

## Argo: The Global Array of Profiling Floats

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**ABSTRACT** – *The Argo network of autonomous profiling floats will provide the first global views of the time-varying temperature (T) and salinity (S) fields of the upper ocean. Argo will serve a broad community of scientific and operational users, with objectives falling into several categories. It will provide a quantitative description of the evolving physical state of the upper ocean and the patterns of ocean climate variability, including heat and freshwater storage and transport. The data will enhance the value of the Jason altimeter through measurement of the subsurface vertical structure of T and S, plus reference velocity, with sufficient coverage and resolution for interpreting altimetric sea surface height variability. Argo data will be used for initializing ocean and coupled forecast models, for data assimilation and for dynamical model testing. A primary focus of Argo is seasonal-to-decadal climate variability and predictability, but many applications for high-quality global ocean analyses are anticipated.*

*The initial design of the Argo network is based on experience from the present observing system, on newly gained knowledge of variability from the TOPEX/Poseidon altimeter, and on estimated requirements for climate and high-resolution ocean models. Argo will provide 100 000 T–S profiles and reference velocity measurements per year from about 3000 floats distributed over the global oceans at 3-degree spacing. Floats will cycle to 2000 m depth every 10 days, with a 4–5 year lifetime for individual instruments. All Argo data will be publicly available in near real-time via the Global Telecommunications System (GTS), and in scientifically quality-controlled form with a few months delay. Global coverage will be achieved during the Global Ocean Data Assimilation Experiment (GODAE, 2003–2005), which together with the Climate Variability and Predictability Programme (CLIVAR) and the Global Climate Observing System/Global Ocean Observing System (GCOS/GOOS), provide the major scientific and operational impetus for Argo. The design emphasizes the need to integrate Argo within the overall framework of a comprehensive ocean observing system.*

*International planning for Argo, including sampling and technical issues, is coordinated by the Argo Science Team ([www-argo.ucsd.edu](http://www-argo.ucsd.edu)). Nations presently having Argo plans that include float procurement or production include Australia, Canada, China, France, Denmark, Germany, India, Japan, the Republic of Korea, New Zealand, Spain, the UK, and the USA, plus a European Union proposal. Combined deployments from these nations may exceed 700 floats per year as early as 2003. Broad participation in Argo by many nations is anticipated and encouraged either through float procurement, logistical support for float deployment, or through analysis and assimilation of Argo data.*

### The genesis and design of Argo

A broad-scale global array of temperature–salinity profiling floats, known as Argo, is planned as a major component of the ocean observing system, with initial deployments having begun in 2000. Conceptually, Argo builds on the existing upper-ocean thermal networks, extending their spatial

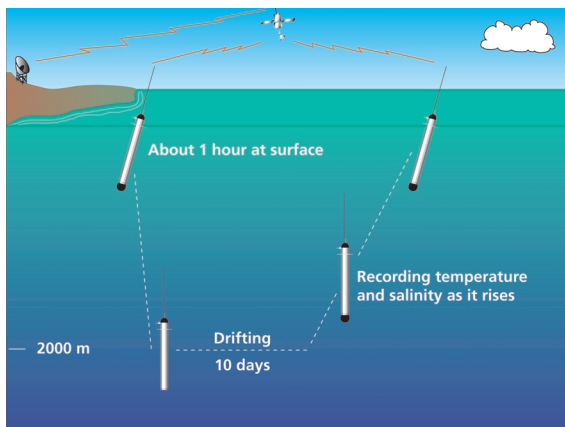
and temporal coverage, depth range and accuracy, and enhancing them through the addition of salinity and velocity measurements. The name Argo is chosen to emphasize the strong complementary relationship of the global float array with the Jason altimeter mission. For the first time, the physical state of the upper ocean will be systematically measured and assimilated in near real-time.

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Three recent developments make Argo a key step for oceanography and climate science.

1. Development of the profiling float (Fig. 1) makes it feasible to observe the physical state of the ocean (T, S and reference level velocity) on a regular basis anywhere in the world. This is particularly significant because it means that heat and freshwater storage in the global air–sea–land climate system, both of which are dominated by oceanic variability, can be measured accurately for the first time.
2. The availability of precision satellite altimeters, measuring sea surface height globally every 10 days, creates a compelling rationale for complementary *in situ* data sets to better interpret the surface measurement.
3. The maturation of data assimilation capabilities—including developments in both hardware and assimilation techniques—provides a framework to integrate the subsurface and remotely sensed surface data sets in a dynamically consistent fashion. The data requirements include wind and air–sea flux forcing (heat and precipitation minus evaporation) as well as the oceanic response–sea level variability and its subsurface counterparts.

With a comprehensive satellite remote sensing system now in place, and the powerful machinery for data assimilation available, the deployment of a global subsurface array becomes a top priority with a wide spectrum of scientific and operational applications.



**Figure 1.** Schematic of a single cycle in the mission of a profiling float. Float lifetime is expected to average about 4 years. Note that the parking depth may be shallower than the profiling depth.

It should be emphasized that Argo is not a complete *in situ* observing system. Its purpose is to provide global coverage of the upper ocean on broad spatial scales and on timescales of months and longer. The array's spatial resolution will not be fine enough to resolve boundary currents nor its time sampling adequate for the equatorial wave-guide. Initially, its domain will be limited to the upper 2000 m. Hence the global float array must be supplemented in ways that are regionally appropriate and dynamically sensible. Argo must knit together the regional enhancements and provide them with a global context. Climate is intrinsically a global problem that cannot be addressed comprehensively with regional measurements.

Having recognized the need for a global subsurface array, the design of Argo is an ongoing exercise in balancing the array's requirements against the practical limitations imposed by technology and resources. A complicating factor is that the statistics of ocean variability are poorly known in many regions, making array design a necessarily iterative process. The Argo Science Team was instructed to view the design question from a number of different angles. It is reassuring that these varying perspectives provide consistent estimates of what is needed in a global array (Argo Science Team, 1998, 1999). In brief summary, these perspectives follow.

1. *Previous and ongoing float studies:* A five-year deployment of about 300 floats in the tropical and South Pacific Ocean (Davis, 1998) was found to be adequate for mapping the mean geostrophic pressure field at mid-depth but not its time variability. The domain included nearly half the global ocean. These results showed that a large increase in float density was needed in order to map time varying fields. Recent experience with profiling floats in the North Atlantic at much higher spatial density emphasizes this finding (Lavender et al., 2000).
2. *The existing upper ocean thermal network:* Numerous network design studies have been carried out, using the expendable bathythermograph (XBT) data sets to provide the necessary statistics, as summarized by White (1995). In approximate terms, an array with spacing of a few hundred kilometres is sufficient to determine heat storage in the

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surface layer with an accuracy of  $10 \text{ W/m}^2$  on seasonal time-scales and over areas  $1000 \text{ km}$  on a side. This improves to about  $3 \text{ W/m}^2$  for interannual fluctuations. The combination of XBT and altimetric data can improve this further.

3. *The altimetric data set:* Spectral analysis of altimetric data shows that on a global basis, half of the variance in sea level is at wavelengths shorter than  $1000 \text{ km}$  (Wunsch and Stammer, 1995). If the climate signal of interest is defined to include all wavelengths longer than  $1000 \text{ km}$ , then an array with  $500 \text{ km}$  spacing provides a 1:1 signal to noise ratio. Spacing of  $250 \text{ km}$  would improve this ratio by more than a factor of 3. The unresolved variability—fronts, mesoscale eddies etc.—has a short decorrelation time, typically 10–20 days, compared with the seasonal and longer climate signals of interest. Therefore, the signal-to-noise ratio can be increased by temporal or multi-track averaging. As a function of latitude, the half-power point varies from  $1300 \text{ km}$  wavelength in the tropics to  $700 \text{ km}$  at  $50^\circ\text{N}$  (Stammer, 1997).
4. *Climate signals in WOCE hydrographic data:* Decadal variability in the subtropical North Atlantic has been described using comparisons of WOCE hydrographic transects with previous hydrography along the same tracks (Parilla et al., 1994, Joyce and Robbins, 1996). Subsampling experiments show that these basin-scale signals can be recovered by using stations at  $3^\circ$  spacing, which provides enough independent samples to average out the eddy noise.
5. *Requirements for assimilating models:* Initially, these are not distinctly different from the requirements for pure data analysis. The models require sufficient data to determine the statistics linking point measurements to the smoothed fields of the simulations. They also require sufficient data to estimate comparison fields for rigorous testing of model results. While there is still much to be done to determine the optimal data sets for assimilation, it is clear that the requirements remain substantial (see Le Traon et al., this volume).

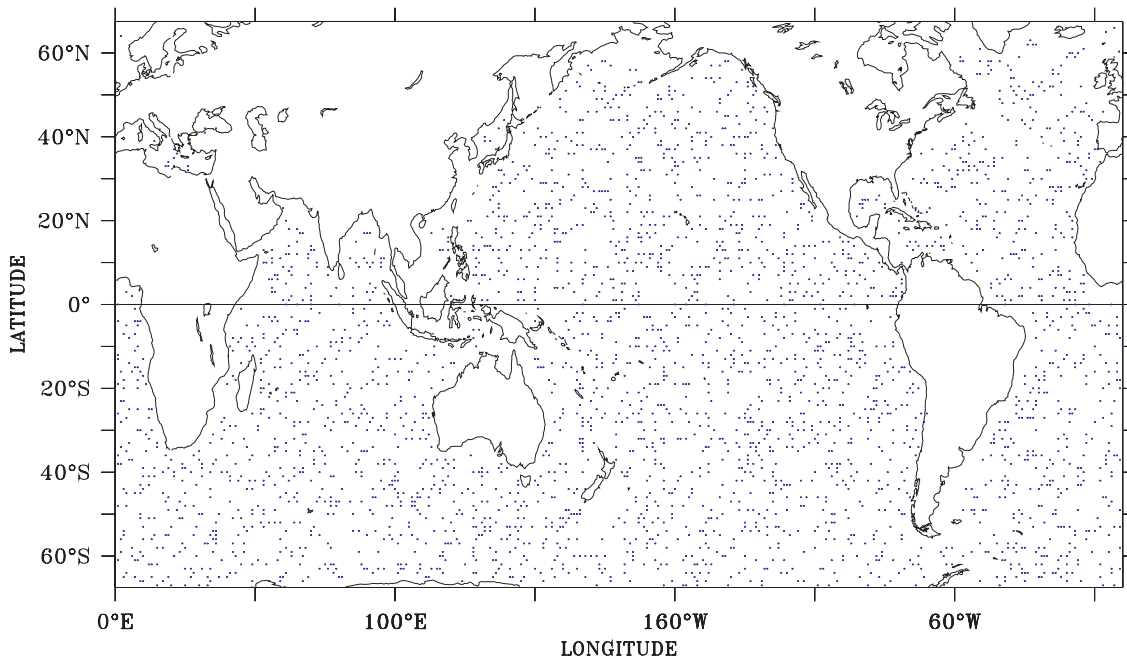
The Argo Science Team concluded that a global array of about 3000 profiling floats with uniform

$3^\circ$  spacing in latitude and longitude is practical and should be the initial target for Argo (Fig. 2). With the array specified in this way, the spatial density of floats will be twice as great at  $60^\circ$  latitude as at the equator. This is not as steep an increase with latitude as is suggested by wavenumber spectra from altimetric sea level (see point 3 above—this would require about a factor of 4 increase in the number of floats per unit area at high latitude). However, a relatively higher signal to noise ratio in tropical latitudes is justified given the known importance of climate signals in the tropics. Argo deployments at high latitudes are viewed as more exploratory in nature, while those in the tropics are made with a practical view of improving seasonal to interannual prediction.

It is recognized that the design of the Argo array is not static. It will continue to evolve as the scientific requirements are refined and as the array itself provides sufficient statistical information to improve its own design. The instrumentation itself will also continue to evolve. Gains in depth range, energy efficiency and salinity stability are anticipated, as well as the development of new sensors and the emergence of glider technology. The glider, a winged and streamlined float with control over its movements, will be able to take on a variety of new missions such as time-series measurements at fixed locations and repeated hydrographic sections. The challenge will be to evolve the Argo design in a way that maintains continuity of the basic broad-scale physical measurements while expanding value and applications through regional or global enhancements.

#### Anticipating Argo's achievements

Argo is conceptually an extension of today's upper ocean thermal networks. Some of its achievements can be anticipated by extrapolating from the present capabilities to more comprehensively sampled global coverage. Much will be gained by freeing the present-day networks of the constraints imposed by sampling along commercial ship tracks and by the use of XBT technology. The gains to be derived from systematic salinity sampling are harder to quantify because there is no precursor salinity network. However, the lack of background knowledge of the time-varying salinity field makes establishment of the network even more compelling. Salinity variations form a substantial part of the density signals in many regions, and salinity is a primary diagnostic variable for the hydrologic cycle.



**Figure 2.** Schematic of the Argo float array. Locations of 3000 randomly chosen positions are shown as blue dots in waters deeper than 2000 m.

Assuming the global float array is deployed as planned and maintained for at least a decade, its principal achievements will include the following:

1. Obtaining an unprecedented data set for model initialization, data assimilation and dynamical consistency testing of the next generation of global ocean and coupled models.
2. Enabling realistic real-time global ocean forecasting for the first time. Argo is not the only data set needed, but it is an essential one.
3. Producing an accurate global climatology, with error bars and statistics of variability and valid for the specific period of the array, of monthly mean temperature and salinity as a function of depth.
4. Producing accurate time series of heat and freshwater storage (globally) and of the temperature–salinity structure and volume of the world’s intermediate and thermocline water masses.
5. Providing large-scale constraints for atmospheric model-derived surface heat and freshwater fluxes on seasonal and longer timescales.
6. Completing the global description of the mean and variability of large-scale ocean circulation, including interior ocean mass, heat and freshwater transports—the equivalent for large-scale ocean circulation of a real-time synoptic upper ocean World Ocean Circulation Experiment (WOCE).
7. Determining the dominant patterns and evolution of interannual variability in temperature and salinity, e.g. for analysis of coupled modes of air–sea interaction. Discover other El Niño-like phenomena in the global oceans and their impact on improvement of seasonal-to-interannual atmospheric forecasts.
8. Providing global maps of the absolute height of the sea surface, with an accuracy of about 2 cm on periods of a year and longer—allowing Jason (altimeter)–Argo combinations to examine a broad range of space and time scales.
9. Enabling the interpretation of (altimetric) sea surface height by determining the statistical relationship between sea surface height and subsurface temperature and salinity variability.
10. Directly interpreting sea surface height anomalies—for example due to global sea level

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change, El Niño, etc.—by separating them into contributions due to the effects of (i) evaporation minus precipitation, (ii) differential heating and cooling, (iii) advection of heat and freshwater, and (iv) wind-driven redistribution of mass.

11. Providing a large-scale context for regional process studies.

#### Implementation of Argo

Argo is now entering its initial implementation phase, including pilot float deployments and data system development as well as further instrumentation development and array design studies. Early deployments of Argo floats are presently funded or proposed in Australia, Canada, China, France, Germany, India, Japan, New Zealand, Norway, the Republic of Korea, Spain, the UK, the USA and the European Union. More than 600 Argo floats are funded as of early 2001, with proposals being considered for more than 2000 within the next 3 years. The first deployments are presently occurring in the Atlantic, Pacific and Indian oceans, with most of the floats deployed to date in the tropics. The global array will grow rapidly from these pilot arrays.

Full-scale Argo deployment, with more than 700 floats per year entering the ocean, may occur as early as 2003. An array with global scope (but large gaps remaining) is expected by 2004, during GODAE (see Le Traon et al., 2001, this volume). A complete Argo array will be in place by 2005. The principal issues for achieving complete Argo deployment are the total number of floats committed to the program and the commitments for deployment in remote ocean regions.

It is recognized that initial national interests are focused on coverage of the Atlantic Ocean and the tropical and North Pacific. Complete coverage in the Atlantic is expected in 2003. Cooperative agreements will be needed to implement a global array, with all nations necessarily contributing to regions outside their highest priorities. The most difficult regions to instrument (Fig. 2) will be the South Pacific and South Indian oceans. Most of the float-providing nations are in the northern hemisphere, whereas about two-thirds of the required floats are south of the equator. Moreover, south of about 30°S, commercial ship traffic is sparse, and access for float deployments is sometimes problematic. Special attention must be directed to building the array in the southern

hemisphere. It is necessary to emphasize the high scientific benefits of sampling in a vast and largely unexplored region of the world's ocean, and the cost effectiveness of profiling float technology compared to conventional measurement techniques in remote and harsh environments. It is necessary to emphasize the high scientific benefits of sampling in a vast and largely unexplored region of the world's ocean, and the cost effectiveness of profiling float technology compared to conventional measurement techniques in remote and harsh environments. It is further necessary to develop effective deployment strategies including the use of air deployment of floats in addition to the opportunistic use of research vessels, naval vessels, commercial ships, and Antarctic supply vessels.

#### Technical issues for Argo

##### Communications

Present float deployments are using System ARGOS satellite communications. In addition, global cellular networks are being examined as possible future options. Greater bandwidth is needed than the present ARGOS capability so that floats can transmit more data while remaining on the sea surface for a shorter period of time. Concerns related to communications, in addition to cost, include the following.

1. *Data quantity*: Present profiles include about 50 T-S pairs, with variable data precision depending on depth. The aim is to improve profiles to about 500 T-S pairs with 0.001 precision. This will require 2 kilobytes of data per profile (in compressed formats), allowing 2 m depth intervals from 0 to 500 m and 5 m intervals from 500 to 2000 m.
2. *Time spent on the sea surface*: Present instruments remain on the sea surface for 12–24 hours to allow multiple ARGOS satellite passes. The target for future improvement is 1 hour or less. Minimizing this time will lower risk to the instrument and its sensors (i.e. biofouling) as well as decreasing the displacement of the float by surface currents. The time required for profile communication also directly affects the 'age' of real-time data.
3. *Power consumption*: The target is for communications to consume less than 10% of the energy budget per cycle (or <1 kJ). In this

regard, satellite systems that acknowledge receipt of data are desirable, eliminating the need for multiple transmissions.

It is not presently possible to focus on a single communications system, as several have the potential to meet requirements in the future. Given the multiyear lifetime of floats, another important consideration is the financial stability of privately financed communications systems.

### **Salinity**

It is recognized that the development of stable salinity sensors for 4-year and longer missions is the most difficult technical issue for Argo. The main cause of problems is biofouling. Present work focuses both on determining the long-term capabilities of present sensors and on development of better ones. There are now many examples of 1–3 year records from profiling floats in the Atlantic, providing stable salinity data (e.g. Fig. 3) and using sensors from two different manufacturers. The adoption of 2000 m as the target for profiling depth in Argo provides water masses over most of the global ocean with sufficiently stable T–S to use as a salinity standard. Using more than 30 float-years of data from profiling floats equipped with SeaBird (SBE) CTD sensors in the North Atlantic and Japan Sea, Riser and Swift (2001 pers. comm.) showed that in over 90% of cases, records longer than 6 months had stable deep (>750 m) salinity measurements, with salinity differences from climatology generally less than 0.015. Several of these floats had been in the water for over 3 years, with no detectable drift in the salinity measurement. Furthermore, several of the floats were recovered from the ocean and returned to the manufacturer for recalibration; the results showed that the calibration of the CTD sensor had changed by less than 0.004 psu in all cases, over times ranging from 8 months to more than 3 years. While these results are encouraging, it is necessary to accumulate data from many more floats and over longer periods of time to adequately characterize the current salinity sensors.

### **Energy use**

Considerable progress has been made in reducing energy usage, with improvements due to use of efficient single stroke pumps and better energy use in communications. Energy budgets for all types of Argo floats indicate in all cases that a battery lifetime of more than 200 profile cycles to 2000 m

depth is feasible. The gains in energy efficiency have had two major impacts on experimental design: enabling deeper profiling for salinity calibration checking, and increasing the profiling frequency to a profile per 10 days, without compromising float lifetimes.

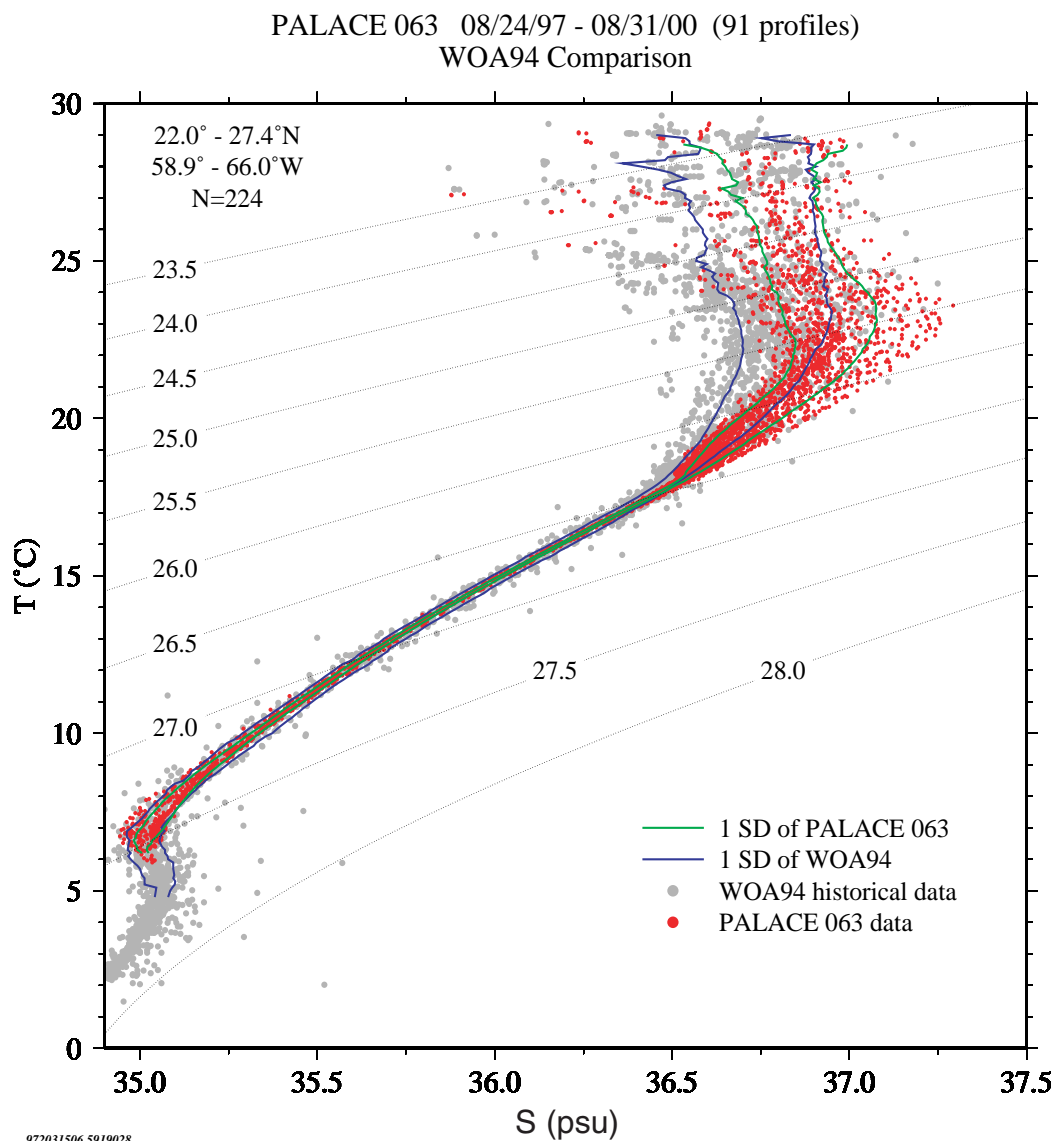
### **Deployment technique**

Argo floats will be deployed by Volunteer Observing Ships (VOS), aircraft, naval ships and research vessels. VOS deployments have been successfully implemented and aircraft deployment has been demonstrated. Dedicated use of research vessels will be minimized due to high cost, but research vessels with planned trips to remote regions may be very useful. The distribution of VOS XBT and meteorological reports demonstrates that much of the ocean is accessible from VOS, with dispersion of floats by mean and time-varying flows an effective means of filling gaps between VOS routes. The efficiency of float dispersion by the flow field is demonstrated by Fig. 4, which shows the initial positions of all WOCE floats together with their most recent or final positions. The WOCE floats were deployed from widely spaced research vessel tracks, drifting for several years at about 900 m depth. Additional studies are needed of the relative efficiency of VOS deployment and dispersion versus aircraft deployment for achieving optimal float distribution.

The choice of parking depth—the depth at which a float drifts between profiles—has impacts on deployment efficiency, on susceptibility to biofouling, and on scientific objectives related to observing ocean circulation. The new generation of floats can park at one or more depths, and the parking depth is chosen independently of the profile depth. Deeper parking will produce less dispersion away from initial deployment sites and less biofouling of salinity sensors. Shallow parking in the thermocline may be desirable to enhance dispersion away from deployment tracks or for determining flow trajectories at that level. Because of these tradeoffs, it is recognized that no single choice of parking depth is possible for the global array. However, we reiterate that deep profiling is desirable and 2000 m is the present target for profiling depth.

### **The Argo data system**

The Argo data system (Fig. 5) will evolve from the present Upper Ocean Thermal Data Centers so



**Figure 3.** Temperature–salinity values (raw values, red dots) from a float operating in the Sargasso Sea for 3 years. Measured T–S variability is small ( $<0.01$  psu) in the thermocline, where natural variability is also small, indicating little or no drift in the salinity sensor.

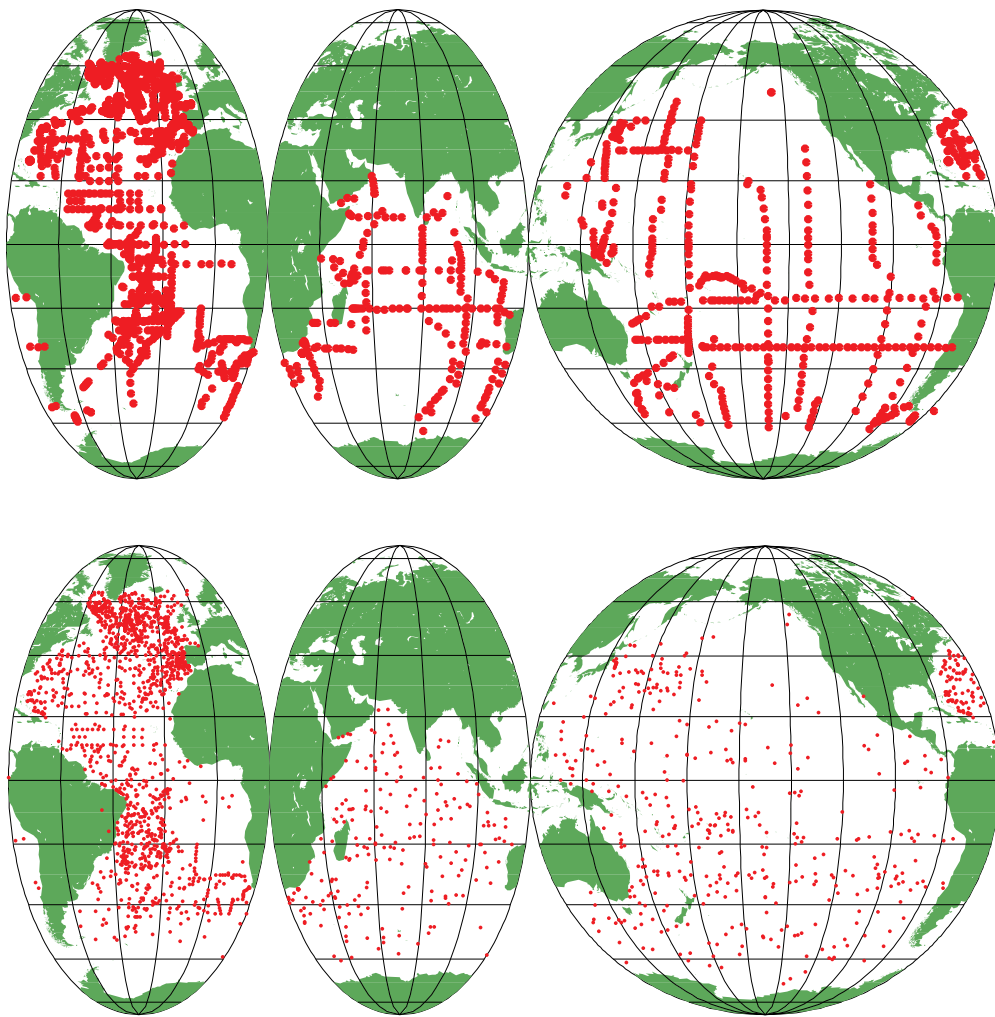
that it can be inclusive of all forms of real-time upper-ocean temperature and salinity profile data. It is recognized, however, that quality control of salinity data is much more difficult than temperature alone, so this evolution is a major step. For salinity quality control, partnerships between data centres and float and salinity experts are needed. Participation by scientists in the data system should be explicitly included in Argo resource requirements.

Argo data will be publicly available, initially through two pathways (Fig. 5): a near real-time path via the GTS for operational modelling and

forecasting, and a slower path for scientific applications requiring the best attainable data quality. The use of e-mail and ftp is being studied as possible real-time and delayed mode access methods. The elements of the data system are as follows.

#### Data transmission

Data transmission is via satellite, with profiles received at data centres within a day of collection. This system yields large advantages over present VOS XBT networks both in timeliness of data and in the assurance that appropriate identification information and meta-data are attached to profiles.



**Figure 4.** Initial (top panel) and final or most recent (bottom panel) position of all floats deployed in WOCE. Floats deployed along widely spaced lines tend to fill in the areas between the lines through random dispersion by the flow field (Courtesy R. Davis).

### Real-time quality control

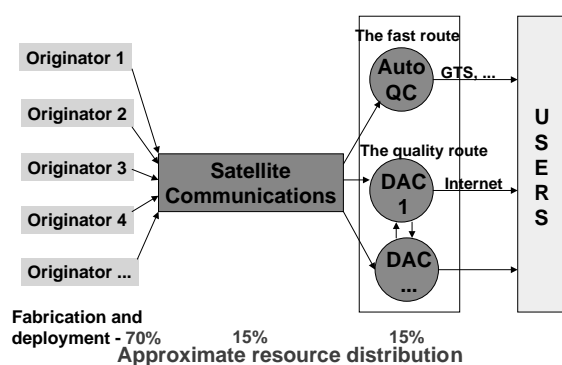
The real-time quality control (QC) procedures must be fully automated and carried out on a 7 days per week, 24 hours per day basis. The goal is to make data available to operational users within 24 hours of collection. Procedures consist of statistical tests of temperature and salinity and their vertical gradients against climatological data, comparison of profiles with previous data from the same instrument, plus platform speed and checksum tests. Salinity checking uses assumptions of vertical density stability and of limits on deep T-S variability. Real-time QC includes flagging of outlier values and recalibration of salinity using instrument histories.

### Data tracking

Once collected it is essential to ensure that data get to users. For the global XBT network, a set of 'pipelines' defines the path of data from VOS to user. Taps are placed in the pipeline at strategic locations. Data counts are made at the taps and discrepancies are noted. When differences are greater than some predetermined values, causes are determined and problems remedied. With Argo data, a somewhat more sophisticated tracking system is possible. A unique tag is associated with every profile and the time and location of each profile is anticipated by the data system. The existence or lack of valid profile data is used to monitor the status of each instrument and to update a master profile inventory.



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**Figure 5.** Schematic of the Argo data system. Data follows a fast pathway to operational assimilation and prediction centres and a slower route with more complete quality control for scientific analyses.

#### Delayed-mode QC

Delayed mode QC is required to ensure that a scientifically reviewed data set of highest quality is available to present and future researchers. In this process, it is necessary to use as much upper ocean temperature and salinity data as possible. Individual float profiles are compared with neighboring floats as well as XBT, XCTD and thermosalinograph data to generate products for comparison. For example, temperature maps using neighboring floats and XBTs can be used to identify outliers. Another essential element of delayed-mode QC is examination of sequences of profiles from individual instruments by a scientist, by using information from the history of each instrument as well as from nearby instruments. Completion of delayed-mode quality control should occur within a few months of data collection.

#### Evaluation of the data

Operational forecast centres are primary users of Argo data, so the acceptability of profile data in assimilating models is an important form of evaluation. Data that are not usable in assimilation will be reviewed to determine if the problem is likely to be in the instrument or the assimilation. If the problem is in the data, solutions at the data collection end will be implemented. If the problem is with the assimilation system, revisions in the procedure are needed. This last step in the data system ensures maximum usefulness of Argo data.

#### International issues

Argo is inherently international in its inception and implementation. Formally, it is a pilot project

of the GOOS. Argo is the primary *in situ* data-gathering component of GODAE and it is strongly endorsed as part of the CLIVAR. The Thirteenth World Meteorological Conference (Geneva, May 1999) and the Twentieth Intergovernmental Oceanographic Commission Assembly (Paris, June 1999) both accepted the Argo project as an important component of the operational ocean observing system as well as a major contributor to scientific research programs. All nations will have immediate and equal access to Argo data and all will benefit from the resulting improvements in regional and global climate observation and prediction. Argo has received strong international support, and the continuation of that support is expected and essential.

International participation in Argo can take on a number of forms. Float production is technically difficult and expensive, so the burden of production or procurement of floats will fall on nations having strong interest and the necessary resources. Presently, float-producing nations are the USA and France, with production facilities also being built in Japan and Canada. The open availability of the design of the Scripps SOLO float enables interested countries, institutions or companies to obtain state-of-the-art profiling float technology. Participation in Argo by many nations is strongly encouraged, if not via float production or procurement then through logistical support for float deployments and in establishment of regional analysis, assimilation and prediction centres. Expressions of interest are welcomed by the Argo Science Team ([www-argo.ucsd.edu](http://www-argo.ucsd.edu)).

The existence of a comprehensive data system including float tracking and inventories makes it feasible to monitor the Argo array in real time. One aspect of array monitoring will be to identify and correct gaps in global sampling. This will be a responsibility of the Argo Science Team, drawing on the priorities and commitments of participating nations to fill gaps in a timely manner. A second aspect of array monitoring is to address the possibility of random float entry into 200 mile Exclusive Economic Zones (EEZs). An international Argo Information Center (AIC, see [argo.jcommops.org](http://argo.jcommops.org)) in Toulouse, France, maintains up-to-date information on float deployments and positions, informing coastal states of floats that may drift into EEZs. The AIC will support the international program in a number of ways, including providing liaison between float providers and float-deployment opportunities.

Argo is a unique undertaking for oceanography. It is a multinational partnership of scientists, government agencies and private industry, formed to produce a global data set for immediate release to a broad community of users. Participating scientists include the world's experts in these technologies, giving their expertise to the project, while placing the group objectives above individual science. The scope and completeness of the global array, and the rapid public delivery of high quality data are the driving motivations. The result will be a data set of enormous value both in its immediate uses and in its long-term legacy in the data archive.

## Conclusion

There is now a broad international consensus that the deployment of a global array of profiling floats is a high priority in the integrated ocean observing system. The scientific and operational objectives are compelling. For the first time, the technology exists to implement global *in situ* observations that are the subsurface counterpart of the remotely sensed satellite networks. The Argo array will provide the capability to knit together many regional components of the ocean observing system, and will provide the global broadscale context for it. Assimilation techniques and computing resources are available to combine the remotely sensed and subsurface data sets for ocean state estimation and prediction. The undertaking is an ambitious one, requiring a major commitment of resources over a sustained period of time. It is unprecedented in the field of oceanography. An international partnership is being built that includes academic and government scientists and operational agencies with the combined abilities and resources to put the array into the water and produce a high-quality

near real-time data stream. Additional linkages must be built to ensure the rapid utilization of Argo data and the worldwide dissemination of analyses and forecasts for the benefit of mankind.

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## Question and Answer Session

**Kessler:** The floats will be produced in several countries and, presumably, the designs will differ. How will the different float models be identified to the user and how will you do the quality control of the different instruments to provide a consistent measurement?

**Roemmich:** It will be relatively easy in the Argo data system to insure that the metadata in the records are attached to the information. The data centres will know what type of instruments made the measurements, what type of CTD made the profile of temperature and salinity on each specific float.

With regard to the quality control, it is very important that the scientists stay strongly involved. That will absolutely be a key for the success of Argo. It is not going to be operational in the sense that we have meant operational in the past or in the way the meteorological community may mean operational. What we must have will very much be a partnership between scientists, the float experts, the float data centres, and the operational centres to produce a high quality dataset.

**Anonymous:** Given the possibilities of Argo being a trend-setter for global cooperation, certain sensitivities of various governments need to be addressed. While Argo will do yoman service to the scientific community, it also makes the oceans acoustically transparent in areas of concern. This being a transcontinental venture, would it not be correct to set up a mechanism where there would be an interface at the policy or decision making levels of governments so that we could promote Argo as quickly as possible.

**Roemmich:** From the standpoint of a scientist, we will fail in this endeavor if we do not persuade all of the nations involved that there is a huge gain for them individually from participating in ARGO. We have seen that the ENSO observing system produced enormous economic gain in the United States. We need to make this point in other counties, that there is a huge economic gain from participation. Secondly, there is a gain to be made through participation in technology. The technology is openly available. Any nation, any agency, any company can have the profiling float technology. Anybody can go into the float production business. Its an open design. These are the things that we as scientists have to make known widely. These are the advantages of participation. The concerns have to be aired appropriately and internationally, so to whatever extent possible, these concerns can be mitigated.

**Summerhayes:** The WMO and IOC member states have been exposed to the idea of Argo and they have accepted the idea enthusiastically. Some nations are concerned about floats drifting into their exclusive economic zones. We are in the process of writing letters from the IOC and WMO to the different countries to explain the mechanism as to how they can access the data and how they can find out where the floats are. This is a deliberate attempt to engage these nations in the Argo project and allow them to make sure they fully understand the benefits. There are no secrets. The data are freely available to all nations. This will take place before the end of the year in consultation with the Argo science team.

**Hacker:** Has the Science Team looked at regions that might be undersampled, such as complicated equatorial current systems or western boundary current regions, where you may have to supplement the program with moorings, for example.

**Roemmich:** Argo is fundamentally a broad-scale array. This technology will not address boundary currents. What are the appropriate technologies needed to address western and eastern boundary currents? This will be discussed later in the conference. The edges of the ocean need to be seriously addressed.

Where are we going to have the hardest time implementing the Argo array to achieve the global array? The answer is the Southern Ocean. There are a large number of floats needed, order 1000, south of 40S. This tends not to be the top priority region for the float producing nations. That is one of the hardest implementation items for the Argo science team. In order to achieve a global array we will need to set some fraction of floats aside for a region that is not the top priority of any single government.