Argo Australia National Report 2022 – AST-23

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1. The status of implementation of the new global, full-depth, multidisciplinary Argo array (major achievements and problems in 2021)

a. Floats deployed and their performance

During 2021, Argo Australia deployed 76 floats, including 67 Core floats, 7 BGC floats, and 2 Deep floats. The locations of the floats deployed in 2021 are shown in in Figure 1. We deployed floats from 9 different vessels[1].

We had more early failures than usual during 2021. We had 7 core floats fail with early battery depletion, and we had 15 (out of 35) core APF11s, all ordered in 2019, that have developed a bladder air entrapment problem.

We deployed 7 BGC floats in 2021, including a mix of APEX and PROVOR, all with 6 BGC sensors. Three floats (all APEX) went under the ice (and haven't resurfaced). The other four, all deployed in the tropics and subtropics, are operating well. However, the pH sensor on two of those floats (one APEX and one PROVOR) failed on deployment.

One of the 2 MRV Deep SOLO floats deployed this year (7900923) failed early after 40 cycles. Fortunately, the float had not drifted too far in the month after deployment and was able to be retrieved by L'Astrolabe on their second search attempt. The float has been returned to MRV so that we can determine what happened. We also had some issues with our first cohort of Deep floats not reliably picking up new missions (some did and some didn't, and we are unsure of the exact cause).

b. Technical problems encountered and solved

Argo Australia activities that have encountered technical problems or identified technical solutions include:

- Establishing an Argo Technical Community of Practice;
- Development of a remote-controlled Argo Release;
- BGC decoding;

[1] Aurora Australis, Everest, RV Investigator, Falkor, Antarctic Discovery, Tangaroa, Antarctic Aurora, RV Kaharoa, Outer Limit

- Identification of APF11s with early battery depletion;
- Identification of pneumatic air loss issues seen on a subset of APF11's ordered in 2019;
- Identification of cohort of BGC APF11 floats that failed to surface after going under ice;
- Floats with RBR CTDs; and
- Estimation of Argo trajectories under ice.

These activities and issues are described below.

Argo Technical Community of Practice

A new Argo Technical Community of Practice (CoP) was established in 2021. The Argo Technical CoP is a forum for collaboration, knowledge sharing, and coordinated action between Argo Technicians. The CoP aims to establish, review, and refine best practice procedures for pre-deployment testing of floats to eliminate premature deaths and performance-debilitating failures for core and BGC Argo. A summary of recent and upcoming Argo Technical CoP activities follows:

- September 2021 – Argo Technical CoP endorsed by AST Co-Chairs
- October 2021 – Established Terms of Reference with founding group
- January 2022 – Discussion of NAVIS floats
- April 2022 – Discussion of APEX floats

The group nominally meet each quarter. Founding members are Pat McMahon (CSIRO, Founding Chair), Deb West-Mack (WHOI), Ryan Anderson (WHOI), Rick Rupan (UW), Elizabeth Steffan (PMEL), and Chanelle Cadot (PMEL). A website containing more information is at:
http://www.cmar.csiro.au/argo/dmqc/html/ArgoCop.html

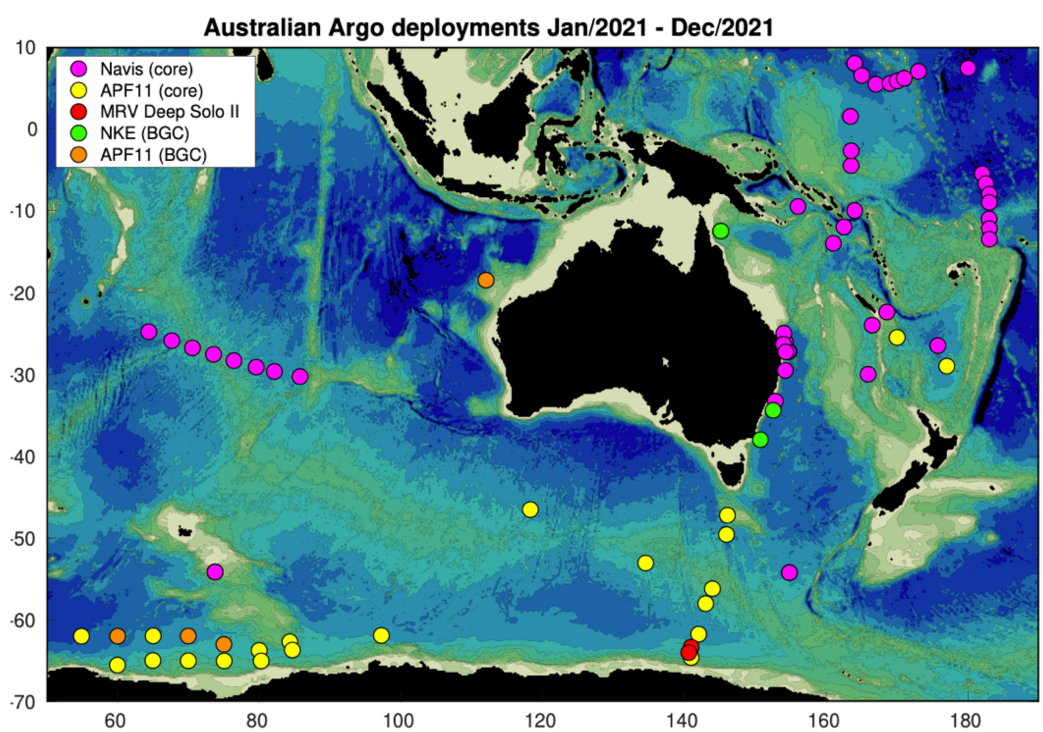

Figure 1: Map showing the deployment locations for floats deployed by Argo Australia in 2021. The colours of the dots denote the float types.

Remote-Controlled Argo Release

Early morning on 23 February 2022, the L'Astrolabe deployed an Argo float at 60S using a Remote-Controlled Argo release. The deployment was uneventful and the float started operating on deployment as expected. The Argo release is the first of its kind, invented by Pat McMahon. Use of the Argo Release significantly reduces the safety risks associated with Argo deployments, which is particularly important at high latitudes and in rough seas, and reduces the risk of failed deployments (which risks damage to floats). Some photos of the release are presented in Figure 2.

Figure 2: Photos of the Argo Release gear (left), the unit ready for deployment (middle), and a test on CSIRO's wharf in Hobart (right).

APF11s with early battery depletion

CSIRO noticed that a batch of APEX floats have shown an early battery depletion – often at around profile 88 (with all floats on a standard 10-day mission). We traced this to a batch of floats ordered from TWR in 2018. That order included 24 APEX floats. Of those 24 floats, 7 are dead, apparently with early battery depletion; 3 others are showing signs of early battery depletion. It's possible that the problem is unique to CSIRO's floats. Floats operated by other DACs that failed around 80 to 110 profiles might be worth assessing for this problem. Perhaps the Argo Technician CoP will look at this together.

Pneumatic air loss issues seen on a subset of APF11's ordered in 2019

A number of APF11's, ordered in 2019, have developed a bladder air entrapment problem. It causes air to be forced out of the bladder and results in a high internal vacuum, which the air pumps can't overcome to fully inflate the bladder at the surface. The problem causes floats to intermittently miss GPS fixes and results in poor telecommunication (resulting in higher-than-normal telecommunication costs). Once the internal vacuum reaches 5 dbar, the air pumps will run for 10 minutes before timing out, when they can't overcome the increased internal vacuum to inflate the bladders. We're working with TWR to estimate the number of years per float until the vacuums reach 5 dbar.

We are also working with TWR to diagnose whether a firmware problem in 2.15.0 and earlier could also be causing the bladders to not fully inflate. We identified four undeployed floats in the same Hull range as the floats which developed the bladder air entrapment problem. These have been returned to TWR for a bladder replacement.

Suspected Failed BGC floats

During Austral summer 2021, we deployed 12 APF11 floats, including 3 APF11 BGC floats. All floats used firmware version 2.15.0 or an earlier revision with the exception of one float which used UW Swiftware. All three BGC floats failed to resurface after going under ice. Seven other floats, deployed on the same voyage, but farther south, have all reported after going under ice and the two floats deployed further north have reported as expected in February 2022. Only the BGC floats in this cohort failed to surface.

After deployment, we learnt that all of these floats were incorrectly ballasted. They all have a carbon hull, but were ballasted as if they have aluminium hulls. Probably as a result of the ballasting, two of the three floats descended deeper than 2000m on deployment (they all had a park depth of 2000m). After the floats performed 16 profiles, we changed the park depth to 1500m for winter.

Also, after deployment, TWR requested that undeployed floats running firmware version 2.15.0 be upgraded to 2.15.4 or 2.15.5. They noted that using version 2.15.0, a float may perform a fake inflate – causing the air bladder to inflate too early. This behaviour was fixed in 2.15.1. We note that two of the three BGC floats which failed to surface after going under ice attempted to inflate the air bladders early during the first 16 profiles.

We deployed a fourth APF11 BGC float (with hull number 9279 – WMO 7900935) the sub-tropics. Unlike the floats deployed at high latitude, this BGC float had its firmware updated to 2.15.4 before leaving TWR and was corrected ballasted as a carbon hull. It's performing well.

Floats with RBR CTDs

Nine ALTO floats with RBR sensors are operating. The presentation by M.Dever at ADMT22 listed all nine as having reference data identified. We have not yet received updated calibration coefficients for these floats. In addition, one float with an early pilot RBR sensor has recently died. Processing of the data from this float will require collaboration with RBR to determine calibration procedures.

In addition, we have 8 floats in the lab that have RBR sensors. We intend to deploy each of these with a 'buddy' float that has a Seabird CTD and to sample daily for an initial period in order to collect a good reference dataset.

Estimating Argo trajectories under ice

It's well known that Over 26,000 Argo profiles have sampled under ice at high-southern latitudes, and are disseminated without measured positions. We know of three papers that describe methods for estimating these trajectories: one applied to grounded floats, using bathymetry and depth of bottom measurements; and two that assume trajectories approximately follow depth, or potential vorticity contours. We developed a system that assumes trajectories approximately follow contours of potential vorticity. We found that it failed in some regions. We generalised the method to assume that other fields might be approximately conserved along trajectories. We used mean sea-level and density at 1000 m depth. All of these constraints failed for some cases. But when used together, we found that we could produce trajectories for over 99% of cases. In some cases, our method produces three estimates for unknown trajectories. We could easily add additional fields to produce more. We wonder whether this estimation could be part of the DMQC process. Perhaps multiple estimates of trajectories could be produced – and then an expert operator could look at the estimated trajectories, and considering the oceanography, past trajectories in the region, etc, they could select the trajectory that they think is most realistic. An example is presented in Figure 3. We've submitted a paper describing our method for peer review:

Oke, P. R., T. Rykova, G. S. Pilo, J. L. Lovell, 2022: Estimating Argo float trajectories under ice, *submitted to JGR Earth and Space Science.*

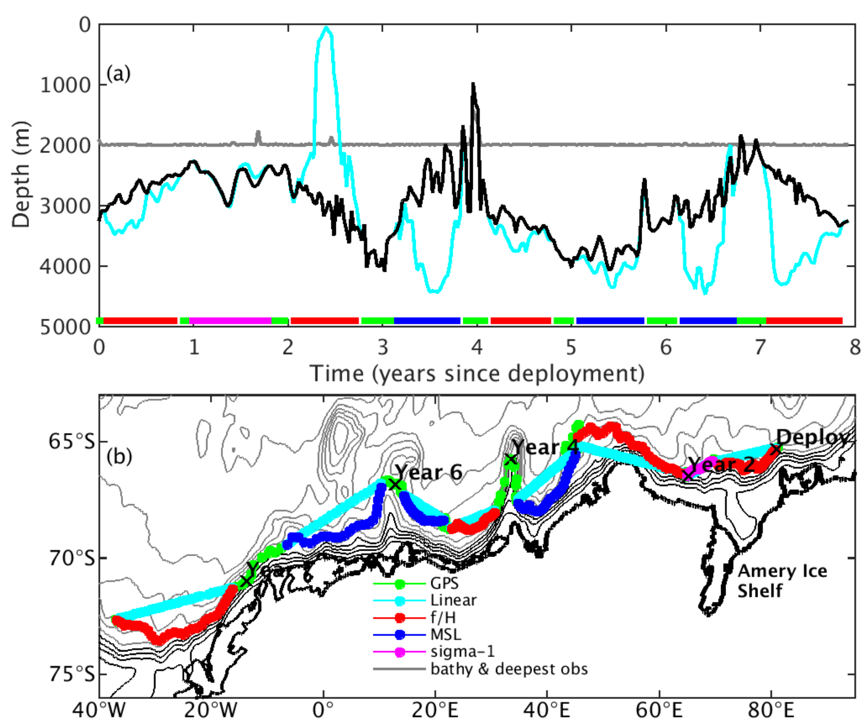

Figure 3: Example of the estimated trajectory for float 7900310. Showing (a) time-series of the depth of the deepest measurement (grey), and bottom depth beneath the trajectory for the linear (cyan) and multiple-constraint (black) method; and (b) the trajectory (overlaying bathymetry) from by GPS (green), and from the linear (cyan) multiple-constraint method - showing when we use f/H (red), MSL (blue), and sigma-1 (magenta). The coloured lines along the bottom of panel (a) show which method is used at different times. Time references along the trajectory are shown in panel (b) along the float's path.

c. Status of contributions to Argo data management (including status of high salinity drift floats, decoding difficulties, ramping up to include BGC or Deep floats, etc)

High salinity drift floats

We have 42 floats listed on the Abrupt Salty Drift spreadsheet (float that showed significant PSAL drift before cycle 80). Only 8 of these floats are still returning correctable data, the others have either died or are returning uncorrectable PSAL data.

Decoding difficulties

We're struggling to find the best way to decode BGC profiles. PROVOR and APEX floats report pressure for the BGC sensors very differently. APEX only provide a time stamp, which then requires interpolation to get to pressure. At the moment, the file structure coming out of the two float types differs for our DAC (6 BGC pressure profiles for PROVOR, 1 BGC pressure profile for APEX, resulting in sparse profiles for each BGC variable). The GDAC seems happy with what we do, but our own DOXY DMQC software is struggling. We've identified a work-around for this problem, but we're thinking about how to solve this problem eloquently.

Deep floats

Our deep float data has thus far been QC'd independently by Annie Foppert (outside of our existing DMQC software suit for core and DOXY). It is our intention to update the DMQC software to be able to handle and QC Deep Floats in the future.

BGC floats

Christina took a leading role to update the document outlining RTQC for CHLA and CHLA_FLUORESCENCE; the international BGC team has finally agreed on the tests and procedures for these variables, which took a lot of testing, meetings and compromises, but we got there; Christina has also been part of two international BGC working groups: one about BBP RTQC tests, with a publication in prep (Dall'Olmo is lead author), and she has also been part of a radiometry working group, with the goal to optimize the 4 wavelengths measured by radiometers mounted on BGC Argo floats.

With respect to our RTQC efforts: pH is finally up and running (nitrate and oxygen have been good for a while), so now CHLA is the last outstanding variable for RTQC that we need to tackle (until the BBP documentation is available; then we need to do BBP as well).

d. Status of delayed mode quality control process

Our Matlab-based DMQC system is actively maintained to ensure that all of our data can be processed efficiently. Our system now uses OWC-v3. We are using the ARGO_for_DMQC_2020V03 and CTD_for_DOMQ_2021V01 reference databases. We currently have three DMQC Operators regularly performing DMQC on our data, and one software engineer supporting the code.

To date, we have processed about 93% of eligible T/S/P data. We have updated our list of floats on the Abrupt Salty Drift spreadsheet and responded to alerts in the Coriolis reports. We have not started DMQC of our floats with RBR sensors. RT processing is being modified to include the updated calibration factors and then the further calibration will be included in the DMQC code. The calibration factors for our float are not yet available on the git repository. In addition, we have one older RBR float that needs individual attention to determine calibration.

Our over-all capacity in DMQC was reduced for 2022, as staff effort has shifted between projects. We are hoping to recruit a new DMQC Operator soon.

DMQC of BGC variables is starting to take shape, but with slow process. The Matlab code for DOXY DMQC has been updated and is in the testing phase. Hopefully it will be ready for action in the next few weeks. DMQC for CHLA and BBP (the most abundant sensors in our BGC array, when including dead floats) is being coded in Matlab and has been tested on a few floats. It is ready to go from the QC perspective for these floats, but we're still understanding how to update history fields etc in the netcdf files (hoping to not corrupt other aspects of the files).

Tatiana Rykova initiated a virtual discussion with the DMQC community on challenging/interesting floats in January 2022. The first meeting included a presentation on Abrupt Salty Drifters (by Annie Wong) and a presentation of two challenging floats (led by Tatiana Rykova). A second meeting is planned for April 2022, and will focus on DMQC of Deep floats. If there's interest, this series of meetings may continue.

2. Present level of and future prospects for national funding for Argo including a summary of the level of human resources devoted to Argo, and funding for sustaining the core mission and the enhancements: BGC, Deep, Spatial (Polar, equator, WBCs)

Argo Australia has secured funding for salary and operating costs to support our Argo operations until June 2023 from the Australian Integrated Marine Observing System (IMOS). We expect this funding to continue until at least 2028 at an equivalent level. This includes support for salary and operating costs for the Australian Argo Program.

In 2022, we expect to acquire 59 Core floats, 12 Deep floats, and 4-6 BGC floats. Core and BGC floats are funded from a strong partnership between IMOS (contracted until June 2023, and likely extended until June 2028), CSIRO (reviewed annually), the Australian Department of Defence (reviewed annually), BoM (reviewed annually), and AAPP (contracted until 2029). BGC floats are funded by IMOS, CSIRO, UTAS, and AAPP. Deep floats are funded by AAPP and CSIRO.

Argo Australia has (some fraction of) two technical officers; one person running real-time operations and maintaining our Matlab-based RT system; one person developing a new Python-based system and doing most of the decoding; six people contributing to the delayed-mode operations (including one dedicated to BGC and one dedicated to software development and maintenance). Our operational team supports activities of Core, BGC, and Deep Argo. Argo Australia also supports a number of people not directly contributing to the technical, RT, or DM elements of the program. This includes two people in Core Argo, two in BGC Argo, and three in Deep Argo – although the lines distinguishing between these efforts is becoming blurred – something that our program is embracing. In total, Australian Argo draws on ~6 FTE, with ~4.5 FTE for operations; ~0.5 FTE for Core Argo leadership and applications, ~0.5 for BGC Argo leadership and applications, and ~0.5 FTE for Deep Argo leadership and applications.

Argo Australia intends to continue providing AUD$100K funding to support operations of the RV Kaharoa (and its successor), and AUD$30K funding to support OceanOps. We received greater scrutiny over this budget item than previously. We've secured this funding until June 2022, and we will work hard to keep it as an ongoing budget item.

3. **Summary of deployment plans (level of commitment, areas of float deployment, Argo missions and extensions) and other commitments to Argo (data management) for the upcoming year and beyond where possible.**

We currently have 59 Core floats, 6 six-sensor BGC floats, and 12 Deep floats either in our laboratory or on order. Our deployment plans for 2022 and 2023 are represented in Figure 4. We plan to focus deployments around Australia in the coming season – mostly so that we can use deployment opportunities that we think are reliable. Regular replanning because of COVID-related restrictions has taken a lot of time. We hope to avoid that if we can. We haven't planned all of our deployments – particularly for BGC floats. We hope to identify appropriate cruises that have capacity to perform CTD profiles on deployment. Our experience over the past two years has led us to take every opportunity to deploy. In the past, we planned more carefully. But with travel restrictions, and lost opportunities, we're taking a more pragmatic approach for the near-term.

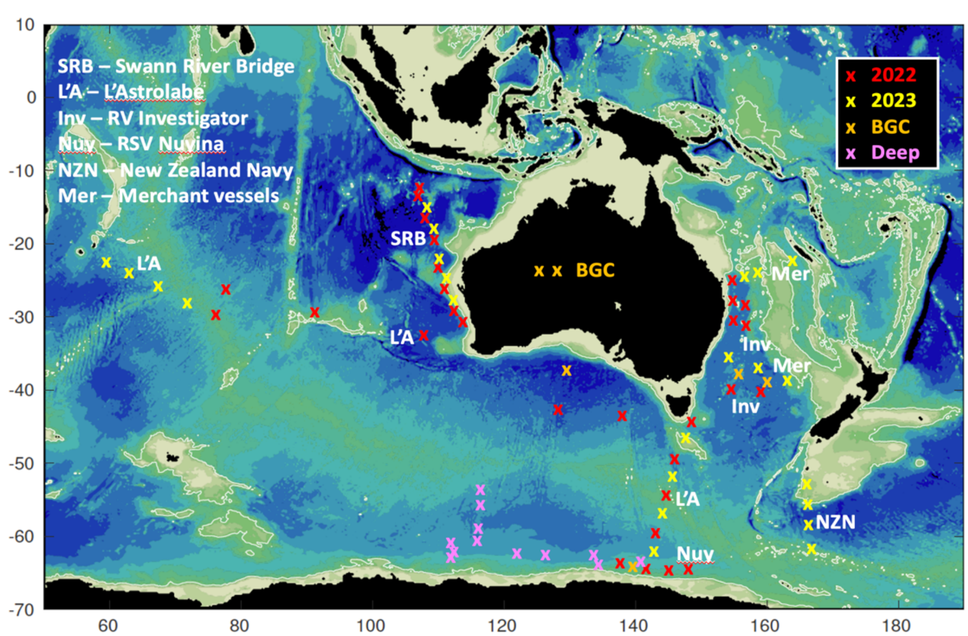

Figure 4: Approximate locations of planned core deployments for 2022 (red) and 2023 (yellow); and BGC (orange) and Deep floats (blue) floats planned for 2022/23. Locations for 2 BGC floats are yet planned (but we won't deploy these in central Australia).

We have a preliminary plan for the deployment of the 12 Deep Floats. The voyage that these floats were originally planned for has now been delayed by one more year, so these floats will not now be deployed until Austral summer 2024. There is a possibility to deploy these earlier on a voyage in Sep 2023 but as this is a marginal ice zone voyage, there may be too much ice around for safe deployment.

4. **Summary of national research and operational uses of Argo data as well as contributions to Argo Regional Centers. Please also include any links to national program Argo web pages to update links on the AST and AIC websites.**

A new modelling activity to examine the impact of data from Abrupt Salty Drifters (ASDs) in assimilating models/systems has been initiated under the OceanPredict Observing System Evaluation Task Team. This study involves a series of Observing System Experiments, where a sub-set of data are systematically with-held from assimilating systems. For the planned experiments, data from the floats with potential ASDs are with-held from some calculations to quantify their impacts. Systems included in the study use different models and different data assimilation methods. There will be at least three different systems included. Using this approach, we hope to identify the robust impacts, rather than the system-specific impacts. The lead for this study is Yosuke Fujii, from JMA. Others involved include Peter Oke (CSIRO) and Hao Zhu (ECMWF).

Argo data are used operationally to underpin Australia's short-range ocean forecast system (OceanMAPS; www.bom.gov.au/oceanography/forecasts/), ocean, and seasonal prediction systems (POAMA; www.bom.gov.au/climate/ocean/outlooks/). Science applications include the investigation of decadal prediction, climate studies, biogeochemical response to dust and smoke, and some studies into mesoscale variability around Australia.

Argo data is one of the key data sets that underpin Australian ocean reanalysis efforts. A paper describing the 2020 version of our reanalysis – called the Bluelink ReANalysis, BRAN 2020 – has been published. Data span 1993-2021 and are publicly available. BRAN2020 assimilates Argo data, altimetry, and satellite SST data, plus other in situ data sources. The main improvement in BRAN2020, compared to previous versions, is the reduction (almost elimination) of deep biases. This improvement is attributed to a new multi-scale data assimilation approach that constrains broad-scales separately from mesoscales, in a two-step assimilation process. A link to the BRAN2020 data follows:
https://geonetwork.nci.org.au/geonetwork/srv/eng/catalog.search#/metadata/f9372_7752_2015_3718

Argo data is one of the key data sets that underpin our new analysis system – called Blue Maps. A paper describing Blue Maps has been published. Work on the evaluation and development of Blue Maps is ongoing. Data currently available from Blue Maps spans 2006 to present. Blue Maps grids data from Argo, satellite altimetry, and satellite SST. A link to Blue Maps data follows:
https://dapds00.nci.org.au/thredds/catalog/gb6/BRAN/Blue_Maps/MAPS-v1p0/catalog.html

National Argo program web pages include:

- imos.org.au/facilities/argofloats; and
- imos.org.au/facilities/argofloats/bgcargo.

5. Issues that your country wishes to be considered and resolved by the Argo Steering Team regarding the international operation of Argo. These might include tasks performed by the AIC, the coordination of activities at an international level and the performance of the Argo data system. If you have specific comments, please include them in your national report.

We know that the Deep Argo community are looking at options for sampling with Deep floats on ascent, as well as on descent. We would support sampling on ascent, so that this data can be used for operational purposes, as well as research purposes.

COVID has resulted in many cancelled voyages. As we try to recover from this, we'd welcome extra international coordination for deployments. We understand that Go-BGC is working hard on this.

6. To continue improving the quality and quantity of CTD cruise data being added to the reference database by Argo PIs, it is requested that you include any CTD station data that was taken at the time of float deployments this year. Additionally, please list CTD data (calibrated with bottle data) taken by your country in the past year that may be added to the reference database. These cruises could be ones designated for Argo calibration purposes only or could be cruises that are open to the public. To help CCHDO track down this data, please list the dates of the cruise and the PI to contact about the data.

If a float is deployed on a research voyage with a co-located CTD then, shipboard CTD data is correctly populated in the CSIRO float meta files if the PI sends the CTD information in the deployment email (this is not always done). We will remind our PI's that if CTD's are planned then that information must be provided to us – so that we can improve this in future. There is some work to do to correct this information in the files retrospectively.

CTD Profiles coincident with Argo float deployments are summarised in the Table below.

WMO ID	Deployment date	PI (CSIRO)	Ship & Cruise	CTD Cast
5906635 (BGC)	09/5/2021	Dr. Chris Chapman	RV Investigator IN2021_V03 EAC Mooring	#3
5906636 (BGC)	11/5/2021	Dr. Chris Chapman	RV Investigator IN2021_V03 EAC Mooring	#4
5906638 (core)	13/5/2021	Dr. Chris Chapman	RV Investigator IN2021_V03 EAC Mooring	#6
5906639 (core)	14/5/2021	Dr. Chris Chapman	RV Investigator IN2021_V03 EAC Mooring	#9

5906642 (core)	24/5/2021	Dr. Chris Chapman	RV Investigator IN2021_V03 EAC Mooring	#25
5906645 (BGC)	16/6/2021	Rod Palmer or Claire Grubb	RV Investigator IN2021_T01	#8

7. Bibliography

We use the Argo Bibliography, maintained by UCSD, as the definitive source of papers that use Argo data. We know of no additional publications that should be included.

8. How has COVID-19 impacted your National Program's ability to implement Argo in the past year? This can include impacts on deployments, procurements, data processing, budgets, etc.

COVID-19 has impacted all areas of our operation, but we have actively adapted to restrictions to maintain the overall performance. Impacts on each area of our work are summarized below:

- Float Procurement
    - Manufacturers of Argo floats have done really well to maintain production of floats despite the pandemic. We're grateful for their efforts. Despite this, we've encountered some delays, which have had flow-on effects to our finance – resulting in additional challenges to maintain funding from some sources.
- Automated pre-deployment testing:
    - COVID-19 travel bans encouraged us to continue developing pre-deployment scripts and applications to simplify final shipside tests so any person can perform a thorough test and identify outliers. We see it as an opportunity to further adapt our operations to reduce our dependency on travel.
    - We developed a Python based program to perform automated tests on NAVIS Argo floats and reduce our reliance on travel during the pandemic.
    - The program provides an increased number of checks over a built-in self-test.
    - We used the program to identify a serious bladder problem in a NAVIS float where the float still passed the built-in self-test.
    - We tested 21 floats at a destination port with the assistance of suitably trained technicians who gained exposure to scientific instrumentation.
- Deployments
    - Some deployment opportunities were lost, when cruises were cancelled or postponed. In those instances, we changed our deployment plans and shifted floats to other opportunities. This resulted in deployments in locations that were not our first choice. But we tried to make sensible choices that would positively contribute to the global array.
    - In some cases, a delay in a voyage has meant that some ice floats were deployed very late in the season, and some of these have disappeared early under winter ice before it could be verified that they were working correctly, or the float missions updated.

- Our usual practice has been to ship floats to their final port, and then one of our Argo Technicians travels to that port to perform final pre-deployment checks. This wasn't possible. Instead, we recruited suitably-skilled technicians near each final port, and worked with them to perform the final tests for us. This turned out to be a significant cost saving, and is something we may consider continuing in the future, regardless of travel restrictions.

- Data processing
  - Our work-force was not directly impacted by COVID-19. However, staff all worked from home for most of 2021, especially after the dirty Mainlanders were allowed to bring disease to our pristine southern state. This has made everything harder – collaboration, coordination, motivation.
- Budgets
  - Our travel budgets were all frozen. We adapted to this, as noted above, but it's possible that post-pandemic travel budgets may be lean.

9. Argo is still interested in piloting the RBR CTD. Does your National Program have any deployment plans for RBR floats in the next couple years? If so, please indicate how many floats will you be buying in 2021 and 2022 (if known) and where they might be deployed.

Despite the challenges we've faced during our initial deployment of ALTOs with RBR sensors, it is our intention to include some portion of floats with RBR sensors each year. We still have 11 floats with RBR sensors in our labs that are awaiting deployment, so we may not order floats with RBR sensors this year. But once we have ironed out the issues with manufacturers, we will purchase floats with RBR sensors each year – perhaps 4-8 floats per year (representing ~10-20% of our annual investment).