RBR

# Long-term salinity stability assessment of the RBRargo CTD: CSIO float #2902730



## 1 Summary

An analysis of the data collected by the Argo float #2902730, operated by the Chinese Second Institute of Oceanography (CSIO), over the period of January 2018 to May 2019 demonstrated highly stable salinity measurements performed by the RBR*argo* CTD #40528 mounted on the float. Stability was assessed with the *Owens and Wong [2009]* method using World Ocean Atlas as a reference. The analysis showed that the RBRargo salinity had a small bias (<0.006psu), and demonstrated very low drift. These results are substantially smaller than the target accuracy requirements of the Argo program (0.01psu). Further analysis using recent reference data from other nearby Argo floats is ongoing.

## 2 Introduction

The Argo project (http://www.argo.ucsd.edu/) is focused on documenting the current and changing state of the upper ocean, including heat and freshwater storage and transport. At present, it operates the data collected by about 3800 autonomous Lagrangian profiling floats disseminated throughout the World Ocean and measuring temperature and conductivity from a depth of 2000m to the vicinity of the sea surface and transmitting their data via satellite first to the national Argo Data Assembly Centers (DACs) and then to the Argo Global Data Assembly Centers (GDAC).

The target accuracies for Argo measurements were estimated as 5dbar for pressure, 0.005°C for temperature, and 0.01psu for salinity *[Argo Data Management Team, 2017]*. Although pressure and temperature measurements are accurate in most Argo floats, conductivity measurements are often problematic due to biofouling, cell contamination and other technical problems. As recalibration of the float sensors is generally not possible, the drift in salinity is usually checked by an indirect method based on comparison of the salinities from floats with those obtained from climatology or measured by a shipboard high-resolution CTD or other Argo floats.

The international Argo program recommends quality control (QC) for Argo to be done in two steps: 1) “real-time” QC by automatic screening of errors and spikes, etc., and data transmission within 24 h to Argo Global Data Assembly Centers (GDACs); and 2) “delayed-mode” QC (DMQC) performed by the principal investigators (PIs) with more sophisticated procedures and data transmitted to GDACs every 1–2 years. The first step includes conventional QC procedures consisting of a duplication/inversion check for pressure, an impossible value check for position and date, and a range/spike/gradient check for temperature/salinity. The second (DMQC) step is focused on correcting salinity drift using the method developed by Argo team *[Wong et al., 2003; Owens and Wong, 2009; Cabanes et al., 2016]* and implemented in the freely available MATLAB toolbox OW2009 (https://github.com/ArgoDMQC/matlab_owc). It includes 1) objective mapping of available reference salinity data to the potential temperature (θ) surfaces at the float positions; 2) choosing 10 ‘best’ θ levels characterized by minimum salinity variability; and 3) fitting a piece-wise linear temporally varying multiplicative adjustment (correction) to the float potential conductivities.

The major problem in correcting salinity drift is the difficulty in separating sensor drift from water mass change. As such, the performance of the OW2009 calibration depends critically on the reference datasets. This problem is especially serious when recently collected data are analyzed and Argo profiles which passed DMQC are not available. In this study, we analyze Argo float collecting data during 2018-2019 using the World Ocean Atlas *[Garcia et al., 2018]* as a reference. We are currently working to assemble ship-based CTD profiles and Argo data as references.

# 3 Salinity stability analysis

To assess salinity stability from RBRargo CSIO float #2902730, we use a combination of methods implemented in three MATLAB toolboxes:

1. Interactive tool **Argo_ncdf2mat_GUI** performs preliminary visualization of the NetCDF datafile obtained from GDAC and its conversion to the MATLAB ‘.mat’ format compatible with the OW2009 toolbox.
2. Interactive tool **Argo_viewer_GUI** performs visualization of the ‘.mat’ datafile produced by **Argo_ncdf2mat_GUI** and its statistical comparison to reference data extracted from the World Ocean Atlas.
3. The **OW2009** toolbox obtained from Argo program (https://github.com/ArgoDMQC/matlab_owc).

**Argo_ncdf2mat_GUI** and **Argo_viewer_GUI** were written by RBR to expedite the stability assessment. **Argo_viewer_GUI** essentially performs a highly-simplified version of the analysis performed by the **OW2009** toolbox.

## 3.1 Preliminary visualization of CSIO #2902730 dataset and its conversion to OW2009 format

All of the data available for #2902730 was downloaded from an Argo GDAC in late May 2019 using the Matlab toolbox **Argo_ncdf2mat_GUI** [*Argo, 2019*].

The output of the **Argo_ncdf2mat_GUI** tool demonstrated that the analyzed data were collected by Argo float #2902730 in the Philippine Sea during the period of 12 January 2018 to 26 May 2019 (Figure 1).

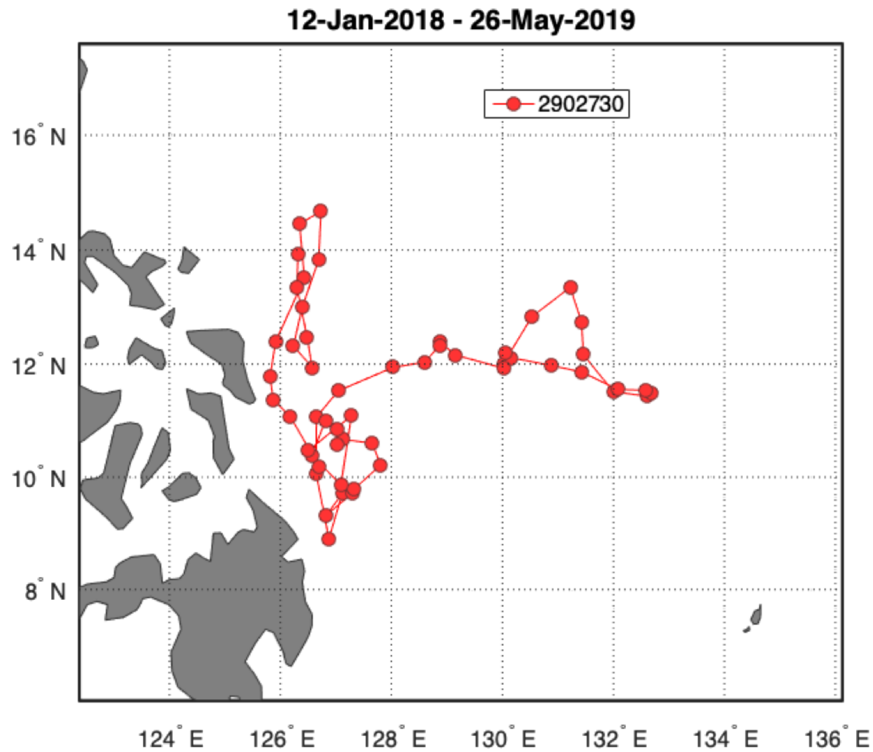


Fig. 1 Trajectory of float #2902730 over the study period, 12 January 2018 to 26 May 2019.

The float metadata indicates that the third-order correction developed by RBR to compensate for pressure effects on conductivity measurements *[RBR Ltd., 2018]* has been applied. Only 103 of 31853 (0.32%) of salinity observations contained 'missing value' code (NaN). All salinity measurements had QC flag '3' following the Test 24 of the Argo Quality Control Manual, Section 2.7. 'Interim Real-time Quality Control Flag Scheme for RBR CTD data' *[Wong et al., 2019]*.

## 3.2 Assessment of stability of RBR*argo* CSIO #2902730 salinity vs. World Ocean Atlas using Argo_viewer_GUI

First, we use RBR's interactive tool **Argo_viewer_GUI** to assess the stability of salinity measured by the SIO RBR*argo*, WMO ID #2902730. The first step in the analysis is the selection of ten potential temperature values on which to evaluate salinity stability. The potential temperature levels are selected algorithmically as those with the lowest salinity variance.

Figure 2 demonstrates that salinity in the 1000–2000dbar layer varied in the range of 34.53–34.65psu. Ten potential temperature (θ) levels with minimum salinity variability were selected using the method described in *Owens and Wong [2009]* (Table 1).

**Table 1. Ten levels of potential temperature with minimum salinity variability selected for salinity drift assessment using the Owens and Wong [2009] method.**

| Potential temperature (°C) | Averaged pressure (dbar) | Salinity variance (psu) |
|---|---|---|
| 3.42 | 1251.4 | 6.452e-06 |
| 3.28 | 1301.4 | 7.485e-06 |
| 3.14 | 1351.4 | 7.127e-06 |
| 2.91 | 1451.4 | 6.444e-06 |
| 2.80 | 1501.4 | 6.112e-06 |
| 2.44 | 1701.4 | 7.283e-06 |
| 2.36 | 1751.4 | 6.255e-06 |
| 2.29 | 1801.4 | 5.819e-06 |
| 2.10 | 1951.4 | 6.946e-06 |
| 2.06 | 2001.4 | 5.831e-06 |

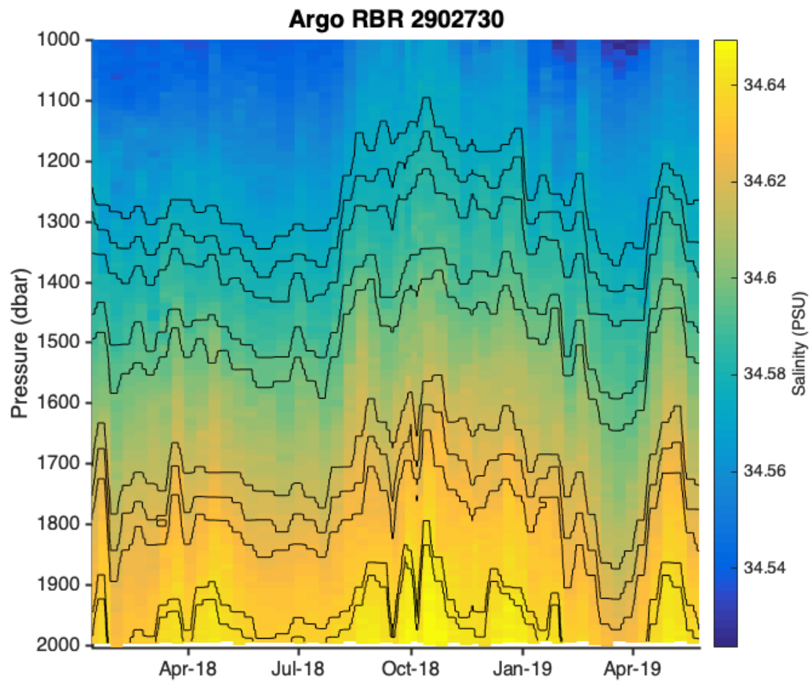


Fig. 2 Salinity observed by the CSIO #2902730 float in the 1000–2000dbar layer. Black lines indicate the depths of the ten levels of potential temperature (θ) with minimum salinity variations selected by OW2009 for salinity drift assessment.

Figure 3 is similar to Figure 2, but the vertical axis is potential temperature (θ) rather than pressure.

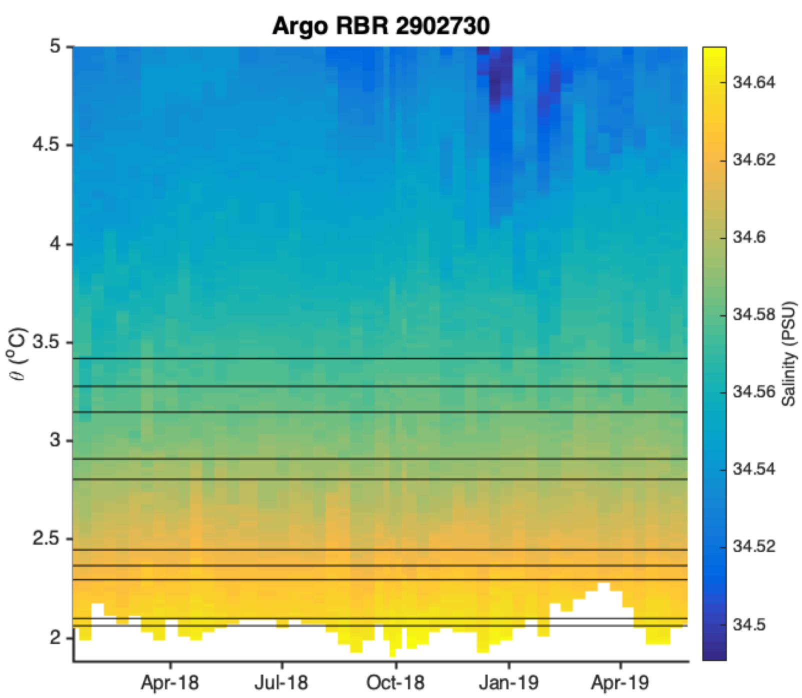


Fig. 3 Salinity observed by the CSIO #2902730 float at the potential temperature (θ) levels. Black horizontal lines denote the ten θ levels by OW2009 for salinity drift assessment.

Figure 4 demonstrates salinity anomalies at potential temperature levels calculated as the difference between salinity profiles observed by the CSIO #2902730 float and the data extracted from the World Ocean Atlas (2005–2017) *[Garcia et al., 2018].*

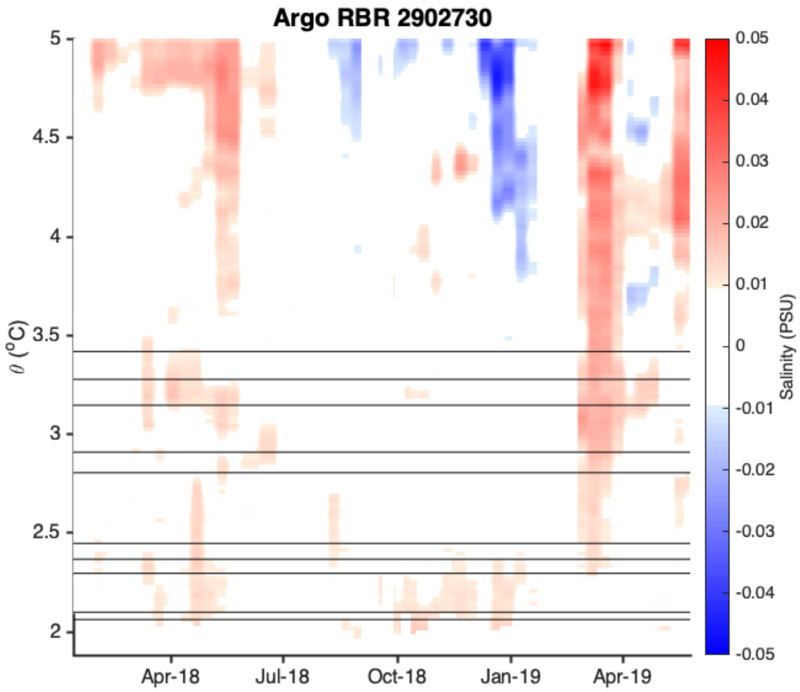


Fig. 4 Salinity anomalies (relative to the World Ocean Atlas) observed by the RBRargo CSIO #2902730 float at the potential temperature (θ) levels. Black lines denote the 10 θ levels selected by OW2009 for salinity drift assessment.

The linear salinity drift rate on each of the ten potential temperature levels is very small (Table 2; Figure 5). The mean linear salinity drift rate, computed by averaging the rates from each of the ten potential temperature levels, is $3.2 \cdot 10^{-7}$ psu/d , which is equal to 0.00012psu/year. The slope of the salinity anomaly trend line is *statistically insignificant* (St.Err. > Estimate; p > 0.05). The averaged bias of salinity is 0.0058psu, which is lower than the Argo target accuracy (0.01psu) *[Argo Data Management Team, 2017].* In short, the drift analysis using RBR's code indicates that the salinity measured by RBR*argo* CSIO #2902730 is both stable (no detectable drift) and accurate (within target Argo accuracy).

**Table 2. The averaged coefficients of linear trend lines fit to salinity measured by RBR*argo* CSIO #2902730 calculated against the data from the World Ocean Atlas.**

| | Estimate | St.Err. | p-value |
|---|---|---|---|
| Bias | 0.00582 | 0.00020 | 5.03e-106 |
| Slope | 3.220e-07 | 1.380e-06 | 0.816 |

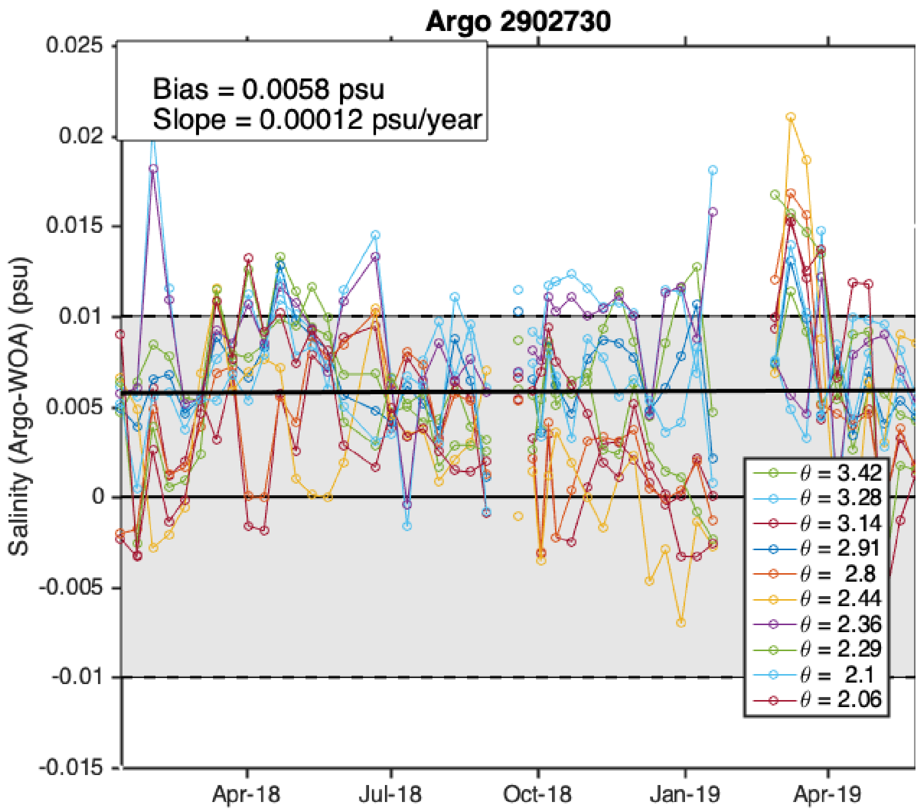


Fig. 5 Salinity difference between RBRargo CSIO #2902730 and the World Ocean Atlas on the 10 levels of θ with minimum salinity variability.

## 3.3 Assessment of stability of CSIO #2902730 salinity vs. World Ocean Atlas using OW2009 toolbox

Analysis of salinity drift of the CSIO #2902730 using the **OW2009** toolbox also revealed no significant drift, which is not surprising given that the reference data were extracted from the same World Ocean Atlas (WOA) *[Garcia et al., 2018]*. Although the *source* of reference data is the same, the reference datasets are not identical. **Argo_viewer_GUI** compared each Argo profile with one (nearest) profile extracted from the WOA, whereas **OW2009** used as reference 300 salinity profiles extracted from WOA of 1° resolution (blue dots in Figure 6) and selected based on the specified values of spatial and temporal decorrelation. Salinities from all these profiles were interpolated to the locations of Argo stations using objective mapping approach.

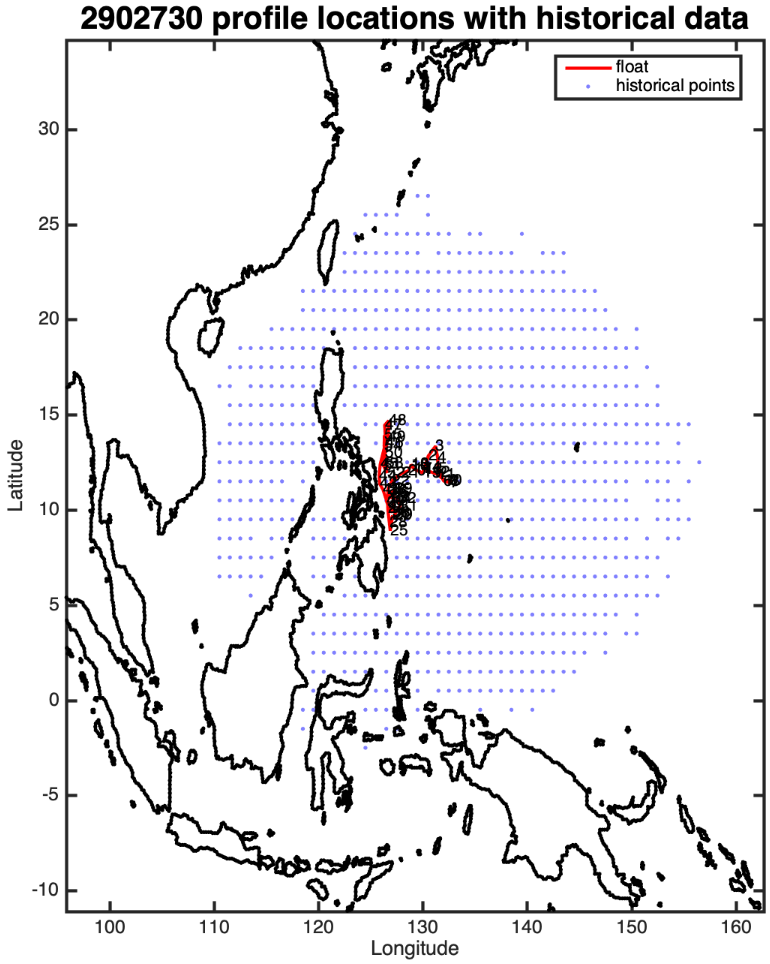


Fig. 6 Output of the OW2009 toolbox: the map of CSIO #2902730 float (12 January 2018–26 May 2019) and the locations of reference stations extracted from the World Ocean Atlas.

Salinity drift was calculated at the same ten potential temperature levels like in **Argo_viewer_GUI** (Figure 7). The potential temperature levels with minimum salinity variability were selected using the same function from the OW2009 toolbox.

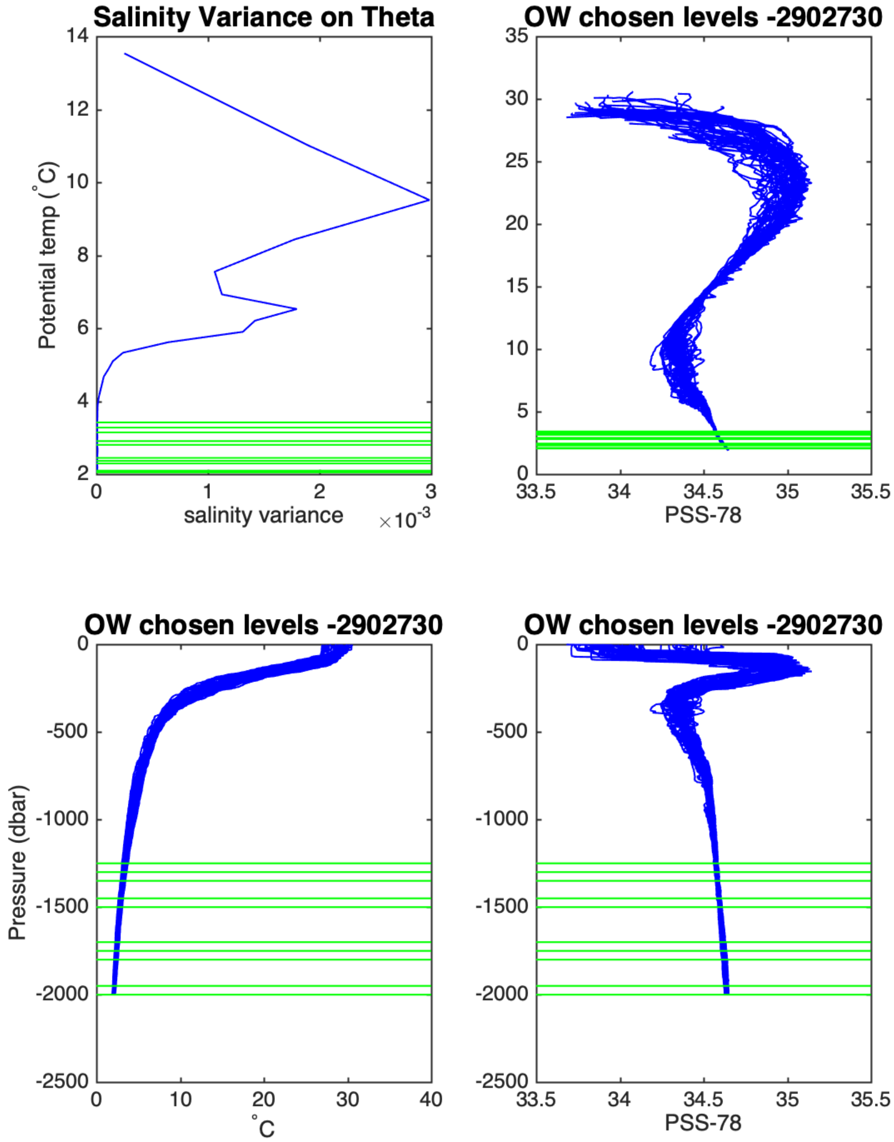


Fig. 7 Output of the OW2009 toolbox: ten potential temperature (θ) reference profiles with minimum salinity variability selected for salinity drift assessment.

OW2009 toolbox calculates salinities corrected for drift (green lines in Figure 8). The authors of OW2009 toolbox use the term ‘calibration’ for this correction process. The statistical assessment of drift in OW2009 demonstrated no significant drift and the correction (‘calibration’) included only a stable multiplicative factor estimated for conductivities calculated from the Argo salinity measurements.

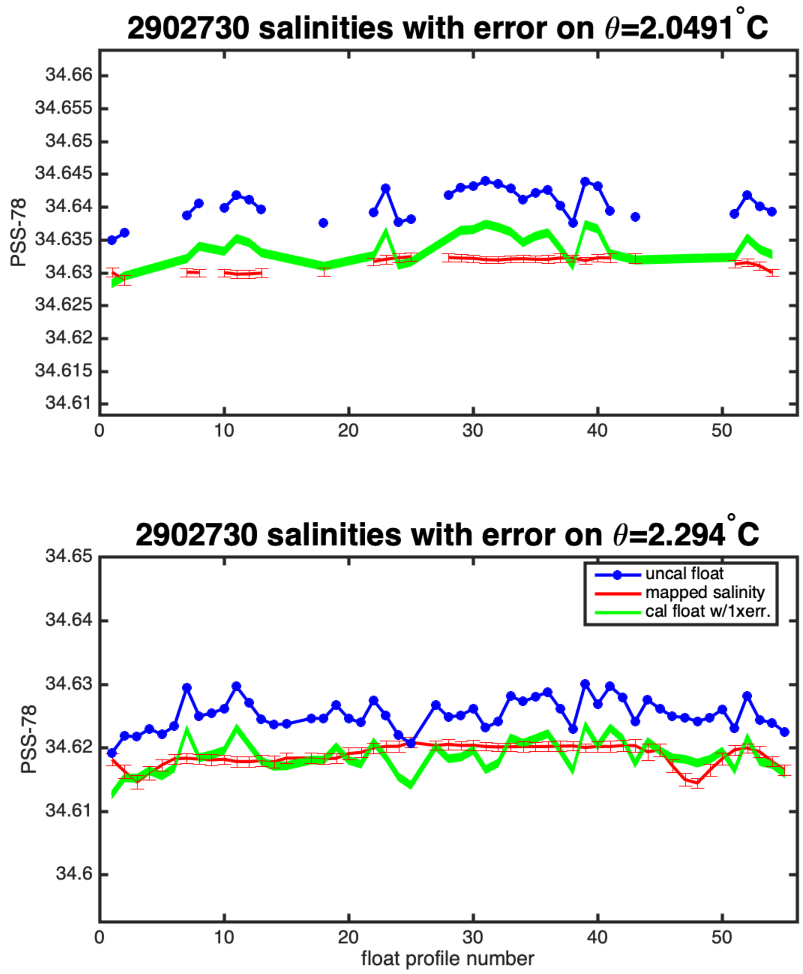


Fig. 8 Output of the OW2009 toolbox: salinity at two potential temperature levels with minimum salinity variability. Blue line is uncalibrated salinity; red line is salinity interpolated using objective mapping from reference profiles; green line is corrected salinity.

# 4 Conclusion

A comparison of the first 18 months of data from CSIO float #2902730 to the World Ocean Atlas indicates that the RBR*argo* CTD salinity is both stable (no detectable drift) and accurate (within target Argo accuracy). A more comprehensive analysis is in progress, and it will include reference data from other Argo floats working simultaneously in the same area.

# 5 Data acknowledgment

These data were collected and made freely available by the International Argo Program and the national programs that contribute to it (http://www.argo.ucsd.edu, http://argo.jcommops.org). The Argo Program is part of the Global Ocean Observing System. https://doi.org/10.17882/42182#64047

# 6 References

Argo (2019). Argo float data and metadata from Global Data Assembly Centre (Argo GDAC) - Snapshot of Argo GDAC of May 8st 2019. SEANOE. https://doi.org/10.17882/42182#64047

Argo Data Management Team (2017). Argo user's manual V3.2. https://doi.org/10.13155/29825

RBR Ltd. (2018). Conductivity pressure correction for the 2000dbar conductivity cell, P/N 0006610 , https://oem.rbr-global.com/floats/0006610

Cabanes, C., V. Thierry, and C. Lagadec, 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, http://dx.doi.org/10.1016/j.dsr.2016.05.007

Garcia H.E., T. Boyer, O.K. Baranova, R.A. Locarnini, A.V. Mishonov, C.R. Paver, J.R. Reagan, D. Seidov, I.V. Smolyar, K.W. Weathers, M.M. Zweng (2018). World Ocean Atlas 2018 (pre-release): Product Documentation. A. Mishonov, Technical Editor.

Owens, W.B., Wong, A.P.S., 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. http://dx.doi.org/10.1016/j.dsr.2008.09.008

Wong, A.P.S., Johnson, G.C. and Owens, W.B., 2003. Delayed-Mode Calibration of Autonomous CTD Profiling Float Salinity Data by θ–S Climatology. Journal of Atmospheric and Oceanic Technology, 20, 308-318.

Wong, A., Keeley, R., Carval, T. and the Argo Data Management Team, (2019). Argo Quality Control Manual for CTD and Trajectory Data. http://dx.doi.org/10.13155/33951

# 7 Revision History

| Date | Revision | Description |
|---|---|---|
| 2019/08/14 | B | Title fixed. |
| 2019/08/02 | A | Initial release. |