FY2013 Annual Report

The Argo Project: Global Observations for Understanding and Prediction of Climate Variability

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Submitted by Stephen R. Piotrowicz, US Argo Program Manager, on behalf of the US Argo Consortium 1 October 2013 :

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1. Project Summary

The Argo Program obtains systematic global observations of subsurface ocean temperature, salinity, and circulation. These key variables describe the physical state of the ocean, including its heat and fresh water content and their transport by ocean currents, and the contribution of changes in seawater temperature and salinity to sea surface height. Over 3500 Argo floats presently provide over 120,000 ocean profiles each year.

Argo data are used in (i) basic oceanographic research, (ii) operational analyses of the ocean including initialization of ocean and ocean-atmosphere forecast models, (iii) national and international assessments of climate, and (iv) secondary and tertiary education. Basic research using Argo data spans a broad range of investigations aimed at improved understanding of the oceans, their variability, and their interactions with the atmosphere. The phenomena studied range from rapid weather events, such as tropical cyclones – whose heat source is the warm oceans, to multidecadal trends in heat and freshwater that are key indices of climate change. They include seasonal exchanges of heat and freshwater on hemispheric scales, water mass formation processes embedded in the seasonal cycle, interannual climate phenomena such as El Niño/La Niña, and decadal variability in the Pacific Decadal Oscillation and the Southern Annular Mode. For all of these, it is important to study not only air-sea interactions, but their cumulative impact on ocean properties, including temperature and salinity. The ocean is the climate system's dominant reservoir for storage of heat and water, which it exchanges with the atmosphere, land, and cryosphere, and transports through ocean circulation. The ocean's great capacity for storage and its slow circulation provide long time scales in the climate system, smoothing the rapid changes of the atmosphere forcing.

The knowledge gained through basic research is applied in global and regional models for understanding and prediction of the economic and human impacts related to variability in the physical state of the oceans. Interactions in the ocean-atmosphere system are responsible for extreme weather events and for extended periods of drought or flooding. The warming and expansion of the oceans is a large component in regional and global sea level rise, and therefore important in assessing risks to coastlines and coastal infrastructure. Ocean temperature and circulation are also primary factors influencing marine ecosystems, and their systematic observation is essential for ecosystem management. There remains a great deal to be learned to connect the fundamental properties of the oceans with the societal impacts of climate variability and change. The Argo Program provides the baseline ocean observing system that, together with related satellite and in situ global ocean observations, will continue to underpin the progress in these areas.

Success in realizing U.S. Argo Program objectives will depend on year-to-year availability of resources and on mean float lifetimes. The US Argo Program has been able to maintain over 1500 active floats since 2007. With a constant budget since 2003, the deployment rate has dropped from around 400 a year to 310-340 a year for the last three years. The U.S. has been able to sustain an array of >1500 operating floats because of tehnological developments that extended the lifetime of floats to more than four years. International Argo partners have also experienced diminished resources. Not only the Argo array but also its data system is impacted, ane there is concern for the ability of the data system to accommodate chnges in data formats and new requirements.

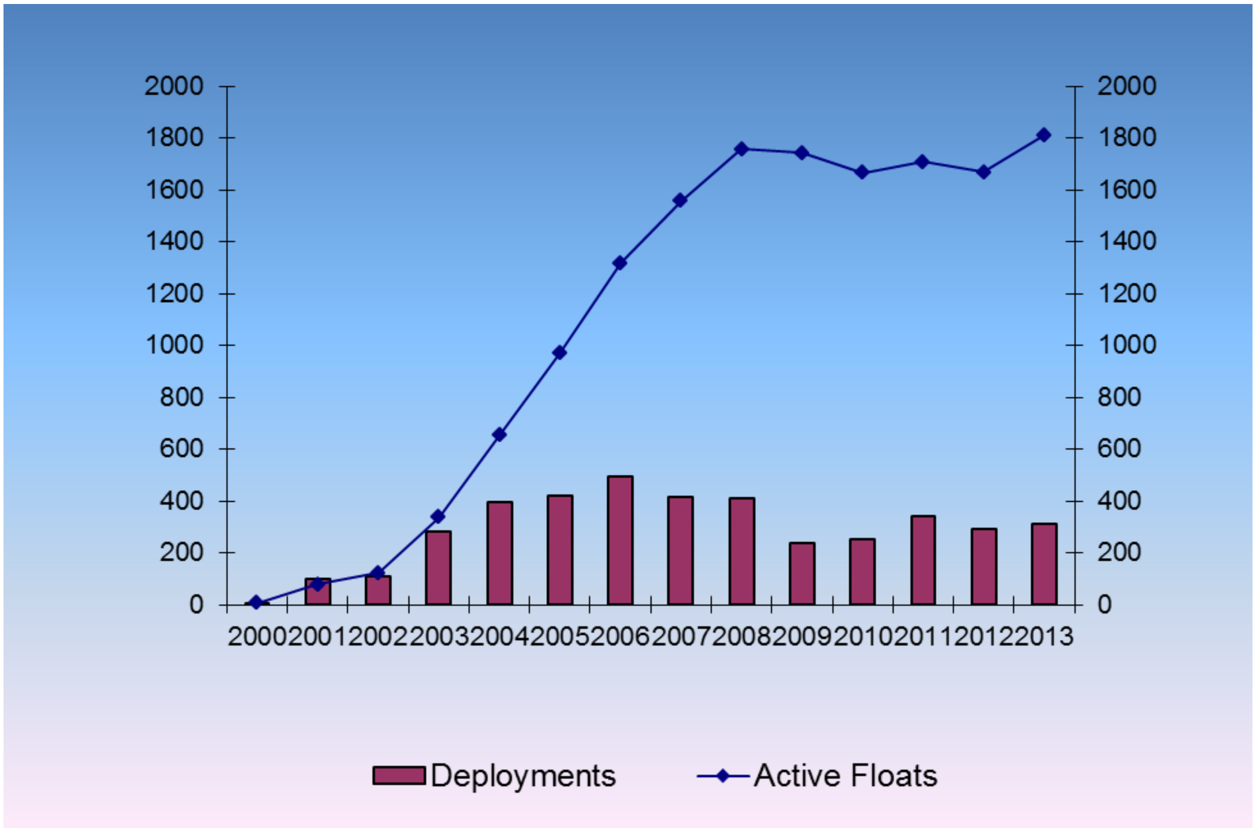


***Figure 1**: Yearly deployments by the United States Argo Program through 28 August 2013 and the number of active U.S. floats.*

2. Scientific and Observing System Accomplishments

The Argo Program, through its global collection of temperature and salinity profile data and ocean circulation observations, contributes importantly to each of the NOAA/Climate Observation Division Program Deliverables:

• ***Sea Surface Temperature and Surface Currents.*** Argo profile data provide the near-surface temperature structure globally, with ongoing improvements in vertical resolution and in proximity to the sea surface. Argo profiles and trajectory data together provide the absolute geostrophic current from 0 – 2000 m.

• ***Ocean Heat Content and Transport.*** Argo temperature profile data is the primary source for global estimation of 0–2000 m ocean heat content, including for national and international climate assessments (e.g. IPCC AR5). Argo includes estimates of temperature and absolute geostrophic velocity, from which heat transport is calculated on the large spatial scales resolved by the Argo array.

• ***Air-Sea Exchanges of Heat, Momentum, and Fresh Water***. The impact of air-sea exchanges on water column properties is observed by Argo including exchanges of heat (temperature variability), fresh water (salinity variability) and momentum (ocean circulation variability).

• ***Sea Level.*** Sea level variability and change is caused by both mass and density components. Argo provides global and regional estimates of steric sea level (0-2000 m), and is the only observing system component to do so.

• ***Ocean Carbon Uptake and Content.*** Ocean-atmosphere exchanges of carbon dioxide are dependent on surface layer temperature variability. In addition, Argo monitoring of the changing ocean temperature field could be exploited to interpolate temporally and spatially between sparse ship-based estimates of ocean carbon storage

• ***Sea Ice Thickness and Extent*** are strongly affected by the salt and heat content of the underlying waters in contact with sea ice. Argo coverage in the seasonal ice zone continues to be expanded for better observation and understanding of ocean/ice interactions. Changes in temperature of waters offshore of ice sheets also affects basal melting of ice sheets, and Argo's expansion into the seasonal ice zone increases observations offshore of ice sheets as well.

2.1 Observing System

U.S. Argo float production and deployment are accomplished by four facilities – SIO (production and deployment), WHOI (production)/AOML (deployment), UW (assembly and deployment), and PMEL (testing and deployment of commercially manufactured floats). This distributed effort has been designed to safeguard the US contribution to the Argo Program from unforeseen problems at any one of the partner institutions. It also makes Argo success independent of the participation of any individual PI and institution or of any single float design. It allows the large amount of effort to be shared. It encourages individual, technical innovation and enhancement. The number of U.S. Argo floats deployed per year varies according to funding levels and technical constraints (Figure 1), but the number of active floats has increased above 1600 and remained fairly level. Presently there are1808 active U.S. Argo Program floats plus 153 U.S. Argo-equivalent instruments that also feed data to the US Argo DAC. Floats are presently being deployed at a rate of ~330 per year.

The U.S. Argo data system is also distributed. AOML is the Data Assembly Center (DAC), responsible for acquiring the float data received by satellite communications, for carrying out real-time quality control, and for distribution of data via the GTS and to the Global Argo Data Assembly Centers. The second step in data management is a semi-automated drift-adjustment of the salinity sensor carried out by each float-providing PI, using nearby high quality CTD data for comparison with float temperature/salinity data (Wong et al, 2003, Owens and Wong, 2009). The final step is individual examination of all profiles by the float-providing PIs, in order to provide high-quality data suitable for research applications. Approximately 95% of Argo data meet the timeliness target, being available within 24 hours of collection via the GTS and/or internet (http://www.usgodae.org/ or http://www.coriolis.eu.org/).

Of the 1808 active US Argo floats, 1171 are in the Southern Hemisphere (Figure 2), reflecting the US commitment to eliminate the northern bias of historical opportunistic data collection and achieve uniform global coverage. A notable effort has been the collaboration between US Argo and NIWA (Argo-New Zealand) and Australia (Argo-Australia), resulting in more than 1134 (1085 U.S.) deployments since 2004 in remote ocean locations by NIWA’s R/V Kaharoa (1089) and Tangaroa (45).

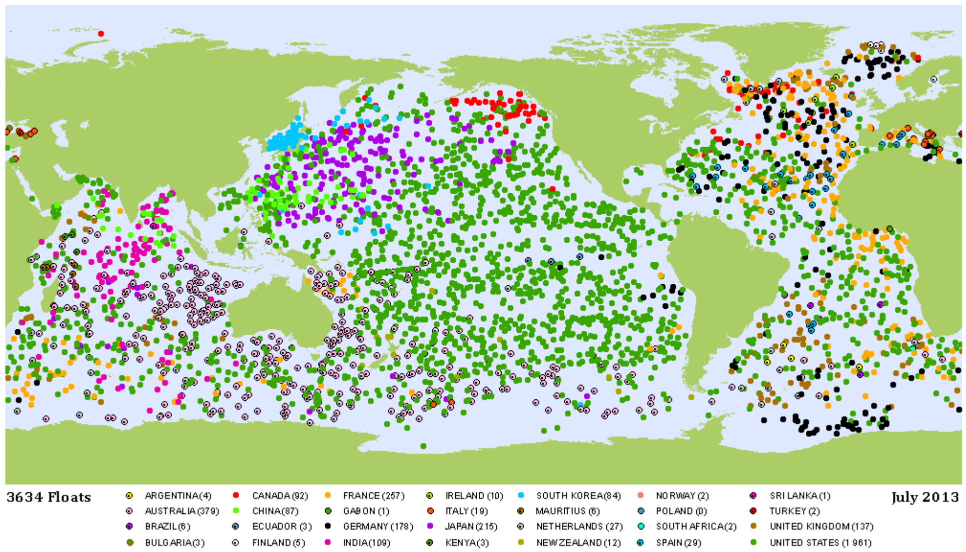


Figure 2*: The Argo Array as of 30 July 2013. As of 30 July 2013 there were 1961 active US floats including 1808 floats funded under the U.S. Argo Program, and 153 other US (Argo-equivalent) floats whose data are released by the PIs via the U.S. Argo Data Assembly Center.*

Good progress has been made in increasing float lifetimes (Fig. 3). Figure 3 is based on calendar years. It is likely that the goal of a 4-year mean lifetime has been met for both APEX and SOLO designs. Floats deployed in 2006-2008 exhibited a higher failure rate due to a problem in CTDs manufactured by Sea-Bird Electronics discussed in previous reports. Prototype SOLO-II floats have been deployed, the first float achieving over 300 cycles in an accelerated testing program. Commercial production of the SOLO-II has begun and the first US purchases of the SOLO-II have occurred. The US is the technology leader in profiling floats and about 90% of floats in the international array are made in the US.

The Argo data system continues to operate well, with the AOML DAC providing near-real time data to the GDACs in NetCDF format consistent with international specifications. Improvements in procedures continue to be implemented as required by the International Argo Data Management Team. A backlog in processing of research-quality delayed-mode data has been substantially reduced and will be eliminated in the coming year. The pressure offset error detected in some WHOI floats in 2008 has been corrected (http://www-argo.ucsd.edu/Acpres_offset2.html). Procedures are being considered for more effective detection of systematic data errors.

The US Argo consortium plays strong leadership roles in the international Argo project. This includes the international Argo Steering Team Co-Chairman (Dean Roemmich, SIO), the international Argo Data Management Team and many international panel memberships. US partners provide international leadership in float technology and data management techniques through workshops and training of international colleagues. The US is also a leader in utilization of Argo data, organizing international symposia and through sharing of research results and operational capabilities.

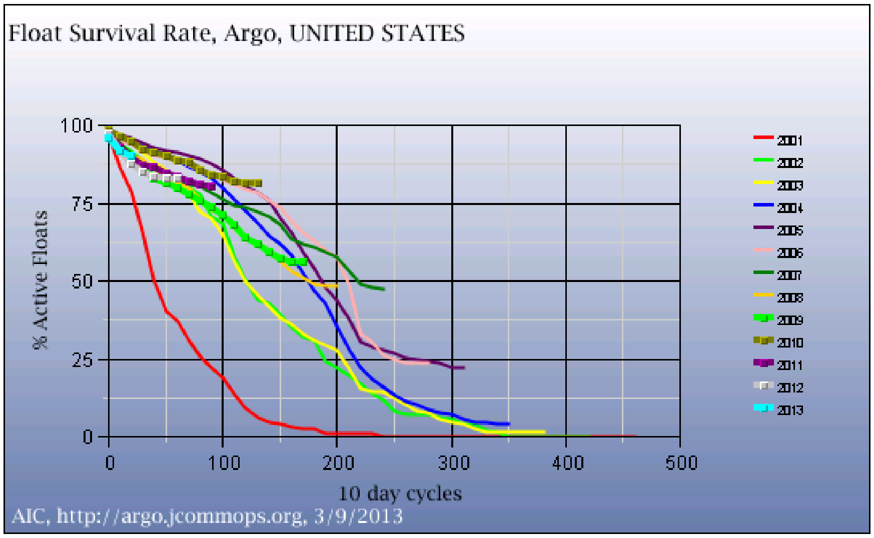
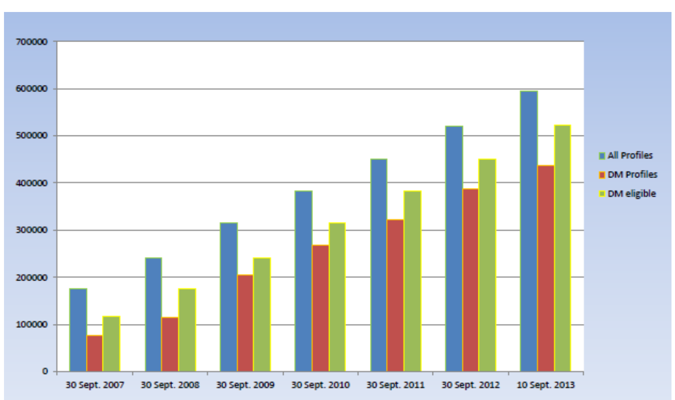
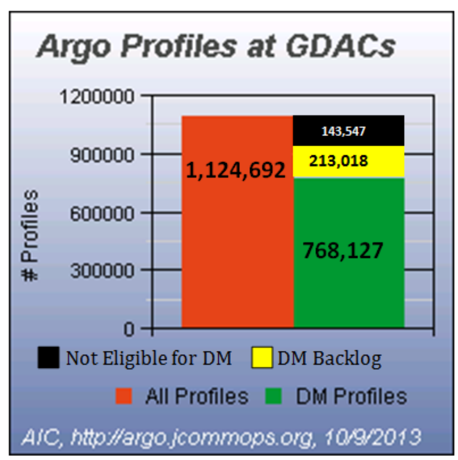


Figure 3: *Float reliability: The average number of cycles for U.S. Argo Program Floats deployed in 2008 (all floats having been deployed for over 4 years) is 138 with 55% still active.*

A sparse global Argo array was achieved in 2004, and so there are now 8 years of continuous global coverage. Today Argo is providing over 120,000 high quality profiles of temperature and salinity annually, most to 2,000 meters, homogeneously distributed over the global ocean, without seasonal bias. Beginning in 2007, more than 100,000 profiles a year are being received with 91% being distributed on the GTS within 24 hours of collection (U.S. – 96% within 24 hours), and approximate 96% available within 72 hours via the GTS and Internet. Figure 4(a) shows the growth of U.S. Argo Program profiles available at the GDACs since June 2007 and the status of the Delayed-Mode Quality Control processing as of September 2013.



(a) U.S. Argo Program profiles at the GDACs from June 2007 through 10 September 2013



(b) Status of Global Argo Delayed-Mode Quality Control (DMQC) processing as of 10 Setember 2013.

Figure 4: *Argo Profiles at the Global Data Assembly Centers (GDACs)*

Because of the need to obtain extended data records to assess instrument drift, profiles are considered "eligible for DMQC when a one-year record has been obtained from the instrument. As of this report, approximately 80% of the total number of profiles eligible for DMQC processing have been processed. The U.S. Argo Program has processed approximately 89% of its eligible profiles. DMQC processing is a labor intensive process. Three generations of software routines have been published and used to process profiles in an semi-automated mode, however, a large fraction (8-20% depending on float type, float age, etc.) have to be manually inspected to determine if a signal represents sensor drift or represents changing water masses. Assessing water mass changes requires inspection of the T-S profiles, an understanding of the dynamics of the region, and often access to other data sets such as high-quality, shipboard CTDs. Figure 4(b) presents the status of DMQC processing for the global Argo Program.

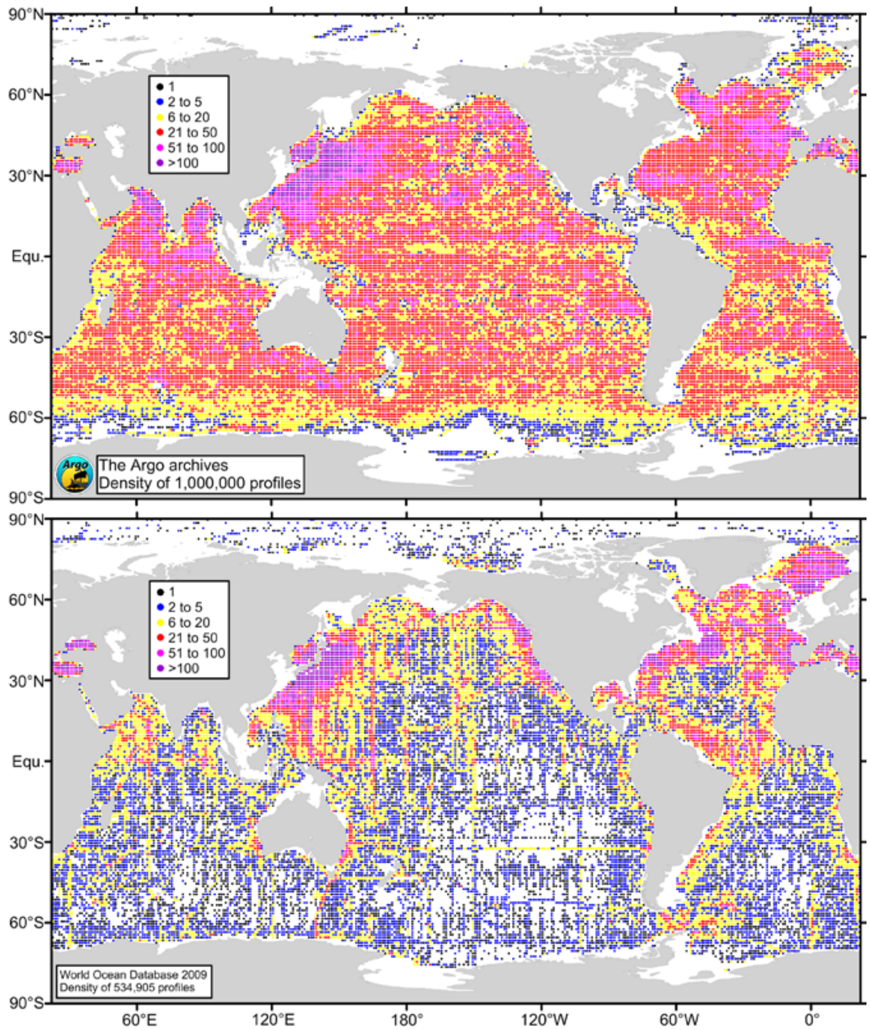


Figure 5: *Density of profiles, 1˚ x 1˚ grid, of T&S below 1,000 m (top) in the Argo database as of 4 November 2012 and non-Argo profiles (bottom) in WOD09. The median value for Argo profiles in a 1˚ x 1˚ box is 24 while for WOD2009 the median is 2.*

In November 2012 the 1,000,000th Argo T&S profile was acquired and uploaded to the Argo GDACs. The top panel of Figure 5 is a plot of the density distribution on a 1˚ x 1˚ grid of profiles in the Argo database as of November 2012. The lower panel of Figure 5 is a similar plot of all of the non-Argo T&S profiles (i.e., hydrographic casts, CTD profiles, etc.) below 1,000 m contained in the entire historical data archive. In only 8 years of global coverage Argo has not only nearly doubled the number of T&S profiles below 1,000 m from all other sources but it has provided relatively homogeneous coverage throughout the global oceans without temporal bias.

The Argo array is providing unprecedented views of the evolving physical state of the ocean. It reveals the physical processes that balance the large-scale heat and freshwater budgets of the ocean and provides a crucial dataset for initialization of and assimilation in seasonal-to-decadal forecast models. The present 8-year global dataset provides a well-resolved baseline of the present climate-state of the oceans against which future variability can be observed by a sustained Argo array, and against which past variability can be better assessed with sparse historical data. With 8 years of global data we have, for the first time, a stable estimate of the mean of the global ocean over a fixed period of time.

2.1 Extending Argo into the Deep Ocean

In FY2011, U.S. Argo began the development of Deep Argo floats. While the present Argo array, sampling the upper 2000 m, is of high value in a broad range of applications, the need to sample the full ocean water column (0 – 6000 m) is also recognized. Issues of interest for Deep Argo include regional and global deep ocean heat storage, deep contributions to steric sea level variability and change, and deep ocean components of meridional overturning circulations. As with the upper ocean Argo array, we believe a diversified approach to float design and production will produce the best and most cost effective instruments. Therefore, SIO has undertaken in-house development of Deep SOLO floats, and simultaneously UW has entered into a partnership with a commercial entity (Teledyne Webb Research, TWR) for development of Deep APEX. As of mid-2013, prototypes of both float types have been deployed, by TWR to 4000 m off Hawaii and 6000 in the Puerto Rico Trench. A prototype SIO Deep SOLO deployed off California made about 70 cycles to 4000 m (including CTD profiling), and is awaiting recovery while continuing to cycle to 3000 m. In parallel with the float developments,

SeaBird Electronics is developing a deep float CTD (SBE 61) with enhanced stability and accuracy requirements needed for abyssal temperature/salinity/pressure measurement. A tentative plan has been made for a dedicated cruise to deploy additional prototype Deep APEX and Deep SOLO floats around June 2014. This will be a joint effort by the New Zealand, Australian and U.S. Argo Programs, using N.Z.'s RV Tangaroa to reach a deployment site on the abyssal plain northeast of New Zealand, with bottom depth around 5500 m. NIWA (N.Z.) will provide most of the ship time cost, plus a shipboard 911 CTD/rosette system that will be used for calibration and validation of the SBE-61. About 4 prototype U.S. Deep Argo floats will be deployed. In addition, we will invite participation by France and Japan Argo programs, who are partners in commercial development of mid-depth floats (3500 – 4000 m capability).

2.2 Scientific Highlights

2.2.1 Scripps Institution of Oceanography, UCSD

Within the Argo group at SIO, researchers include D. Roemmich (P.I.), J. Gilson (Co. I.), N. Zilberman (post-doctoral investigator), F. Gasparin (post-doctoral investigator), and D. Giglio (PhD student). Many other SIO academics who are not formally part of the Argo group have each published multiple papers utilizing Argo data, including S. Gille, B. Cornuelle, L. Talley, T. Chereskin, J. Sprintall, and M. Mazloff. J. Gilson continues to provide a publicly available gridded (objectively mapped) monthly global Argo dataset, plus experimental versions with higher spatial and/or temporal resolution.

The focus of the SIO Argo group is on ocean-scale to global analyses that exploit Argo's unique coverage and demonstrate its value on a broad range of time-scales from intra-seasonal, seasonal, and interannual, to decadal and multi-decadal. Two highlights from recent analyses are provided below.

1. Interannual variability in the circulation of the North Pacific Gyre. D. Giglio showed that the North Pacific gyre changed in amplitude, from stronger in 2004/05 to weaker in 2008/09 and in orientation, with its zonal axis shifting toward northwest-southeast in 2004 (Fig. 6). This work illustrates the capacity of the Argo dataset to resolve interannual variability in gyre-scale circulation.

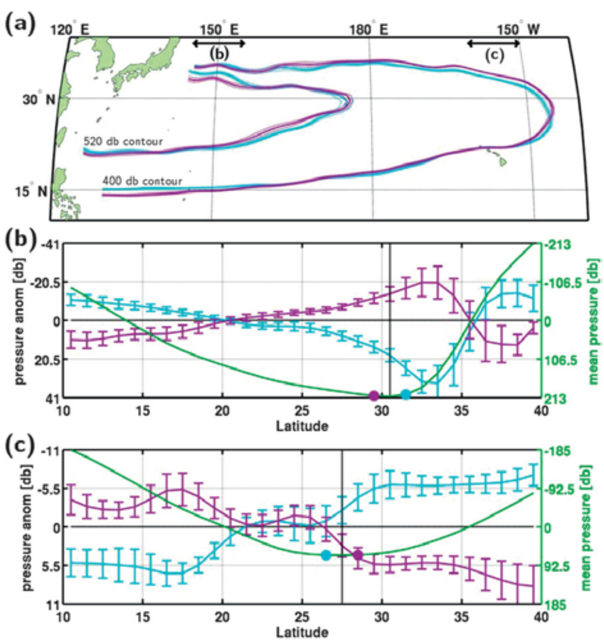


***Figure 6:** (a) Schematic of the gyre movement, showing the 400 and 520 db pressure contour on the sigma-theta 26.4 isopycnal surface. Cyan line: position in 2004/05. Purple line: same, but in 2008/09. (b) Green line: temporal mean field of pressure (db) on sigma-theta 26.4 kg, averaged over 150°–160°E; the spatial mean is removed at every point in time. Cyan and purple lines: anomaly of the same variable averaged in 2004/05 (cyan line) and in 2008/09 (purple line). Error bars are also shown. The vertical black line indicates the mean location of maximum pressure;*

circles show the location of the same in 2004/05 (cyan circle) and in 2008/09 (purple circle). (c) As in (b), but the zonal average is over 160° – 150°W. From Giglio et al. (2012).

2. The shallow meridional overturning circulation (subtropical cell) and its El Niño/La Niña variability were analyzed by Zilberman et al. (2013). Equatorward geostrophic transport within the subtropical cell is stronger in the ocean interior and weaker in the western boundary during La Niña, with changes in the interior being greater than in the western boundary region (Fig. 7). The shallow overturning circulation dominates the ocean heat transport at this latitude.

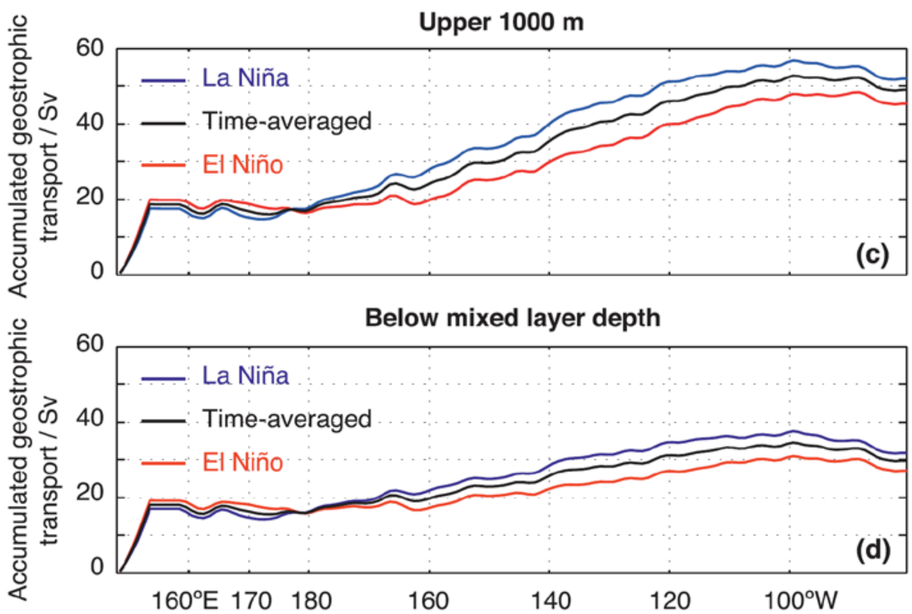


Figure 7: *Geostrophic transport accumulated from the coast of New Guinea eastward at 7.5°S (c) for the upper 1000 m averaged from 2004 to 2011 and (d) below the mixed layer depth (black) and for La Niña (blue) and El Niño (red) events of 2004–11. From Zilberman et al. (2013).*

2.2.2 University of Washington

(1) *Argo in the Antarctic*

In the past year the UW group has continued to explore the addition of new capabilities and sensors to US Argo floats. In 2011 we published a paper (Wong and Riser, *Journal of Physical Oceanography*, Volume 41, 1102-1115) showing how floats could be used in the seasonal ice zone in the Antarctic (a second paper on this topic [Wong and Riser, 2013] has recently been submitted to *Geophysical Research Letters*). We used a suite of 19 floats in this study that were equipped with an ice-avoidance algorithm. Many of these floats survived for at least 4 winters in the ice zone south of Australia, and the resulting data give a unique view of mixing and stratification under the ice in winter and the restratification in spring as the ice melts (Fig. 8). In the past year we have deployed another set of floats in the Ross Sea region, with similar under-ice capabilities, and we expect to see the first set of profiles from these floats in the upcoming austral summer. Additionally, we have built and shipped a suite of 24 floats (funded jointly by NOAA and NSF) for deployment in the Pacific sector of the Southern Ocean in the coming austral summer. These floats are equipped with oxygen, nitrate, chlorophyll, and pH sensors, with the goal of examining the interplay of physical, chemical, and biological processes in the seasonal ice zone. The pH sensor should prove to be especially useful in beginning to examine ocean acidification in this region. The Southern Ocean has been highlighted by the International Argo Steering Team for a number of years as a region that is undersampled by Argo, in spite of its prominent importance in the global climate system, and we hope that our float deployments in this region will help to remedy this deficiency.

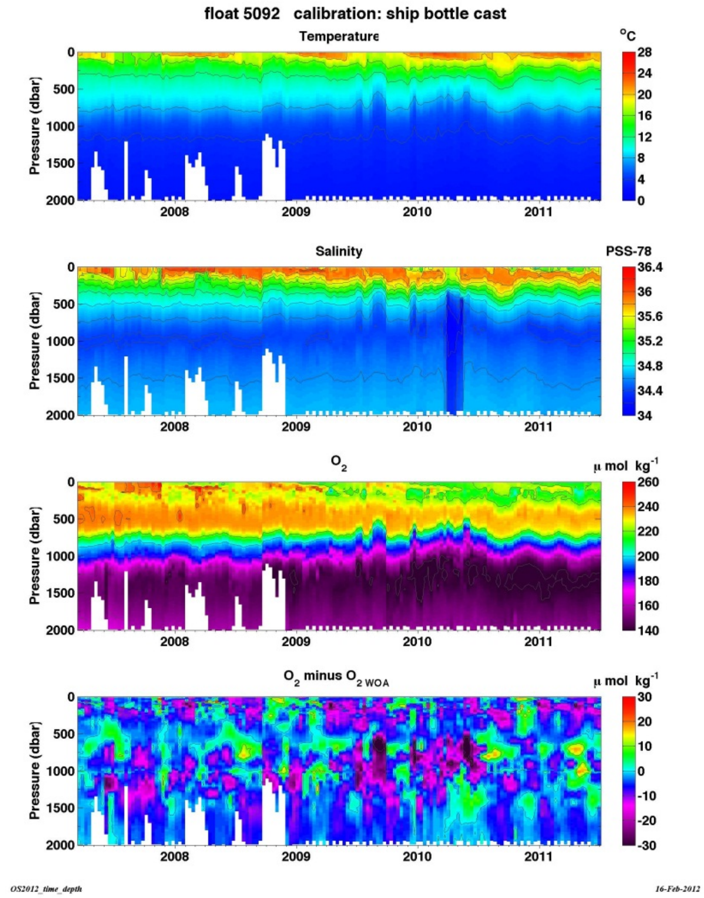


Figure 8: Evolution of temperature, salinity, and dissolved oxygen in the seasonal ice zone of the Antarctic from 2007 through late 2011.

(2) *Studies of small-scale mixing from Argo floats*

Besides the usual profiles of temperature and salinity collected by Argo floats at roughly 10-day intervals, many floats collect other observations that, while not directly relevant to the central issue of ocean/atmosphere/climate interactions, can be used to investigate scientific issues related to climate. One of these issues is the mixing of the ocean on 10-100 meter vertical scales. Since many floats now use the Iridium satellite system and are transmit data at 2 decibar intervals, it is possible to examine the variability of the ocean on smaller vertical scales than has previously been possible. To this end, several studies have been completed that attempt to assess the magnitude of this small-scale mixing in the ocean. In one study (Whalen et al., 2012) the UW Iridium float data were used to investigate the global distribution of mixing on small scales. In a similar vein, another paper (Wu et al., 2011; Fig. 9) showed that mixing in the Antarctic was highest to the east of Drake Passage, where the flow moves over topography, out of the Passage, and into the South Atlantic.

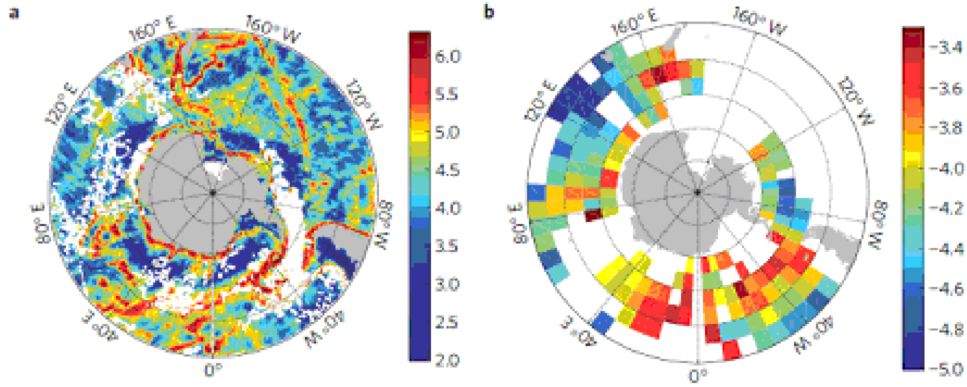


Figure 9: *Horizontal distribution of topographic roughness and diapycnal diffusivity in the Southern Ocean. a – Topographic roughness and geographic distribution of high-resolution profiles (white dots) obtained from the Argo Iridium floats used in the Southern Ocean and described in this paper. The color scale represents* Log_{10}*(Roughness) in* m^2*. b – Horizontal distribution of diapycnal diffusivity, vertically averaged of the depth range 300-1,800 m, on a 6º x 5º spatial grid. The color scale represents* $Log_{10}(K)$ *in* m^2s^{-1}*.*

We are presently continuing a project related to this. A graduate student, Mr. Tyler Hennon, has recently completed a study that estimates the strength of global mixing from internal gravity waves using the same UW Argo float data. In this case the data are used are underway temperature and salinity measurements, collected once per hour while the floats are in their park phase. These data have been fit to simple models of internal gravity wave behavior and the global distribution of kinetic energy and energy flux from these waves have been estimate. Once again, the effects of bottom topography in the Antarctic appear to be especially strong. This work (Hennon, Riser, and Alford, 2013) is now under review for publication in *Journal of Physical Oceanography*.

2.2.3 Pacific Marine Environmental Laboratory

In FY2013 PMEL released a new ocean temperature and salinity climatology (http://www.pmel.noaa.gov/mimoc/; Schmidtko et al., 2013) entitled MIMOC (Monthly Isopycnal/Mixed layer Ocean Climatology). This climatology includes both Argo and historical CTD data. It is dominated by Argo data over most of the globe, but the historical data are useful to fill in coastal regions, polar oceans, and marginal seas where Argo data are sill sparse. MIMOC is monthly climatology of the modern global ocean, documenting the seasonal cycle with several innovations that allow it to closely resemble what a synoptic survey of the ocean in a typical month would look like, while still averaging out eddy signals (Fig. 10).

MIMOC provides maps of mixed -layer properties (temperature, salinity, and maximum pressure), as well as subsurface maps of properties on density surfaces (temperature, salinity, and pressure), with the innovation that it carefully merges the two sets of maps to provide properties (temperature and salinity) on a vertical pressure grid. This mapping and gridding procedure allows preservation of a sharp mixed layer in the pressure-gridded fields, and better preserves water properties and vertical density structures by mapping on density surfaces in the interior, since water moves along density surfaces. Second, MIMOC introduces the "fast-marching" algorithm to oceanography, using it to transform horizontal coordinates of the maps to better reflect how water parcels tend to move along the equator and follow isobaths (surfaces of constant depth). Finally, MIMOC also employs a front-sharpening algorithm in the horizontal to preserve the sharp density and temperature-salinity fronts that are often observed in synoptic surveys, but usually not well represented in climatologies.

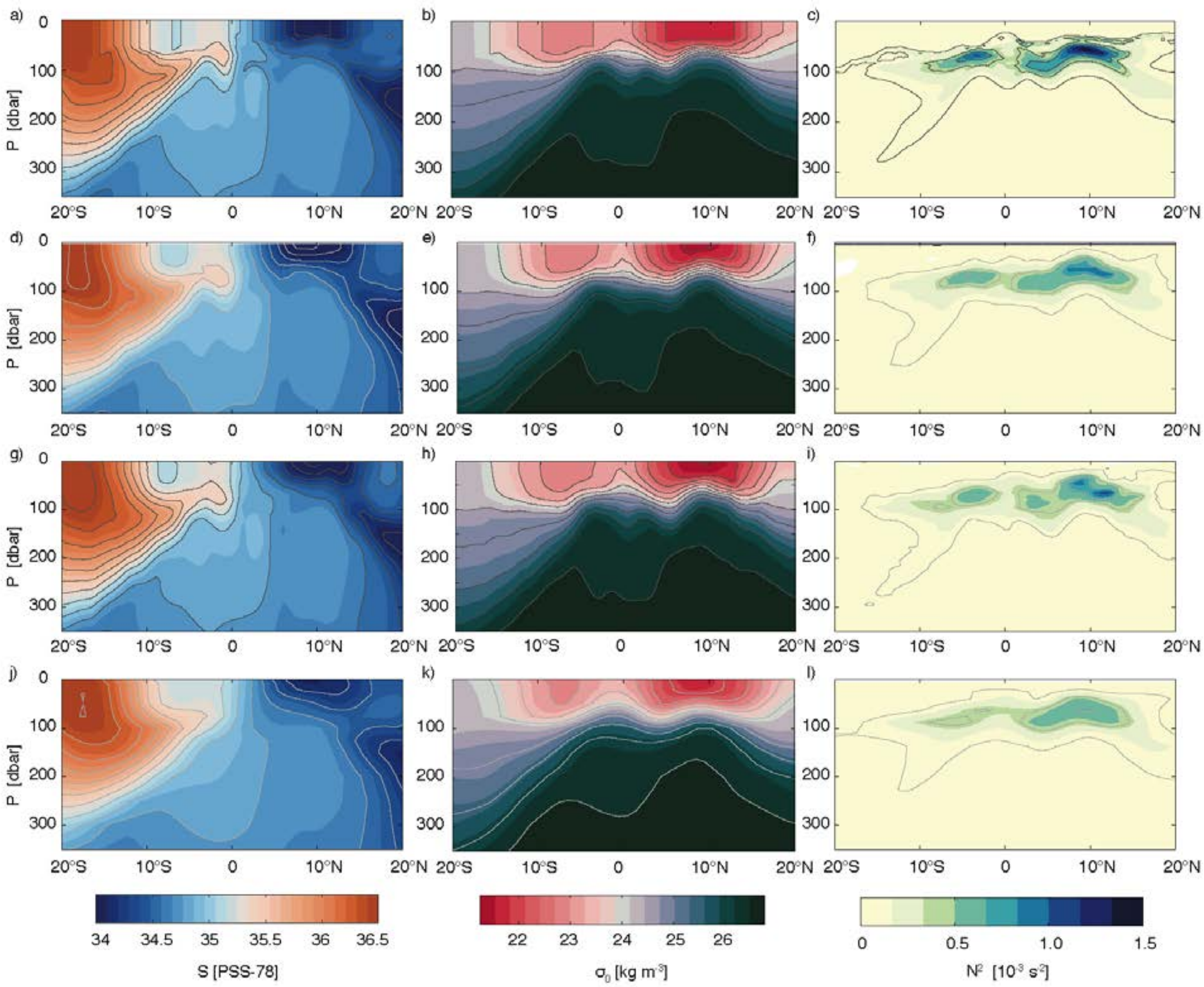


Figure 10: *Absolute salinity (left columns), potential density (middle column), and buoyancy frequency squared (right column) along 125ºW in June for MIMOC (top row), and three other commonly used climatologies (lower three rows). MIMOC best preserves the tongues of salty water from the south and fresh water from the north that meet in a strong front at the equator (left panels). MIMOC also best preserves the uniform properties within the mixed layer and well resolves dynamical current structures such as the equatorial undercurrent, north equatorial countercurrent, and subsurface countercurrents (middle panels). Finally MIMOC preserves the strong vertical stratification in the pycnocline typically found in the tropical Pacific (right panels).*

Producing a climatology (MIMOC) that more faithfully represents the ocean structure should allow advances in diagnoses of ocean currents, transport, and air-sea exchanges. It should also provide a useful benchmark for ocean and climate model validation. Since ocean mixed layer properties and upper ocean stratification are vital for biogeochemical and ecosystem research, MIMOC should be of use to the wider oceanographic community. Likely acknowledging the potential for widespread use of this product, the manuscript documenting MIMOC was featured in J. Geophys. Res. - Oceans "Editors' Highlights" and in an EOS Transactions AGU "Research Spotlight" (http://onlinelibrary.wiley.com/doi/10.1002/2013EO210016/abstract). MIMOC is freely available online (http://www.pmel.noaa.gov/mimoc/)

2.2.4 Woods Hole Oceanographic Institution

WHOI has taken on deploying floats in the Gulf of Mexico in order to expand the Argo Array into this marginal sea. This year six floats were launched on a cruise that also launched RAFOS floats to investigate details of the mid-depth circulation. The launch sites and initial trajectories can be seen in Figure 11. These floats are SOLO-2 floats which are actively managed to change their profiling schedule. For example, they profiled daily as Tropical Storm Karen passed through the region in October, 2013. In the future, we plan to continue deploying a similar number of floats each year in the Gulf of Mexico and also develop collaborations with South American countries to further expand the array into the Caribbean Sea.

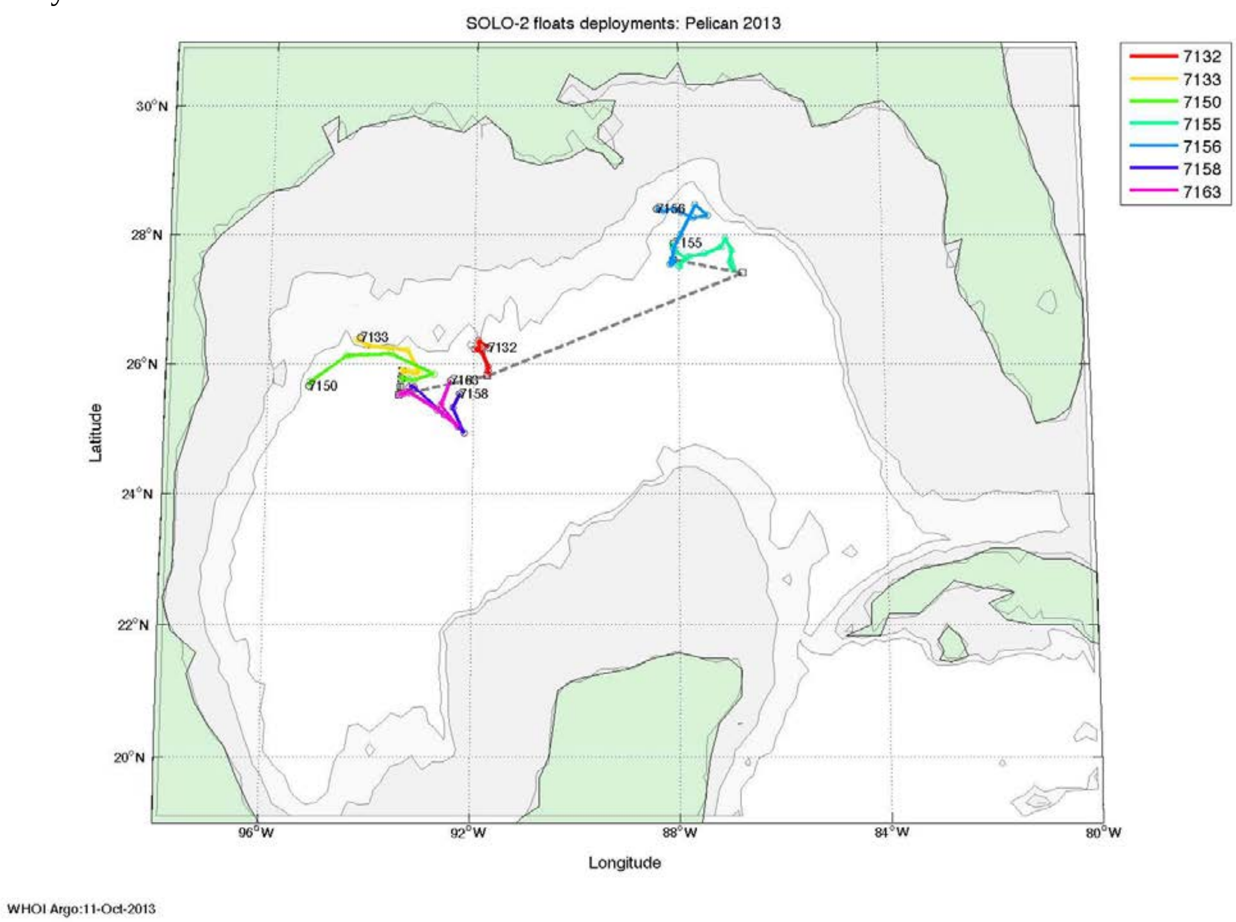


Figure 11: *Launch sites and initial trajectories of WHOI floats deployed in the Gulf of Mexico.*

WHOI continues to collaborate with Sea Education Association (SEA). This includes both float deployments and WHOI personnel giving guest lectures during the six week education program in Woods Hole. We have launched floats on an irregular schedule, but have now organized a more routine collaboration where we will launch 2 floats on the Fall cruise from Woods Hole to the Caribbean. Dedicated storage cradles for the Salon have been designed by the WHOI Float Group and have been installed on the M.S. Cramer. Plans include deploying floats in the Caribbean in Winter 2013-14.

In collaboration with Tammy Morris, who is the South African representative to the Argo Steering Team (AST), we launched 5 SOLO-2 floats in an eddy in the Mozambique Channel, Figure 12. Initially the floats were on a one-day cycle so that we actually have trajectories which resolve the mesoscale in a western boundary region. Float #7094 has almost completed a recirculation loop and appears to have re-entrain into the Agulhas (Fig. 13). Tammy is working on a manuscript with us describing the trajectories and initial evolution of the eddy.

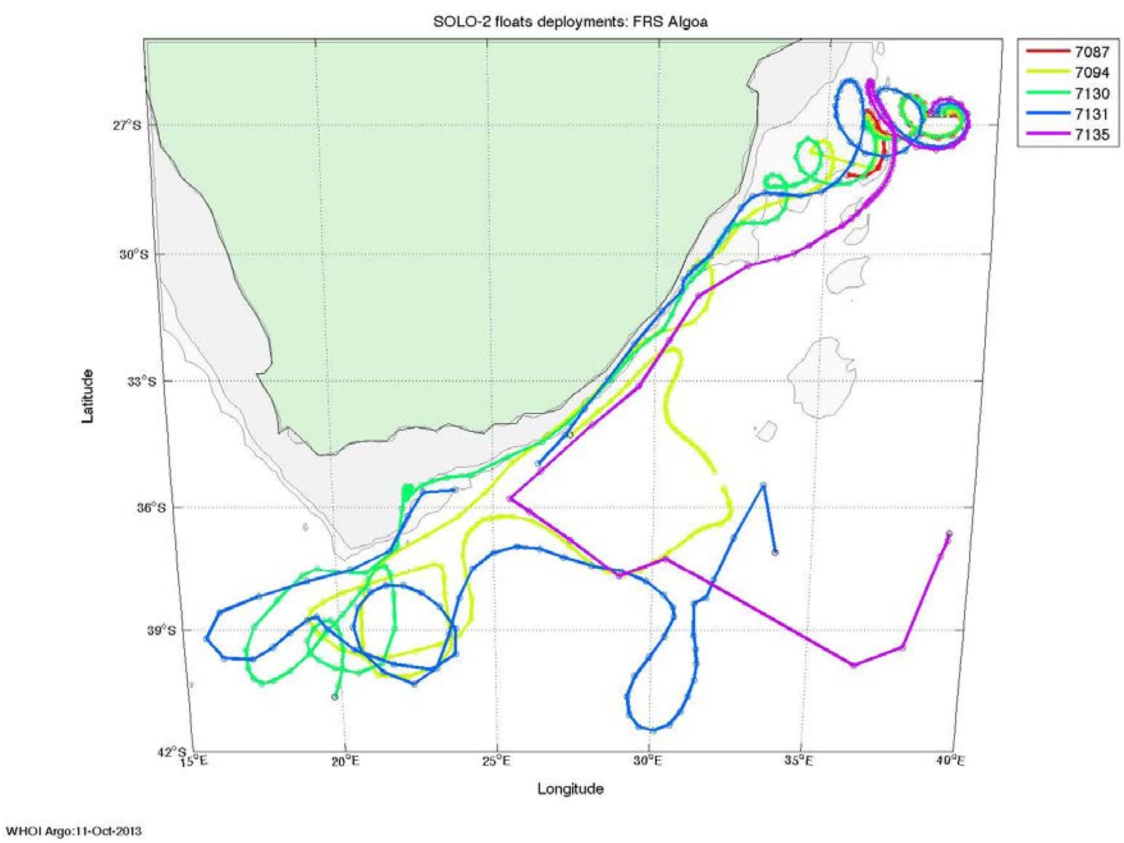


Figure 12**:** Launch positions and trajectories of 5 SOLO-2 floats deployed in an eddy in the Mozambique Channel.

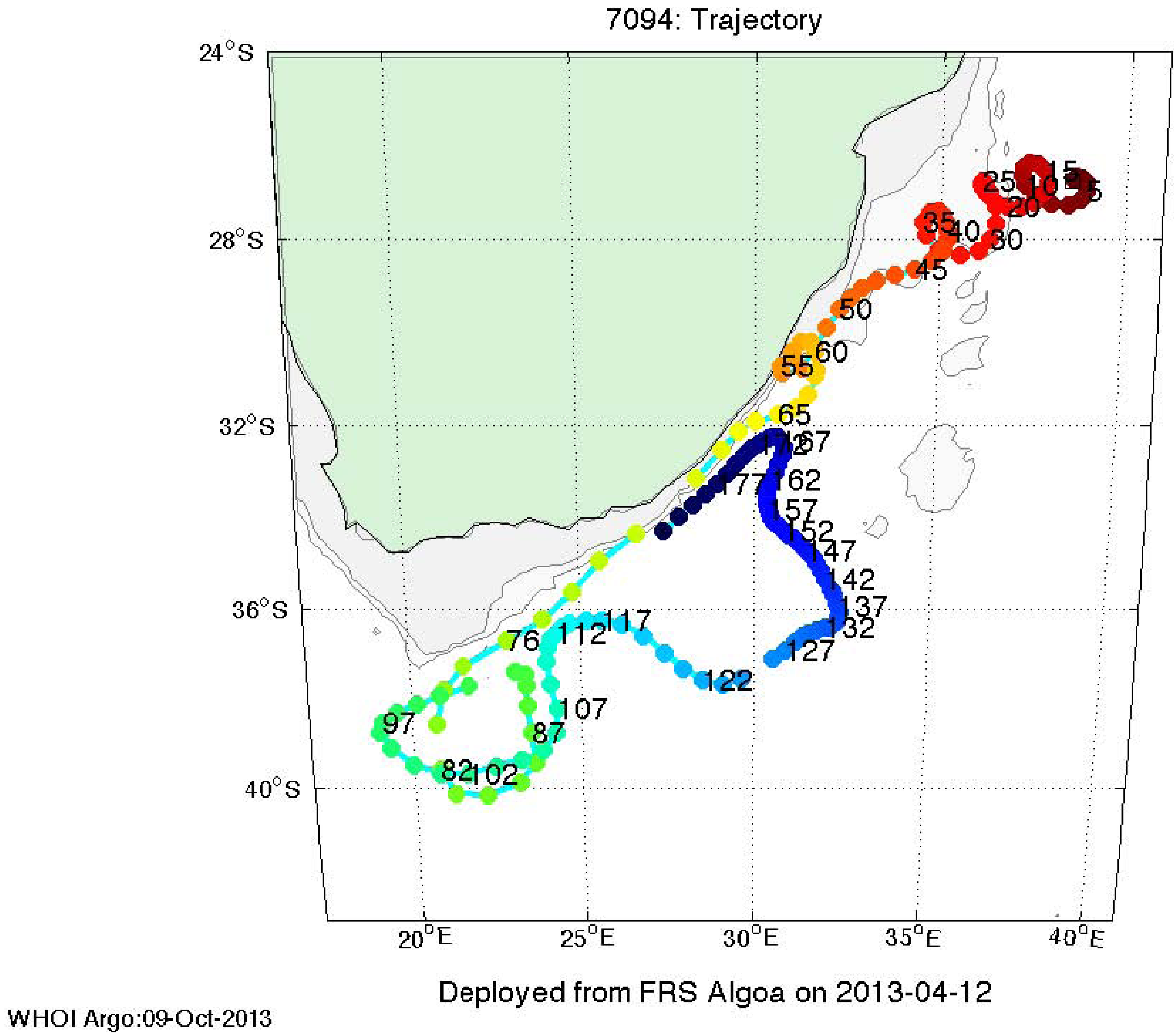


Figure 13: *Trajectory of Float 7094.*

Jayne has continued to develop a methodology to combine Argo float profiles and trajectories with absolute surface height estimates. from altimetry satellites and the Grace gravity mission, and surface drifter trajectories to produce estimates of the 3-D circulation. A manuscript describing this work is in preparation.

2.2.5 Atlantic Oceanographic and Meteorological Laboratory

(1) The seasonal cycle of the heat budget in the Tropical Atlantic

Argo observations were used in a study analyzing the seasonal cycle of the heat budget in the tropical Atlantic (Foltz et al., 2013, in press). The thinnest mixed layer (<20 m) during April is found in the southern half of the study region, where winds are weakest (Fig. 14a). The mixed layer depth increases northward and reaches 35m at 25N. The region with the thickest mixed layer between 20–25N also experiences a thick barrier layer (>30 m), consistent with Tanguy et al. (2010). Both layer thicknesses experience significant seasonal changes. Main differences between the heat budget terms in the two regions can be seen in the surface flux terms as well as the heat storage and the horizontal advection of heat (Fig. 14c, d) In the trade wind region, these terms are dominated be an annual cycle, while there is a significant semi-annual cycle in the Intertropical Convergence Zone (ITCZ) core region. There are also quite large differences in the variability of the latent and the longwave plus sensible heat flux between the two regions. The large residual in April-October in the trade wind regions indicates that significant cooling from vertical turbulent mixing has to occur during those months. In the ITCZ core region, the largest cooling due to vertical turbulent mixing occurs in February-April.

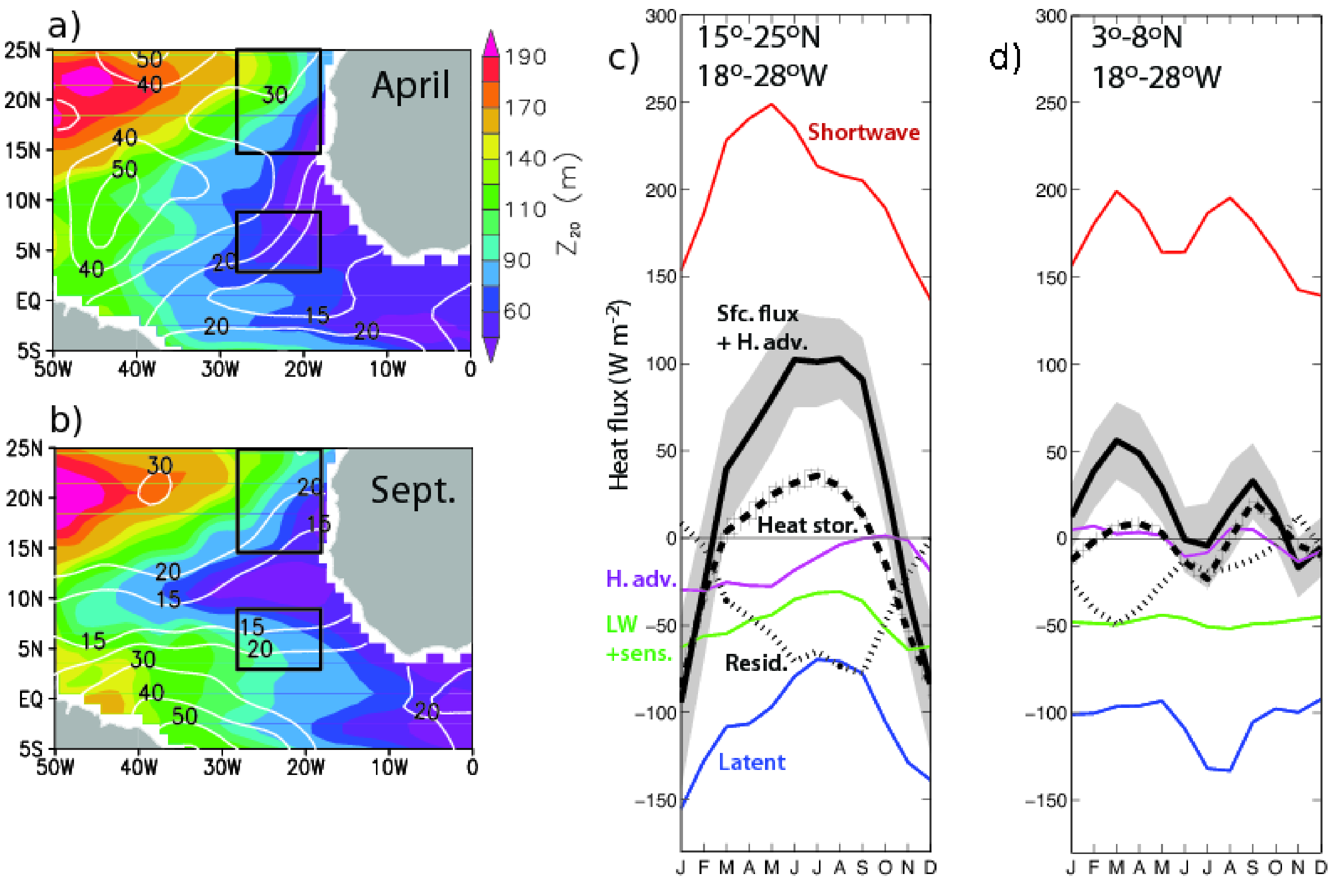
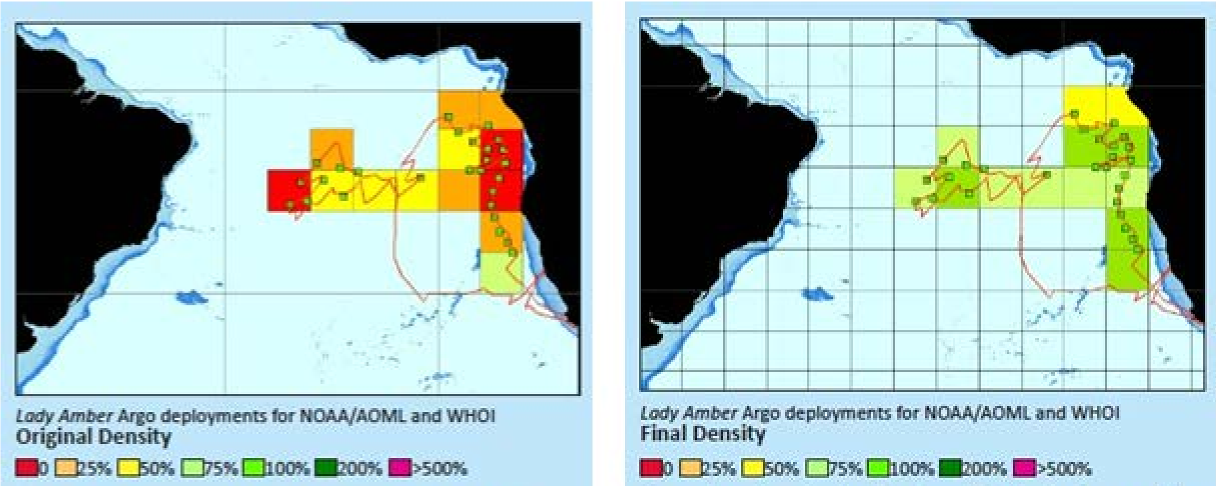


Figure 14: *Mean April (a) and September (b) thermocline depth (shaded; estimated as the depth of the 20C isotherm) and mixed layer depth (white contours) derived from Argo profiles collected in the period 2001-2011. Terms in the mixed layer heat balance averaged in the trade wind core region (c) and the ITCZ core region (d). The averaging regions are shown in (a) and (b). Shown are the shortwave radiation (from TropFlux) absorbed in the mixed layer (red curve), latent heat flux (blue, from Tropflux), sum (green) of longwave radiation (from NCEP–NCAR reanalysis, with bias correction using PIRATA data) and sensible heat flux (from TropFlux), horizontal heat advection (purple, derived using OSCAR velocities and TMI SST gradients), heat storage rate (dashed black, derived from Argo profiles), sum of the net surface heat flux and horizontal advection (solid black), and the residual (storage rate minus the sum of the net surface heat flux and horizontal advection, dotted black). Gray shading and hatching indicate one standard error for the sum and storage terms, respectively.*

(2) The Argo array depends upon ships of opportunity for the deployment of floats, and data gaps often emerge in regions not easily accessed by large ships. To improve data density in the South Atlantic, NOAA's Climate Observation Program provided support to charter the sailing vessel Lady Amber to deploy Argo floats in regions where few observations were previously collected (Fig. 15). The Lady Amber is a 38 ton, 20 meter, South African flagged schooner operated by a crew of four under Captain Peter Flanagan.



Argo float deployments in the South Atlantic Ocean superimposed on the data density before the *Lady Amber* cruise. Figure courtesy of Mathieu Belbeoch (Argo Information Center).

Argo data density in the South Atlantic Ocean after the *Lady Amber* float deployments. Figure courtesy of Mathieu Belbeoch (Argo Information Center).

Figure 15: *The Lady Amber expedition departed from Cape Town on December 12, 2012 and returned to Cape Town after 124 days at sea. During this journey, the Lady Amber deployed 28 Argo floats in an area of the South Atlantic where data density was extremely low. Following the cruise, data density increased sharply for Argo floats, as shown by the figures in the right-hand column.*

2.3 Data Management

The US Argo Data Assembly Center (DAC) at AOML is in charge of the real-time processing of all US Argo floats and of the verification and distribution of data that went through the scientific quality control performed in delayed-mode. Information on the procedures at the US DAC, helpful links and various products can be found online (http://www.aoml.noaa.gov/phod/argo/index.php). In the real-time processing, which runs twice a day 7 days a week, the collected profile data are distributed via the Global Telecommunications System (GTS) in two formats (TESAC and BUFR) and via the Argo Global Data Assembly Centers (GDAC) in the USA (www.usgodae.org/argo/argo.html) and in France (www.argodatamgt.org/Access-to-data). The meta, technical and trajectory data are sent to the GDACs as well. On average, profiles measured by up-profiling floats are available to users within less than 24 hours of the time when they were measured. The two GDACs synchronize their data sets to ensure that both have the newest version of all data. In addition to these public distributions of the data, the US DAC provides the real-time data to the US PIs via an ftp server. The delayed-mode pathway for research-quality data at the US Argo DAC consists of a verification of the soundness of the files before they are passed on to the GDACs on a 24/7 schedule. Data access at the GDACs is done on a regular basis without problems. All data collected by US Argo are also retained at the US DAC and checks are performed regularly to ensure that all data stored at the US DAC are also at the GDACs. The National Weather Service monitors the GTS data stream 24/7 and reports any issues immediately. The data from the French GDAC are downloaded daily by NODC and a snapshot is archived once a month. As an international program, the data management is planned by the International Argo Data Management Team, with strong participation on the part of US Argo and the US DAC. All documents related to the Argo Data Management are available at www.argodatamgt.org.

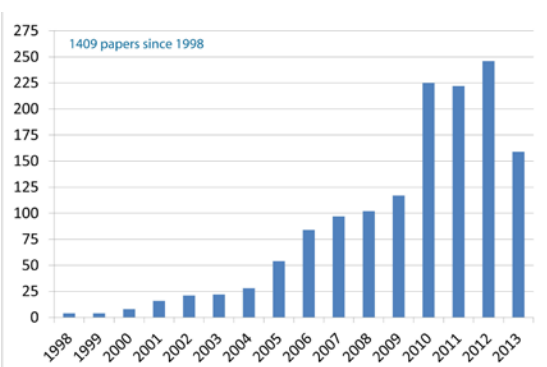
3. Outreach and Education

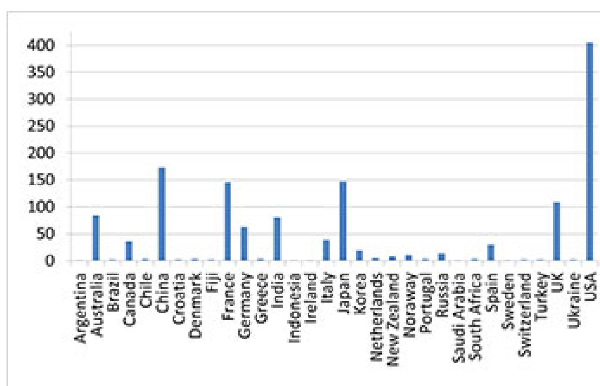
3.1 Operational Applications

At least 13 operational centers around the world are using Argo data on a routine basis (http://www.argo.ucsd.edu/Use_by_Operational.html). Operational applications include ocean state estimation, short-term ocean forecasting, atmosphere/ocean seasonal-to-interannual prediction, and coupled climate modeling. Ocean state estimation has an increasing number of valuable uses including climate monitoring, forecast initialization, fisheries and ecosystem modeling, provision of boundary conditions for regional and coastal modeling, and others. Operational centers have noted that the use of Argo data has had positive impacts in all the above applications.

3.2 Research Applications

Figure 16 shows (a) the number of research publications per year and (b) the national origin of the lead authors of papers. Approximately 1400 research publications from 32 countries have resulted so far from Argo data, including over 200 annually since 2010. The growth in publications is dramatic since reasonable, global coverage was attained in the 2004-2006 period. These publications span a wide variety of research topics from small spatial-scale/short time-scale phenomena such tropical cyclone intensification, to studies of mesoscale eddies, to large-scale phenomena such as water mass variability and basin-scale ocean circulation. Argo is among the most heavily used resources in modern oceanography, comparable for example in terms of publications per year to satellite altimetry.





(a) (b)

Figure 16: *Research publications using Argo data (30 August 2013)*

3.3 Science Education

Although the Argo project is still very new, it is proving to be an attractive educational asset for secondary, tertiary, and post-graduate levels. For secondary education, the web-based and real-time nature of the Argo data system, as well as Argo's strong climate-relevance, have been keys to engaging student interest in the oceans. Our consortium participates in a Pacific Island GOOS-sponsored initiative called SEREAD (http://www.argo.ucsd.edu/SEREAD.html) that uses Argo data in existing secondary science curricula in Pacific Island countries. In post-graduate education, Argo is already providing primary data for dissertation research of graduate students in the U.S. and other countries. Central to all educational uses of Argo data is easy access and display of the data in gridded formats. US Argo has developed a PC-based Global Marine Atlas (http://www.argo.ucsd.edu/Marine_Atlas.html) allowing users to produce graphical displays of Argo data, including maps, vertical sections, and time-series plots.

3.3.1 Scripps Institution of Oceanography

D. Roemmich presently advises two postdoctoral investigators and one PhD student, all working on analyses of Argo data. To date, 8 PhD theses at SIO have utilized Argo data. Roemmich also serves on steering committees for the SEREAD education program (http://www.argo.ucsd.edu/SEREAD.html) and the Pacific Islands Global Ocean Observing System (PI-GOOS, http://www.sprep.org/pi-goos). He consults with the PI-GOOS coordinator regarding applications of Argo data in the Pacific Islands. M. Scanderbeg continues to update and improve the Global Marine Atlas, a product designed to facilitate access by students and government agencies to Argo data and its content.

3.3.2 Pacific Marine Environmental Laboratory

Johnson currently advises a University of Washington School of Oceanography Graduate Student and an NRC Postdoctoral Research Fellow. On 31 July 2013, Gregory Johnson gave a public lecture on "The Warming Ocean's Role in Climate" at the Nisqually Wildlife Refuge Summer Lecture Series to a full auditorium. The following are links to news stories, NOAA outreach pieces, or AGU highlights in FY2013 regarding Argo or on various publications co-authored by Johnson which use Argo data:

Abraham, John (28 August 2013). Global warming and oceans: what are the known unknowns?. *Climate Consensus - the 97%, hosted by The Guardian*.

Clarke, Sarah, and Katie Hamann (20 May 2013). New reports suggests global warming could be slower than first thought. *ABC News*.

Marshall, Michael (19 May 2013). A second chance to save the climate . *New Scientist*.

Harvey, Fiona (19 May 2013). Climate change: human disaster looms, claims new research. *The Guardian*.

McGrath, Matt (19 May 2013). Climate slowdown means extreme rates of warming 'not as likely'. *BBC News*.

Schultz, Colin (21 May 2013). A global map of the ocean's climate. *EOS-Transactions American Geophysical Union, Vol. 94, Issue 21, pages 196-197*.

Kelly, Daniel (11 February 2013). Jason and the Argo Network. *Environmental Monitor - Application and technology news for environmental professionals*.

One in a million: NOAA ocean profilers hit new data transmission milestone . *NOAA Research News Release*. 11 December 2012.

Kennedy, Caitlyn (30 July 2013). 2012 State of the Climate: Ocean Heat Content. *ClimateWatch Magazine*.
Kennedy, Caitlyn (28 August 2013). Ocean Saltiness Provides Clues to Precipitation Patterns. *ClimateWatch Magazine*.

Section 3.3.3 University of Washington

S. Riser currently serves on the PhD committees of 14 graduate students in physical and chemical oceanography. Each of these students is using Argo data in some fashion as a part of their PhD dissertation. Of these 14 students, Riser serves as the primary adviser to two students (Alison Gray and Tyler Hennon); both are being supported using US Argo funds. Both have submitted first-authored papers to major peer-reviewed journals in the past year. In addition to working with graduate students, Riser is also involved with undergraduate education at UW. He employs two undergraduate students as part-time technicicans in the UW Argo laboratory, and in February of 2013 he participated in a month-long cruise in the western North Pacific where 15 undergraduate students were trained in modern oceanographic methods at sea, including Argo float technology and deployment methods. Two of the students used Argo data collected on the cruise as the basis for their senior undergraduate thesis at UW. Beginning in the next academic year, Riser will teach a new undergraduate course entitled Methods of Oceanographic Data Analysis that will use Argo data in the context of learning modern programming techniques and analysis tools. Further, in addition to several papers submitted and published in the refereed oceanographic literature in the past year, Riser (with co-author Susan Lozier of Duke University) published an article in *Scientific American* in 2013 entitled "Rethinking the Gulf Stream" that made use of Argo observations in order to explore the Gulf Stream's role in the climate of western Europe.

3.3.4 Atlantic Oceanographic and Meteorological Laboratory

There is an educational benefit to the Lady Amber deployments - schools from the Indian Ocean island nation of Mauritius adopted every float deployed by the Lady Amber, enabling students to observe the data stream from their adopted floats via the Internet and learn about the role of oceans in the process. Captain Flanagan also visited Mauritius in June to participate in the launch of an educational program to further increase awareness of this unique ocean observing program.

4. Publications and Reports

4.1 Publications by Principal Investigators

Abraham, J. P., M. Baringer, N. L. Bindoff, T. Boyer, L. J. Cheng, J. A. Church, J. L. Conroy, C. M. Domingues, J. T. Fasullo, J. Gilson, G. Goni, S. A. Good, J. M. Gorman, V. Gouretski, M. Ishii, G. C. Johnson, S. Kizu, J. M. Lyman, A. M. Macdonald, W. J. Minkowycz, S. E. Moffitt, M. D. Palmer, A. R. Piola, F. Reseghetti, K. Schuckmann, K. E. Trenberth, I. Velicogna, and J. K. Willis, 2013: A review of global ocean temperature observations: Implications for ocean heat content estimates and climate change. *Rev. Geophys.*, **51**, 450–483, doi: 10.1002/rog.20022.

Argo Steering Team, 2013: Argo – Providing systematic observations of the subsurface global ocean [in “State of the Climate in 2012”]. *Bulletin of the American Meteorological Society*, **94** (8), S54–S55.

Baringer, M. O., W. E. Johns, G. McCarthy, J. Willis, S. Garzoli, M. Lankhorst, C. S. Meinen, U. Send, W. R. Hobbs, S. A. Cunningham, D. Rayner, D. A. Smeed, T. O. Kanzow, P. Heimbach, E. Frajka-Williams, A. Macdonald, S. Dong and J. Marotzke, Meridional Overturning Circulation and Heat Transport Observations in the Atlantic Ocean. 2013. [Global Oceans] Meridional Overturning Circulation and Heat Transport Observations in the Atlantic Ocean [in State of the Climate in 2012], Bull. Am. Met. Soc.,94 (8) S65-68.

Boyer, T., S. Levitus, J. Antonov, J. Reagan, C. Schmid**,** and R. Locarnini, 2013: Subsurface salinity. [in "State of the Climate in 2012"]. *Bull. Amer. Meteor. Soc*., 94 (8) S60-61.

Czeschel, R., L. Stramma, and G. C. Johnson, 2012: Oxygen decreases and variability in the eastern equatorial Pacific*. J. Geophys. Res.*, **117**, C11019, doi: 10.1029/2012JC008043.

de Souza, G. F., B. C. Reynolds, G. C. Johnson, J. L. Bullister, and B. Bourdon, 2012: Silicon stable isotope distribution traces Southern Ocean export of Si to the eastern South Pacific thermocline. *Biogeosciences*, **9**, 4199–4213, doi: 10.5194/bg-9-4199-2012.

Garzoli, S., M.O. Baringer, S. Dong, R. Perez, and Q. Yao: South Atlantic meridional fluxes. 2013. *Deep-Sea Research I*, 71:21-32, doi:10.1016/j.dsr.2012.09.003

Giglio, D., D. Roemmich, and S. T. Gille, 2012: Wind-Driven Variability of the Subtropical North Pacific Ocean. *Journal of Physical Oceanography*, **42,** 2089-2100, http://dx.doi.org/10.1175/JPO-D-12-029.1

Giglio, D., D. Roemmich, and B. Cornuelle, 2013: Understanding the annual cycle in global steric height, *Geophys. Res. Lett.*, *40*, doi:10.1002/grl.50774.

Johnson, G.C ., and D. P. Chambers, 2013: Ocean bottom pressure seasonal cycles and decadal trends from GRACE Release-05: Ocean circulation implications. *J. Geophys. Res.*, **118**, doi: 10.1002/jgrc.20307.

Johnson, G. C., J. M. Lyman, J. K. Willis, S. Levitus, T. Boyer, J. Antonov, S. A. Good, C. M. Domingues, S. Wijffels, and N. Bindoff, 2013: Ocean heat content. In *State of the Climate in 2012*, Global Oceans, *Bull. Am. Meteorol. Soc.*, **94**, S50–S53, doi:10.1175/2013BAMSStateoftheClimate.1.

Johnson, G. C., J. M. Lyman, G. S. E. Lagerloef, and H.-Y. Kao, 2013: Sea surface salinity. In *State of the Climate in 2012*, Global Oceans. *Bull. Am. Meteorol. Soc.*, **94**, S57–S60. doi: 10.1175/2013BAMSStateoftheClimate.1.

Johnson, G. C., and S. G. Purkey, 2013: Slow-down of the lower, southern limb of the meridional overturning circulation in recent decades. In *State of the Climate in 2012*, Global Oceans, *Bull. Am. Meteorol. Soc.*, **94**, S68–S69. doi:10.1175/2013BAMSStateoftheClimate.1.

Johnson, K.S., L.J. Coletti, H.W. Jannasch, C.M. Sakamo, D. Swift, and S. Riser, 2013: Long-term nitrate measurements in the ocean using the In Situ Ultraviolet Spectrophotometer: sensor integration into the Apex profiling float. *Journal of Atmospheric and Oceanic Technology*, **30**, 1854-1886.

Lumpkin, R., and G. C. Johnson, 2013: Global ocean surface velocities from drifters: Mean, variance, El Niño–Southern Oscillation response, and seasonal cycle. *J. Geophys. Res.*, **118**, 2992–3006, doi: 10.1002/jgrc.20210,

Otto, A., F. E. L. Otto, O. Boucher, J. Church, G. Hegerl, P. M. Forster, N. Gillett, J. Gregory, G. C. Johnson, R. Knutti, N. Lewis, U. Lohmann, J. Marotzke, G. Myhre, D. Shindell, B. Stevens, and M. R. Allen, 2013: Energy budget constraints on climate response. *Nature Geosci.*, **6**, 415–416, doi: 10.1038/ngeo1836.

Purkey, S. G., and G. C. Johnson, 2013: Antarctic Bottom Water warming and freshening: Contributions to sea level rise, ocean freshwater budgets, and global heat gain. *J. Climate*, **26**, 6105–6122, doi: 10.1175/JCLI-D-12-00834.1.
Ravichandran,M., M. Girishkumar, and S. Riser, 2012: Observed variability in chlorophyll-a using profiling floats in the southwestern Arabian Sea. *Deep-Sea Research* 1, **65**, 15-25.
Schmidtko, S., G. C. Johnson, and J. M. Lyman, 2013: MIMOC: A global monthly isopycnal upper-ocean climatology with mixed layers. *J. Geophys. Res.*, **118**, 1658–1672, doi: 10.1002/jgrc.20122.
Zhang, X., B. Cornuelle, and D. Roemmich, 2012: Sensitivity of western boundary transport at the mean North Equatorial Current bifurcation latitude to wind forcing. Journal of Physical Oceanography, 42, 2056-2072. DOI: 10.1175/JPO-D-11-0229.1.
Zilberman, N. V., D. H. Roemmich, and S. T. Gille, 2013: The Mean and the Time Variability of the Shallow Meridional Overturning Circulation in the Tropical South Pacific Ocean. *Journal of Climate*, **26,** 4069-4087, http://dx.doi.org/10.1175/JCLI-D-12-00120.1

In press:

Foltz, G**.** R., C. Schmid and R. Lumpkin, 2013**:** Seasonal cycle of the mixed layer heat budget in the northeastern tropical Atlantic Ocean. J. Climate, in press.
Takeshita, Y., T.R. Martz, K. S. Johnson, J.N. Plant, D. Gilbert, S. Riser, C. Neill, and B. Tilbrook, 2013: A climatology-based quality control procedure for profiling float oxygen data. *Journal of Geophysical Research*, in press.

Accepted with minor revisions:

Meinen Christopher S., Sabrina Speich, Renellys C. Perez, Shenfu Dong, Alberto R. Piola, Silvia L. Garzoli, Molly Baringer, and Edmo Campos, 2013, Temporal variability of the Meridional Overturning Circulation at 34.5°S: Preliminary results from two boundary arrays. Journal of Geophysical Research – Oceans. Accepted with minor revisions. Resubmitted
Meinen, C. S. and S. L. Garzoli, 2013. Attribution of Deep Western Boundary Current variability at 26.5°N, Deep Sea Research. Accepted with revisions. Resubmitted

4.2 Other Relevant Publications

Over 1000 research publications have resulted so far from Argo data (http://www.argo.ucsd.edu/Bibliography.html), with over 200 having been published annually since 2010, a pace that appears to be continuing. These publications span a wide variety of research topics from small spatial-scale/short time-scale phenomena such tropical cyclone intensification, to studies of mesoscale eddies, to large-scale phenomena such as water mass variability, basin-scale ocean circulation, and climate change. Almost none of this work would have been possible without the contributions of US Argo to building, sustaining, and utilizing the global Argo array.

US Argo Consortium relevant web sites:

Argo Steering Team home page http://www.argo.ucsd.edu
Argo Information Center http://argo.jcommops.org
Scripps Institution of Oceanography http://sio-argo.ucsd.edu
Woods Hole Oceanographic Institution http://ursa.whoi.edu/~argo/

University of Washington http://flux.ocean.washington.edu/argo/
NOAA PMEL http://floats.pmel.noaa.gov
NOAA AOML(US DAC and South Atlantic Argo Regional Center)
http://www.aoml.noaa.gov/phod/argo/index.php

US GDAC http://www.usgodae.org

Primary Contact Person for Finance: Dr. Stephen R. Piotrowicz; Tel..: 301-427-2493; e-Mail – steve.piotrowicz@noaa.gov

References

Foltz, G**.** R., C. Schmid and R. Lumpkin, 2013**:** Seasonal cycle of the mixed layer heat budget in the northeastern tropical Atlantic Ocean. J. Climate, in press.

Giglio, D., D. Roemmich, and S. T. Gille, 2012: Wind-Driven Variability of the Subtropical North Pacific Ocean. *Journal of Physical Oceanography*, **42,** 2089-2100, http://dx.doi.org/10.1175/JPO-D-12-029.1

Owens, W. B. and A. P. S. Wong, 2009. An improved calibration method for the drift of the conductivity sensor on autonomous CTD profiling floats by theta-S climatology. *Deep Sea Research Part I: Oceanographic Research Papers*, **56,** 450-457.

Schmidtko, S., G. C. Johnson, and J. M. Lyman, 2013: MIMOC: A global monthly isopycnal upper-ocean climatology with mixed layers. *J. Geophys. Res.*, **118**, 1658–1672, doi: 10.1002/jgrc.20122.

Tanguy, Y., S. Arnault, and P. Lattes, 2010: Isothermal, mixed, and barrier layers in the subtropical and tropical Atlantic Ocean during the ARAMIS experiment. *Deep-Sea Research Part I-Oceanographic Research Papers*, **57,** 501-517, http://dx.doi.org/10.1016/j.dsr.2009.12.012

Whalen, C. B., L. D. Talley, and J. A. MacKinnon, Spatial and temporal variability of global ocean mixing inferred from Argo profiles. *Geophys. Res. Lett.*, **39,** L18612, doi:10.1029/2012GL053196.

Wong, A., G. Johnson and W.B. Owens, 2003. Delayed-Mode Calibration of Autonomous CTD Profiling Float Salinity Data by θ–S Climatology. Journal of Atmospheric and Oceanic Technology, 20, 308 – 318.

Wong, A. P. S. and S. C. Riser, 2011: Profiling Float Observations of the Upper Ocean Under Sea Ice off the Wilkes Land Coast of Antarctica. *Journal of Physical Oceanography*, **41,** 1102-1115, http://dx.doi.org/10.1175/2011JPO4516.1

Wu, L., Z. Jing, S. Riser, and M. Visbeck, 2011: Seasonal and spatial variations of Southern Ocean diapycnal mixing from Argo profiling floats. *Nature Geoscience*, **4,** 363-366.

Zilberman, N. V., D. H. Roemmich, and S. T. Gille, 2013: The Mean and the Time Variability of the Shallow Meridional Overturning Circulation in the Tropical South Pacific Ocean. *Journal of Climate*, **26,** 4069-4087, http://dx.doi.org/10.1175/JCLI-D-12-00120.1