UK ARGO PROGRAMME

REPORT FOR 18TH ARGO STEERING TEAM MEETING, MARCH 2017

The UK Argo programme is undertaken by a partnership between the Met Office, the National Oceanography Centre Southampton (NOC), the British Oceanographic Data Centre (BODC) and Plymouth Marine Laboratory (PML). The Met Office are responsible for programme management and coordination, organizing float deployments, preparation of floats for deployment, telecommunications (costs) and international contributions. NOC and BODC have responsibility for Argo science and data management respectively. PML play a leading role in the recent expansion of the UK programme into BGC-Argo.

The most pressing issue for the UK programme remains on securing ongoing funding for UK Argo, in particular for core Argo floats, and ensuring that data is delivered (in real-time and delayed-mode) from our non-core (e.g. float with additional sensors) to the WMO GTS and GDACs.

Internationally, it is imperative to the UK that the core Argo array is complemented by the Argo extensions into deeper profiling, bio-geochemistry and high latitudes, such that these do not lead to a reduction in core Argo below its target density or its ability to deliver core data to users.

1. Floats procured and deployed

Figure 1 shows the number of floats purchased each year and the number deployed. The number purchased each year has been somewhat variable as it has largely been reliant on the release of additional in-year or end-year (under-spend) funding. As a result, the number of deployments each year has also been variable, with 37 floats deployed in 2016, with over the last five years an average of 38 floats/year having been deployed.

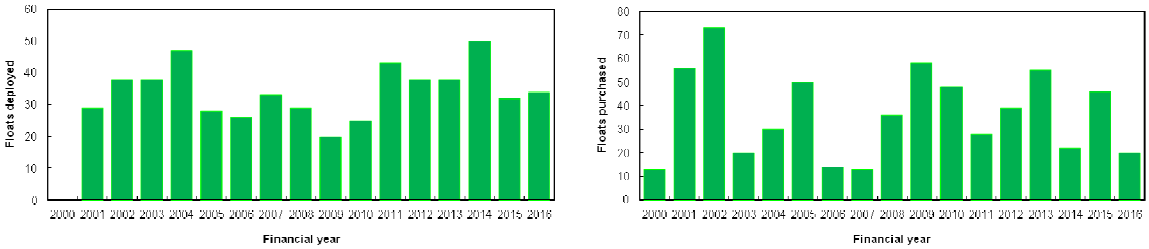

Figure 1. Showing (right) the number of floats procured each financial year (Apr-Mar) and (left) the number deployed in each calendar year.

In 2016 float deployments have been made in the North Atlantic, South Atlantic, Western Indian, Bay of Bengal and the Eastern Tropical Pacific. The 37 floats deployed include: 20 core Argo floats, five deep floats (three of which were subsequently recovered), four STS (surface temperature and salinity) floats, three floats with radiometers, two bio-geochemical (BGC) floats and three floats with the experimental RBR CTD. Of these three floats failed on

or shortly after deployment - one core float, one deep float and one RBR float. Also six oxygen floats were deployed in January 2017 in the South Atlantic. At present only data from the core floats are being processed by BODC and delivering data to the GTS and GDACs.

With the floats deployed the number of UK floats presently contributing data to Argo (including those provided to and deployed by Mauritius) is around 130, as shown in Figure 2, with their geographic distribution shown by Figure 3.

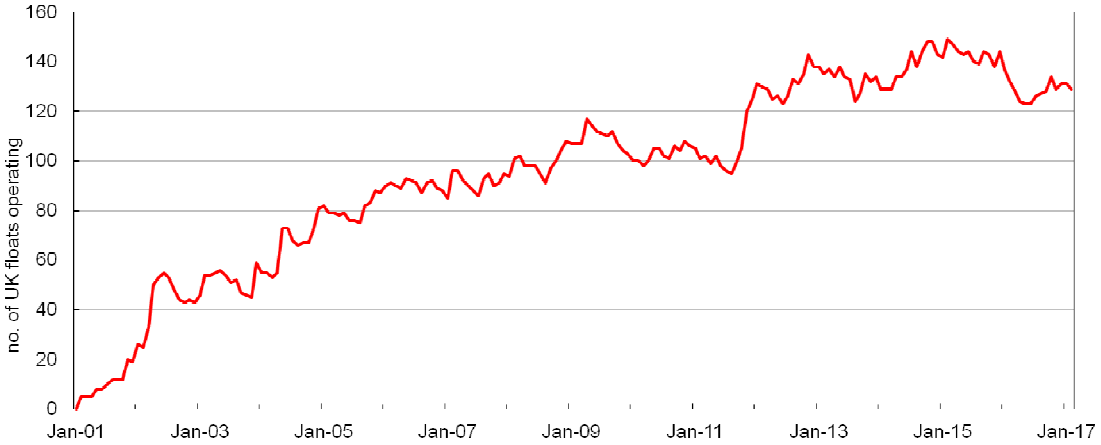

Figure 2. Number of UK (including Mauritius) floats with data on Coriolis GDAC by month.

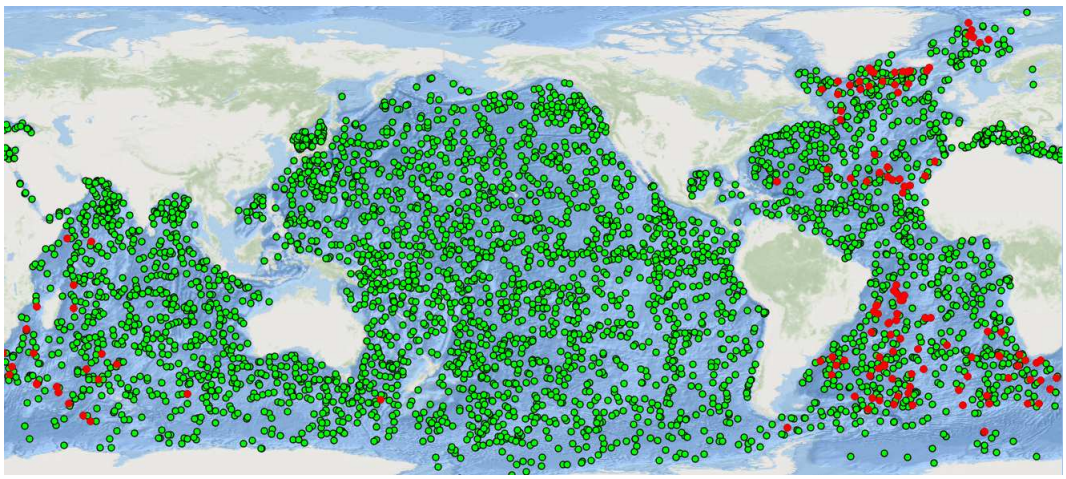

Figure 3. Showing the locations of reporting UK (and Mauritius) floats (in red) as at 1st March 2017.

However, as noted above, there are a number of active floats (additional sensors, deep, RBR CTD) deployed in recent years for which data processing has not yet been set up (so are not shown in Figures 2 or 3). At end February 2017, in addition to the core floats, we have in operation:

4 STS floats
3 floats with radiometers
6 floats with dissolved oxygen
2 floats with RBR CTD sensor
14 bio-geochemical floats
3 deep floats.

At this time, we have 64 un-deployed core floats, four deep floats, three bio-geochemical floats, two oxygen floats and two with the RBR CTD in our inventory, with a further 20 core floats (including two with oxygen sensors) expected to be delivered in February and March. This should allow for continuity of deployments for several years if there is a funding shortfall over the coming years (see §7).

2. Float technology

Bio-geochermical Argo. During the year PML arranged for the deployment of their last two ProvBio floats on the P18 line in the eastern Tropical Pacific. The data from these floats, together with all our ProvBio floats are available at http://www.oao.obs-vlfr.fr/bioargo/summary_UK-Bio-Argo.html and a priority will be to get the floats set up for GTS (temperature and salinity) and GDAC data distribution.

Deep Argo. In December 2015 and January 2016 we deployed two Apex Deep and two Deep Arvor floats in the North Atlantic. All of these are presently operating apart from one Deep Arvor that failed after one cycle. In December 2016 we deployed three Deep Apex from the James Clark Ross (JCR) during the Drake Passage section. One started leaking after two cycles and entered emergency abort mode, returning to surface and staying there, and was picked up by the ship on its way back north. Subsequently, the other two also started leaking after around seven cycles, while the JCR was then operating near South Georgia, but the US National Science Foundation (NSF) R/V Laurence M. Gould was nearby and the NSF agreed that the Gould could take a few hours to go hunting for our deep floats. By changing the float position transmissions to hourly and then to 15-minute updates as the Gould got closer and by sending position updates to the Gould we were able to successfully recover the two floats. This would not have been possible without a multi-way cooperation between NOC, BAS, CLS, Teledyne Webb, NSF and the Gould, for which we are most grateful. The three Deep AEPXs have all been shipped back to Teledyne Webb for investigation, to find out the cause of the leak.

BoBBLE (Bay of Bengal Boundary Layer Experiment). In June/July 2017 7 floats were deployed from the Indian RV Sindhu Sadhana for BoBBLE, this included four STS floats to provide detailed measurements through the surface freshwater layer, together with three floats with radiometers. In addition a float with the new RBR CTD sensor was deployed for comparison but this failed so the second RBR float was not deployed and returned to India for a firmware upgrade, this float was subsequently deployed in February 2017 but failed (in spite of passing all pre-deployment checks).

3. Float performance

Float lifetime. At last year's Argo Steering Team meeting it was reported that float longevity had improved up to 2005, but since then there have been dips in longevity. There is also great diversity in performance across programs, some achieving long life (50% reaching 200 profiles) and others short lifetimes (50% only reaching 100 profiles). This behaviour is clearly evident in the UK's floats, the vast majority of which have been Webb Apex floats, as shown in Figure 4. For floats deployed 2004-2006 50% of floats exceeded 160 cycles, for 2007-2009 floats 48% reached 170 cycles but for floats deployed 2010-2012 only 47% of floats reached 160 cycles. Since 2007 we have fitted lithium batteries in over 50% of Apex floats deployed, so those floats deployed 2007-2009 are showing the greatest longevity. However, for floats deployed 2013-2015 it looks as if fewer than 50% of floats will exceed 120 cycles, suggesting a downturn in longevity of our core Apex floats.

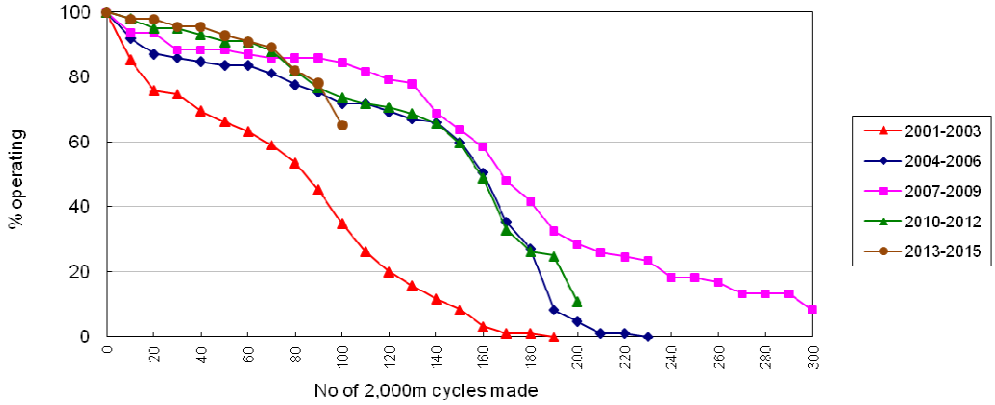

Figure 4. Number of (normalised to 2,000m) cycles made by UK standard Apex floats deployed in 2001-2003, 2004-2006, 2007-2009, 2010-2012 and 2013-2015.

4. Outline deployment plans for 2017

So far in 2017 we have deployed six floats with oxygen sensors in the South Atlantic and the second Apex RBR float in the Bay of Bengal (which has failed). At present planned deployments for 2017 include:

4 core floats North Atlantic (26N RAPID cruise, February)
5 core floats South Atlantic (Royal Navy, Drake Passage/Argentine Basin, March)
4 core floats Drake Passage / Orkney Deep (DynoPO cruise, March)
4 core floats SE Atlantic / Agulhas (SAMBA cruise, April)
4 core floats Rockall Trough/Iceland Basin (Extended Ellett Line, May)
4 core floats SE Atlantic / Agulhas (SEAmester cruise, July)
4 core floats S Atlantic (AMT cruise, October)
4 core floats N Atlantic (AMT cruise, October) (2 RBR & 2 Iridium) **
4 core floats Mozambique Channel (ASCA and/or IIOE2 cruise, November)

** We aim to deploy two pairs of RBR and Iridium floats to compare the RBR sensor with the high resolution Iridium profiles. They will only be deployed after the 2 RBRs are returned from Webb's, where they are currently being refurbished.

Possible deployments in 2017, still to be arranged:

2 core floats for Mauritius
2 core floats for Arabian Sea (VOS)
2 core floats Somali Basin (VOS)

Other deployments will be arranged as opportunities arise. The aim is to deploy a minimum of 35 floats (but ideally as many as 44) during the year, including those provided to Mauritius.

5. Data management

<u>BODC</u>
BODC is the data centre for UK Argo funded by NERC and is responsible for data management of UK and Irish floats. UK Argo is a member of Euro-Argo and is managing

European floats as part of the MOCCA project. BODC is also the lead for the Southern Ocean Argo Regional Centre (SOARC).

During 2016 the priorities for data management were set as follows (highest priority first):

1. Core UK Argo near real-time & core Euro-Argo near real-time
2. Core UK Argo delayed-mode QC & core Euro-Argo delayed-mode QC
3. Bio-geochemical UK Argo near real-time
4. AST/ADMT ratified extensions to Argo near real-time (deep, NST etc)
5. Argo equivalent near real-time (AST/ADMT non-ratified extensions to Argo).

In a time of limited resource (and a growing number and diversity of floats to manage) this year BODC have concentrated efforts on processing near real-time data and improving the efficiency and resilience of the near real-time data system. Unfortunately, the Argo team at BODC have been affected by disruption to IT infrastructure, which has resulted in limited resources being stretched even further. However, the team have recovered system performance, protected the integrity of the Argo data and made progress with system development. The improved efficiency of the near real-time system will enable us to progress the development required to process BGC and Deep floats in the coming year.

Progress this year includes the replacement of the data retrieval method from CLS for Argos floats with the CLS Web Service and working with CLS to migrate to a new SFTP service for Iridium floats. The CLS SFTP service will be extended to include older Iridium floats in the near future. For the first time BODC has delivered V3.1 Argo NetCDF metadata files for >95% of our legacy and active floats as well as V3.1 Argo NetCDF profile files for over 50% of the >60,000 profiles that we hold data for. The development of V3.1 NetCDF files continues for the remaining profile files and for technical and trajectory files.

BODC are also currently processing nine MOCCA floats in near real-time. It is expected that a total of 75 floats will be hosted by BODC from the MOCCA project. System development and processing carried out for this project includes:·

- Development of new retrieval and archiving methods for raw data from short burst data (SBD) Iridium floats including handling emails and attachments, safely archiving raw data and preparation of files for decoding.
- Integration and testing of the Coriolis decoder into our existing system. The decoder also requires interaction with existing database and file infrastructure so these processes have been developed and tested.
- Preparation for new floats including review of float manuals and database population of metadata in advance of float deployment.
- Improving resilience of near real-time data systems and efficiency of monitoring process so that BODC can handle the increase in float numbers expected over the next year and can process data efficiently and without loss of performance of existing workflows.
- Loading new floats into our system with the minimum of delay and decoding the data in near real-time for delivery to the GTS and GDACs.

All delayed-mode QC for BODC hosted floats is done within BODC (when resource is available). The OW (Owens-Wong) software is used along with the latest reference data available from Coriolis (CTD climatology and Argo profile climatology) for guidance. 55 % of BODC hosted profiles eligible for delayed mode QC have been processed and submitted to the GDACs in delayed mode. Addressing the backlog in the delayed mode QC for core Argo floats is the second highest priority after the real-time delivery. We have also begun training for newer members of the BODC team to expand the number of DMQC operators at

BODC. This year we have also provided introductory training on DAC and DMQC operations to South Africa as part of a POGO grant.

With increasing numbers of enhanced floats with oxygen, radiometers, bio-geochemical sensors, there is a recognised need to ensure that (at least) the temperature and salinity data are made available in real-time and this should be addressed in 2017. The integration of the Coriolis decoder into our existing system for the MOCCA project (see below) opens the way for processing much of the existing biogeochemical and deep data. Work has started to prepare the BODC system for decoding these data.

Met Office
The UK Met Office has commissioned the development of a Python-based Argo netCDF to BUFR converter that will be implemented operationally at Exeter. The code is presently undergoing pre-operational testing. It is expected that the software will be made freely available when fully tested and proven operationally. At present the code is for temperature and salinity only, but has been designed so that the addition of oxygen (and other bio-geochemical variables) can be added relatively easily (with oxygen at least to be included before the end of the year).

The bio-geochemical (chlorophyll-A fluorescence, dissolved nitrate, pH and backscatter) enhancements to the BUFR format have been approved by the WMO for validation, but resources have precluded this during 2016. It is hoped that the enhancements will be validated in 2017 such that the enhanced BUFR message can be approved by WMO for operational use in 2018.

6. Scientific and operational use of Argo data

Operational oceanography.
Argo profiles are assimilated into the global and shelf-seas FOAM (Forecasting Ocean Assimilation Model) systems run operationally in near real-time to produce short-range (out to 6 days) ocean forecasts of the 3D ocean temperature, salinity, and currents as well as sea-ice variables (Blockley et al. 2014). FOAM is also used to provide the initial ocean and sea-ice conditions for coupled seasonal forecasts using the GloSea5 system (MacLachlan et al., 2015), so the Argo data have an impact on forecasts out to months ahead. See http://www.metoffice.gov.uk/research/weather/ocean-forecasting.

Recent and on-going developments relevant to Argo include:

- The use of near-surface Argo measurements in assessing a new operational global product of the diurnal cycle of SST (While et al. 2017) which is freely available through the Copernicus Marine Environment Monitoring System (CMEMS; http://marine.copernicus.eu/).
- A coupled ocean/atmosphere prediction system is being developed on weather forecasting timescales, including assimilating Argo data in a coupled data assimilation framework (Lea et al. 2015). A demonstration coupled NWP system is being run operationally at the Met Office. The timeliness constraints on Argo for this application are even more stringent than for operational ocean forecasting systems. The impact of Argo on this system was assessed as part of the E-AIMS EU project (King et al. 2015). The ocean component of global short-range coupled forecasts are freely available through CMEMS.
- FOAM is also being used to contribute to AtlantOS, an EU project to assess the observing system in the Atlantic, including potential Argo sampling changes, deep Argo and other in situ observing network extensions.

Blockley, E. W., M. J. Martin, A. J. McLaren, A. G. Ryan, J. Waters, D. J. Lea, I. Mirouze, K. A. Peterson, A. Sellar, and D. Storkey, 2014: Recent development of the Met Office operational ocean forecasting system: an overview and assessment of the new Global FOAM forecasts. Geosci. Model Dev., 7, 2613–2638, doi:10.5194/gmd-7-2613-2014.

King, R.R., M. Martin, A. Stearl, 2015. Weather, seasonal and decadal forecasting: OSE/OSSE results and recommendations. E-AIMS deliverable report D3.323. http://www.euro-argo.eu/content/download/88659/1093576/file/E-AIMS_D3.323-v2.pdf?version=1

Lea, D. J., I. Mirouze, M. J. Martin, R. R. King, A. Hines, D. Walters, and M. Thurlow, 2015: Assessing a New Coupled Data Assimilation System Based on the Met Office Coupled Atmosphere–Land–Ocean–Sea Ice Model. Monthly Weather Review, 143, 4678–4694, doi: 10.1175/MWR-D-15-0174.1.

While, J., C. Mao, M. Martin, J. Roberts-Jones, P. Sykes, S. Good and A. McLaren. An operational analysis system for the global diurnal cycle of sea surface temperature: implementation and validation. Accepted subject to minor corrections in QJRMS.

Climate monitoring.

The Hadley Centre maintains two data products that incorporate Argo observations:

- EN4 contains in-situ ocean temperature and salinity profiles and objective analyses. It is updated monthly using real-time Argo profiles, and annually using delayed-mode Argo profiles. EN4 is freely available for scientific research use (see http://www.metoffice.gov.uk/hadobs/en4/).
- HadIOD is an integrated database of surface and sub-surface temperature and salinity observations for the period 1850 to present. It includes quality flags, bias corrections and uncertainty information (Atkinson et al., 2014). At present, HadIOD obtains sub-surface profile data from EN4. Public release of the data are expected in spring 2017. HadIOD is expected to supersede the HadGOA data product, which had not been updated for approximately 5 years (http://www.metoffice.gov.uk/hadobs/hadgoa/).

The datasets are used for climate and global change studies, including ocean heat content analysis.

Atkinson, C. P., N. A. Rayner, J. J. Kennedy, and S. A. Good (2014), An integrated database of ocean temperature and salinity observations, J. Geophys. Res. Oceans, 119, 7139–7163, doi:10.1002/2014JC010053.

Science use.

Data from Argo and Bio-Argo floats are currently used in combination with satellite ocean colour measurements to investigate the ocean biological carbon pump. Specific research focuses on the dynamics of oceanic organic particles in the upper ocean (0-1000 m), their stocks, fluxes, disaggregation and remineralization. Satellite data and Bio-Argo floats are also exploited to better understand the effect of Saharan dust deposition on upper ocean biogeochemistry. Finally, satellite altimetry, ocean colour, Argo and Bio-Argo data are used to study eddy transport of heat, salt and biogeochemical properties.

Dall'Olmo, G.; Dingle, J.; Polimene, L.; Brewin, R. J. W. & Claustre, H. Substantial energy input to the mesopelagic ecosystem from the seasonal mixed-layer pump. Nature Geoscience, 2016, 9, 820-823.

Organelli, E.; Claustre, H.; Bricaud, A.; Schmechtig, C.; Poteau, A.; Xing, X. G.; Prieur, L.; D'Ortenzio, F.; Dall'Olmo, G. & Vellucci, V. A Novel Near-Real-Time Quality-Control Procedure for Radiometric Profiles Measured by Bio-Argo Floats: Protocols and Performances. Journal of Atmospheric and Oceanic Technology, 2016, 33, 937-951.

Sauzede, R.; Claustre, H.; Uitz, J.; Jamet, C.; Dall'Olmo, G.; D'Ortenzio, F.; Gentili, B.; Poteau, A. & Schmechtig, C. A neural network-based method for merging ocean color and Argo data to extend surface bio-optical properties to depth: Retrieval of the particulate backscattering coefficient. Journal of Geophysical Research-Oceans, 2016, 121, 2552-2571.

Schabetsberger, R.; Miller, M. J.; Dall'Olmo, G.; Kaiser, R.; Okland, F.; Watanabe, S.; Aarestrup, K. & Tsukamoto, K. Hydrographic features of anguillid spawning areas: potential signposts for migrating eels. Marine Ecology Progress Series, 2016, 554, 141-155.

7. Funding

Over the last five years funding for the UK Argo Programme has been provided by DECC, NERC and (since 2012) the Met Office. The Met Office and DECC-funded element of the UK Argo Programme supports the Met Office's activities and includes: programme management and coordination, float procurement, preparation of floats for deployment, organisation of float deployments and representation in the international Argo Steering Team and Euro-Argo. Argo science and data management aspects are funded by NERC and led by NOCS and BODC respectively. NERC has also provided ad-hoc funding for floats, which has been directed through NOC, PML and other delivery partners.

During 2016 DECC advised that as a consequence of savings to be made under the Government's Comprehensive Spending Review their funding for Argo will cease from April 2018. Since then the majority of the activities previously delivered by DECC have been moved into the new Department for Business, Energy and Industrial Strategy (BEIS) which is also the owning department for the Met Office and NERC. The Met Office are actively pursuing the issue to see if there is a way to recover the position, as the DECC funding provided for the majority of our core Argo floats.

From 2018 it is expected that NERC will continue to fund deep and bio-geochemical floats through projects (e.g. ORCHESTRA, BoBBLE and ACSIS), but they are unlikely to fund many (if any) core Argo floats.

BODC NERC National Capability funding, which funds Argo data management, is currently under long-term review. For the coming year we expect funding to remain at the same cash amount as it has been for the previous few years, which, when inflation is taken into account, is a net reduction in real terms. Data management for the BoBBLE floats has been funded but data management budgets for ORCHESTRA and ACSIS are still to be confirmed. The European funded MOCCA project will support real time processing of 75 Euro-Argo ERIC floats and delayed mode quality control for 38 ERIC floats for 4 years. AtlantOS will support delayed-mode QC of bio-geochemical Argo data over the next two years.

8. Euro-Argo ERIC

The Euro-Argo ERIC (European Research Infrastructure Consortium) was formally established on 12th May 2014 following notification in the OJEU (Official Journal of the European Union). UK is one of the founding members of Euro-Argo alongside Finland, France, Germany, Greece, Italy, Netherlands, Norway (Observer) and Poland (Observer). The key Euro-Argo ERIC project that the UK is involved in is MOCCA as noted above.