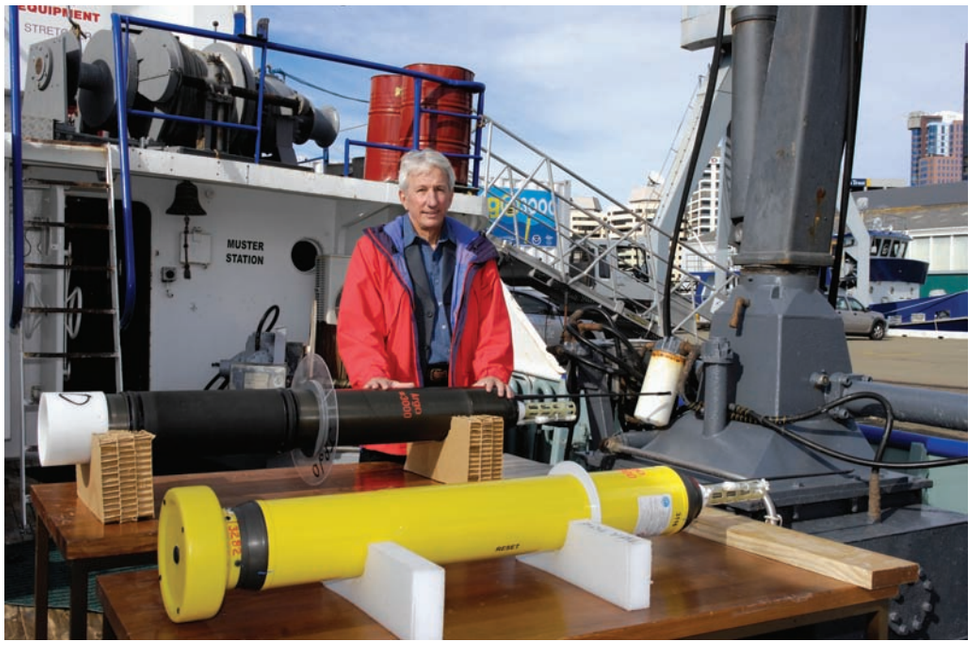
Monitoring the world's

Dean Roemmich is a physical oceanographer at Scripps Institution of Oceanography San Diego, and a leading force behind the revolutionary array of ocean-monitoring sensors called Argo. He also recently won the coveted 2008 Sverdrup Gold Medal awarded by the American Meteorological Society (AMS). *The Marine Scientist* caught up with him to find out about his views on monitoring the world's oceans



Professor Dean Roemmich with two Argo_3000 floats. (Dark coloured float in rear is a SOLO float from Scripps Institution of Oceanography. The yellow float in foreground is an APEX float from University of Washington, Seattle.)

Q) Could you start by giving us a brief overview of your background and career as a physical oceanographer?

In 1974, I was a U.S. Peace Corps Volunteer with an undergraduate degree in physics, teaching university-preparatory courses at the University of the South Pacific in Fiji. I wanted a future in research as well as teaching, and looking out of the window I noticed the ocean. I planned to study physical oceanography at the WHOI/MIT Joint Program and then go back to work in Fiji, but only managed to do the former. After a post-doc at WHOI, I moved to Scripps in 1981.

I've been interested in the ocean's role in the climate system since my graduate studies. During the 1980's and early 1990's, I participated in research vessel voyages aimed at observing how ocean currents carry heat on global scales and how the oceans change in response to climate variability on decadal timescales. It became clear that there was a pressing need for systematic large-scale datasets that could be repeated regularly in time.

Research vessels are too expensive to be used to collect transects across the Pacific every few months, so a colleague and I started riding container ships in 1986. We dropped expendable bathythermograph (XBT) probes every hour or so to measure the detailed temperature structure of the upper ocean, and then repeated these transects to see changes over seasons and years. This High Resolution XBT program has been going on for more than 20 years now, providing a lot of interesting data (http://www-hrx.ucsd.edu), thanks to the technical staff who took over ship-riding duties.

It was still very limiting that measurements of the subsurface oceans could only be made from commercial ships or research vessels. What about the vast areas of unsampled ocean between ship tracks? The development of profiling floats provided the answer. Ocean-scale profiling float arrays were deployed by Russ Davis and others during the 1990's in the World Ocean Circulation Experiment (WOCE). The next logical step would be to install and maintain a global float array, so we began discussing and promoting this idea in 1997-98. The global array would be called Argo to emphasize its close scientific relationship to the JASON satellite altimetry missions.

Q) The Argo network of 3000 monitoring buoys in the world's oceans is a hugely ambitious project– why do you think it has been so successful and what worked and didn't work?

Argo has succeeded so far for three reasons. First, the technology of profiling floats is a revolutionary advance for oceanography, making global ocean observations possible. Second, global observation of climate is scientifically a compelling problem, a very important thing to do. Colleagues all over the world agreed that, whether or not the Argo program proved to be feasible, it was certainly worth a try.

Finally, it was not only scientists

who bought into the Argo concept, but also the government agencies that would have to fund it. The National Oceanic and Atmospheric Administration (NOAA) has been enormously helpful, not only by providing support for U.S. Argo, but through entraining partner agencies in many other countries.

Q) What do you think will be the key benefits of the Argo network and what have scientists already learnt from the buoys?

In order to say that we understand climate, it's necessary to know how heat and water, the fundamental elements of climate, are stored, exchanged, and transported by the atmosphere/ocean/land/cryosphere. The oceans have stored over 80% of the excess heat added to this system in the past 50 years, and the oceans are an important part of the planetary heat engine that exports heat from the tropics to higher latitudes.

Argo observes the time-varying heat content and the large-scale transport of heat by the oceans. Further, it observes the planetary water balance, through measurements of salinity, and the climate-induced changes in precipitation-minus-evaporation. Through comparison of Argo with historical measurements we now have the best estimates of multi-decadal ocean warming, and of changes in salinity that appear consistent with an acceleration of the global hydrological cycle. Argo has shown a levelling off of ocean warming over the past 5 years.

Argo also contributes to understanding the global rise in sea level. Sea level is rising partly because of melting glaciers and continental ice, and partly because of ocean warming (thermal expansion). The JASON-series satellite altimeters show the global pattern of sea level variability and change in wonderful detail, and Argo tells us what part of the sea level signals are due to changes in ocean temperature and salinity. The understanding of present sea level change is important for projecting future sea level.

During 2007 alone there were over 100 research papers using Argo data, addressing a great many different topics. The results mentioned above are only a small part of the work being done. There are also about 15 operational agencies around the world that routinely use Argo data for their products – including seasonal prediction (e.g. El Nino), decadal coupled climate prediction, and short-term ocean forecasting (e.g. for fisheries management or pollution forecasting).

Argo has only had global coverage since 2004. Its most interesting findings are years in the future, assuming that the array can be sustained and improved over the next decade and longer.

Photo of the RV Roger Revelle deploying Argo floats in Antarctic waters
Photo by: Chief Engineer Paul Mauricio

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Q) What has been the most difficult challenge that the Argo collaborators have had to overcome?

The technology improvements that have happened during Argo were quite significant, challenging, and essential. All models of Argo floats (APEX, SOLO, PROVOR) are now much longer lived than the ones deployed in 1999-2003. Also, the low power conductivity-temperature-depth (CTD) sensors developed for Argo by Sea-Bird Electronics have proven to be very accurate and stable. Without these improvements in float lifetime and sensor stability, Argo

The *RV Kaharoa*
Photo by A. Blacklock

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would not have been practical.

The other great challenge continues to be global deployment, and this is getting harder with tightening budgets and spiralling fuel costs. Most floats are deployed inexpensively by opportunistic use of research vessels, commercial ships and Antarctic supply vessels. But this leaves huge areas of the South Pacific and South Indian Ocean with no passing ships.

In 2004, the New Zealand Argo program (NIWA N.Z.) offered the use of the cost-effective *RV Kaharoa*, a 28-m vessel with crew of 5, for global deployment. Kaharoa has now deployed over 500 Argo floats on 8 long voyages from Wellington to Valparaiso, Honolulu, Tahiti, San Diego, and even Mauritius. (http://www-argo.ucsd.edu/kaharoa_news.html)

Q) How long will the Argo floats last and has funding been earmarked to maintain the system for the long term?

Of the 398 U.S. Argo floats that were deployed during 2004, 69% are still active in mid-2008. So I think Argo's target of a 4-year float lifetime has been achieved. If that sounds simple, try building an instrument that descends to 2000 m and returns to the sea surface 150 times.

The 4-year lifetime means a quarter of the array must be redeployed each year. Argo is deploying 800 floats per year, and there are presently 3200 active instruments. Some of the partner nations are committed to long-term support for the array, including the U.S. (NOAA), but in some others funding is still on a year-to-year basis. Unfortunately, there is no international agreement or commitment to share the cost of global observations.

Q) Organising the Argo network has involved working with more than 24 countries around the world – what was the secret to getting the active involvement of so many countries and scientists?

The "secret" is that everyone working in the program believes in the value of what we're accomplishing collaboratively, and everyone is able to see great leverage from their individual contribution. As proven by New Zealand's *RV Kaharoa* voyages, even small nations can make critical contributions. The Argo Steering Team, Argo Data Management Team, and Argo Information Centre have been effective at promoting the collaborative spirit and enlisting new partner nations. There has never been a lack of willingness in Argo to do what needs to be done.

While there are 24 nations providing floats for Argo, many more nations are involved in the program by helping with logistics

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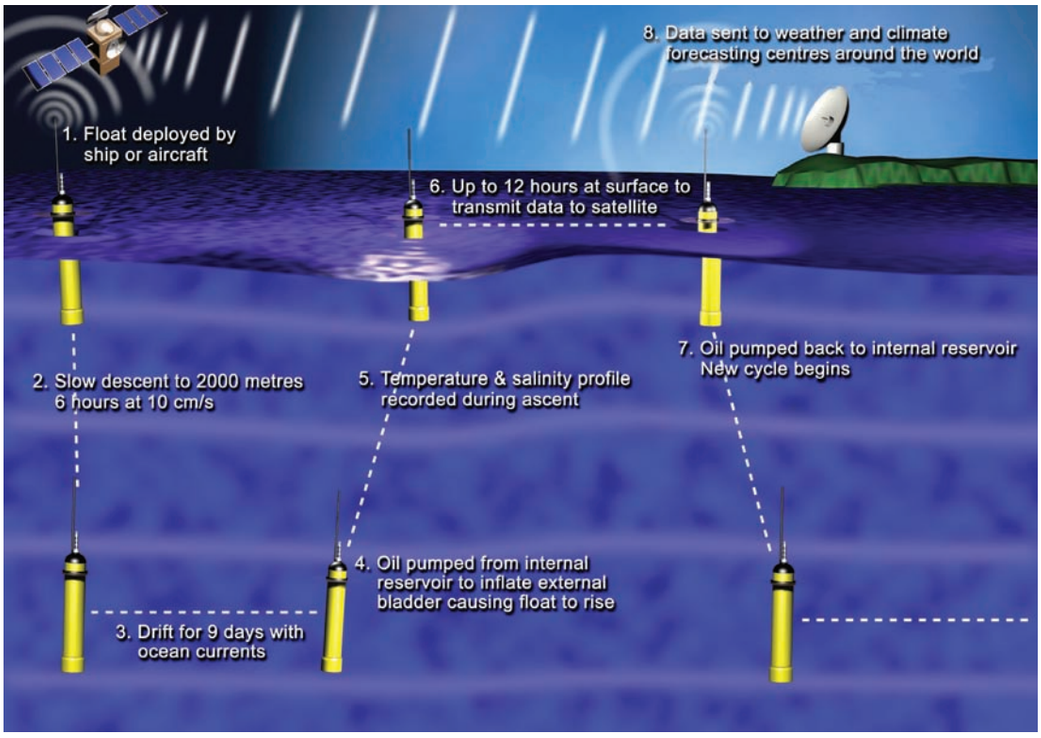

An Argo float in action

Courtesy of National Oceanography Centre. Southampton

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and float deployment or by developing regional applications for Argo data. It's really important to engage all nations in the process of global observations, and to ensure that people everywhere can access the data and benefit from the knowledge that is gained.

Q) If you had an unlimited supply of funding for research/monitoring work, what would you use it for?

There is much more that could be done to observe the global oceans comprehensively:

New sensors make biological and geochemical measurements from floats possible. There is tremendous potential for multi-disciplinary float observations, but a lot of development work is needed.

Deep-ocean floats are feasible (present floats go only to 2,000 m depth). Decadal climate signals extend to the ocean bottom.

High latitude floats are now possible (operating in seasonal ice zones). The polar oceans are of tremendous importance in climate; float deployment opportunities are a further challenge there.

Ocean glider technology could provide high resolution measurements systematically in the world's boundary currents, complementing Argo's broad-scale measurements of the ocean interior.

Q) Which ocean technology most excites you at the moment?

Certainly gliders are causing a lot of excitement but I think the profiling float will continue to develop and to be the real workhorse for large-scale observations.

Q) What sort of ocean technology do you think oceanographers will have access to in 50 years?

Many new sensors and miniaturization of autonomous instruments are the goals; smaller is more efficient.

Q) Which oceanographer or marine scientist do you most admire, and why?

Three answers. Henry Stommel had wonderful vision of the potential of autonomous instruments for global ocean observation, as well as being an inspiration for me personally. His 1989 paper in Oceanography magazine describes an array of 1,000 satellite-communicating profiling instruments measuring all of the world's oceans, much like Argo.

Carl Wunsch inspired me as a graduate student to study the ocean's role in climate. No one has contributed more than Carl to oceanography's coming of age as a science.

Russ Davis, through his development work on profiling floats and gliders, made the vision of autonomous instruments into reality. Progress in the science of oceanography closely parallels technology development, and Russ has done more than anyone to push the limits of technology for ocean science.

Q) What has been the highlight of your career as an oceanographer?

Certainly the most satisfying experience in my career is being a member of the Argo team. A couple of hundred individuals in a couple of dozen countries around the world are working together to achieve something of lasting value. I think Argo is probably the most internationally collaborative effort in the history of oceanography.

For more information please see:

http://www.argo.net