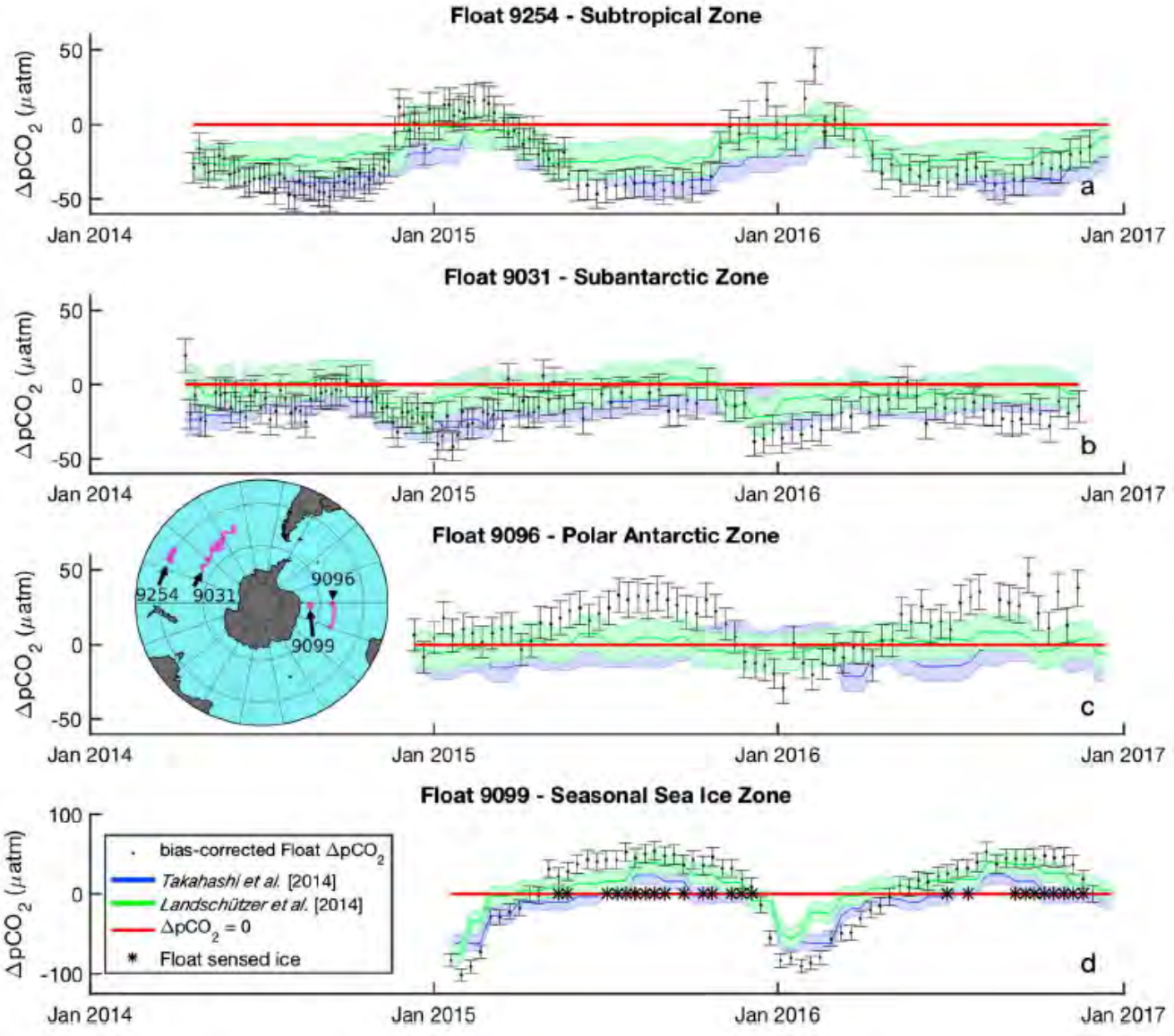
Calculating surface ocean pCO_2 from biogeochemical Argo floats equipped with pH: An uncertainty analysis

N. L. Williams[1], L. W. Juranek[1], R. A. Feely[2], K. S. Johnson[3], J. L. Sarmiento[4], L. D. Talley[5], A. G. Dickson[5], A. R. Gray[4], R. Wanninkhof[6], J. L. Russell[7], S. C. Riser[8], and Y. Takeshita[3]

Key Points:
- Surface ocean partial pressure of carbon dioxide (pCO_{2sw}) is calculated

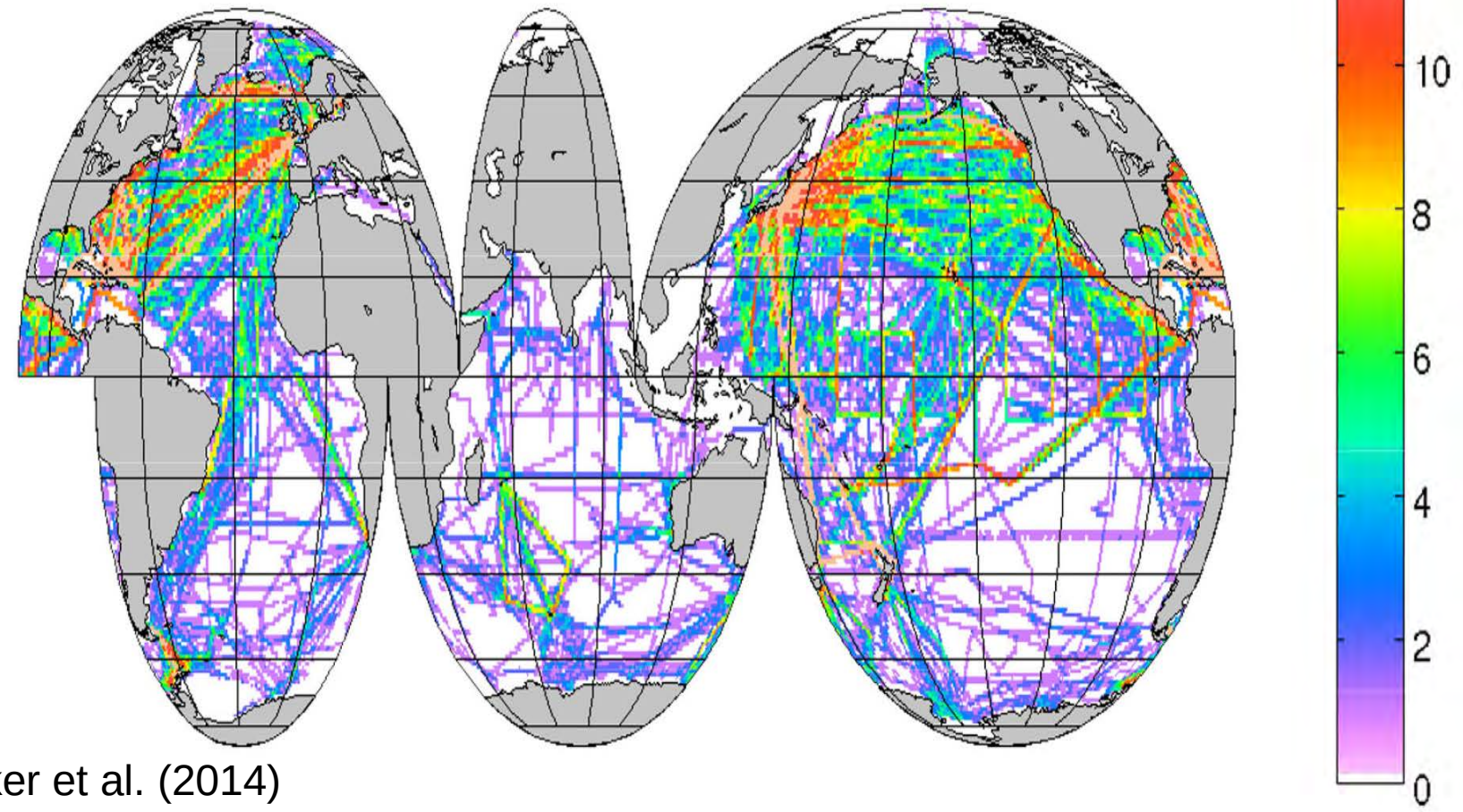
SOCCOM

SOCAT
SURFACE OCEAN CO_2 ATLAS
www.socat.info



Undersampling of pCO_2

Months of year with surface pCO_2 measurements based on all measurements between 1970 to 2011 binned in 1° squares.
White = no data



Bakker et al. (2014)

Defining array size

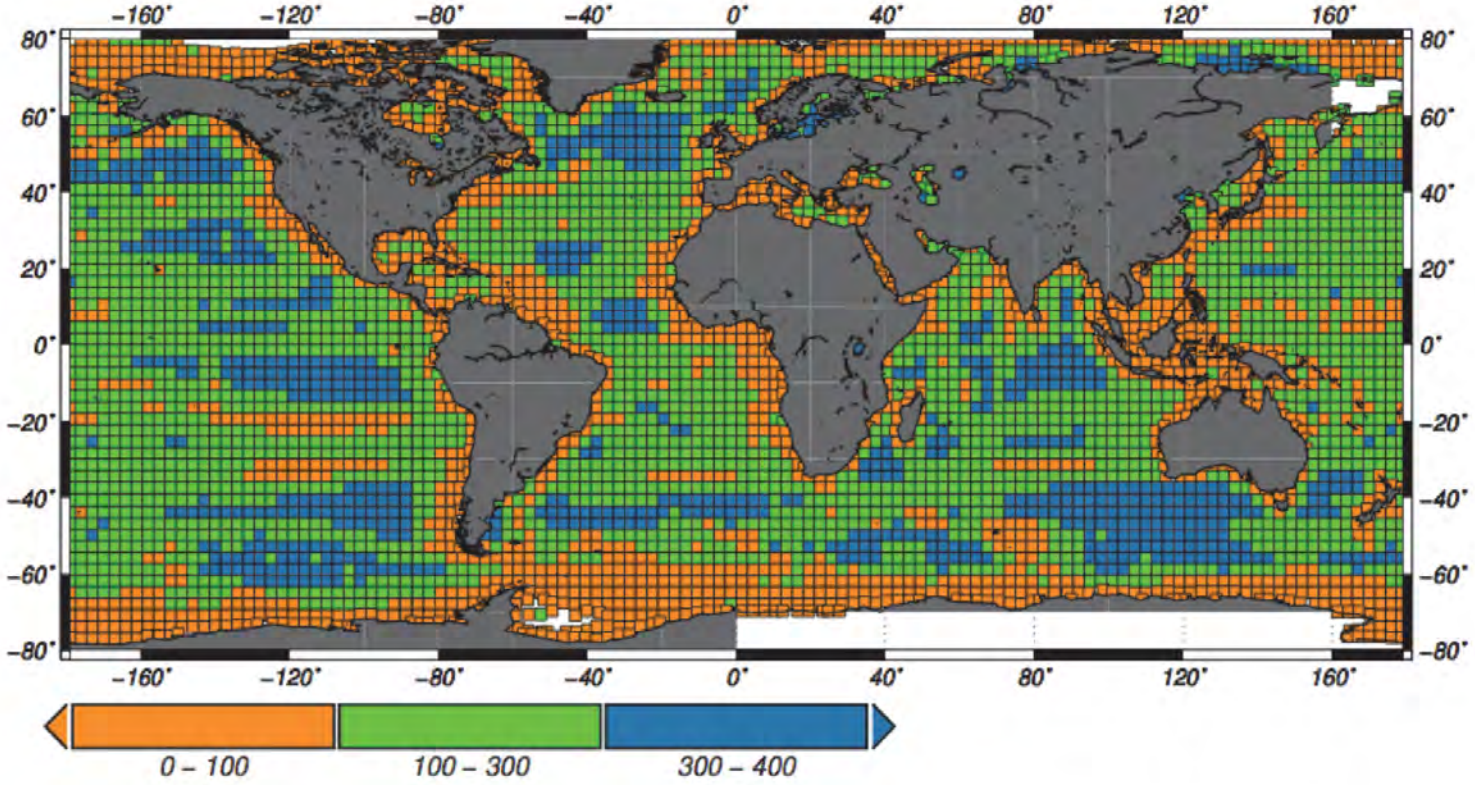


Figure 10. Map of the minimum distances at which, for each pixel, the Chl concentration is 5% greater than the Chl observed at that pixel. Chl concentrations are obtained by the 15-years climatology of MODIS OC sensor.

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

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

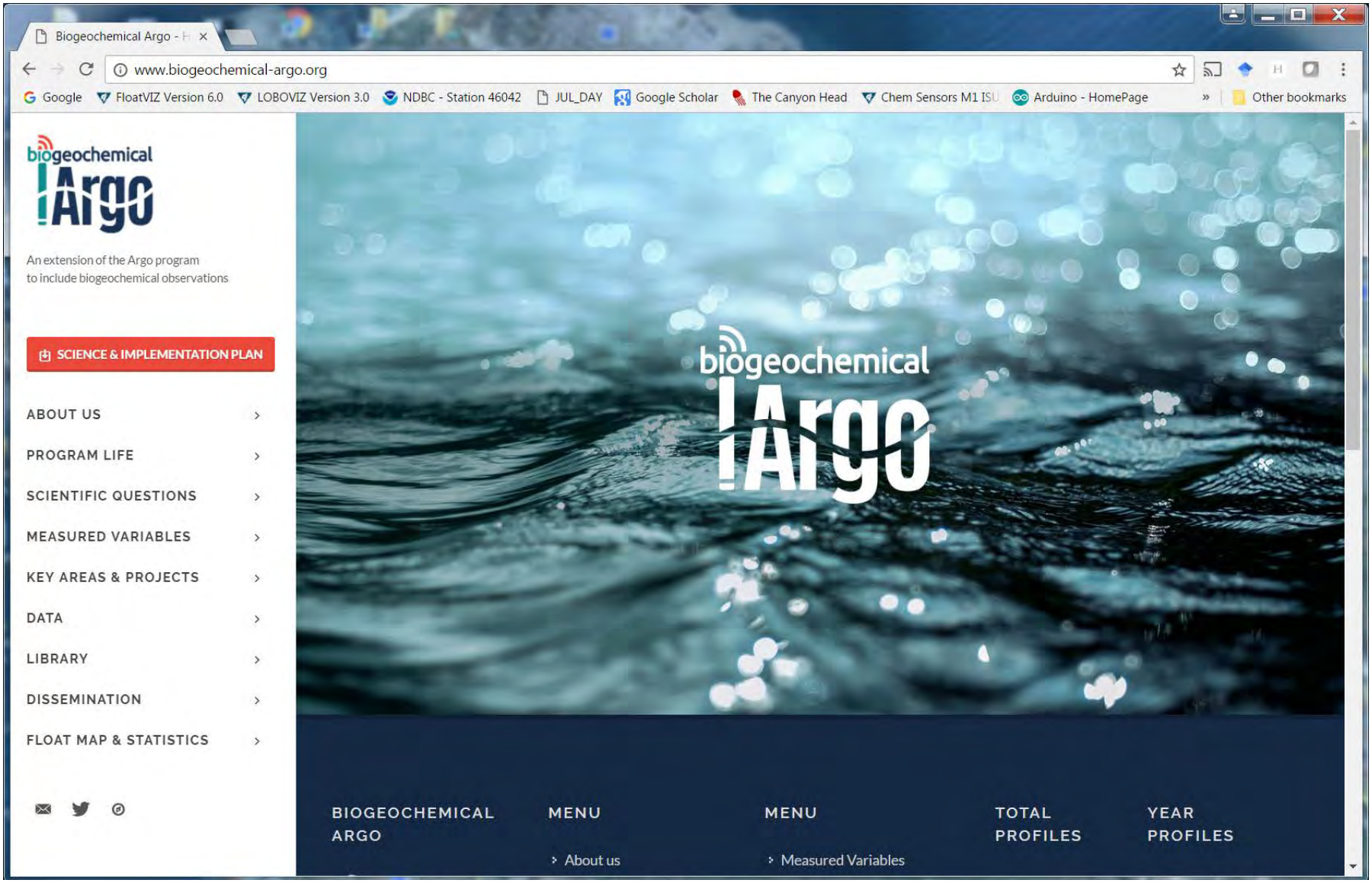
Table 2. Biogeochemical-Argo system costs*		
Item	Capital cost	Total cost (capital + data transmission + data processing and QC).
Core Argo T/S float	$22,000	$33,000
Add O_2 to Argo	$7,000	$10,200
Add nitrate	$24,000	$31,000
Add biooptics (Chl, BB, Ed)	$17,000	$20,200
Add pH	$10,000	$13,200
Cost per 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.

Major US facility costs*:

- US Deep-Sea Drilling Program order of $58 million/year.
- Academic research fleet $83 million/year just 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.

*Compiled from NRC Sea Change report and NSF response.



http://biogeochemical-argo.org