

Delayed mode salinity quality control of Southern Ocean
ARGO floats.

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1 Introduction

In 1999, to combat the lack of in-situ data needed to monitor the ocean physics and its role in the global climate change, an innovative scientist program was launched by scientists to greatly improve the collection of observations within the ocean interior with better spatial and temporal coverage. This international program known as ARGO aimed to deploy 3,000 free-drifting profiling floats that measure the temperature and salinity over the upper 2000 m of the ocean, with a regular sampling every 10 days. Today, the program is almost reaching its objective and provides an unprecedented array of subsurface casts of the global ocean, which are freely available.

Argo floats are programmed to drift freely at a preset parking depth. They measure temperature, salinity and pressure profiles during each ascent to the sea surface every 10 days. At the sea surface they send their profile information by satellite, and return to their parking depth. The expected lifetime of a float is about 4 years (about 150 cycles due to battery capacity) during which it receives no maintenance. Therefore it's very difficult to calibrate their CTD (Conductivity-Temperature-Depth) sensor once deployed in the ocean. The ARGO Science Team (2000) have set the ARGO accuracy target to be 5 dbar for pressure, 0.005°C for temperature, and 0.01 psu for salinity. Pressure and temperature sensors are robust enough to reach the accuracy target during the whole float life with only an initial calibration before their deployment. However, the conductivity sensors are much more sensitive and reaching the accuracy target of 0.01 psu is a challenge for scientists. Salinity measurements are subject to drifts and offsets due to biofouling (Freeland, 1997), cell contamination (Oka and Ando, 2004; Oka, 2005), or other technical problems.

Several methods have been attempted to evaluate the performance and correct the errors of the ARGO salinity sensors in the ocean. The only "direct" way is to recover the floats at sea and send them back to the laboratory to directly test their sensors. This method has given valuable results (Oka and Ando, 2004; Oka, 2005) but remains rare and costly, and cannot be generalized to the entire ARGO project due to the difficulty and the expensive cost of the recovery float operation.

Another possibility for calibrating the ARGO salinity measurement is to compare nearby measurements of different random ARGO floats. This has showed good results especially where historical data are rare (Durand and Reverdin, 2005; Bohme and Send, 2005). However, when differences are found it is difficult to affirm which of the floats are providing the "true" salinity (if one is "true"). Nevertheless, if an ARGO float has been calibrated by another technique, this method can then be applied using the calibrated float as the reference.

The more common method is to compare ARGO measurement with nearby shipboard CTD data. The problem is that shipboard CTD are not available around every ARGO profile. That's why a calibration method based on a local climatology are used. Feng and Wijffels (2001) or Kobayashi et al. (2002) have corrected float salinity using nearby CTD casts obtained in the World Ocean Circulation Experiment (WOCE). Wong et al. (2003; hereafter WJO) developed a calibration method that uses an objective mapping based on the World Ocean Database 1998 (WOD98). This method was the first proposed to the ARGO community during the Argo Science Team in 2001 (Argo Science, 2001). After testing the WJO method has been confirmed as effectively having the potential to reach the ARGO salinity target. It has therefore been adopted as the standard method for delayed mode calibration of ARGO salinity sensors at the third ARGO Data Management Meeting in 2002 (Argo Data Management Team, 2002).

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Bohme and Send (2005 ; hereafter BS) found that the WJO method failed in highly variable environments and can be substantially improved in regions where the flow is bathymetrically controlled. For example, their new method, largely based on the WJO method, greatly improves the correction in the North Atlantic Ocean. Their method was presented for the first time to the ARGO community during the 4th meeting of the International ARGO Data Management in 2003 (Argo Data Management Team, 2003). Faced with the great improvement brought by the BS technique, in 2005, the ARGO community charged B.Owens and A.Wong with merging the two methods (WJO and BS) in a new correction product.

This merged correction method is now freely available¹ and provides good correction in the most parts of the world ocean (hereafter this method will be mentioned as BWC). However, the density of the reference database remains a key point of this method (Kobayashi and Minato, 2005). When these algorithms are applied to floats drifting in regions with very sparse historical CTD data such as the Southern Ocean, the existing methods give either large errors or no estimated correction. Errors are also increased when float data are close to strong hydrological fronts such as the Subantarctic Front (SAF) in the Southern Ocean. The SAF is associated with strong changes in hydrological characteristics and water mass structure. Since the salinity algorithms are compared to historical in-situ data within a certain radius (the basic influence bulb) it can choose historic profiles from each side of the SAF and mix them in the objective analysis, resulting in large salinity correction errors (see Figure 1). Since Lagrangian floats often converge towards hydrological fronts, this is a real issue for correcting Southern Ocean ARGO data.

Due to the specific problems in the Southern Ocean, we propose to improve the existing OWC calibration method. Our technique to improve the salinity correction in the Southern Ocean is based on a better choice of historical data profiles. The improvement are made in two ways : 1) by improving the number of historical data profiles available, and 2) by improving the choice of profiles close to the main polar fronts. We will finally test our calibration method on the 30 floats deployed during the FLOSTRAL program.

¹<http://prelude.ocean.washington.edu/references.html>

2 Original calibration algorithm

Since the beginning of the ARGO program the ARGO Data Management Team (ADMT) have promoted the homogenisation of the delayed-mode salinity correction. Wong et al (2003) (hereafter WJO) has provided to the community a robust correction based on statistics and easily adaptable to different region of the world. Thus, it has been being a reference calibration in the ARGO community on which PIs and regional experts have been adding their own algorithms developed more specifically for one part of the globe.

WJO 's algorithm use climatological potential temperature and salinity (θ /S) relationships and their variability to estimate errors on ARGO salinity measurements. Their algorithm can be summarized by several key points :

- Based on the regional hydrography, WJO start by choosing θ -levels which are evenly distributed in the water column.
- The mapping scheme is constrained by a set of spatial decorrelation scales and a temporal decorrelation scale. Anisotropic large spatial scales : L_x and L_y can be introduced, which reflect the regional water mass variability. To include the meso-scale variability of the basin they also define small-spatial scales. The temporal scale is representative of the ventilation time-scale.
- A set of 600 historic profiles are selected from the World Ocean Database (1998) (WOD98) for the mapping. The selection of these best historical points is based on three criteria : that they provide a good representation of the large scale mean around the profile, they include the closest profiles (in a spatial sense) and they include profiles with the best spatial-temporal separation factor relative to the small length scales and the temporal scale.
- At each level, WJO map the salinity from the historical set onto the ARGO float location. The mapping is done in a two-step manner based on Roemmich et al. (1983) and by assuming the covariance of the data to be Gaussian. It provides a first estimate of the mapping by considering the covariance function to be function of the large-scale spatial separation, and the Gaussian decay scale to be determinated by the large spatial scales. In the second stage, the residuals from the first stage are mapped using a covariance function based on the temporal separation and the small-scale spatial separation.
- Finally, they find a unique multiplicative correction for the entire profile by a weighted least square fit to all of the correction at each level. For this last point, they work with the potential conductivity instead of the salinity. This conversion has two great advantages. First, potential conductivity is not affected by pressure, hence all of the conductivity measurements at different level are easily comparable. The second advantage is that an error in salinity is represented by an additive correction, whereas the same error in potential conductivity is translated by a multiplicative correction, hence the problem is easier to solve by considering the potential conductivity.

In most part of the world ocean this method provides good calibration and allow us to reach the accuracy target of 0.01 psu. However, this reference algorithm does not provide well constrained salinities in regions where the water column is weakly stratified, highly variable, or exhibiting multiple temperature inversion. Bohme and Send (2005) (hereafter BS) have then developed an algorithm specifically adapted for these circumstances. Their algorithm is very close to the WJO technique. However, they introduced mainly two big differences :

2 Original calibration algorithm

- First, they change the selection of the θ -levels. In WJO the levels are a-priori chosen by considering the local hydrography. But in a highly variable environment the water mass structure can change, so that the best levels selected at one time can be different from the best levels that should have been selected at another time. BS resolved this problem by automatically selecting 10 “best” depth levels which are based on the float measurement. They then use the potential temperature at those 10 depth levels as the set of θ surfaces.
- They also defined a generalized distance following the idea of Davis (1998). The idea is introduce into the mapping the fact that in a bathymetrically constrained flow, two profiles with a closer planetary vorticity (f/H) are likely to have a more similar water mass structures. Thus they include planetary vorticity as a weighting factor in their covariance function to account for the cross-isobath separation in the bathymetrically constrained flows. This new scale is used in the same way as the spatial scales, hence BS have defined small and large cross-isobath scales.

This method yields strongly reduced errors compared to WJO for the mapped reference salinities in highly variable environments such as the North Atlantic Ocean. As such, this algorithm has quickly became a reference calibration process for ARGO PIs.

Recently Owens, Wong, and Campion (2006) (hereafter OWC) have developed a new algorithm which merge the objective mapping schemes of WJO, BS, and some new features. Potential vorticity has been added as an optional weighting function that can be switched on and off by users depending on which basin they work in. They have also updated the historical database from WOD98 to the WOCE Ocean Database 2001 (WOD01). The total number of reference stations used in the mapping has become variable, input as a user parameter. The selection of the θ -levels is made as in the BS technique. The 10 levels are : the shallowest and deepest P levels (2 levels), the minimum and maximum in θ and S on P levels (4 levels), the minimum θ and S variance on P levels (2 levels), and the minimum P and S variance on θ -levels (2 levels).

Finally, for each float, the correction is adjusted by an optimal piecewise linear fitting looking a-posteriori at the entire correction time-series to find consistent offsets and drifts. The method has been made freely available on <http://prelude.ocean.washington.edu/references.html>. Further details on this algorithm can be found on the same website.

3 Historical data density

The calibration technique developed by B.Owens and A.Wong uses WOD01 for their historical data base, which includes 6646 profiles South of 25°S after processing. Our technique uses the WOCE Southern Ocean Data Base (SODB), which has been quality checked and made freely available by Orsi, A. H., and T. Whitworth III in 2005². This dataset consists of about 93,000 hydrographic (bottle and ctd) stations south of 25S. We have applied to this dataset the same processing steps defined by B.Owens and A.Wong for the WOD2001 data, i.e :

1. We only used casts that sampled deeper than 900 dbar.
2. We weeded out all data points outside these ranges : $24 < S < 40$, $0.01 < P < 9999$, $0.01 < T < 40$, except for profiles located north of 60°N or south of 50°S, where $-2 < T < 40$ was used.
3. We eliminated nearby duplicates, i.e. profiles closer than 1 minute for latitude and longitude and 1 day for time. Stations with the most levels were kept.

After this processing, we have a final total of 31,582 historical profiles South of 25 °S. In addition to increasing the total number of profiles by more than 475 %, we note that the SODB also provides a broader spatial coverage of the Southern Ocean (see [Figure 2](#)).

[Figure 3](#) shows the differences in the corrected salinity when either WOD or SODB is used in the objective analysis. The salinity corrected with the WOD dataset are completely unrealistic and so no correction would be performed. Applying the same correction method but using the SODB historical data provides a more acceptable corrected salinity.

²<http://wocesoa.tamu.edu/>

4 Hydrological front issue

Improving the data density is not enough. Lets consider one profile from cycle 21 of the previous ARGO float (1900042) when it passes through the frontal interleaving region. Even when using the improved SODB database, we see that the automatic choice of selecting historical profiles within the influence bulb around the ARGO profile mixes data from very different water masses (see [Figure 5a](#)). In fact we recognize two different groups of profiles : warm, salty profiles typical from north of the SAF and fresh, cold profiles from south of the front. Since the ARGO profile (cycle 21) is typically from south of the SAF we choose to only select historic profiles from south of the SAF to improve the salinity correction.

How do we detect whether the historic profiles are north or south of a given front ? Sallée et al. (2006) have developed an automatic method to detect time evolution of the SAF positions, using contours of altimetric SSH. This allows us to calculate the distance of the ARGO float position with respect to the SAF localized by their method. This distance is then compared to the temperature at 300m depth from historic profiles (SODB and Argo) sampled during the altimetric years from 1992 to 2005. The two parameters provide a tight relation (see [Figure 4a](#)) and allow us to define a robust criterion to detect whether a profile is north or south of the SAF. This criterion is consistent around the circumpolar path. Hence we divided the Southern Ocean in three areas : (i) North of the SAF where $T_{300m} > 5^{\circ}\text{C}$; (ii) South of SAF where $T_{300m} < 3^{\circ}\text{C}$; and (iii) the “frontal zone” where $3^{\circ}\text{C} \geq T_{300m} \geq 5^{\circ}\text{C}$.

The frontal zone still needs particular processing, and we have added a second criterion for profiles localized in the “frontal zone” region.

Again, we use all of the WOCE historic data available during the altimetric years and localize these data with respect to the SAF, and then calculate a typical T/S profile envelope from south of the SAF, and a typical T/S profile envelope from north of the front (see [Figure 4b](#)). Hence all of the profiles which fall into the “frontal zone” in the first phase are then tested to see whether they lie inside the Southern or the Northern envelope (the envelope is defined by the mean T/S profile plus or minus the standard deviation). If the ARGO profile can't be localized after these two steps we use all of the historic profiles, as in the basic method.

This “front detection” is used as a pre-selection of the historical data in the OWC 's method. We select the best historical casts for the calibration from a subset of historical data that have passed the front criterion step.

An example of the results obtained by adding this step is given in [Figure 5b](#). It shows the selection of historic profiles when we use the two step front criterion method. Clearly for profiles close to the SAF the two-step method provides a better representation of the water mass structure observed by ARGO.

Another striking example of the improvement made by the frontal criterion is given for the float WMO 1900314. This float flows in the Fawn Trough Current, south of the Kuerguelen Plateau, in a very poorly sampled area and near the ACC frontal structure. [Figure 6a](#) show the uncalibrated profile of this float and a OISO/FLOSTRAL CTD profile sampled at the location and date of the

first cycle of the float. There is a net offset between the pack of initial ARGO profiles and the CTD profile. The classical OWC correction with the SAD2001 historical database proposes an unrealistic correction (Figure 6b). The mapped salinities are clearly affected by the lack of data in the region and give absurd results. When applying the same method with the denser database SODB2005, we obtain a much more coherent result (Figure 6c). However the result proposed by this method “spread” the hydrological characteristics in the bottom of the profile (saltiest and coldest part of the profiles). In the bottom of the water column the hydrological characteristics are very stable and we expect to observe the same characteristics for all of the bottom calibrated profiles, as measured by the uncalibrated data. This “spreading” is probably due to a comparison with historical data on the other side of the front. Even without this clue we would reject the proposed correction since it does not match the CTD control profile. We now apply the method with frontal criterion and the SODB2005 historical database. The result in Figure 6d clearly show an improvement of the correction. The stable characteristic at the bottom of the water column is respected and the first cycle perfectly match the WOCE control profile. We consider then to have reached a satisfying correction that detects the offset of the float.

5 FLOSTRAL project floats

We have tested this improved correction method for the 30 floats which were deployed as part of the FLOSTRAL project. The FLOSTRAL project is a french contribution to the ARGO project in the Southern Ocean. 30 PROVOR floats were deployed in 2003 and 2004. The first 20 sensors were FSI sensors with known problems of offset and drift. At the time of the first deployments of the program these problems were unknown. For the second series of deployments the scientific community were aware of the problems and more floats were equipped with SEABIRD sensors.

In this section we list remarks associated with the corrections made for each profile of the FLOSTRAL project. These corrections have been transferred to the CORIOLIS DAC and GDAC center and are thus available as the delayed-mode correction data on their website³. Table 1 summarizes information on these 30 floats. [Figure 7](#) show the trajectories of each float.

WMO 1900123

The calibration method has detected a drift of the salinity sensor. Based on the knowledge of the area sampled we accept this drift as a sensor problem and then accept the calibration of the method.

WMO 1900124

No salinity profile passed the real time test (flag > 2).

WMO 1900125

The calibration method has detected a drift of the salinity sensor. Based on the knowledge of the area sampled we accept this drift as a sensor problem and then accept the calibration of the method.

WMO 1900126

The uncalibrated data are in good agreement with the historical knowledge of the area. We validate the sampled salinity of this float. The associated error is the typical instrumental (FSI) error : 0.01 psu.

WMO 1900127

No salinity profile passed the real time test (flag>2).

³www.coriolis.eu.org

WMO 1900128

The calibration method has detected an offset of approximately 0.1 psu. The proposition of correction is in good agreement with the hydrology of the area. We accepted then the calibration of the method. The associated error is approximately 0.04 psu.

WMO 1900129

The uncalibrated data are in good agreement with the historical knowledge of the area. However, profiles sampled after the 80th cycle are found to be wrong. We keep the original data and flag the profiles after the 80th cycle as wrong (flag 4). The associated error is the typical instrumental (FSI) error : 0.01 psu.

WMO 1900130

No salinity profile passed the real time test (flag>2).

WMO 1900131

Only 7 salinity profiles passed the real time test (flag>2). There is too few data to be able to correct the float with confidence. We don't provide delayed time quality control for this float.

WMO 1900132

No salinity profile passed the real time test (flag>2).

WMO 1900133

The calibration method has detected a drift which is well corrected. Considering the historical data and our knowledge of the sampled basin we considered this drift. We accepted then the calibration of the method. However profiles between the cycle 17 and 20 are very noisy in salinity and have been considered as wrong (flag 4).

WMO 1900224

The calibration method has detected an offset of approximately 0.1 psu. The proposition of correction is in good agreement with the hydrology of the area. We accepted then the calibration of the method. The associated error is approximately 0.03 psu.

WMO 1900312

The uncalibrated data are in good agreement with the historical knowledge of the area. However, some profiles around the cycle 42 are found to be very noisy in salinity. We keep the original data and flag the profiles around the cycle 42 as wrong (flag 4). The associated error is the typical instrumental (FSI) error : 0.01 psu.

WMO 1900313

The uncalibrated data are in good agreement with the historical knowledge of the area. We validate the sampled salinity as good. The associated error is the typical instrumental (FSI) error : 0.01 psu.

WMO 1900314

The calibration method shows an offset and corrects it. The WOCE control profile sampled at the location and date of the first cycle (by the OISO project team) confirm the coherence of the calibration proposed. We accept the calibration proposed by the method.

WMO 1900315

A strong offset is detected by the method. The offset is corrected by the method and has been validated as good by the P.I. who based his analysis on historical knowledge of the basin. However, the first 15 profiles are very noisy in salinity and thus are flagged as wrong data (flag 4). The error associated with the calibration of this float is approximately 0.027 psu.

WMO 1900316

The uncalibrated data are in good agreement with the historical knowledge of the area. No problem have been detected for this float. We validate the sampled salinity. The associated error is the typical instrumental (SEABIRD) error : 0.005 psu.

WMO 1900317

The uncalibrated data are in good agreement with the historical knowledge of the area. The calibration method proposed an offset considered as unreal by the experts of the area. We validate the sampled salinity. The associated error is the typical instrumental (SEABIRD) error : 0.005 psu.

WMO 1900318

The uncalibrated data are in good agreement with the historical knowledge of the area. The profiles show strong noise that have been interpreted as physically meaningful interleaving based

5 FLOSTRAL project floats

on the knowledge of the area. We validate the sampled salinity. The associated error is the typical instrumental (SEABIRD) error : 0.005 psu.

WMO 1900319

The calibration method proposes to correct a small drift in the salinity. This drift have been considered has a physically realistic salinity drift in the ocean based on the studies of Bryden et al. (2003) and Toole and Warren (1993). Thus the drift is not corrected and we validate the sampled salinity. The associated error is the typical instrumental (SEABIRD) error : 0.005 psu.

WMO 1900320-1900324

The uncalibrated data are in good agreement with the historical knowledge of the area. We validate the sampled salinity of these 5 floats. The associated error is the typical instrumental (SEABIRD) error : 0.005 psu.

WMO 1900325

The uncalibrated data are in good agreement with the historical knowledge of the area. We validate the sampled salinity except for the first profile which is extremely noisy. The first profile is flagged as a bad profile (flag 4). The associated error of the other profiles is the typical instrumental (SEABIRD) error : 0.005 psu.

WMO 1900134-1900137

A similar offset have been found in each of these 4 floats that sampled approximately the same area. The uncalibrated profiles show Intermediate Water (IW) at a salinity of approximately 34.3 psu although the historical data show them around a salinity of 34.4 psu. Previous studies (e.g. Toole and Warren, 1993) found also IW at a salinity of 34.4 psu in this area. We also compared this data with another float (WMO 1900321) sampling in the same period of time in the same basin. The uncalibrated profiles of this float have already been validated without any problem raised and show IW at 34.4 psu. This last test puts into question any possible freshening of the IW and give us confidence to correct the offset detected by the calibration method. We accept the correction of the method for each of these float.

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WMO ID	Lat	Lon	Total Profiles (profiles that passes the RT test - qcflag;2)	type of sensor	Controlled by the original algorithm	Controlled by the new algorithm
1900123	-27.7/-25.2	50.7/57.3	63(55)	CTF2	•	•
1900124	-28/-18.4	38.5/54.5	76(0)	CTF2	-	-
1900125	-30.1/-27.3	52.9/60.5	99(47)	CTF2	•	•
1900126	-36.6/-27.9	31.4/52.8	33(28)	CTF2	-	•
1900127	-38.9/-31.3	43.9/53.6	102(0)	CTF2	-	•
1900128	-42.9/-38.2	51.1/70.3	17(11)	CTF2	•	•
1900129	-44.3/-36.9	48.9/63.3	91(85)	CTF2	•	•
1900130	-43/-36.8	53.2/68.8	95(0)	CTF2	-	-
1900131	-47.9/-45.4	60.4/68.2	13(7)	CTF2	-	-
1900132	-44.1/-35.1	76.3/98.9	97(4)	CTF2	-	-
1900133	-41.6/-33.2	73/77.5	109(99)	CTF2	-	•
1900134	-35.9/-26.2	55.6/81.2	52(25)	CTF2	-	•
1900135	-36/-29.8	73.9/81.2	108(28)	CTF2	•	•
1900136	-37.2/-32.8	69.4/89.5	59(29)	CTF2	•	•
1900137	-37.2/-34.5	82/86.9	101(58)	CTF2	-	•
1900224	-33.8/-22.3	34.3/42.8	72(41)	CTF2-3.A	-	•
1900312	-36.9/-32.1	37.6/46.2	72(72)	CTF2-3.A	-	•
1900313	-45.1/-38.4	42.6/60.8	41(41)	CTF2-3.A	-	•
1900314	-57.6/-50.9	62.3/86.8	67(66)	CTF2-3.A	-	•
1900315	-40.8/-36.6	50.6/65.6	66(64)	CTF2-3.A	-	•
1900316	-38.1/-31.7	17.9/62.3	71(67)	CTS2-4.1	-	•
1900317	-37.4/-33.3	59.7/64.5	70(66)	CTS2-4.1	•	•
1900318	-33.2/-26.4	40.8/59.4	71(68)	CTS2-4.1	-	•
1900319	-31/-27.7	54.7/59.4	55(51)	CTS2-4.1	•	•
1900320	-27.3/-24	48.7/57.6	71(68)	CTS2-4.1	-	•
1900321	-46/-35	69.1/119.5	65(65)	CTS2-4.1	-	•
1900322	-39.7/-35.6	67.3/74.1	65(65)	CTS2-4.1	•	•
1900323	-36.7/-29.1	41.3/66.4	57(56)	CTS2-4.1	-	•
1900324	-31.3/-29.7	65/66.9	35(34)	CTS2-4.1	-	•
1900325	-24.5/-21.3	57.2/60.3	65(65)	CTS2-4.1	•	•

TAB. 1 – FLOSTRAL floats

6 Conclusion

These new salinity correction techniques are giving promising results for correcting Southern Ocean ARGO profiles. The technique can also be applied in other regions with strong frontal conditions, as long as reliable frontal criteria can be derived based on the temperature structure. Work is underway to continue validating the technique in different circumpolar regions, with the aim of making the algorithms available for the international community.

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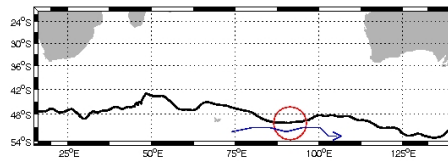


FIG. 1 – Mean position of the SAF in the Southern Indian Ocean (black line) from Sallée et al. (2006). The basic influence bulb (red circle) for a drifting ARGO float (blue line) which is close to the SAF can include historic profiles from either side of the front.

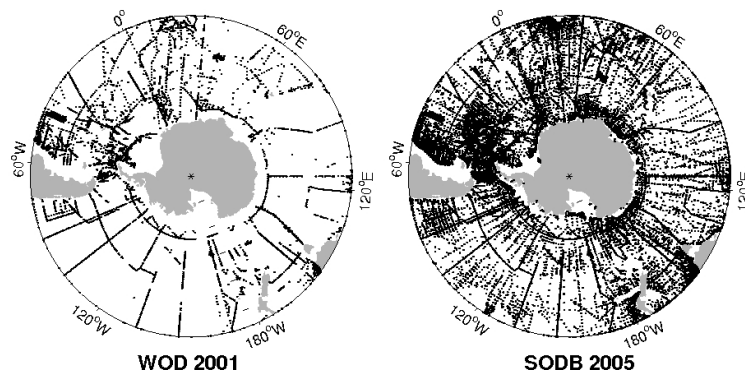


FIG. 2 – Spatial distribution of historical data from WOD2001 (left) and SODB2005 (right) in the Southern Ocean after the same database treatment is applied following Wong et al (2006)

RÉFÉRENCES

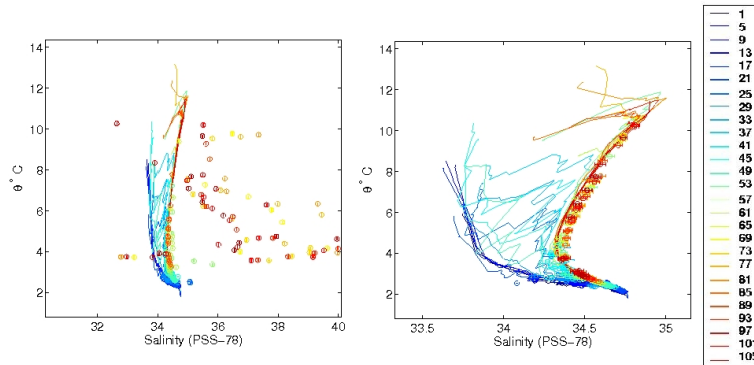


FIG. 3 – Uncalibrated $\theta - S$ profiles for float n° 1900042 (solid lines) compared with the estimated salinity correction from the objective analysis along theta levels for each profile (circles). Left panel : correction based on WOD2001 historical database ; right panel : SODB2005 historical database. The colours show the time evolution from cycle 1 (blue) to cycle 108 (red) three years later. The float starts south of the SAF (cold fresh profiles) and moves north of the front (warm, salty profiles) passing through the frontal region with strong interleaving.

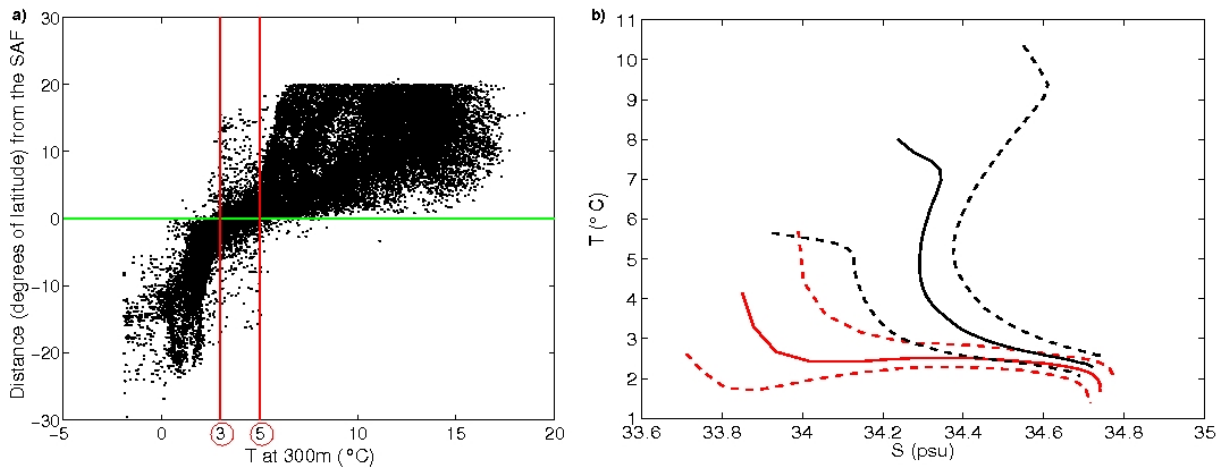


FIG. 4 – (a) Temperature at 300m depth versus the distance from the SAF. Temperature data are from all of the SODB2005 and ARGO profiles available during the altimetric years (1992-2005). The SAF location is found following the Sallée et al. (2006)'s altimetric method. A positive (negative) distance means the profile is north (south) of the SAF.

(b) Mean T/S profile from south of the SAF (solid red line) with its standard deviation (dashed red line) ; mean T/S profile from north of the SAF (solid black line) plus standard deviation (dashed black line), derived from all SODB2005 profiles available during the altimetric years. The SAF location is found following the Sallée et al. (2006) altimetric method.

RÉFÉRENCES

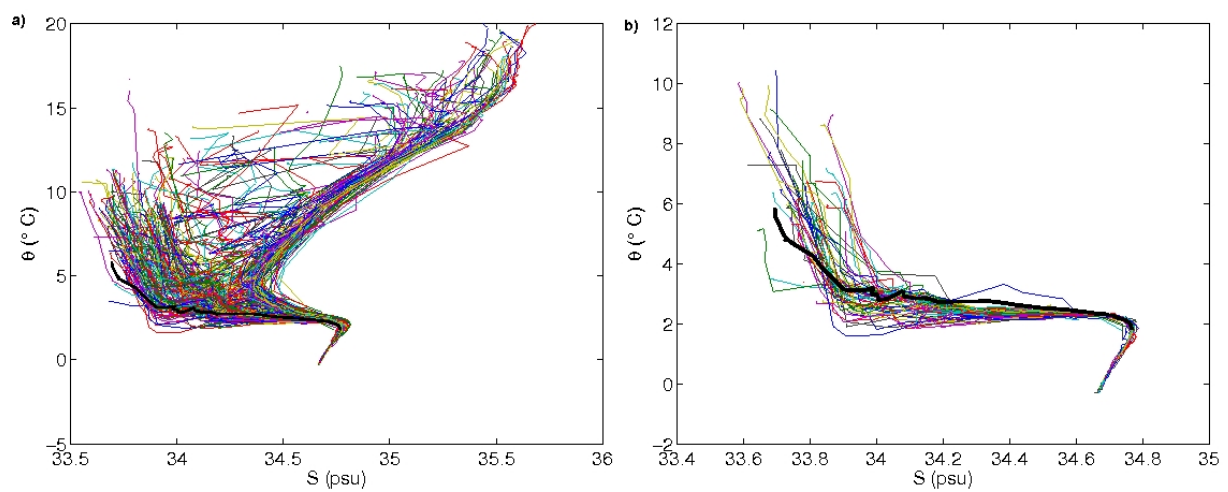


FIG. 5 – Choice of historical profiles used to calibrate cycle 21 of float 1900042. The 21th $\theta - S$ profile sampled by the Argo float 1900042 is superimposed (bold black). (a) SODB2005 historic profiles selected without using the front criterion method. (b) SODB2005 historic profiles selected using the front criterion method

RÉFÉRENCES

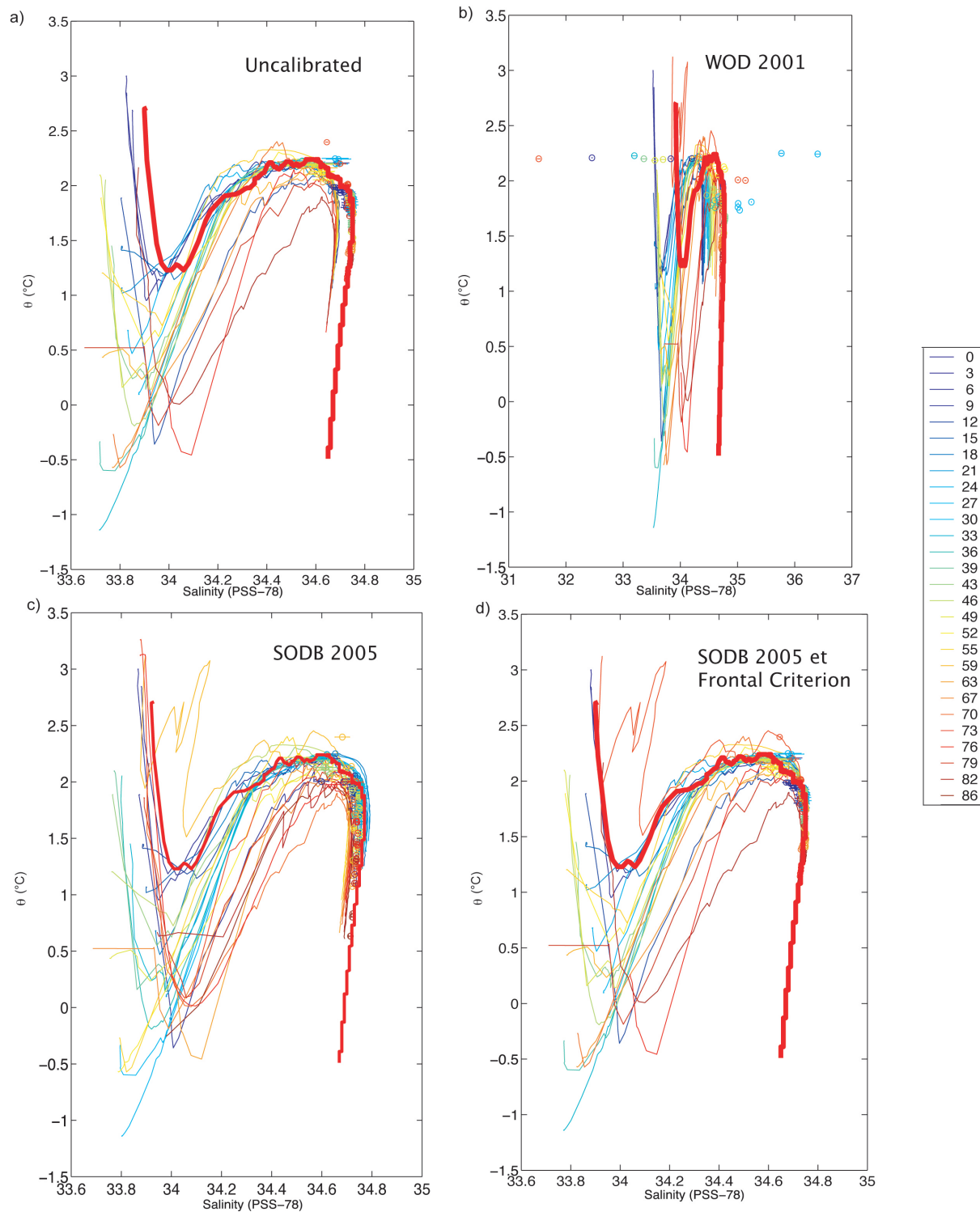


FIG. 6 – θ – S profiles for float n° 1900314 (solid lines) compared with the estimated salinity correction from the objective analysis along theta levels for each profile (circles). The number of cycle of each profile is shown by color. The red bold line represents the CTD profiles sampled at the location and date of the first cycle of the float. **a)** show the uncalibrated profiles. **b)** show the calibrated profiles when using the WOD2001 historical database without the frontal criterion. **c)** show the calibrated profiles when using the SODB2005 historical database without the frontal criterion. **d)** show the calibrated profiles when using the SODB2005 historical database with the frontal criterion.

RÉFÉRENCES

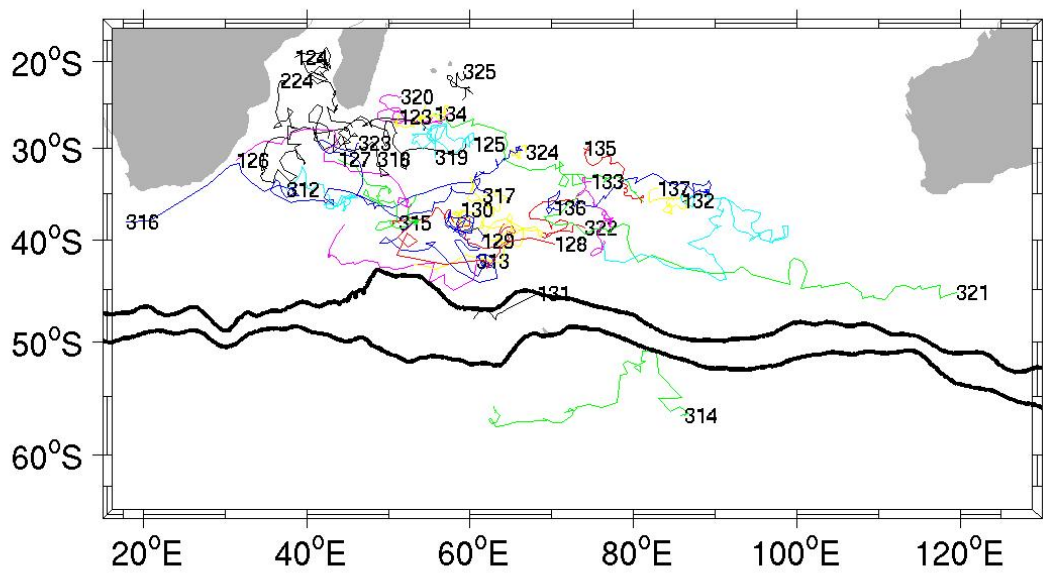


FIG. 7 – Flostral floats trajectories