ARGO FLOAT WMO 6901041 MISSION AND CTD CALIBRATION

Massimo Pacciaroni,
Pierre-Marie Poulain, Giulio Notarstefano,
Rajesh Nair, Nevio Medeot

Produced by the Mediterranean Argo Regional Centre (MedArgo), OGS, Trieste, Italy

Approved for release by: ....

Dr. Paola Del Negro
Director, Oceanography Section

Table of Contents

1. Introduction

This report briefly describes the mission of Argo float WMO 6901041 in the western Mediterranean Sea and the calibration of its Conductivity-Temperature-Depth (CTD) sensors after stranding on the Spanish coast. Information about the float mission and collected data is given in Sections 2 and 3, respectively. Details about the CTD post-mission calibration can be found in Section 4. Discussion of the calibration results and conclusions are in Section 5.

2. Float information

The Argo float with WMO number 6901041 is an Arvor I, s/n 12 IT ARI 04, manufactured by NKE in Hennebont, France. It was deployed on 3 August 2012 in the Tyrrhenian Sea (see Figure 1) from R/V Urania as part of the Argo Italy program.

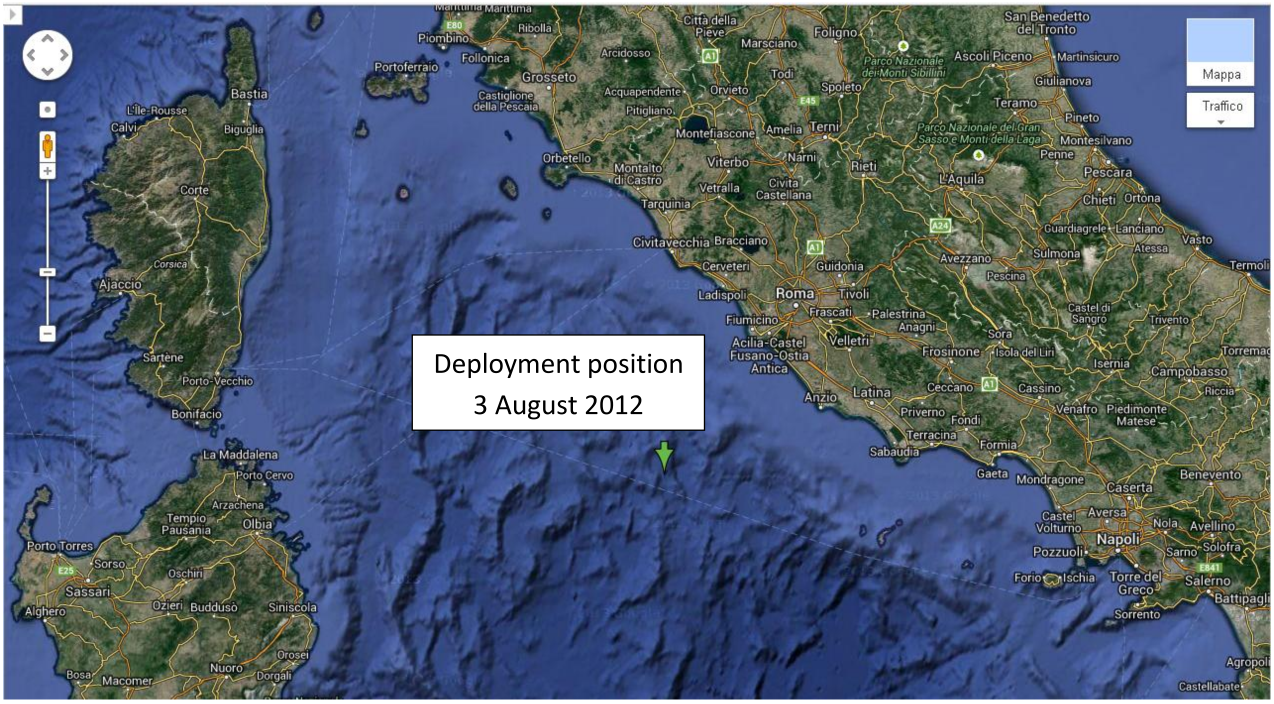

Figure 1. Float deployment position in the Tyrrhenian Sea.

The float was programmed to cycle every 5 days and to profile alternatively from 700 and 2000 m to the surface. The vertical resolution was set to 5 m from 0 to 100 m, 10 m from 100 to 700 m and 50 m from 700 to 2000 m. Its parking depth was set to 350 m. The float was localized with a GPS and the data were telemetered with the Iridium satellite system.

The float performed 125 cycles and then reached the Spanish coast, near the city of Tarragona (Figure 2) where it stranded on 22 April 2014 (Figure 3). The instrument last transmission occurred on 13 July 2014 (Table 1). The float covered a vertical distance of about 107.7 km when putting together all the vertical profiles during the whole mission. The percentage of grounding (or sea bottom contacts) was 55.6%.

Model	WMO	Deploy Date	Lat	Lon	Cycles	Last Date	Lat	Lon
Arvor I	6901041	3 May 2012	41.17	11.75	125	13 July 2014	41.11	1.24

Table 1. Float deployment and recovery information.

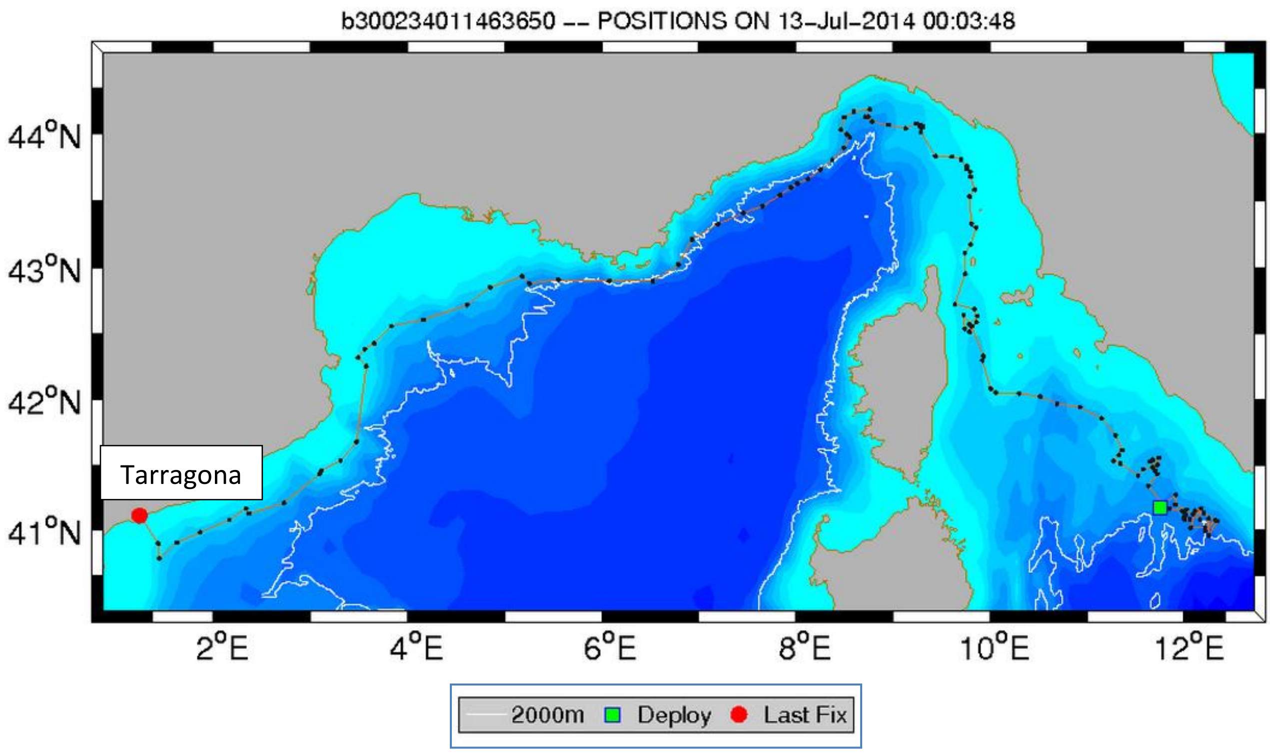

Figure 2. Trajectory and CTD profile locations (black dots) of float WMO 6901041.

Figure 3. Float position in Tarragona harbor after its recovery by the fishing boat.

Spanish colleagues of the Institut de Ciències del Mar (ICM), Consejo Superior de Investigaciones Cientifícas (CSIC) in Barcelona, were contacted at the beginning of May 2014 in order to recover and put the instrument in more secure place. We were informed that in fact it got entangled in a fishing net during the passage of a trawler and then placed in Tarragona harbor (on small boat or on pier). From the end of April to the middle of July 2014 the float was working although being out of the water. See Table 2 for timing period details.

Float	3May_2012÷22Apr2014	May_2014÷20Oct_2014	21Oct_2014÷Nov_2014
6901041	In water, 125 cycles (622 days)	Recovering after stranding and subsequently shipment to OGS	Recalibration and shipment to NKE instrumentation

Table 2. Timetable with history of float WMO 6901041.

The float was photographed once it arrived in Barcelona; it appeared in good conditions except for the GPS antenna (Figure 4), which was bended.

Figure 4. Picture of the float in CSIC-ICM laboratory, at the beginning of August 2014.

3. Float data visualization

The float data were downloaded from the Coriolis Data Centre (a GDAC center), in NetCDF format and immediately converted into Matlab files. Temperature and salinity vertical profiles are shown in Figures 5 and 6, respectively. The red squares represent the instrument contact with the sea bottom, which is detected and registered by the software. Data collected while the float was out of seawater were excluded.

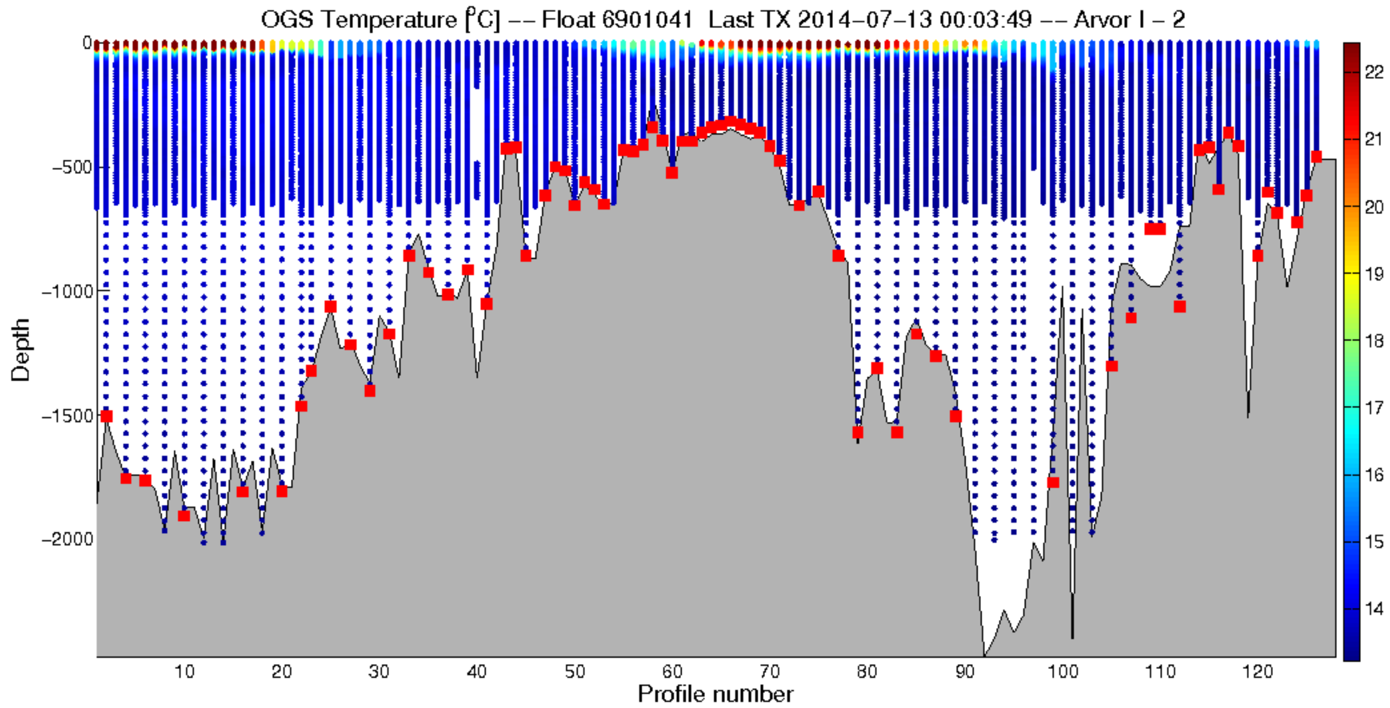

Figure 5. Temperature scatter plot. Red squares indicate profiles where the float touched the bottom.

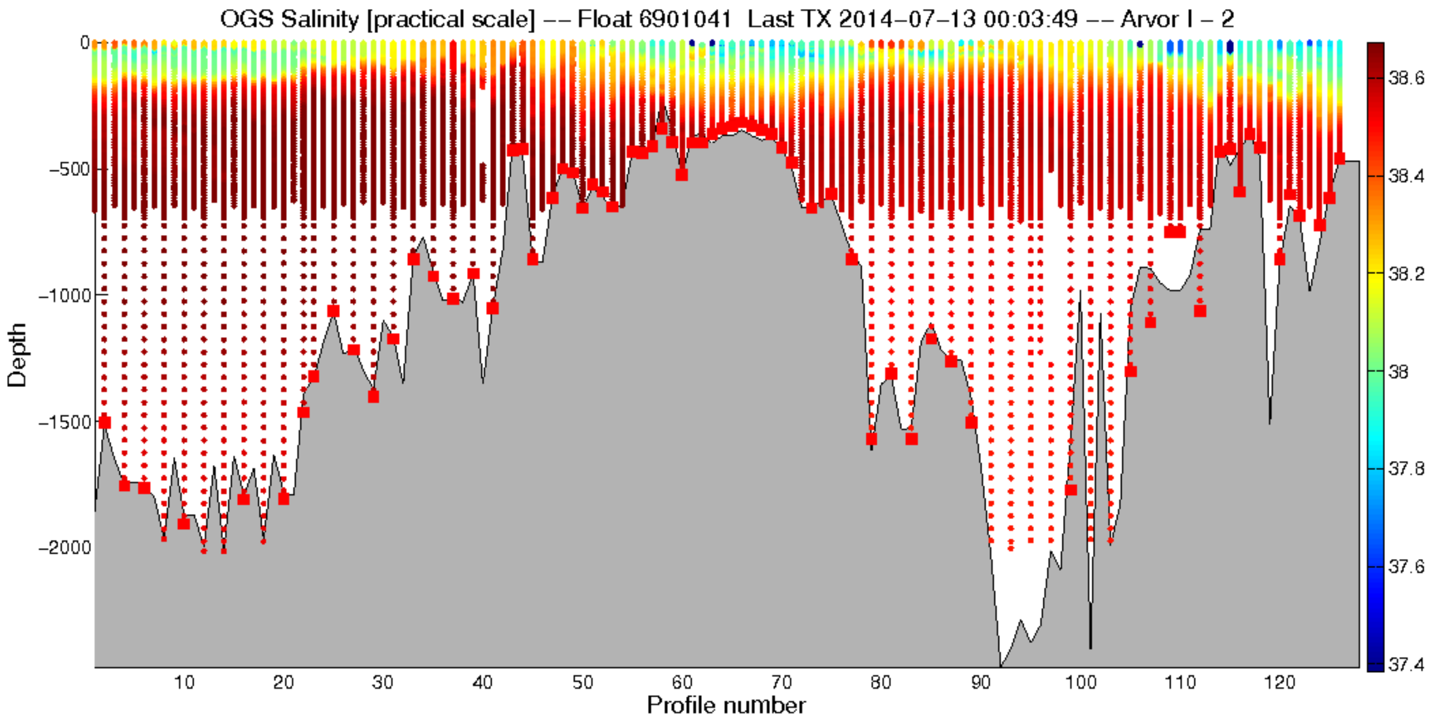

Figure 6. Same as Figure 5 but for salinity.

The battery voltage is shown in Figure 7. There is no indication of significant decreasing voltage trend.

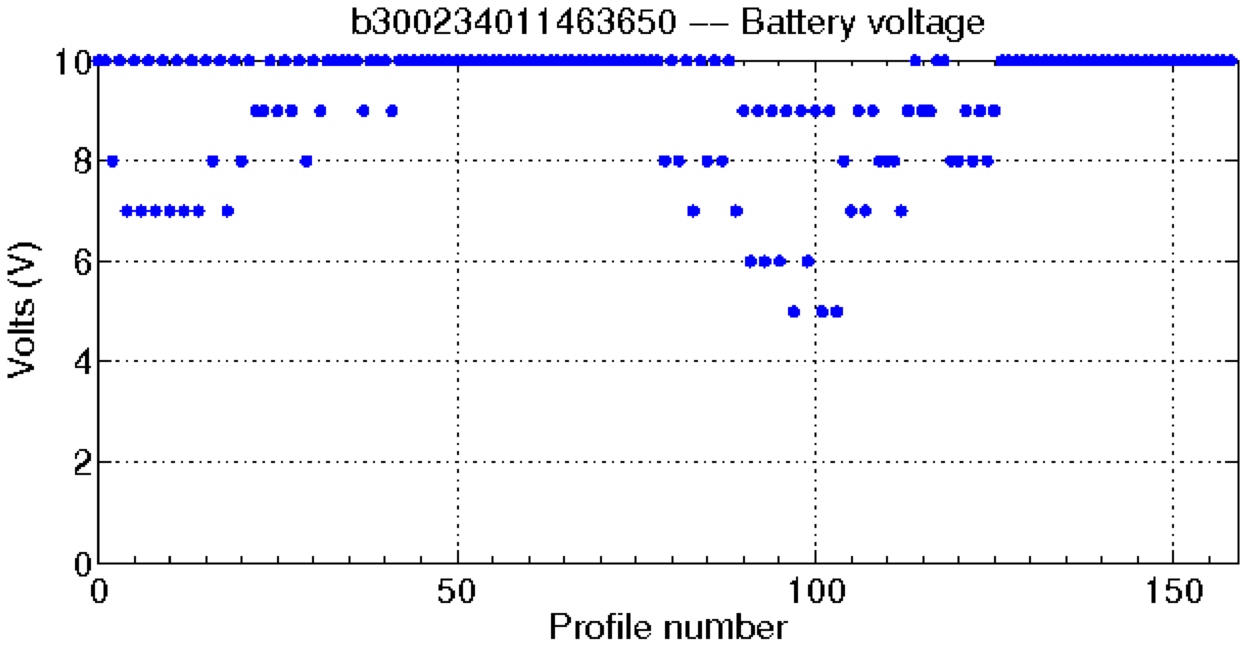

Figure 7. Battery voltage versus profile number for float WMO 6901041.

4. CTD post-mission calibration

The float was shipped to OGS by our CSIC-ICM colleagues in October 2014, and then disassembled by the Centro di Taratura Oceanografico (CTO) group at OGS in order to calibrate and verify the integrity of CTD probes before complete refurbishing by NKE in France. The work at CTO consisted in providing communication between the probe and a PC, this was carried out constructing a specifically designed circuit and employing a terminal emulator software (Nair and Medeot, 2014). Very accurate measurements were achieved by means of reference Standard Platinum Resistance Thermometer (accuracy better than 0.001 °C, ITS-90) and the laboratory salinometer (accuracy better than 0.002 Practical Salinity Scale units); all calibrations are traceable to certified reference material.

In Figures 8-9 some highlights of the calibration procedure are shown. Particularly in Figure 8 the CTD probes and the electronics appears disassembled to facilitate the operations, in Figure 9 the entire system is shown. Note that the probes are upside-down with respect to normal operability hence a special system was designed to allow the seawater to cross the sensors and to escape outside.

Figure 8. The float upper part which was removed to access the electronics board.

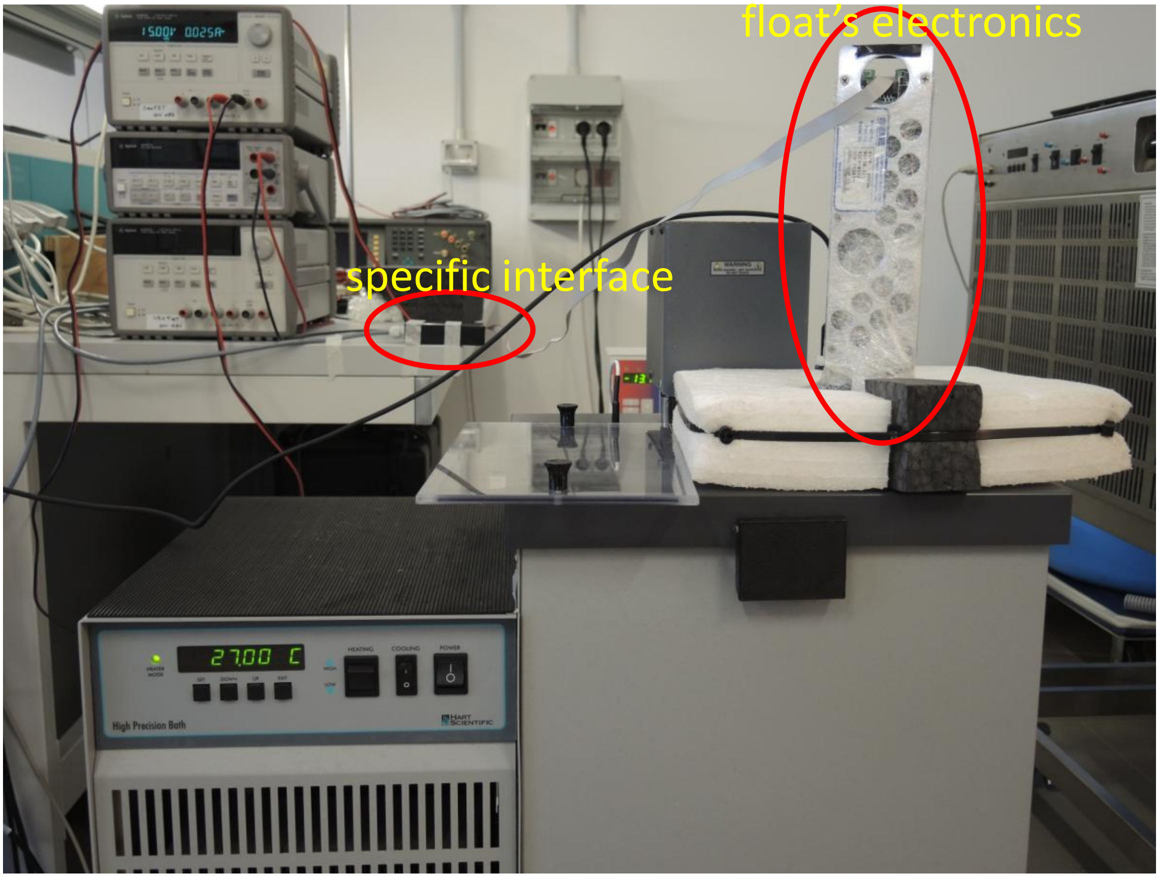

Figure 9. The float CTD immersed into the thermostatic bath and connected to a PC by means of a specifically constructed interface.

The observed accuracies for temperature and salinity are summarized in Tables 3 and 4, respectively. There was no need of re-calibration of the temperature sensors. The conductivity sensors were intensively cleaned during the checking and therefore were re-calibrated (see Nair and Medeot 2014 report in Appendix A for further details). The equivalent salinity was conform to the NKE specifications, after re-calibration.

Temperature

REF TEMP (°C)	INST TEMP (°C)	RESIDUAL (°C)
3.0326	3.0328	0.0002
5.1484	5.1482	-0.0002
10.2509	10.2508	-0.0001
15.2254	15.2249	-0.0005
20.1297	20.1294	-0.0003
25.0393	25.0384	-0.0009
27.0118	27.0106	-0.0012

Manufacturer ±0.002° C

Table 3. Declared and observed instrument accuracies for temperature.

Salinity

REF TEMP (°C)	REF SAL (PSS-78)	INST SAL (PSS-78)	RESIDUAL (PSS-78)
3.0326	37.6035	37.6044	0.0009
5.1484	37.6053	37.6053	-0.0000
10.2509	37.6119	37.6092	-0.0027
15.2254	37.6340	37.6316	-0.0024
20.1297	37.6510	37.6493	-0.0017
25.0393	37.6673	37.6665	-0.0008
27.0118	37.6811	37.6813	0.0002

Manufacturer ±0.005

Table 4. Declared and observed instrument accuracies for salinity.

5. Conclusions

The recovery of Argo float WMO 6901041 after about 2 years of operation in the western Mediterranean provided a good opportunity to calibrate its CTD sensors at the end of its mission. The results show excellent post-mission accuracy of both the temperature and conductivity sensors, which is much higher than the standard Argo accuracy (0.005 °C and 0.01 p.s.u. for temperature and salinity respectively). Therefore, we hereby provide a confirmation that Argo floats operated for multiple years in the Mediterranean can remain well calibrated throughout their operating life.

6. References

Arvor I User manual, 2011. DOC33-16-007rev.6 du 20/02/12

Nair Rajesh and Medeot Nevio, 2014. Post-deployment evaluation and recalibration of temperature and conductivity sensors on NKE ARVOR float CTDs, Activity Report, rel. 2014/76 OCE 28 CTO-TECDEV.

7. Acknowledgements

We thank Dr. Jordi Font and Kintxo Salvador at Institut de Ciències del Mar, CSIC-ICM Barcelona for their help and economical support to recuperate the float from the fisherman and organize its shipment to OGS.

8. Appendix A

Activity Report

Post-deployment evaluation and recalibration of temperature and conductivity sensors on nke ARVOR float CTDs

SBE 41 ALACE-CP-MO V 1.3, Serial No. 2754

&

SBE 41 ALACE-CP-MO V 1.2, Serial No. 4522

Rajesh Nair, Nevio Medeot
Oceanographic Calibration Centre, Oceanography Section

Approved for release by:

Dr. Paola Del Negro
The Director, Oceanography Section.

REL. 2014/76 OCE 28 CTO-TECDEV, Borgo Grotta Gigante (TS), 09 December 2014

A1. Instrument description

The SBE 41/41CP CTD module, designed for use on profiling floats typically during the ascent phase, samples temperature (T), conductivity (C), and pressure continuously at a rate of 1 Hz when powered on. The module is manufactured by Sea-Bird Electronics, Inc., and incorporates their trademark pump-controlled, T-C ducted flow configuration to minimize salinity spiking caused by mismatch of temperature and conductivity measurements. The pump is normally turned off between profiles. The indispensable anti-fouling protection necessary to ensure high-quality data includes anti-foulant devices to minimize bio-fouling of the module's conductivity cell, a U-shaped flow path, and a programmable pump cutoff setting, (usually 10-5 dbars) to switch off the integral pump as the float approaches the sea surface. The U-shaped flow path prevents oils and contaminants from being ingested as the float breaks through the surface skin of the sea. It also prevents water from flowing through the system due to waves or currents while the float is at the surface transmitting the data it has collected.

The characteristics of the T and C sensors when these CTD modules are mounted on ARVOR-C profiling floats manufactured by nke Instrumentation are reported in the table below.

Table. ARVOR-C temperature and conductivity sensor specifications.

PARAMETER	SPECIFICATION	
	Initial Accuracy	**Resolution**
Temperature (°C, ITS-90)	±0.002	0.001
Conductivity (equivalent salinity, PSS-78)	±0.005	0.001

A2. Units under test

Instrument	Vector	Launch date & location	Recovery date & location	Period of deployment	Area of Operation
SBE 41 ALACE-CP-MO, V 1.3, Serial No. 2754	nke ARVOR-C: @BT2011 04 70, O/N 11IT ARC 01	10/10/2011, Tyrrhenian Sea	27/10/2011, Tyrrhenian Sea	~17 days	Western Mediterranean Sea
		18/10/2012, Adriatic Sea	27/10/2012, Adriatic Sea	~4 days	Eastern Mediterranean Sea

Instrument	Vector	Launch date & location	Recovery date & location	Period of deployment	Area of Operation
SBE 41 ALACE-CP-MO, V 1.2, Serial No. 4522	nke ARVOR-I: @BT2012 03 14, O/N 12IT-ARI-04	03/05/2012, Tyrrhenian Sea	22/04/2014, Tarragona (Spain)	~2 years	Western Mediterranean Sea

B1. Calibration apparatus

Instrument description	Model	Serial number
Laboratory Salinometer[a]	Guildline Autosal 8400B	65744
Standard Platinum Resistance Thermometer (SPRT)[b]	Hart 5699	0103
Precision Digital Thermometer	Hart - Fluke 1595A	B46159
Seawater Calibration Bath[c]	Hart 7052	A1A003
PC Interface Box for SBE 41CP CTD Module	FL-CTD2008	OGS001
DC Power Supply	Agilent E3631A	MY40007143

[a]Laboratory Salinometer standardized using freshly-opened IAPSO Standard Seawater bottles (Batch: P156) at the start of every 24 hours of operation;
[b]Reference SPRT calibration to sub-range 11 (0.01 °C - 29.7646 °C) of the International Temperature Scale of 1990 (ITS-90) last checked on 25 June 2014 using a Hart Scientific 5901 Triple Point of Water cell and a Hart Scientific 5943 Gallium Melting Point cell;
[c]Calibration bath filled with natural, filtered seawater (filter size/type: 0.22 μm/Millipore).

B2. Pre-treatment of sensors

The T and C sensors of the two SBE 41 ALACE-CP units were rinsed by flushing fresh deionized water through their U-shaped sample flow paths for a few minutes for the purpose of the post-deployment evaluation. No other cleaning operation was performed.

On the contrary, preparing both units for calibration involved repeated cleaning of their C sensors, implementing the manufacturer's instructions for this operation ("Instructions for Care and Cleaning of Conductivity Cells", Sea-Bird Electronics, Inc. Application Note No. 2D, last revision: March 2014). After each cleaning cycle, the C sensor responses were tested at a convenient bath temperature set-point (21 °C for unit 2754 and 20 °C for unit 4522) until the conductivity residuals from consecutive sets of measurements showed no further significant differences from the corresponding reference values.

Section C

Data & Results

POST-DEPLOYMENT

TEMPERATURE

Test date: 13 November 2014

Ambient conditions:
Temperature: 21.7 °C ± 1 °C
Relative Humidity: 52% ± 10%
Atmospheric pressure: 978.4 hPa

As-received temperature calibration coefficients

a0 = 1.574572e-05
a1 = 2.773593e-04
a2 = -2.712031e-06
a3 = 1.570812e-07

$$T\,(°C) = 1/\ \{[a0 + a1\,[ln\,(n)] + a2\,[ln^{2}\,(n)] + a3\,[ln^{3}\,(n)]\} - 273.15$$

REF TEMP (°C)	INST OUTPUT (n)	INST TEMP (°C)	TEMP RESIDUAL (°C)
3.0327	654242.0	3.0316	-0.0011
5.1475	594806.6	5.1464	-0.0011
10.2503	475043.1	10.2489	-0.0014
15.2259	384041.5	15.2237	-0.0022
20.1292	313312.1	20.1275	-0.0017
25.0381	257042.9	25.0362	-0.0019
27.0100	237771.2	27.0079	-0.0021

where:

REF TEMP = bath set-point temperature (°C, ITS-90), measured using the reference Standard Platinum Resistance Thermometer;
INST OUTPUT = Instrument output at **REF TEMP**;
INST TEMP = bath temperature (°C, ITS-90), measured by Instrument;
TEMP RESIDUAL = temperature residual: **INST TEMP - REF TEMP**.

CONDUCTIVITY

Test date: 13 November 2014

Ambient conditions:
Temperature: 21.7 °C ± 1 °C
Relative Humidity: 52% ± 10%
Atmospheric pressure: 978.4 hPa

As-received conductivity calibration coefficients

g = -1.010586e+00 CPcor = -9.570001e-08
h = 1.483483e-01 CTcor = 3.250000e-06
i = -3.440286e-04 WBOTC = 1.593064e-07
j = 4.595743e-05

Conductivity (Siemens/m) = $(g + hf^2 + if^3 + jf^4) / (1 + \delta t + \varepsilon p)$

Note: f = Inst Freq * sqrt (1.0 + WBOTC * t) / 1000.0
t = Temperature (°C); p = Pressure (dBar); δ = CTcor; ε = CPcor.

REF TEMP (°C)	BATH SAL (PSS-78)	REF COND (S/m)	INST OUTPUT (Hz)	INST COND (S/m)	COND RESIDUAL (S/m)	SAL RESIDUAL (PSS-78)
21.1527	0	0	2615.24[1]	0.00004	0.00004	-
3.0327	37.5471	3.37605	5447.25	3.37612	0.00007	0.0021
5.1475	37.5479	3.57801	5570.83	3.57801	0.00000	0.0013
10.2503	37.5511	4.08188	5867.65	4.08180	-0.00008	0.0007
15.2259	37.5531	4.59365	6154.22	4.59355	-0.00010	0.0012
20.1292	37.5542	5.11560	6433.18	5.11574	0.00014	0.0027
25.0381	37.5587	5.65416	6708.41	5.65427	0.00011	0.0024
27.0100	37.5701	5.87580	6818.37	5.87594	0.00014	0.0028

where:

REF TEMP = bath set-point temperature (°C, ITS-90), measured using the reference Standard Platinum Resistance Thermometer;
BATH SAL = bath salinity (PSS-78), measured using the reference Laboratory Salinometer;
REF COND = conductivity set-point (S/m), obtained from inverted **BATH SAL**;
INST OUTPUT = Instrument output frequency (Hz) at **REF TEMP**;
INST COND = bath conductivity (S/m), measured by Instrument;
COND RESIDUAL = conductivity residual: **INST COND - REF COND**;
SAL RESIDUAL = salinity residual: **INST SAL - REF SAL**.

[1] In air, with a perfectly dry conductivity cell.

TEMPERATURE

Test date: 21 November 2014

Ambient conditions:
Temperature: 21.2 °C ± 1 °C
Relative Humidity: 47% ± 10%
Atmospheric pressure: 981.4 hPa

As-received temperature calibration coefficients

a0 = -1.098629e-06
a1 = 2.728035e-04
a2 = -2.385421e-06
a3 = 1.468875e-07

$$T\,(°C) = 1/\ \{[a0 + a1\,[\ln(n)] + a2\,[\ln^2(n)] + a3\,[\ln^3(n)]\} - 273.15$$

REF TEMP (°C)	INST OUTPUT (n)	INST TEMP (°C)	TEMP RESIDUAL (°C)
3.0326	761372.9	3.0328	0.0002
5.1484	692136.4	5.1482	-0.0002
10.2509	552686.2	10.2508	-0.0001
15.2254	446755.3	15.2249	-0.0005
20.1297	364410.1	20.1294	-0.0003
25.0393	298915.7	25.0384	-0.0009
27.0118	276483.5	27.0106	-0.0012

where:

REF TEMP = bath set-point temperature (°C, ITS-90), measured using the reference Standard Platinum Resistance Thermometer;
INST OUTPUT = Instrument output at **REF TEMP**;
INST TEMP = bath temperature (°C, ITS-90), measured by Instrument;
TEMP RESIDUAL = temperature residual: **INST TEMP - REF TEMP**.

CONDUCTIVITY

Test date: 21 November 2014

Ambient conditions:
Temperature: 21.2 °C ± 1 °C
Relative Humidity: 47% ± 10%
Atmospheric pressure: 981.4 hPa

As-received conductivity calibration coefficients

g = -9.861773e-01   CPcor = -9.570001e-08
h = 1.523203e-01   CTcor = 3.250000e-06
i = -4.120115e-04   WBOTC = -2.352400e-07
j = 5.421455e-05

Conductivity (Siemens/m) = $(g + hf^2 + if^3 + jf^4) / (1 + \delta t + \varepsilon p)$

Note: f = Inst Freq * sqrt (1.0 + WBOTC * t) / 1000.0
t = Temperature (°C); p = Pressure (dBar); δ = CTcor; ε = CPcor.

REF TEMP (°C)	BATH SAL (PSS-78)	REF COND (S/m)	INST OUTPUT (Hz)	INST COND (S/m)	COND RESIDUAL (S/m)	SAL RESIDUAL (PSS-78)
21.3862	0	0	2550.51[2]	0.00014	0.00014	-
3.0326	37.6035	3.38061	5365.83	3.38070	0.00009	0.0009
5.1484	37.6053	3.58300	5488.32	3.58298	-0.00002	-0.0001
10.2509	37.6119	4.08785	5782.37	4.08757	-0.00028	-0.0028
15.2254	37.6340	4.60241	6067.22	4.60210	-0.00031	-0.0024
20.1297	37.6510	5.12736	6344.37	5.12712	-0.00024	-0.0017
25.0393	37.6673	5.66877	6617.68	5.66857	-0.00020	-0.0008
27.0118	37.6811	5.89135	6726.76	5.89124	-0.00011	0.0002

where:
REF TEMP = bath set-point temperature (°C, ITS-90), measured using the reference Standard Platinum Resistance Thermometer;
BATH SAL = bath salinity (PSS-78), measured using the reference Laboratory Salinometer;
REF COND = conductivity set-point (S/m), obtained from inverted **BATH SAL**;
INST OUTPUT = Instrument output frequency (Hz) at **REF TEMP**;
INST COND = bath conductivity (S/m), measured by Instrument;
COND RESIDUAL = conductivity residual: **INST COND - REF COND**;
SAL RESIDUAL = salinity residual: **INST SAL - REF SAL**.

[2] In air, with a perfectly dry conductivity cell.

Section D

Data & Results

CALIBRATION

CONDUCTIVITY

Test date: 24 November 2014

Ambient conditions:
Temperature: 21.3 °C ± 1 °C
Relative Humidity: 48% ± 10%
Atmospheric pressure: 990.7 hPa

New conductivity calibration coefficients

g = -1.0086453e+00 CPcor = -9.570001e-08
h = 1.4765360e-01 CTcor = 3.250000e-06
i = -1.5132195e-04 WBOTC = 1.593064e-07
j = 3.1584722e-05

Conductivity (Siemens/m) = $(g + hf^2 + if^3 + jf^4) / (1 + \delta t + \varepsilon p)$

Note: f = Inst Freq * sqrt (1.0 + WBOTC * t) / 1000.0
t = Temperature (°C); p = Pressure (dBar); δ = CTcor; ε = CPcor.

REF TEMP (°C)	BATH SAL (PSS-78)	REF COND (S/m)	INST OUTPUT (Hz)	INST COND (S/m)	COND RESIDUAL (S/m)
21.1527	0	0	2615.24[3]	0	0
3.0329	37.8606	3.40142	5463.01	3.40142	0
5.1473	37.6574	3.58735	5576.57	3.58735	0
10.2508	37.6605	4.09256	5873.87	4.09255	-0.00001
15.2246	37.6293	4.60181	6158.77	4.60180	-0.00001
20.1304	37.6329	5.12525	6438.23	5.12529	0.00004
25.0384	37.8890	5.69820	6730.44	5.69814	-0.00006
27.0101	37.7968	5.90716	6833.9	5.90720	0.00004

where:

REF TEMP = bath set-point temperature (°C, ITS-90), measured using the reference Standard Platinum Resistance Thermometer;
BATH SAL = bath salinity (PSS-78), measured using the reference Laboratory Salinometer;
REF COND = conductivity set-point (S/m), obtained from inverted **BATH SAL**;
INST OUTPUT = Instrument output frequency (Hz) at **REF TEMP**;
INST COND = bath conductivity (S/m), measured by Instrument;
COND RESIDUAL = conductivity residual: **INST COND - REF COND**.

[3] In air, with a perfectly dry conductivity cell.

CONDUCTIVITY

Test date: 25 November 2014

Ambient conditions:
Temperature: 21.2 °C ± 1 °C
Relative Humidity: 43% ± 10%
Atmospheric pressure: 989.6 hPa

New conductivity calibration coefficients

g = -9.8102801e-01
h = 1.5039891e-01
i = 1.2384635e-04
j = 1.4582308e-05

CPcor = -9.570001e-08
CTcor = 3.250000e-06
WBOTC = -2.352400e-07

Conductivity (Siemens/m) = $(g + hf^2 + if^3 + jf^4) / (1 + \delta t + \varepsilon p)$

Note: f = Inst Freq * sqrt (1.0 + WBOTC * t) / 1000.0
t = Temperature (°C); p = Pressure (dBar); δ = CTcor; ε = CPcor.

REF TEMP (°C)	BATH SAL (PSS-78)	REF COND (S/m)	INST OUTPUT (Hz)	INST COND (S/m)	COND RESIDUAL (S/m)
21.3862	0	0	2550.51[4]	0	0
3.0329	37.7677	3.39391	5374.06	3.39392	0.00001
5.1474	37.7622	3.59632	5496.36	3.59633	0.00001
10.2510	37.7567	4.10192	5790.36	4.10187	-0.00005
15.2245	37.8602	4.62694	6080.42	4.62696	0.00002
20.1304	37.8676	5.15361	6357.81	5.15365	0.00004
25.0380	37.7626	5.68132	6623.81	5.68126	-0.00006
27.0096	37.7659	5.90283	6732.32	5.90286	0.00003

where:

REF TEMP = bath set-point temperature (°C, ITS-90), measured using the reference Standard Platinum Resistance Thermometer;
BATH SAL = bath salinity (PSS-78), measured using the reference Laboratory Salinometer;
REF COND = conductivity set-point (S/m), obtained from inverted **BATH SAL**;
INST OUTPUT = Instrument output frequency (Hz) at **REF TEMP**;
INST COND = bath conductivity (S/m), measured by Instrument;
COND RESIDUAL = conductivity residual: **INST COND - REF COND**.

[4] In air, with a perfectly dry conductivity cell.

Section E

Summary of work done

Two SBE 41 ALACE-CP CTD modules, identified by the serial numbers 2754 and 4522, were detached from their respective ARVOR floats. The T and C sensors of the modules were rinsed perfunctorily with deionized water and subjected to a post-deployment evaluation of their performances.

The results of the evaluation showed that all the sensors were functioning properly, in line with the float manufacturer's specifications for them.

Following the evaluation, the conductivity sensors of both the units were cleaned intensively following recommended practice, and therefore re-calibrated to account for any possible changes ensuing from this operation.

The calibration settings of the conductivity sensors of the two units were updated, and the floats were reconstituted to return them to their original state.

Measurements performed by: Nevio Medeot, Rajesh Nair.

Approved by:
N. Medeot, CTO Unit.