UK ARGO PROGRAMME

REPORT FOR ARGO STEERING TEAM 12TH MEETING, MARCH 2011

The UK Argo programme is undertaken by a partnership between the Met Office (who manage the programme), the National Oceanography Centre Southampton (NOCS) and the British Oceanographic Data Centre (BODC).

The most pressing issue for the UK programme remains on securing continuing and ongoing funding for UK Argo and internationally on ensuring the long-term delivery of data from the global 3,000 float Argo array.

Floats deployed and their performance

Floats deployed. Since 2001, over 315 floats have been deployed (including 5 floats donated to Mauritius) in support of the Argo array since January 2001. Of these 23 floats have been Argo-equivalent floats as they have been procured using research grants rather than from designated UK Argo funding. As can be seen from the figures below the number of floats purchased each year has been very variable, often due to funding being supplemented by end-of-year under-spend monies. As a result, the number of deployments each year has also been rather variable. In 2010 we had hoped to deploy around 40 floats but actually only deployed 25 floats, this being due to funding issues that were not resolved until end 2010. As can be seen funding for floats (as opposed to personnel effort) has not been a problem and we presently have over 100 floats available for deployment.

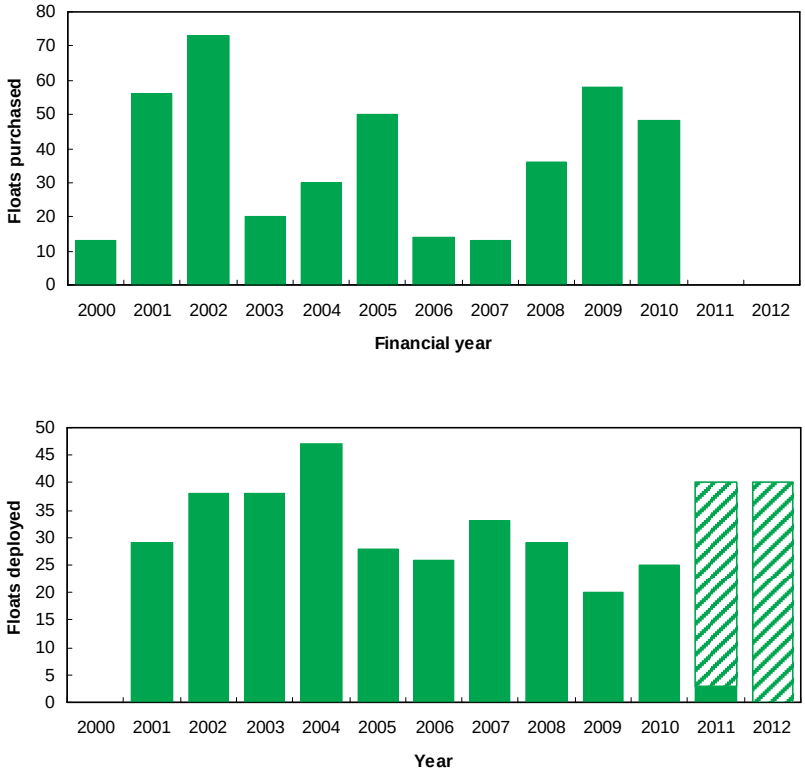

Figure 1. Showing (top) the number of floats procured each financial year (Apr-Mar) and (bottom) deployed in each calendar year.

At the end of February 2011 the Argo Information Centre listed 109 active UK floats (as shown below in red) contributing to the global Argo array, plus 2 active floats (shown in blue) that were provided to Mauritius and deployed by them in 2006.

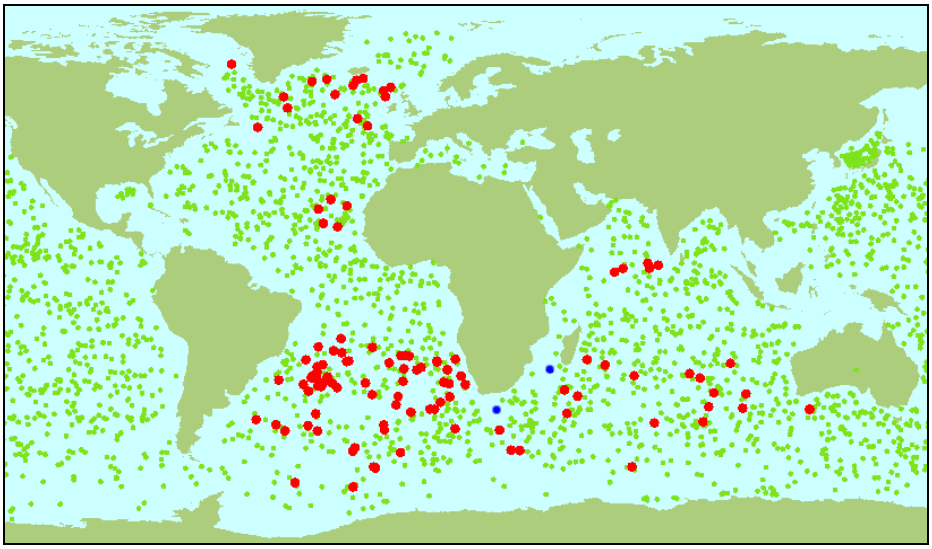

Figure 2. Showing the locations of operating UK floats (in red) and the two surviving Mauritian floats (in blue) at end February 2011.

Float performance. However, despite the lower number of floats deployed in the last 6 years, the number of operating floats still appears to be on an upward trajectory due to improved reliability and lifetime, as shown in Figure 3 below.

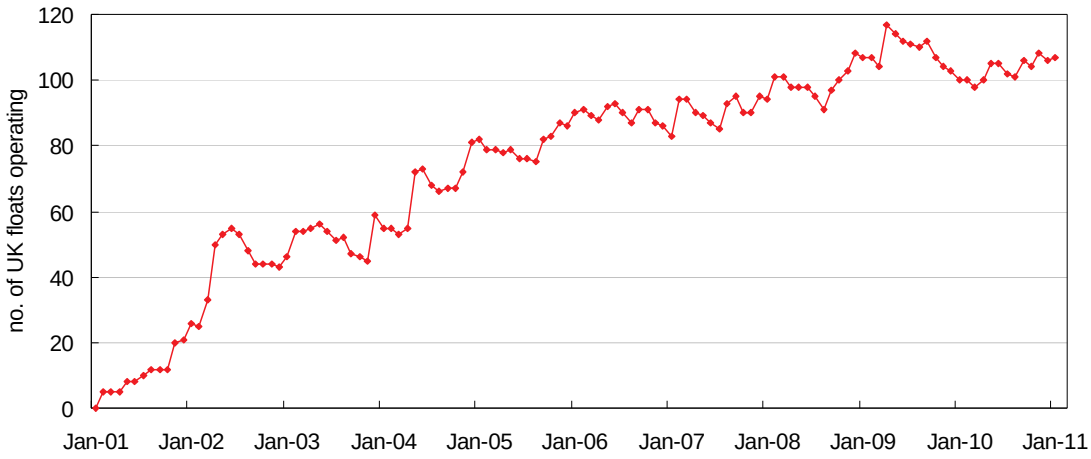

Figure 3. Number of active UK floats contributing to Argo by month.

There has been a distinct improvement in the survival of our Apex floats deployed since 2004 compared to those deployed in the earlier years in terms of cycles completed (normalised to 2,000m for floats that make shallower profiles or only profile to 2,000m intermittently, with invalid cycles due to pressure transducer failure discounted and deployment failures omitted), as shown in Figure 4.

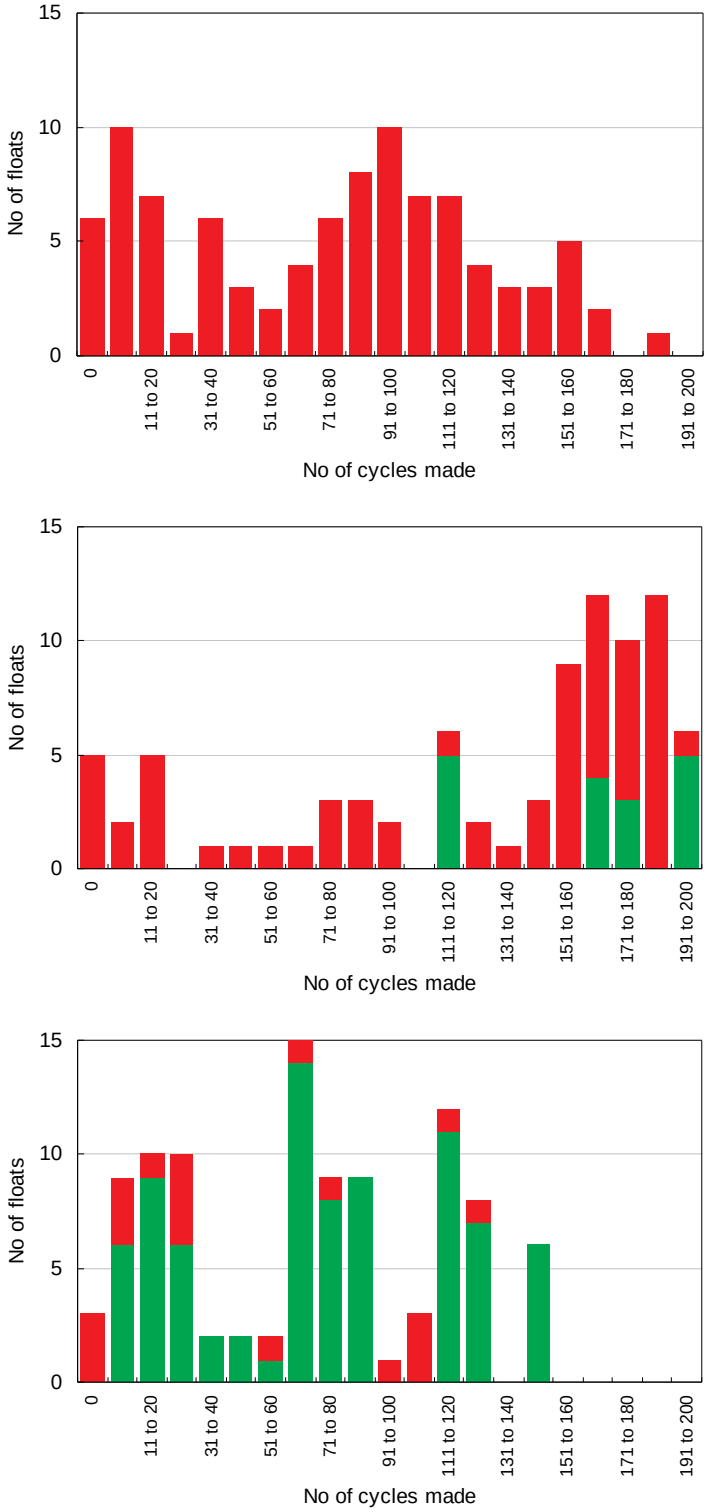

Figure 4. Number of (normalised) cycles made by UK Apex floats deployed in 2001-2003 (top), 2004-2006 (centre) and 2007-2010 (bottom). Operating floats are shown in green, with dead/failed floats in red.

Only 30-40% of floats deployed before 2004 made more than 100 cycles. However, for floats deployed between 2004 and 2006 around 72% of floats exceeded the 110 cycle mark. This performance is also likely to be achieved for those floats deployed since 2007.

Float enhancements. In 2007 we deployed our first 14 Apex floats with lithium batteries and have now deployed 39 such floats with lithiums. 4 of the first 14 floats failed early: 1 on deployment and 1 after 29 cycles (suspected failure due to a slow water leak), the 2 other early failures were after 21 cycles and almost certainly due to damage from Antarctic ice. Since then another 2 have stopped after 101 cycles (nearly 3 years operation) again almost certainly due to Antarctic ice damage. In 2008 we deployed another 14 floats with lithiums, 1 failed early after 3 cycles and 1 stopped after 2 years (77 cycles), the other 12 are all working normally. In 2009 and 2010 we deployed 11 floats with lithiums, with 10 working normally, the other failed on deployment. At this stage it is too early to demonstrate extended longevity from fitting lithium batteries (although data from University of Washington floats does show an extended average lifetime should be expected).

Following the early float losses to ice damage in 2007, from 2008 all new Southern Ocean floats considered at risk of ice have been specified with ice-avoidance capability. So far 11 floats with ice-avoidance have been deployed and none have failed due to ice damage.

From 2008 all our new Apex floats have been with the newer apf9 controller, although we still have 4 older apf8 floats awaiting deployment.

In 2008 our first 2 Apex floats with near surface temperature measurement capability (un-pumped measurements) were deployed, with another 4 deployed in 2009 and 12 in 2010 (plus another 2 in Jan 2011). All are working normally at present. All those floats (apart from those with ice-avoidance) ordered in 2009 and 2010 have this capability as standard. As yet only an initial evaluation (June 2010) of the data has been made, with 2 of the floats clearly measuring marked near surface warm layers that would otherwise be unobserved.

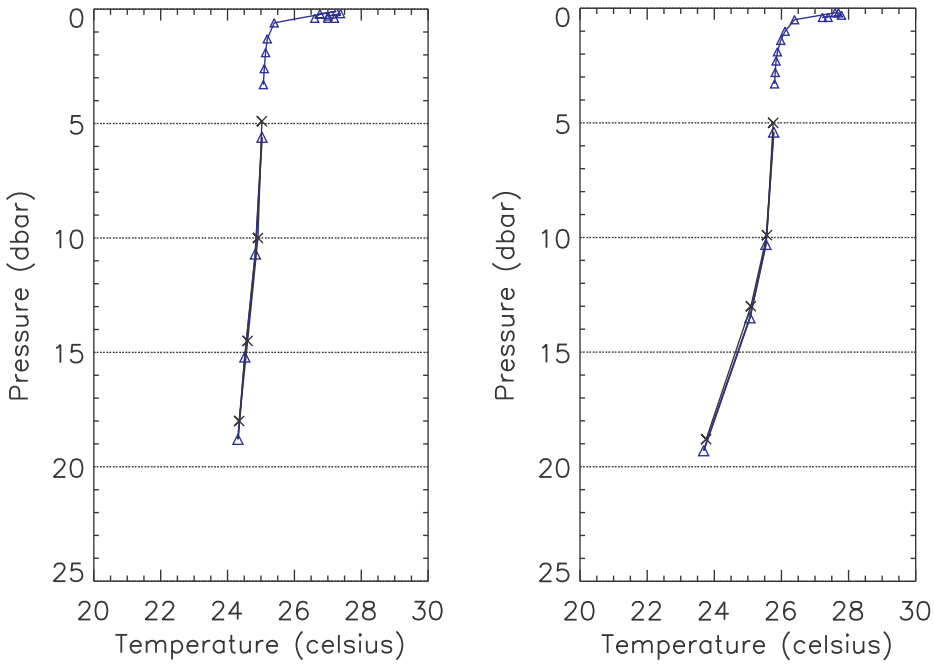

Figure 5. Temperature profiles showing the corresponding pumped and non-pumped measurements and the non-pumped near-surface measurements (pumped measurements in black with crosses and non-pumped measurements in blue with triangles) for (left) float 1901072 on 20/12/2008 15:51 GMT and (right) float 1901073 on 10/1/2009 15:31 GMT.

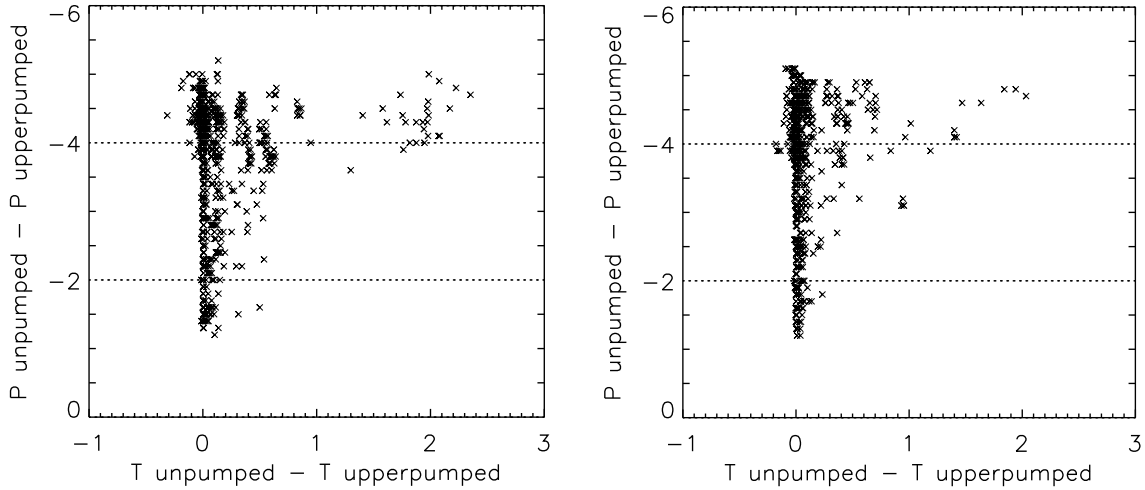

Figure 6. For float 1901072 (left) and 1901073 (right) non-pumped minus the uppermost pumped temperature differences showing the existence of temperatures up to 2.5 ℃ warmer than the uppermost pumped temperature (at nominally 4 or 5m depth).

Examination of these data has revealed one float (1901243) where the un-pumped temperatures were consistently warmer than the pumped temperatures (at the same depths). These data were referred to Dana Swift at the University of Washington who has suggested it is a problem with the electronics and the same cause as "pressure divergence" errors in SBE41s where reported pressures can differ depending on whether they are P-only sample-requests or STP-sample requests.

Technical/engineering web-site. We have established a partnership with CSIRO, Australia to develop an engineering web-site for UK and Australian Apex floats (see http://www.cmar.csiro.au/argo/) enabling the performance of deployed UK (and Australian) Apex floats to be monitored and assisting failure cause diagnosis. However the web-site is presently inoperable and this needs to be discussed with CSIRO.

BODC are currently developing a UK Argo website which will bring together much of the Argo information spread across multiple UK sites. The need for the site came out of the UK Argo user group meeting in spring 2010. This will likely include a technical monitoring section so additional detailed technical information is more accessible.

Deployment plans for 2011 and 2012

As at the end of Feb 2011 we have over 100 Apex floats available for deployment for the coming years. Proposed deployments for 2011 are shown in Table 1, with further deployments in 2011 still to be arranged.

Our aspiration is to make between 35 to 45 deployments in 2011 and maintain this level into 2012 and 2013, however achieving this will be subject to adequate funding to cover the personnel time involved in planning and arranging deployments.

Proposed deployments	
2 Apex for Mauritius	March 2011
4 Apex for north-east Atlantic (Iceland Basin/Rockall Trough)	May 2011 (RRS Discovery)
6 Apex for south-east Atlantic (~36S)	Sept 2011 (SA Agulhas)
6 Apex for South Atlantic(~15S)	AMT cruise autumn 2011
2 Apex for Mauritius	Autumn 2011
6 Apex for Drake Passage	Autumn/Winter 2011
Other floats available for deployment	
6 Apex for Mauritius	
5 Apex for north-east Atlantic (Iceland Basin/Rockall Trough)	
15 Apex for Arabian Sea	
12 Apex for Somali Basin	
6 Apex for South Indian Ocean (~40S)	
13 Apex for North Atlantic (~26N)	
11 Apex for Southern Ocean	
5 Apex for the south-east Atlantic	
5 Apex for the South Atlantic (~15S)	

Table 1. Floats available for deployment.

Data management

The UK Argo Data Centre, established at BODC, processes all our float data (including the floats donated to Mauritius and also floats for the Irish Argo programme).

Real-time. An automatic system processes the data in real-time and generates the profile data in WMO TESAC and BUFR and Argo netCDF formats. The TESAC/BUFR messages are relayed to GTS via the Met Office (EGRR). Almost 100% of GTS messages are available within 24h. Occasional disruptions happen due to email server failures and server problems. Data in netCDF format are also sent (by FTP) to the two GDACs. The real-time processing system operates every 12 hours and delivers data twice daily. The data are also available from the UK Argo Data Centre web-site via an interactive map interface. In addition the technical files are updated once a week and these files are provided to CSIRO Marine to populate the technical web-site.

Delayed-mode. Delayed-mode processing is carried out by BODC using the OW software and the CTD_for_DMQC_V1 and ARGO_for_DMQC_V02 reference datasets. Reference data are updated when new versions are available. During the summer of 2010 the backlog in DMQC of BODC hosted (Argo UK, Ireland, Mauritius, Saudi Arabia) Argo profiles was cleared. As of February 2011, 99.8% of eligible BODC profiles (profiles older than one year) had been submitted to the GDACs in delayed mode. This equates to 90.0% of BODC hosted profiles.

Work in 2010 included the following improvements to the BODC data system and delayed-mode data files:

- The resolution of existing format errors identified by John Gilson's format checker. A format checker has not currently been implemented at the DAC level meaning a few profiles that fail the checks get to the GDACs. It is hoped that that this check can be introduced operationally at GDAC level in the near future.
- Resolution of issues in BODC technical files identified by Jeff Dunn's (CSIRO) audit of pressure corrections applied to Argo profiles.
- The flagging of data for APEX TNPD issues is complete.

- Jointly reviewing the definition of TNPD with other members of the ADMT (primarily CSIRO and UW) and (re)adjustment of floats according to the new definition.
- Production of notes for the historic "sharing of regional DMQC expertise" ADMT action item.
- The cell thermal lag corrections are not applied by BODC yet.

Southern Ocean. BODC works with three other organizations to operate a Southern Ocean Argo Regional Centre (SOARC) covering the entire Southern Ocean. Responsibilities are: BODC - Atlantic Ocean Sector, CSIRO - 'Australian' sector, JAMSTEC - Pacific Ocean Sector and the University of Washington - Indian Ocean Sector. BODC hosts the main SOARC data and information web pages. These pages contain an animation of the Met Office Forecast Ocean Assimilation Model (FOAM) outputs (potential temperature, salinity and velocity at 5m and around 1,000m depth) and an interactive map giving information on last known positions, deployment positions and direct links to both GDACs ftp sites.

Under the EC-funded MyOcean project the level of SOARC activities at BODC is increasing. So far, the following activities have been initiated at BODC:

- Working up and submission of relevant CTD profiles to the CCHDO and US NODC which will then filter through to the Argo delayed-mode QC reference data.
- An increase in support for the Partnership for Observation of the Global Oceans (POGO) research cruise programme information system with the goal of improving knowledge of potential Argo deployment opportunities within the Argo community.
- Collaborative work with the Environmental Systems Science Centre (ESSC) at Reading is beginning that will compare the results of Argo QC to several Met Office operational assimilation QC tests. It is hoped to identify potential improvements for both the Argo QC and operational data assimilation QC systems.

Operational and scientific use of Argo data

Argo has an open data policy which means that all Argo data are freely available without any restrictions, for both scientific research and operational applications. The data are used extensively in a wide range of research projects in UK Universities and research laboratories and is a central component of several PhD and MSc projects covering a broad range of topics including water mass properties and formation, air-sea interaction, ocean circulation, mesoscale eddies, ocean dynamics and seasonal-to-decadal variability. In recent years there have been between 100 and 120 Argo based papers per year, of which between 10 and 15% have a UK lead author or co-author.

Operational and scientific use of Argo data at the Met Office

Operational ocean forecasting. FOAM is the "Forecasting Ocean Assimilation Model" which is the Met Office deep ocean forecasting system. It comprises a global ¼ degree model (ORCA025) and nested $^{1}/_{12}$ degree North Atlantic, Mediterranean and Indian Ocean limited area models. A recent description of the system can be found in Storkey et al. 2010.

(Storkey, D., Barciela, R.M., Blockley, E.W., Furner, R., Guiavarc'h, C., Hines, A., Lea, D., Martin, M.J., Siddorn, J.R. 2010. Forecasting the ocean state using NEMO: The new FOAM system. J. Operational Oceanography, 3(1), pp. 3-15.)

The system is run operationally at around 0500 UTC every day. The system assimilates in-situ profile temperature and salinity data (e.g. Argo data obtained over the WMO GTS), sea surface temperature (in-situ and satellite), sea level anomaly data, and sea-ice concentration

data. The system was recently developed to improve its use of Argo data by going back an extra day in order to assimilate Argo observations which would otherwise be missed (because of the receipt time delay which can be up to 24 hours between the float surfacing and transmitting its data and it being available for use), as shown in the table and figures below.

Delay	% of Argo floats received
0 to 6 hours:	9%
6 to 12 hours:	39%
12 to 18 hours:	31%

Table 2. Receipt time delays for Argo data on GTS.

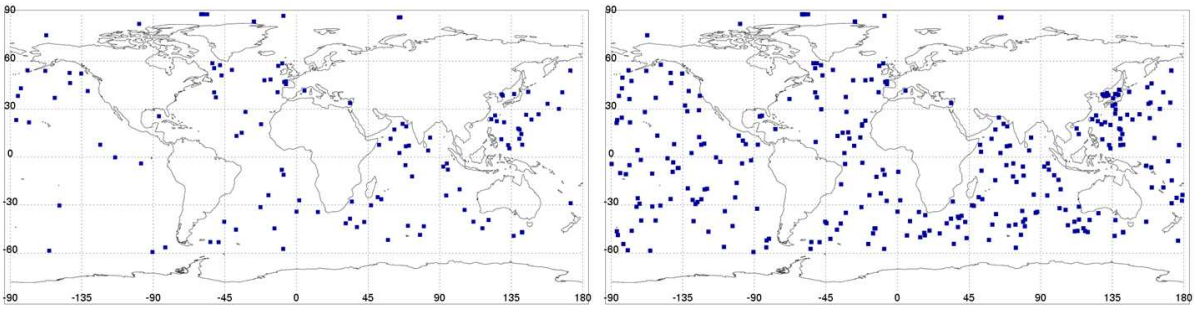

Figure 7. Left, Argo profiles received from the previous day (6 July 2010) at 05:00UTC 7 July 2011; right, Argo profiles received over previous 2 days (6 and 7 July 2010) at 05:00UTC 8 July 2010.

This change results in a significant (5-10% RMS) reduction in the model forecast errors in temperature and salinity.

For further details on ocean forecasting research at the Met Office see http://www.metoffice.gov.uk/research/weather/ocean-forecasting.

Seasonal to decadal prediction. Argo data are also used in the GloSea (Global Seasonal) coupled model run by the Met Office to make seasonal forecasts for several months ahead. Such forecasts are more reliable for tropical regions (such as the Sahel, East Africa and north-east Brazil) than for temperate climates and seasonal forecasting is still an area in which the science is being developed.

A recent paper by Nick Dunstone, Doug Smith and Rosemary Eade (Hadley Centre) describes some idealised experiments which demonstrate predictability of the tropical Atlantic atmosphere in the hurricane development region on inter-annual timescales. Data denial experiments highlight the importance of knowing the sub-surface conditions (temperature and salinity – as is currently delivered by Argo) of the high latitude north Atlantic for making such predictions.

Dunstone, N.J., Smith, D.M. and Eade, R. 2011: Multi-year predictability of the tropical Atlantic atmosphere driven by the high latitude north Atlantic Ocean. Submitted to Geophysical Research Letters.

On longer timescales the Hadley Centre DePreSys (Decadal Prediction System) is being developed for climate predictions on decadal timescales, where the impact of Argo data on decadal climate forecasts has been assessed in idealised experiments (Dunstone and Smith, 2010).

Dunstone, N.J. and Smith, D.M. 2010: Impact of atmosphere and sub-surface ocean data on decadal climate prediction. Geophysical Research Letters. Vol. 37, No 2.

For further information and experimental forecasts see
http://www.metoffice.gov.uk/research/climate/seasonal-to-decadal.

Climate monitoring and prediction. The Hadley Centre maintains the HadGOA (sub-surface global analysis) dataset of historical temperature and salinity. Variables are on a 2-degree grid and computed on number of fixed isotherms and fixed depths at monthly resolution. The dataset includes available Argo data and will include near real-time updates using Argo data. The dataset is used for global ocean heat content analyses.

For further information see
http://www.metoffice.gov.uk/research/climate/climate-monitoring/oceans-and-sea-ice.

Research using Argo data at NOC

Research using Argo data at NOC is carried forward mainly, though not exclusively, through graduate students. Current projects include:

Upper ocean circulation and variability in the North Atlantic. Alex Brearley, a PhD student at the National Oceanography Centre, Southampton, has been using Argo data to investigate processes that control the variability at 36°N. Can everything be explained by variations in local winds, or are other processes at work ? Brearley's work has shown that on time scales up to the annual cycle, the ocean responds mainly to local wind forcing. On longer time scales, the ocean responds to basin-scale changes in the winds, including changes due to the North Atlantic Oscillation (NAO). Brearley's work has also shown the power of combining data from Argo, which provides good coverage away from ocean boundaries, with data from 'Line W', a set of moorings maintained on the western boundary at that latitude by the Woods Hole Oceanographic Institution. Further addition of satellite altimeter data provides a more complete picture of mid-latitude Gulf Stream variability than could be achieved form any of the three techniques alone.

Brearley, J.A. 2010, Upper Ocean Transport Variability in the subtropical North Alantic. University of Southampton, PhD thesis, 242pp.

Ocean correlation scales in the Pacific and Atlantic oceans. Assimilation of observations is a critical element in either present state estimation or forecasting using atmosphere or ocean numerical models. A model representation of the ocean at some location in space and time should be improved by adjusting it to be in closer agreement with nearby observations. But what does 'nearby' mean in practice? A data assimilation procedure must have a way of assigning importance (or 'weight') to an observation. Nearby observations are highly correlated with the point of interest and are given a high weight. Distant observations are uncorrelated and are given a low weight. The rate at which the weight should be reduced with distance is the correlation length scale. Previous studies disagree about whether the scales are the same in all directions, or whether for example variability is more correlated in an east-west direction than north-south, and whether the scales are the same at all ocean depths. The most comprehensive study of this question to date has been undertaken by Lorna Mclean, a PhD student at the National Oceanography Centre, Southampton. Using the best-quality Argo temperature and salinity data, McLean has described the difference in correlation scales between east-west and north-south, (east-west scales are generally longer, as expected from ocean dynamics), and the variation of scales in the vertical. The majority of previous studies have used just temperature data from the historical databases. McLean's work exploits the availability of Argo salinity data to show that the most effective

way to assimilate salinity observations is to do so at ocean depths defined by temperature rather than by pressure.

McLean, L.M. 2010 The Determination of Ocean Correlation Scales Using Argo Float Data. University of Southampton, PhD thesis, 185pp.

Sally Close is studying seasonal to decadal variations in water mass properties (SAMW, AAIW, NADW, UCDW) in the SE Pacific/Drake Passage/Atlantic sector of the Southern Ocean. All available data are being used, including repeat hydrography, Argo profiles and animal-borne sensors.

Gerard McCarthy is studying decadal changes in intermediate and thermocline water properties in the subtropical South Atlantic, from CLIVAR/GO-SHIP repeat hydrography lines. Argo profile data are being used in support of this study to determine the magnitude of interannual variability and hence to clarify the timescale of observed changes.

The NOC satellite oceanography group is involved in ground truth for SMOS and is evaluating ways in which Argo near-surface data can be used for SMOS evaluation.

Funding

It was initially agreed in 1999 that MoD and DETR (then Defra, Dept of Environment, Fisheries and Rural Affairs and now DECC, Dept of Energy and Climate Change) would provide matching funding (through the Met Office) for UK Argo, and that NERC would also provide funding and support through NOCS and BODC. Figure 8 shows the funding for UK Argo on an annual basis since 2000.

As can be seen the funding from MoD has declined from 2005 and ceased after March 2010. Regular funding from DECC (ex Defra) has also reduced since then, although it has been supplemented in some years with year-end under-spend funding for floats. Hence the funding through the Met Office has exhibited large year-to-year variations. The MoD support for Argo data processing at the UK Hydrographic Office has also now ceased.

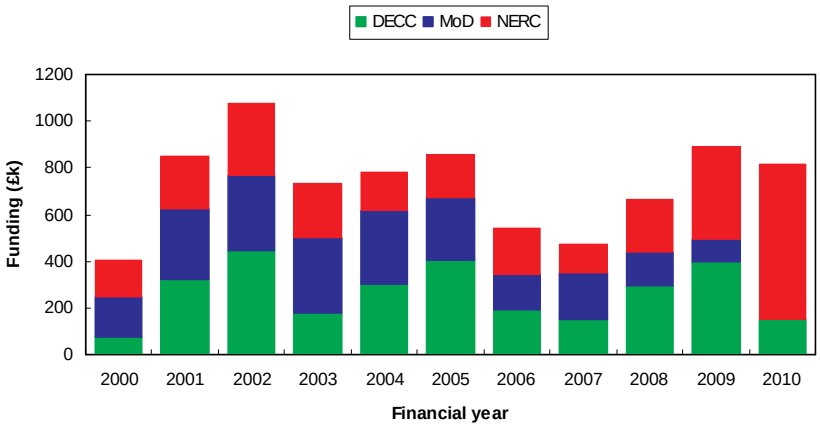

Figure 8. Showing the variability in annual funding for UK Argo from DECC, MoD and NERC.

Securing an adequate level of regular funding for UK Argo activities at the Met Office continues to be an issue, particularly with the cessation of the MoD funding line in 2010. In the last few years, funding for personnel (programme management, coordination and technical support) has been at a minimum level (hence the relatively low number of float deployments in recent years) and has not kept up with the funding for floats; hence the

backlog of floats to be deployed. At this time (March 2011) the level of DECC funding for UK Argo for FY2011 and subsequent years is not known.

NERC funding has also been variable due to funding for floats relying largely on bids to thematic programmes and end-of-year under-spends, although the regular funding for support activities (e.g. data processing, science leadership) has been relatively stable. In 2010 additional staff resource was provided at BODC such that there are now two people involved in Argo data processing and this has been instrumental in enabling them to clear in 2010 the backlog of UK floats that needed to be subjected to delayed-mode QC. NERC funding for these support activities has been allocated to March 2012 through the Oceans2025 settlement, with the expectation it will continue after the 5-year Oceans2025 period. Significant capital funding was provided by NERC for floats in FYs 2009 and 2010 and there are reasonable prospects of ongoing capital from NERC for floats.

With the variable funding the number of floats procured each year has also been variable, as shown in Figure 1 earlier.

Considerable time and effort has been (and continues to be) expended in trying to secure longer-term funding for UK ocean observations that have been committed to international programmes such as the GOOS, GCOS and the GEOSS; with Argo as a pressing example for the need for a solution. This has so far been unsuccessful as there is no mechanism within UK Government to transition funding from research to operational funding lines. In 2009 a new high-level cross departmental Marine Science Coordination Committee (MSCC) was established, reporting to a Ministerial Marine Science Group. One of the priority tasks of the MSCC is to "*develop a transparent prioritisation tool to help inform decisions on the funding of observation systems (for both starting and stopping observation systems)*" and to "*also develop practical proposals to provide cross-cutting, longer-term funding for priority long term monitoring systems*" to help address this problem. This is being carried out by a Long Term Monitoring Working Group which is due to report to MSCC in 2011. However, securing adequate long-term funding for Argo is likely to remain a challenge particularly given the significant reductions in UK government spending (an average 19% cut in departmental budgets) outlined for the coming four-year period.

Euro-Argo

Both the Met Office and NERC are involved in the Euro-Argo project (January 2008 to end June 2011) to develop and establish a longer-term European infrastructure for Argo with longer-term commitments from both the member countries and the EU (e.g. through GMES). It has been agreed by DECC (and supported by NERC) that UK should become full members of Euro-Argo and expected that the Met Office will lead on representing UK in Euro-Argo, with the support of NERC (NOCS). The expected timescale for formal UK agreement to sign-up to the Euro-Argo ERIC (European Research Infrastructure Consortium) is likely to be mid-summer 2011.