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

Report on Progress in FY08, October 1, 2007 – September 30, 2008

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Award Numbers: *NA17RJ1231 (SIO), NA17RJ1223 (WHOI), NA17RJ1232 (UW)*

LONG-TERM GOALS

The U.S. component of the international Argo Project (http://www.argo.ucsd.edu), a global array of autonomous profiling floats, is implemented through this award. The present report covers Year 1 of the 5-year "sustained phase" of the project, which builds on progress made under previous awards (Phases 1,2 and 3) for pilot float arrays, data system development, and global implementation.

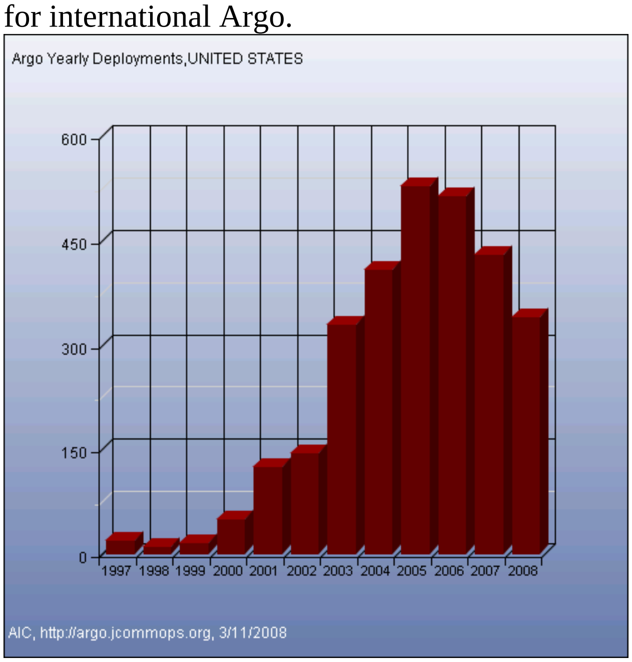
As of November 1, 2007, the international Argo Project, including the US contribution, has met its goal of building a global array of 3000 active profiling CTD floats (Roemmich and Owens, 2000, Roemmich et al, 2001, 2002, Gould et al., 2004), and established a data system to meet the needs of both operational and scientific users for data delivery in real time and delayed mode. In order to maintain the Argo array, it is necessary to replace over 25% (800) instruments every year. Argo is a major initiative in oceanography, with research and operational objectives, providing a global dataset for climate science and other applications. It is a pilot project of the Global Ocean Observing System (GOOS).

OBJECTIVES

Phase 1 (9/99 – 9/02) and Phase 2 (7/00 – 6/02) of US Argo provided regional arrays of CTD profiling floats to demonstrate technological capabilities for fabrication and for deployment of float arrays in remote ocean locations (Phase 1) and to demonstrate the capability for manufacture and deployment of large float arrays (Phase 2). Development of the U.S. Argo Data System was carried out to make Argo data publicly available within a day of collection, to apply automated quality control procedures consistent with international Argo practices, and to provide research-quality data in delayed-mode.

Phase 3 of US Argo was a 5-year project (8/01 – 6/06) aimed at full implementation of the US component of Argo. Float deployment rates were increased to more than 400 per year beginning in CY 2004 (Fig 1). Objectives were to achieve 1500 active US Argo floats (50% of the global array), to improve the spatial distribution of floats toward the target of uniform 3^{o} spacing, to increase the mean lifetime of floats to 4 years, to operate the near-real time and delayed-mode data systems consistent with international agreements, and to provide substantial leadership and coordination roles for international Argo.

Phase 4 of US Argo is a follow-on 5-year project (7/06 – 6/11) aimed at improving and sustaining the US component of Argo. Float deployment rates should continue at about 400 per year. Objectives are to complete and sustain the array of 1500 active US Argo floats, to further improve the spatial distribution of floats through targeted deployments, to further increase the mean lifetime of floats beyond 4 years, to continue to improve and operate the near-real time and delayed-mode data systems consistent with international agreements, and to provide substantial leadership and coordination roles for international Argo.



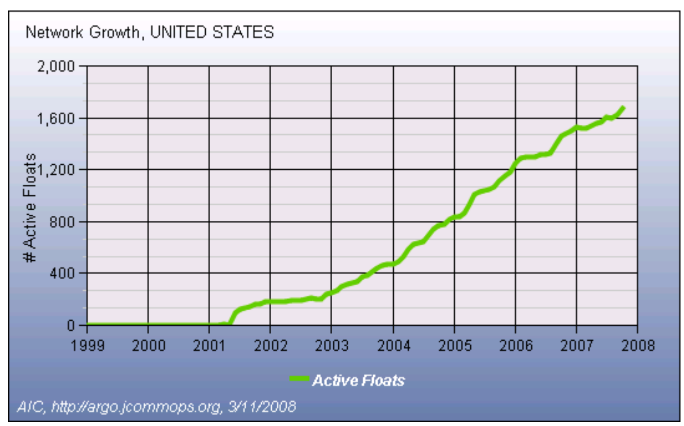


Figure 1: *Yearly deployments of United States Argo floats through 11 November 2008 (including Argo-equivalent), and growth in the number of active US floats. (Source:AIC)*

APPROACH AND WORK PLAN

Float production and deployment are accomplished by four facilities – SIO (production and deployment), WHOI (production)/AOML (deployment), UW (assembly and deployment), and PMEL (thorough testing and deployment of commercially manufactured floats). This distributed effort has been designed to safeguard the US contribution to the Argo project 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. While the initial focus has been on improving float technical performance, attention of the PIs will increasingly focus on demonstrating the scientific value of Argo.

The data system is also distributed. AOML is the US Argo 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). 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.

All Argo data are freely available within about 24 hours of collection, and can be accessed from the GTS or internet (http://www.usgodae.org/, or http://www.ifremer.fr/coriolis/cdc/argo.htm).

WORK COMPLETED

The goal of 1500 active US Argo floats has been achieved (Fig 2). As of October 2007 there are 1521 active US Argo floats, plus 88 US Argo-equivalent instruments that also feed data to the US Argo DAC. Float deployments have continued at 400 per year through the first year of Phase 4. 1155 of

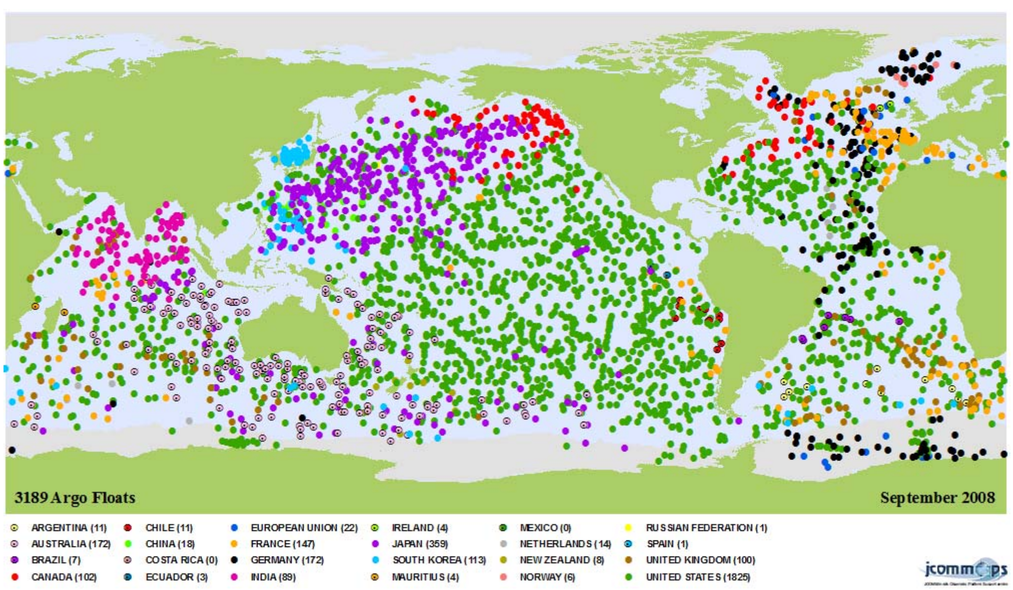


***Figure 2**: The Argo Array as of 30 September 2008. The 1825 active US floats (Green), included 1750 floats funded via US Argo, and 75 other US (Argo-equivalent) floats whose data are released by the PIs via the US Argo Data Assembly Center.*

the 1855 active US Argo floats are in the Southern Hemisphere, reflecting the US commitment to eliminate the northern bias of the international Argo array and achieve uniform global coverage. A notable effort has been the collaboration between US Argo and NIWA (Argo-New Zealand), resulting in more than 450 deployments since 2004 in remote ocean locations by NIWA's R/V Kaharoa. Funding shortfalls may decrease the level of this work in future.

Good progress has been made in increasing float lifetimes (Fig 3). For floats deployed in 2004, about 75% remain active after 130 cycles. Nearly 90% of 2005 deployments remain active after 100 cycles. It is likely that the goal of a 4-year mean lifetime has been met for both APEX and SOLO designs. The re-design of the SOLO float (SIO) is nearly complete for increased lifetime and capabilities. Prototypes will be deployed in the coming year. 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. A pressure-offset error was detected in some WHOI floats this year and corrective steps have been taken (http://www-argo.ucsd.edu/Acpres_offset2.html). Procedures are being considered for more effective detection of systematic data errors.

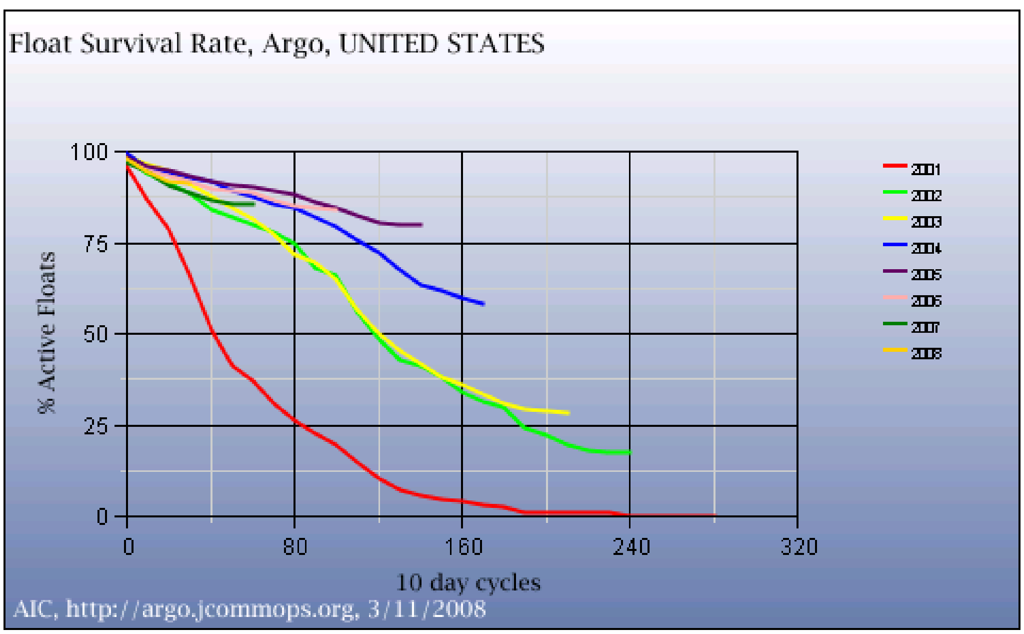


Figure 3: *Float reliability. Note that the percentage of floats surviving for at least 100 cycles increased from about 65% for 2002/03 deployments to about 85% for 2005 deployments.*

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) and the international Argo Data Management Team Co-Chairman (Mark Ignaszewski, FNMOC) as well as many international panel memberships. US partners provide international leadership in float technology and data management techniques through workshops and training of international colleagues. US partners provide coordination for deployment planning activities in the Pacific, Atlantic, and Southern Oceans. The US is also a leader in utilization of Argo data, organizing international symposia such as the Argo session at the 2007 IUGG conference, and through sharing of research results and operational capabilities.

RESULTS

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.

About 300 research publications have resulted so far from Argo data, including 132 in 2006-2007 (to date). 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. Almost none of this work would have been possible without the contributions of US Argo to building, sustaining, and utilizing the array.

A sparse global Argo array was achieved in 2004, and so there are now nearly 4 years of continuous global coverage. The 4-year global dataset provides a baseline of the present climate-state of the oceans (Fig 4), against which future variability can be observed by a sustained Argo array. It also provides a comparison point for past datasets to describe decadal change in the oceans. With 4-years of data we have, for the first time, a stable estimate of the mean and annual cycle of the global ocean over a fixed period of time (Fig 5).

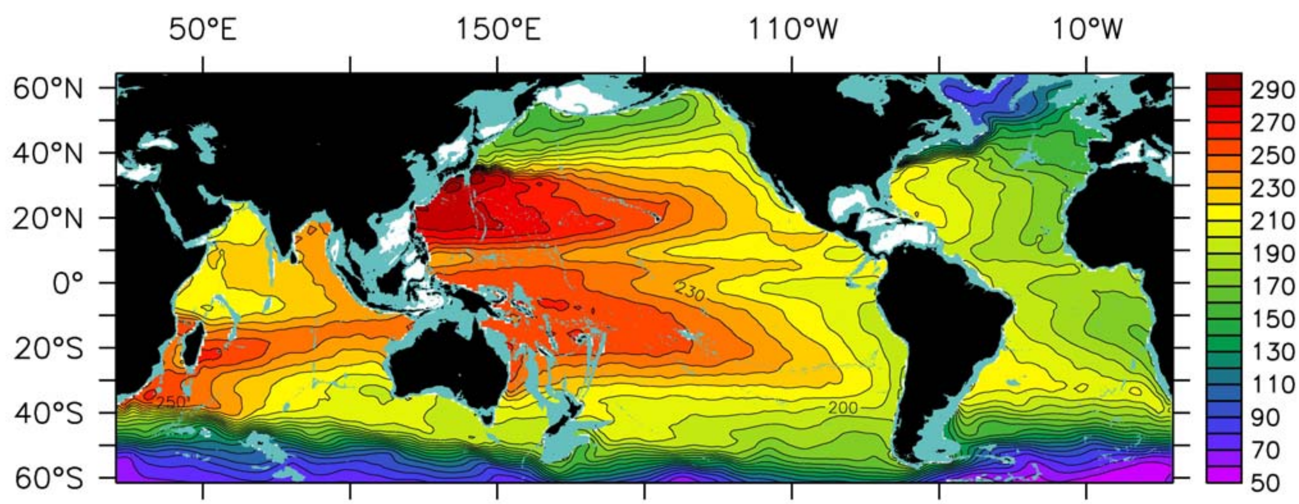


Figure 4: *Argo observes the mean state of the oceans, 2004 – 2006: mean dynamic height of the sea surface relative to 2000 dbar (dyn-cm).*

At least 13 operational centers around the world are using Argo data on a routine basis (http://www.argo.ucsd.edu/FrUse_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. At the most recent Argo Steering Team meeting, operational centers reported on their use of Argo data, and noted positive impacts in all the above applications.

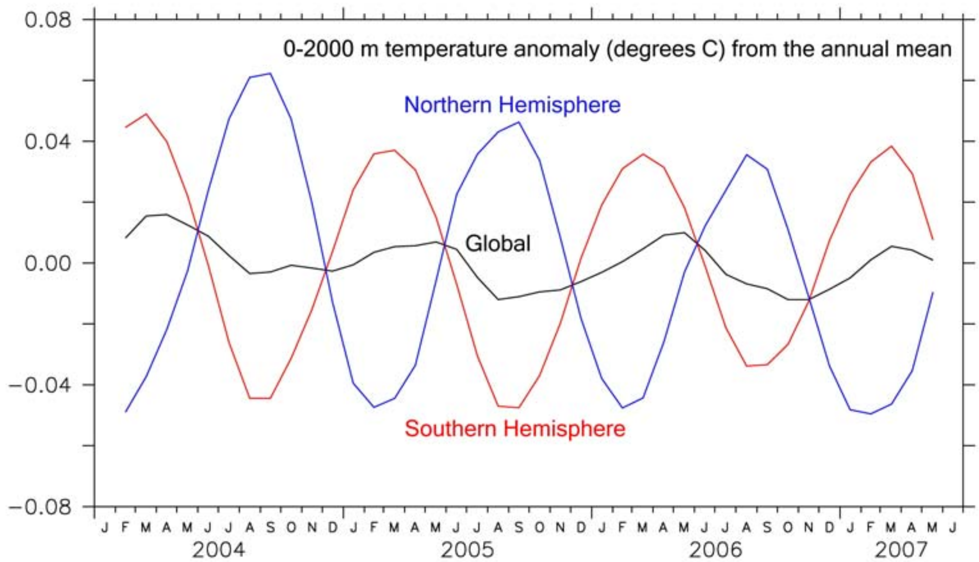


Figure 5: *Argo takes the ocean's "pulse": Time-series of global (black), Southern Hemisphere (red) and Northern Hemisphere (blue) averaged ocean temperature (anomaly from the annual mean), 0-2000 m, from Argo data.*

IMPACT, APPLICATIONS AND TRANSITIONS

National Security

The US Navy has a strong interest in accurate estimates and forecasts of the physical state of the ocean and the coupled air-sea system, because of the obvious impacts of wind, waves, currents, and temperature on virtually all aspects of naval operations. The Navy has experimental ocean state estimation and forecasting efforts, using both regional and global models, for which Argo provides a central contribution for ocean data assimilation. The Navy interest is further expressed by the hosting of one of the two Global Argo Data Centers (at FNMOC, Monterey), by NAVOCEANO participation as a provider of floats for international Argo, and by NAVOCEANO participation in air deployment of Argo floats. Phase 1 of US Argo was supported by ONR.

Economic Development

The Global Ocean Data Assimilation Experiment (GODAE) has identified a number of applications with substantial economic impacts arising from ocean observations, including improved seasonal-to-interannual (S-I) forecasting, state estimation (now-casting), and coupled physical/biological modeling (e.g., for fisheries). The El Niño/Southern Oscillation (ENSO) Observing System in the tropical Pacific has demonstrated over the past decade that economic gains in energy, agriculture, and insurance sectors are possible from successful seasonal forecasts. Improvement in S-I forecasting is expected as the tropical observing system is extended and expanded to global coverage, and Argo plays a key role in that expansion.

Quality of Life

Argo is central to an unprecedented capability for global assessment of the evolving climate state of the ocean. The thermal structure of the upper ocean controls the temperature of the lower atmosphere, and is the primary variable defining the physical environment of ocean ecosystems. Over 80% of the increased heat content due to global warming of the air/sea/ice climate system in the past 50 years occurred in the oceans (Levitus *et al.*, 2001). Climate stresses on ocean ecosystems have serious consequences, and sometimes dramatic ones, such as coral reef bleaching. Conversely the ocean can impact the atmosphere even on short time-scales such as through intensification of tropical cyclones. In the future, the impacts of a varying climate on the health of the seas and coastal ecosystems will become an increasingly important aspect of resource management. The unique niche of the Argo array is to provide global broadscale observations of the upper ocean.

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/FrEducational_use.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.

RELATED PROJECTS

GODAE: The Global Ocean Data Assimilation Experiment uses satellite and in situ ocean datasets in data assimilation models for practical applications. Argo plays a special role in GODAE because it is the only globally repeating subsurface ocean dataset, and is strongly complementary to its satellite counterparts. GODAE's vision is "A global system of observations, communications, modeling and assimilation, that will deliver regular, comprehensive information on the state of the oceans, in a way that will promote and engender wide utility and availability of this resource for maximum benefit to the community" (http://www.bom.gov.au/bmrc/ocean/GODAE/).

CLIVAR: (Climate Variability and Predictability program of the World Climate Research Project). Argo provides a primary ocean dataset for this experiment targeting better understanding of the climate system, including its variability and predictability. (See http://www.clivar.org.) CLIVAR's aim is to exploit the research value of broadscale climate observations and focused process experiments. In this context, Argo measures the storage and transport of heat and freshwater globally on broad spatial scales.

GOOS: (Global Ocean Observing System, see http://www.ioc-goos.org): "GOOS is a permanent global system for observations, modeling and analysis of marine and ocean variabiles to support operational ocean services worldwide. GOOS provides accurate descriptions of the present state of the oceans, including living resources, continuous forecasts of the future conditions of the sea for as far ahead as possible, and the basis for forecasts of climate change." As the only subsurface ocean element of GOOS with global extent, Argo plays a key role.

Global CO2 Flux Map Project: Argo provides near surface salinity and temperature to the NOAA Office of Global Programs funded project directed at providing global maps of CO2 surface fluxes.

The float data will be used in algorithms (developed from pCO2 observations) that provide estimates of surface carbon fluxes from surface salinity and temperature data.

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

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REFEREED PUBLICATIONS:

See http://www.argo.ucsd.edu/FrBibliography.html .

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