DY034 CTD processing report

August 2015
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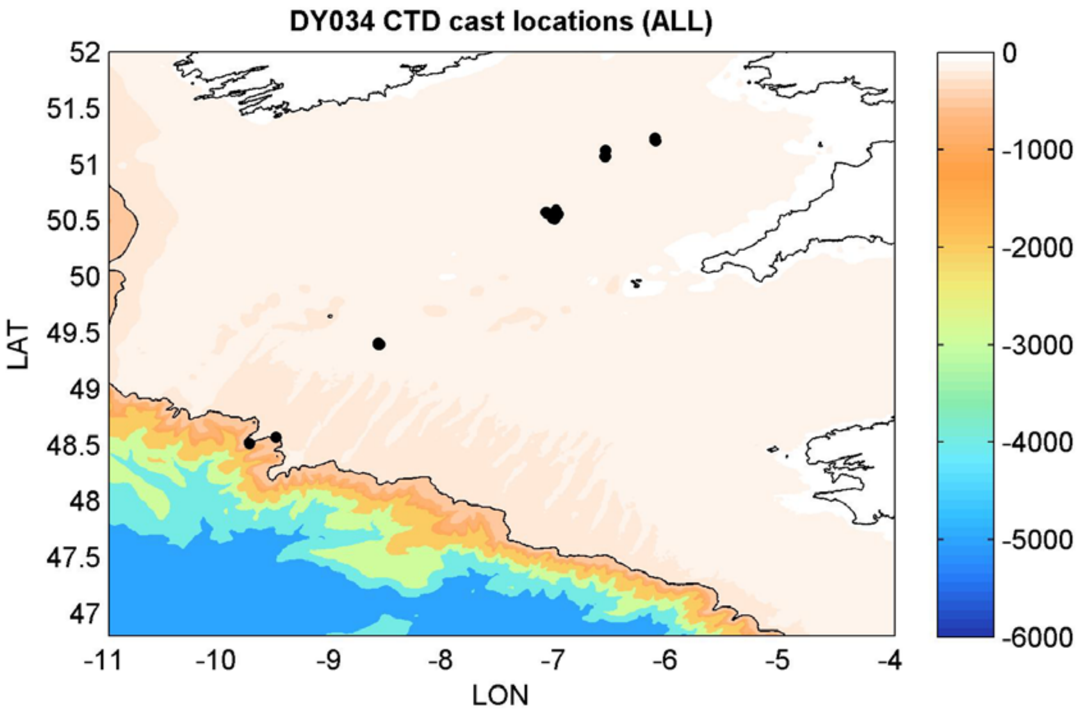
A total of 25 useable casts with the stainless steel frame and 10 useable casts with the titanium CTD frame were completed. See technical reports for sensor serial numbers and channels.

Map of CTD cast locations



Raw data files:

The following raw data files were generated:

DY034_001.bl (a record of bottle firing locations)
DY034_001.hdr (header file)
DY034_001.hex (raw data file)
DY034_001.con (configuration file)

Where _001 is the cast number (not STNNBR)

Titanium cast numbers are 1, 2, 7, 14, 15, 17, 20, 26, 30 and 34

SBEDataProcessing steps

The following processing routines were run in the SBEDataProcessing software (Seasave Version 7.23.2):

1. **DatCnv:** A conversion routine to read in the raw CTD data file (.hex) containing data in engineering units output by the CTD hardware. Calibrations as appropriate though the instrument configuration file (.CON) are applied.

Data Setup options were set to the following:
Process scans to end of file: yes
Scans to skip: 0
Output format: ascii
Convert data from: upcast & downcast
Create file types: both bottle and data
Source of scan range data: bottle log .BL file
Scan range offset: -2.5 seconds
Scan range duration: 5 seconds
Merge separate header file: No
Apply oxygen hysteresis correction: yes (2 second window)
Apply oxygen Tau correction: yes

Selected output variables:

- Time [seconds]
- Pressure [db]
- Temperature [ITS-90, °C] and Temperature 2 [ITS-90, °C], referring to primary and secondary sensors)
- Conductivity and Conductivity 2 [S/m]
- Salinity and salinity 2 [PSU, PSS-78]
- Oxygen raw, SBE 43 [V]
- Oxygen, SBE 43 [µmol/l]
- Beam attenuation [1/m]
- Fluorescence [µg/l]
- PAR/irradiance, downwelling [W m^2]
- Turbidity [m^{-1} sr^{-1}]
- Altimeter [m]
- Voltage channel 2: Light scattering Wetlabs BBRTD *[Stainless]*; Downwelling Irradiance sensor (DWIRR) *[Titanium]*
- Voltage channel 3: Altimeter *[Stainless]*; Upwelling Irradiance sensor (UWIRR) *[Titanium]*
- Voltage channel 4: Fluorometer *[Stainless]*; Altimeter *[Titanium]*
- Voltage channel 5: Transmissometer *[Stainless]*; Light scattering Wetlabs BBRTD *[Titanium]*
- Voltage channel 6: Upwelling Irradiance sensor (UWIRR) [*Stainless]*; Transmissometer *[Titanium]*
- Voltage channel 7: Downwelling Irradiance sensor (DWIRR) *[Stainless]*; Fluorometer *[Titanium]*

2. **Bottle Summary** was run to create a .BTL file containing the average, standard deviation, min and max values at bottle firings. .ROS files were placed in the same directory as the .bl files during this routine to ensure that bottle rosette position was captured in the .btl file.

   Output saved to DY034_001.btl

3. **Wild Edit:** Removal of pressure spikes
   Standard deviations for pass 1: 2
   Standard deviations for pass 2: 20
   Scans per black: 100
   Keep data within this distance of the mean: 0
   Exclude scans marked as bad: yes
4. **Filter:** Run on the pressure channel to smooth out high frequency data

Low pass filter time B: 0.15 seconds

5. **AlignCTD:** Based on examination of different casts a 3 second advance was chosen for alignment of the oxygen sensor on the stainless steel CTD and 2 seconds for the titanium casts. This alignment is a function of the temperature and the state of the oxygen sensor membrane. The colder (deeper) the water the greater the advance needed. The above alignments were chosen as a compromise between results in deep (cold) and shallow (warmer) waters.

6. **CellTM:** Removes the effect of thermal inertia on the conductivity cells. Alpha = 0.03 (thermal anomaly amplitude) and 1/beta = 7 (thermal anomaly time constant) for both cells.

   Output of steps 1-6 above saved in DY034_001.cnv (24 Hz resolution)

7. **Derive:** Variables selected are
   Salinity and Salinty 2 [PSU, PSS-78]
   Oxygen SBE43 [µmol/l]
   Oxygen Tau correction: yes (2 second window)

   Output saved to DY034_001_derive.cnv (24 Hz resolution)

8. **BinAverage:** Average into 2Hz (0.5 seconds),
   Exclude bad scans: yes
   Scans to skip over: 0
   Casts to process: Up and down

9. **Strip:** Remove salinity and oxygen channels from the 2 Hz file that were originally created by DatCnv, but then later regenerated by Derive.

   Output saved to DY034_001_derive_2Hz.cnv

Matlab processing steps

The following processing steps were performed in MATLAB:

(1) Create a .mat file of meta data extracted from the cruise Event Log with the following variables:

CRUISECODE e.g. DY034
STNNBR (as per BODC data management guidance for the Shelf Sea Biogeochemistry programme) **
DATE and TIME of the cast at the start of the profile
LAT and LON when the CTD was at the start of the profile
DEPTH (nominal water depth in metres from echo sounder)
CAST (CTD cast number, e.g. 001)

File created: DY034_metadata.mat

** CTD cast # 17 (Titanium) has STNNBR 292b in the Event Log. In these files the 'b' has been omitted **

(2) Extract data from 2Hz averaged files (e.g. DY034_001_derive_2Hz.cnv), merge with metadata and save into a matlab structure for each cast. Each file (DY034_001_derive_2Hz.mat) contains the following <u>un-calibrated</u> channels.

```
CTD003 =

         CRUISE: 'DY034'
           CAST: 3
         STNNBR: 4
           DATE: '08/08/2015'
           TIME: '01:25'
            LAT: 51.2109
            LON: -6.1309
          DEPTH: 106                 [m]
        CTDtime: [4276x1 double]     [seconds]
        CTDpres: [4276x1 double]     [db]
       CTDtemp1: [4276x1 double]     [°C]
       CTDtemp2: [4276x1 double]     [°C]
       CTDcond1: [4276x1 double]     [S/m]
       CTDcond2: [4276x1 double]     [S/m]
     CTDoxy_raw: [4276x1 double]     [V]
         CTDatt: [4276x1 double]     [1/m]
       CTDfluor: [4276x1 double]     [µg/l]
         CTDpar: [4276x1 double]     [Wm2]
        CTDturb: [4276x1 double]     [m-1 sr-1]
         CTDalt: [4276x1 double]     [m]
    CTDturb_raw: [4276x1 double]     [V]
     CTDalt_raw: [4276x1 double]     [V]
   CTDfluor_raw: [4276x1 double]     [V]
     CTDatt_raw: [4276x1 double]     [V]
  CTDpar_dn_raw: [4276x1 double]     [V]
  CTDpar_up_raw: [4276x1 double]     [V]
        CTDsal1: [4276x1 double]     [PSU]
        CTDsal2: [4276x1 double]     [PSU]
   CTDoxy_umoll: [4276x1 double]     [µmol/l]
        CTDflag: [4276x1 double]
```

(3) Extract data from 24Hz files (e.g. DY034_001_derive.cnv), merge with metadata and save into a matlab structure for each cast. Each file (DY034_001_derive.mat) contains the following <u>un-calibrated</u> channels.

```
CTD003 =

         CRUISE: 'DY034'
           CAST: 3
         STNNBR: 4
           DATE: '08/08/2015'
           TIME: '01:25'
            LAT: 51.2109
            LON: -6.1309
          DEPTH: 106                 [m]
       CTDtime: [51306x1 double]     [seconds]
       CTDpres: [51306x1 double]     [db]
      CTDtemp1: [51306x1 double]     [°C]
      CTDtemp2: [51306x1 double]     [°C]
      CTDcond1: [51306x1 double]     [S/m]
      CTDcond2: [51306x1 double]     [S/m]
     CTDsal1_1: [51306x1 double]     [PSU]
     CTDsal2_1: [51306x1 double]     [PSU]
```

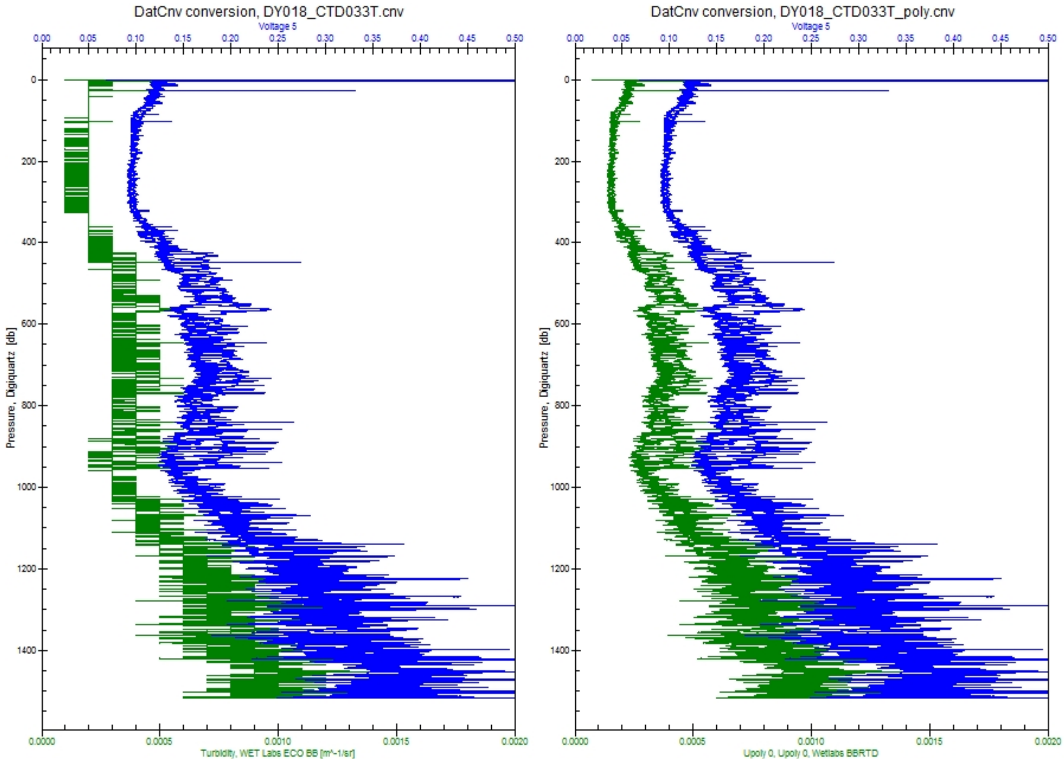
```
       CTDoxy_raw: [51306x1 double]    [V]
 CTD_oxy_umoll_1: [51306x1 double]    [µmol/l]
          CTDatt: [51306x1 double]    [1/m]
        CTDfluor: [51306x1 double]    [µg/l]
          CTDpar: [51306x1 double]    [Wm2]
         CTDturb: [51306x1 double]    [m-1 sr-1]
          CTDalt: [51306x1 double]    [m]
     CTDturb_raw: [51306x1 double]    [V]
      CTDalt_raw: [51306x1 double]    [V]
    CTDfluor_raw: [51306x1 double]    [V]
      CTDatt_raw: [51306x1 double]    [V]
   CTDpar_dn_raw: [51306x1 double]    [V]
   CTDpar_up_raw: [51306x1 double]    [V]
         CTDsal1: [51306x1 double]    [PSU]
         CTDsal2: [51306x1 double]    [PSU]
     CTDoxy_umoll: [51306x1 double]    [µmol/l]
         CTDflag: [51306x1 double]
```

Note that '_1' for the first instances of salinity and oxygen in this file are variables before re-derivation in the SeaBird Processing routines.

Inspection of the turbidity channel (CTDturb) and comparison to the original raw voltage (CTDturb_raw) reveals a bug in the SeaBird DatCnv conversion module whereby the converted ECO-BB output is reported to a fixed precision. This has been confirmed by SeaBird (see email chain at the end of cruise DY018). It is demonstrated below (left) where the raw voltage channel (blue) is compared to the SeaBird DatCnv output (green). Direct conversion using the scale factor (SF) and dark counts (DC) supplied in the manufacturer's calibration appears to rectify this problem (right plot). We therefore replace the original turbidity channel in the .cnv files with a corrected version using:

CTDturb = CTDturb_raw .* SF - (SF x DC);

This appears to reinstate the original resolution.



(4) Manual identification of the surface soak (while waiting for pumps to turn on) and the end of the downcast using the 2Hz files. Times to crop were saved to DY034_stainless_castcrop_times.mat and DY034_titanium_castcrop_times.mat

This was then used to crop both the 2Hz and 24Hz files and output (i.e. just the downcast recordings) saved to DY034_CTD001_derive_2Hz_cropped.mat and DY034_CTD001_derive_cropped.mat respectively.

(5) De-spiking of downcast 24 Hz data. The salinity, conductivity, temperature, oxygen, attenuation, turbidity and fluorescence channels were all de-spiked. The worst spikes were identified using an automated routine (similar to WildEdit) where the data was scanned twice and points falling outside a threshold of *nstd* x standard deviations from the mean within a set window size were removed (turned into NaNs).

Window size (#scans) and number of standard deviations from the mean (nstd) used for each channel.

Channel	*Pass 1 window*	*Pass 1 nstd*	*Pass 2 window*	*Pass 2 nstd*
Temperature, conductivity, fluorescence	100	3	200	3
Salinity, turbidity	200	2	200	3
Oxygen	100	2	200	3

Auto-despiking saved to DY034_CTD001_derived_cropped_autospike.mat

Large ‘spikes’ were often observed in the CT sensors lasting a few seconds, predominantly in the thermocline. This is a persistent problem in shallow water with strong property gradients (e.g. see for example D352, D376); particularly where a large CTD package carrying large volume bottles is used. The spikes coincide with a decrease in the decent rate of the CTD package and are therefore likely associated with inefficient flushing of water around the sensors. It is caused by the pitch and roll of the boat, so is accentuated in rough weather. As the decent rate of the CTD package slows on the downcast 'old' water (from above and therefore typically warmer) is pushed back passed the sensors. As the decent rate increases again 'new' water is flushed past the sensors. A similar problem can occur if the veer rate on the CTD winch varies (as was the case on CD173).

The largest and most significant warm anomalies identified in the primary and secondary CT sensors were removed. This was at times up to 5 m of the profile. The impact of smaller scale anomalies that were not removed is mostly minimised during the averaging processes, but care should be taken when interpreting smaller scale features, particularly through the thermocline. The casts are more than good enough for looking at large scale trends and anomalies but should probably not be used for Thorpe scale analysis and interpretation of fine scale structures. To achieve this in a shelf sea environment free fall profiling techniques are more suitable. The worst spiking is seen in the primary CT channels.

Although 'old' water would also have been flushed back past the auxiliary sensors (turbidity, oxygen, chlorophyll, attenuation) the coincident measurements in these channels were (a) not always anomalous and/or (b) any associated anomaly did not always exactly coincide (or could even be confidently identified, especially for oxygen). As such removal of data from auxiliary channels using scans flagged as bad in the primary/secondary CT channels was not always appropriate or did not improve data quality. The worst individual spikes within these channels however were manually identified and removed (NaN'd).

Output saved to DY034_CTD001_derived_cropped_autospike_manualspike.mat

Additional channels added into this file:

Vectors of 0's and 1's indicating data that has been NaN'd (=1). Outputs depend on channels loaded and viewed so each column may have variable meaning and is saved for processing archive purposes only.

(6) Average 24Hz (cropped and de-spiked data) into 1 db. Linear interpolation used when no data available for averaging.

Files for each cast were created: DY034_CTD001_1db_dn.mat

All the 1 db profiles (except PAR and fluor) are then further smoothed with a 5 m running median window. To help preserve fine scale structure through the SCM a 3 m window was used for the fluorescence. Note that all non-smoothed (24 Hz) data is available on request.

File output: DY034_CTD001_1db_dn_smth.mat

(7) Application of calibrations to salinity, chlorophyll and oxygen in 1db smoothed downcasts. Calibrated files saved to DY034_001_1db_dn_smth_calib.mat.

Sigma theta (σ_θ) (relative to 0 pressure) is also calculated at this stage using the matlab function `sw_pden-1000` from the `SEAWATER` toolkit.

```
CTD003 =

          CRUISE: 'DY034'
            CAST: 3
          STNNBR: 4
            DATE: '08/08/2015'
            TIME: '01:25'
             LAT: 51.2109
             LON: -6.1309
           DEPTH: 106
            pres: [140x1 double] [db]
            time: [140x1 double] [seconds]
           temp1: [140x1 double] [°C]
           temp2: [140x1 double] [°C]
            sal1: [140x1 double] [PSU] - calibrated
            sal2: [140x1 double] [PSU] - calibrated
           cond1: [140x1 double] [S/m] – not calibrated
           cond2: [140x1 double] [S/m] – not calibrated
       oxy_umoll: [140x1 double] [µmol/l] – calibrated
           fluor: [140x1 double] [µg/l] – calibrated
             par: [140x1 double] [Wm2]
            turb: [140x1 double] [m-1 sr-1]
             att: [140x1 double] [1/m]
     sigma_theta: [140x1 double]
```

The calibrations were also applied to the 24 Hz data (cropped and de-spiked) and output to .mat files DY034_001_derive_cropped_autospike_manualspike_calib.mat containing the same variables as above.

(8) Application of salinity, chlorophyll and oxygen calibrations to bottle firing data. A new file, DY034_stainless_btl_calib.mat/ DY034_titanium_btl_calib.mat, with variables CTDsal1_cal, CTDsal2_cal, CTDoxy_umoll_cal and CTDfluor_cal was created.

Calibrations

Salinity

82 salinity samples that could be matched against a bottle firing in the CTD logs (54 stainless, 28 titanium) were analysed on a Guildline 8400B. 9 samples which presumably came from CTD niskin bottles in crate 19 (numbers 482-492) could not be matched.

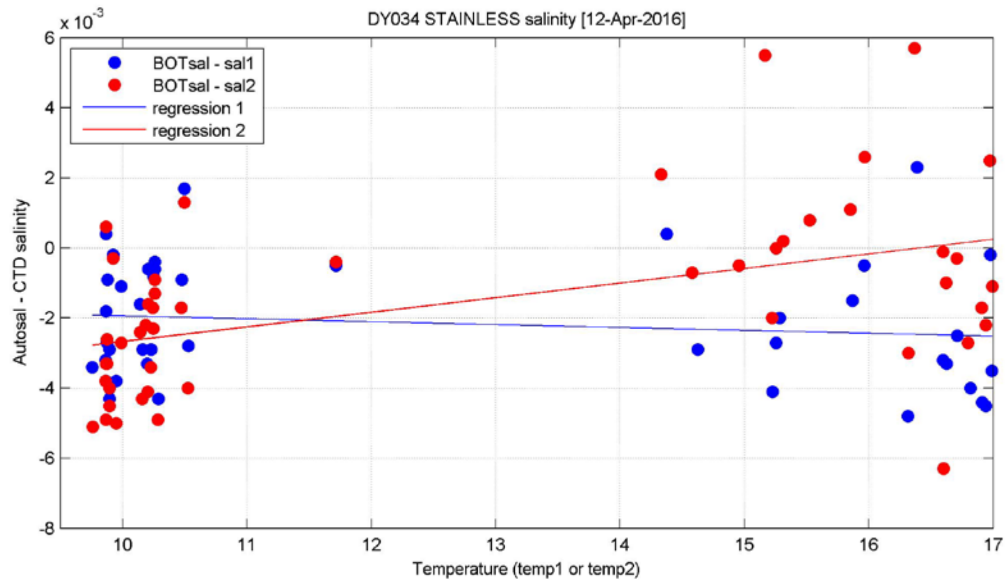
Stainless

Using <u>all</u> samples the mean and standard deviation of residuals from the primary and secondary sensors were -0.001725 ± 0.0028635 and -0.0016481 ± 0.0054021 respectively. Any differences greater than 1.5 standard deviations above or below the mean offset were removed. A point where the difference between the primary and secondary channels was <-0.0025 psu was also removed.

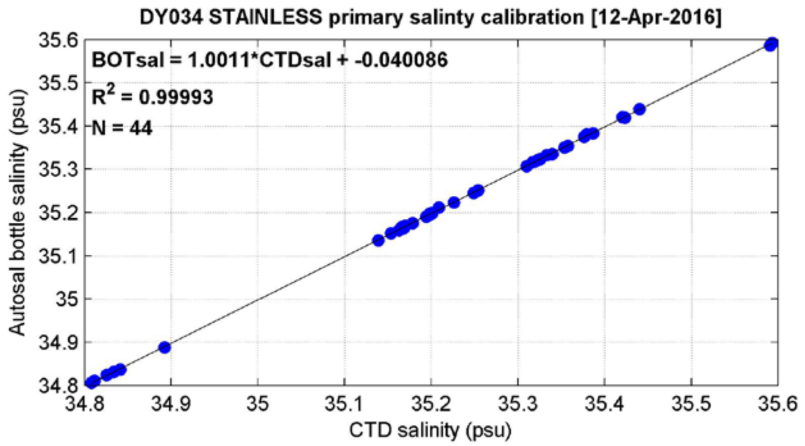
Using the remaining values, there is a significant linear trend in the winkler – CTD oxygen offsets for the secondary salinity channel (p-val = 5×10^{-5}). This is corrected using the following equation

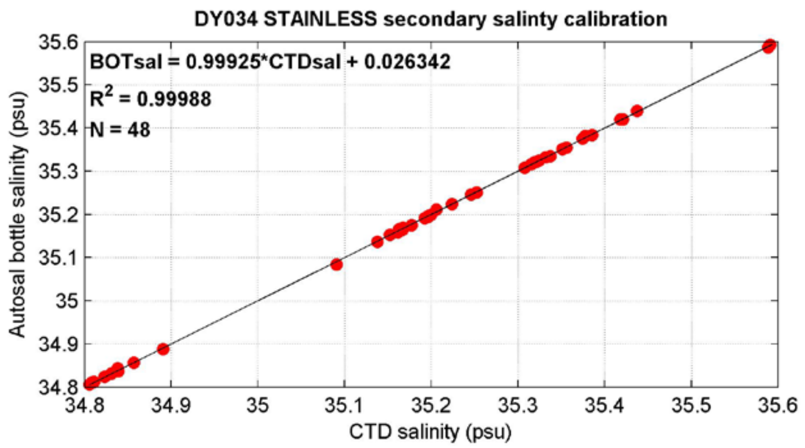
$$new\_sal2 = ((temp2 * 4.17\times10^{-4}) -0.0068) + sal2$$

The primary channel trend is not significant and no correction is applied.

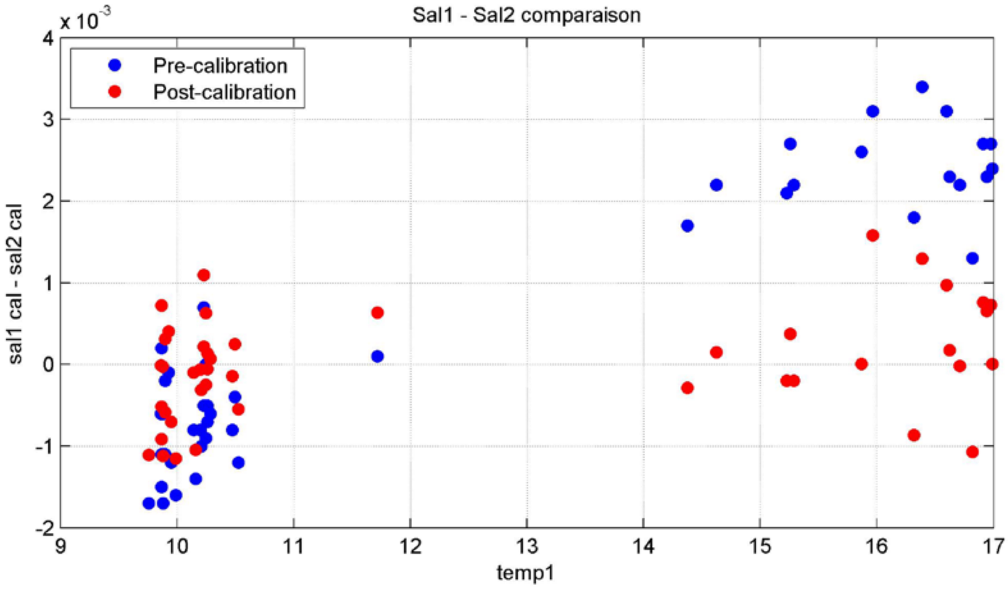


The following regressions are subsequently applied. For the secondary channel new_sal2 is used.





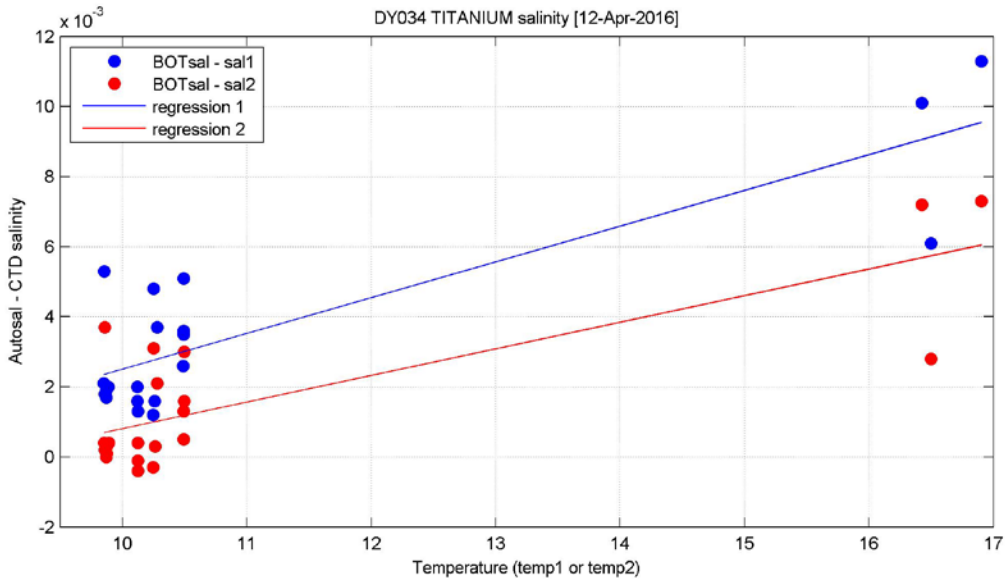
Following calibration the mean ± standard deviations for the primary and secondary sensors (winkler-CTD) was reduced to -1.8894e-14 ± 0.0017068 and 9.3259e-15 ± 0.00227respectively. The trend in the primary-secondary salinity offset associated with temperature is removed.



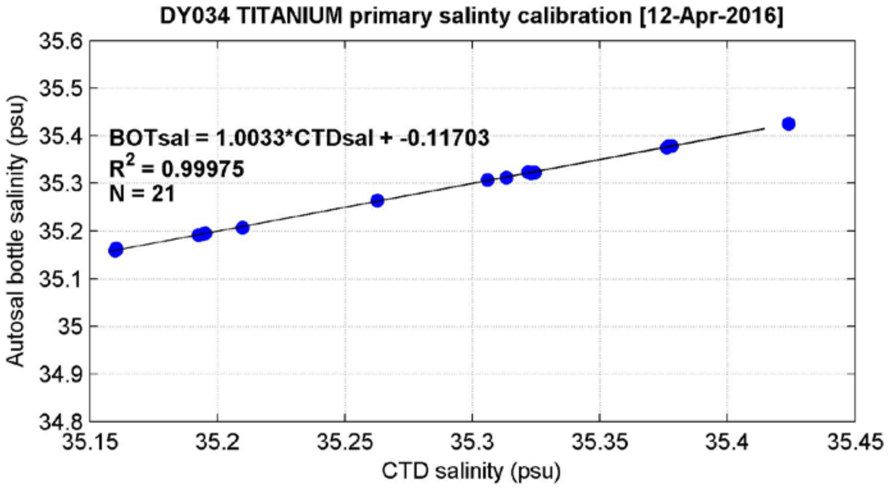
Titanium
Using all samples the mean and standard deviation of residuals from the primary and secondary sensors were 0.0059429± 0.014831 and 0.004375 ± 0.01461 respectively. Any differences greater than 1 standard deviations above or below the mean offset were removed. Points where the standard deviation in temperature at the time of bottle firing was > 0.01 were also removed. Finally, a sample taken at 41 metres from niskin 19 on cast 2 was removed.

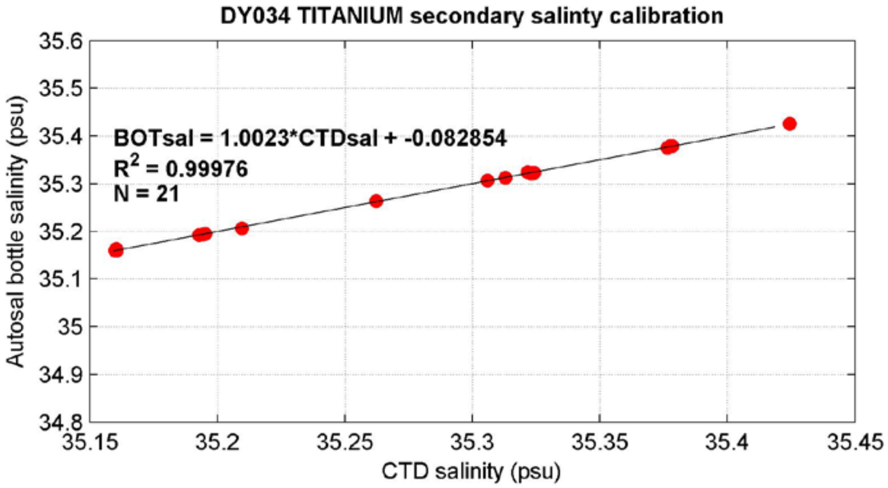
Using the remaining values, there is a significant linear trend in the winkler – CTD oxygen offsets for both the primary and secondary channels (p-vals <<0.05). This is corrected using the following equations

new_sal1 = ((temp1 * 0.0010211) -0.007707) + sal1
new_sal2 = ((temp2 * 0.0007589) -0.006781) + sal2

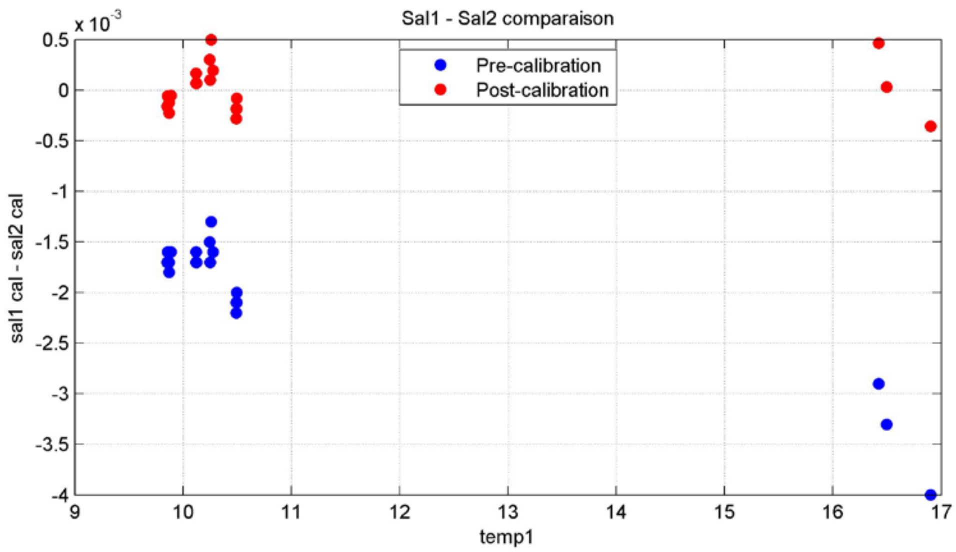


The following regressions are subsequently applied using the new_sal1 and new_sal2 values.





Following calibration the mean ± standard deviations for the primary and secondary sensors (winkler-CTD) was reduced to -1.3196e-14± 0.0013929 and -2.0301e-14 ± 0.0013569 respectively. The trend in the primary-secondary salinity offset associated with temperature is removed.

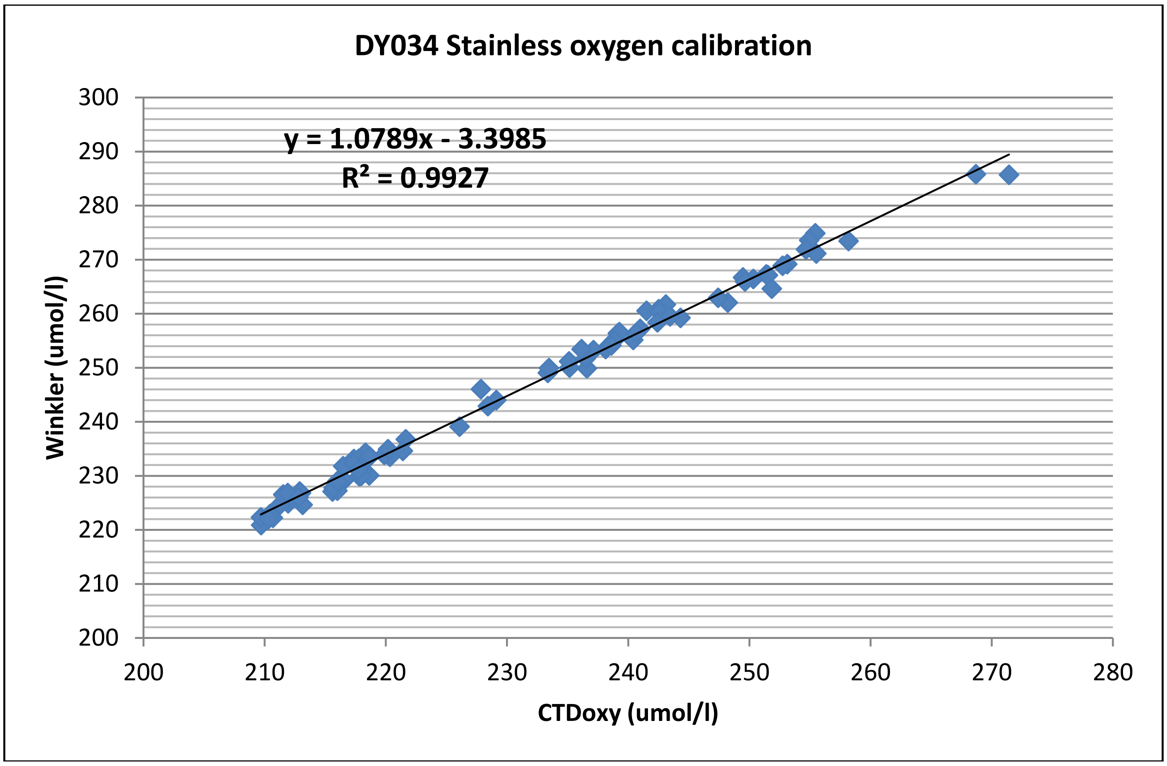


Oxygen
The oxygen titrations were performed by Louis Byrne (BODC).

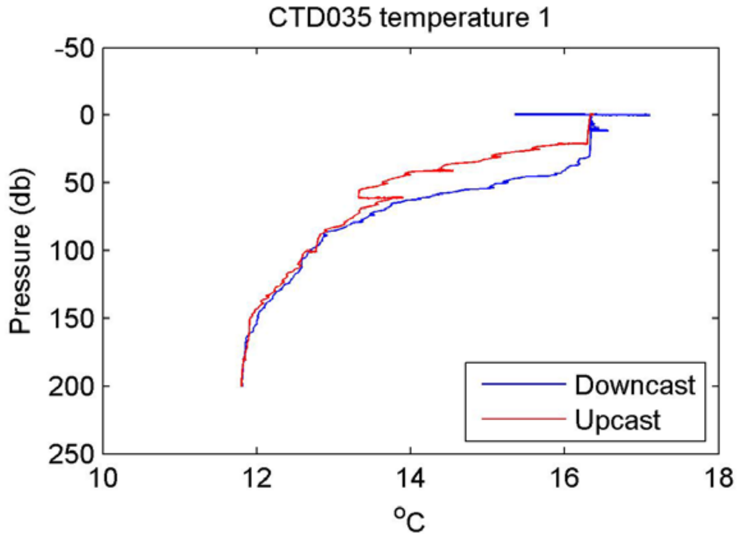
Stainless

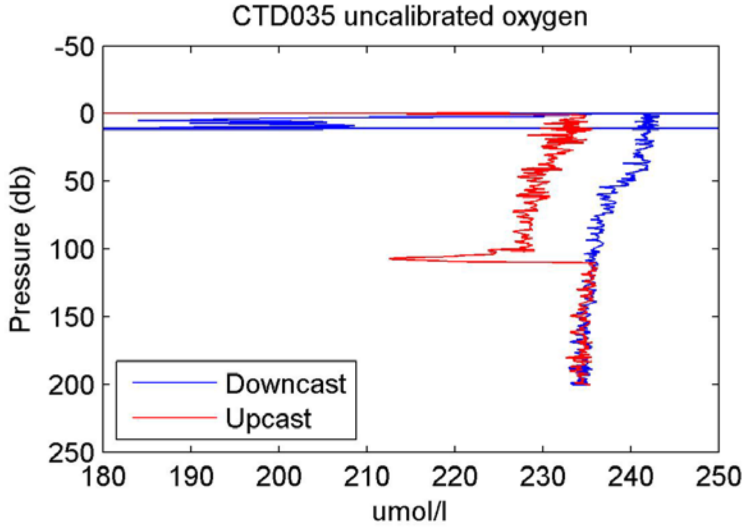
The following stainless steel oxygen calibration was determined by Louis Byrne

Calibrated Oxygen = 1.0789*CTDoxy + -3.3985



The oxygen on CTD035 should be treated with caution since at 100 m on the upcast the oxygen sensor appears to fail.



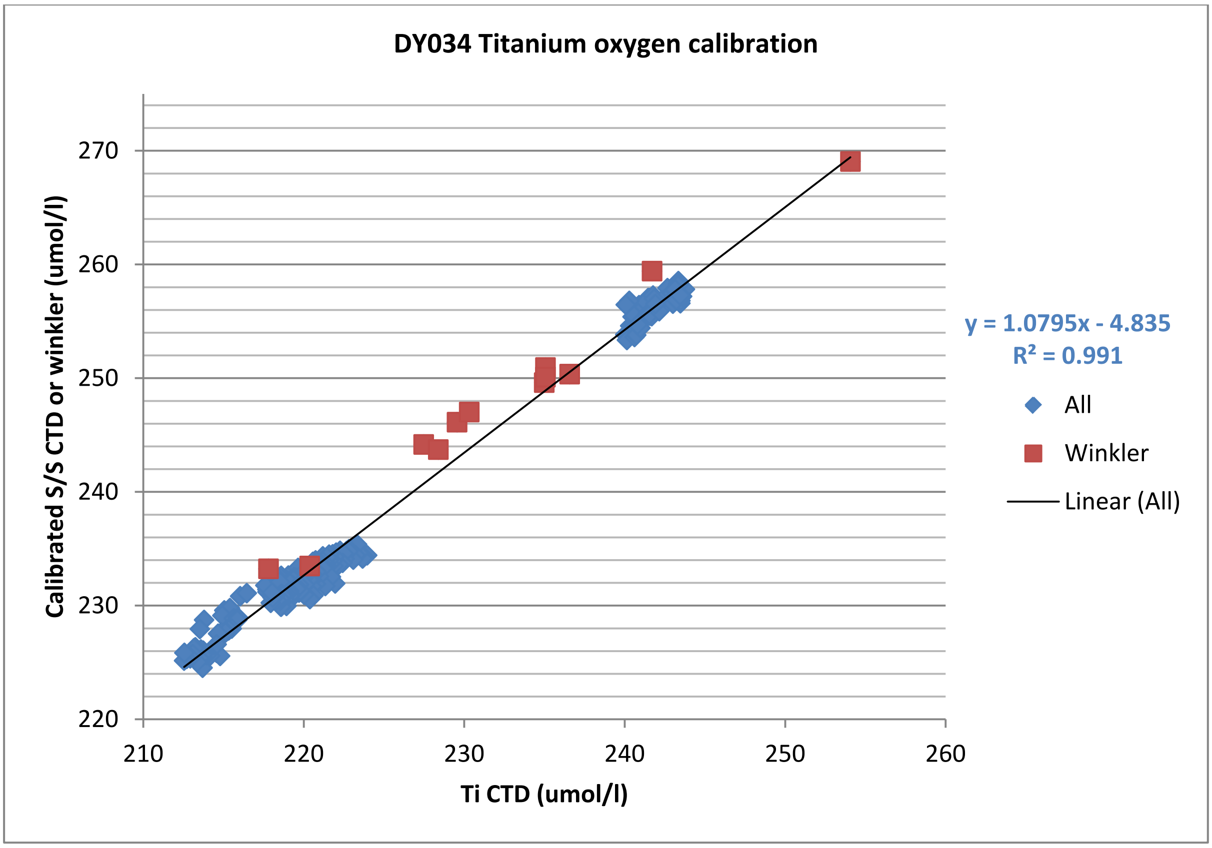


Titanium

Calibrated Oxygen = 1.0795*CTDoxy + -4.835

12 oxygen samples from the titanium frame were combined with data from calibrated stainless steel casts (as in DY021). Calibrated oxygen values from 1m averaged stainless steel CTDs that immediatey followed titanium casts at the same location were extracted. Only depths in the well mixed surface and bottom layers were matched. The following CTD pairs were used:

Titaniuim cast	Stainless steel cast	Depth ranges matched
CTD002	CTD003	> 60 m
CTD007	CTD008	> 50 m
CTD015	CTD016	< 30 m and > 60 m
CTD017	CTD018	< 30 m and > 60 m
CTD020	CTD021	< 30 m and > 60 m



Chlorophyll

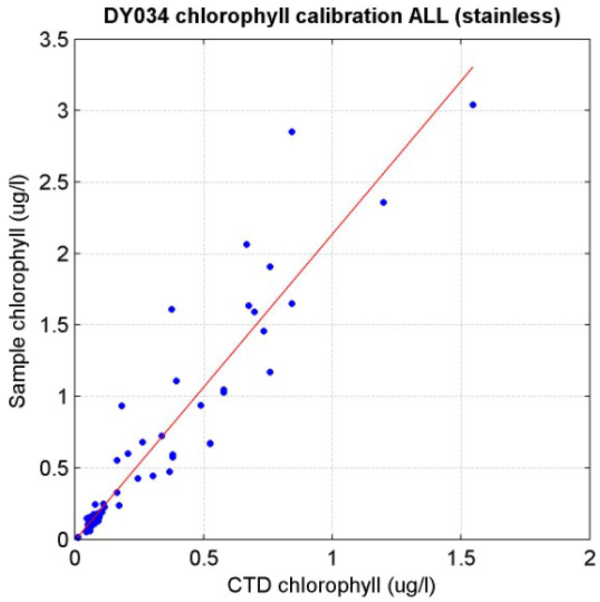
A total of 150 samples were taken for calibration of the CTD chlorophyll fluoresence (stainless+titanium). Samples taken during daylight hours at depths shallower than 30 m were removed. Outliers from sampling and/or recording errors were also discarded.

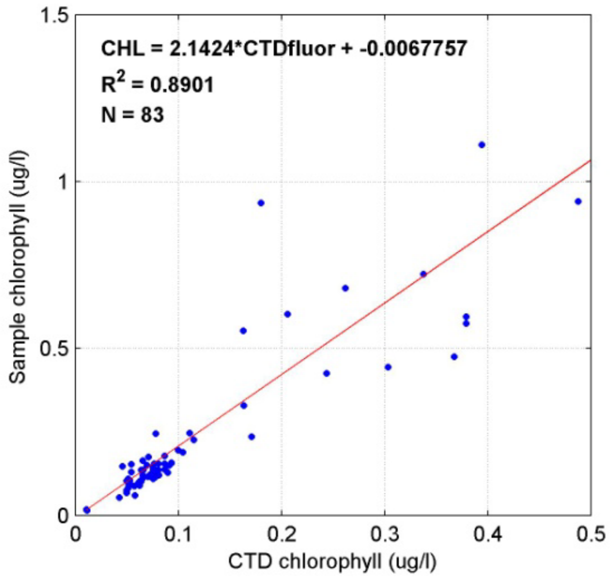
For both the stainless and titanium sensor a linear trend was fitted. This however is a simplification of the more complicated relationship between the extracted chlorophyll and that reported by the CTD. DY033 shows that there are clear regional differences (e.g. on-shelf vs off-shelf) and separate calibrations could be applied to regional subsets (see DY033 cruise report). Defining these regions however is subjective and in realitity there are likely to be gradients between them. There are also probably vertical and horizontal gradients in physiology (e.g. taxonomy, light, other environmental factors...) that account for some of the remaining scatter. To maintain consistency across all SSB cruises a linear trend was fitted to all the data.

Stainless

The following regression was applied:

CHL= 2.1424 * CTDfluor – 0.0067757 [ug/l]





Titanium

The following regression was applied:

CHL= 2.2506 * CTDfluor -0.0033446 [ug/l]