Argo — A Global Ocean Observing System for the 21st Century

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Argo is an innovative ocean monitoring programme that is entirely different from anything undertaken previously in the oceans of the world. To understand how different it is from earlier approaches, it is instructive to compare it with the only previous attempt to observe the climate state of the oceans.

The World Ocean Circulation Experiment (WOCE) was first suggested in the late 1970s, and following a decade of planning, it became reality with an intensive field programme between 1990 and 1997. During that period, scientists from 25 nations collaborated in a top-to-bottom survey of the world's ice-free oceans.

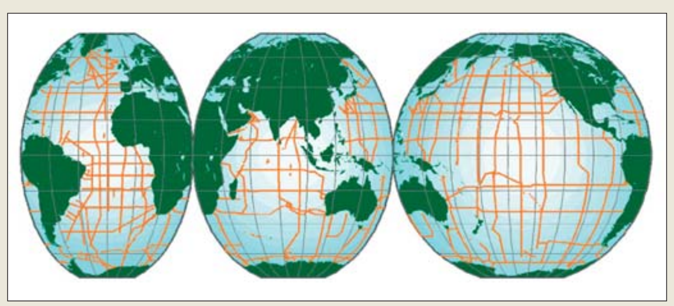
During WOCE, research vessels carrying large science teams occupied more than 20,000 sampling stations, measuring temperature, salinity, velocity, dissolved oxygen, nutrients and geochemical tracers. The ship-time alone, 25 ship-years spread across the international research fleet, cost about USD200 million. The WOCE survey was of enormous scientific value, not least in providing a baseline against which change can be measured. But in being tied to the research fleet, it had intrinsic limitations. There were large unobserved areas between the survey lines. Not only were there gaps in spatial coverage, but the long time required to complete the global survey also posed problems. This 'snapshot' of the oceans extended over seven years during which there were seasonal changes but also, more importantly, climate shifts came and went. There were strong interannual changes due to El Niño and other climate phenomena and so this snapshot raises serious issues of representation. Finally, and perhaps most significantly, the high cost of research vessel surveys allows only a subset of the WOCE lines to be resampled approximately every decade, giving limited information on global scale climate variability.

A technological breakthrough was needed to enable regular sampling of the ocean's interior, and the seeds of that breakthrough sprouted early in the WOCE survey itself. As a part of WOCE, free-drifting buoys were developed to measure ocean circulation patterns at about 1 km depth. These instruments rose to the sea-surface on a monthly basis to have their positions determined by satellite, and then sank again to their drifting depth. As the technology matured, temperature sensors were added to the buoys, and then salinity. By the late 1990s it became apparent that a revolutionary new way of doing oceanography had been developed.

In 1998, the Argo Prospectus was circulated, outlining this new method. Scientists of all nations were invited to participate in the deployment of a global array of 3,000 robotic drifting buoys. These would drift in deep water; have lifetimes of four-to-five years and supply profiles of ocean properties every ten days. By collecting over 100,000 profiles per year of temperature and salinity and drift measurements of ocean circulation, Argo would be able to track the physical state of the oceans. So in only a decade, the time required to obtain a snapshot of the climate state of the oceans had been reduced from seven years to just ten days!

The Argo plan was enthusiastically received, being quickly endorsed by the World Climate Research Programme's Climate Variability and Predictability (CLIVAR) study, the Global Ocean Data Assimilation

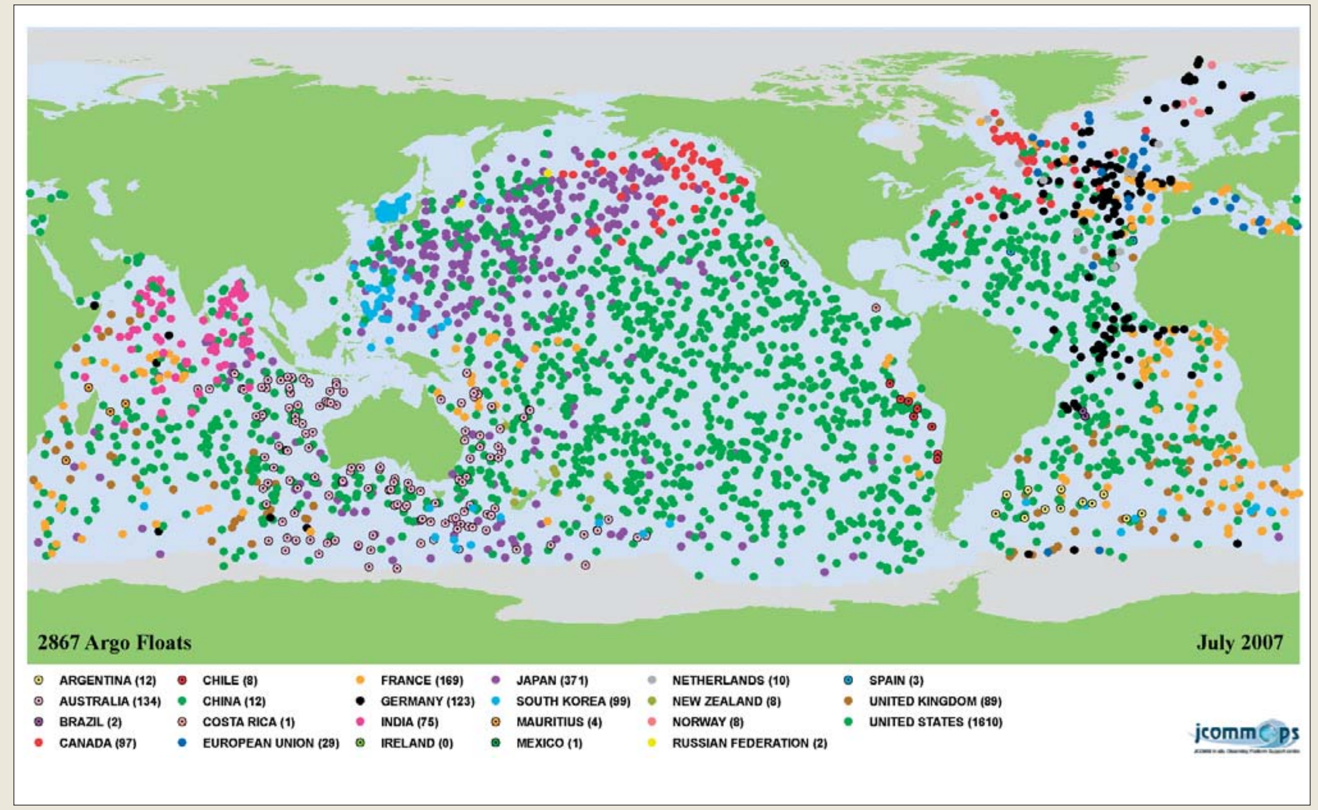
Survey lines occupied during the field programme phase of WOCE



This 'snapshot' technique had intrinsic limitations, with large unobserved areas between survey lines, gaps in spatial coverage and a long timescale that did not necessarily observe climate shifts and interannual changes. Thus, it raised serious issues of representation

Source:

The distribution of floats in the Argo array, July 2007



As of mid-2007, 26 nations were deploying floats in support of Argo.
The initial objective of a global array of instruments at about 3° spacing had been achieved

Source:

Experiment (GODAE), and the Global Ocean Observing System (GOOS). The strong consensus for a global Argo array was promoted by national agencies as well as by scientists around the world, and plans to begin deploying Argo floats developed rapidly. Initial deployments began in 2000, with regional arrays expanding and technological hurdles being overcome in 2001-2003. By 2004 deployments were on a global scale and the target rate of around 800 floats per year was achieved. As of mid-2007 there are 26 nations deploying floats in support of Argo, and the initial objective of a global array of instruments at about 3° spacing has been reached.

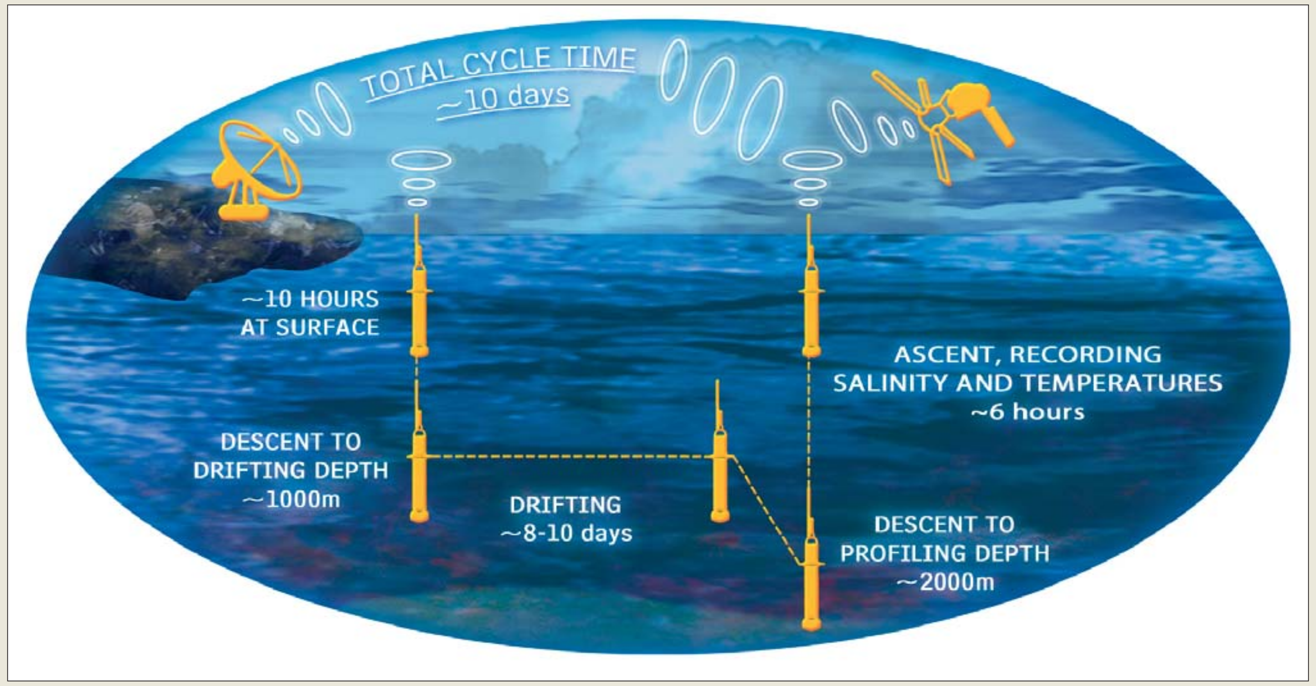
How do Argo floats work?

Argo floats are made in several countries, and while there are differences in design, the basic concept does not vary. A float is launched at the sea surface from a research vessel, commercial ship or aeroplane. The float sinks to about 1,000 metres depth, and drifts with ocean currents for ten days. After this interval, the float dives to about 2,000 metres, and then ascends to the sea surface, measuring temperature and salinity on the way up. At the sea surface, the data are transmitted to a satellite and relayed to a ground station and data centre. Meanwhile, the float again sinks to 1,000 metres to start a new ten-day cycle. To achieve this ascent and descent, floats change their buoyancy using a high-pressure pump that moves mineral oil into an external rubber bladder for ascent, or draws it back inside the instrument for descent.

Argo data are subjected to automated quality checks and made publicly available within about 24 hours of collection at two Global Data Assembly Centers (GDACs). Operational centres and other users may acquire this near real-time data either from GDAC via the Internet or from the World Meteorological Organization's Global Telecommunications System. A research-quality version of the data is prepared by expert examination of all float data, using internationally agreed protocols, and is similarly available from the GDACs. The Argo Information Centre maintains a searchable database of all float positions, and serves the programme in many different ways by facilitating communication and exchange between national Argo programmes and users.

While the basic Argo float collects temperature and salinity profiles in the upper 2 km of the oceans, technological advances will broaden the use and applications of Argo in the future. Argo floats can carry additional sensors for dissolved oxygen and other ocean properties. Several approaches are being tested to allow sampling under seasonal ice cover. The present 2,000-metre depth limitation could be extended with modifications to the pressure hull and pumping system. Finally, a sophisticated new version of the instrument (the glider) with wings, a streamlined hull and active

A typical duty cycle for an Argo float

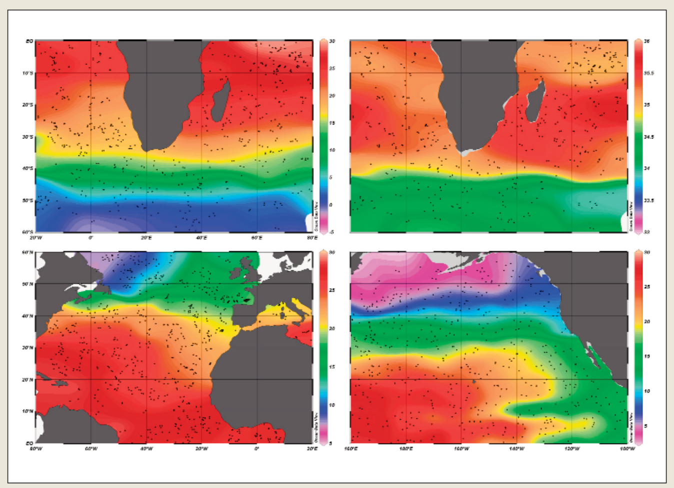


An Argo float is launched on the sea surface. It sinks to around 1,000 metres depth and then drifts with ocean currents for ten days before diving to around 2,000 metres. It then ascends to the sea surface, measuring temperature and salinity on the way up, before repeating the process

Source:

ballasting, 'glides' along programmed track lines to collect data with much higher spatial resolution than conventional Argo floats, near ocean boundaries or other special regions.

Distribution of ocean properties



Plots of the distribution of some ocean properties using data acquired during the last ten days of July 2007. Clockwise from top left the plots show sea surface temperature surrounding southern Africa, salinity at a depth of 200 metres, temperature at 100 metres in the North Pacific and sea surface temperature again, this time in the North Atlantic

Source:

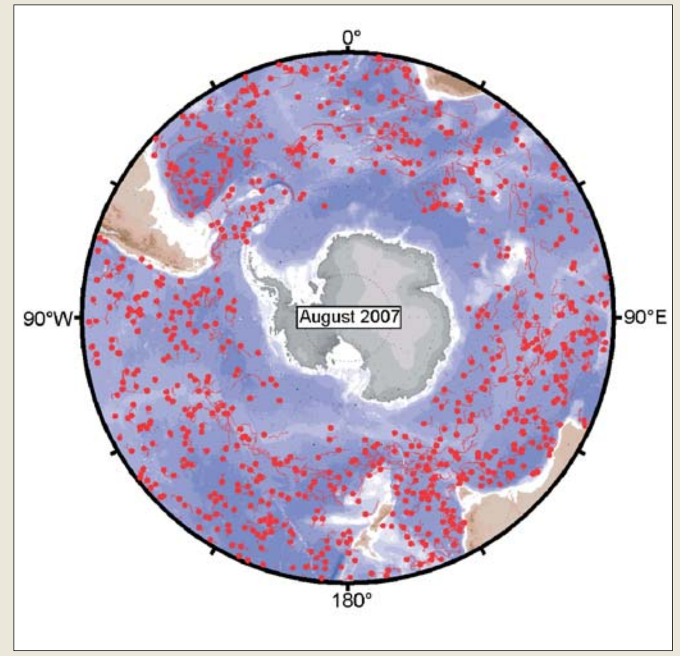
The international essence of the Argo programme

The creation of the Argo array has involved a degree of international collaboration that is unprecedented in oceanography. The goal of achieving global coverage requires that national Argo programmes put their regional priorities second to the global objective. Two-thirds of the ocean is in the southern hemisphere while most Argo floats are provided by northern hemisphere nations. The international Argo Steering Team (AST) coordinates the national efforts, working on the basis of consensus among partners to encourage and ensure nearly uniform coverage of the global oceans.

The AST is also responsible for uniform standards of data quality, in terms of float hardware and data processing, and uniform data formatting. The latter functions are overseen by the AST's Data Management Team. All Argo national programmes adhere strictly to Argo's policy of free and unfettered exchange of data. Argo is carried out for the benefit of all nations, not for individual participants. Similarly, all nations can contribute to Argo, if not by providing floats and data management services, then by facilitating float deployments and helping to analyse and gain value from Argo data. Through collaboration, the national origins of floats become irrelevant and the Argo array becomes an asset for all mankind.

The benefits of the collaborative international approach are demonstrated in the image above, which shows, maps of recent ocean conditions in several regions. The data to make these plots were gathered during the last ten days

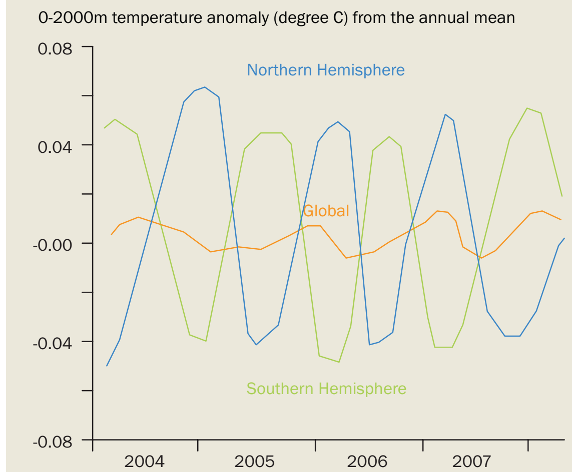
Distribution of floats in the Southern Ocean, August 2007



Some of the blank areas close to Antarctica contain floats, but at the time of this image these are under winter ice cover. They and will reappear in austral spring

Source:

Argo floats observe the pulse of the oceans



Time-series of 0-2,000 metre temperature, degrees Celsius anomaly from the annual mean, for the northern (blue) and southern (red) hemisphere oceans and the global ocean (black), from Argo data. Each line is plotted as the anomaly from a three-year, 2004-2006 mean value

Source:

of July 2007 and downloaded directly from the US Global Data Centre via the Internet, in time for their inclusion in this article, which was written during August 2007. The data were plotted using Ocean Data View, which is publicly available software. This capability places the power to map present ocean conditions right where it belongs, at the fingertips of local scientists, government agencies, interested students or public users anywhere in the world.

This is a blue planet whose surface area is dominated by oceans. Between the equator and 60°S, 84 per cent of the globe is ocean, including the most remote and inaccessible regions of the world. The Argo programme committed at an early stage to sample the northern and southern hemispheres equally, and progress continues toward that objective. Already, Argo's dataset in the critical but remote region of the Southern Ocean greatly exceeds, in number and coverage, the total of all previous Southern Ocean observations.

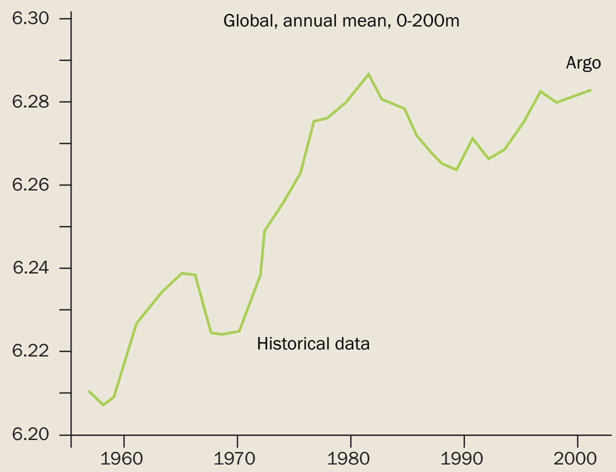
The future of Argo

The future of Argo depends on demonstrating the value of systematically repeated observation of the global oceans. Already, at least 14 operational centres in the US, Europe, Asia and Australia are ingesting Argo data into ocean data assimilation and forecast models to improve estimates of the state of the ocean and to initialize seasonal and interannual predictions. Scientists from all over the world have used Argo data in more than 100 research publications in the past few years. Nevertheless, since a primary objective of Argo is the ocean's role in climate, its value can be realized only when the array has been sustained over climate-relevant timescales. While Argo already observes seasonal variability on global scales, it will take a decade to show its power in observing interannual variability.

Fortunately, many of Argo's capabilities are simple and straightforward – for example, a monthly time-series can be produced, showing the ocean's temperature, averaged from the sea surface to 2,000 metres, globally as well as separately in the northern and southern hemisphere. This is the seasonal 'heartbeat' of the oceans, showing that the annual and the interannual variability in temperature are greater in the northern hemisphere, but that the southern hemisphere, by virtue of its larger ocean area, controls the April maximum in global mean temperature.

While the ocean's annual mean temperature has been fairly constant over the past three years, this was not the case over the past 50 years, with ocean warming accounting for more than 80 per cent of the total heat absorbed by the climate system (air, sea, land and ice). When the global mean ocean temperature from Argo is compared to earlier estimates made from much sparser datasets by S. Levitus and colleagues, the surface layer of the oceans is thought to have warmed by about 0.4°C over the 50-year period, with the 0-2,000 metre average warming by about .07°C. Unfortunately, the sparseness of pre-Argo data, particularly in the Southern Ocean, means that the pace of change is highly uncertain; the actual warming could have been twice the estimated rate. This is critical information for the testing and verification of climate models. For the future, Argo eliminates the uncertainty that has been experienced due to under-sampling.

Global annual mean ocean temperature, 0-2,000 metres



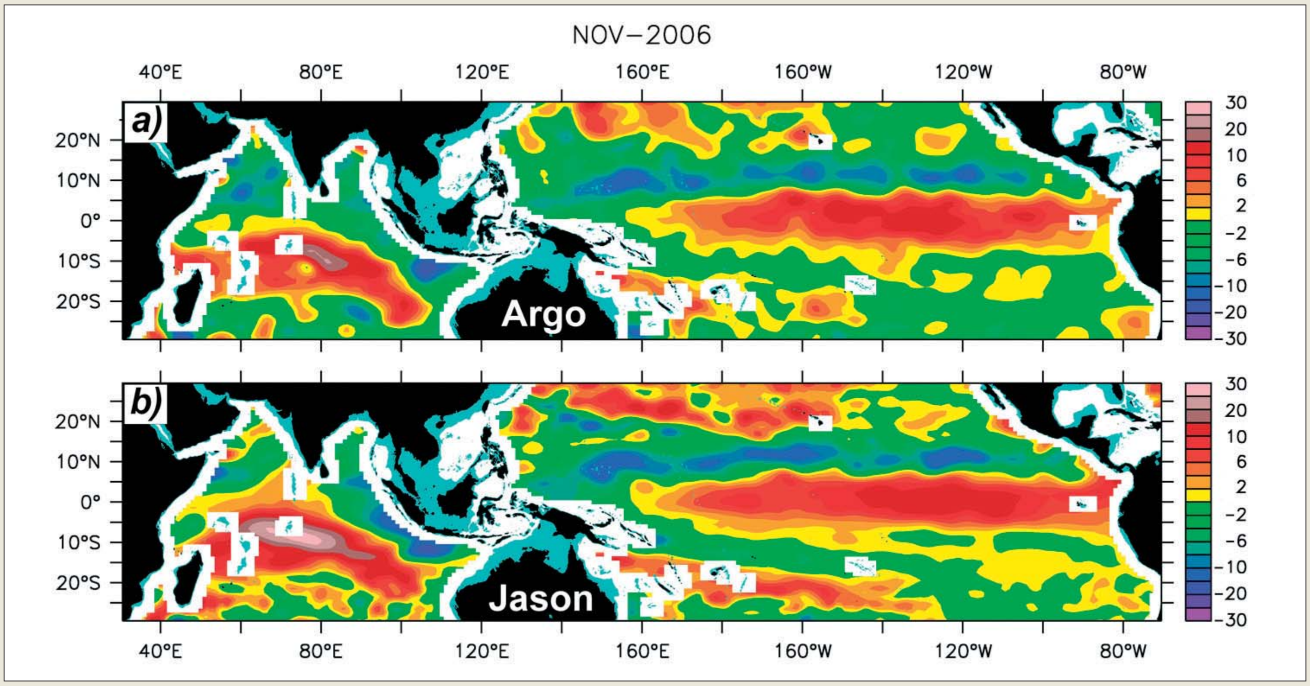
Historical (pre-Argo) data and Argo data showing the global annual mean ocean temperature at 0-2,000 metres

Source:

Argo was designed specifically to exploit the complementary relationship between satellite measurements of sea surface height (SSH) and subsurface profile measurements of temperature, salinity and velocity. Indeed, the name Argo was chosen to underline the float programme's synergy with the Jason satellite altimeter. On seasonal and longer timescales, SSH changes measured by Jason are largely due to temperature and salinity changes in the water column, measured by Argo. SSH during the El Niño event of late 2006 (centimetres difference from the 2004-2006 mean) measured by Jason and the part of SSH due to ocean temperature and salinity changes measured by Argo show a striking similarity, demonstrating that these key observing systems are operating in tandem to capture large-scale phenomena. Differences between the two sets of measurements can be exploited to determine previously inaccessible features of ocean change.

The Argo array, while still growing in coverage and capabilities, is moving into a pre-operational phase that requires the array to be sustained for a ten-year period, while its value in various applications is assessed. This will allow time for the operational agencies and the scientific researchers of the world to learn how to use the new dataset, understand its synergy with other observing system elements and its role in both new and existing applications. The societal need for climate observations to monitor the state of the planet and give early warning of significant change creates a responsibility to implement and sustain measurement systems that are matched to the global scope of the climate problem.

Argo and Jason offer complementary views of the oceans



Sea surface height anomaly in November 2006 (cm, relative to a three-year mean 2004-2006) estimated from Argo profile data (a) and from satellite altimetry (b). High values in the eastern equatorial Pacific indicate El Niño conditions

Source: