Marine National Facility

RV *Investigator*

CTD Processing Report

Voyage ID:	in2021_v01
Voyage title:	Quantifying krill abundance for krill monitoring and management off the Australian Antarctic Territory
Depart:	Hobart, 1200 Friday, 29 January 2021
Return:	Hobart, 0800 Wednesday, 24 March 2021

Document History

Date	Version	Author	Comments
23 Mar 2021	1.0	Francis Chui	Initial version
6 Oct 2021	1.1	Francis Chui	Adjusted conductivity advance to primary by 1 scan and secondary by 2 scans
11 Oct 2021	1.2	Francis Chui	Adjusted conductivity advance by 1.15 scans for primary and 1.75 scans for the secondary

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Contents

1 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage in2021_v01, from 06 Feb 2021 – 12 Mar 2021. These were conducted along six transects within the Krill Survey area as outlined in 2.4 Area of operation. A number of addition casts were made for an initial test cast on deployment 1, a winch spooling maintenance cast on deployment 5, and deployments 58 and 59 were to 300 decibar as part of the swarm study system to collect eDNA samples in close proximity to the krill swarm.

Data for 66 deployments were acquired using the Sea-Bird SBE911 CTD 24, fitted with 31 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.

The final conductivity calibration was based on a single deployment grouping. The final calibration from the primary sensor had a standard deviation (SD) of 0.0013317 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 had a SD of 0.87886 µM. The agreement between the CTD and bottle data was good.

Transmissometer, Wetlabs FLBBRTD, Altimeter and Wetlabs FLCDRTD were also installed on the auxiliary A/D channels of the CTD.

An advance of 1.15 scans was made to the primary conductivity data and 1.75 scans for the secondary conductivity data from the originally acquired raw data which had 0.6 and 0 scan advance respectively. This aligns the data to the Sea-Bird recommendation of 0.073s.

2 Voyage Details

2.1 Title

Quantifying krill abundance for krill monitoring and management off the Australian Antarctic Territory

2.2 Principal Investigators

So Kawaguchi (Chief Scientist) and Karen Westwood (Principal for the Biological Oceanography Team).

2.3 Voyage Objectives

The scientific objectives for in2021_v01 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

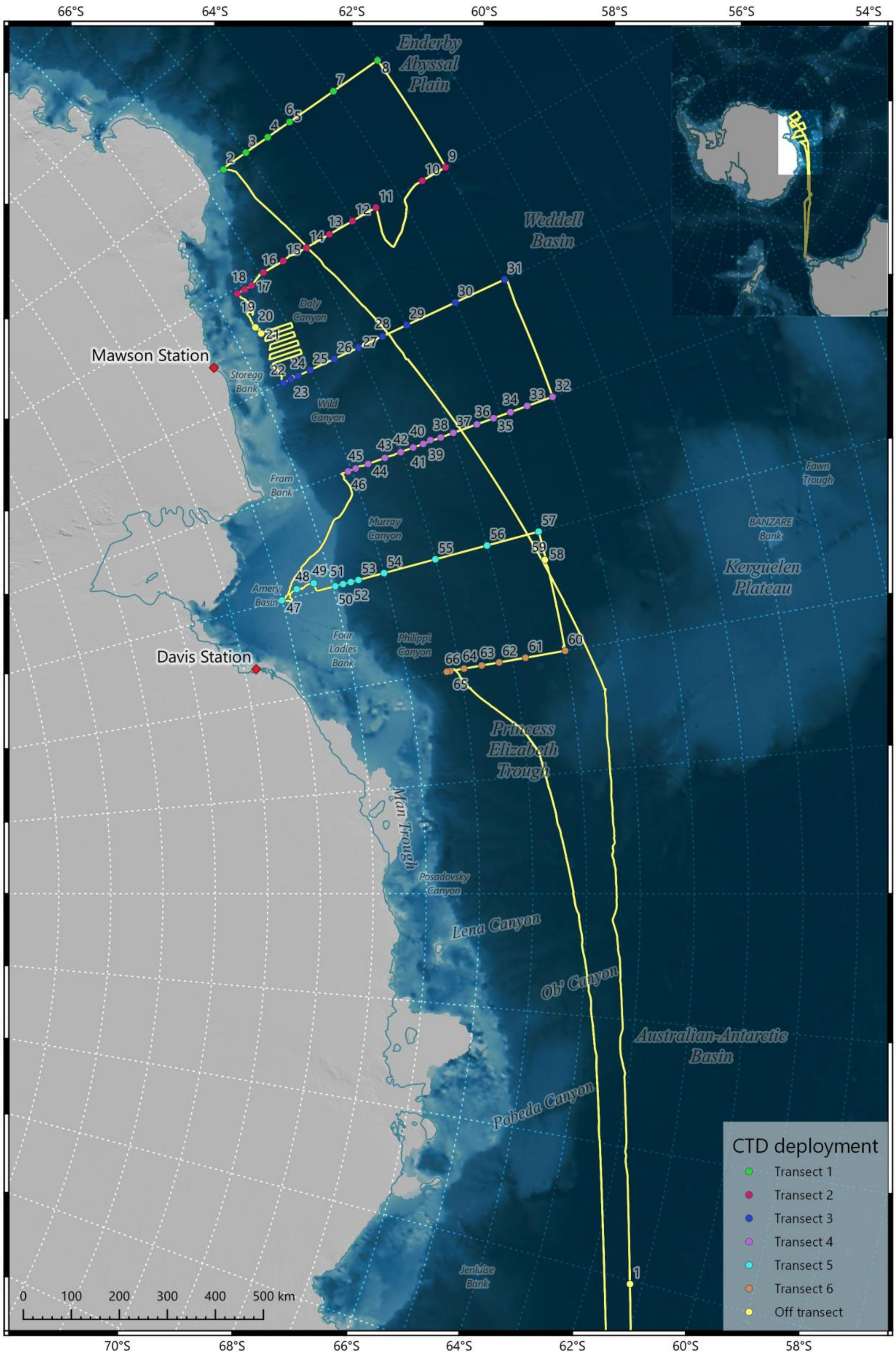


Figure 1 Area of operation for in2021_v01

3 Processing Notes

3.1 Background Information

The data for this voyage 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, transmissometer, Wetlabs FLBBRTD, altimeter and Wetlabs FLCDRTD. These sensors are described in Table 1 below.

Table 1 CTD Sensor configuration on in2021_v01

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Pressure	Digiquartz 410K-134	1332	P	2-Jul-2020	CSIRO Cal Lab
Primary Temperature	Sea-Bird SBE3*plus*	6189	T0	25-Sep-2020	CSIRO Cal Lab
Secondary Temperature	Sea-Bird SBE3*plus*	6285	T1	25-Sep-2020	CSIRO Cal Lab
Primary Conductivity	Sea-Bird SBE4C	4773	C0	21-Sep-2020	CSIRO Cal Lab
Secondary Conductivity	Sea-Bird SBE4C	4774	C1	21-Sep-2020	CSIRO Cal Lab
Primary Dissolved Oxygen	SBE43	3155	A0	14-Oct-2020	CSIRO Cal Lab
Secondary Dissolved Oxygen	SBE43	1794	A1	21-Nov-2020	Sea-Bird
Altimeter	Tritech PA500	316739	A2	7-May-2019	Tritech
PAR	Biospherical QCP2300HP	70111	A3	20-Oct-2020	Biospherical
Transmissometer	Wetlabs C-Star	CST-2009DR	A4	23-Oct-2020	Wet Labs
CDOM	Wetlabs CDOM FLCDRTD	4367	A5	18-May-2020	Wet Labs
Chlorophyll	Wetlabs ECO FLBBRTD	5169	A6	16-Nov-2020	Wet Labs
Scattering	Wetlabs ECO FLBBRTD	5169	A7	16-Nov-2020	Wet Labs

Table 2 CTD Sensor configuration changes from deployment 2 onwards

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Primary Temperature	Sea-Bird SBE3*plus*	6180	T0	23-Jan-2021	CSIRO Cal Lab

Table 3 CTD Sensor configuration changes from deployment 4 onwards

Description	Sensor	Serial No.	A/D	Calibration Date	Calibration Source
Altimeter	Tritech PA500	228403	A2	29-May-2020	Tritech

Water samples were collected using a Sea-Bird SBE32, 36-bottle rosette sampler. Sampling was from 31 twelve litre bottles which were fitted to the frame.

There were 66 deployments and of these, deployments 0 were on-deck TSG calibration runs.

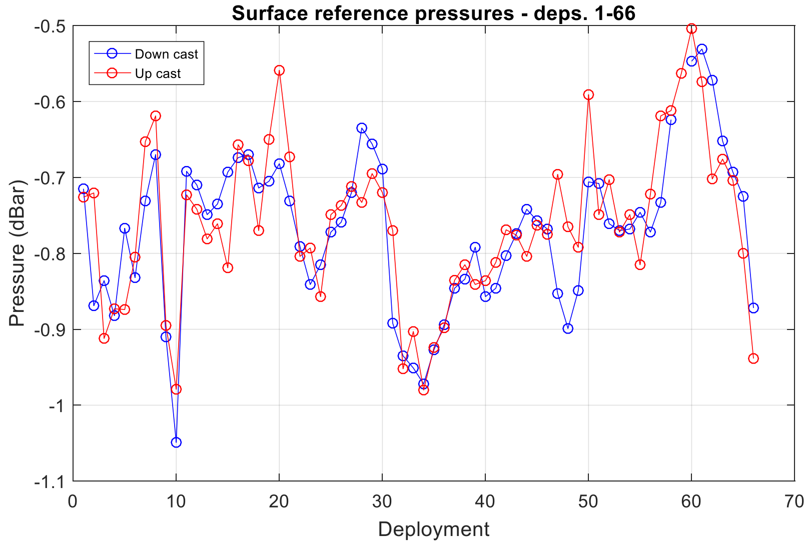
The raw CTD data were collected in SBE SeaSave version 7.26.7.110, converted to scientific units using SBE Data Processing version 7.26.7.129 and written to NetCDF format files with CNV_to_Scan for processing using the Matlab-base, CapPro package version 2.11.

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, 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.

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.



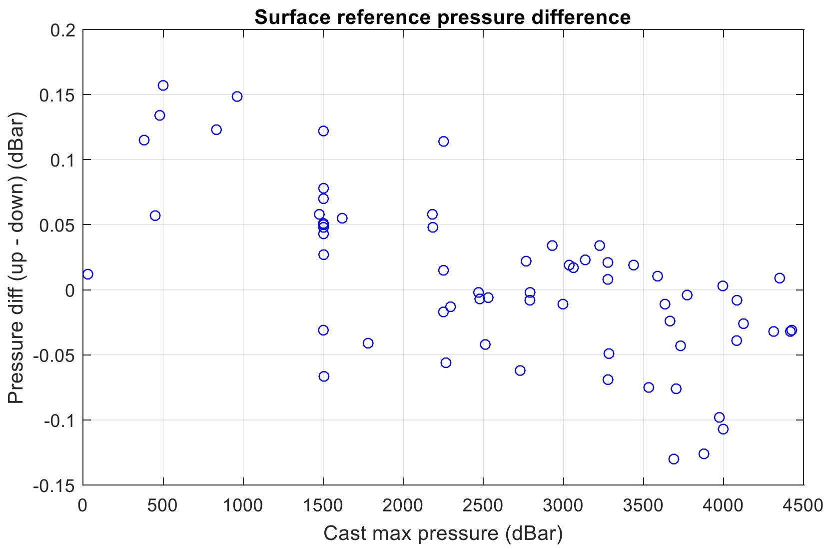


Figure 2 CTD pressure offsets

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. This indicates neither sensor has drifted significantly from its calibration.

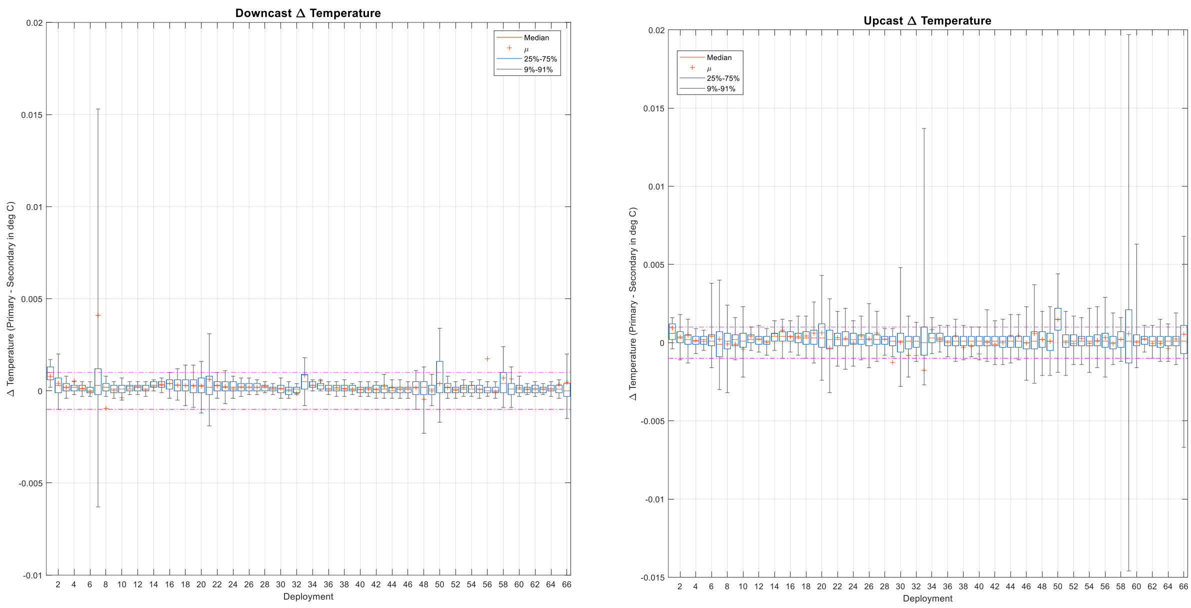


Figure 3 Difference between primary and secondary temperature sensors

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 707/699 of the total of 1106 samples taken during deployments which are below our target of 70%.

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.

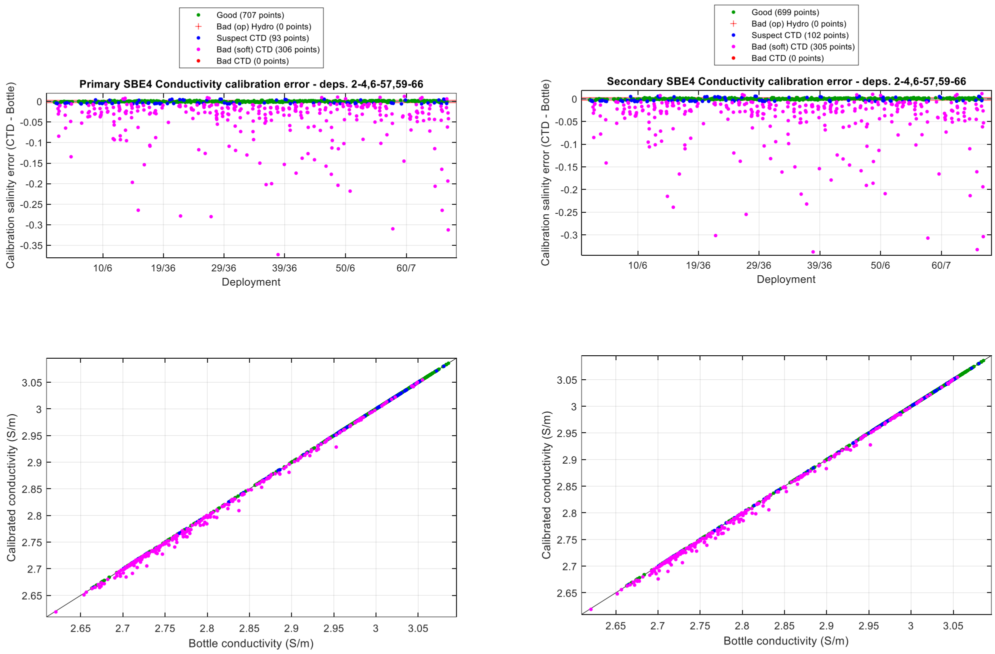


Figure 4 CTD - bottle salinity plot

The box plot of calibrated downcast and upcast conductivities (primary - secondary) for all deployments in Figure 5 shows that the calibrated conductivity cell responses corresponded very well with the majority of differences within ±0.0001 S/m as highlighted by the dashed magenta line. Outliers cast 59 can be seen Appendix III: Downcast Delta Conductivity Outliers.

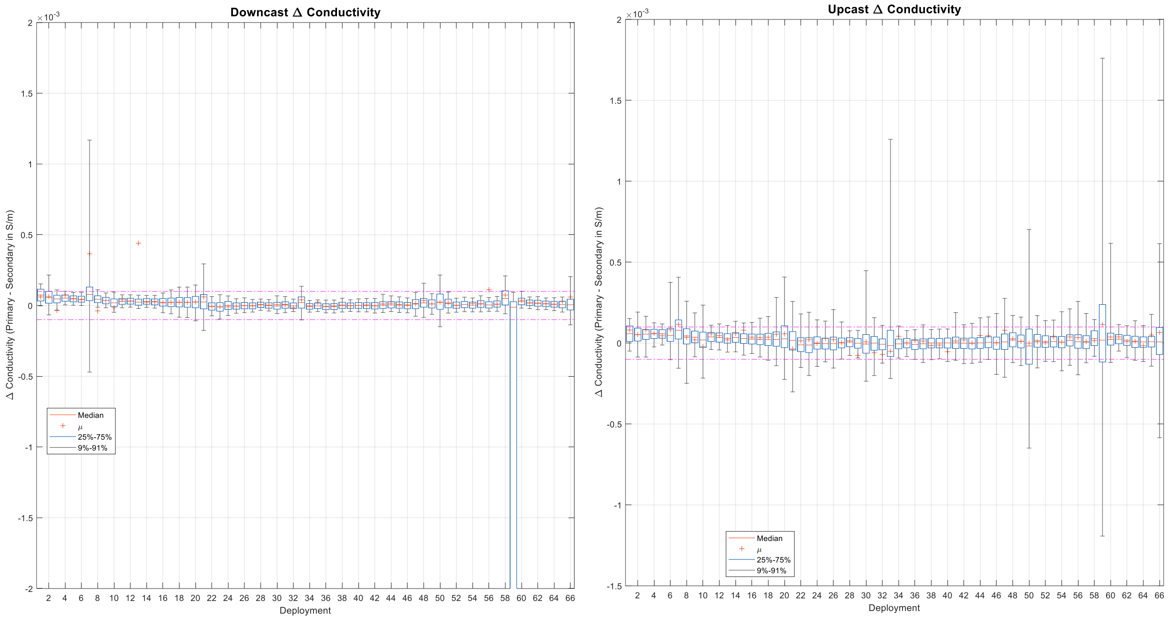


Figure 5 Difference between primary and secondary conductivity sensors

The final result for the primary and secondary conductivity sensors with respect to their original calibrations are shown in Table 4 and Table 5.

Table 4 Conductivity calibration with respect to manufacturers' calibration coefficients and post-calibration results

Sensor Group	Deployments	Scale Factor		Offset		Salinity (PSU)	
		a1	**±**	**a0**	**±**	**Residual SD**	**M.A.D.**
Primary	002-066	0.99970	0.0010948	0.001027	0.0031898	0.0013317	0.0010458
Secondary	002-066	0.99961	0.0011178	8.8455e-4	0.0032553	0.0013349	0.0011423

Table 5 Calculated CPcor for primary and secondary compared to the manufacturer nominal value of -9.5700e-08

Conductivity Sensor	Deployments	CPcor	±
Primary	002-066	-7.4907e-08	3.3496e-08
Secondary	002-066	-7.3486e-08	3.4424e-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 secondary conductivity and temperature sensors were used to produce the averaged salinities with primary 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.

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

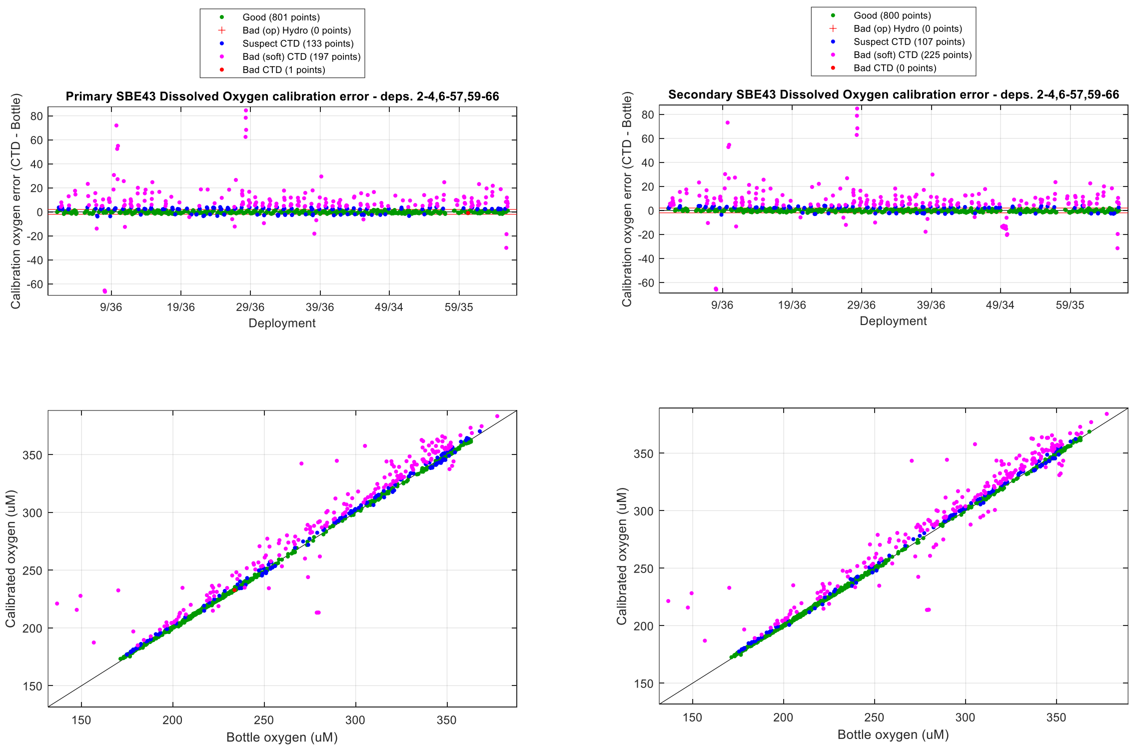


Figure 6 Dissolved Oxygen Difference with upcast CTD data (SBE43 - Bottle)

The box plot of calibrated downcast and upcast Dissolved Oxygen readings (primary - secondary) for all deployments in Figure 7 shows that the calibrated Dissolved Oxygen sensor responses corresponded well with the majority of differences within ±1 µM as highlighted by the dashed magenta line. The one exception was deployment 50, where outliers were caused by a blockage during the upcast resulting in the mean difference above 15 µM.

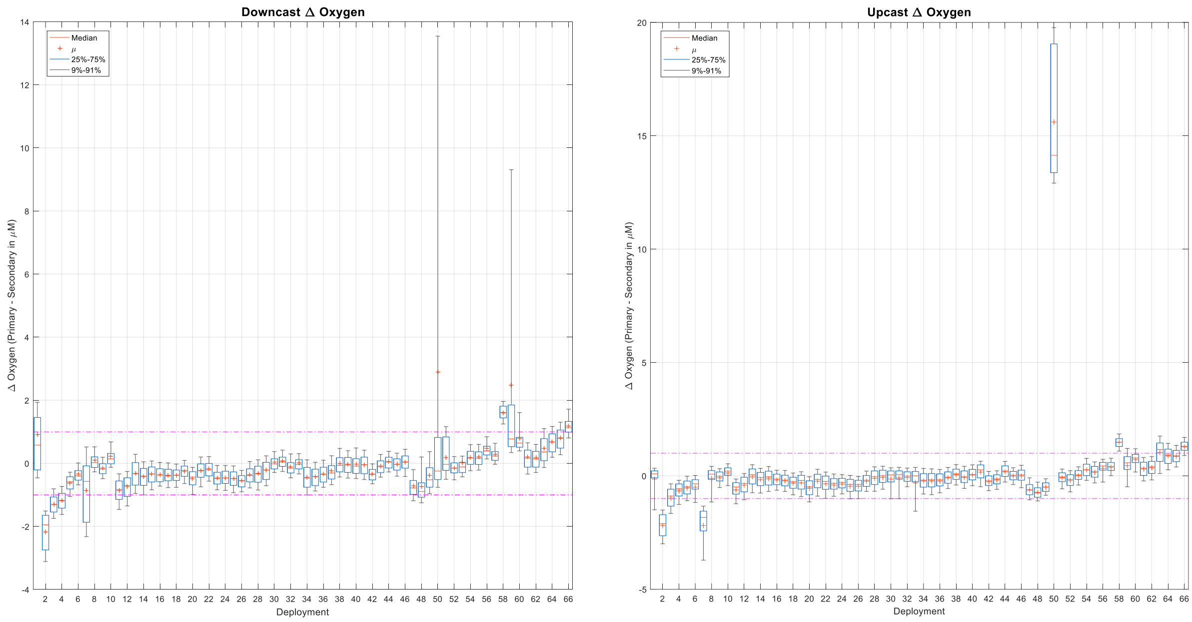


Figure 7 Difference between primary and secondary Dissolved Oxygen sensors

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

Table 6 Dissolved oxygen calibrations

Sensor	Calibration Source	Deployments	Calibration Coefficients				Dissolved Oxygen (µM)	
			Voffset	±	*Soc*	±	Residual SD	M.A.D.
Primary DO	CapPro	002-066	-0.47900	0.00098315	0.53283	0.00046552	0.87886	0.76103
	CSIRO Cal Lab	001-066	-0.50539		0.52968			
Secondary DO	CapPro	002-066	-0.44497	0.00099319	0.48533	0.00039465	0.85139	0.63350
	Sea-Bird	001-066	-0.47500		0.47800			

3.5 Other sensors

The C-Star transmissometer was used on all deployments. It was calibrated by the manufacturer with the measured 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.

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 WET labs coloured dissolved organic matter (CDOM) sensor has been calibrated by the manufacturer with Quinine Dihydrate equivalent to convert the voltage sensor outputs to a measurement in ppb.

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.

Table 7 Sensor limits for bad data detection

Sensor	Units	Range minimum	Range maximum	Maximum Second Difference
Pressure	decibar	-7	6500	0.5
Temperature	degC	-10	40	0.05
Conductivity	S/m	-0.01	7	0.01
Oxygen	µM	-0.1	500	0.5
Fluorometer	mg/m^3	0	30	0.5
PAR	$\mu E/m^2/sec$	-5	5000	0.5
Transmissometer	%	0	100	0.5
OBS	m^{-1}/sr	0	0.0008	0.5
CDOM	ppb	-5	515	0.5
Altimeter	m	0	50	0.5

3.7 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.

3.8 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.

3.9 Data Issues

The raw data collected in SeaSave had a conductivity advance set by the SBE11 deck unit of 0.025 seconds on the primary channel. No conductivity advance was set in the secondary channel. The recommendation by Sea-Bird is to advance both by 0.073 seconds on the deck unit. To correct for this discrepancy, an advance of 1.15 scans on the primary conductivity sensor data and 1.75 scans for the secondary conductivity sensor. This adjustment moves both conductivity advances to 0.073 seconds.

4 References

Kawaguchi, S. (2021). *The RV Investigator. Voyage Plan* in2021_v01. 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

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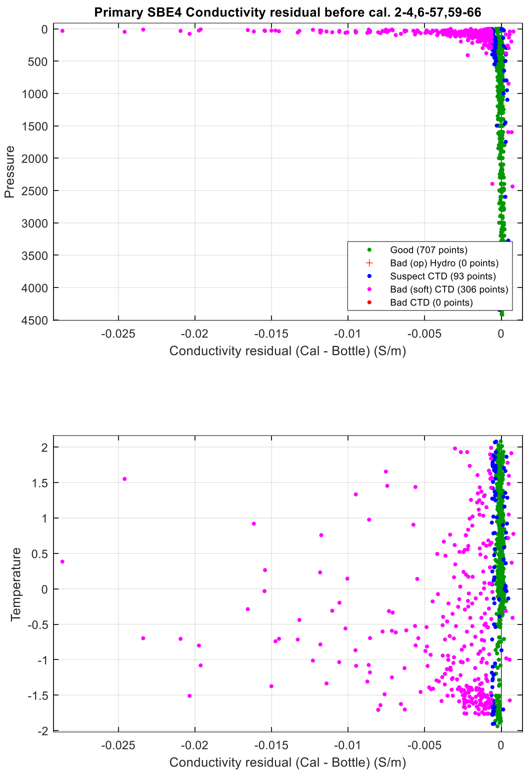
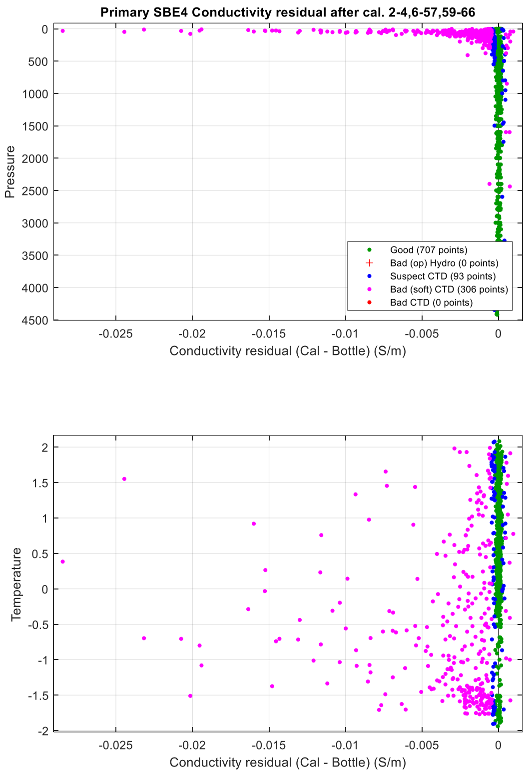
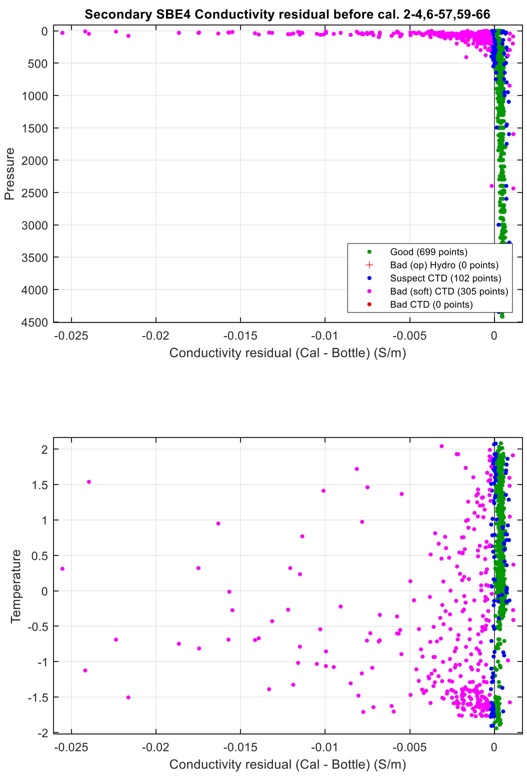
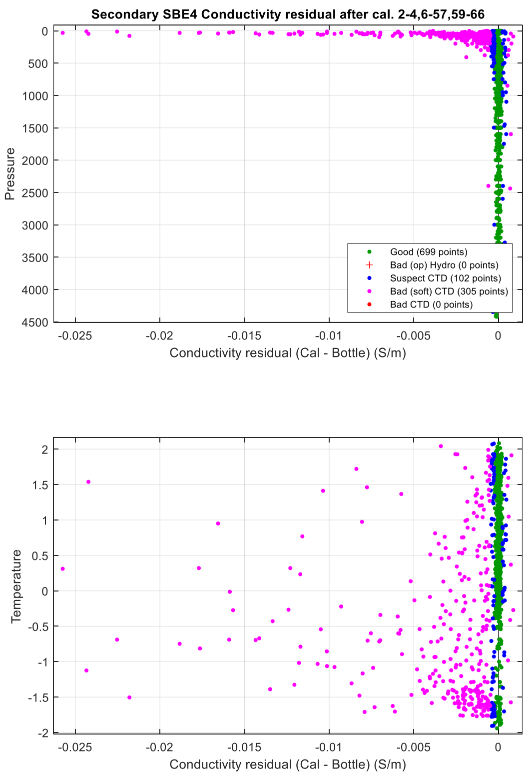
Appendix I: Conductivity Calibration Residual Plots

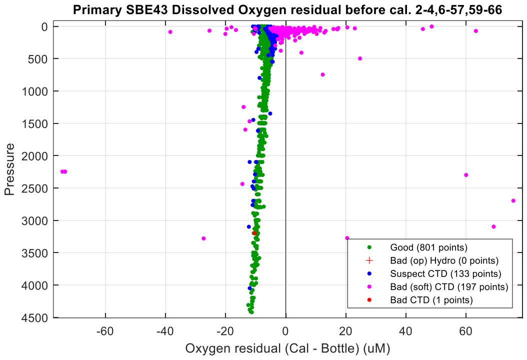


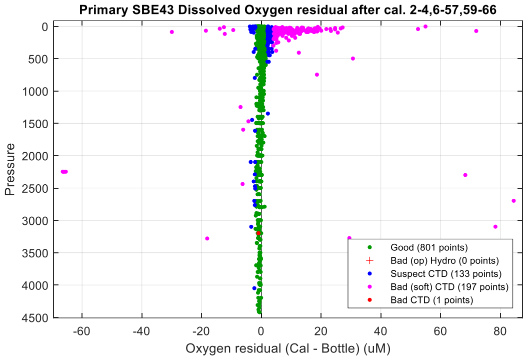


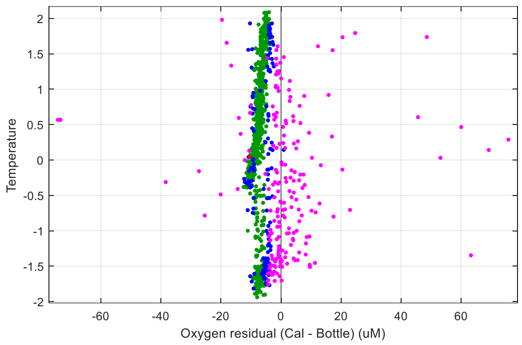


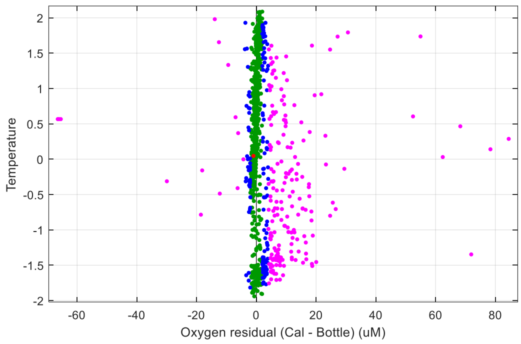


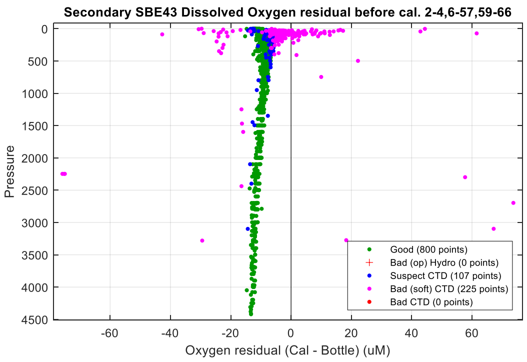
Appendix II: Dissolved Oxygen Calibration Residual Plots

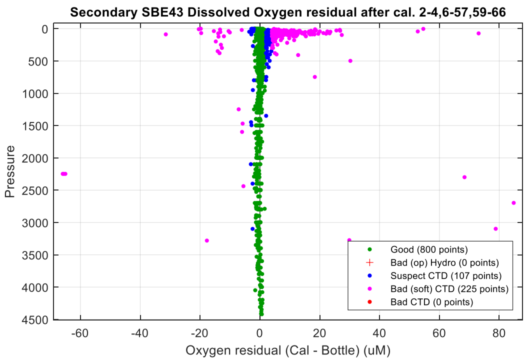


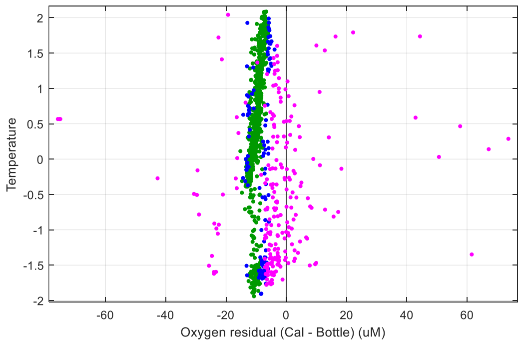


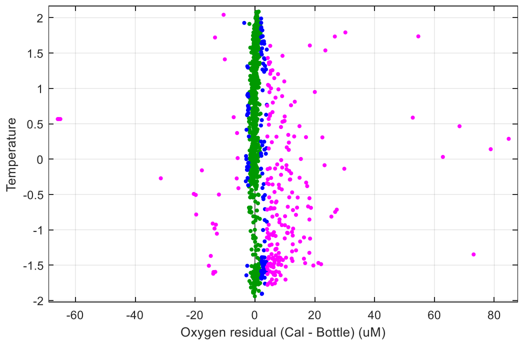












Appendix III: Downcast Delta Conductivity Outliers

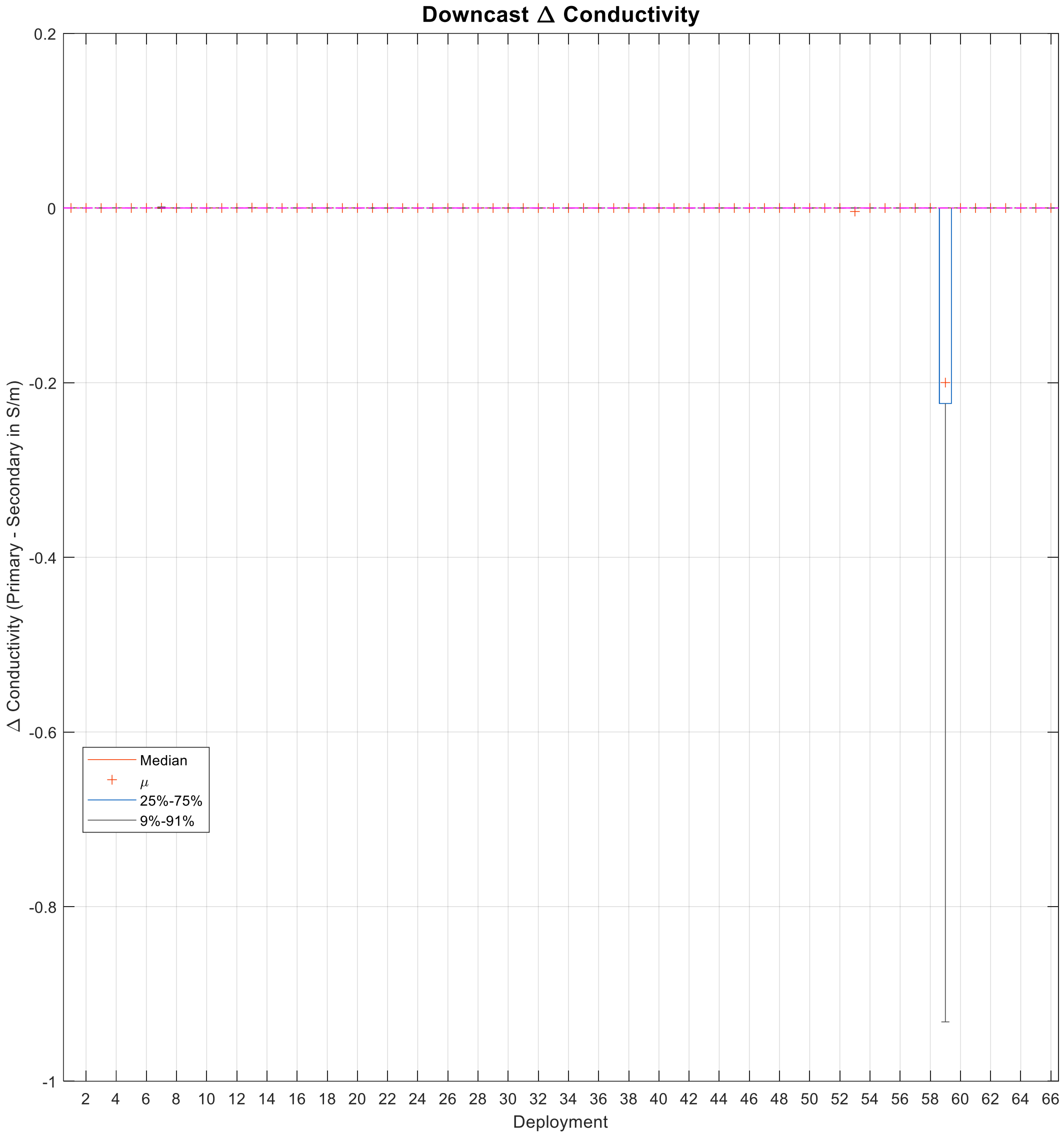


Figure 8 Downcast difference between primary and secondary conductivity sensor with all outliers. Refer to Figure 5 for a more detailed plot.