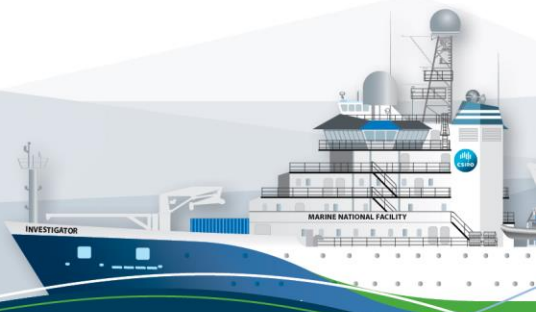
RV *Investigator*

CTD Processing Report

Voyage ID:	IN2019_V07
Voyage title:	RAN Hydrographic and Maritime Heritage Surveys
Depart:	Hobart, 0830 Thursday, 11 April 2019
Return:	Hobart, 0830 Tuesday, 23 April 2019
Report compiled by:	Stephanie Zeliadt



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1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage IN2019_V07, from 11 Apr 2019 – 23 Apr 2019.

Data for 10 deployments were acquired using the Sea-Bird SBE911 CTD 23, fitted with 36 twelve litre bottles on the rosette sampler. Sea-Bird-supplied calibration factors were used to compute the pressures and preliminary conductivity values. CSIRO-supplied calibrations were applied to the temperature data. The data were subjected to automated QC to remove spikes and out-of-range values.

Casts 1, 2, and 3 were test casts to verify the recently serviced secondary altimeter data and no bottles were fired during those deployments.

The final conductivity calibration was based on a single deployment grouping. The final calibration from the secondary sensor had a standard deviation (SD) of 0.0011363 PSU, well within our target of 'better than 0.002 PSU'. The standard product of 1 decibar binned averaged were produced using data from the secondary sensors.

The dissolved oxygen data calibration fit from the secondary sensor had a SD of 0.83634µM. The agreement between the CTD and bottle data was good for the secondary sensor. The primary sensor data had a significant offset from the secondary sensor on deployments 4, 6, and 7.

A Wetlabs CSTAR Transmissometer, Wetlabs CDOM Fluorometer, and PAR sensor were also installed on the auxiliary A/D channels of the CTD.

2 Voyage Details

2.1 Title

RAN Hydrographic and Maritime Heritage Surveys

2.2 Principal Investigators

Emily Jateff

2.3 Voyage Objectives

The scientific objectives for IN2019_V07 were outlined in the Voyage Plan.

For further details, refer to the Voyage Plan and/or summary which can be viewed on the Marine National Facility web site.

2.4 Area of operation

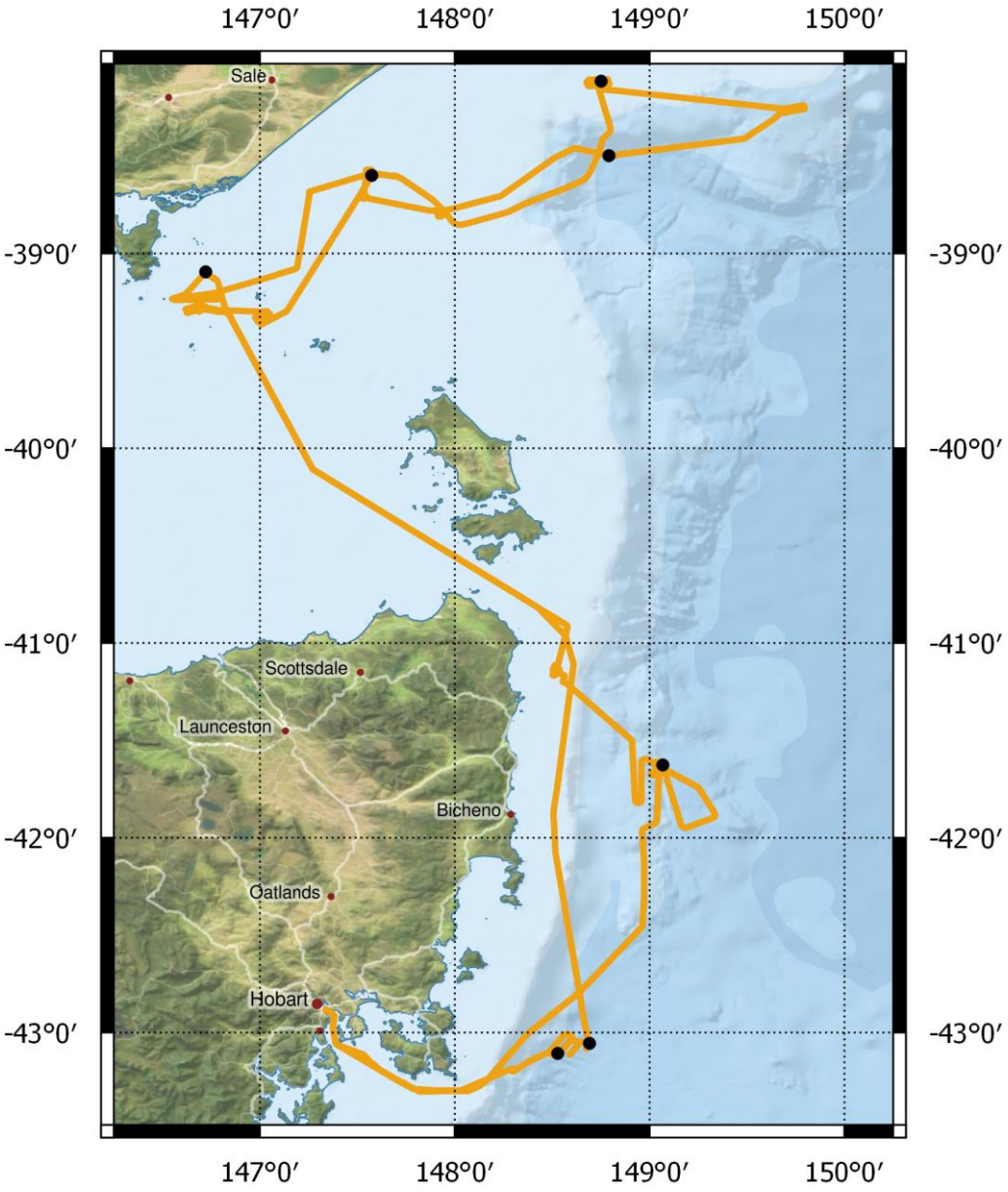


Figure 1 Area of operation for IN2019_V07

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with the CSIRO CTD unit 23, a Sea-Bird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors, a Wetlabs CSTAR Transmissometer, Wetlabs CDOM Fluorometer, and PAR sensor. These sensors are described in Table 1 below.

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1312	P	20-Jul-2018	CSIRO
Primary Temperature	Sea-Bird SBE3*plus*	4522	T0	26-Jun-2018	CSIRO
Secondary Temperature	Sea-Bird SBE3*plus*	4722	T1	26-Jun-2018	CSIRO
Primary Conductivity	Sea-Bird SBE4C	2312	C0	26-Jun-2018	CSIRO
Secondary Conductivity	Sea-Bird SBE4C	3168	C1	26-Jun-2018	CSIRO
Primary Dissolved Oxygen	SBE43	3154	A0	24-May-2018	CSIRO
Secondary Dissolved Oxygen	SBE43	3198	A1	25-May-2018	CSIRO
PAR	QCP – 2300 HP	70111	A3	1-Aug-2018	Manufacturer
Altimeter 1	PA 200	313642	A4	N/A	
Altimeter 2	PA 500	310747	A5	N/A	
Wetlabs ECO – Chlorophyll (A6)	FLBBNTU	5169	A6	24-Aug-2018	Manufacturer
Wetlabs ECO – Scattering (A6)	FLBBNTU	5169	A7	24-Aug-2018	Manufacturer

Table 1 CTD Sensor configuration on IN2019_V07

Water samples were collected using a Sea-Bird SBE911, 36-bottle rosette sampler. Sampling was from 36 twelve litre bottles which were fitted to the frame.

There were 10 deployments and of these, deployments 1, 2, and 3 were shallow cast test runs with no bottles fired.

The raw CTD data were collected in SBE SeaSave version 7.26.4.0, converted to scientific units using SBE Data Processing version 7.26.7.129 and written to netCDF format files with CNV_to_Scan for processing using the Matlab-base, CapPro package version 2.9.

The CapPro software was used to apply automated QC and preliminary processing to the data. This included spike removal, identification of water entry and exit times, conductivity sensor lag corrections and the determination of the pressure offsets. It also loaded the hydrology data and computed the matching CTD sample burst data. The automatically determined pressure offsets and in-water points were inspected.

The bottle sample data were used to compute final conductivity and dissolved oxygen calibrations. These were applied to the data, after which files of binned 1 decibar averaged data were produced.

3.2 Pressure and temperature calibration

The pressure offsets are plotted in Figure 2 below. The blue circles refer to initial out-of-water values and the red circles the final out-of-water values.

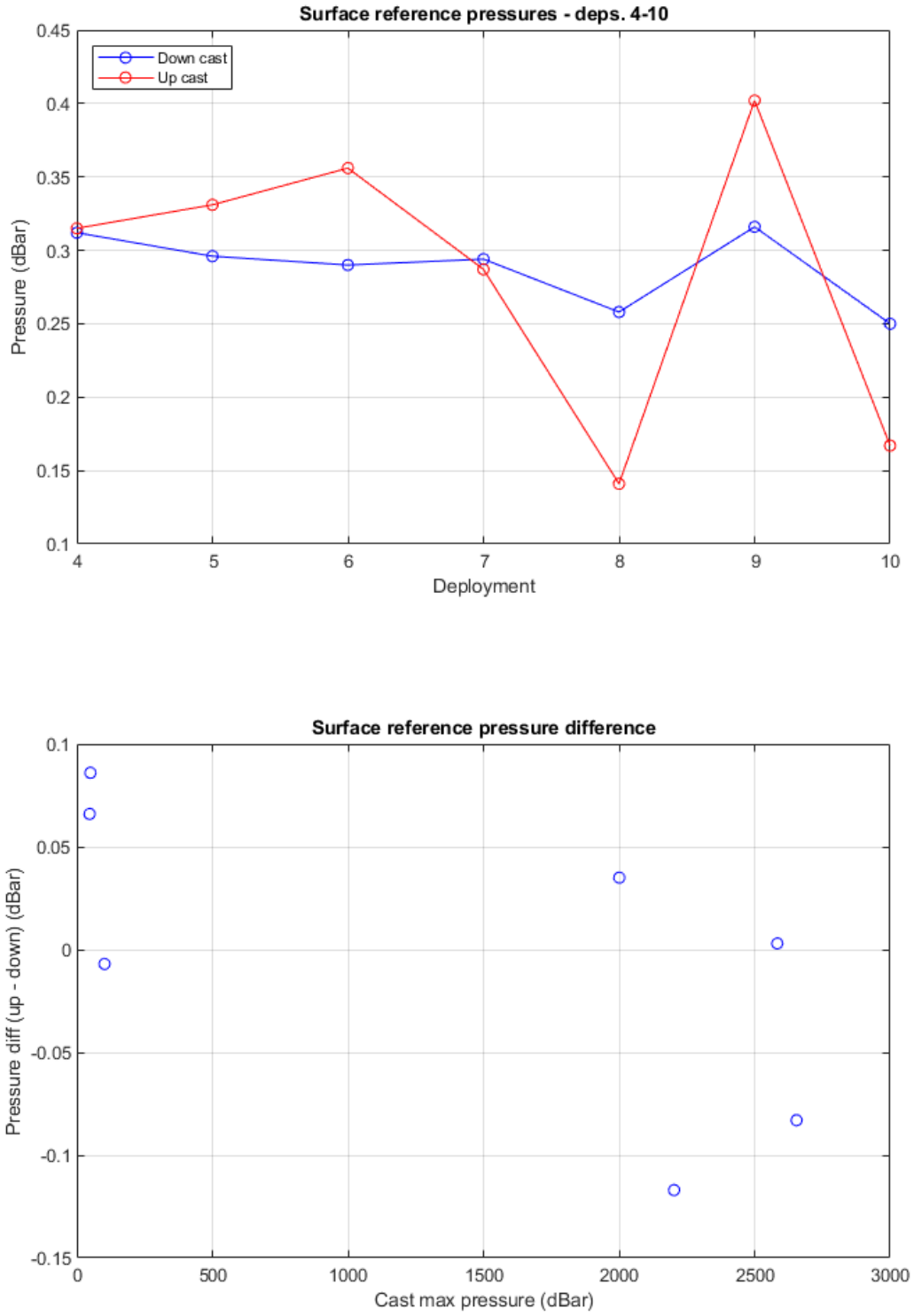


Figure 2 CTD pressure offsets

The difference between the primary and secondary temperature sensors at the bottle sampling depths is plotted below. Most deployments plot within ±0.001°C of zero – outliers result from sampling in regions of high vertical temperature gradient as supported by the similarity between the temperature and conductivity difference shown in Figure 3 and Figure 6. This indicates neither sensor has drifted significantly from its calibration.

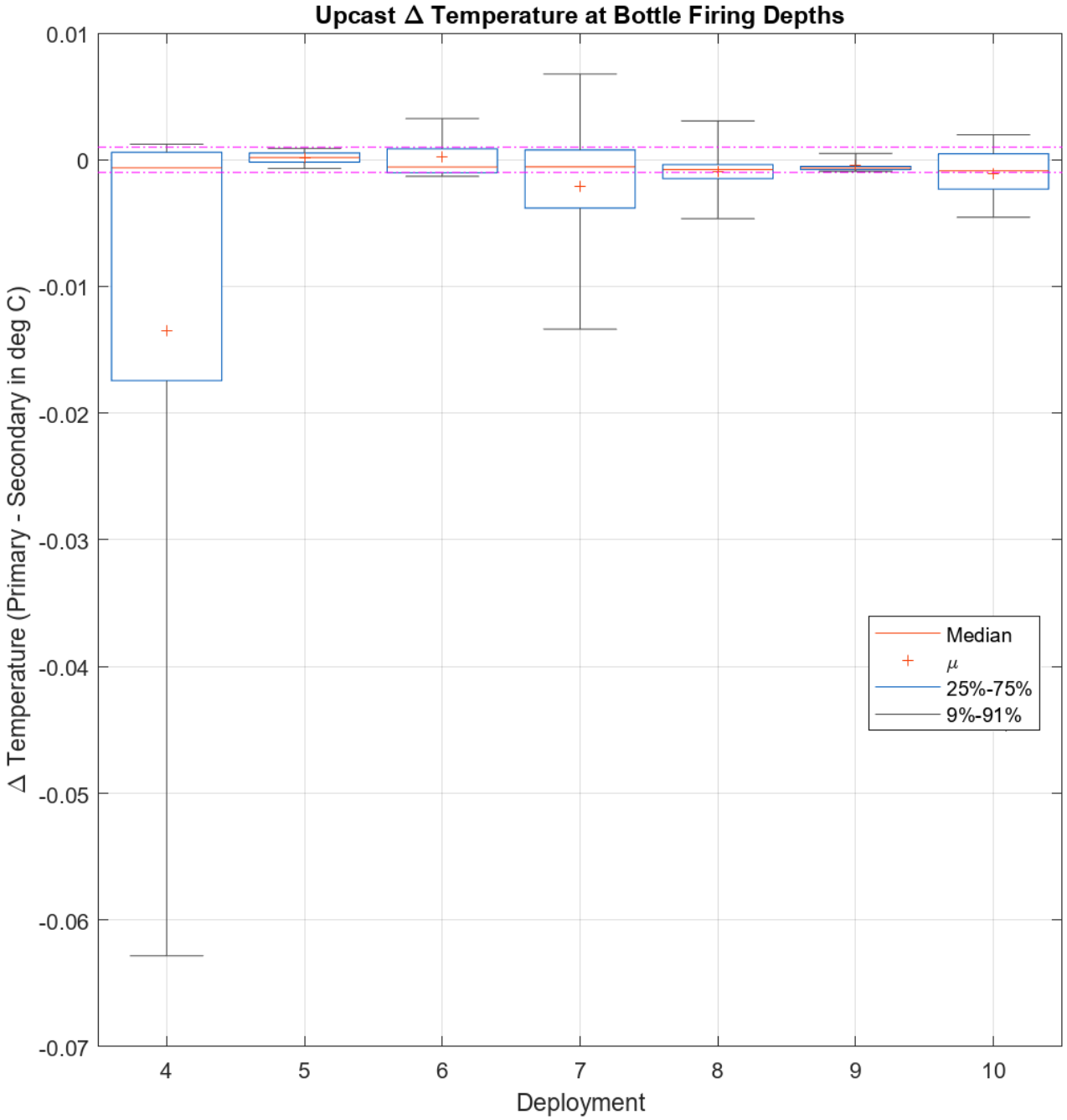


Figure 3 Difference between primary and secondary temperature sensors

3.3 Conductivity Calibration

Discrepancies and possible sampling problems between bottle and CTD salinities for the primary conductivity sensor would show in Figure 4 the plot of calibrated (CTD - Bottle) salinity below. The calibration was based upon the sample data (primary/secondary) for 103/95 of the total of 133 samples taken during deployments which are above our target of 75%.

The outliers marked in Figure 4 below with magenta dots are excluded from the calibration, the outliers marked with blue dots are used in the calibration but are weighted based on their distance from the mean. Any outliers marked with red crosses or dots are also excluded from the calibration.

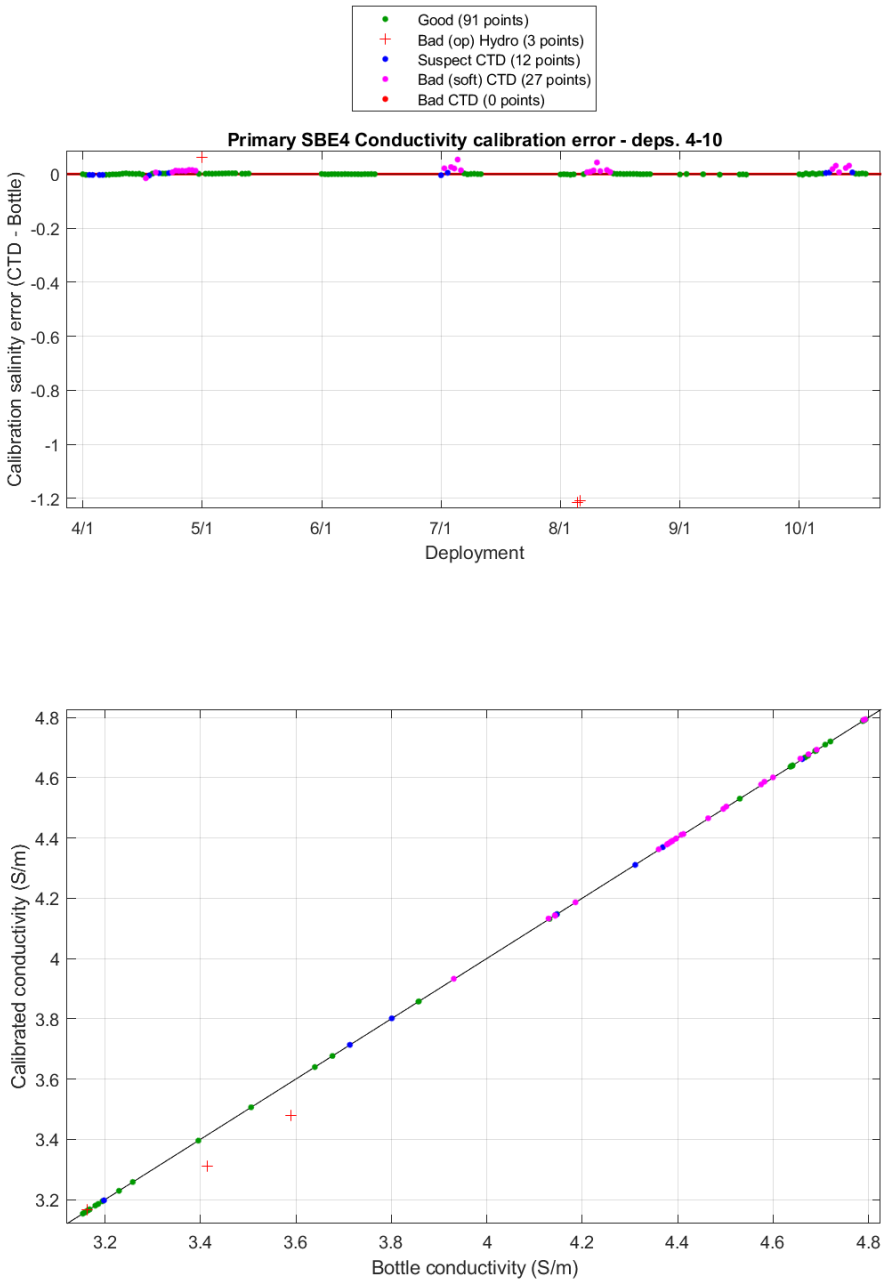


Figure 4 CTD - bottle salinity plot

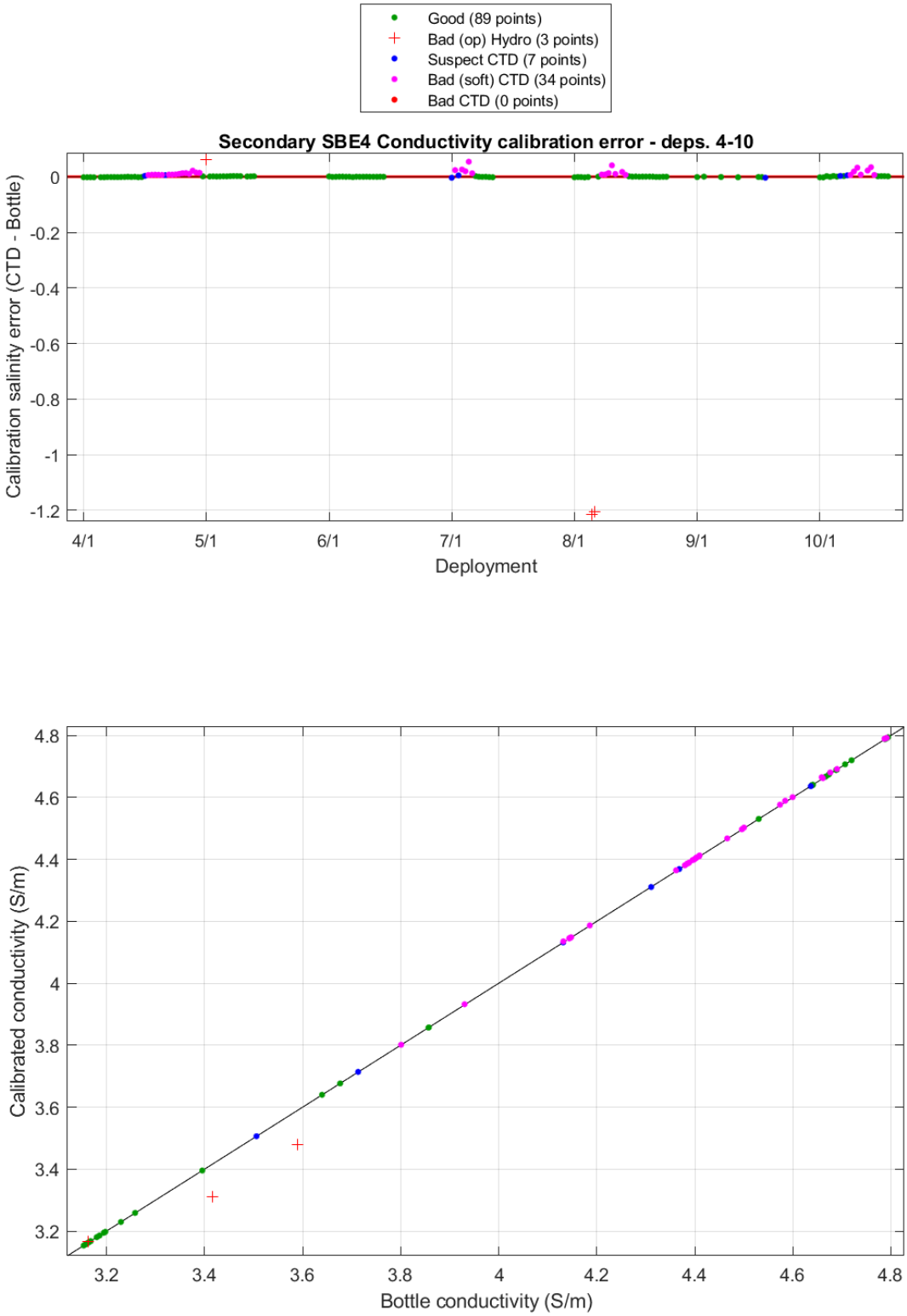


Figure 5 CTD - bottle salinity plot

The box plot of calibrated downcast conductivities (primary – secondary) for all deployments in Figure 6 shows that the calibrated conductivity cell responses corresponded very well.

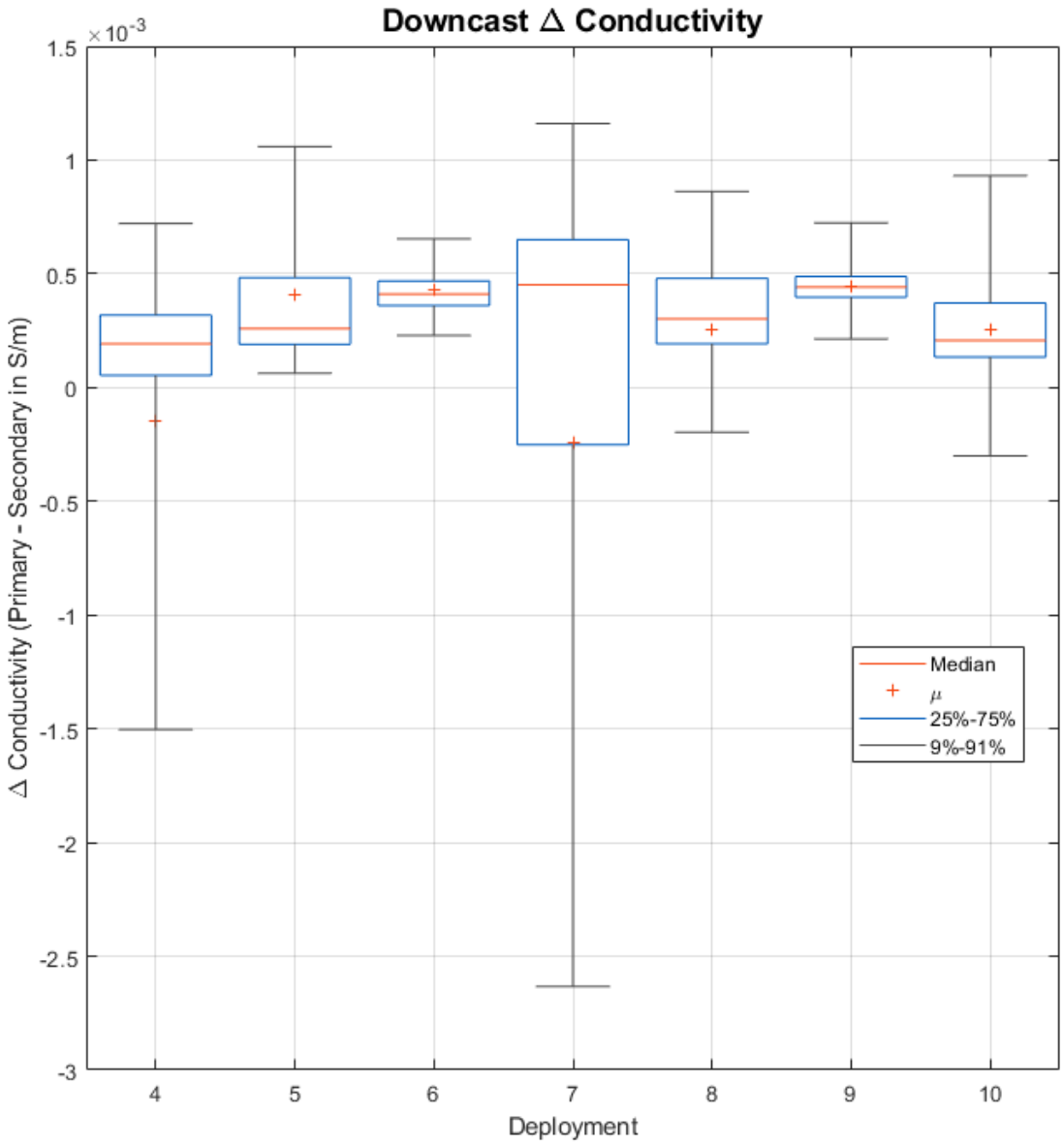


Figure 6 Difference between primary and secondary conductivity sensors

The final result for the primary and secondary conductivity sensors with respect to their original calibrations are shown in Table 2 and Table 3.

Sensor Group	Deployments	Scale Factor		Offset		Salinity (PSU)	
		a1	±	a0	±	Residual SD	M.A.D.
Primary	4-10	0.99983	0.0013331	0.00013456	0.0061073	0.0012688	0.0011004
Secondary	4-10	0.99987	0.0012218	0.00048643	0.0056209	0.0011363	0.0011668

Table 2 Conductivity calibration with respect to manufacturers' calibration coefficients and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	4-10	-1.1042e-07	3.4362e-07
Secondary	4-10	-7.3956e-08	3.1647e-07

Table 3 Calculated CPcor for primary and secondary compared to the manufacturer nominal value of -9.5700e-08

This is a good calibration. We normally aim for a S.D. of 0.002 PSU for 'typical' oceanographic voyages. The above calibration factors were applied to all deployments. Full plots of residuals before and after calibration are available in Conductivity Calibration Residual Plots.

Data from the primary conductivity and temperature sensors were used to produce the averaged salinities with secondary sensors included with a suffix '_2'.

3.4 Dissolved Oxygen Sensor Calibration

3.4.1 SBE calibration procedure

AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage (Sea-Bird, 2013) describes the SBE43 as "a polarographic membrane oxygen sensor having a single output signal of 0 to +5 volts, which is proportional to the temperature-compensated current flow occurring when oxygen is reacted inside the membrane. A Sea-Bird CTD that is equipped with an SBE43 oxygen sensor records this voltage for later conversion to oxygen concentration, using a modified version of the algorithm by Owens and Millard (1985)".

Calibration involves performing a linear regression, as per *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections* (Sea-Bird, 2012) to produce new estimates of the calibration coefficients Soc and $Voffset$. These new coefficients are used, along with the other, manufacturer-supplied coefficients, to derive oxygen concentrations from the sensor voltages.

3.4.2 Results

Deeper casts (>1000m) are known to be affected by pressure-induced hysteresis with this sensor. This is corrected automatically within CapPro using the method discussed in *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections* (Sea-Bird, 2014).

There is a small mismatch between downcast and upcast dissolved oxygen due to the response time of the sensor. No correction for the sensor lag effect has been applied.

Two calibration groups were used with the associated SBE43 up-cast data to compute the new Soc and $Voffset$ coefficients. The deployments 4, 6, and 7 which had a significant offset in the primary sensor were grouped and deployments 5, 8, 9 and 10 with no offset were grouped to provide a better calibration for each deployment set. The plot below is of CTD - bottle oxygen differences for both upcast and downcast data (red indicates 'bad' data; + for upcast and square for downcast).

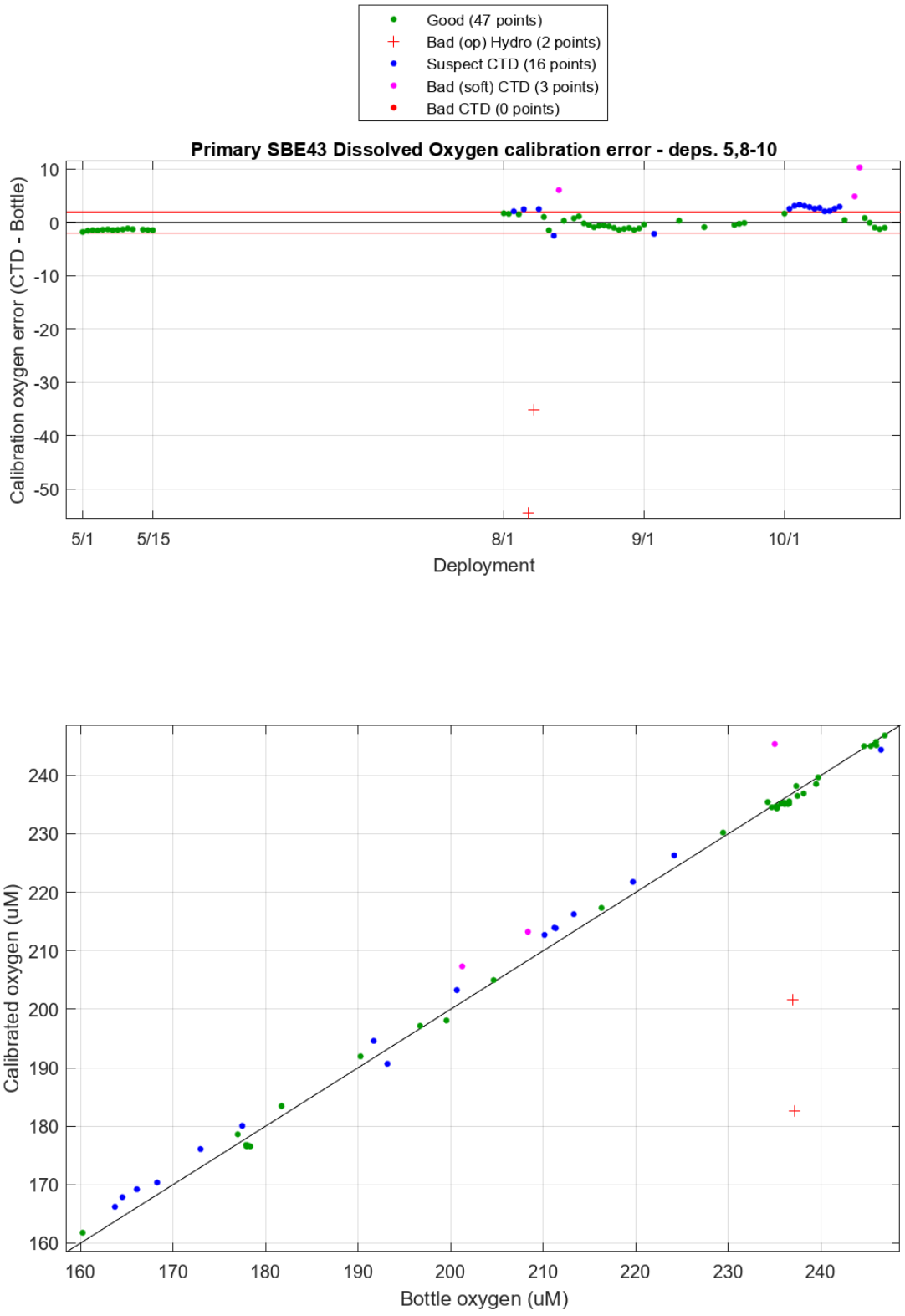


Figure 7 CTD - bottle oxygen plot for primary sensor, deployments 5, 8, 9, 10

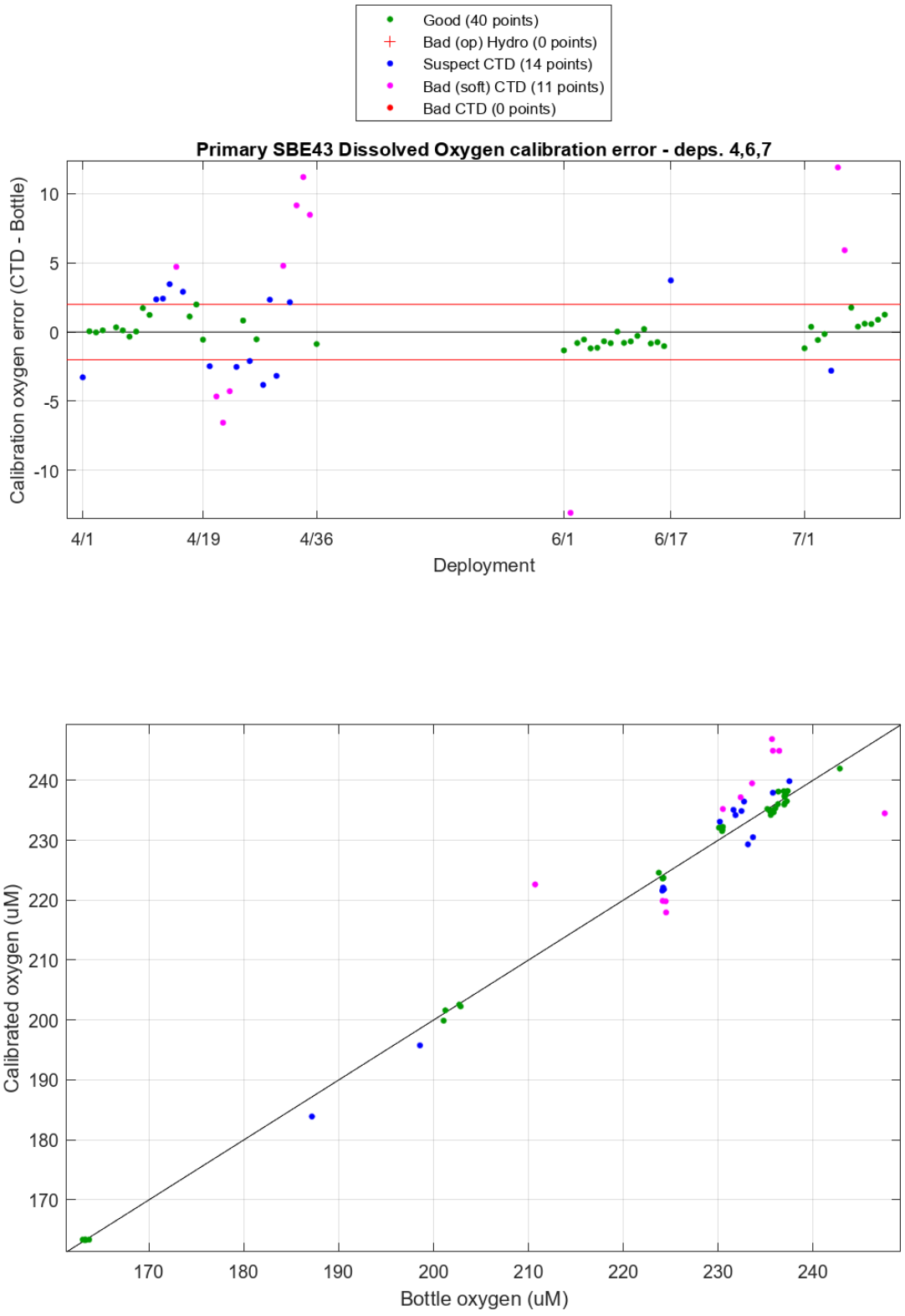


Figure 7 CTD - bottle oxygen plot for primary sensor, deployments 4, 6, 7

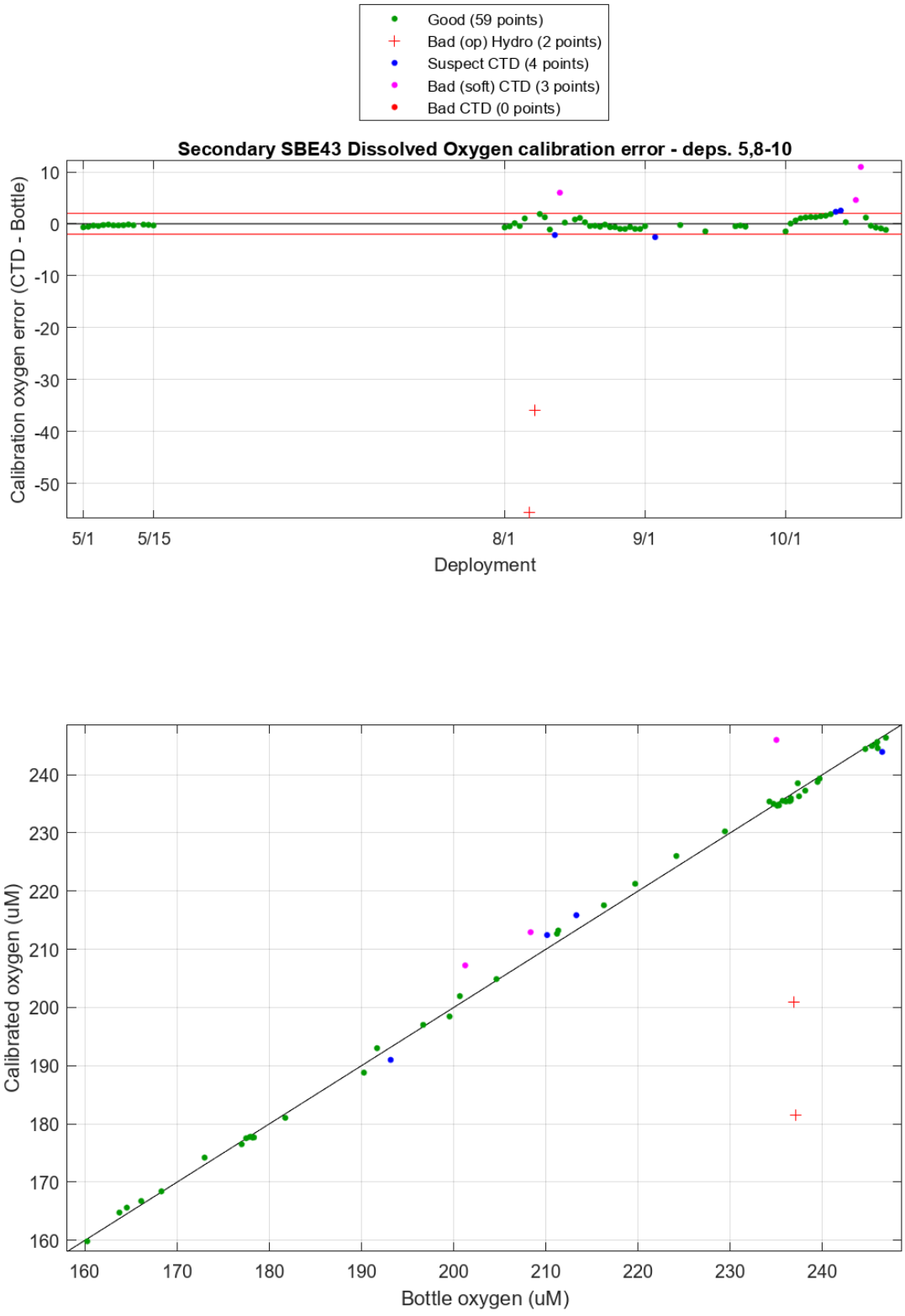


Figure 8 CTD - bottle oxygen plot for secondary sensor, deployments 5, 8, 9, 10

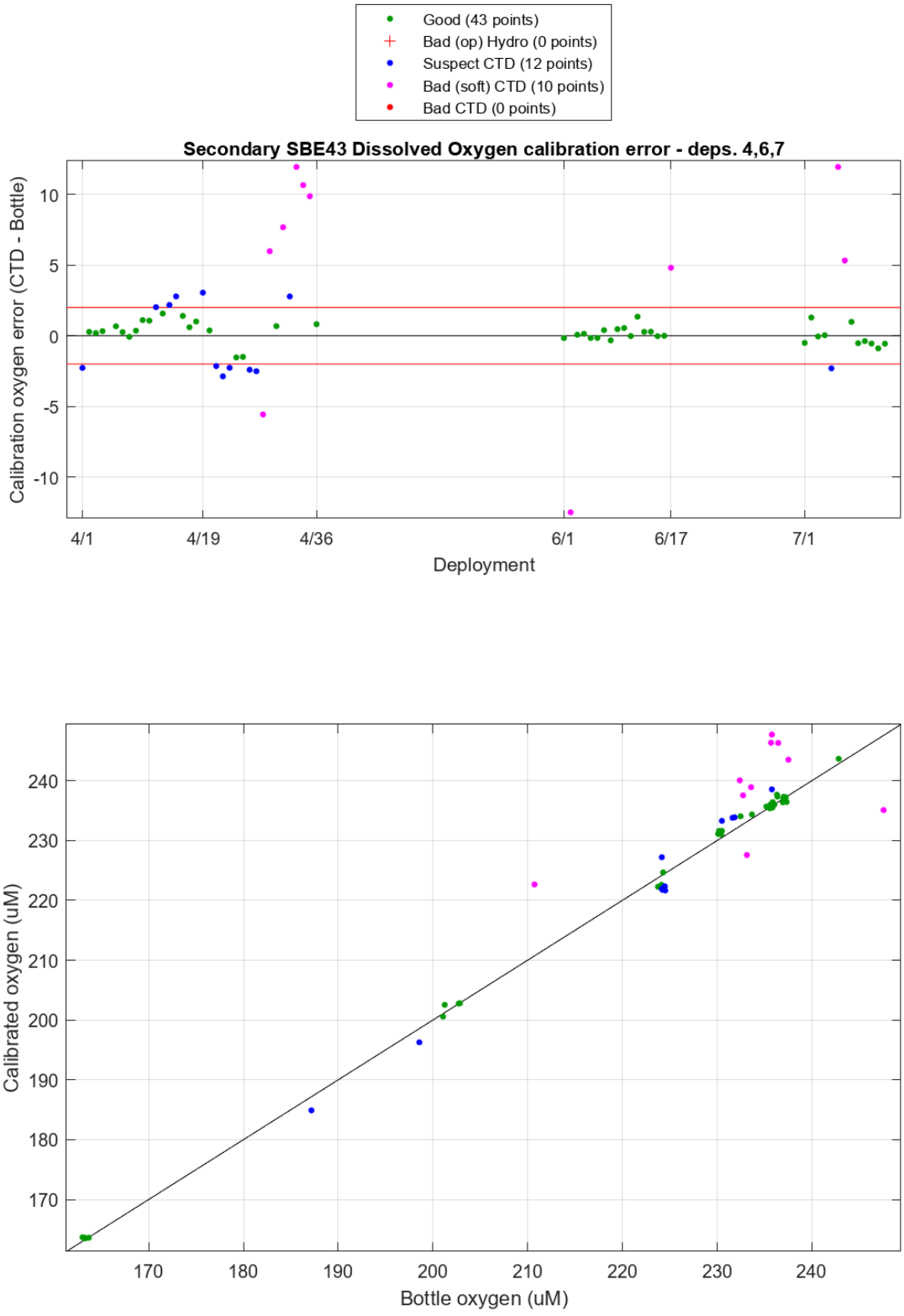


Figure 8 CTD - bottle oxygen plot for secondary sensor, deployments 4, 6, 7

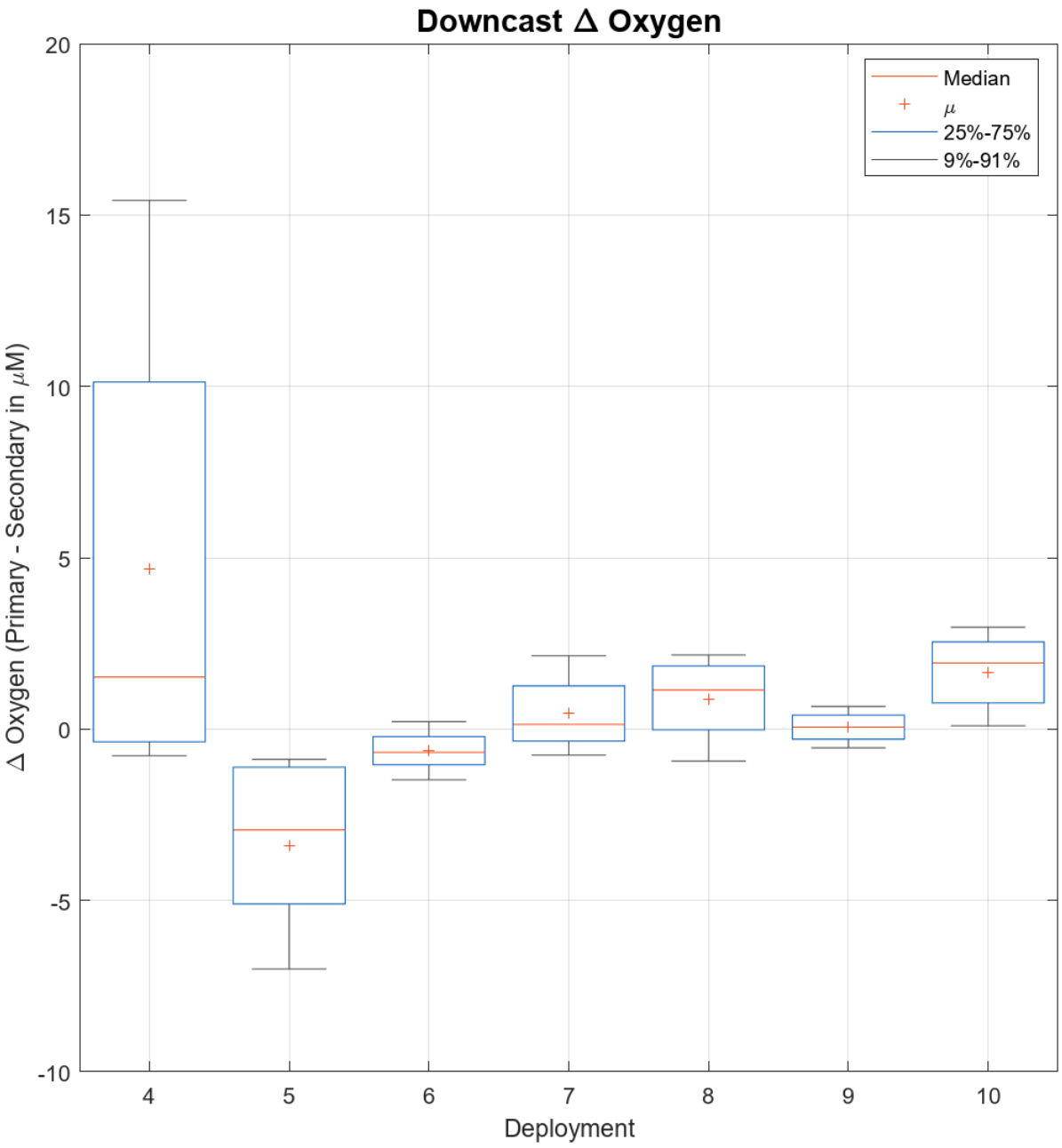


Figure 9 Dissolved Oxygen Difference with downcast CTD data (SBE43 - Bottle)

The old and new *Soc* and *Voffset* values for DO sensors are listed in Table 4 and Table 5 below. The Soc value is a linear slope scaling coefficient; *Voffset* is the fixed sensor voltage at zero oxygen. As expected, over time, the increasing *Soc* scale factors show the SBE43 sensor is losing sensitivity. Full plots of residuals before and after calibration are available in Dissolved Oxygen Calibration Residual Plots.

The calibrations were applied for each sensor and the averaged files were created using the result from the secondary sensor.

Sensor	Calibration Source	Deployments	Calibration Coefficients				Dissolved Oxygen (µM)	
			Voffset	±	*Soc*	±	Residual SD	M.A.D.
Primary DO	Hydrochemistry	5, 8, 9, 10	-0.47522	0.0066139	0.42292	0.0018642	0.82897	1.3671
	Sea-Bird	5, 8, 9, 10	-0.53160		0.52312			
Secondary DO	Hydrochemistry	5, 8, 9, 10	-0.49049	0.003623	0.43054	0.0010531	0.61732	0.64117
	Sea-Bird	5, 8, 9, 10	-0.49890		0.41551			

Table 4 Dissolved oxygen calibrations deployments 5, 8, 9, 10

Sensor	Calibration Source	Deployments	Calibration Coefficients				Dissolved Oxygen (µM)	
			Voffset	±	*Soc*	±	Residual SD	M.A.D.
Primary DO	Hydrochemistry	4, 6, 7	-0.58988	0.0085298	0.4664	0.0023494	1.0644	0.8477
	Sea-Bird	4, 6, 7	-0.53160		0.52312			
Secondary DO	Hydrochemistry	4, 6, 7	-0.50323	0.0070234	0.4338	0.0016665	0.9068	0.56354
	Sea-Bird	4, 6, 7	-0.49890		0.41551			

Table 5 Dissolved oxygen calibrations deployments 4, 6, 7

3.5 Other sensors

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
PAR	QCP – 2300 HP	70111	A3	1-Aug-2018	Manufacturer
Altimeter 1	PA 200	313642	A4	N/A	
Altimeter 2	PA 500	310747	A5	N/A	
Wetlabs ECO – Chlorophyll (A6)	FLBBNTU	5169	A6	24-Aug-2018	Manufacturer
Wetlabs ECO – Scattering (A6)	FLBBNTU	5169	A7	24-Aug-2018	Manufacturer

Table 6 Additional Sensor Configuration

The WET labs ECO Fluorometer-Scattering sensor was used for all deployments. The fluorometer has been calibrated with manufacturer supplied coefficients to give outputs in mg/m3. The scattering (OBS) has been calibrated with manufacturer supplied coefficients to give outputs in m-1/sr.

The Biospherical PAR sensor was also used for all deployments. The output is a nominal 0-5 volts which is converted to the unit µEinsteins/m2/second using manufacturer supplied wet calibration factor and the dark voltage determined at calibration. This data channel has been included in the output files for all deployments. Clearly, time of day and environmental factors such as sea state and cloud cover impact on

these readings. If most or all of the values for a deployment are near zero it indicates a night-time cast. In deployments where the PAR profiles have sub-surface maxima the CTD may have been shaded by the ship.

3.6 Bad data detection

The limits for each sensor are configured in CNV_to_Scan conversion software and are written to the netCDF scan file. Typical limits used for the sensor range and maximum second difference are in Table 7 below. The rejection rate is recorded in the CapPro processing log file.

Sensor	Range minimum	Range maximum	Maximum Second Difference
Pressure	-7	6500	0.5
Temperature	-2	40	0.05
Conductivity	-0.01	7	0.01
Oxygen	-1	500	0.5
Fluorometer	0	100	0.5
PAR	-5	2000	0.5
Transmissometer	0	100	0.5

Table 7 Sensor limits for bad data detection

3.7 Averaging

The calibrated data were 'filtered' to remove pressure reversals and binned into the standard product of 1 decibar averaged netCDF files. The binned values were calculated by applying a linear, least-squares fit as a function of pressure to the sensor data for each bin, using this to interpolate the value for the bin mid-point. This method is used to avoid possible biases which would result from averaging with respect to time.

Each binned parameter is assigned a QC flag. Our quality control flagging scheme is described in *Data Quality Control Flags* (Pender, 2000).

The QC Flag for each bin is estimated from the values for the bin components. The QC Flag for derived quantities, such as Salinity and Dissolved Oxygen are taken to be the worst of the estimates for the parameters from which they are derived.

4 References

Jateff, Emily. (2019). *The RV Investigator. Voyage Plan* IN2019_V07. Retrieved from Marine National Facility: Voyage Plans and summaries: http://mnf.csiro.au/Voyages/Investigator-schedules/Plans-and-summaries/

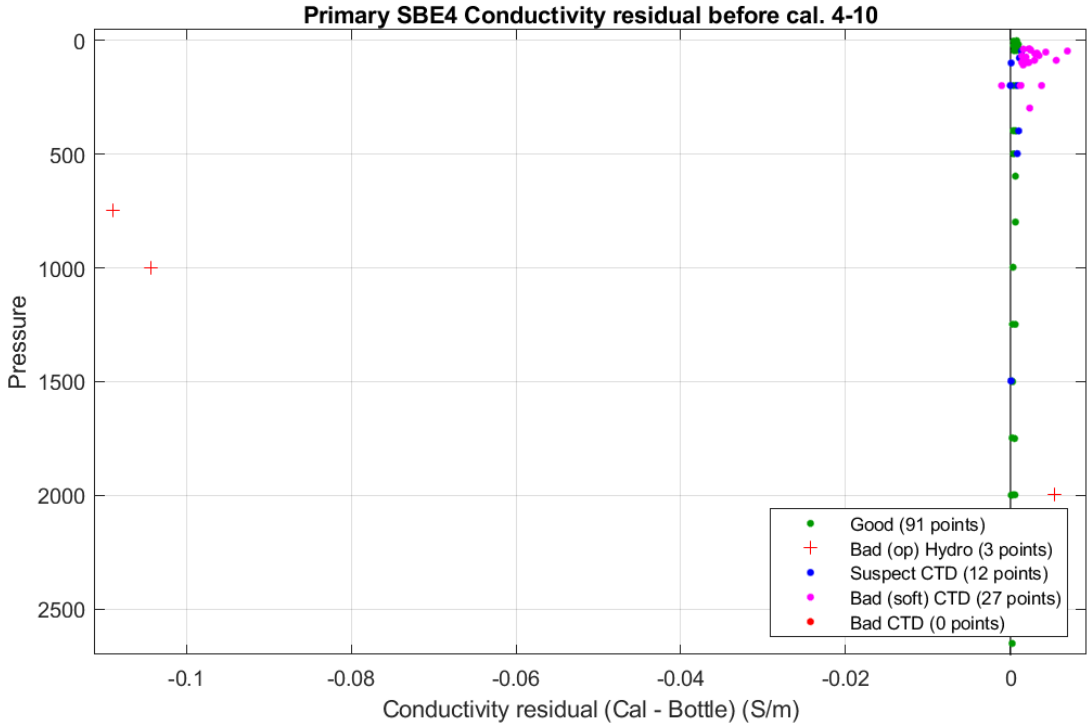
Pender, L. (2000). *Data Quality Control Flags.* Retrieved from Oceans & Atmosphere Information and Data Centre: http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

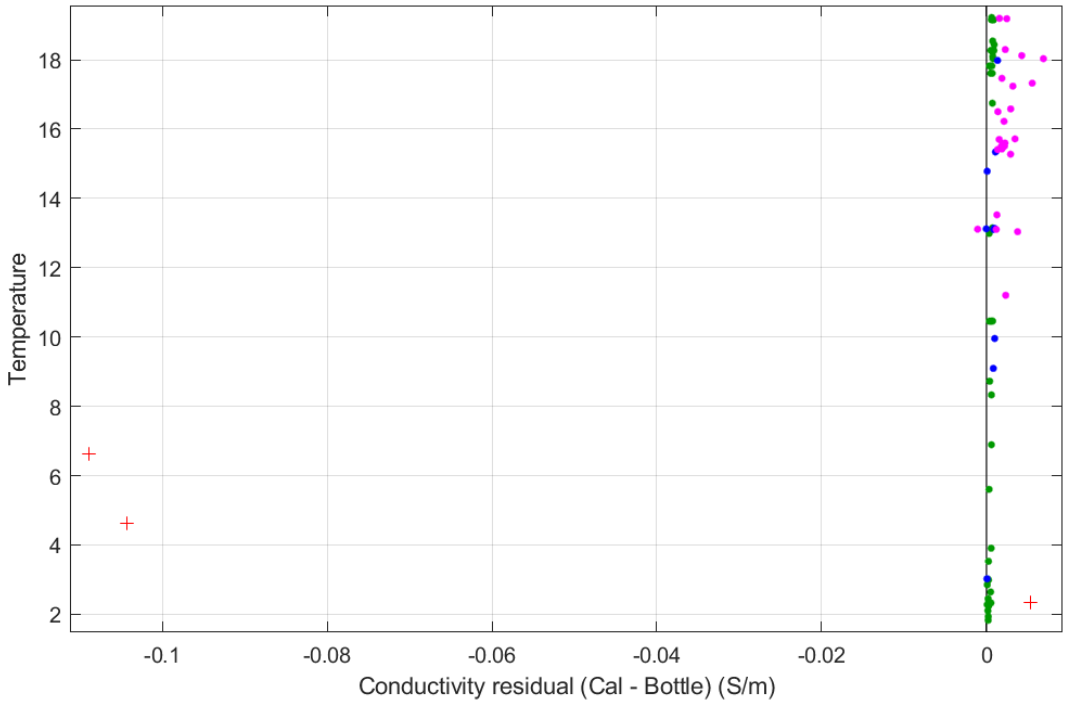
Sea-Bird. (2012). *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-2-sbe-43-dissolved-oxygen-sensor-calibration-and-data-corrections

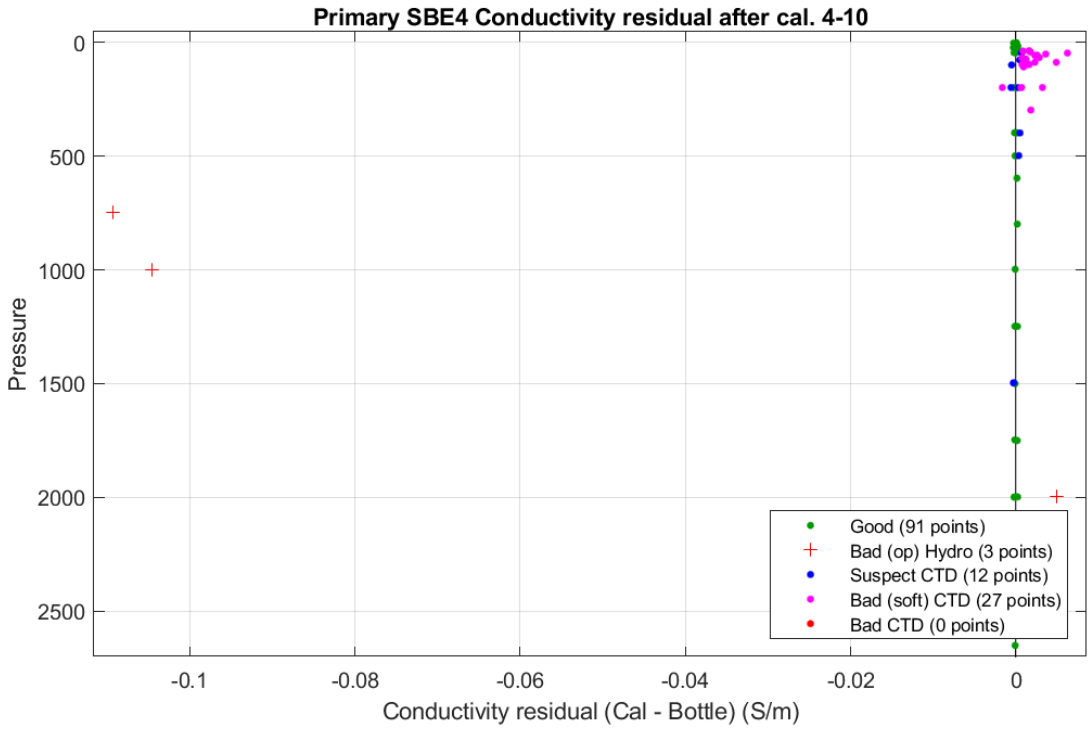
Sea-Bird. (2013). *AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-sbe-43-dissolved-oxygen-sensor-background-information-deployment-recommendations

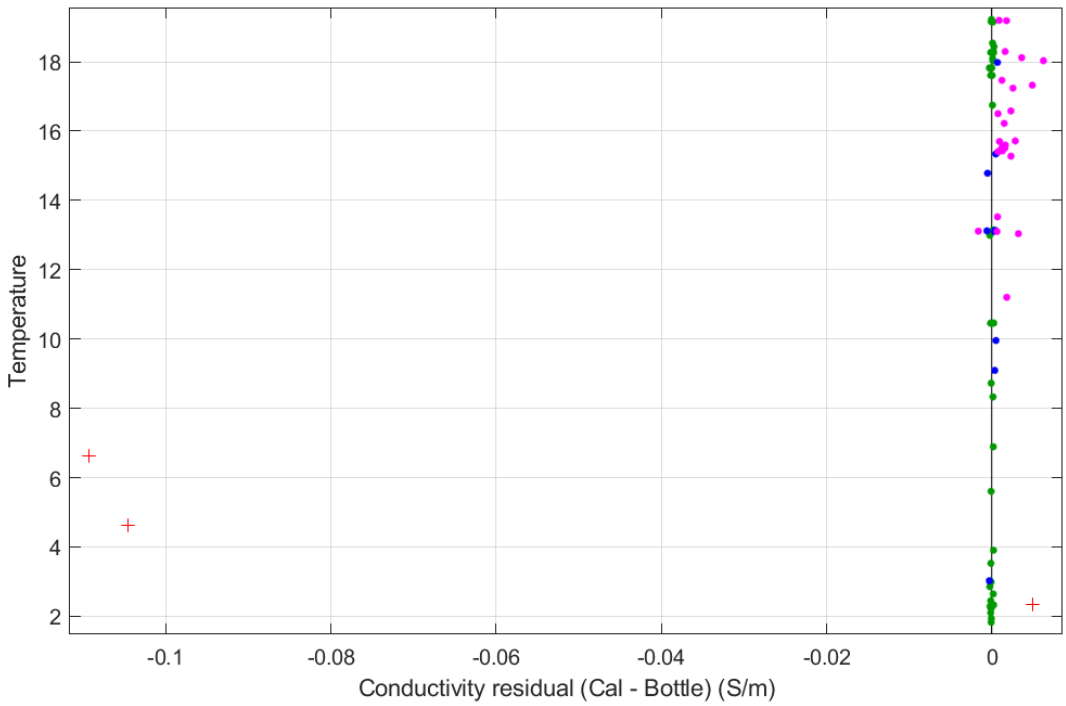
Sea-Bird. (2014). *AN64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-3-sbe-43-dissolved-oxygen-do-sensor-hysteresis-corrections

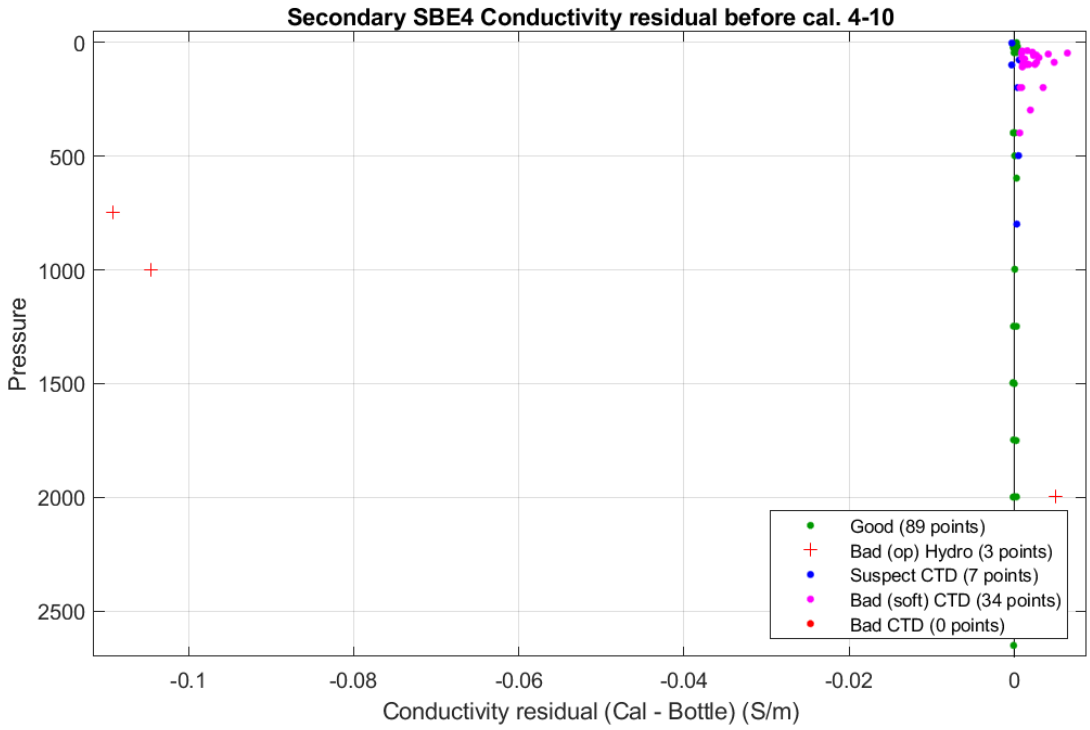
Appendix I: Conductivity Calibration Residual Plots

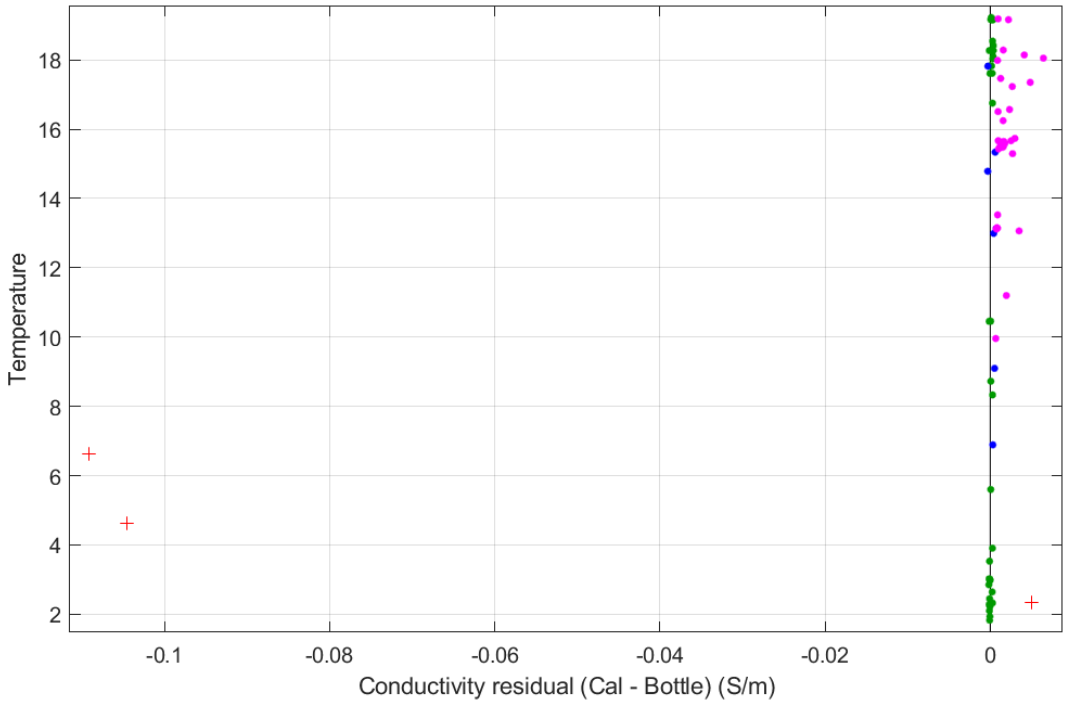


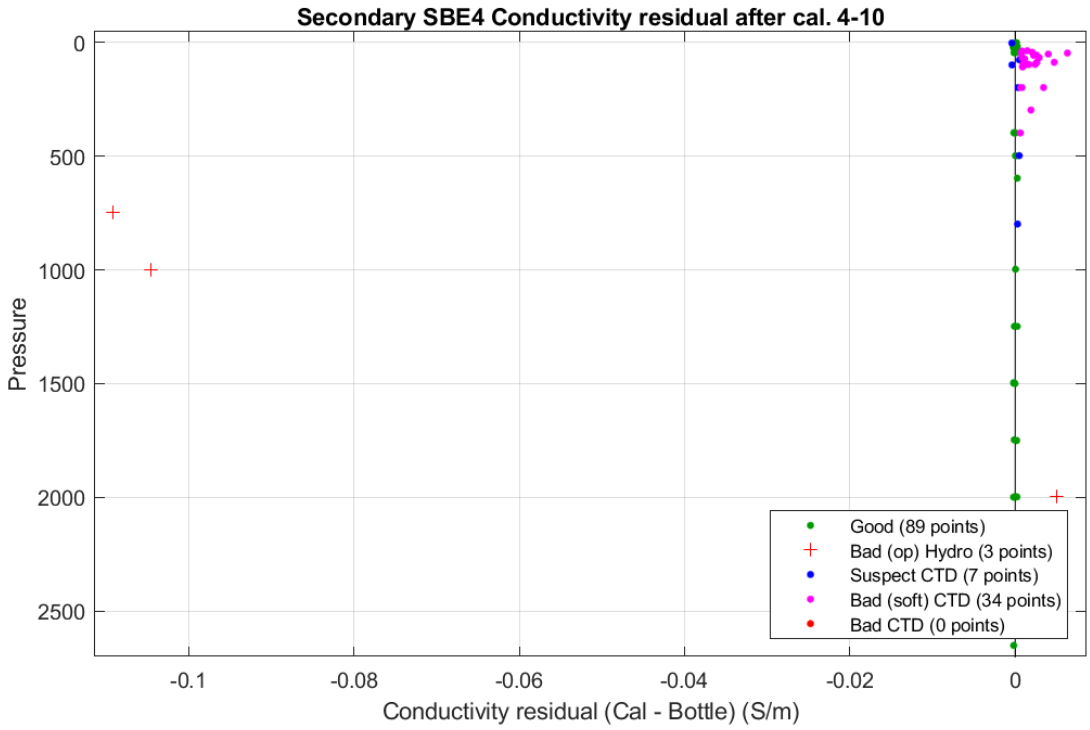


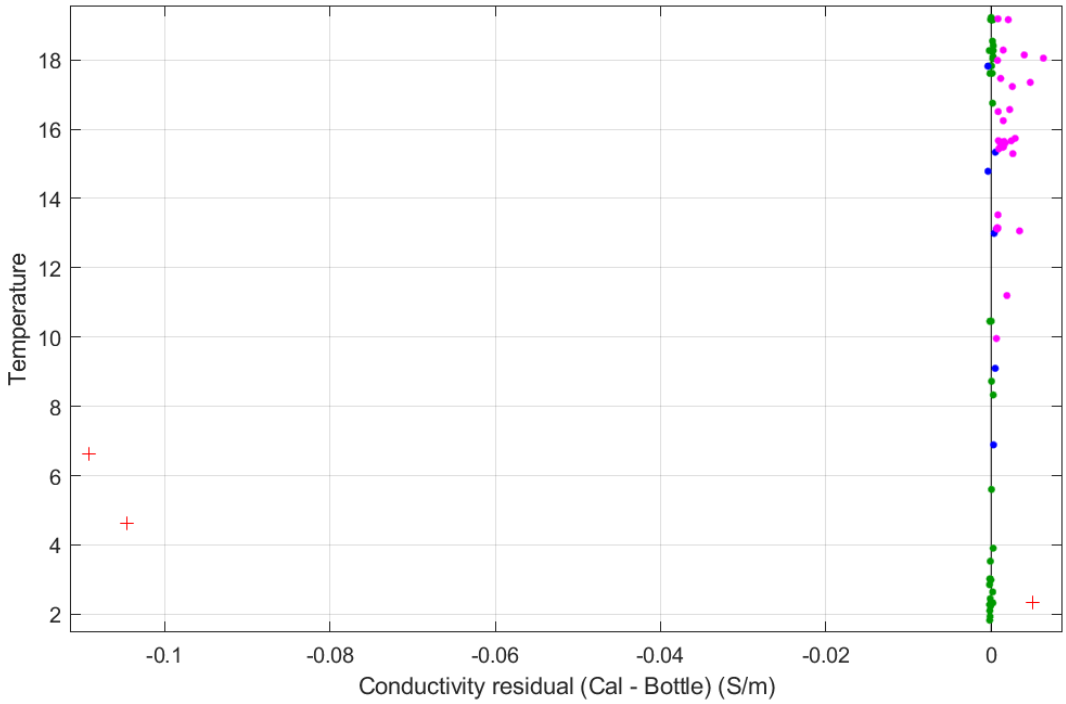

Primary SBE4 Conductivity residual after cal. 4-10
Pressure
0
500
1000
1500
2000
2500
-0.1
-0.08
-0.06
-0.04
-0.02
0
Conductivity residual (Cal - Bottle) (S/m)
Good (91 points)
Bad (op) Hydro (3 points)
Suspect CTD (12 points)
Bad (soft) CTD (27 points)
Bad CTD (0 points)


Temperature
18
16
14
12
10
8
6
4
2
-0.1
-0.08
-0.06
-0.04
-0.02
0
Conductivity residual (Cal - Bottle) (S/m)

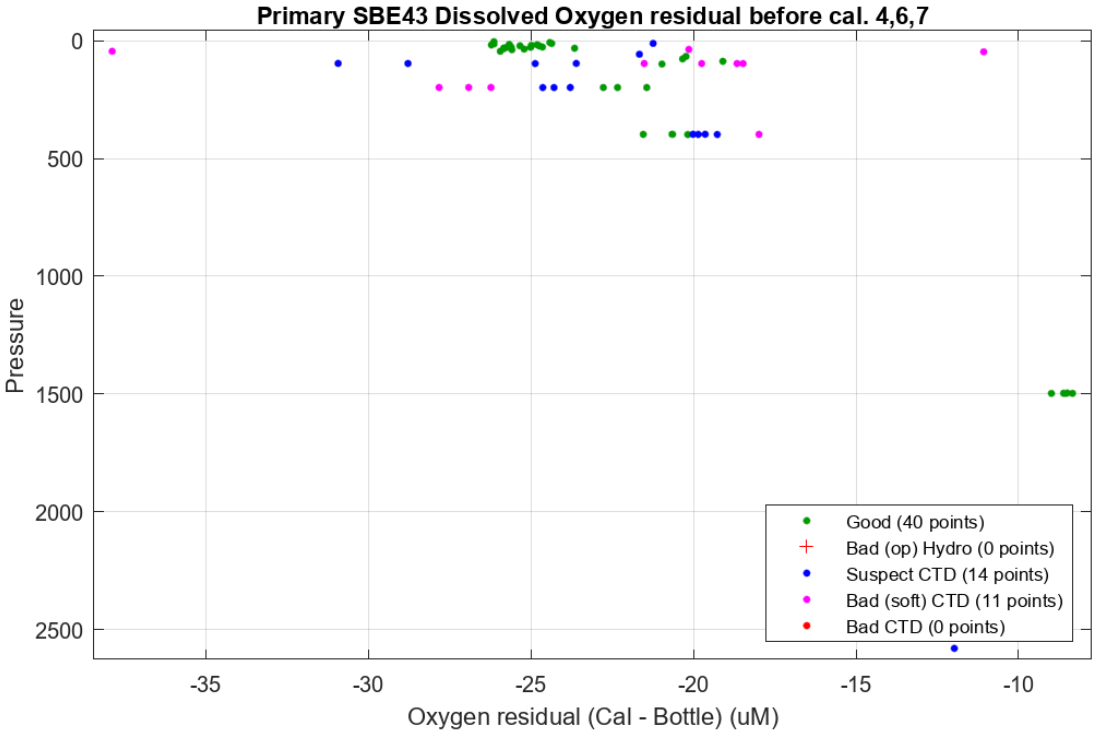

Secondary SBE4 Conductivity residual before cal. 4-10
Pressure
0
500
1000
1500
2000
2500
-0.1
-0.08
-0.06
-0.04
-0.02
0
Conductivity residual (Cal - Bottle) (S/m)
Good (89 points)
Bad (op) Hydro (3 points)
Suspect CTD (7 points)
Bad (soft) CTD (34 points)
Bad CTD (0 points)

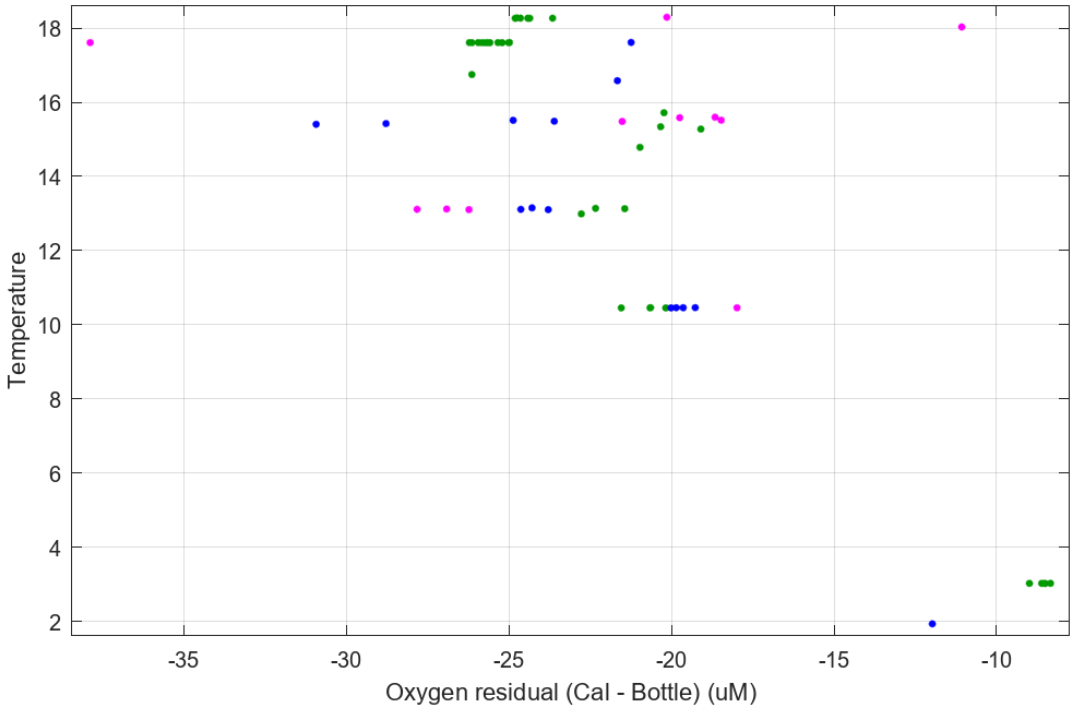

Temperature
18
16
14
12
10
8
6
4
2
-0.1
-0.08
-0.06
-0.04
-0.02
0
Conductivity residual (Cal - Bottle) (S/m)

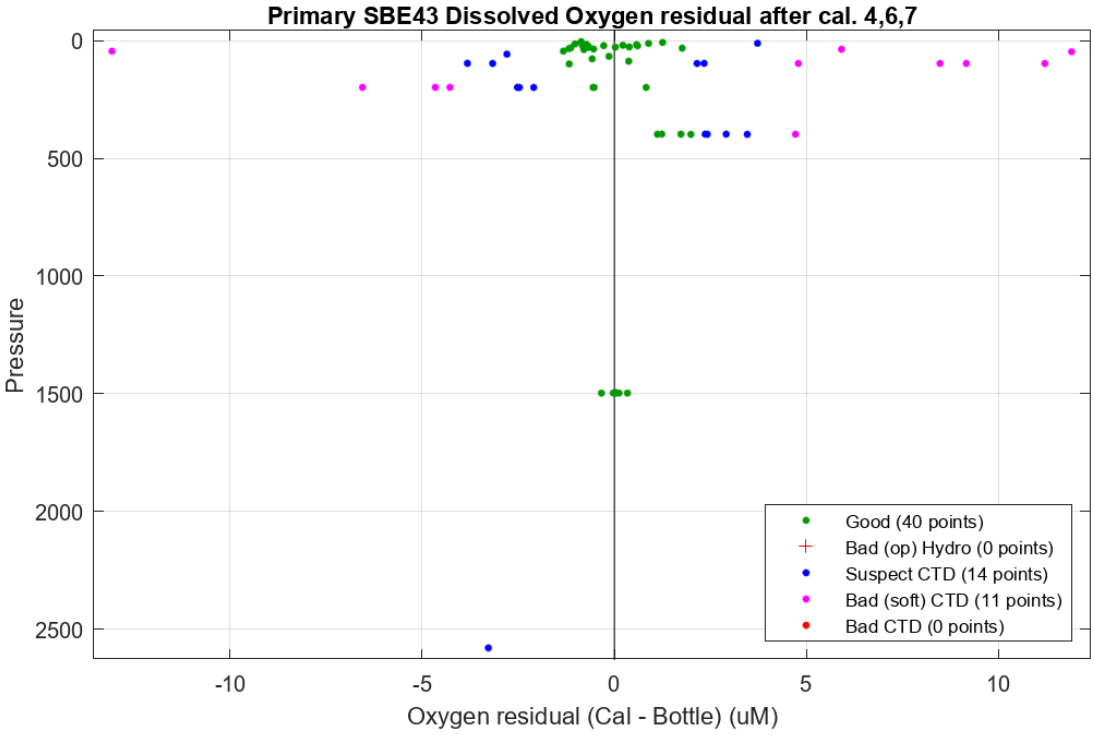

Secondary SBE4 Conductivity residual after cal. 4-10
Pressure
0
500
1000
1500
2000
2500
-0.1
-0.08
-0.06
-0.04
-0.02
0
Conductivity residual (Cal - Bottle) (S/m)
Good (89 points)
Bad (op) Hydro (3 points)
Suspect CTD (7 points)
Bad (soft) CTD (34 points)
Bad CTD (0 points)

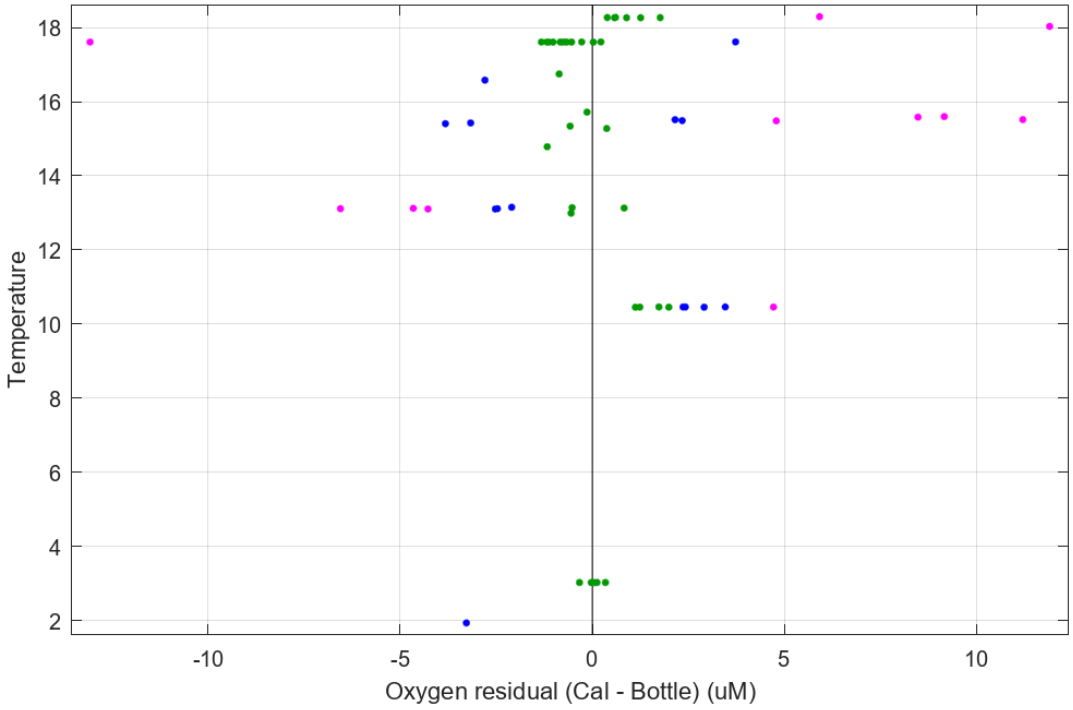

Temperature
18
16
14
12
10
8
6
4
2
-0.1
-0.08
-0.06
-0.04
-0.02
0
Conductivity residual (Cal - Bottle) (S/m)

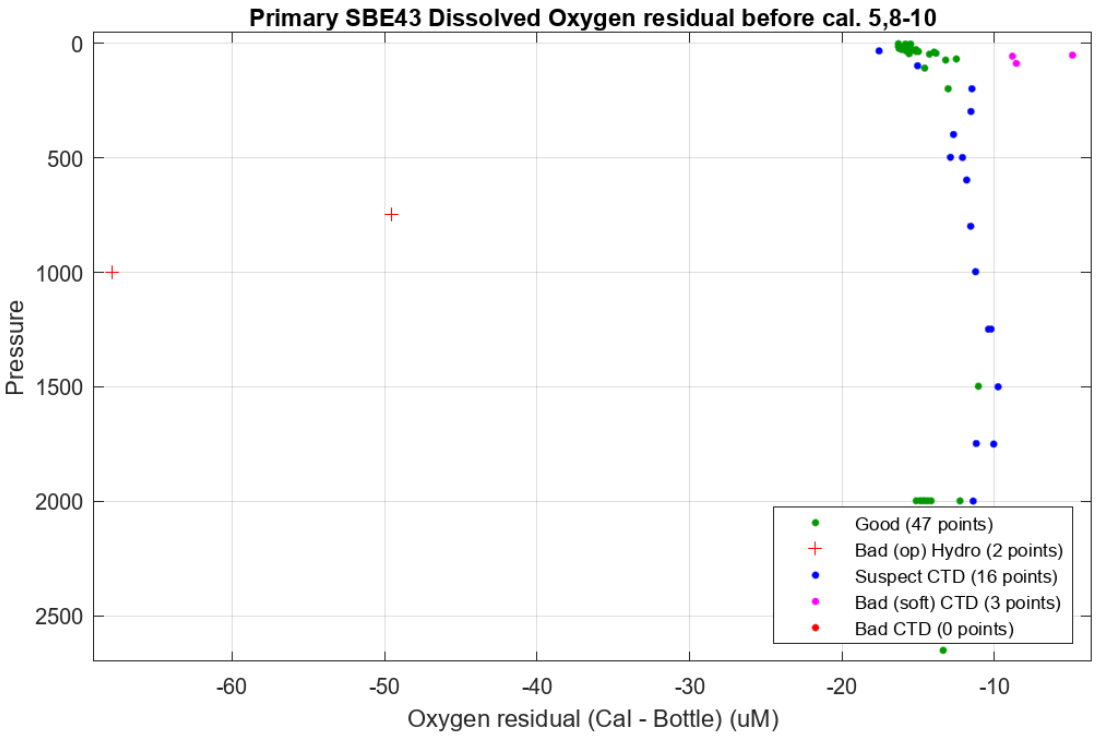
Appendix II: Dissolved Oxygen Calibration Residual Plots

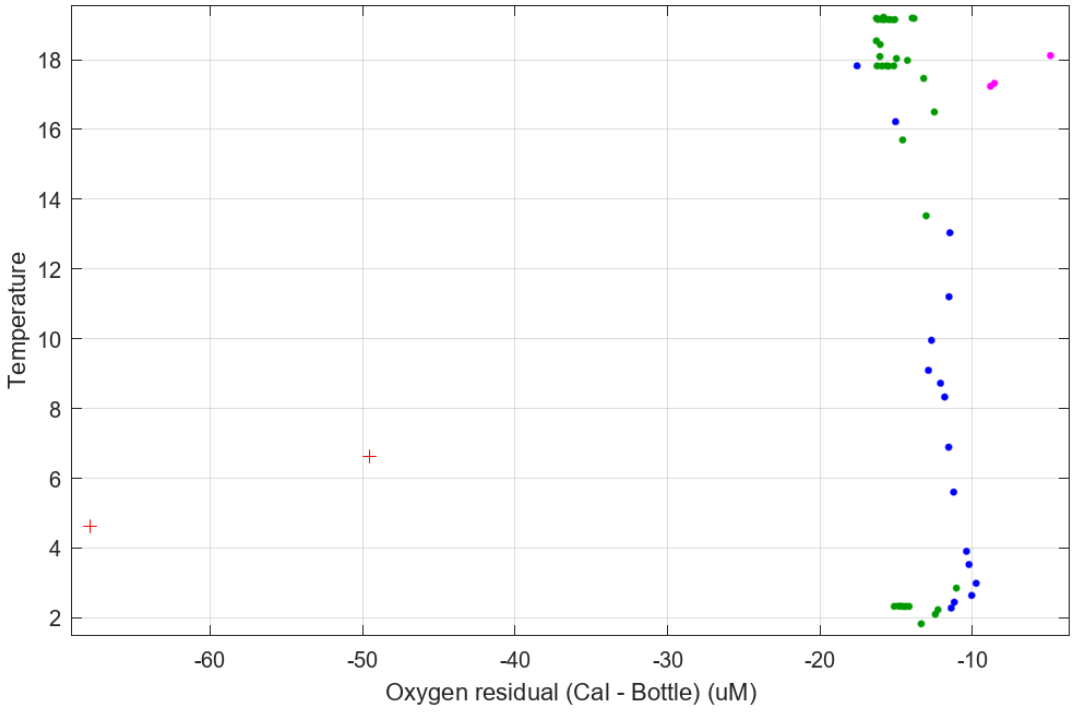


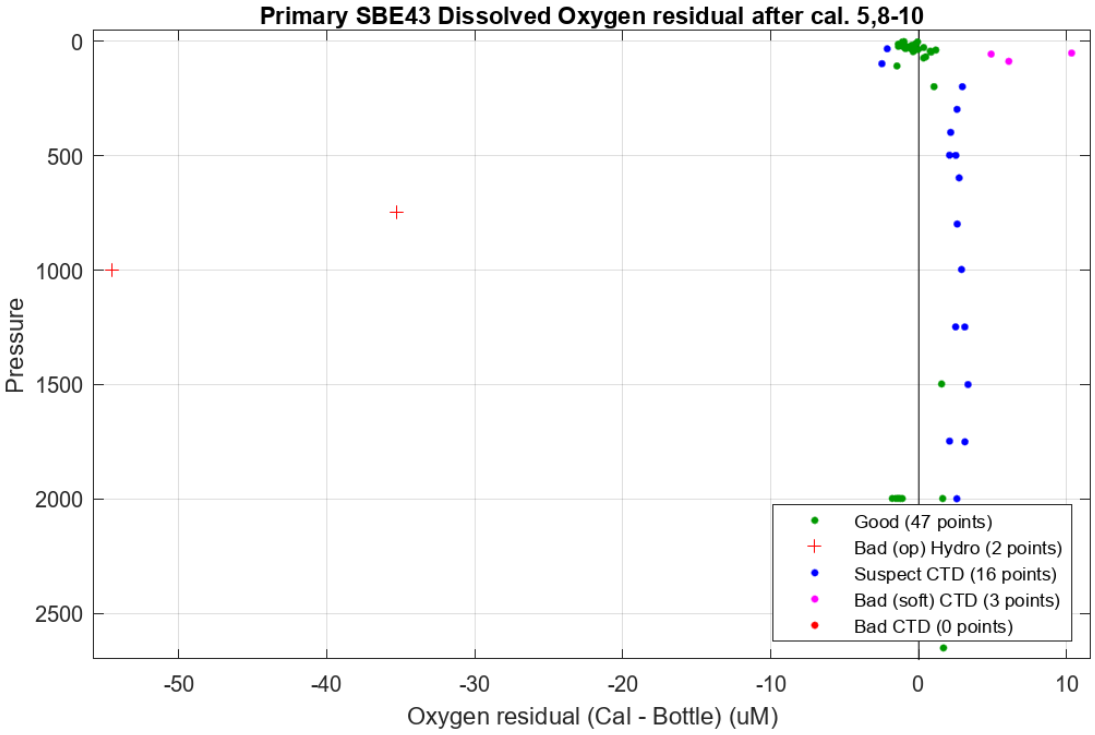


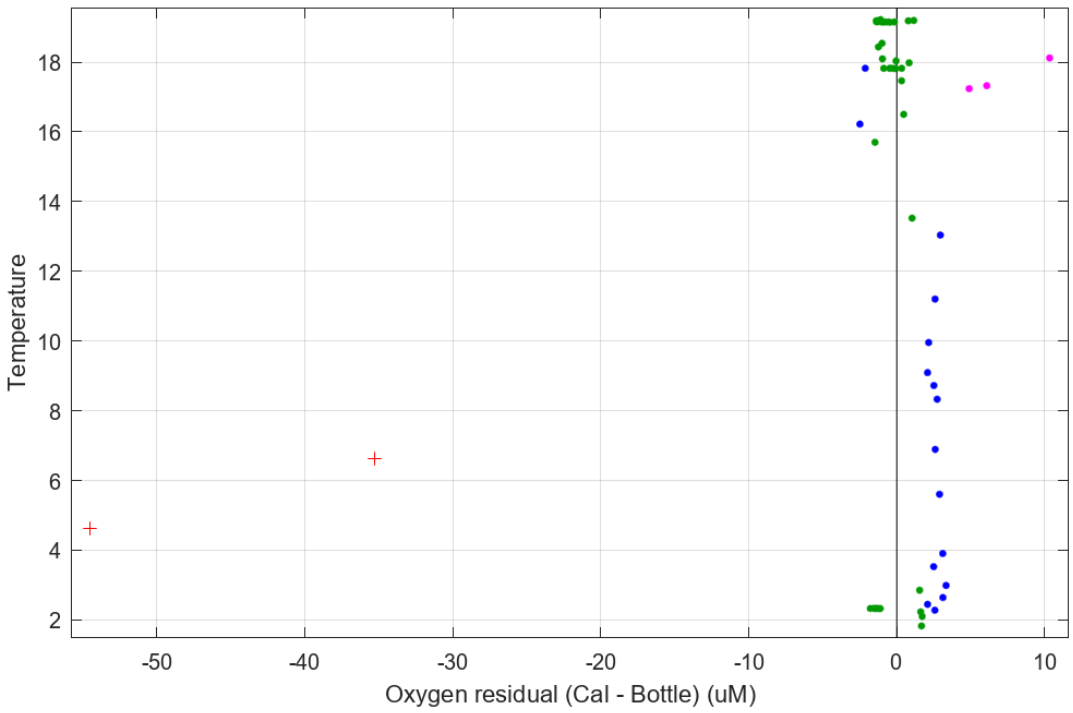

Primary SBE43 Dissolved Oxygen residual after cal. 4,6,7
Pressure
0
500
1000
1500
2000
2500
-10
-5
0
5
10
Oxygen residual (Cal - Bottle) (uM)
Good (40 points)
Bad (op) Hydro (0 points)
Suspect CTD (14 points)
Bad (soft) CTD (11 points)
Bad CTD (0 points)

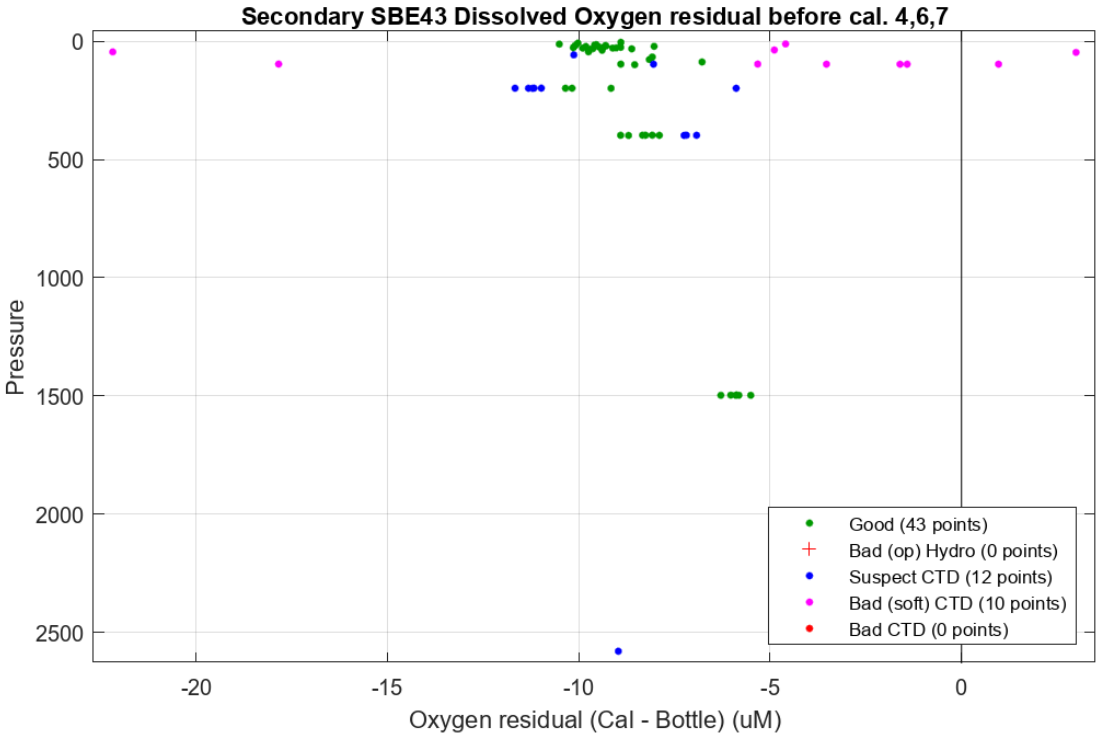

Temperature
18
16
14
12
10
8
6
4
2
-10
-5
0
5
10
Oxygen residual (Cal - Bottle) (uM)

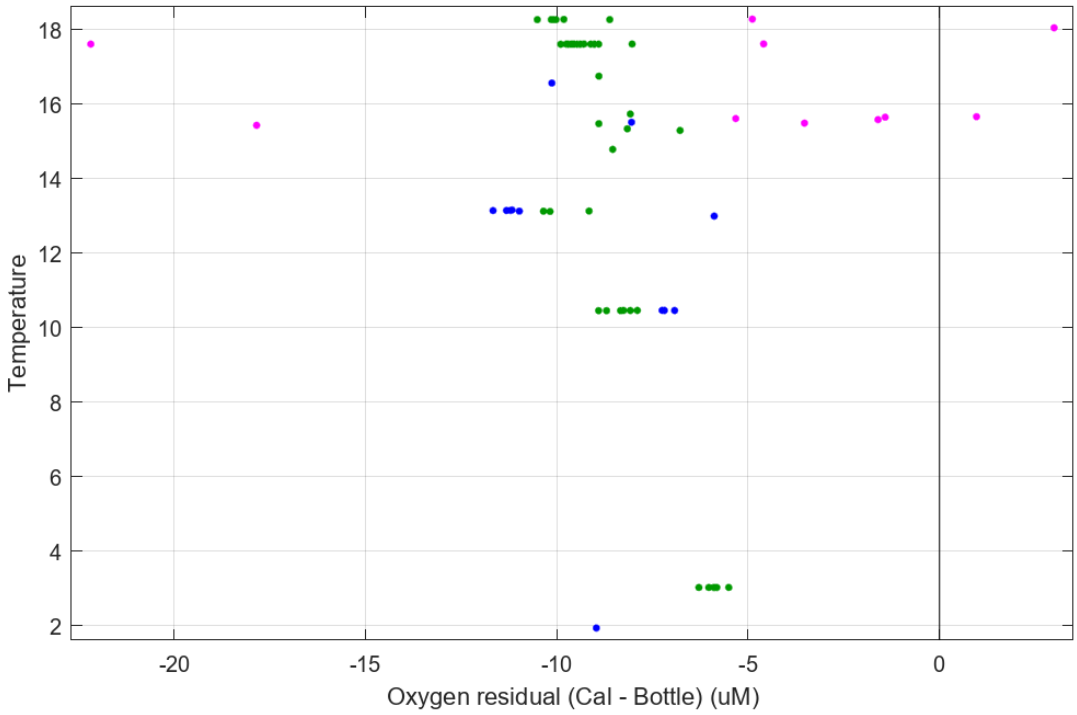

Primary SBE43 Dissolved Oxygen residual before cal. 5,8-10
Pressure
0
500
1000
1500
2000
2500
-60
-50
-40
-30
-20
-10
Oxygen residual (Cal - Bottle) (uM)
Good (47 points)
Bad (op) Hydro (2 points)
Suspect CTD (16 points)
Bad (soft) CTD (3 points)
Bad CTD (0 points)

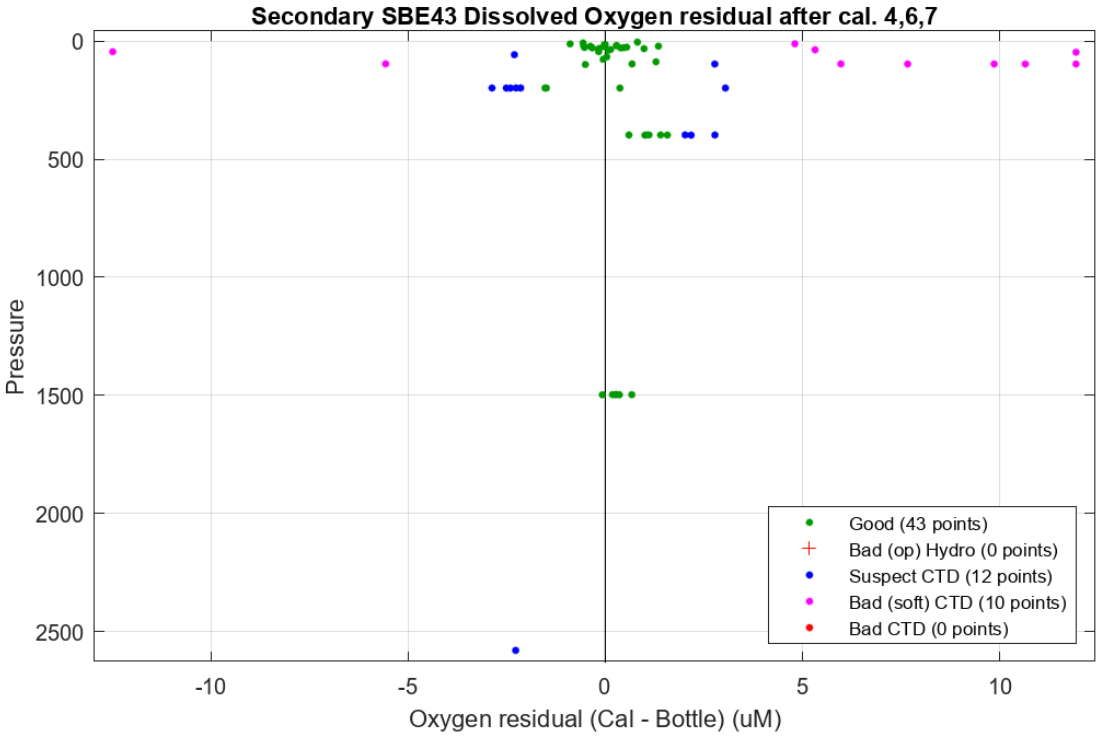

Temperature
18
16
14
12
10
8
6
4
2
-60
-50
-40
-30
-20
-10
Oxygen residual (Cal - Bottle) (uM)

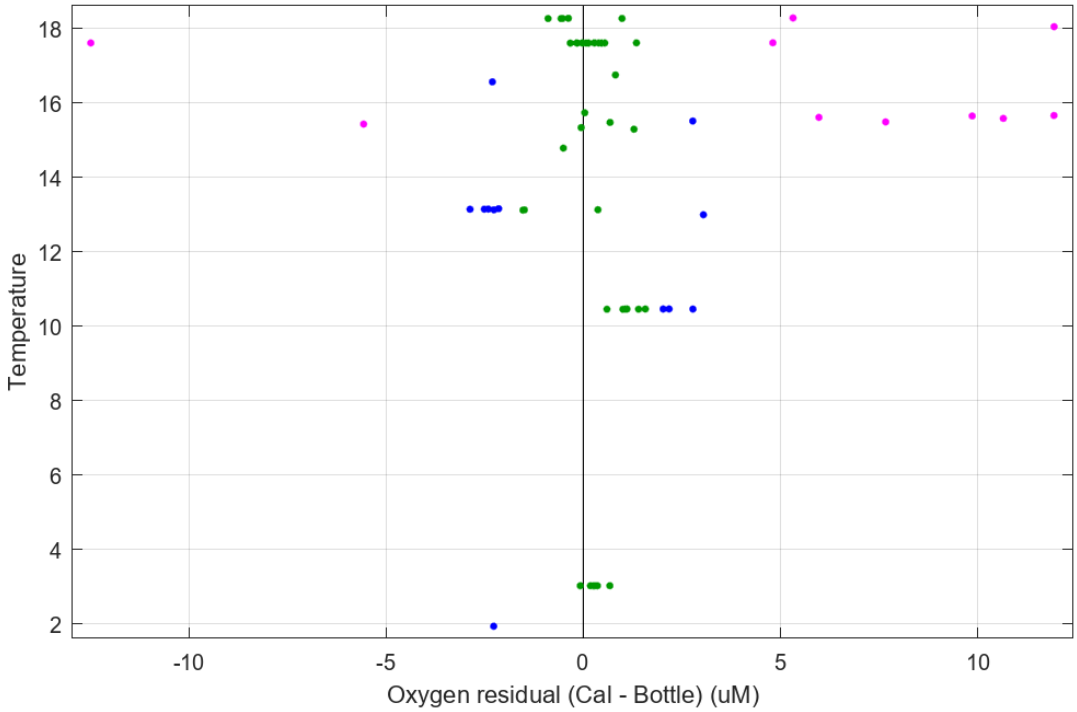

Primary SBE43 Dissolved Oxygen residual after cal. 5,8-10
Pressure
0
500
1000
1500
2000
2500
-50
-40
-30
-20
-10
0
10
Oxygen residual (Cal - Bottle) (uM)
Good (47 points)
Bad (op) Hydro (2 points)
Suspect CTD (16 points)
Bad (soft) CTD (3 points)
Bad CTD (0 points)

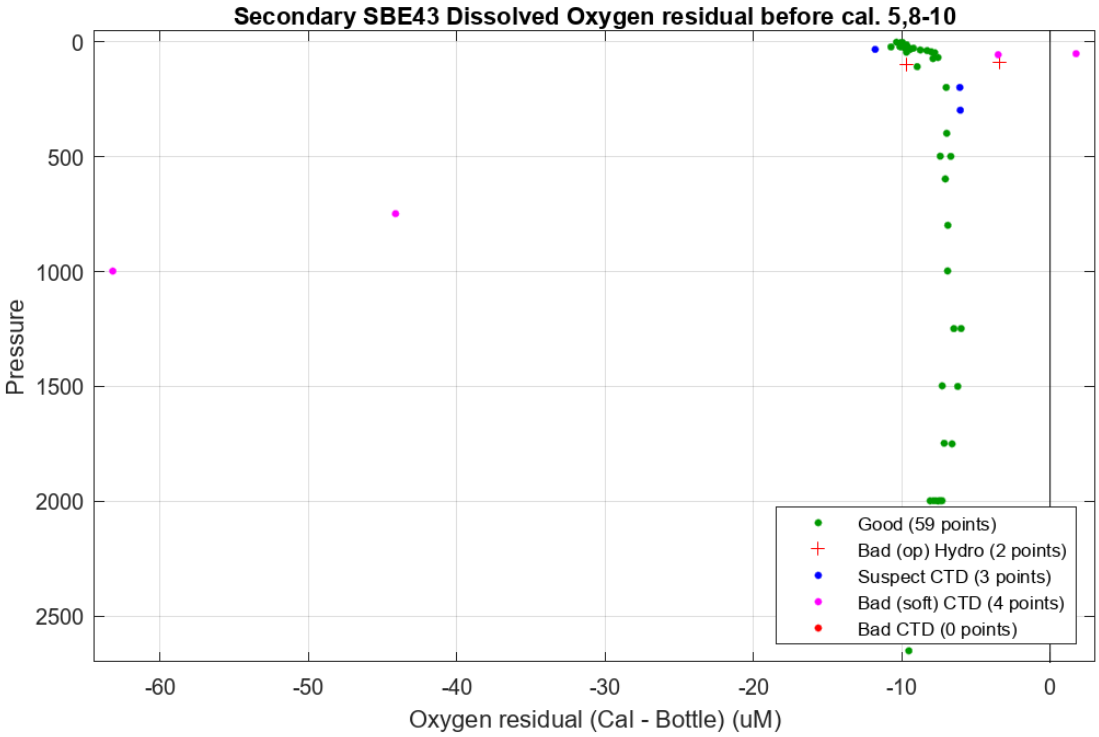

Temperature
2
4
6
8
10
12
14
16
18
-50
-40
-30
-20
-10
0
10
Oxygen residual (Cal - Bottle) (uM)

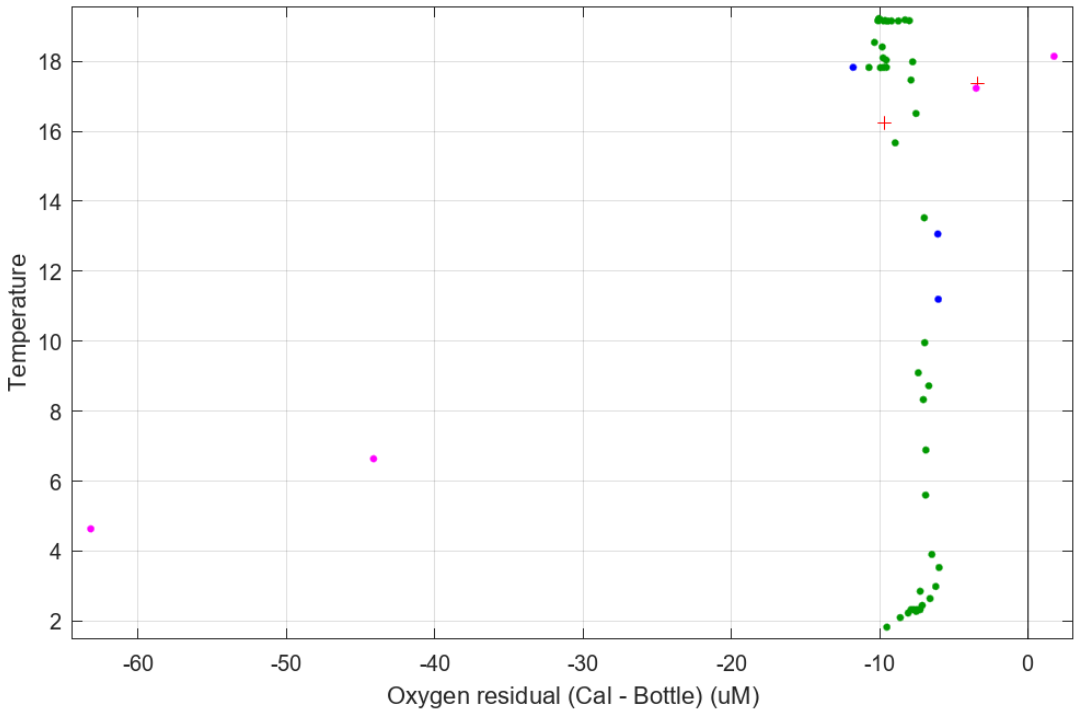

Secondary SBE43 Dissolved Oxygen residual before cal. 4,6,7
Pressure
0
500
1000
1500
2000
2500
-20
-15
-10
-5
0
Oxygen residual (Cal - Bottle) (uM)
Good (43 points)
Bad (op) Hydro (0 points)
Suspect CTD (12 points)
Bad (soft) CTD (10 points)
Bad CTD (0 points)

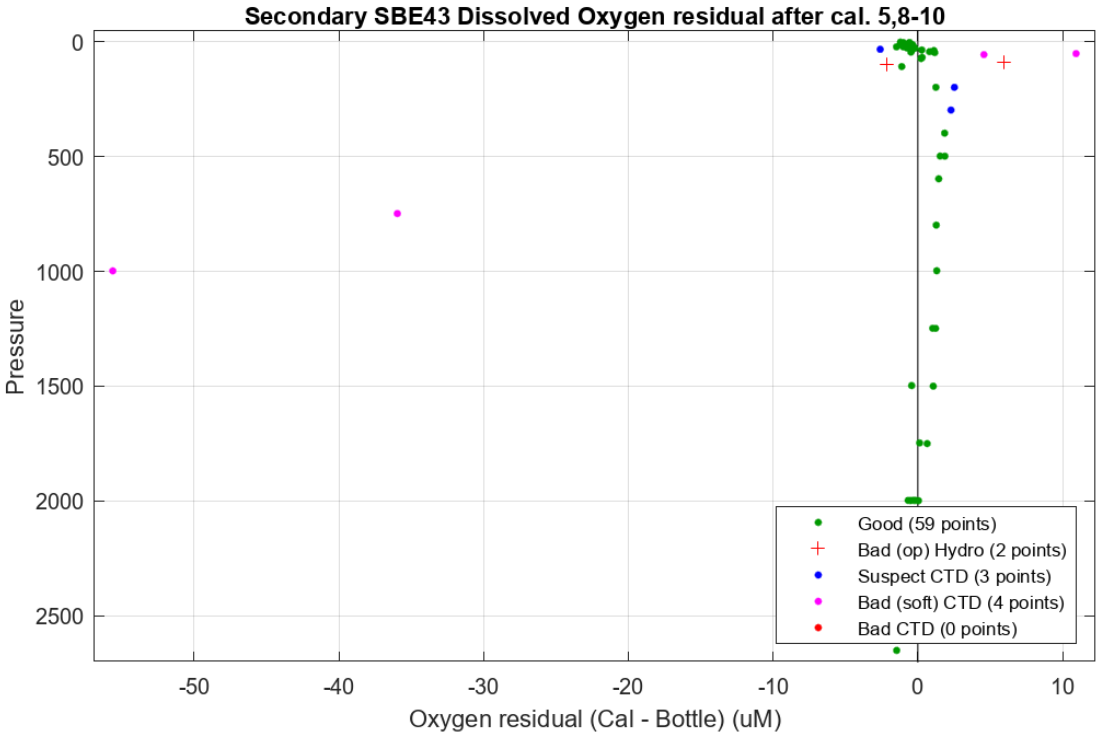

Temperature
18
16
14
12
10
8
6
4
2
-20
-15
-10
-5
0
Oxygen residual (Cal - Bottle) (uM)

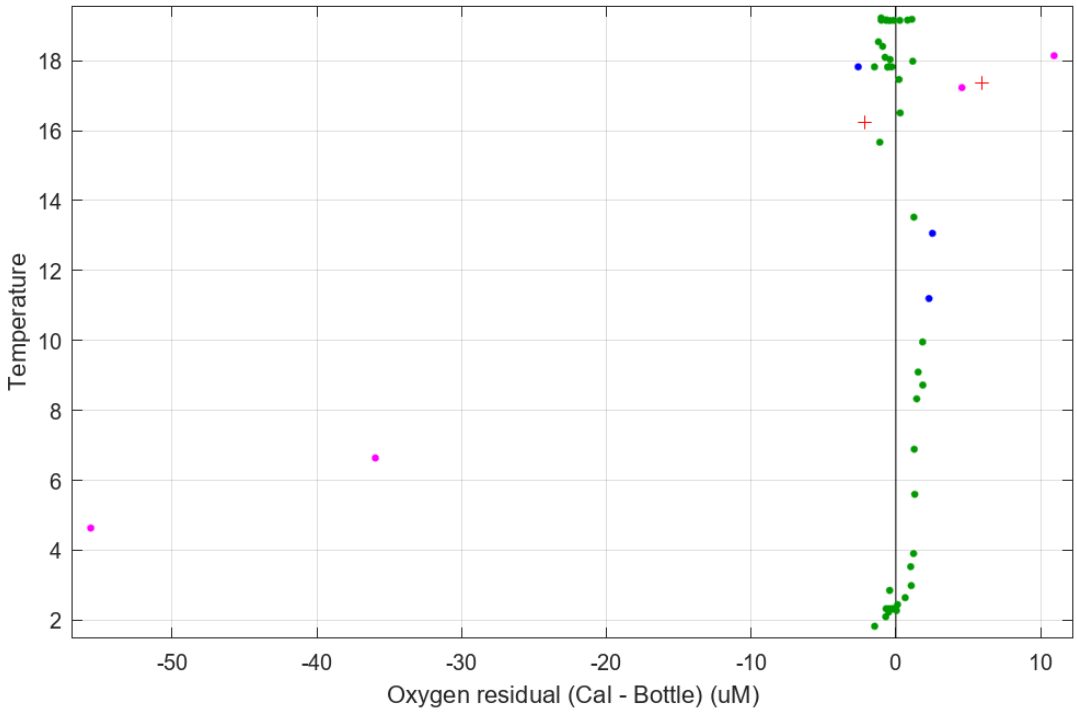

Secondary SBE43 Dissolved Oxygen residual after cal. 4,6,7
Pressure
0
500
1000
1500
2000
2500
-10
-5
0
5
10
Oxygen residual (Cal - Bottle) (uM)
Good (43 points)
Bad (op) Hydro (0 points)
Suspect CTD (12 points)
Bad (soft) CTD (10 points)
Bad CTD (0 points)


Temperature
18
16
14
12
10
8
6
4
2
-10
-5
0
5
10
Oxygen residual (Cal - Bottle) (uM)


Secondary SBE43 Dissolved Oxygen residual before cal. 5,8-10
Pressure
0
500
1000
1500
2000
2500
-60
-50
-40
-30
-20
-10
0
Oxygen residual (Cal - Bottle) (uM)
Good (59 points)
Bad (op) Hydro (2 points)
Suspect CTD (3 points)
Bad (soft) CTD (4 points)
Bad CTD (0 points)


Temperature
18
16
14
12
10
8
6
4
2
-60
-50
-40
-30
-20
-10
0
Oxygen residual (Cal - Bottle) (uM)


Secondary SBE43 Dissolved Oxygen residual after cal. 5,8-10
Pressure
0
500
1000
1500
2000
2500
-50
-40
-30
-20
-10
0
10
Oxygen residual (Cal - Bottle) (uM)
Good (59 points)
Bad (op) Hydro (2 points)
Suspect CTD (3 points)
Bad (soft) CTD (4 points)
Bad CTD (0 points)


Temperature
2
4
6
8
10
12
14
16
18
-50
-40
-30
-20
-10
0
10
Oxygen residual (Cal - Bottle) (uM)