

Deep Argo

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Ocean's Carbon and Heat Uptake: Uncertainties and Metrics.

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Outline

1. Why is Deep Argo needed?
2. Deep Argo float and CTD development.
3. Deep Argo CTD validation and float deployment cruise.
4. Deep Argo pilot deployments and planning for global sampling.



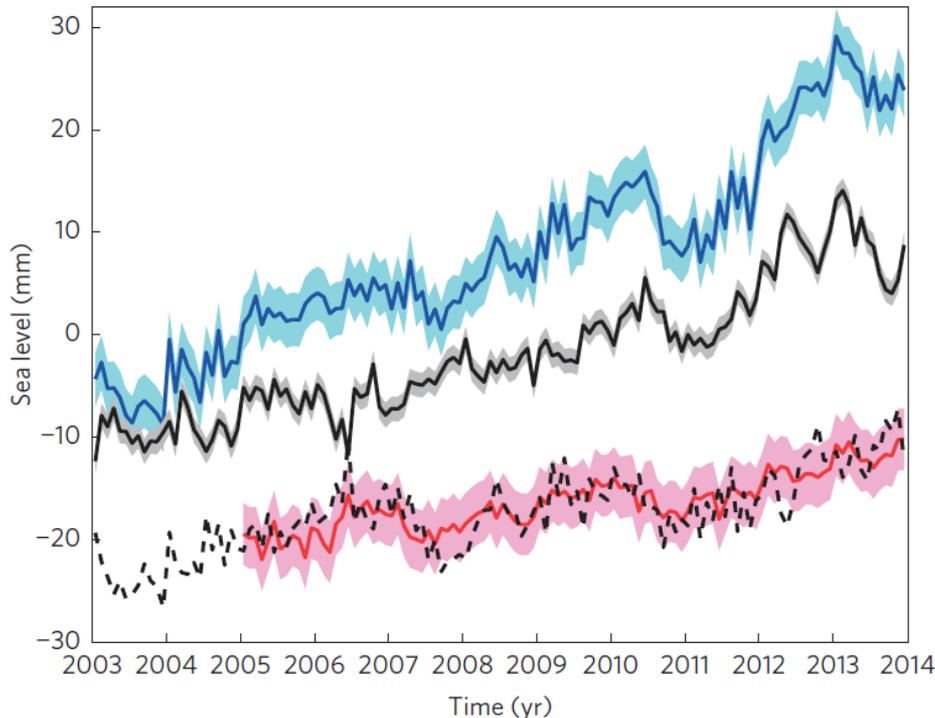
Deep SOLO 6000 m float prior to deployment, RV Tangaroa, June 2014





1. Why is Deep Argo needed?

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



SSH (Blue)

Mass (Black)

Upper Ocean Steric (Red) from Argo

Deep Ocean = SSH – Mass – Upper Ocean Steric
Deep Ocean = $-1.3 (\pm 7.2)$ mm decade⁻¹

From Llovel et al. (2014)

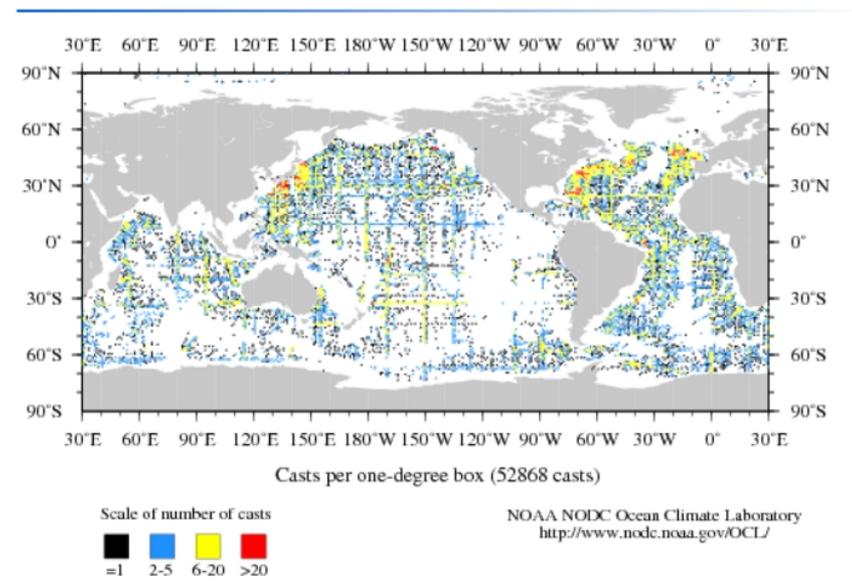
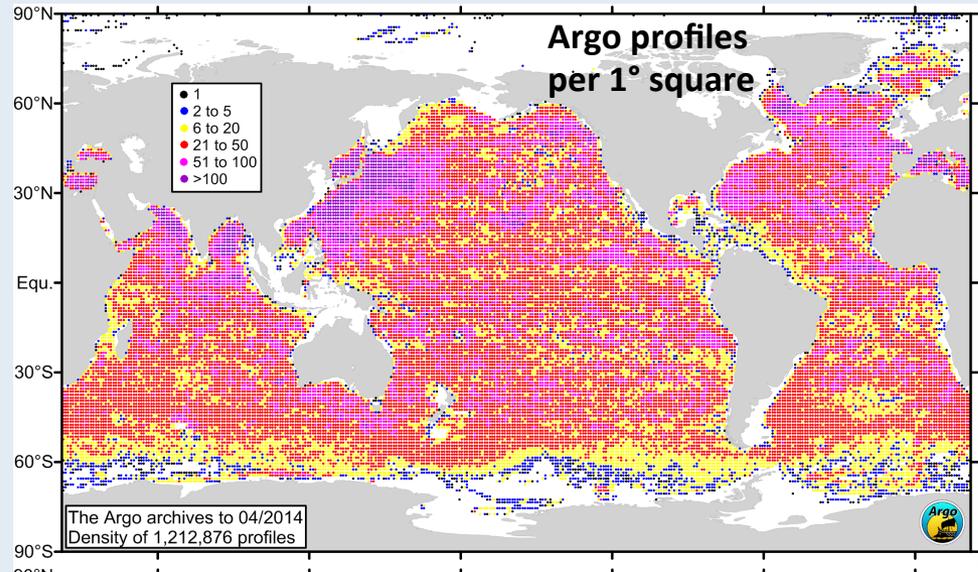
Argo is observing only 1/2 of the ocean.

Argo's 1.2 million T/S profiles cover the upper ocean, 0 – 2000 m, providing data for >1800 research papers.

Systematic global obs > 2000 m mostly from the sparse decadal ship survey (WOCE, CLIVAR/CO₂, 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 and water properties in many regions, much less their decadal variations.

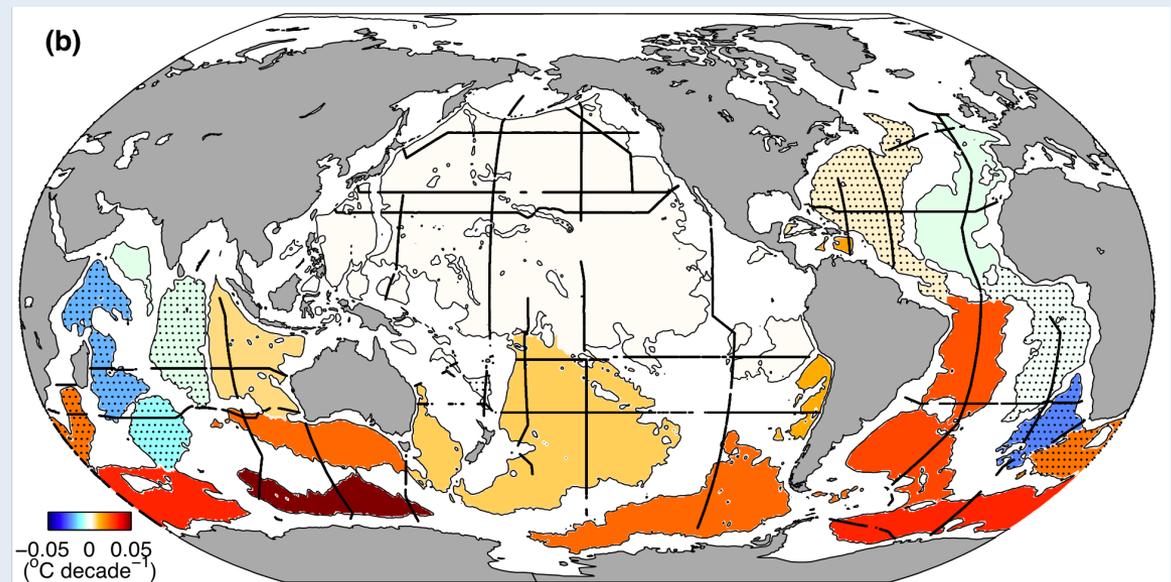


Global budgets of heat, freshwater, and sea level require deep ocean data

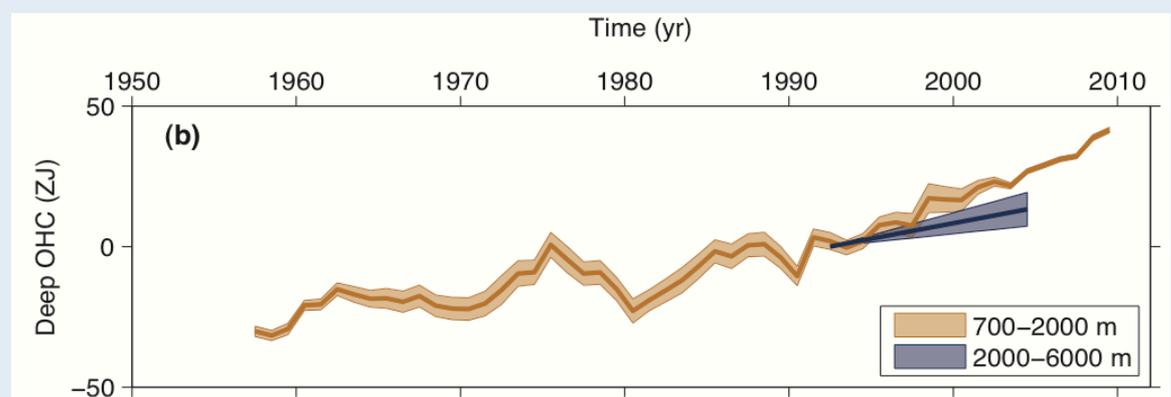
With their present 2000 m depth limit, conventional Argo floats are missing an estimated 0.1 W m^{-2} of ocean heat gain (about 20% of the total), and 1 mm decade^{-1} of steric sea level increase.

Moreover, regional patterns of decadal variability and multi-decadal change are not well known.

Southern Hemisphere deep basins have the strongest abyssal warming signals in recent decades.



Rate of warming below 4000 m based on repeat hydrography (*Purkey and Johnson (2010)*).



Ocean Heat content increases from 700-2000 m, and 2000-600 m (*IPCC, WG1, AR5, Chapter 3, 2013*)

2. Deep Argo float and CTD development.



Deep NINJA

TSK Co LTD, JAMSTEC

0 – 4000 m

SBE-41 CTD

50 kg

14 deployed so far

Deep APEX

TWR, UW

0 – 6000 m

SBE-61 CTD

43 cm glass sphere

Prototypes deployed



Deep ARVOR

NKE, CNRS, IFREMER

0 – 4000 m

SBE-41 CTD

26 kg

Prototypes deployed

Deep SOLO

SIO

0 – 6000 m

SBE-61 CTD

25 kg

33 cm glass sphere

Prototypes deployed



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 reduce possible environmental effects.
- Target accuracy (not yet achieved) in P, T, and S is ± 3 dbar, $\pm 0.001^\circ\text{C}$, and ± 0.002 .
- 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



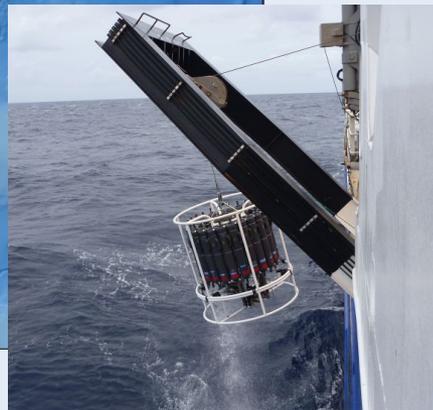
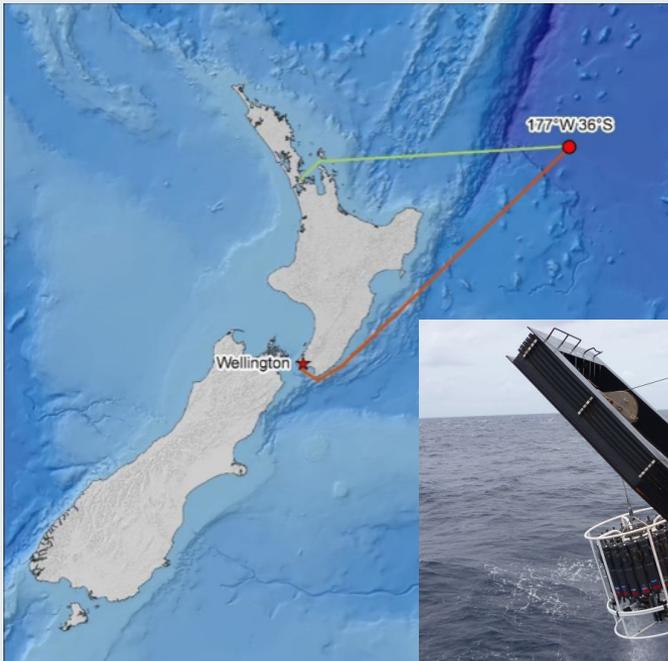
3. Deep Argo CTD validation & float deployment cruise



- N.Z./U.S./Aus. Argo and Sea-Bird Partnership
- R/V Tangaroa, June 16-25th 2014

Voyage Plan and Goals

- Compare SBE-61 CTD pressure, temperature, salinity with shipboard SBE 9plus CTD (newly calibrated).
- Three SBE-61 CTDs integrated in the shipboard system (one more internally recording)
- 15 casts to 5600 m with water samples at 177°W, 36°S.
- Two Deep SOLO floats (SIO/NIWA) with SBE 61 CTDs deployed.



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. A 0.5 m height difference is uncorrected.

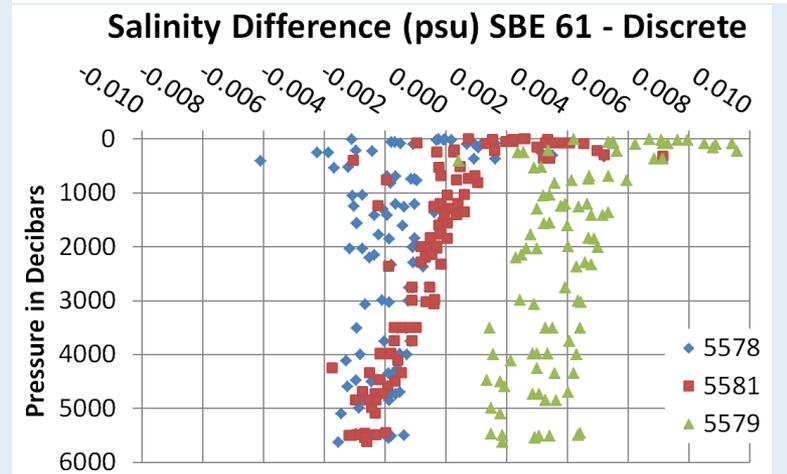
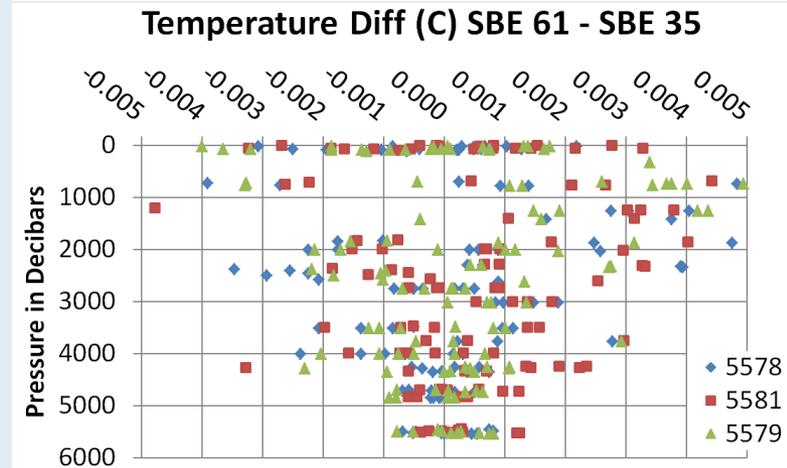
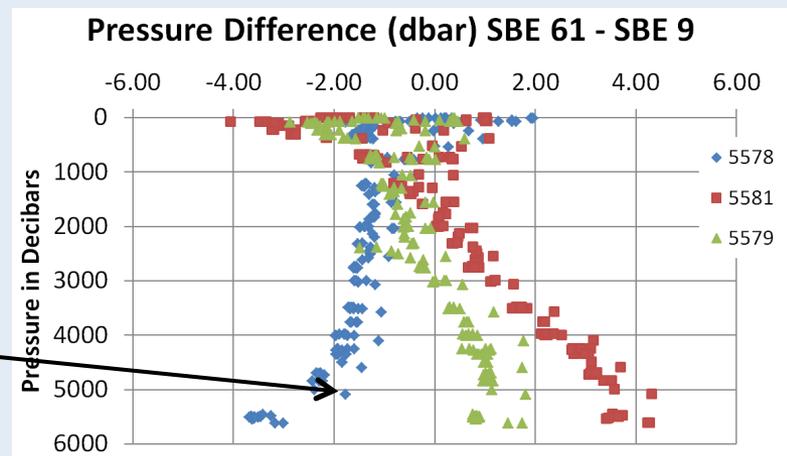
Temperature: Agreement below 4500 decibars is $\pm 0.001^\circ\text{C}$, excepting 3 points out of 142.

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

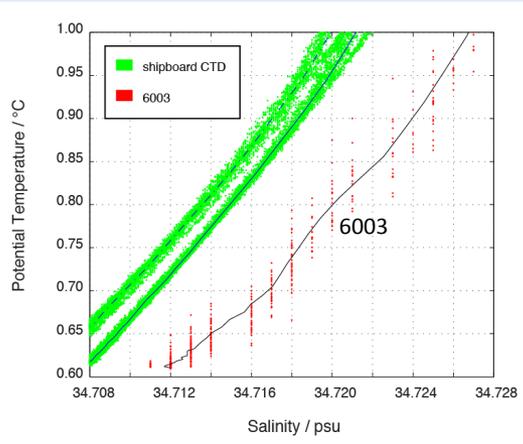


Salinity: Agreement between SBE-61 and discrete samples below 2000 decibars is ± 0.005

Figures by D. Murphy, Sea-Bird



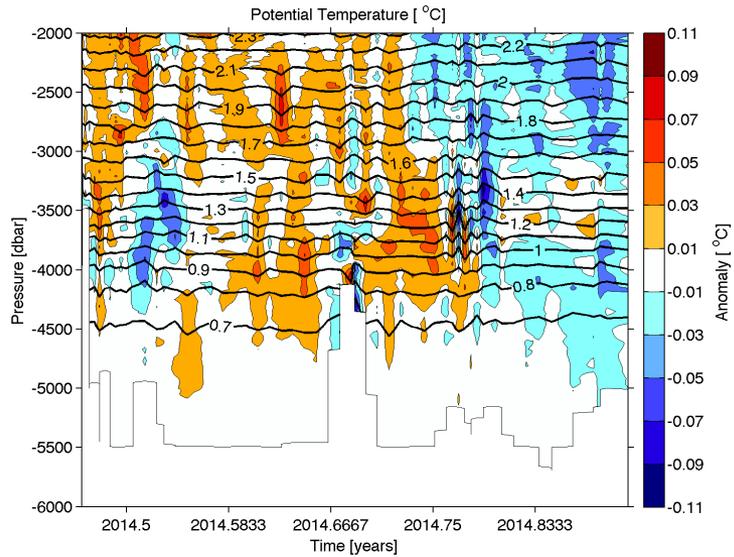
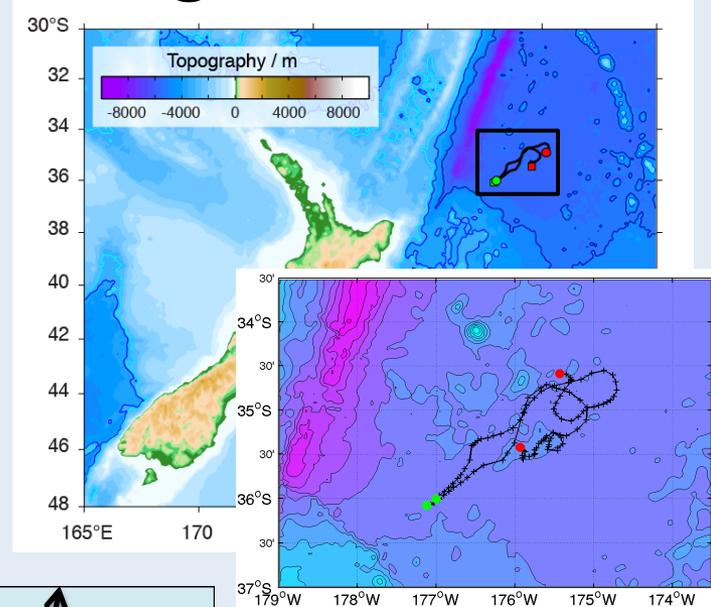
Deep SOLO floats deployed by RV Tangaroa



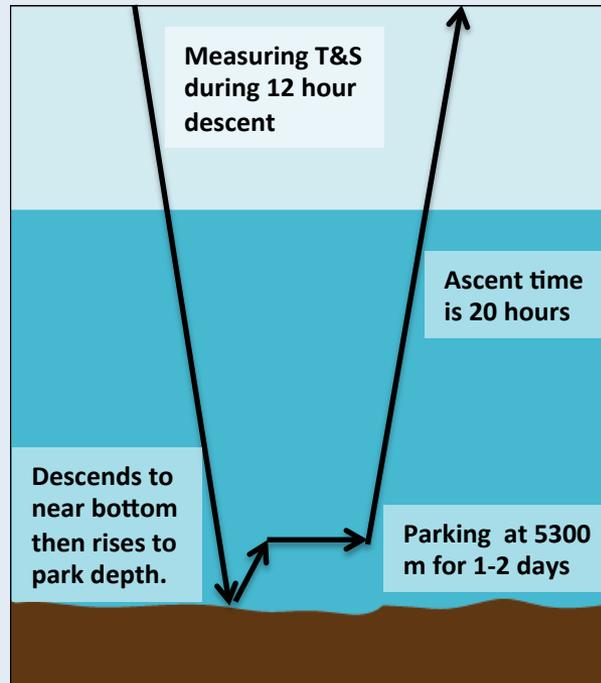
T/S offset and variability

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

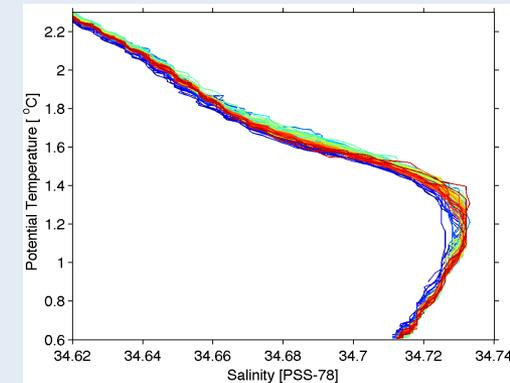
6002 is 0.04 too fresh. Recovery of 6002 and 6003 is planned, for better understanding of the offsets.



Deep SOLO 6002 and 6003 have each completed over 50 cycles. Θ anomaly plot (relative to multi-cycle mean) for 6003.



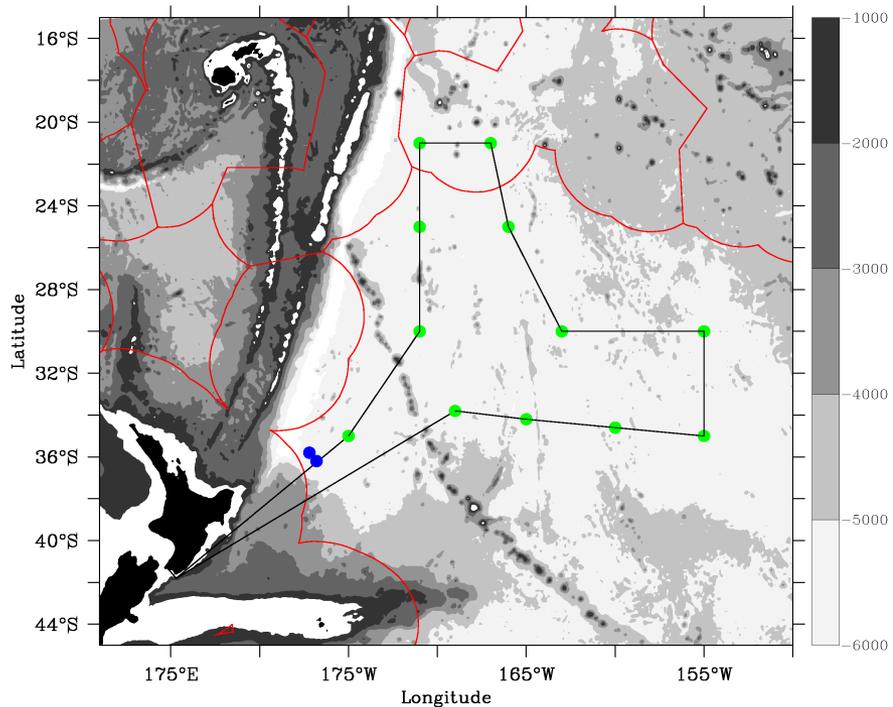
Path of 2 Deep SOLOs. Bottom depth is ~5600 m.



Θ -S plot for 6003



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



Deep Argo float deployment in the SW Pacific Basin - 2015

Tentative plan

- Mid 2015; US, NZ, Aus Argo
- R/V 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 R/V Kaharoa has deployed 20% of all presently active Argo floats.



Summary



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



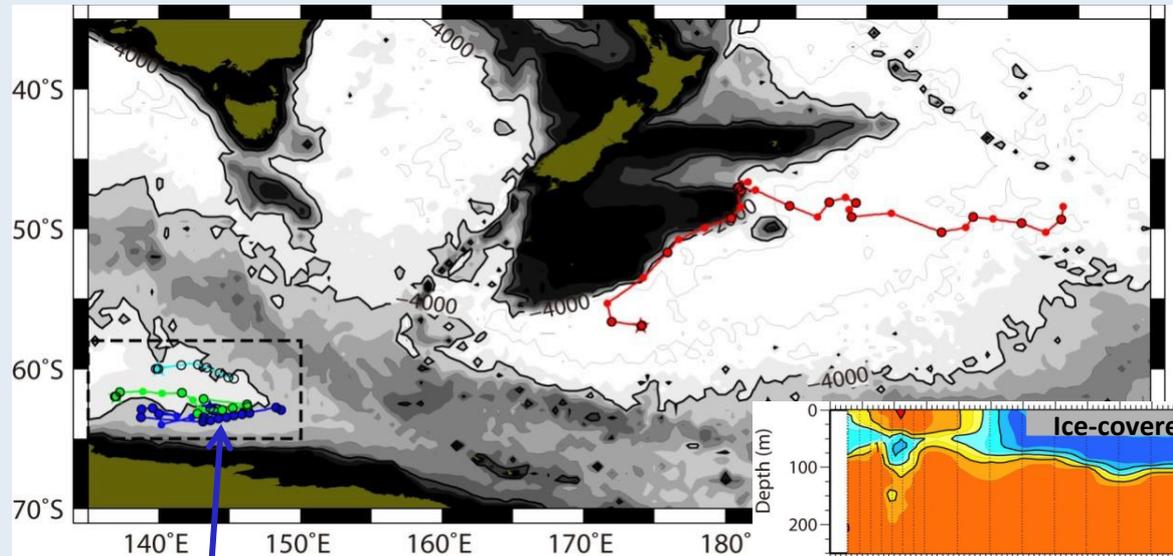
*Abysal waters:
Heat, salt, flows, chemistry change
in inky darkness.*



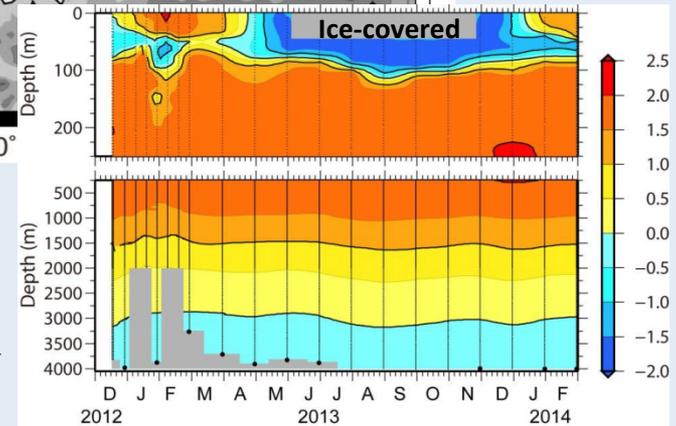
Deep NINJA

In production since 4/2013

11 deep NINJA floats deployed in Southern Ocean, 2012 – 2014,
3 in North Pacific

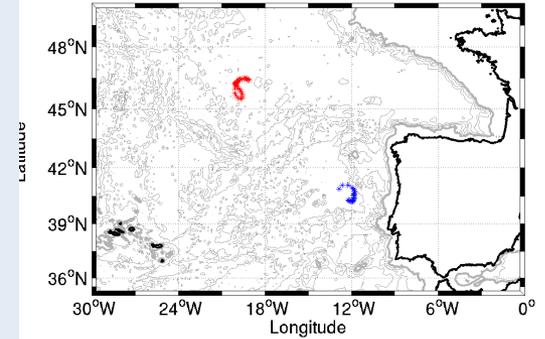


Potential temperature observed
by a Deep NINJA, including a
period with sea-ice cover.

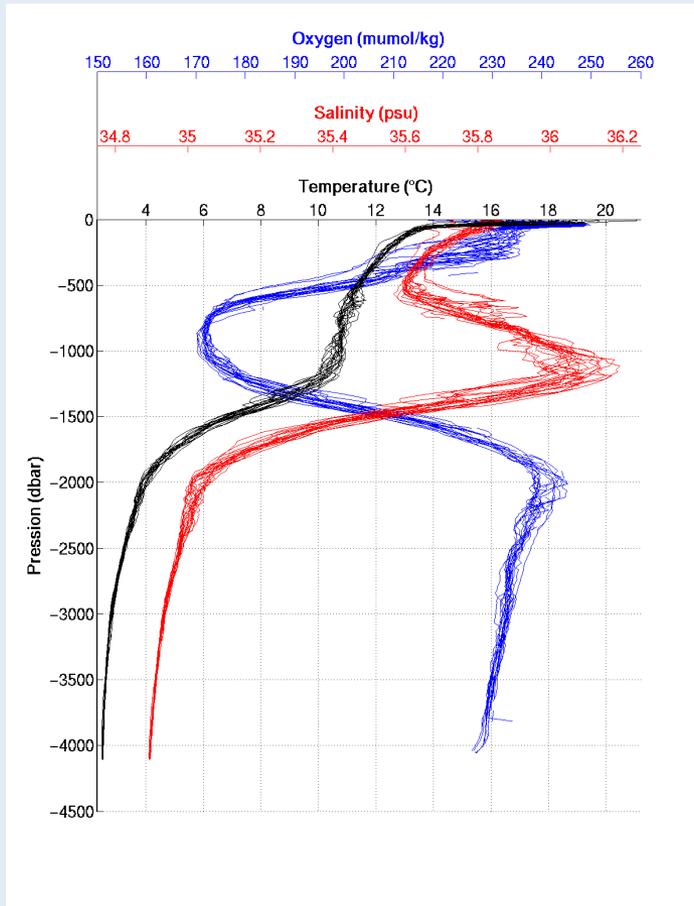


Deep ARVOR

- 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, O₂ option



Positions of 4000 m prototypes



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

