Argo Ocean Float System

Part 1

Development Basis and Background

December 2014

Bernie McCune

In the beginning

- Argo - a global array of autonomous profiling floats
- The original concept grew out of two independent, but connected, initiatives
- "A Proposal for Global Ocean Observations for Climate: the Array for Real-time Geostrophic Oceanography" (ARGO), by Dean Roemmich,
- "A program for Global Ocean SAlinity MonitORing" (GOSAMOR), by Ray Schmitt.

And it grew

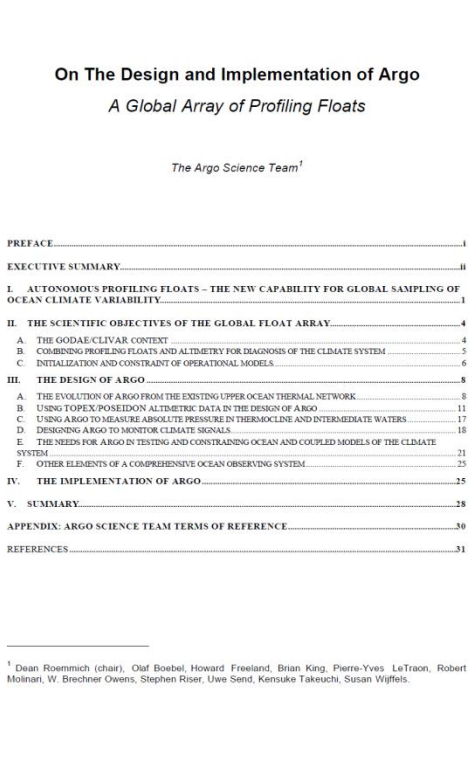
- Early in 1998 the International Steering Team for GODAE (the Global Ocean Data Assimilation Experiment) endorsed the broad concept of such an array and undertook to develop a plan.
- In the 2nd quarter of 1998 the Upper Ocean Panel of CLIVAR* also considered these proposals and agreed that such an initiative must be given high priority in the CLIVAR Implementation plans.

* Climate and Ocean Variability, Predictability and Change

A Plan emerges

- In July of 1998 a Workshop was jointly convened by GODAE and CLIVAR and held in Tokyo
- Discussed the prospects for Argo
- An initial outline for a plan was drawn up
- An Argo Science Team was appointed
- They were charged with producing an initial design and implementation plan.

- October 1997 – A global ocean array of profiling floats is discussed over lunch in the NCAR cafeteria (D. Roemmich, B. Owens, E. Lindstrom).
- Late 1997 – *"The ARGO White Paper".* (1-pager)
- Early 1998 – "*A Proposal for Global Ocean Observations for Climate: the Array for Real-time Geostrophic Oceanography (ARGO)"* by D. Roemmich; and, *"A Program for Global Ocean Salinity Monitoring (GOSAMOR)"* by R. Schmitt.
- 1999 – "On the Design and Implementation of Argo", Argo Science Team

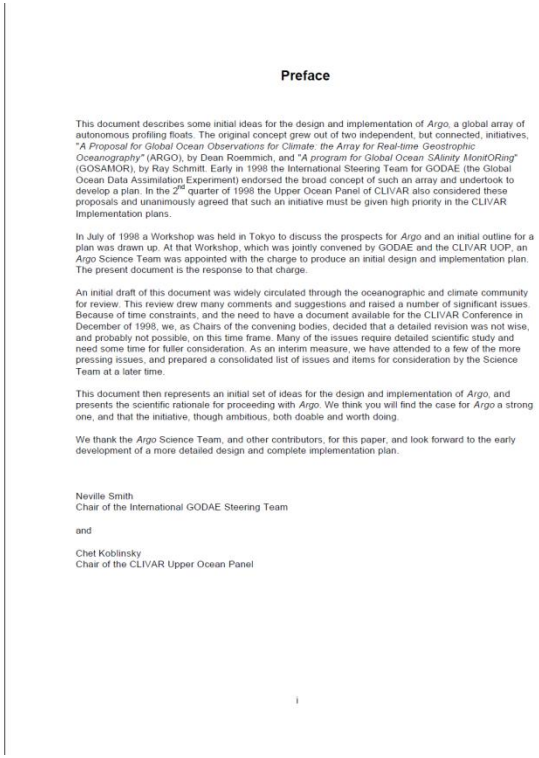


On The Design and Implementation of Argo

A Global Array of Profiling Floats

The Argo Science Team[1]

[1] Dean Roemmich (chair), Olaf Boebel, Howard Freeland, Brian King, Pierre-Yves LeTraon, Robert Molinari, W. Brechner Owens, Stephen Riser, Uwe Send, Kensuke Takeuchi, Susan Wijffels.



Preface

This document describes some initial ideas for the design and implementation of *Argo*, a global array of autonomous profiling floats. The original concept grew out of two independent, but connected, initiatives; "*A Proposal for Global Ocean Observations for Climate: the Array for Real-time Geostrophic Oceanography*" (ARGO), by Dean Roemmich, and "*A program for Global Ocean SAlinity MonitORing*" (GOSAMOR), by Ray Schmitt. Early in 1998 the International Steering Team for GODAE (the Global Ocean Data Assimilation Experiment) endorsed the broad concept of such an array and undertook to develop a plan. In the 2nd quarter of 1998 the Upper Ocean Panel of CLIVAR also considered these proposals and unanimously agreed that such an initiative must be given high priority in the CLIVAR Implementation plans.

In July of 1998 a Workshop was held in Tokyo to discuss the prospects for *Argo* and an initial outline for a plan was drawn up. At that Workshop, which was jointly convened by GODAE and the CLIVAR UOP, an *Argo* Science Team was appointed with the charge to produce an initial design and implementation plan. The present document is the response to that charge.

An initial draft of this document was widely circulated through the oceanographic and climate community for review. This review drew many comments and suggestions and raised a number of significant issues. Because of time constraints, and the need to have a document available for the CLIVAR Conference in December of 1998, we, as Chairs of the convening bodies, decided that a detailed revision was not wise, and probably not possible, on this time frame. Many of the issues require detailed scientific study and need some time for fuller consideration. As an interim measure, we have attended to a few of the more pressing issues, and prepared a consolidated list of issues and items for consideration by the Science Team at a later time.

This document then represents an initial set of ideas for the design and implementation of *Argo*, and presents the scientific rationale for proceeding with *Argo*. We think you will find the case for *Argo* a strong one, and that the initiative, though ambitious, both doable and worth doing.

We thank the *Argo* Science Team, and other contributors, for this paper, and look forward to the early development of a more detailed design and complete implementation plan.

Neville Smith
Chair of the International GODAE Steering Team

and

Chet Koblinsky
Chair of the CLIVAR Upper Ocean Panel

i

The Concept Grows

- An initial draft of this last document was widely circulated through the oceanographic and climate community for review.
- This review drew many comments and suggestions and raised a number of significant issues.
- Because of time constraints, and the need to have a document available for the CLIVAR Conference in December of 1998, the Chairs of the convening bodies, decided that a detailed revision was not possible in this time frame.
- Many of the issues would require detailed scientific study and fuller consideration.

Broad Description – ARGO Page1

- The Plan – a network of profiling floats used to determine upper ocean temperature/salinity (T/S)
- Primary Goal – enhanced real-time capability of these measurements in the upper 2000M of the ocean
- Float Capability – 100 profiles of T/S with a lifetime of 3-4 years
- Integrate ARGO w/altimetry to explore upper ocean stratification

Broad Description – ARGO Page2

- Float data – used to initialize global ocean and climate models and provide an “adequate sampling network” as a basis for future work
- Initial Design – based on experience gained with:
  - existing climate observing systems
  - Topex/Poseidon altimeter
  - estimates of requirements for climate and high resolution ocean models (continued)

Broad Description – ARGO Page3

- Initial Design – based on:
  - 3° X 3° ideal grid
- Expected design changes coming from lessons learned
- Drift estimates from ARGO array that will provide data to estimate deep pressure fields

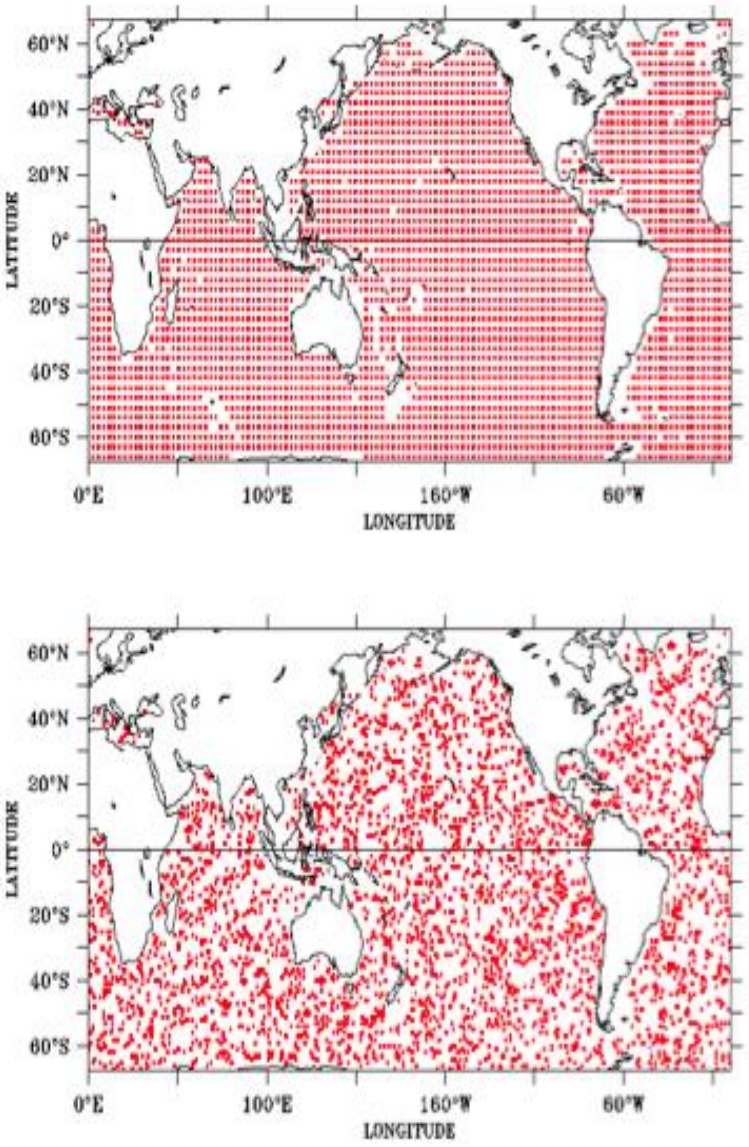


Figure 6. Upper panel – a regular array with 3,300 locations at 3° by 3° spacing with depth greater than 2000 m. Lower panel – a random array of 3,300 locations.

Initial Goals

- “The oceanographic community is entering a new era where ocean models and data assimilation and ocean state estimation will be the preferred methods for utilizing data”
- Applications - numerous and varied
  - initialization of ENSO forecast models
  - initialization of short-range ocean forecasts
  - routine production of high-quality global ocean analyses, and studies of predictability on interannual and decadal time scales

Some Expectations

- The Argo array will provide unprecedented information, particularly with respect to salinity in meeting the goals
- Information exploited to improve/develop for the first time, estimates of process and error covariances – a pre-requisite for ocean estimation
- Level of precision and detail enabled by Argo - not possible with present networks

Appropriate technology:

Development of the profiling float as an element of WOCE made global sampling possible.

Before floats, subsurface ocean data could only be collected by a ship or a fixed-point mooring.

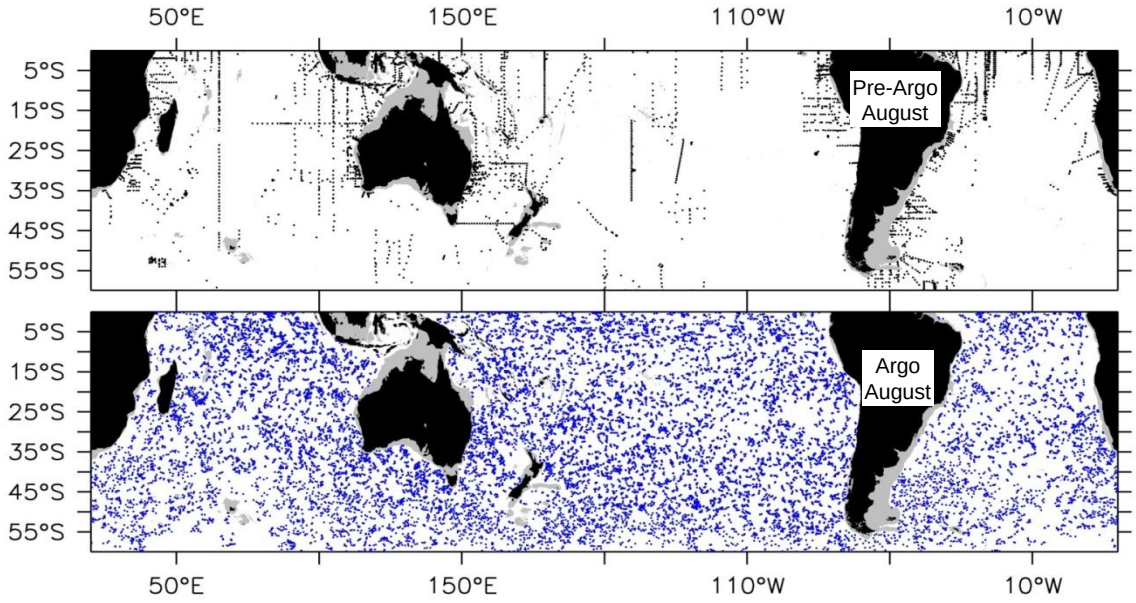
Cost of an Argo T,S profile is < $200 (all-inclusive).

Cost of a WOCE profile was ~$12,000.

All August research vessel Temperature/Salinity profiles (> 1000 m, 1951 – 2000, source: NODC).

Before Argo

The Argo era



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

WOCE = World Ocean Circulation Experiment

Modeling Studies

- Use a range of modeling studies to support and develop the Argo design using eddy-resolving models
- Models will be seeded with synthetic particles (floats) to test the appropriateness of:

  - proposed sampling rates

  - the optimum profile characteristics (including park depth)

  - possible effects (positive and negative) of dispersion and congregation of floats

Some References

from “On the Design and Implementation of ARGO”

Acero-Scherzer, C.E., D.V. Hansen and M.S. Swenson, 1997. Evaluation and diagnosis of surface currents in the National Centers for Environmental Prediction's ocean analyses. Journal of Geophysical Research, 102, 21037-21048.

Bindoff, N. and J. Church, 1992. Warming of the water column in the southwest Pacific. Nature, 357, 59- 62.

Clancy, R.M., P.A. Phoebus, and K.D. Pollack, 1990. An operational global-scale ocean thermal analysis system, Journal of Atmospheric and Oceanic Technology,2, 233-254.

CLIVAR Scientific Steering Group, 1998. CLIVAR Initial Implementation Plan. World Climate Research Programme Report No. 103. , WMO/TD No. 869, June 1998.

Davis, 1998. Preliminary results from directly measuring mid-depth circulation in the tropical and South Pacific. Journal of Geophysical Research, in press.

Deser, C, M. Alexander and M. Timlin, 1996. Upper ocean thermal variations in the North Pacific during 1970-1991. Journal of Climate, 9, 1840-1855.

Dickson, R., J. Lazier, J. Meincke, P. Rhines, and J. Swift, Long-term coordinated changes in the convective activity of the North Atlantic, Progress in Oceanography, 38, 241-295, 1996.

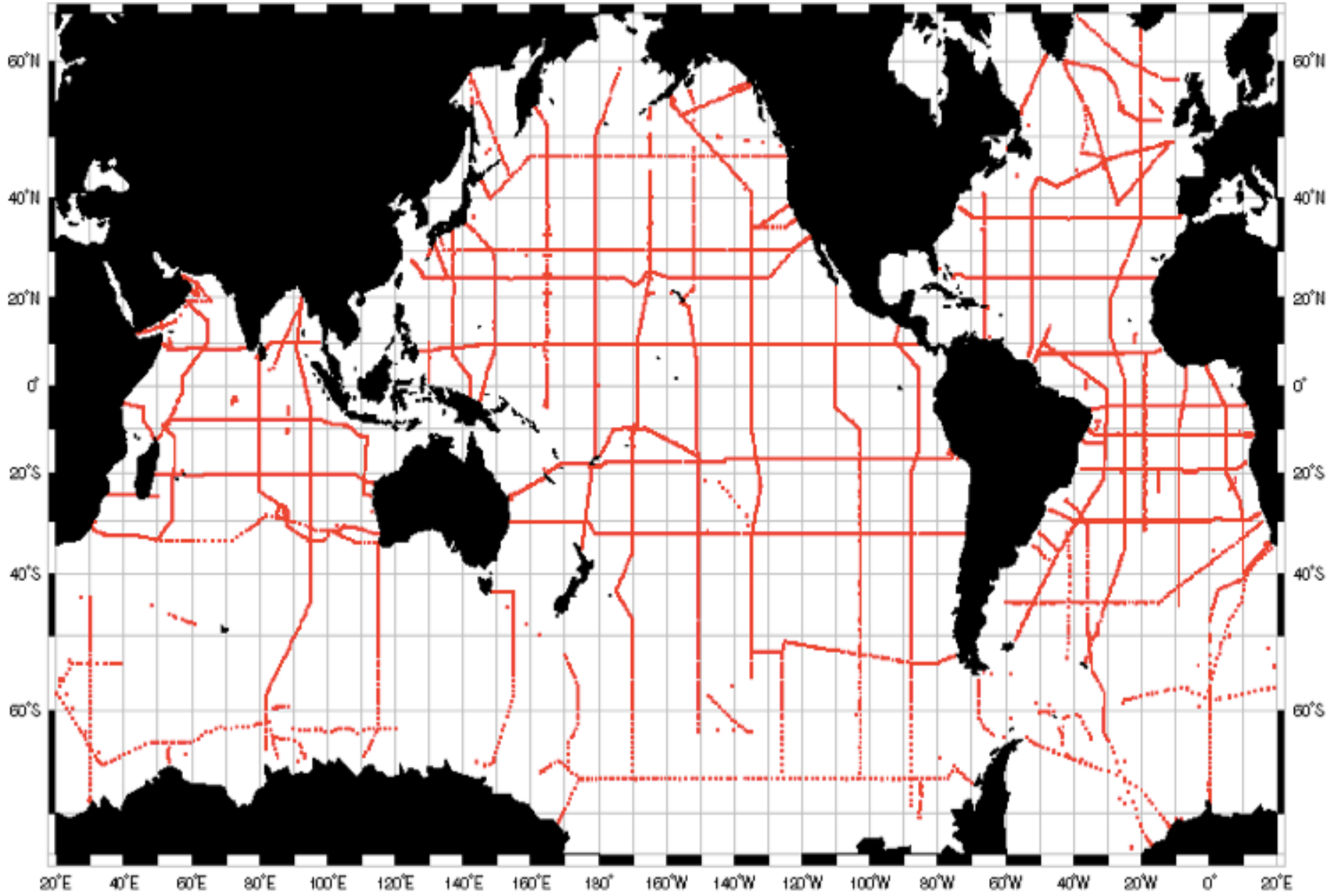
Douglas, B., 1991. Global sea level rise. Journal of Geophysical Research, 96, 6981-6992.

World Ocean Circulation Experiment*

- 1998 Year of the Oceans and focus on oceans
- Difficulty of obtaining data and the lack of it
- New technologies will allow us to gain more, deeper and with longer time frames
- Need for high quality temp and salinity profiles
- See the next chart for a sense of the limitations with the results of 7 years of effort (9000 profiles)

*WOCE

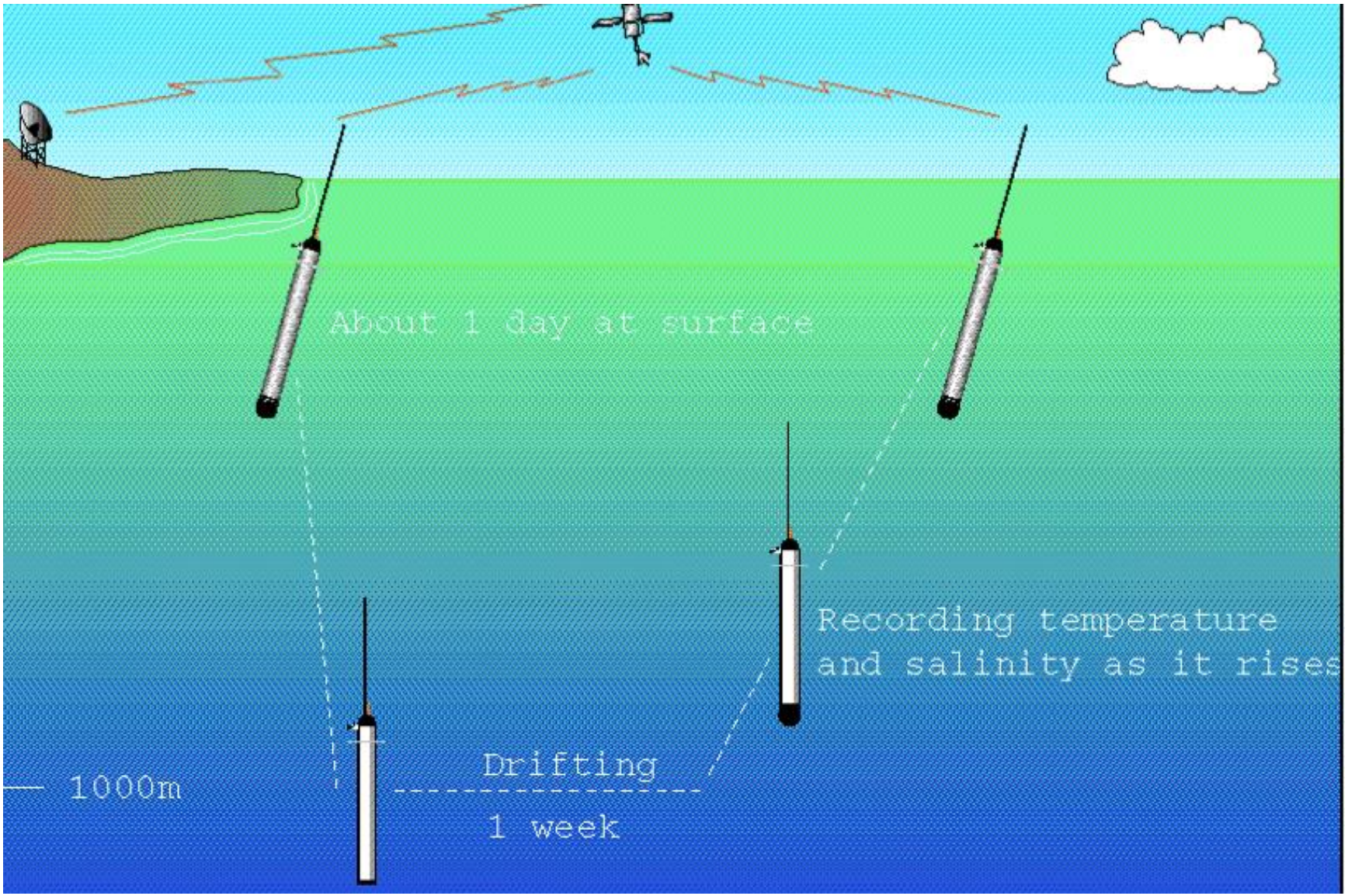
WOCE One-time Stations 1991-1997



Historical Projects

- Extremely spotty data pre-1950s
- 1960s Expendable bathythermograph (XBT) and the “Ship of Opportunity Program”
- During the 1990s – 40,000 XBT profiles per year at depths of 450m or 750m
- Tropical Atmosphere Ocean array (TAO) additional 20,000 additional vertical profiles
- Serious deficiencies = temp only (of poor quality) – no salinity or velocity data and no samples south of 30°

The New Autonomous Profiling Floats



ARGO Floats

- A neutrally buoyant satellite tracked float was designed and developed under WOCE
- Temperature and salinity profiling to 1200m and capable of 100 cycles
- Later technology expanded the capabilities to profiles to 1500m with drift velocity measurements throughout the profile
- Accuracy of 0.01° C in temperature and 0.01 psu in salinity (practical salinity unit)

Practical Salinity Units (psu)

- Ocean average psu ≈ 35 psu
- River mouth ≈ 15 psu Dead Sea ≈ 40 psu
- Chloride 19 grams Sodium 11 grams

  Sulfate 3 grams Magnesium 1.5 grams

  Calcium .35 grams Potassium .35 grams

Per kg of water = total of 35.2 grams/kg

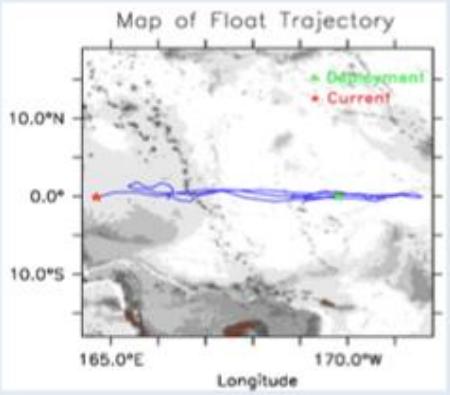
New and Specialized Floats

- Operate 3-4 years to depths of 2000m with a profile each 10 days
- Deliver 80-100 temp/salinity profiles per deployment
- Winged float for dynamic positioning during ascent and descent to possibly attain a fixed position
- As of 2013 – More improvements

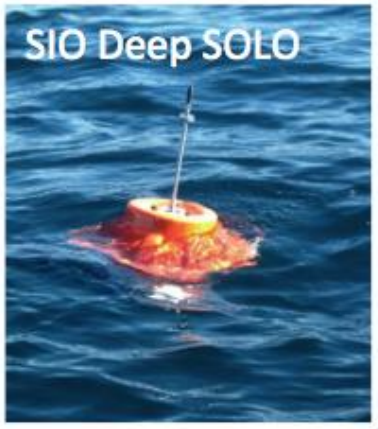
Float technology improvements

New generation floats (SOLO-II, Navis, ARVOR, NOVA)

- Profile 0-2000 dbar anywhere in the world ocean.
- Use Iridium 2-way telecoms:
  - Short surface time (15 mins) greatly reduces surface divergence, grounding, bio-fouling, damage.
  - High vertical resolution (2 dbar full profile).
  - Improved surface layer sampling (1 dbar resolution, with pump cutoff at 1 dbar).
- Lightweight (18 kg) for shipping and deployment.
- Increased battery life for > 300 cycles (6 years @ 7-days).



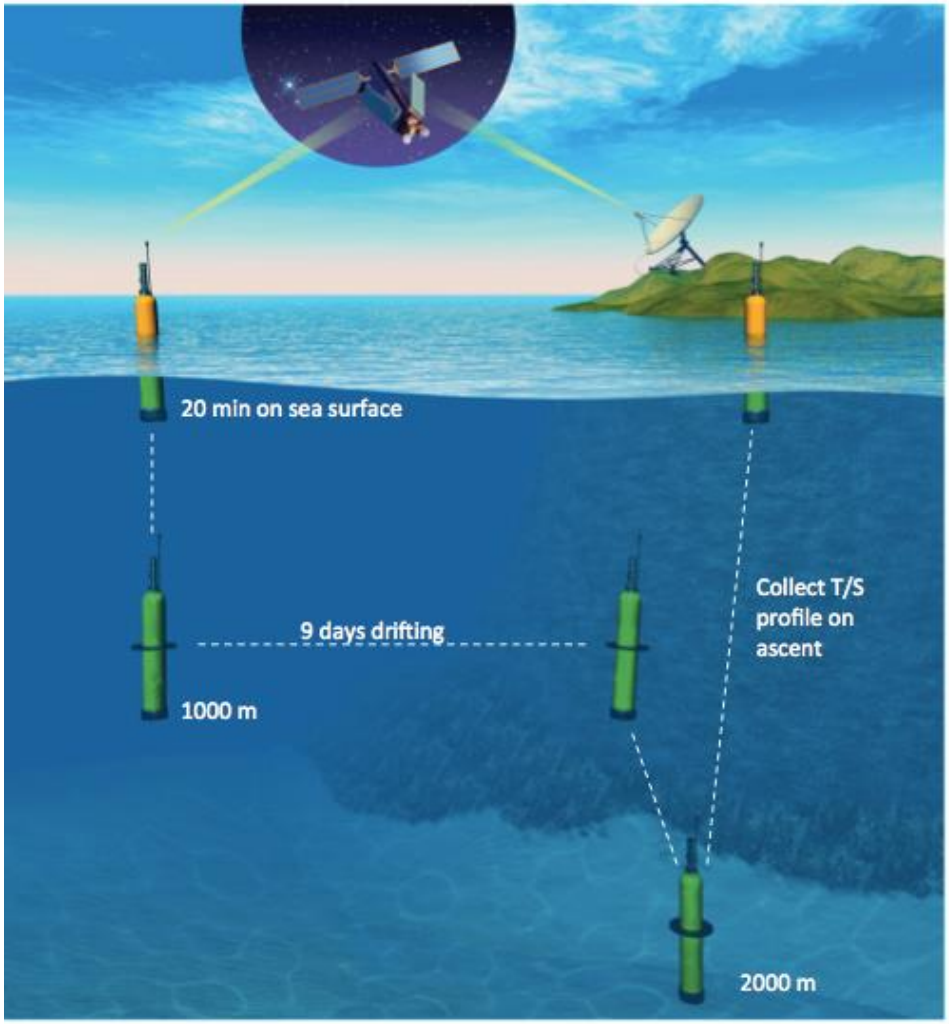
SOLO-II, WMO ID 5903539 (left), deployed 4/2011.
Note strong (10 cm/s) annual velocities at 1000 m

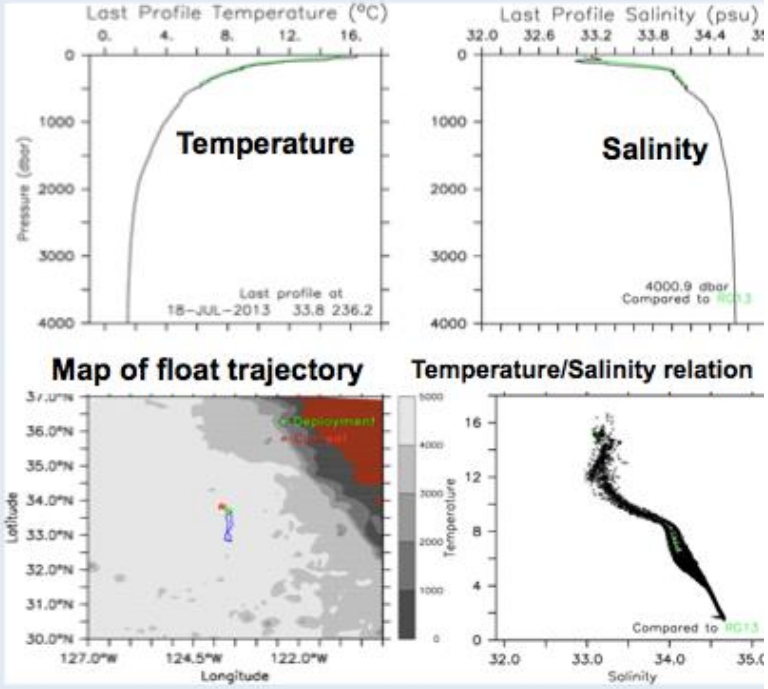


This Deep SOLO completed 65 cycles to 4000 m and is rated to 6000 m.

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) .





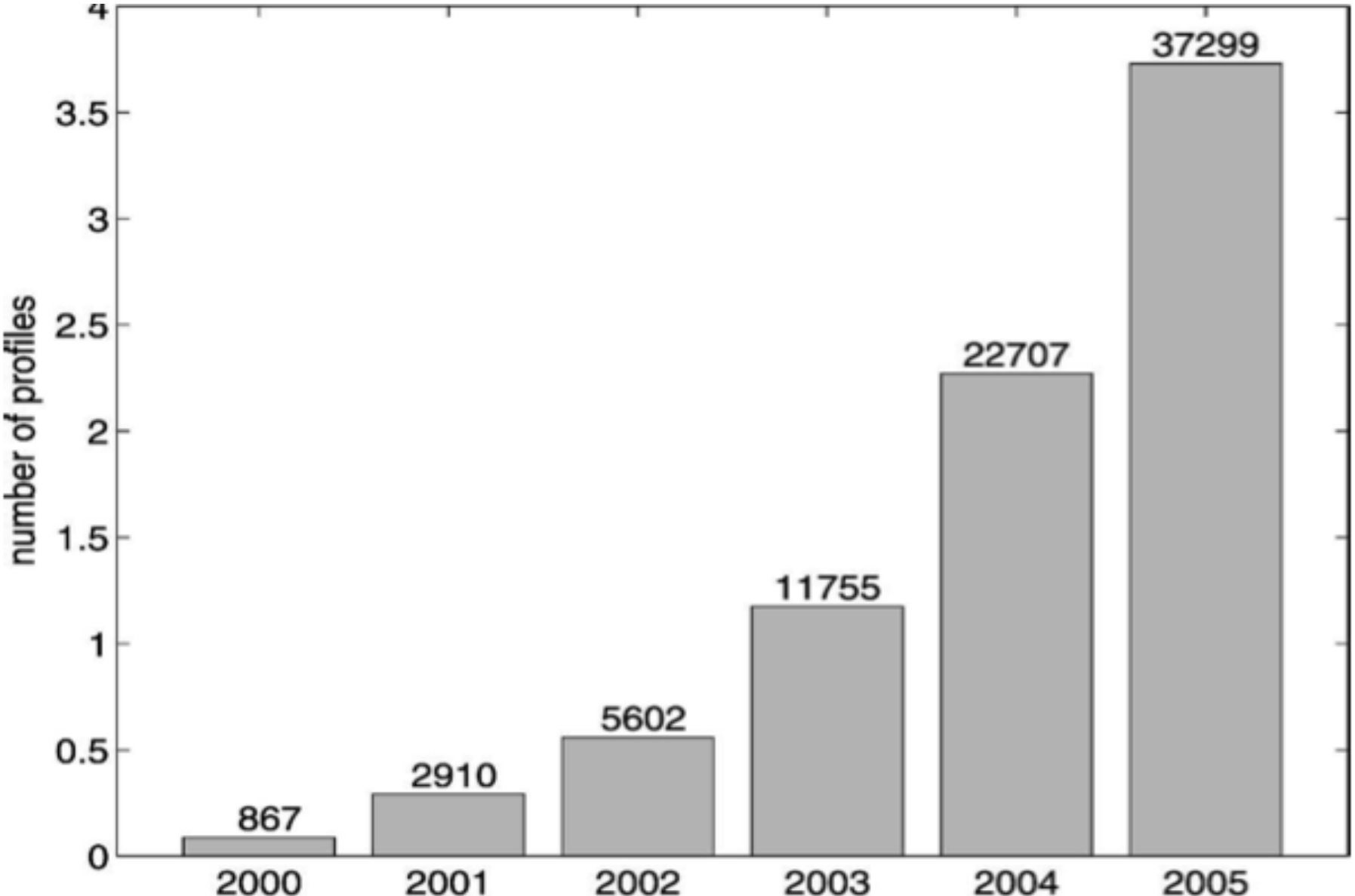
Cost of an Argo T,S profile is ~ $170.

Typical cost of a shipboard CTD profile ~$10,000.

Other “New” Features

- Nominal 1000m drift depths can be modified by a particular scientist’s interest to reach a float field of for example 400m
- The ARGO Science Team now consists of 30 different countries
- A sophisticated data handling protocol has been developed as ARGO data volume grows
- There is a US ARGO Consortium that uses specialized floats in unique global deployment patterns

Evolution # of Profiles US Array



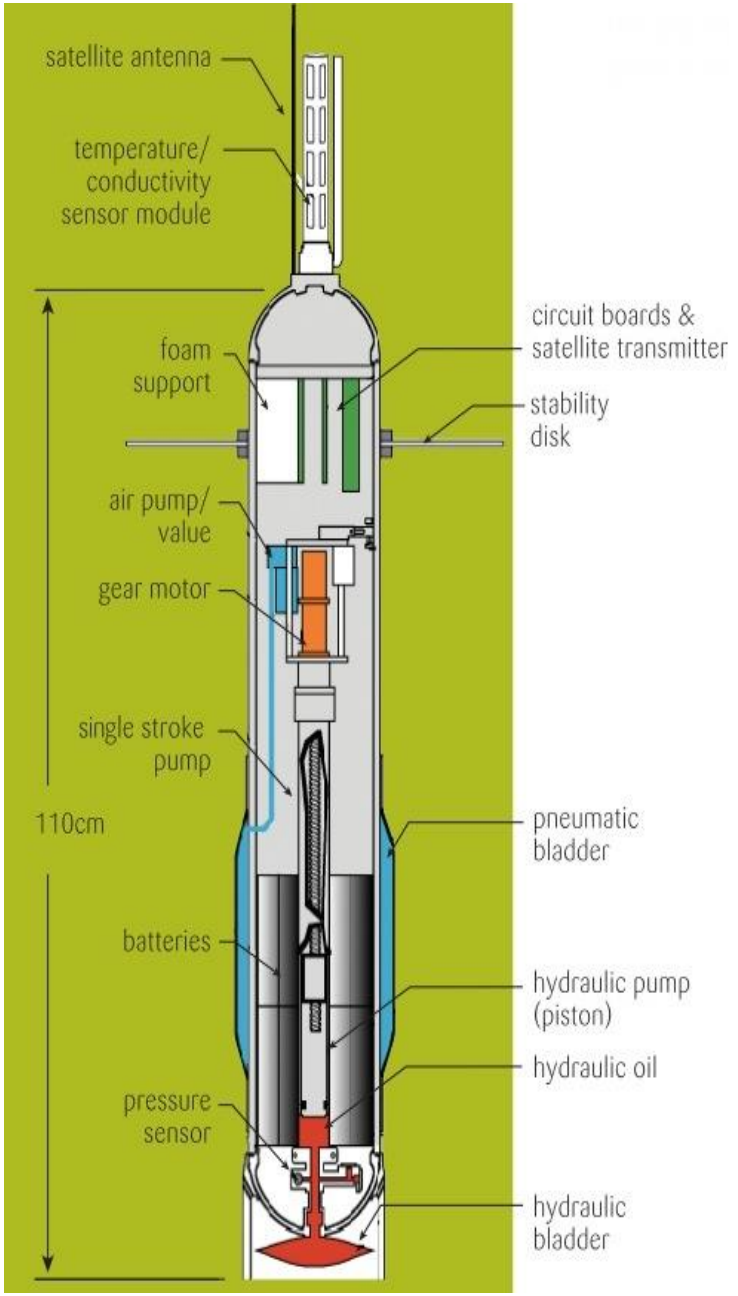
Float Technical and Quality Issues

- Floats must work 4-5 years delivering high quality data while immersed in a corrosive fluid
- Floats must cycle over a pressure range of 200 atmospheres
- They sometimes relay their data from the surface of a stormy, ice filled ocean
- Communicate in a 12 hour window every 10 days with very limited bandwidth

How it works

Changing depth and drop to drift depth by pumping oil in and out of an external bladder

Limit of 100 levels per profile due to data limits



Some more Interesting Points

- Each standard float costs about $15,500
- There are now 4 float models – 3 early models were French PROVOR and US APEX which are commercially built and US SOLO built by Scripps
- Total Program cost per year is about $24M
- They are expendable but a few are recovered when found for design engineering reasons
- Buoyancy, physical dimensions and crush depth constrain present profile depth to 2000m

International Participation

- There were 10 nations at the beginning of the program
- There are now 30 nations involved

With

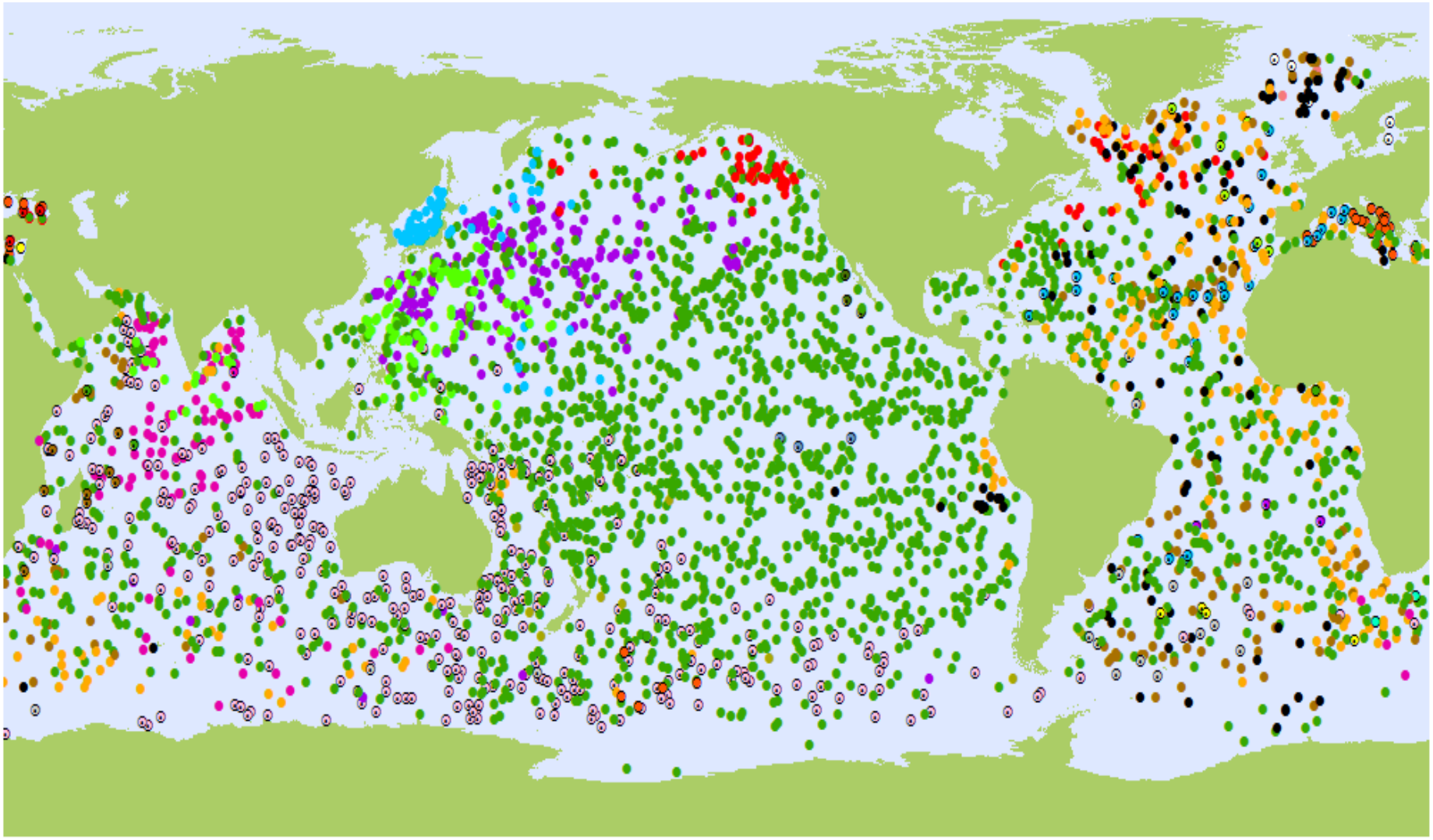
- Financing, building, deploying, development of the science, expanding the network and data plans, data handling
- Data and results are open to all

Future Development

- Presently 60 floats with dissolved oxygen measuring capability (expand this)
- Develop floats that can operate under the ice with delayed data transfer
- Floats capable of acoustic measurements
- Measure heat transfer and water momentum under tropical cyclones
- Improve limited data transfer with more modern communication systems

Expansion of Float Tasks

- With the present parameters being measured there are some interesting new properties that can be determined
- 3D regional and global ocean parameters (temperature, salinity, etc) measured over long periods
- Patterns of complex ocean surface and sub-surface currents
- Sea height related to currents (ENSO & other)


3603
Floats
ARGENTINA (4)
AUSTRALIA (377)
BRAZIL (3)
BULGARIA (5)
CANADA (71)
CHINA (111)
ECUADOR (3)
FINLAND (6)
FRANCE (242)
GABON (1)
GERMANY (122)
GREECE (3)
INDIA (105)
IRELAND (7)
ITALY (29)
JAPAN (186)
KENYA (2)
SOUTH KOREA (71)
LEBANON (1)
MAURITIUS (8)
MEXICO (3)
NETHERLANDS (17)
NEW ZEALAND (11)
NORWAY (4)
SOUTH AFRICA (2)
SPAIN (30)
SRI LANKA (1)
TURKEY (4)
UNITED KINGDOM (148)
UNITED STATES (2 026)
May 2014
jcommops

Argo “Tie-ins” to many Science Issues

- Thermo-haline and other ocean currents
- Deep ocean pressure changes and gradients
- Horizontal ocean thermal pathways surface to 1000m layers
- Vertical ocean thermal pathways to and from the deep ocean
- Global long term effects from the changing oceans (one unusual one is LOD effect)
- Millions of profiles over decades = ?

Data Set to the Present

- Limited, Short and Quality
- There will be a Part 2 Presentation on the data and the preliminary analysis of the data later
- There are thousands of papers now that have used ARGO data
- There are already alarmist interpretations of a brief decade of data
- Many of the papers acknowledge the data limits (spatial, temporal (for 1 profile or for one decade), quality, etc)

My Thoughts

- There are many results showing “serious” warming (most cases a few tenths of a degree C)
- Regional ocean warming is discussed as “global warming” – some ocean regions are warming and some are flat or actually slightly cooling
- Many of the papers are on some very interesting ideas using ARGO data and most of these acknowledge that this whole idea is very early and useful results will require some time
- The Team wants more and more capable floats
- This program in my opinion deserves more funding and more attention by the scientific community

Blind Men and the Elephant

Points for Us to Ponder

- The deep ocean thermohaline currents take about 1000 years to cycle (Jeopardy - what is the Bond cycle?)
- Between the sun and the oceans we probably have about 90% or more of the drivers of climate
- How much do we really know about the oceans?
- Let me know when you want to see Part 2