RV *Investigator*

CTD Processing Report

Voyage #:	IN2018_V05
Voyage title:	How does a standing meander south-east of Tasmania brake the Antarctic Circumpolar Current?
Depart:	Hobart, Tuesday 16 October 2018, 1600
Return:	Hobart, Friday, 16 November 2018, 1000
Report compiled by:	Pamela Brodie, Peter Shanks, Steven Van Graas

Contents

1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage in2018_v05, from 16 Oct 2018 to 16 Nov 2018.

Data for 77 deployments were acquired using the Seabird SBE911 CTD unit 24, fitted with 36 twelve litre bottles on the rosette sampler. Samples were collected on all casts. Sea-Bird-supplied and CSIRO calibration factors were used to compute the pressures and preliminary conductivity, oxygen and temperature data. Automated QC was applied to the data to remove spikes and out-of-range values.

The final conductivity calibration was based on a single deployment grouping. The final calibration from the primary sensor had a standard deviation (SD) of 0.0012194 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 primary sensors.

The dissolved oxygen data calibration fit had a SD of 0.81391µM. The agreement between the CTD and bottle data was good.

A Biospherical photosynthetically active radiation (PAR), Wetlabs transmissometer and Chelsea fluorometer were installed on the auxiliary A/D channels of the CTD. Two altimeters, a serial IMU and the LADCP unit was also attached to the rosette for all casts. A high resolution magnetometer/accelerometer to assist processing the LADCP data was attached to the frame, supplied by the University of Columbia, it was logging internally and the data downloaded to the ~\in2018_v05\science\CTD\Magnetometer folder in the voyage record.

2 Voyage Details

2.1 Title

How does a standing meander south-east of Tasmania brake the Antarctic Circumpolar Current?

2.2 Principal Investigators

The Chief Scientist Prof. Nathan Bindoff (IMAS, University of Tasmania) with Principal Investigators Dr Helen Phillips (IMAS, University of Tasmania) and Dr Kurt Polzin (Woods Hole Oceanographic Institution) were on board.

2.3 Voyage Objectives

For details on the objectives of the voyage, refer to the Voyage Plan and/or summary which can be viewed on the CSIRO MNF web site.

The scientific objectives for in2018_v05 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

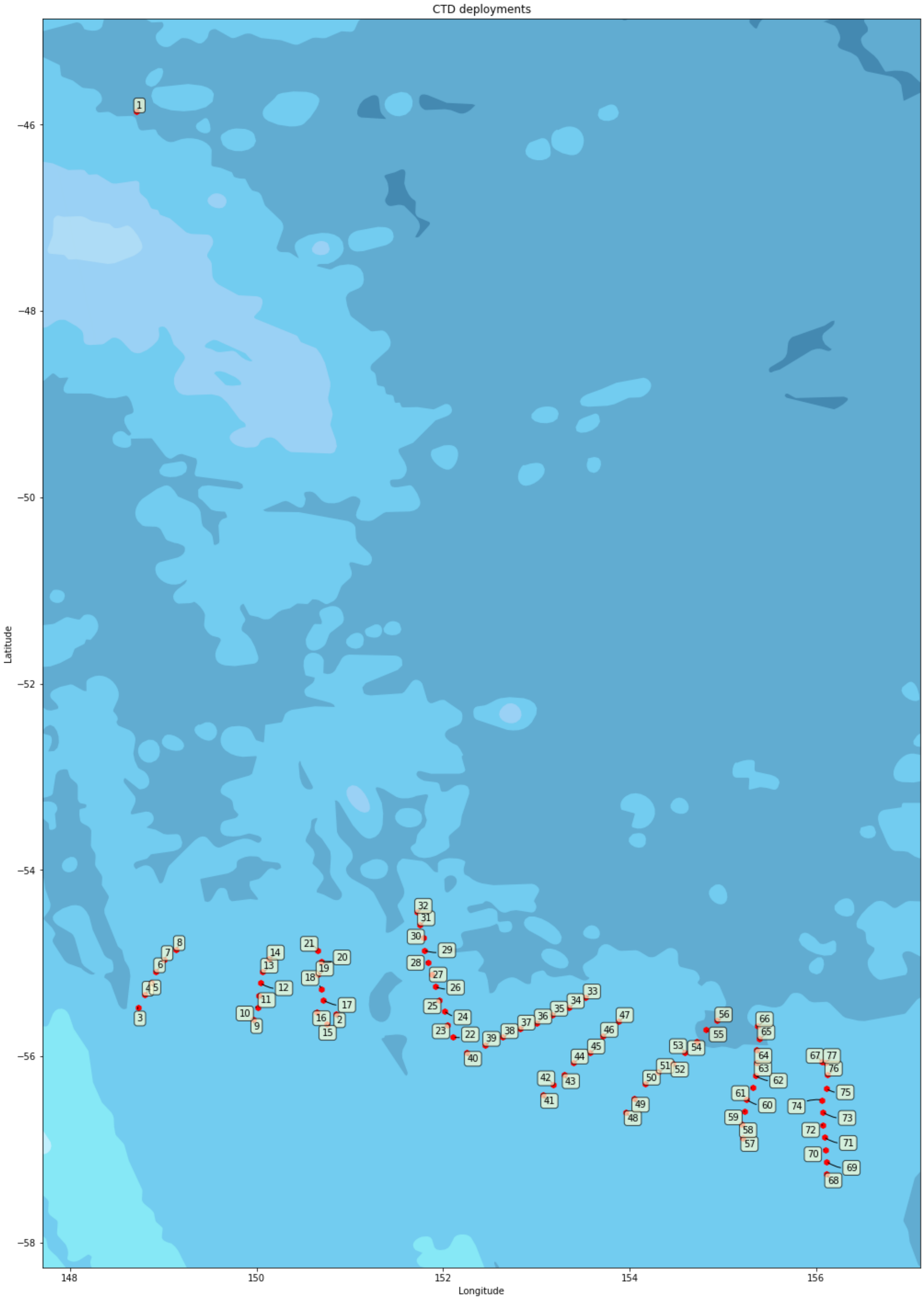


Figure 1. Area of Operation for in2018_v05 CTDs

3 Processing Notes

3.1 Background Information

The data for this voyage were acquired with CTD SBE9+ unit 24 with dual conductivity and temperature sensors. Rapp Hydema heave compensation was used on the CTD winch for all casts. There were 77 CTD deployments, as shown in Figure 1.

A Biospherical photosynthetically active radiation (PAR), Wetlabs Transmissometer and the Wetlabs ECO chlorophyll and scattering sensors were also installed on the auxiliary A/D channels of the CTD. These sensors are described in Table 1 below.

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	#24- 1332	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
	Sea-Bird SBE3*plus*	6180*	T1	27-Feb-2018	CSIRO
Primary Conductivity	Sea-Bird SBE4C	2312	C0	26-Jun-2018	CSIRO
Secondary Conductivity	Sea-Bird SBE4C	3168	C1	26-Jun-2018	CSIRO
	Sea-Bird SBE4C	2235**	C1	26 Jun 2018	CSIRO
Primary Dissolved Oxygen	SBE43	3534	A0	26-Feb-2018	CSIRO
Secondary Dissolved Oxygen	SBE43	3155	A1	29-Nov-2017	CSIRO
Transmissometer	Wetlabs CSTAR	1735DR	A2	27-Feb-2018	Manufacturer
PAR	QCP2300-HP	70677	A3	7-Feb-2018	Manufacturer
Wetlabs ECO – Chlorophyll	FLBBNTU	5169	A4	24-Aug-2018	Manufacturer
Wetlabs ECO – Scattering	FLBBNTU	5169	A5	24-Aug-2018	Manufacturer
Altimeter	Tritech PA200	313624	A6	N/A	N/A
Altimeter 2 (User Polynomial)	Tritech PA500	228403***	A7	N/A	N/A
	Tritech PA500	310747	A7	N/A	N/A

* 6180 for secondary temperature from CTD 40.

** 2235 used as secondary conductivity from CTDs 35 to 37 and determined unsatisfactory.

*** 228403 for casts 1 to 17 and CTD 51. Otherwise 310747 was used.

Table 1. CTD Sensor configuration on in2018_v05

There were 77 CTD casts.

The raw CTD data were acquired and converted to scientific units using SeaSave Software Version V 7.26.7.110. A conductivity advance of 0.073 seconds was applied in the deck box to both the primary and secondary conductivity. The SeaBird hex files were converted to scientific units using SeaSave data processing. NetCDF files were created from the resultant CNV files with cnv_to_scan, an in-house python script.

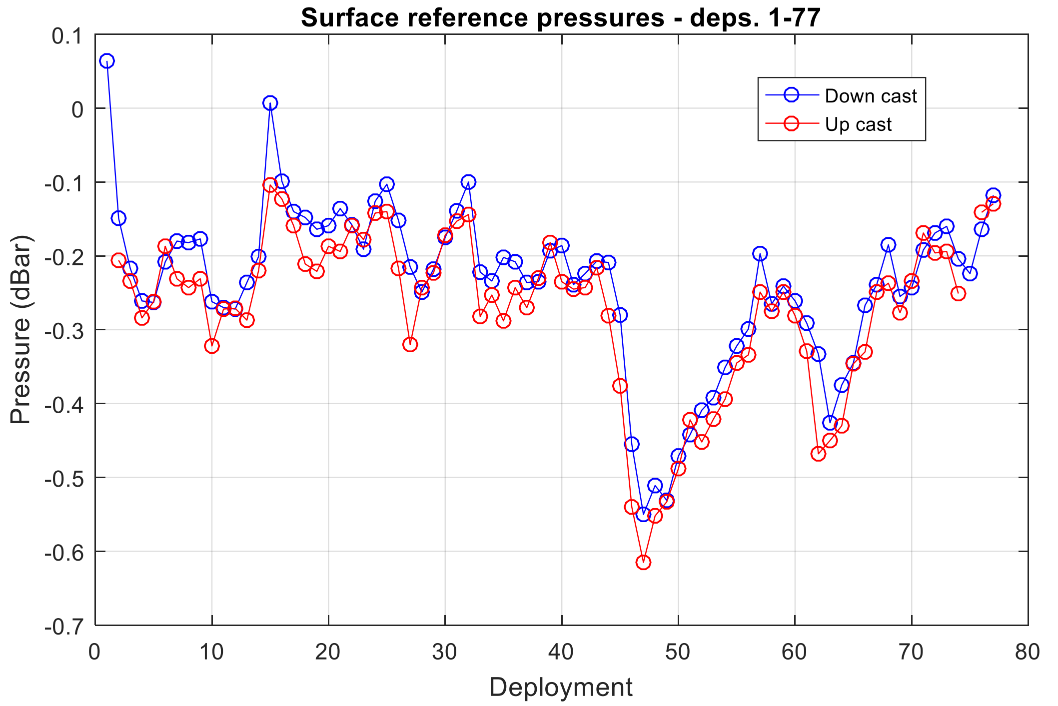
The netCDF files were processed using CapPro v2.9. This Matlab software was used to apply automated QC and preliminary processing to the data. This included spike removal, identification of water entry and exit times, conductivity sensor lag corrections and the determination of the pressure offsets. The automatically determined pressure offsets and in-water points were inspected and adjusted where necessary. The hydrology data were loaded and CapPro computed the matching CTD sample burst data.

The bottle sample data were used to compute final conductivity and dissolved oxygen calibrations. These were applied to the data and binned 1dB averaged data files were produced.

CTD cast 77 is a repeat of cast 67 at station Transect 9.1. After cast 67 the transect was performed from south to north.

3.2 Pressure reference

The surface 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.



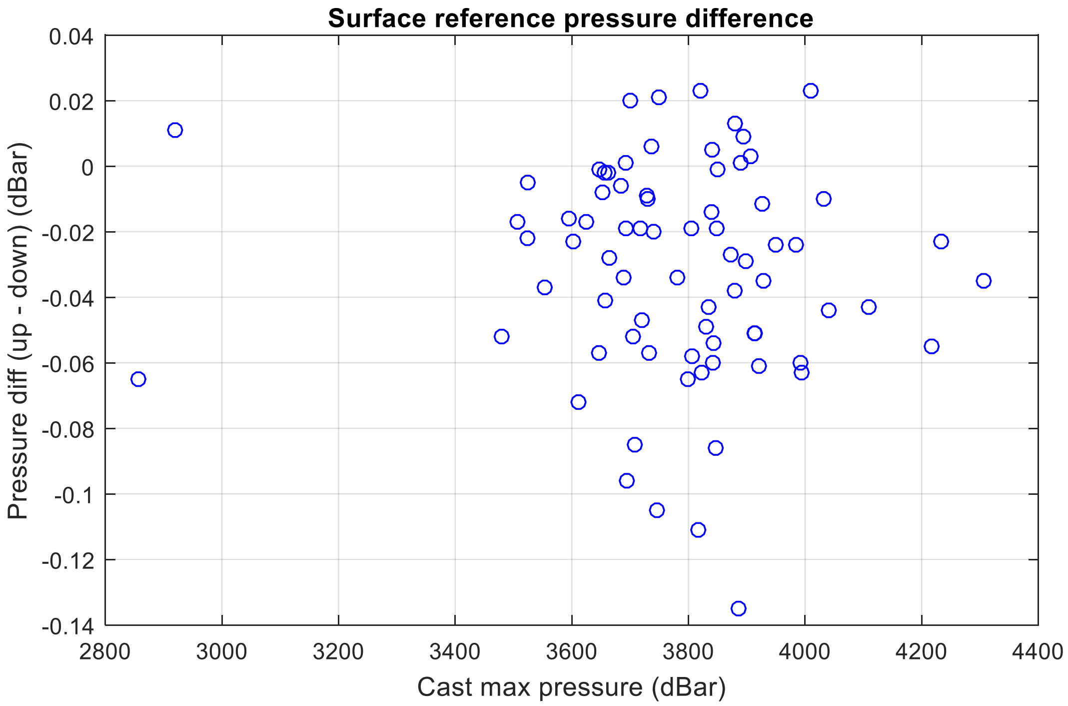


Figure 2. CTD pressure reference

The mean difference between the primary and secondary temperature sensors is plotted below. Most deployments should plot within ±1 m°C. Figure 3 indicates neither sensor has drifted significantly from its calibration.

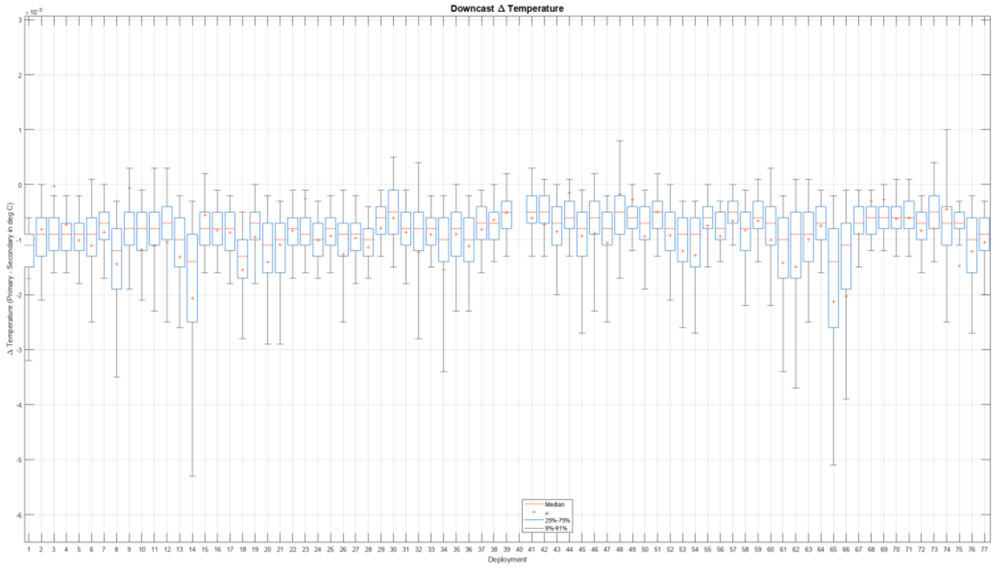
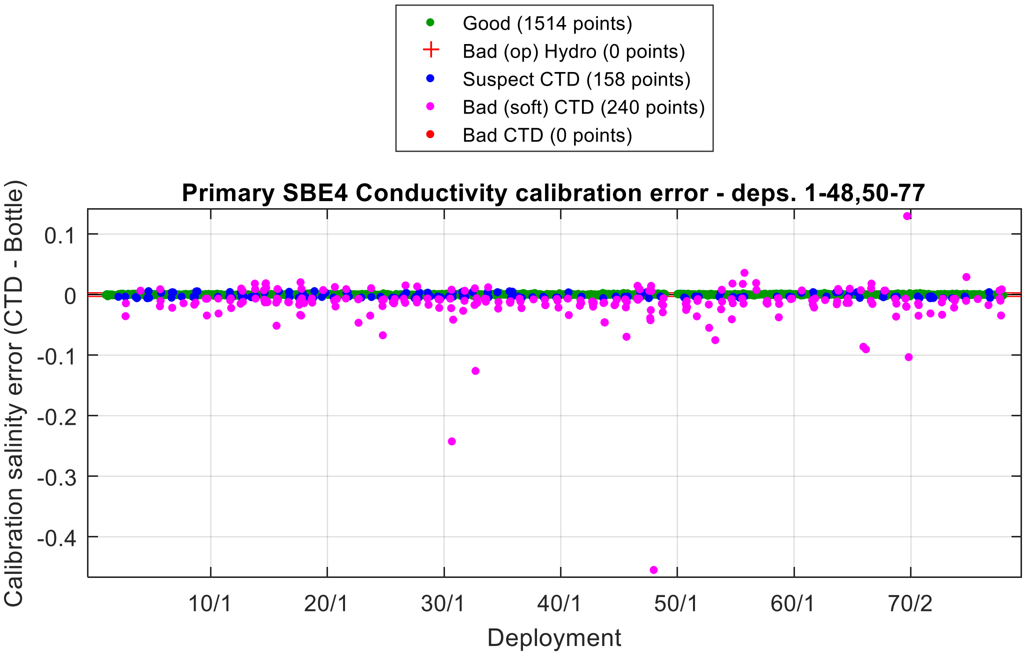


Figure 3. Temperature sensor difference

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 final calibration used the primary conductivity sensor, and was based upon the sample data for 1514 of the total of the 1912 samples taken during deployments. The secondary sensor calibrations were applied in three groups. The first was during the time the initial secondary temperature sensor (4722) was used. A different secondary conductivity sensor (2235) was tested during casts 35 to 37. This is the second calibration group. The third group is from cast 40 to cast 77. These were all within our target of including no less than 75% of samples. The outliers marked in the figures 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.



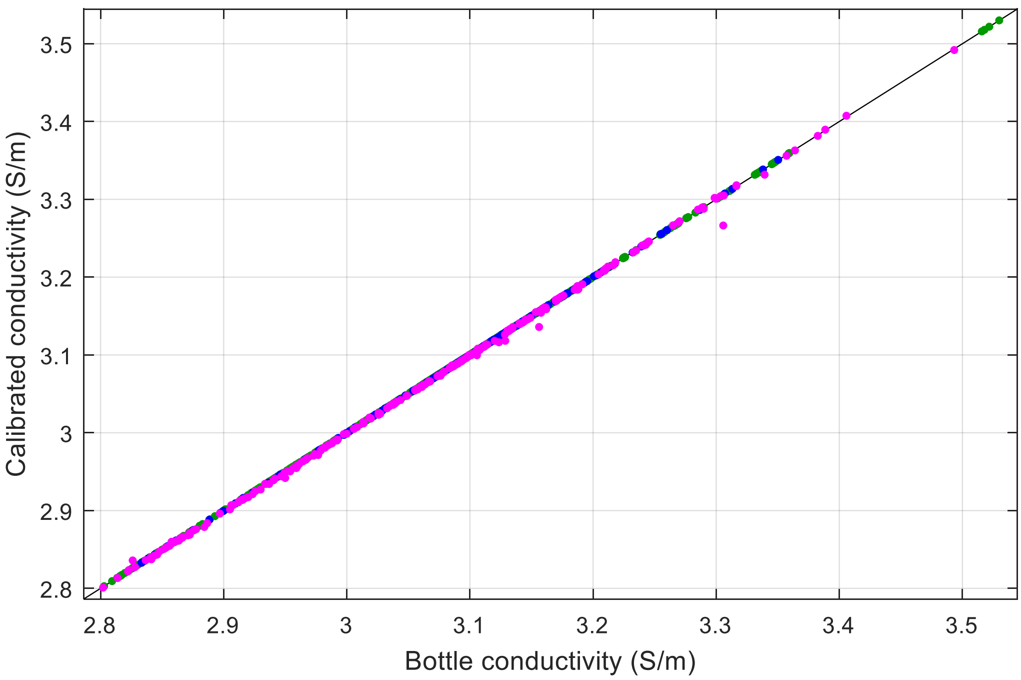
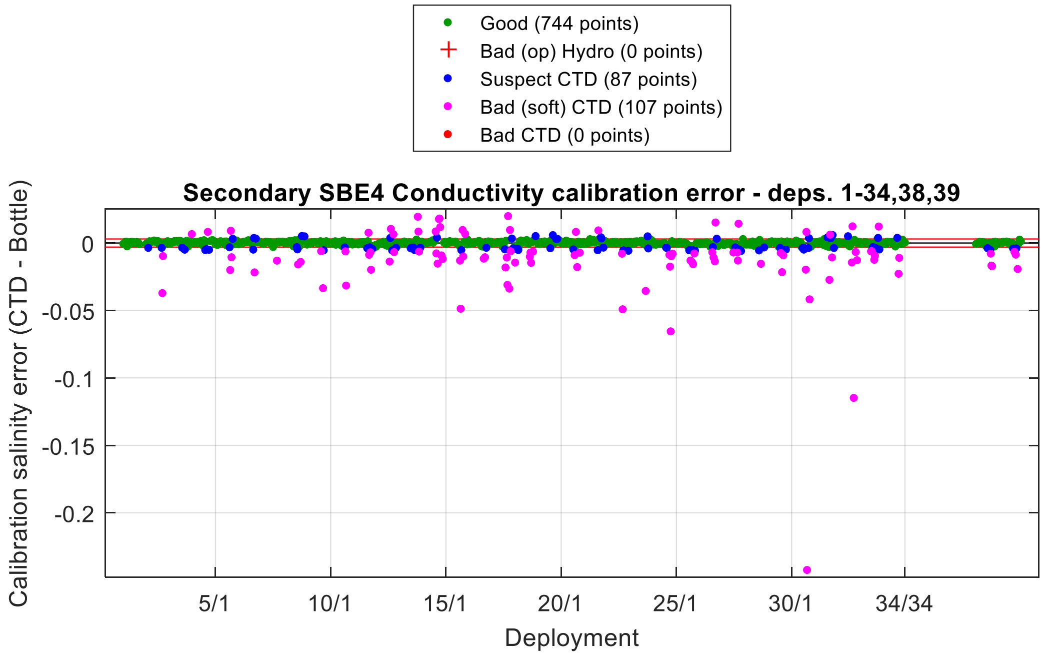
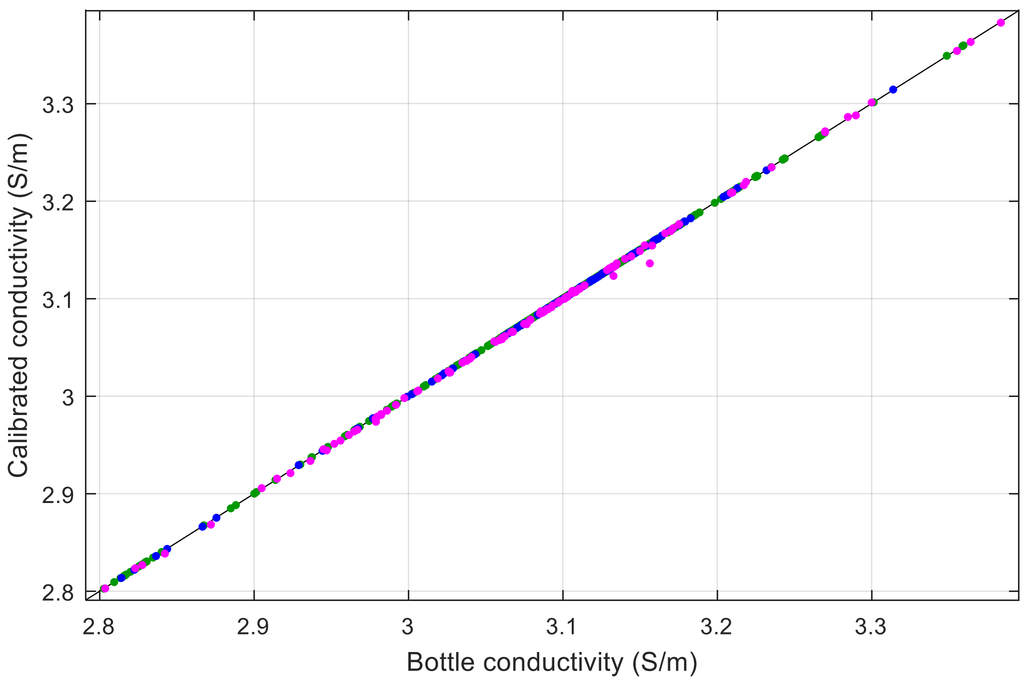
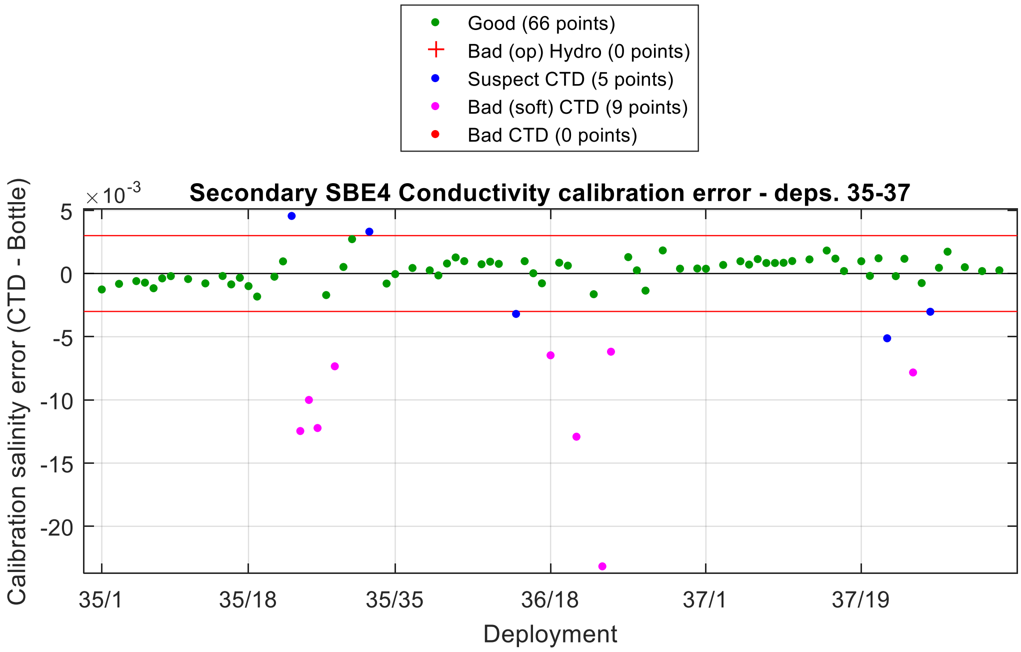


Figure 4. Primary conductivity calibrations


Good (744 points)
Bad (op) Hydro (0 points)
Suspect CTD (87 points)
Bad (soft) CTD (107 points)
Bad CTD (0 points)
Secondary SBE4 Conductivity calibration error - deps. 1-34,38,39
Calibration salinity error (CTD - Bottle)
0
-0.05
-0.1
-0.15
-0.2
5/1
10/1
15/1
20/1
25/1
30/1
34/34
Deployment


Calibrated conductivity (S/m)
3.3
3.2
3.1
3
2.9
2.8
2.8
2.9
3
3.1
3.2
3.3
Bottle conductivity (S/m)


Good (66 points)
Bad (op) Hydro (0 points)
Suspect CTD (5 points)
Bad (soft) CTD (9 points)
Bad CTD (0 points)
Secondary SBE4 Conductivity calibration error - deps. 35-37
×10-3
Calibration salinity error (CTD - Bottle)
5
0
-5
-10
-15
-20
35/1
35/18
35/35
36/18
37/1
37/19
Deployment

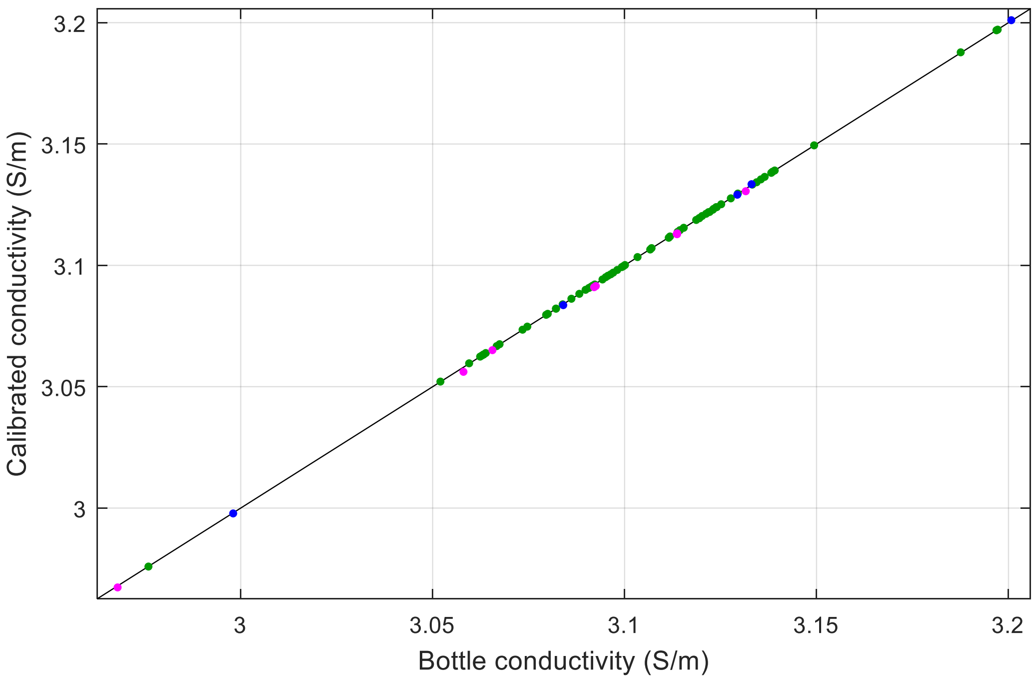

Calibrated conductivity (S/m)
3.2
3.15
3.1
3.05
3
Bottle conductivity (S/m)

Figure 5. Secondary conductivity calibrations

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

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Sensor Group	Deployments	Scale Factor		Offset		Salinity (PSU)	
		a1	±	a0	±	Residual SD	M.A.D.
Primary	1-77	0.99973	0.00085777	0.00090326	0.0026461	0.0011865	0.00057254
Secondary	1–34, 38-39	0.99973	0.0011427	0.0008698	0.0035349	0.0012523	0.00073162
Secondary	35-37	1.0	0.0068724	-0.0002685	0.02139	0.00095616	0.00081729
Secondary	40-77	0.99973	0.00085777	0.00090326	0.0026461	0.0011865	0.00057254

Table 2 Conductivity calibration with respect to manufacturer calibration and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	1-77	-7.2762e-08	1.3510e-08
Secondary	1-34,38-39	-7.8030e-08	2.1522e-08
Secondary	35-37	-7.9574e-08	6.4495e-08
Secondary	40-77	-7.4533e-08	1.8427e-08

Table 3 Calculated CPcor compared with 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 Appendix A.
Data from the primary conductivity and temperature sensors were used to produce the averaged salinities with secondary sensors included with a suffix '_2'.

The cut-off of 0.003 was used in all cases. Calibration standard deviation is the standard deviation of the difference between the calibrated values and the bottle values. This calibration was well within the range we normally aim for, an S.D. of 0.002 psu or lower for 'typical' oceanographic voyages.

Data from the primary conductivity and temperature sensors were used to produce the averaged salinities.

3.4 Dissolved Oxygen Sensor Calibration

3.4.1 SBE calibration procedure

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 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

All casts were deep casts (>1000m) which are known to be affected by pressure-induced hysteresis with this SBE43 sensor. This is corrected automatically within CapPro using the method discussed by 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.

The plots below in Figures 6 and 7 are of CTD - bottle oxygen differences for both upcast and downcast data (red indicates 'bad' data).

A single calibration group from the each sensor was used with the associated SBE43 up-cast data to compute the new *Soc* and *Voffset* coefficients.

The old and new *Soc* and *Voffset* values for DO sensors are listed in Table 2 below, which includes the result from use of the same sensors on in2018_v03. The *Soc* value is a linear slope scaling coefficient; *Voffset* is the fixed sensor voltage at zero oxygen.

The calibrations below were applied for deployments 1 to 77 for both the primary and secondary sensors. 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	1-77	-0.47903	0.0005888	0.49521	0.00025263	0.81391	0.77098
	CSIRO Cal Lab	1-77	-5.3082e-01		5.3284e-01			
Secondary DO	Hydrochemistry	1-77	-0.48285	0.00049764	0.53093	0.00024606	0.80541	0.64204
	CSIRO Cal Lab	1-77	-5.134e-01		5.3853e-01			

Table 4. Dissolved Oxygen calibration

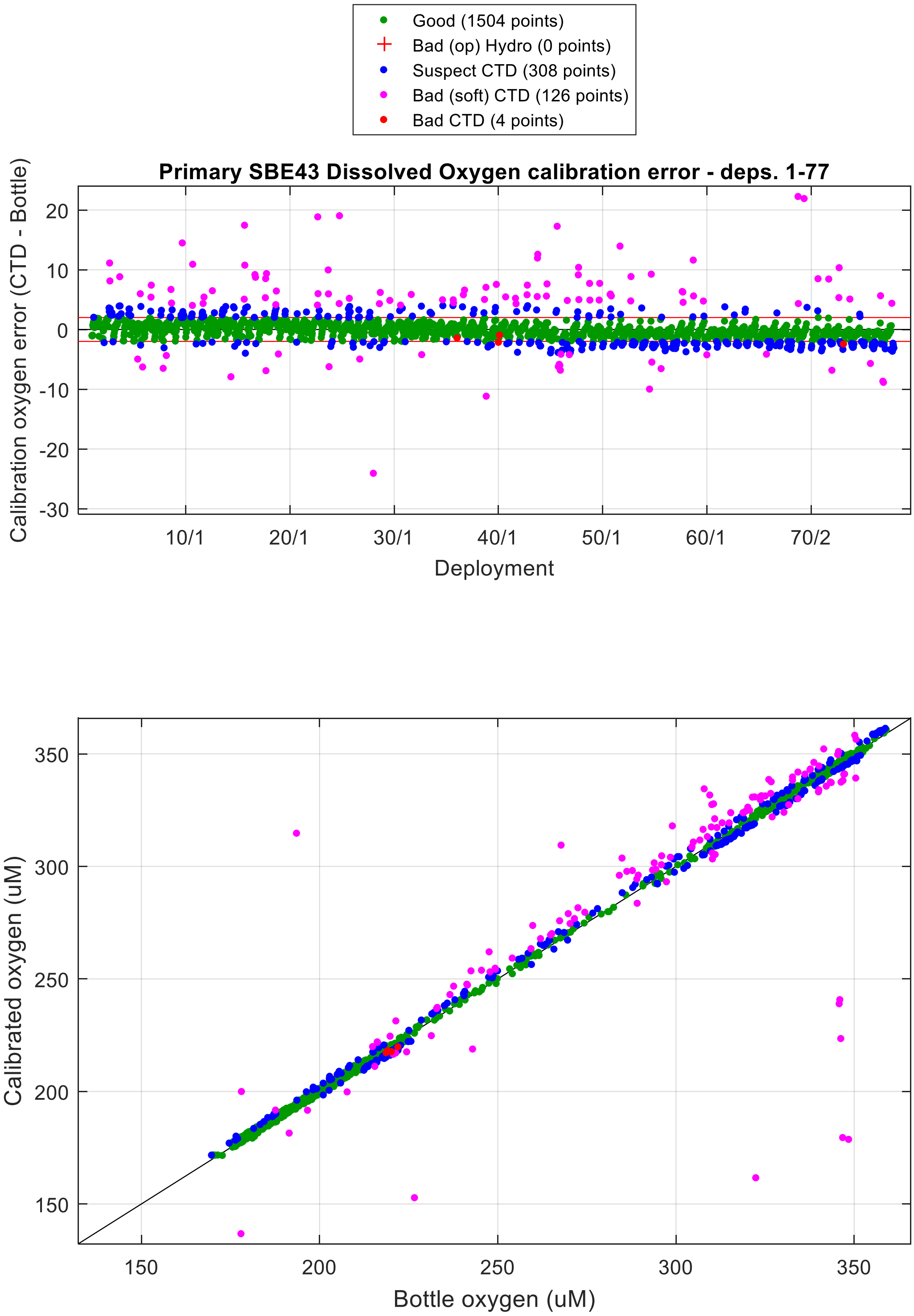


Figure 6. Dissolved Oxygen calibration, all deployments – primary sensor

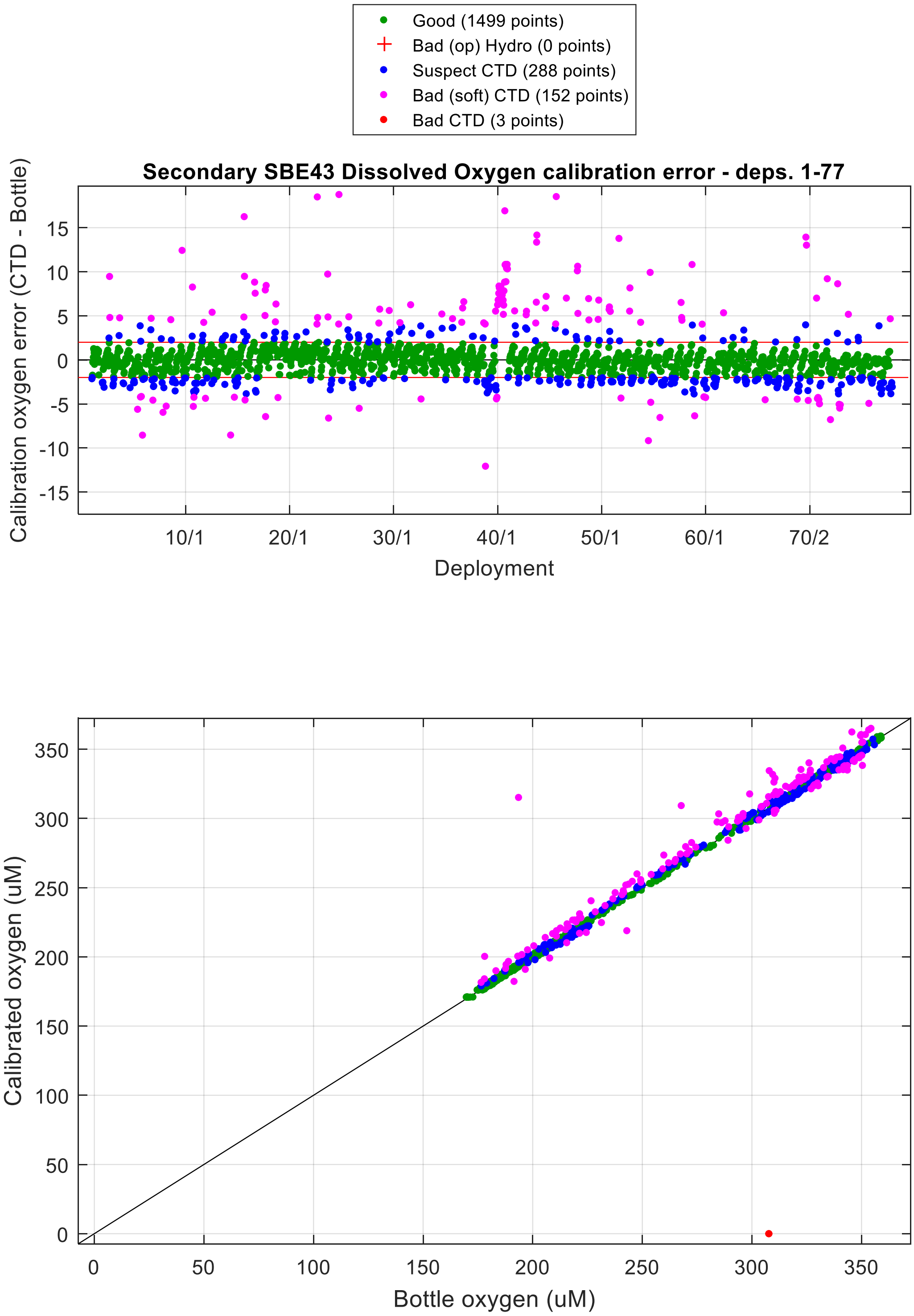


Figure 7. Dissolved Oxygen calibration, all deployments – secondary sensor

3.5 Other sensors

The C-Star transmissometer was used for all deployments. They were calibrated to give nominal outputs of 0-100 fsd (full scale deflection).

The Biospherical PAR sensor was also used for all deployments. The output is in umol photons/m^2/s. 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.

The WET Labs ECO-AFL/FL Fluorometer, and WET Labs ECO-BB Optical Backscatter were used for all deployments. Factory calibration coefficients were entered into Seasave, and provide the output results. The calibration coefficients are listed below.

Sensor	Deployments	Cal Date	Calibration Coefficients
PAR	1-77	17 Feb 2018	Calibration Constant: 19417476000
			Multiplier: 1.000
			Offset: -0.05218038
Transmissometer	1-77	27 Feb 2018	M: 21.3747
			B: -0.0214
			Path length: 0.250
Fluorometer	1-77	24 Aug 2018	Scale Factor: 1.466e-002
			Dark Output: 5.300e-002
Optical Backscatter	1-77	24 Aug 2018	Scale Factor: 6.000
			Dark Output: 0.0700

Table 5. Auxiliary Sensor Calibration Coefficients

3.6 Bad data detection

The limits for each sensor are configured in CNVtoScan conversion software and are written to the netCDF scan file. Typical limits used for the sensor range and maximum second difference are in

Table 6 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	5	0.5
PAR	-5	2000	0.5
Transmissometer	0	105	0.5

Table 6 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 1dbar 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 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

Bindoff, N., 2018: The RV Investigator Voyage Plan in2018_v05.

Pender, L., 2000: Data Quality Control Flags.
http://www.cmar.csiro.au/datacentre/ext_docs/DataQualityControlFlags.pdf

Sea-Bird Electronics Inc., 2008: Application Note No 64.1: SBE 43 Dissolved Oxygen Sensor and Pump on a CTD.

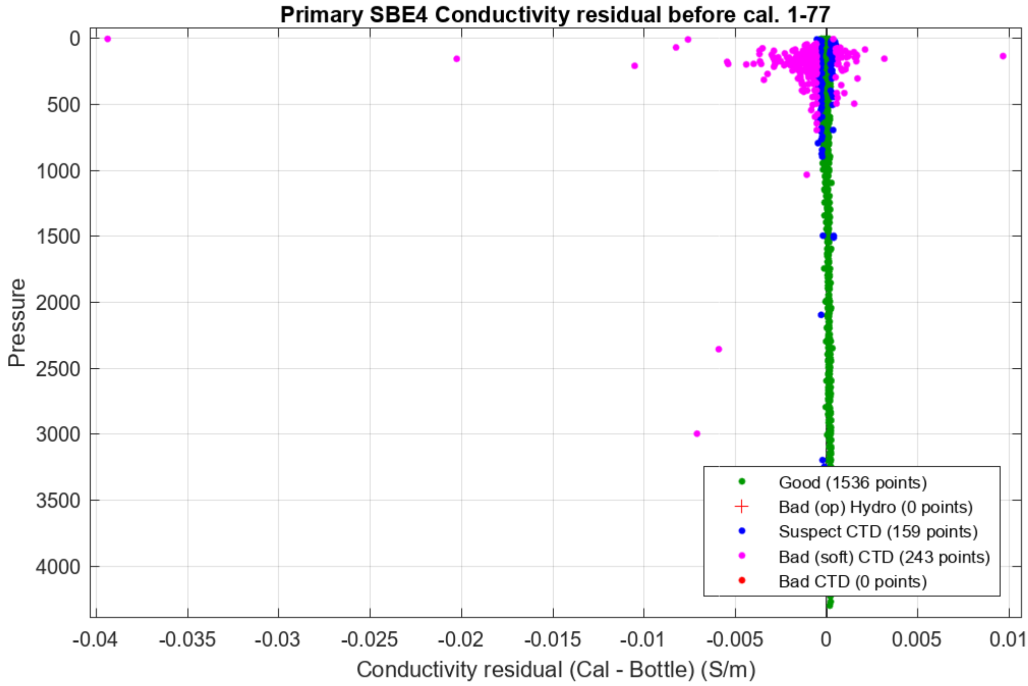
https://www.seabird.com/asset-get.download.jsa?id=54627861703

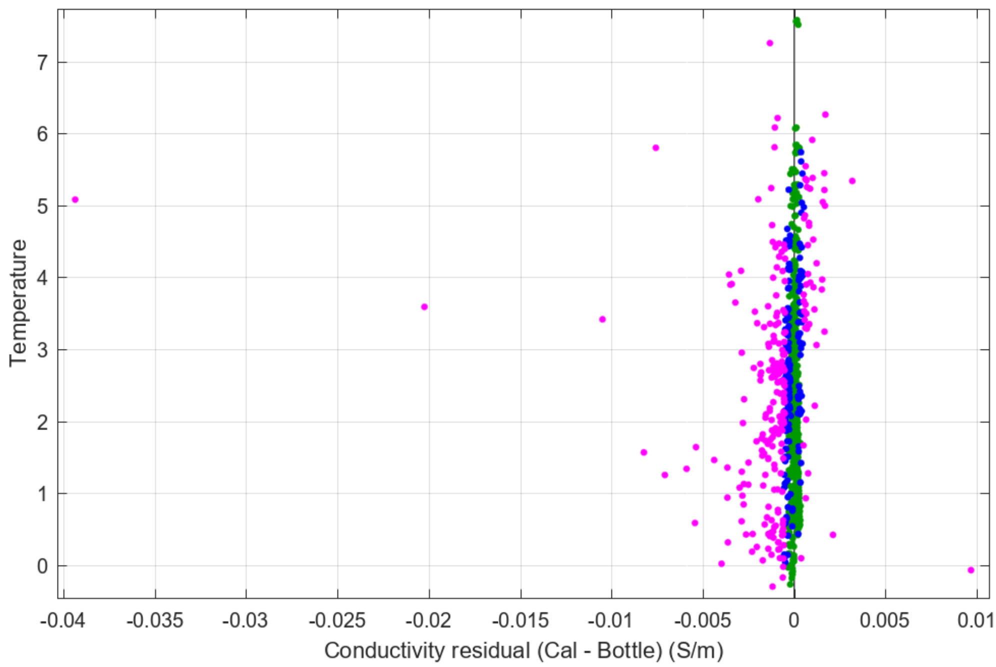
Sea-Bird Electronics Inc., 2012: Application Note No 64-2: SBE 43 Dissolved Oxygen Sensor Calibration and data Corrections.
https://www.seabird.com/asset-get.download.jsa?id=54627861704

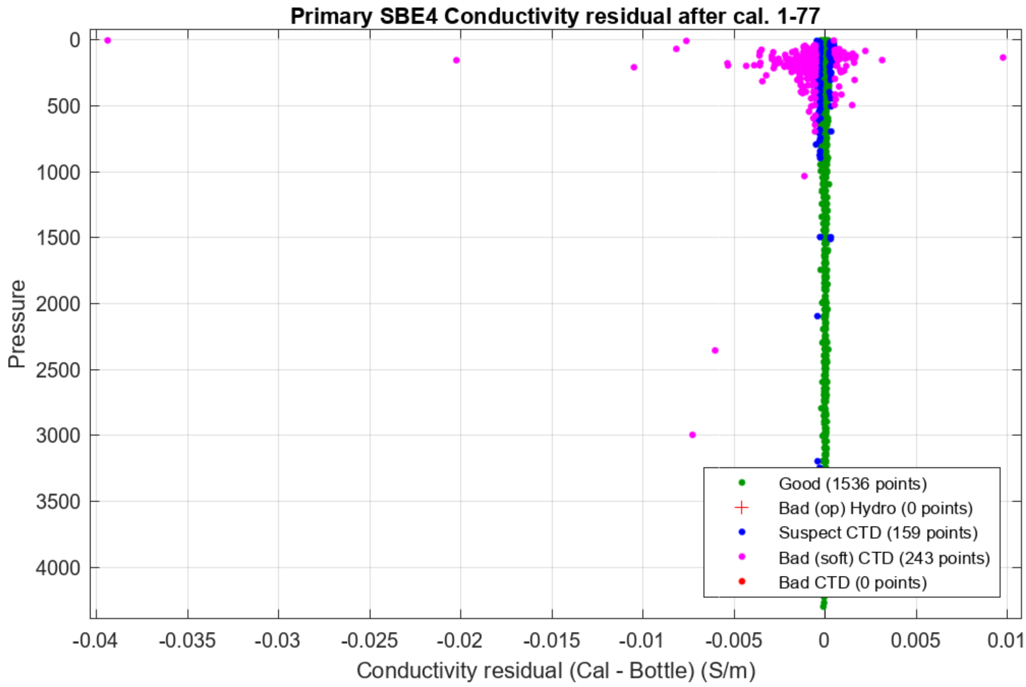
Sea-Bird Electronics Inc., 2014: Application Note No 64-3: SBE 43 Dissolved Oxygen (DO) Sensor - Hysteresis Corrections.

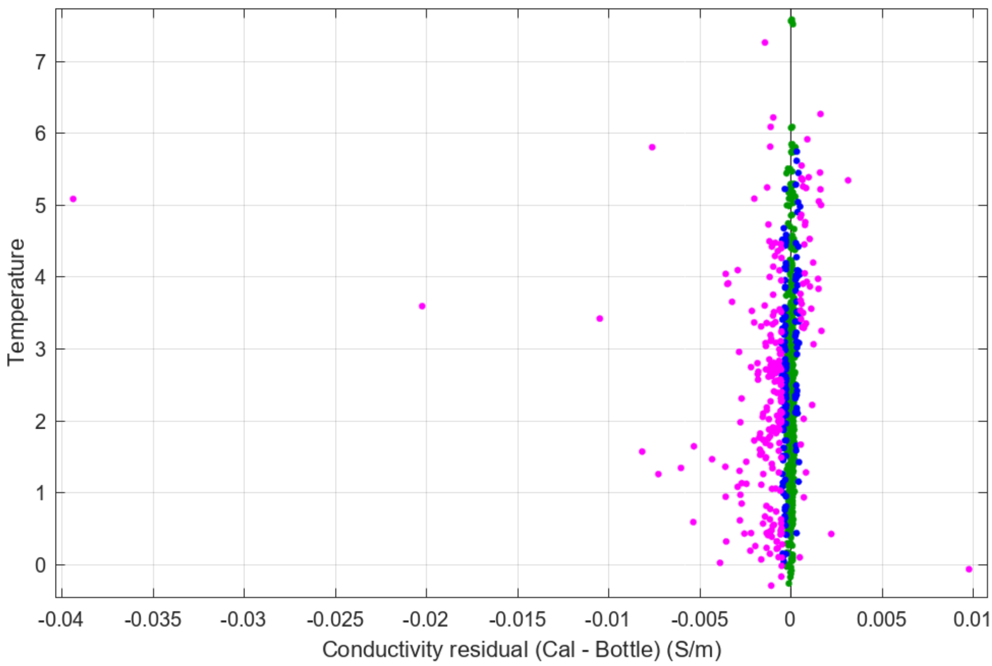
https://www.seabird.com/asset-get.download.jsa?id=54627861705

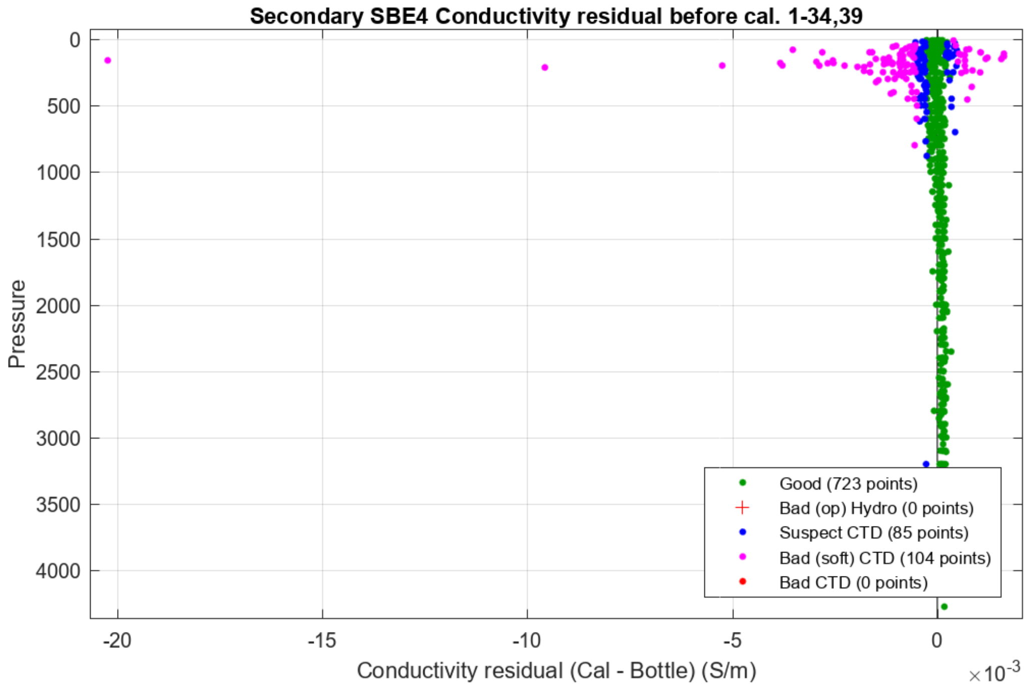
5 Appendix A – Residuals for primary and secondary sensors

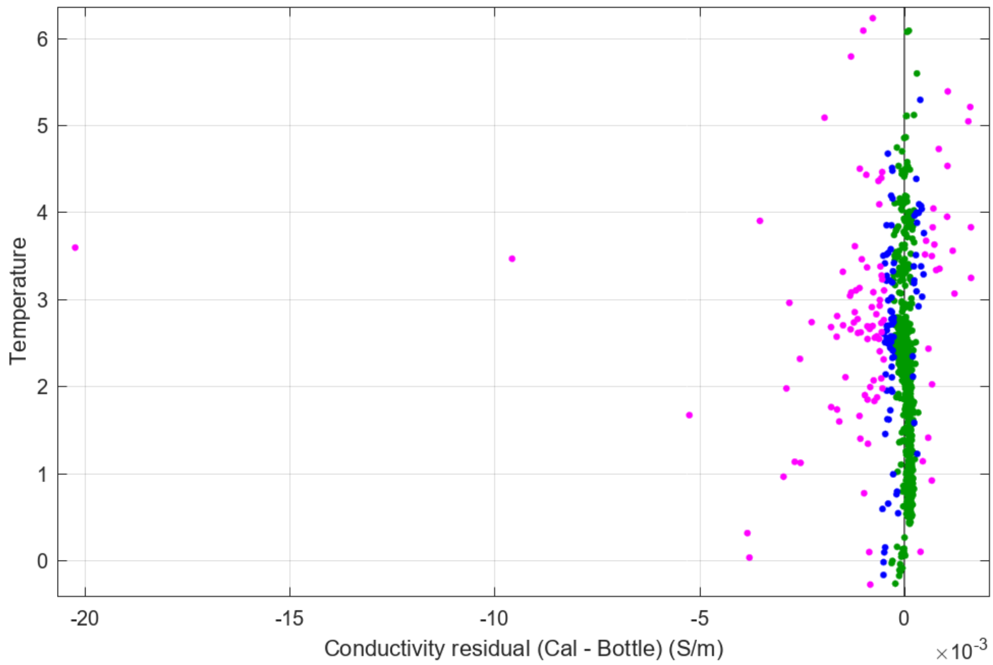


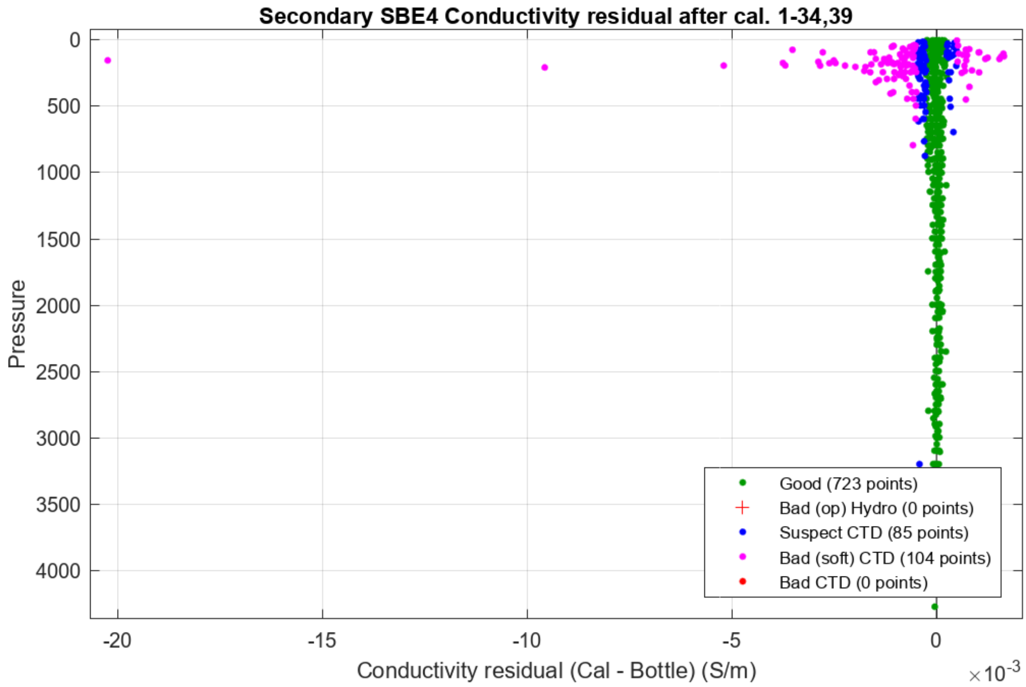


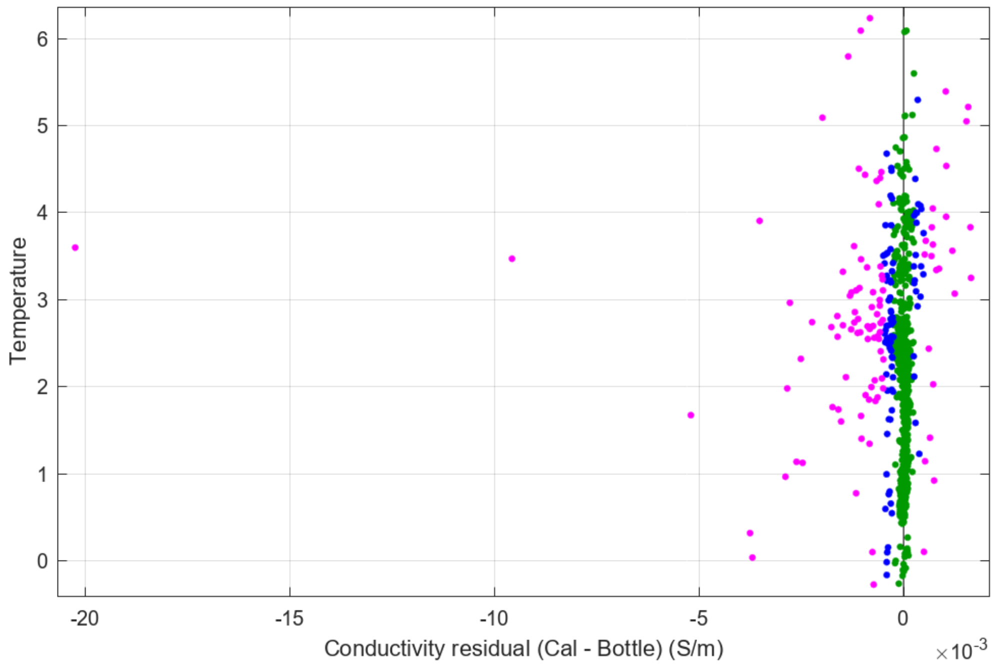

Primary SBE4 Conductivity residual after cal. 1-77
Pressure
Conductivity residual (Cal - Bottle) (S/m)
Good (1536 points)
Bad (op) Hydro (0 points)
Suspect CTD (159 points)
Bad (soft) CTD (243 points)
Bad CTD (0 points)

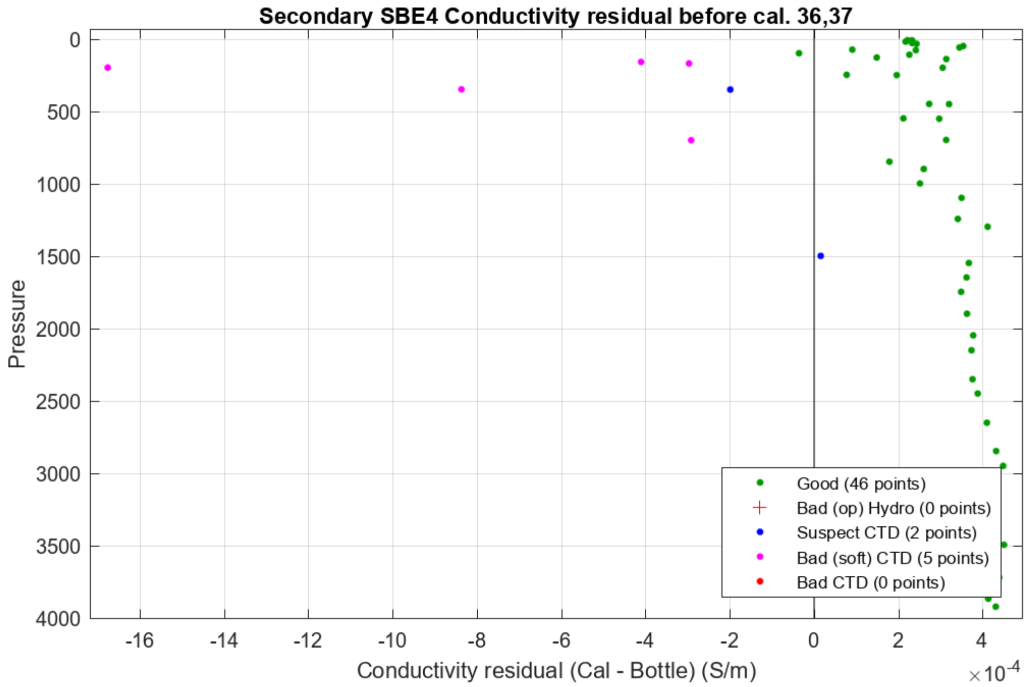

Temperature
Conductivity residual (Cal - Bottle) (S/m)

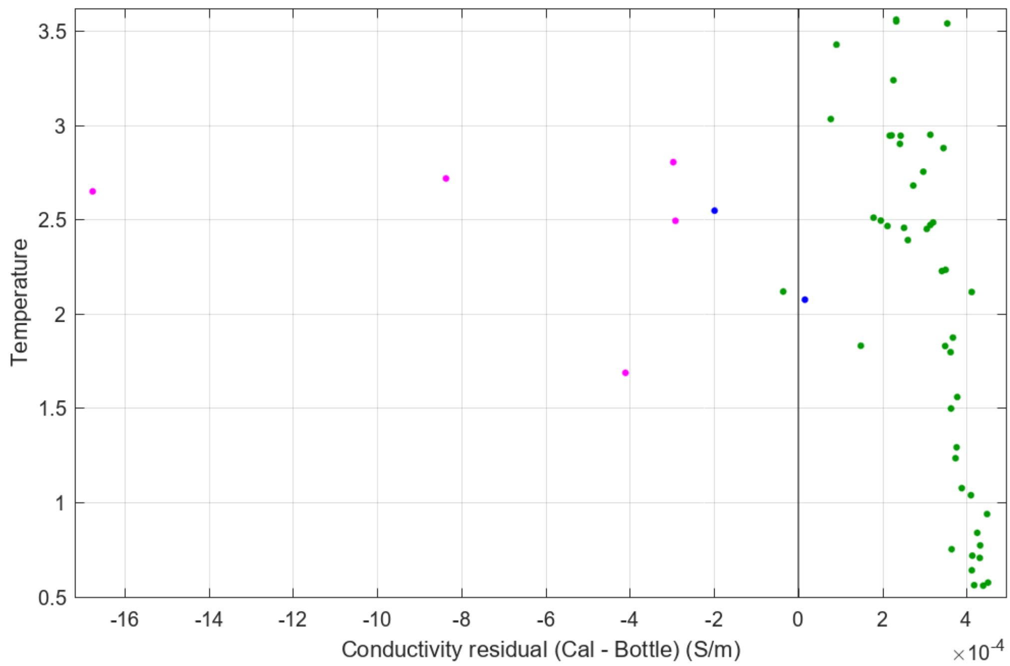

Secondary SBE4 Conductivity residual before cal. 1-34,39
Pressure
0
500
1000
1500
2000
2500
3000
3500
4000
Good (723 points)
Bad (op) Hydro (0 points)
Suspect CTD (85 points)
Bad (soft) CTD (104 points)
Bad CTD (0 points)
-20
-15
-10
-5
0
Conductivity residual (Cal - Bottle) (S/m)
×10^-3

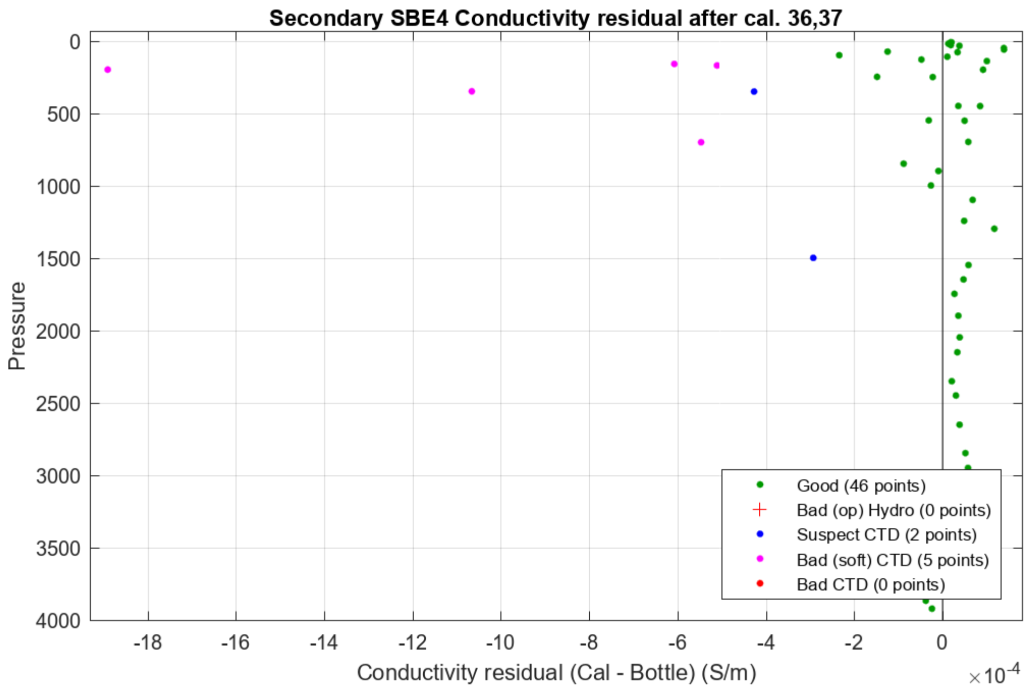

Temperature
0
1
2
3
4
5
6
-20
-15
-10
-5
0
Conductivity residual (Cal - Bottle) (S/m)
×10^-3

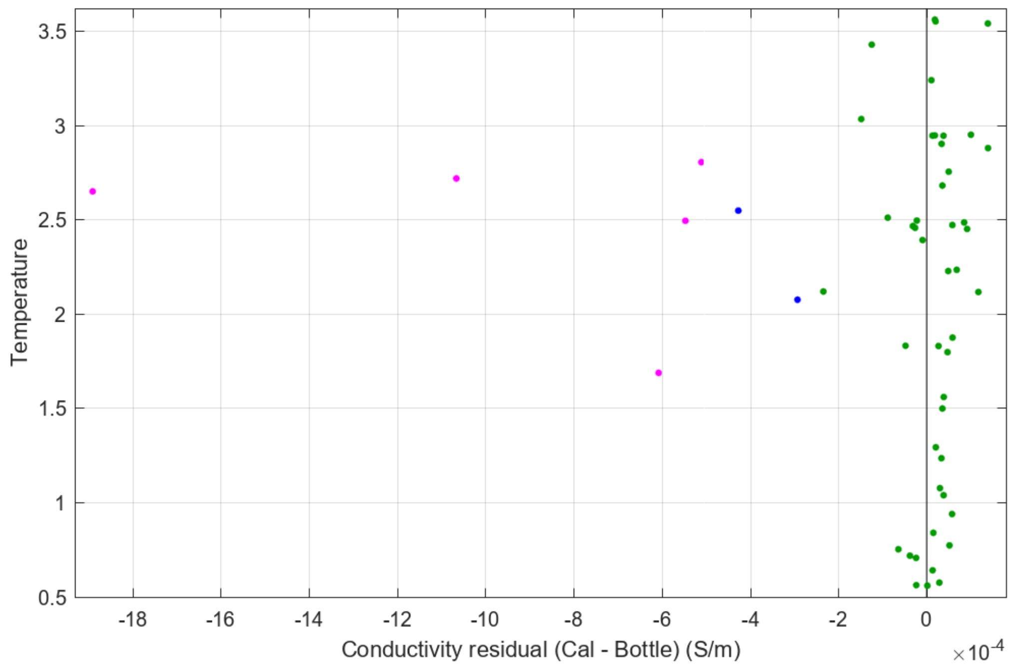

Secondary SBE4 Conductivity residual after cal. 1-34,39
Pressure
0
500
1000
1500
2000
2500
3000
3500
4000
Good (723 points)
Bad (op) Hydro (0 points)
Suspect CTD (85 points)
Bad (soft) CTD (104 points)
Bad CTD (0 points)
-20
-15
-10
-5
0
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-3}$

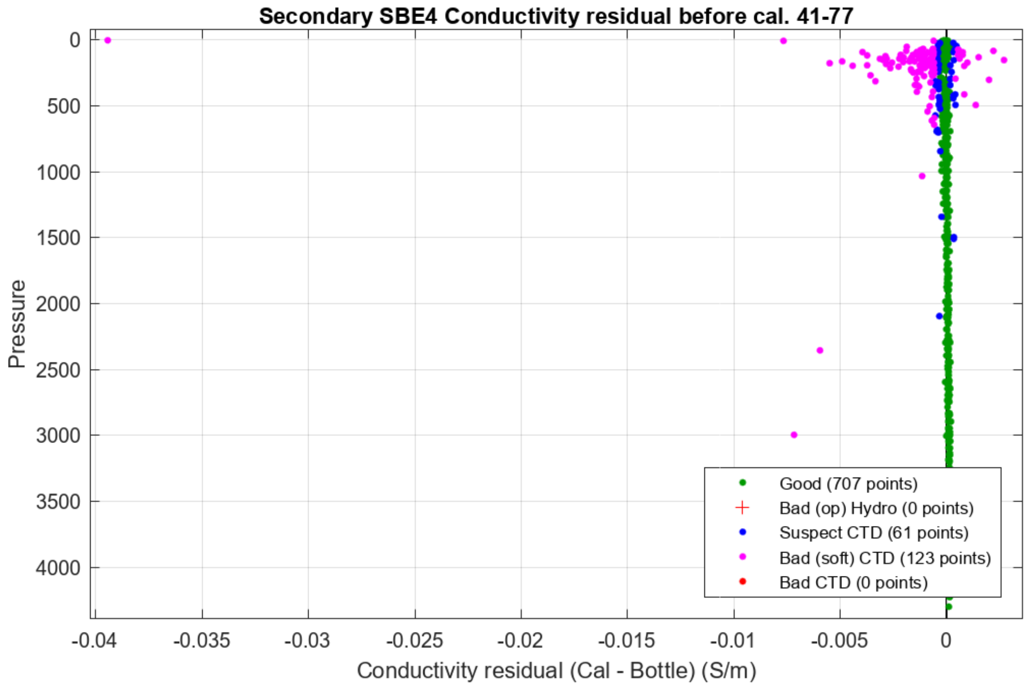

Temperature
6
5
4
3
2
1
0
-20
-15
-10
-5
0
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-3}$

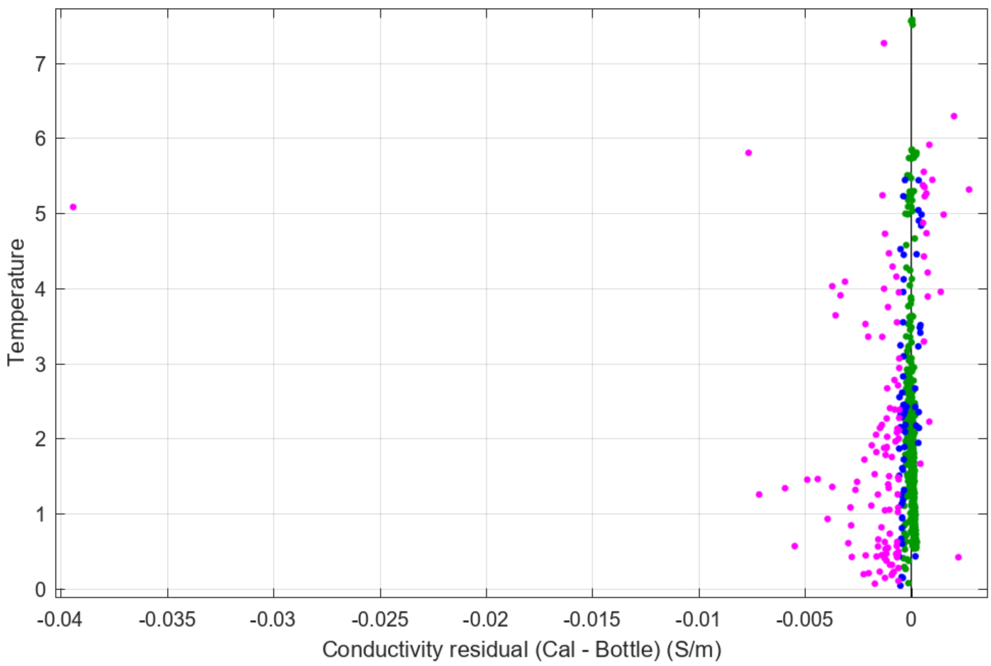

Secondary SBE4 Conductivity residual before cal. 36,37
Pressure
0
500
1000
1500
2000
2500
3000
3500
4000
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
Conductivity residual (Cal - Bottle) (S/m)
×10^-4
Good (46 points)
Bad (op) Hydro (0 points)
Suspect CTD (2 points)
Bad (soft) CTD (5 points)
Bad CTD (0 points)

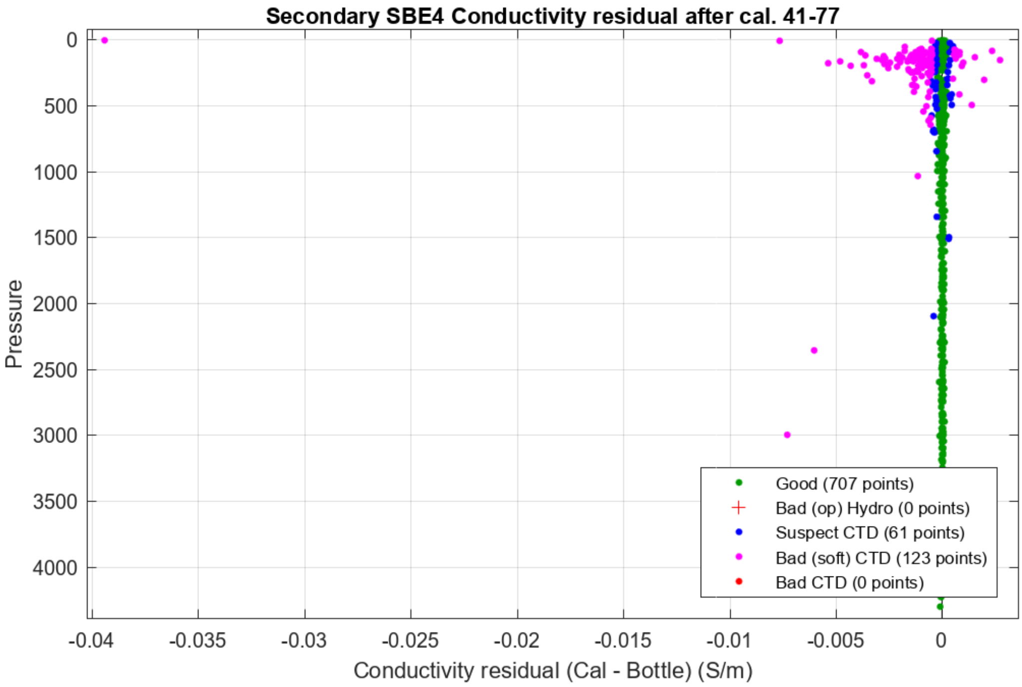

Temperature
3.5
3
2.5
2
1.5
1
0.5
-16
-14
-12
-10
-8
-6
-4
-2
0
2
4
Conductivity residual (Cal - Bottle) (S/m)
×10^-4

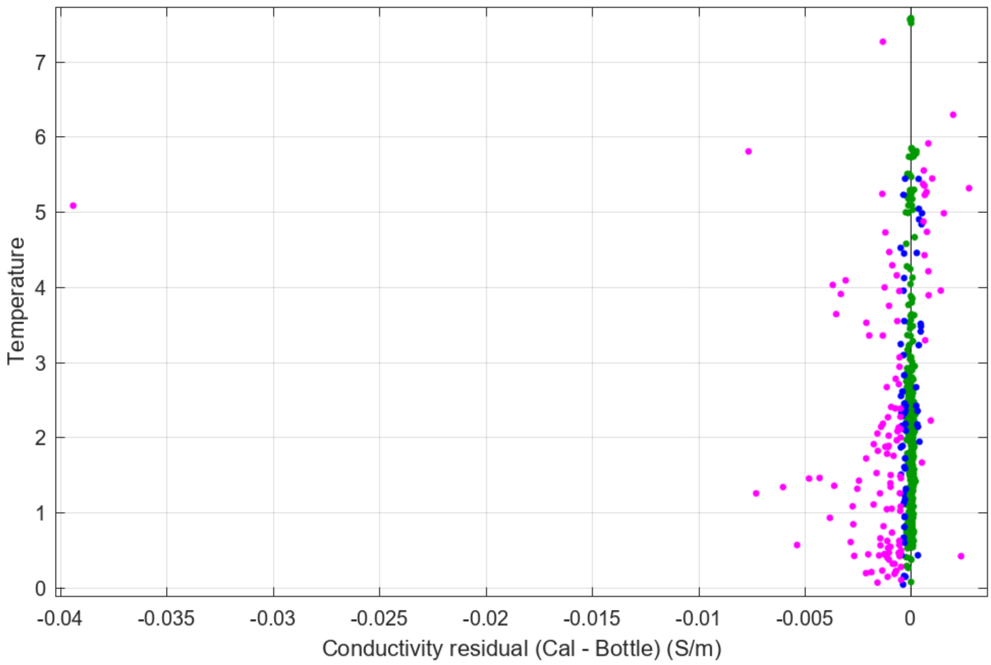

Secondary SBE4 Conductivity residual after cal. 36,37
Pressure
0
500
1000
1500
2000
2500
3000
3500
4000
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
Conductivity residual (Cal - Bottle) (S/m)
×10^-4
Good (46 points)
Bad (op) Hydro (0 points)
Suspect CTD (2 points)
Bad (soft) CTD (5 points)
Bad CTD (0 points)

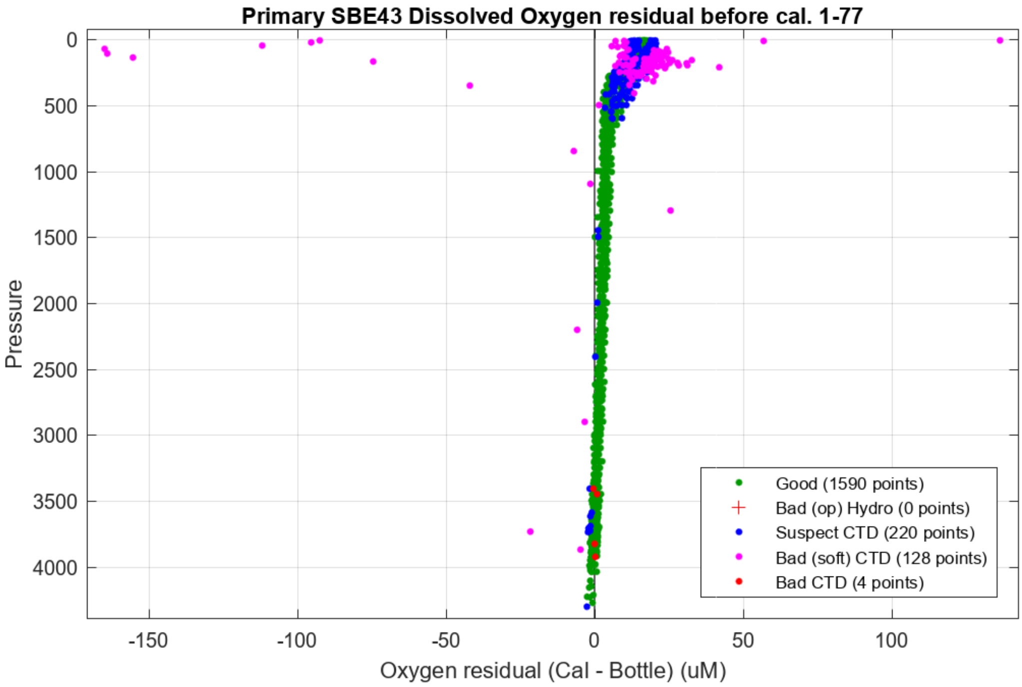

Temperature
3.5
3
2.5
2
1.5
1
0.5
-18
-16
-14
-12
-10
-8
-6
-4
-2
0
Conductivity residual (Cal - Bottle) (S/m)
×10^-4

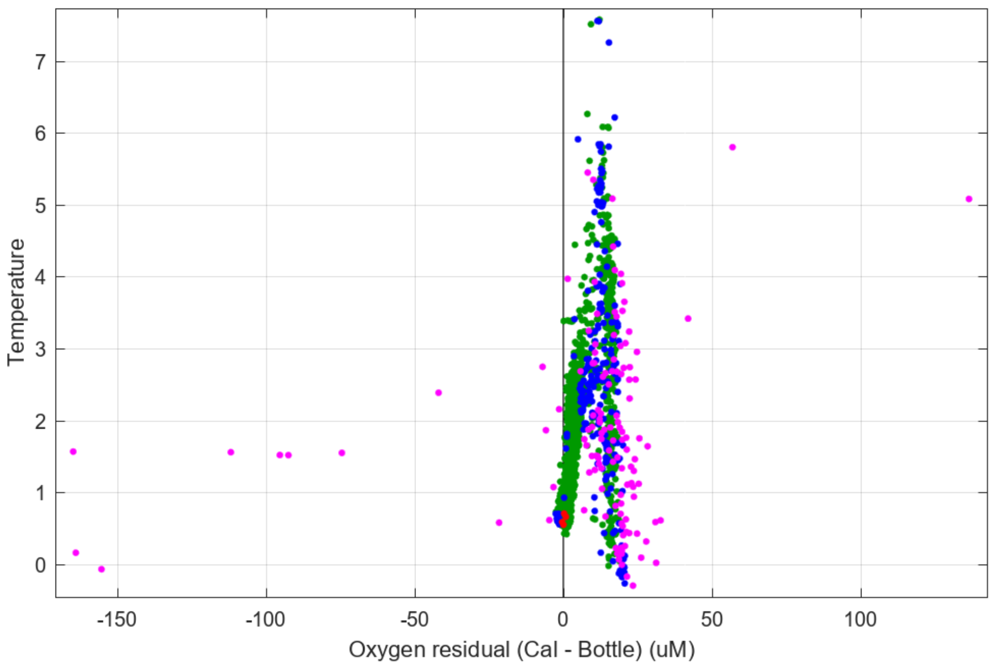

Secondary SBE4 Conductivity residual before cal. 41-77
Pressure
Conductivity residual (Cal - Bottle) (S/m)
Good (707 points)
Bad (op) Hydro (0 points)
Suspect CTD (61 points)
Bad (soft) CTD (123 points)
Bad CTD (0 points)

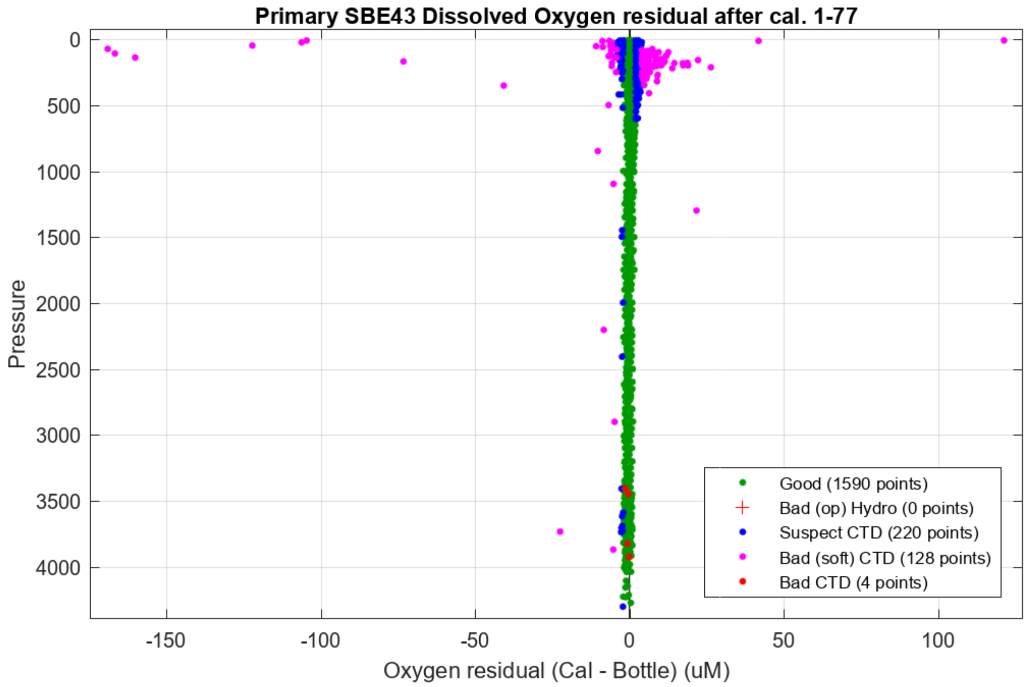

Temperature
Conductivity residual (Cal - Bottle) (S/m)

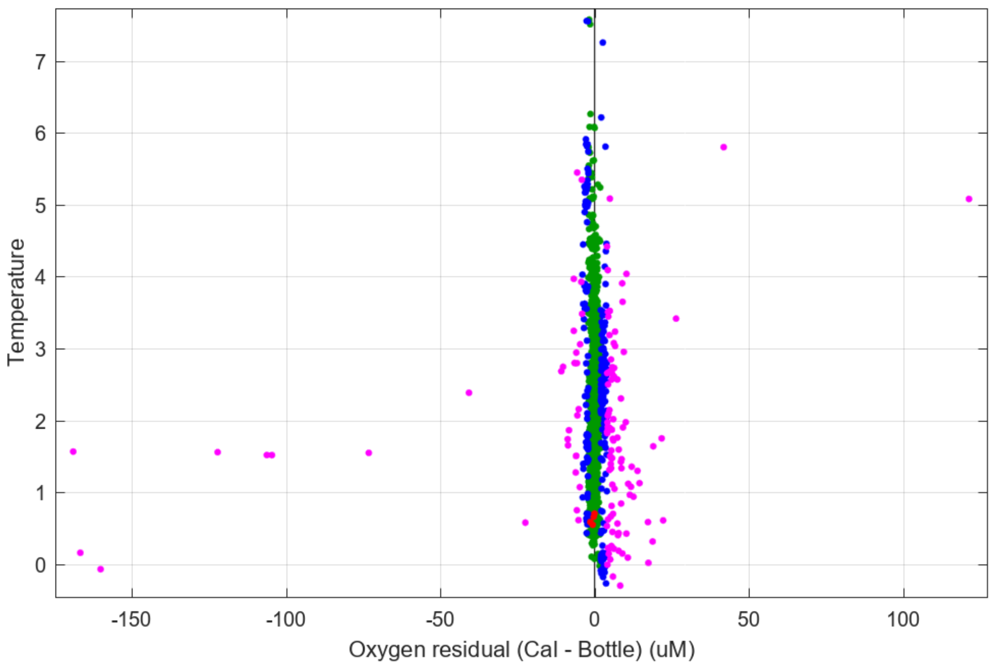

Secondary SBE4 Conductivity residual after cal. 41-77
Pressure
Conductivity residual (Cal - Bottle) (S/m)
Good (707 points)
Bad (op) Hydro (0 points)
Suspect CTD (61 points)
Bad (soft) CTD (123 points)
Bad CTD (0 points)

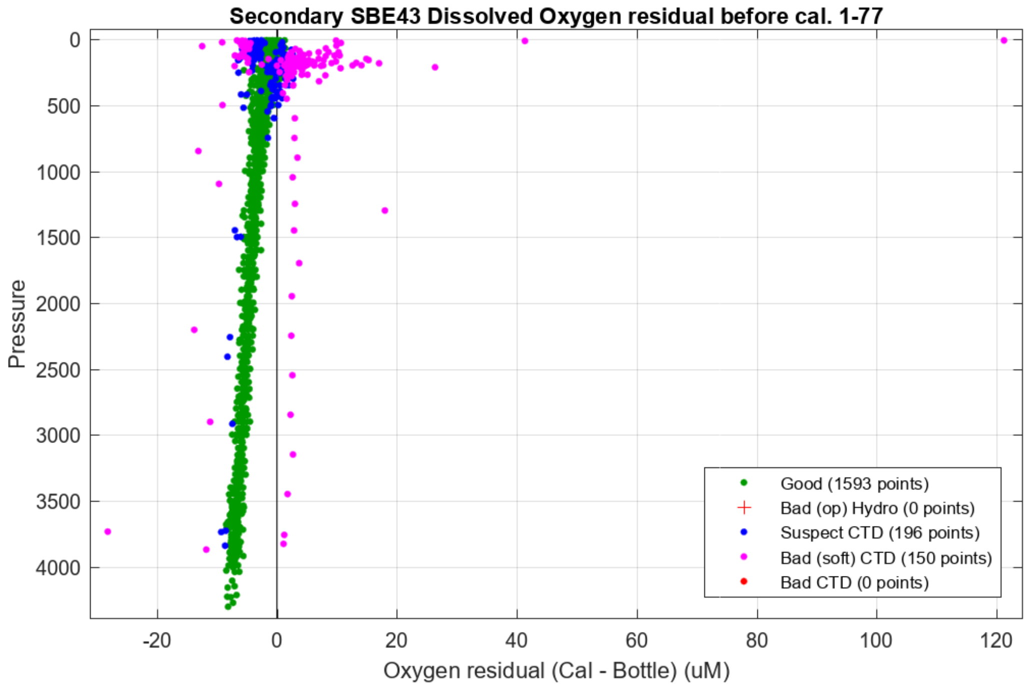

Temperature
Conductivity residual (Cal - Bottle) (S/m)

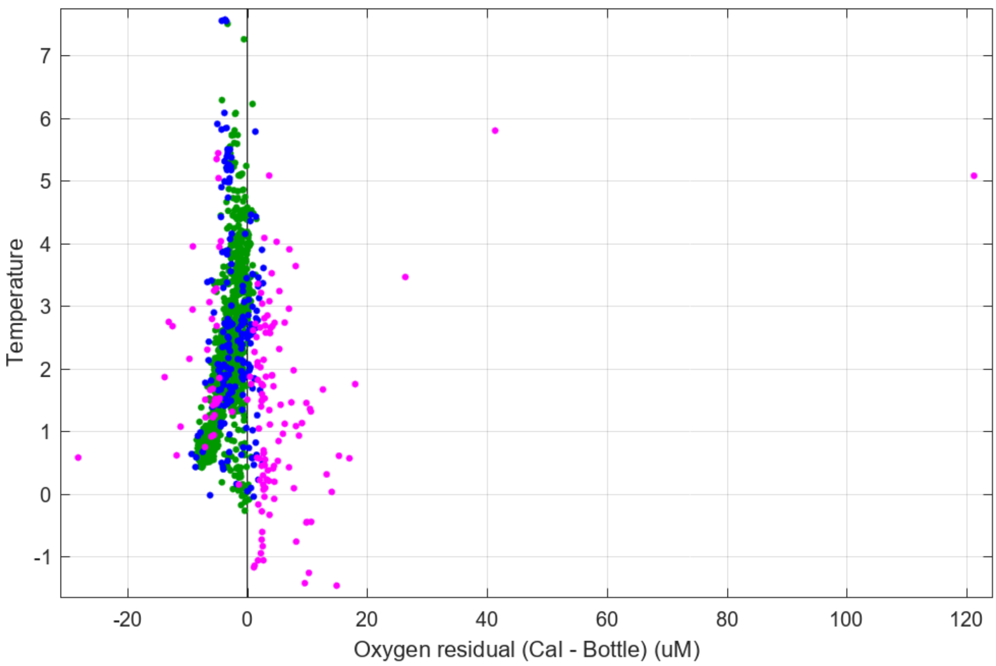

Primary SBE43 Dissolved Oxygen residual before cal. 1-77
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (1590 points)
Bad (op) Hydro (0 points)
Suspect CTD (220 points)
Bad (soft) CTD (128 points)
Bad CTD (4 points)

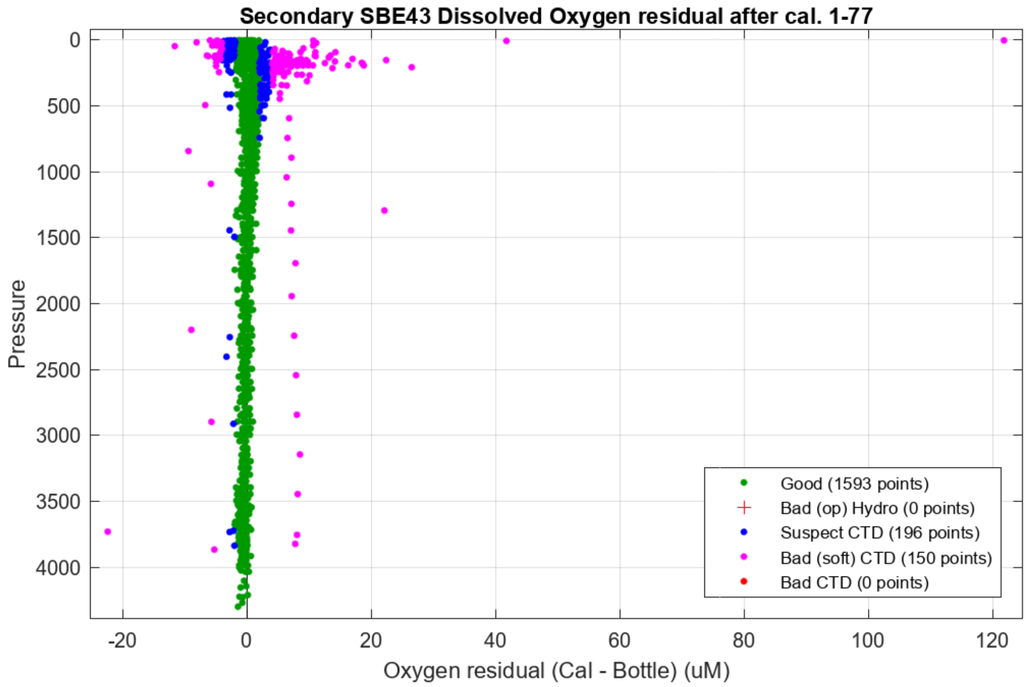

Temperature
Oxygen residual (Cal - Bottle) (uM)

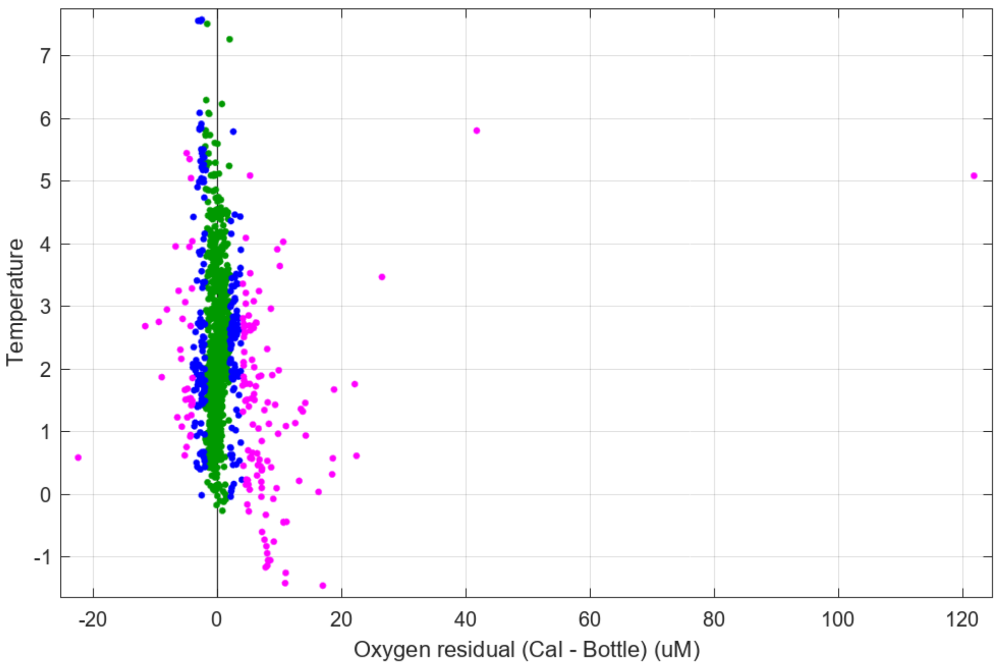

Primary SBE43 Dissolved Oxygen residual after cal. 1-77
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (1590 points)
Bad (op) Hydro (0 points)
Suspect CTD (220 points)
Bad (soft) CTD (128 points)
Bad CTD (4 points)


Temperature
Oxygen residual (Cal - Bottle) (uM)


Secondary SBE43 Dissolved Oxygen residual before cal. 1-77
Pressure
0
500
1000
1500
2000
2500
3000
3500
4000
-20
0
20
40
60
80
100
120
Oxygen residual (Cal - Bottle) (uM)
Good (1593 points)
Bad (op) Hydro (0 points)
Suspect CTD (196 points)
Bad (soft) CTD (150 points)
Bad CTD (0 points)


Temperature
7
6
5
4
3
2
1
0
-1
-20
0
20
40
60
80
100
120
Oxygen residual (Cal - Bottle) (uM)


Secondary SBE43 Dissolved Oxygen residual after cal. 1-77
Pressure
Oxygen residual (Cal - Bottle) (uM)
Good (1593 points)
Bad (op) Hydro (0 points)
Suspect CTD (196 points)
Bad (soft) CTD (150 points)
Bad CTD (0 points)


Temperature
Oxygen residual (Cal - Bottle) (uM)