A Paradigm for Ocean Observations in the 21st Century

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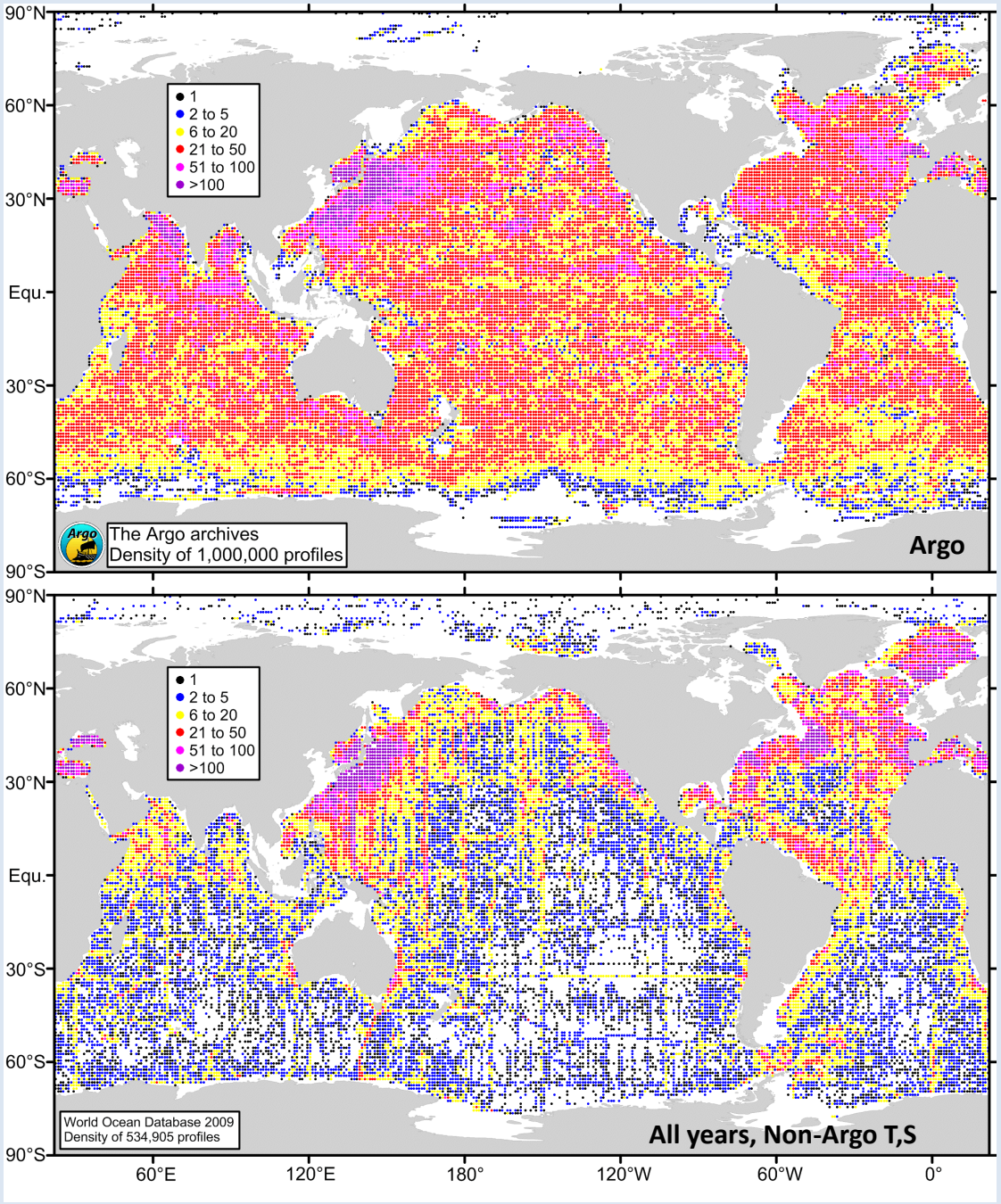
Outline

- The roots of Argo: From 20th century global-*scale* oceanography to 21st century global oceanography.
- What has Argo achieved relative to its initial objectives?
- What are the next challenges for Argo?



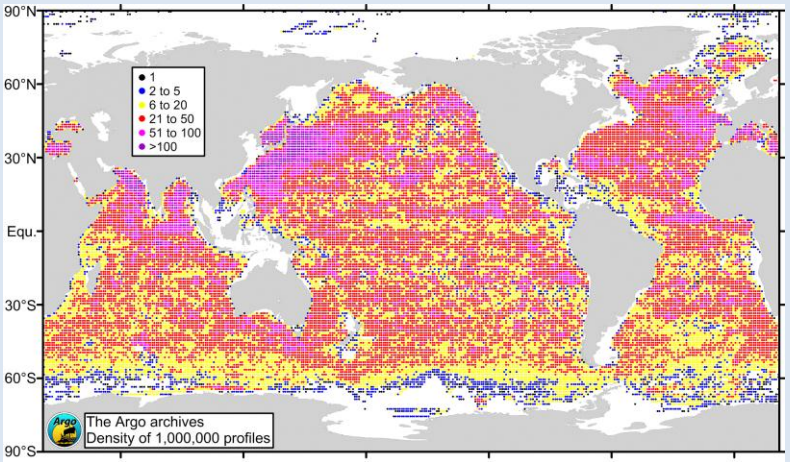
Argo's 1,000,000th profile was collected a month ago!

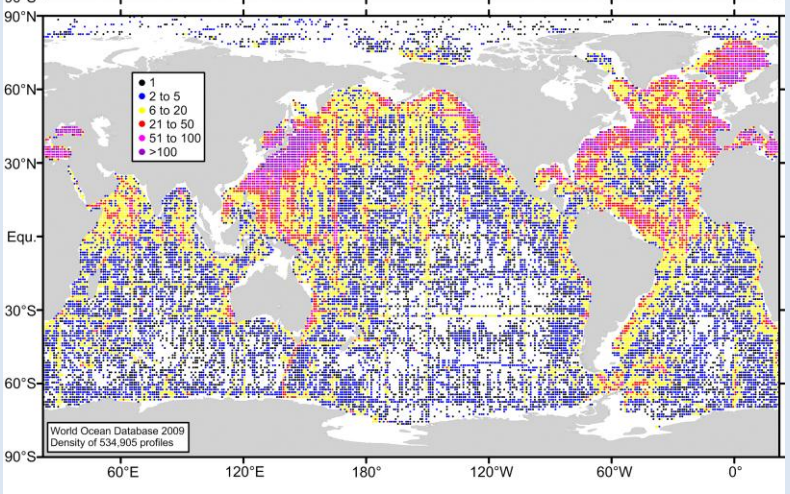
Global Oceanography

Global-*scale* Oceanography

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

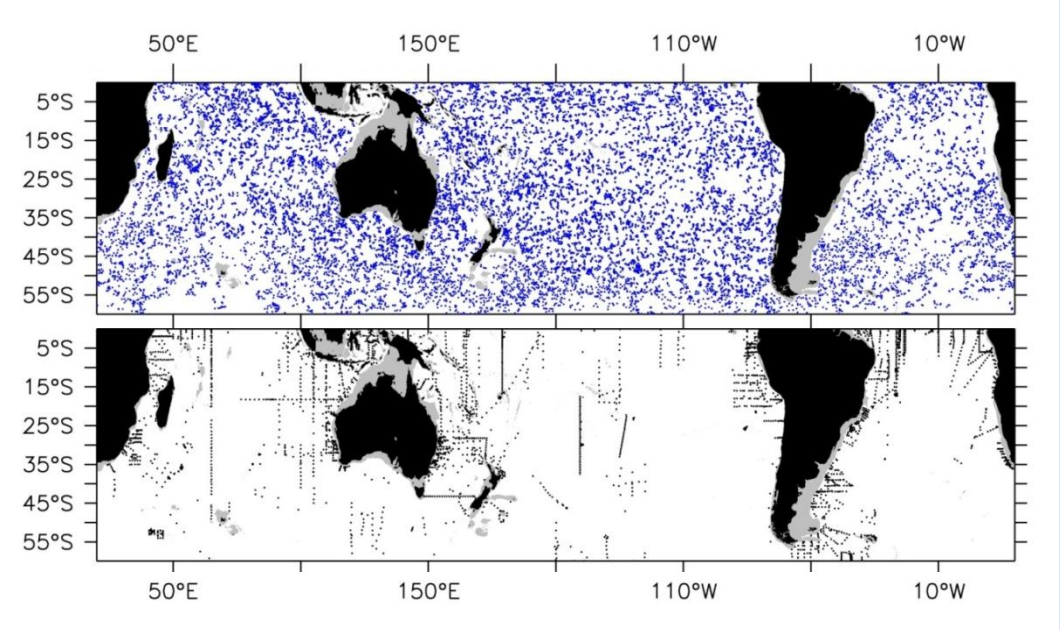
Argo: 1,000,000 T/S profiles.





20th Century: 534,905 T/S profiles > 1000 m

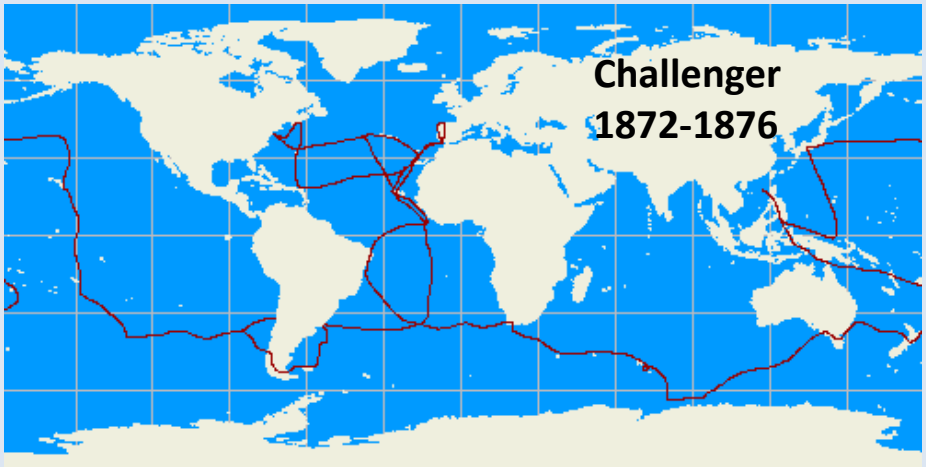
5 years of August Argo T,S profiles (2007-2011).



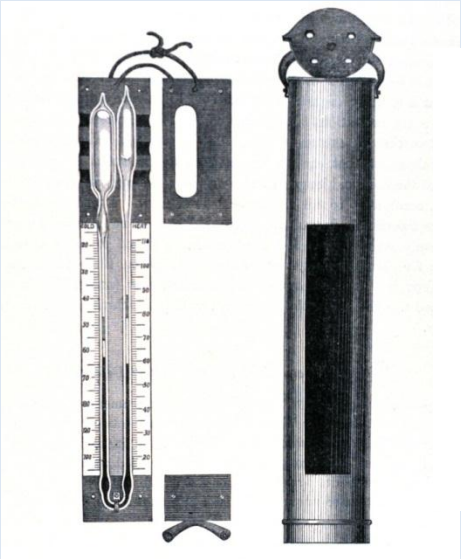
All August T/S profiles (> 1000 m, 1951 - 2000).

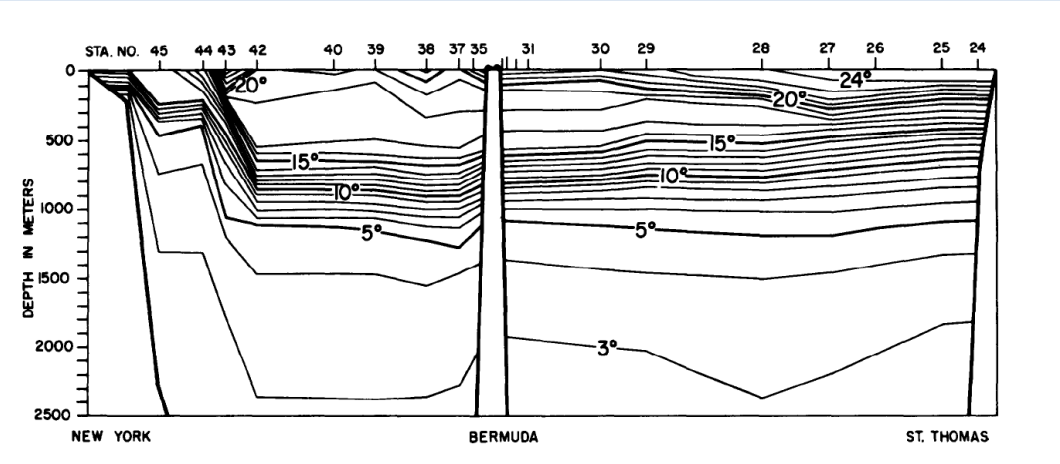
The 21st century paradigm is *systematic global ocean observations*: a subsurface observing system having "satellite-like" space-time coverage.

Global-scale oceanography began with the Challenger Expedition (1872 – 1876)



``One of the objects of the Expedition was to collect information as to the distribution of temperature in the waters of the ocean . . . not only at the surface, but at the bottom, and at intermediate depths'' (Wyville Thomson and Murray, 1885)

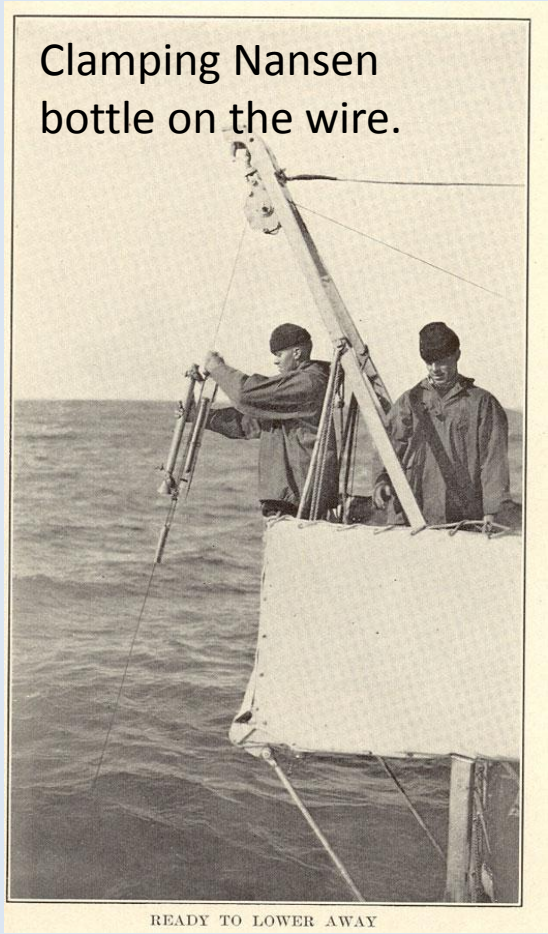


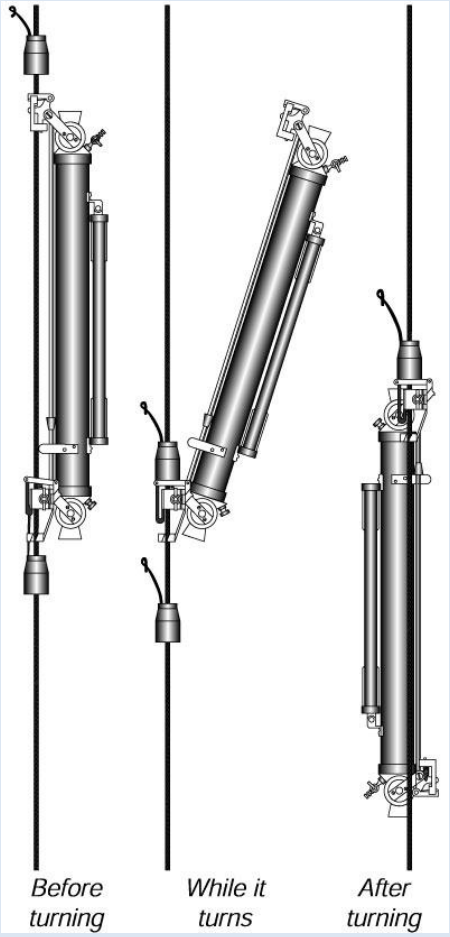


Charles Wyville Thomson

Progress in oceanography is synonymous with advances in technology

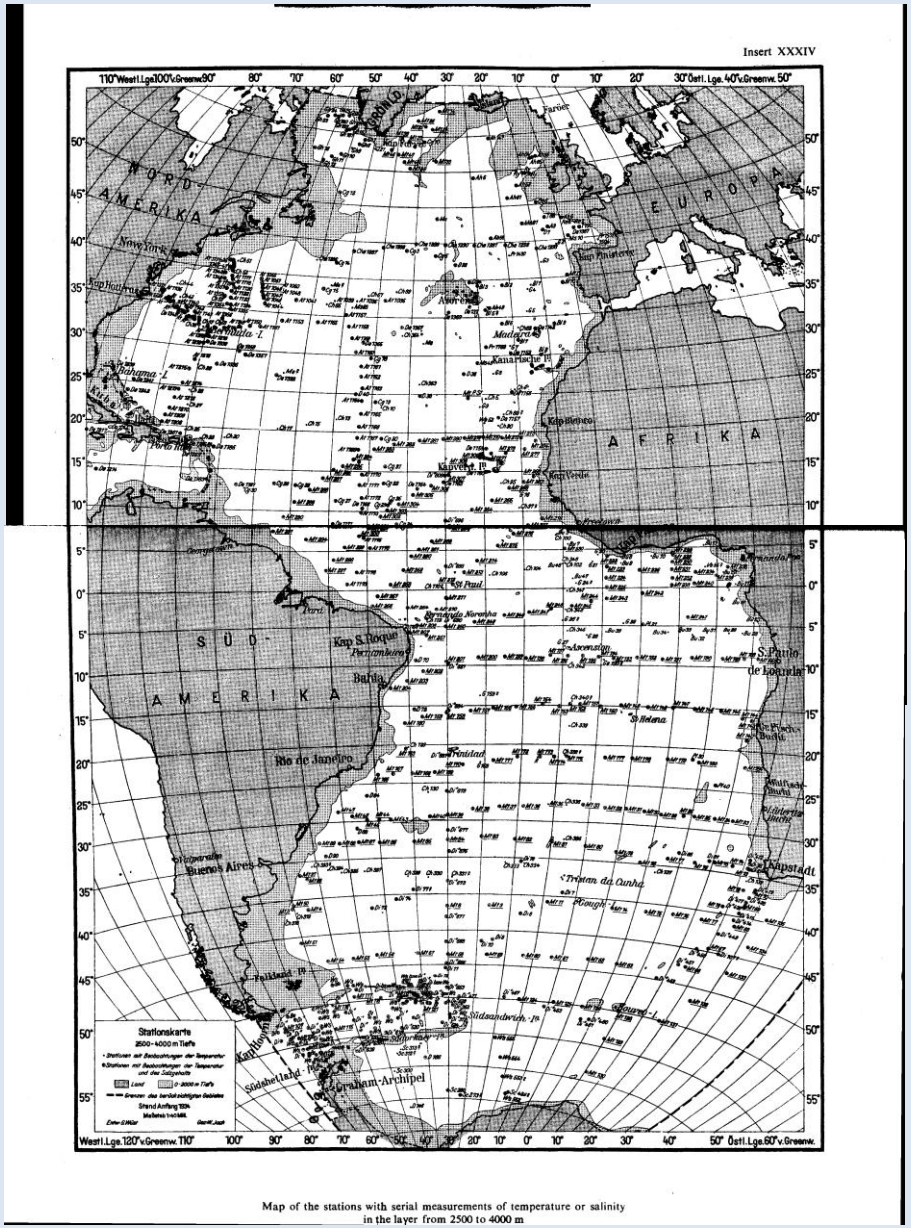
Basic tools of mid-20th century physical oceanography: Nansen bottles and DSRTs





A pressure-protected Deep-Sea Reversing thermometer

Nansen bottles came into use around 1910.
DSRT's were accurate to a few thousandths of a °C
Depth, from protected/unprotected pairs of thermometers, to ~5 m.



The era of research vessels began in the 1920s:

Following Challenger, there were few ocean-scale expeditions until the 1920's, when R/V Atlantis, Meteor, and Discovery were all commissioned and made ocean-scale surveys.

As of 1935, nearly all deep temperature data in the Atlantic came from a few expeditions by Challenger, Meteor, Discovery and Atlantis.

Coverage in the Pacific and Indian Oceans was even sparser.

Map of stations containing temperature observations > 2500 m
From Wust, The Stratosphere of the Atlantic Ocean, 1935

Electronic measurement of salinity

1956 Schleicher Bradshaw salinometer

Modern Guildline Autosal

Until the 1950s, salinity was measured by chemical titration.

Much more accurate salinity, based on measurement of conductivity ratios (water sample compared to standard sea water) began in the late 1950s.

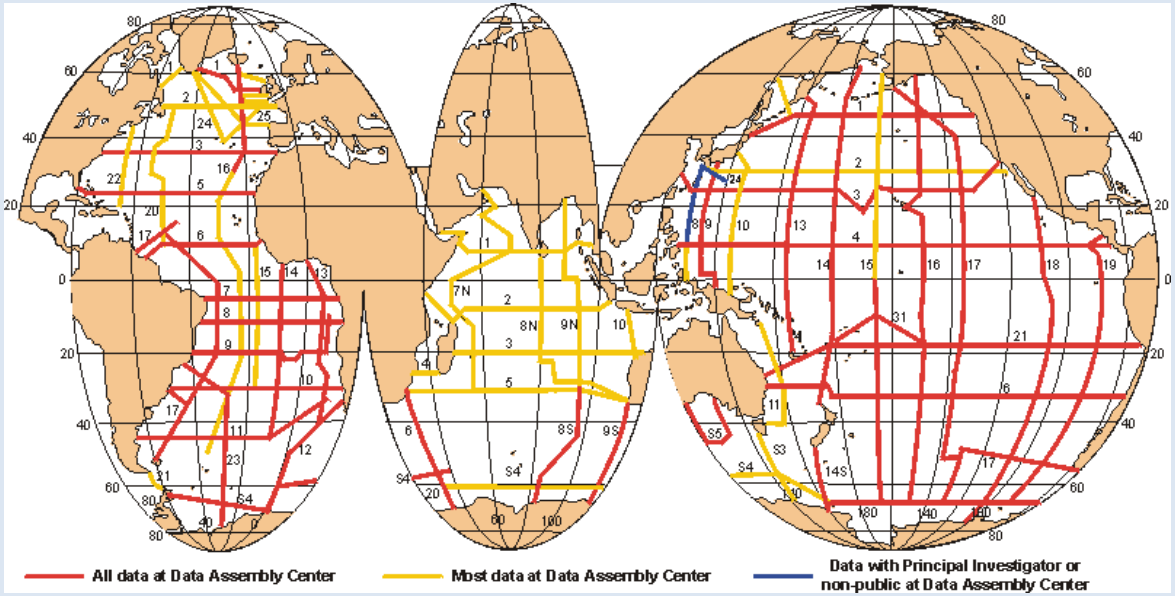
Electronic Conductivity-Temperature-Depth recorders

CTDs were developed in the late 1960s and gradually refined over time.

High accuracy electronic measurements of temperature, salinity, and depth (.002°C, .003 psu, 5 m) became routine in the 1980s.

The only drawback: a research vessel had to be present.

A modern 24-bottle Niskin rosette and CTD (U Hawaii).



The culmination of the "global-scale" era – the World Ocean Circulation Experiment – was carried out in 1991-1997, obtaining about 8000 CTD profiles to the sea bottom.

The shift to autonomous instruments (floats and gliders)

John Swallow, with ship's cat, preparing an early neutrally buoyant "Swallow float" in 1955

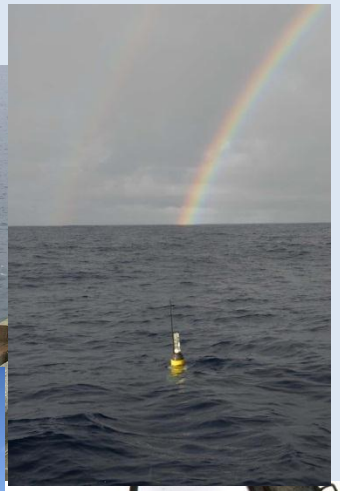
An acoustically-tracked SOFAR float, ~1973 (URI), T. Rossby and D. Webb.

The purpose of these instruments was to measure ocean current (drift).

Floats first go global, then combine with a CTD

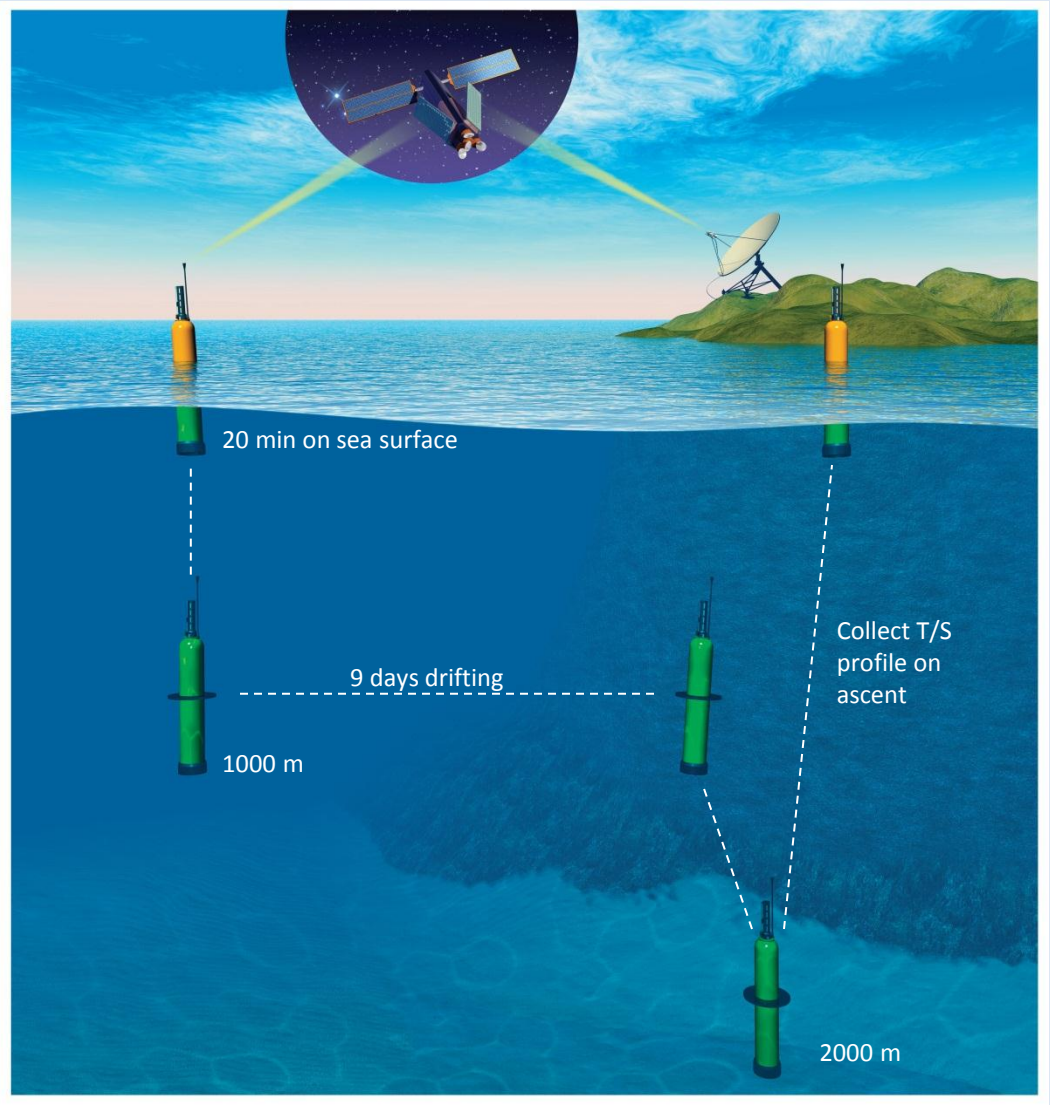
By moving from acoustic to satellite tracking, R. Davis/D. Webb floats in the early 1990s could operate globally.

Five years later, addition of a CTD made the Argo Program a possibility.

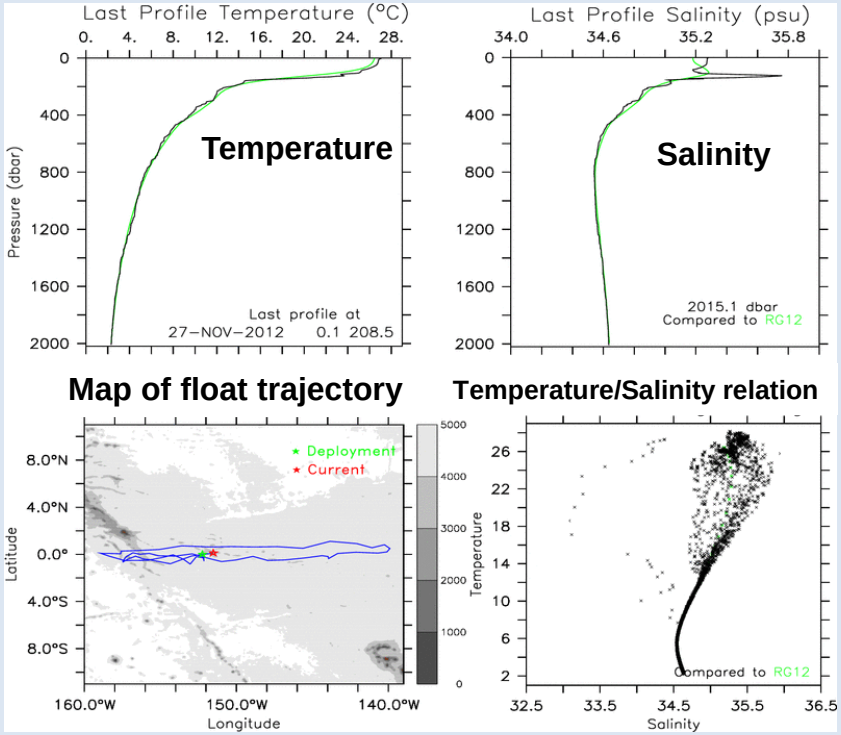


A closely related technology, the glider, is a profiling float with positioning control.

How do Argo floats work?



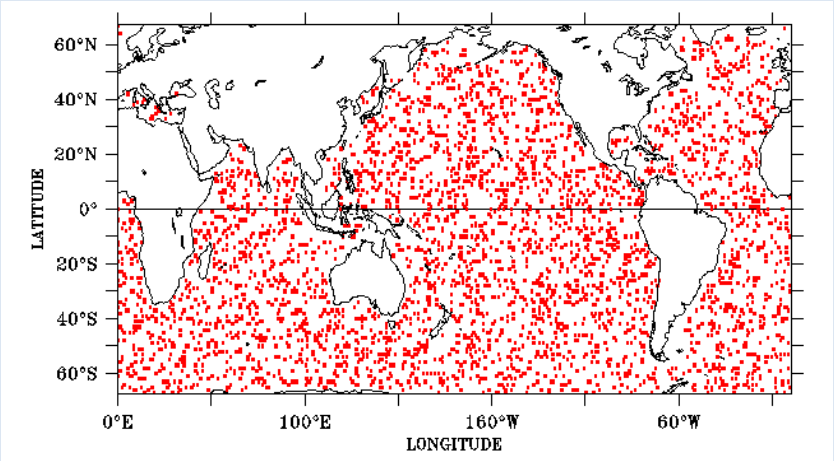
Argo floats collect a temperature and salinity profile and a trajectory every 10 days, with data returned by satellite and made available within 24 hours via the GTS and internet (http://www.argo.net) .



Cost of an Argo T,S profile is ~ $170.

Cost of a WOCE profile was > $10,000.

Beginnings of the Argo array.



Argo concept diagram: Argo was planned in 1997-1998 and the scientific consensus took hold through CLIVAR and GODAE forums.

Summary Record of the Regional Workshop
Potential Applications of Ocean Observations
for the Pacific Islands Region

Report of the Indian Ocean Argo Implementation Planning Meeting

Introduction. An Implementation Planning Meeting for Argo in the Indian Ocean was held in Hyderabad, India on July 26 and 27, 2001. Conceived just three and a half years ago, Argo—an international effort to provide real-time observations of the upper-ocean temperature and salinity field—has made significant progress toward its goal of deploying 3,000 profiling floats to cover the global ocean.

Tokyo Statement

The participants from Australia, Canada, France, Republic of Korea, United States and Japan held an International Implementation Planning Meeting for Argo Floats in the Pacific Ocean and Adjacent Regions on 13 and 14 April, 2000 in Tokyo. Argo has been endorsed by a decision of WMO and Resolution of IOC as an important contribution in support of the operational and scientific research goals of the observing system, and they have expressed their support to the aims of this meeting.

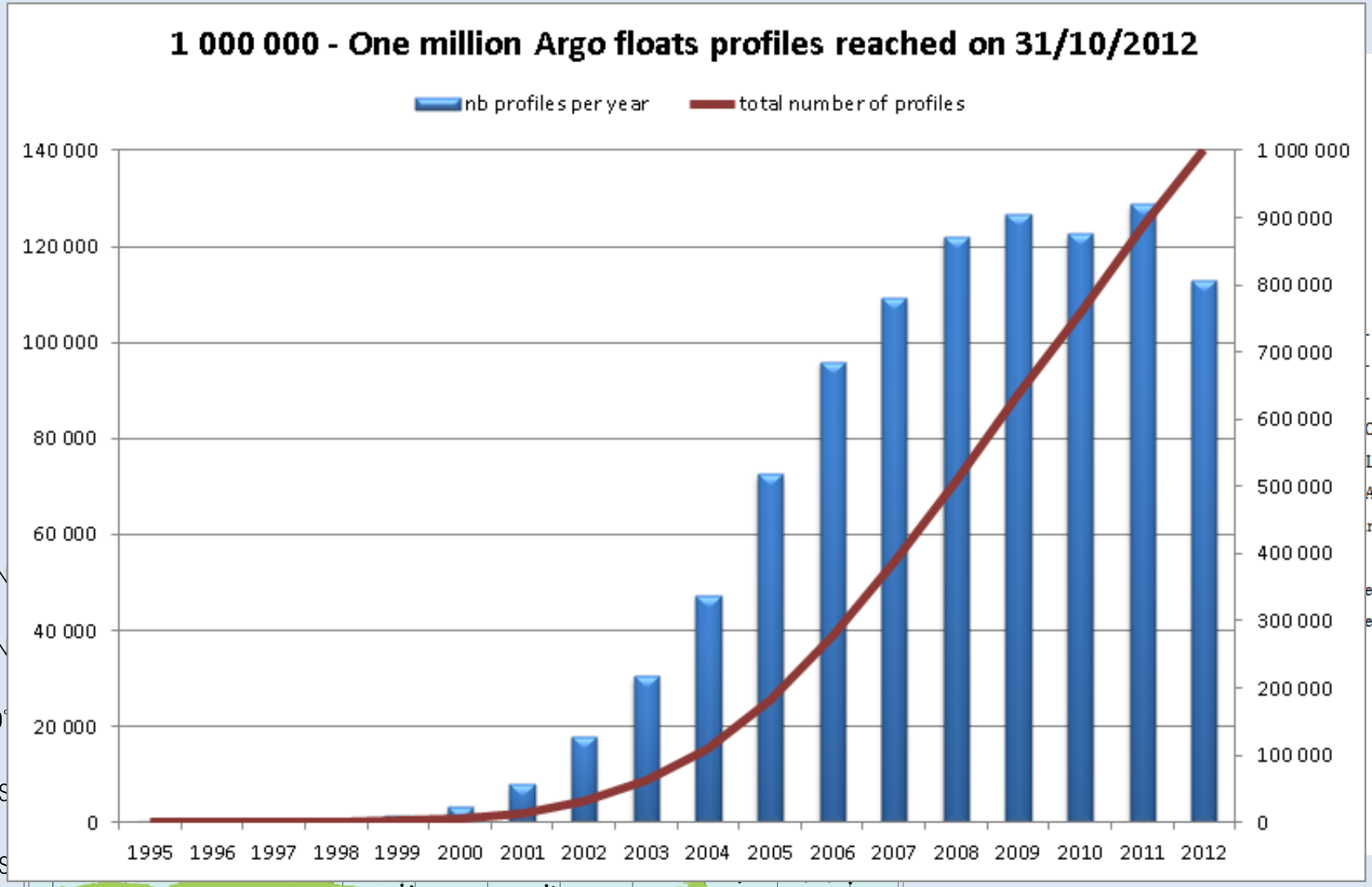
The global environment is experiencing regional and global impacts through anomalous climate events and other extreme conditions. It is essential to implement observing systems and undertake research to understand the mechanisms that lead to such conditions and to provide a capacity for predicting extreme events and climate variability. Such capacity will allow the Pacific Ocean countries and adjacent regions to adapt to, and take advantage of, climate and environmental change.

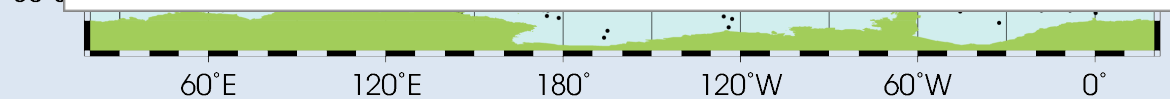
The Argo program, in which profiling floats will be deployed in the global ocean to routinely and consistently observe the state of the upper ocean, will contribute to research and prediction of seasonal to decadal climate variability and climate change, and to significant improvements in environmental prediction.

The agency role: For Argo to become reality, agency engagement was critical. Key roles were filled by Stan Wilson and Jim Baker, not only through NOAA support for Argo but by directly and successfully enlisting partner agencies around the world. ONR provided the initial support for U.S. Argo.

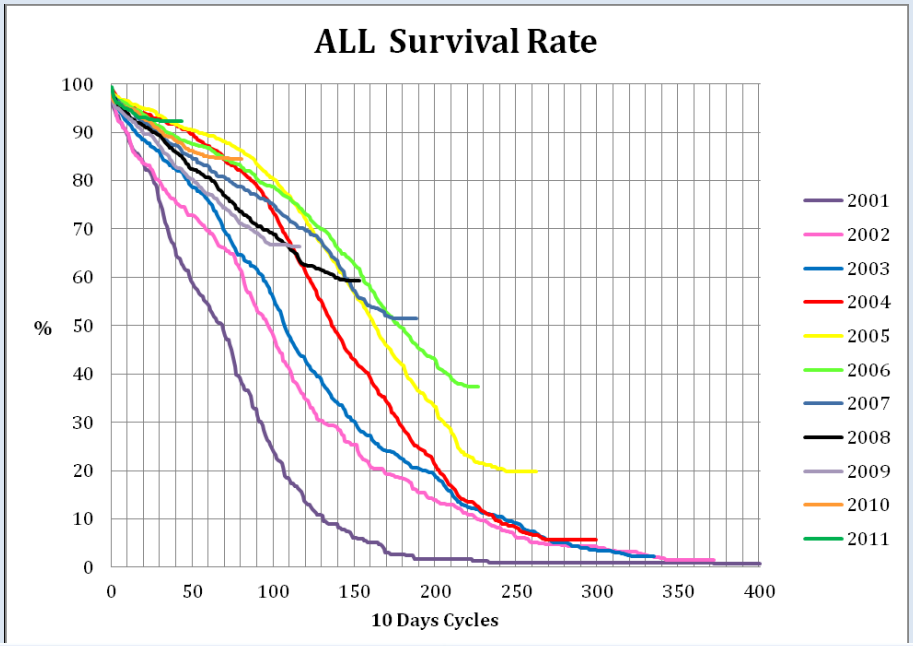
Stan Wilson discusses Argo with President Bush, 2002.

Today's Argo array closely resembles the concept diagram



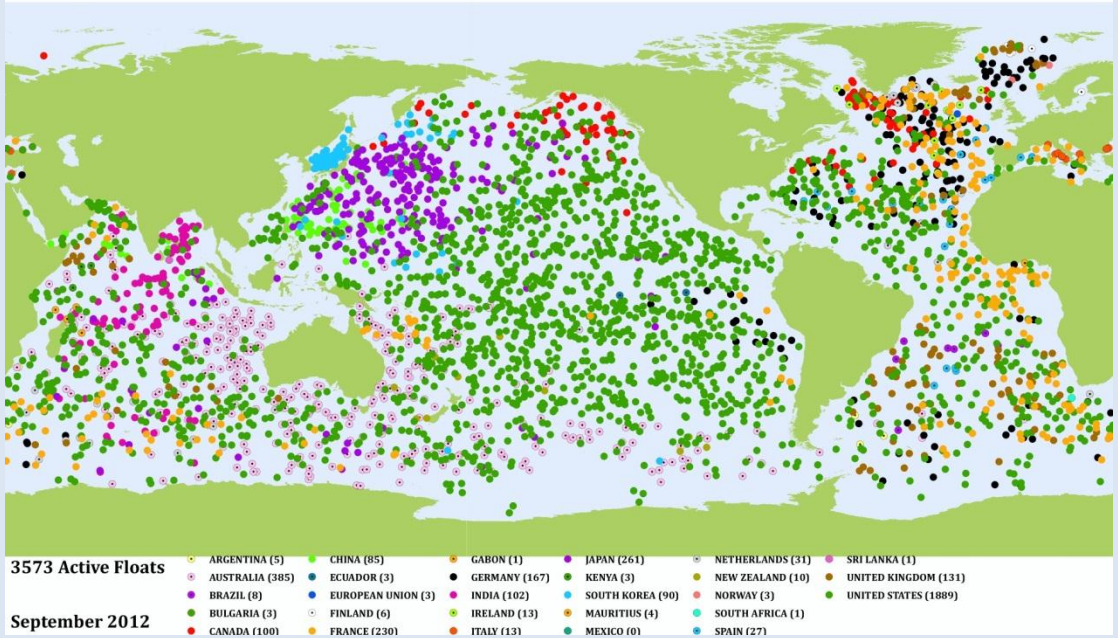


Keys to Argo success



Making the technology work

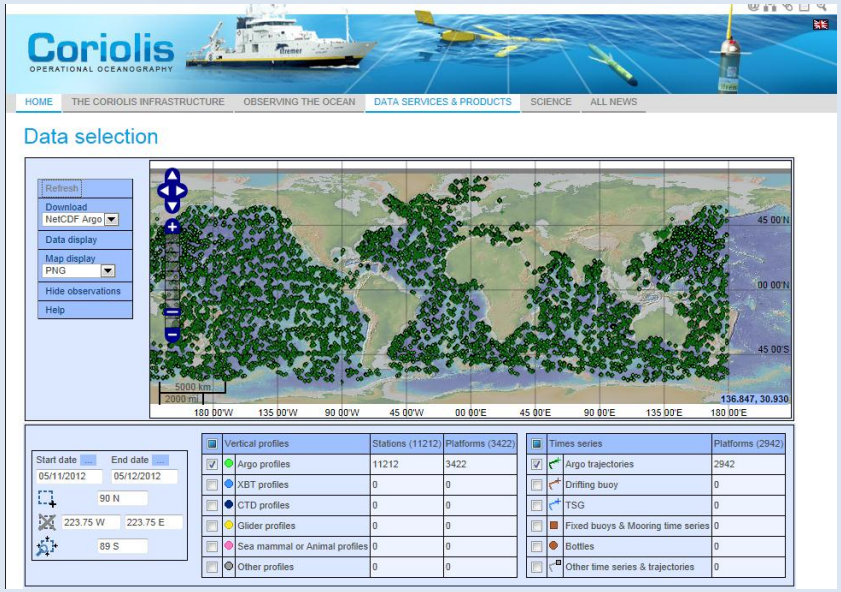
Collaboration with manufacturers and investment in technical teams has resulted in float lifetimes exceeding the initial Argo goals of 3-4 year lifetimes profiling every 10 days (~100 profiles)



International cooperation

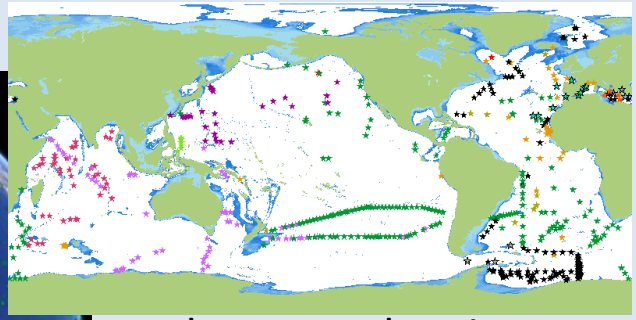
The Argo Steering Team and Argo Data Management Team coordinate contributions of 28 national programs.

Keys to Argo success



An innovative and comprehensive data management system.

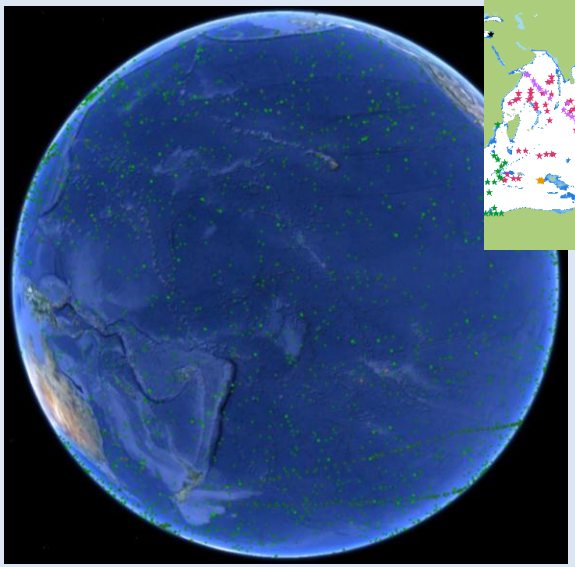
Provides near realtime (< 24 hours) and research-quality delayed mode data, including profiles and trajectories, with metadata and technical data. Delayed-mode profiles are expertly examined for sensor stability and accuracy.



Deployment planning map

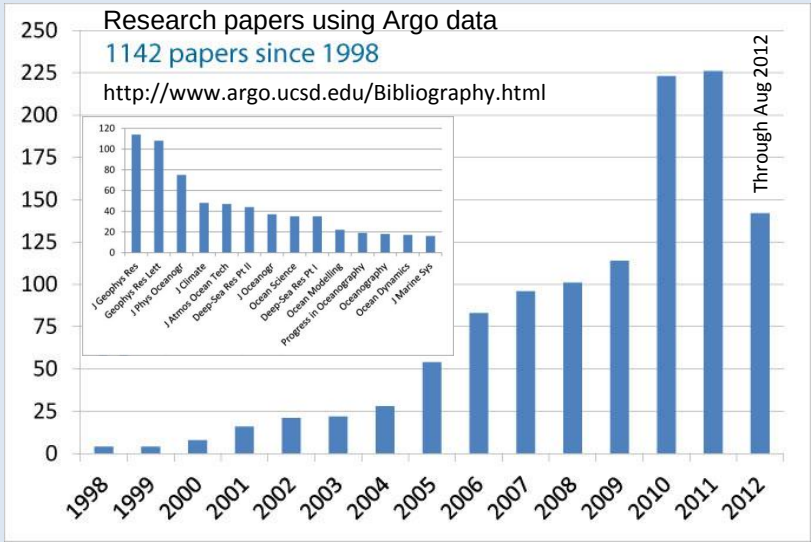
The Argo Information Center

Tracks float locations and exchanges information on deployment plans, float performance and progress of the Argo Program.



Float locations in Google Earth

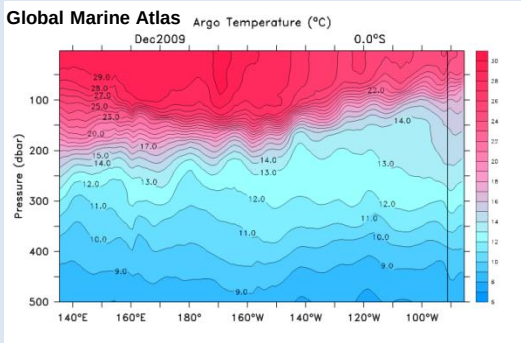
Keys to Argo success: High value in applications



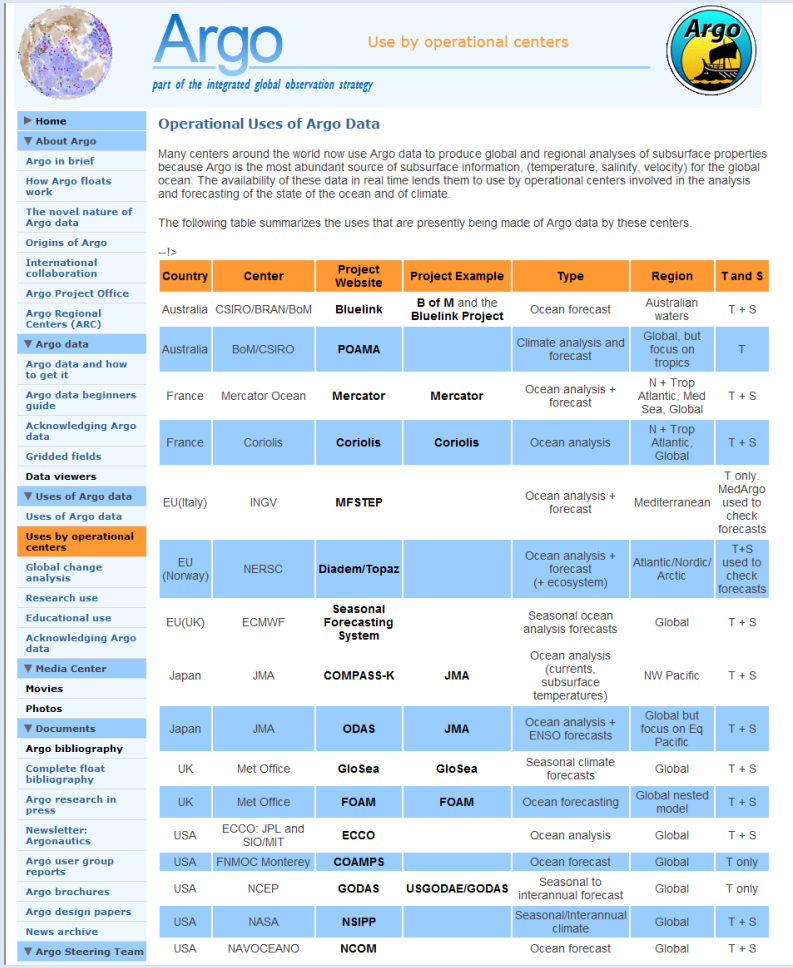
Research: Over 1000 papers have been published using Argo data; Argo is a major resource in ocean science, and is prominent in national and international assessments of the state of the oceans.

Education programs 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



Argo
Use by operational centers
part of the integrated global observation strategy

- Home
- About Argo
  - Argo in brief
  - How Argo floats work
  - The novel nature of Argo data
  - Origins of Argo
  - International collaboration
  - Argo Project Office
  - Argo Regional Centers (ARC)
- Argo data
  - Argo data and how to get it
  - Argo data beginners guide
  - Acknowledging Argo data
  - Gridded fields
  - Data viewers
- Uses of Argo data
  - Uses of Argo data
  - Uses by operational centers
  - Global change analysis
  - Research use
  - Educational use
  - Acknowledging Argo data
- Media Center
  - Movies
  - Photos
- Documents
  - Argo bibliography
  - Complete float bibliography
  - Argo research in press
  - Newsletter: Argonautics
  - Argo user group reports
  - Argo brochures
  - Argo design papers
  - News archive
- Argo Steering Team

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.

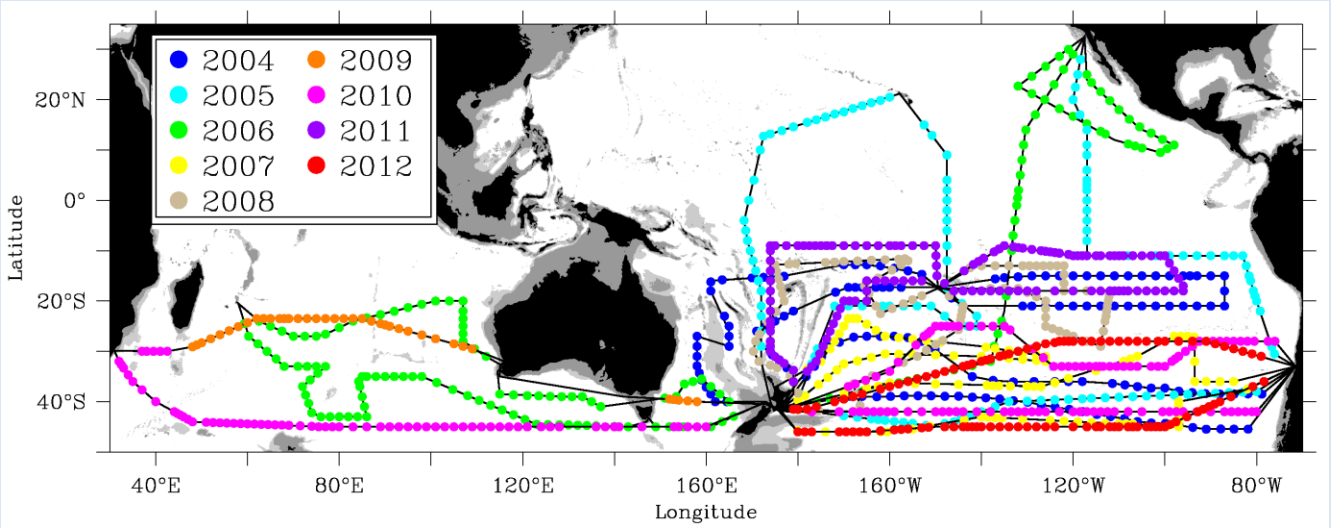
--!>

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

Operational centers use Argo data in ocean state estimation, short-term forecasting and seasonal to decadal prediction.

Issues for sustaining Argo:

- There is high and increasing stress on the national research budgets that sustain Argo.
- A global Argo float deployment strategy is needed including dedicated vessel time. Commercial shipping and RV traffic are increasingly sparse in some remote regions.
- Continuing priority is needed on (i) technology improvement and (ii) data management, to reduce systematic errors in pressure and salinity (for global change studies) and to avoid or identify major technical failures.



1140 Argo floats deployed by New Zealand's RV Kaharoa since 2004 for US, Australia, and NZ Argo

How will Argo evolve for new objectives?

Complete the <u>global climate mission</u>:

- High latitudes and marginal seas.
- Denser arrays in the boundary currents for improved signal to noise.
- Deep Argo (6000 m) – a major expansion

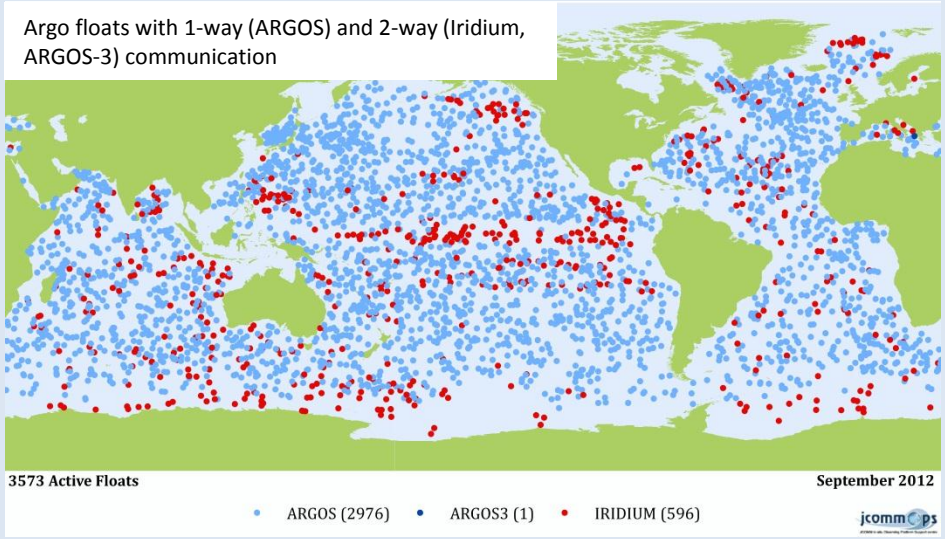
New missions:

- Improved surface layer sampling.
- Enhanced vertical resolution.

} Via 2-way high bandwidth communications

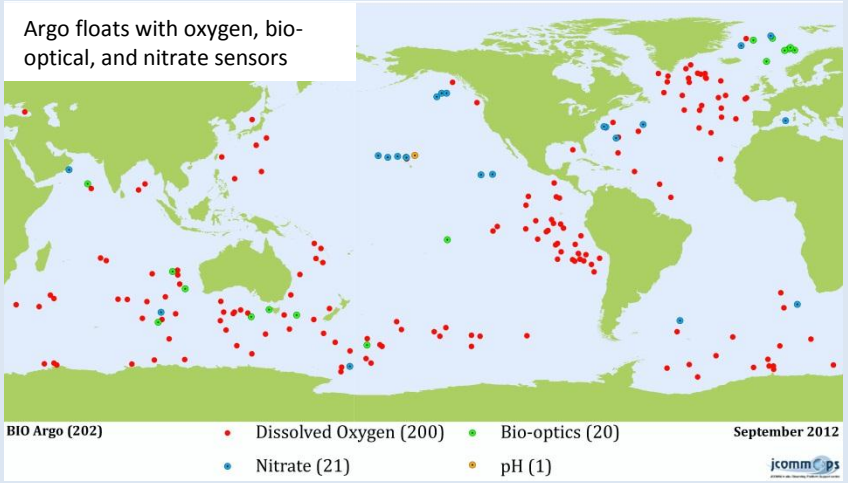
- Multidisciplinary sensors – a major expansion

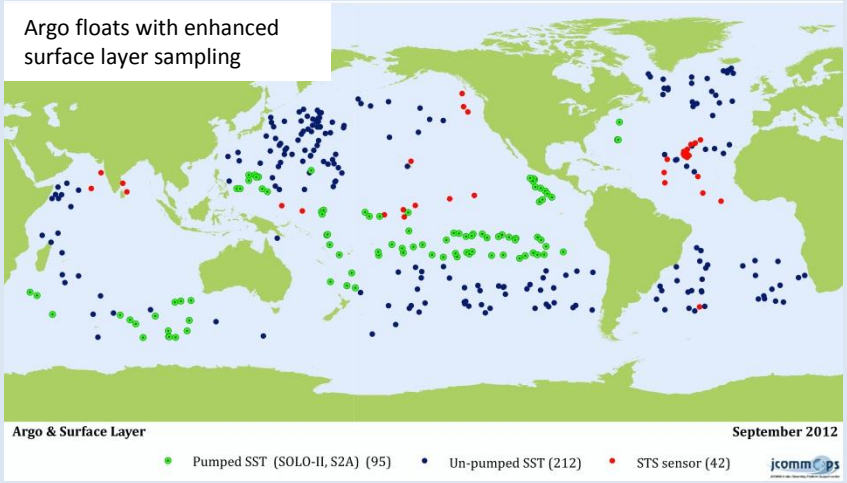
Around 17% of the array is now returning high resolution profiles using 2-way satellite communications



Challenges for broadening Argo:

- Argo's evolution will maximize the value of the integrated ocean/climate observing system, so synergies of Argo and gliders, Deep Argo and repeat hydrography are important.
- Global sampling requires an international consensus on global deployment. This has been elusive.
- Deep Argo and Multi-sensor Argo present difficult technology development problems.
  - Deep Argo – CTD stability and float energy efficiency.
  - Multi-sensor Argo – sensor stability and management of new data streams.





In 1998, the Argo Steering Team described "The Principal Achievements of a Decade of Argo"

1. Obtain an unprecedented dataset for model initialization and data assimilation …
2. Enable operational real-time global ocean forecasting...
3. Produce an accurate global climatology, with error bars and statistics of variability…
4. Produce accurate time-series of heat and freshwater storage...
5. Provide large-scale constraints for atmospheric model-derived surface heat and freshwater fluxes…
6. Complete the global description of the mean and variability of large-scale ocean circulation…
7. Determine the dominant patterns and evolution of interannual variability in temperature and salinity…
8. Provide global maps of the absolute height of the sea surface…
9. Enable the interpretation of (altimetric) sea surface height…
10. Directly interpret sea surface height anomalies….

After the first 1,000,000 Argo profiles, all of these are well advanced!

Summary

- Argo has achieved and exceeded many of its initial goals. *Systematic observation of the global ocean is a reality.*
- Data from the Argo Program are finding many valuable applications: in basic research, operational oceanography, climate assessments, and education and outreach.
- Advances in float technology continue to be important, including increases in float lifetimes and capabilities.
- Incremental enhancements to Argo could include: improved coverage in marginal seas, high latitudes, and western boundary regions, better sampling of the surface layer, and higher vertical resolution.
- Major enhancements to Argo could include: new biogeochemical sensors, Deep Argo (profiling to the sea bottom).

The international Argo partnership:

Argo is a key component of the Global Ocean Observing System.
All Argo data are freely available: http://www.argo.net