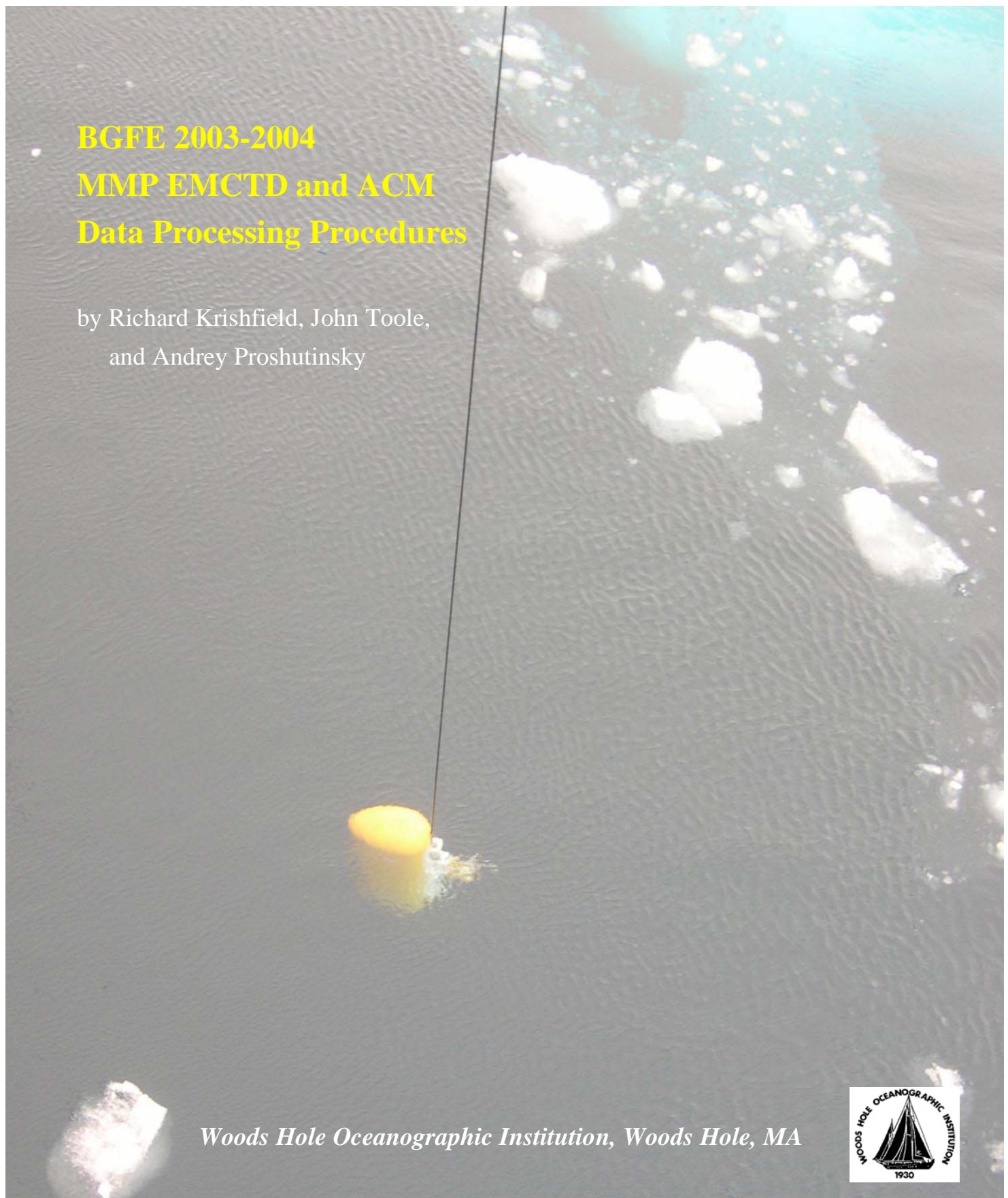


**BGFE 2003-2004**  
**MMP EMCTD and ACM**  
**Data Processing Procedures**

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## BGFE 2003-2004 MMP EMCTD and ACM Data Processing Procedures

By R. Krishfield, J. Toole, and A. Proshutinsky

Three bottom-tethered moorings were deployed in the Beaufort Sea from the *Canadian Coast Guard Icebreaker Louis S. St. Laurent* (LSL) in August 2003 as part of the Beaufort Gyre Freshwater Experiment (BGFE). The moorings were designated A, B, and C, and were configured with the same scientific instrumentation, including a McLane Moored Profiler (MMP; Morrison et al., 2000) profiling instrument with Falmouth Scientific, Incorporated conductivity, temperature and depth recorder (EMCTD) and 2-D acoustic current meter (ACM). Each MMP was installed on its mooring below a subsurface flotation sphere on a 2000 m segment of 5/16" wire rope and configured to profile one way between 50 and 2000 m at alternate intervals of 6 and 48 hours for up to 400 days. Further details on the MMP instrument is available in the MMP Operator's Manual (McLane Research Laboratories, 2002) and the configuration during the BGFE 2003 experiment in WHOI Technical Report 2004-01 (Ostrom et al., 2004).

In August 2004, the moorings and instruments were recovered from the LSL, refurbished and redeployed for another year (Kemp et al., 2005). Here the details of the procedure for downloading, processing, and archiving the BGFE MMP data acquired in 2003-2004 are described by 8 operations:

- 1) Retrieving MMP binary data files.
- 2) Unpacking binary data to ASCII.
- 3) Converting ASCII data to raw Matlab format files.
- 4) Determining ACM heading angle and adjusting velocity biases.
- 5) Pre-filtering, applying EMCTD and ACM corrections, and gridding.
- 6) Removing spurious temperatures and salinities and adjusting to fixed reference layer.
- 7) Interpolating to pressure grid and correcting velocities for sound speed.
- 8) Archiving data in several formats.

Table 1 lists specifics about the hardware and placement of each BGFE MMP during 2003-2004, and provides information on some of the parameters used or statistics determined during the data processing.

Table 1: BGFE MMP Processing 2003-2004

Mooring designation	A	B	C
MMP number	114	113	112
EMCTD number	1353	1316	1352
ACM number	1617	1654	1653
2003 deployment	14-Aug-2003 12:20 UTC	23-Aug-2003 22:05 UTC	26-Aug-2003 19:03 UTC
Location	75° 00.39'N 149° 58.752'W	78° 01.491'N 149° 49.378'W	76° 59.254'N 139° 54.229'W
2004 recovery	10-Aug-2004 14:34 UTC	15-Aug-2004 13:23 UTC	20-Aug-2004 18:57 UTC

<i>MMP data</i>	<b>A</b>	<b>B</b>	<b>C</b>
Scheduled profiles	314	319	322
Processed profiles	180	319	318
First good profile	16-Aug-2003 18:00 UTC	25-Aug-2003 18:00 UTC	28-Aug-2003 06:00 UTC
Last good profile	31-Jul-2004 18:00 UTC	16-Aug-2004 06:00 UTC	21-Aug-2004 00:00 UTC
Pressure grid (first:step:last)	91:2:2005	55:2:2005	81:2:2005
<i>Pre-filter</i>			
Pressure edit bounds	91, 2005	55, 2007	81, 2005
Temperature edit bounds	-2, 1.71	-2, 1.71	-2, 1
Conductivity edit bounds	25, 30.7	25, 30.65	25, 30
Velocity edit bounds	-50, 50	-50, 50	-50, 50
Compass edit bounds	-1.1, 1.1	-1.1, 1.1	-1.1, 1.1
<i>EMCTD calibration</i>			
Pressure coefficients	1.0005, -1.0005	1.0005, 0	1, -0.8
Temperature coefficients	1.001, 0.0015	1, -0.035	1, -0.0015
Conductivity coefficients	1, 0	1, 0	1, 0
Temperature lag	1	1	1
<i>ACM calibration</i>			
Hx_bias	0.0492	-0.01	-0.000598
Hx_range	0.1352	0.1	0.1037
Hy_bias	0.1189	0.0677	0.0495
Hy_range	0.132	0.1	0.1007
Vab_bias*	0	0	0
Vcd_bias*	0	0	0
Vef_bias*	0	0	0
Vgh_bias*	0	0	0
Compass bias	-0.4038	-0.4429	-0.3188
Direction sign	1	1	1
Velocity scale	1	1	1
Magnetic declination	-28.25	-30.75	-36.3
<i>Manually removed</i>			
Temperature points	0	1	0
Salinity points	3	35	5
<i>O-S adjustment</i>			
Raw S range @ $\Theta = -0.5$	0.0095	0.0370	0.0117
Raw S std @ $\Theta = -0.5$	0.0021	0.0069	0.0023
Adjusted S range @ $\Theta = -0.5$	0.0038	0.0121	0.0047
Adjusted S std @ $\Theta = -0.5$	0.0006	0.0021	0.0008

\*V biases are adjusted for each pressure average prior to adding calibrations.

## **1. Retrieving MMP binary data files**

After recovering each MMP instrument, the engineering, EMCTD and ACM binary data files must be extracted from the MMP controller's 512 Mb PC flashcard. The raw MMP data are primarily stored in 3 binary file types: engineering data files (**E#####.DAT**), EMCTD data files (**C#####.DAT**), and ACM data files (**A#####.DAT**). The number of profiles stored in each **E#####.DAT**, **C#####.DAT**, and **A#####.DAT** file set depends on the number of profiles per file set specified in the deployment configuration. This parameter was set to 10 during the BGFE 2003 MMP deployments, so the data from 10 successive profiles are recorded in each file, and the file number (#####) is incremented in units of 10 (padding with leading 0s). Also stored on the flashcard is the MMP operating program (version **MMP-3\_00.RUN** for BGFE), a file called **DEPLOY.DAT** that includes the deployment specific configuration parameters, a file called **PROFILES.DAT** which keeps track of the number of completed profiles, and a file called **IRQ\_XCPT.LOG** which records the execution of the watchdog timer functions.

The MMP operating software includes a provision to download the data files in ASCII format over a serial link to the MMP controller, but a typical deployment stores so much data (over 100 Mb) that this method would take a prohibitively long time. Consequently, the preferred method to retrieve the data files is to remove the flashcard from the MMP, install it into a PCMCIA port on a laptop, and copy all the files to the computer's hard disk.

Before removing the flashcard from an operating MMP, the operation program must be halted. A communication cable is connected between the MMP and a terminal (laptop computer running a terminal emulation program); sending several CTRL-C characters breaks the operation routine and calls the MMP main menu. At this time, the time clock of the MMP may be checked for drift. For the BGFE 2003-2004 moorings, the MMP clock on mooring A lost 10 minutes between the times of deployment and recovery, MMP B lost 20 minutes, and MMP C lost 25 minutes. It should be noted that no corrections on the recorded profiling times were made to correct for clock drifts.

In addition to the clock check, the operation log files were dumped from the BGFE MMPs and A/D and motor functions were checked from the bench test menu. Then the battery was disconnected from the MMP controller, removing all power from the instrument so that the flashcard could be safely removed. (Alternately there is an MMP menu item that allows the card to be removed from the MMP controller without disconnecting the battery).

A laptop computer running Windows XP was used to acquire the data from the flashcard. Once inserted into the laptop's PCMCIA port, the Windows operating system detects it as a removable hard disk, and the objects (files) may be dragged (copied) into a folder on the laptop's hard disk (or onto a writeable CD or USB memory key, if desired). There is no distinction between the data file names from different MMPs, so each MMP data retrieval requires a separate directory. All of the files from each BGFE MMP flashcard were copied two times into separate directories on the laptop's hard disk to provide backups in case a file somehow became corrupted. When the copy procedure is complete, the Windows "safely remove hardware" function is used to turn off the PCMCIA port for safe removal of the flashcard from the laptop.

## **2. Unpacking binary data to ASCII**

With every MMP, McLane Research Laboratories provides a data Unpacker program for Windows that converts binary data files to ASCII. For the BGFE data collected under version 3.00 of the MMP operating software, Unpacker version 2.0.1 (program **PDP-3\_00.exe**) was used. The Unpacker program was run once for each retrieved MMP dataset. From the options menu (main menu command O), the data input and output directories were specified, the format of the data was set for MACHINE READABLE (for subsequent processing operations), and screen display of data was set to NONE (to speed the operation of the program). Then the data were offloaded from all data files (main menu command 1). This version of the Unpacker program also provides a function to convert the **IRQ\_XCPT.LOG** to ASCII readable format.

Regardless of the number of profiles per files set, the Unpacker program produces separate **E#####.TXT**, **C#####.TXT**, and **A#####.TXT** files for each profile. Each **E#####.TXT** file consists of 10 columns of data containing: month, year, day, hour, min, second, motor current (mA), battery voltage (V), pressure (dbar), and profile speed (dP/dt). While the MMP motor current is ramping up, pressure is not obtained by the MMP controller, so values of 0 are recorded at the beginning of each profile, and when the MMP reverses directions. (When faced with an obstruction on the wire, the MMP reverses and retries profiling up to 5 times before shutting down if unsuccessful. It turned out that the top bumpers of BGFE moorings A and C were deeper than the minimum pressure specified for the profiling interval by a distance that fell outside the specified depth error window of the operations program, so those MMPs impacted the top physical stops on each up-going profile and attempted 5 times to ram through the stop before ending each profile. (This behavior may have contributed to some of the profiling difficulty experienced by the MMP on mooring A, see below.) Each **C#####.TXT** file consists of 3 columns of data containing: conductivity (mmho), temperature (deg C), and pressure (dbar). Each **A#####.TXT** file consists of 9 columns of data containing: tilt x (deg), tilt y (deg), normalized compass horizontal x, horizontal y, vertical z, and raw path velocities ab (cm/s), cd (cm/s), ef (cm/s), and gh (cm/s).

In addition, the Unpacker program also produces two other ASCII files: **SNSRTIME.TXT** and **TIMETAGS.TXT**. **SNSRTIME.TXT** lists the times that the EMCTD was turned on and off for every profile. **TIMETAGS.TXT** consists of 26 columns of data including: profile number, EMCTD start and stop date and time, motor start and stop date and time, and two performance flags. These two timing files are not used in subsequent processing operations.

## **3. Converting ASCII data to raw Matlab format files**

The next several processing procedures utilized “McLane Moored Profiler Data Reduction and Processing Procedures” developed by John Toole (WHOI) that operate in the Matlab technical computing environment (under either Windows or Unix operating systems). First, the three raw ASCII data files are merged and stored in a single Matlab format (.mat) file per profile, using the routine **MMP\_asc2mat.m**. Input to this routine are the directory of the source ASCII data files, directory to the output combined Matlab format files, and ranges of profiles to process (profile 0, when the MMP first climbs down the wire after deployment, is an incomplete profile and was not specified when processing the BGFE MMP data). The output data files are named **raw####.mat**, and each file contains the following variables:

**psdate**: profile start date  
**pedate**: profile end date  
**pstart**: profile start time  
**pstop**: profile end time  
**esnum**: index of the engineering scans  
**epres**: engineering pressure in decibars  
**ecurr**: motor current in milli-Amps  
**evolt**: battery Voltage  
**edpdt**: profile speed dbars/s from the engineering data  
**engtime**: time of each engineering scan coded with Matlab function datenum.m  
**csnum**: index of the EMCTD scans  
**ccond**: conductivity in nominal mmho  
**ctemp**: temperature in nominal degrees C  
**cpres**: pressure in decibars  
**asnum**: index of the ACM scans  
**Vab**: raw path velocities in nominal cm/s  
**Vcd**: raw path velocities in nominal cm/s  
**Vef**: raw path velocities in nominal cm/s  
**Vgh**: raw path velocities in nominal cm/s  
**aTx**: tilt in fore-aft and athwartships degrees  
**aTy**: tilt in fore-aft and athwartships degrees  
**aHx**: horizontal (x) normalized compass readings  
**aHy**: horizontal (y) normalized compass readings  
**aHz**: vertical normalized compass readings

Using the combined raw Matlab format files, the function **MMP\_raw\_summary.m** quantifies and stores summary data from an entire deployment, including minimum and maximum pressure sampled on each profile and the profile-averaged speed, motor current and battery voltage. These data from the 3 BGFE MMP moorings are presented in multiple panels in Figures 1-3.

In the top left panels, the vertical ranges of each profile are indicated. After the 151<sup>st</sup> profile, the MMP on mooring A only profiled the full range intermittently, while the MMP on mooring B profiled the full range every profile, and the MMP on mooring C missed only a few. Out of all scheduled profiles, only profiles that covered a vertical distance of 600 m or more were processed (Table 1).

As indicated in the top right panels, the measured battery voltages were always above the minimum operating voltage of 7.5 V for every instrument. (The MMP controller shuts down operations once the battery voltage falls below this value to guard against fully draining the lithium battery pack.)

Differences in the up-going and down-going average currents (in the bottom right panels) indicate that all 3 MMP motors drew more current on down profiles than on up profiles. Since the instruments were redeployed at the same locations for another year, the ballast of the instruments was increased to compensate for the motor current differences, which should increase the efficiency of power consumption and extend the lifetime of the battery pack.

#### **4. Determining ACM heading angle and adjusting velocity biases**

The MMP ACMs acquire 2-axis tilt, 3-axis compass, and 4-axis velocity measurements every scan. Several steps are required to transform the raw measurements from each MMP ACM into accurate Earth-referenced velocity measurements. First, the heading angle of the ACM sting and bias corrections to the raw path velocity data must be precisely determined. These calibration numbers are needed to accurately map the velocities to the local Cartesian earth coordinates.

The theory of calibrating the ACM compass is described thoroughly in the MMP Operation Manual. To determine the physical orientation of the compass coordinate system within the MMP body coordinate system (x-axis oriented along the ACM sting, z-axis positive up, y-axis to establish a right hand coordinate system), spin tests on each MMP were conducted at WHOI prior to deployment (Figure 4-6). The compass orientation is dictated by the position of the ACM pressure case. There is no exact way to repeatably fix the position the ACM pressure case in the MMP body, and since ACM's are often removed from the MMP frame for refurbishment between deployments, spin tests to determine bias angles are typically performed before each deployment.

The spin test records compass headings referenced to independent accurate magnetic compass headings, and the mean offsets are determined. During spin testing, each MMP was loaded with the battery pack that would be used for deployment (since the different magnetic field of different packs can influence the compass readings), a laptop computer was connected to the MMP and configured to capture the displayed information from the MMP, and the “ACM tilt and compass” bench test was run. Meanwhile the MMP was positioned vertically in a area free of magnetic deviations, and the current meter sting aligned exactly to magnetic north determined by the independent reference, then rotated clockwise for a full circle, pausing exactly at every 45 degree increment (also based on the independent reference). The captured text file is edited to keep only the 5 columns of ACM tilt and compass data and renamed. The renamed file is entered into the routine **spin\_analysis.m**, bounds are input by the user to delineate the scans for each of the nine 45 degree increments on the compass circle (north is included twice, at the beginning and end), and the compass bias angle is determined at each increment. Although there does tend to be a sinusoidal pattern in the differences between the MMP and reference heading estimates, only the mean deviation is used in subsequent processing steps. These mean bias angles from the spin tests for the BGFE MMP ACMs for the 2003-2004 deployment are listed in Table 1.

Field data are used to estimate the horizontal compass channel bias and range coefficients by mapping the horizontal compass components to the unit circle. Since mooring tilt is ordinarily negligible during the deployment, the vertical compass component is neglected in the calibration. A single set of horizontal coefficients is calculated, based on the assumption that the parameters do not vary with depth, or over the time of the deployment. Instead of field data, pre-deployment spin test data could also be used, but are more likely to be influenced by local magnetic fields from ships, buildings or other structures. For the BGFE 2003-2004 data, profiles were selected where the (MMP) ACM experienced at least 360 degrees of rotation, and the bias and slope adjustments were worked out manually so that the horizontal components described a full circle about the origin (Table 1). Alternately, McLane Research provides a fitting routine (**p\_corr.m**) to determine the adjustment coefficients using a least squares algorithm.

Ideally, offsets in the ACM velocity measurements would also be independent of depth, but in fact are not. It has recently been determined that the capacitance in the leads between the

acoustic transducers and the ACM electronics might vary with pressure and temperature leading to bias variations in the recorded raw path velocities. If the ocean's temperature profile is relatively stable in time through a deployment, it really doesn't matter if the bias profile is defined in terms of pressure or temperature. If the errors are due to temperature of the electronics, there might be an issue with the finite time it takes for a transient temperature signal to get from the outside water to inside the pressure case. Therefore, it is important to separately analyze the up- and down-going profiles (grouping profiles with similar time history of temperature in the pressure case). Up and down groupings are also important for analyzing the vertical angled paths because of wake effects off the transducer sting.

The procedure implemented for quantifying and applying horizontal bias corrections to the ACM velocity data, assumes that the errors are steady in time but are a function of pressure. Consequently, different velocity corrections need to be computed and applied over the vertical extent of the profile (unlike the compass corrections which are deemed to be constant over the vertical extent of the profile). The basic idea is that the minimum speed sampled by each of the horizontal paths (AB or EF) at each depth during a given deployment is a measure of the bias in that path. The scheme to estimate the bias profile for the vertically-angled paths (CD and GH) assumes that the ensemble-mean vertical velocity of the ocean is zero. Biases are derived based on the derived relative vertical velocity and  $dP/dt$  to make this so. One shortcoming of this empirical correction scheme is that it may result in an underestimation of the ocean currents if there were no times during the deployment when the MMP sampled true zero flow at each depth. (A non-zero current would be interpreted as the bias.) A second issue is scale adjustment. Recent joint analysis of velocity data acquired with MMPs and from conventional, fixed-depth current meters on the same moorings finds that the raw current speeds reported by FSI ACMs can read low by a factor of 1.25 or more. Lacking reference current meter data, no adjustment was made to the 2003-4 BGFE MMP data.

The routines for correcting the horizontal velocity biases operate on the raw Matlab format files as well as companion gridded files processed with initial estimates of the ACM calibration coefficients using **MMP\_pgrid.m**. The first routine creates a file per profile of pressure-binned raw path velocity data. The second reads in a specified set of these files, and works out separate bias profiles for upgoing and downgoing casts. The absolute minimum speed at each depth is not taken as the bias as there is always some noise in the data. Rather, some low percentile of the data in each pressure bin is used. These derived path bias profiles are then manually edited to remove spikes at the ends and apply a low-pass filter. Finally, a new set of raw Matlab format files are created in which the bias adjustments are applied to the raw velocity data.

## *5. Pre-filtering, applying EMCTD and ACM corrections, and gridding*

The raw files with velocity bias adjustments are then ready for processing into pressure-binned files using **MMP\_pgrid.m**. The input processing parameters may be defined in a Matlab script file before running the program, or entered manually. Specifically, the gridding program expects general information on the MMP and deployment (MMP number, EMCTD and ACM serial numbers, experiment name, and mooring position), profile processing information (input and output file directories, profile numbers to process, and minimum number of scans), pre-filtering limits (minimum and maximum pressure, temperature, salinity, and velocity bounds), calibration information (EMCTD and ACM calibration filenames, and geomagnetic declination),

and gridding information (minimum and maximum pressure extents, and increment). The parameters used for processing the BGFE 2003-3004 MMP data are given in Table 1.

**MMP\_pgrid.m** sequentially operates on each **raw####.mat** profile indicated by specified profile numbers to process in the specified input directory. First, raw ACM current velocities with speeds very close to zero are flagged (to remove some occasional spikes). Then each raw sensor data series (**cpres**, **ctemp**, **ccond**, **aHx**, **aHy**, **Vab**, **Vcd**, **Vef**, and **Vgh**) are pre-filtered by interpolating around each of the sensor data that exceed the specified limits (function **MMP\_edit.m**), and interpolating over spikes detected from high pass portions of each series using a median filter (function **MMP\_clean.m**). The length of the median filter is typically 3 scans for the EMCTD series and 11 scans for the ACM series. However, occasional dropouts (once or twice per profile) in the pressure series from mooring B required that a filter length of 11 scans be used for pre-filtering those data. Next, time information is determined for each EMCTD scan by interpolating the engineering data (**epres** and **etime**) to the EMCTD pressure series (**cpres**), and calibration adjustments are applied to the EMCTD and ACM series.

**MMP\_pgrid.m** acquires the calibration coefficients by loading the parameters from the user-specified Matlab format calibration files. These calibration files are produced using **create\_ctd\_calfile.m** and **create\_acm\_calfile.m**. Determination of the ACM horizontal heading bias and range coefficients was described in the previous section. Since the ACM velocity biases were already applied in previous processing step, 0's were entered for those parameters in the calibration file at this stage.

Calibration coefficients for the EMCTD were determined from field calibrations of the EMCTD against bottle-calibrated Sea-Bird SBE-19 CTD profiler data. Within 1 day after recovering each MMP, the EMCTD was deployed on the CTD frame for a cast to acquire simultaneous data. The package was stopped at 7 depths on descent so that the sensors could completely stabilize and many measurements could be recorded. The mean EMCTD and CTD pressure, temperature, and conductivity measurements at 7 depths (Figure 3) were linearly regressed, and those coefficients (slope and offset) were stored in the EMCTD calibration files. The EMCTDs on mooring A and C compared satisfactorily with the CTD measurements and were reinstalled on the MMPs and redeployed. The temperature channel on the EMCTD on mooring B was consistently significantly greater than the CTD (by 0.035 deg C on average) so was replaced.

After the calibrations were applied, the EMCTD pressure and conductivity data were recursively filtered to match the time-response of the temperature sensor (function **MMP\_recur\_filt.m**), and the EMCTD and ACM calibrated data series were low-pass filtered with a Butterworth filter (function **myfiltfilt.m**). Then the velocity is converted to instrument Cartesian coordinates, the compass heading coefficients are applied, and the compass angle is adjusted for instrument bias and the specified geomagnetic declination. The declination used for the BGFE 2003-2004 data was determined from the National Geophysical Data Center IGRF model (using **pcgeomag40.exe**), averaged over the year of the observations. The upstream vertical velocity component is selected, the east and north velocity components are computed, and the ACM series are aligned with the EMCTD series (function **MMP\_align\_ctdacm.m**).

Each series is subsequently bin-averaged on a uniformly-incrementing pressure as specified in Table 1, which for the BGFE 2003-2004 data was in 2 db bin widths. NaNs indicate no data in a cell. Derived quantities (salinity, theta, and sigma-theta) are calculated, and the data are saved in Matlab format files. The output data files generated by **MMP\_pgrid.m** are named **grd####.mat**, and each file contains the following variables:

**startdaytime**: start day and time of the profile (encoded with **datenum.m**)  
**stopdaytime**: stop day and time of the profile (encoded with **datenum.m**)  
**pgrid**: the center values of the pressure grid used in the bin-average  
**ctimave**: day and time of values averaged in each pgrid bin (**datenum.m**)  
**pave**: average of the pressure values in each pgrid bin dbars  
**tave**: average of the temperature values in each pgrid bin degC  
**s\_ave**: salinity computed pave, tave and cave pss  
**thetave**: potential temperature computed from pave, tave, and s\_ave degC  
**sighave**: potential density computed from pave, tave and s\_ave kg/m<sup>3</sup>  
**cave**: average scaled conductivity in each pgrid bin mmho  
**uave**: average east velocity in each pgrid bin cm/s  
**vave**: average north velocity in each pgrid bin cm/s  
**wave**: average relative vertical velocity in each pgrid bin cm/s  
**dpttave**: average time rate of change of pressure dbars/s  
**escan1 escan2**: indices of the CTD data averaged in each pgrid bin  
**ascan1 ascan2**: indices of the ACM data averaged in each pgrid bin

A documentation file is also created by the gridding routine that includes the processing parameters and indicates the success of processing each profile.

## 6. Removing spurious temperatures and salinities and adjusting to fixed reference layer

For further processing, the individual grid files from each MMP mooring deployment were loaded into a single Matlab format file with each variable stored in an array by time and pressure. Despite the pre-filtering and averaging performed by **MMP\_pgrid.m**, some spurious temperature and salinity points still needed to be filtered out of the dataset. The EMCTD conductivity cell (and to a lesser extent, the temperature probe) is occasionally subject to contamination by biology in the water column causing sharp deviations in the measurements, which sometimes take several minutes or more to clear. Fortunately for the BGFE MMPs, this problem is less prevalent in the Arctic water column beneath sea ice than at lower latitudes.

To help identify the flawed data, a Matlab script file (**mmp\_cln\_view.m**) was created to flag possible outliers. Timeseries means and standard deviations were computed for temperature and salinity for each gridded pressure, as well as the vertical gradients of the properties for each profile. Looping through each profile, any points that were more than 5 standard deviations away from the mean were flagged, as well as any points where the vertical gradient exceeded a threshold inversely related to pressure in one direction, and the vertical gradient of the next point exceeded the same threshold in the opposite direction. High-resolution plots of the temperature, salinity and velocity profiles, their vertical gradients, and the data in temperature-salinity space were generated and examined manually to determine whether a point, or group of points, needed to be removed. This method removed only one temperature point and a total of 43 salinity points from all the gridded profiles from all three BGFE moorings (Table 1).

The final adjustment to the EMCTD data corrects for small profile-to-profile variations of the conductivity measurement, based on the assumptions that: 1) the temperature measurement is stable, and 2) that at certain (deeper) isotherms the salinity changes are negligible over the course of the deployment. Using the combined gridded data, potential conductivity (= **sw\_cndr(salinity,theta,0) \* sw\_c3515**) was calculated for each profile and interpolated at selected stable theta surfaces. Since no single theta surface was either intersected or appeared to

be completely stable for every profile over the course of the deployment, three theta surfaces deeper than 500 m (-0.1, -0.25, and -0.5 deg C) were chosen by inspection from the BGFE 2003-2004 data. Potential conductivity was also calculated and interpolated at the same theta surfaces from calibrated ship CTD casts conducted on or near the mooring sites before and after deployment. Ratio factors were determined for each profile at each theta surface of: the mean potential conductivity from both pre- and post-cruise ship CTD casts, over potential conductivity from the MMP (Figures 7, 9, and 11). The mean ratio factor for each profile was applied to the potential conductivity profile from the MMP, and salinity, theta and sigma-theta were recalculated. The statistics in Table 1 demonstrate that the range and standard deviation of salinity at theta = -0.5 deg C were reduced by approximately one-third for each MMP using this method. Theta-salinity plots based on data before and after the adjustments are presented in Figures 8, 10 and 12.

## ***7. Interpolating to pressure grid and correcting velocities for sound speed***

During the gridding operation, the data values were averaged in pressure bins but depending on the distribution of the data with respect to pressure within each bin, the average pressure may be offset from the bin center pressure. In order to fit the profile data exactly to the **pgrid** pressure grid and to fill in missing points, each data variable was linearly interpolated to **pgrid**. Missing points within the vertical extents of profile data were filled by interpolation, but missing endpoints were not filled and were instead assigned NaNs. Gaps at the profile ends are usually due to instances where the MMP drifted off of its stopped position between profiles, causing it to begin sampling a few meters away from the wire stop on its next profile. Derived variables theta and sigma-theta are recomputed. Also, while looping through every profile during the interpolation operation, scheduled profile events that did not contain data were not included in the interpolated data array. Scheduled profiles may not return full profiles of data when the MMP instrument is unable to profile (usually due to slipping on the wire).

The final adjustment to the ACM velocities corrects for the variations in the speed of sound due to the seawater characteristics. The ACM circuitry actually makes a correction for speed of sound based on a temperature sensor mounted within the endcap of the ACM electronics pressure housing that is mounted inside the MMP cowling. However, the temperature sensed by the ACM probably lags significantly from that of the water surrounding the ACM transducer sting due to the thermal mass of the ACM pressure vessel and the trapped water inside the cowling. Furthermore, the speed of sound calculation that is made within the ACM also neglects salinity and pressure variations (salinity is fixed at 35, and pressure at 0 dbar). Because the temperature used by the ACM in the calculation is not available, we have to assume that it is correct. We are able to correct for pressure effects in the speed of sound by scaling the velocities by the ratio of the square of the speed of sound calculated from the EMCTD data over the square of the speed of sound calculated by the ACM (=  $\text{sw\_svel}(S,T,\text{pgrid})^2 / \text{sw\_svel}(35,T,0)^2$ ). Figure 13 plots the profiles of this scaling factor for mooring A data (the curves for B and C data are essentially the same). In the surface waters where the currents are usually the greatest, the scaling factor only slightly reduces the magnitude, and increases it by less than 5% in the deeper waters where the currents are small. Either way, the correction amounts to a difference of only a few mm/s for the BGFE 2003-2004 data.

## **8. Archiving data in several formats**

Composite plots by depth and temporal contours of the fully processed set of time series profiles of temperature, salinity and velocity (speed and direction) are presented in Figures 14 and 15 from mooring A, in Figures 16 and 17 from mooring B, and in Figures 18 and 19 from mooring C. These results are digitally archived in three formats that are being made publicly available at the BGFE website (<http://www.whoi.edu/beaufortgyre>) along with this documentation. The data are identical regardless of the format.

The first format stores all of the processed data from all profiles from a single MMP into single Matlab-format files: **bg0304\_mmp\_a.mat**, **bg0304\_mmp\_b.mat**, and **bg0304\_mmp\_c.mat**, where a, b, and c identify the mooring. Each file contains the following variables:

**DPDT**: array of profiling speeds cm/s  
**S**: array of salinity pss  
**SIGTH**: array of sigma-theta kg/m<sup>3</sup>  
**T**: array of temperature deg C  
**THETA**: array of potential temperature  
**TIME**: array of time of each measurement (encoded with **datenum.m**)  
**U**: array of east velocity cm/s  
**V**: array of north velocity cm/s  
**W**: array of measured vertical velocity (includes profiling velocity) cm/s  
**dates**: vector string with profiler start date  
**day**: vector of decimal year day (2003)  
**location**: string with location of mooring  
**name**: string with dataset name  
**number**: vector of profile number  
**pgrid**: vector of pressure grid m

The remaining two formats contain the same information in multiple ASCII text files with all the data from each profile in a single file, but differ in the method of storage to accommodate both PC and UNIX computer systems. In either case, the individual ASCII profile data files are named **bg0304\_mmp\_a###.mat**, **bg0304\_mmp\_b###.mat**, and **bg0304\_mmp\_c###.mat**, where a, b, and c identify the mooring and ### is the profile number. For PC systems, all of the files from a single MMP are zipped into single files: **bg0304\_mmp\_a.zip**, **bg0304\_mmp\_b.zip**, and **bg0304\_mmp\_c.zip**. For UNIX systems, all of the files from a single MMP are compressed and tarred into single files: **bg0304\_mmp\_a.tar.Z**, **bg0304\_mmp\_b.tar.Z**, and **bg0304\_mmp\_c.tar.Z**. Each individual data files includes two lines of header information. The first line provides general information:

project and mooring **name**: profile **number**, start **date** and time, **location**

The second line describes the columns of data:

hr:min:sec **P**(Dbar) **T**(degC) **S**(PSU) **U**(cm/s) **V**(cm/s) **W**(cm/s) **DPDT**(cm/s)

The remaining lines comprise the processed data from the profile in the following format:

'%02d:%02d:%02.0f %4d %6.3f %6.3f %6.2f %6.2f %6.2f %6.2f\n'

The lines of data increase sequentially based on the time of the observation, so downgoing profiles start at the shallowest depth and upgoing profiles start at the deepest depth. Grid points with no data (that were filled with NaNs) are omitted in the ASCII files.

Finally, it should be noted that the first burst of profiles in each deployment (1 and 2) occur at specific start times as configured prior to deployment (see Ostrom et al., 2004 for the BGFE 2003-2004 MMP deployment parameters), which are not necessarily synchronous with the timing of the remainder of the profiles. Beginning with the second burst (profiles 3 and 4), the rest of the profiling schedule is synchronized to a reference date (which was 08/01/2003 00:00:00 for the BGFE MMPs).

### *Acknowledgements*

The BGFE project was funded by the NSF Office of Polar Programs ARCSS Program grant number OPP-0230184, including support for the first year of the field program (including deployment and recovery of the moorings). Any opinions, findings, and conclusions or recommendations expressed in this material are those of the authors and do not necessarily reflect the views of the National Science Foundation.

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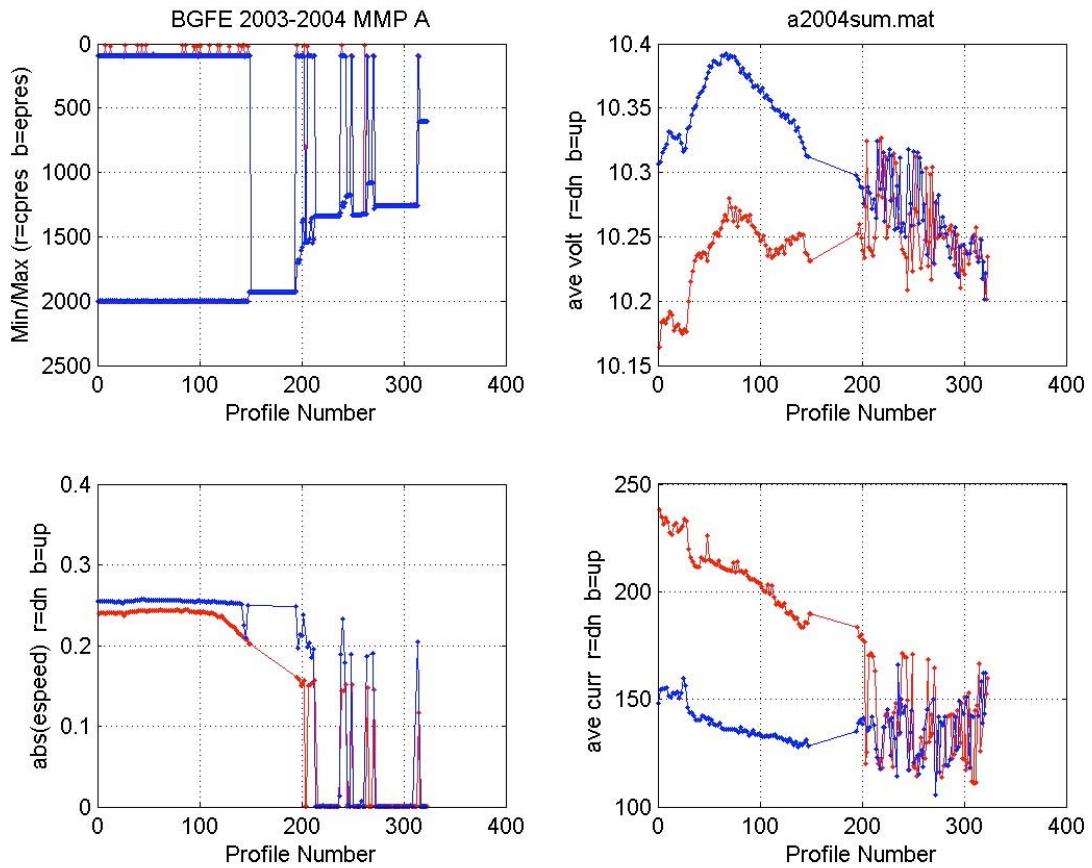


Figure 1. Plots of summary information from BGFE 2003-2004 mooring A MMP.

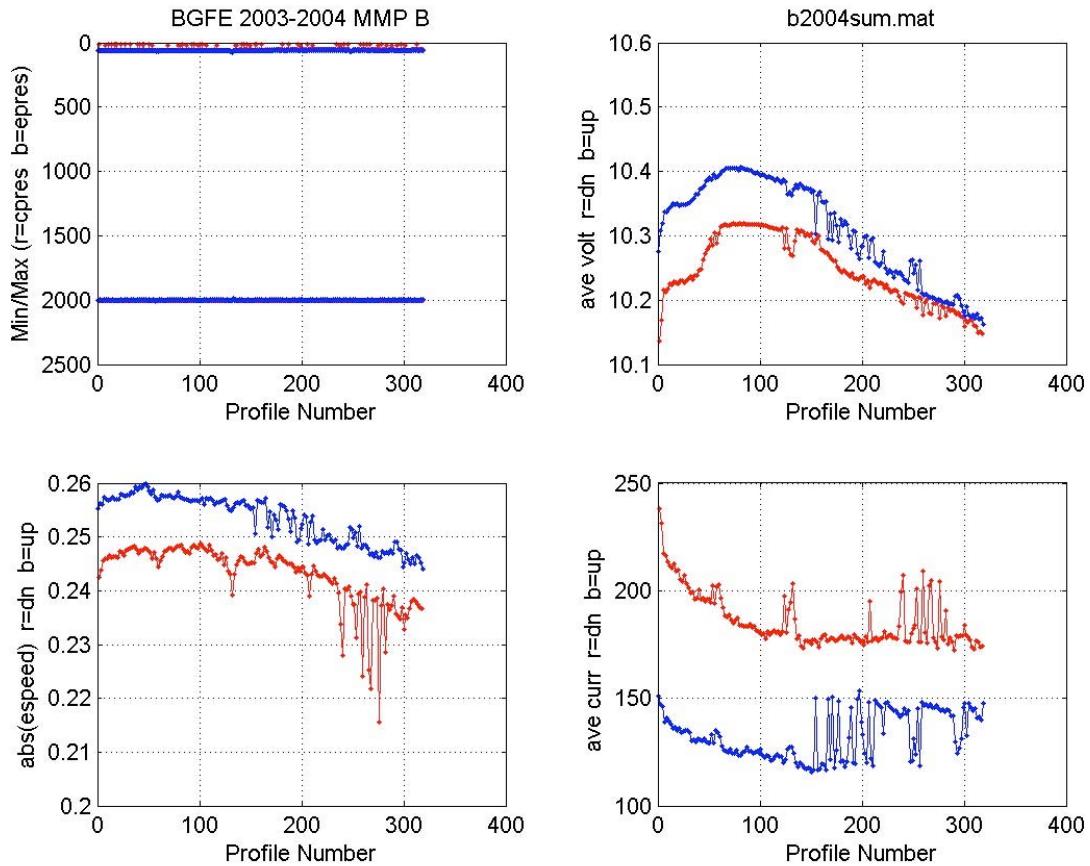


Figure 2. Plots of summary information from BGFE 2003-2004 mooring B MMP.

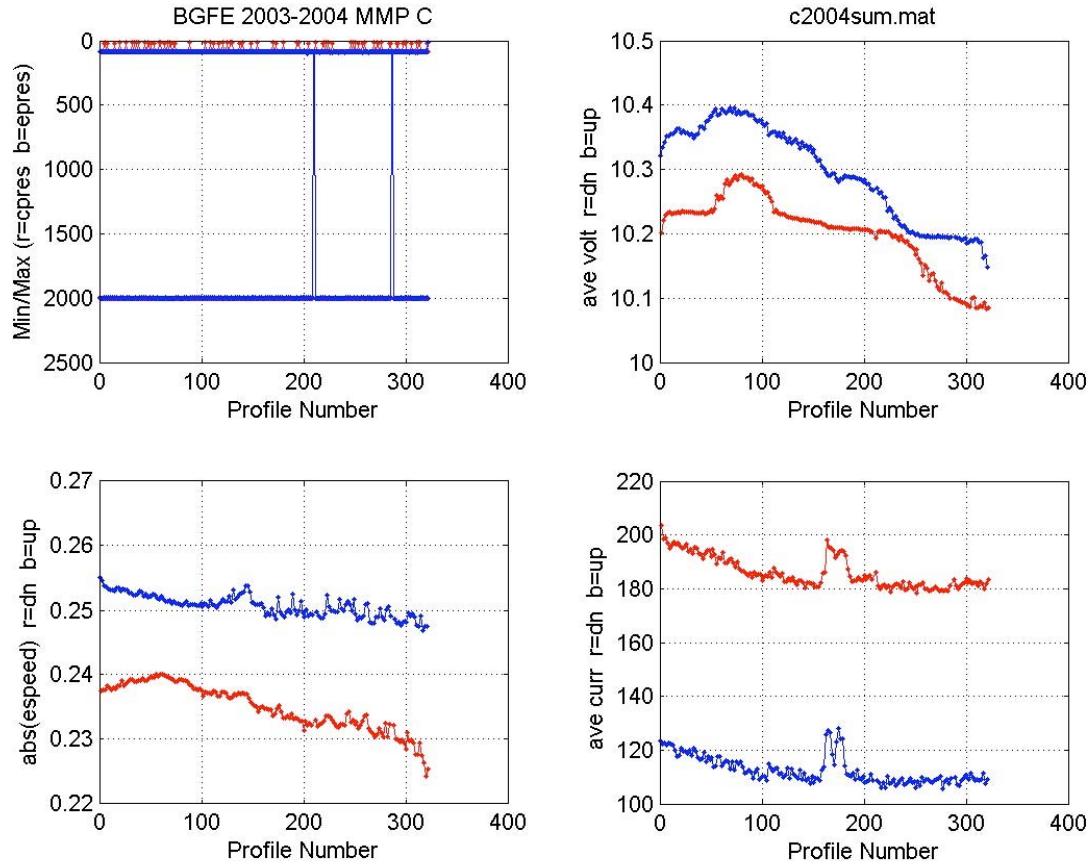


Figure 3. Plots of summary information from BGFE 2003-2004 mooring C MMP.

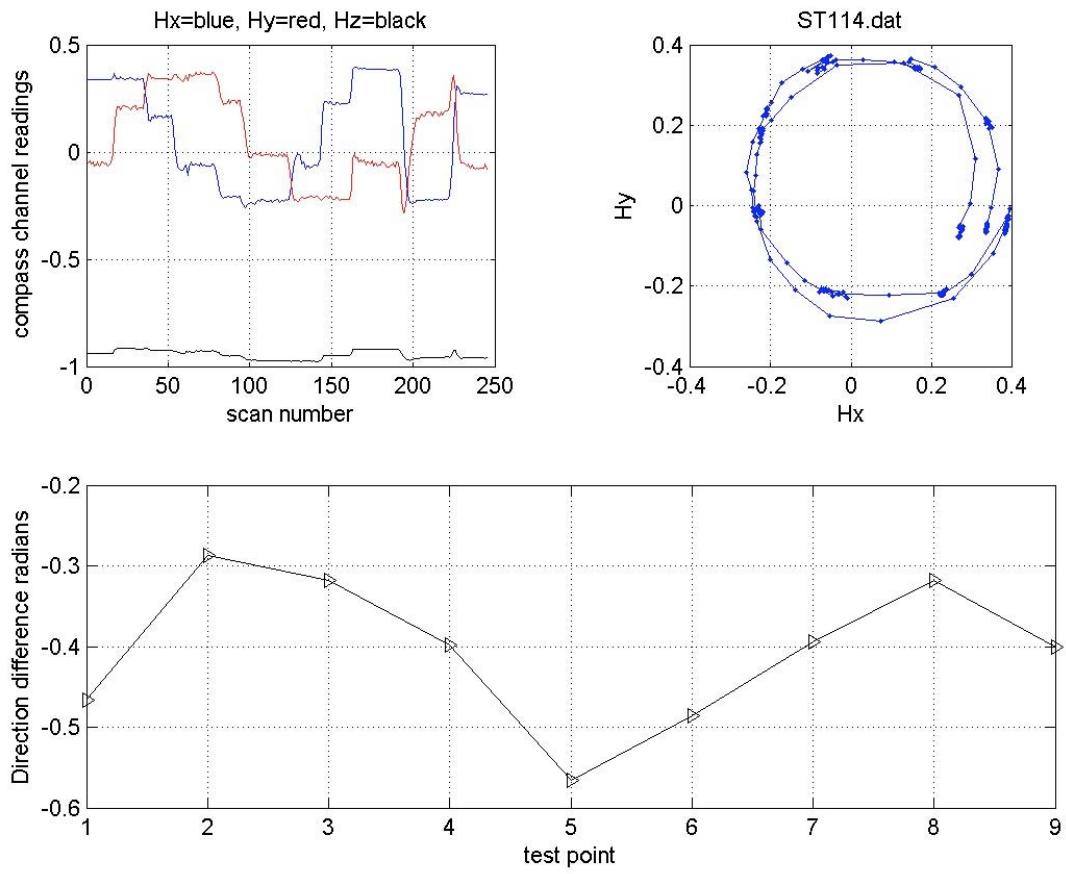


Figure 4. Spin test plots from MMP used on BGFE 2003-2004 mooring A.

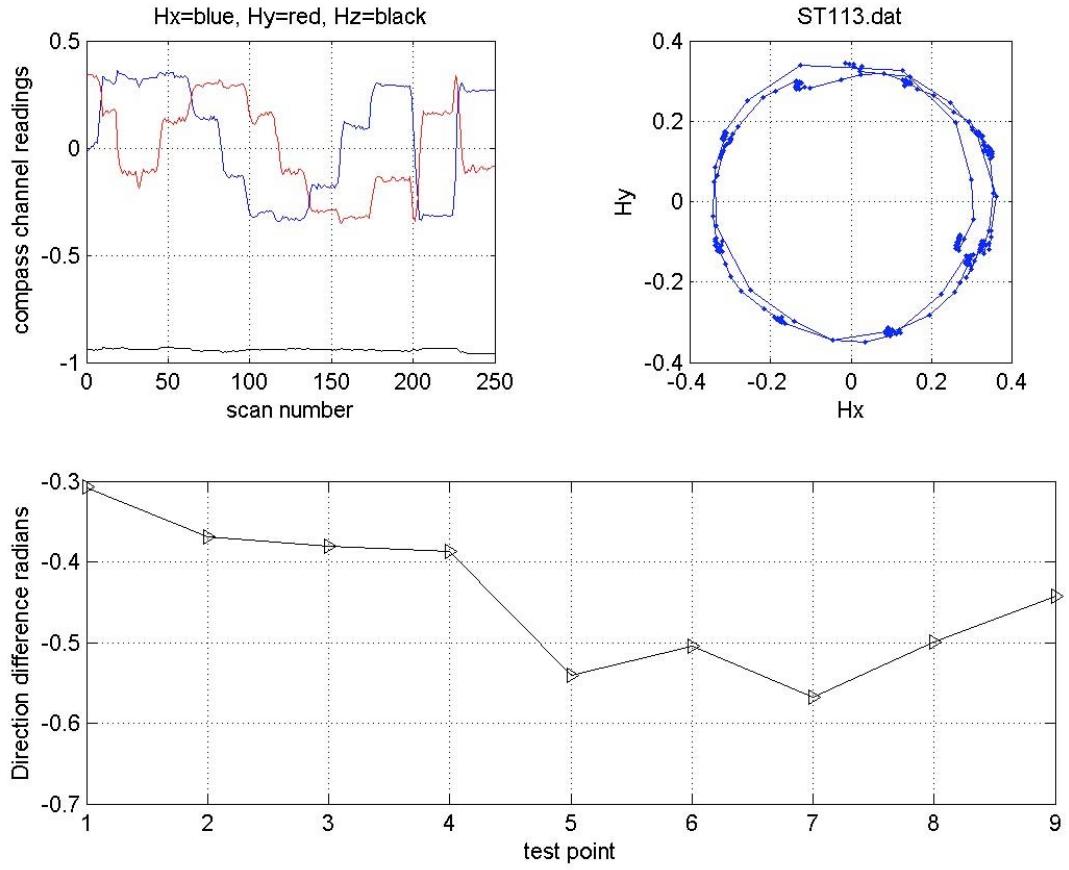


Figure 5. Spin test plots from MMP used on BGFE 2003-2004 mooring B.

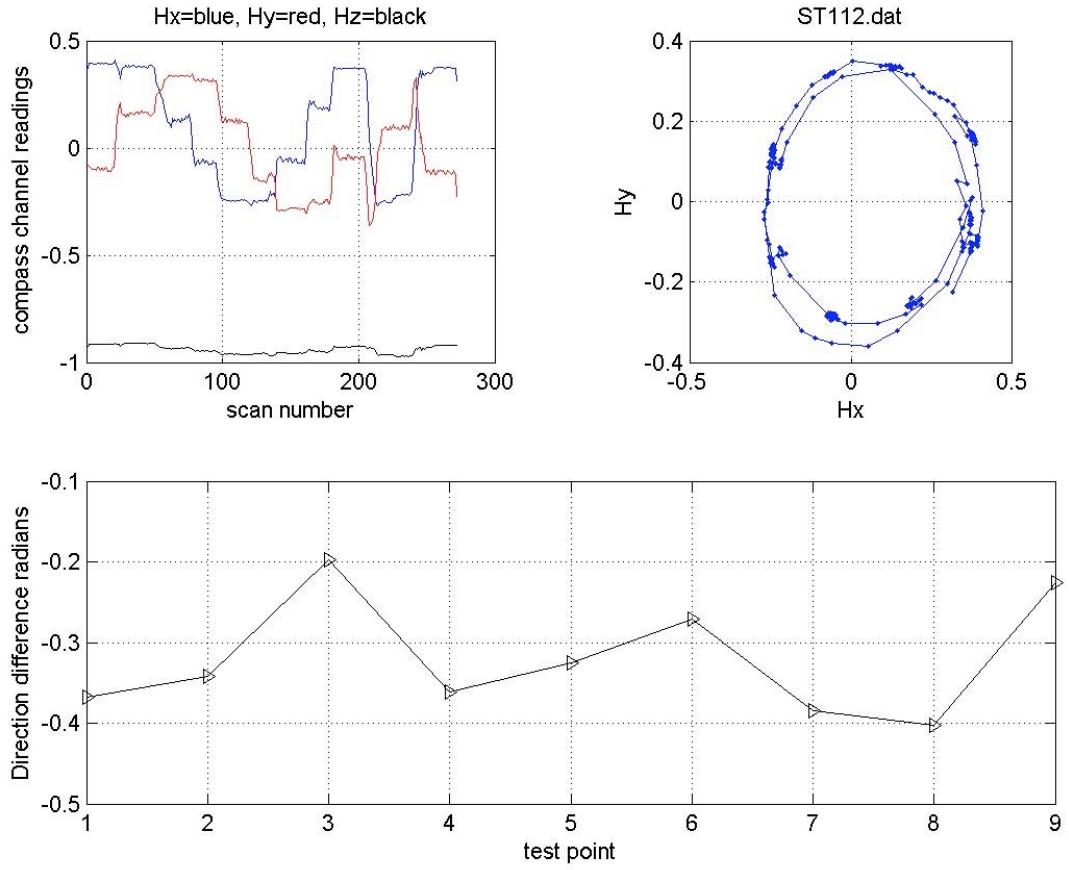


Figure 6. Spin test plots from MMP used on BGFE 2003-2004 mooring C.

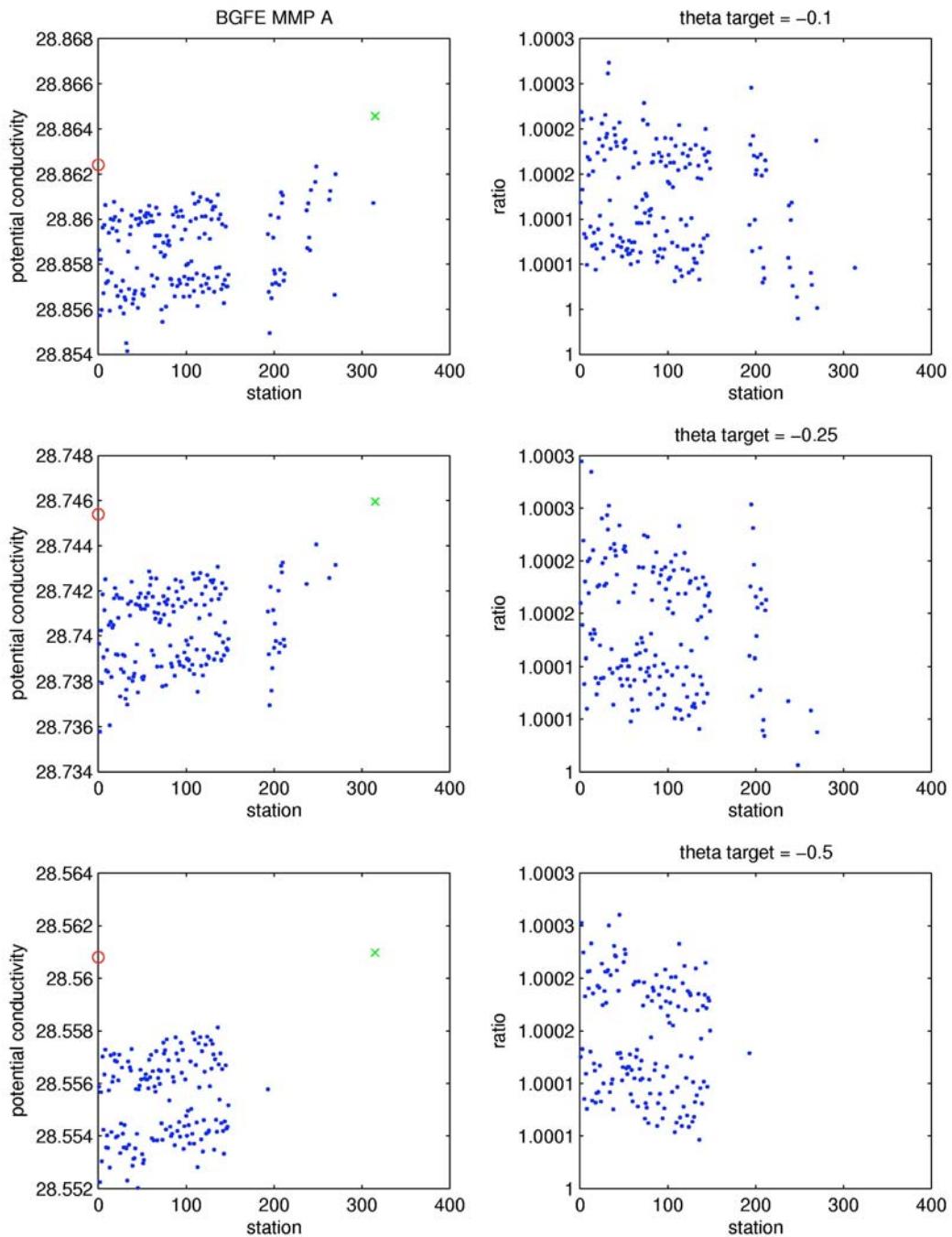


Figure 7. Potential conductivity (left) and adjustment ratios (right) at 3 theta surfaces for BGFE 2003-2004 mooring A MMP. Circles and crosses mark potential conductivities from calibrated reference CTD casts before and after deployment.

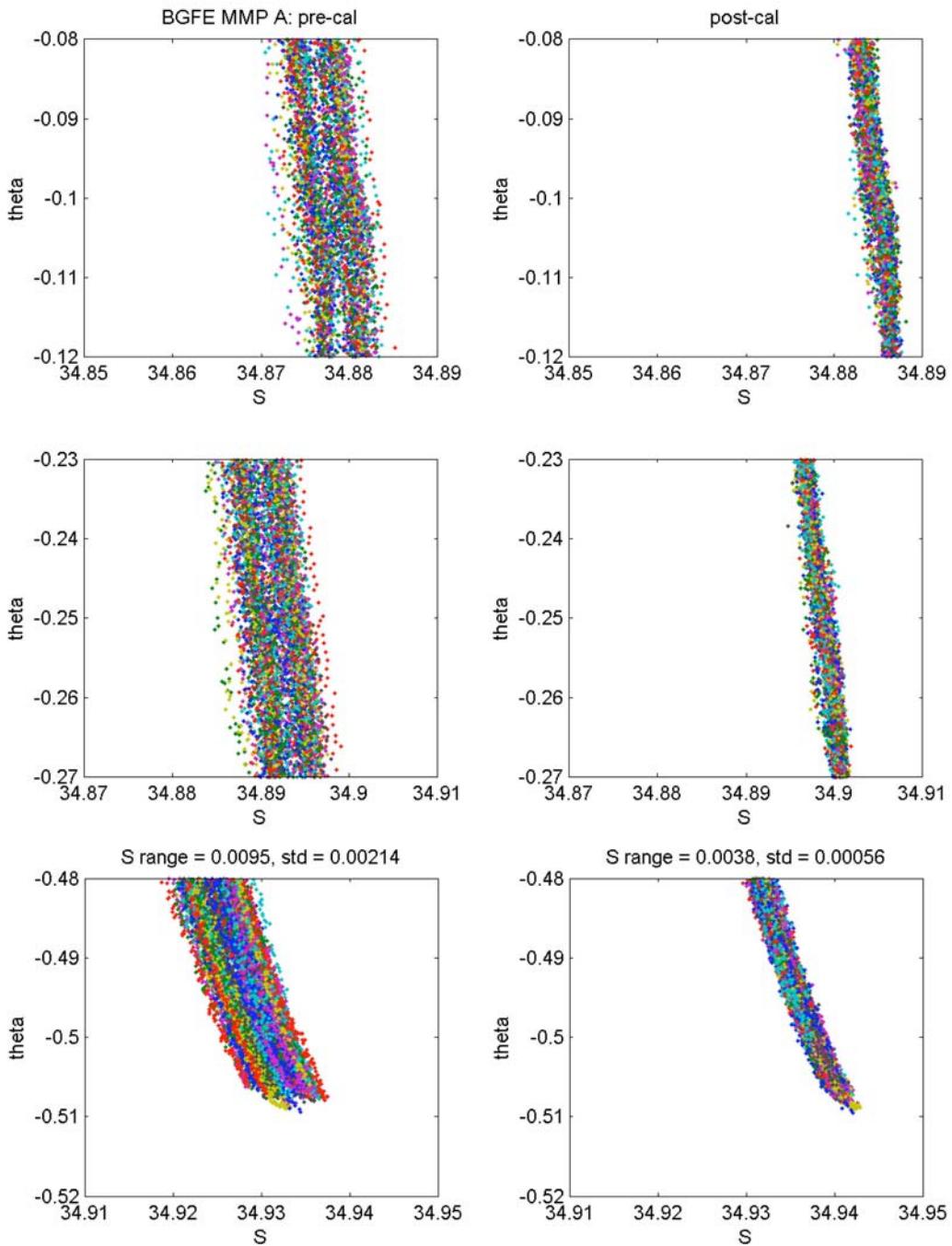


Figure 8. Enlarged theta-salinity plots around 3 theta surfaces before and after potential conductivity adjustment from BGFE 2003-2004 mooring A MMP.

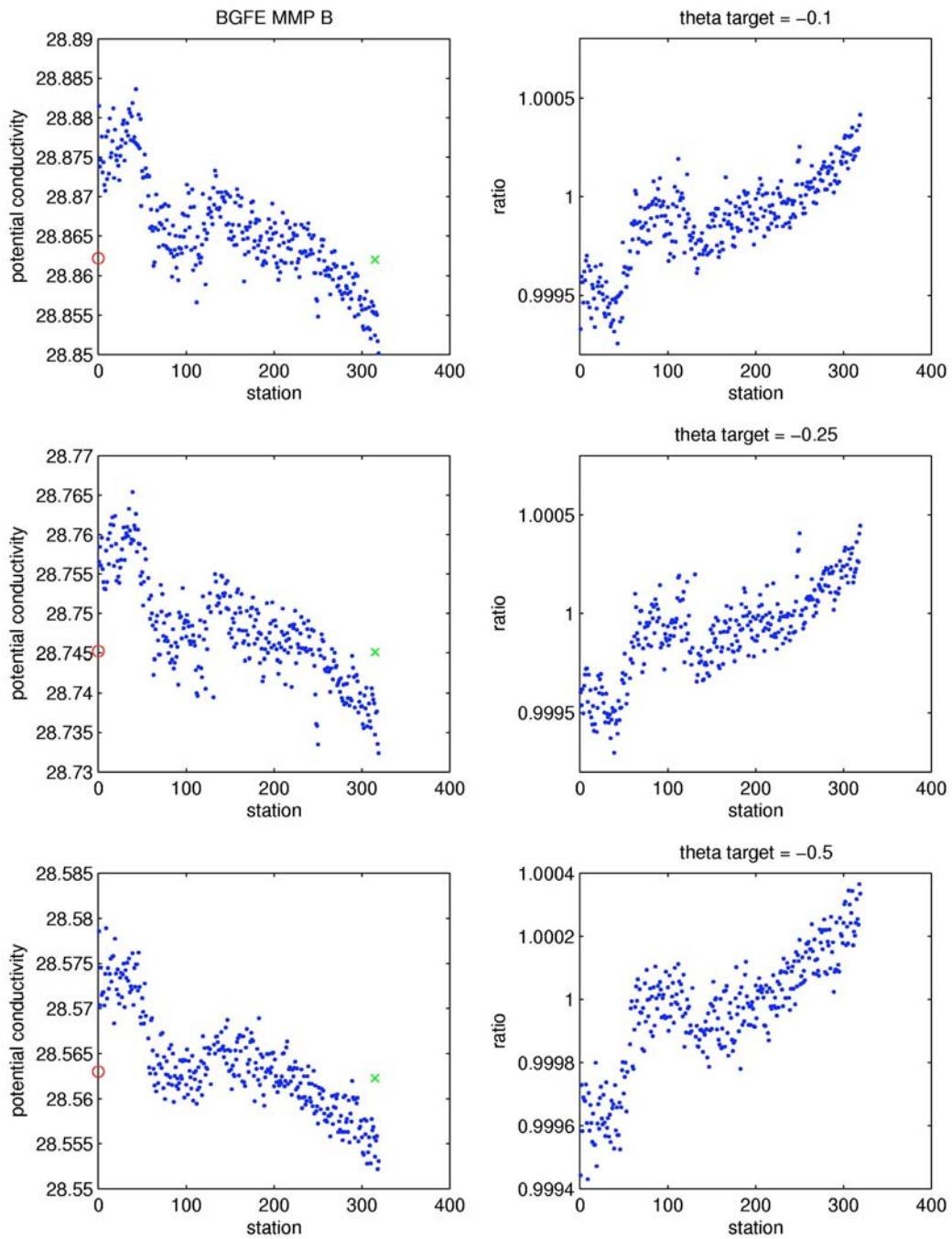


Figure 9. Potential conductivity (left) and adjustment ratios (right) at 3 theta surfaces for BGFE 2003-2004 mooring B MMP. Circles and crosses mark potential conductivities from calibrated reference CTD casts before and after deployment.

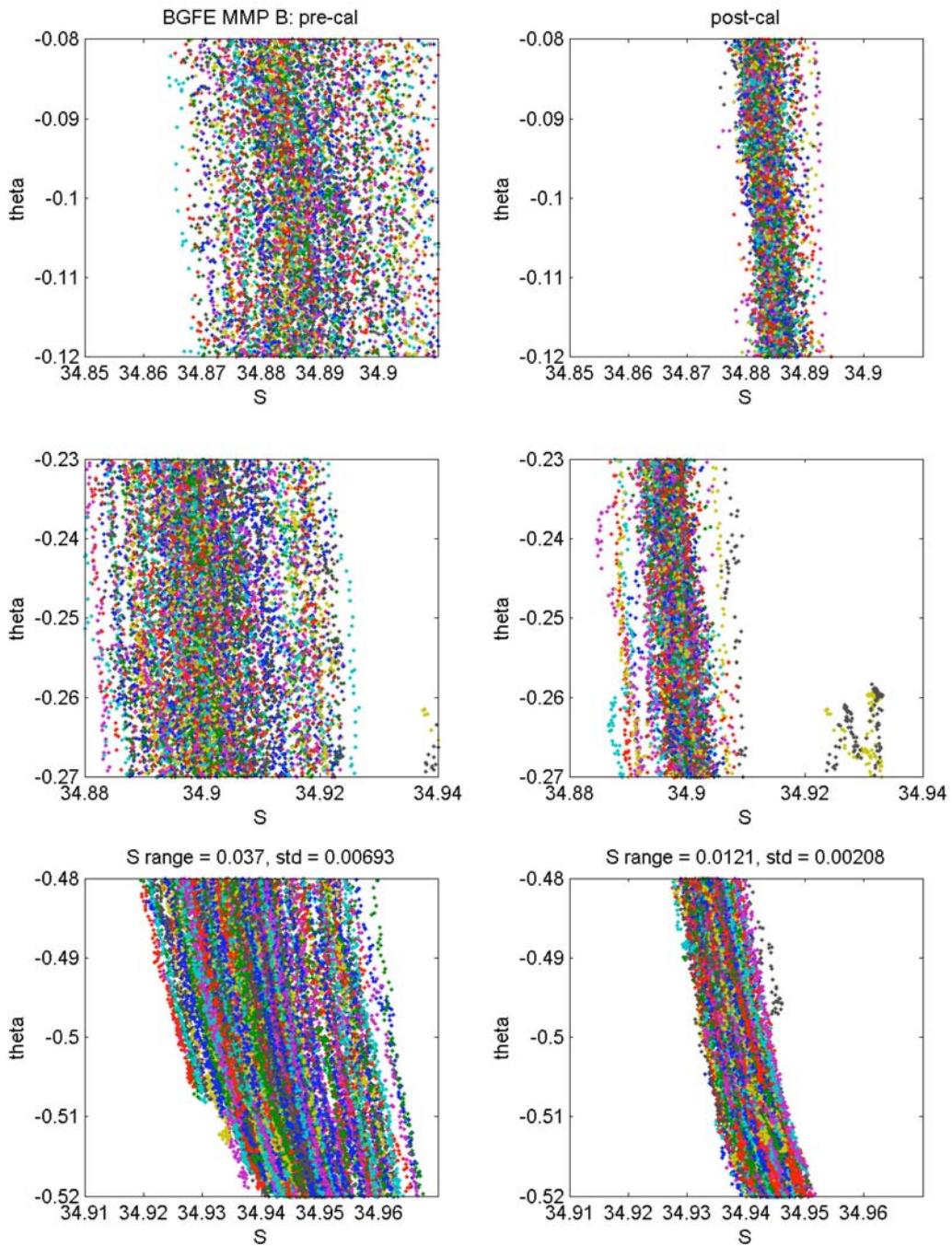


Figure 10. Enlarged theta-salinity plots around 3 theta surfaces before and after potential conductivity adjustment from BGFE 2003-2004 mooring B MMP.

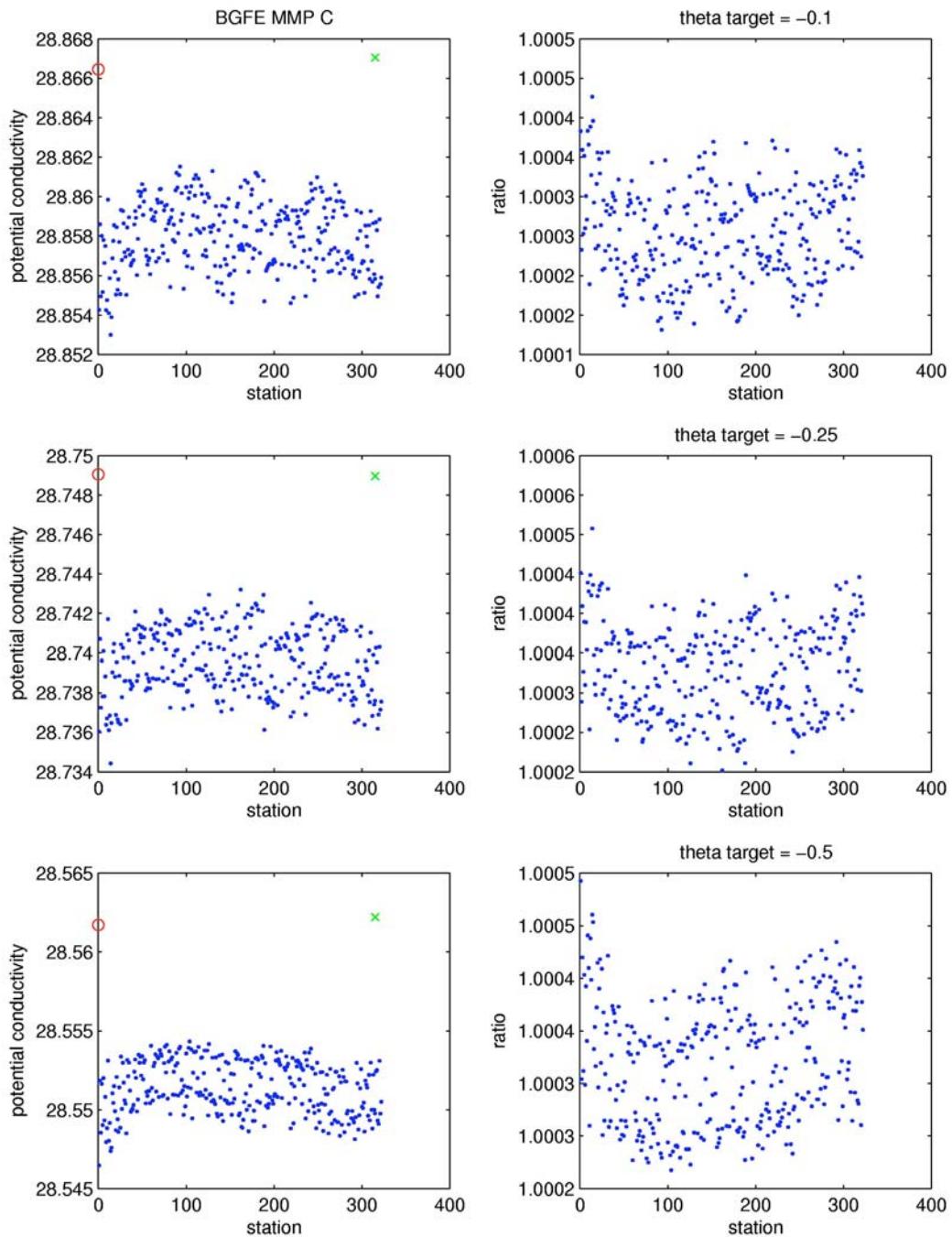


Figure 11. Potential conductivity (left) and adjustment ratios (right) at 3 theta surfaces for BGFE 2003-2004 mooring C MMP. Circles and crosses mark potential conductivities from calibrated reference CTD casts before and after deployment

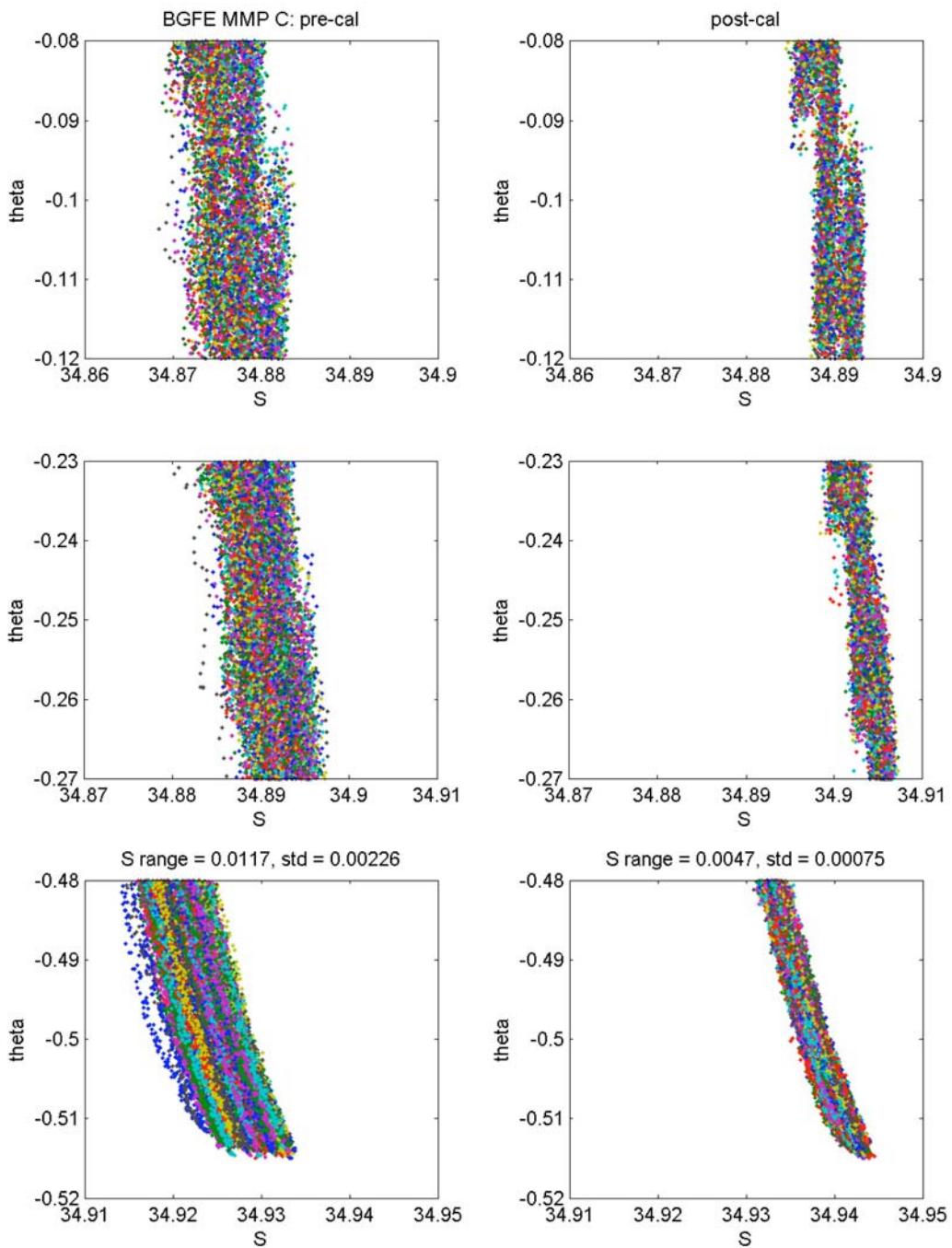


Figure 12. Enlarged theta-salinity plots around 3 theta surfaces before and after potential conductivity adjustment from BGFE 2003-2004 mooring C MMP.

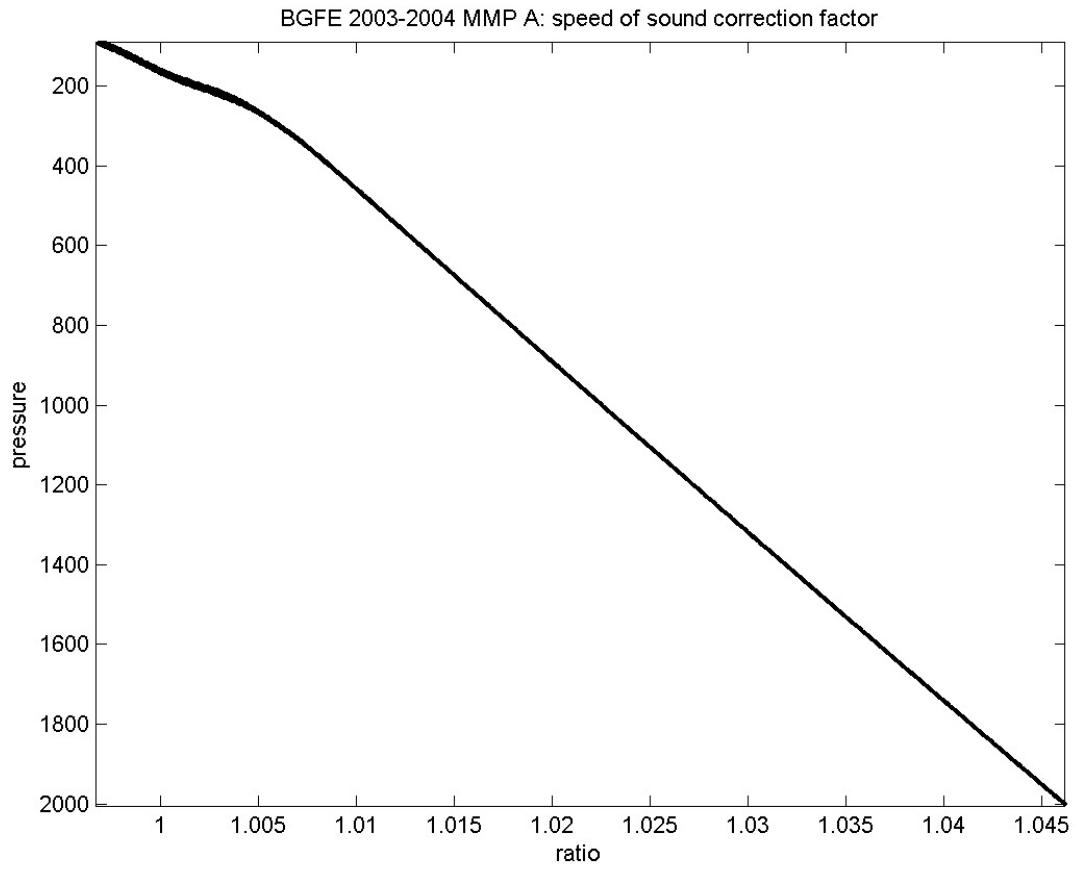


Figure 13. All profiles of speed of sound correction factor for ACM velocities based on seawater properties for BGFE 2003-2004 mooring A MMP.

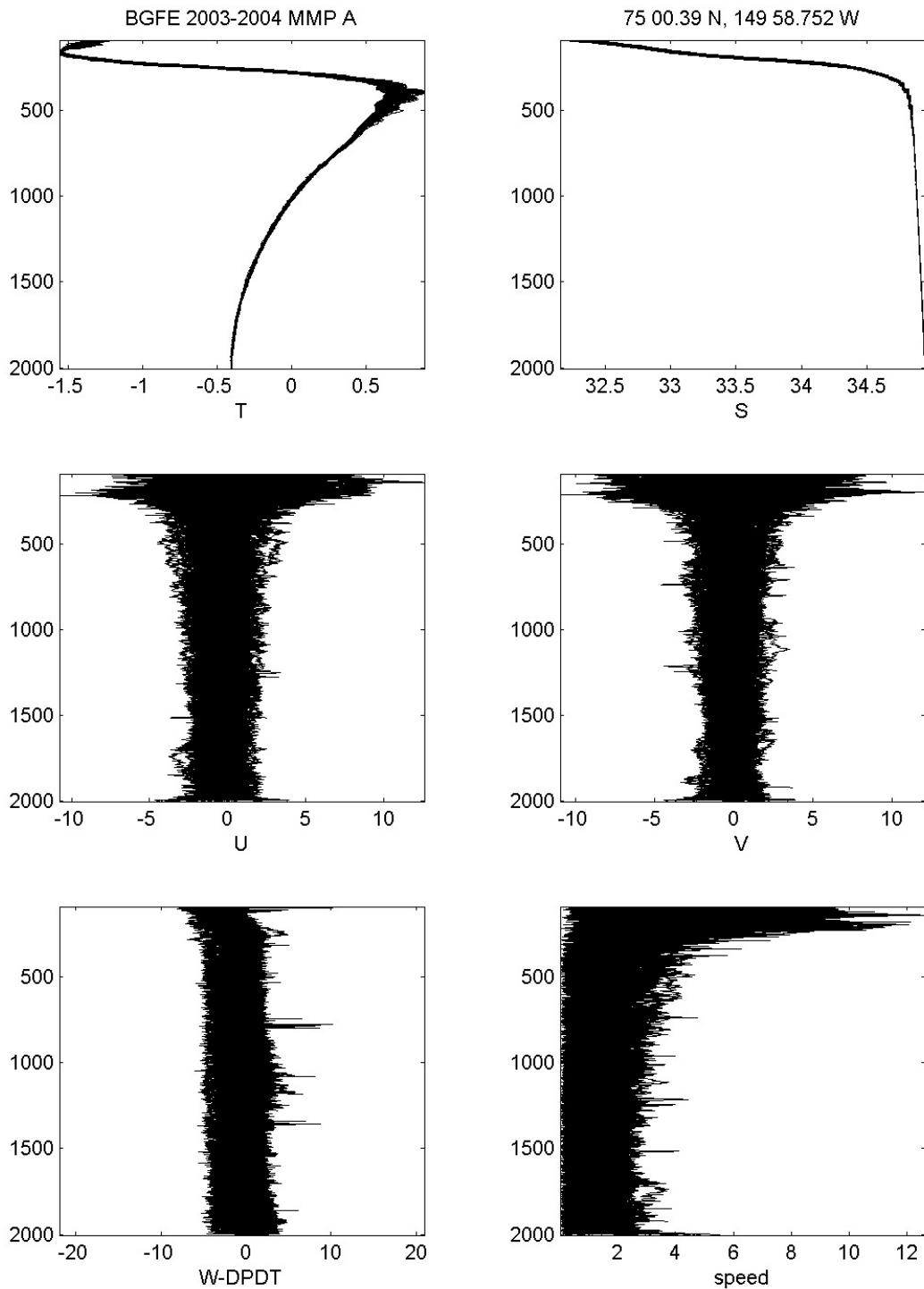


Figure 14. All temperature, salinity and velocity (speed and direction) profiles from BGFE 2003-2004 mooring A MMP.

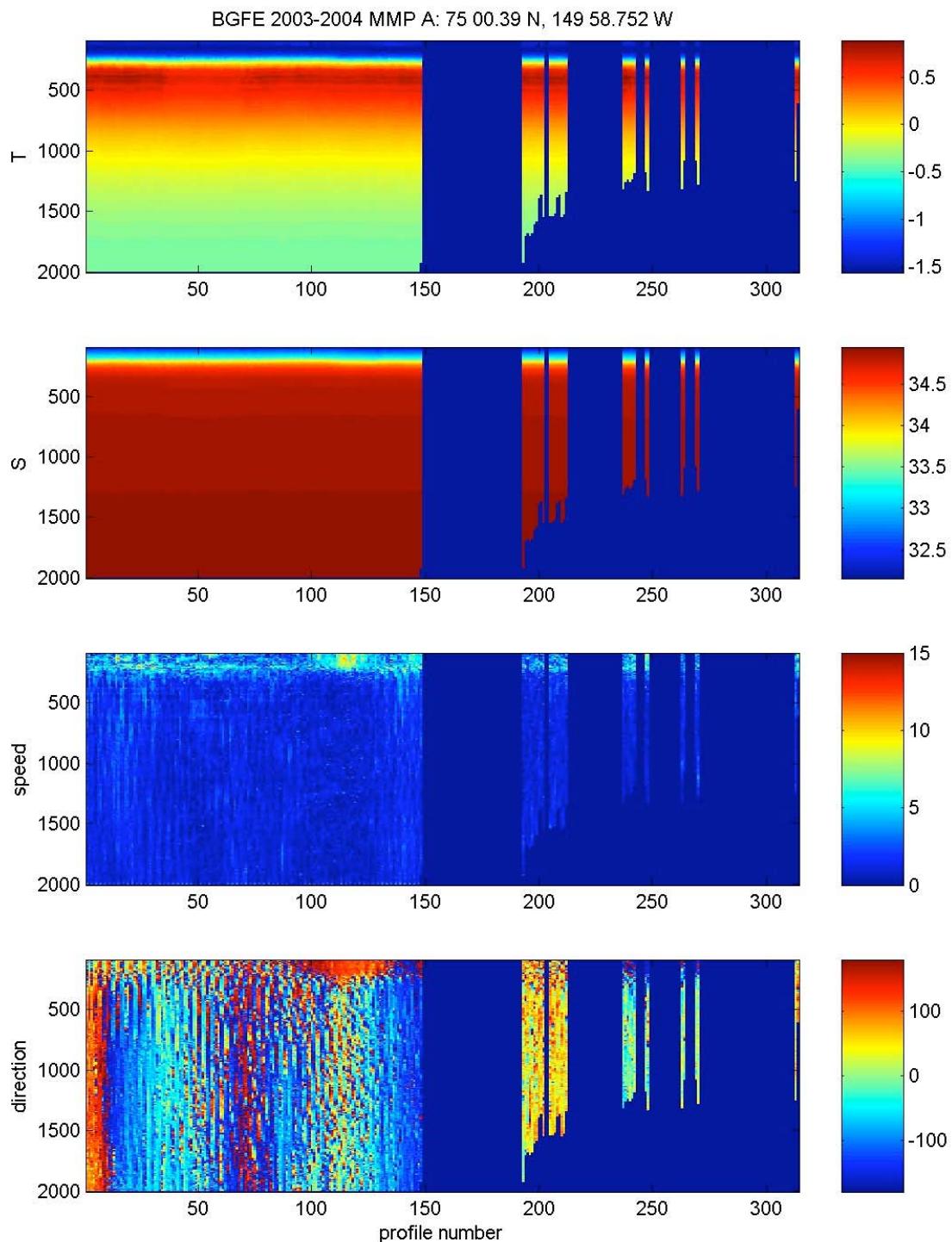


Figure 15. Temperature, salinity and velocity (speed and direction) contours from BGFE 2003-2004 mooring A MMP.

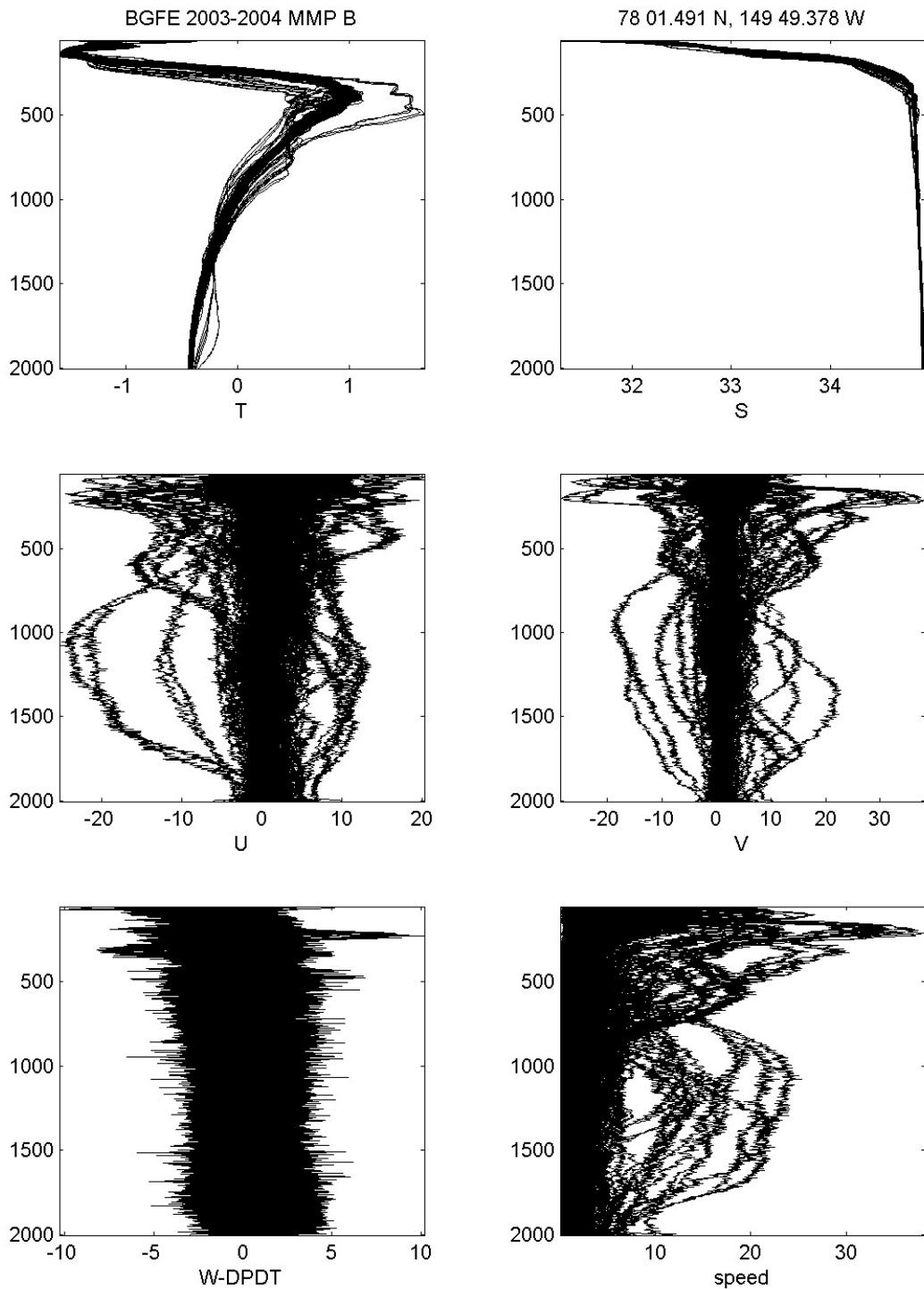


Figure 16. All temperature, salinity and velocity (speed and direction) profiles from BGFE 2003-2004 mooring B MMP.

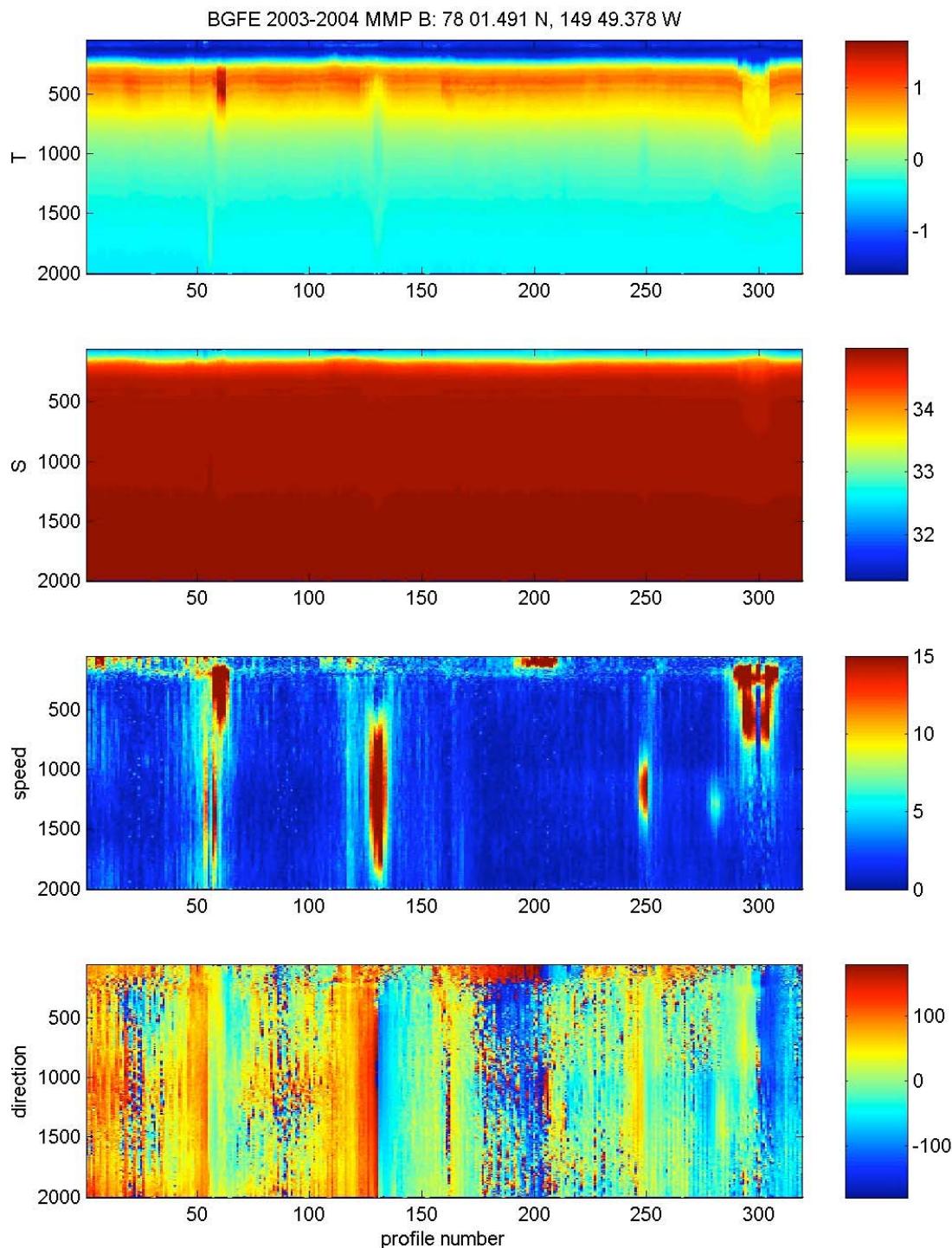


Figure 17. Temperature, salinity and velocity (speed and direction) contours from BGFE 2003-2004 mooring B MMP.

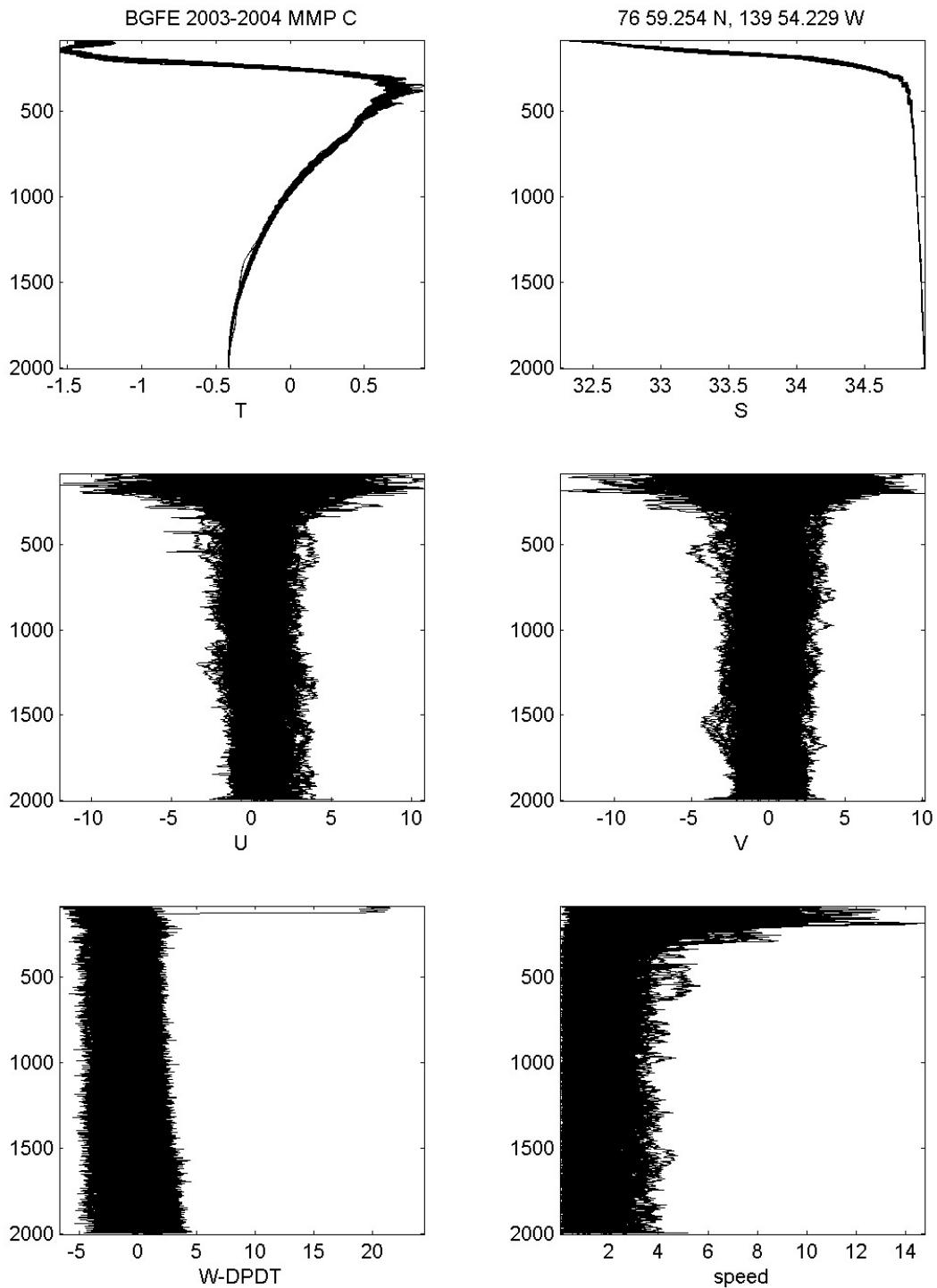


Figure 18. All temperature, salinity and velocity (speed and direction) profiles from BGFE 2003-2004 mooring C MMP.

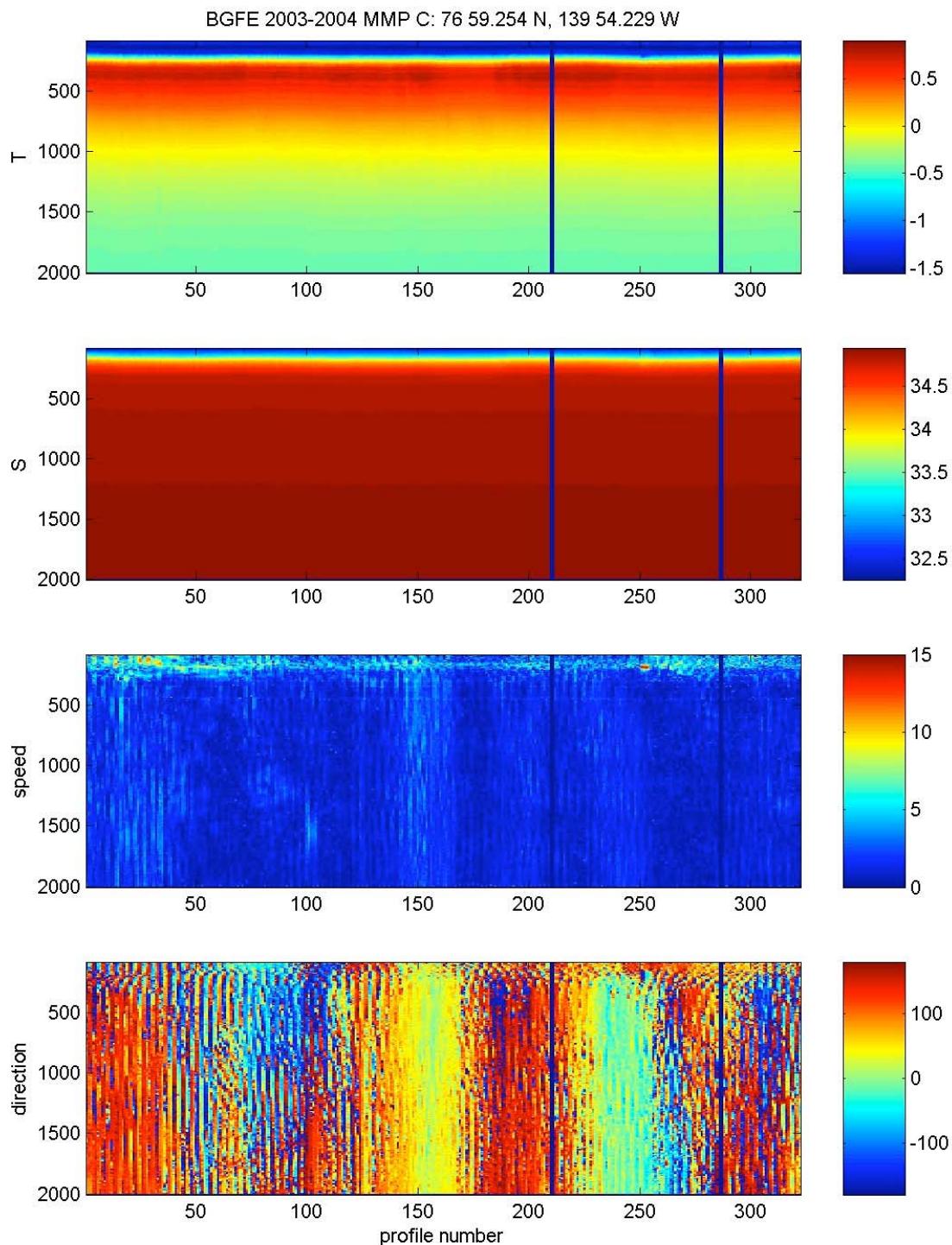


Figure 19. Temperature, salinity and velocity (speed and direction) contours from BGFE 2003-2004 mooring C MMP.