Conductivity, Temperature and Depth (CTD) Processing

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CTD Operations

One hundred and eighteen, 24 bottle rosette CTD-O (Conductivity-Temperature-Depth-Oxygen) stations were occupied during JC032. Stations 1-9 comprised a transect of the Brazil Current near Uruguay. A second transect of the Brazil Current was completed through stations 10-22. Stations 23-118 comprised the main section. This work was accomplished in two parts. Stations 23-35 were those within the Brazilian 200 mile zone. After station 35, the ship sailed to Arrial de Cabo to put the Brazilian observer ashore. A termination of the CTD wire was redone while alongside. This resulted in a two day break in work. The section recommenced with station 36 which was a repeat of station 35.

Stations 1-47 were completed routinely. On the downcast on stations 48 a problem occurred with the gears on the CTD002 drum failed. This resulted in the CTD having to be manually retrieved from 3000m depth. The CTD was reterminated with the wire from the CTD001 drum and work recommenced with station 49. On deployment at station 61 a problem occurred where the remote winch operation failed as did the emergency stop. This lead to the CTD being dropped from a height of about 2 metres when the wire snapped. One niskin bottle was broken and the primary conductivity and temperature sensors were knocked loose from the CTD frame. This resulted in a constant offset in both the primary conductivity and the oxygen. The decision was made not to change the sensors at this stage. The CTD was reterminated and work commenced again. On cast 89, near the bottom of the downcast, the deck unit went down and had to be restarted. Shortly after this the primary conductivity sensor received another offset. This lasted until station 93 when the primary conductivity sensor failed completely near the end of the downcast and had to be replaced.

Initial Processing using Sea-Bird Programs

The files output by Seasave (version 7.18) have appendices: .hex, .HDR, .bl, .CON. The .CON files for each cast contain the calibration coefficients for the instrument. The .HDR files contain the information in the header of each cast file. The .hex files are the data files for each cast and are in hex format. The .bl files contain information on bottle firings of the rosette.

Initial data processing was performed on a PC using the Sea-Bird processing software SBE Data Processing, Version 7.18. We used the following options in the given order:

Data Conversion
Align CTD
Cell Thermal Mass

Data Conversion turns the raw data into physical units. It takes the .CON files and .hex files. The input files were named ctdnnn.hex where nnn refers to the three digit station number. The output files were specified to be called ctd_jc032_nnn_ctm.cnv. Where *nnn* is the station number.

Align CTD takes the .cnv file and applies a temporal shift to align the sensor readings. The offsets applied were zero for the primary and secondary temperature and conductivity as the CTD deck unit automatically applies the conductivity lag to the conductivity sensors. An offset of 5 was applied to the oxygen sensor.

Cell Thermal Mass takes the .cnv files output from Align CTD and makes corrections for the thermal mass of the cell, in an attempt to minimize salinity spiking in steep vertical gradients due to a temperature/conductivity mismatch. The constants applied were thermal anomaly amplitude $\alpha= 0.03$; thermal anomaly time constant $1/\beta= 7$.

Mstar CTD Processing

The entire mstar software suite is written in Matlab and uses NetCDF file format to store all data. There are four principal types of files:

- SAM files: store all information about rosette bottles samples, including upcast CTD data from when the bottles were fired. Data from chemistry samples correspondent with each bottle are uploaded into this file as well. Other information about the station is stored too.
- CTD files: store all data from CTD sensors. There are five ctd files: raw, 24hz,, 1hz, psal and 2db. From the raw data the program does averages and interpolaties until it has 2db resolution;
- DCS files: store information necessary to know CTD downcast (for e.g. start, bottom and end points of the cast). It is also used to merge in latitude and longitude.
- FIR files: keep information about CTD data in points when each rosette bottle was fired. Also stores information about winch work.

Processing Procedure used on JC032

After having converted CTD with the SBE processes, there were two files to work on: *ctd_jc032_nnn_ctm.cnv* and *ctd_jc032_nnn.bl*. The first one contains all raw CTD data including cast information. The other one contains information about the firing of each bottle on the cast.

To start the CTD data processing, run *m_setup* in matlab to add mstar tools and information needed to the process.

msam_01: create an empty sam file to store all information about rosette bottle samples. The set of variables are available on M_TEMPLATES directory and can be changed according with what it needs to store. This file named as *sam_jc032_nnn.nc* contains space to store data for each sample bottle, their flags, some CTD data at firing time.

mctd_01: read the raw data (*ctd_jc032_nnn_ctm.cnv*) and store it in a NetCDF file named *ctd_jc032_nnn_raw.nc*, which becomes write protected.

mctd_02: copy *ctd_jc032_nnn_raw.nc* into *ctd_jc032_nnn_24hz.nc* renaming SBE sensor's variable's names.

mctd_03: using 24hz data (*ctd_jc032_nnn_24hz*) it calculates average to 1hz. Then, using 1hz file (*ctd_jc032_nnn_1hz*) calculates potential salinity and potential temperature (*ctd_jc032_nnn_psal*).

mdcs_01: create empty file named as *dcs_jc032_nnn* to store information about start, bottom and end of the cast.

mdcs_02: populate *dcs_jc032_nnn* with information from the bottom cast. It takes the highest pressure point as bottom.

mdcs_03: selects and shows surface data < 20db (*ctd_jc032_nnn_surf*) then you choose when are the start and the end scan numbers.

The start is selected by scrolling from the top of data printed out by *mdcs_03*. The operator identifies where the CTD went from the deck (zero/negative pressure) to roughly 10 dbar, then where is it was brought back to the surface for start the downcast. The scan number at which the pressure begins to increase is selected as the start point of the downcast. To find the end of upcast, scrolling the data from the bottom of the data printed by *mdcs_03*, identify where the CTD came back on board. The operator chooses the point that is before where the conductivity jumps due to the CTD coming out of the water.

mctd_04: using information on *dcs_jc032_nnn* it selects the CTD downcast data from *ctd_jc032_nnn_psal* file and averages it into 2db resolution (*ctd_jc032_nnn_2db*).

mdcs_04: load position from navigation file and merge it on the cast's points previously defined in mdcs_03 and store it in *dcs_jc032_nnn_pos.nc*.

mfir_01: extract information about fired bottles working from *ctd_jc032_nnn.bl* and copy them into a new file named as *fir_jc032_nnn_bl.nc*.

mfir_02: using *fir_jc032_nnn_bl* and *ctd_jc032_nnn_1hz* it merges time from CTD using scan numbers and put it in a new file (*fir_jc032_nnn_time.nc*).

mfir_03: store on *fir_jc032_nnn_ctd* CTD data at each bottle firing time. The CTD data are taken from *ctd_jc032_nnn_psal* and selected according with firing time information stored on *fir_jc032_nnn_time*.

mfir_04: copy information of each bottle from *fir_jc032_nnn_ctd* onto *sam_jc032_nnn*.

mwin_01: create a new file named as *win_jc032_nnn.nc* to store information about winch working (for e.g. angles, rate and tension).

mwin_03: using time stored on *fir_jc032_nnn_time* it selects wire out from *win_jc032_nnn* of each bottle firing to *fir_jc032_nnn_winch*.

mwin_04: pastes wire out information from *fir_jc032_nnn_winch* into *sam_jc032_nnn.nc*.

mbot_01: create a bottle file (*bot_jc032_nnn*) to store information of the state of each Niskin bottle. It uses a text file named as *bot_jc032_01.csv* (on BOTTLE_FILE/ directory) that must be always updated after each station with number of the bottle, position on rosette, and flag number.

mbot_02: copy information from *bot_jc032_nnn* to *sam_jc032_nnn.nc*.

mdep_01: apply full water depth into all files.

mdcs_05: apply positions from *dcs_jc032_nnn_pos.nc* to all files. If a file in the set doesn’t exist yet it won’t be uploaded.

Sample Files

Chemistry and tracer data from the various scientific disciplines were merged with CTD data to create master sample files. Sample files sam_jc032_nnn.nc were created when processing each CTD station. These were at this stage filled with upcast conductivity, temperature, oxygen and pressure from both primary and secondary sensors coincident with bottle firings. Winch data were merged in at this stage as were niskin bottle flags.

Merging of these data took two steps for each tracer: the first step generated an mstar file which contained all the tracer data for a given section – these were the programs named moxy_01, mnut_01, mcfc_01 and mco2_01. This step contained code specific to the format of the data received from the various scientific disciplines. The files were named oxy_jc032_nnn.nc, for example in the case of oxygen. The second step was to merge these individual mstar files onto the master sam file for the station. This was performed by the programs moxy_02 etc.

This method of processing provided an efficient and consistent method of assimilating data from the many different components of an interdisciplinary cruise like JC032. It also facilitated the production of contour plots of the various section data as we progressed through the station.

Calibration of the Primary Conductivity Sensor

The conductivity sensor was calibrated against conductivity derived from bottle samples. The CTD in use on JC032 was equipped with two conductivity and temperature sensors. The primary conductivity-temperature sensor pair was attached near the bottom of the main frame. The secondary sensor pair was attached to the fin of the CTD. The secondary conductivity sensor was noted to have hysteresis and hence the primary sensor was chosen for calibration as the final conductivity. The differences between the two sensors and their uncorrected offsets are shown in Figure 1.

Upcast conductivity – present in the sam file at bottle depths as ucond – was calibrated against conductivity derived from bottle samples. A multiplicative correction factor applied to conductivity is associated with a deformation of the conductivity cell. The shape of this correction is comparable to an additative correction to salinity. As the calibration was applied at the transition between the raw files and the 24hz files, it was necessary to do a conductivity correction.

The ratio between conductivity derived from bottle samples and upcast conductivity was investigated. While the ratio was close to unity, there was an offset roughly equivalent to 0.002 in salinity. The ratio also showed a trend against pressure. From 1000m to 4500m, the CTD conductivity had a linearly decreasing trend with depth and from 4500 to the maximum depths encountered (around 5700m) the conductivity trend was towards higher conductivities. No trends were noted in salinity residual against temperature or conductivity.

The calibration was applied by correcting conductivities with a multiplicative factor decided by a pressure lookup table. This reduced the interquartile range of salinity residual to 0.001 (equivalent to an interquartile range of 0.00003 in conductivity ratio). This calibration removed the trend with pressure deeper than 1000m. Above 1000m there were large gradients in both temperature and salinity. In this region the bottle conductivities often read lower than those of the CTD. This was interpreted as a Niskin bottle flushing issue. The water in the Niskin was from a few metres deeper than the CTD was reading. Hence no extra correction was applied to the CTD in this region.

The calibration had to be reviewed after the CTD was dropped at station 61. The primary conductivity did receive a conductivity offset of 1.0001 (equivalent to 0.004 in salinity). This was traced to the primary conductivity by comparison with both the secondary sensors and previous casts. Close investigation of the temperature sensors revealed no similar offset. The same procedure as mentioned previously was applied to calibrate these data. The result was similar. The spread of the data was restricted to 0.002 in salinity and the trends with pressure were removed.

The primary conductivity sensor began to fail on station 89. Near the bottom of the downcast, at scan 155720, the conductivity ratio jumped by a factor of 1.000076 (equivalent to 0.003 in salinity). This adjustment was made to the 24hz files before the pressure correction was applied. This remained a constant offset until the sensor had failed completely on station 93 and began wandering in comparison to the secondary sensor. It failed near the bottom of the downcast at scan 143986. For the remainder of the downcast the conductivity data from the secondary sensor were pasted in so as to have the most accurate data available in the 2db file. The upcast data were not corrected for this cast.

The new conductivity sensor was fitted from station 94. This sensor was seen to be stable and well calibrated. A small pressure effect of a similar shape to that seen in the original sensor was noted though the effect was less obvious with this sensor. This was corrected for in the same manner as before. The similarity of the shape of the pressure offset which needed to be applied to both of the primary sensors may indicate was some issue with the pressure sensor.

Calibration of the Oxygen Sensor

The oxygen sensor was attached to the primary conductivity-temperature sensor on the CTD frame. Early on in the cruise, the sensor was noted to suffer from large hysteresis between the down and up casts. This is shown in Figure 3. No correction for this hysteresis was applied but the downcast oxygen – rather than the upcast – was calibrated against bottle samples. The downcast data were matched with the bottle samples – taken on the upcast – on density. Density was chosen as a coordinate more representative of the water mass than pressure/depth which may change between down and upcasts. The residuals calculated were shown to have a dependence on pressure. This pressure effect was corrected for by applying an additive correction with respect to pressure. The results reduced the residuals to below 1 µmol/kg.

After the drop on station 61, the oxygen sensor received an offset of roughly 2.5µmol/kg. Due to the sensors excellent stability before the drop, the decision was taken not to replace the sensor. The sensor remained stable after this and did not change after the primary conductivity was replaced after station 93. The correction to this jump involved the same procedure as for beforehand. The final residuals are shown in Figure 4.

Calibration of the Transmittance Sensor

The transmittance sensor was noted to be producing values of the order of 104 – 105% in clear water. This was adjusted in post-processing by capturing the maximum voltage recorded in clear water and setting this to a transmittance of 99.9%. The other values in the station were adjusted accordingly.

Addition of Metadata to the Mstar files

Position, time and full water depth were added to all the header of all Mstar files including the sam and ctd_2db files.

Time: Time exists in Mstar files in seconds from the Mstar time origin. The Mstar time origin is parsed out from a UTC time stamp in the header of the Sea-Bird CTD files.

Position: Latitude and longitude in both decimal degrees and degrees and minutes were pasted into the files. The time according to the bottom of the cast was found from the dcs files and the posmvpos position merged on.

Water Depth: Water depth was added after processing of the LADCP was complete. The LDEO with CTD processing provides and estimate of full water depth by combining CTD depth with a height from bottom estimate provided by the LADCP. A backup water depth was provided by a combination of the altimeter and depth of the package from the CTD data. This was not used in the final file.

Niskin Bottles

Four 20L bottles were used for the surface measurements (positions 21 to 24) and the remaining twenty positions held 10L bottles. During sampling the bottles were checked for problems such as leaking and dribbling and any issues were noted on the deck log. During the processing of the data quality control flags were assigned and are as follows (ref. WOCE operations manual):

2 = No problems noted (data assumed to be good)
3 = Leaking (these bottles are therefore not sampled)
9 = Samples not drawn from this bottle (e.g. a duplicate depth but no issues with bottle)
10 = Tap dribbling before the top valve was opened

Flag number 10 was introduced on this cruise after a number of incidences where the tap of a bottle was dribbling before the valve was opened. It was thought unlikely that the water in these bottles would have been contaminated (often it was the surface bottle affected) but it was flagged as anomalous and data was recorded from these bottles. Flags 2, 3 and 9 are taken from the WOCE operations manual.

During station 61 the CTD was dropped on deck during deployment. As a result the 20L niskin bottle in position 21 was broken and was replaced by a spare 20L bottle which was subsequently named number 25 for processing purposes.

On a number of casts the chemistry team reported anomalous results in oxygen and nutrient samples from bottle 3 suggesting that water had been picked up in another part of the water column. Anomalous salinity samples furthered the suspicion that the bottle contained water from higher in water the column. This was reported in four stations (81, 85, 91 and 93) and the bottle was given a quality control flag of 3. A new 10L bottle was installed in position 3 (this was named number 26 for processing) before the deployment of cast 95. However, after analysing data from cast 96 the nutrient team once again reported anomalous data. For two additional casts the bottle was not fired in order to determine if bottle 3 was closing under its own steam somewhere else in the water column. On both occasions when the CTD was recovered this bottle remained open. Again on cast number 107 anomalous results in oxygen and nutrients and salinity were found. On following casts, where possible, this bottle was used as a duplicate of the 'bottom-50' depth and was not sampled.

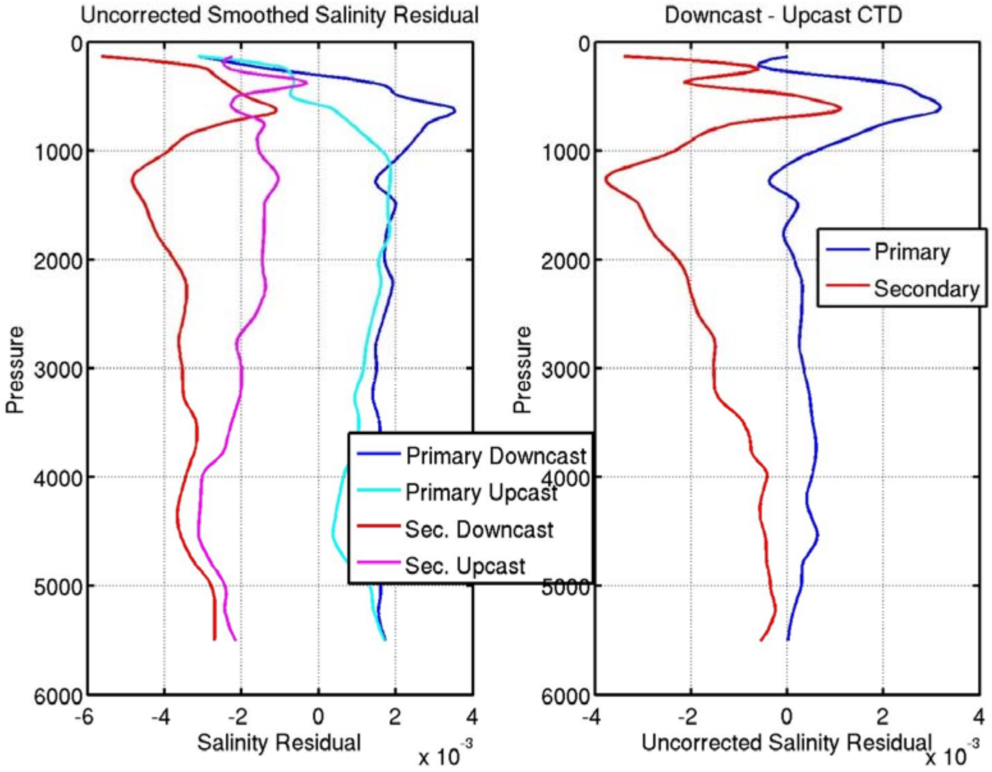


Figure 1: Raw data from the original primary and secondary conductivity (salinity) sensors.

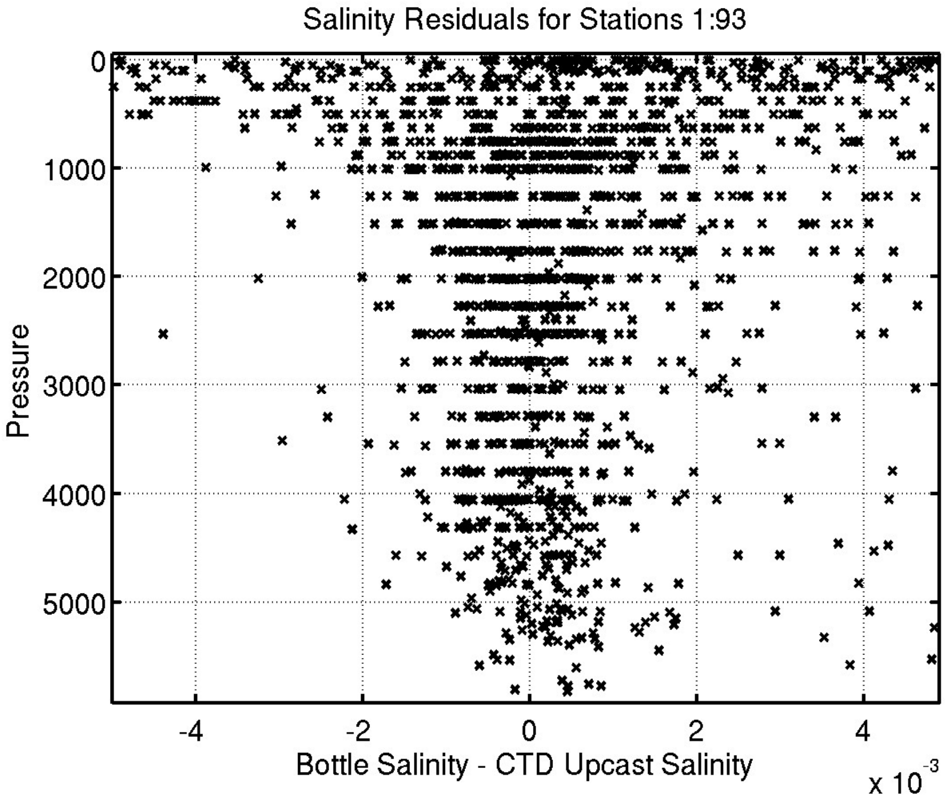


Figure 2: Salinity Residuals for the original Conductivity Sensor after adjustment for a pressure effect.

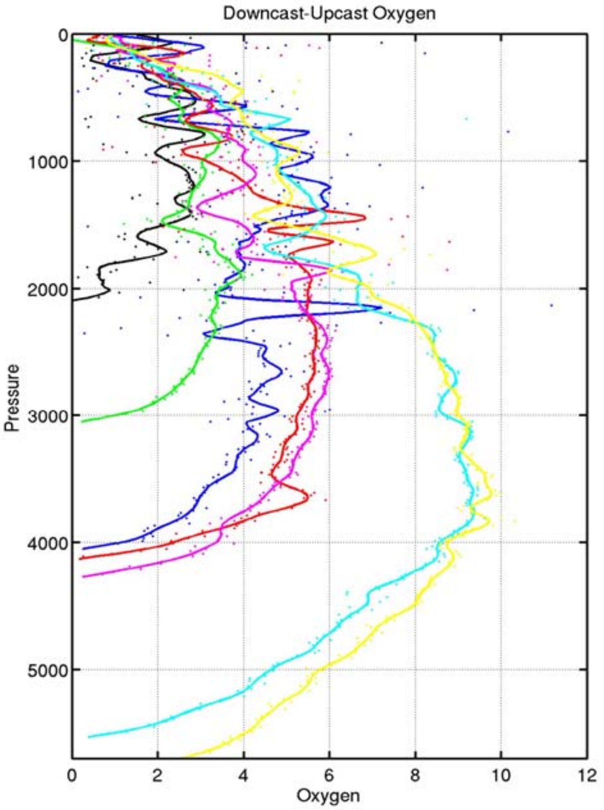


Figure 3: Hysteresis was seen to be present in the oxygen sensor. The downcast oxygen was reading higher than the upcast up to a maximum of 10 µmol/kg on the deepest casts.

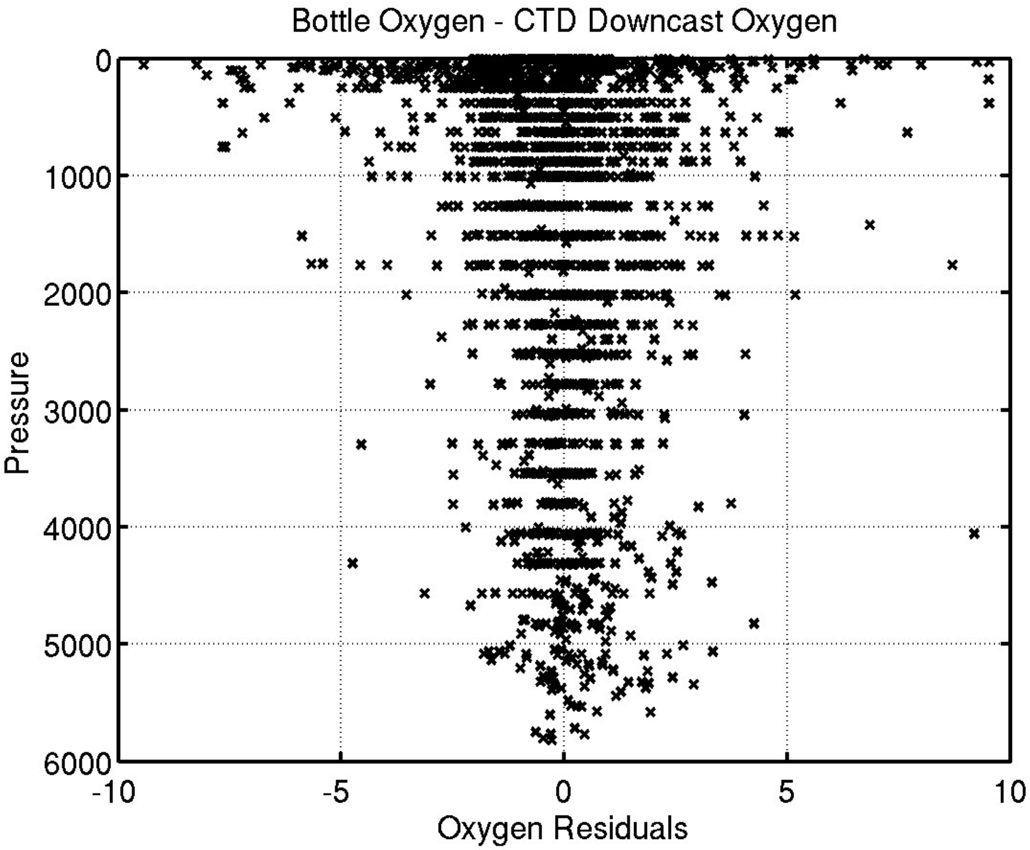


Figure 4: Oxygen residuals from bottle oxygen and pressure corrected downcast CTD data

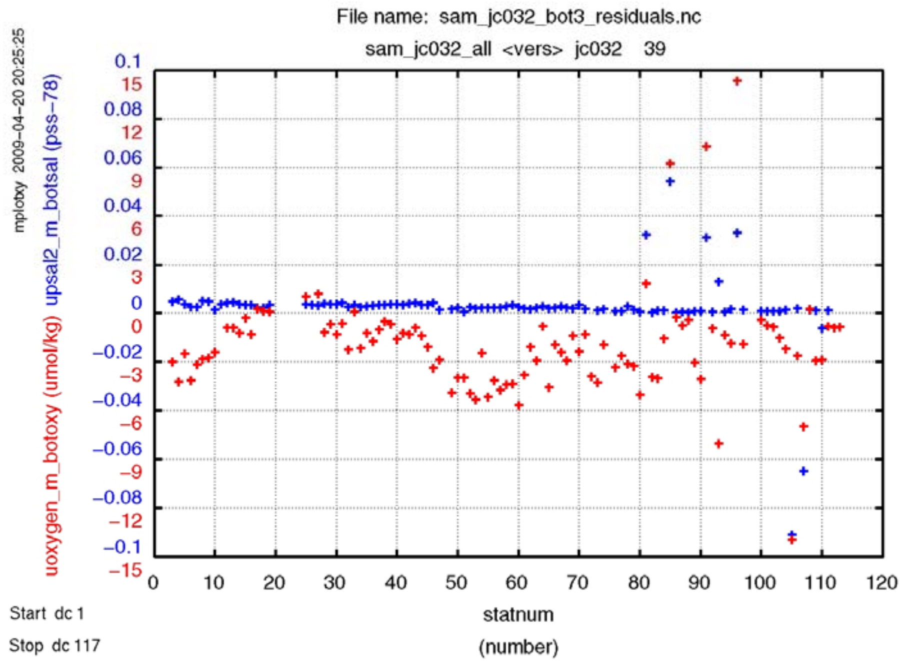
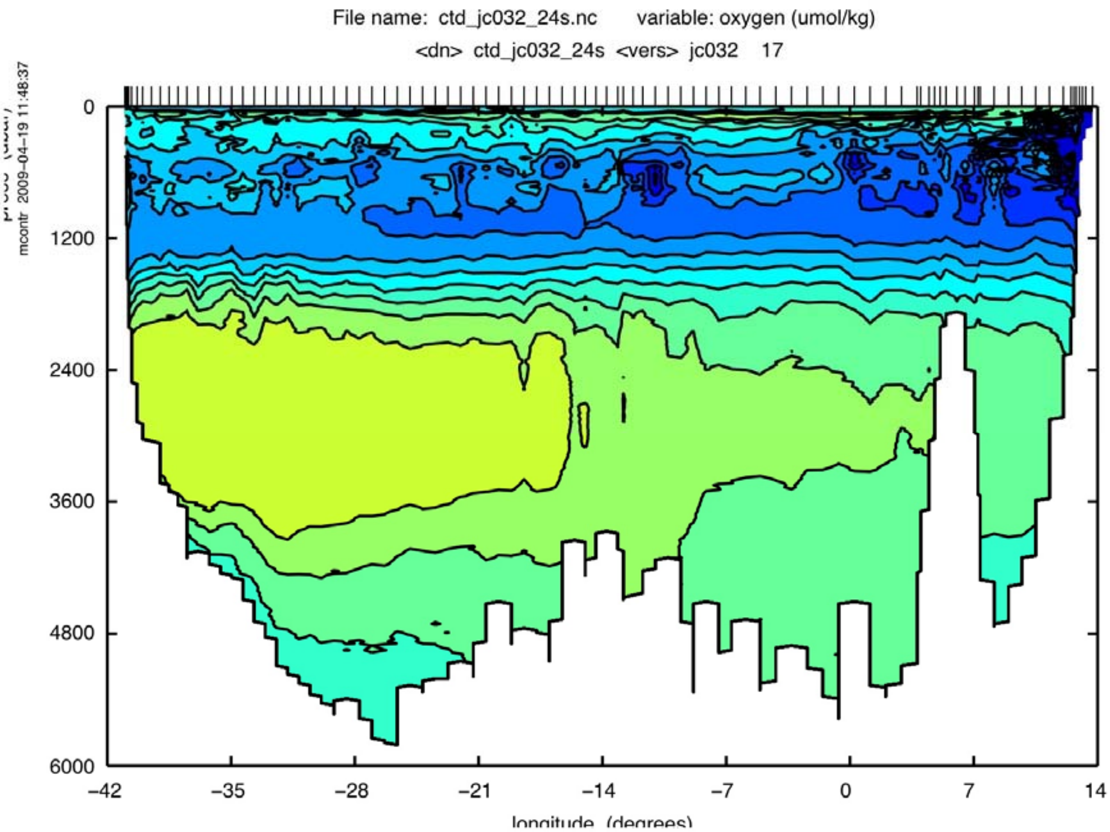


Figure 5: Outliers found from Niskin 3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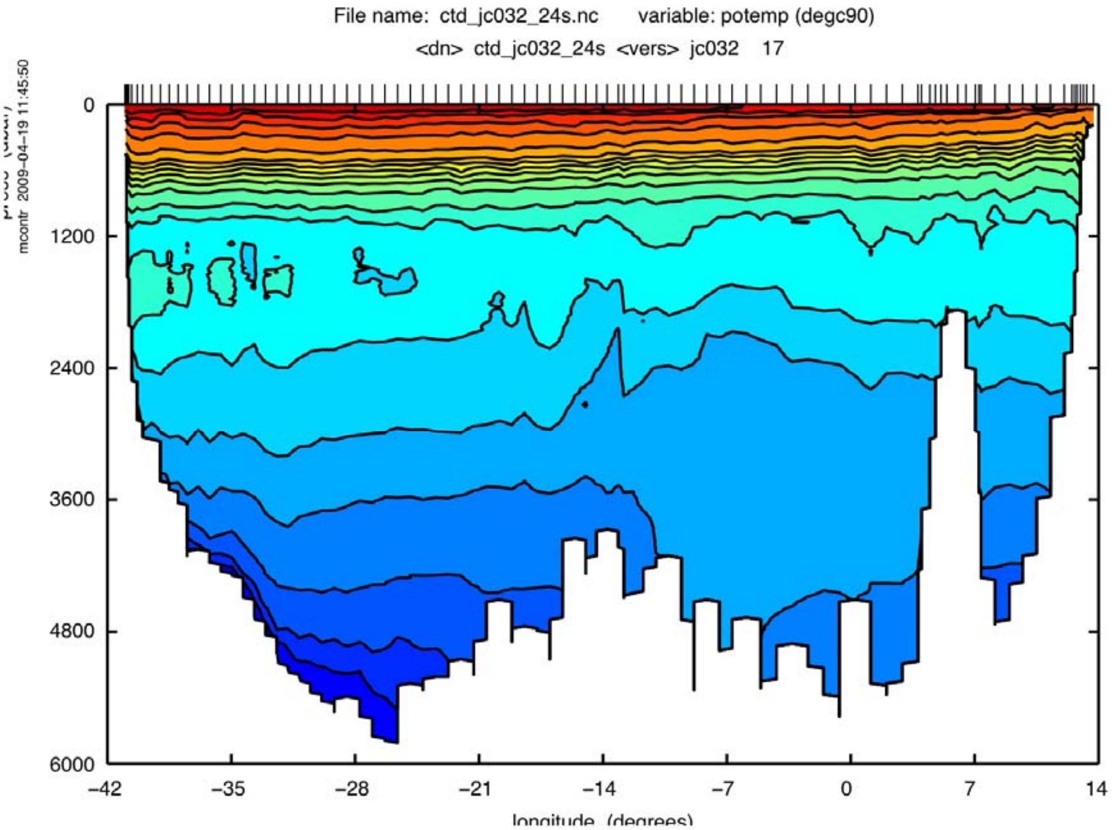
1200
2400
3600
4800
6000
−42
−35
−28
−21
−14
−7
0
7
14
longitude (degrees)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6000
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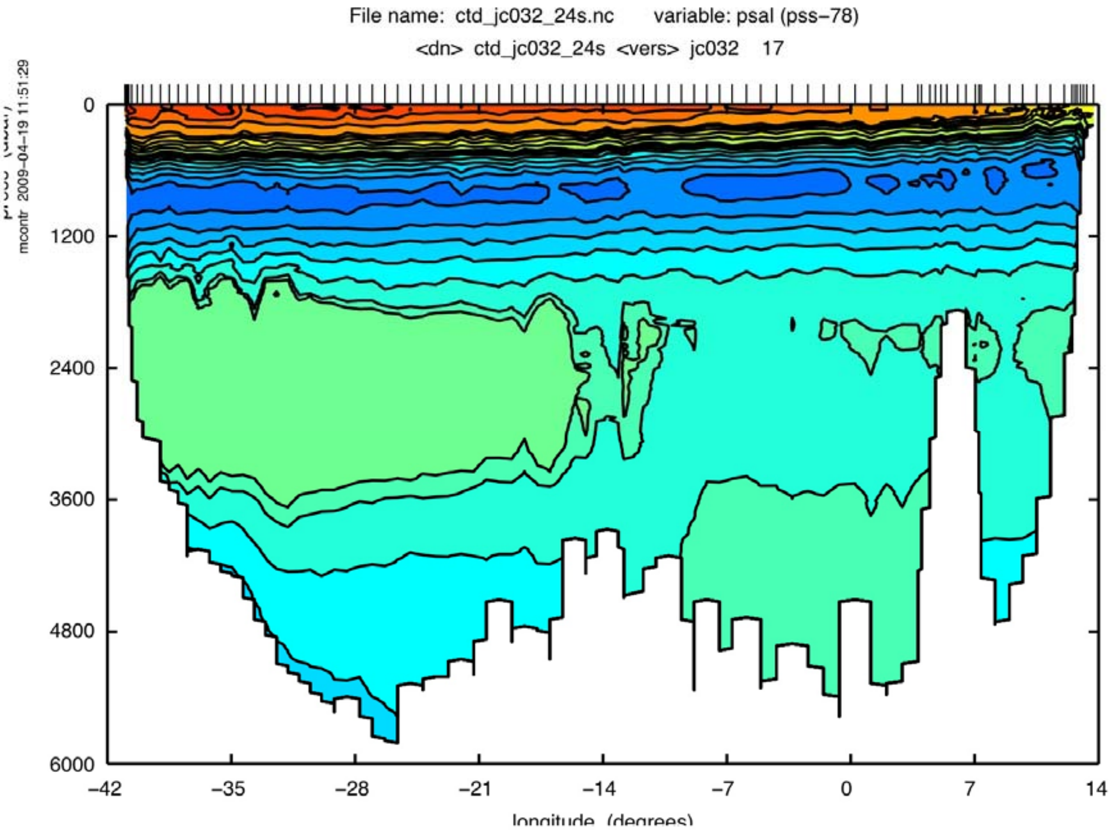
−28
−21
−14
−7
0
7
14
longitude (degrees)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−14
−7
0
7
14
longitude (degrees)