Development of the Deep Argo Program

Dean Roemmich, Nathalie Zilberman, Philip Sutton,
Russ Davis, John Gilson, Kyle Grindley, Carol Janzen, Gregory Johnson, Taiyo Kobayashi, Nordeen Larson, Serge Le Reste, Guillaume Maze, Robert Melvin, David Murphy, Ernest Petzrick, Stephen Riser, Jeff Sherman, Toshio Suga, Michihiko Tachikawa, Esmee van Wijk, Matthew Walkington, and Susan Wijffels

Ocean Surface Topography Science Team Meeting
Lake Constance, October 28 – 31, 2014

“That system, known as Argo, is one of the scientific triumphs of the age”

- New York Times, August 11, 2014

Outline

1. Why is Deep Argo needed?

2. Deep Argo float and CTD development.

3. The Deep Argo CTD validation and float deployment cruise on RV Tangaroa.

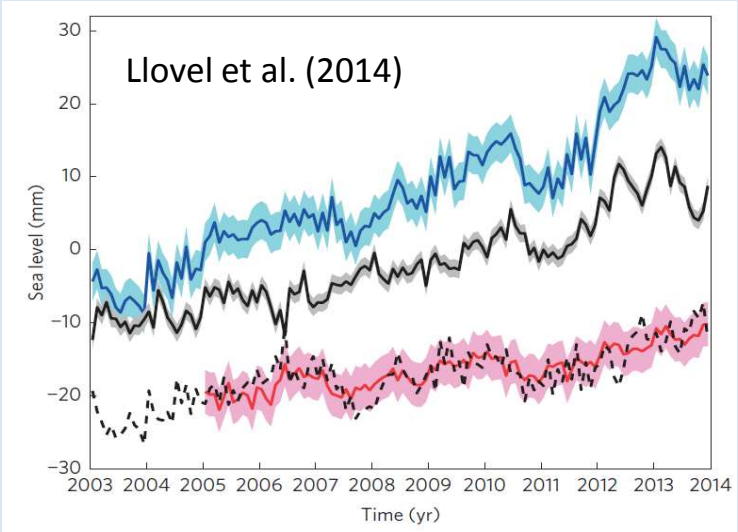
4. Deep Argo pilot deployments and planning for global sampling.

Deep SOLO 6000 m float prior to deployment, RV Tangaroa, June 2014

1. Why is Deep Argo needed?

- Argo is observing only 1/2 of the ocean.
- For closing global budgets and determining large-scale patterns of heat and freshwater storage and steric sea level change.
- For exploration of the mean and decadal variability in abyssal ocean circulation including meridional overturning circulations.
- For use in ocean reanalyses and forecast models.
- Deep Argo will complement satellite altimetry!

Deep steric change, as a residual of SSH, mass, and shallow steric, has large errors.



SSH

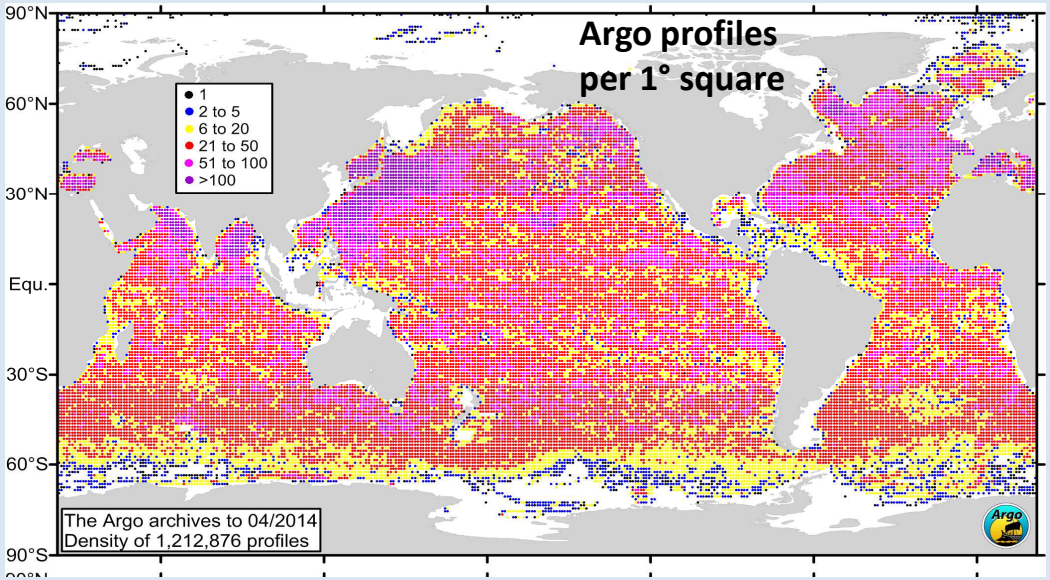
Mass-related component

Steric height, Red: upper ocean; Dashed: residual

Argo is observing only 1/2 of the ocean.

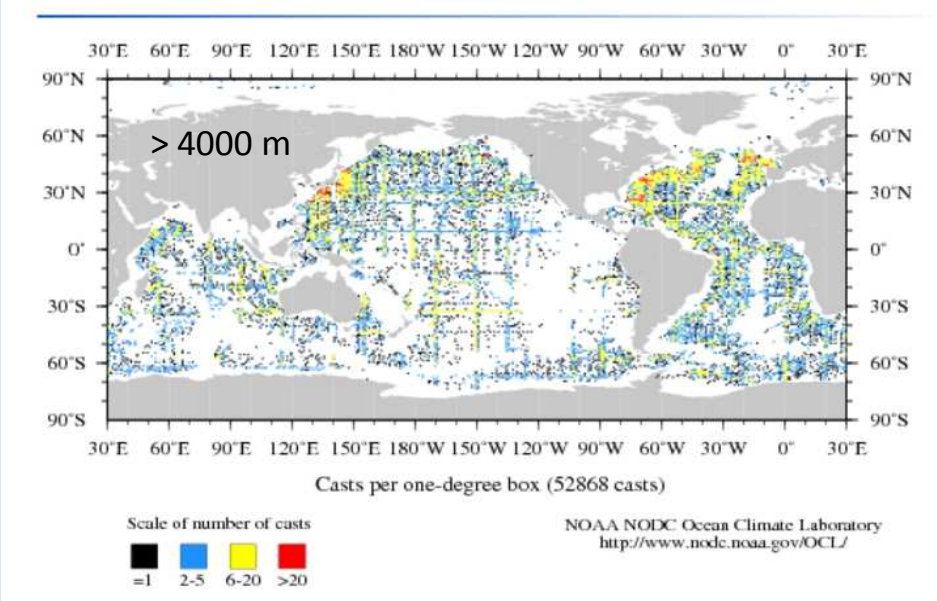
Argo's 1.2 million T/S profiles cover the upper ocean, 0 – 2000 m, providing data for 1700 research papers.

Systematic observations > 2000 m are made only by the sparse decadal ship survey (GO-SHIP).



The World Ocean Database includes just 52,868 T/S profiles deeper than 4000 m, with the coverage biased toward Northern Hemisphere continents.

Coverage is not sufficient to describe the mean ocean circulation in many regions or the decadal property variations.



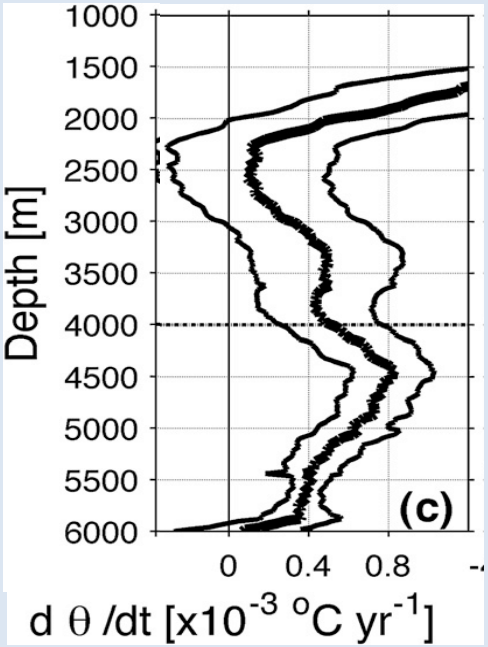
Global budgets of heat, freshwater, and sea level require deep ocean data

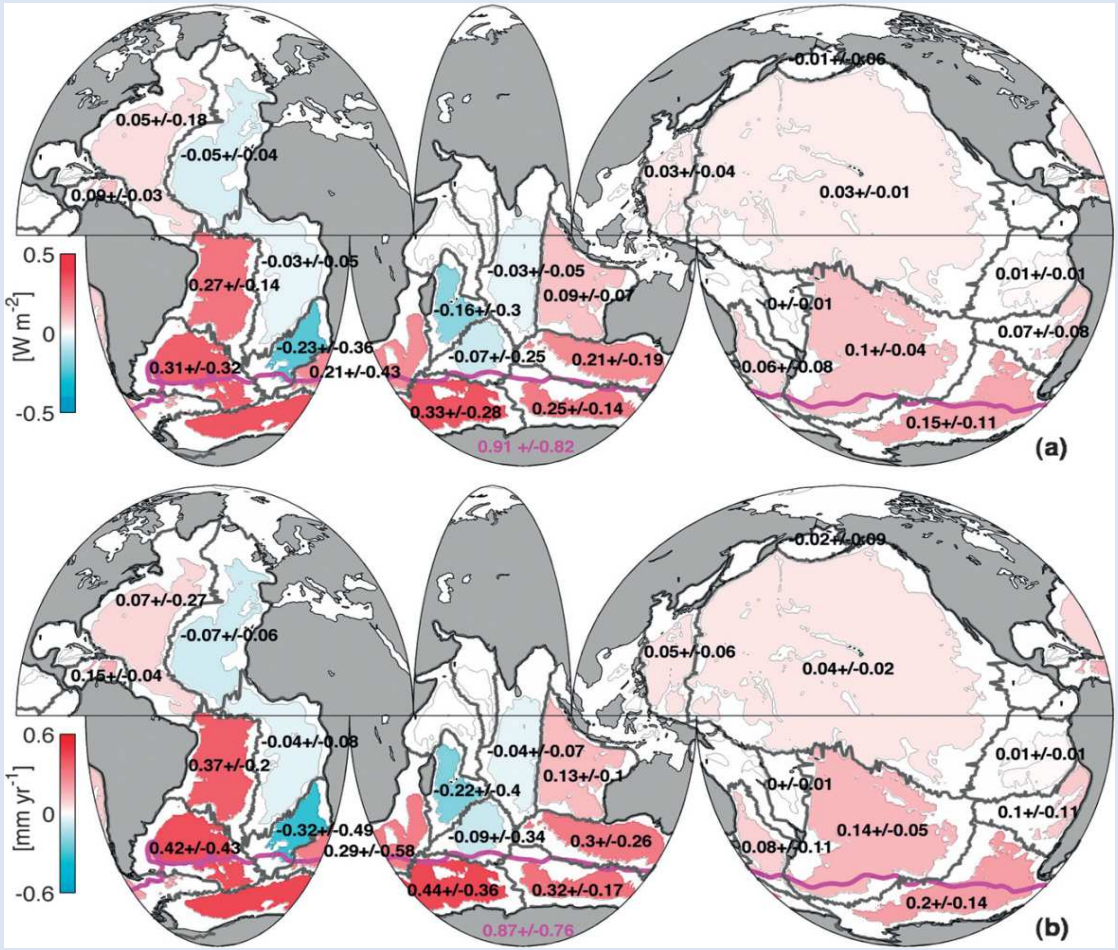
Conventional Argo floats (2000 m) miss an estimated 0.1 W m^{-2} of ocean heat gain (about 20% of the total), and .1 mm yr^{-1} of steric sea level rise.

Regional patterns of decadal variability are unknown.

Southern Hemisphere deep basins have the strongest warming signals.

Purkey and Johnson (2010) global warming rate °C yr^{-1} in the deep ocean.



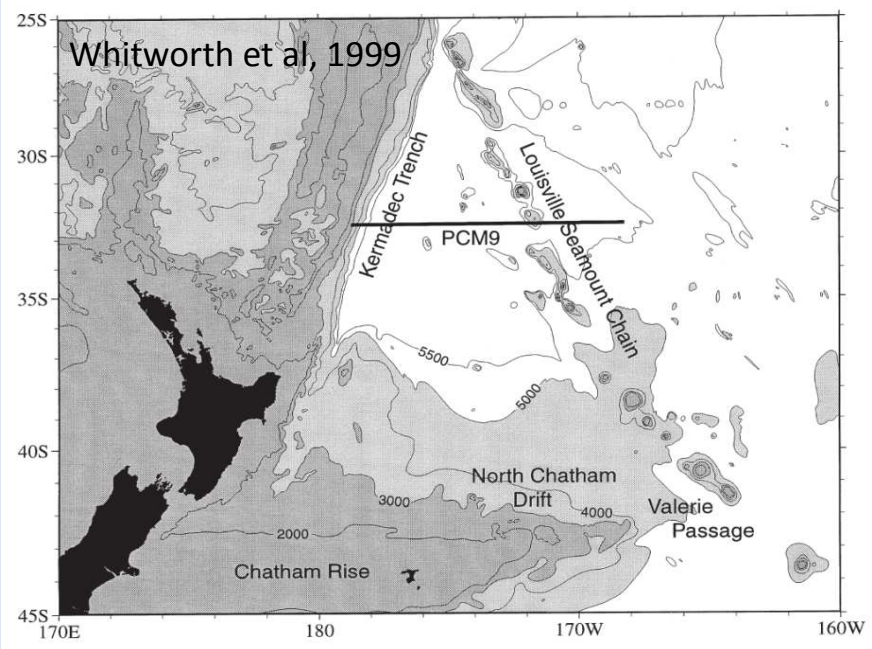


Purkey and Johnson (2010) rate of warming below 4000 m (top) and rate of steric height increase (bottom), based on repeat hydrography. Rates are for waters below 1000 m south of the Sub-Antarctic Front.

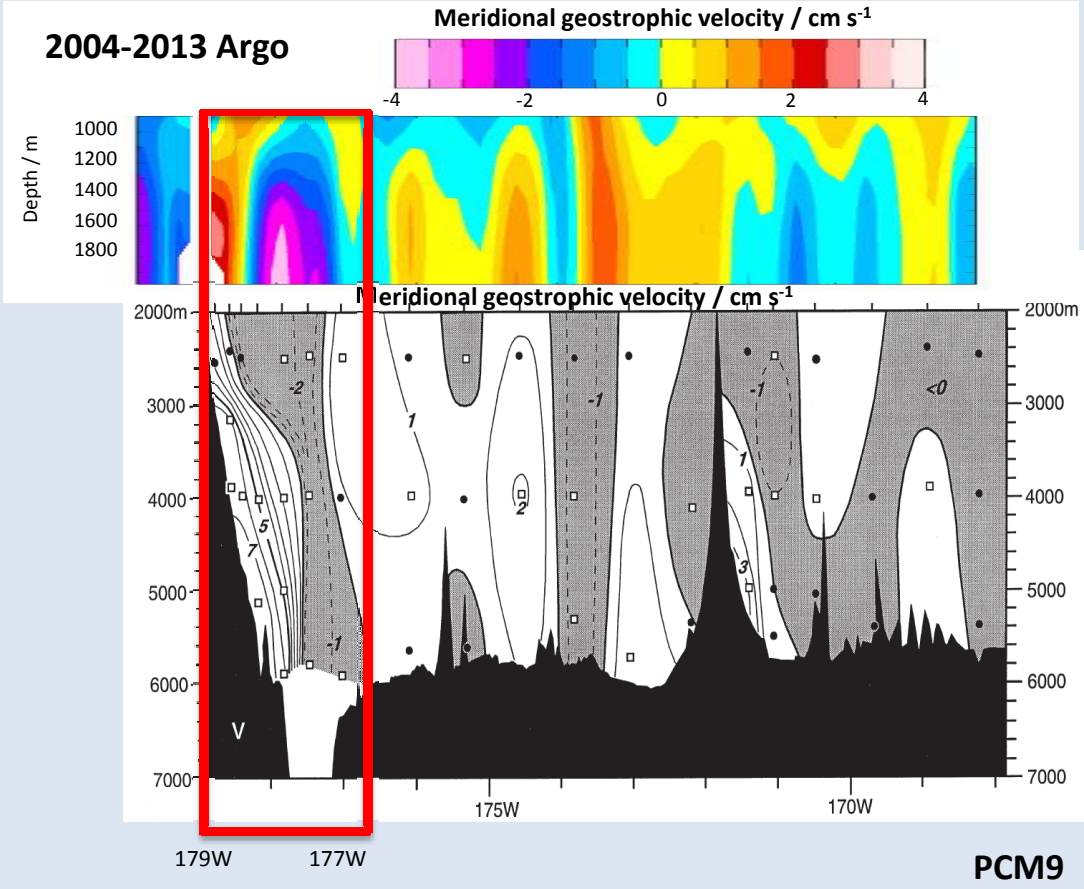
Exploring the mean and decadal variability in abyssal ocean circulation including MOC's

Zilberman et al., In prep. Shallow signature of the deep Western Boundary Current east of the Tonga Kermadec Ridge.

PCM9 moored array [1991-1992]

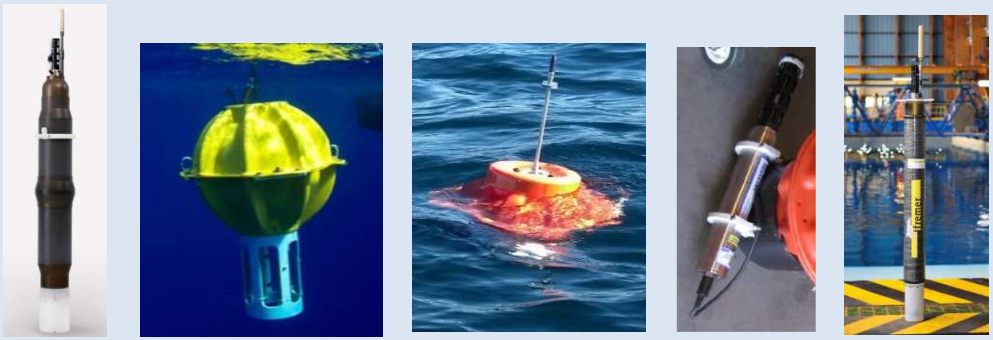


Combination of 0-2000 m and Deep Argo data will provide top-to-bottom ocean circulation (1000 m trajectory ref. vel.)



(top) The DWBC and recirculation east of the Tonga-Kermadec Ridge as seen in the "shallow" (< 2000 m) Argo data, including the 1000 m reference velocity from Argo trajectory data, (bottom) WOCE PCM9 mean currents, Whitworth et al (1999).

2. Deep Argo float and CTD development.



4 models of Deep Argo floats and a Deep Argo CTD

There are 4 Deep Argo float models

Deep NINJA
TSK Co LTD, JAMSTEC
0 – 4000 m
SBE-41 CTD
50 kg
14 deployed so far

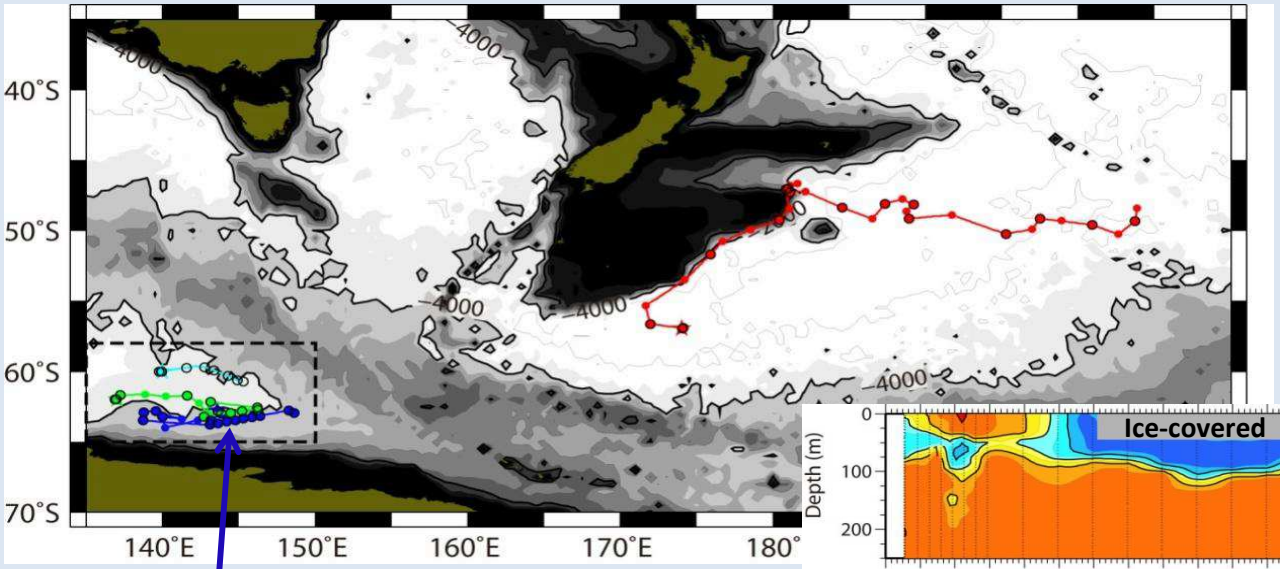
Deep APEX
TWR, UW/NOAA
0 – 6000 m
SBE-61 CTD
43 cm glass sphere
Prototypes deployed

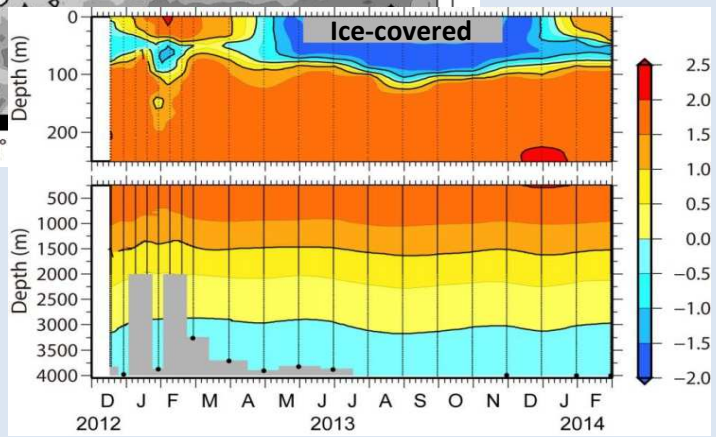
Deep ARVOR
NKE, IFREMER
0 – 4000 m
SBE-41 CTD
26 kg
Prototypes deployed

Deep SOLO
SIO/NOAA
0 – 6000 m
SBE-61 CTD
25 kg
33 cm glass sphere
Prototypes deployed

Deep NINJA

In production since 4/2013
11 deep NINJA floats deployed in Southern Ocean, 2012 – 2014,
3 in North Pacific

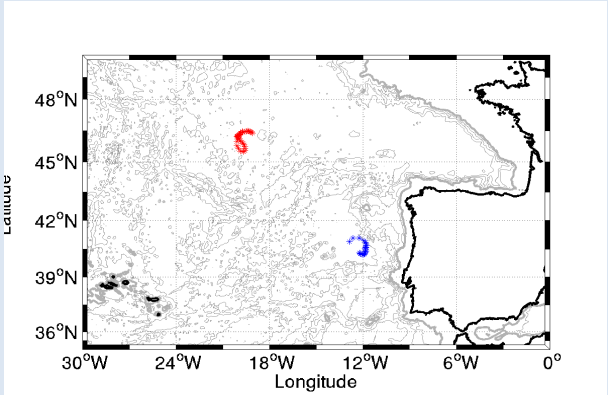




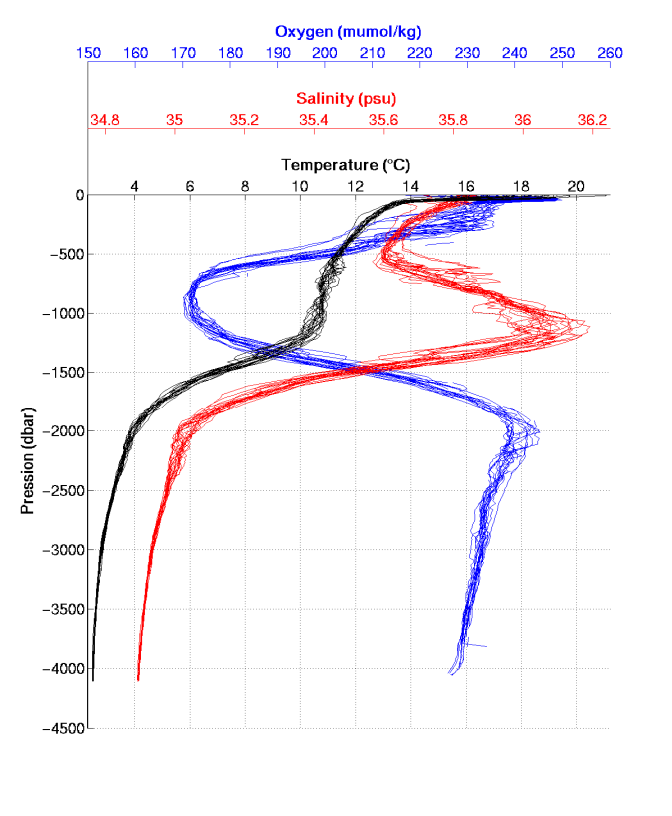
Potential temperature observed by a Deep NINJA, including a period with sea-ice cover.

Deep ARVOR

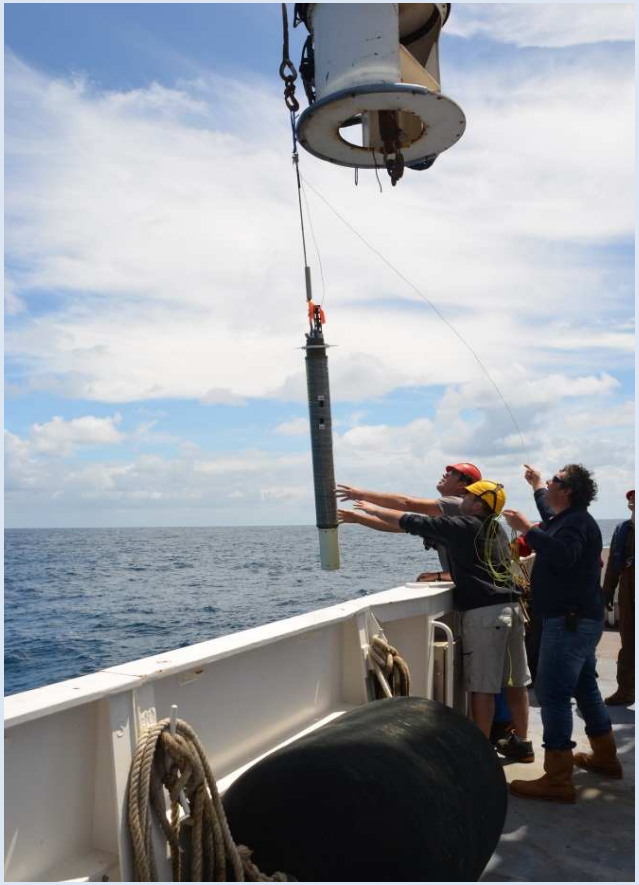
- Two 3500 m prototypes deployed in 2012-2013
- Two improved 4000 m prototypes deployed in May 2014
- 150 cycle lifetime; #2 has completed 54 cycles so far
- SBE 41cp CTD, O_2 option
- A North Atlantic 12-float pilot experiment is planned for mid-2015



Positions of 4000 m prototypes

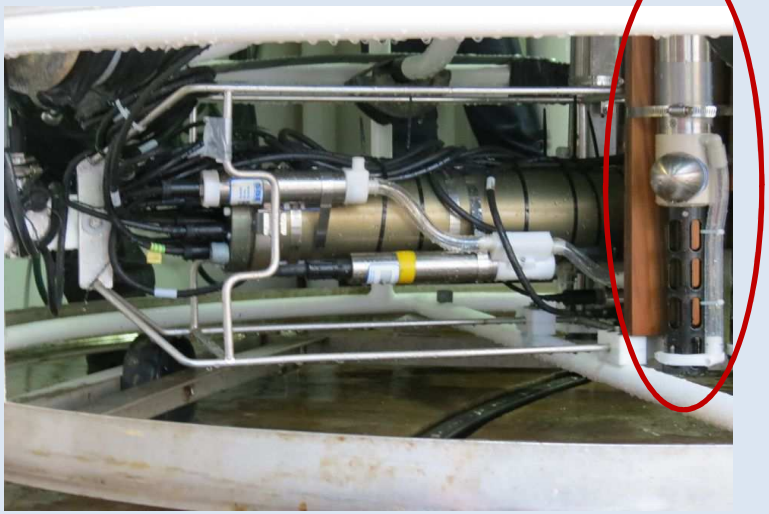


T, S, O2 profiles from 4000 m prototype #1



SBE-61 CTD

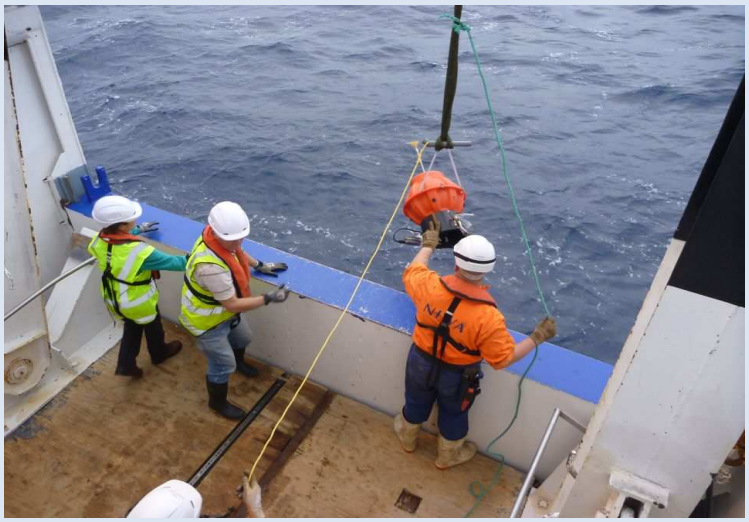
- Developed by Sea-Bird Electronics for use in Deep Argo floats to 6000 m.
- Continuous and discrete sampling modes.
- Pressure case is separate from the float, to eliminate possible environmental effects.
- Target accuracy (not yet achieved) in P,T,S is 3 dbar, .001°C, .002.
- Argo will conduct further validation experiments using the SBE-61 integrated with shipboard CTDs and on Deep Argo floats.



SBE-61 CTD mounted alongside shipboard CTD for performance validation.

SBE-61 CTD mounted on Deep SOLO float

3. The Deep Argo CTD validation and float deployment cruise on RV Tangaroa.



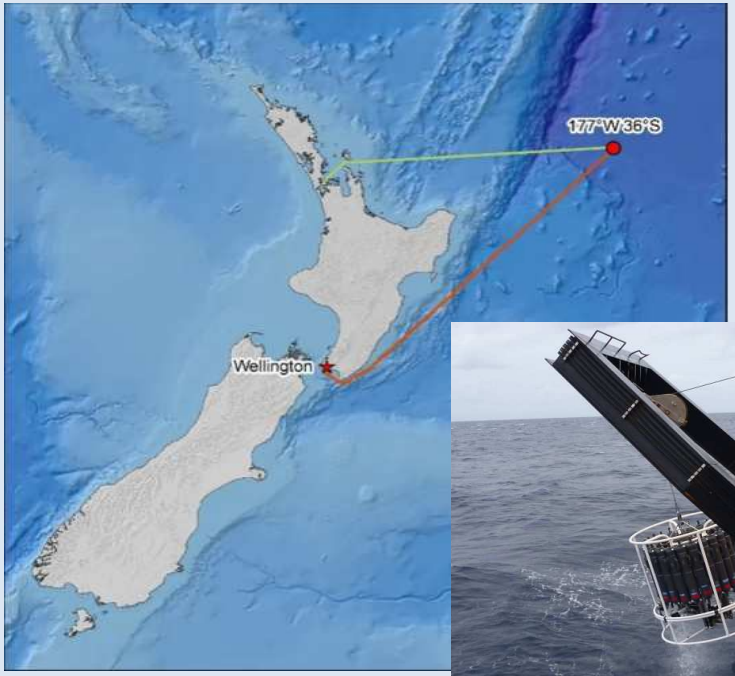
Photos: LEARNZ. For additional photos and video see http://www.learnz.org.nz/argofloats142/photogallery

Deep Argo deployment and CTD validation cruise – June 2014

- Partnership of N.Z/U.S./Aus. Argo + Seabird Electronics
- U.S. Deep Argo is a NOAA program
- RV Tangaroa, June 16-25th 2014

Voyage Plan and Goals

- Compare SBE-61 CTD pressure, temperature, salinity with shipboard CTD (calibrated for this voyage).
- 3 SBE-61 CTDs were integrated in the shipboard system (+1 internally recording), and 12 casts obtained, with water samples, in 5600 m depth at 177°W, 36°S.
- Deploy 2 Deep SOLO floats (SIO/NIWA) w/ SBE 61 CTDs.



Right: Deep SOLO deployment.
Left: CTD recovery
Photos: LEARNZ

Deep Argo cruise: CTD comparisons

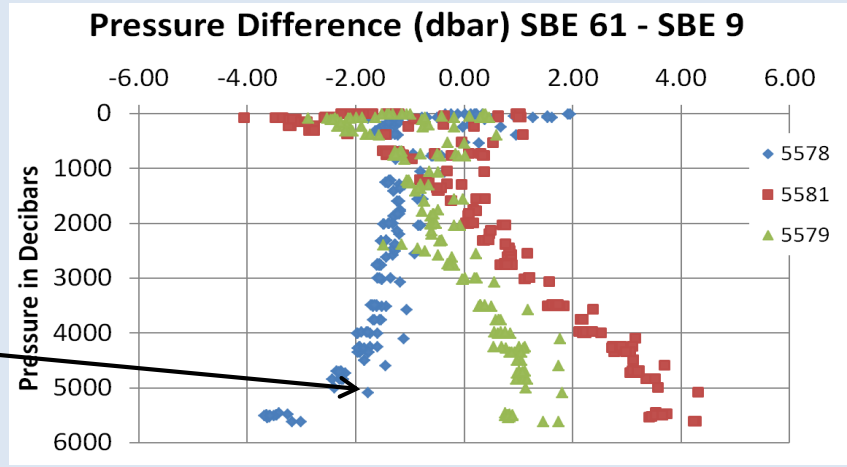
Pressure: Difference is ± 4.5 decibars
Thermal equilibrium of strain gauge has significant impact on error (see long soak data), 0.5 m height difference is uncorrected.

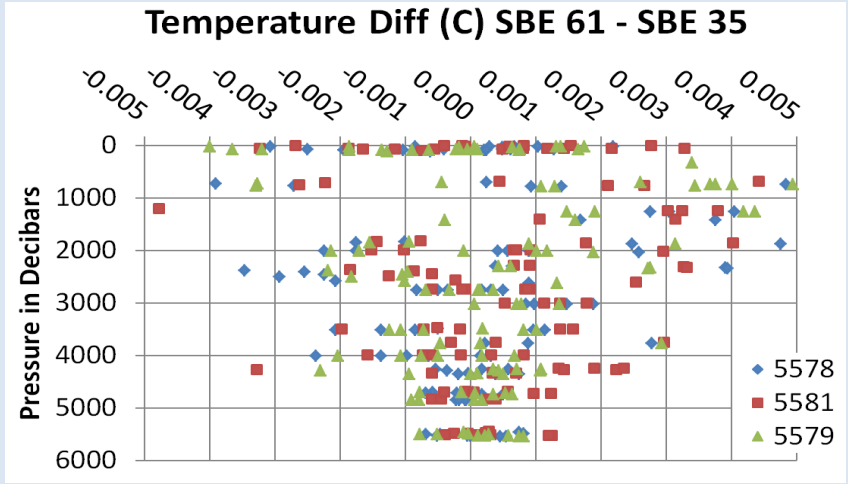
Temperature: Agreement below 4500 decibars is about ± 0.001.

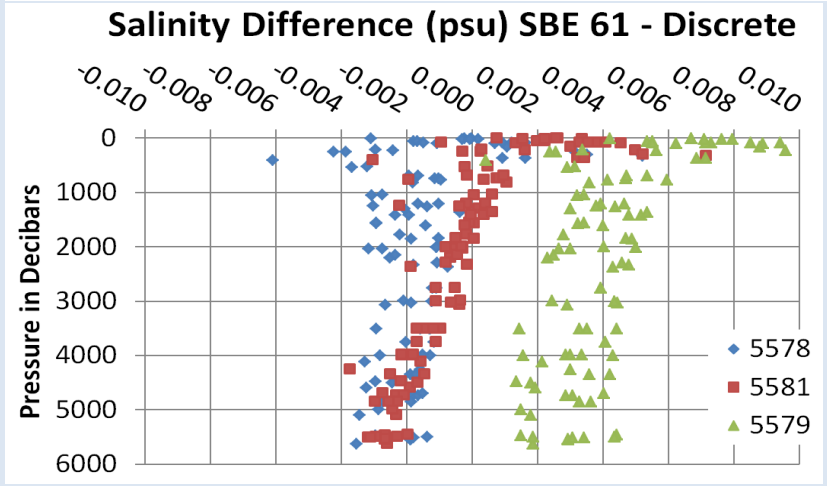
Sensors were mounted as close to one another as practical. Photo: LEARNZ

Salinity: Agreement between SBE-61 and discrete samples below 2000 decibars is ± .005

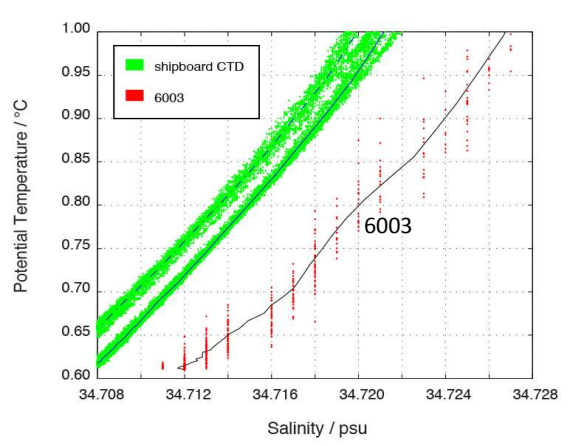
Figures by D. Murphy, Sea-Bird







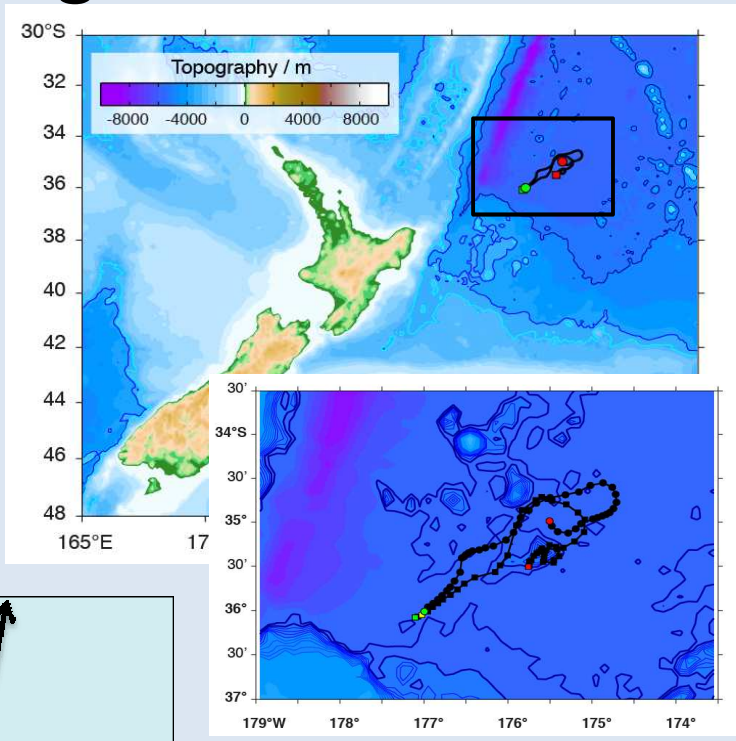
Deep SOLO floats deployed by RV Tangaroa



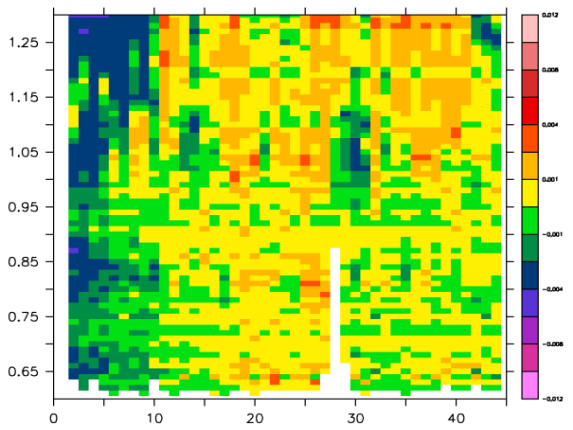
T/S offset and variability

6003 CTD salinity is 0.005-0.006 saltier than shipboard CTD at pressure > 2000 dbar.

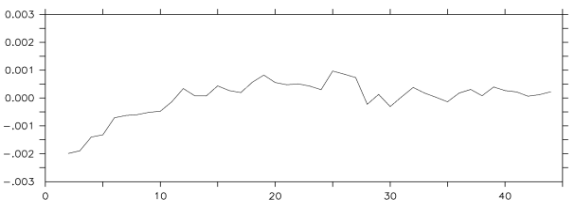
6002 is 0.04 too fresh. Recovery of 6002 and 6003 is planned, for better understanding of the offsets.



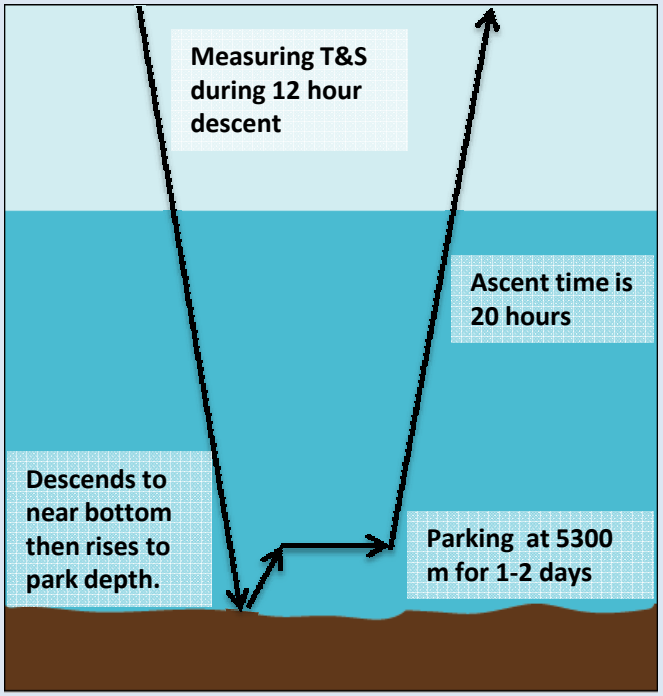
Path of 2 Deep SOLOs. Bottom depth is ~5600 m.



6003: multi-cycle salinity anomaly on Θ

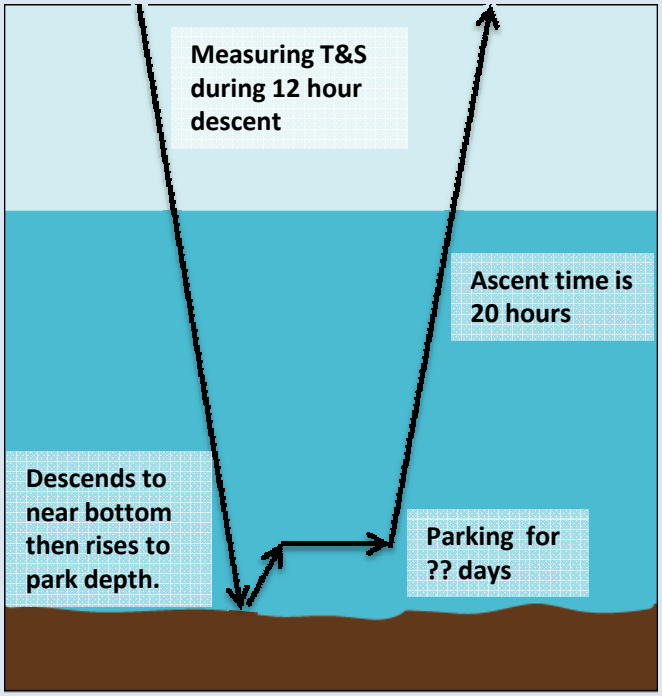


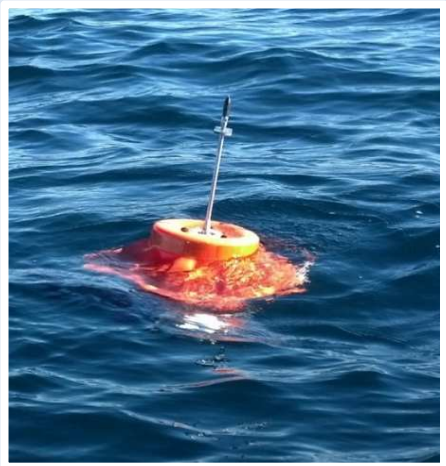
6003: Mean S-anomaly from Θ = 0.65 to 1.0°C (5000 to 3700 m)



Technical aspects of Deep Argo floats for community discussion.

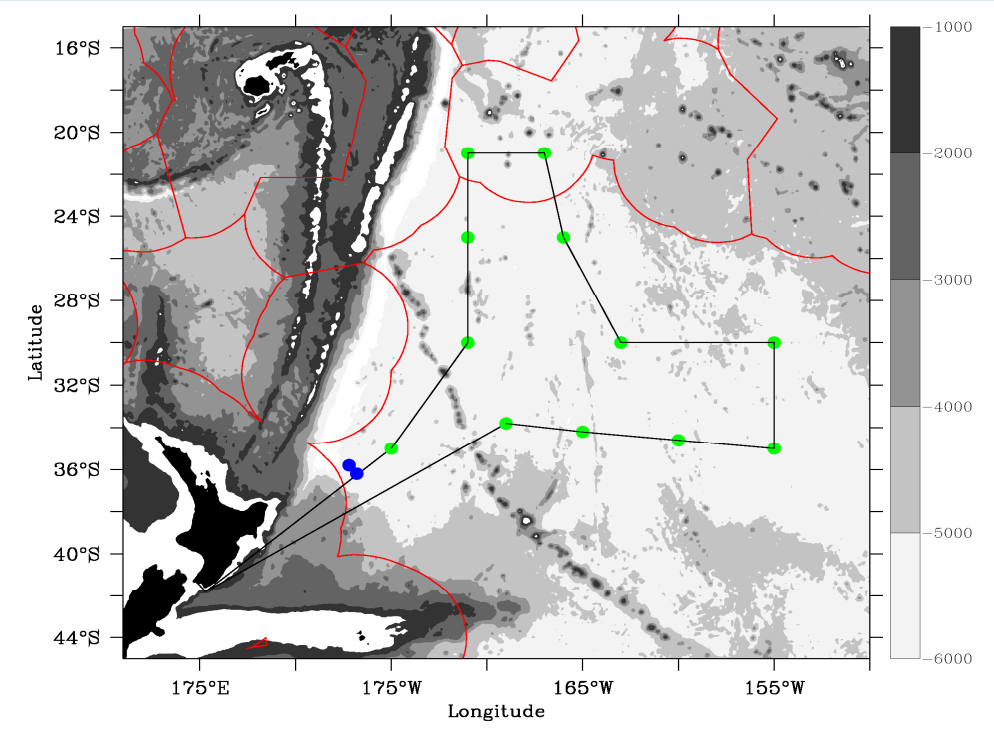
- Cycle time – aim for float lifetime (and array refresh time) of 5 years? (150 cycles @15 days = 6 years)
- Collect data during ascent or descent (how important is near real-time)?
- Any value in trajectory data given slow descent and ascent? What parking depth should be used?
- Vertical resolution of profile (continuous or discrete, given long times for ascent/descent)
- Requirements for CTD accuracy? Should floats be recovered for recalibration and reconditioning?
- Deep Argo array requirements – number of floats (1200?), scientific objectives.
- How can 4000 m and 6000 m models be deployed for most cost-effective global observation?





Deep SOLO

4. Deep Argo pilot deployments and planning for global sampling.



i) Deep Argo pilot deployment in the SW Pacific Basin - 2015

Tentative plan

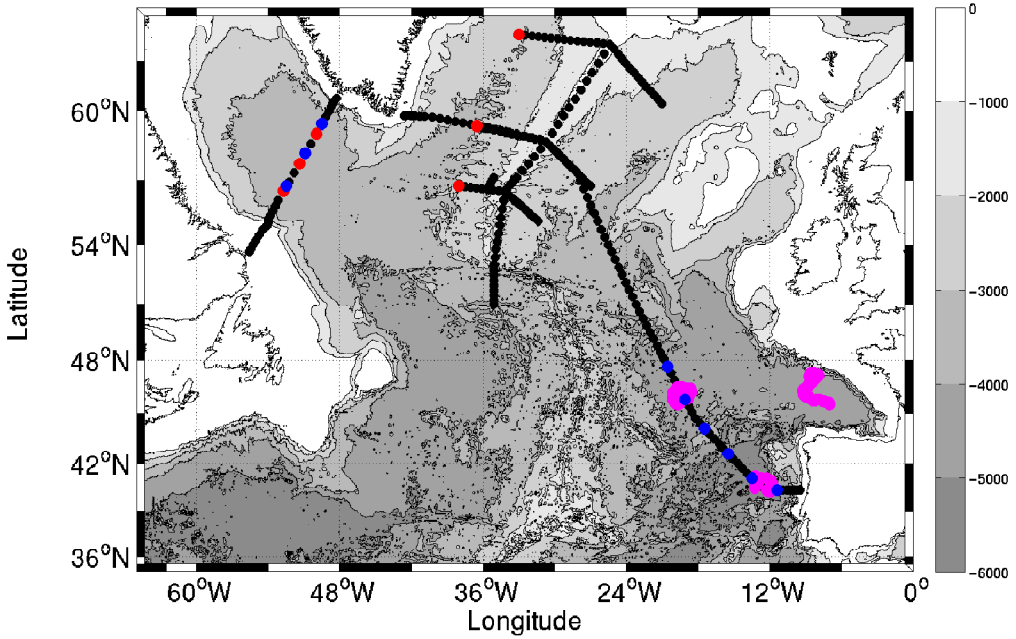
- Mid 2015; US, NZ, Aus Argo
- RV Kaharoa
- Recover (maybe) 2 deep SOLO floats deployed in June 2014.
- Deploy 12 Deep SOLO and Deep APEX floats.

Scientific objectives

- Deep water mass variability and trends.
- Circulation pathways and transports in the southwestern Pacific Ocean
- Regional pilot for planning global Deep Argo sampling.

NIWA's RV Kaharoa has deployed 20% of all presently active Argo floats.

ii) Deep Argo pilot experiment in the North-Atlantic



- Existing floats
- 2015 deployments
- 2016 deployments

- Deployment of 12 Deep ARVOR floats in 2015 and 2016 depending on cruise availability
- Deployment of 2 floats at the same location for intercomparison and to investigate sampling strategies
- Deployment in the Labrador and Irminger Sea to follow deep water masses (although bottom depth < 4000m)
- In the future, deployment further south to follow deep signal
- Deploy in the intergyre area where deep water masses are stable to investigate sensor behavior on the long term

Summary

- Deep Argo is needed to close full-ocean depth budgets of heat, freshwater, and steric sea level, plus a broad range research and operational applications.
- Deep Argo and altimetry will be a valuable combination.
- Four models of Deep Argo floats are under development plus a CTD with high accuracy and stability.
- Early deployments have demonstrated the capabilities of deep profiling floats, and progress in the SBE-61 CTD (Tangaroa cruise).
- Planning for Deep Argo pilot and global deployment is underway. Community input is needed.
- Next steps:
  - A Deep Argo Implementation Workshop
  - Pilot arrays in several deep basins
  - Implementation of a global array begins (2017?).