# Sustaining and Enhancing Argo for Observing the Global Ocean

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For the International Argo Steering Team

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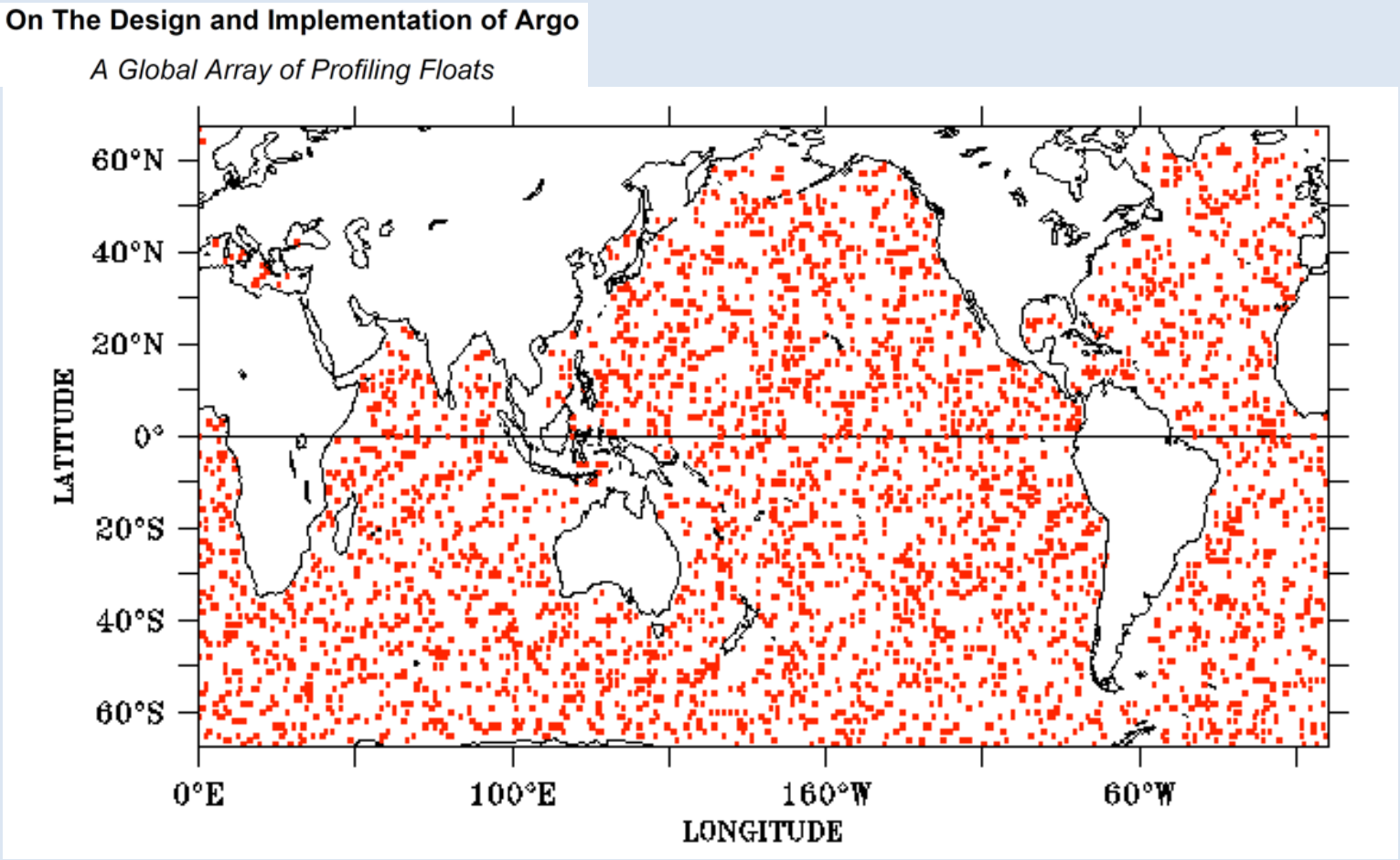
# Outline

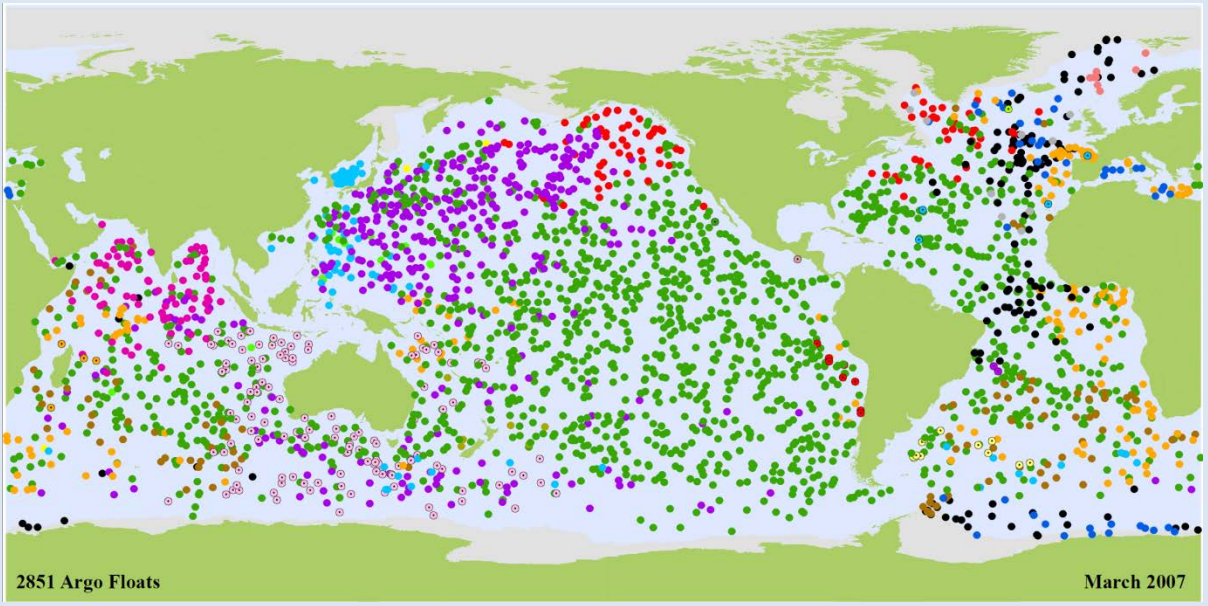
- The status of Argo
- Enhancements to Argo's upper ocean mission: sampling more of the global ocean area and sampling it more effectively.
  - Marginal seas
  - Equatorial variability
  - Seasonal ice zones
  - Western boundary current regions
- New Argo missions
  - Deep Argo
  - BGC Argo
- Changes to Argo coverage, depth, sensors, and technologies have profound impacts on how Argo observations are used.
- Issues for sustaining Argo over the long-term, and practical actions.
- The importance of ongoing technology improvement.

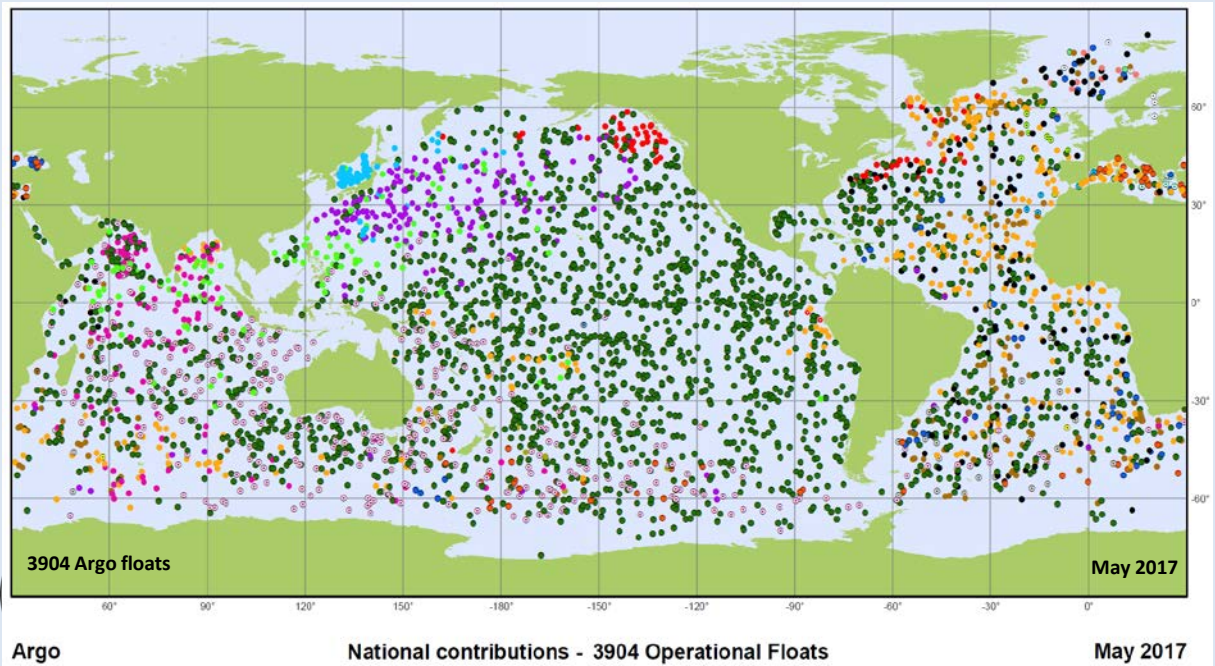
# Argo in 1998: an idea




From the 1998 Argo Design document: See http://www.argo.ucsd.edu/argo-design.pdf

# Argo in 2007 to 2017



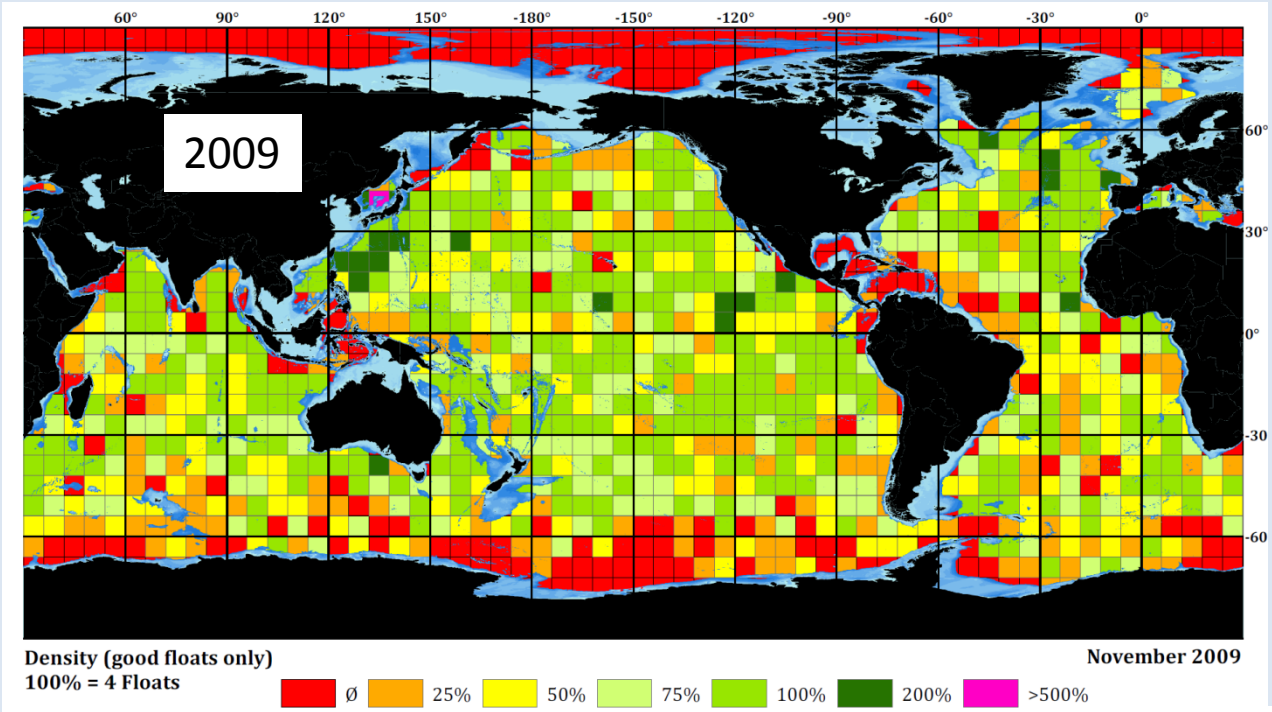

- The Argo array is remarkably similar to the original 1998 design, with contributions from over 28 nations.
- More than 1.6 million T/S profiles and trajectories have been acquired, presently > 10,000 per month.
- Argo profile data quality is better than originally expected, thanks to SeaBird, the Argo Data Management Team, and users.
- Since the 3000-float mark in 2007, further gains have been made in coverage and data quality.

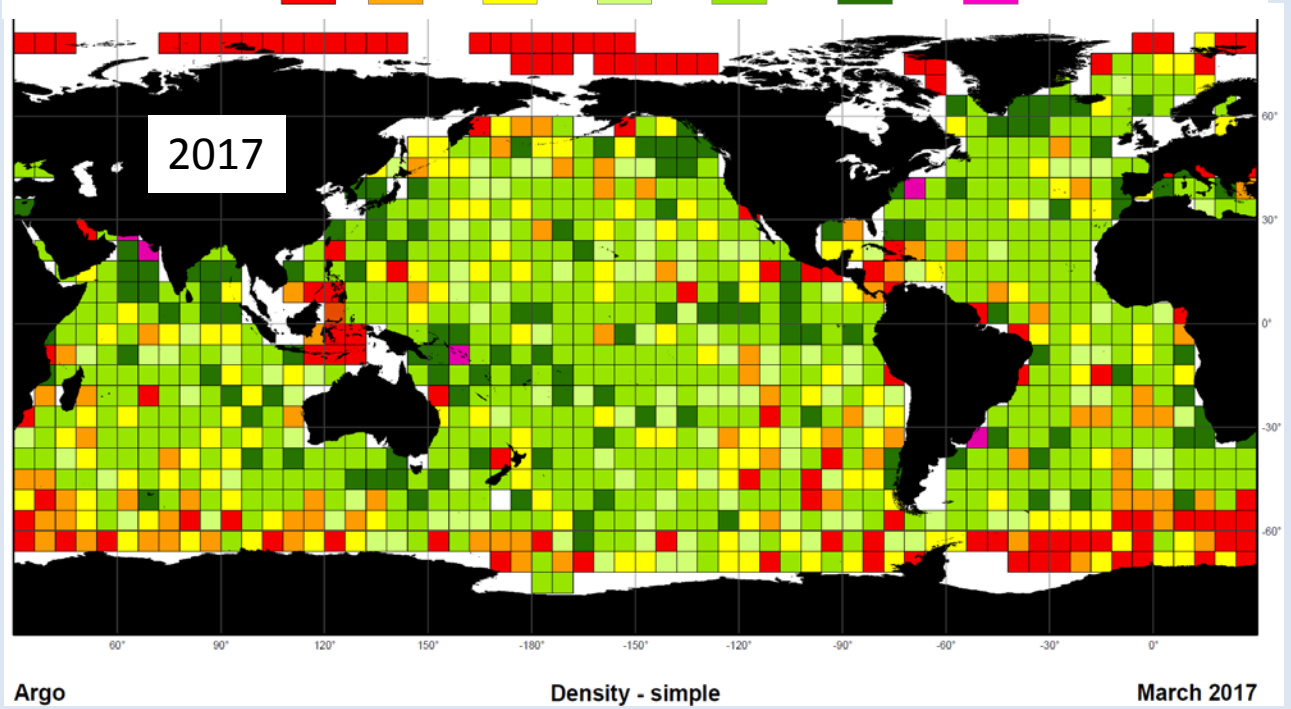
Figures: JCOMMOPS

# Density of coverage:

Floats per 6° square
2009 and 2017

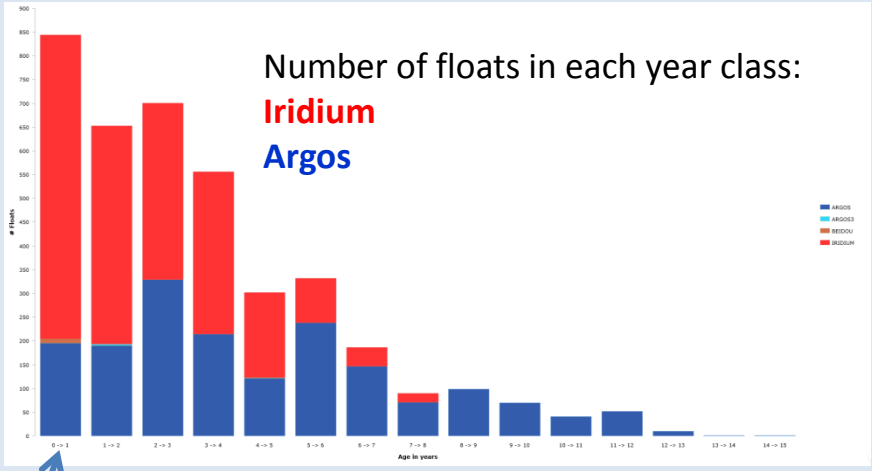
Improvements:
South of 60°S
Eq. Pacific
Gulf of Mexico/Caribbean
Mediterranean
S. Atlantic
Some coastal regions




Figures: JCOMMOPS

# Bi-directional comms.



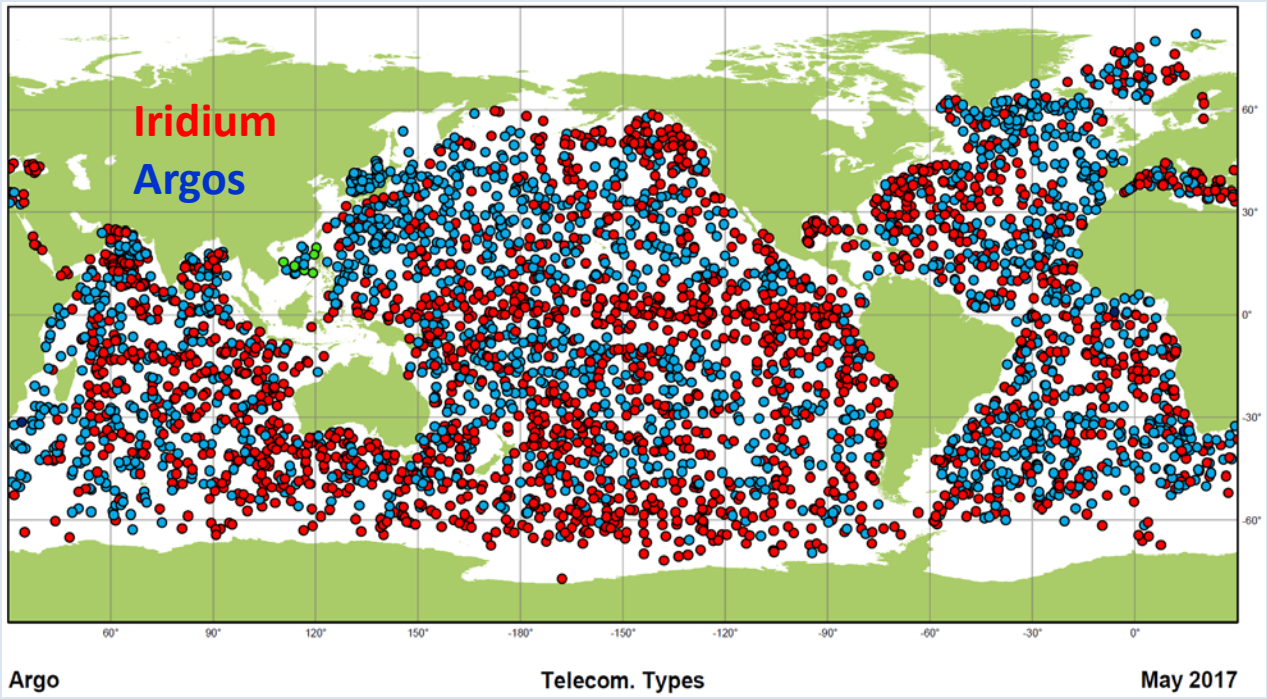

0 - 1 year old

Today, over half of operational Argo floats use Iridium, including 80% of those deployed in the past year.

Below: Note the Equatorial Pacific, high southern latitudes, and some marginal seas.

Bi-directional communication is having major impacts on Argo:

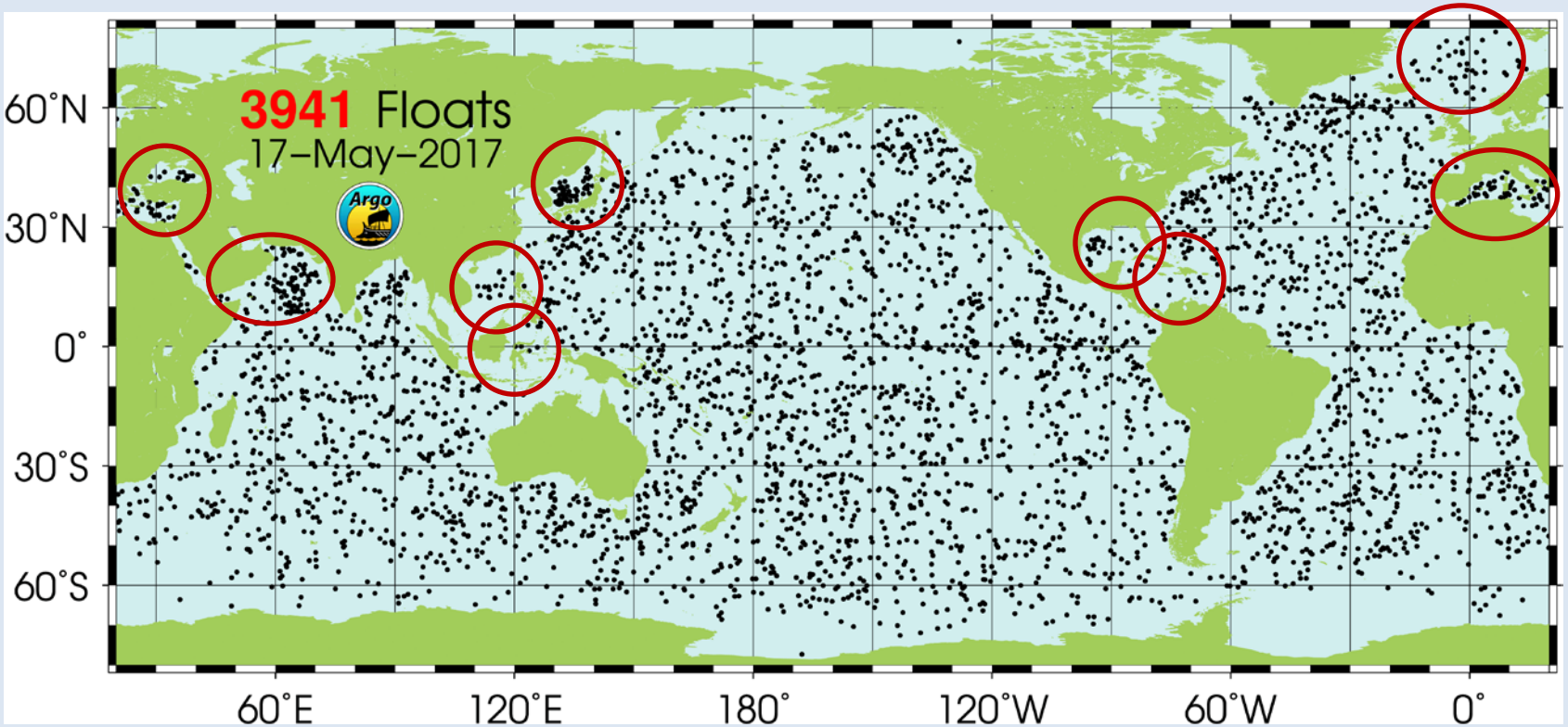
- Minimizing sea surface hazards and
- Enabling mission changes.




Figures: JCOMMOPS

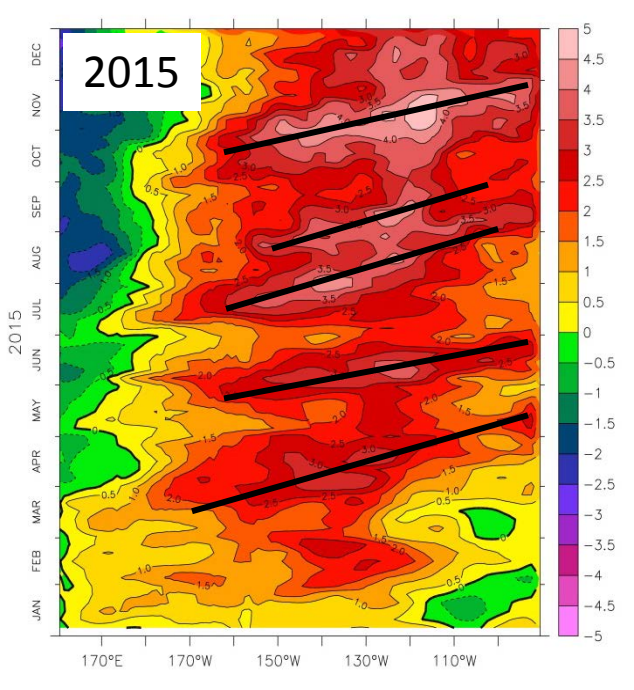
# Marginal Seas

- Target density 2 x global design = 2 floats every 3° x 3°
- Demand for biogeochemistry and optics is high
- Present coverage is uneven, with about 200 active floats.
- Implementation can only happen within strong functioning GOOS regional alliances which are able to  overcome EEZ sensitivities



# Equatorial Enhancement

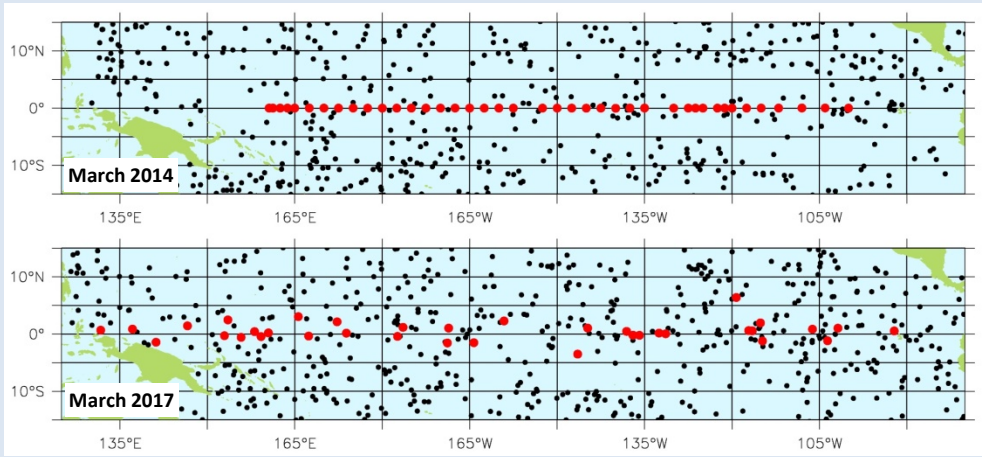
- *TPOS 2020 First Report* recommends doubled Argo coverage in the Pacific from 10°S to 10°N, beginning with the western Pacific and along the equator.
- Improved spatial resolution of intraseasonal to interannual variability is important for observation of ENSO/monsoon/IOD

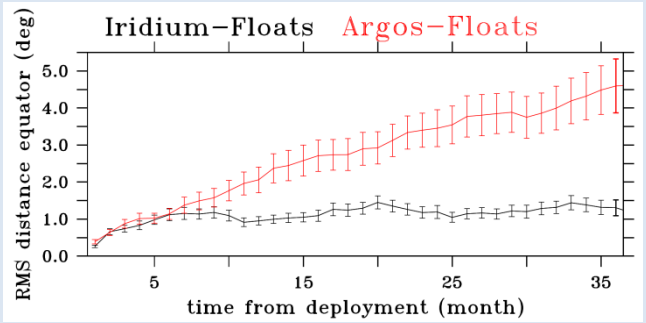



0-200m vertically-averaged temperature anomaly along the Equator in 2015, showing the sequence of Equatorial Kelvin waves.

Mapping improvements: Gasparin et al (2015, JAOT)

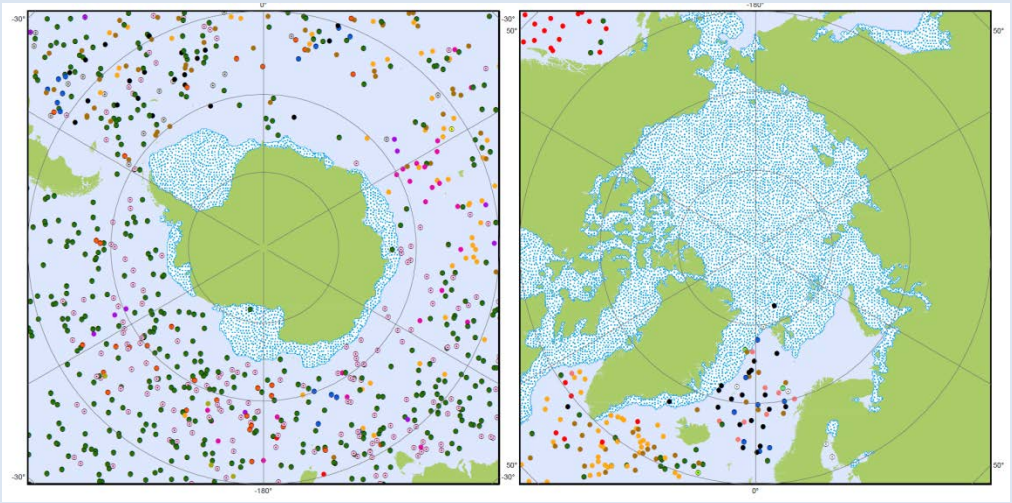
2014 pilot deployment of 41 Argo floats (red)



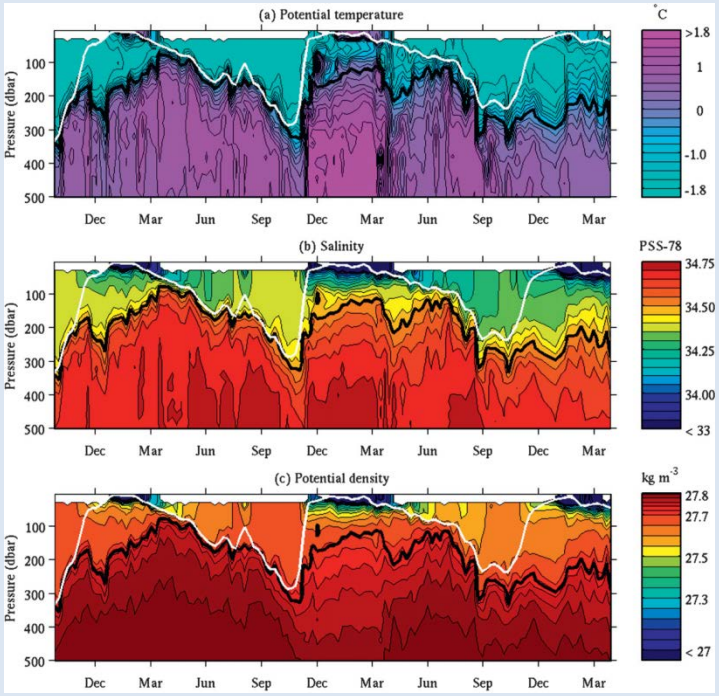



# Seasonal Sea-Ice Zone

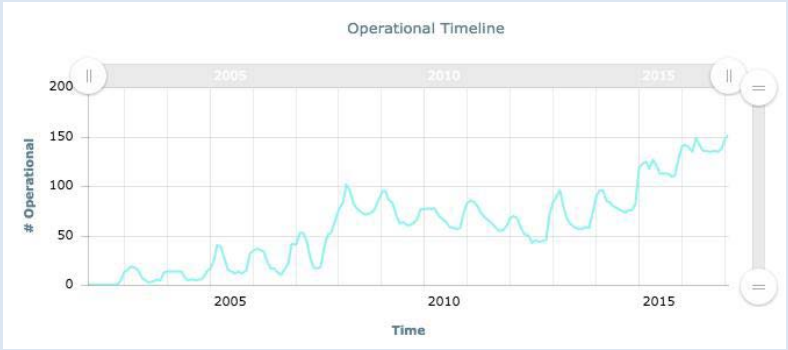
- A blind spot in the GOOS – needs to be urgently addressed due to links between ocean warming – ice sheet loss – future sea level rise.
- Arctic- 86 active floats north of 60°N.
- Antarctic- 154 active floats south of 60°S. Deployment opportunities are limiting.
- Floats use an “Ice-avoiding” algorithm to remain below ice during winter.



Active Southern Ocean and Arctic floats, 5/2017



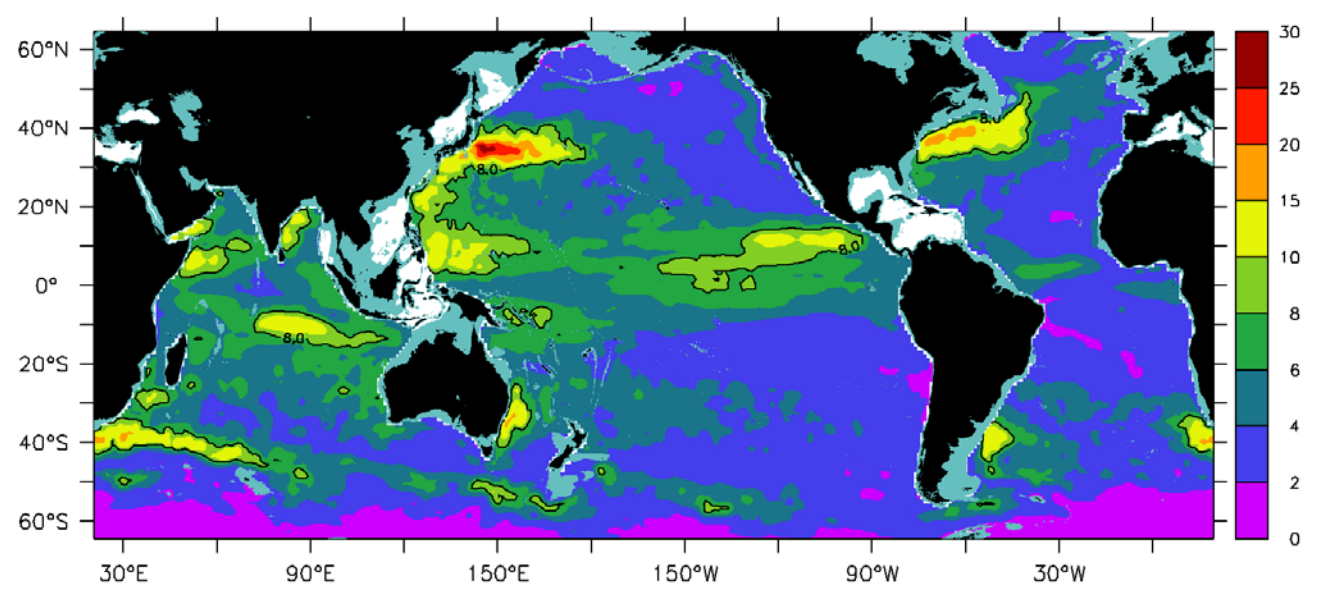

Modification of surface waters in the ice zone (Wong and Riser, JPO 2011)




Timeline of active Southern Ocean floats

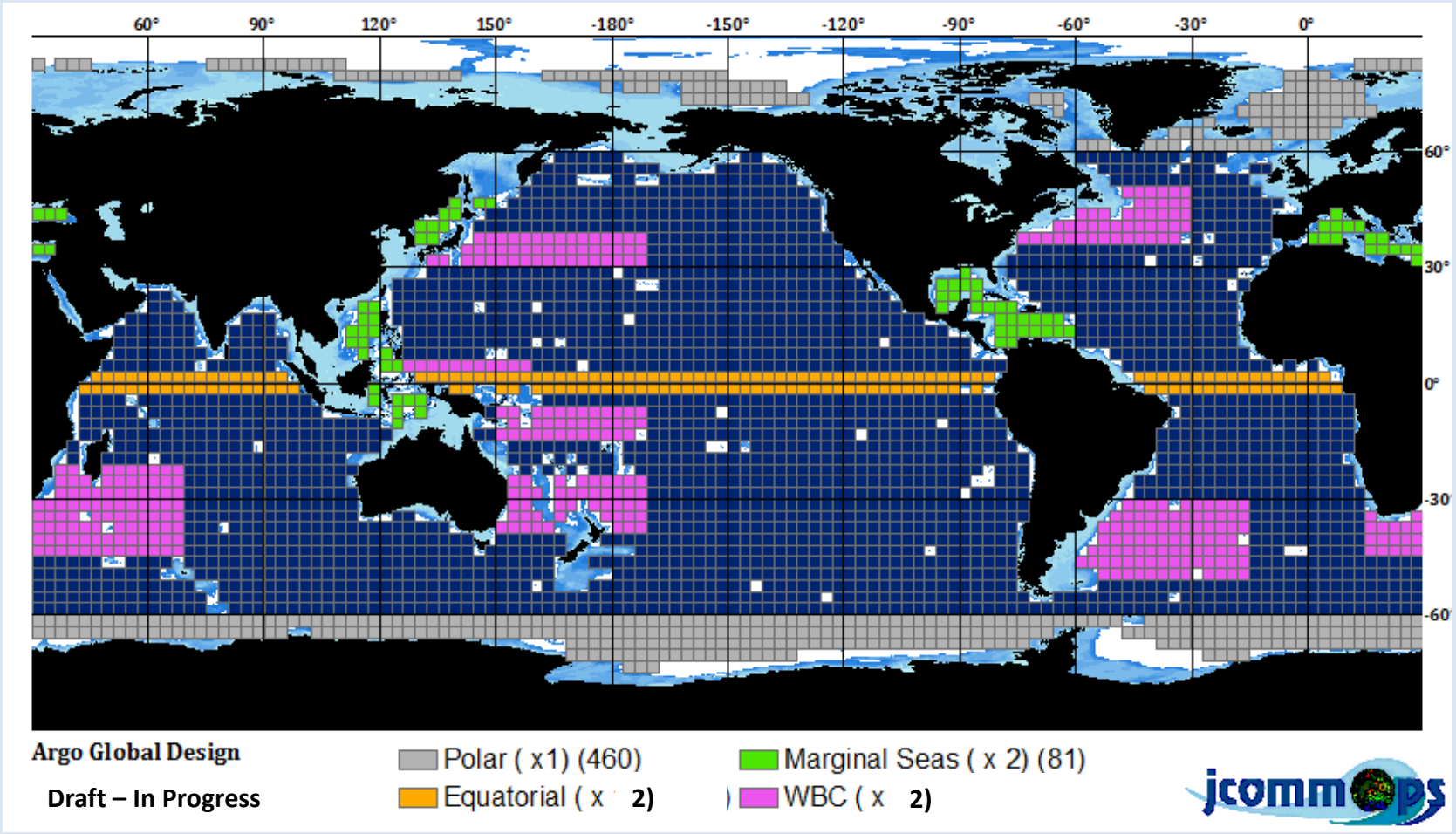
# Western Boundary Regional Enhancements

- High eddy activity drives a lower signal/noise ratio for Argo's target space/time scales. Enhanced resolution needed.
- Target density 2 x global design = 2 floats every 3° x 3° in high energy regions.
- Due to process studies and regional interest, the Kuroshio/Oyashio system has been a pilot of this coverage enhancement.
- Engagement with OSE/OSSE activities useful to clarify benefits from and to obtain further guidance for this enhancement.




Standard deviation of monthly Argo dynamic height (cm, 0/2000)

# Going Forward - Revising Global Argo Design

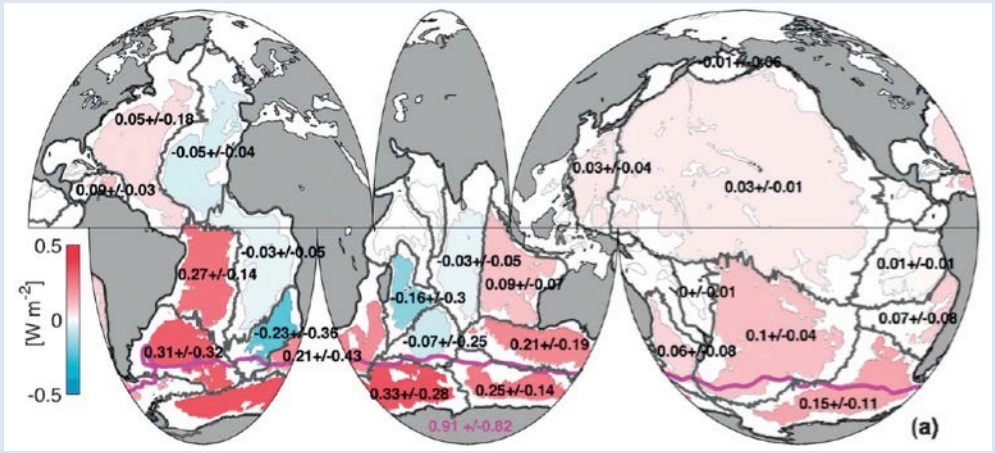



- Same mission – but more spatially complete and better signal to noise ratio. The total requirement is 4400 floats
- Double coverage in WBCs and equatorial regions
- Marginal Seas: enhanced sampling - determined by regional partnerships
- Seasonal Ice zone: normal sampling

# New Missions: Deep Argo

**Why?**

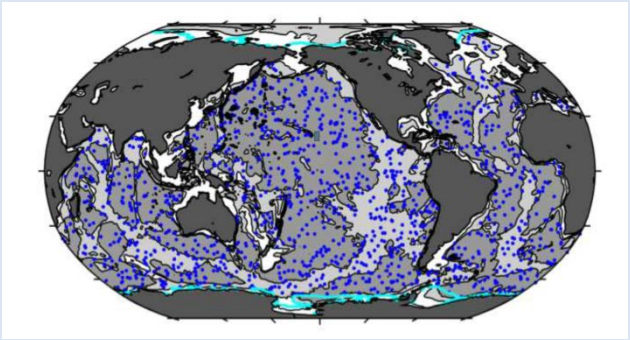
- Sparse repeat hydrographic data show that the ocean below Argo-depth is warming consistently, particularly in the Southern Hemisphere.
- This matters for sea level rise and the Earth's energy budget.
- Important elements of deep circulation and MOCs are below 2000 m .
- Model initialization/assimilation requires data below 2000 m.




Bottom Water warming from 1990's to 2000's
Purkey and Johnson (2010)


Report of the Deep Argo Implementation Workshop
http://www.argo.ucsd.edu/DAIW1report.pdf

# Deep Argo

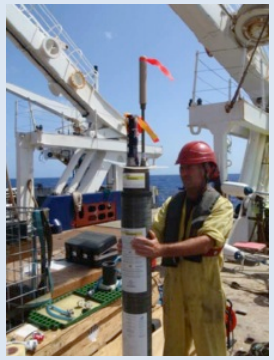


Left: Strawplan for 1228 Deep Argo floats at nominal 5° x 5° spacing (Johnson et al, JAOT, 2015) over the global ocean where depth exceeds 2000 m. (Based on decorrelation statistics from GO-SHIP decadal repeat hydrography.

## Status

- Four Deep Argo float models have been developed and tested.
- New CTDs (6000 m SBE-61, plus 4000 m version of SBE-41) are under assessment for stability and accuracy.
- Coordinated regional Deep Argo pilots are being deployed in the N. and S. Atlantic, S. Pacific, and Southern Ocean

Deep NINJA (left) and Deep PROVOR (below) 4000 m floats.



Deep APEX (above left) and Deep SOLO (above right) 6000 m floats.

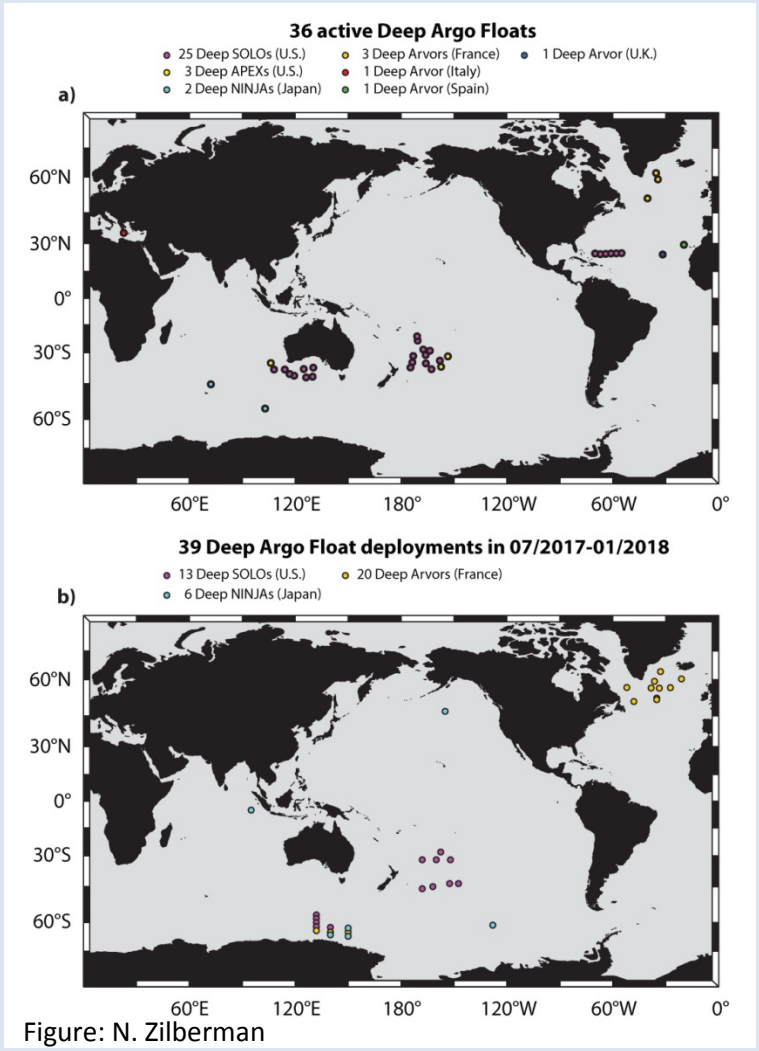



Figure: N. Zilberman

# New Missions: BGC-Argo

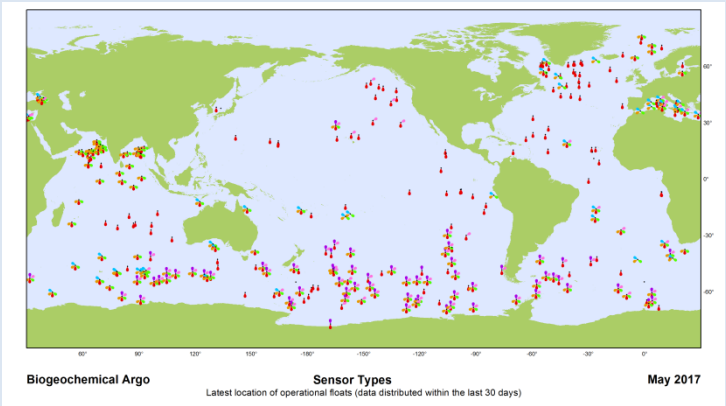
## Why

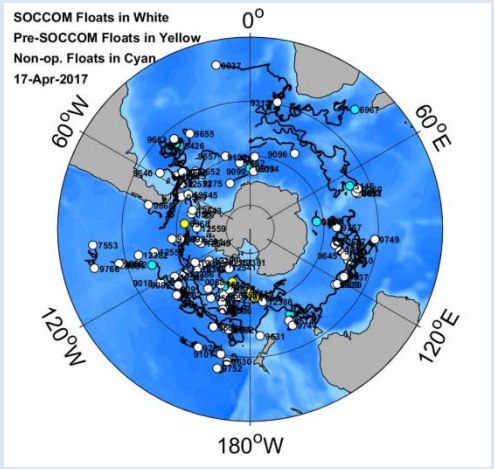
- Understand the fundamental bio-geochemical cycling in the oceans, and thus the foundation of biological productivity patterns and carbon uptake
- To track any long term trends – e.g there is already evidence of significant ocean oxygen changes

## Status

- > 200 floats already carry oxygen – QC and sensor stability work is progressing well
- Nitrate, pH (acidity), and bio-optical sensors have been developed and now deployed on a subset of Argo floats
- Regional pilot arrays (Atlantic, Southern Ocean, Med Sea) are rolling out, including SOCCOM
- Progress on data handling and QC via partnership with the Argo Data System
- Strong links to **GOSHIP/IOCCP/GOOS.**

**Location of 284 active floats carrying one or more BGC sensors.**




**SOCCOM float locations: 68 active (JCOMMOPS)**

# Summary and Challenges

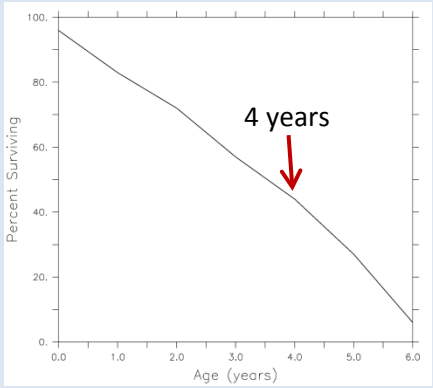
## GOOD NEWS

- The Core Argo array is in a healthy state.
- Argo enhancements are valuable and practical, and developing as part of the integrated GOOS.
- Research and operational uptake of Argo data continues to grow.
- Argo's future will fulfill the vision of comprehensive global ocean observation.

## CHALLENGES: SHORT AND LONG-TERM

- National Argo budgets have not kept up with inflation. Can the inflationary loss continue to be offset by increasing float lifetimes?
- New initiatives generate excitement and sometimes new funding, but Argo's first priority is to sustain the original Argo mission.
- Argo enhancements and extensions pose new challenges for data management and for synthesis/analysis
- Deployment inside EEZs remains an issue.
- The AST is considering these and other issues for sustaining Argo over the coming decades (see draft document on AST-18 web page). Comments are invited.

# What are key practical actions for sustaining Argo?




"Survival Rate 2" (JCOMMOPS) for all 1966 Argo floats deployed in 2011-2012. 44% have lasted for 4 years or longer.

Four Programs have 4-year survival rates > 70%

1. Argo mean float lifetimes should be extended beyond 6 years to increase cost-effectiveness of the program and to stretch the array's refresh time. This can be accomplished through technology improvements and effective commercial partnerships. Take advantage of Argo technical workshops!

2. Argo should work with its user community to articulate more effectively and broadly the high value of the Argo Program and its critical importance in the integrated Global Ocean Observing System and Global Climate Observing System.

3. In order to encourage participation in "doing" Argo, the creative contributions by individuals and groups to the implementation and improvement of the Argo array, and its dataset, should be documented.

4. A more systematic approach should be taken to the problems of global Argo deployment, including both the logistical issue of reaching remote ocean regions and the problems of international governance.


Argo

# Hybrid lithium batteries for extended lifetimes

- Use of hybrid lithium batteries increases deliverable energy (by about 40%).
- Battery passivation losses are eliminated.
- In future, Deep SOLOs with 5 hybrid lithium packs will be capable of > 250 cycles to 6000 dbar (at 25 kJ per cycle).
- No added cost.

*Float technology improvement must be ongoing for better performance and longer lifetime.*