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Validation of Salinity Data from ARGO Floats: Comparison between the Older ARGO Floats and that of Later Deployments

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Abstract: Continued observation of ARGO floats for years (about 4 years) makes the conductivity sensor more vulnerable to fouling by marine life and associated drift in salinity measurements. In this paper, we address this issue by making use of floats deployed in different years. Floats deployed in the East Sea and the Indian Ocean are examined to find out float-to-float match-ups in such a way that an older float pops up simultaneously with a newer deployment (with tolerable space-time difference). A time difference of less than five days and space difference of less than 100 km are considered for the match-up data sets. For analysis of the salinity drift under the stable water mass, observations of the floats from deepest water masses have been used. From the cross-check of ARGO floats in the East Sea and the Indian Ocean, it is found that there is a systematic drift in the older float compared to later deployments. All drift results, consistently show negative bias indicating the typical nature of drift from fouled sensors. However, the drift is much less than 0.01, the specified accuracy of ARGO program.

Keywords: ARGO float, salinity drift, the East Sea, the Indian Ocean

Introduction

Under the international ARGO program, a pilot project of the Global Ocean and Global Climate Observing Systems, nearly 1500 floats have been deployed globally that each deliver profiles of temperature and salinity between the ocean surface and 2000 m at 10 day intervals. By the year 2006, the total number of floats are expected to reach 3000. The expected accuracies of temperature and salinity from the ARGO floats are 0.005°C and 0.01 psu, respectively (Argo Science Report, 2000). Since it is unattended for years together (4 years), the sensors may get drift during their unattended years in the ocean. Compared to temperature sensor, the conductivity cell is more susceptible to fouling and associated drift because of the possible change in the dimension of the conductivity cell due to fouling.

Among the floats deployed under the ARGO program, there are both electrode type and inductive type of conductivity cells. The general feeling is that the electrode type conductivity cells are more susceptible to micro-fouling compared to inductive type due to poor flushing. However, even in inductive type, the chances of fouling the core area are high to cause change in the inductive fields. Sensor manufacturers have improved the anti-fouling measures with biocide rings and anti-fouling paint (Tri-Butyl Tin Oxide, TBTO). However, since the ARGO floats remain in the waters for years together, it is uncertain about the effectiveness of such anti-fouling measures till the completion of the mission of each floats (~4 years). Therefore, it is too early to rule-out the possibility of sensor drift due to fouling as majority of the floats deployed are yet to complete their half-life span.

Retrieving the deployed floats and re-calibrating the sensors are the appropriate way to know about possible drift. Because of the moving nature of the float, post calibration of the deployed floats on a routine basis is not feasible. However, there are two reports on post-deployment calibrations (Riser and

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Swift, 2003; Oka and Ando, 2004; here-in-after referred as RS and OA). In the study of RS, comparisons of pre-deployment and post-recovery conductivity calibrations for 3 floats equipped with SBE-41 conductivity sensors have shown salinity calibrations to be stable to within 0.006 over periods of 5 months to 3 years. The study of OA shows that out of the three floats recovered after 4 to 9 months deployment, two of them show temperature and salinity calibrations stable within the uncertainties of 0.002°C and 0.004 psu, respectively. The third float consistently reported fresh salinity by 0.02 when compared with other hydrographic data throughout the float mission.

The delayed mode calibration for ARGO CTD data suggested by Wong et al. (2003) is an efficient way to know about the long term drift in the conductivity/salinity. However, the efficiency of this method degrades where climatological data is sparse. Post deployment calibrations can also be done by identifying collocated ship-board CTD observations with the random moving floats as done by Bacon et al. (2001) for PALACE profiling floats.

In the present study, we propose a new approach to know about any possible drift in the float's salinity without doing any post-deployment recovery operations.

Since the floats are passive drifters and they are deployed in different years by batches, there is a likely-hood for a fresh float (conductivity sensor not yet fouled) deployed in later years pops-up simultaneously and collocated with a float deployed in early years (fouled sensors). Salinity comparisons from the observed deeper water masses of such fresh floats (new) with old floats match-ups shall identify the salinity drift in the older deployments.

Old versus New-floats match-ups

The "old" and "new" float concepts are relative to the birth of the ARGO program in the year 2000 and have been adopted considering the four year life span of the floats. Accordingly, a float completed more than one year in water is considered to be old enough to get fouled and float completed less than 3 months are considered too young (new) to get fouled. Since the above criteria on fouling are hypothetical (studies on fouling are limited to shallow waters), in order to make the difference in fouling substantial, a minimum of about 50 cycles difference are is between the old and new floats.

Floats deployed in the East Sea and the Indian Ocean are examined to find out float-to-float match-ups in such a way that an older float pops up simultaneously with a newer deployment (with tolerable space-time difference).

For this purpose, the float trajectory data and meta data available from the date of commencement of the ARGO programs were screened. While screening, first, we kept the time-space tolerance of the match-up data as one day and 10 km, respectively. However, except a few, there were not enough match-up data fulfilling the time-space criteria. Accordingly, we enlarged the screening window and found that a time difference of less than five days and space difference of less than 100 km are reasonable for getting the match-up data sets, considering the fact that such synoptic scale variability (of the order of less than 5 days and 100 km) does not affect the deeper water masses, where the float's salinity comparisons are made. Though the upper limit of the space tolerance is 100 km, for most of the match-ups it is less than 50 km.

Considering that the number of floats deployed in the Indian Ocean is more compared to that from the East Sea, we started the screening of the float trajectories from the Indian Ocean. From the Indian Ocean, we could get only one float match-up data (also, only with one cycle match-up) satisfying the criteria. This could be because of the wide nature of the Indian Ocean basins and of its large gyres. However, from the East Sea, where the basin and gyres are narrow, it is found that there are three match-ups satisfying the old-new float criteria. Therefore, in the present study, the major float match-up data sets are from the East Sea, except

Table 1. Details of the match-up data from the East Sea

Match-up floats 24892/4252									
Date	2002-10-01 2002-10-02	2002-11-05 2002-11-01	2003-01-21 2003-01-20	2003-02-11 2003-02-09	2003-02-18 2003-02-19	2003-04-29 2003-04-30	2003-05-13 2003-05-10	2003-05-20 2003-05-20	2003-06-10 2003-06-09
Lat.	37.035 36.389	37.002 36.17	36.299 35.856	36.245 35.86	36.157 35.938	35.653 35.956	35.866 36.027	35.961 36.085	35.944 36.089
Long.	129.976 130.289	129.934 129.899	130.444 130.503	130.688 130.706	130.69 131.07	130.931 131.269	131.410 131.175	131.404 131.058	131.342 130.899
Match-up floats 24892/4664									
Date	2002-11-05 2002-11-01	2003-01-21 2003-01-20	2003-01-28 2003-01-30	2003-02-11 2003-02-9	2003-02-18 2003-02-19	2003-03-04 2003-03-03	2003-03-18 2003-03-21	2003-06-10 2003-06-09	
Lat.	37.002 36.16	36.299 36.307	36.385 35.974	36.245 36.177	36.157 36.131	36.014 36.011	35.743 36.357	35.944 36.464	
Long.	129.934 129.916	130.444 130.488	130.444 130.792	130.688 130.622	130.69 130.689	130.656 130.705	130.926 131.435	131.342 131.615	
Match-up floats 24892/4684									
Date	2001-10-01 2002-10-02	2002-10-22 2002-10-22	2002-11-05 2002-11-01	2003-01-21 2003-01-20	2003-02-11 2003-02-20	2003-02-18 2003-02-19	2003-03-04 2003-03-01	2003-03-11 2003-03-11	2003-04-29 2003-04-30
Lat.	37.035 36.279	37.193 36.304	37.002 36.16	36.299 36.307	36.245 36.177	36.157 36.131	36.014 36.011	35.889 35.95	35.653 35.778
Long.	129.976 130.185	129.944 130.099	129.934 129.916	130.444 130.488	130.688 130.622	130.69 130.689	130.656 130.705	130.798 130.733	130.931 130.805

Table 2. Details of the match-up data from the Indian Ocean

Match-up Floats 56510/5900043				
Float-ID	Profile	Date	Latitude	Longitude
56510	99	2003-03-03	-14.413	109.783
5900043	2	2003-03-03	-14.888	108.62

the one cycle match-up from the Indian Ocean, which is used in the study only to substantiate the findings from the East Sea. The details of the match-up data sets finally selected from the East Sea and from the Indian Ocean are given in Table 1 and Table 2, respectively. The regions where the match-up data are available are shown in Fig. 1.

The selected float match-up trajectories are shown in Fig. 2. In the East Sea, the three float match-ups are with the same float (24892). The other three floats in the three match-ups are 04252, 04664 and 04684. All of match-up floats are APEX types with SBE-41 conductivity sensors. These ARGO floats in the East Sea were deployed by the Korea Meteorological Administration (KMA) and the Korean Oceanographic Research and Development Institute (KORDI). In the Indian Ocean, the two APEX floats (56510 and 5900043) were deployed by the Commonwealth Scientific and Industrial Research Organization (CSIRO, Australia). Profile-to-profile cycle for the East Sea floats is 7 days, for the CSIRO floats, the profile to profile cycle is 10 days. And the East Sea profiles are limited to maximum depth of 800 m, while the float observations from the Indian Ocean include deep water masses of nearly 2000 m.

Salinity drift estimation

Salinity is derived from conductivity of the sampled volume of sea water based on the following equation.

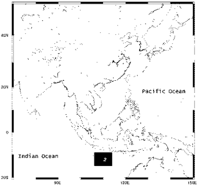

Fig. 1. Regions where the match-up data are available. The red shaded box (1) shows the locations of float 04252, 04664, 04684 and 42892 in the East Sea. The blue shaded box (2) shows the locations of floats 56510 and 5900043.

$$R = \frac{r \cdot l}{A}$$

where, R is resistance, l is sampled volume of sea water, r is resistivity and A is area of cross-section. Since fouling decreases the area of cross-section, A, and increase in R, the result is freshening (less) in salinity. Therefore, older floats, which are affected by fouling should show fresher salinity compared to new floats.

Considering the above aspects, the salinity from new floats is treated as reference salinity and if an older float really get fouled, then the expected result from the comparison with the reference salinity is a negative bias.

The error in salinity was calculated on potential temperature surfaces rather than on pressure surfaces in order to remove the apparent variation in

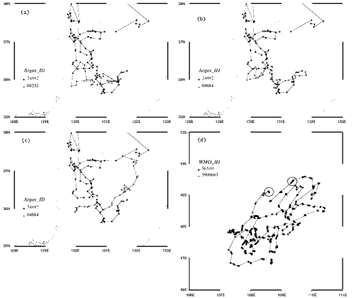

Fig. 2. (a) Trajectories of float match-up pair of 04252 and 24892. (b) Same as in Fig. 2 (a), but for 04664 and 24892. (c) Same as in Fig. 2 (a), but for 04684 and 24892. (d) Same as in Fig. 2 (a), but for 56510 and 5900043. Open black circles denote the match-up points.

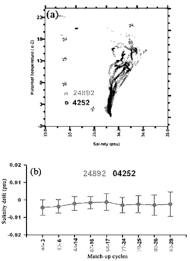

Fig. 3. (a) Potential temperature-salinity (θ-S) diagram for floats 24892 and 04252. (b) Salinity drift for float 24892 derived by comparing with float 04252.

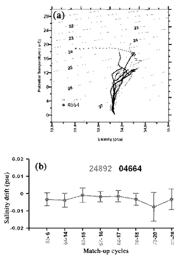

Fig. 4. Same as Fig. 3, but for floats 24892 and 04664.

salinity caused by the vertical displacement of the same water mass. Through out the analysis, data from deeper observations has been considered in order to make use of the stable θ-s relationships in deeper layers.

Results

The potential temperature-salinity (θ-s) diagrams of the match-up profiles of the corresponding floats are given in Fig. 3(a), 4(a) and 5(a), respectively. The salinity drifts computed for float 24892 based on the salinity from floats 04252, 04664 and 04684 (all from the East Sea) are also given in Fig. 3(b), 4(b) and 5(b), respectively. Salinity drift for the float 24892 has been calculated by comparing salinity on potential temperature surfaces varying from 0.4~1.0 °C, representing the East Sea Intermediate Water (Kim and Kim, 1999). In all three cases, the salinity drift for the float 24892 is consistently showing negative bias as expected from a fouled float (discussed in previous section). However, in all cases, the bias is less than 0.01, the accuracy specified by the ARGO program.

While the float 24892 was deployed in early November 2001, the other three floats were deployed in early September 2002. This means that the float 24892 is nearly one year old when the three floats (04252, 04664 and 04684) were deployed. The cycle numbers of the float match-ups are so considered that the latest cycles of the old deployment are compared with the cycles in the early stages of the later deployments. For example, in the case of match-ups for float 24892 the cycle start from 53 and for float 4252, the first match-up is of cycle 6, giving a time difference of nearly 50 cycles, equivalent to one year. The same is true for the other two floats from the East Sea.

As discussed in section-2, in the Indian ocean, the float match-up pair is of floats 56510 and 5900043. Though there is only one match-up cycle for the two floats (cycle-99 of 56510 and cycle-3 of

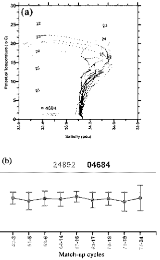

Fig. 5. Same as Fig. 3, but for floats 24892 and 04684.

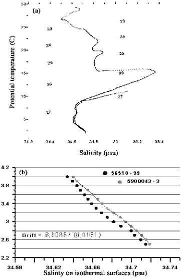

Fig. 6. (a) θ-S diagram for float 56510 and 5900043. (b) Salinity drift for float 56510 by comparing with 5900043.

5900043), the time lag between the two cycles of the floats is well suitable for the old/new float concept adopted in this paper. While 56510 was deployed on 23 July 2000, 5900043 was on 7 March 2003. The time lag of more than 3 years is very appropriate to find the salinity drift of 56510 associated with fouling. The last data received from 56510 is for the cycle 104 and after that the float ceased its functioning and had been declared 'dead'.

Fig. 6(a) gives the θ-s diagram from the match-up floats 56510/590043 and corresponding salinity drift obtained from the match-up floats is also given in Fig. 6(b). As depicted in Fig. 6(b), the salinity drift is at about 0.00867 with a standard deviation of 0.0031.

Discussion and Conclusions

In the present study, the issue under discussion is the conductivity cell fouling during its unattended years in the ocean and possible drift in the salinity sensor. Without retrieving any floats and doing the post-deployment calibrations, an indirect method has been worked out to find the salinity drift. From all the four float match-ups from the East Sea and the Indian Ocean, it is found that there is a systematic drift in the older float compared to later deployments. All drift results, consistently show negative bias indicating the typical nature of drift from a fouled sensor. However, the drift is much less than the 0.01 psu, the specified accuracy of ARGO program. The result is very well comparable to the post-deployment calibrations of Riser and Swift (2003) and Oka and Ando (2003). The fact that the conductivity cell of CSIRO float 56510 has not yet been affected even after its three years of presence in the ocean is very encouraging for the ARGO program.

The advantage of the float match-ups from the East Sea is that the salinity from the same older

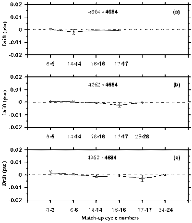

Fig. 7. Salinity drift derived for new floats (floats deployed recently). (a) Salinity drift derived for float 4664 based on the same cycles of contemporary float 4684. (b) Same as in Fig. 8 (a), but for float 4252 based on 4664. (c) Same as in Fig. 8 (a), but for float 4252 based on 4684.

float (24892) is compared with three later deployments of almost same cycles. This enabled us to substantiate the observed drift in the salinity of 24892 as per the hypothesis discussed about the fouled floats in section-2. The observed systematic negative bias is not because of any biased location of the old float (42892) in the less salinity region of the deep water mass compared to the three floats deployed later (04252, 04664, and 04684). This conclusion could be inferred from the fact that there are number of crossings between the old and new floats as seen in the floats trajectories from Fig. 2.

According to the hypothesis discussed in section-2, older fouled floats should show less salinity compared to that of later deployments. As per the same hypothesis, it is obvious that comparisons of floats of same age should show no systematic bias as the fouling effect is on minimum. From the same match-up data from the East Sea, inter-comparisons of the salinity from 04252, 04664 and 04684 (all of same age) for the same cycles reveal that the salinity drift in such comparisons is nearly zero as anticipated from the fouling hypothesis. This is illustrated in Fig. 7(a) (4664/4684), 7(b) (4252/4664), and 7(c) (4252/4684).

Though the observed results on fouling associated drift are not discouraging, there is an element of concern to be added as we consider that the float we discussed has completed less than its half-life span. If the fouling associated error is progressive (cumulative) with time, then at the present rate of drift, the salinity drift may exceed 0.01 threshold set by the ARGO science team. In this context, in the delayed mode quality control of the ARGO program, it is important to continue post deployment calibrations (as discussed in this study or based on any of the other methods referred in the introduction), especially in the coming years when majority of the floats will be completing their half life and some, even, full life.

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