Report of the outcome of the comparative study for the deep Argo quality control processing

Ref.: D3.4_V1.0

Date: 25/10/2022

Euro-Argo Research Infrastructure Sustainability and Enhancement Project (EA RISE Project) - 824131

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement no 824131.
Call INFRADEV-03-2018-2019: Individual support to ESFRI and other world-class research infrastructures

Disclaimer:

This Deliverable reflects only the author's views and the European Commission is not responsible for any use that may be made of the information contained therein.

Document Reference

Project	**Euro-Argo RISE - 824131**
Deliverable number	3.4
Deliverable title	Report of the outcome of the comparative study for the deep Argo quality control processing
Description	Report of the most appropriate methods and tools in the quality control of deep Argo floats.
Work Package number	3
Work Package title	Extension to deep ocean
Lead Institute	National Oceanography Centre (British Oceanographic Data Centre)
Lead authors	Kamila Walicka; Brian King; Virginie Thierry, Cecile Cabanes, Pedro Velez, Christine Coatanoan, Giulio Notarstefano, Antonella Gallo, Alberto Gonzalez Santana
Contributors	
Submission date	25 October 2022
Due date	31 October 2022
Comments	
Accepted by	Pedro Velez-Belchi

Document History

Version	Issue Date	Author	Comments
v0.1	28 April 2022	Kamila Walicka; Brian King; Virginie Thierry, Cecile Cabanes, Pedro Velez, Christine Coatanoan, Giulio Notarstefano, Antonella Gallo, Alberto Gonzalez Santana	Outline of the deliverable document
v0.2	23/09/2022	Kamila Walicka	writing an introduction, description of guidelines and recommendations, shared software, described the issue with the SBE sensor calibration, started overall recommendations, started the section with the CPcor values list

v0.3	27/09/2022	Antonella Gallo	contribution to example, and summary
v1.0	20/10/2022	Kamila Walicka	Final deliverable report

EXECUTIVE SUMMARY

This report presents the outcome of the comparative study of the Euro-Argo RISE partners and the international deep Argo for the deep Argo quality control processing. These works led to further clarification and complementation of the existing procedures in real-time and delayed mode calibrations previously identified in the Deliverable report 3.2. The combined efforts of the involved partners resulted in identifying the most up-to-date recommendations, guidelines and also best practices for the quality control analysis.

The newly adapted practices by the DMQC operators in analysing their deep Argo fleet create a great opportunity for collecting and monitoring the values calculated for each float separately compared to those currently recommended by the Deep Argo Team experts. The current findings show some indications of the spread of the compressibility constant value (CPcor) across the various Argo groups. The assessment of monitored values used by operators will be a base to verify whether any additional sensor-by-sensor calibration by SBE is necessary and will help to eventually re-evaluate the new standard Cpcor values.

This report is also highlighting the observed issue of discrepancies related to the procedures and practices made by the manufacturers in the calibration of the conductivity sensors used in the deep Argo floats. These have remarkable implications for the quality and consistency of the measured data by the sensor.

This project contributed to developing a shared repository with Matlab software helping the DMQC operator to estimate their optimised CPcor value, necessary for the most appropriate estimates of the salinity corrections due to a bias resulting from the conductivity cell compressibility with increased pressure. Moreover, the European partners shared additional software on GitHub to help other DMQC operators in the process of applying the CPcor corrections and suggested salinity corrections from the OWC analysis to the Argo float data and generating the NetCDF files. The European partners lead the initiative of collections of DMQC analysis report examples and share them on the GitHub repository to support and better familiarise the operators with the decision-making process.

The key identified recommendations to all European and international partners regarding the deep Argo mission are a need for: continuously monitoring the recommended fleet average CPcor value to ensure the best estimate of this parameter; performing a shipboard CTD cast at float deployment to allow CPcor estimates for the float deployed and DMQC analysis of deep Argo floats; regular submit the CTD-ship base data to Ifremer to sustain a high quality of reference data for the DMQC analysis, encourage the manufacturer to perform in-facility pressure calibrations for conductivity sensor to avoid bias in collected data; encourage, at the European level, to have a reference laboratory for pressure calibrations in the salty water of the conductivity sensor that allows us to monitor the network and avoid bias in the observations; continue to use the currently available tools and methods for deep Argo DMQC analysis; and continue to improve the overall consistency of DMQC procedures and skills across the DMQC operators thought the regular workshops and training.

TABLE OF CONTENT

1. Introduction

This report aims to state the appropriateness of the existing delayed mode quality control (DMQC) methods for the deep Argo extension and highlight any necessary requirements needed to enhance this method to the deep Argo extension. Additionally, this report contributes to creating a framework for collaboration in the development of the deep DMQC.

Among others, deep Argo salinity data are affected by a bias resulting from the conductivity cell compressibility with increased pressure. This bias can be corrected by applying a correction to the compressibility constant term (CPcor) used to calculate the salinity from the conductivity collected by the deep CTD sensors. However, the initial overestimation of the CPcor constant value suggested and implemented by the Sea-Bird factory to correct this issue was underestimated and often led to a fresh bias at depth (Kobayashi et al., 2021). To reduce the effect of this bias the new CPcor value needs to be changed from the default value. The key challenge is, however, to establish a procedure and obtain the most appropriate CPcor value, as well as understand the need to modify the CPcor values for different floats.

The review of the existing methods and tools used to adjust salinity from deep Argo floats with Sea-Bird CTDs (Euro-Argo RISE Deliverable 3.2) reveals a lack of uniform approach in procedures and calculations across the international community. Furthermore, the Deliverable 3.2 report strongly enhanced an understanding of the state of development and practice in deep Argo floats and revealed a direction for further investigations and needs. When the D3.2 report was written, the method to estimate the most appropriate CPcor value was still under investigation for Argo data in real-time (RT). The international deep Argo operators favoured the use of the CPcor value suggested by Sea-Bird (SBE) (-13.5×10^{-8} $dbar^{-1}$). The common tool used for DMQC of salinity data was the OWC software, which is currently used for the core Argo DMQC analysis. Some DMQC operators have used the standard core distribution of CTD reference data. Other groups used ship-based CTD profiles collected at float deployments, however, such profiles are not available for all floats. The key aspect which needed to be addressed was to establish the most appropriate value of the CPcor, agree on the best practices in DMQC analysis of deep Argo data (mapping scales for specific regions, interpreting estimates of salinity drift, agreeing on the thresholds in applying salinity corrections) including upskilling the DMQC Argo operators with the new procedures and practices.

This report provides the most updated state of the current recommendations and guidelines to perform the RT and DMQC of the deep Argo floats data agreed upon at the Argo Steering Team meeting by the deep Argo community. Moreover, it also highlights the best practices to follow by the DMQC operators in analysing the deep Argo data. The report gives an overview of the shared tools for the estimation of the optimised CPcor value and implementing a shared repository for the DMQC examples. Some examples are also included in this report. The final part of the report includes a summary of limitations and future recommendations related to the quality control of the deep Argo floats.

2. Current recommendations and guidelines for deep Argo processing

The recent works undertaken by the Euro-Argo RISE partners in collaboration with the international deep Argo community strongly enhanced the deep Argo quality control procedures for both RT and DM data. The detailed recommendations and guidelines currently agreed on are published in the Argo quality control manual for CTD and trajectory data (Wong et al., 2022, sections 2.6 and 3.10). The delayed-mode groups who are working with Deep Argo floats are advised to start implementing these delayed-mode procedures for DMQC analysis of Deep Argo floats.

The key aspects for RT data processing for deep Argo data are:
It has been agreed that the salinity data from deep Argo profiles with SBE CTDs needs to be adjusted in RT to remove the pressure-dependent salinity bias. The bias can be corrected by using the new CPcor value to correct conductivity. The corrected data will have the real-time ‘A’ (adjusted) mode. The community agreed on the most appropriate values for the new CPcor value for SBE-61 and SBE-41Cp, respectively. The recommendation is to use in the calculations the
CPcor_new = –12.5e–8 dbar–1 for SBE-61 data and
CPcor_new = –13.5e–8 dbar–1 for Deep SBE-41CP data.

Another agreement has been made to estimate the ‘A’ mode adjusted error and QC flags. These are as follows
PRES_ADJUSTED_ERROR = (2.5/6000) * PRES + 2.
PRES_ADJUSTED_QC = '2' below 2000 dbar, if all rtqc tests are passed.

TEMP_ADJUSTED_ERROR = 0.002°C.
TEMP_ADJUSTED_QC = '2' below 2000 dbar, if all rtqc tests are passed.

PSAL_ADJUSTED_ERROR = 0.004.
PSAL_ADJUSTED_QC = '2' below 2000 dbar, if all rtqc tests are passed.

The delayed mode guidelines and recommendations are as follows.
Similar to the RT workflow, the re-calculation of the salinity data needs to be made using the new recommended standard CPcor values specific for the type of SBE sensor (CPcor_new as in RT).

Eventually, in DM if other more refined estimates are available the operator may also use them instead. The more refined CPcor estimate can be obtained by comparing it with synonymous available deep reference CTD casts. The more refined estimates should only be applied if they are robust and provide better results than the recommended standard values. The software enables the estimates of the optimised (refined) value described in section 3. It has been agreed that the refined estimates of CPcor_new should lie within the limits: –20e–08 dbar–1 <= CPcor_new <= –5e–08 dbar–1.

After the pressure dependency in salinity is adjusted, a time-varying correction of salinity based on a comparison with climatological data can be applied in the OWC method (Owens and Wong, 2009; Cabanes et al., 2016). The Deep-Argo expected uncertainty for salinity (after CPcor adjustment) is

0.004. Hence evaluation of salinity sensor drift should be done at the 0.004 level, and not the usual 0.01 level for the core Argo floats.

The climatological data used for this analysis represent a collection of high-quality ship-based CTD (Katsumata K., 2022).

In DM error and QC flags for deep Argo floats parameters are as follows
PRES_ADJUSTED_ERROR = (2.5/6000) * PRES + 2.
PRES_ADJUSTED_QC ='1' below 2000 dbar, if no error is found.

TEMP_ADJUSTED_ERROR = 0.002°C.
TEMP_ADJUSTED_QC = '1' below 2000 dbar, if no error is found.

PSAL_ADJUSTED_ERROR = minimum 0.004. However, the DMQC operators should consider increasing this error in case of sensor drift adjustment, to take into account possible pressure dependency of the sensor drift that cannot be detected with certainty.
PSAL_ADJUSTED_QC = '1' below 2000 dbar, if no error is found.

3. Software with shared codes and repositories

The Euro-Argo RISE partners have collaboratively developed a Matlab routine for the estimation of the refined CPcor value for a float in DMQC. This method is based on the comparison of a Deep-Argo profile to a reference profile (e.g. deployment CTD casts). The code is available in the shared GitHub repository of Argo DMQC codes and can be downloaded from DM_CPcor. That refined CPcor value can be used in delayed mode to correct a pressure-dependent salinity bias for the Deep Argo floats.

The shared software which can be used to apply the CPcor parameters to the Argo data in Matlab is available in the Euro-Argo GitHub repository dm_float_deep. This code can be also used to pre-process files to generate OWC input (including the CPcor correction) and further can be used to apply the corrections suggested by the OWC software and generate NetCDF D-mode files for deep floats.

The OWC software used to calculate a time-varying correction of salinity based on a comparison with climatological data is available in both Matlab (matlab_owc) and Python (argodmqc_owc) versions. These tools have been traditionally used for the DMQC analysis of core Argo parameters, however, they can be also successfully used for DMQC of deep Argo floats.

Additional software available on GitHub for DMQC operators is the Deep_CTD_selection. This code allows the selection of specific profiles in the CTD reference data set to be deeper than a set pressure level. This functionality allows the operator to avoid an automatic selection of the theta levels made by the OWC software and helps to use a more specific part in the water column for comparison. The code can be easily incorporated into the OWC software as additional functionality.

Additionally, there is a public repository, developed by the Euro-Argo RISE partners that contain DMQC examples that allow less experienced operators in the decision-making process to better understand the best practice in processing the deep Argo floats. The example can be found in the Euro-Argo GitHub repository (dmqc_deep_examples) and DMQC Argo cookbook. All Euro-Argo RISE and international partners are encouraged to submit the examples with DMQC analysis of deep Argo floats of their floats to this repository.

Moreover, we are strongly recommending that all Euro-Argo RISE and international partners use the DMQC discussion repository at the GitHub publicQCforum. This repository has been created to build a knowledge database and create a space for discussion about the Quality Control (QC) of Argo data. This forum is focused on every aspect related to Argo QC. The operators can, for instance, engage with the Argo QC community by posting issues and can share use cases and your expertise with codes (through fork and pull-request) and wiki pages.

4. CPcor estimates

4.1. Best practices

A refined and optimised estimate of CPcor for a float can be obtained in delayed mode by comparing a deep float profile to a reference profile (e.g. deployment CTD casts). However, depending on the variability in the region considered, it may be difficult to estimate an optimal CPcor value, as this estimate may be very sensitive to the reference layer used or outliers. Some good practices are proposed here on how to calculate the optimal CPcor value, in which case it is better to use it instead of the recommended CPcor value provided by the deep Argo team to correct the salinity of deep Argo floats.

Figure 4.1 shows the salinity differences between the first Argo ascending profile and the deployment CTD when using different CPcor values (nominal, optimised and recommended values) for three deep-Arvor floats deployed in the North Atlantic and equipped with an SBE41 sensor.

In example A), the optimised CPcor value is obtained by selecting layers below 2000 db, the differences between the deep Argo profile and the deployment CTD being highly variable in the upper layer. In example B) of Figure 4.1, the first profiles of this float, located above the Reykjanes Ridge, are very short (down to 1200 db) and with large variability, and therefore it is not possible to obtain a reliable estimate of the optimised CPcor in this case.

In both examples A) and B), the CPcor value used to correct salinity is the one recommended by the deep Argo team for SBE41 sensors, i.e. -13.5 e-08. Indeed, in example A), the recommended value is close to the optimised value and using the optimised value does not show a significant improvement (i.e slope reduction). In example B), due to the short profile, we do not have a reliable estimate of the optimised value, so the recommended value was applied.

Example C) is a case where we did not apply the recommended CPcor value. The optimised value (-11.58e-08) is obtained by selecting layers under 1500 db. Under 1500 db the comparison between the argo profile and the deployed CTD is sufficiently smooth so that it is possible to clearly see a change in slope when changing the CPcor value. When we apply the recommended CPcor value (-13.5e-08), we introduce a positive slope and a salty bias of about 0.004 at 4000 db (green curve).

However, when we apply the optimised value of CPcor (-11.58e-08), the slope is no longer visible and the bias is very close to zero at 4000 db (red curve). It is therefore the optimised CPcor value that we have chosen to apply.

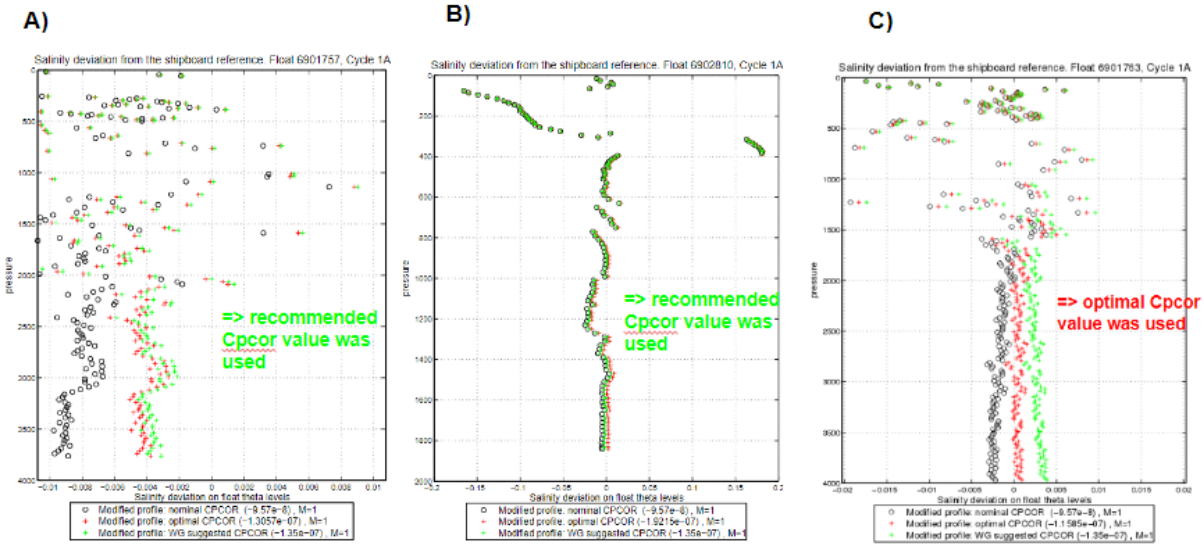


Figure 4.1: Salinity differences between the first Argo ascending profile and the deployment CTD when using different CPcor values: the nominal CPcor value -9.57e-08 (black circles), the optimised CPcor value (red circles) and the recommended new CPcor value for SBE41, -13.5e-08 (green circles). Salinity differences are computed on float theta levels. Example A) is for float 6091757, example B) is for float 6902810 and example C) is for float 6901763.

Some good practices can be drawn from the experience of Euro-Argo RISE partners that have been summarised in the previous examples:

- It is recommended to compute the optimised CPcor value over a vertical layer as thick as possible while removing the outliers and the layers with large variability before doing the optimization.
- Most of the time, it is best to use the recommended value of CPcor to correct the salinity, especially if the comparison with the deployment CTD is too variable or if the first Argo profiles are not deep enough to clearly see a change in slope as CPcor varies. DM operators should try to use different reference depths when calculating the optimal CPcor value. Too much variation in the optimal CPcor value (+/- 0.5 e-08) should lead them to use the recommended value instead.
- The use of the optimal CPcor value should be explained, e.g., if the use of the recommended value clearly degrades the comparison with the deployment CTD (residual slope that disappears when using the optimised value).
- Optimised CPcor values should be monitored (optimal_CPcor_vs_SN) to allow the Deep Argo team to provide updated recommended CPcor values if needed.

4.2. Review the list of the optimal CPcor values

The growing interest and adaptation of the new recommended procedures and guidelines across the deep Argo community allows continuous verification of our current state of knowledge regarding correcting the bias resulting from the conductivity of cell compressibility with increased pressure. The observation of the DMQC analysis performed on deep Argo floats by the Euro-Argo RISE partners identified a notable spread of the CPcor optimised values estimated for each float separately. This value is different across the various groups of the deep Argo community. To better identify this behaviour, the Deep Argo Team experts suggested a need to start recording a rate of spread of this parameter for each float. This investigation is needed to specify if the currently recommended CPcor average value is accurate enough to the CPcor optimized value. In the case where the spread of the CPcor parameter is relatively large then this issue would need to be reported to the SBE. This assessment will be a base to verify whether any additional sensor-by-sensor calibration by SBE is necessary.

Euro-Argo RISE partners took an initiative to create a shared spreadsheet to monitor the CPcor optimised values obtained for each float in DM. The spreadsheet is available at optimal_CPcor_vs_SN and has started to be populated by both the European and international Deep Argo communities. Figure 4.2 shows the collided records of the current list of CPcor optimised values for both SBE41 and SBE61 sensors. The mean CPcor optimised value is -12.43 ± 2.64 e-8 for SBE41 sensors and -11.40 ± 1.25 e-8 for SBE61. We noticed that the mean CPcor optimised value for the oldest SBE41 sensors is a bit smaller and with a larger spread than for more recent SBE41 sensors (-12.96 ± 3.12e-8 for SN<11252 compared to -11.72 ± 1.56 e-8 for SN > 11252, SN=11252 corresponds to some manufacturing changes at SBE, although we do not have precise information from SBE).

These results show that it might be necessary to re-evaluate the new standard CPcor values recommended by the deep-Argo Team as new optimised CPcor values become available. This will ensure obtaining the most appropriate adjustment to the RT and DM salinity data made by DMQC operators which reduces a bias to be on average close to zero allowing their further usage in the research applications.

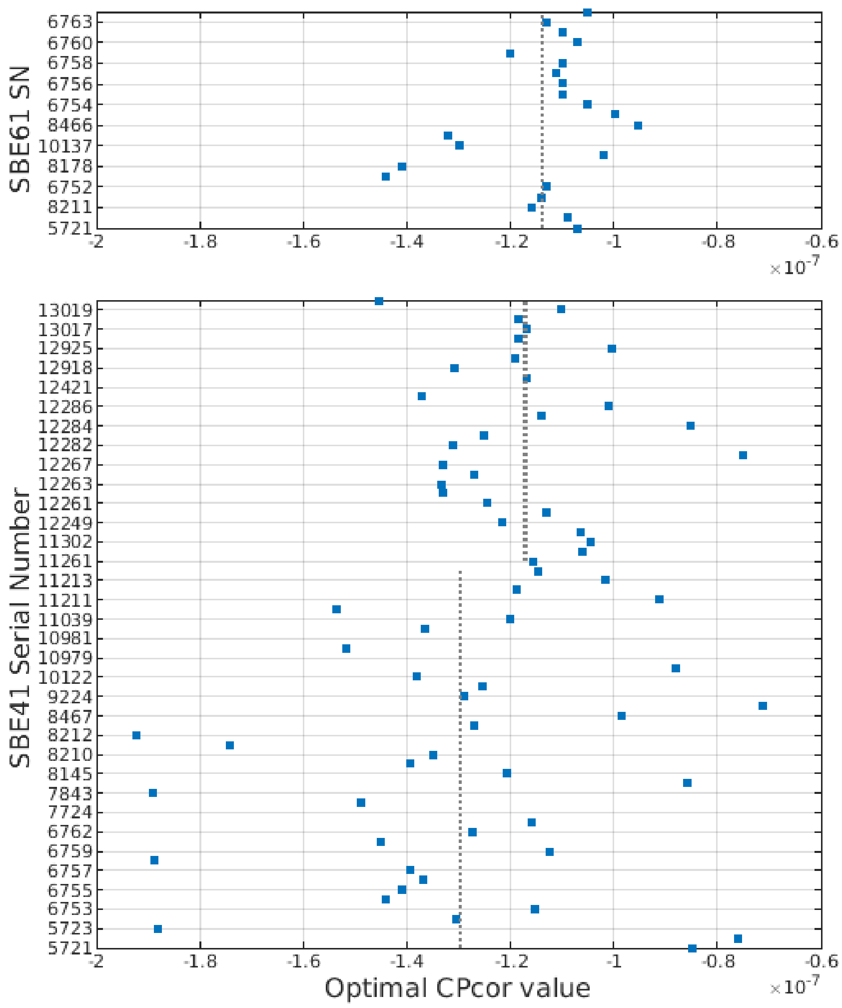


Figure 4.2: Optimal CPcor values (blue squares) obtained by comparing a deep-Argo profile with a reference profile (e.g deployment CTD) for 21 SBE61 sensors (upper panel) and 68 SBE41 sensors (lower panel). Sensor serial numbers in the Y-axis are in ascending order from the oldest sensors to the more recent ones. The black dot lines represent the average CPcor value obtained for different sensor batches (October 2022).

4.3. Need for factor determination of CPcor

After the interaction between the Euro-Argo RISE partners and the main manufacturers of conductivity sensors (RBR and SBE) various procedures and practices observed across the sensor manufacturers were reviewed. It revealed some inconsistencies in the procedures for performing the calibrations of the conductivity sensors. The common practice in the RBR is that the conductivity calibrations are separately performed for each sensor at each float under pressure and with salty waters, as a means to change the conductivity, which allows the calculation of the most appropriate CPcor value for each float. However, SBE is not following this procedure, since the conductivity calibration is carried out at atmospheric pressure and modifying the temperature as a means to modify conductivity. Although SBE is planning to start under pressure calibrations, only for the SBE 61 sensors, but not for SBE 41cp sensors. This discrepancy in procedures of pressure sensor calibrations has significant implications for the quality and consistency of the measured data by sensors delivered by the SBE. The limited intention of calibrating the SBE 41cp by the manufacturer is a very concerning issue, given the impact of inappropriate CPcorr values on the accuracy of the salinity observations since most of the deep Argo fleet is equipped with SBE41cp sensors. The suggested recommendation in this issue is to convince SBE to do pressure calibrations in salty water for all the conductivity sensors which will lead to uniform calibration practices of sensors used in deep Argo floats.

Additionally, we encourage, at the European level, to have a reference laboratory for pressure calibrations in the salty water of the conductivity sensor that allows us to monitor the network and avoid bias in the observations. This will allow the Euro-Argo RISE partners to obtain the highest quality of collected data from all manufacturers, uniform the procedures and best practices for further re-processing of these data and ensure the best practices and methods in the assessment of the quality of the deep Argo data.

5. Examples of DMQC analysis

5.1. SBE 61

North Atlantic

Float 6903719

BODC deployed 23 deep Argo floats. Three of them failed during deployment. 12 deep Argo floats (SBE61) floats have been initially analysed in NOC using their in-house methods. These floats were deployed in the North Atlantic (RAPID 26 N) and the South Atlantic (Argentine Basin). The general behaviour was that few of these floats showed various behaviours of salty drifts. BODC has started performing the DMQC analysis of deep floats following the most recent guidelines (Wong et al., 2022, sections 2.6 and 3.10), however, due to the internal system developments work the d-mode data are not yet distributed to GDAC.

Float 6903719 was deployed in the southwestern Sargasso Sea. The optimised CPcor value (-11.659 e-08 dbar–1) was obtained by comparing the first ascending profile with the deployment CTD (figure 5.1.A). This calculated value is very close to those recommended by the deep-Argo team for SBE 61 floats (–12.5e–8 dbar–1). In this float example, the recommended value shows the smallest deviation from zero and will be further applied to the data. The initial OWC analysis (figure 5.1.B) shows a small fresh offset of around 0.0025. The comparison of the first Argo profile with the CTD casts collected during the float deployment shows a salinity difference of 0.0014. This difference is within the uncertainty of the float and we will not apply any corrections to the salinity data.

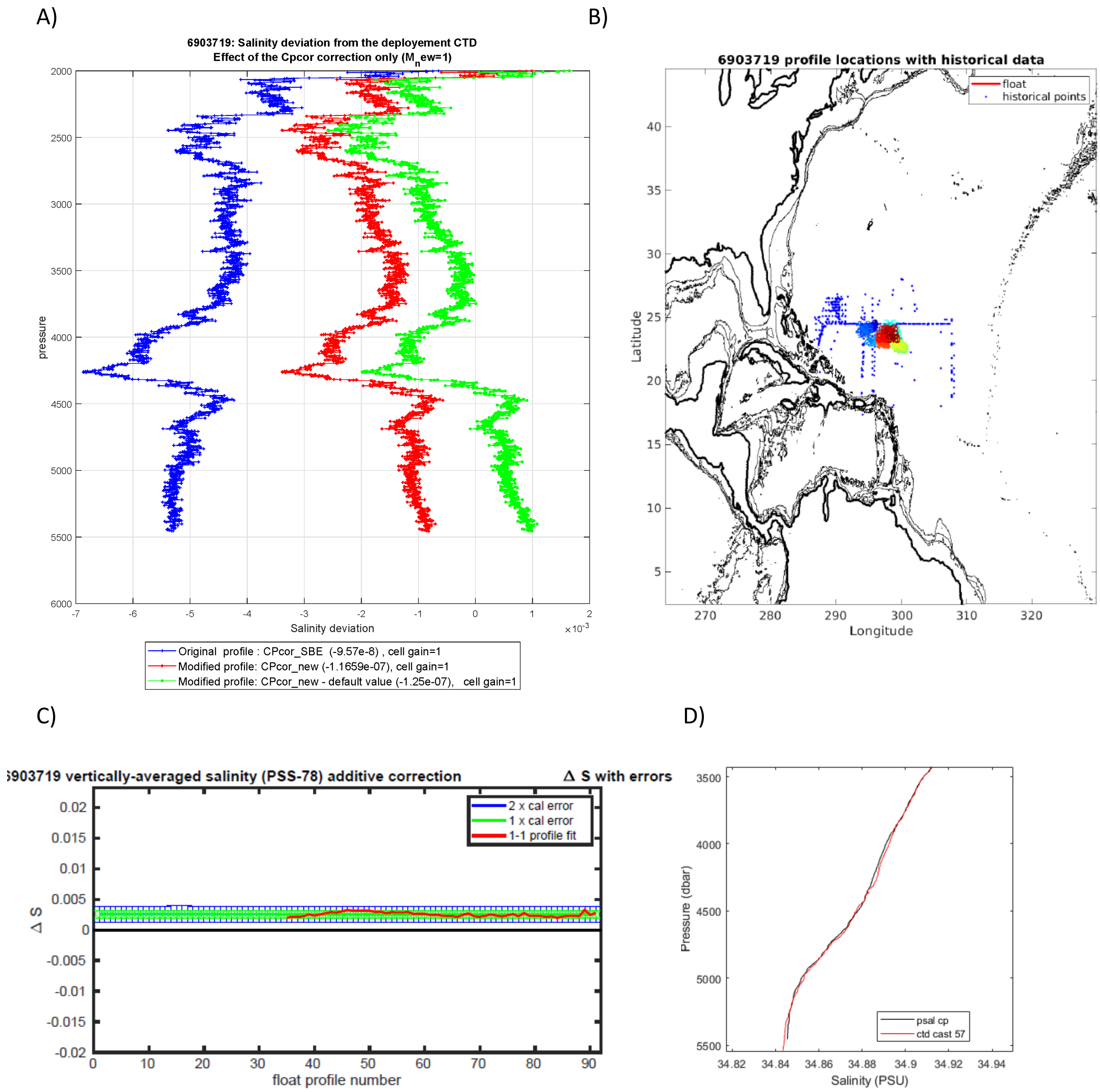


Figure 5.1: Float 6903719. A) Comparison of the salinity of the first ascending Argo profile and the deployment CTD. Three values of CPcor are used: the nominal CPcor value from Sea-Bird (-9.57e-8 dbar–1), the CPcor_new recommended default value obtained by Deep-Argo deep team (–12.5e–8 dbar–1) and the optimised CPcor value obtained by minimising the difference between the argo profile and the reference profile (-11.659 e-08 dbar–1). Results of the OWC analysis for float 6903719. (B) The trajectory of the float (from the blue for the first profile to red for the last profile) and reference data selected for mapping (blue dots). (C) Vertically-averaged mapped salinities minus float salinities with the associated errors (green). D) The first Argo profiles plotted with the CTD cast at the float deployment.

5.2. SBE 41cp

North Atlantic

Float 6901248

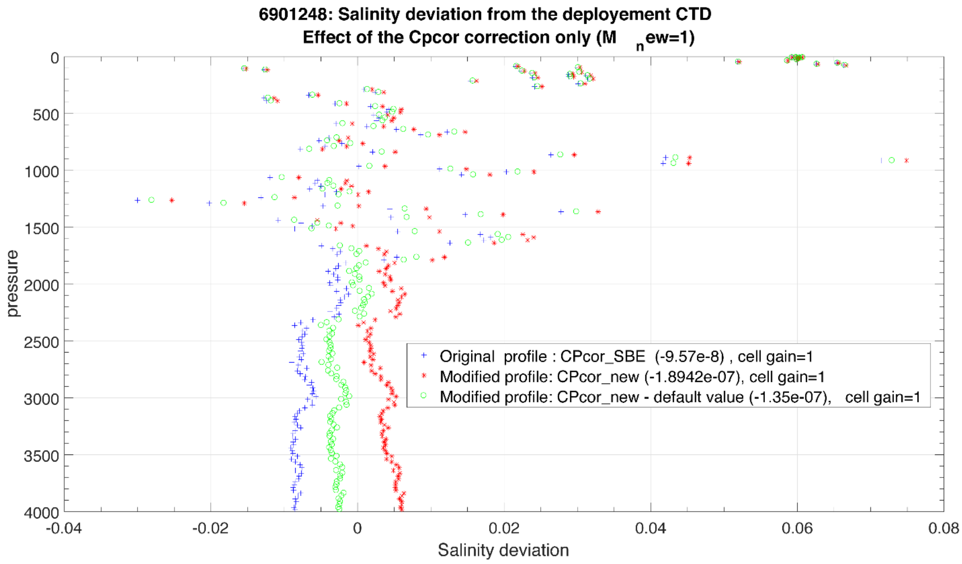
As part of the Deep Argo network, IEO contributed to it with the deployment of four Deep Argo floats, equipped with SBE 41CP, two of them under the contribution of ArgoSpain/EAIMS (6901246 and 6901248) and the remaining two from Euro-Argo (3902126 and 3902127) under the framework of the AtlantOS project. The deployment zones were located on the eastern margin of the subtropical gyre, specifically in the Canary basin (Atlantic Ocean) and in the Galician Bank, where the ocean bathymetry of the area exceeds 4000 m depth. These areas are characterised by a weak interannual temperature and salinity variability in the North Atlantic Central Waters (NACW) and the North Atlantic Deep Waters (NADW). These trends have been recorded over a long-time series of several decades by the IEO through repeated biannual hydrographic surveys.

Float 6901248 was launched on November 1st 2016 and sent its last data on April 27th 2018 after performing 82 cycles. Its basic configuration consisted of a total depth of 4000 m and a parking depth of 3000 m.

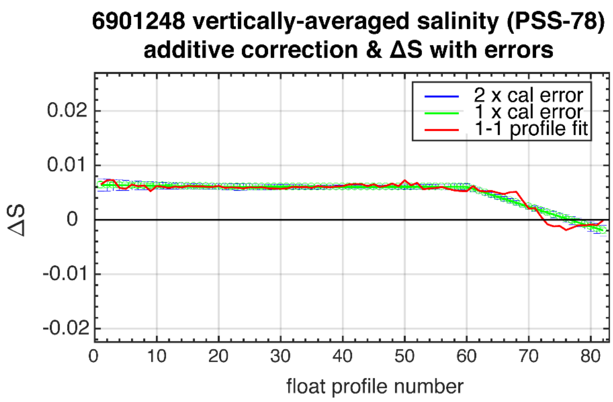
Firstly, the float salinity data were compared to the mapped historical data of the CTD data. After manual evaluation and inspection, an offset of -0.011 in salinity after comparison with CTD cast the at deployment location was detected and corrected. Salinity data was exhaustively inspected through DMQC, taking into account the station CTD cast and the CPcor conductivity adjustment. For the estimation of the latter, the DM_CPcor software was used.

In the analysis, three CPcor values were used: (1) the nominal CPcor value from Sea-Bird (-9.57 e-8 dbar–1), (2) the default value suggested in the Argo manual (–13.5e–8 dbar–1), and (3) the value computed using the CTD cast (-1.89 e-7 dbar–1). The most appropriate estimate was obtained for the default CPcor value suggested in the Argo manual (–13.5e–8 dbar–1) (figure 5.2 A). After the CPcorr correction, the OWC analysis suggested a small drift in salinity data from profile number 1 to profile number 82 (figure 5.2 B). Although the entire signal was affected, the decision was to apply the correction proposed by the OWC method. The calibration was also set to select the CTD historical data deeper than 2000 dbar in order to achieve the best results in terms of the requested accuracy, and based on the regional expertise of the Delayed Mode operator.

A)



B)



C)

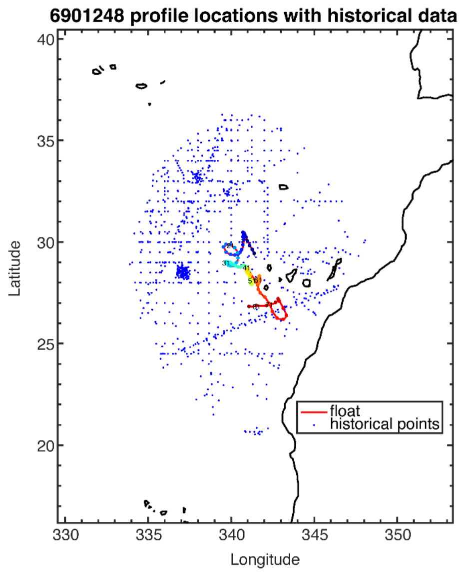


Figure 5.2: Float 6901248. A) Upper panel: Salinity deviation from the CTD due to the CPcor correction using the three values: the nominal CPcor value from Sea-Bird (-9.57e-8 dbar–1), the CPcor_new recommended default value obtained by Deep-Argo deep team (–13.5e-08 dbar–1) and the optimised CPcor value obtained in delayed-mode by comparing a deep float profile to a reference profile (-1.89 e-7). B) Left picture below: Vertically-averaged mapped salinity minus float salinity on the 10 θ levels (red) and the computed offset (green). C) Right picture below: Float trajectory in the study area and the reference data (blue dots).

Float 6903719

So far, 58 deep-Arvor floats have been deployed in the North Atlantic by LOPS and 20 floats have been processed in delayed mode with DM data transmitted to the GDAC.

Float 6902818 was launched during the OVIDE 2018 campaign in the Irminger basin. The results of the DMQC analysis of this float are presented below. The optimised CPcor value (-13.9e-8) was obtained by comparing the first ascending profile with the deployment CTD (Figure 5.3.A). This optimised value is in agreement with the standard CPcor_new value for SBE41 sensors recommended by the deep-Argo team (-13.5e-8), which was therefore applied. Once the CPcor is corrected, a small fresh vertically-uniform bias (-0.004) is still observed for the first ascending profile. The OWC analysis was then run on the salinity after applying the CPcor correction. The reference data used are generally within 5 years of the Argo profiles or even within 1 year when the float is in the vicinity of the OVIDE section. The correction proposed by the OWC run (Figure 5.3.B) shows a salty drift (≈0.037/yr) starting cycle 14. The salinity is slightly biassed fresh cycle 1-14, which is consistent with the deployment CTD comparison. The correction proposed by OWC was then applied.

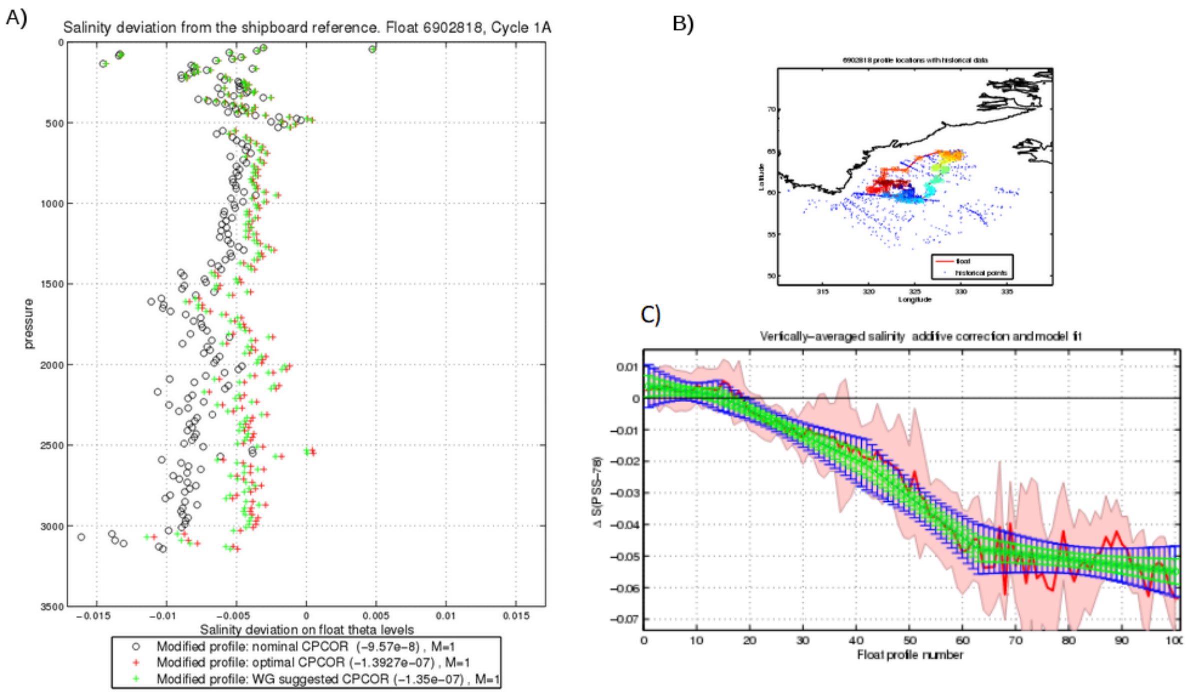


Figure 5.3: Float 6902818. A) Comparison of the salinity of the first ascending Argo profile and the deployment CTD. Three values of CPcor are used: the nominal CPcor value from Sea-Bird (-9.57e-8 dbar–1), the CPcor_new recommended default value obtained by Deep-Argo deep team (–13.5e-08 dbar–1) and the optimised CPcor value obtained by minimising the difference between the argo profile and the reference profile (-13.9 e-08). Results of the OWC analysis for float 6902818. B) The trajectory of the float (from blue for the first profile to red for the last profile) and reference data selected for mapping (blue dots). C) Vertically-averaged mapped salinities minus float salinities on the 10 θ levels (red) and the computed offset (green).

Mediterranean Sea

OGS started to deploy Deep-Argo floats in the Mediterranean Sea in 2016. The six floats were deployed in the Hellenic Trench (Easter Ionian Sea, central Mediterranean Sea) and in the Rhodes Gyre area (Levantine Sea, Eastern Mediterranean Sea) which are two of the deepest regions of this marginal sea. These two regions allow testing Deep-Argo floats (Deep-Arvor model, manufactured by NKE, France) at their maximum sampling depth reaching up to 4000 dbar.

The float 6903203 was deployed in the Ionian Sub-basin within the Hellenic Trench area (figure 5.4) in December 2016 and after 81 cycles it died. Firstly, before applying the DMQC analysis, the best CPcor value needed to be calculated. The estimations of the most appropriate CPcor were made using the suggested DM_CPcor software. Due to the lack of ship-based CTD data collected during the float deployment, the CTD profile selected from the nearest in time and space to the first float profile (left panel in figure 5.4) was used. In the analysis, three CPcor values were analysed: (1) the nominal CPcor value from Sea-Bird (-9.57 e-8 dbar–1), (2) the default value suggested in the Argo manual (–13.5e–8 dbar–1), and (3) the value computed using the nearest ship-based CTD data (-7.1387 e-08 dbar–1). The most appropriate estimate was obtained for the default CPcor value suggested in the Argo manual (–13.5e–8 dbar–1). This choice is justified in that the default CPcor value (–13.5 e–8 dbar–1) shows the smallest deviation from zero (green circles in the right panel of figure 5.4).

A) B)

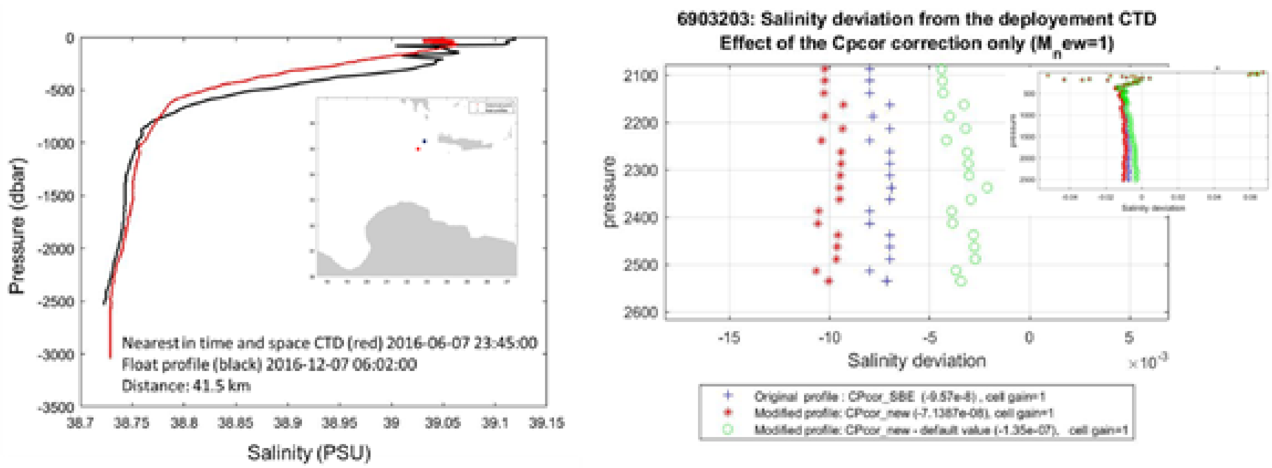


Figure 5.4: Float 6903203. A) The salinity of the first float profile (black line) compared to the nearest in time and space CTD reference profile (red line). B) Salinity deviation from the CTD due to the CPcor correction using the three values: the nominal CPcor value from Sea-Bird (-9.57e-8 dbar–1), the CPcor_new recommended default value obtained by Deep-Argo deep team (–13.5e-08 dbar–1) and the optimised CPcor value obtained in delayed-mode by comparing a deep float profile to a reference profile (-7.1387 e-08).

After applying the most appropriate CPcor correction, the OWC analysis was made (figure 5.5). The OWC configuration has been set to select the CTD historical data deeper than 2000 dbar in order to achieve the best results in terms of the requested accuracy. The reference data used in OWC software analysis are sparse and much older than the float profiles (the maximal difference is 9 years), in particular, in the first part of the float lifetime. The latter is also due to the constraint of the reference data deeper than 2000 dbar, where the dataset is more scarce, however, the water masses characteristics are very stable over time. The OWC correction suggests that the sensor started to drift salty from around cycle 30 by the end of the time series. The correction suggested by the software (up to 0.015) is larger than the deep Argo recommended accuracy (0.004).

The decision made on the salinity data of WMO 6903203 Deep-Argo float was to correct the float in delayed mode from cycles 30 to 81 by applying the correction proposed by the OWC method. The associated error of these data has been set to 0.01 and a QC flag of 1 was applied.

A) B)

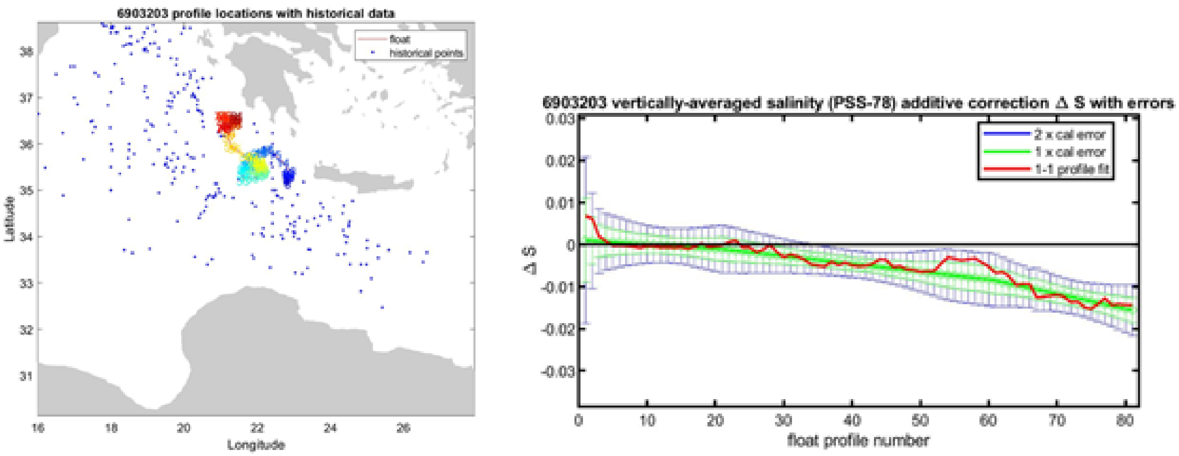


Figure 5.5: Float 6903203. A) The location of the float profiles (red line with coloured numbers) and the mapping reference data (blue dots). B) The time series of the vertically averaged salinity with the associated errors.

Additionally, the float salinity data were compared to the mapped historical data of the CTD data (see report in 6903203_DMQCreport). The observed shift between reference data and Argo float profiles also indicates a salty sensor drift. The systematic vertical shift suggests salinity drift was identified also from the θ-S relationship diagram. The comparison with the historical profiles closest in time and space agreed with the result obtained from the OWC method.

6. Summary

6.1. Estimates of the CPcor value

The DMQC of deep Argo float data relies on the estimate of the CPcor value to reduce the bias resulting from the conductivity cell compressibility with increased pressure. The precise estimates of the CPcor value are crucial to ensure the high quality of deep Argo data. Due to the observed spread of the optimised values of the CPcor values applied by DMQC operators, **the European partners recommend a need to continuously record and review the recommended fleet average CPcor values to obtain the best estimate of this parameter (optimal_CPcor_vs_SN).** This will help to assess the appropriateness of the currently recommended CPcor values and might help to re-evaluate the new standard CPcor values as new optimised CPcor values become available. This will ensure obtaining the most appropriate adjustment to the RT and DM salinity data.

The assessment of the CPcor value in the DMQC analysis is performed using the CTD ship-based reference data. Some groups have made use of ship-based CTD profiles collected at float deployments, but such profiles are not available for all floats. They will not generally be available for Deep Argo due to the limited capacity for undertaking high-quality hydrographic casts on deployment. **We strongly recommend performing a shipboard CTD cast at float deployment to allow CPcor estimates for the float deployed.**

However, the actual need to establish this protocol in order to have a proper estimation of the CPcor values is the lack of pressure calibration of the SBE conductivity sensor. Nowadays, this requirement of pressure calibrations in salty water is technically feasible and some other manufacturers are implementing it routinely. The estimation that the Argo community is doing of the CPcor values is an in-situ calibration using the profiles from the Argo floats and the CTD cast at float deployment. This in-situ calibration is much more expensive than in-facility calibrations since we are using the ship-time and argo floats for it. Additionally, it is not as accurate as in-facility calibrations since it is not possible to evaluate the causes of the difference in the CPcorr values. **We strongly recommend that manufacturers perform in-facility pressure calibrations in the salty water of the conductivity sensor for all the Argo floats. Additionally, we encourage, at the European level, to have a reference laboratory for pressure calibrations in the salty water of the conductivity sensor that allows us to monitor the network and avoid bias in the observations.**

6.2. Disruption in the quality control analysis due to limited reference data

Regular submission of the CTD data from the ship deployment to the CTD reference database for Argo is very crucial for the DMQC analyses which is a key source of data to verify the quality of deep Argo data. Limited availability of the reference data during the DMQC analysis of deep Argo floats may lead to less reliable results obtained from the OWC software because the scarcity of reference data influences the suggested salinity correction. An example of bias resulting from the use of different pressure levels has been observed for float 6903204 deployed in the Mediterranean Sea. In this example, the use of two different ranges of pressure levels in two separate iterations of the software shows significant differences in the suggested corrections from the OWC analysis. This can cause difficulties in the decision-making process for the DMQC operators and therefore the reliability of the results. More detailed results are described in paragraph 2.3 of Deliverable 3.5.

It is strongly recommended to all European partners and the International community to submit the CTD ship-base data to Ifremer to be able to sustain well-updated and high-quality reference data for Argo DMQC analysis.

6.3. Tools and methods used for quality control analysis

The assessment of the tools and methods used for the DMQC analysis of deep Argo floats by operators show that the currently used DM_CPcor and OWC software tools are very suitable for this analysis. This tool allows the DMQC operators to easily use the CTD reference data suitable for the deep Argo floats analysis for some regions. The tested software, developed by the Euro-Argo RISE partners for the calculation of the optimised CPcor value was well adapted by many DMQC operators helping them to estimate the most appropriate CPcor values for their floats. Moreover, the deep DMQC operators usually perform the OWC analysis for core Argo floats with which operators are well acquainted. This reduces the learning curve of the software. **We recommend that the Euro-Argo RISE partners and the entire International deep Argo community continue the use of the mentioned tools in processing their deep float data in D-mode.**

The currently available software to calculate the optimised CPcor value and to apply this value to the Argo data has been developed in Matlab. It would be beneficial for the entire Argo community to adapt these codes in an open-source and free language such as Python.

6.4. Consolidation of quality control procedures and skills

Although there is an overall consistency of the deep Argo DMQC procedures it is necessary to organise regular meetings that ensure the coherence of these procedures and therefore the homogeneity of the uncertainty and accuracy of the observations. This will allow new DMQC operators to adjust their internal software and better adapt to the new procedures of analysis.

International Argo Delayed-mode QC Workshop for CTD data that was planned on 12-15 May 2020 in Liverpool, UK. The meeting was going to cover the review of Deep-Argo QC procedures used by the international deep Argo community. However, this workshop has been postponed due to the COVID-19 situation.

In October 2021 European partners organised the 3rd International Deep argo workshop, organised as part of the EuroSea H2020 EU project. One of the objectives was to review the DMQC strategy and progress on the CPcor estimations. The report from the meeting is available at DeepArgoWorkshop2021-Report.

The support to the DMQC operators in their analysis is a series of *Argo DMQC Discussion* online meetings initiated and led by the CSIRO (ArgoDM-Disc). The Euro-Argo RISE partners have been very active contributors to these meetings by leading the session focused on the deep Argo analysis. During that meeting, there was a very valuable discussion about the CPcor corrections and other matters related to DMQC. Moreover, this virtual discussion helped to promote collaboration between DMQC operators and interested members of the Argo community. This forum gives an opportunity for newer operators to improve their skills and get advice on the concerning and difficult floats, promote a sense of community, and contribute to the adaptation of more consistent DMQC practices.

However, there is still a need for deep Argo DMQC workshops in person to improve the overall consistency of the Argo delayed-mode quality control procedures and operator skills development. All Euro-Argo RISE partners should contribute to this workshop, with the aim of contributing experience to date, and implementing decisions in the European Argo data system.

7. References

Cabanes, C., Thierry, V., & Lagadec, C. (2016). Improvement of bias detection in Argo float conductivity sensors and its application in the North Atlantic. Deep-Sea Research Part I: Oceanographic Research Papers, 114, 128-136.https://doi.org/10.1016/j.dsr.2016.05.007

Katsumata K., Purkey S.G., Cowley R., Sloyan B.M., Diggs S.C, Moore T.S. 2nd, Talley L.D., Swift J.H. (2022). GO-SHIP Easy Ocean: Gridded ship-based hydrographic section of temperature, salinity, and dissolved oxygen. Sci Data. Mar 25;9(1):103. doi: 10.1038/s41597-022-01212-w. PMID: 35338149; PMCID: PMC8956735.

Kobayashi, T. (2021), Salinity bias with negative pressure dependency caused by anisotropic deformation of CTD measuring cell under pressure examined with a dual-cylinder cell model, Deep Sea Research Part I: Oceanographic Research Papers, 167, 103420, doi: https://doi.org/10.1016/j.dsr.2020.103420

Owens, W.B. and A.P.S. Wong, 2009. An improved calibration method for the drift of the conductivity sensor on autonomous CTD profiling floats by Θ -S climatology. Deep-Sea Res. Part I, 56, 450–457. doi:10.1016/j.dsr.2008.09.008

Wong Annie, Keeley Robert, Carval Thierry, Argo Data Management Team (2022). Argo Quality Control Manual for CTD and Trajectory Data. https://doi.org/10.13155/33951