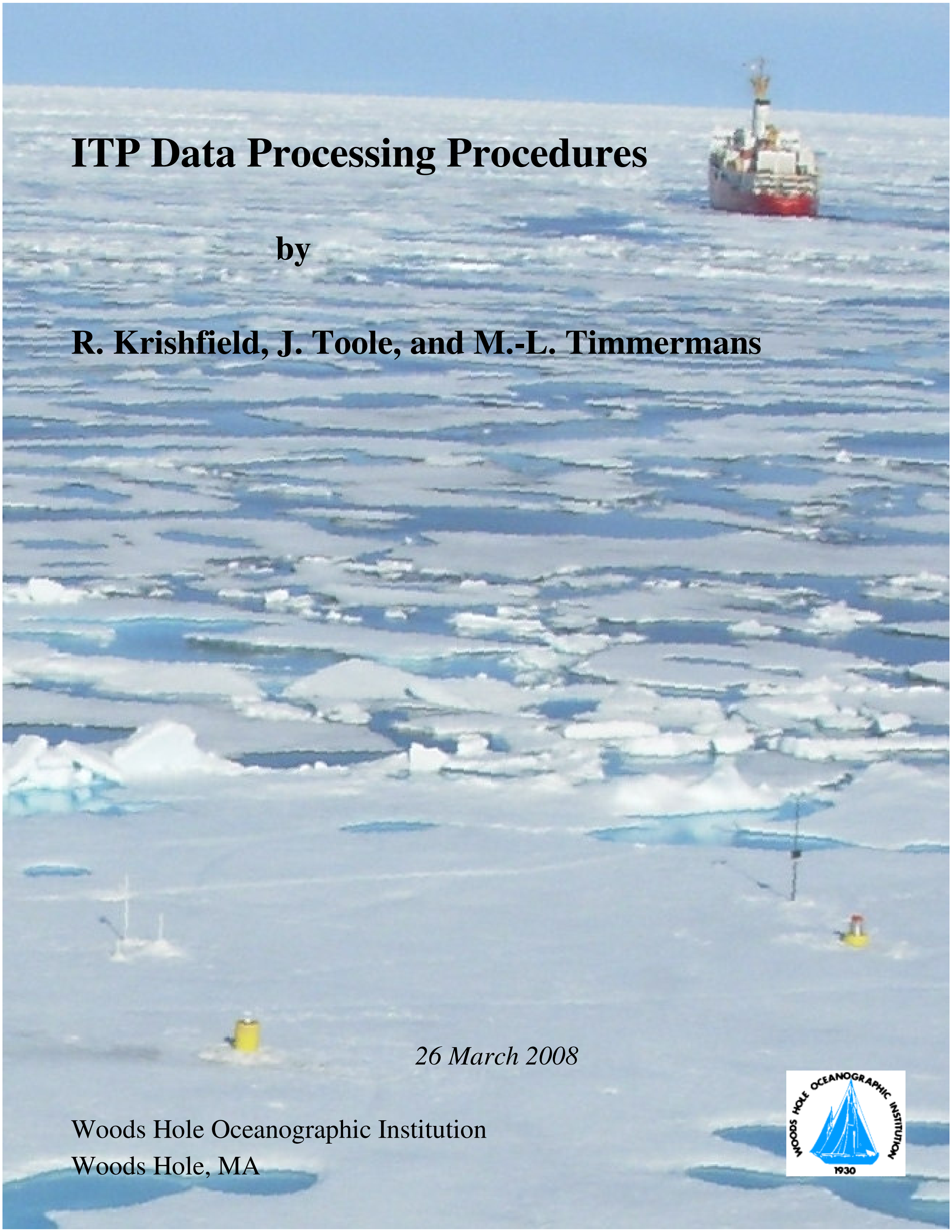

ITP Data Processing Procedures

by

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Abstract

Beginning in 2004, upper ocean water property observations from the Arctic have been reported from a series of autonomous Ice-Tethered Profilers (ITPs; www.whoi.edu/itp). Conductivity-Temperature-Depth (CTD) and engineering data from ITPs are typically telemetered from the Arctic to a laboratory computer several times per day. A preliminary processing routine unpacks the binary profiler data, applies scaling, and outputs the raw profile data to MATLAB-format files (so-called Level 1 data) and as an ASCII-format 2-m gridded product (Level 2 data). Here, by way of documenting the techniques employed to create "final" ITP data, the processing procedure implemented on data from the first 5 ITPs that were deployed to produce final (Level 3 data) is described and the format of the output data is detailed. The procedure includes removal of corrupted data, corrections for the sensor response behavior (including thermistor lag, temperature and conductivity sensor physical separation, conductivity thermal mass and a pressure offset correction for the effects of instrument wake on down profiles), profile-by-profile conductivity calibration using deep water references, and final screening of spurious outliers. Derivation of the sensor response corrections exploit the existence of a double-diffusive staircase stratification (or region characterized by steppy vertical temperature and salinity profiles) in the Canada Basin region where the ITPs were deployed, following the procedures of Johnson *et al.*, 2007. Repeated summer icebreaker-based CTD sections calibrated with water sample analyses provide the basis for the deep water references used in the profile-by-profile calibration of the conductivity data. While the automated data processing make the Level 1 and 2 data available for operational needs (and other interested users) in near-real time, the Level 3 processing procedures refine the data to the highest possible scientific standards so that they may be used in detailed high resolution process and climate studies, and for calibrating satellite and model generated data sets. All three levels of ITP data products are available at ftp://ftp.whoi.edu/whoinet/itpdata.

I. Introduction

The challenges of acquiring oceanic data from beneath the Arctic ice pack are many. Ice-Tethered Profiler (ITP; www.whoi.edu/itp) systems have been broadcasting profiles of seawater temperature and salinity at high vertical resolution (1 Hz, equivalent to about 0.25 m vertical spacing at the nominal instrument profiling speed of 25 cm/s) and during all seasons, since 2004 (Toole *et al.*, 2006; Krishfield *et al.*, 2008). Near-real-time, minimally-processed (raw) data are made available at the ITP website within hours of each profile. After the great amount of time and effort expended to construct, thoroughly test, and deploy each instrument in the Arctic, it is extremely satisfying to receive the live transmitted data from the instruments.

However, the raw data still require a significant amount of processing to realize the true environmental conditions. Orientation of the Conductivity-Temperature-Depth (CTD) sensor (on top of the ITP profiling package), sensor fouling (including possible icing effects), variable water flow rates past the sensors, profile-by-profile conductivity offsets and calibration drift, and other unattributable random errors corrupt the raw data. Some errors are clearly visible in the plots of the raw (or 2-m-gridded) real time data displayed on the ITP website, while others are more subtle, only showing up when closely examining the 1-Hz data. During the data processing procedure described here, methods are implemented to correct the measured temperature and conductivity data, using information from the full time series for each instrument, the platform drift speed, and spatially gridded seawater properties from recent icebreaker surveys.

The first 5 ITPs were deployed in the Canada Basin of the western Arctic Ocean within the Beaufort Gyre (www.whoi.edu/beaufortgyre) where intrusions and steps are present in the temperature and salinity profile data (Figure 1) above and in the Atlantic water layer (centered between 300-400 m in the Beaufort Gyre region). Previous studies have shown that the vertical gradients of these steps are sharp and coherent between temperature and salinity and the layers between the steps are effectively homogeneous. This provides an opportunity to constrain CTD sensor response characteristics wherever steps exist.

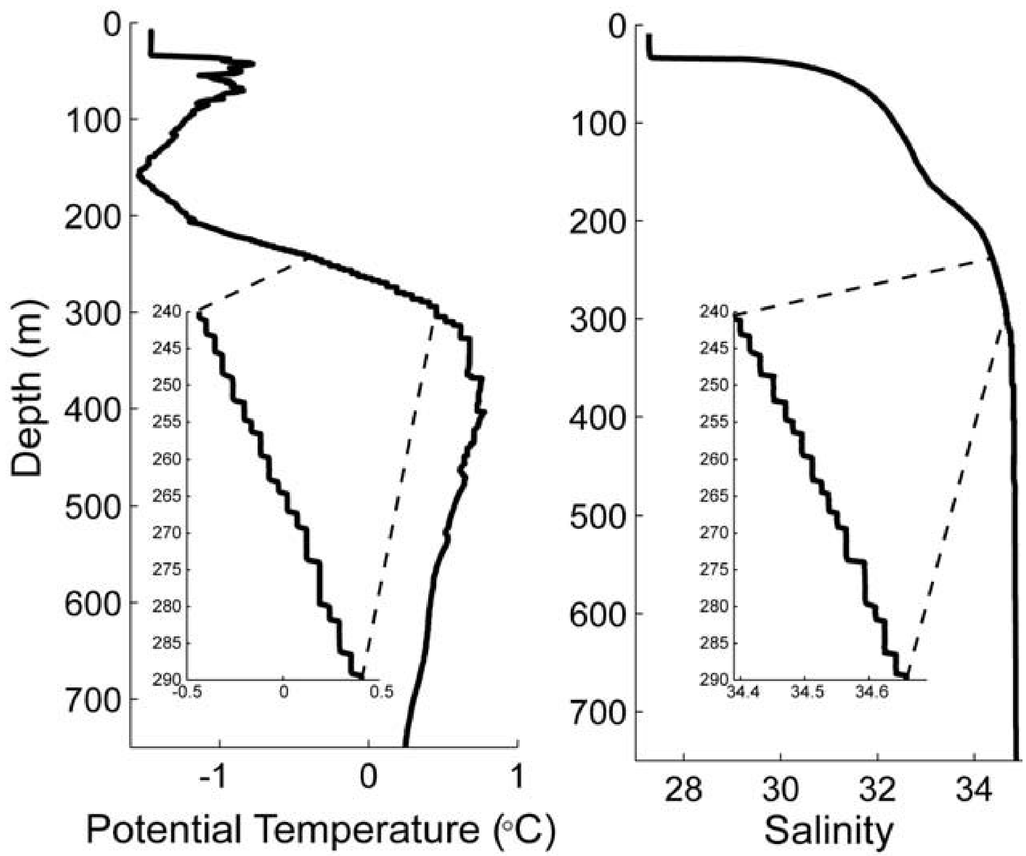

Figure 1: Example of potential temperature and salinity profiles in the Canada Basin (ITP 3, profile 1073, 05/19/2006, 138° W, 75° N). The insets with expanded scales show the double-diffusive staircase. Figure from Timmermans *et al.* (2008b).

II. Raw data

On ITPs, the raw temperature, conductivity and pressure measurements are made using Sea-Bird SBE-41CP CTDs (same as employed on some of the Argo profiling floats; Roemmich *et al.*, 2004). These data are digitized and passed to a McLane ITP controller at the end of each one-way profile which stores the data in a binary file (see Krishfield *et al.*, 2006 for complete technical description of ITP). This binary data file is subsequently transferred by inductive modem to the ITP surface buoy which in turn uploads the profile data (along with geographic position and engineering data) to a laboratory computer via satellite.

Several times each day, a preliminary processing routine running on a laboratory computer unpacks the received telemetered binary profiler data, applies scaling to convert the data to the proper sensor specific units, and outputs the raw profile data to MATLAB format *rawNNNN.mat* files (Level 1 data) where *NNNN* indicates profile number and 2-m gridded properties in ASCII format (Level 2 data). The raw files hold the following variables:

ccond	raw 1 Hz CTD conductivity data (mmho)
cpres	raw 1 Hz CTD pressure data (dbars)
csnum	index (counter) for CTD data
ctemp	raw 1 Hz CTD temperature data (°C ITS 90)
ecurr	engineering motor current data (mA)
edpdt	time rate of change in engineering pressure (dbars/s)
engtime	engineering data sample time (encoded with datenum.m)
epres	engineering pressure (dbars)
esnum	index (counter) for engineering pressure data
evolt	battery voltage of the profiler
ofreq	oxygen frequency (for those ITPs fitted with SBE O_2 sensor)
pedate	profile UTC end date (mm/dd/yy)
psdate	profile UTC start date (mm/dd/yy)
pstart	profile UTC start time (hh:mm:ss)
pstop	profile UTC end time (hh:mm:ss)

In addition, a daily status message from the surface controller that includes hourly (ITPs 1-3 sampled once every 2 hours) GPS position fixes along with internal temperature data and battery voltage are combined with all the prior position data and written to files *itpXrawlocs.dat* (where *X* is the ITP number). These data are all made immediately available for all ITPs at www.whoi.edu/itp/data. The raw Level 1 data (and GPS locations) are the source data used for all subsequent processing described here.

III. Level 2 data

The preliminary processing routine subsequently operates on the Level 1 CTD data to produce a pressure-bin averaged data set at 2 db vertical resolution and salinity derived from the averaged pressure, temperature and conductivity data. No sensor response corrections, calibrations or editing are applied at this stage (beyond the internal sensor calibrations applied in the CTD instruments). These Level 2 products are displayed in plots on the ITP web site and archived in ASCII data files (one file per vertical profile) named *itpXgrdNNNN.dat*, where *X* indicates ITP number and *NNNN* is profile number. The individual profile files are grouped together in *itpXgrddata.zip* or *itpXgrddata.tar.Z* files on the ITP website. An example of a Level 2 data file is here:

```
%year day longitude(E+) latitude(N+) ndepths
2004  233.00000  -141.1760  77.1699  371
%year day pressure(dbar) temperature(C) salinity (pss)
2004  233.03071   10   -1.4853   29.0619
2004  233.03062   12   -1.4790   29.0889
2004  233.03054   14   -1.4681   29.1503
2004  233.03045   16   -1.4648   29.1756
…
2004  233.00039  744    0.2551   34.8497
2004  233.00030  746    0.2505   34.8503
2004  233.00021  748    0.2467   34.8509
2004  233.00013  750    0.2411   34.8510
%endofdat
```

IV. Level 3 data processing procedures

The processing procedure described here was implemented on the first 5 ITPs which were deployed between 2004 and 2006, and which all had finished acquiring data in 2007. Briefly, the procedure includes removal of corrupted data, corrections for sensor response errors, profile-by-profile conductivity calibration and editing of any remaining spurious data values. Table 1 provides a summary of the processing statistics and the derived response correction parameters for the first 5 ITPs.

Table 1: ITP data processing statistics

ITP	profiles	bad.t	bad.s	ups	steps	Median tlag	Median cshift	Median alpha	Median tau	Median prd	Median ratio-up	Median ratio-dn	filt-t	filt-s
1	2043	261	69984	1022	849	0.42	0.11	0.18	5.0	1.71	0.99997	0.99992	29	1205
2	244	0	8250	122	121	0.39	0.10	0.21	5.0	1.13	1.00020	1.00016	7	20
3	1532	259	58922	766	699	0.57	0.05	0.18	3.8	1.77	0.99993	0.99989	23	253
4	698	0	0	349	269	0.53	0.11	0.15	6.0	1.76	1.00016	1.00011	49	139
5	1095	0	36550	548	358	0.49	0.10	0.18	4.6	1.46	1.00021	1.00018	72	526

ITP = ITP number; profiles = total number of acquired profiles; bad.t = total number of bad temperature points removed; bad.s = total number of bad salinity points removed; ups = total number of up profiles; steps = total number of up profiles with well-defined step stratification; tlag = temperature lag; cshift = physical sensor separation lag; alpha = conductivity thermal mass correction amplitude correction; tau = conductivity thermal mass lag correction; prd = down pressure deviation correction; ratio-up = profile-by-profile salinity ratio adjustment for up profiles; ratio-dn = profile-by-profile salinity ratio adjustment for down profiles; filt-t = total number of filtered temperature spikes; filt-s = total number of filtered salinity spikes.

IV.A. Removal of corrupted data

The first step in any processing procedure usually involves some sort of filtering or data screening procedure. Here, a routine was developed to step through each *rawNNNN.mat* profile and plot the individual profiles of temperature and uncalibrated salinity versus pressure, and salinity versus temperature, the property gradients and limits, and the mean values at each depth for the full time series. Automated criteria were developed to flag points in temperature or salinity that exceed thresholds in variance divided by pressure. The operator analyzes the plots to determine points that appear to be corrupted beyond repair. Scan numbers for corrupt measurements are saved in the variable *bad.t* (profile number, scan number) for temperature, and in *bad.s* for conductivity (based on salinity). In subsequent processing steps, these bad points are removed before any other operations are performed. Furthermore, the first and last 90 points of each data file are removed. Operationally, ITPs sit for 2 minute periods of time at the beginning and end of each profile logging data from the same depth. Truncating the files eliminates redundant data as well as some obviously erroneous startup data values.

Commonly in the raw data sets, the number of salinity points flagged as bad exceeds the number of bad temperature points by a large amount, which seems to indicate that the conductivity sensors are more sensitive to fouling than the temperature sensors. Furthermore, while the temperature calibration is believed to be quite stable in time, measured variations of salinity in presumably stable deeper layers of the ocean indicate that the conductivity also appears to shift subtlety from profile-to-profile (which is compensated for later by the adjustment described in section IV.D).

Jitter in the pressure measurement is handled by low pass filtering the pressure data with a 15 point Hanning filter.

IV.B. Sensor corrections

Johnson *et al.* (2007) discussed the sensor response corrections that can be applied to raw data from SBE-41CP CTDS mounted on ITPs (they analyzed partial year series of ITP 1, 2 and 3 data). While, Argo floats typically telemeter data at specified pressure levels (in order to reduce transmission messages), ITPs transmit the complete 1Hz profiles with vertical spacing approximately 0.25 m between samples (at the typical profiling speed). This higher resolution discerns finestructure in the profile thermo- and halo-clines such as double-diffusive steps, and intrusions. However, where thermohaline staircases occur in the main thermocline above the Atlantic layer (between about 200 and 300 m in the Beaufort Gyre), sensor lags cause these features to exhibit rounded edges in the temperature and conductivity, and spikes in derived salinity (spuriously suggesting density inversions). Assuming that the steps are in reality sharp and coherent between temperature and salinity, sensor response corrections may be determined by minimizing the deviations in the raw profiles from the (assumed) ideal. When the sensor lags are removed from the raw profiles, data more representative of the actual conditions are produced without reducing the vertical resolution by averaging.

Following Johnson *et al.* (2007), three sensor response corrections were determined for each of the first five ITPs from the lag features in the steps: 1) the thermistor response, 2) the physical separation of the conductivity cell from the thermistor (temperature delay at the conductivity cell), and 3) the conductivity cell thermal mass correction (temperature delay due to instrument housing temperature changes). While there do seem to be median values of each of the lags that are appropriate most of the time, there are a substantial number of instances where the lags deviate from the median values, perhaps due to sensor fouling or contamination. Consequently, in the present processing scheme, the lags are allowed to vary in time. Response parameters are derived only for the upward-going profiles (odd numbered profiles) where the sensor head is pointed into the relative flow and not influenced by the wake of the instrument body (as the down profiles are). Furthermore, response parameter values are only deemed trustworthy for those profiles which contain well defined temperature-conductivity steps. Linear interpolation is used to estimate response parameters for down-going profiles and times when there are no steps in the profiles.

IV.B.1. Step detection criteria

The depth range containing thermohaline steps in profiles is manually selected for each ITP after examining the raw data. For the first 5 ITP systems analyzed, this range usually fell between 200 and 320 m. The first criterion for determining that a profile contains steps is where the variance of the vertical difference of temperature in the depth range exceeds a selected threshold (fixed at 4×10^{-5} °C^2 from observation). At times, ITP temperature sensors become fouled, resulting in highly smoothed temperature data (and abnormally-large inferred temperature lag). In these cases, a second criterion is used where the variance of the vertical difference of conductivity in the target depth interval exceeds the same threshold (4 x 10^{-5} $mmho^2$). Profiles where the estimated variances are below both thresholds are considered not to have strong staircase stratification, so cannot be used for determining lags. As noted above, interpolated values from neighboring profiles that do contain steps were used.

For the first five ITPs which were all deployed in the Beaufort Gyre, strong staircase stratifications were detected in 82% of the up-going profiles.

IV.B.2. Thermistor lag correction

The optimal thermistor response lag for the temperature data from a given profile is determined by applying a range of lag corrections to the temperature data, and selecting the correction which minimizes the deviations of the vertical temperature gradient through the layers. The thermistor response correction follows that of Fofonoff *et al.* (1974). Based on Johnson *et al.*'s (2007) results, lags ranging between 0.01 and 3 s (incremented by 0.01 s) are applied to the temperature profile, and instances where the first-differences in the staircase region are less than 0.5 mdeg C are counted. The lag which results in the greatest number of counts (less than 0.5 mdeg C) is selected for each profile. While lags are computed for every profile, only values from up profiles and where steps are present (according to the criteria described previously) are subsequently used for the correction. Lags for down profiles and where steps are not present are determined from time series linear interpolation.

The median temperature lags for the first 5 ITPs range between 0.39 and 0.57 s (Table 1), consistent with Johnson *et al.*'s (2007) results. However, while in theory the temperature lag should be a fixed physical constant dependent on the particular sensor characteristics, lags determined from the ITP data often exceed the median value by as much as several seconds (*e.g.* Figure 2), presumably due to sensor biological fouling or icing. Allowing the lag to vary in time allows reasonably-good data to be recovered during these events.

IV.B.3. Conductivity-Temperature time offset

The physical separation between the thermistor and the conductivity cell in the SeaBird CTD results in a delay between when the temperature of a given water parcel is measured by the thermistor and when its conductivity is measured by the conductivity cell.

This delay influences the salinity calculation, and can cause spikes in the data, particularly where sharp gradients due to steps are present.

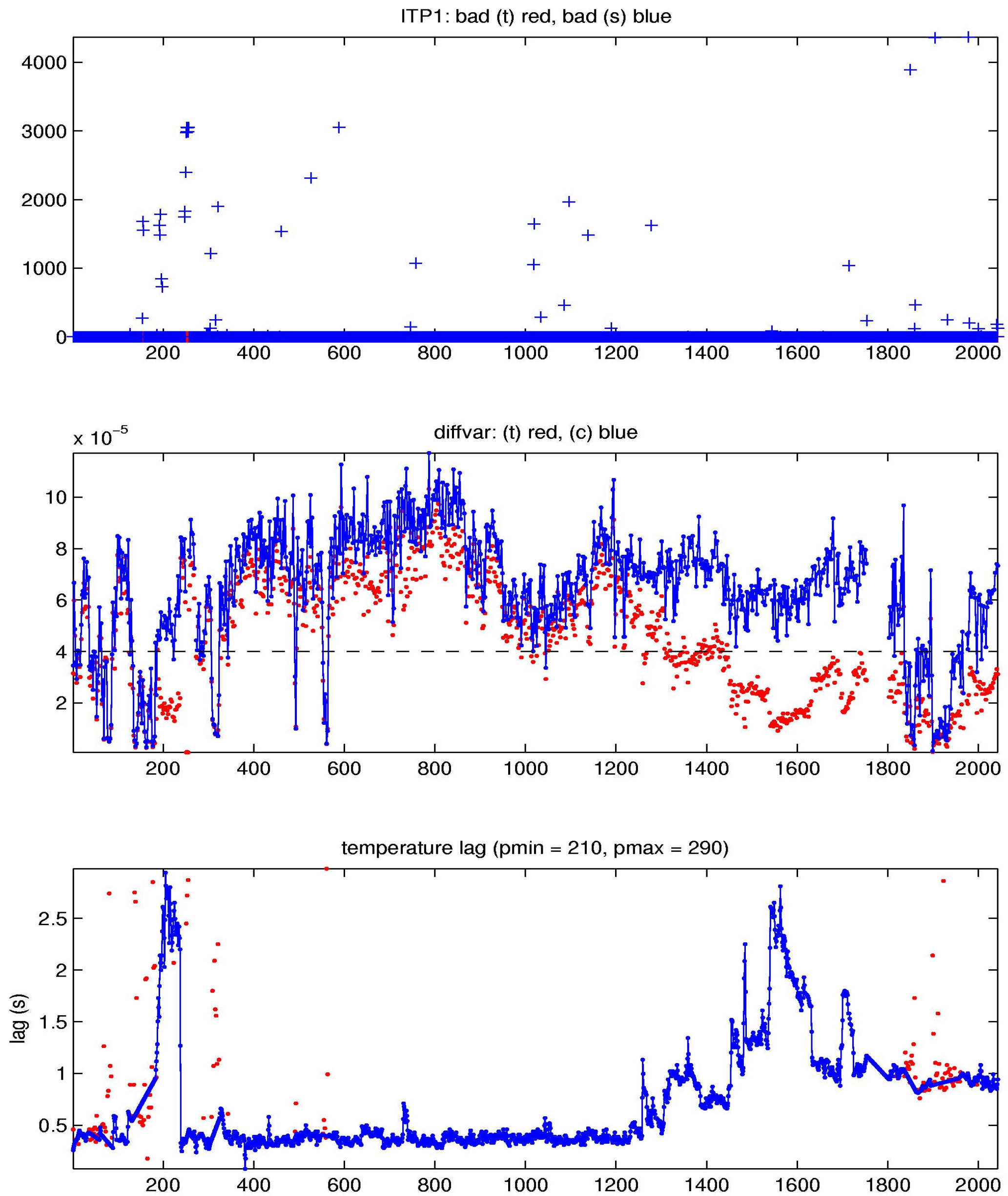

Figure 2: Top: Number of bad temperature (red) and salinity (blue) points removed versus profile number for data from ITP1. Middle: Variance of vertical difference of temperature (red) and salinity (blue) in step region for up-going profiles. Steps exist where the variance of either exceeds the dashed line threshold. Bottom: Estimated thermistor lag versus profile number for ITP1 (blue). Linear timeseries interpolation is used to derive lags for the down-going profiles and for up-going profiles where well-defined steps were not present (red). Larger lags around profile 200 and after profile 1250 are presumably due to sensor fouling or other undetermined causes.

After applying the thermistor lag correction described in section IV.B.2., the conductivity-temperature lag is determined for each profile by applying a range of lag corrections (between -0.5 and 2 s, incrementing by 0.01 s) to the conductivity profile, calculating lag-applied salinity, and selecting the lag which minimizes the variance of salinity from a straight-line fit versus temperature within the staircase stratification region. The lag-corrected conductivity time series is derived by applying a time offset to the conductivity and interpolating back to the time base of the temperature data. As for the temperature lag correction, only values determined from up-going profiles and where steps are present are subsequently used for the correction; missing values are filled by time series linear interpolation (*e.g.* Figure 3).

The median conductivity-temperature lags from the first 5 ITPs ranged between 0.05 and 0.11 s (Table 1), consistent with Johnson *et al.* (2007) results. As with the temperature lag, the conductivity-temperature lag is allowed to vary in time in order to account for changes in the response of the instrument. These events are largely synchronized with the periods of larger inferred temperature lag, but are not coincident all of the time. One possible explanation for this behavior is variation in the pumping rate through the CTD due to fouling or icing.

IV.B.4. Conductivity thermal mass correction

As first documented by Lueck and Picklo (1990) and later discussed by Morison *et al.* (1994), in a time-varying environment (such as during profiling) the thermal mass of the SBE conductivity cell alters the temperature (and thus conductivity) of the water parcel whose conductivity is being sensed. Following Johnson *et al.* (2007), the temperature of the water inside the conductivity sensor is estimated using the measured temperature time series and a two-coefficient model (amplitude adjustment - *alpha*, and time constant - *tau*). This modified temperature and measured conductivity are then used to estimate salinity. After applying the temperature lag and sensor physical separation lags, the conductivity thermal mass correction is determined by applying a range of *alpha* and *tau* corrections to the temperature profile, computing corrected salinity, and selecting the coefficient values that minimize the variance of salinity differences for each layer in the staircase region. *Alpha* is allowed to vary from 0.03 to 0.4, incrementing by 0.03, and *tau* is allowed to vary from 1 to 10 s, incrementing by 0.2 s. To be included in the assessment, individual layers must consist of at least 5 data points, and are identified where the magnitude of the first differences of the (1 Hz) temperature values are less than 1.5 x 10^{-3} °C.

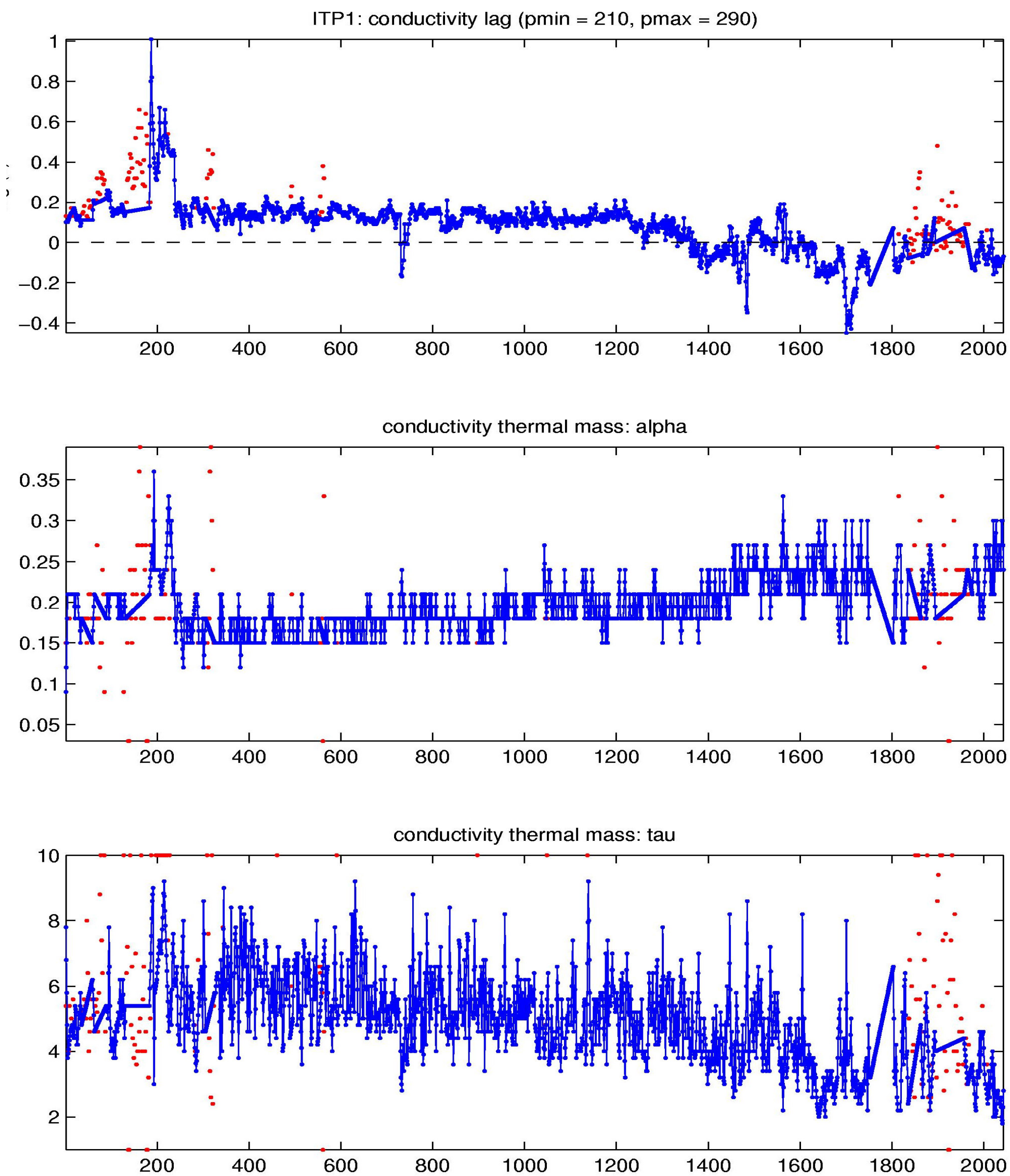

Figure 3: Top: Time series of conductivity-temperature time offset versus profile number for ITP1. Blue line indicates corrections computed from up-going profiles where steps are present and interpolation for down-going profiles and for up-going profiles where steps are not present (red points). Middle: Time series of conductivity thermal mass amplitude correction (*alpha*) versus profile number from ITP1 up-going profiles and interpolated values as above. Bottom: Time series of conductivity thermal mass lag correction (*tau*) versus profile number from ITP1 up-going profiles and interpolated values as above.

Median *alpha* values varied between 0.15 and 0.2, while median *tau* values vary between 3.8 and 6 for the first 5 ITPs (Table 1). Only values from up-going profiles and where a well defined staircase is present are subsequently used for the conductivity thermal mass correction, and profiles where values could not be determined are filled by time series linear interpolation (*e.g.* Figure 3).

IV.C. Down-going profile pressure adjustments

The SeaBird 41-CP CTD is designed to operate with the thermistor and conductivity cell intake pointed into the flow, which in the case of the ITP is when the instrument is conducting up profiles. While fluid is pumped through the cell during profiling, the CTD intake needs to be oriented into the flow in order to obtain the proper flow rate past the sensors. When the ITP is profiling down, the CTD intake can lie within the wake of the ITP instrument. Furthermore, the opposite flow direction can reduce the flow rate through the T-C sensor plumbing. These effects act to delay and distort the measurements relative to the up-going profiles which is manifested in the data as offsets in reported pressure of selected potential isotherms or isohalines between up- and down-going profiles. These offsets are not consistent however; examination of the transmitted data from ITPs indicates that during times when a system is moving rapidly with its supporting ice floe, the wake effects on the measurements are reduced (Figure 4). It is theorized that the horizontal relative flow at times of fast ice floe drift acts to advect the instrument wake downstream of the CTD intake, resulting in more consistent down- and up-going data.

It is assumed that the pressure levels of the selected potential isotherms and isohalines for the up-going profiles are correct, so a scheme was devised to correct the down-going profiles so as to obtain a consistent data set. A pressure correction algorithm was developed based on the ITP drift speed. Although one would expect that the bias would respond near-instantaneously to changes in the ice drift speed, it was determined that the deviations were better correlated after applying a 7-day low-pass filter. By inspection, the pressure deviation was related to the smoothed drift speed by:

$$\text{Pressure deviation} = 3 - \text{drift speed} / 6$$

where the units of pressure deviation are db and drift speed are cm/s, and the calculated pressure deviation is limited to be not less than zero (Figure 4). Consequently, when the ice-floe drift speed is zero, the pressure deviation correction is greatest (3 m), while no pressure deviation correction is applied when smoothed drift speeds are greater than 18 cm/s.

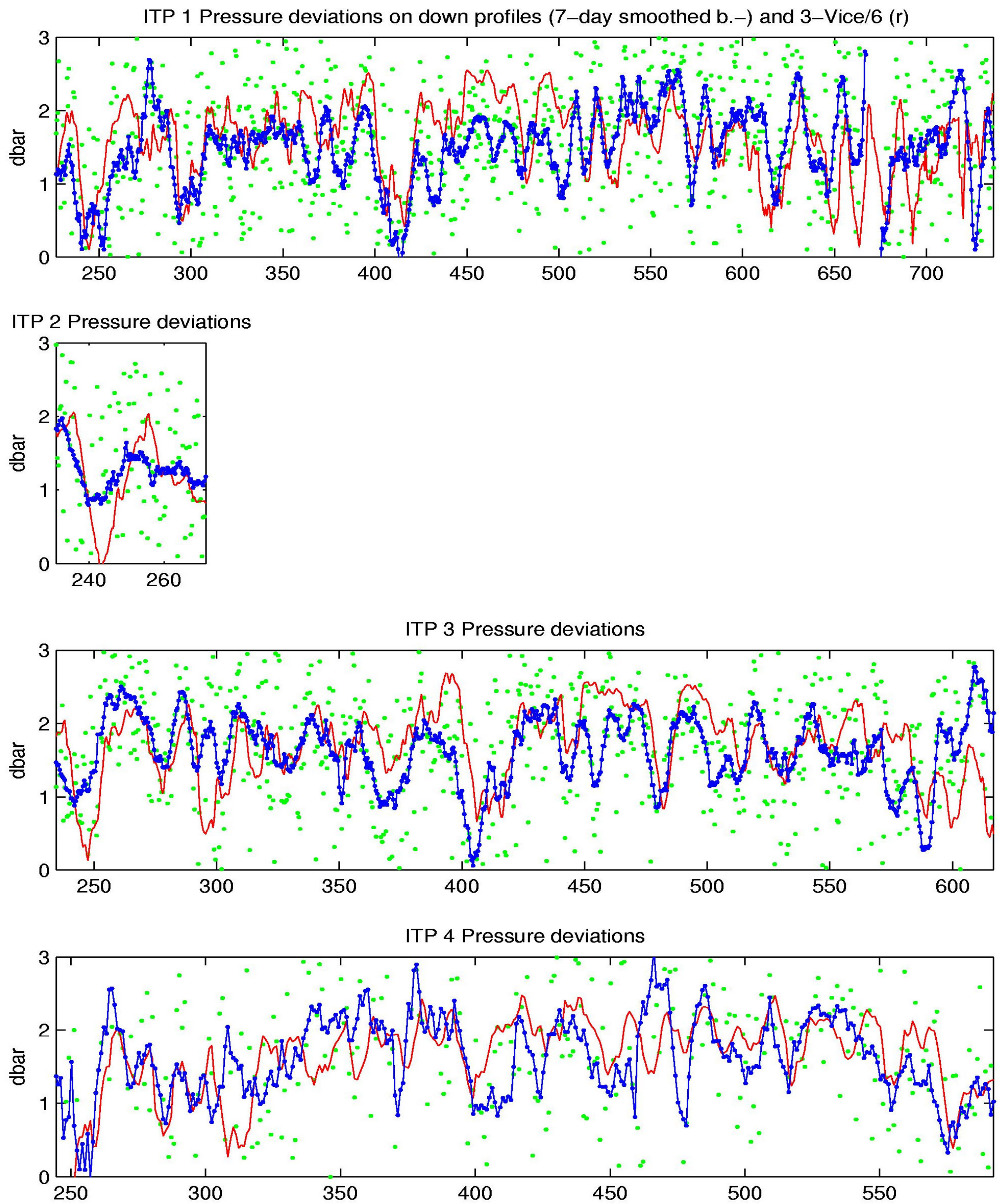

Figure 4. Observed differences between the estimated pressure of selected potential isotherms on up-going and adjacent down-going profiles (green points) versus profile number, and after smoothing with a 7-day low-pass filter (blue line). Shown with red line are modeled pressure offsets based on low-pass-filtered ice floe speed estimates. Results from ITPs 1-4 are shown (top to bottom).

Examination of the resultant potential temperature and salinity time series after applying the pressure correction confirms the validity of the adjustment. For the first 5 ITPs, the typical deviation is approximately 1.7 m (Table 1). Applying the pressure deviation correction reduces the pressure level differences between up- and down-going profiles to less than +/-1 m 95% of the time. Note that perfect agreement between successive profiles is not expected due to real internal wave and baroclinic motions inducing vertical heave.

IV.D. Profile-by-profile conductivity calibration

While the thermistor and pressure sensors on the SBE-41CP CTD are believed to be very stable over time, the conductivity sensor is subject to drift, and as indicated earlier, is more susceptible to fouling than is the temperature sensor. Consequently, a calibration procedure is used to correct for small variations of the conductivity measurement for each individual profile, based on the assumptions that: 1) the temperature and pressure measurements are stable, and 2) that at certain (deeper) potential isotherms, the real salinity changes in time are negligible over the course of an ITP deployment.

Repeated icebreaker CTD surveys in the BG region have been conducted each summer since 2003 as part of the collaboration between the Beaufort Gyre Observing System and the Joint Western Arctic Climate Study programs. To provide a reference for the ITP calibrations, all of the (bottle-calibrated) CTD station data obtained from 2003 to 2006 were used to estimate potential conductivity at selected isotherms in the BG region, where potential conductivity is derived from estimated salinity, potential temperature and zero pressure). Like salinity and potential temperature, potential conductivity is invariant to adiabatic vertical heave.

Potential conductivity planes were constructed from the CTD stations at potential temperature surfaces 0.4 and 0.5 °C (>500 db), as these are deeper than the core of the Atlantic layer and within the maximum depth range of the ITP profilers (<760 m). Two surfaces were selected since no single potential temperature surface was either intersected or appeared to be completely stable for every ITP profile over the course of all of the deployments. A contour map of the potential conductivity on the 0.4 °C potential temperature surface from all 196 available CTD stations (Figure 5) shows that a plane fit to the data is reasonable. Deviations from the plane fits are typically less than 0.005 mmho at the 0.4 °C isotherm in the middle of the basin with an overall standard deviation of less than

0.003 mmho (Figure 6). Somewhat larger deviations are found near the basin margins. Similar behavior is found at the 0.5 °C surface but with approximately two times larger deviations. Objective mapping is being considered to better deal with spatial structure in the reference fields.

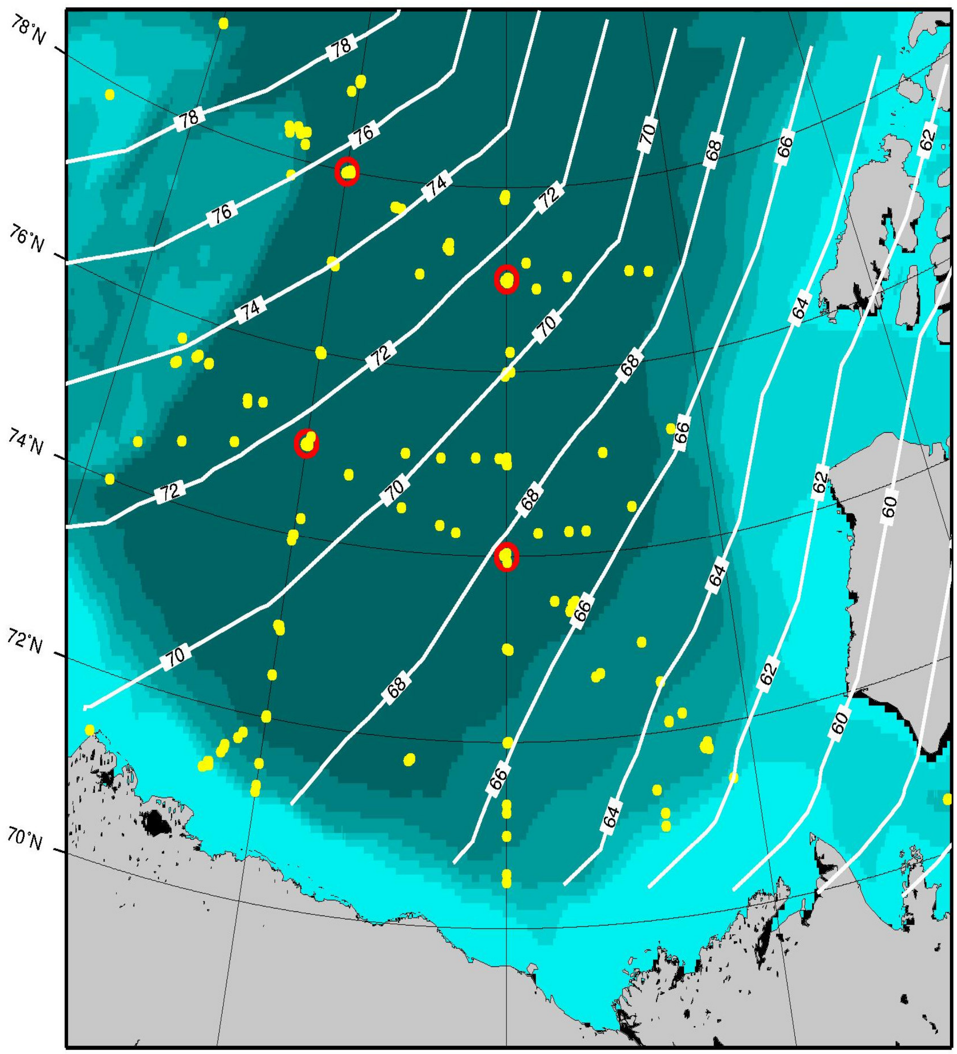

Figure 5. Potential conductivity estimated at the 0.4 °C potential temperature surface from all 196 CTD icebreaker stations collected between 2003 and 2006 (contours = 1000 * ([potential_conductivity_at_0.4] - 29.2 mmho)).

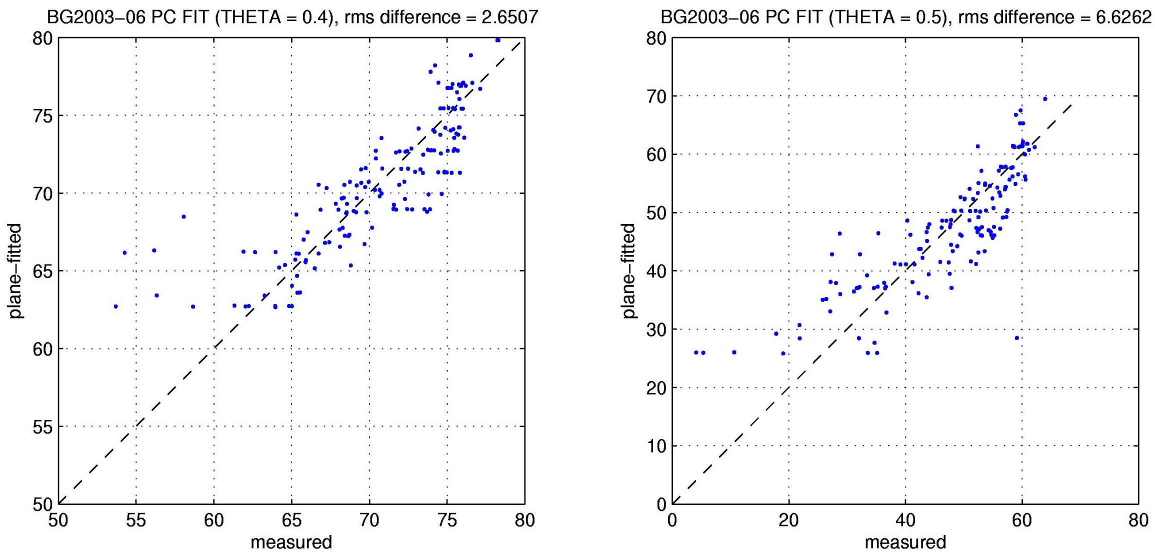

Figure 6. Scatter plot of observed potential conductivity from the icebreaker stations versus the plane fits to the data for the 0.4 °C (left) and 0.5 °C (right) potential isotherm surfaces. Shown are values in mmho x 1000.

For each ITP profile, a multiplicative scaling factor is determined so that the ITP potential conductivity matches the plane fit values at the ITP profile location. The final scaling that is applied to the conductivity profile consists of the average of two parts scaling from the 0.4 °C surface and one part scaling from the 0.5 °C surface, thus giving the deeper scaling estimate more weight. Short profiles that do not reach the 0.4 and 0.5 °C isotherms are more crudely adjusted by scaling the upper ocean conductivity to match the previous station upper ocean conductivity. Missing values are filled by linear interpolation, where missing up-going scaling factors are interpolated from adjacent up-going ratios, and missing down-going factors are interpolated from adjacent down-going estimates. Some manual adjustment of these scaling factors to achieve better consistency between successive profiles was also conducted. Figure 7 gives an example of the final scale factors for ITP1.

IV.E. Final filtering

Despite the care to pre-filter and align the temperature and conductivity lags, a few data spikes still remain after all the corrections and adjustments have been applied. Consequently, the final processing procedure consists of removing clear outliers in the data.

An automated routine detects and removes points where the vertical gradient of temperature or salinity at one point exceeds a threshold in one sense, and then immediately falls below the threshold in the negative sense at the next point (or vice versa). In order to account for the different data types and reduced variability of each with depth, threshold values for

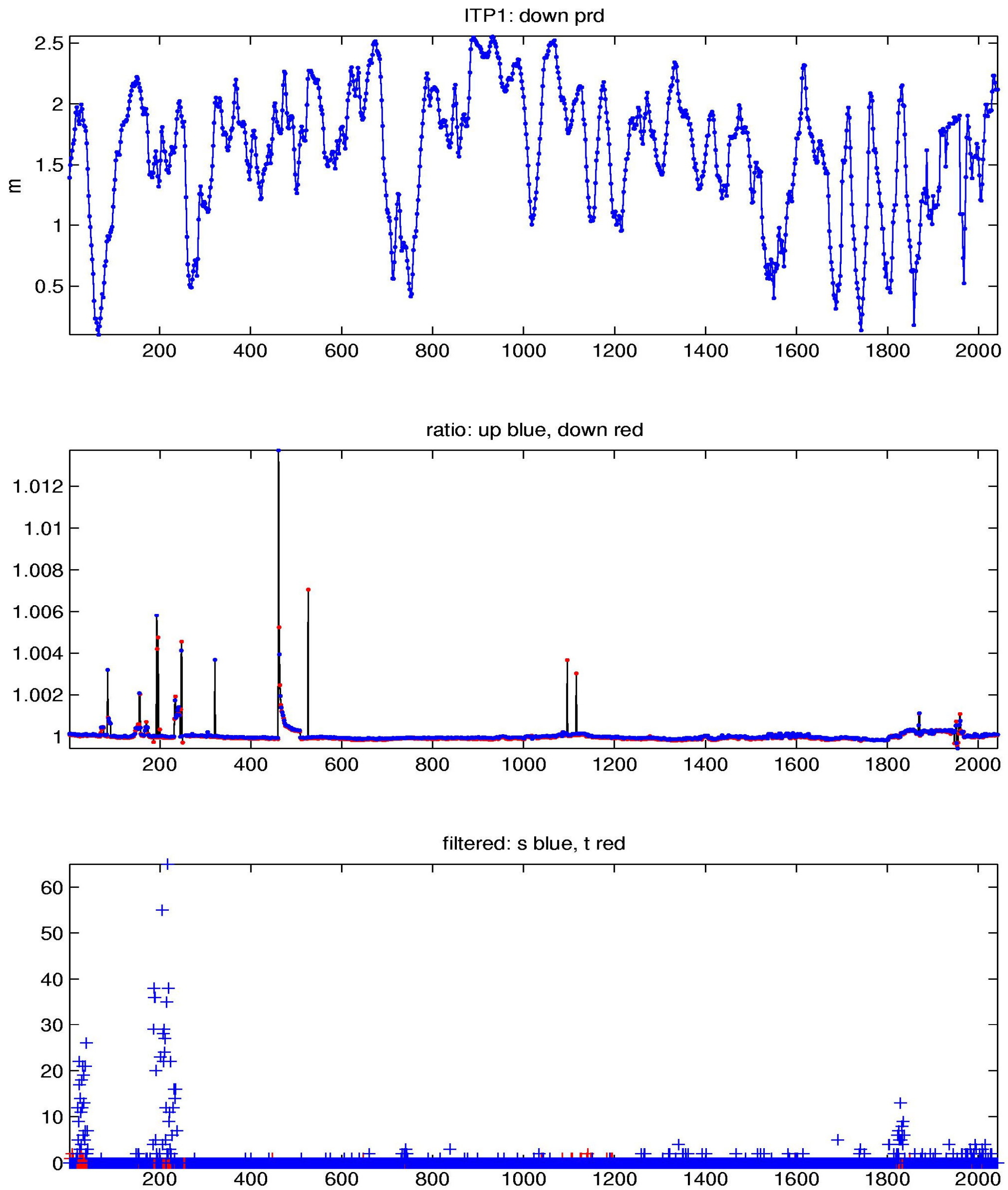

Figure 7. Top: Down-going pressure deviation correction (in db) for ITP 1 versus profile number estimated from ice-floe drift speed. Middle: Conductivity calibration factor for each ITP profile based on 2003-2006 summer icebreaker CTD stations. Bottom: Number of ITP 1 data spikes removed per profile based on final filtering routine. Blue indicates salinity points, red are temperature points.

temperature outliers are given by $T\_err = 3$ / pressure (where pressure is in db), and for salinity by $S\_err = 1.5$ / pressure. In most cases, less than 5 points (1-Hz sample rate) were removed from a typical profile (that typically totals over 3000 points) in this final filtering step (Table 1).

IV.F. Output data format

The output data after all the filtering, corrections, adjustments, and calibrations are applied are classified as Level 3 data on the ITP website. Three sets of data are provided for each ITP and are available at: ftp://ftp.whoi.edu/whoinet/itpdata.

The first set of (MATLAB-format) files for each ITP hold the data that have had all of the filtering, adjustments, and calibrations applied. For each *rawNNNN.mat* file (where *NNNN* indicates profile number) there is a corresponding *corNNNN.mat* file. All of the *corNNNN.mat* profiles for a particular ITP are grouped in files *itpXcormat.zip* and *itpXcormat.tar.Z* (where *X* stands for ITP number). The data in these files are reported at the same 1 Hz resolution as the Level 1 files, with NaNs filling gaps where bad data was removed. The variables included in the *corNNNN.mat* files are:

co_adj	conductivity (mmho) after lags and calibration adjustment
co_cor	conductivity (mmho) after lags applied
itpno	ITP number
latitude	start latitude (N+) of profile
longitude	start longitude (E+) of profile
pedate	profile UTC end date (mm/dd/yy)
pr_filt	low pass filtered pressure (dbar)
psdate	profile UTC start date (mm/dd/yy)
pstart	profile UTC start time (hh:mm:ss)
pstop	profile UTC stop time (hh:mm:ss)
sa_adj	salinity after lags and calibration adjustment
sa_cor	salinity after lags applied
te_adj	temperature (C) in conductivity cell after lags
te_cor	temperature (C) at thermistor after lags applied

The best-estimated pressure, temperature and salinity in these files are contained in variables *pr_filt*, *te_cor* and *sa_adj*. Note that *sa_adj* is derived from *pr_filt*, *te_adj* and *co_adj* (*i.e.*, salinity is derived with the best estimate of the temperature and conductivity of the water in the cell).

The second set of Level 3 files for each ITP hold ASCII-format 1-db bin-averaged data for each profile named *itpXgrdNNNN.dat*, where *X* is the ITP number and *NNNN* is the profile number. All of the ASCII files for each ITP are grouped in *itpXfinal.zip* and *itpXfinal.tar.Z* files. Following is a sample from *itp1grd0001.dat*:

```
%ITP 1, profile 1: year day longitude(E+) latitude(N+) ndepths
2005  228.25001  -150.1313  78.8267  751
%pressure(dbar) temperature(C) salinity nobs
  9.7   -1.4637   28.9558  34
 11.0   -1.4608   28.9696   4
...
758.0    0.2420   34.8679   5
759.1    0.2405   34.8681   6
760.1    0.2406   34.8679  26
%endofdat
```

The first line is a header line which includes the ITP and profile numbers and describes the variables included on the second line. The third line describes the profile variables which follow.

The reported pressure, temperature, and salinity values are derived from the averages of the *corNNNN.mat* values that lie within +/-0.5 db about the bin center; *nobs* is the number of individual points in each average. Bins that have both temperature and salinity data reported represent averages of only the points where both variables are not NaNs. In cases where the ITP may have reversed and profiled several times over the same depth range (usually due to encountering an obstruction on the wire), only the first traverse of the depth range is included in the reported average for that bin. Pressure, temperature and conductivity values are averaged before salinity is derived.

The third dataset is a single MATLAB format file for each ITP named *itpXfinal.mat* (where *X* is ITP number) with the 1-db bin-averaged data for each engineering and CTD variable in a single array (capital letters), and vector series of the other profile information and processing parameters. Specifically, the variables in the final MATLAB-format files are:

E	1-m averaged engineering pressure (dbar)
I	1-m averaged engineering motor current (mA)
J	1-m averaged profile year day
N	number of CTD points in 1-m average
P	1-m averaged pressure (dbar)
S	1-m averaged salinity
T	1-m averaged temperature (°C)
V	1-m averaged engineering voltage (V)
Y	1-m averaged profile year
alph	conductivity thermal mass amplitude correction series
bad.s	profile and index numbers of removed raw salinity points
bad.t	profile and index numbers of removed raw temperature points
cshift	sensor physical separation lag correction series
date	profile start date and time [year month day hour minute second]
di	1-m bin centers
filts	number of filtered temperature (column 1) and salinity (column 2) points per profile
idn	index of down profiles
iup	index of up profiles
jday	start year day of profile
lag	temperature lag correction series (s)
lat	start latitude (N+) of profiles
lon	start longitude (E+) of profiles
n	total number of profiles
prd	down pressure deviations correction series (m)
rat	ratio for conductivity calibration series
stas	index of all profiles
tao	conductivity thermal mass lag correction series (s)

V. Concluding remarks

The first 5 ITPs that were deployed obtained a total of 5612 CTD profiles in all seasons for 1947 buoy-days, while traversing more than 14,200 km with the pack ice in the Arctic Beaufort Gyre (Krishfield *et al.*, 2008). The automated data processing made these invaluable (Level 1 and 2) data available for operational needs (and other interested users) in near-real time at the ITP website. The Level 3 processing described in this report, refine the data to the highest possible scientific standards so that they may be used in detailed high resolution process and climate studies, and for calibrating satellite and model generated data sets.

For instance, these ITP data show interesting spatial variations in the major water masses of the Canada Basin, including the low-salinity surface mixed layer, the multiple temperature extrema between 40 and 180 m depth forming the Pacific Halocline Waters, and the temperature maximum around 350 m depth characterizing the Atlantic Water (Krishfield *et al.*, 2008). They have also provided a detailed view of the spatial distribution of fronts, seasonal changes in the mixed-layer, and warm and cold core eddies. Twenty-one anticyclonic cold core eddies centered between 42 and 69 m depth were identified from ITP 1, 2, and 3 data in the Canada Basin and shown to be consistent with formation by instability of a surface front at about 80°N (Timmermans *et al.*, 2008a). Furthermore, a rare observation of a deeper and much thicker Atlantic Layer eddy was made by ITP 1 in 2005 (Toole *et al.*, 2006). Finally, the recovered 1 Hz CTD data resolve fairly well the thermohaline staircase stratification above the Atlantic Layer thought to be caused by double diffusion (Timmermans *et al.*, 2008b) and the "nested" intrusive structures that incise the Atlantic Layer.

Together with European investigators involved in the DAMOCLES (Developing Arctic Modeling and Observing Capabilities for Long-term Environment Studies) program, 13 more ITPs were deployed before 2008, and more will be deployed in 2009. As with previous ITPs, the information acquired from these new systems will be shared publicly in real time at the ITP website and contribute to the Arctic Observing Network (http://www.eol.ucar.edu/projects/aon-cadis/).

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