



Argo, an array of profiling floats
observing the ocean in real-time



FIVE YEARS OF PROGRESS - DECADES OF POTENTIAL

why we need ocean observations

This brochure describes Argo.

Argo is an international programme using autonomous floats to collect temperature, salinity and current data in the ice-free oceans.

It is teamed with the Jason ocean satellite series.

Argo will soon reach its target of 3000 floats delivering data within 24 hours to researchers and operational centres worldwide. 23 countries contribute floats to Argo and many others help with float deployments.

Argo has revolutionized the collection of information from inside the oceans.

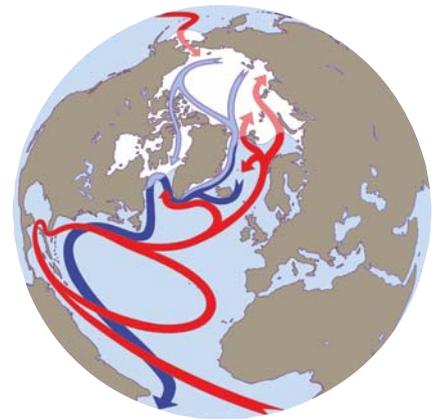


Courtesy Proudman Oceanographic Laboratory

There is increasing concern about global change and its regional impacts. Sea level is rising at an accelerating rate of 3 mm/year, Arctic sea ice cover is shrinking and high latitude areas are warming rapidly. Extreme weather events cause loss of life and enormous burdens on the insurance industry. Globally, 8 of the 10 warmest years since 1860, when instrumental records began, were in the past decade. Measurements of the Earth's radiation budget and the oceans' heat storage both indicate nearly 1 Wm⁻² of global heating in the past decade.

These effects are caused by a mix of long-term climate change and natural variability. Their impacts are in some cases beneficial (lengthened growing seasons, opening of Arctic shipping routes) and in others adverse (increased coastal flooding, severe droughts, more extreme and frequent heat waves and weather events such as severe tropical cyclones).

Understanding (and eventually predicting) changes in both the atmosphere and ocean are needed to guide international actions, to optimize governments' policies and to shape industrial strategies. To make those predictions we need to know the relative importance of natural



Atlantic Ocean circulation plays a key role in the global climate.

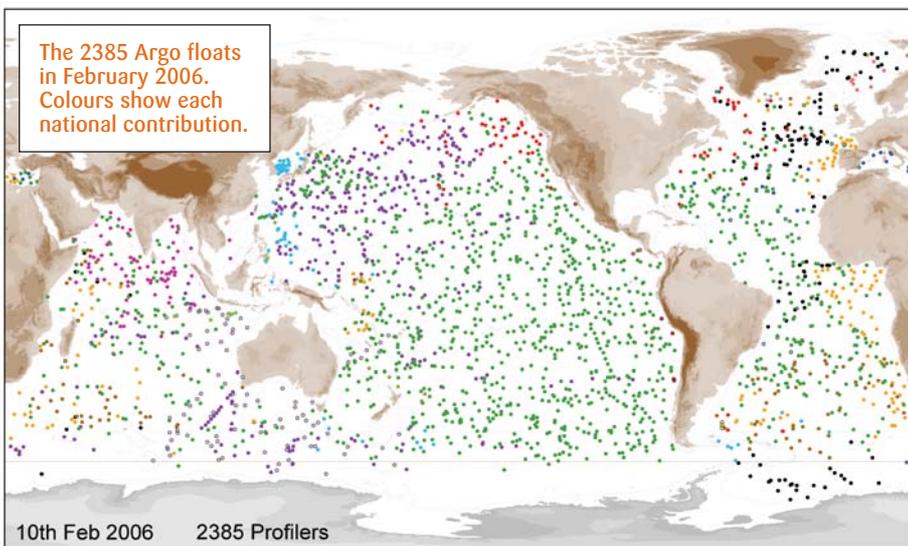
variability and long-term change. This will come through improved models of climate and of the entire earth system (including socio-economic factors).

Lack of sustained observations of the atmosphere, oceans and land have hindered the development and validation of climate models. A recent analysis concluded that the currents transporting heat northwards in the Atlantic and influencing western European climate had weakened by 30% in the past decade. This result had to be based on just five research measurement campaigns spread over 40 years. Was this change part of a trend that might lead to a major change in the Atlantic circulation, or due to natural variability that will reverse in the future, or is it an artifact of the limited observations?

Concerns about the lack of observations of key factors that influence earth's climate led governments to form the Global Earth Observation System of Systems (GEOSS) in 2003. In Europe there is an initiative on Global Monitoring for Environment and Security (GMES). GEOSS and GMES aim to provide the measurements needed to make predictions of how global change will influence weather, climate, energy, water, health and disasters. The climate and ocean components of GEOSS are delivered by the Global Climate Observing System (GCOS) and the Global Ocean Observing System (GOOS).

In 1999, before GEOSS was set up, an innovative step had been taken by scientists to greatly improve the collection of observations inside the ocean.

That initiative was Argo.



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| ● Argentina (3) | ● Costa Rica (2) | ● Japan (342) | ● Norway (9) |
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| ● Canada (70) | ● Germany (126) | ● Mexico (1) | ● United Kingdom (97) |
| ● Chile (4) | ● India (75) | ● Netherlands (7) | ● United States (1253) |
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the rationale behind Argo



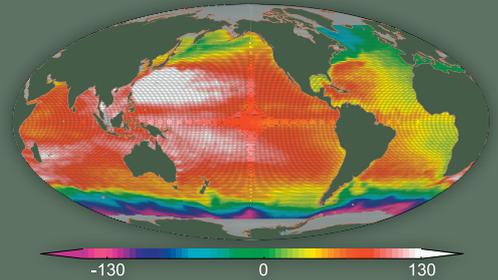
ALACE float as used in WOCE.

Courtesy Scripps Institution of Oceanography

Before Argo, most of our knowledge about the interior of the ocean came from research ship measurements and from temperature probes (XBTs) dropped from merchant ships. These observations were relatively sparse, there were more in summer than in winter and there were very few in the remote but climatically important Southern Ocean. Almost all these research observations were maintained only for short periods making it hard to monitor ocean changes. We were poorly equipped to observe and understand ocean climate.

An important exception was the Tropical Atmosphere Ocean (TAO)/Triton mooring array spanning the Pacific and making its data available immediately. The array was completed in 1994. Data from TAO/Triton enabled models to forecast El Niño events up to a year ahead of their peak. These forecasts have measurable economic benefit in the Americas and Australasia and show the real value of sustained and systematic ocean observations.

The 1990s marked another important advance. Researchers mounted the World Ocean Circulation Experiment (WOCE) – the largest ocean experiment ever



Global ocean dynamic topography (cm) from Jason-1 corrected using the GRACE gravity satellite.

V. Zlotnicki and L-L. Fu

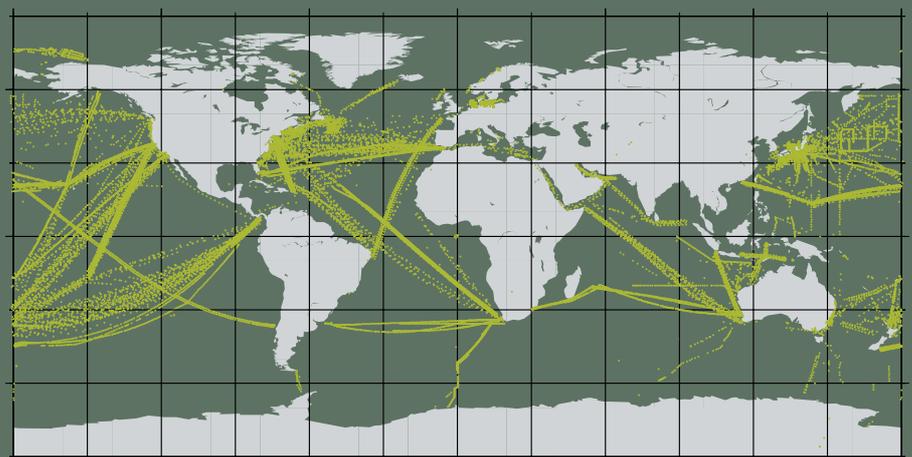
undertaken. WOCE set out to improve the ocean models used in global climate research by collecting an unprecedented set of observations. These came from a new generation of radar satellites that continuously monitor the shape of the ocean surface and its roughness. For the first time they began showing the strength and direction of surface currents, the effects of thermal expansion of the oceans caused by heat storage and the patterns of wind that drive the oceans.

WOCE needed to know the temperature and salinity of the oceans and this data came from 20,000 observations made over 8 years by instruments lowered from research ships. It took a total of 25 years of ship time at a total cost of \$220 million but still left large areas unsampled.

To measure currents below the surface WOCE used battery-powered neutrally buoyant floats that hovered at mid-depth and surfaced every few weeks to be positioned by satellites. These Autonomous Lagrangian Circulation Explorers (ALACE) mapped currents across entire ocean basins.



WOCE stations with temperature salinity profiles between 1990 and 1998. *Courtesy WOCE International Project Office*



Positions of 30,000 XBT real-time temperature profiles in 2004 (note large unsampled areas). *Data from NOAA, AOML*

Argo's origins



Dr John Swallow (1923 - 1994) invented the neutrally buoyant float and made the first deep current measurements in 1955. The Argo float is a direct descendant of this creation.

Courtesy National Oceanography Centre, UK

After it was shown that the ALACE floats used in WOCE could measure global subsurface currents, the floats were modified to measure profiles of temperature and salinity each time they surfaced. These profiling floats could then make the same measurements that previously took so much research ship time.

Based on the experience in WOCE, a plan was presented in 1998 to develop a global array of profiling floats spaced every 3° throughout the ice-free areas of the deep ocean. Together with a new generation of Jason radar satellites, the float array would for the first time systematically monitor the state of the global ocean (temperature, salinity, currents and winds) so that we could address the serious issues of climate variability and change.

The float plan was called Argo after the ship in which, according to Greek mythology, Jason set sail in search of the golden fleece.

Combining the satellite and float data to define the "state of the ocean" required the use of data assimilation; a technique used in weather forecasting that was applied to the oceans during WOCE. Assimilation combines observations with detailed computer models in a way that ensures that the results agree with the fundamental physical laws that govern ocean dynamics.



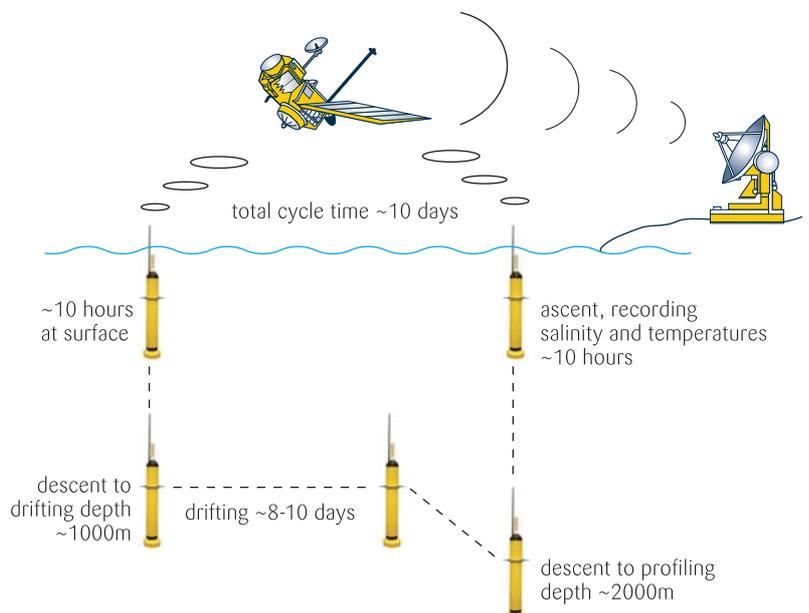
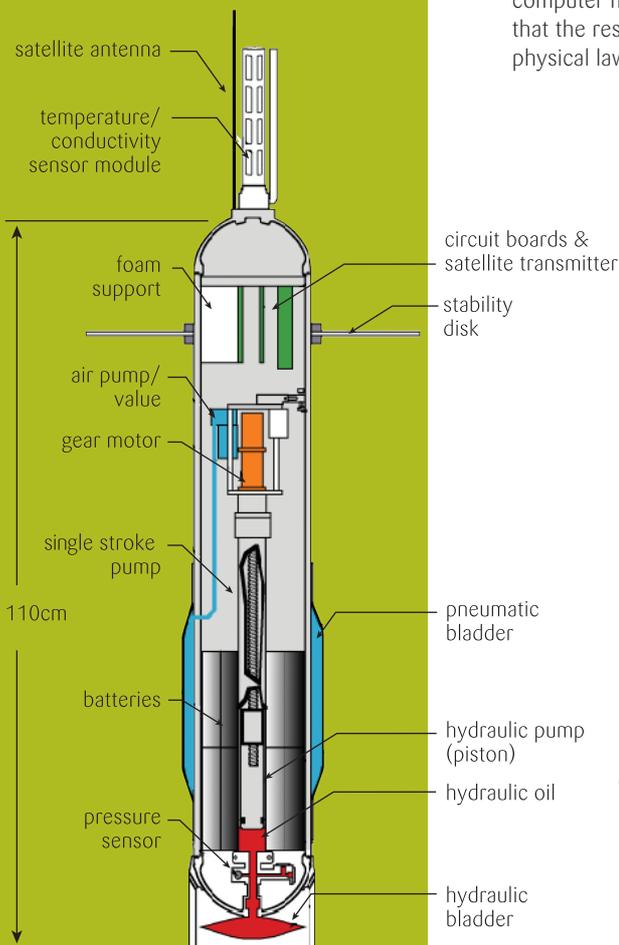
Large container ships like this are deploying Argo floats along shipping lanes at high speed.

Argo was a totally new concept and required ocean scientists to work in a multinational collaboration to monitor the global ocean for the benefit of all. Argo would be made up of contributions from individual countries, all of which would share their data and make it available to any user anywhere in the world within 24 hours.

In order to provide information on the constantly-changing array, float deployments and positions would be tracked through an Argo Information Centre (AIC) established under the Intergovernmental Oceanographic Commission (IOC) of UNESCO.

The floats would have a design life of at least 4 years meaning that 800 floats per year would be needed to maintain the 3° x 3° array of 3000 floats.

The first Argo floats were deployed in late 1999.



progress to date

How many countries are now involved in Argo and how are floats launched?

Many new countries have joined the original 10 that launched floats in 2000. At the latest count 27 countries have deployed and operated floats or assisted with float deployments (Argentina, Australia, Brazil, Canada, Chile, China, Costa Rica, Denmark, France, Germany, Iceland, India, Indonesia, Ireland, Japan, Korea, Mauritius, Mexico, Mozambique, the Netherlands, New Zealand, Norway, Russia, South Africa, Spain, the UK and the USA, as well as the European Union and Pacific Island nations). Floats have been deployed from ships ranging from small research vessels to huge container ships and also from aircraft.

How many floats are operating and how much data do they produce?

In mid-February 2006 Argo had a global array of 2355 floats in the ice-free areas deeper than 2000 m. This represents almost 80% of the target array.

The number of profiles has risen steadily and since mid-2002 Argo has been the largest single source of ocean profile data. As well as being more numerous, the Argo data go deeper than the 750 m XBTs, measure temperature much more accurately, and also collect salinity and ocean current data. In the Southern Ocean Argo now collects temperature/salinity profiles at 50x the pre-Argo rate.

How deep do they operate?

Argo recommends that all floats drift at a depth of 1000 m (to give a uniform velocity field) and profile to 2000 m so as to capture important variability. To save energy, not all floats profile that deeply on every 10-day cycle. In the present array 66% of profiles extend to greater than 1500 m and 46% to around 2000 m.

When and where are data available?

Argo has built an efficient data management network of national centres that provides data in real time (90% of profiles available within 24 hours and almost all within 48 hours) and delayed mode, from two global hubs, one hosted by Coriolis (France) and the other by GODAE (USA). Operational weather and climate centres can also get the real-time data from the WMO Global Telecommunication System.

How accurate are the data?

Temperatures are accurate to ± 0.005 °C and depths to ± 5 m. For salinity there are two answers. The data delivered in real time are sometimes affected by sensor drift. For many floats this drift is small, and the uncorrected salinities are accurate to ± 0.01 p.s.u. At a later stage salinities are corrected by expert examination, comparing older floats with newly deployed instruments and with ship-based data. Following this delayed-mode correction, salinity errors are reduced further and in most cases the data become good enough to detect subtle ocean changes.



Small vessels can deploy floats in remote areas. The Kaharoa, from New Zealand, at only 28m length is the most prolific deployer of Argo floats in the world.



When will the array be completed?

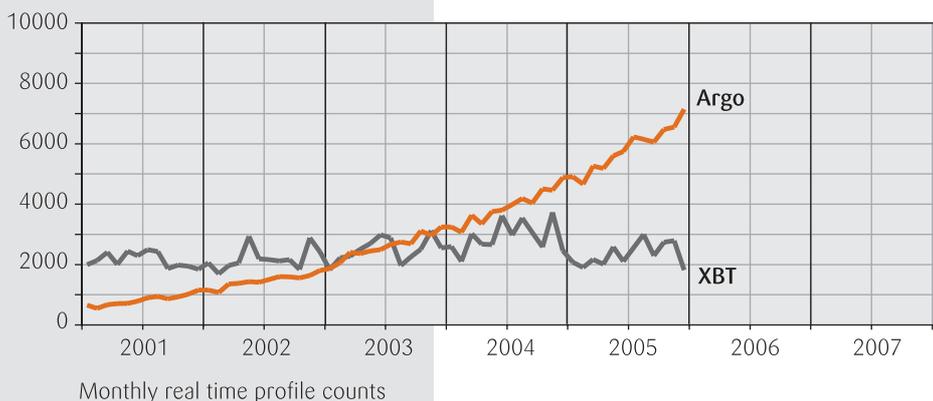
The Argo array should approach 3000 floats by the end of 2006, and can be maintained at that level as long as national commitments provide about 800 floats per year. The need for global Argo observations will continue indefinitely, though the technologies and design of the array will evolve as better instruments are built, models are improved and more is learned about ocean variability.

How is Argo managed?

Argo has an international Steering Team and a Data Management Team made up of scientists from countries involved in Argo. An Argo Technical Co-ordinator monitors the array and registers each float deployment in accordance with international agreements. Argo also has an international Director. Each country finds its own funding and sets its own priorities for where floats are deployed in consultation with other countries.

How much does Argo cost?

The total annual cost of Argo is about \$20 million, or roughly \$25 thousand per float-lifetime, which means that each profile costs around \$200.



present uses of Argo

Argo is sponsored by two international programmes that needed more and better ocean observations. The World Climate Research Programme's CLIVAR seeks to understand CLimate VARIability and predictability from years to decades. GODAE (the Global Ocean Data Assimilation Experiment) demonstrates the value of real-time operational ocean prediction. Argo and satellite data are assimilated into ocean circulation models to make detailed global analyses and forecasts of ocean properties. Operational oceanography centres and climate centres use Argo data in a wide range of applications: climate and seasonal forecasting, weather (e.g. hurricanes) forecasting, marine safety, maritime transport, fishery management, offshore industry, and defence.

Operational uses

Centres in Australia, France, Japan, the UK and the USA routinely produce global and regional analyses of subsurface properties using the Argo data stream. These are available on the WWW and will give early warning of significant temperature and salinity anomalies and changes in ocean circulation.

In the Gulf of Alaska and around Japan Argo data are being used to aid the monitoring of environmental conditions that affect fish stocks and biological productivity.

Each summer the UK Met Office issues a forecast of conditions for the following winter based on the subsurface temperatures in the Atlantic. Argo data now allow these forecasts to be made with greater confidence.

Several groups are using Argo to try to improve the accuracy and lead time of forecasts of El Niño and La Niña events.

Research applications

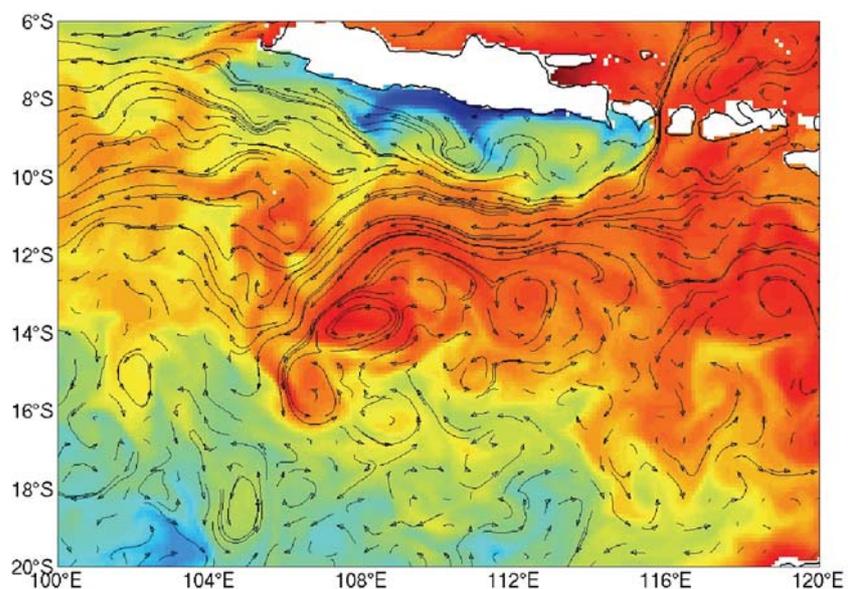
Never before have oceanographers and climate scientists had such comprehensive subsurface ocean data. The number of publications based on Argo is growing rapidly. The range of applications is enormous

- In the subtropical South Pacific, Argo data have shown that the ocean circulation has increased by over 20% since the 1990s largely due to changes in the deep density structure. Argo will allow future monitoring of similar changes throughout the oceans.

- In the South Indian Ocean Argo has started to monitor changes in the subsurface temperature and salinity that will help determine whether these are part of the natural variability or are the long-term changes predicted in models of human-induced climate change.
- In the western Atlantic year-to-year changes in the properties and circulation of water masses formed each winter have been analyzed for the first time. These changes are a sensitive indicator of the interaction between the atmosphere and ocean.
- In the North Atlantic we have been able to calculate where the ocean has warmed and where it has cooled in the past 5 years. The calculation can now be repeated globally.
- Flow through the Indonesian archipelago is a vital link in the global circulation of fresh water. We have monitored the year-to-year changes of its influence on the salinity of the central Indian Ocean.
- For the first time we have been able to monitor the impact of the Asian Monsoon on the temperature and salinity of the Arabian Sea.
- Argo float data have revealed the global statistics of wind-forced inertial currents at the ocean surface.

For the first time we can monitor the seasonal cycles and slower changes anywhere in the open ocean. Argo has become the oceans' climate warning system.

Example of currents and sea-surface temperature off Indonesia September 27, 1997 from the Australian BLUElink reanalysis showing strong currents associated with the Indonesian Throughflow. This area is populated with Argo floats. Temperature and salinity information from these floats together with altimetric and other *in situ* observations is assimilated into an ocean model resulting in a simulation which is in close agreement with observations.



prospects for the future

Challenges

Argo is still a young project but it has the milestone of completing the global $3^\circ \times 3^\circ$ array in sight. The main challenge is then to sustain funding long enough to fully evaluate the array's capabilities and to optimize its design. (Where do the floats need to be most dense? How deep do they need to profile and how often?)

Most countries are now making the transition from short-term, research-based funding to more sustained mechanisms. As well as funding floats, these need to fund Argo's organizational infrastructure.

The fundamental technology of Argo has remained stable for the past 5 years but during that time float life has been extended dramatically through the diagnosis and correction of problems that caused early Argo floats to fail prematurely.

New systems have been tested that allow two-way communication and greater information transmission. Here is a float equipped to use Iridium communication and GPS navigation.



Courtesy of the University of Washington

Temperature along the track of float 4900072 in the northern North Pacific. This float was launched in October 2001 off Dutch Harbour, and eventually entered the Bering Sea through the Kamchatka Strait.

Adding sensors

Argo's floats make a global array of platforms from which additional measurements could be made. There have already been many such experimental applications.

- Sixty floats are presently measuring dissolved oxygen using two types of sensors. Both give stable results over periods in excess of a year. It is believed that by measuring oxygen distributions from Argo we may be able to estimate the oceans' uptake of carbon dioxide.
- Floats are ideal platforms from which to make acoustic measurements and acoustic wind and rain gauges have been tested on floats in the Bay of Bengal.
- Many important climate processes take place in the frozen areas of the ocean. Standard Argo floats cannot operate under ice but acoustically tracked floats that store the temperature/salinity profiles and transmit them in spring have been used in the Antarctic.
- Rapidly profiling floats are ideal for monitoring the transfer of heat, water and momentum under tropical cyclones. These are starting to shed new light on cyclone generation and on water and energy budgets, and may lead to improved predictions.
- Argo floats cannot operate over the steep continental slope, nor can the array adequately measure the oceans' narrow and swift western boundary currents. Here autonomous gliders integrated with Argo will help to link the deep ocean to the boundary currents and continental shelves. The Argo data system can also handle data from gliders.

- Ocean biology can be monitored using floats with fluorimeters and optical plankton counters.

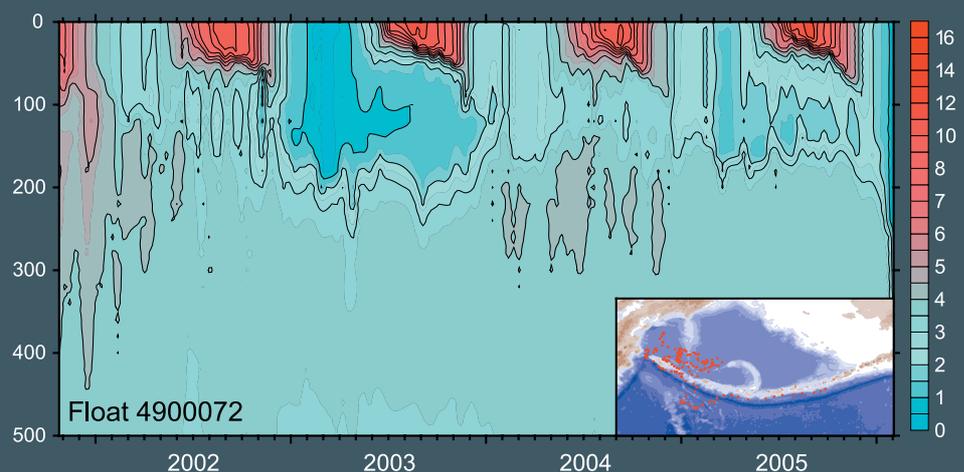
Argo's first priority is to complete the basic temperature/salinity array. New sensors that attract additional funding can be operated within the array and their data can be handled by Argo provided their scientific value and the additional funding they bring compensates for any decrease in float life due to decreased reliability and increased energy consumption.

Argo is limited by its present satellite communication system to transmitting data from only about 100 levels in each profile. To ensure reliable data transmission each float must spend several hours at the surface. New communication technologies coupled with GPS navigation promises to remove the present restrictions on data transmission.

In Conclusion

Argo has made remarkable progress towards its objectives that were set in 1998. It is already the mainstay of the *in situ* ocean-observing system and its data have made possible research and operational activities that were previously impossible. Argo data have started to shed light on some of the key questions about the oceans' role in the earth's climate system.

Sustained support in the coming decade will enable the Argo array to be fully implemented, utilized, and assessed, and to realize its value as the key element of the global ocean observing system.



Sources of Argo information

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Web sites

- Argo portal: <http://www.argo.net>
- General information: <http://www.argo.ucsd.edu>
- AIC: <http://argo.jcommops.org>
- Coriolis Global Data Centre: http://www.coriolis.eu.org/cdc/argo_rfc.htm
- US Global Data Centre: <http://www.usgodae.org/argo/argo.html>
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