Argo Canada – Report of Activities for 2021

(submitted by Blair Greenan, Fisheries and Oceans Canada)

23rd meeting of the Argo Steering Team (AST-23)

Location: Monaco & Virtual

21-25 March 2022

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

    From January 2021 to December 2021, Argo Canada deployed at total of 25 floats in the following regions:

    - Northeast Pacific: 13 NKE Arvor floats
    - Northwest Atlantic: 3 NKE Arvor floats
    - Caribbean Sea: 2 NKE Arvor (RBR CTD) floats (A20/A22 GO-SHIP mission)
    - Baffin Bay: 3 NKE Arvor (SBE CTD) floats (CCGS Amundsen)
    - North Atlantic: 4 NKE Arvor (SBE CTD) floats (Blue Observer Mission)
    - Of these 25 floats, 1 Arvor (RBR CTD) float failed after 18 cycles over the period 26 April 2021 to 28 May 2021. The 24 remaining floats are still operational and functioning properly.
    - As of 31 January 2022, Canada has 124 operational floats in the Argo Canada program.
    - In addition, the Takuvik lab deployed the following floats in Baffin Bay in October and November 2021 (DarkEdge misson on CCGS Amundsen):
        - 4 BGC floats (model CTS5-Usea by NKE)
        - 3 of them were refurbished floats (after recovery) with new high sensitive PAR (MPE by Biospherical/collaboration Takuvik)
        - 1 with UVP6 / Hydroptics particle size abundance

    b. technical problems encountered and solved

    A failure in an O-ring seal on the RBR CTD resulted in an ingress of seawater and thereby a failure of the Arvor float. This float beached in the Turks and Caicos Islands and was recovered through joint coordination between RBR and Fisheries and Oceans Canada. RBR has updated the assembly procedure for the CTD units to reduce the risk of this type of failure in the future.

All of the NKE Arvor and PROVOR floats delivered to DFO in 2021 were recalled for a warranty repair. These floats have now been returned to our facilities, but this resulted in some missed opportunities for deployments.

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 125 Argo floats of which 6 floats has had trouble reporting in the last 6 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. The data of all Canadian floats together with some graphics are posted on a website and updated daily: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/index-eng.html

From January 2021 to January 2022, on average, 327 messages per month were issued to the GTS in BUFR format, of which 83 % of the data were within 12 hours of the float reporting.

Since AST-22, the following tasks have been completed:

- Developing the modules to decode data from BGC floats in anticipation of new BGC floats deployments in 2022.
- Correct DOXY data using the quarterly reports provided by Monterey Bay Aquarium Research Institute.
- Modifying BUFR encoder to include DOXY data and sharing it with NOAA'S Atlantic Oceanographic and Meteorological Laboratory (AOML).
- Implementing multi-profiles and MTIME in the NETCDF profile file.
- Testing the Python core real-time QC package before implementing it in the processing chain
- 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: http://www.meds-sdmm.dfo-mpo.gc.ca/isdm-gdsi/argo/canadian-products/index-eng.html.

d. status of delayed mode quality control process

As of November 17, 2021, there is a total of 611 Argo Canada floats with their profiles on GDAC sites. O theses 611 floats, 31 (i.e., 5%) have no profile files. 76% of all active floats, had their profiles DMQCed following the latest delayed-mode procedures at least once, greater than the last year's percentage of 67%. About 10,008 profiles from 96 active core

Argo floats have been DMQCed within the last year; 8,678 of these profiles have been fully QCed and 1330 have partially QCed profiles.

Of all BGC floats, 12% have had their profiles either visually QCed or fully DMQCed at least once. It should be noted that DMQC only applies to DOXY for Argo B-profiles.

The DMQC tool for core Argo floats has been updated to the latest OWC method as well as the most recent climatology and reference database. There is also a plan to develop the DMQC procedures for time and position according to the latest DMQC manual version 3.5. The DMQC procedure for deep-Argo floats was revisited last year in preparation of upcoming deployments. The DMQC tool for BGC Argo floats focusing on DOXY is coded by python and under development with notable improvements. All source codes have been shared on Github (https://github.com/ArgoCanada/bgcArgoDMQC).

The monthly anomaly reports issued by Ifremer (French GDAC) were carefully reviewed and the anomalies were flagged and updated to GDAC NETCDF files.

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)

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.

Ongoing capital for float purchases has not been identified and, therefore, it remains necessary to request capital resources on an annual basis to obtain the funding required to purchase new floats. The Government of Canada (DFO and Department of National Defence – DND) committed $1.03M for purchases of core NKE Arvor-I, NKE Arvor-RBR, and Provor CTS4 floats in the Fiscal Year 1 April 2021 to 31 March 2022. The funding will result in acquisition of 14 core Argo floats, 10 BGC-Argo floats (3 or 4- BGC sensors) and 3 NKE Arvor floats with RBR CTDs.

At the G7 meeting in Halifax in October 2018, the Government of Canada announced new funding for the International Argo Program (up to $5.6M over 4 years ending in March 2023). The primary intention of this investment is to support the implementation of the BGC-Argo array with a strong emphasis on having ocean observations benefit Small Island Developing States. This initiative also links to Canada's leadership on the Ocean Observations Action Group under the Commonwealth Blue Charter.

In addition, funding for "A BGC Argo Program for the NW North Atlantic Ocean" led by Dalhousie University and the Memorial University of Newfoundland, is conditionally approved by CFI for a total cost of $8.8M. Final approval is still pending, but expected shortly as all

conditions imposed by the funder have been met. The plan is to acquire about 40 BGC-Argo floats for deployment in the NW North Atlantic.

In addition, CFI funding held jointly by the Universities of Victoria and British Columbia (C-PROOF, see details in Section 4) that has been providing additionally oxygen sensors for floats deployed in the Northeast Pacific will be ending in 2022. In addition to the add-on oxygen sensors, they plan to purchase 8 BGC Argo floats in 2022.

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, RBRArgo data task team member, ArgoFloats R package development
- Jaimie Harbin (DFO, BIO, Halifax) – ArgoFloats R package developer 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

In addition to the above persons, 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 and BGC-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.

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.

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.

   Here is a link to the commitments table at OceanOPS. If you cannot edit the online table, please send a list of deployment plans for each of the columns in the table as needed.

   Argo Canada (with financial contributions from Fisheries and Oceans Canada and the Department of National Defence) will procure the following 27 floats by March 2022 (end of fiscal year):

   - 9 NKE Arvor-I with SBE41 CTD
   - 5 NKE Arvor-I with SBE41 CTD + DO
   - 3 NKE Arvor with RBR CTD
   - 6 NKE Provor CTS4 with SBE41 CTD + DO + chla + backscatter
   - 4 NKE Provor CTS4 with SBE41 CTD + DO + pH + chla + backscatter

   In 2022, Argo Canada plans to deploy about 38 of the floats in the Northeast Pacific and North/South Atlantic (firm commitment):

   - 22 Argo Core (18 SBE CTD, 4 RBR CTD)
   - 16 Argo BioGeoChemical (14 O2 only, 2 O2 + bio-optical triplet)

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). 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. The applications of this include providing lateral open boundary condition 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 (http://navigator.oceansdata.ca/public/) to assist with these activities.

Argo data are used in the preparation of Fisheries and Oceans Canada's State of the Ocean reporting (e.g. https://www.dfo-mpo.gc.ca/oceans/publications/soto-rceo/2019/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. C-PROOF has ordered 5 dissolved oxygen sensors to add to some of the DFO Arvor floats ordered for delivery in March 2022; however, supply issues with pH sensors precluded UVic from being able to add some of these sensors to the DFO Provor floats.

The Argo Canada web site is maintained by Fisheries and Oceans Canada at http://www.isdm.gc.ca/isdm-gdsi/argo/index-eng.html

The Canadian BGC Argo website is maintained by Katja Fennel at http://bgc-argo.ocean.dal.ca/

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.

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. Also, during the AST-23 plenary, each national program will be asked to mention a single highlight or issue via a very brief oral report.

   Nothing to report this year.

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

   Kelley, D. E., J. Harbin, and C. Richards (2021), argoFloats: An R Package for Analyzing Argo Data, Frontiers in Marine Science, 8(409), doi:
   https://www.frontiersin.org/article/10.3389/fmars.2021.635922

Koelling, J., D. Atamanchuk, J. Karstensen, P. Handmann, and D. W. R. Wallace (2022), Oxygen export to the deep ocean following Labrador Sea Water formation, Biogeosciences, 19, 437–454, https://doi.org/10.5194/bg-19-437-2022.

Pennelly, C., and P. G. Myers (2021), Impact of Different Atmospheric Forcing Sets on Modeling Labrador Sea Water Production, Journal of Geophysical Research: Oceans, 126(2), e2020JC016452, doi: https://doi.org/10.1029/2020JC016452

Rühs, S., E. C. J. Oliver, A. Biastoch, C. W. Böning, M. Dowd, K. Getzlaff, T. Martin, and P. G. Myers (2021), Changing Spatial Patterns of Deep Convection in the Subpolar North Atlantic, Journal of Geophysical Research: Oceans, 126(7), e2021JC017245, doi: https://doi.org/10.1029/2021JC017245

Smith, G.C., Y. Liu, M. Benkiran, K. Chikhar, D. Surcel Colan, A. A. Gauthier, C. E. Testut, F. Dupont, J. Lei, F. Roy and J. F. Lemieux (2021), The Regional Ice Ocean Prediction System v2: a pan-Canadian ocean analysis system using an online tidal harmonic analysis. Geoscientific Model Development, 14(3), pp.1445-1467, https://doi.org/10.5194/gmd-14-1445-2021

Wang, B., K. Fennel and L. Yu (2021), Can assimilation of satellite observations improve subsurface biological properties in a numerical model? A case study for the Gulf of Mexico, Ocean Science, 17, 1141–1156, https://doi.org/10.5194/os-17-1141-2021

Ph.D./M.Sc. Thesis

Cervania, A. (2021), Isopycnal Shoaling Causes Interannual Variability in Oxygen on Isopycnals in the Subarctic Northeast Pacific, M.Sc. thesis, 64 pp., University of Victoria, http://hdl.handle.net/1828/13441

Izett, R. W. (2021), Improved estimates of net community production in the Subarctic Pacific and Canadian Arctic Ocean using ship-based autonomous measurements and computational approaches. Ph.D. Thesis, 229 pp., University of British Columbia, Vancouver, British Coumbia, https://dx.doi.org/10.14288/1.0398454

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 2021 were impacted by a combination of COVID-19 and vessel availability issues. The primary platform for oceanographic research on the east coast of Canada has been the CCGS Hudson which is almost 60 years old. In 2021, the Hudson availability for operations

was very limited due to repair issues and resulted in a loss of opportunity to deploy Argo floats in the region east of Newfoundland and Labrador. It was announced recently that the Hudson was being decommissioned and it will be approximately 5 years before the replacement vessel goes into service. DFO has committed to find solutions for the gap before the replacement vessel arrives, but at this time the future remains uncertain.

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 2022 and 2023 (if known) and where they might be deployed.

   Argo Canada is committed to deploying additional floats equipped with RBR CTDs. In 2022, our program will be deploying 4 floats and are purchasing an additional 3 floats. The procurement plan for 2023 is not known at this time. We have 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.