RV *Investigator*

CTD Processing Report

Voyage #:	IN2016_V02
Voyage title:	**SOTS:** Southern Ocean Time Series automated moorings for climate and carbon cycle studies southwest of Tasmania
Depart:	Hobart, 1000 Sunday, 13 March 2016
Return:	Hobart, 1930 Saturday, 15 April 2016
Processing completed:	25 August, 2017
Report completed:	28 August, 2017
Data Revision:	Version 2.0
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Contents

1 Revision History

- 11 August 2017: version 1.0
- 28 August 2017: version 2.0 – correction to thermal inertia correction coefficients for conductivity cells

2 Summary

These notes relate to the production of quality controlled, calibrated CTD data from RV Investigator voyage in2016_v02, between 11 March and 12 April 2016.

CTD processing for voyages from 2016 onward has been completed using CapPro software. CapPro Version 1.14, dated 07 Mar 2017, was used in the final processing run.

Data for 40 deployments were acquired using the Seabird SBE911 CTD 20, fitted with 24 ten litre bottles on the rosette sampler. Sea-Bird-supplied and O&A Calibration Facility calibration factors were used to compute the pressures and preliminary conductivity values. CSIRO calibrations were applied to the temperature data. The data were subjected to automated QC to remove spikes and out-of-range values.

The secondary conductivity and primary oxygen sensors were replaced after cast 1 due to suspicious readings. The binned CTD output required re-processing due to incorrect thermal inertia coefficients being applied. Correct coefficients have now been configured as default in CapPro processing software.

The final conductivity calibration for casts 2-40 from the secondary sensor had a standard deviation (S.D) of 0.00138 PSU, well within our target of 'better than 0.002 PSU'. The standard product of 1dbar binned averaged were produced using data from the secondary sensors for casts 2-40, with the primary sensor used for cast 1.

The dissolved oxygen data calibration from the secondary sensor was used for the final calibration. The fit had a S.D. of 0.792 uM. The agreement between the CTD and bottle data was good.

The Biospherical photosynthetically active radiation (PAR), C-Star transmissometer and the Wetlabs ECO chlorophyll and scattering sensors were also installed on the auxiliary A/D channels of the CTD. The lowered ADCP was also attached to the package, logging internally during each cast.

3 Voyage Details

3.1 Title

The Southern Ocean Time Series (SOTS) automated moorings for climate and carbon cycle studies southwest of Tasmania voyage comprised 3 separate projects: SOTS, CAPRICORN and Eddy.

3.2 Principal Investigators

On board was Tom Trull (CSIRO O&A) the Chief Scientist, with Alain Protat (BOM) and Peter Strutton (University of Tasmania) also on board as Lead Principle Investigators.

3.3 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 Marine and Atmospheric Research web site.

3.4 Area of operation

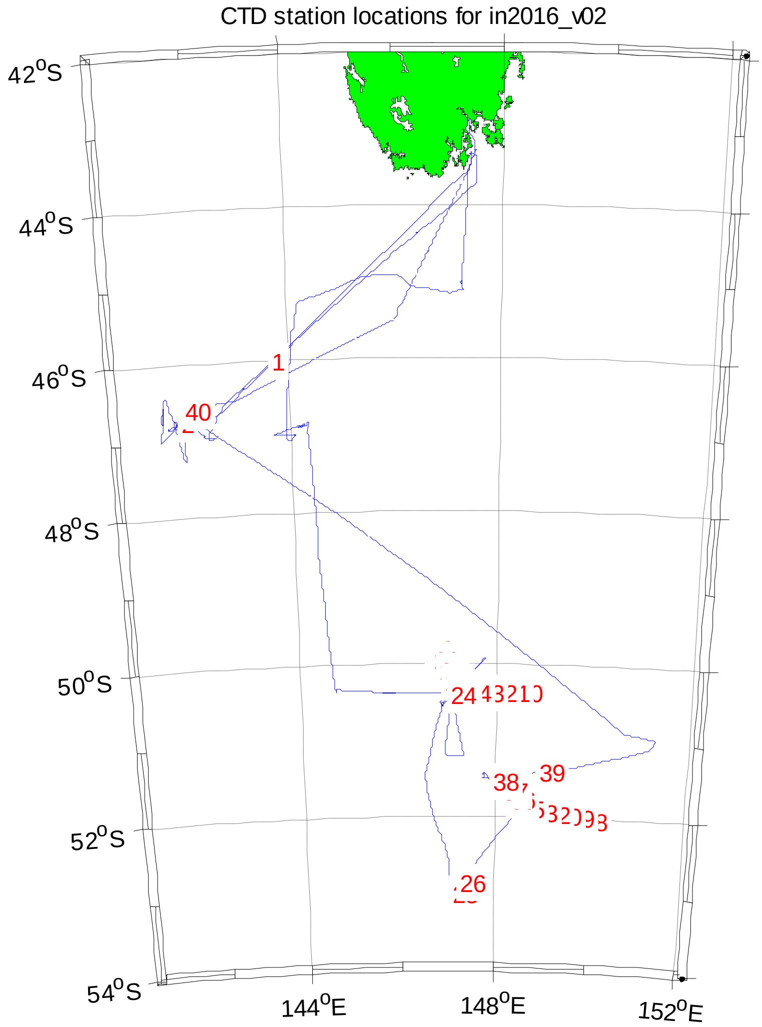


FIGURE 1. Area of operation for in2016_v02

4 Processing Notes

4.1 Background Information

The data for this voyage were acquired with the CSIRO CTD unit 20, a Seabird SBE911 with dual conductivity and temperature sensors.

There were 40 deployments for this voyage. Samples were taken and analysed from casts 2-23, 25-30 and 32-40. On the first cast, a test during mobilization, all bottles were fired at 1500m with the samples taken for training purposes only. No sampling was conducted on casts 24 and 31. Bottles were fired at 500m to collect water for the O&A Calibration Facility.

Rapp Hydema heave compensation was not used on the CTD winch. There was a software update required for spooling to be safe with HC active.

The Biospherical photosynthetically active radiation (PAR), C-Star transmissometer and the Wetlabs ECO chlorophyll and scattering sensors were also installed on the auxiliary A/D channels of the CTD. The LADCP was also fitted. These sensors are described for CTD 20 in Table 1 below.

Description	**Sensor**	**Serial No.**	**A/D**	**Calibration Date**	**Calibration Source**
Pressure	SBE9 *plus*	552	P	9/3/2016	CSIRO 3825P
Primary Temperature	Seabird SBE3*plus*	4722	T0	1/3/2016	CSIRO 3829T
Secondary Temperature	Seabird SBE3*plus*	4522	T1	1/3/2016	CSIRO 3828T
Primary Conductivity	Seabird SBE4C	3868	C0	2/3/2016	CSIRO 3834C
Secondary Conductivity	Seabird SBE4C	3168* 2235 4426#	C1	26/2/2015 24/11/2015 08/7/2015	CSIRO 3098C CSIRO 3527C Manufacturer
Primary Oxygen	Seabird SBE43	1794* 3154	A0	10/3/2016 10/3/2016	CSIRO 3836DO CSIRO 3837DO
Secondary Oxygen	Seabird SBE43	3159 3198#	A1	10/3/2016 12/8/2015	3389 DO Manufacturer
PAR	QCP2300	70111	A2	25/8/2015	R12343
Altimeter	PA500	5301	A3	22/5/2015	
Transmissometer	C-Star	CST-1421DR	A4	14/8/2015	
Wetlabs ECO - Chlorophyll	FLBBNTU	3698	A6	23/9/2014	% (cal not applied)
Wetlabs ECO - Scattering	FLBBNTU	3698	A7	23/9/2014	% (cal not applied)
LADCP–150kHz (Upward)	Sentinel WHM150	16710	-	-	-
LADCP–300kHz (Downward)	Sentinel WHS300	16673	-	-	-

* sensors used only for cast 1 (secondary conductivity reading high; primary oxygen erratic)
# sensors used only for cast 40
% data output in percent, as configured for in2016_v01

TABLE 1. CTD Sensor configuration on in2016_v02

Water samples were collected using a Seabird SBE32, 24-bottle rosette sampler. Sampling was as required from the 24 ten litre bottles which were fitted to the frame.

On board the raw CTD data were converted to scientific units and written to netCDF format files for processing using the Matlab CapPro package. Final CTD processing was completed with CapPro, the new Matlab software first used for processing in2016_v01 data.

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. The automatically determined pressure offsets and in-water points were inspected and adjusted where necessary. It also loaded the hydrology data and 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, after which files of binned 1dB averaged data were produced.

4.2 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.

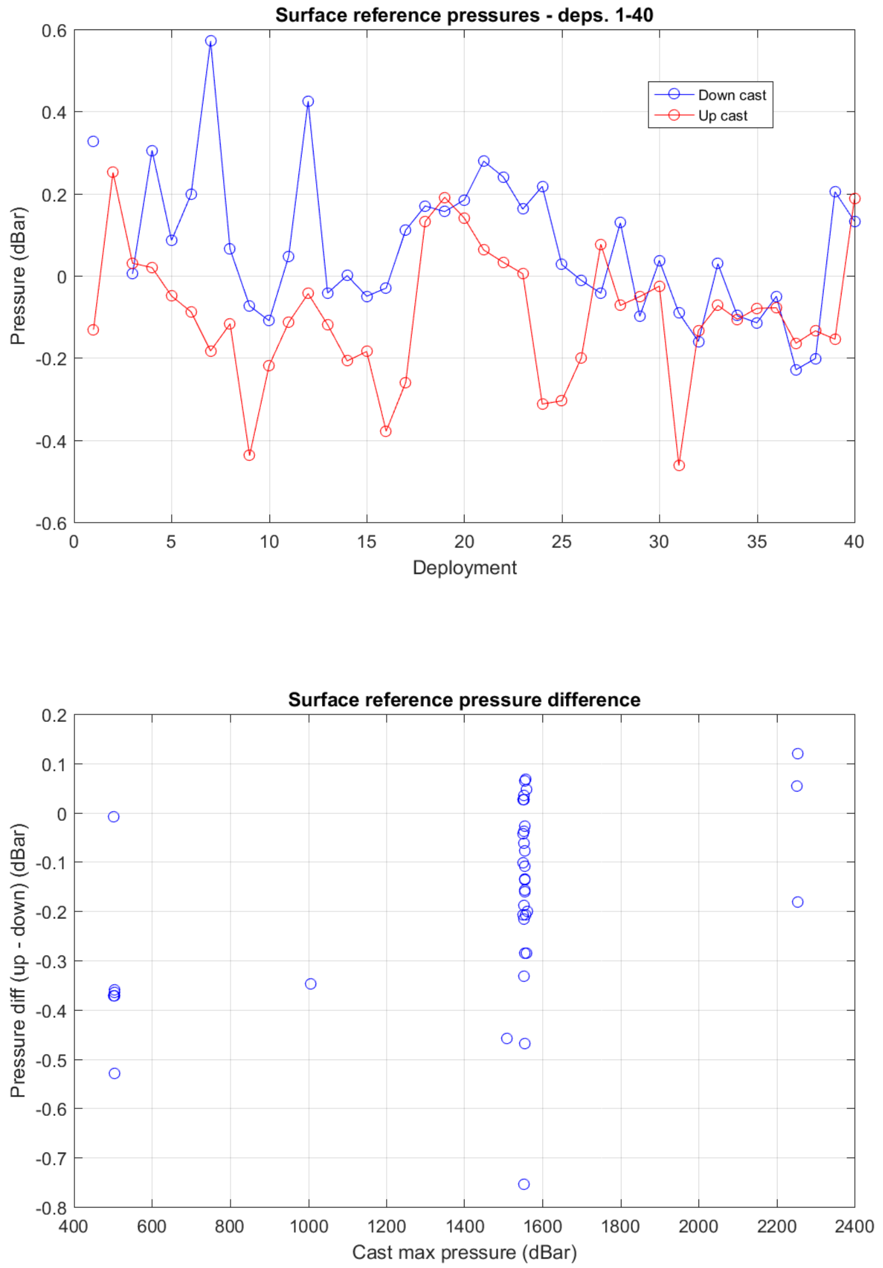


FIGURE 2. CTD pressure offsets

The difference between the primary and secondary temperature is plotted below. All deployments plot within ±1 m°C of the mean. This indicates neither sensor has drifted significantly from its calibration.

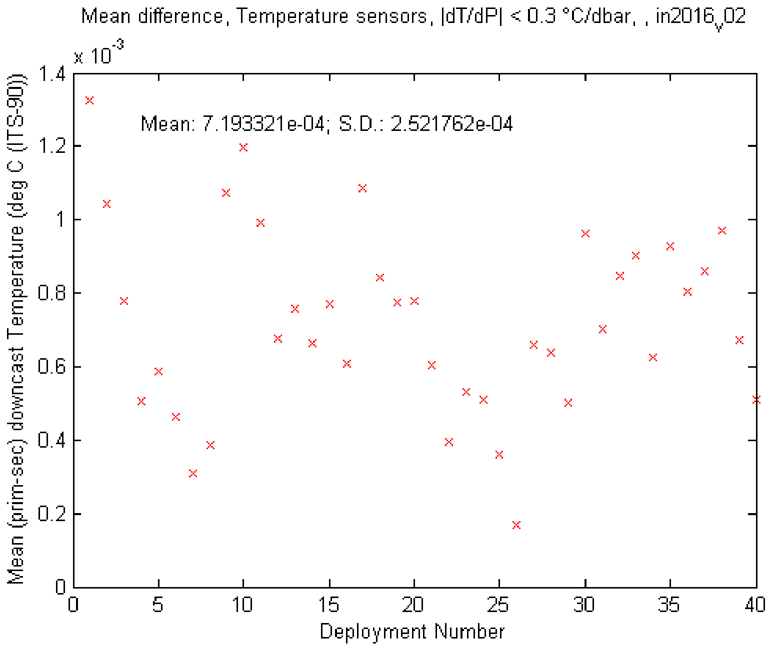


FIGURE 3. Mean difference between primary and secondary temperature sensors

4.3 Conductivity Calibration

Discrepancies and possible sampling problems between bottle and CTD salinities for the primary and secondary conductivity sensors would show in Figures 4 and 5, plots of calibrated (CTD - Bottle) salinity below. The calibration for the primary sensor was based upon the sample data for 305 of the total of 450 samples taken during deployments. The calibration for the secondary sensor was based upon the sample data for 289 of the total of 450 samples taken during deployments (the outliers marked in Figure 4 and 5 below with the red '+' and magenta circles are excluded from the calibration).

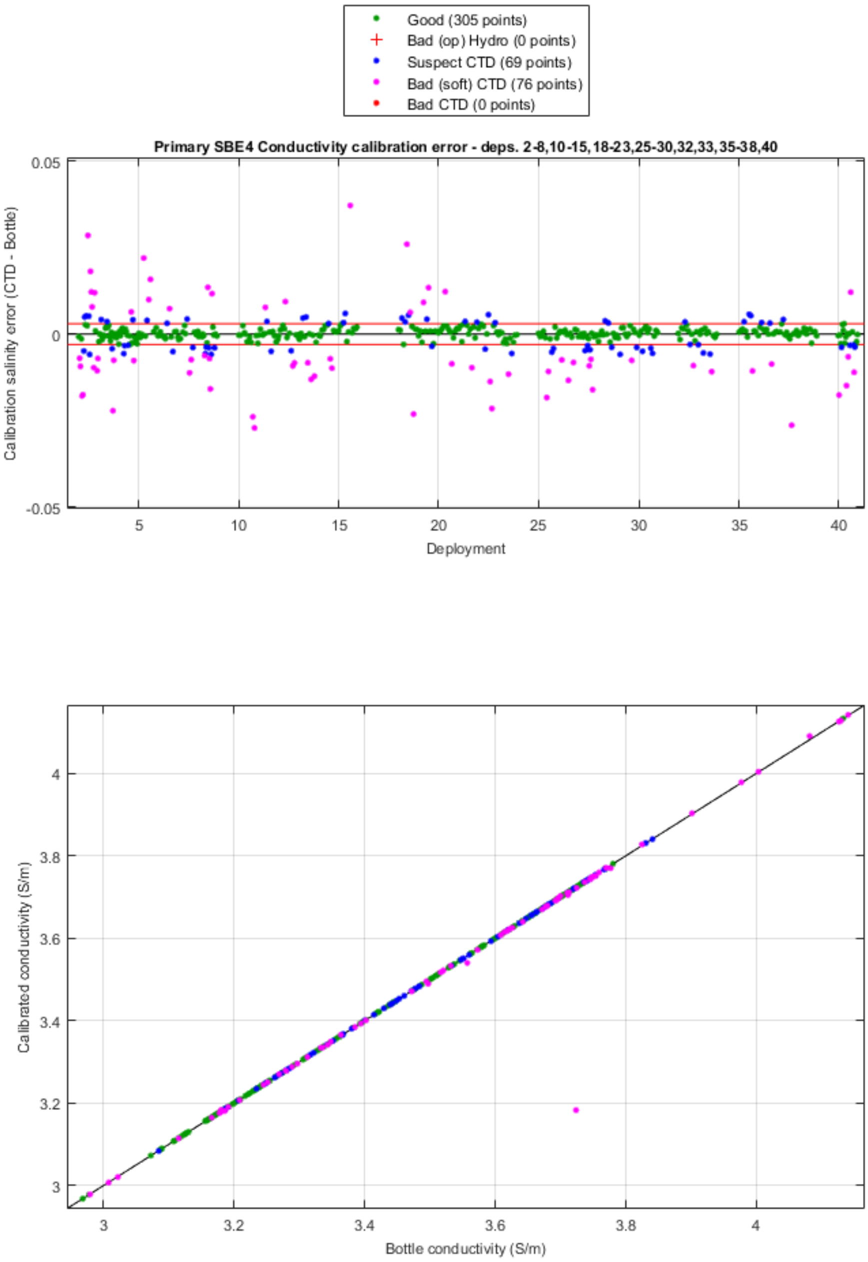


FIGURE 4. Primary sensor CTD – bottle salinity plot.

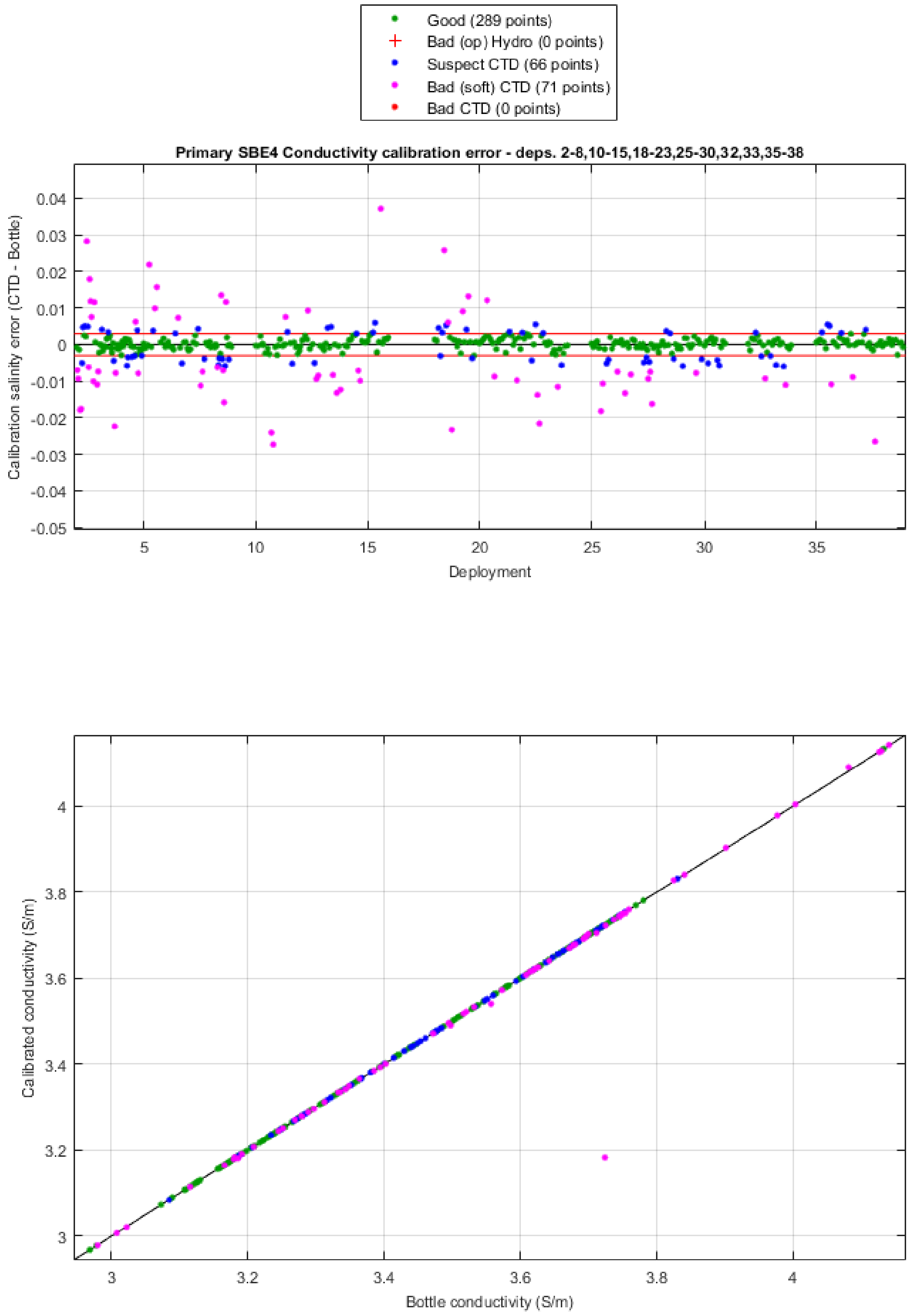


FIGURE 5. Secondary sensor CTD – bottle salinity plot.

The plot in figure 4 shows the distribution of the difference between sensor salinity and bottle sample salinity for all casts. An extreme outlier was omitted from the top plot, aligned by deployment. The datum omitted was for rosette position 24 for cast 35, which was flagged as bad and did not contribute to the calibration.

The plot of calibrated mean (primary - secondary) downcast conductivities at the bottle sampling depths for all deployments in Figure 5 shows a close correspondence of calibrated conductivity cell responses apart from the first cast, which has been excluded as it was such an extreme outlier it removed any significance from the rest of the plot. The mean difference between primary and secondary sensors for cast 1 was -0.3399, around three orders of magnitude bigger than differences found in subsequent casts.

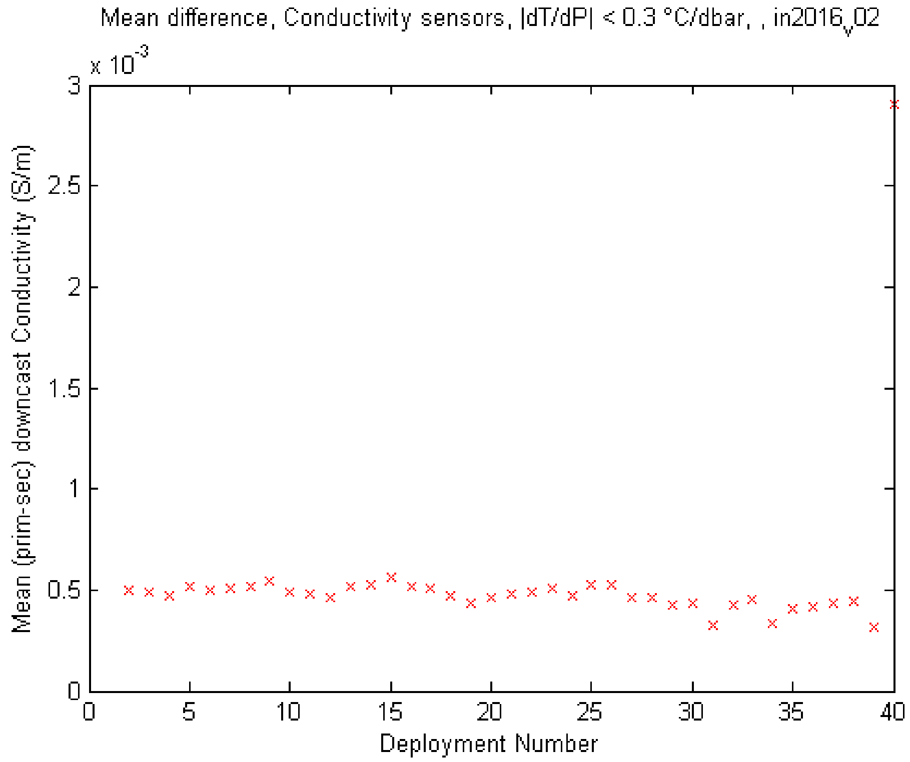


FIGURE 6. Mean difference between primary and secondary conductivity sensors (excluding cast 1)

The final result for the primary conductivity sensor was –

Scale Factor (a1)	0.99928	wrt. Manufacturer's calibration
Offset (a0)	0.00065211	ditto
Calibration S.D. (Sal)	0.0015162 PSU	

The calibration using the secondary conductivity sensor was –

Scale Factor (a1)	0.9988	wrt. Manufacturer's calibration
Offset (a0)	0.0027179	ditto
Calibration S.D. (Sal)	0.0013786 PSU	

This calibration is well within the range we normally aim for, an S.D. of 0.002 psu or lower for 'typical' oceanographic voyages. The above calibration factors were applied to all deployments.

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

4.4 Dissolved Oxygen Sensor Calibration

4.4.1 SBE Calibration Procedure

Sea-Bird (2010a) 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)”.

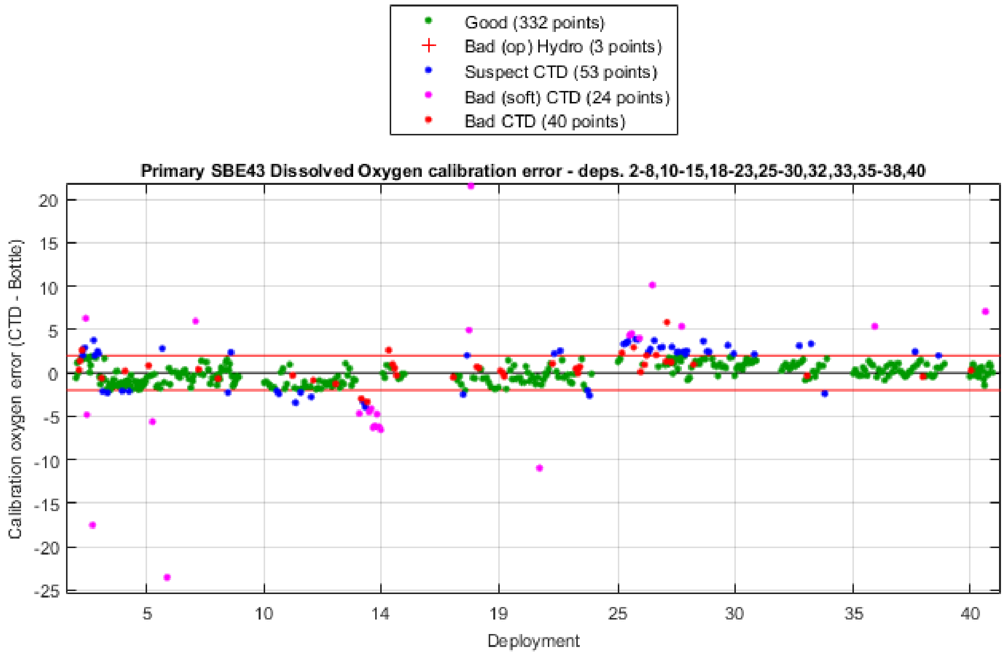
Calibration involves performing a linear regression, as per Sea-Bird (2010b) to produce new estimates of the calibration coefficients Soc and Voffset. These new coefficients are used, along with the other, manufacturer-supplied coefficients, to derive oxygen concentrations from the sensor voltages.

4.4.2 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 by Sea-Bird (2010c).

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.

Only one dissolved oxygen sensor was on the CTD, and 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).



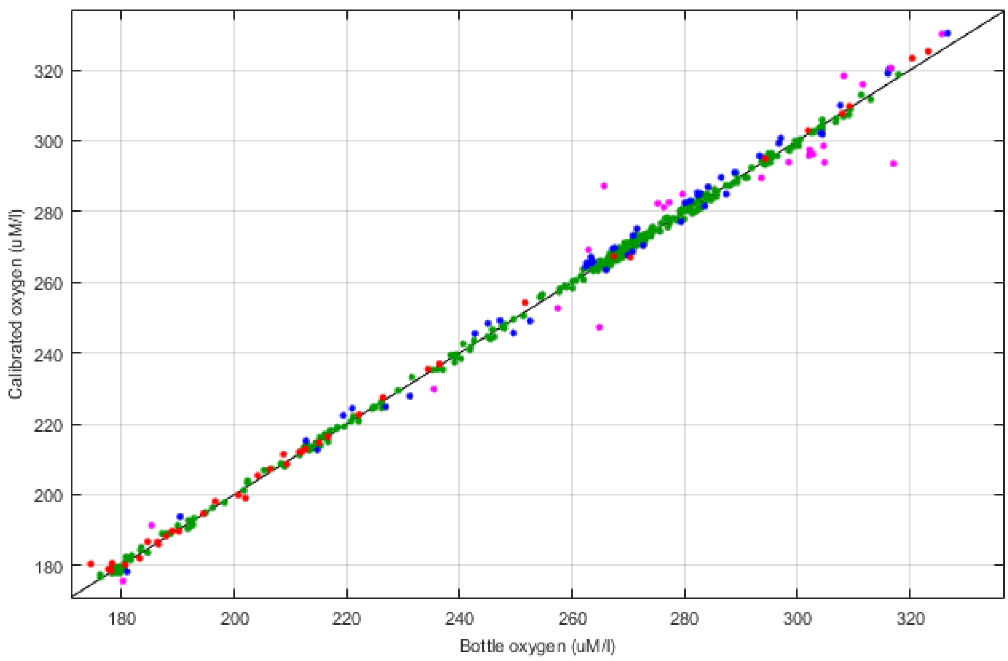


FIGURE 7. Primary Sensor (SBE43 - Bottle) Oxygen Difference with upcast CTD data

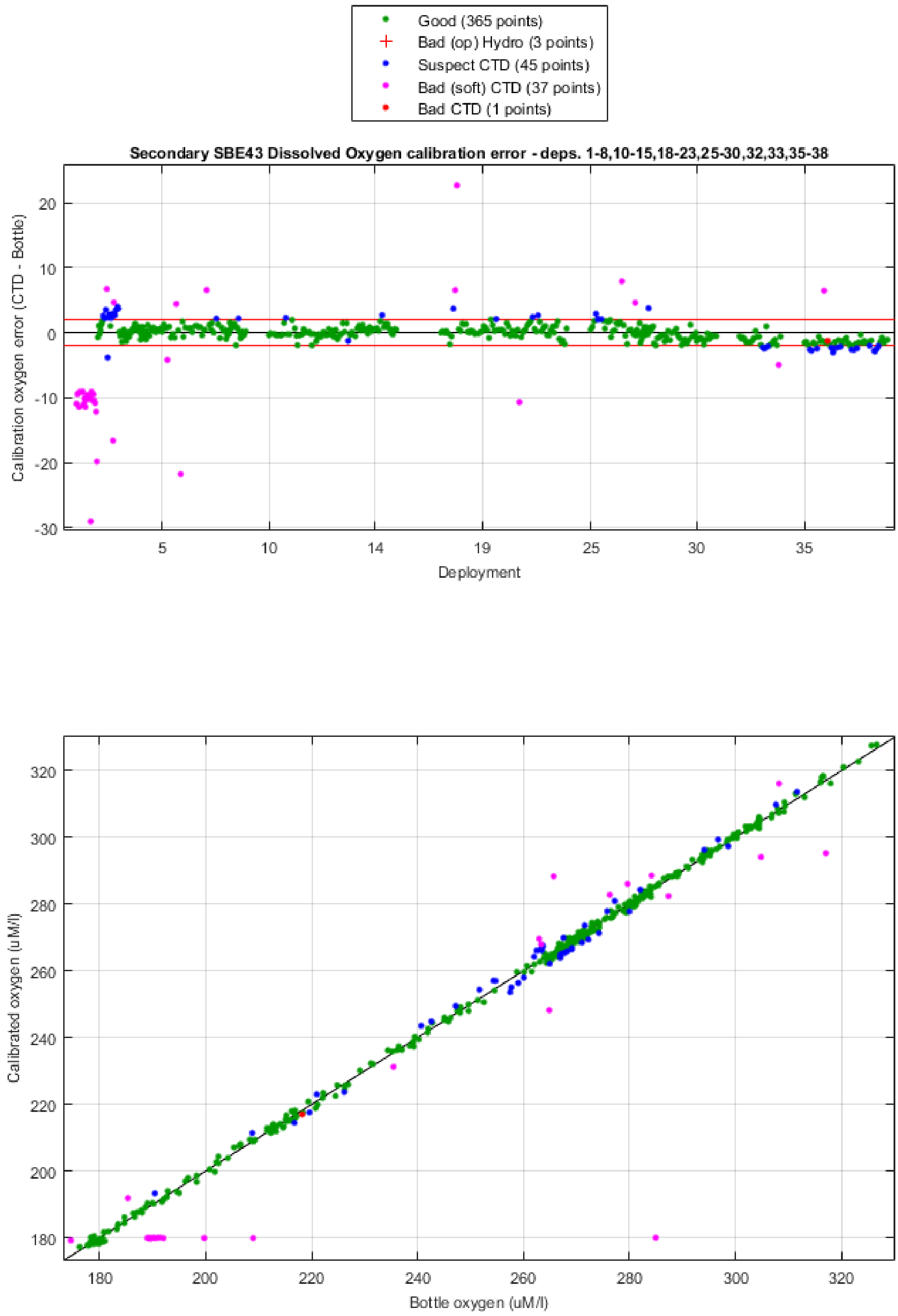


FIGURE 8. Secondary Sensor (SBE43 - Bottle) Oxygen Difference with upcast CTD data

The old and new Soc and Voffset values for DO sensors are listed in Table 3 below. The Soc value is a linear slope scaling coefficient; Voffset is the fixed sensor voltage at zero oxygen. The calibrations were applied for each sensor and the averaged files were created using the result from the secondary sensor.

	March 2016 CSIRO Primary sensor calibration (3154)	**Primary sensor calibration**	**March 2016 CSIRO Secondary sensor calibration (3159)**	**Secondary sensor calibration**
Voffset	-5.0133997e-01	-4.7242e-01	-5.05678e-01	-4.698e-01
Soc	4.7520554e-01	4.7907e-01	5.457332e-01	5.4946e-01
Fit SD (uM)		0.839		0.79208

TABLE 3. Dissolved oxygen calibration

4.5 Other sensors

The C-Star transmissometer and the Wetlabs ECO and scattering sensors were 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 a nominal 0-5 volts. 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.

4.6 Bad data detection

The limits for each sensor are configured in the CAP CTD acquisition software and are written to the netCDF scan file. Typical limits used for the sensor range and maximum second difference are in Table 3 below.

Sensor	**Range min**	**Range max**	**Max Second Diff**
temperature	-2	40	0.05
conductivity	-0.01	7	0.01
oxygen	-0.1	500	0.5
fluorometer	0	100	0.5

TABLE 4. Sensor limits for bad data detection

4.7 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.

5 References

Trull, T., 2016: The RV Investigator. Voyage Plan in2016_V02 –

http://mnf.csiro.au/~/media/Files/Voyage-plans-and-summaries/Investigator/Voyage%20Plans%20summaries/2016/IN2016_V02_Voyage%20Plan-FINAL-20160314-optimised.ashx

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Sea-Bird Electronics Inc., 2012: Application Note No 64-3: SBE 43 Dissolved Oxygen Sensor Calibration and Data Corrections. http://www.seabird.com/document/an64-2-sbe-43-dissolved-oxygen-sensor-calibration-and-data-corrections