Argo Canada – Report of Activities for 2023

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25th meeting of the Argo Steering Team (AST-25)

Location: Hybrid (Southampton & Virtual)

18-22 March 2024

1. The status of implementation of the new global, full-depth, multidisciplinary Argo array (major achievements and problems in 2023)
    a. floats deployed and their performance

As of 25 January 2024, there are 166 operational floats in the Argo Canada program.

From January to December 2023, Argo Canada deployed at total of 33 floats in the following Basins, managed by the MEDS DAC:

- Pacific Ocean (12 floats):
    - 1 NKE ARVOR floats (SBE CTD)
    - 4 NKE ARVOR floats (SBE CTD + O2)
    - 2 NKE PROVOR CTS4 floats (SBE CTD, O2, Chla, backscatter)
    - 5 NKE Deep-ARVOR floats (SBE CTD + O2)
- Atlantic Ocean (19 floats):
    - 11 NKE ARVOR floats (5 SBE CTD, 6 RBR CTD)
    - 2 NKE ARVOR floats (SBE CTD + O2)
    - 3 NKE PROVOR CTS4 floats (SBE CTD, O2, Chla, backscatter)
    - 1 NKE PROVOR CTS4 float (SBE CTD, O2, Chla, backscatter, pH)
    - 2 NKE PROVOR CTS5 floats (SBE CTD, O2, Chla, backscatter, radiometry)
- Arctic Ocean (2 floats):
    - 2 NKE Arvor floats (SBE CTD)

In the fall 2023, the Takuvik lab (Université Laval) carreid out the following floats in Baffin Bay (CCGS Amundsen), managed by the Coriolis DAC:

- 2 BGC floats (model JUMBO, developed by H. Claustre)
- 2 BGC NAOS floats have were recovered in central Baffin Bay

To improve communication among the groups within Canada that are deploying Argo floats, a tracking system has been developed which provides information on completed and upcoming deployments, as well as existing inventories at each facility. The website is available at: Argo Canada Development Blog: Deployment Planning with a summary for 2023 available at: Argo Canada Development Blog: 2023

b. technical problems encountered and solved

One each of NKE ARVOR and NKE PROVOR CTS4 floats had elevated vacuum pressures indicative of a bladder problem. These floats were not deployed and will likely require return to manufacturer for repair. It should be noted, however, that these floats failed this test in September 2023 and at the time of writing this report we have not been given instructions from the manufacturer on what to do with them.

NKE ARVOR floats equipped with RBR CTD sensors delivered in 2023 have upgraded firmware that allowed the float to sample and transmit CTD at a frequency of 1Hz over a segment of the water column up to 200m. Two floats (4902670, 4902671) deployed in the Labrador Sea had this feature activated in mid-October 2023, collecting 1Hz data in the top 200m. One lesson learned from operating these floats is that because of how the float slows down as it approaches the sea surface, data volume in the top 5-10dbar is significantly greater than expected.

In addition to 2023 floats being delivered with this upgraded firmware, NKE ARVOR floats with RBR sensors delivered in 2022 were also able to be upgraded. 3 floats (4902617, 4902618, 4902619) were upgraded to have this capability and deployed in the South Atlantic off Western Africa, however their 1Hz capability has not yet been activated. 1 of these 3 floats (4902617) failed upon deployment and is currently in end-of-life mode, drifting at the surface. We continue to await a response from NKE since initially inquiring following the float's deployment in early December 2023 to see if it is possible to fix this float remotely.

1 refurbished NKE ARVOR float was deployed this year but failed before reporting a profile. This float was originally recovered after it beached due to drifting at the surface because of a sensor failure (RBR CTD).

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)

The MEDS DAC continues to acquire data from 179 Argo floats of which 5 floats have had trouble reporting in the last 2 months. Data are issued to the GTS and GDACs hourly

in BUFR TM315003 and NetCDF formats. Data are available for delayed mode QC as soon as they are sent to the GDACs.

From January 2023 to January 2024, on average, 429 messages per month were issued to the GTS in BUFR format, of which 84% of the data were available within 12 hours of the float reporting.

Since AST-24, the following tasks have been completed:

- Develop and implement the modules to decode PROVOR CTS5 and to create the meta, profile and technical NETCDF files for GDACs submission.
- Continue processing of core Argo variables and DOXY data after they have been delayed mode QC to GDAC and updating the internal database.
- Provide ADMT reports on the performance of Argo data on the GTS in BUFR formats to assist DACs in monitoring the BUFR timeliness transmission.
- Yearly update of the monthly maps and anomaly maps of temperature and salinity along line P in the Gulf of Alaska. For more information on the Line-P products and other uses of Argo to monitor the N.E. Pacific go to: https://www.isdm.gc.ca/isdm-gdsi/argo/canadian-products/Argo-LineP-eng.html
- RTQC of backscatter data has been updated to comply with tests published by Dall'Olmo et al. 2023 (https://doi.org/10.12688/openreseurope.15047.2)
- All eligible floats are surfacing at varying local times of day in accordance with recommendations by the Argo Sampling Committee

d. status of delayed mode quality control process

Delayed mode QC has resumed at MEDS, with 1,105 profiles processed since last year. Approximately 71% of eligible profiles have been DMQC'd at least once, and 72% of eligible floats have been DMQC'd at least once for salinity, while 53% of floats have been DMQC'd at least once with both salinity and pressure. The DMQC process is sporadic because of short staffing. MEDS is looking into filling the staff's shortage to address the backlog of DMQC of core floats and monthly anomaly reports and OCEANOPS altimetric checks .

Of all BGC floats, currently 2034 of 7545 profiles (27%) are in delayed mode. 1374 profiles (18%) are adjusted.

As of the DOXY audit published in October 2023, 8 Canadian floats were flagged as containing potentially bad data. 5 of 8 of these floats have since been DMQC'ed and

hence should be resolved. The remaining 3 floats (4900637, 4900883, 4901786) are actively being worked on and should be resolved shortly.

All DOXY DMQC was done using the python tool developed by Argo Canada (https://github.com/ArgoCanada/bgcArgoDMQC). While to WOA method for calculating DOXY gain is quite robust, in-air calculations remain under active development and should be used with close attention.

Changing historical DOXY_QC flags from 1 to 3 is an immediate priority.

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 OneArgo mission: Core, BGC, Deep, Spatial (Polar, equator, WBCs)

Financial resources

Argo Canada has ongoing funding for the O&M expenditures related to the International Argo program. The majority of these expenditures are related to Iridium telecommunications costs which are managed by Shared Services Canada (SSC) and paid for by DFO. The Iridium SBD and RUDICS services are provided by MetOcean Telematics, which has a contract to supply Iridium services to the whole of the Government of Canada.

Ongoing capital for float purchases has not been identified, so it remains necessary to request capital resources annually to obtain the funding required to purchase new floats. The Government of Canada (DFO and Department of National Defence – DND) committed $337k CAD for purchases of core NKE Arvor-I (SBE CTD) floats in the Fiscal Year 1 April 2023 to 31 March 2024. The funding will result in the acquisition of 13 core Argo floats. This represents a significant reduction in DFO procurements relative to the preceding 5 years when additional funding was made available to initiate development of the BGC-Argo program in Canada.

The project “A BGC Argo Program for the NW North Atlantic Ocean” led by Dalhousie University and the Memorial University of Newfoundland, has been funded by the Canadian Foundation for Innovation (CFI), Research Nova Scotia (RNS), and the province of Newfoundland for a total cost of $8.8M. The current plan is to acquire 33 BGC-Argo floats for deployment in the NW North Atlantic. 5 NKE CTS5 floats with oxygen, backscatter, chlorophyll, and irradiance sensors

have been delivered to date, and two of these floats were deployed in the Labrador Sea in December 2023.

CFI funding held jointly by the Universities of Victoria and British Columbia (C-PROOF, see details in Section 4) that has been providing BGC sensors for floats deployed in the Northeast Pacific. In March 2023, floats were delivered with four O2 sensors (purchased by UVIC) added to DFO Arvor floats and five SUNA (nitrate) sensors plus the jumbo option (purchased by UVic) added to DFO Provor floats. In addition, two Provor floats (oxygen, nitrate, irradiance, chlorophyll, and backscatter sensors) were purchased by UVic and delivered in October 2023.

In 2023, Ocean Networks Canada (ONC) received 18 NKE Deep ARVOR floats, which can profile to 4000 m and carry a dissolved oxygen sensor. Five of these floats were successfully deployed in the NE Pacific in the summer during DFO led cruises. An additional 2 floats are anticipated to be deployed in the Southern Ocean sometime before the end of January 2024, during an ongoing cruise in the Drake Passage.

Since 2016, Takuvik has deployed 24 BGC Argo floats (funding being provided by French and Canadian projects, each up to 50 %), which have acquired more than 2,500 profiles (temperature, salinity, backscattering coefficient at 700 nm, radiometric data along 4 channels, as well as concentrations of a) dissolved oxygen, b) chlorophyll-a, c) colored dissolved organic matter, d) nitrate.

The development of close links between the Argo Canada program and both the operational meteorology and operational oceanography R&D activities at the Canadian Meteorological Centre (Dorval, Québec) has been beneficial. An inter-departmental (Environment and Climate Change Canada, Department of National Defence, Fisheries and Oceans) Memorandum of Understanding entitled CONCEPTS (Canadian Operation Network of Coupled Environmental PredicTion Systems) has provided strong advocacy for the Argo program.

Human resources

The following people contribute to the logistics and data management for Argo Canada:

- Anh Tran (DFO, MEDS, Ottawa) – DAC lead, RTQC Operator
- Zhimin Ma (DFO, MEDS, Ottawa) – DMQC Operator (core Argo)
- Jenny Chiu (DFO, MEDS, Ottawa) – RTQC support

- Andrew Stewart (DFO, OSB, Ottawa) – National Manager, Ocean Monitoring and Observing
- Tyler Emmott (DFO, OSB, Ottawa) – Float procurement, contracting
- Blair Greenan (DFO, BIO, Halifax) – AST member, Argo Canada lead
- Chris Gordon (DFO, BIO, Halifax) – DMQC Operator (BGC), deployment planning, logistics, performance monitoring
- Clark Richards (DFO, BIO, Halifax) – Research scientist, Argo Polar Task Team member, RBRArgo data task team member, ArgoFloats R package development
- Jaimie Harbin (DFO, BIO, Halifax) – ArgoFloats R package developer and Commonwealth Blue Charter training coordinator
- Igor Yashayaev (DFO, BIO, Halifax) – Research Scientist
- Adam Hartling (DFO, BIO, Halifax) – Field support
- Tetjana Ross (DFO, IOS, Sidney) – Pacific deployment planning, Canadian member of the International Deep Argo Mission Team
- Lindsay Mazzei (DFO, IOS, Sidney) – Field support
- Katja Fennel (Dalhousie University, Halifax) – Canadian member of the International BGC-Argo Steering Committee
- Dan Kelley (Dalhousie University, Halifax) – ArgoFloats R package developer
- Kohen Bauer (Ocean Networks Canada) – Principal Investigator, Deep Argo
- Richard Dewey (Ocean Networks Canada) – Principal Investigator, Deep Argo
- Herminio Folio Neto, Jeannette Bedard, and Kohen Bauer (Ocean Networks Canada) – DMQC Operators, Deep Argo

In addition to the above people, we benefit from the technical support of many sea-going staff that follow pre-deployment protocols and perform the float deployments.

National Coordination

With increasing participation in the Argo program within Canada, both in core Argo, BGC-Argo and Deep Argo, it was decided to establish a new governance structure in 2018. The Canadian Argo Steering Team (CAST) provides scientific leadership and oversees the development and implementation of the Canadian contribution to the International Argo Program. The CAST is chaired by Blair Greenan and meets annually prior to the Argo Steering Team meeting.

The Canadian Biogeochemical-Argo Committee facilitates the implementation of the Canadian contribution to the Biogeochemical-Argo program by coordinating and advising national efforts and acting as liaison to the International Biogeochemical-Argo Steering Committee. The Committee is chaired by Katja Fennel.

Float Testing Facility

In partnership with Defence Research and Development Canada (DRDC), DFO has established a testing facility on the DRDC Barge in Bedford Basin. This facility will enable us to do short-term testing of floats and sensors to evaluate performance. This is a low-current environment that facilitates tethered profiling to a water depth of 35 m.

3. Summary of deployment plans: please see the separate documents explaining the longer term outlook this year as a response to G7 requests. This spreadsheet is to be **returned separately ASAP** to help prepare for the meeting. It can be sent to Megan or dropped in the folder link containing the instructions.

In 2024, Argo Canada plans to deploy approximately 38 floats in the Northeast Pacific, North/South Atlantic, and in polar regions:

- 15 Core
- 4 Core + O
- 6 BGC (2-3 sensors)
- 7 BGC (4-6 sensors)
- 6 Deep + O

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.

The Government of Canada CONCEPTS initiative (Canadian Operational Network for Coupled Environmental Prediction Systems; http://science.gc.ca/eic/site/063.nsf/eng/h_97620.html) uses observations from the Argo array for a variety of operational and research applications. These include direct assimilation into operational weather and environmental prediction systems, monitoring of forecast quality (verification), and well as detailed research to improve model physics (e.g. further development and optimization of model parameterizations) and data assimilation (e.g. Observing System Experiments). The CONCEPTS Global and Regional Ice Ocean Prediction Systems (GIOPS and RIOPS) provide daily estimates (analyses) of ocean and sea ice properties using a multi-variate data assimilation system assimilating Argo observations together with other sources of in situ temperature and salinity, satellite altimetry, and sea surface temperature data. GIOPS analyses are used to initialize the ice-ocean components of the coupled Global Deterministic Prediction System (GDPS), responsible for providing operational medium-range weather forecasts for Canadians. GIOPS analyses are also used to initialize the operational forecasts from the Canadian Seasonal-Interannual Prediction System (CanSIPS).

Temperature and salinity from GIOPS analyses are also used to represent the baroclinic effects in the Global Deterministic storm Surge Prediction System (GDSPS). RIOPS analyses are produced in a model that includes tides and provides daily three-dimensional state of the ocean estimates for Canada's three coastlines on a domain covering the North Pacific, Arctic, and North Atlantic Oceans. An observing system experiment is underway to assess the impact and potential benefits of assimilating seasonal Argo floats from the Arctic Ocean into RIOPS. Coastal forecasts are produced for the east and west coast of Canada at 2km resolution using a spectrally nudging to RIOPS analyses.

DFO also extensively used the GLORYS global ocean reanalysis product from Mercator-Ocean International, produced with assimilating Argo data. This includes providing lateral open boundary conditions for regional models and analyses for interpreting observations and understanding ocean variability.

Argo data is used in the verification of Canadian and international prediction systems to enable predicted and observed profile comparison. Part of OceanPredict Inter-comparison and Validation Task Team. Comparisons of Argo based class 4 is visible on https://navigator.oceansdata.ca under the class 4 tab.

The Department of National Defence (DND) scientists, operational oceanographers and sonar operators routinely use real time Argo vertical profiles to assess model performance and, in some instances, use as data to compute acoustic range predictions (both at sea and in the Meteorology and Oceanography Centres (Esquimalt and Halifax)). DND uses the web-based Ocean Navigator tool to assist with these activities.

The Argo Canada web site is maintained by Fisheries and Oceans Canada at http://www.isdm.gc.ca/isdm-gdsi/argo/index-eng.html. A repository of Argo-related code under development through DFO has been made available on Github at https://github.com/argoCanada. Repositories include the under-development python BGC DMQC tools, the argoFloats and argodata R packages, a new python package for finding and working with Argo data (argopandas), and an informal blog used to highlight interesting floats and issues encountered when working on Argo DMQC.

Argo data are used in the preparation of Fisheries and Oceans Canada's State of the Ocean reporting (https://www.dfo-mpo.gc.ca/oceans/publications/index-eng.html).

The Canadian-Pacific Robotic Ocean Observing Facility (C-PROOF, http://cproof.uvic.ca/) is funded by the Canadian Foundation for Innovation (CFI) and B.C. Knowledge Development Fund (BCKDF) to build ocean observing capacity off the British Columbia coast. C-PROOF is based at the University of Victoria. A fleet of autonomous gliders, Argo floats, and moorings will provide ocean scientists with long-term monitoring of the ocean at the small scales important to resolve upper ocean physical and biological properties. The C-PROOF project ended in 2023.

Dalhousie University and the University of Newfoundland are leading an infrastructure project for implementation of a regional BGC Argo array in the northwest North Atlantic with funding from the Canada Foundation for Innovation, Research Nova Scotia, and the province of Newfoundland. Research questions to be addressed include the sensitivity of carbon sequestration and ocean ventilation in the Labrador Sea to changing atmospheric and oceanic conditions, new approaches to biological rate measurements using Argo measurements (e.g., NCP, vertical carbon flux), assessment of the skill of climate models in the region, and implementation of a data-assimilative physical-biogeochemical ocean model for the region. As part of the project, a Canadian adopt-a-float program was launched (https://adopt-a-float.ocean.dal.ca/). The Canadian BGC Argo website is maintained by Katja Fennel's research group at http://bgc-argo.ocean.dal.ca/

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 OceanOPS, 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. Also, during the AST-25 plenary, each national program will be asked to mention a single highlight or issue via a very brief oral report.

Argo Canada would like to once again thank the leads for the Basin Planning Working Groups. This has improved information-sharing among the groups deploying floats and is helping to identify deployment opportunities.

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.

CCHDO currently acquires Line-P data up directly from the https://waterproperties.ca/linep website. MEDS will send CTD data collected by other DFO institutions to NOAA NCEI and then the data will be available to CCHDO.

7. Keeping the Argo bibliography (Bibliography | Argo (ucsd.edu)) up to date and accurate is an important part of the Argo website. This document helps demonstrate the value of Argo and can possibly help countries when applying for continued Argo funding. To help me with this effort, please include a list of all papers published by scientists within your country in the past year using Argo data, including non-English publications.
There is also the thesis citation list (Thesis Citations | Argo (ucsd.edu)). If you know of any doctorate theses published in your country that are missing from the list, please let me know. Finally, if you haven't already sent me a list of Argo PIs in your country, please do so to help improve the statistics on how many papers are published including an Argo PI vs no Argo PIs.

Journal Publications

Fu, Y., et al. (2023), Seasonality of the Meridional Overturning Circulation in the subpolar North Atlantic, Communications Earth & Environment, 4(1), 181, doi: https://doi.org/10.1038/s43247-023-00848-9

Greenan B. J., A. P. Wong, T. Morris, E. A. Smith and M. Bollard (2023), Keeping an Eye on Earth's Oceans With Argo Robots, Front. Young Minds. 11:943491. doi: https://doi.org/10.3389/frym.2023.943491

Li, M., Y. He, and G. Liu (2023), Atmospheric and oceanic responses to Super Typhoon Mangkhut in the South China Sea: a coupled CROCO-WRF simulation, Journal of Oceanology and Limnology, 41(4), 1369-1388, doi: https://doi.org/10.1007/s00343-022-1328-6

Neukermans, G., L. T. Bach, A. Butterley, Q. Sun, H. Claustre, and G. R. Fournier (2023), Quantitative and mechanistic understanding of the open ocean carbonate pump – perspectives for remote sensing and autonomous in situ observation, Earth-Science Reviews, 239, 104359, doi: https://doi.org/10.1016/j.earscirev.2023.104359

Stoer, A. C., et al. (2023), A census of quality-controlled Biogeochemical-Argo float measurements, Frontiers in Marine Science, 10, doi: https://doi.org/10.3389/fmars.2023.1233289

Wang, B., and K. Fennel (2023), An Assessment of Vertical Carbon Flux Parameterizations Using Backscatter Data from BGC Argo, Geophysical Research Letters, 50, e2022GL101220. doi: https://doi.org/10.1029/2022GL101220

Ph.D./M.Sc. Thesis

Adam Stoer, ESTIMATING MARINE PHYTOPLANKTON BIOMASS AND PRODUCTIVITY FROM AUTONOMOUS PROFILING FLOATS, Dalhousie M.Sc. thesis, 2023

Books

Nothing to report

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.

Deployments for 2023 were not impacted by COVID-19 restrictions. DFO is still experiencing research vessel availability issues. The primary platform for oceanographic research on the east coast of Canada (CCGS Hudson) was decommissioned in January 2022. A replacement research vessel is scheduled to be in service in 2026. In the intervening period, we are reliant on vessel charters, which presents challenges for Argo float deployment planning in the Atlantic.

9. 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 2024 and 2025 (if known) and where they might be deployed.

Argo Canada is committed to deploying additional floats equipped with RBR CTDs. The procurement plan for 2024 is not known at this time, but we expect to procure about 50% of our core Argo floats with RBR CTDs. We had encouraged NKE to consider upgrading the Arvor float firmware to enable sampling and transmitting RBR CTD data at ~1 Hz to allow for further research on the CTD response characteristics in a range of oceanographic conditions. This change in the capability of the Arvor float has been implemented and we have deployed most of these floats that are in our inventory.

Dalhousie University and the Memorial University of Newfoundland are interested in procuring BGC Argo floats with the RBR CTD and possibly other RBR sensors.