A Decade of global Argo: Achievements and Future Challenges

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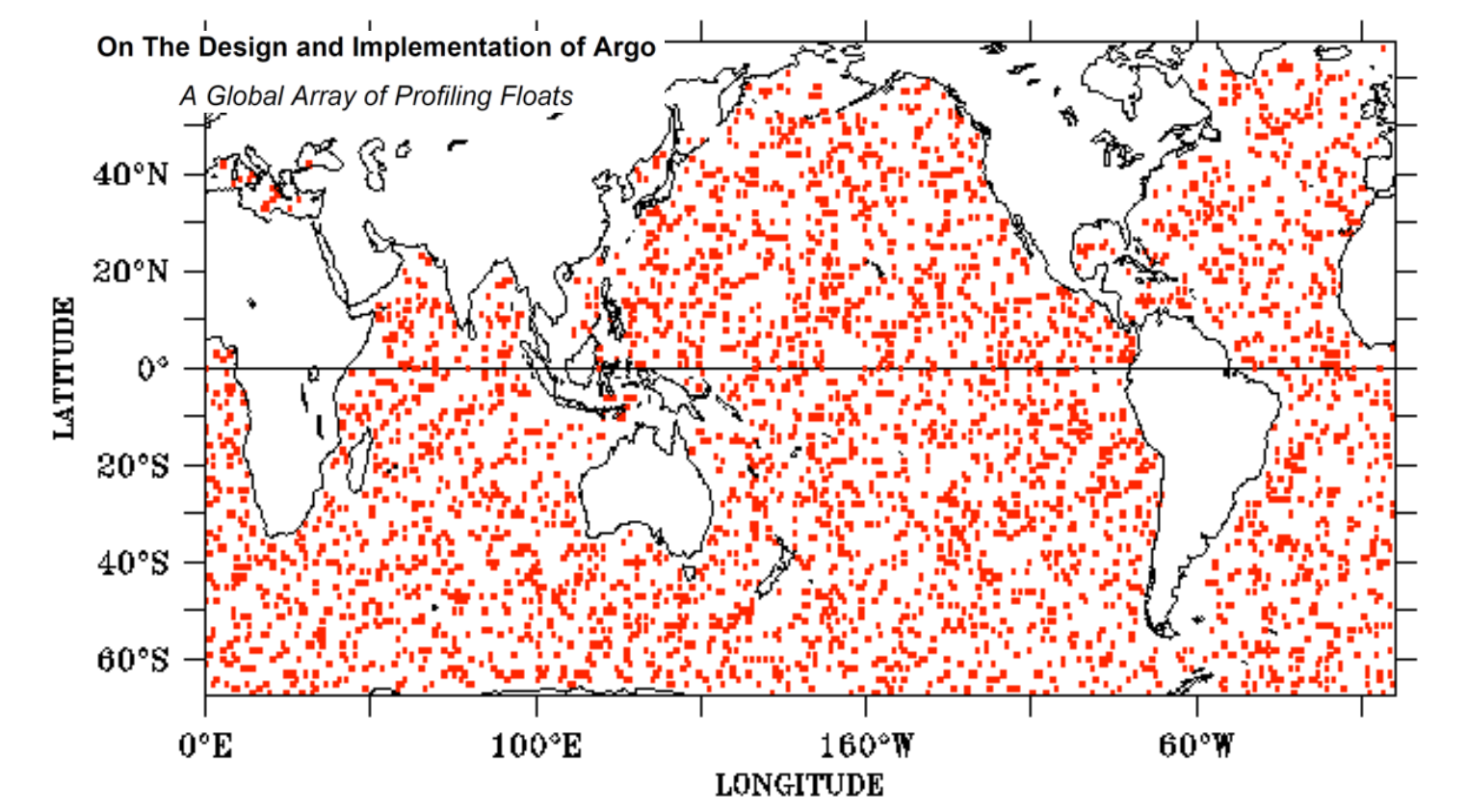
and
The Argo Steering Team

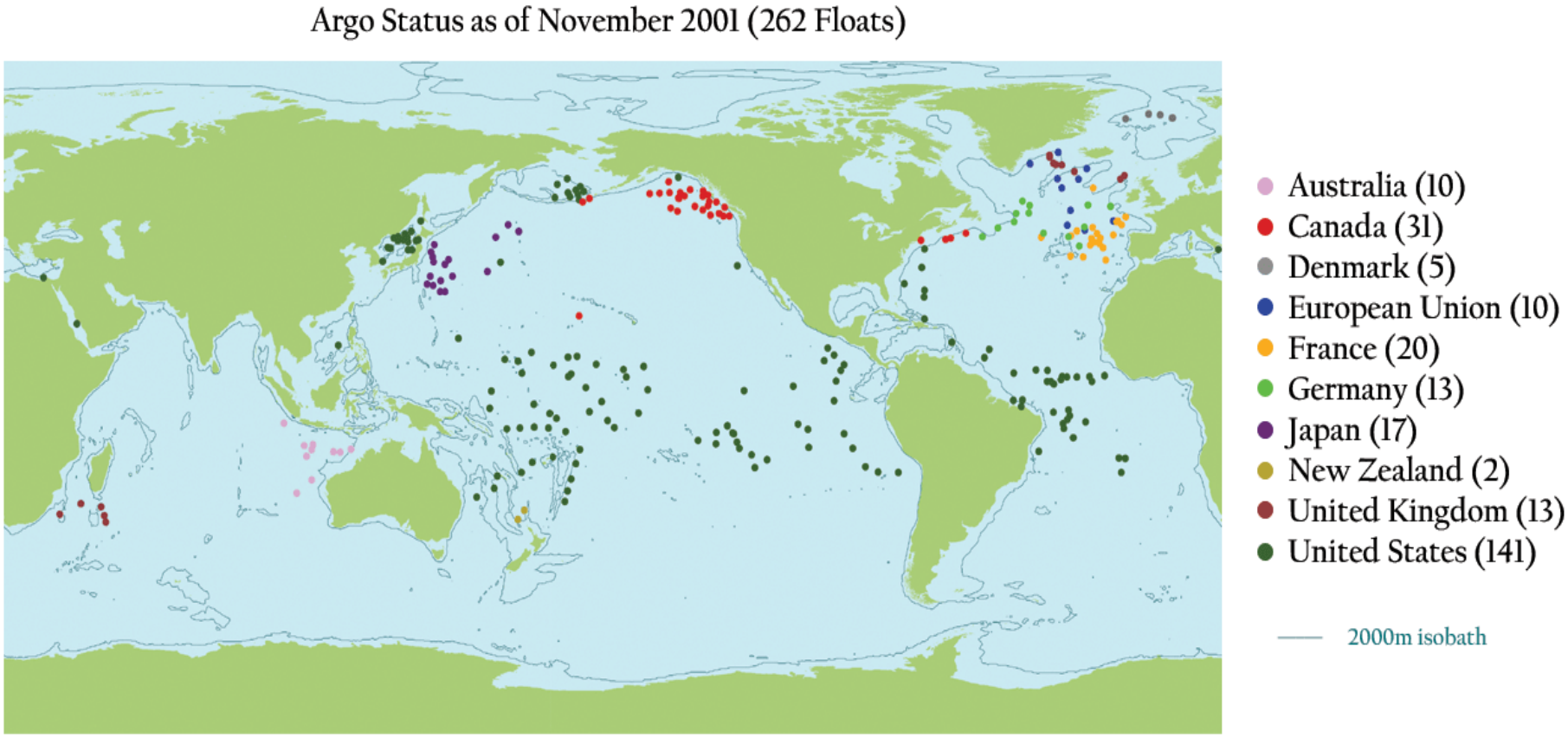
Euro-Argo, Brest, France, 2015

Argo in 1998
an idea

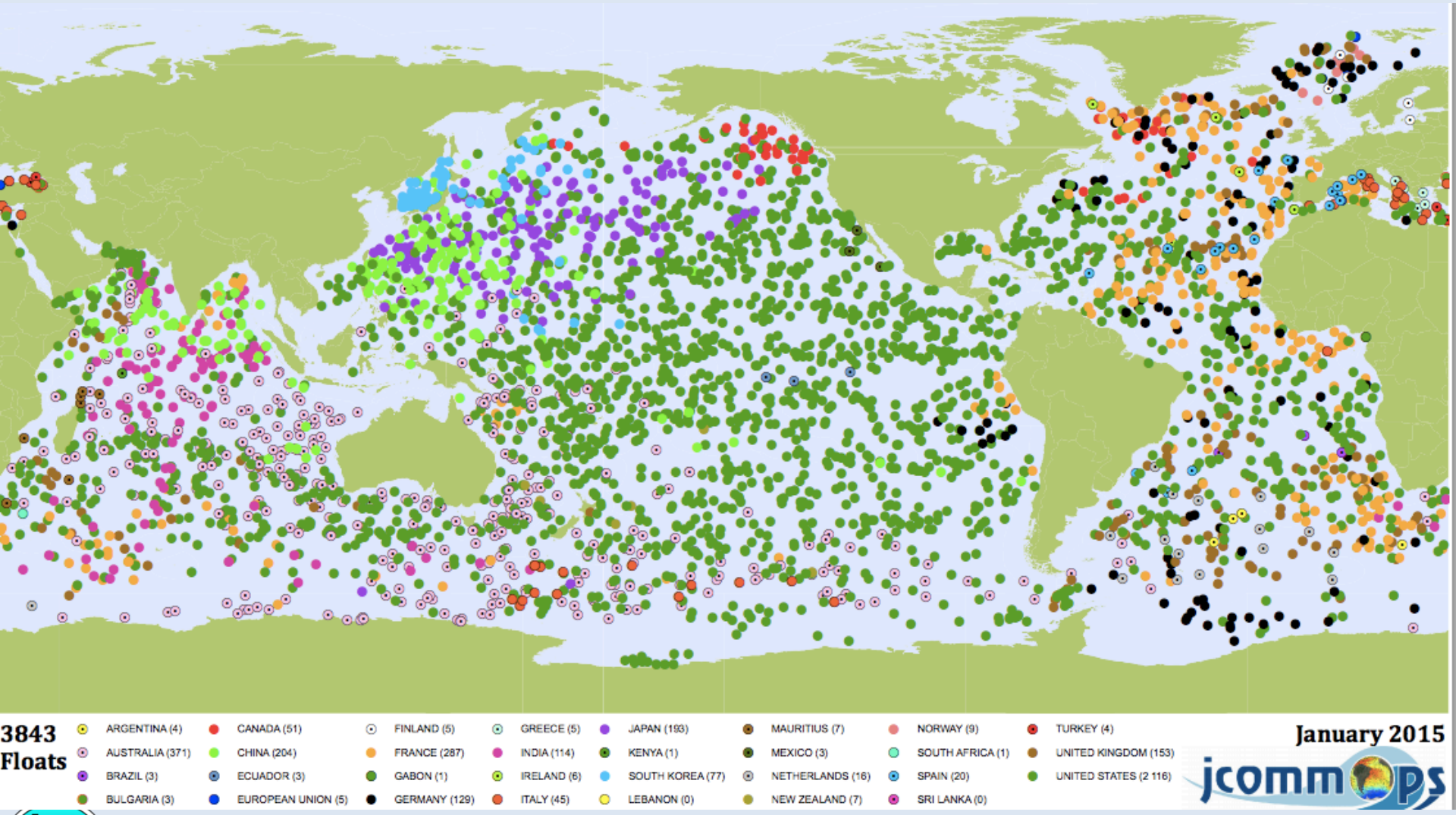


Fom the 1998 Argo Design document: See http://www.argo.ucsd.edu/argo-design.pdf

Argo in 2001

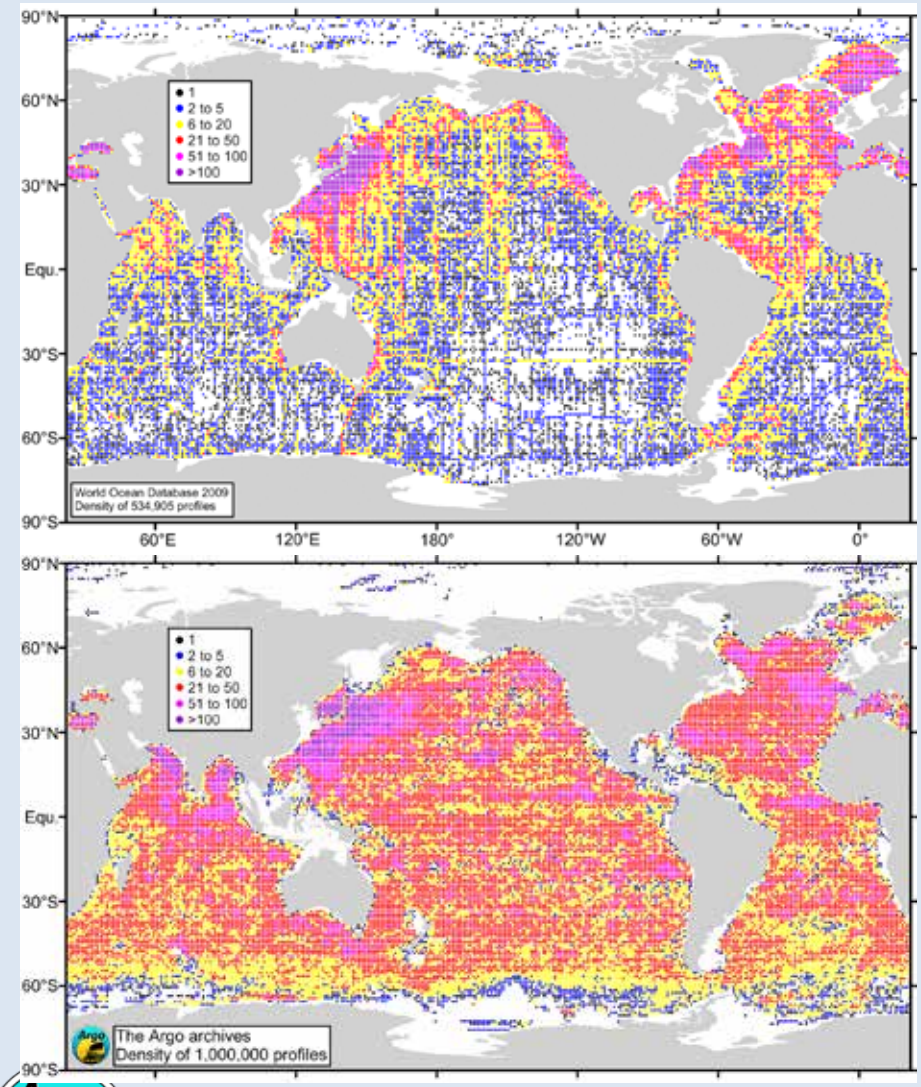

Argo Status as of November 2001 (262 Floats)
Australia (10)
Canada (31)
Denmark (5)
European Union (10)
France (20)
Germany (13)
Japan (17)
New Zealand (2)
United Kingdom (13)
United States (141)
2000m isobath

Argo in 2015

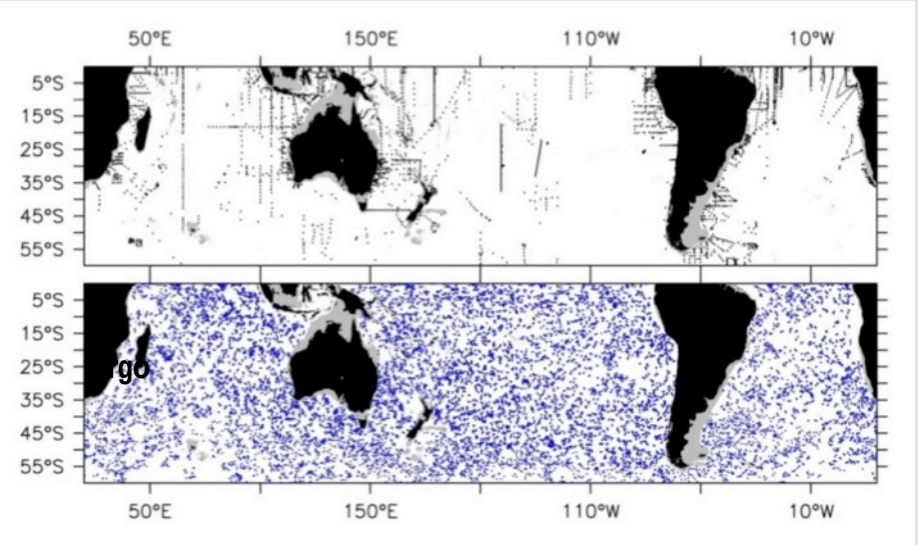

3843 Floats
ARGENTINA (4)
AUSTRALIA (371)
BRAZIL (3)
BULGARIA (3)
CANADA (51)
CHINA (204)
ECUADOR (3)
EUROPEAN UNION (5)
FINLAND (5)
FRANCE (287)
GABON (1)
GERMANY (129)
GREECE (5)
INDIA (114)
IRELAND (6)
ITALY (45)
JAPAN (193)
KENYA (1)
SOUTH KOREA (77)
LEBANON (0)
MAURITIUS (7)
MEXICO (3)
NETHERLANDS (16)
NEW ZEALAND (7)
NORWAY (9)
SOUTH AFRICA (1)
SPAIN (20)
SRI LANKA (0)
TURKEY (4)
UNITED KINGDOM (153)
UNITED STATES (2 116)
January 2015
jcommops

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

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



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



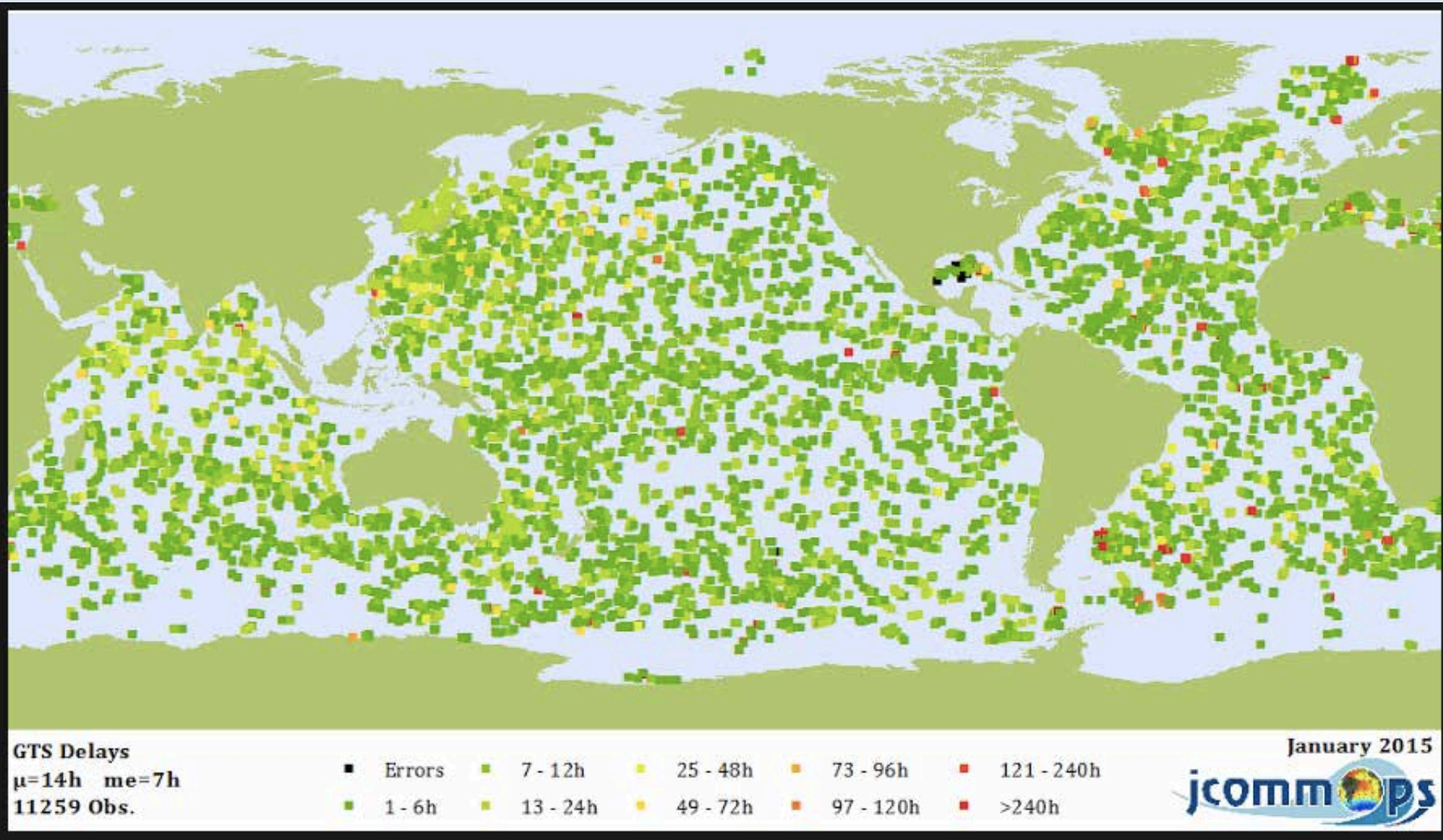
5 years of August Argo T,S profiles (2008-2012).

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 10,000 T/S profiles every month.

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

Argo delivers in real time

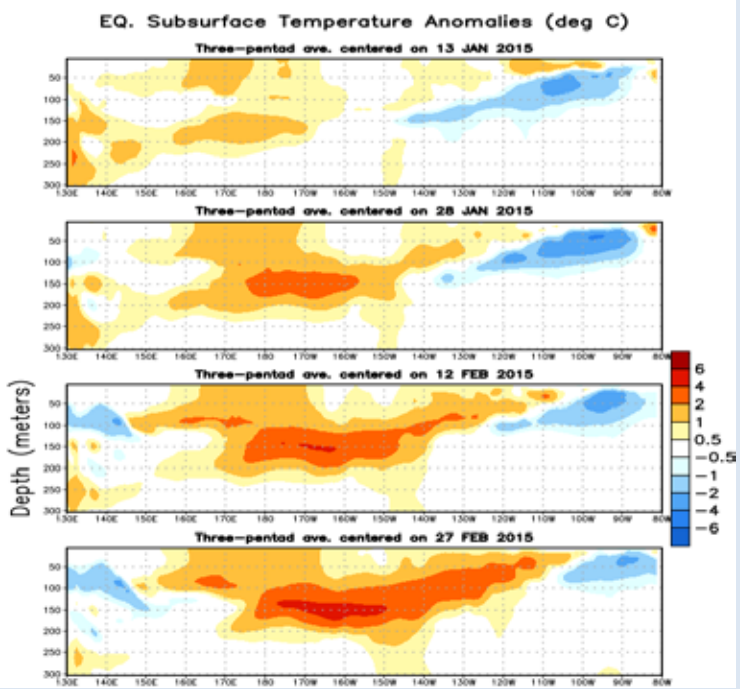


Operational applications of Argo

About 15 operational centers around the world use Argo data for:

- Ocean state estimation.
- Short-term forecasting.
- Seasonal-to-interannual prediction.
- Decadal climate prediction.

See: http://www.argo.ucsd.edu/FrUse_by_Operational.html



Present equatorial temperature anomaly.
Argo is the dominant global data source.

Argo — part of the integrated global observation strategy

Use by operational centers

Operational Uses of Argo Data

Many centers around the world now use Argo data to produce global and regional analyses of subsurface properties because Argo is the most abundant source of subsurface information, (temperature, salinity, velocity) for the global ocean. The availability of these data in real time lends them to use by operational centers involved in the analysis and forecasting of the state of the ocean and of climate.

The following table summarizes the uses that are presently being made of Argo data by these centers.

Country	Center	Project Website	Project Example	Type	Region	T and S
Australia	CSIRO/BRAN/BoM	Bluelink	B of M and the Bluelink Project	Ocean forecast	Australian waters	T + S
Australia	BoM/CSIRO	POAMA		Climate analysis and forecast	Global, but focus on tropics	T
France	Mercator Ocean	Mercator	Mercator	Ocean analysis + forecast	N + Trop Atlantic, Med Sea, Global	T + S
France	Coriolis	Coriolis	Coriolis	Ocean analysis	N + Trop Atlantic, Global	T + S
EU(Italy)	INGV	MFSTEP		Ocean analysis + forecast	Mediterranean	T only MedArgo used to check forecasts
EU (Norway)	NERSC	Diadem/Topaz		Ocean analysis + forecast (+ ecosystem)	Atlantic/Nordic/ Arctic	T+S used to check forecasts
EU(UK)	ECMWF	Seasonal Forecasting System		Seasonal ocean analysis forecasts	Global	T + S
Japan	JMA	COMPASS-K	JMA	Ocean analysis (currents subsurface temperatures)	NW Pacific	T + S
Japan	JMA	ODAS	JMA	Ocean analysis + ENSO forecasts	Global but focus on Eq Pacific	T + S
UK	Met Office	GloSea	GloSea	Seasonal climate forecasts	Global	T + S
UK	Met Office	FOAM	FOAM	Ocean forecasting	Global nested model	T + S
USA	ECCO JPL and SIO/MIT	ECCO		Ocean analysis	Global	T + S
USA	FNMOC Monterey	COAMPS		Ocean forecast	Global	T only
USA	NCEP	GODAS	USGODAE/GODAS	Seasonal to interannual forecast	Global	T only
USA	NASA	NSIPP		Seasonal/Interannual climate	Global	T + S
USA	NAVOCEANO	NCOM		Ocean forecast	Global	T + S

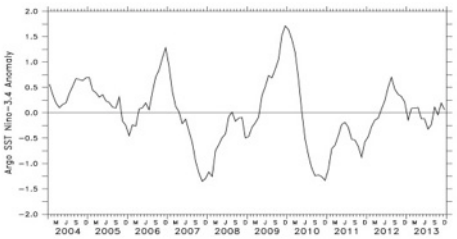
Education and outreach applications of Argo

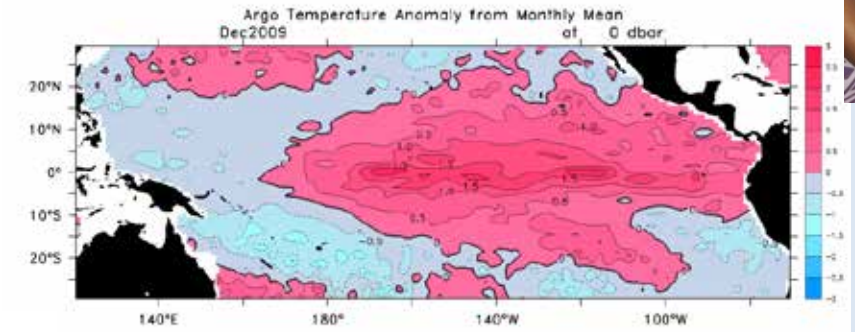
- Education programs (secondary and primary) using Argo data are being developed in many nations.
- Education/outreach tools: The Global Marine Atlas was created for easy interactive display of data:
  http://www.argo.ucsd.edu/Marine_Atlas.html .
- Argo in Google Earth.
  ftp://ftp.jcommops.org/Argo/TMP/Google/kmz_ocean_data.kmz
- Over 100 PhD theses have used Argo data so far.

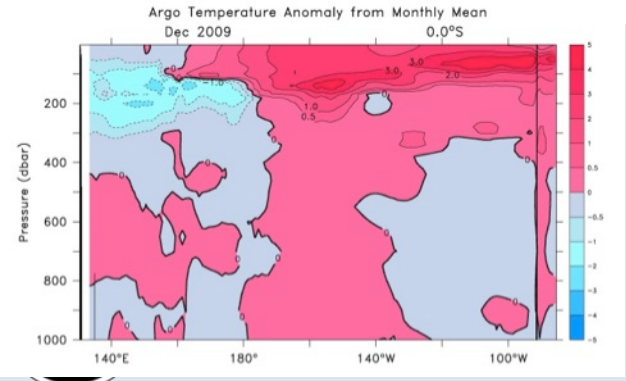
Above: Argo SEREAD teacher training workshops in Tonga and Samoa

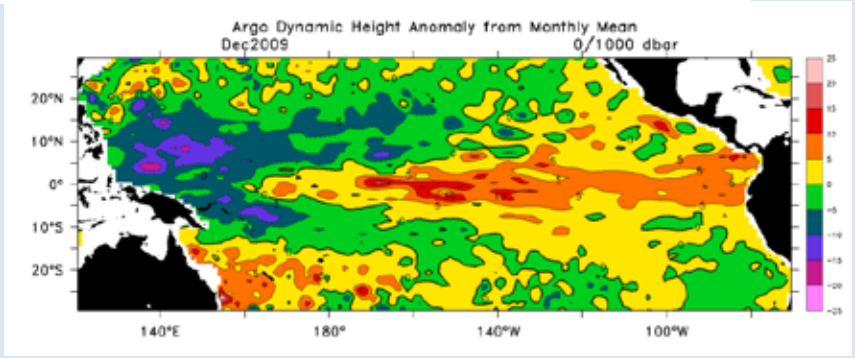
Below: Exploring the 2009/2010 El Niño with the Global Marine Atlas

Niño 3.4 temperature anomaly





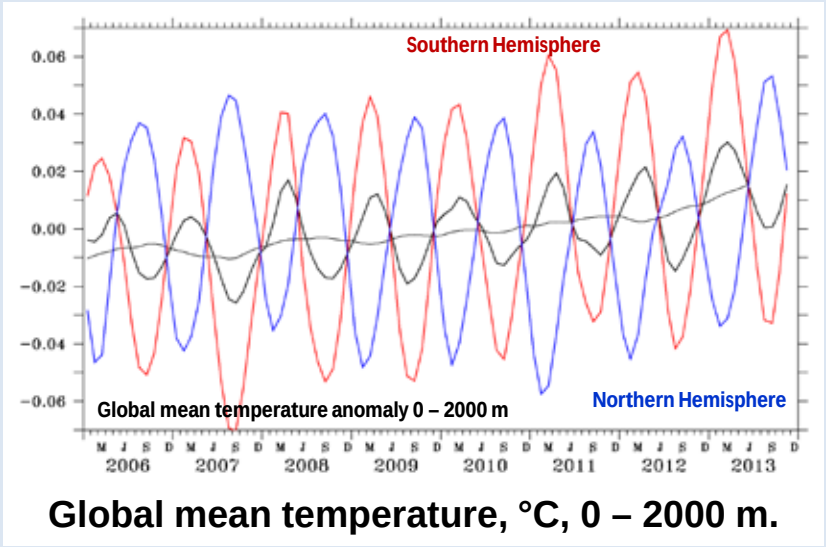




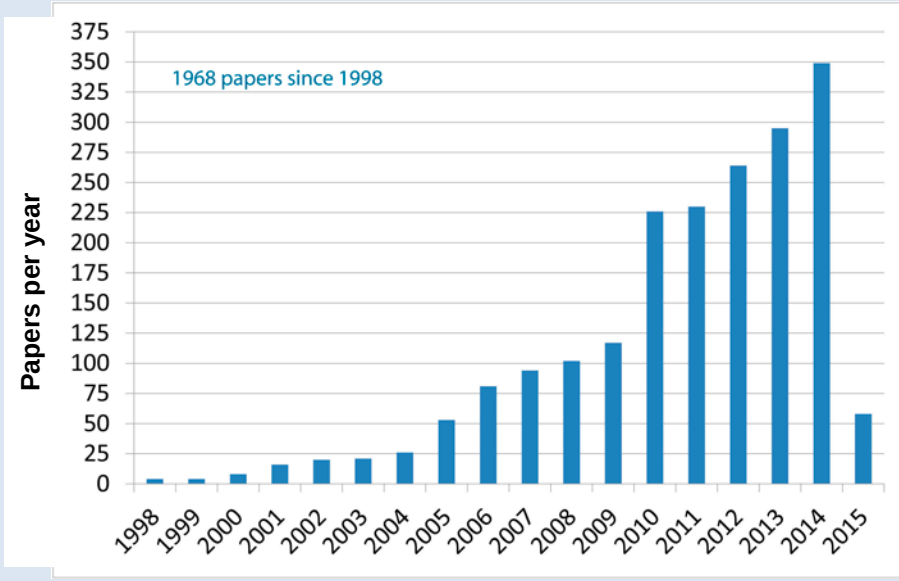
Research applications of Argo

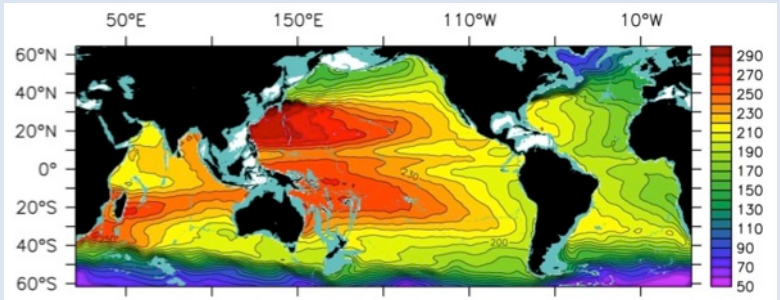
http://www.argo.ucsd.edu/Bibliography.html

- Heat and freshwater storage
- Water mass formation and characteristics
- Ocean circulation and transport
- Large-scale ocean dynamics
- Global change assessments

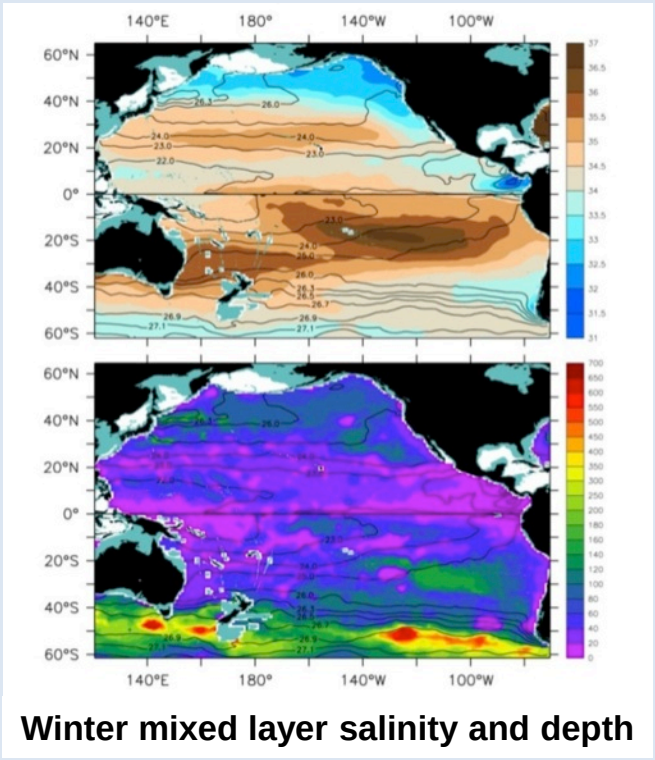


Global mean temperature, °C, 0 – 2000 m.





Mean dynamic height of the sea surface.



Winter mixed layer salinity and depth

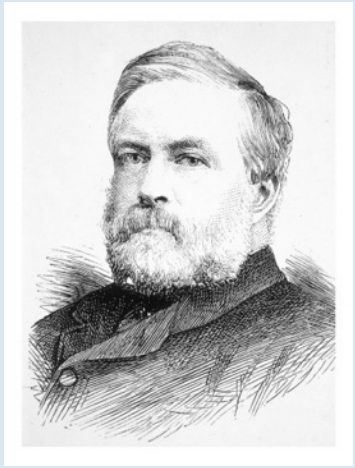
Global-scale oceanography (including ocean temperature measurements) began with the Challenger Expedition (1872 – 1876)

HMS Challenger was a square-rigged wooden ship, 2300 tons displacement, 60 m overall. (R/V Revelle is ~80 m, 3200 tons, 59 berths). All but 2 guns were removed to make way for laboratories and workrooms.

The commanding officer was Captain George Nares, with about 20 naval officers and 200 crew. The six civilian staff/scientists were under the direction of Charles Wyville Thomson.

Between her departure in December 1872 and her return to Spithead on 24 May 1876, *H.M.S. Challenger* traversed 68,890 nautical miles.

Capt. George Nares

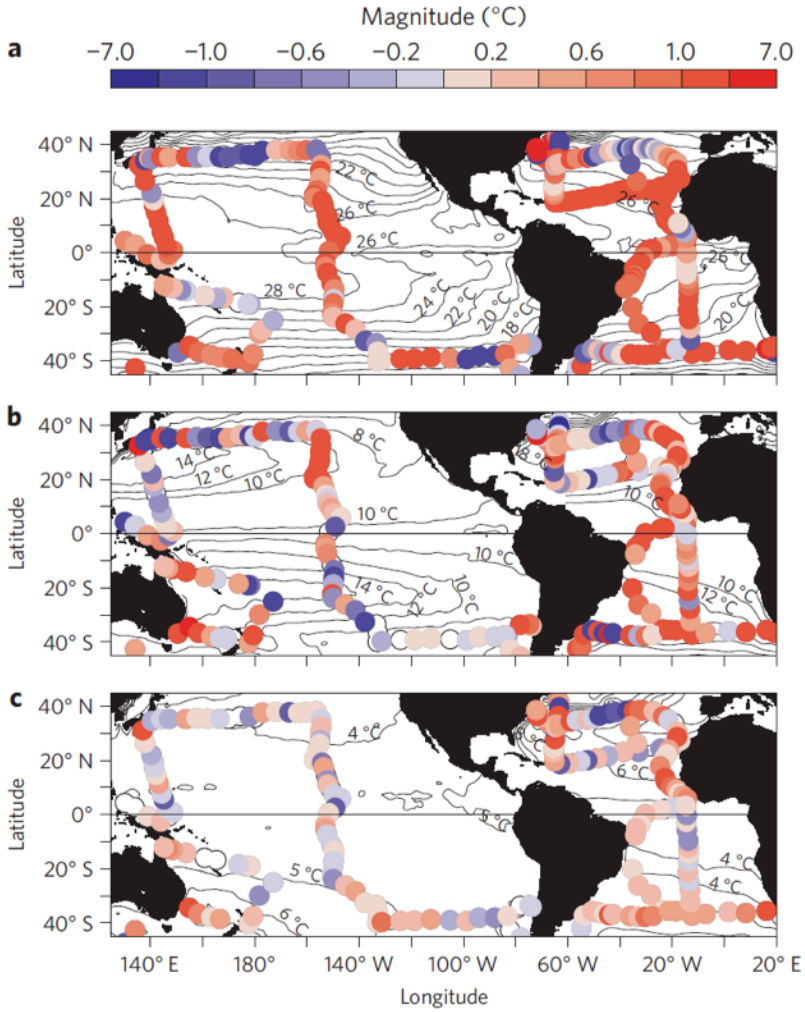


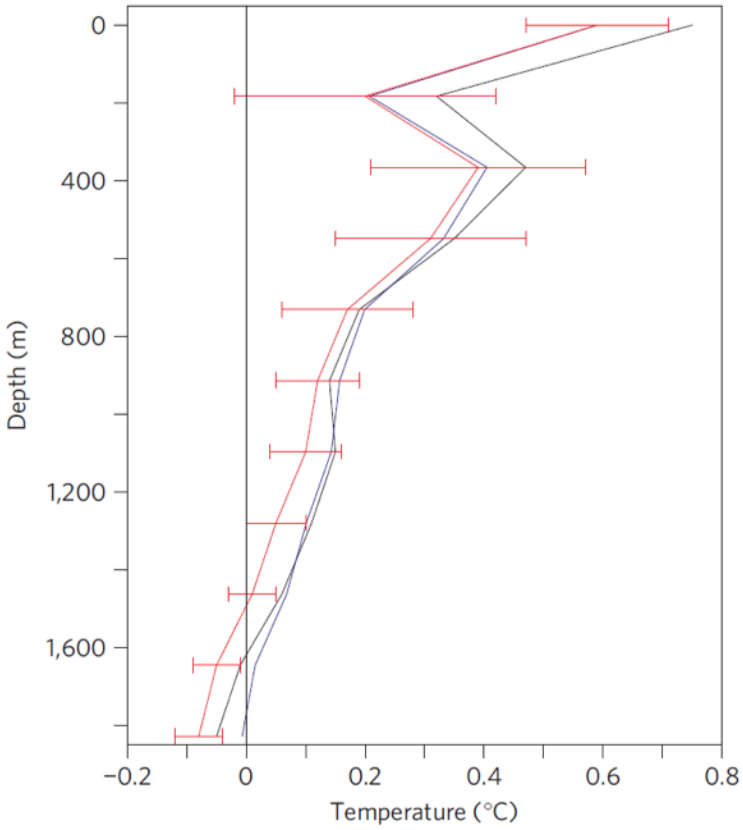
Charles Wyville Thomson

Track of the Challenger Expedition, 1872-1876

We can detect a 135 years of warming

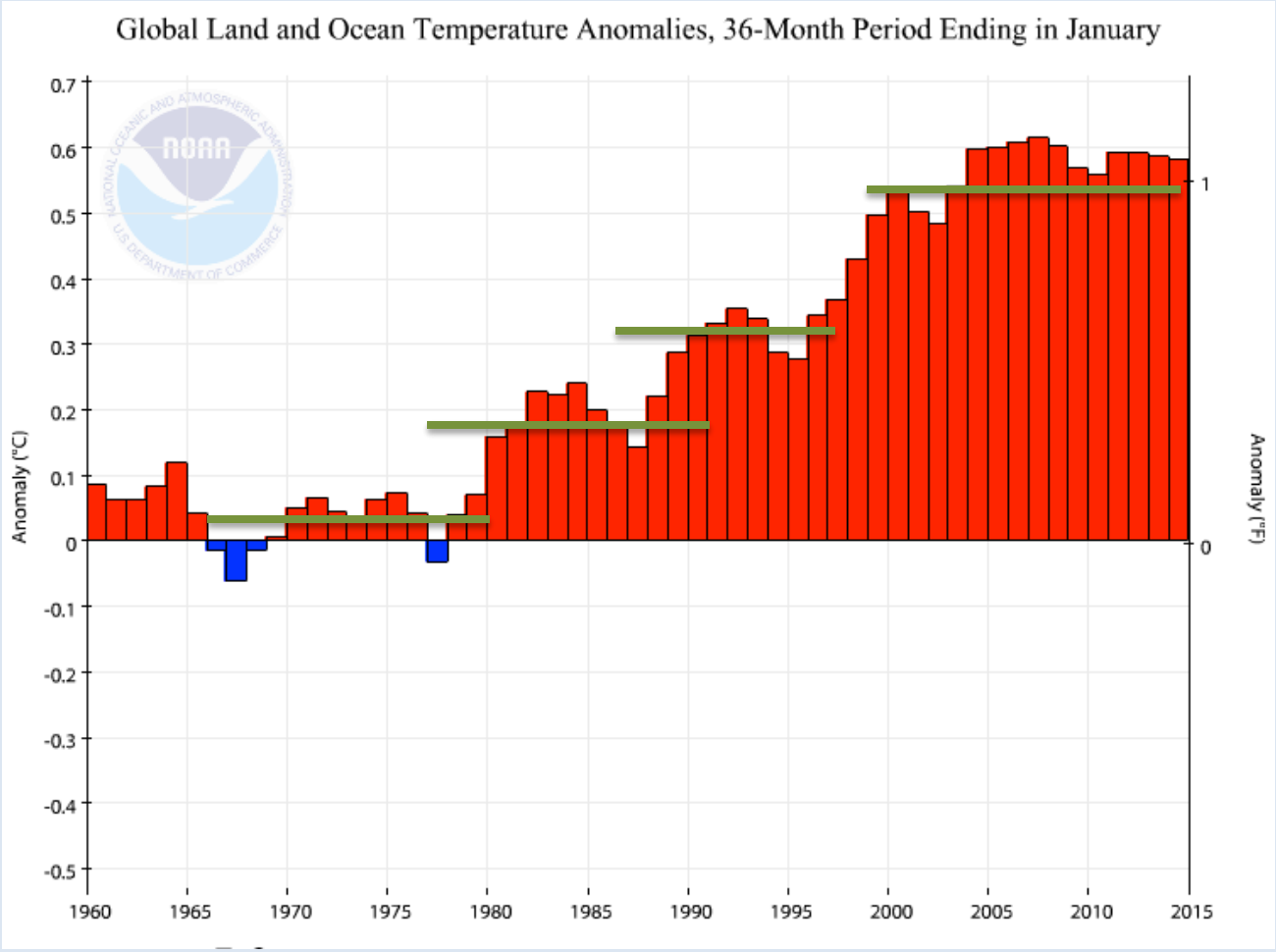
Argo(2004-2010)-HMS Challenger (1872-76)





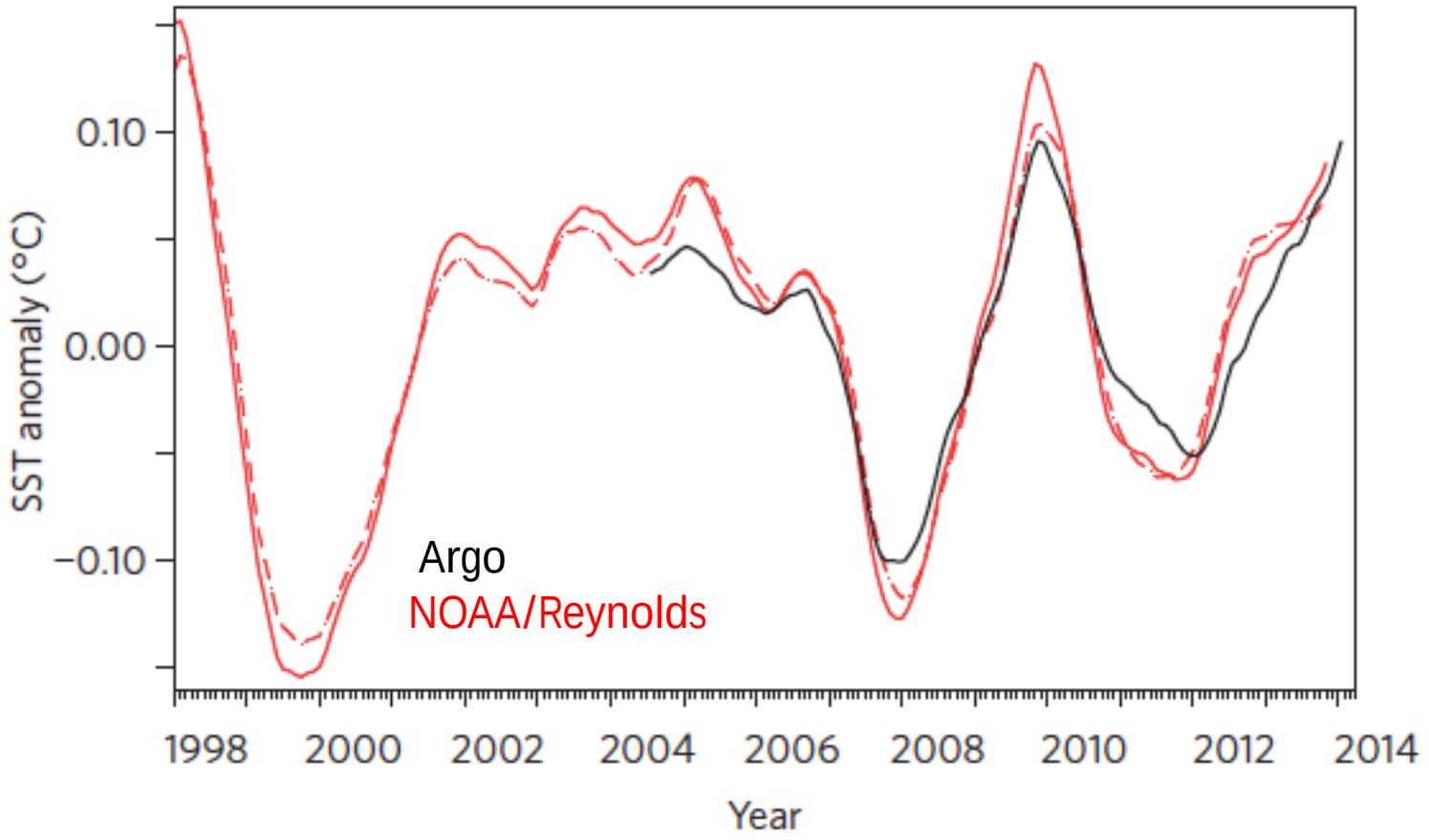
Roemmich, Gould and Gilson, NCC, 2012

A warming hiatus?



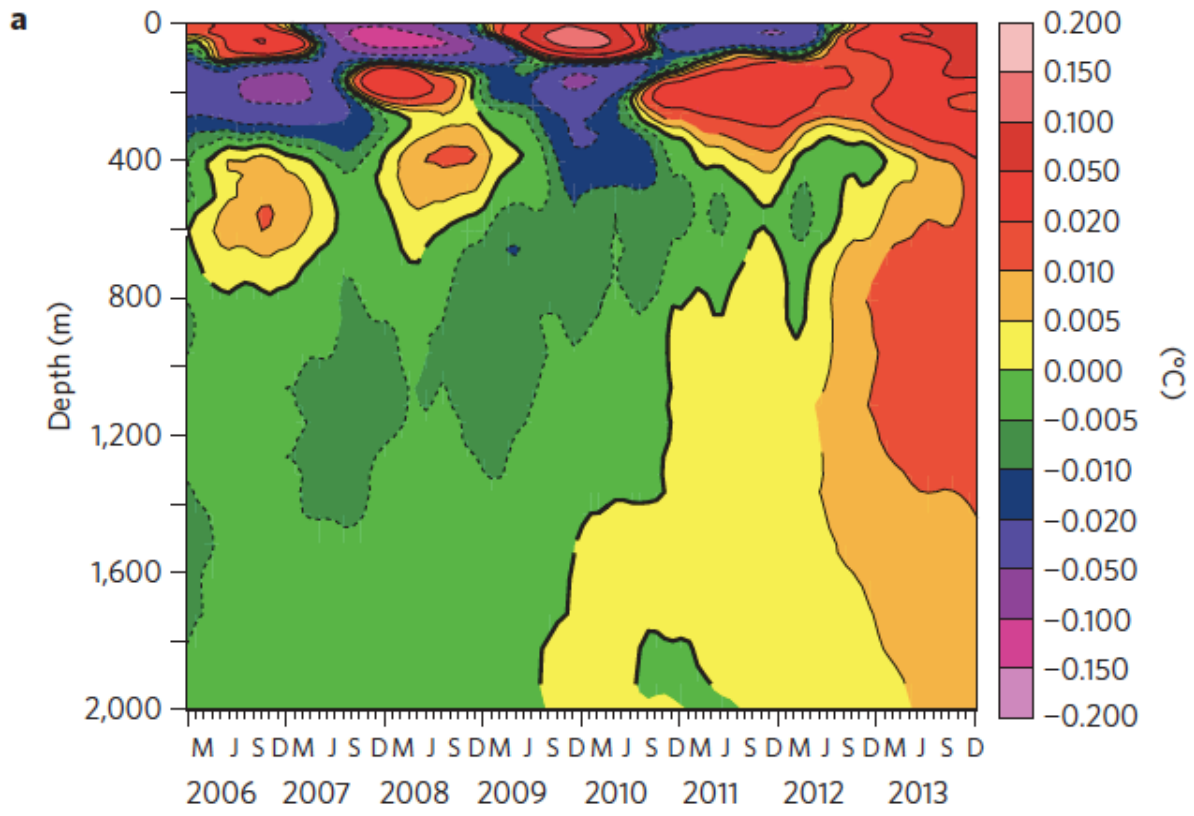
Surface global temperatures rise rates have ‘stalled’ several times, recently since ~1998

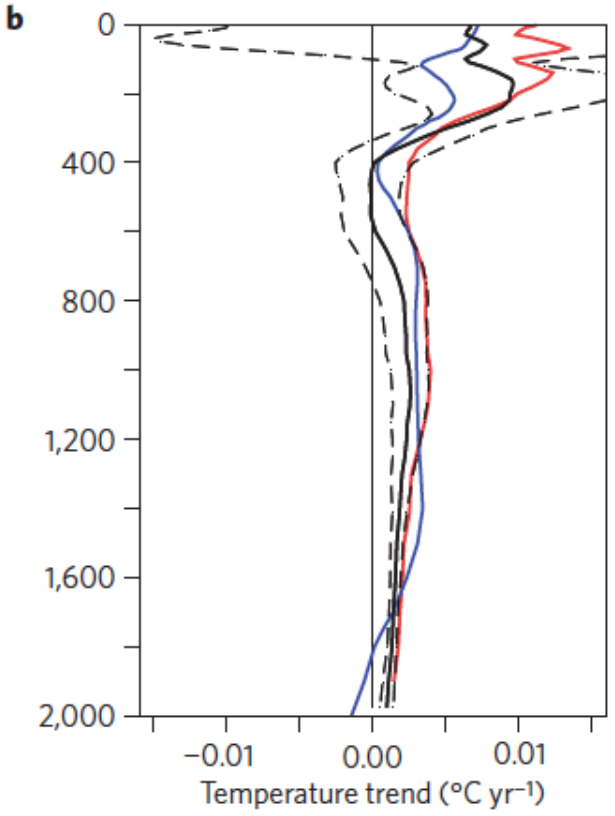
A warming hiatus?
Argo sees it at the surface too.



Roemmich, et al, NCC, 2015

A warming hiatus?
The subsurface view is very different

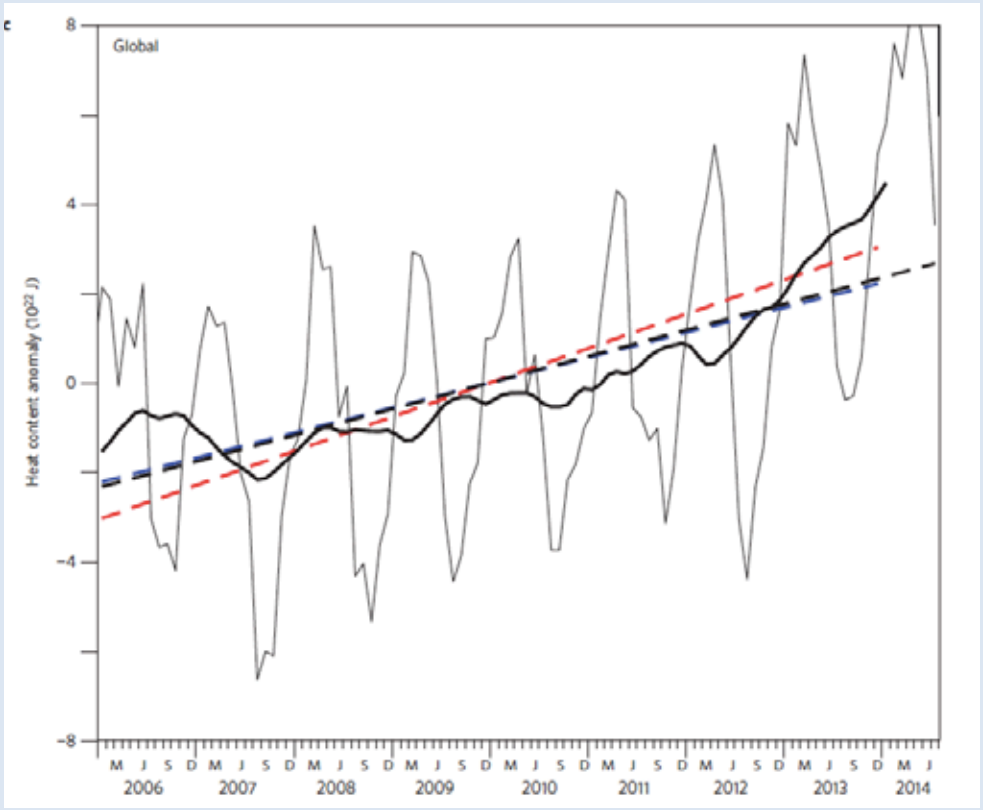


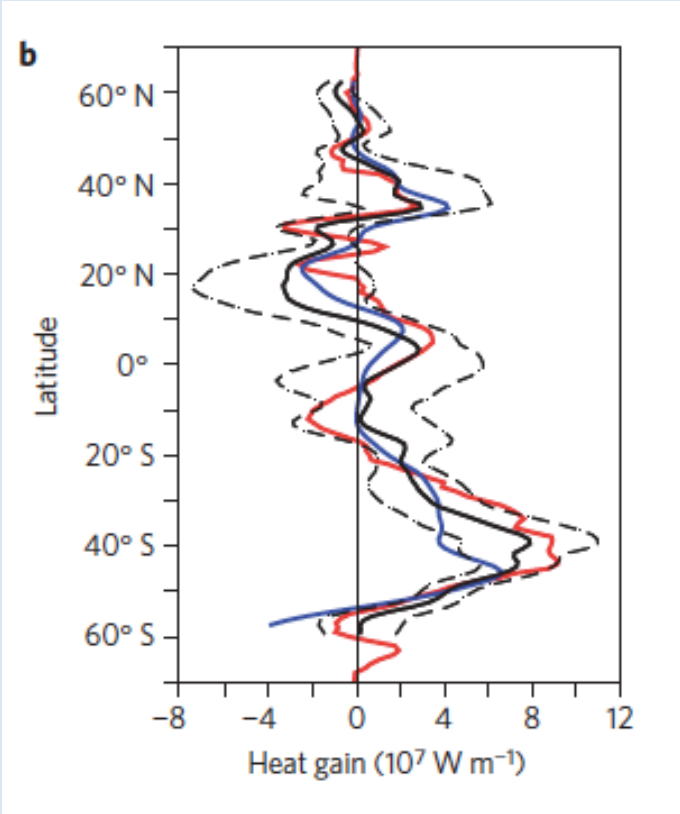


- near cancellation of surface variability by 400m
- steadier warming below this – extending to 2000m

Roemmich, et al, NCC, 2015

Ocean warming has continued unabated over the Argo record

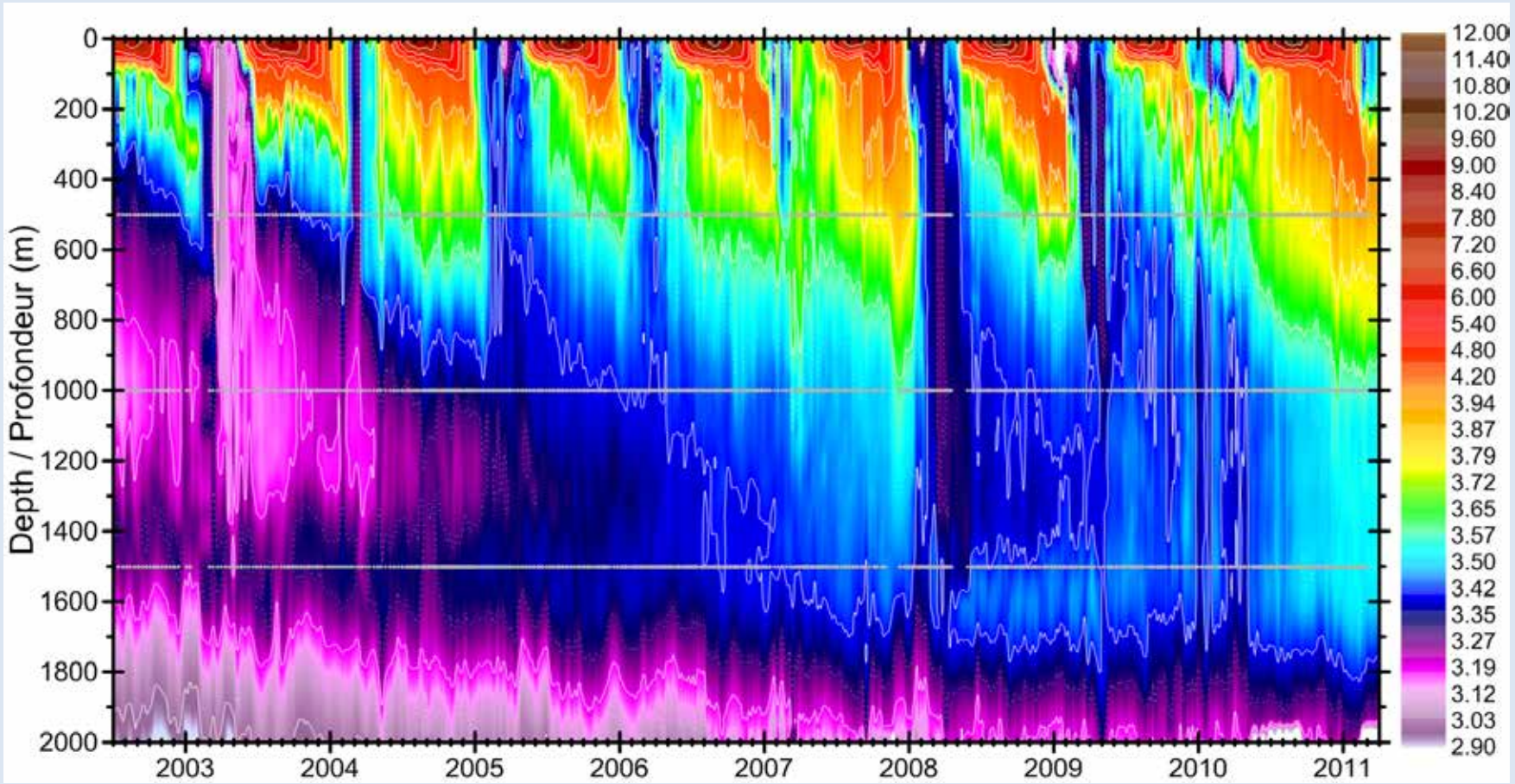




- integrated globally and to 2000m, the warming rate is very steady: 0.4-0.6W/m^2
- similar to rates over recent decades
- most of the heat has accumulated between 20-50ºS

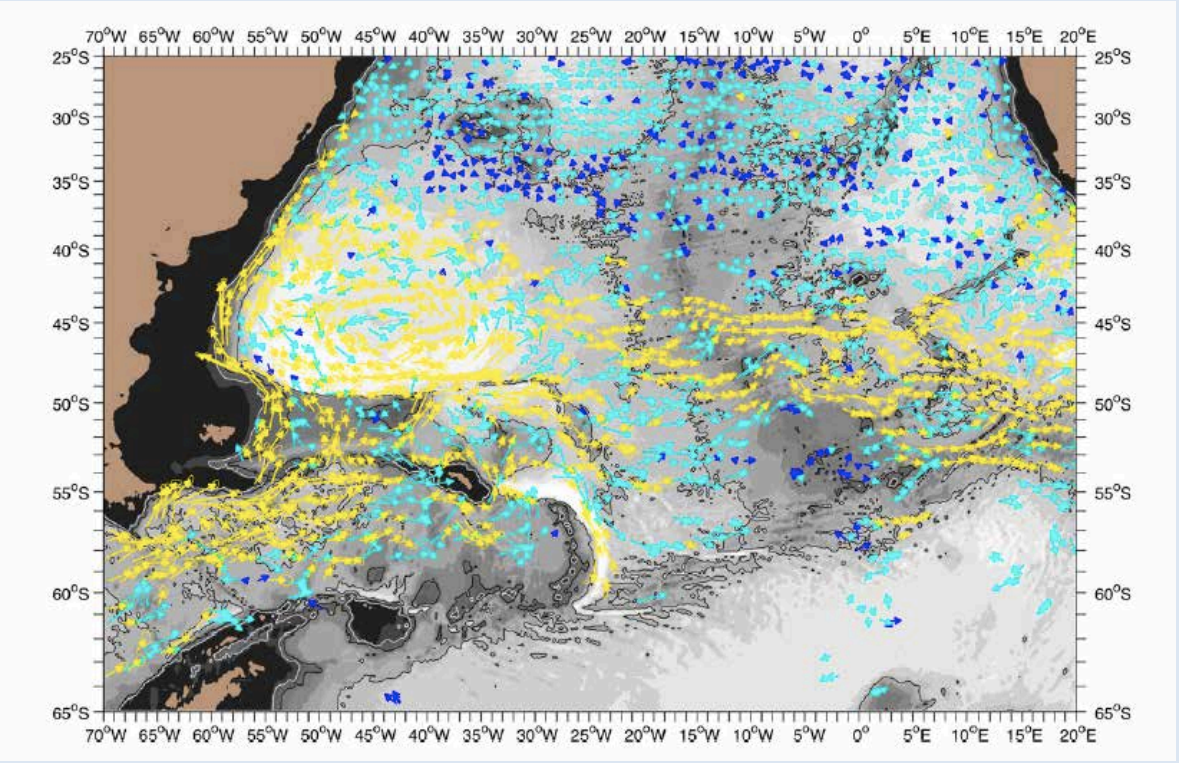
Argo allows detection of this small signal in only 8 years – this is remarkable and due to the uniform coverage and the high quality of the data

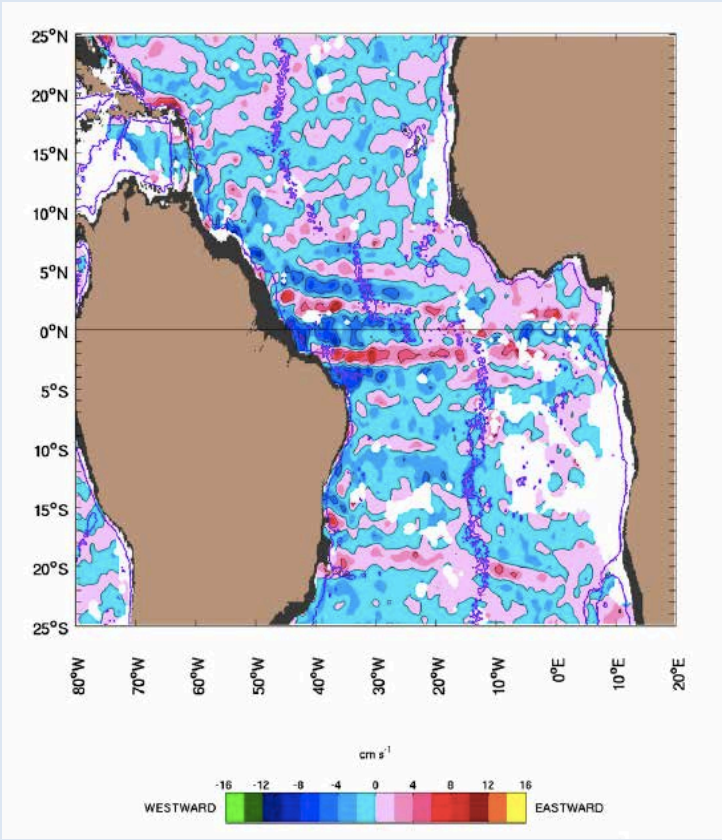
Tracking Polar ocean convection



Canada's Bedford Institution of Oceanography uses Argo to track conditions in the Labrador Sea [Igor Yashayaev , BIO]

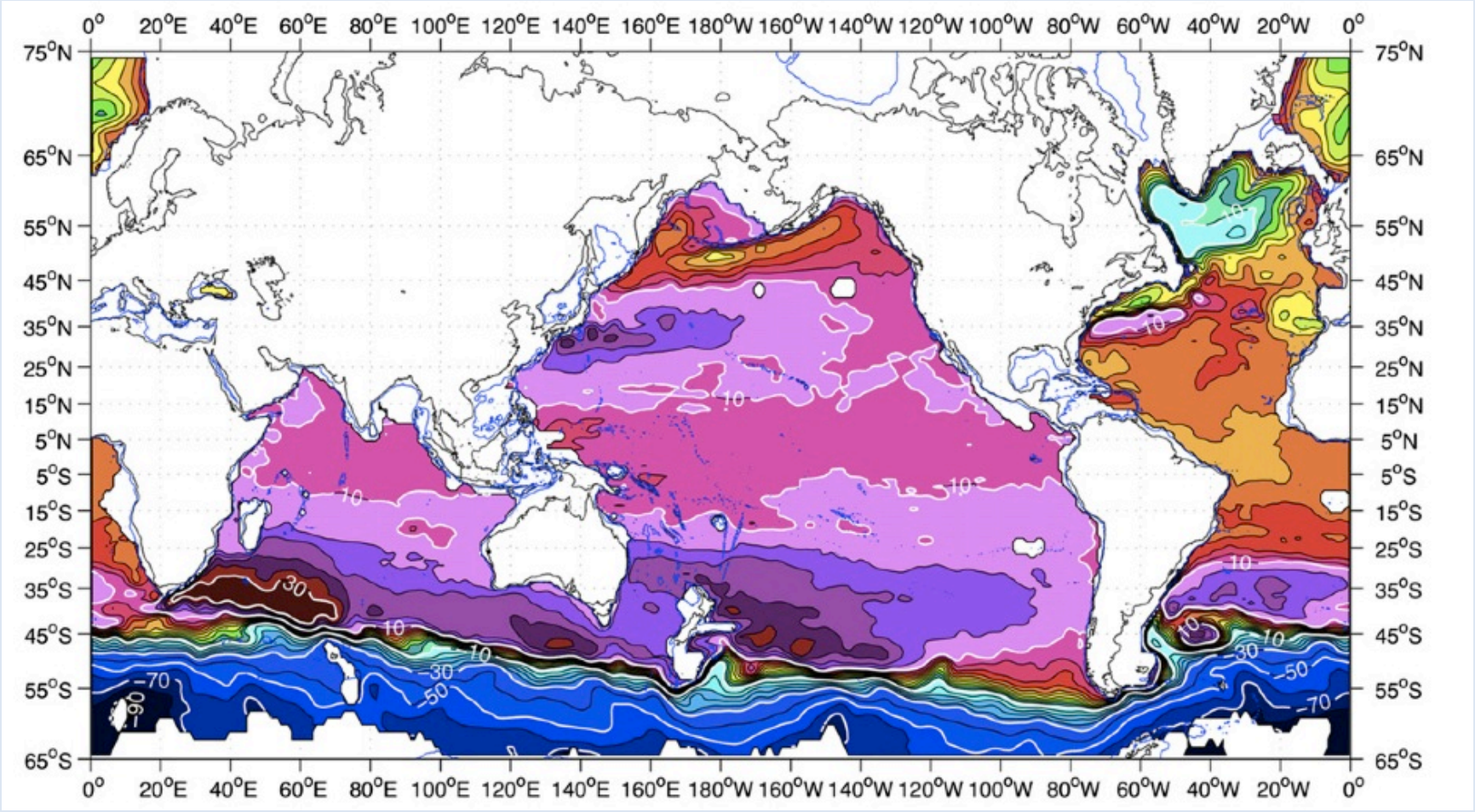
Argo trajectories give unprecedented details of ocean circulation at 1000m





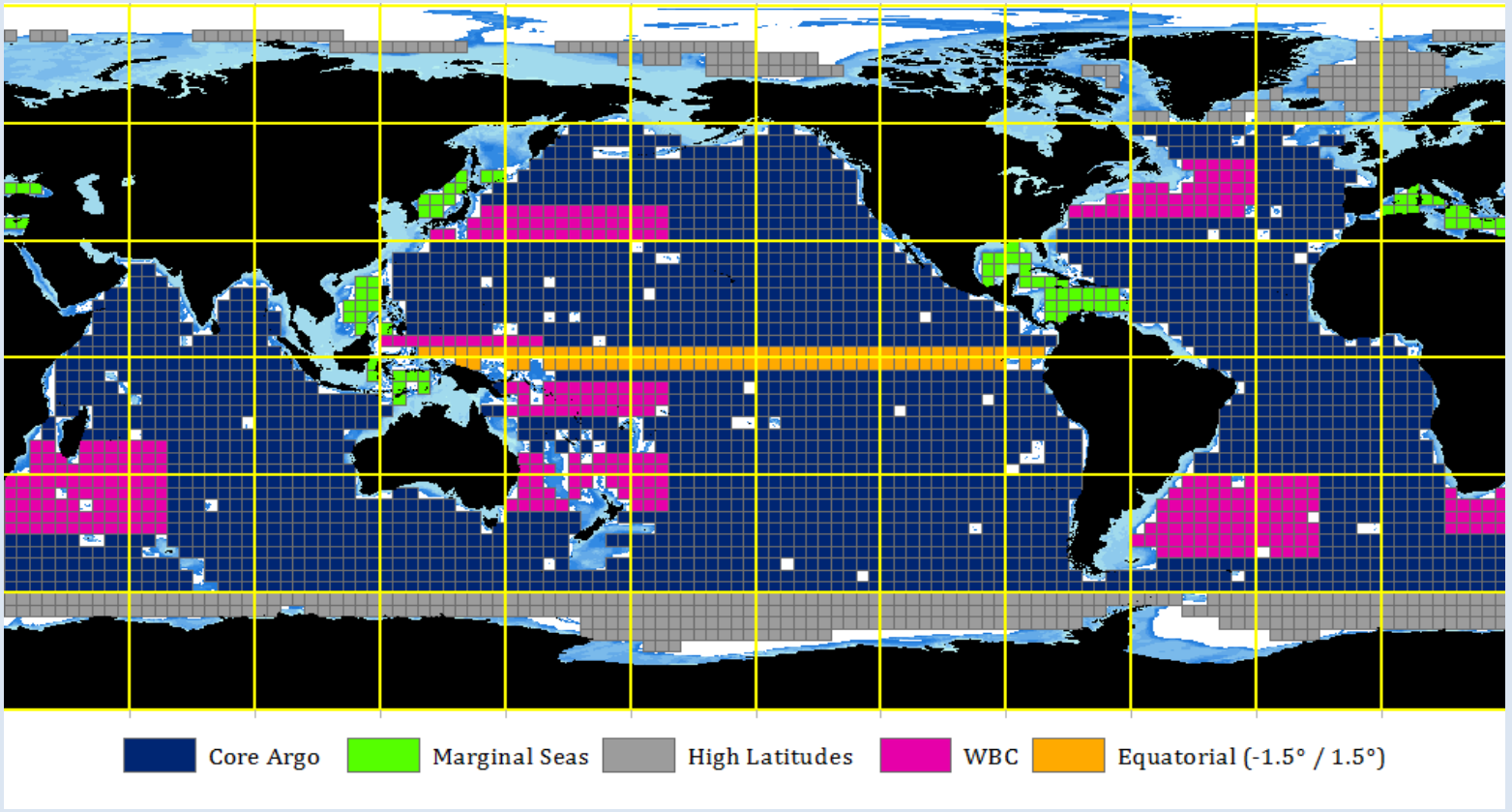
Ollitrault and Colin De Verdiere, 2014

Argo-based 1000m dynamic topography



Ollitrault and Colin De Verdiere, 2014

A Design for Global Argo?



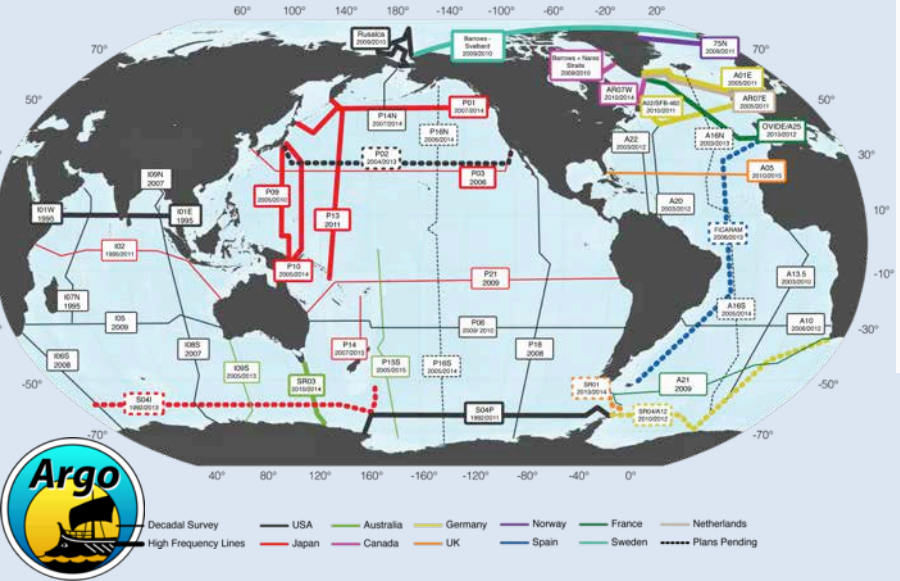
- Same mission – tracking the slow manifold - more spatially complete and better signal to noise
- Double sampling in WBCs and equatorial regions
- Marginal Seas: enhanced sampling - determined by regional partnerships
- Seasonal Ice zone: normal sampling [Fast ice zone requires different technology]

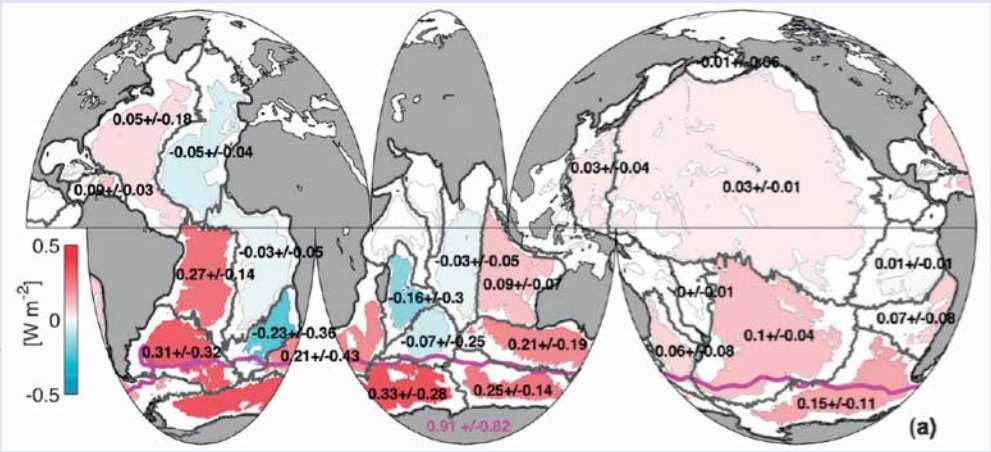
~4200 float array

New Missions ?
Deep Argo

Why?

- Sparse repeat ship data show us that the ocean below Argo is warming consistently, particularly in the Southern Hemisphere
- This matters for sea level rise and the Earth's energy budget
- Ocean and climate forecasters also want data below 2000 m





Bottom Water warming from 1990's to 2000's

Purkey and Johnson (2010)

Deep Argo

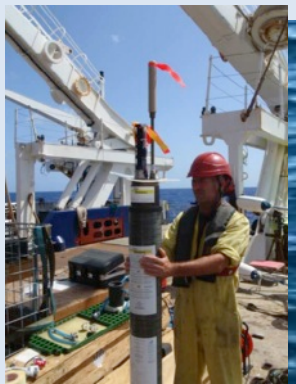
Readiness?

Deep floats are being developed and tested by several groups

A new CTD sensor is under parallel development with improved stability is needed for the smaller deep signals

Field tests of handfuls of floats are underway

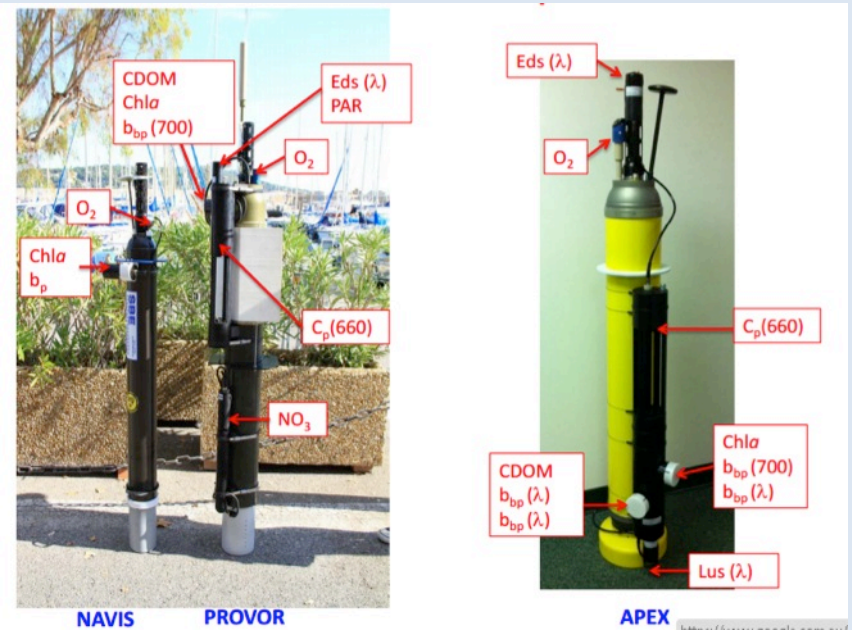
A regional pilot is being discussed, coordination is beginning



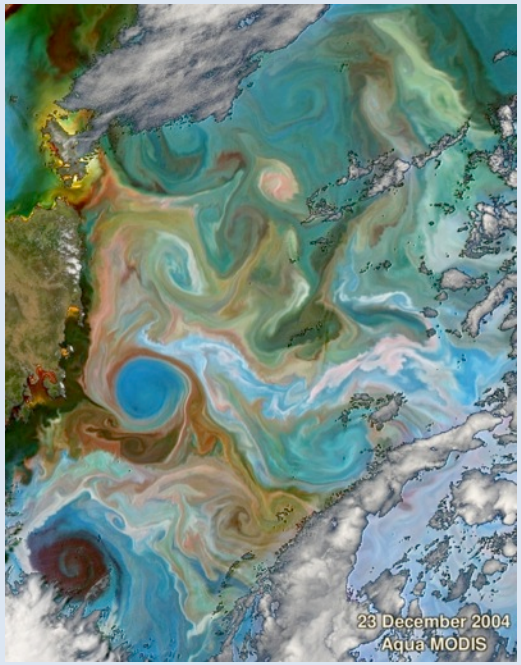
New Missions?
Bio-Argo

Why?

- Understand the fundamental bio-geo-chemical cycling in the oceans, and thus the foundation of biological productivity patterns
- To track any long term trends – there is already evidence of significant ocean oxygen changes



Subsurface partner of ocean colour satellite data



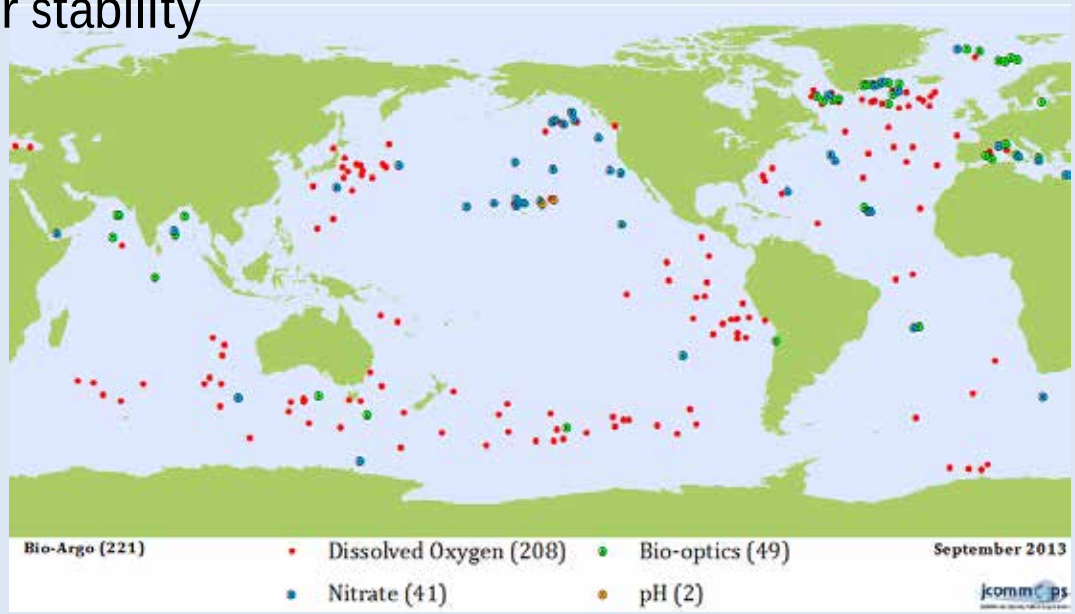
Bio-Argo

Readiness?

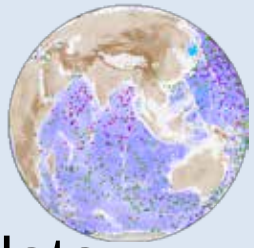
- > 200 floats already carry oxygen – QC and sensor stability work is progressing well now
- nitrate, pH (acidity), and bio-optical sensors are being developed and now deployed on a subset of Argo floats (regional pilots)

Challenges

- ongoing improvement in sensor stability
- resourcing and development of data management protocols, especially for quality control.
- Territorial sensitivities are high with many nations

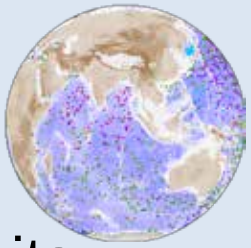


Challenges



- Sustaining our achievements and delivering fully on data quality and completeness
- Evolving to meet new needs and to exploit new technologies without endangering progress to date
- Working with other elements of the Global Ocean Observing System on network design and data management. Argo cannot become the global ocean profile data system, it is just one element
- Spatial completeness remains subject to both technology advances but also regional political advances in data sharing and cooperation.

Summary



- Argo currently is operating well and largely achieving its goals
- Argo now provides a key dataset for global change studies, ocean research and operational forecasting, delivering >120,000 temperature/salinity profiles every year.
- The coming decade will see Argo extended into the deep ocean, marginal and coastal seas, and seasonal ice zones, and including new biogeochemical sensors
- Argo needs your help in evolving its new design to be: scientifically rigorous, realistic (robust technology) and multi-application (value for investing nations).
- Euro-Argo is an essential partner and is helping Argo meet its future challenges!

Argo is a large endeavor that would not be possible without important contributions by hundreds of individuals around the world:

- Argo Steering Team members
- Argo Directors - W.J. Gould and H. Freeland – with support of M. Scanderbeg
- Argo Tech. Coordinator M. Belbeoch and JCOMM-OPS team
- Argo Data Management Team members including A. Thresher, S. Pouliquen and the IFREMER team, and M. Ignaszewski.
- Float and sensor engineers and manufacturers.
- Logistics experts.
- Float deployers.
- Data quality control experts.
- National agency representatives.
- And many others!