

UK Argo Users' workshop

Met Office, Exeter: 16 March 2010

1. Background

The UK was a founder contributor to the global array of Argo profiling floats. Argo is arguably the key component of the global-scale sustained *in situ* ocean observing system and was recently endorsed as such at OceanObs'09. Main website: <http://wo.jcommops.org/cgi-bin/WebObjects/Argo>; also see www.bodc.ac.uk/projects/international/argo/introduction.

Argo data (temperature and salinity profiles to 2000m depth, some dissolved oxygen profiles and position data from which subsurface velocities can be calculated;) are freely and rapidly available to any user via two global data centres with no restrictions on access to the global data set – even to data within EEZ areas. This open data policy has resulted in a very large and diverse user community. In late 2009, an e-mail sent to contacts in a wide range of academic and research institutions in the UK with the subject line 'Are you using Argo data?' identified 50 individual users or projects.

At its meeting in December 2009, the UK Argo Expert Group made up of representatives of the major institutions in the UK involved in Argo, suggested that it would be valuable to hold a meeting of as wide a range as possible of UK Argo data users. The Met Office agreed to host the meeting, with co-support from the Strategic Ocean Funding Initiative (SOFI) Workshop Fund.

2. Relevance to Oceans 2025

Argo data, their analysis and interpretation are central to several elements of Oceans 2025 Theme 1 (Climate, Ocean Circulation and Sea Level) and Argo is the particular focus of SO5 in Theme 10 (Integration of Sustained Observations in the Marine Environment). BODC hosts the UK Argo Data Centre and the Argo Southern Ocean Regional Data Centre (with CSIRO, Australia)

3. Aims of the meeting

- To determine the full extent of Argo data use in the UK (number of institutions and range of applications),
- To inform participants about the international project, the UK's involvement in it and the system by which data are delivered
- To start the process of interaction between the diverse users and to learn of problems that they may encounter in accessing data or determining its quality
- To consider the most effective means by which UK users of Argo data might continue to interact with one another so as to strengthen the UK's scientific stature within the international Argo project.

4. Proceedings

4.1 *Welcome and introduction*

Jon Turton, UK Argo Project Manager, welcomed attendees and gave a brief introduction to the present state of the UK programme. He noted particularly that the number of floats deployed each year had fluctuated greatly as a result of uncertainties in the level of commitment of the agencies funding the UK programme: viz, NERC; Defra/DECC (with switch of responsibilities from former to latter); and MoD (no longer a contributor to UK Argo). UK Argo is run by a

consortium of the Met Office (who manage the project and whose interest Argo is in the study of climate predictability and change), NERC (NOCS involved in a wide range of science and BODC who are responsible for data management), and the UK Hydrographic Office who are involved in the real-time management of data from UK floats. The main areas of deployment for UK floats are the North Atlantic, South Atlantic, Atlantic sector of the Southern Ocean and the North and South Indian Ocean.

4.2 *Argo – its origins, progress and objectives*

John Gould, former international Director of the Argo project, described the steps that led to the establishment of the Argo project. He started with describing the development of the neutrally buoyant (Swallow) float in 1955 by John Swallow and the use of these floats to explore ocean circulation and later on the Aries expedition in 1960 to discover the ocean mesoscale variability. Longer-range acoustically tracked floats were used in the mid Ocean Dynamics Experiment (MODE) in 1973 to map deep mesoscale eddies for the first time. A new generation of altimeter satellites in the 1990s (ERS-1, Topex-Poseidon) led to the World Ocean Circulation Experiment in which ship-based observations (the WOCE Hydrographic Programme produced 20,000 full depth CTD and tracer profiles but took 8 years and cost \$150m) were supplemented by subsurface velocity measurements using ALACE floats tracked by satellite when they surfaced at two week intervals by pumping fluid into an external bladder. Later profiling ALACE floats collected temperature and then T and S profiles.

Two white papers by Dean Roemmich (Array for Real Time Geostrophic Oceanography – ARGO) and Ray Schmitt (Global Ocean SALinity MonitORing) led to a proposal presented at OceanObs '99 for an Argo array of 3000 T and S profiling floats paired with the Jason altimeter satellites. Principles of Argo were that it should be the summation of national programmes but with free and rapid availability of data even from within EEZ areas. Following international lobbying by Jim Baker and Stan Wilson (NOAA) first Argo floats were deployed and the 3000 float target reached in November 2007. The array is still short of its target (by about 200 floats) since some, while operating, do not have good profile data, others are in marginal seas (not part of the original Argo plan) and there is still a surplus in the N Hemisphere and deficit in the southern. The array is made up of three primary float types (Apex, Provor and Solo) but all rely on Seabird sensors. A major challenge is maintaining float reliability while keeping costs low but reliability has improved steadily.

The project is overseen by a steering team and data management team and is supported by an Argo Information Centre whose technical Co-ordinator (Mathieu Belbéoch) is employed by IOC to monitor float deployments. There is at present no funding for a project office or project Director though this may change with the establishment of a European contribution to Argo (30% of the global array) supported by National and GMES funding. The major challenges facing Argo are firstly the transition of its present (primarily research) funding to a more sustained, long-term funding model and secondly the maintenance of high standards of float and sensor reliability to ensure the integrity of the array. Finally, despite the fact that the global array has reached the target of 3000 operating floats there remains a surplus of floats in the Northern hemisphere and a deficit in the Southern hemisphere.

4.3 *Delivering Argo data*

Justin Buck (BODC) described the process by which Argo profile data were quality controlled in both real-time and delayed-mode streams by BODC and, by analogy, in other elements of the

Argo data system. He noted that the Real-Time QC was an automated process that implemented a set of internationally-agreed checks. Each data point was then assigned a QC flag. It is essential that these flags are taken into account when using Argo data. They are:

- 0 No QC has been performed
- 1 Good data
- 2 Probably good data
- 3 Bad data but potentially correctable
- 4 Bad data
- 5 Value changed (but not by calibration)
- 8 Interpolated value
- 9 Bad data

The salinities are adjusted in delayed mode by comparison of float profiles with a reference data set made from ship-based hydrography. In some ocean areas ship based data are sparse and the quality of the corrections may be degraded by the age of the nearest ship-based profile or its distance from the float. In some cases salinities may be calibrated by comparison between floats. DMQC is carried out only on float profiles that are typically more than 6-9 months in the past so as to allow the time-dependant changes to be obvious. An indirect method of detecting floats that may have incorrect salinities or other data quality problems is to compare steric heights computed from the float with sea surface height from satellite altimetry. This allows a list of “questionable” floats to be published.

All data are available from two global data assembly centres (GDACs) in France and the USA.

4.4 Profiles and velocities: pushing the limits of data quality

Brian King (NOC) started by describing the work of the Delayed Mode Quality control Group in Argo that he leads jointly with Annie Wong. He went on to focus on the limitations on the overall quality of Argo profile data imposed by the pressure sensors. Accuracy of pressures is fundamental (after temperature) in the calculation of such variables as ocean heat content and steric sea level anomalies. In 2009 a problem was detected with the SBE pressure sensors that is known as the Druck Microleak problem. A change in manufacturing practice led to small leaks that appear to affect about 20% of pressure sensors. Floats reference their pressure data to atmospheric pressure at the sea surface enabling sensor drift to be determined. This microleaks cause the pressure to drift towards towards low values (negative pressure offsets). Unfortunately some models of APEX float with the APF8 and earlier models of the float controller record all negative offsets as zero and so do not allow the offsets to be corrected. An added complication is that for offsets greater than 10db the offsets may be pressure- (and possibly pressure-) dependent.

Once the defect was detected, float deployments were stopped (for over 6 months) until the manufacturing problem was rectified.

The DMQC group is considering how to flag defective (or possibly defective) float data due to these problems in both the delayed mode and real time data streams.

4.5 Argo and HiGEM: initialising and evaluating decadal climate predictions

David Stevens (UEA) explained the role of Argo data in the use of the HiGEM model planned for decadal prediction experiments in the IPCC’s 5th assessment report (AR5). The 10 year

simulations will be initialized towards the end of years 1960, 1965, 1970, 1975, 1980, 1985, 1990, 1995, 2000 and 2005. 30 year simulations will be initialised near the ends of 1960, 1980 and 2005. Additional runs initialized near the end of 2001, 2002, 2003, 2004, 2005, 2006, 2007 (and beyond) will take advantage of the improved ocean data coverage of the Argo float era. He emphasised the paucity of ocean data for the initialisation of runs before the Argo era. The model runs will be carried out using anomaly assimilations following Smith *et al.* (2007) *Science* 317, 796-9.

He then went on to describe the results of recent HiGEM assimilations and their ability to reproduce MOC and Nino 3.4 variability. The AR5 runs will be an excellent opportunity to assess the value of Argo but a high priority must be the continued deployment of floats and the delivery of their data.

4.6 *Near surface stratification*

Gary Corlett (U Leicester) summarised work that he was doing with Chris Merchant (U Edinburgh) on the value of Argo for the validation of SST products. This is part of an international effort by the Group for High Resolution Sea Surface Temperature (GHRSSST) in which Merchant contributes to the Diurnal variability working group and he is in the SST validation technical advisory group. The work also contributes to MyOcean (operational oceanography services for Europe), the new European Research Network for Estimation from Space of Surface Temperature (ERNESST) and US Interim Sea Surface Temperature Science Team (ISSTST).

In situ data for SST validation include:

- *Drifting buoys*. Unknown calibration; global data; SST-depth; good (but variable) coverage
- *GTMB*. Better calibration; SST-1m; acceptable coverage (influenced by data collection)
- *Ship-borne radiometers*. Traceable to SI; SST-skin; high accuracy; very-poor coverage
- *VOS and VOSclim*. Generally poor coverage; very high uncertainty on single sample
- *Coastal moorings*. Questionable uncertainty; tough areas to validate
- *Argo temperatures at 4 m*. Global; acceptable sampling; very-high accuracy (calibration method to be analysed)

Normally Argo floats stop reporting temperature at around 10m in order to avoid the pumped flow of surface water contaminating the salinity sensor. The new near surface temperature measurements from Argo are in two forms. Some are from separate fast response sensors: others are from un-pumped sampling of the SeaBird temperature sensor. The latter incur no additional cost to the float operator but may suffer inaccuracies in high gradient regions due to the slow sensor response speed.

The global SST community sees value in the routine collection of near surface profiles from Argo in understanding and inter-relating all the other types of SST measurements. However, a concerted effort is needed to evaluate the data and to determine the best means of incorporating the near surface profiles into the Argo data stream.

4.7 *Argo and the steric contribution to sea level*

Rory Bingham (U Newcastle) discussed his use of a combination of data from the Grace satellite gravity mission, satellite altimeter products and Argo data to study the various contributions the global sea level budget. The results of his work show that the global mean sea level budget can

be almost closed. There is little trend in steric or (pre Glacial Isostatic Adjustment, GIA, correction) mass between 2004-2009. The GIA almost exactly balances melting so that no mass trend is actually observed. Increased melting balances decreased ocean warming by just the right amount to maintain steady trend in total sea level. Consistency at the regional level is less good, particularly for trends and interannual variability. Model analysis suggest that a reference level of 900m is sufficient for steric height calculations but that there are some differences between Argo and ocean models in the vertical structure of steric height variability. Argo sampling results in the under-estimation of steric height variability, though this has improved significantly since the array has become truly global in 2007.

4.8 Skill in decadal climate forecasting: Argo's contribution

Nick Dunstone, Met Office, described Argo's contribution to decadal climate prediction (intermediate between seasonal and centennial timescales). He focussed on the link between Euro Argo and the EU THOR project on climate change risks to the Thermohaline Circulation. Both the real world and computer models of the climate exhibit 'natural variability' in the band from years to decades. Crucially this natural variability can be of similar magnitude to the external forcing provided by anthropogenic global warming over the decadal timescale. At short lead times decadal variance is dominated by model error and initial conditions but these reduce significantly beyond 60 years.

Monthly 2000m T & S observations, now provided by the Argo array, have the potential to successfully initialise Meridional Overturning Circulation (MOC) in the model and produce skilful forecasts. Full depth (2000m and deeper) data always improves forecast skill of top 360m ocean temperature, with the greatest improvement found in the Southern Ocean. Assimilating atmospheric variables gives improved skill in the first year of the forecast, but little improvement thereafter. Assimilating only SST, in the manner of Keenlyside (Nature, 1 May 2008), appears to give poor skill in the extra-tropics (at least for the HadCM3 model). It is possible that other initialisation schemes using only surface forcings may give improved results.

These idealised experiments have identified other problems with our assimilation technique which can now be investigated. They are also useful for assessing predictability of variables we are attempting to forecast in the real world.

A new set of idealised experiments is underway that simulate a realistic spatial distribution of Argo floats. For example they are testing the contribution to the scheme of sub-surface ocean data at basin boundaries. Experiments are also planned that simulate assimilating both Argo and data from the RAPID moored array at 26.5° N; collaboration with VALOR (Assessing the Value of Monitoring the Atlantic; MOC project). Future experiments will also attempt to simulate model bias by performing 'idealised sibling' experiments – using one model to predict the evolution of another, e.g. using HiGEM as reality.

4.9 North Atlantic heat and salt

Neil Wells (NOC) was unable to attend because of illness and his talk on the MONACO (Meridional Overturning and North Atlantic heat Content) was summarised by Brian King. MONACO seeks to link changes in the Meridional Heat Transport monitored at 26N by the Rapid Watch array to sub-annual oceanic heat contact and SST.

North Atlantic heat and salt content timeseries have been calculated for the Argo era from 1999 to 2009. First indications are that the MOC leads both the development of heat content and SST anomalies. North Atlantic heat content fluctuations inferred from Argo and airsea heat fluxes have similar amplitudes and phase differences and may allow us to infer the oceanic contribution to heat content changes. The RAPID MOC timeseries still short (April 2004 – April 2008) more and work is needed to assess the robustness of the observed lag correlations (using longer timeseries in models).

4.10 Argo data quality control

Justin Buck (BODC) presented an analysis carried out by Alasdair Gemmill (BODC) of the results of a data portal that has been constructed to allow analysis of which Argo data in the delayed mode stream are being rejected by the Met Office (UK), FNMOC (USA), BMRC(Australia) and MEDS (Canada) operational analysis centres. The preliminary analysis shows that while there are variations from centre to centre for both salinity and temperature data there are few rejections of data deemed as good by Argo QC. On the contrary, the assimilation schemes of some centres accept a high percentage of data deemed bad by Argo QC. The results need to be treated with some caution since much data has yet to undergo DMQC but the mechanism now exists to monitor the acceptance or rejection of data.

4.11 Argo outreach

John Gould (NOC) presented information on an educational outreach website that has been developed under the Euro-Argo project (www.noc.soton.ac.uk/o4s/euroargo) that will enable non-experts to learn about the interior of the ocean and the role of the oceans in climate by accessing Argo data through Google Earth.

5. Conclusions and actions resulting from discussions

- i) There is a wide range of uses of Argo data in the UK (research, operational and educational) of which only a small cross-section was represented at this workshop. The workshop timing was unfortunate since it followed shortly after Ocean Sciences in Portland ORE. In terms of making the case for sustained funding of UK Argo it is important that a comprehensive inventory should be assembled and maintained.
- ii) A UK Argo Users' group has potential both as a forum for scientific and technical exchanges and also as an advocacy group that might influence UK Argo strategy and funding as well as acting as a forum for the exchange of technical and scientific information
- iii) Users were concerned at the difficulty of finding information on the various UK and International Argo web sites. The AIC web site (<http://wo.jcommops.org/cgi-bin/WebObjects/Argo>) was thought to be particularly difficult but it was pointed out that much of the information there was of a technical nature and designed to aid the internal running of the Argo project and to fulfil the requirements placed on Argo by the Intergovernmental Oceanographic Commission (IOC).
- iv) A beginner's guide to Argo data would be extremely useful. One is available at (http://www.argo.ucsd.edu/Argo_Date_Guide.html) but needs to be brought up to date to include caveats about data quality and to describe the uncertainties in velocity data.

v) The users represented at the meeting were adamant that the global Argo array was an important resource for both oceanographic and climate science and that they wished to see it continue and that the UK's contribution ought to be at an appropriate and sustained level deploying ~50 floats per year.

vi) The UK Argo programme has a number of related web sites:

BODC www.bodc.ac.uk/projects/international/argo/

NOC www.noc.soton.ac.uk/JRD/HYDRO/argo/index.php

Met Office www.metoffice.gov.uk/weather/marine/observations/gathering_data/argo.html

The best aspects of all of these need to be rationalised into a single UK site with links to other material. An offer to host this site has been made by BODC. It should :

- Describe the organisation and funding of UK Argo and the role of the UK programme in international and European Argo.
- Provide information on all UK funded floats (position, operational status, sensors)
- Give a guide as to how to access Argo data that is understandable by a non-specialist
- Provide an inventory of UK funded research being carried out
- Include a bibliography of Argo-related publications to which UK researchers have contributed (This would be a subset of the bibliography available at www.argo.ucsd.edu/Bibliography.html).

vii) It was felt that a newsletter would be helpful in strengthening the identity of the UK Argo user community. It was thought that this might take the form of an e-zine consisting of brief introductory paragraphs in an e-mail together with web links to further information. The International CLIVAR Project Office (CLIVAR is one of the sponsors of Argo) may be willing to compile and circulate the UK Argo e-zine.

viii) Future meetings of the UK Argo User group could perhaps be run as add-ons to major UK meetings such as the Challenger Society biennial meeting or to meetings of the R Met Soc. A Euro-Argo Users meeting will be held in Paris in June 2010. UK participation is encouraged (www.euro-argo.eu/users_and_applications/user_meetings/3rd_user_meeting_june_2010)

Report prepared by John Gould NOC

APPENDICES

1. Programme

UK Argo Users' Workshop
Met Office, Exeter, Tuesday March 16th 2010

0915	Welcome	<i>Jon Turton, MetO</i>
0925	Argo – Its origins, progress and objectives	<i>John Gould, NOCS</i>
0945	Delivering Argo data. How are they processed? Where can I get them?	<i>Justin Buck, BODC</i>
1005	Profiles and velocities: pushing the limits of data quality	<i>Brian King, NOCS</i>
1025	Discussion followed by coffee.	

Science presentations

1100	Argo and HiGEM (initialising and evaluating decadal climate predictions)	<i>David Stevens, UEA</i>
1120	Near surface stratification	<i>Gary Corlett, U. Leicester</i> <i>Chris Merchant, U. Edinburgh</i>
1140	Argo and the steric contribution to sea level	<i>Rory Bingham, U Newcastle</i>
1200	Skill in decadal climate forecasting: Argo's contribution	<i>Nick Dunstone, MetO</i>
1220	North Atlantic heat and salt	<i>Neil Wells, NOCS</i> <i>Summarised by Brian King</i>
1240	Discussion	
1300-1400	Lunch and poster viewing	
1300	Opportunity for data demonstrations if required	
1430	Discussion – is Argo (internationally/nationally) meeting your needs?	
1520	Euro-Argo outreach web site	<i>John Gould, NOCS</i>
1540	Tea and next steps -	
	<ul style="list-style-type: none">• Supporting UK users• Developing European links• The UK contribution to Argo - Visibility/Stability/Continuity• Continuing a UK user group	

2. Attendance

Mike Bell	Met Office
Rory Bingham	U Newcastle
Justin Buck	BODC
Nico Catabiano	NOCS CLIVAR
Gary Corlett	U Leicester
Nick Dunstone	Met Office
Stuart Goldstraw	Met Office
John Gould	NOCS
Aidan Green	Met Office
Simon Good	Met Office
Jerome Grist	NOCS
Trevor Guymer	NOCS
Emma Heslop	IMEDGA/NOCS
Leon Hermanson	U Reading
Penny Holliday	NOCS
Pat Hyder	Met Office
Bruce Ingleby	Met Office
Sam Jones	BODC
Brian King	NOCS
Daniel Lea	Met Office
Stuart Matthews	Met Office
Niall McConnell	Met Office
Matt Palmer	Met Office
Jonah Roberts -Jones	Met Office
Andrew Ryan	Met Office
David Stevens	UEA
Jennie Water	Met Office
James While	Met Office

Registered but presented apologies:

Simon Boxall	NOCS
Helen Johnson	BAS
Simon Josey	NOCS
David Righton	Cefas
Neil Wells	NOCS