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RV *Investigator* CTD Data Processing Report

Voyage ID	**in2022_v06**
Voyage Title	Integrated Marine Observing System: Monitoring of East Australian Current property transports at 27 degrees South
Depart	Brisbane, 14 July 2022, 10:15 UTC
Return	Brisbane, 30 July 2022 08:00 UTC
Chief Scientist	Chris Chapman (CSIRO)
Data Processor	Kieran Sheehan (CSIRO – E&T Data Acquisition & Processing)

Document History

Date	Version	Author	Comments
3 October 2022	1.0	Kieran Sheehan	Initial version
21 December 2022	1.1	Kieran Sheehan	Moved to new template

Contents

1 Summary

The main objective of the voyage was the recovery of six full-depth moorings from the abyssal waters off Brisbane, that were being used to monitor the East Australian Current (EAC), including associated CTD operations for mooring instrument calibration.

This report describes the production of quality controlled, calibrated CTD data from RV *Investigator* voyage in2022_v06.

Data for 22 CTD deployments were acquired using the Sea-Bird SBE911 CTD 24, 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.

Issues with the primary and secondary conductivity sensors were observed in the first 3 casts of the CTD deployment. To resolve these issues, the primary and secondary conductivity sensors were replaced. Subsequently, casts 4-22 were treated as a different deployment group. Casts 5 and 6 were diagnostic casts.

The final conductivity calibration was based on a two-deployment groupings. The final calibration from the primary sensor had a standard deviation (SD) of 0.0011575 PSU, and 0.001534 PSU respectively, well within our target of 'better than 0.002 PSU'. The standard product of 1-decibar binned averages were produced using data from the primary sensors.

The dissolved oxygen data calibration fit had a SD of 0.76684µM. The agreement between the CTD and bottle data was good.

An Altimeter, PAR, Transmissometer, Fluorometer, and Turbidity sensor were also installed on the auxiliary A/D channels of the CTD.

To access the full voyage plan and other reports and data associated with this voyage, please see the contact information at the end of this report.

1.1 Voyage Track

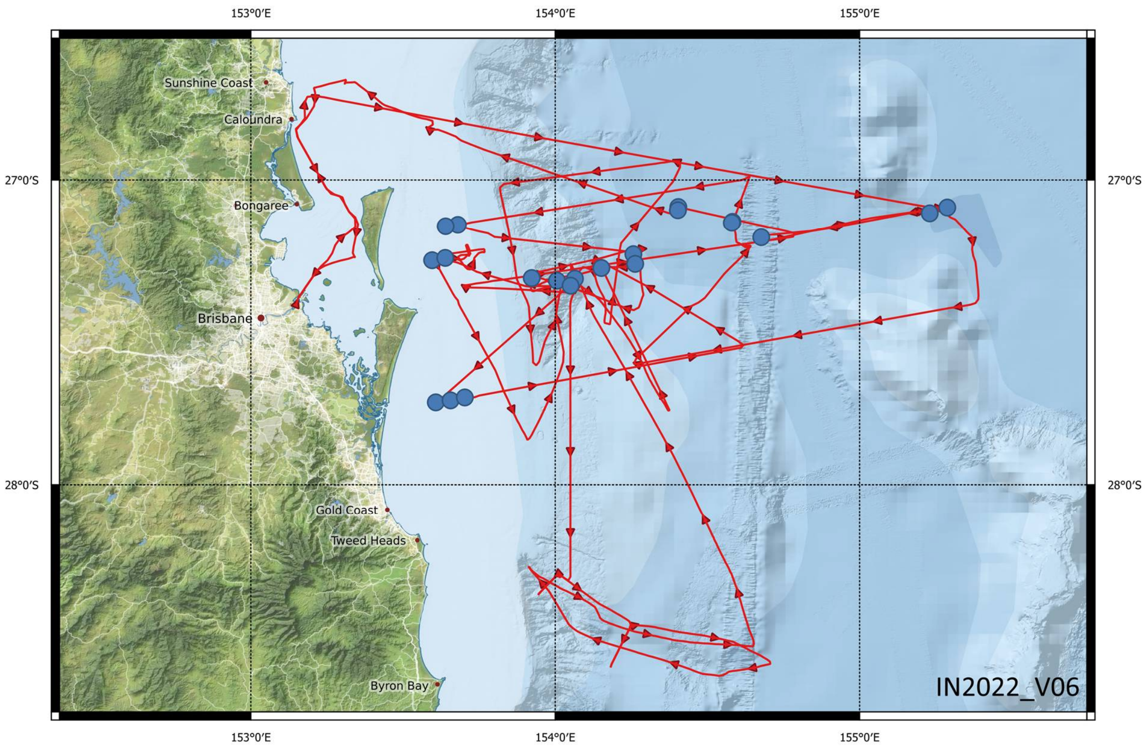


Figure 1: Voyage track with CTD cast locations

2 Data Processing

2.1 Background Information

22 CTD deployments were conducted on this voyage. The data were acquired with the CSIRO CTD unit 24, a Sea-Bird SBE911 with dual conductivity and temperature sensors.

The CTD was additionally fitted with SBE43 dissolved oxygen sensors and Altimeter, PAR, Transmissometer, Fluorometer. These sensors are described in Table 1.

Sensor Description	Model	Serial No.	A/D Channnel	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1332	P	22-Sep-2021	CSIRO
Primary Temperature	Sea-Bird SBE3*plus*	4718	T0	8-Aug-2021	Seabird
Secondary Temperature	Sea-Bird SBE3*plus*	6022	T1	9-Oct-2021	Seabird
Primary Conductivity (1-3)	Sea-Bird SBE4C	4664	C0	10-Aug-2021	CSIRO
Primary Conductivity (4-22)	Sea-Bird SBE4C	4662	C0	6-Apr-2022	Seabird
Secondary Conductivity (1-3)	Sea-Bird SBE4C	4426	C1	10-Aug-2021	CSIRO
Secondary Conductivity (4-22)	Sea-Bird SBE4C	4425	C1	28-Dec-2021	Seabird
Primary Dissolved Oxygen	SBE43	4188	A0	21-Aug-2021	Seabird
Secondary Dissolved Oxygen	SBE43	4187	A1	21-Aug-2021	Seabird
PAR	Biospherical Licor Chelsea Sensor	70562	A3	14-Sep-2021	Biospherical
Transmissometer	WET_LabsCStar	CST-1735DR	A4	16-Jun-2021	Wetlabs
Turbidity	FLBBRTD-6890	6890	A7	27-Jul-2021	Seabird
Fluorescence	FLBBRTD-6890	6890	A6	27-Jul-2021	Seabird
Wetlabs CDOM	Fluoro Wetlab CDOM	7138	A5	8-Dec-2021	Wetlabs
Altimeter	Altimeter	316739	A2	7-May-2019	Tritech

Table 1: CTD Sensor configuration on in2022_v06

Water samples were collected using a Sea-Bird SBE32, 36-bottle rosette sampler. Sampling was from 18 twelve-litre bottles which were fitted to the frame.

The raw CTD data were collected in SBE SeaSave version 7.26.110, converted to scientific units using SBE Data Processing version 7.26.7.129 and written to NetCDF files with CNV_to_Scan for processing using the Matlab-based CapPro software.

The CapPro software version 2.11 dated 23-Aug-2019 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, conductivity cell thermal inertia 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.

2.2 Pressure and Temperature Calibration

The pressure offsets for each deployment are plotted in Figure 2. The blue circles refer to initial out-of-water values (beginning of downcast) and the red circles the final out-of-water values (end of upcast).

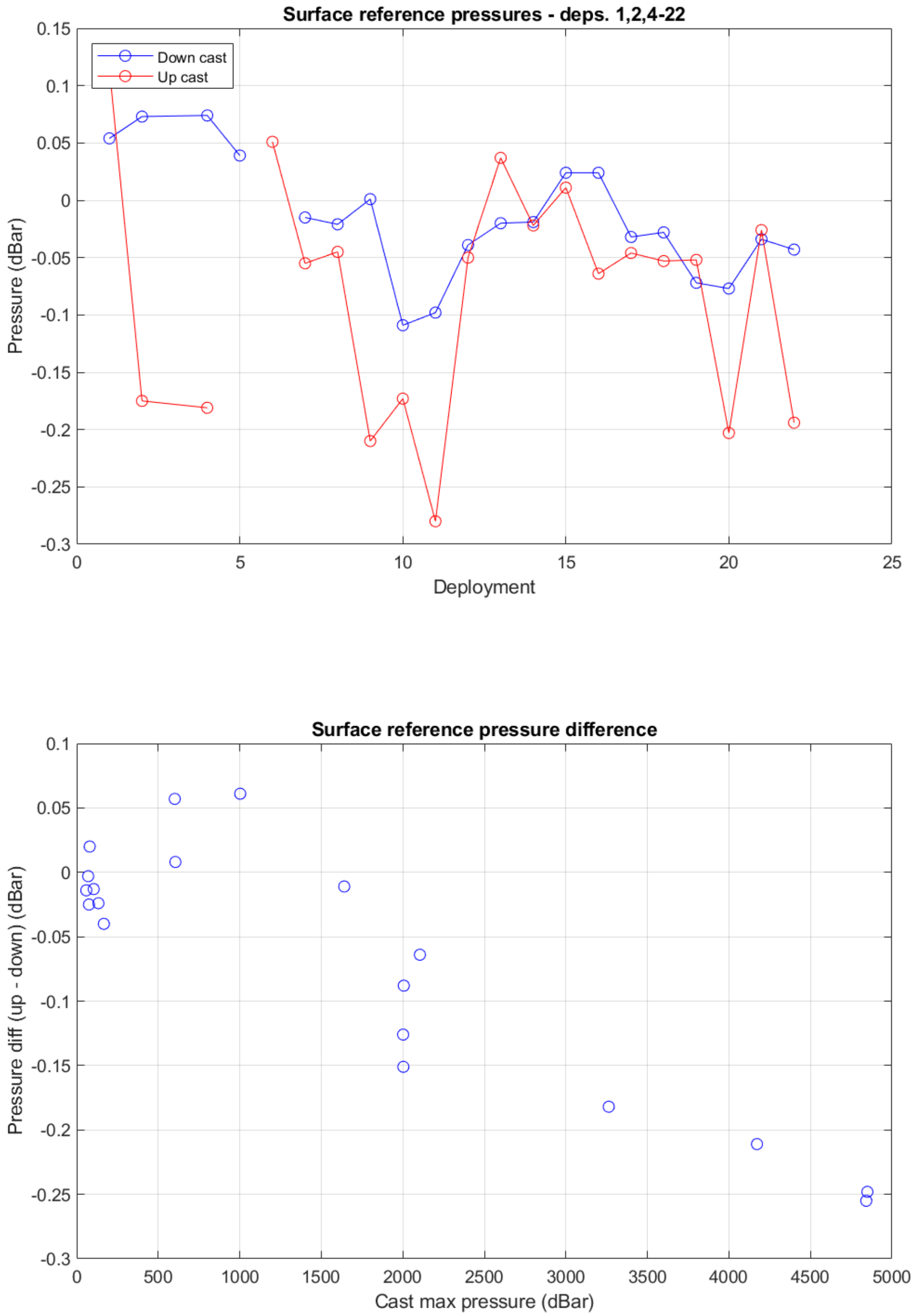


Figure 2: CTD **pressure offsets**

The difference between the primary and secondary temperature sensors at the bottle sampling depths is plotted in Figure 3. Most deployments plot within ±0.001°C of zero – outliers result from sampling in regions of high vertical temperature gradient. The consistent mean difference (red + markers) between the primary and secondary temperature from deployment to deployment indicates neither sensor has drifted significantly from its calibration. Higher fluctuations in difference presented in the plots represent shallower casts, where high gradient is present throughout most of the cast.

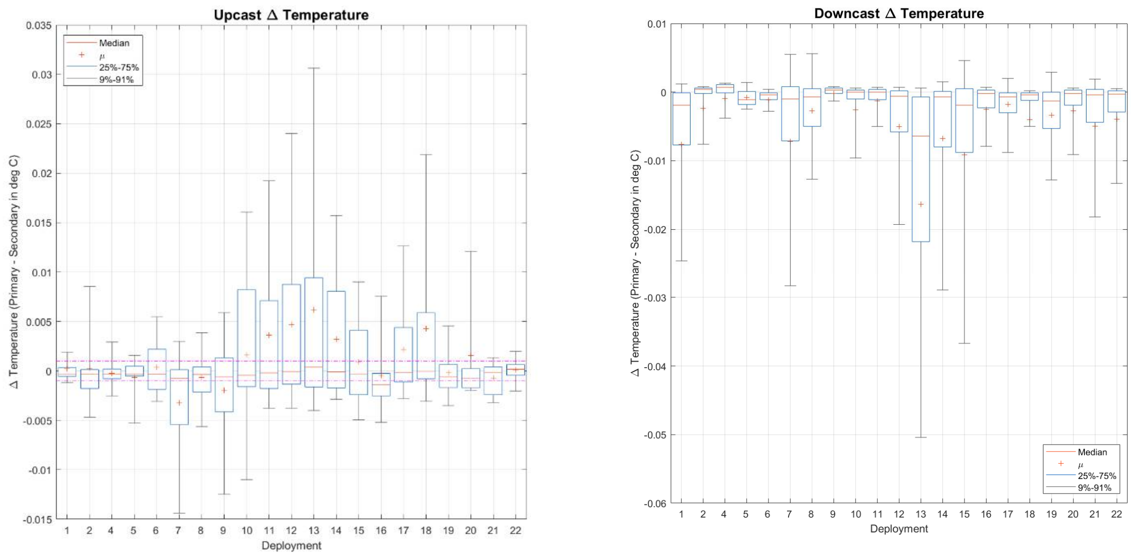


Figure 3: Difference between primary and secondary temperature sensors

2.3 Conductivity Calibration

If any discrepancies or sampling problems occurred during bottle salinity sampling or between primary and secondary CTD conductivity measurements, these would show in the conductivity calibration plots in Figure 4. We did not observe any discrepancies based on these calibration results.

The calibration for deployments 1 and 2 were based upon the percent of ‘good’ sample data (47 good samples from the primary unit and 48 good samples from the secondary unit), out of a total of 51 samples taken during deployments. To perform the calibration, a minimum of 70% of the samples need to be in the ‘good’ range. If there is an insufficient number of good samples for a unit, the conductivity difference ‘cutoff’ value must be increased to continue with the calibration process in CapPro. For this set of conductivity calibrations, the cutoffs used were 0.003 (primary) and 0.003 (secondary).

Figure 4 plots CTD - bottle salinity differences for both upcast (Hydro bottle) and downcast (CTD SBE43) data. The ‘bad’ outliers (magenta dots, red dots and red + markers) are excluded from the calibration, the ‘suspect’ outliers (blue dots) are used in the calibration but are weighted based on their distance from the mean. All green dots are considered ‘good’ data points and are not weighted based on distance from the mean.

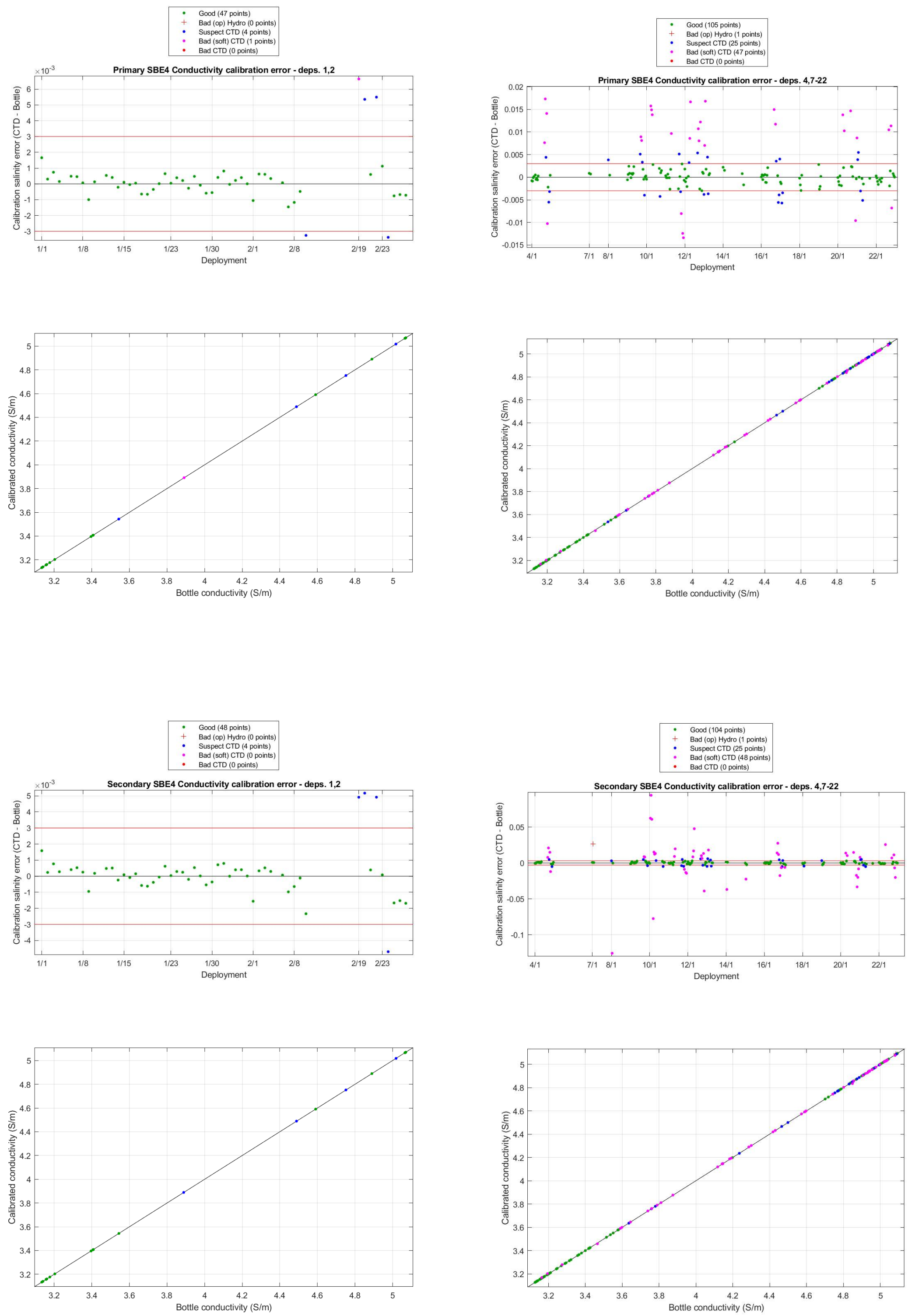


Figure 4: CTD - bottle conductivity difference and salinity calibration error (left: primary, right: secondary)

The box plot (Figure 5) of calibrated downcast conductivities (primary - secondary) at the bottle sampling depths for all deployments shows that the calibrated primary and secondary conductivity cell responses corresponded well to each other.

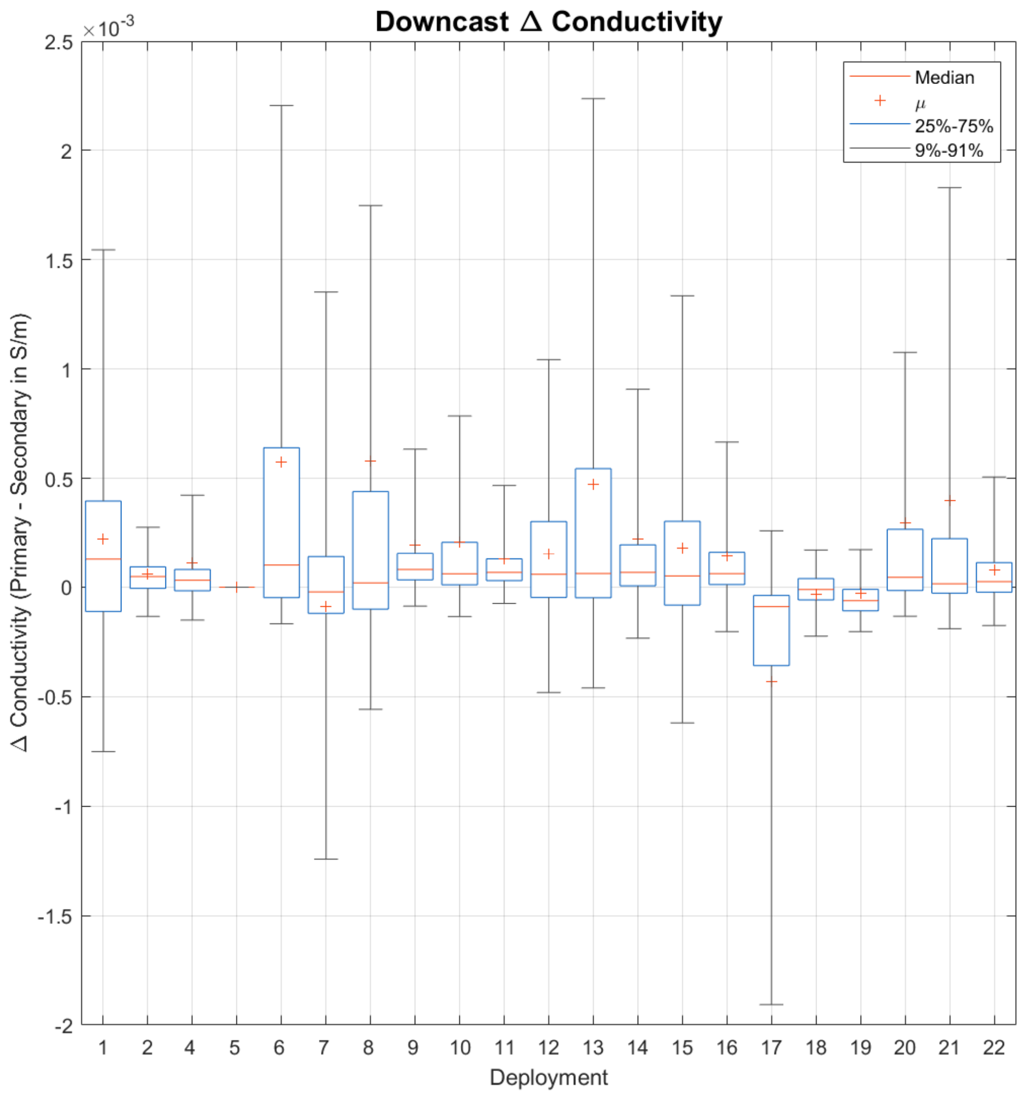


Figure 5: Difference between primary and secondary conductivity sensors

The final results 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	1-2	0.99985	0.00051155	0.00041515	0.0020997	0.0011575	0.00047801
Primary	4, 7-22	0.99965	0.00065793	0.0016719	0.0031559	0.001534	0.0010045
Secondary	1-3	0.99984	0.00056378	0.000045615	0.0023158	0.001284	0.00040507
Secondary	4, 7-22	0.99982	0.00065135	0.000045137	0.0033182	0.0015748	0.00092894

Table 2: Conductivity calibration with respect to manufacturer's calibration coefficients and post-calibration results

Conductivity Sensor	Deployments	CPcor	±
Primary	1-2	-8.1815e-08	1.0049e-07
Primary	4, 7-22	-8.466e-08	1.611e-07
Secondary	1-2	-7.1192e-08	1.1072e-07
Secondary	4, 7-22	-6.8432e-08	1.5954e-07

Table 3: Calculated CPcor for primary and secondary conductivity units compared to the manufacturer's 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 the indicated deployments. Full plots of residuals before and after calibration are available in A.1.

Data from the primary conductivity and temperature sensors were used to produce the averaged salinities with primary sensors included with a suffix '_1'.

2.4 Dissolved Oxygen Sensor Calibration

2.4.1 SBE Calibration Procedure

AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage (Sea-Bird, 2013) describes the SBE43 dissolved oxygen sensor 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 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.

2.4.2 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.

A single calibration group was used with the associated SBE43 upcast data to compute the new Soc and $Voffset$ coefficients. Figure 6 plots CTD SBE43 - bottle oxygen differences for both upcast (Hydro bottle) and downcast (CTD SBE43) data. The 'bad' outliers (magenta dots, red dots and red + markers) are excluded from the calibration, the 'suspect' outliers (blue dots) are used in the calibration but are weighted based on their distance from the mean. All green dots are considered 'good' data points and are not weighted based on distance from the mean.

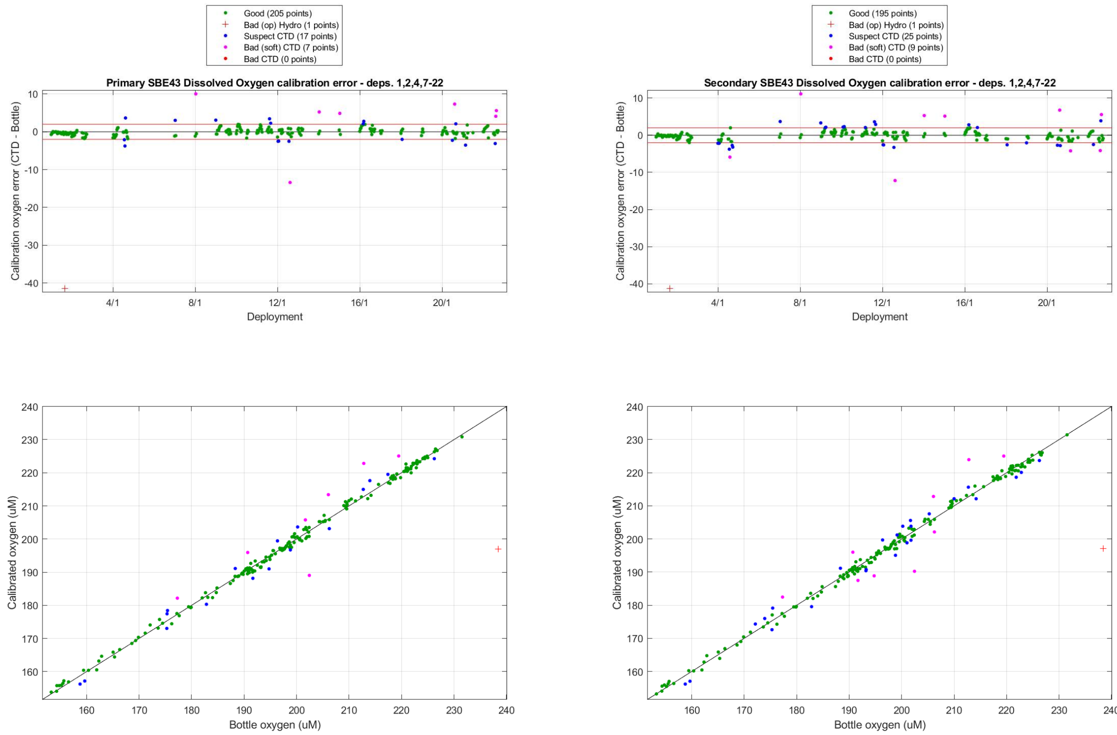


Figure 6: CTD SBE43 - bottle dissolved oxygen difference and calibration error (left: primary, right: secondary)

The box plot (Figure 7) of calibrated downcast dissolved oxygen readings (primary - secondary) at the bottle sampling depths for all deployments shows that the calibrated primary and secondary dissolved oxygen sensor responses corresponded well to each other.

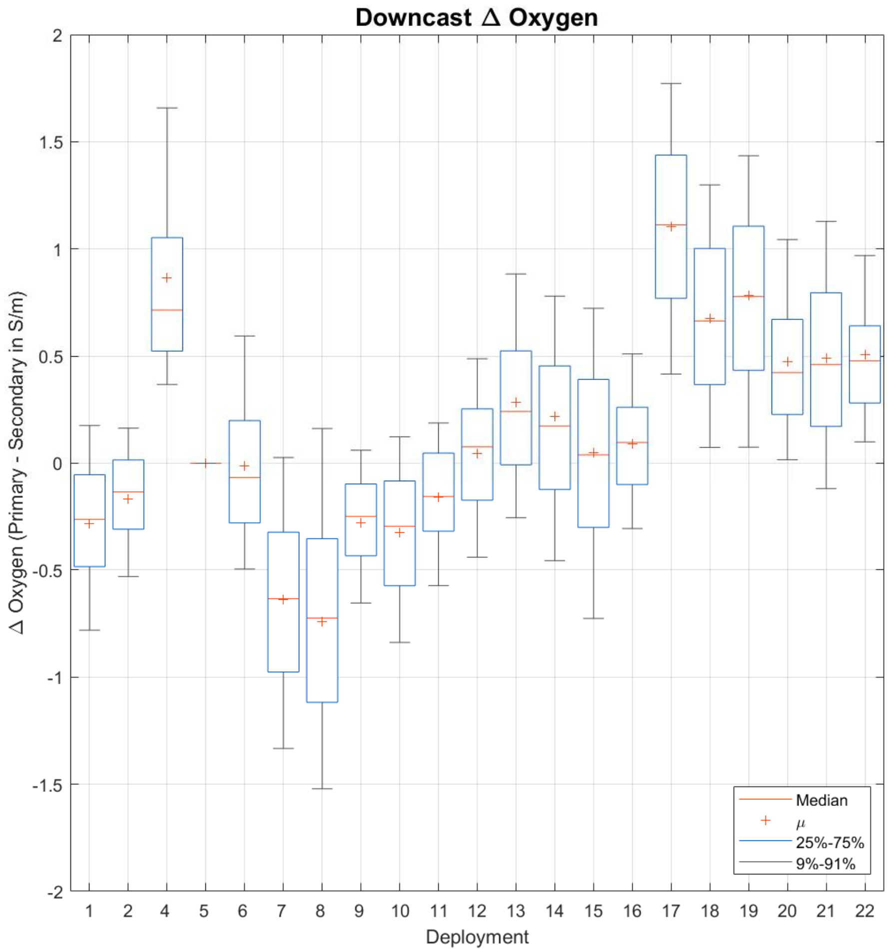


Figure 7: Difference between primary and secondary dissolved oxygen sensors on downcast

The old and new *Soc* and *Voffset* values for DO sensors are listed in Table 4. 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 A.2.

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

Sensor	Calibration Source	Deployments	Calibration Coefficients				Dissolved Oxygen (µM)	
			Voffset	±	*Soc*	±	Residual SD	M.A.D.
Primary DO	CapPro	1,2,4,7-22	-0.50517	0.0015369	0.59984	0.00091243	0.76684	0.53312
	Seabird	1,2,4,7-22	-0.5111		0.5705			
Secondary DO	CapPro	1,2,4,7-22	-0.49334	0.0016704	0.62043	0.0010643	0.84118	0.6787
	Seabird	1,2,4,7-22	-0.4937		0.5833			

Table 4: Dissolved oxygen calibrations

2.5 Other Sensors

2.5.1 C-Star Transmissometer

The C-Star transmissometer was used on all deployments. It was calibrated by the manufacturer with meter outputs with the beam blocked, in air with a clear beam path and with clean water in the path. These values are used to determine a scale and offset for use in SBE Data Processing software to convert the raw counts to a beam transmittance output of 0-100 percent.

This sensor worked as expected during this voyage.

2.5.2 WET Labs ECO Fluorometer-Scattering Sensor

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/m^3. The scattering (OBS) has been calibrated with manufacturer supplied coefficients to give outputs in m^{-1}sr^{-1}.

This sensor worked as expected during this voyage.

2.5.3 Biospherical PAR Sensor

The Biospherical PAR (photosynthetically active radiation) sensor was used for all deployments. The output is a nominal 0-5 volts which is converted to the unit µEinsteins/m^2/second using a 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. Time of day and environmental factors such as sea state and cloud cover impact 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.

This sensor worked as expected during this voyage.

2.6 Bad-Data Detection

The value 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 5:. 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
Dissolved Oxygen	-1	500	0.5
Fluorometer	0	100	0.5
PAR	-5	2000	0.5
Transmissometer	0	100	0.5

Table 5: Sensor limits for bad-data detection

2.7 Heave Filtering

Sensor data impacted by ship heave impeding the CTD deployment is filtered out in three stages and applied during data binning. The first stage detects negative acceleration of the CTD which can cause trailing mixed water to be pumped through the sensors. The second stage looks at all negative density gradients and flags readings which are above 10 times the standard deviation of all negative gradients, for 2 seconds. The third stage flags any pressure reversals which are greater than the height of the CTD sensor pump inlet above the frame.

2.8 Temperature-Conductivity Lag

To precisely align the temperature and conductivity measurements for a sample of water a temporal offset can be applied. A manufacturer-recommended nominal offset (Δt_{c_SBE9+}) of -0.078 seconds is initially applied at time of acquisition by the SBE9+ deck unit on both primary and secondary conductivity channels. This offset advances the conductivity sensor readings in time to compensate for the amount of time it takes for the measured water sample to move from the temperature sensor through into the conductivity sensor cell.

Post-voyage inspection of the temperature and conductivity data in CapPro can determine fine-tuning adjustments to the conductivity sample time offset (Δt_{c_CP}) that will optimally align the data. The final adjustments applied to the conductivity sample time can be found in Table 6 and Table 7. Note that although CapPro can set an offset time ('lag') for both temperature and conductivity samples, DAP processing only sets a lag for the conductivity sample to maintain consistency with the nominal offset applied by the SBE9+ to the conductivity data. The equation governing this conductivity sample time adjustment is given below, where $t_{c\_aligned}$ is the best-estimate of the conductivity measurement time to align it with the temperature measurement from the same sample of water on the downcast, and t_{c_meas} is the original, uncorrected conductivity measurement time.

$$t_{c\_aligned} = t_{c\_meas} + \Delta t_{c\_SBE9+} + \Delta t_{c\_CP}$$

Cast #	Nominal Offset Time Applied by SBE9+, Δt_{c_SBE9+} (sec)	Offset ('Cond lag') Set in CapPro (scans)	Calculated Offset Time from CapPro 'Cond lag', Δt_{c_CP} (sec = scans/24Hz)
1	-0.078	-0.4	-0.0166
2	-0.078	-0.4	-0.0166
4	-0.078	-0.75	-0.03124
5	-0.078	-0.6	-0.025
6	-0.078	-0.7	-0.02916
7	-0.078	-0.7	-0.02916
8	-0.078	-0.8	-0.03333
9	-0.078	-0.8	-0.3333
10	-0.078	-0.9	-0.0375
11	-0.078	-0.7	-0.02916
12	-0.078	-0.8	-0.03333
13	-0.078	-0.8	-0.03333
14	-0.078	-0.8	-0.03333
15	-0.078	-0.6	-0.025
16	-0.078	-0.6	-0.025
17	-0.078	-1	-0.0416
18	-0.078	-1	-0.0416
19	-0.078	-0.9	-0.0375
20	-0.078	-0.9	-0.0375
21	-0.078	-0.75	-0.03124
22	-0.078	-0.7	-0.02916

Table 6: Primary conductivity sensor offset adjustments

Cast #	Nominal Offset Time Applied by SBE9+, Δt_{c_SBE9+} (sec)	Offset ('Cond lag') Set in CapPro (scans)	Calculated Offset Time from CapPro 'Cond lag', Δt_{c_CP} (sec = scans/24Hz)
1	-0.078	-0.4	-0.0166
2	-0.078	-0.4	-0.0166
4	-0.078	-0.3	-0.0125
5	-0.078	-0.2	-0.0083
6	-0.078	0	0
7	-0.078	-0.4	-0.0166
8	-0.078	-0.3	-0.0125
9	-0.078	-0.3	-0.0125
10	-0.078	-0.4	-.0.0166
11	-0.078	-0.2	-0.0083
12	-0.078	-0.2	-0.0083
13	-0.078	-0.3	-0.0125
14	-0.078	-0.4	-0.0166
15	-0.078	-0.3	-0.0125
16	-0.078	-0.2	-0.0083
17	-0.078	-0.3	-0.0125
18	-0.078	-0.2	-0.0083
19	-0.078	-0.2	-0.0083
20	-0.078	-0.1	-0.0041
21	-0.078	-0.3	-0.0125
22	-0.078	-0.3	-0.0125

Table 7: Secondary conductivity sensor offset adjustments

2.9 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 quality control (QC) flag. Our QC 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, is taken to be the worst of the estimates for the parameters from which they are derived.

3 References

Chris Chapman. (2022). *The RV Investigator. Voyage Plan* in2022_v06. Retrieved from Marine National Facility: Voyage Plans and summaries: https://mnf.csiro.au/en/Voyages/Voyage-Catalogue

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

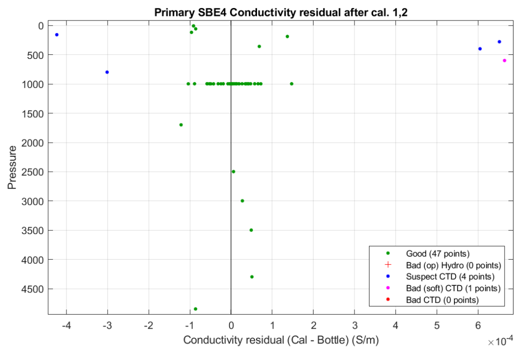
Sea-Bird. (2012). *AN64-2: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-2-sbe-43-dissolved-oxygen-sensor-calibration-and-data-corrections

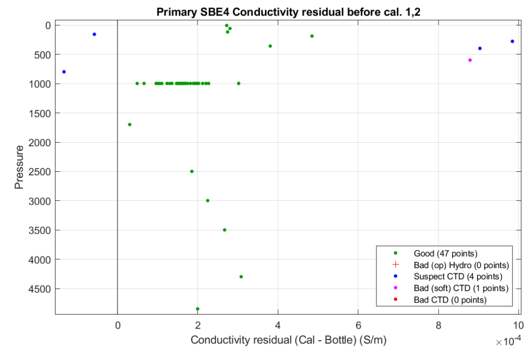
Sea-Bird. (2013). *AN64: SBE 43 Dissolved Oxygen Sensor - Background Information, Deployment Recommendations, and Cleaning and Storage.* Retrieved from Sea-Bird Electronics: http://www.seabird.com/document/an64-sbe-43-dissolved-oxygen-sensor-background-information-deployment-recommendations

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

4 Appendices

A.1 Conductivity Calibration Residual Plots


Primary SBE4 Conductivity residual after cal. 1,2
Pressure
Conductivity residual (Cal - Bottle) (S/m)
×10⁻⁴
Good (47 points)
Bad (op) Hydro (0 points)
Suspect CTD (4 points)
Bad (soft) CTD (1 points)
Bad CTD (0 points)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Pressure
Conductivity residual (Cal - Bottle) (S/m)
×10⁻⁴
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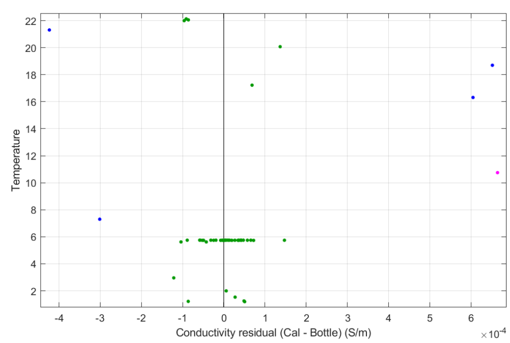
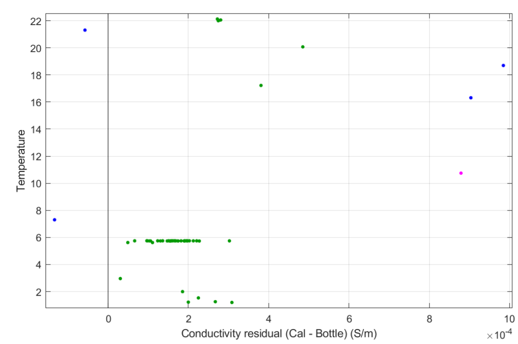
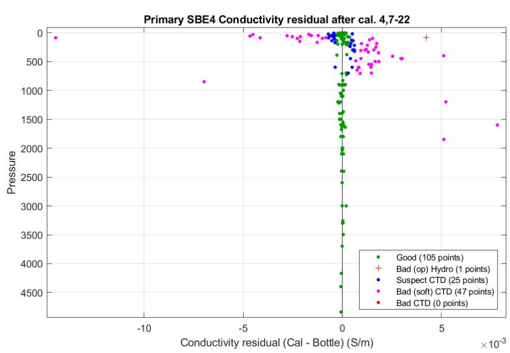
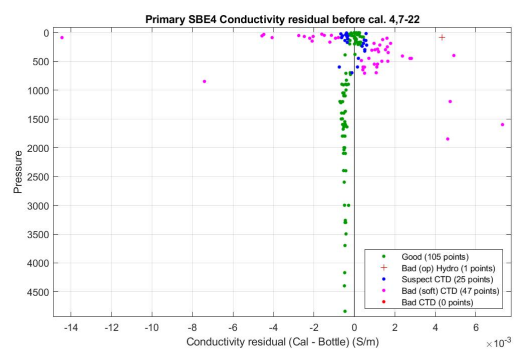

Temperature
Conductivity residual (Cal - Bottle) (S/m)
×10⁻⁴


Temperature
Conductivity residual (Cal - Bottle) (S/m)
×10⁻⁴


Primary SBE4 Conductivity residual after cal. 4,7-22
Pressure
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³
Good (105 points)
Bad (op) Hydro (1 points)
Suspect CTD (25 points)
Bad (soft) CTD (47 points)
Bad CTD (0 points)


Primary SBE4 Conductivity residual before cal. 4,7-22
Pressure
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³
Good (105 points)
Bad (op) Hydro (1 points)
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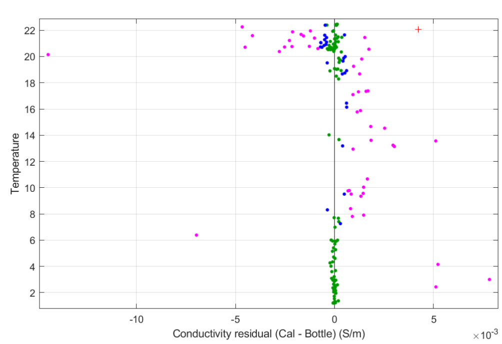
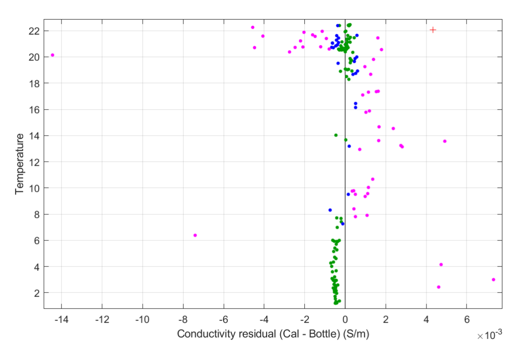
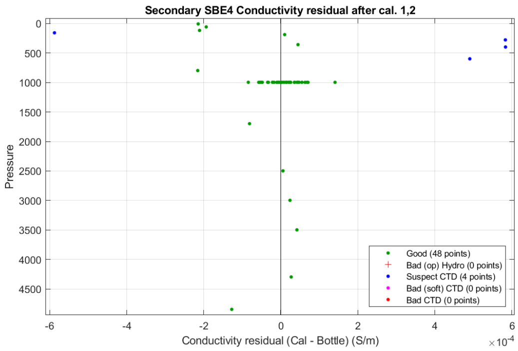
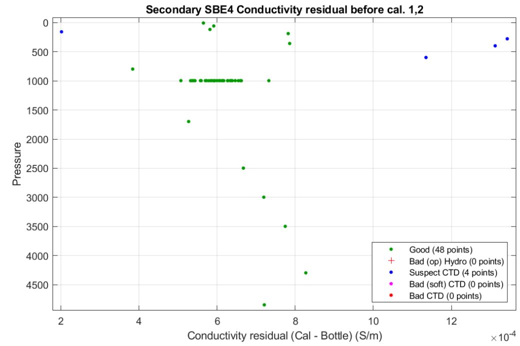
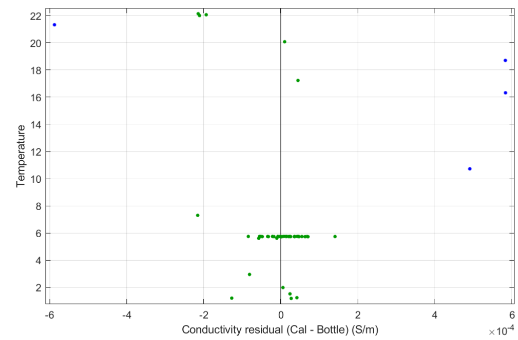
Bad CTD (0 points)

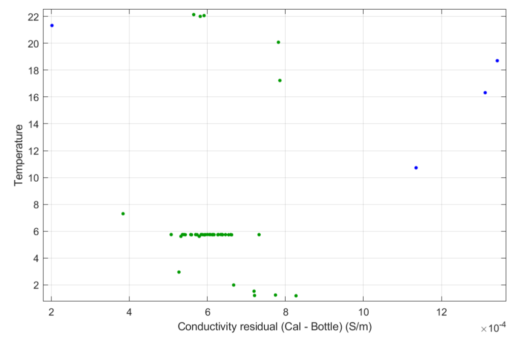

Temperature
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³

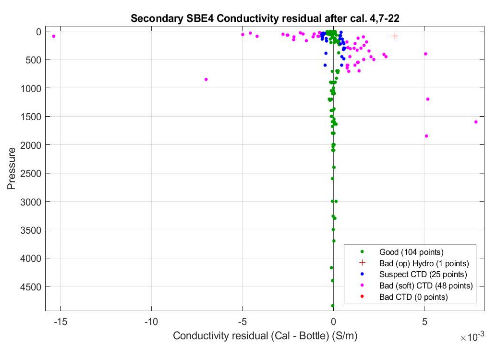

Temperature
Conductivity residual (Cal - Bottle) (S/m)
×10⁻³

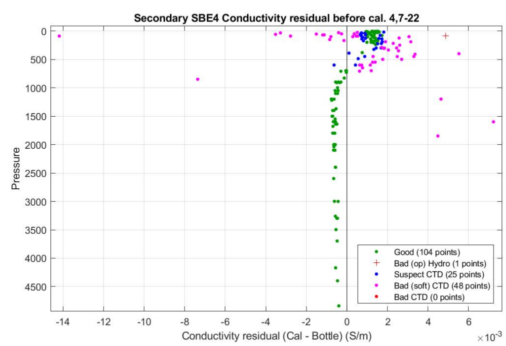

Secondary SBE4 Conductivity residual after cal. 1,2
Pressure
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-4}$
Good (48 points)
Bad (op) Hydro (0 points)
Suspect CTD (4 points)
Bad (soft) CTD (0 points)
Bad CTD (0 points)

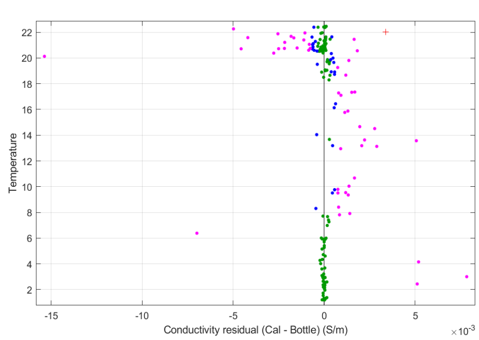

Secondary SBE4 Conductivity residual before cal. 1,2
Pressure
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-4}$
Good (48 points)
Bad (op) Hydro (0 points)
Suspect CTD (4 points)
Bad (soft) CTD (0 points)
Bad CTD (0 points)

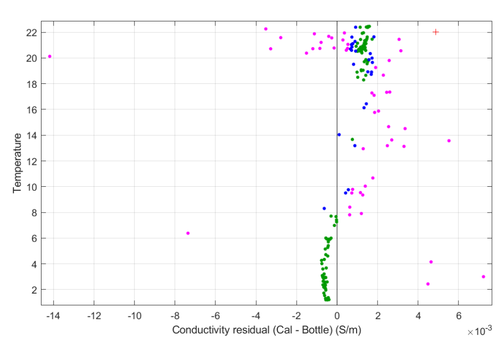

Temperature
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-4}$


Temperature
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-4}$

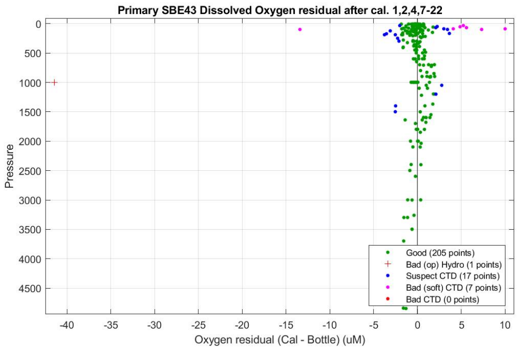

Secondary SBE4 Conductivity residual after cal. 4,7-22
Pressure
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-3}$
Good (104 points)
Bad (op) Hydro (1 points)
Suspect CTD (25 points)
Bad (soft) CTD (48 points)
Bad CTD (0 points)

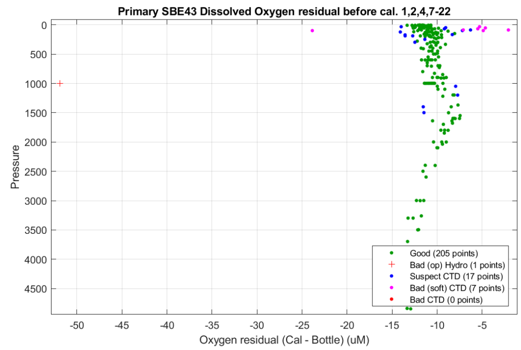

Secondary SBE4 Conductivity residual before cal. 4,7-22
Pressure
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-3}$
Good (104 points)
Bad (op) Hydro (1 points)
Suspect CTD (25 points)
Bad (soft) CTD (48 points)
Bad CTD (0 points)

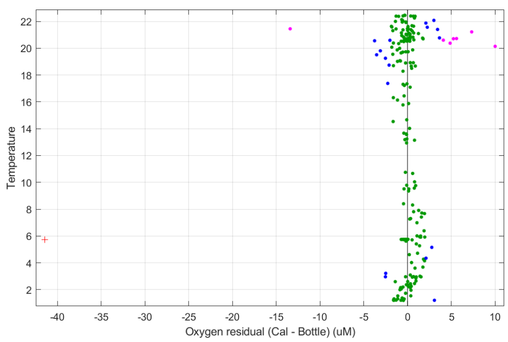

Temperature
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-3}$

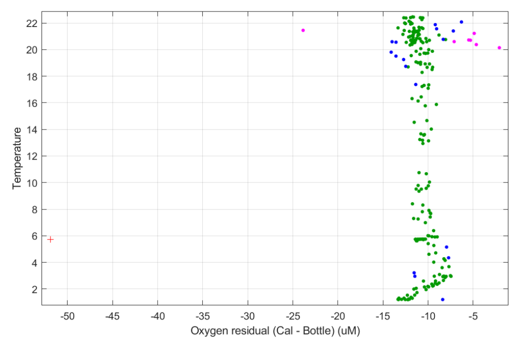

Temperature
Conductivity residual (Cal - Bottle) (S/m)
$\times 10^{-3}$

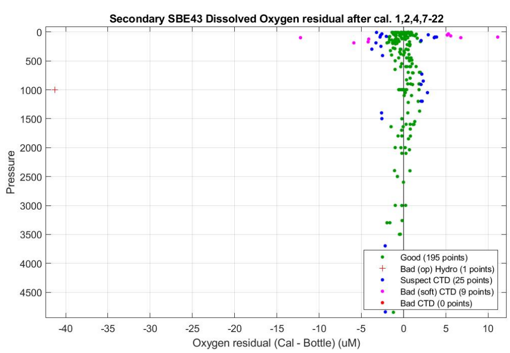
A.2 Dissolved Oxygen Calibration Residual Plots

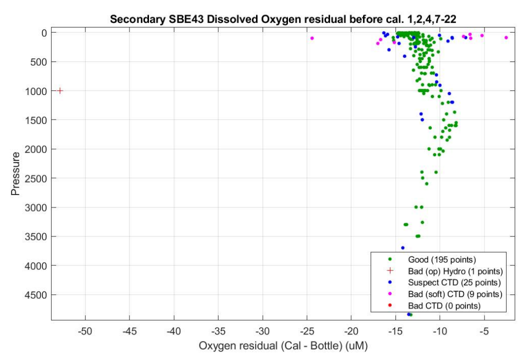


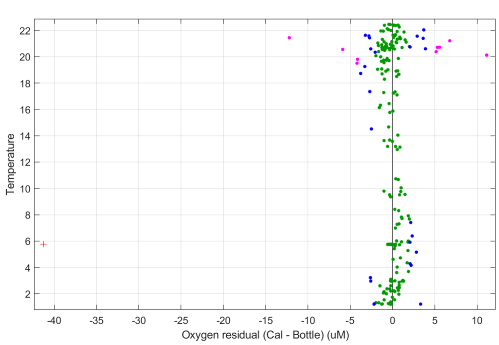


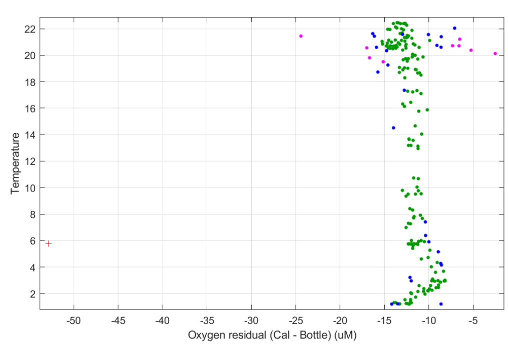












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