DEEP-ARVOR PROGRAMMING AND DEPLOYMENT IN THE WESTERN CRETAN PASSAGE

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Approved for release by ....
Dr. Paola Del Negro
Director, Oceanography Section

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1. Introduction

The Deep-Arvor float is a particular version of the NKE Arvor subsurface profiling float. It is manufactured jointly with Ifremer and allows high resolution and continuous measurement as deep as 4000 dbar in the water column. It is also designed in accordance with Argo program requirements.

The float performs multiple cycles with predefined parking and maximal profiling depths. Data can be registered during descent, parking and ascent periods and then saved into its internal memory. When at surface it establishes a communication with Iridium satellite and, after data reduction by means of a specific algorithm, data transmission begins.

2. The on-board instruments

Temperature and conductivity are measured by a SBE 41-CP ALACE probe providing accuracy of ±0.0001 degrees Celsius (ITS-90 scale) and ±0.00001 S/m for conductivity (see Fig. 1). The pressure sensor accuracy is about ±0.02% of the detected value.

The float is also equipped with an Aanderaa 4330 optical oxygen sensor providing accuracy of about ±1.5 µmol/kg (estimated from calibration certificate, see Appendix A).

Figure 1. SBE 41CP and Aanderaa 4330 detail.

3. Mission parameters

The Deep-Arvor mission is mainly controlled by means of 17 parameters, listed in Table 1.

Mission Parameters	Description	Value	Units
PM0	Number of cycles	255	integer number
PM1	Cycle period	10	days
PM2	Reference Day	2	day
PM3	Estimated time at the surface	6	hour
PM4	Delay before mission	0	minutes
PM5	Descent sampling period	0	seconds
PM6	Drift sampling period	12	hours
PM7	Ascent sampling period	10	seconds
PM8	Drift depth	4000	dbar
PM9	Profile depth	4000	dbar
PM10	Threshold surface/intermediate pressure	100	dbar
PM11	Threshold intermediate /bottom pressure	700	dbar
PM12	Thickness of the surface slices	2	dbar
PM13	Thickness of the intermediate slices	10	dbar
PM14	Thickness of the bottom slices	25	dbar
PM15	Iridium end of life transmission period	60	minutes
PM16	2^{nd} Iridium session waiting period	0	minutes
PM17	Wait at surface after grounding	60	minutes

Table 1. List of mission parameters.

The parameter PM1 was initially set to 2 days in order to have more frequent transmissions, then it was changed to 5 and finally to 10 days.

The parameters that control parking (PM8) and maximal profiling (PM9) depths were set at the same 4000 dbar value in order to try to maintain the float in a deep area, avoiding it to escape with the currents.

Following the configuration shown in Table 1, the float performs a cycle every 10 days; the water column is hypothetically divided into an upper (0-100m), an intermediate (100-700m) and a bottom (700-4000m) layers. The upper, intermediate and deep resolutions are respectively 2, 10, 25 dbar.

In case of contact with the sea floor (grounding) the float can react in two modes, depending on technical parameter PT10 setting:
PT10=0 → the previous programmed depth is disregarded while the new one corresponds to the current pressure minus an offset (about 100 dbar); the floats waits at this depth until it's time to start the ascending phase.
PT10=1 → the floats stays there waiting for the ascent.

Our Deep-Arvor was programmed to stay there in case of grounding (PT10=1).

4. Float deployment

The deployment was carried out from HCMR's R/V AEGAEO during the CRELEV 2016/ EUROFLEETS2 cruise in collaboration with colleagues from OGS and HCMR. The deployment location is shown in Figure 2.

Figure 2. Deep-Arvor deployment location and date.

In Table 2, information about the deployment and the last transmission are summarized.

Model	WMO	Iridium	Deploy Date	Lat	Lon	Cycles	Last Date	Lat	Lon	Status	Cycle
Arvor-D	6903200	300234063647490	08-Jun-2016 05:47	35.25	22.77	8	14-Jul-2016 06:26	35.20	22.47	A	10

Table 2. Status table for the Deep-Arvor as of 14 July 2016.

The pre-deployment checking operations and the float in the water immediately after the launch are shown in Figure 3.

Figure 3. Deployment operations.

5. Decoding aspects and dissolved oxygen computation

Once at surface the Deep-Arvor tries to establish a satellite communication, this can be mainly influenced by two factors: the satellite system operativity and the very bad weather conditions (sometimes compromising the complete antenna emersion for the required time).

The transmitted messages consist of SBD (short burst data) files each containing maximum 3 packets of 100 bytes (see Figure 4).

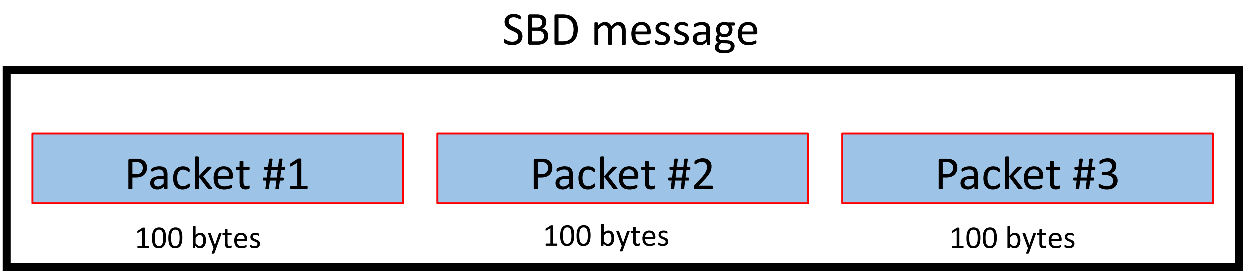


Figure 4. SBD message schematics.

In order to decode the SBD messages a Matlab program was implemented following format instructions described in the user manual (DEEP-ARVOR FLOAT user manual, 2015).
Each packet is classified by an ID number (from 0 to 10) that corresponds to a specific packet type, for example there are technical packets, hydraulic pump or valve ones and CTD data packets.

Particularly the Deep-Arvor described in this report is equipped with an Aanderaa 4330 optical oxygen sensor that provides raw data in form of blu (the excitation signal, *C1phase*) and red (the received signal, *C2phase*) measured phases and *in situ* temperature (*Toxy*) used to calculate the dissolved oxygen. The Stern-Volmer equation is applyied to convert raw data to oxygen measurement (Processing Argo OXYGEN data at the DAC level, 2016).
The procedure begins defining a phase difference between blu and red ligth:

$$Ph\_diff = C1phase - C2phase.$$

Next the Stern-Volmer constant is computed using the measured temperature from Aanderaa 4330:

$$k_{SV} = c0 + c1\,Toxy + c2\,Toxy^2.$$

Then molar (µmol/l) oxygen can be determined:

$$Molar_{OXY} = \left(\frac{c3+c4\,Toxy}{c5+c6\,Ph\_diff} - 1\right)\cdot\frac{1}{k_{SV}}\ .$$

The coefficients $c0$ to $c6$ come from the instrument's calibration certificate (see Appendix A).

The obtained oxygen concentration must then be corrected for salinity and pressure effects. Two coefficients are defined one for pressure and anotherone for reference salinity:

$$P_{coef} = 0.032;\ \ S_{ref} = 0\ .$$

The salinity effect is hence computed:

$$OXY\_psal = Molar_{OXY}\cdot e^{(S_{in}-S_{ref})\cdot(B0+B1\,Ts+B2\,Ts^2+B3\,Ts^3)+C0\,({S_{in}}^2-{S_{ref}}^2)}$$

and then the pressure effect is also taken into account:

$$OXY = OXY\_psal\cdot\left(1+P_{coef}\ \cdot P_{in}/1000\right)\ .$$

It is worth noting that depending on S_{ref} the oxygen computation can considerably change, here S_{ref} =0 (Processing Argo OXYGEN data at the DAC level, 2016).

6. Comparison of ship CTD and Deep-Arvor profiles

Nearby the deployment point (about 2.3 km) the S23 station was sampled by CTD rosette, as a result it is possible to compare data. In Figure 5 potential temperature, salinity and dissolved oxygen are shown, overall indicating good accordance between the two instruments with the exception of oxygen. Anyway, as previously said, the float underestimating could depend on S_{ref} definition.

Seawater samples were collected in station S23 in order to calibrate CTD salinity and also bottle data were closed, at predefined depths, to correct the automatically measured dissolved oxygen (see Figure 5c). The CTD used was a SBE 911plus system equipped with SBE43 oxygen sensor (s/n: 2556) with 0.5 mil membrane and initial accuracy ±2% of saturation. The sensor was connected to the CTD pumped path and was calibrated on December 2015, prior to the cruise.
For the determination of dissolved oxygen (DO), samples were taken from the Niskin sampling bottle with the recommended precautions to prevent any biological activity and gas exchanges with the atmosphere. Reagents were added immediately after collection. DO determination was performed on board by Winkler titration method (Carpenter, 1965a,b).

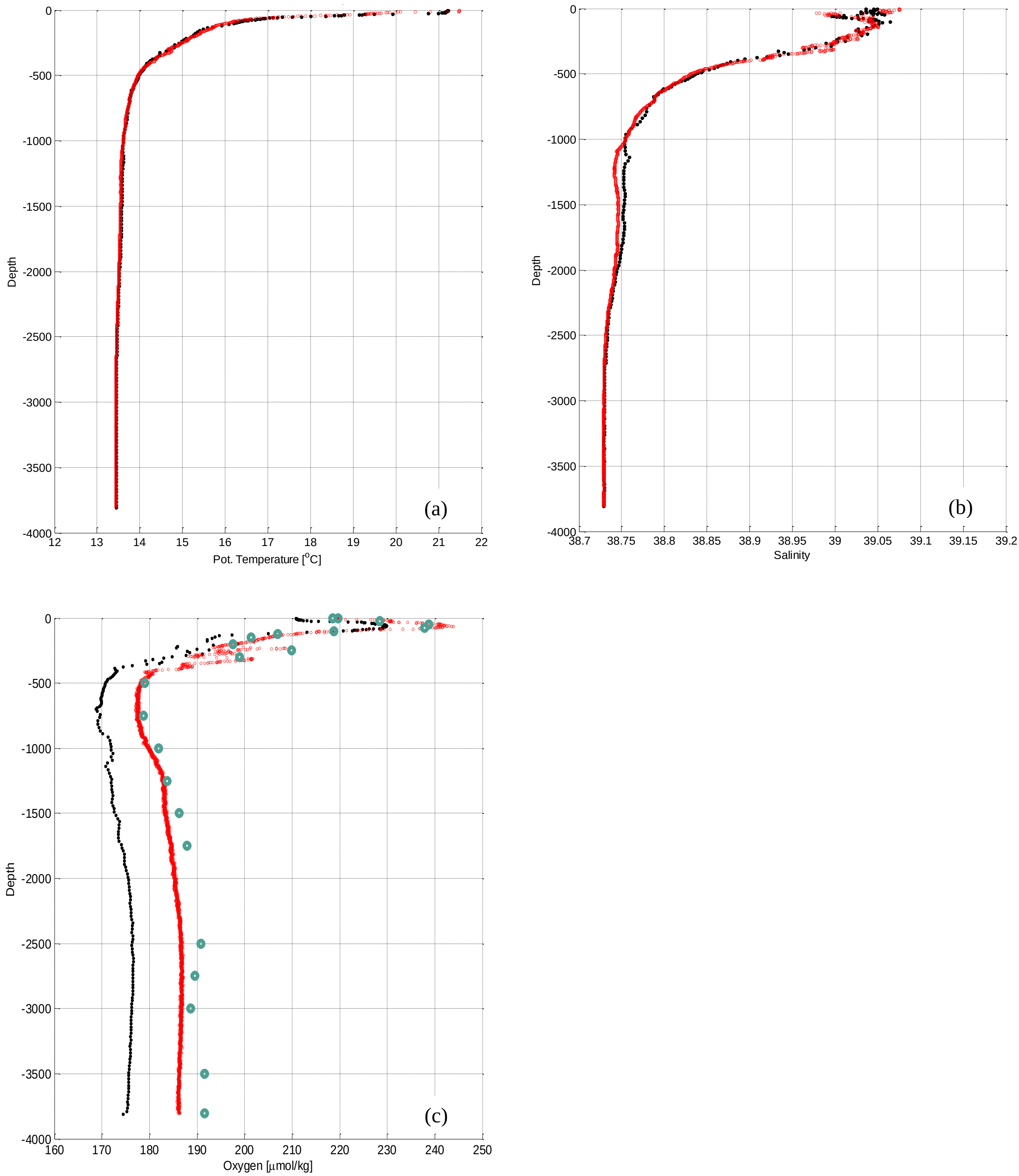


Figure 5. Float (black) to CTD (red) data comparison; (a) potential temperature (b) salinity (c) dissolved oxygen, circles represent bottle quotas.

7. Deep-Arvor profiles

The Deep-Arvor was programmed to sample the water column only during ascending phase, the initial cycling period changes are summarized in Table 3 while in Figure 6 the points of emersion are shown. Figure 7 shows both the trajectory and bathymetry details.

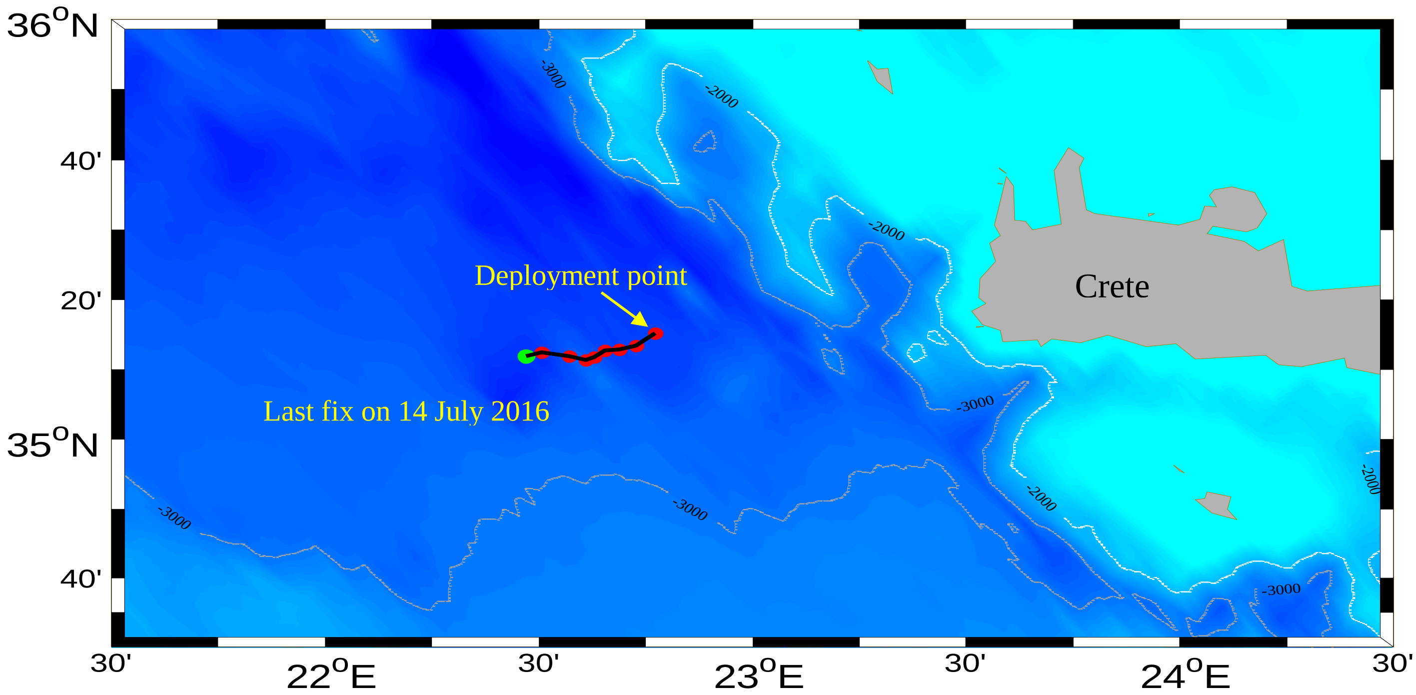


Figure 6. Float's positions in the Cretan western passage.

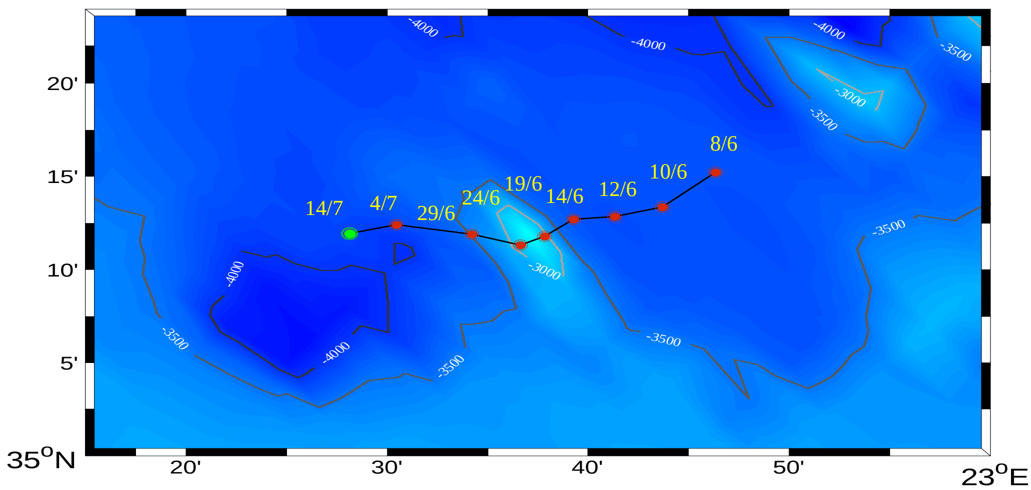


Figure 7. Float's positions detail with relative transmission dates in the Cretan western passage.

Cycling period (days)	Starting date	Lat (°N)	Lon (°E)	Ending date	Lat (°N)	Lon (°E)
2	08-June-2016	35.254	22.772	14-June-2016	35.212	22.655
5	14-June-2016	35.212	22.655	04-July-2016	35.207	22.508
10	04-July-2016	35.207	22.508	14-July-2016	35.199	22.469

Table 3. Cycling changes from deployment until 14 July 2016.

In Figure 8 all the achieved temperature (*in situ* and computed potential temperature), salinity and dissolved oxygen vertical profiles are shown.

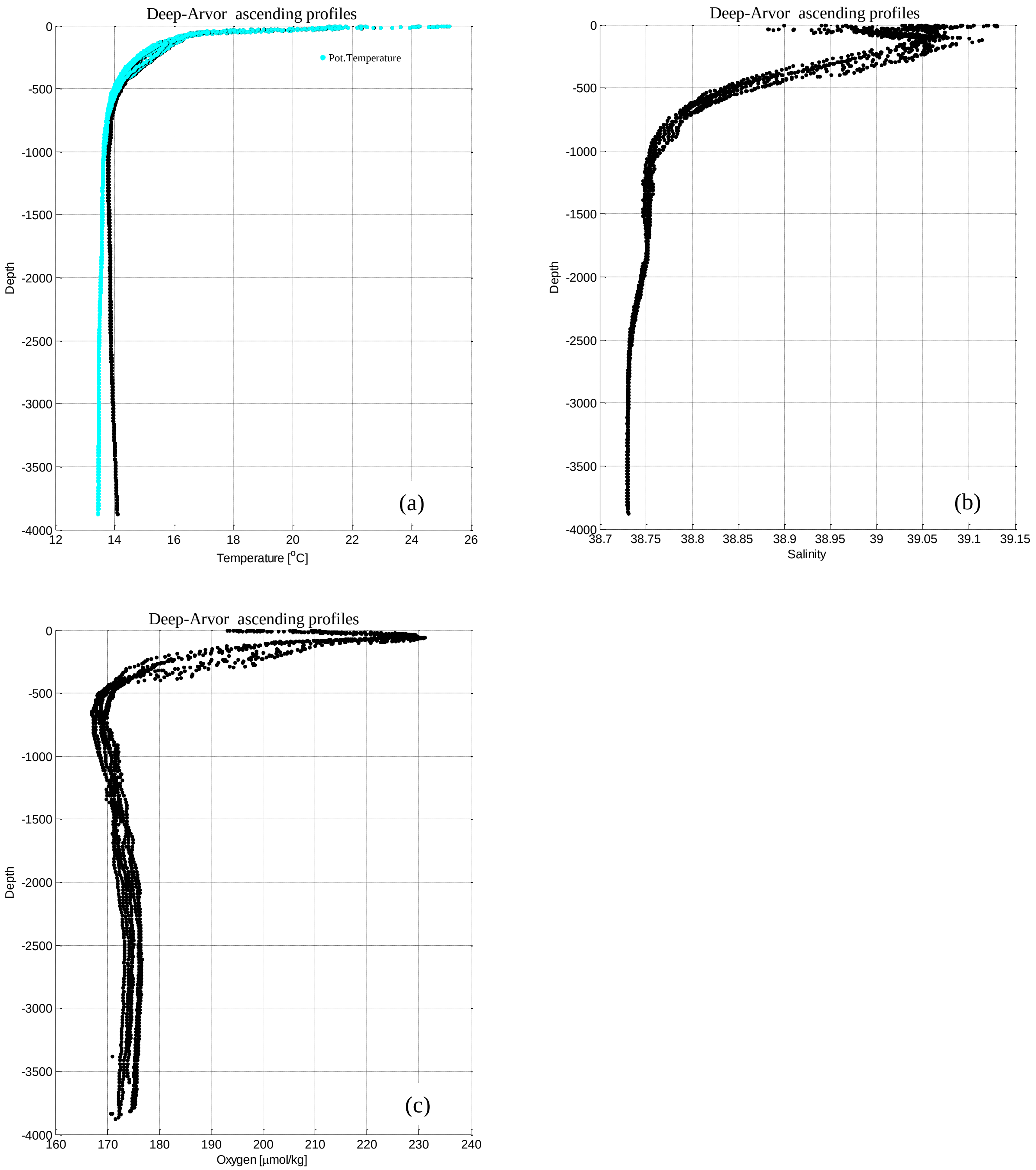


Figure 8. Vertical profiles of (a) *in situ* and potential temperature (b) salinity and (c) dissolved oxygen sampled by the Deep-Arvor.

In Figure 9 the temperature, salinity and oxygen scatter plots are shown relative to each cycle from 8 June 2016 (deployment date) to 14 July 2016. Upper in the graphs the intermediate distances are reported in kilometers, while grounding information is shown with red bottom square (if present the float touched the sea floor). The estimated local bathymetry is also shown with dotted line, the interpolation is based on the ETOPO1 database, 1 arc-minute resolution Global Relief Model (Amante, C. and B.W. Eakins, 2009).

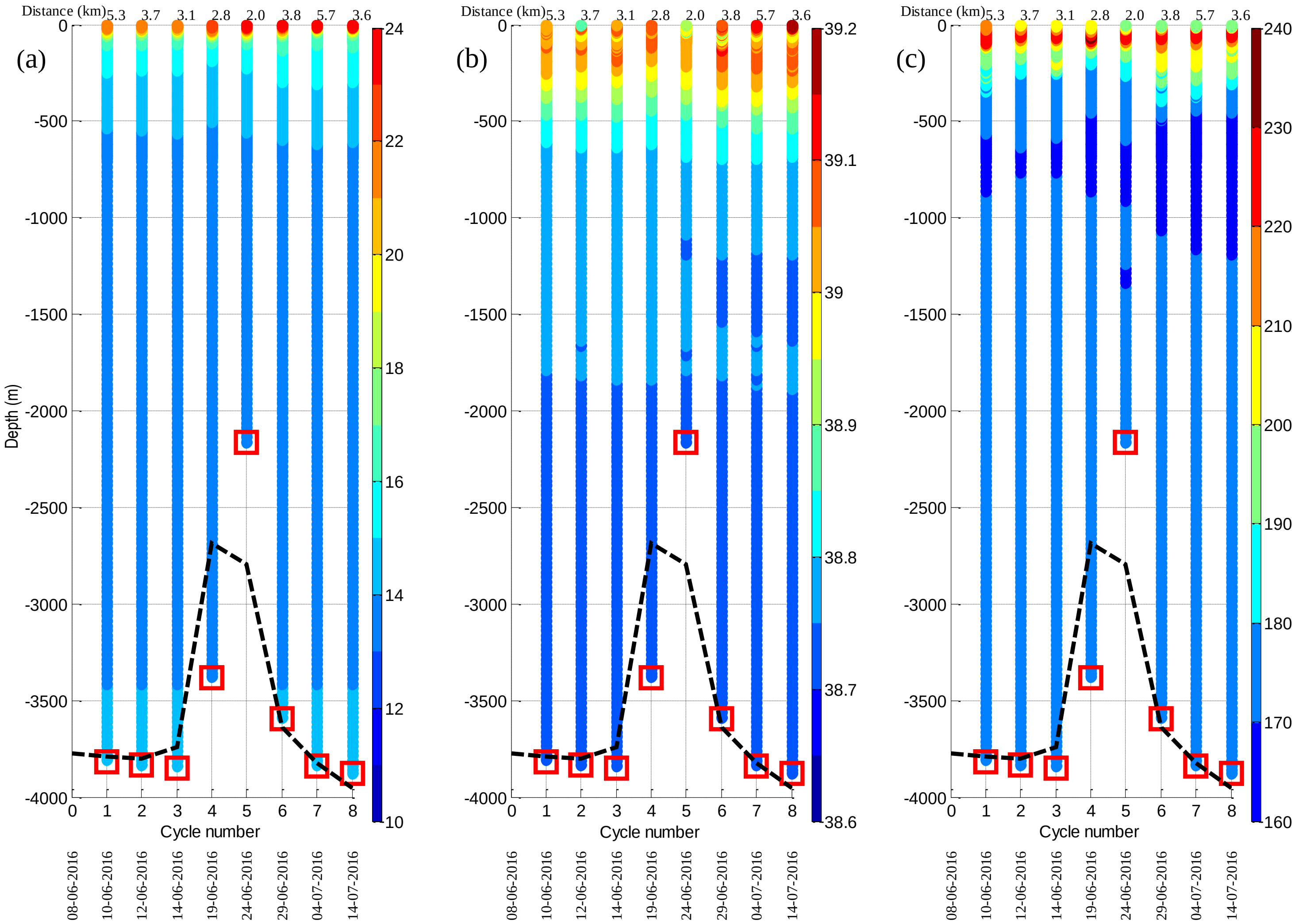


Figure 9. Deep-Arvor measurements *versus* cycle number, (a) temperature (°C), (b) salinity and (c) oxygen (µmol/kg). Black dotted lines represent the estimated ETOPO1 bathymetry.

8. Conclusions

In the Argo program framework a Deep-Arvor float was successfully released in the western Cretan passage (a very deep area in the Mediterranean Sea with depths exceeding 4000 dbar) during the CRELEV 2016/EUROFLEETS2 cruise in June 2016. The float carried out 8 cycles from deployment date (8 June) until 14 July providing high resolution vertical profiles of temperature, salinity and dissolved oxygen. The float touched the bottom at every cycle and its internal vacuum and battery voltage remained within acceptable limits.

Concerning float to CTD data comparison in the deployment area, it is worth noting the very good agreement in temperature values. Similarly there is good accordance in salinity with the exception of the layer between near 1000-2000 dbar where there is a difference of a few hundredths. The oxygen values measured by the float appear mostly underestimated.

9. References

Amante, C. and B.W. Eakins, 2009. ETOPO1 1 Arc-Minute Global Relief Model: Procedures, Data Sources and Analysis. NOAA Technical Memorandum NESDIS NGDC-24. National Geophysical Data Center, NOAA. doi:10.7289/V5C8276M.
Web: https://www.ngdc.noaa.gov/mgg/global/global.html

Carpenter, J. H., 1965(a). The accuracy of the Winkler method for the dissolved oxygen analysis. *Limnology and Oceanography, 10*, 135-140.

Carpenter, J. H., 1965(b). The Chesapeake Bay Institute technique for dissolved oxygen method. *Limnology and Oceanography, 10*, 141-143.

DEEP-ARVOR FLOAT user manual, DOC 33-16-028 Dec. 2015 rev.3, http://www.nke.fr

Processing Argo OXYGEN data at the DAC level Version 2.1, March 1st 2016, doi: 10.13155/39795.

10. Acknowledgments

The authors would like to thank the OGS and HCMR collaborators, in particular C. Reyes Suarez, G. Korres and D. Kassis for their help with the deployment activities. We also thank the ship's captain, official staff and crew for their dedication.

Appendix A

SEA-BIRD SCIENTIFIC

SBE Sea-Bird Electronics

Sea-Bird Electronics
13431 NE 20th Street
Bellevue, Washington
98005 USA

Tel: +1 425-643-9866
seabird@seabird.com
www.seabird.com

SBE41-CP ALACE

Instrument Configuration

Instrument Serial Number:	41-7723
Instrument Firmware Version:	V 7.2.5
Zero Conductivity Frequency:	2554.41
Communications Format:	RS232
Communications Settings:	9600 baud, 8 Data Bits, No Parity

Installed Devices/Sensors

Data Format	*Measurement*	*Sensor Type*	*Serial Number*	*Rating*
Count	Temperature	Internal	N/A	N/A
Frequency	Conductivity	Internal	N/A	N/A
Count	Pressure	Kistler	4750378	4000m(7000 dBar)

Sea-Bird Electronics, Inc.
13431 NE 20th Street, Bellevue, WA 98005-2010 USA
Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

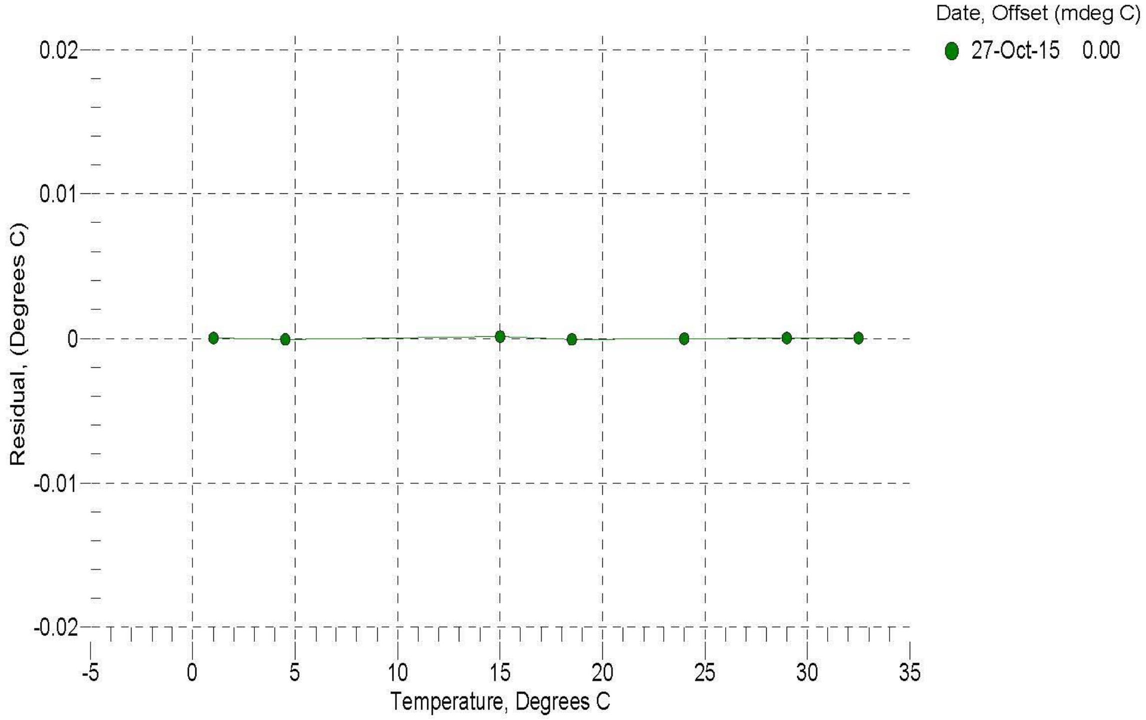
SENSOR SERIAL NUMBER: 7723
CALIBRATION DATE: 27-Oct-15

SBE 41 TEMPERATURE CALIBRATION DATA
ITS-90 TEMPERATURE SCALE

COEFFICIENTS:
a0 = -8.107013e-004
a1 = 2.876144e-004
a2 = -3.453365e-006
a3 = 1.430092e-007

BATH TEMP (ITS-90)	INSTRUMENT OUTPUT	INST TEMP (ITS-90)	RESIDUAL (ITS-90)
1.0001	15187900.6	1.0001	0.0000
4.5000	12962110.3	4.4999	-0.0001
15.0000	8217644.2	15.0001	0.0001
18.5000	7103789.0	18.4999	-0.0001
23.9940	5685689.9	23.9940	-0.0000
29.0000	4670057.9	29.0000	0.0000
32.5000	4083387.3	32.5000	0.0000

Temperature ITS-90 = $1/\{a0 + a1[ln(n)] + a2[ln^2(n)] + a3[ln^3(n)]\} - 273.15$ (°C)
Residual = instrument temperature - bath temperature
n = instrument output



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13431 NE 20th Street, Bellevue, WA 98005-2010 USA
Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 7723
CALIBRATION DATE: 27-Oct-15

SBE 41 CONDUCTIVITY CALIBRATION DATA
PSS 1978: C(35,15,0) = 4.2914 Siemens/meter

COEFFICIENTS:

```
g = -9.926276e-001        CPcor = -9.5700e-008
h =  1.528742e-001        CTcor =  3.2500e-006
i = -4.346620e-004        WBOTC =  2.9358e-007
j =  5.551048e-005
```

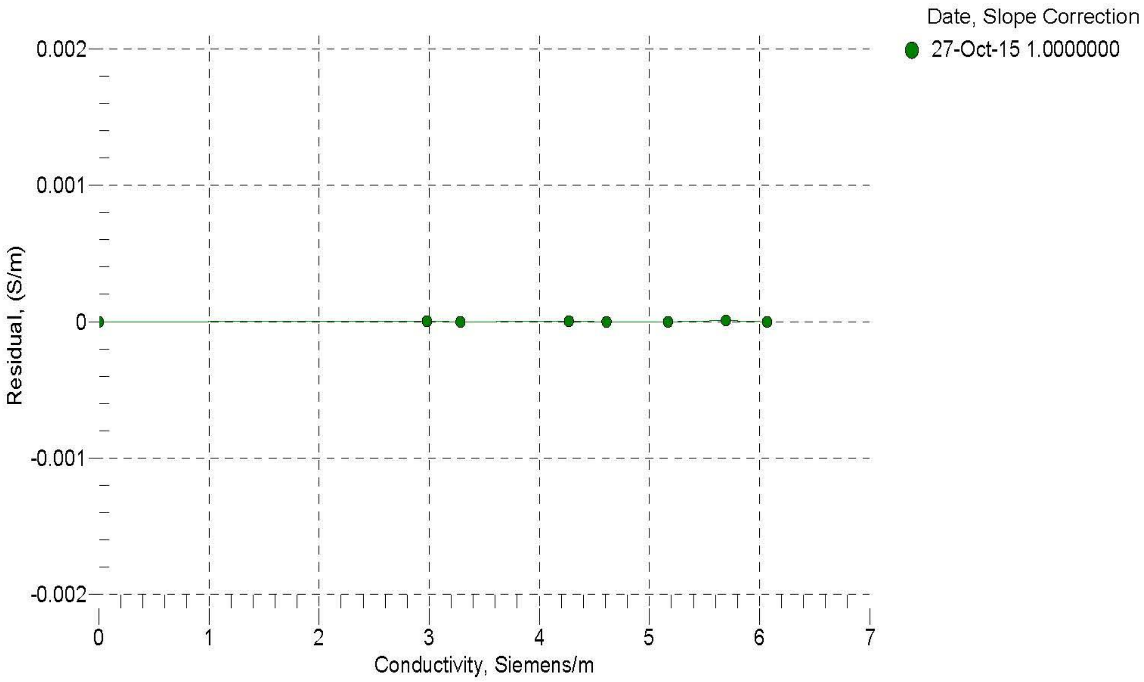
BATH TEMP (ITS-90)	BATH SAL (PSU)	BATH COND (Siemens/m)	INST FREQ (Hz)	INST COND (Siemens/m)	RESIDUAL (Siemens/m)
22.0000	0.0000	0.00000	2554.41	0.00000	0.00000
1.0001	34.8288	2.97694	5108.63	2.97694	0.00000
4.5000	34.8095	3.28415	5302.16	3.28414	-0.00000
15.0000	34.7672	4.26623	5877.51	4.26623	0.00000
18.5000	34.7579	4.61146	6066.53	4.61145	-0.00000
23.9940	34.7477	5.16893	6359.60	5.16893	-0.00000
29.0000	34.7421	5.69153	6622.22	5.69154	0.00001
32.5000	34.7389	6.06402	6803.01	6.06401	-0.00000

f = INST FREQ * sqrt(1.0 + WBOTC * t) / 1000.0

Conductivity = $(g + h * f^2 + i * f^3 + j * f^4) / (1 + \delta * t + \varepsilon * p)$ Siemens / meter

t = temperature[°C)]; p = pressure[decibars]; δ = CTcor; ε = CPcor;

Residual = instrument conductivity - bath conductivity



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13431 NE 20th Street, Bellevue, WA 98005-2010 USA
Phone: (+1) 425-643-9866 Fax (+1) 425-643-9954 Email: seabird@seabird.com

SENSOR SERIAL NUMBER: 7723
CALIBRATION DATE: 20-Oct-15

SBE 41 PRESSURE CALIBRATION DATA
10153 psia S/N 4750378

COEFFICIENTS:

PA0 =	8.307791e-001	PTCA0 =	-7.271075e+003
PA1 =	1.304791e-003	PTCA1 =	-7.185195e+001
PA2 =	4.144946e-012	PTCA2 =	4.423912e+000
PTHA0 =	3.335705e+002	PTCB0 =	1.033709e+002
PTHA1 =	-9.772422e-005	PTCB1 =	-9.334359e-003
PTHA2 =	3.703731e-012	PTCB2 =	0.000000e+000

PRESSURE SPAN CALIBRATION

PRESSURE PSIA	INST OUTPUT	THERMISTOR OUTPUT	COMPUTED PRESSURE	ERROR %FS
14.74	4307.5	3701374.4	15.14	0.00
2001.44	1514500.7	3699951.8	1999.29	-0.02
3988.35	3013029.7	3698935.4	3986.90	-0.01
5975.39	4498333.2	3698061.8	5975.44	0.00
7962.36	5969525.8	3697317.4	7963.22	0.01
9949.85	7425411.2	3696518.2	9948.06	-0.02
7962.33	5970044.4	3697461.4	7963.91	0.02
5975.34	4499246.5	3698026.4	5976.67	0.01
3988.26	3014219.9	3698410.2	3988.50	0.00
2001.43	1515764.3	3698760.4	2000.95	-0.00
14.75	5100.5	3698360.0	16.14	0.01

THERMAL CORRECTION

TEMP ITS90	PRESS TEMP	INST OUTPUT
32.50	3561577.20	6366.50
29.00	3610675.00	5685.87
23.99	3681558.80	4876.85
18.50	3759909.60	4224.02
15.00	3810226.00	3946.29
4.50	3961891.60	3802.80
1.00	4014041.40	3978.66

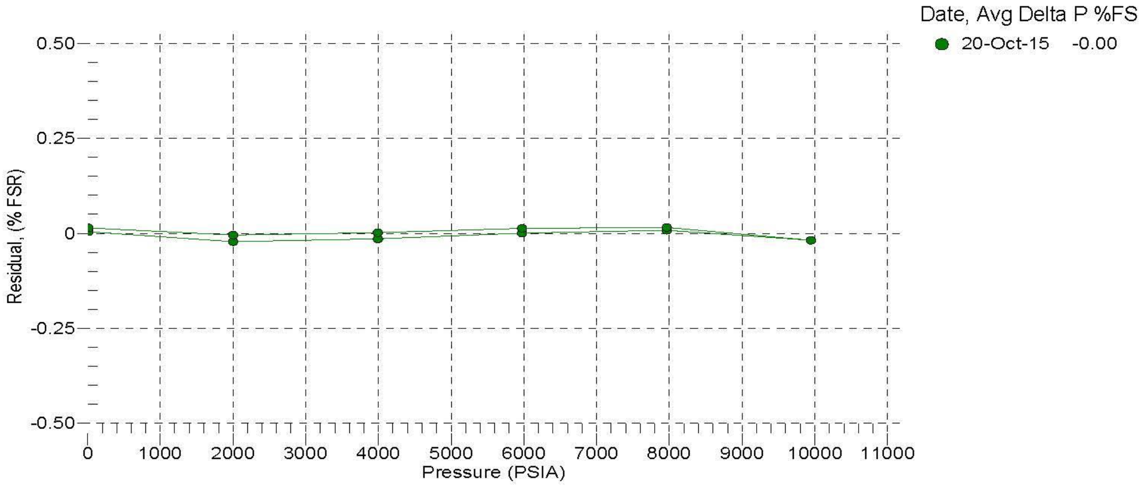
TEMP(ITS90)	SPAN(mV)
-5.25	103.42
35.05	103.04

y = thermistor output; $t = PTHA0 + PTHA1 * y + PTHA2 * y^2$

$x = \text{pressure output} - PTCA0 - PTCA1 * t - PTCA2 * t^2$

$n = x * PTCB0 / (PTCB0 + PTCB1 * t + PTCB2 * t^2)$

$\text{pressure (psia)} = PA0 + PA1 * n + PA2 * n^2$



AANDERAA
a xylem brand

CALIBRATION CERTIFICATE

Form No 830, Juli 2012

Certificate no: 4330_2513_00115020 | Product: 4330 | Serial no: 2513
Foil batch no: 1517M | Calibration date: 22.01.2016 | Page 1 of 2

Index	Temperature reference(°C)	[O2] Reference(μM)	Temperature raw data(mV)	Phase reading(°)
0	30.148	1.13	-165.150	61.29
1	19.669	0.22	172.275	62.66
2	9.759	0.19	496.390	63.51
3	0.653	0.68	775.860	64.22
4	0.608	20.67	777.150	61.60
5	0.576	40.87	778.065	59.22
6	0.547	60.90	778.905	57.08
7	0.515	101.42	779.820	53.30
8	0.488	143.52	780.600	50.03
9	0.472	214.08	781.075	45.62
10	0.464	317.50	781.295	40.79
11	0.458	421.44	781.495	37.24
12	0.449	525.88	781.710	34.51
13	10.189	13.86	482.605	60.84
14	10.100	31.54	485.480	57.86
15	10.025	47.53	487.855	55.47
16	9.950	79.97	490.300	51.34
17	9.893	112.71	492.105	47.94
18	9.853	168.62	493.400	43.37
19	9.836	250.12	493.920	38.54
20	9.831	331.84	494.100	35.06
21	9.828	415.91	494.200	32.39
22	19.972	10.97	162.245	59.75
23	19.892	24.86	164.895	56.50
24	19.814	37.91	167.455	53.83
25	19.738	64.15	169.970	49.38
26	19.699	90.47	171.245	45.80
27	19.680	134.78	171.895	41.17
28	19.674	199.72	172.100	36.39
29	19.670	266.09	172.200	32.98
30	19.669	335.04	172.205	30.38
31	30.109	8.92	-163.970	58.59
32	30.103	20.33	-163.800	54.98
33	30.105	30.98	-163.820	52.10
34	30.112	52.31	-164.020	47.38
35	30.122	73.66	-164.370	43.69
36	30.133	109.48	-164.700	39.05
37	30.142	162.89	-164.995	34.30
38	30.145	217.28	-165.055	31.02
39	30.145	274.93	-165.085	28.53

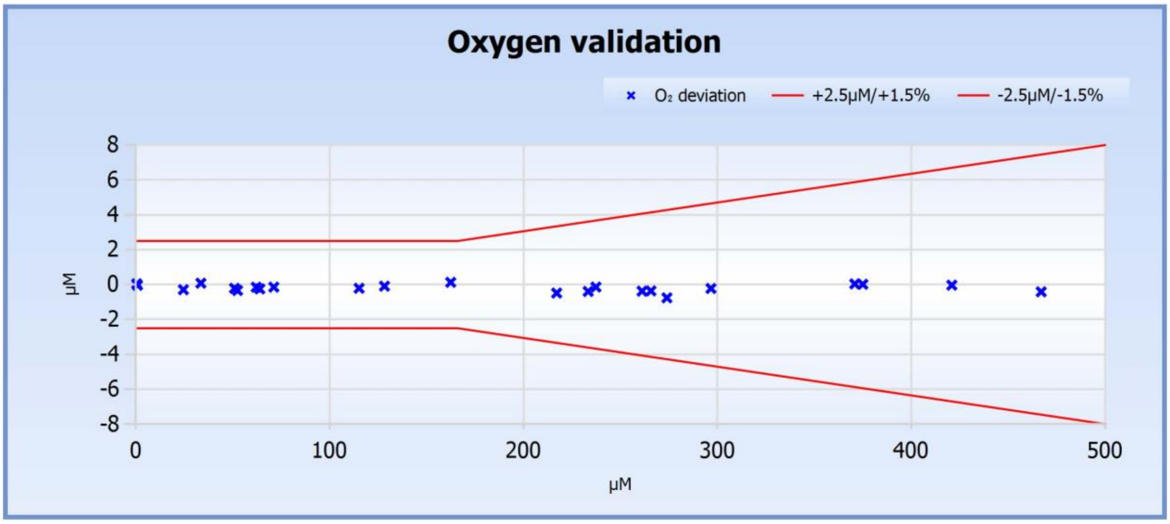
AANDERAA
a xylem brand

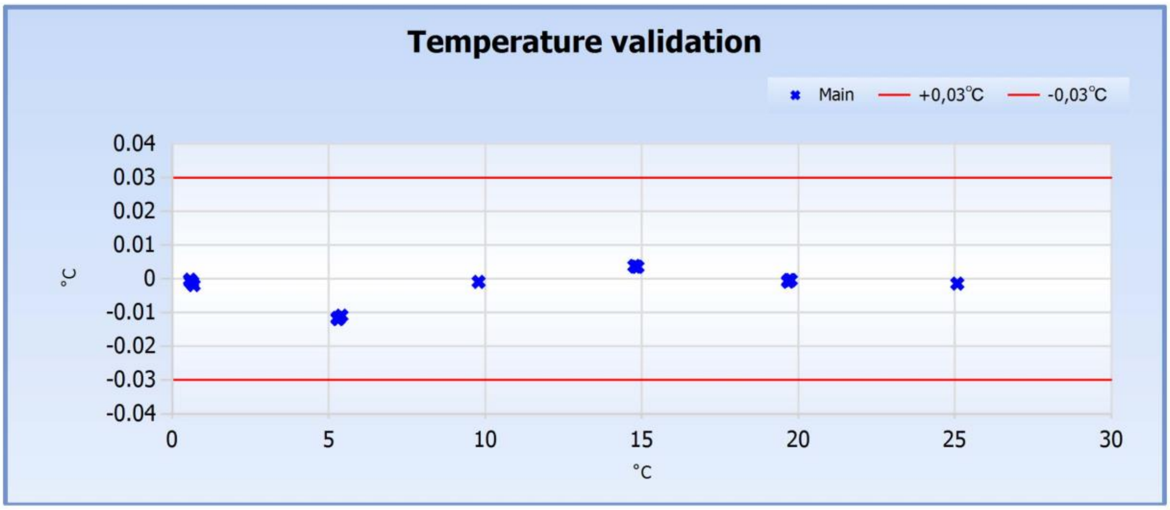
CALIBRATION CERTIFICATE

Form No 830, Juli 2012

Certificate no: 4330_2513_00115020 | Product: 4330 | Serial no: 2513
Foil batch no: 1517M | Calibration date: 22.01.2016 | Page 2 of 2

Index	0	1	2	3	4	5	6
SVUFoilCoef	2.70832E-03	1.15010E-04	2.35887E-06	2.27770E02	-3.74611E-01	-6.30023E01	4.51610E00
TempCoef	2.49364E01	-3.09544E-02	2.91355E-06	-4.33117E-09	0.00000E00	0.00000E00	





Date:22.01.2016

Tor-Ove Kvalvaag, Calibration Engineer