Processing SBE9 Data

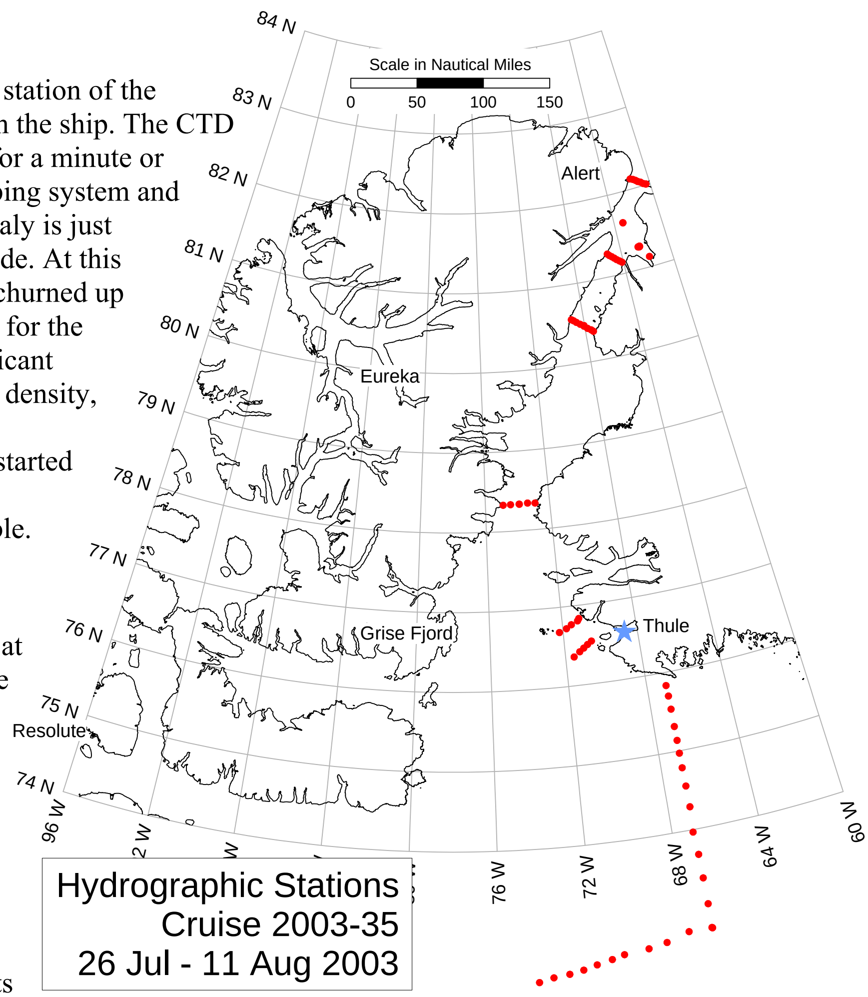
IOS Expedition 2003-35

Project

This expedition was the result of DFO collaboration (Dr H Melling) with Oregon State University (Dr. Kelly Falkner and University of Delaware (Dr Andreas Münchow) in the US NSF-funded project, “Variability and Forcing of Fluxes through Nares Strait and Jones Sound: A Freshwater Emphasis”. The observations were collected during 26 July to 11 August 2003 from the USCGC Healy.

The objective was study of the exchanges of seawater, including added fresh water, heat, and trace chemical constituents, through Nares Strait from the Arctic to Baffin Bay. During the period of the hydrographic survey, 25 moorings were positioned with instruments to measure current, ice drift, seawater temperature and salinity, ice thickness and spatial gradients in hydrostatic pressure. The instruments were set to record data at least hourly for 2-3 years.

Configuration



This survey was conducted from the rosette station of the USCGC Healy, using SBE9 equipment from the ship. The CTD was powered on deck and then submerged for a minute or two to permit stabilization of the SBE pumping system and sensor checks. The rosette station on the Healy is just forward of the propellers on the starboard side. At this location, the upper ocean may be seriously churned up by the screws during positioning of the ship for the rosette cast. At times we could detect significant disturbance to a depth of 15 m (inversion in density, erratic profiles, erratic temperature-salinity correlation). For this reason, we frequently started profiles at 10-m depth, although some data acquired as shallow as 2-3 m seem reasonable. In other cases, data have been removed in processing down to 15-m depth.

The upper 100 m of the cast was conducted at a drop speed of 0.5 m/s. At 100-m depth, the descent rate was increased to 1 m/s. The rosette was again slowed to 0.5 m/s when the altimeter indicated seabed proximity (typically at 50-75 m of the bottom). The slow rate of descent, intended to provide higher resolution in upper-ocean data, was problematic. Even modest waves in Baffin Bay slowed the descent sufficiently that the CTD-rosette was periodically engulfed by its wake. This introduced anomalous pulses in the measured profiles, which had to be removed by cut out in editing.

Water samples were acquired on the up-cast, with the rosette rising at a nominal 1 m/s. The package was not stopped at sampling levels; bottles were closed on the fly. The intent of this approach was avoidance of wake sampling, with the added benefit of much reduced station time. Samples were drawn for the bottles for a variety of geochemical analyses; of these only salinity, analyzed on board via Guildline Autosal in a temperature-controlled room, is of concern here.

Sea Bird SBE-9 CTD Equipment

Two Sea Bird CTD systems were used. Each was equipped with tandem sensors for temperature (SBE3) and conductivity (SBE4), in independent pumped (SBE5) ducts and single sensors for pressure (SBE29), for dissolved oxygen (SBE43, pumped from the secondary TC duct), for chlorophyll fluorescence (Chelsea Instruments Aqua 3), for light transmissivity (Chelsea Cstar) and for seabed proximity (Benthos Echo sounder). The sampling rate was 24 Hz.

System A was used for casts 1-50, when it experienced catastrophic failure in association with a leak of the under-water power connector. System B was used for casts 51-81.

The light transmissivity sensor on System B was unstable. There are no transmittance data available for profiles 51-81.

The temporal response of the primary temperature sensor slowed significantly partway through cast 33, perhaps because of biological fouling of the thermistor pin. The slowed response impeded effective time-response matching with conductivity for calculating salinity. For this reason, data from the secondary temperature-salinity system were used in preference to the primary system for casts 33-47, 49 and 50.

	Sea Bird SBE-9 System A		**Sea Bird SBE-9 System B**		
Variable	**Serial No**	**Calibration Date**	**Serial No**	**Calibration Date**	**Channel**
Temperature:Primary	2796	4 May 2003	2841	4 May 2003	Freq 0
Conductivity:Primary	2545	15 May 2003	2561	2 May 2003	Freq 1
Pressure	83009	9 Jan 2001	83012	9 Jan 2001	Freq 2
Temperature:Secondary	2824	4 May 2003	2945	1 May 2003	Freq 3
Conductivity:Secondary	2568	16 May 2003	2575	2 May 2003	Freq 4
Oxygen:SBE	0459	15 May 2003	0458	21 May 2003	Volt 1
Transmissometer:Primary	390DR	19 Dec 2000	436DR	30 Mar 2001	Volt 2
Fluorometer (Chelsea)	088233	19 Mar 2001	088234	19 Mar 2001	Volt 4
Altimeter (Benthos)					

Summary of Processing

File extension	**Processing step**	**Generated by …**
Hex	Field logging	SeaSave-Win32
Cnv	Convert to ASCII from hexadecimal	Data conversion (SBEDataProcessing-Win32)
Ios	Convert to IOS header format	Convert Sea Bird ASCII Files (IOSSHELL SBE_IOS)

Clip	Remove unwanted records from file	Clip records (IOSSHELL CLIP)
Edt	Correct data spikes by interpolation	View edit (IOSSHELL VIEWEDIT)
Shf1	Shift C1 values to later time	Delay C1 by 0.4 scans (IOSSHELL SHIFTDAT)
Shf1&2	Shift C2 values to earlier time	Advance C2 by 1.3 scans (IOSSHELL SHIFTDAT)
Avp	Smooth pressure values	5-point running average (IOSSHELL FILTERS)
Ctm1	Computes primary cell temperature	Compute cell temperature (IOSSHELL CELLTM)
Ctm1&2	Computes secondary cell temperature	Compute cell temperature (IOSSHELL CELLTM)
Cal	Calibration using T1C1 or T2 C2 for S	Calibration (IOSSHELL CALIBRATE)
Dat	Create files w/o DO sensor voltage	Remove channels (IOSSHELL REMOVECH)
Calo	Duplicate file with p, S, T, DO volts (see below)	Remove channels (IOSSHELL REMOVECH)
View	Interactive T & S editing of wake & ship effects	View edit (IOSSHELL VIEWEDIT)
Bas	Remove unneeded channels	Remove channels (IOSSHELL REMOVECH)
Bin	Average data within 0.2-db bins	Bin averaging (IOSSHELL BINAVE)
Final	Calculate depth, potential temperature, gamma	Derived quantities (IOSSHELL DERIVE)

Processing Notes

1) Verify station information - date, time, latitude, longitude, water depth, number of samples and summarize in a spreadsheet.

2) Convert hex files to ascii form (cnv for profiles & ros for bottle closing depths) using SBE Data Processing 5.25, Data Conversion

3) Convert cnv files to IOSSHELL format

4) Add an "Event Number: " line in *.ios files.

5) Plot all channels of raw signal data against sample number for general assessment of sensor operation, data spiking, etc. Look for spiking, fall speed reversals by surface waves and other irregularities.

   Wave influence is appreciable during casts 1-3, 14-24, 26, 28 and 31. There are fall-speed reversals in profiles 16-21 and appreciable fall-speed variation in 15 & 22-24.

   There are jumps in pressure of about 0.5 db in profile 49, at 29 and 104 db.

   In general, the pressure records are noisy. Smoothing pressure by running average over 5 scans is recommended.

   The values for % transmission dropped down by 12% at cast 51 and shifted up by 21% at cast 61 (values based on maximum transmittance). The shifts at minimum transmittance are consistent with these values, but greater variability in the minimum value precludes an accurate estimate. However, the high values of maximum transmittance for cast 61 et seq. are associated with clipping of the transmittance signal at 80%. There are also uncharacteristic broad smooth dips in transmittance centered on depths between 150-250 m. It appears that the transmissometer on CTD B was unreliable, For this reason the transmittance channel is deleted from casts 51-81.

6) Identify the scans to be used from each file.

7) Use IOSSHELL CLIP programme to remove unwanted scans from each file.

   Certain profiles have problems during the upper few tens of metres on the first drop. These are likely a result of the severe disturbance of the upper 10-20 m of the water column by the ship's propellers. These profile sections have been discarded.

8) Examine the profiles for unreasonable 'spikes' in value. This is a subjective procedure based on the interactive use of the IOSSHELL VIEWEDIT programme, which is used to interpolate or assign values at spikes.

   Pressure: No spikes

   Temperature 1 & 2 and conductivity 1 & 2: Edited for spikes

   Fluorescence and transmissivity: In general NOT edited for spikes. Negative-going spikes may indicate ingestion of plankton. One positive going spike was edited in cast 49. Channels are used qualitatively.

   DO voltage: No spikes, but the DO voltage in profile 1 wraps around from 0V to 5V at very low values. Values at such occurrences are set to zero.

9) Select profiles suited to the determination of TIMING ADJUSTMENTS for T & C. With two SBE9s, each with tandem TC assemblies, there are 4 different configurations requiring assessment.

   Note that different values are appropriate for the primary and secondary TC systems. First, there is a 1.5-scan timing advance of primary conductivity implemented via hardware for the primary system within the SBE9, but not for the secondary system (see Manual for the SBE9). Second, the flow rate through the secondary system is likely slower, because the SBE43 DO sensor is plumbed to it.

   For CTD A, casts 18 and 47 have suitable characteristics for evaluation of timing. For CTD B, only cast 72 is suitable. Casts 60 and 80 can be used for independent assessment of choices. Results are derived from careful inspection of C, T and S relative to Scan No at times of rapid transitions.

   For cast 47, C2 lags C1 by about 2.5 scans; T2 lags T1 by about 1 scan; C1 leads T1 by about 1 scan; C2 leads T2 by about 0.5 scan (not a clear result).

   For cast 18 (at scans 13500-15000), T2 lags by about 0.5-1 scan relative to T1, but may respond slightly faster; C2 lags by slightly more than 2 scans relative to C1, but may respond faster; T1 lags C1 by about 0.5 scan; T2 leads C2 by about 1.5 scan.

   C1 at 0.0; T1 at 0.5 scan lag; T2 at 0.0-0.5 scan lag; C2 at 2.0 scan lag (1.5 scans after T2)

   For cast 71 (CTD B), no lag between T1 & T2; C2 lags C1 by 2-3 scans; C2 lags T2 by 1.5 scans; C1 lags T1 by 0.5 scans.

   Experiment with profiles 18, 60, 72 & 80: Best results come by advancing primary conductivity by -0.4 scans and secondary conductivity by 1.3 scans

10) Select profiles suited to the determination of TIMING LAG for DO voltage. The lag results from the time required to flush the tubing connecting the C-cell to the DO cell. Suitable profiles have a sharp transition in T and S, with indication of an associated abrupt change in DO (i.e. exponential roll-off).

    Only two instances were found, in casts 9 and 41, both by CTD A. The apparent delays in response by the SBE43 were 25 and 22 scans respectively (i.e. about 1 second). A value of 24 scans was adopted for use.

11) The Sea Bird CONDUCTIVITY CELL and its mounting (SBE4) have significant HEAT CAPACITY. Cooling occurs over many seconds following passage from a warm layer into a cold layer. Some heat from the cell is conducted into the water passing through it, raising its temperature and therefore its conductivity. Since this change in temperature is not sensed by the thermistor, values of salinity calculated from raw data on a progressively cooling profile are too high (and vice versa).

    Hydrographic profiles suited to the empirical determination of the correction for cell temperature are rare. A virtually two-layer structure was measured by SBE19 in Bering Strait in 1998 (Cast 1998-26-0050). The temperature gradient was about -1.2 C per db sustained over 5 db. Values of 12.0 s for the C-cell thermal time constant and 0.018 for the contribution factor α gave the best results for the SBE19.

Best estimates for the SBE4 conductivity module used on the SBE25, based on similar analysis, are 9.5-s for the thermal time constant and 0.0245 for the contribution factor α.

12) CALIBRATION of PRESSURE: Extract the value of pressure when the C-cell has drained after the cast (easy using <digitize> feature of Grapher).

The standard deviation of values is about 0.15 db for each of the two SBE9s. The mean values are -0.39 db for CTD A and -0.45 db for CTD B. These values define the calibration offsets for pressure for casts 1-50 (0.39 db) and for casts 51-81 (0.45 db).

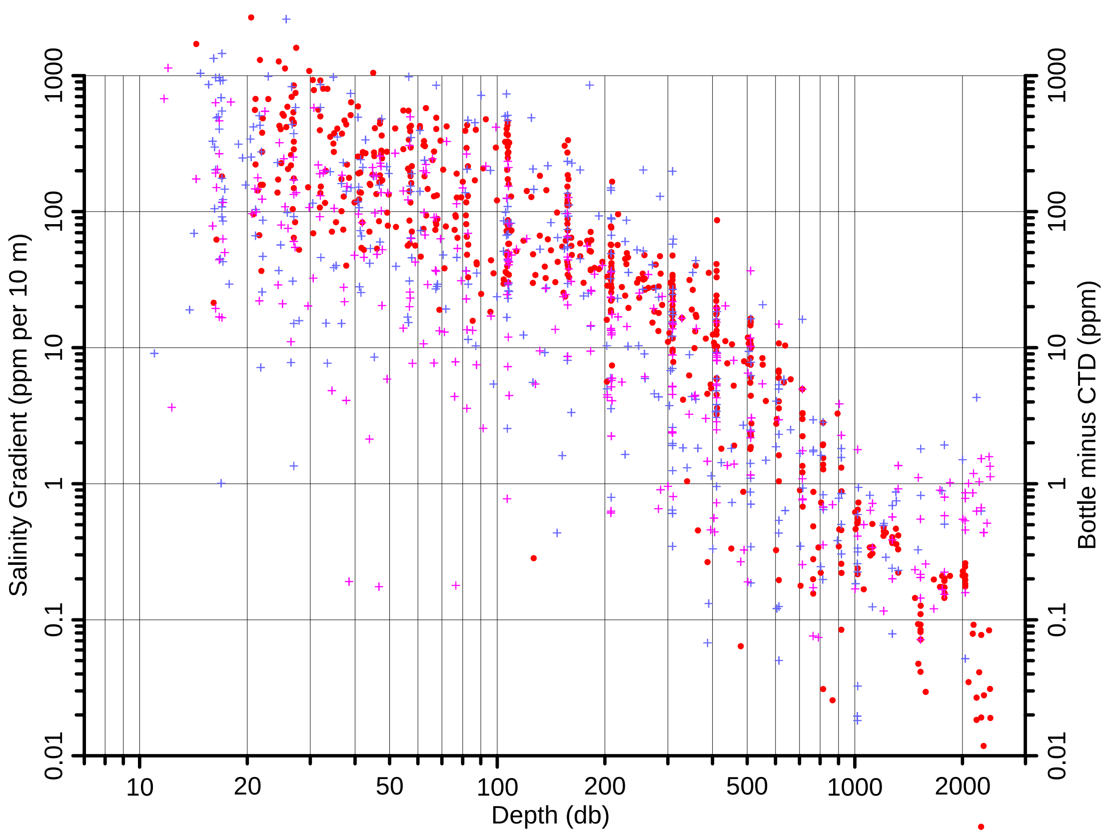
13) Check on CALIBRATION for TEMPERATURE: There was no facility for in situ calibration of temperature. Since the calibrations of aged thermistors are generally stable, we are content with consistency checks. The consistency of temperature values from the SBE4 sensors of the two CTDs was assessed based on values from deep, uniform waters in Baffin Bay (CTD A, cast 9) and in Hall Basin (CTD B, cast 69). Wake effects were judged negligible on both profiles.

On CTD A, thermistor 2 reads warmer than thermistor 1 by only 0.35 m˚C

On CTD B, thermistor 2 reads warmer than thermistor 1 by only 0.3 m˚C

14) Check on CALIBRATION for CONDUCTIVITY (viz.salinity): Salinity calculated from the sensors on the SBE9 probe are compared with values analyzed from water samples. The correspondence between the depth at which the sample was acquired and the CTD data stream was established via a procedure discussed in the next section.

In general, the flushing of sampling bottles on a rosette is a turbulent (i.e. stochastic) process with a relatively long characteristic time. Although a relationship can be established between the average separation of CTD and water sample on the profile, sample-to-sample variations are large. Thus samples acquired (at a poorly known location) in a zone of appreciable vertical salinity gradient are not suitable for calibration. The close relationship between salinity difference (bottle minus CTD) and salinity gradient for the data from cruise 2003-35 is shown below.



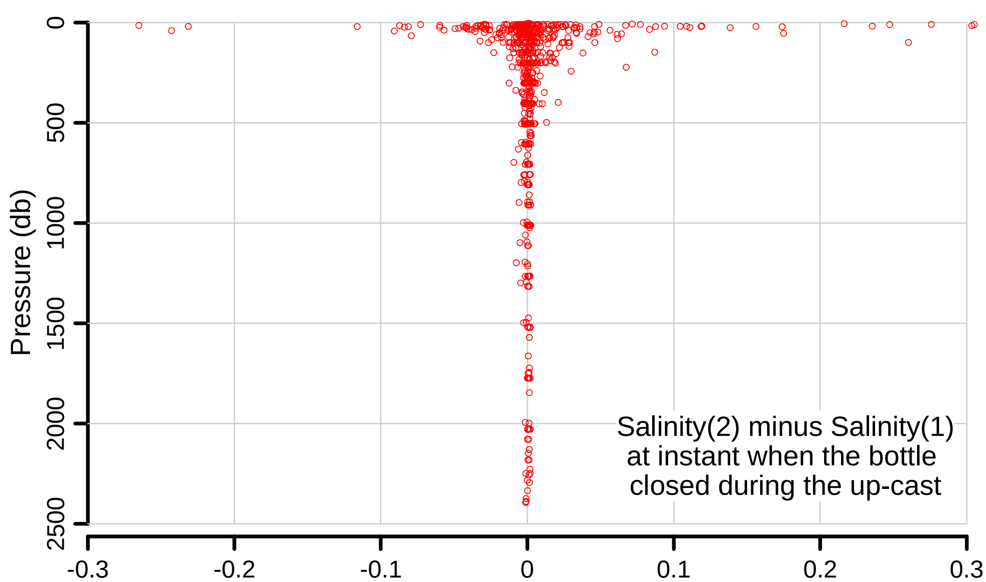
We use data acquired where the salinity gradient is less than 0.001 per metre, typically below 450 m in the region of study. Both TC systems of both SBE9 CTDs indicated salinity too low at 1000 m depth. The calibration data are as follows:

CTD	TC Unit	Bottle minus CTD	Cell Constant
A	1	0.004	1.000 106
A	2	0.001	1.000 026
B	1	0.003	1.000 079
B	2	0.003	1.000 079

15) INVALID PRIMARY TEMPERATURE, casts 33-50 (except not 48): Salinity computed from primary sensors for these casts showed serious impact of response-time mismatch. The temporal response of the primary temperature sensor appeared to slow significantly partway through cast 33, perhaps because of biological fouling of the thermistor pin. For this reason, data from the secondary temperature-salinity system were used in preference to the primary system for casts 33-47, 49 and 50.

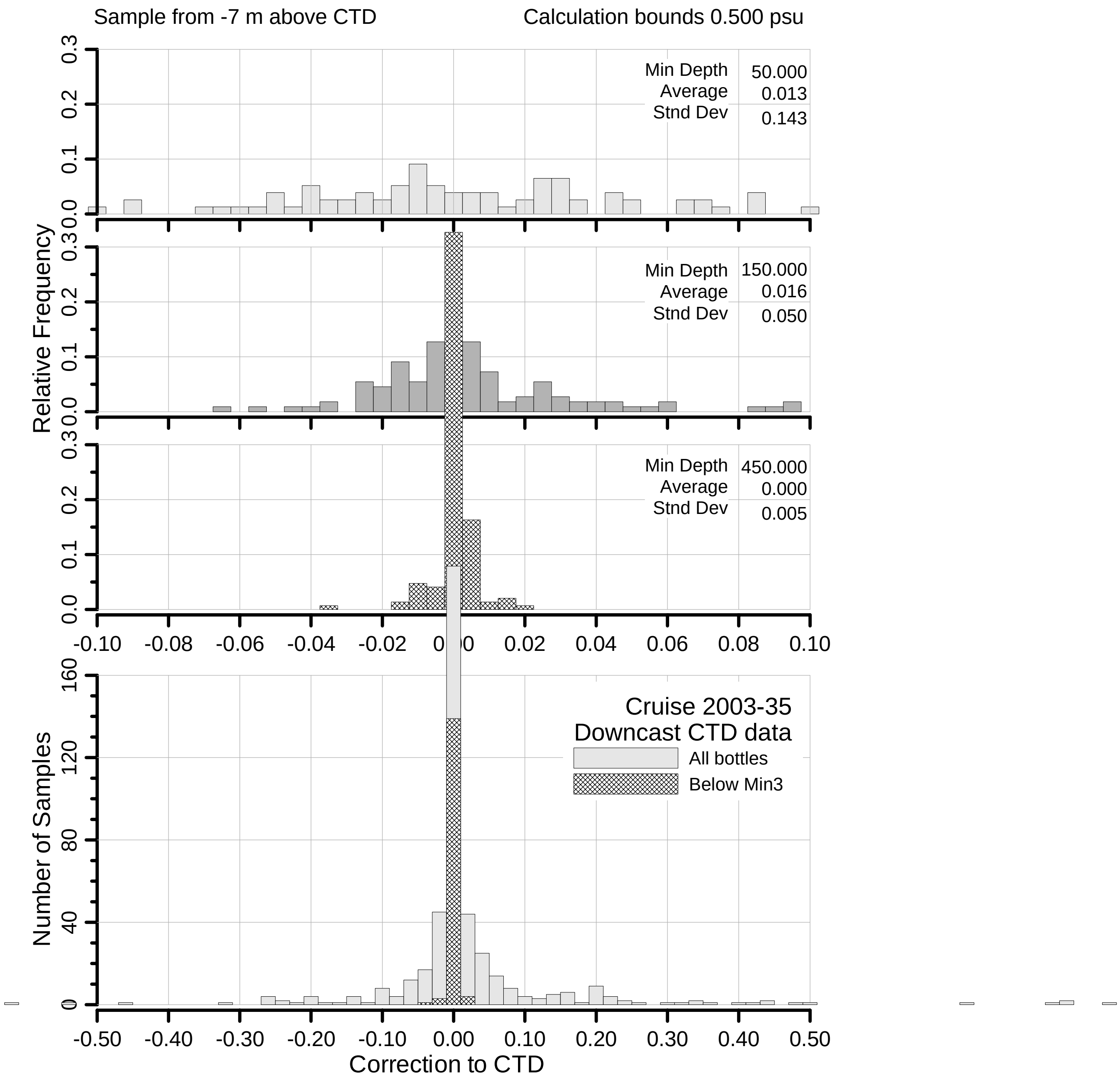
16) LAG DISTANCE for water samples.

Seawater samples were captured on the up-cast without stopping. Salinity values computed from simultaneous data from the two independent pumped systems on the SBE 9 differ by amounts proportional to the vertical salinity gradient. The difference is more than 0.100 near the surface despite the close proximity of the TC-duct intakes. These data illustrate the turbulent and poorly mixed character of the wake that the CTD samples on the way up.



The objective is to establish the relationship between the samples captured on the up-cast, and the undisturbed profiles of temperature and salinity measured by the CTD on the down-cast. The distribution based on CTDSalinity at the depth of bottle closure is skewed to positive values, since the captured sample is water from a depth greater than the CTD at the time of bottle closure. The optimal value is taken to be that which results in a symmetric distribution of (BottleSalinity - CTDSalinity).

For 2003-35, the most symmetrical distribution of salinity difference between bottle and CTD values is obtained when the CTD data are those measured 7 db below the level that the bottle was closed. A summary for data acquired with CTD A is shown in the figure that on the next page.



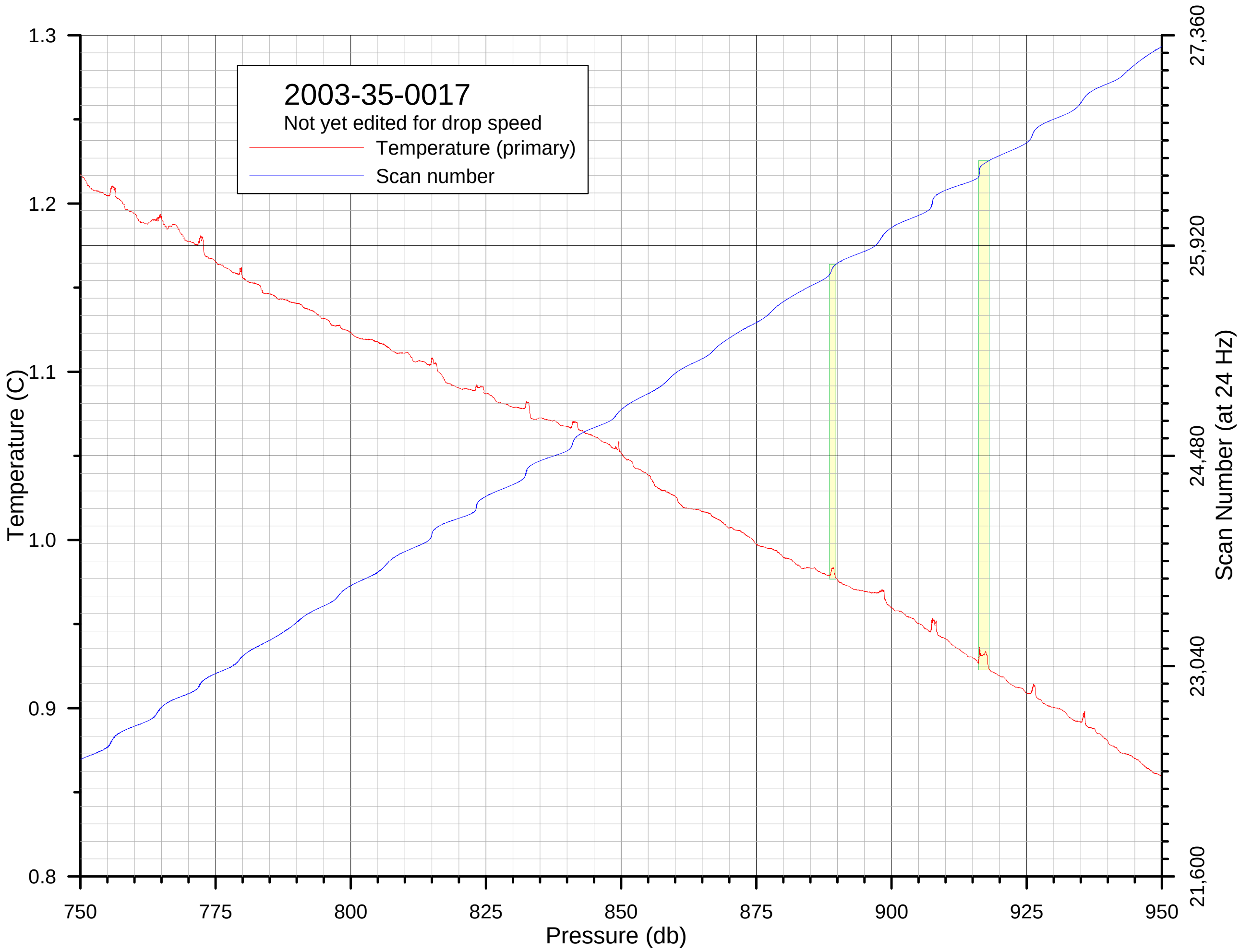
17) TWO VERSIONS OF THE PROFILE DATA were created following calibration and calculation of salinity. One is the standard, high sampling rate stream with variables pressure, temperature, conductivity, salinity, fluorescence and transmissivity. The other is intended for further processing of the DO signal voltage, which is not amenable to further editing since a continuous time series is needed. This second file set contains variables pressure, temperature, salinity and DO voltage. See the end of this document for further information.

18) Examine graphically the top and bottom portions of each profile. Delete scans at either end of the profile that are unrepresentative, because the data are contaminated by ship-generated mixing, or by wake engulfment when the rosette slows down at the bottom of the cast.

    The problem of wake engulfment is frequently characteristic of the entire profile when the ship heaves in a sea. Each time the ship rises, the descent of the rosette-CTD slows, allowing the wake to catch up. It is customary to edit CTD profiles for this effect by removing scans that were acquired at slow descent rate.

This is not appropriate. Engulfment occurs as the probe decelerates, and escape from the wake is not achieved until the probe has fallen some distance at increased speed. Deletions guided by fall speed eliminate some good data early in the heave, and leave some bad data later on.

The figure below illustrates the problem. In the absence of automated methods of removing wake-contaminated data from the profile, those profiles most influenced by waves (1-3, 14-31) were inspected subjectively and temperature and salinity values were edited by interpolation over wake-influenced intervals. Other channels were left untouched.



19) File size is reduced by removing spurious channels (unused temperature and conductivity channels, altimeter data and flags).

20) File size is reduced 5-fold by computing averages of base variables (pressure, temperature, salinity, fluorescence, transmissivity) over 0.2-db increments.

21) Calculate the derived quantities potential temperature (Theta0), depth and gamma (Gamma0) using bin-averaged values of the profile data.

22) Salinity of water samples: Intrinsic to the above analysis is the assumption that all discrepancies in salinity between bottles and the CTD result from stochastic variations in the water retained in the bottle through turbulent wake effects. It is also possible that large discrepancies occur because bottle closed at a depth different from that logged.

The figure illustrating the correlation of bottle-minus-CTD salinity and salinity gradient implies that discrepancies exceeding 0.100 are unlikely to result from wake effects at depths greater than about 100

m. This might figure might be a useful guide in assessing issues related to possible errors in the depth of sample acquisition.

Processing for Dissolved Oxygen Sensor (SBE43)

1) At the processing stage prior to interactive editing of the high-resolution profile data (pressure, temperature and conductivity), a file was retained with variables pressure, temperature, salinity and DO voltage. The reason was to retain continuity of sampling for the variables relevant to the slowly responding DO sensor.

   Plumbing delay in the response of the oxygen sensor relative to pressure, temperature and conductivity was determined in stage 10, using casts 9 and 41. A value of 24 scans was adopted for use (about 1 second).

   Data were corrected for this delay using the IOSSHELL programme SHIFT to advance DO values upward in the file by 24 scans.

2) The response time of the SBE43 sensor is sensitive to pressure and to temperature. The value at 22.7°C is determined during calibration at Sea Bird Electronics. The following algebraic relation is used to compute the effective time constant during field use.

$$\tau(p,T) = \tau_{23} \cdot D_0 \cdot e^{(D_1 \cdot p + D_2 \cdot T)},$$

   where D_0 = 2.5826 at 22.7°C, D_1 = 1.9640 x 10^{-4} and D_2 = -4.1776 x 10-2

   Laboratory values for the two units used in August 2003 were measured on 4 April 2003:

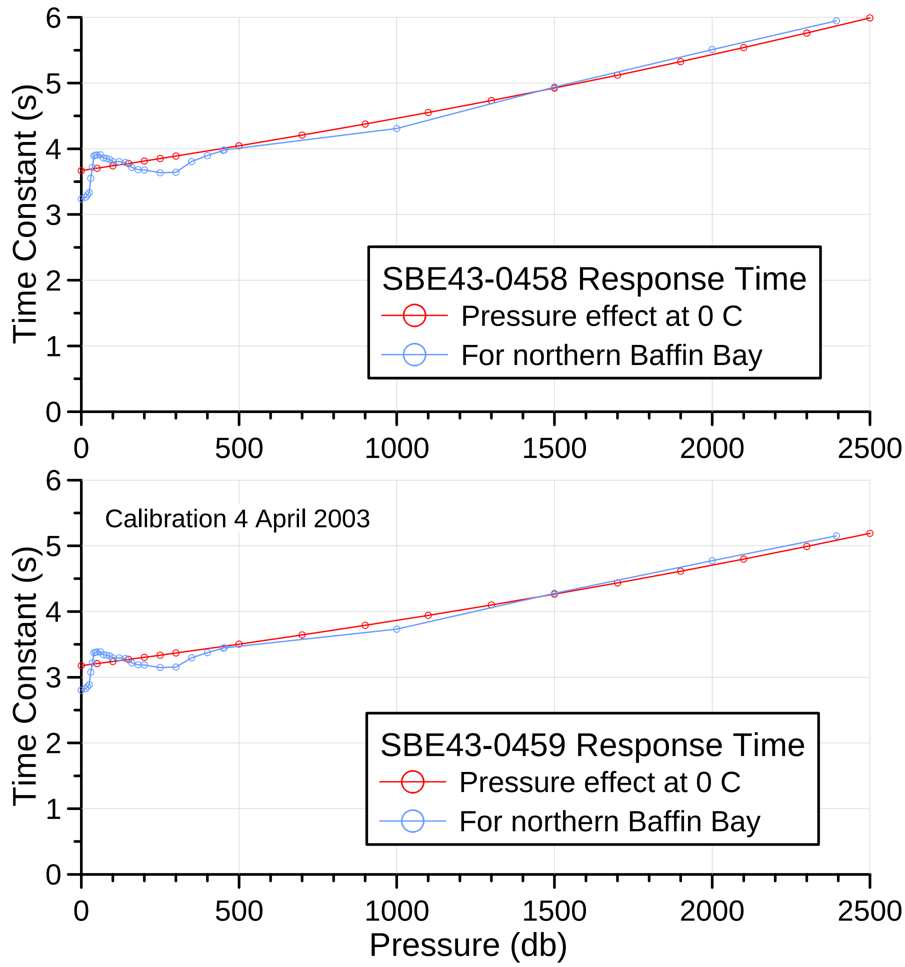
   s/n 0458 τ_{23} = 1.42 s

   s/n 0459 τ_{23} = 1.23 s

   The curves plotted here display the change in these values with pressure at constant temperature (0°C), and with depth at observed temperature in northern Baffin Bay. In view of our incomplete understanding of the SBE43 and of the likely absence of fine-scale vertical structure in DO at depth below 1000 m, we adopt constant values appropriate for the upper kilometre for exploratory processing of these data.

   4.0 s for s/n 0458, CTD-B

   3.5 s for s/n 0459, CTD-A



3) Pressure, temperature and salinity channels are smoothed using an exponential mapped-past filter (IOSSHELL programme EXPFILT) to match the variation in these variables to the slowly responding output voltage of the DO sensor.

   The DO-sensor output is proportional to the fractional saturation of seawater by dissolved oxygen. The actual concentration of dissolved oxygen is calculated by scaling the voltage to the range (0, 1) and multiplying it by a value for the saturation concentration of oxygen calculated using the slowed-down signals for temperature and salinity. There are small corrections for a sensor offset voltage and for changes in the dimensions of the DO cell with pressure and temperature.

   Note that if slowed-down signals for temperature and salinity are not used in computing the saturation concentration, then fine structure in temperature and salinity, to which the DO sensor is not sensitive, will be imprinted upon the profile of oxygen concentration. This is not appropriate.

   $$DO = S_{oc} \cdot (V - V_{off}) \cdot T_{cor}(T) \cdot P_{cor}(p,T) \cdot Ox_{sat}(T,S)$$

   Here $T_{cor}(T)$ is a 3rd order polynomial in temperature [Celsius] with coefficients A, B, C.

   $$P_{cor}(p,T) = e^{E \cdot p/(273.15+T)}$$

   This following step is not recommended until more experience with the DO sensor is gained:

   It may be practical to re-constitute some of the variance lost to the slow response of the DO sensor. Murphy (Sea Bird Electronics, 2005) proposes adding a term $T_{cor}(V, T, p)$ to the signal voltage to restore some high frequency variance that remains small but detectable on the sensor voltage output. The added term uses the temporal derivative of voltage to detect this variance:

   $$T_{cor}(V,T,p) = \tau(T,P) \cdot \frac{dV}{dt}$$

4) Murphy recommends smoothing the 24-Hz DO voltage signal with a 0.5-second running average before differentiation. Files are subsequently thinned to a sampling rate of 2 Hz (1 sample per half second).

5) Subsequent processing and calibration of the DO voltage is pending at this time (18 May 2005).