Status of sustained deep ocean observations

Nathalie Zilberman
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Driving scientific questions

Sustained EOV observations rely on complementary ocean observing programs

Present vision of the deep-ocean observing strategy

- GO-SHIP
- OceanSITES
- Deep Argo
- New technologies

Summary
Recommendations for expanding deep-ocean observing systems - Ocean Obs’09

Science Motivation

- Close the global budgets of heat and freshwater
- Improve knowledge of regional to global sea level variability, and quantify the causes of sea level change
- Provide basin coverage of deep ocean circulation, including the overturning circulation

Repeat hydrography and moored arrays

- Coast-to-coast/ice transport lines, deep boundary currents, inter-basin exchanges, deep water formation regions.
- Global widely-spaced grid of regular deep T, S, P observations is needed

“deeper reaching Argo floats”

(Rintoul et al., 2009) (Garzoli et al., 2009)
Repeat hydrography provides the gold standard for temperature, salinity, and pressure.

GO-SHIP lines are repeated on a decadal basis.

Additional observations are needed to reduce uncertainties in Earth energy and sea level budget.

Most T, S, P data in ocean interior from GO-SHIP repeat hydrography.

Over 10,000 casts depth > 2000 m collected since 2009.

Deep-ocean is under-sampled.

Deep-ocean sections of 2012-2023 survey.
Ocean Stations and Deep Moorings

OceanSITES Network

- Sustained high-frequency time series for at least 5 years
- Network of 200 platforms at fixed locations (mostly moorings)
- Single sites and sections across choke points, boundary currents, and ocean basins
- Coordinates implementation and calibration of sensors, and data distribution

OceanSITES deep TS stations and moorings

- Possibility to install sensors in deep water on all platforms
- Over 88 sites will carry deep T, S, P observations
- Pool of sensors would allow to instrument 10-15 more sites
Deep Argo Program

- 4 Deep Argo float models: Deep NINJA (Japan); Deep Arvor (France), Deep APEX and Deep SOLO (U.S.)
- CTD SBE-41 on 4000 m Deep NINJA and Deep Arvor
- CTD SBE-61 on 6000 m Deep SOLO and Deep APEX
- Target array size: 1228 floats, 5° x 5° Deep Argo float array to estimate annual ocean heat content anomalies and thermosteric sea level anomalies from 2000-6000 m (Johnson et al., 2015)
- 15-day cycles given float lifetime and to maintain 5-year turnover (sensor drift, float and CTD renewal)
- Begin with regional pilot arrays, including seasonally ice-covered regions

Long-term goals – Deep Argo straw plan

- 1228 Deep Argo float array
- Bottom depth < 4000 m
- Bottom depth > 4000 m
Status of Deep Argo

Implementation phase: regional pilot arrays

- Technical capability for floats and CTDs
- Feasibility of large-scale arrays
- Scientific value of systematic observations

75 Deep Argo floats - 4 pilot arrays in regions of significant deep ocean warming signal and near deep water mass formation

- North Atlantic Basin (28 floats)
- Southwest Pacific Basin (21 floats)
- South Australian and Australian Antarctic Basin (21 floats)
- Brazil Basin (28+ floats)

Global implementation of the Deep Argo program could start in 2-3 years
Multidecadal deep warming signal

Elements of deep overturning circulation

Stable $\Theta$–$S$ in AABW layer useful for SBE-61 CTD validation

There are 11 Deep SOLOs and 2 Deep APEXs active in the SW Pacific array

3 Deep SOLO floats (32°S) will be deployed from R/V Palmer - 07/2017 - 5 Deep SOLO floats will be deployed from R/V Kaharoa - 10/2017 - Additional Deep SOLO float deployments likely in 2018
Deep SOLO floats are currently cycling to or near the bottom every 10 days.

Over 400 Deep SOLO float profiles were collected since January 2016 in the SW Pacific.

P06 and P15S CTD profiles from 2009 show tight TS relationship at $\Theta = 0.7^\circ C$ (4800 dbar) and $\Theta = 2.0^\circ C$ (2200 dbar) indicating small spatial variability in $\Theta/S$ characteristics.
Deep SOLO floats 6004 and 6009 drifted at shallow depth (100-200 m), and 6006 and 6007 drifted at 4000-5000 m for 134 days. An impedance mismatch between the float and CTD occurred in early deployments, and was corrected in some by recovery, redeployment and reprogramming.

The fresh bias in Deep SOLO relative to reference data in abyssal layer (-0.0037 psu at 0.7°C) may be due to incorrect value of SBE-61 CTD conductivity cell compressibility. Fresh bias at 2.0°C (-0.0016 psu), smaller than for 0.7°C, suggests, that it is pressure dependent.

Salinity scatter (±0.004 psu at 0.7°C) is partly due to random pressure error (±3 dbar results in ±0.001 psu). Stability is good (±0.001 psu) for most CTDs.

Pressure sensor accuracy is about ±5 dbar from shipboard CTD comparisons.
Geostrophic transport in the Southwest Pacific Ocean

Geostrophic velocity based on Deep SOLO TS profiles and core Argo trajectories at parking depth consistent with inverse solution based on WOCE P06, Argo floats, and moored data.

(Wijffels et al., 2001)
Deep Argo Pilot Array in the North Atlantic Ocean

- Strong interannual variability in NADW TS characteristics near formation regions
- Comparative observations of NADW properties, and circulation in the ocean interior at 24°N.
- Improve knowledge of AMOC, basin-wide integrals of the flow field, and fluxes of heat and freshwater
- Good reference data available, including moored sections (RAPID, OSNAP) and repeat hydrography line (GO-SHIP)
- There are 4 Deep Arvors, 6 Deep SOLOs, and 1 Deep APEX active in the North Atlantic array
- 15 Deep Arvor floats will be deployed from R/V Atalante - 07/2017
- 2 Deep Arvor floats will be deployed from R/V Hudson - 07/2017
Deep Argo Pilot Arrays in the South Australian and Australian Antarctic Basins

- Spreading pathway of AABW in the South Australian Basin – Strong seasonal to interannual signal in the Australian Antarctic Basin – Deep hydrography provides calibration and deployment opportunities

- 8 Deep SOLOs and 1 Deep APEX are currently sampling the South Australian Basin

- Shipboard CTD, bottle sampling, and Deep Argo float deployments of 5 Deep SOLO, 3 Deep Arvor, and 3 Deep NINJA floats scheduled January 2018 onboard R/V Investigator

- Additional Deep Argo float deployments likely in 2020 or sooner
Summary of the Deep Ocean observing system

- GO-SHIP collects highly accurate coast-to-coast hydrographic reference data from spatially-sparse sections repeated on decadal basis.

- OceanSITES provides fixed-point time series of deep properties and velocity at key regions (including choke points and boundary currents)

- Deep Argo will extend conventional Argo sampling to the ocean bottom

- Interannual to decadal variability of deep properties and overturning circulation is not well understood.

- Increased deep-ocean sampling is needed in the ocean interior and at basin boundaries.