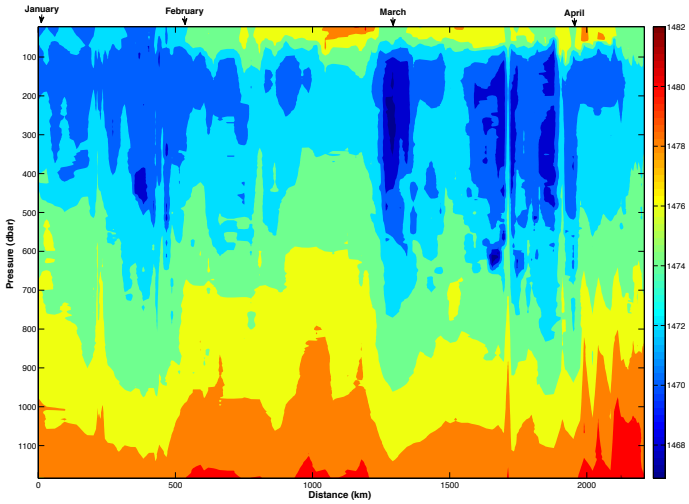
Marine Field Group
Florida State University

Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean
APEX Float Data Report
December 2009 – April 2011

by
Cathrine Hancock & Kevin Speer
Marine Field Group, FSU, FL 32306
May 2013



Technical Report

Funding was provided by the National Science Foundation under Grant Number OCE-06022670
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Abstract

This is the final data report of APEX float data collected by the Marine Field Group, Florida State University, in 2009-2011 during the "Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean" (hereafter DIMES). There were two APEX float deployment: both on RRS James Cook, the first in December 2009 (UK1) and the second in December 2010 (UK2). All APEX floats were programmed to drift at 1200 dbars, profiling up to the surface at select time intervals, and transmitting data via IRIDIUM. Once daily, the APEX, which were RAFOS enabled, listened for sound source transmissions. The objectives of the APEX deployments were to gather CTD data near the Polar and Sub-Antarctic fronts in the Scotia Sea, as well as to acquire information on the sound sources used to track the RAFOS floats.

Front Cover Figure Caption: Speed of sound (m/s) along the track of APEX 4781. 116 CTD profiles were used to create this section. The float profiled from 1200 dbars up to the surface.

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1. Introduction

This is the final data report of APEX float data collected during the 2009-2011 “Diapycnal and Isopycnal Mixing Experiment in the Southern Ocean” (hereafter DIMES).

The objective of each APEX float deployment was (1) to gather CTD data on the stratification near the Polar and Sub-Antarctic fronts in the Scotia Sea, and (2) to acquire information on the sound source clocks. 3 APEX floats were deployed on two cruises, UK1 in December 2009 and UK2 in December 2010. Both were with the RRS James Cook. The floats were tracked via GPS, as well as using four moored sound sources in the Scotia Sea. Data was transmitted via IRIDIUM Satellite.

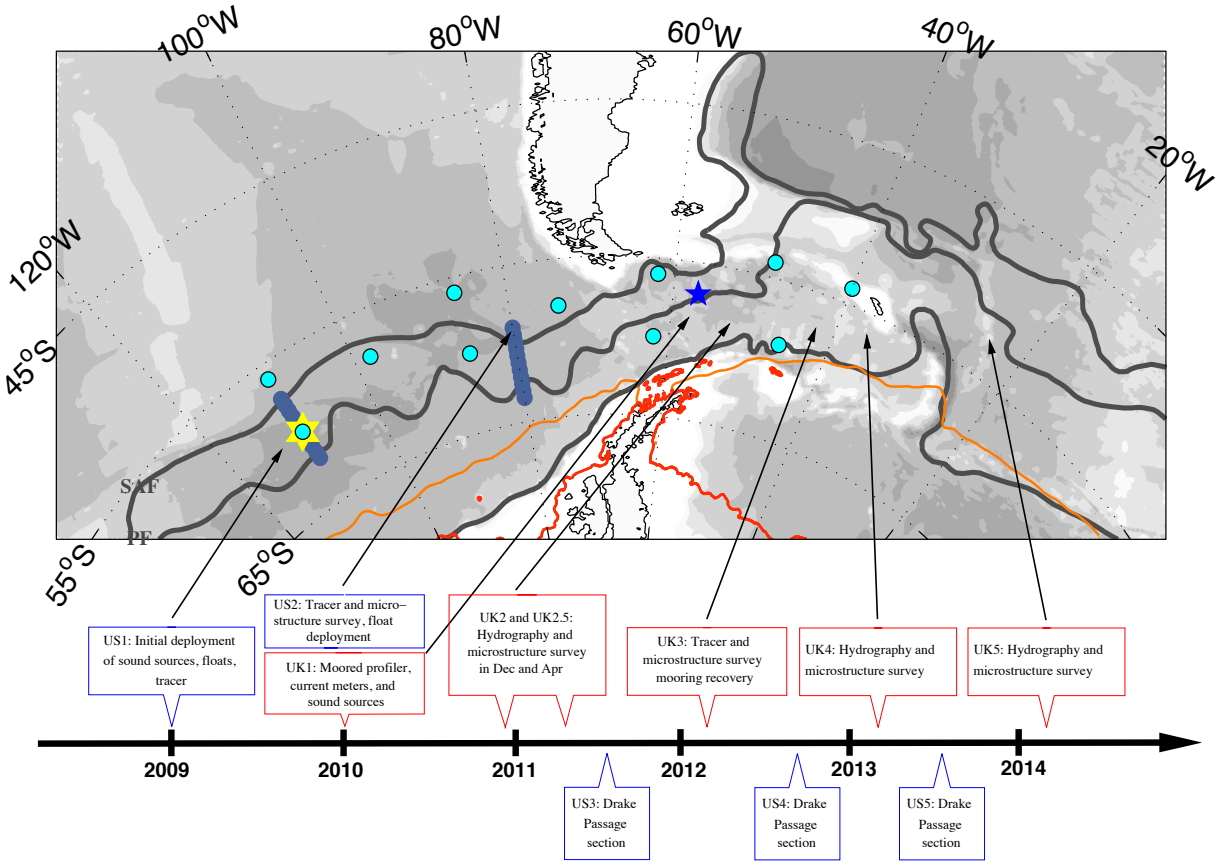

Figure 1: Location and timeline of past and future DIMES cruises. The turquois circles indicate approximate location of sound sources.

2. Description of the APEX Floats

The APEX (***A***utonomous ***P***rofiling ***Ex***plorer) float is a neutrally buoyant profiling drifter, used to measure subsurface currents and make vertical profile measurements (manufactured by Teledyne Webb Research, Falmouth MA). In addition, like RAFOS floats (Rossby et al. 1986), it is capable of listening and recording time-of-arrival (TOA, hereafter) of signals from moored sound sources. It surfaces at programmed intervals to telemeter the data via IRIDIUM satellite. All three APEX floats were ballasted to drift at 1200 dbar.

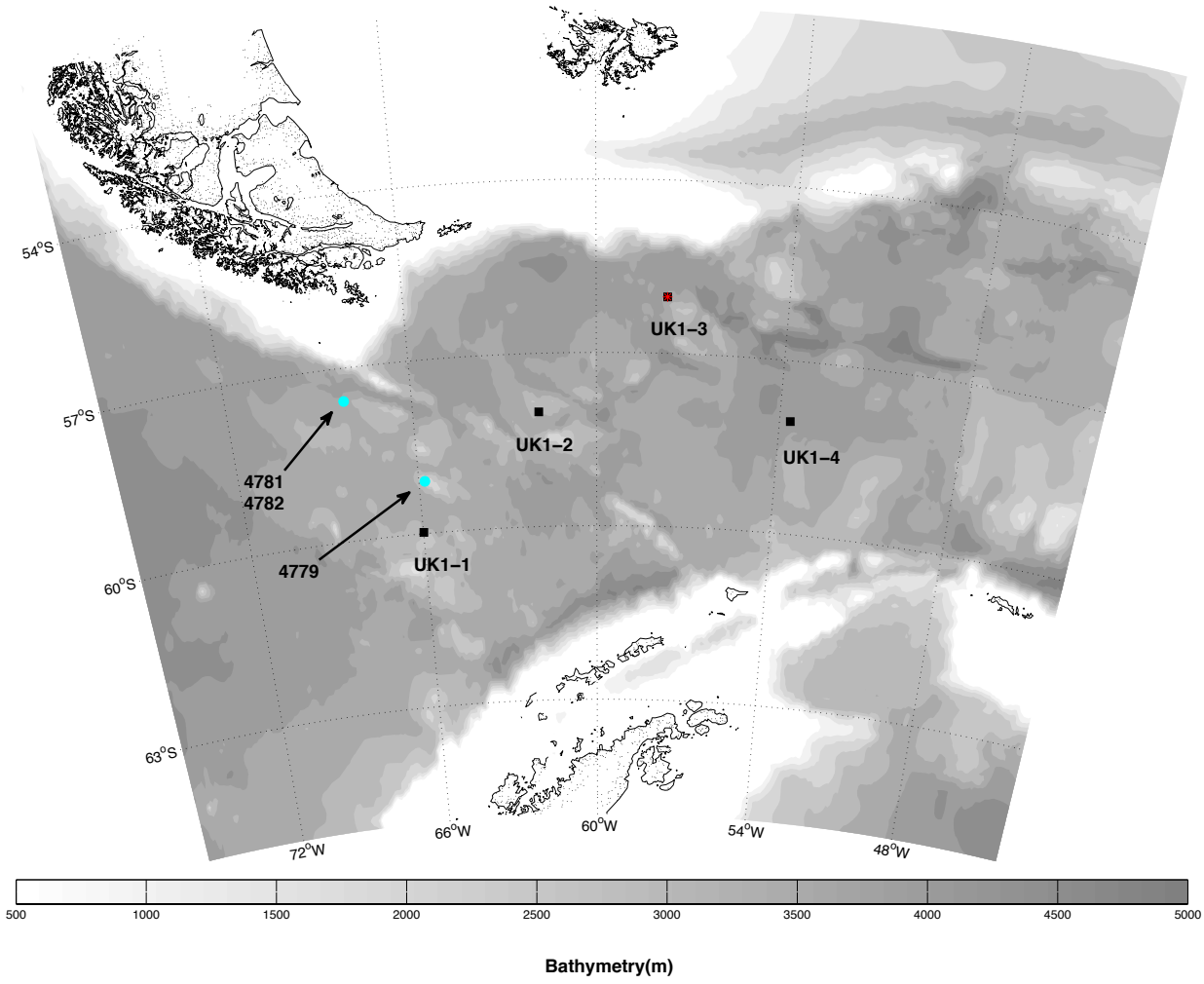

Figure 2: Chart depicting (a) the sound sources in the Scotia Sea (black squares), (b) BAS current meter mooring (red star), and (c) APEX deployment sites (cyan circles).

3. Sound Sources

In this experiment, only four of the twelve moored sound sources were used (Figure 2). These were moored by Florida State University (FSU) and the National Oceanography Center, and are located in the Scotia Sea. A comprehensive list of the sound sources, their locations, and other vital statistics can be found in 'RRS James Cook Cruise 41 (UK DIMES1).

4. Float Deployment

Three APEX were deployed on two cruises. The first cruise (UK1) was in December 2009 on the RRS James Cook, from which APEX 4779 was deployed (Figure 2). The second cruise (UK2) was in December 2010, also on the RRS James Cook, from which APEX 4781 and 4782 were deployed (Figure 2).

A summary of the float launch and surface times and locations is found in Table 1. The strategy for choosing the launch sites was to gather CTD data on the stratification associated with the Polar and Sub-Antarctic fronts in the Scotia Sea.

Table 1. Float Summary

	LAUNCH				*SURFACE*						
APEX ID	*Date*	*Time (GMT)*	*Lat.*	*Long.*	*Date*	*Time (GMT)*	*Lat.*	*Long.*	*% Mess. Transm.*	*Days Deploy.*	*Cruise*
4779	12/17/09	02:00	-59.1	-65.8	1/9/11	10:27	-48.5	-51.2	98	399	UK1
4781	12/30/10	12:17	-57.6	-68.2	4/22/11	21:21	-53.0	-56.4	97	114	UK2
4782	12/30/10	12:17	-57.6	-68.2	4/18/11	21:00	-52.6	-53.3	98	110	UK2

5. Float Performance

All three APEX performed according to their mission statements. APEX 4779 profiled every five days for the first nine months, every two days for the next two weeks, every day for the next two weeks, and every ten days

for the last two months. Both APEX 4781 and 4782 profiled every day for their entire mission length. Median drift depths for 4779, 4781, and 4782 were 1201 dbar, 1201 dbar, and 1202 dbar respectively. Although not evident in the median depth, 4782 experienced 5-6 days throughout the mission length when it drifted ± 200 dbar off programmed depth (see Appendix C).

4779, 4781 and 4782 performed 85, 118 and 113 profiles respectively. The success rate of message transmission via IRIDIUM satellite for all three APEX was 97.7% (see Table 1 for individual success rates). TOA data collected by 4779, 4781 and 4782 was 97.7%, 43.2% and 31%. The reason for such low rates for the latter two is directly related to their mission setup. Each sound source transmits once daily, within the window 01:00-02:00 GMT. If the float is drifting at this time, it will register and record the corresponding TOA and correlation height. However, if the float is performing a profile or is transmitting at the surface, it will not. Since 4781 and 4782 were set to profile every day, only 10-11 hours of each day was spent drifting. Therefore, as can be seen in Figure 3, the floats were often performing other tasks within the listening window.

Appendix A, B and C contain float track (from GPS position), drift data (temperature, salinity and pressure), along track sections from CTD profiles (potential temperature, absolute salinity, potential density, sigma0 and speed of sound), and T-S diagrams, for APEX 4779, 4781 and 4782 respectively.

Table 2. Calibration Summary

APEX ID	*SBE 41CP Ser. No.*	*Maximum Offset*		
		Temperature (˚C)	*Conductivity (Siemens/m)*	*Pressure (PSIA)*
4779	2805	0.0002	0.0002	0.01
4781	2807	0.0001	0.0000	0.01
4782	2808	0.0003	0.0002	0.01

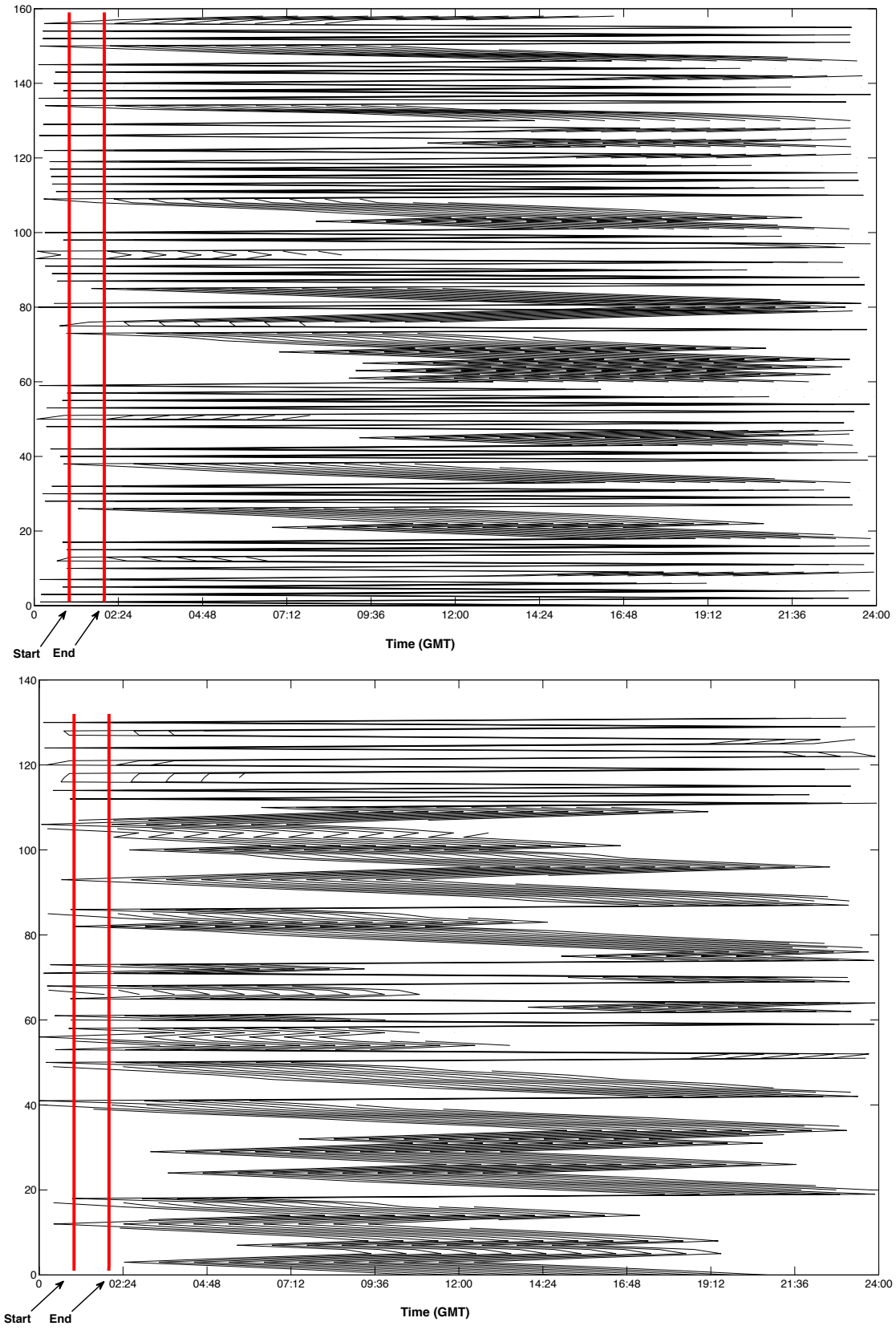

Figure 3: Listening window (black lines) each day for APEX 4781 (top) and 4782 (bottom). The red lines indicate the start and end of the listening window. For a TOA to be registered, the black line must cross both red lines.

6. Data Quality

All three APEX were calibrated by Sea-Bird Electronics, Inc. Table 2 shows the maximum offset in temperature, conductivity and pressure for each. For more information see calibration reports for SBE-41CP, serial numbers 2805, 2807 and 2808.

Data quality is determined using two methods. First, density profiles in the 800-1200 dbar range for each APEX are compared to investigate their 'tightness'. Second, single profiles from each APEX are compared to CTD stations done on each respective cruise (UK1 and UK2), whenever they are within 100 km of each other.

Figure 4 shows the deep section of all profiles for each APEX. All three show fairly good 'tightness' within the deeper regions. Range of distance between single profiles are: 5-5620 km, 30-2210 km and 23-1930 km for APEX 4779, 4781 and 4782 respectively.

In figure 5, single APEX profiles are compared to CTD stations performed during cruises UK1 and UK2. The top figure compares profile 24 (blue line) from APEX 4779 with CTD stations 3 (black line) and 4 (red line) from UK1. These stations were 59 km and 66 km, respectively, east of the APEX profile, and were sampled four months earlier. At depth these profiles are very similar, with a seasonal density change evident in the upper layers. The lower figure compares profile 2 from both APEX 4781 (red) and APEX 4782 (blue) with CTD station 42 (black) from UK2. This CTD station was 55 km west of the APEX profiles and was sampled 2 days earlier. Again the deeper layers have very similar density profiles, however so does the upper layers. This is probably due to the close sampling in time between these sections. Three other profiles from APEX 4781 were compared to a CTD station from UK2 (not shown), with similar results for the deeper layers. From this we conclude that the data quality for all three APEX is good.

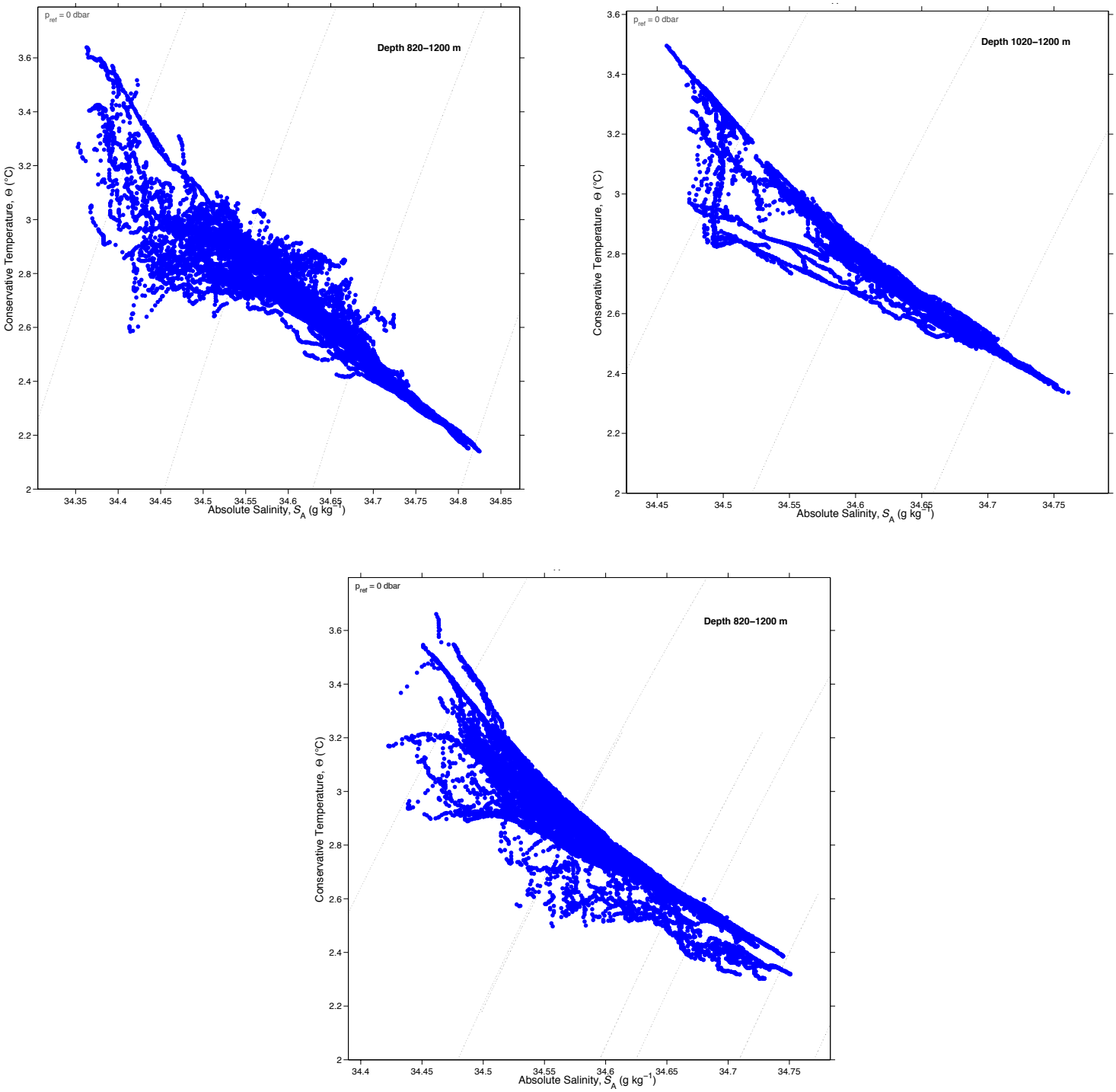

Figure 4. TS relationships for all profiles from APEX 4779 (top left), APEX 4781 (top right) and APEX 4782 (bottom). Depth range for each APEX is indicated in the top right corner of each figure. Range of distance between single profiles for APEX 4779, 4781 and 4782 are as follows: 5-5620 km, 30-2210 km and 23-1930 km.

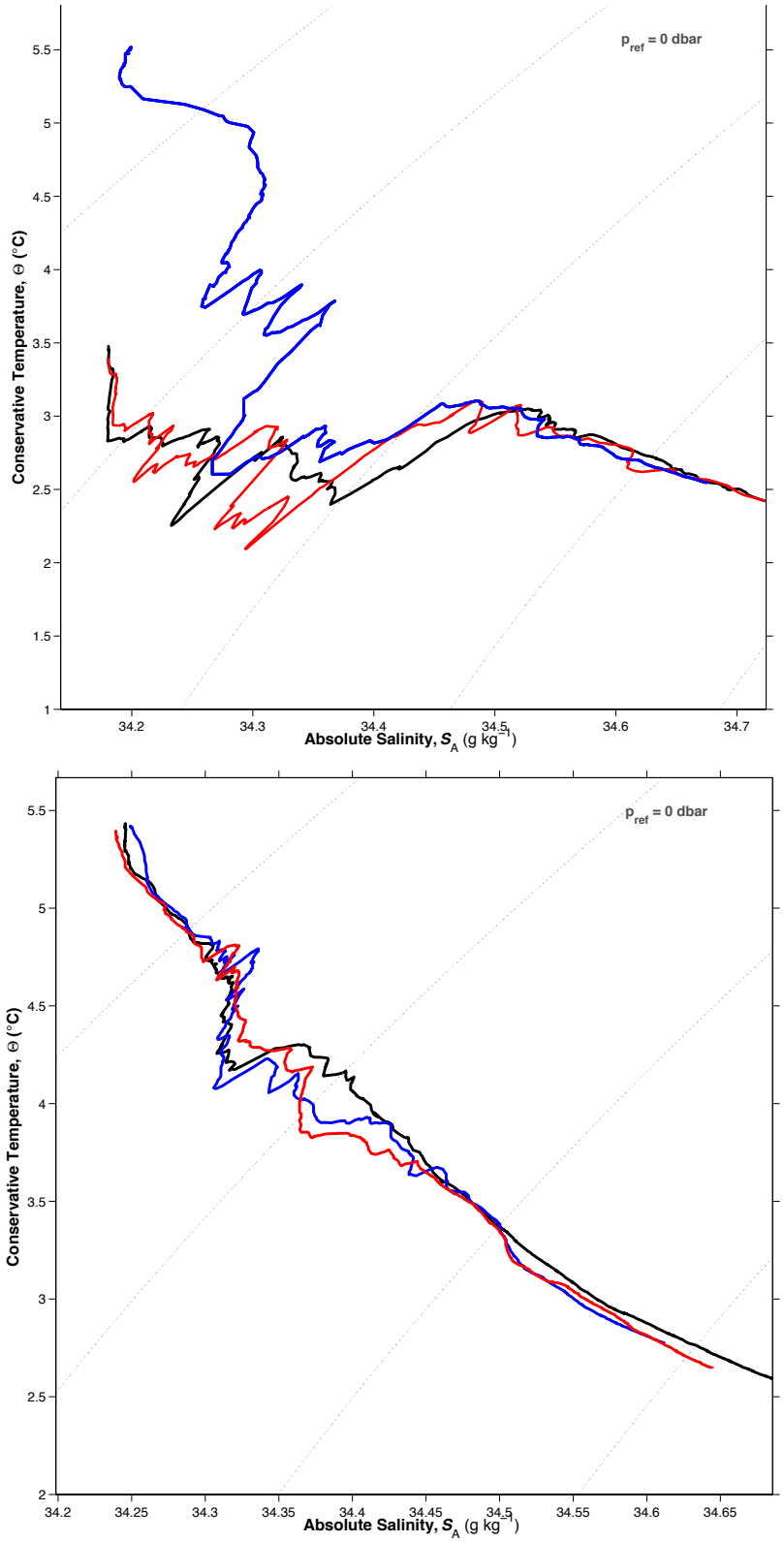

Figure 5. Top: TS relationship for APEX 4779 profile 24 (blue), UK1 station 3(black) and UK1 station 4(red). CTD stations are ~59/66 km (respectively) east of the APEX profile, and sampled four months earlier. Bottom: TS relationship for APEX 4781 profile 2 (red), APEX 4782 profile 2(blue) and UK2 station 42 (black). CTD station is ~55km west of APEX profiles, and sampled 2 days earlier.

7. Float Tracking

In addition to GPS positioning, each APEX was tracked using ARTOA software (Wooding et al. (2005) and WHOI (2005)), which originated at the University of Rhode Island and was further developed at IFREMER. ARTOA, which was used to track the floats, is run on MATLAB. The TOA's were corrected for the Doppler shift and difference in transmission time, and then interpolated using a variable width (usually 20-day) cubic spline filter, before tracking. Tracking used a least-squares method if more than two TOA's were available. The final sound velocity chosen for this experiment was 1.5 km/sec. Variations of sound velocity are partially accounted for by the sound source offsets used in tracking.

Upon surfacing, each APEX acquires a GPS fix and records position, date and time. The GPS time is then compared to that of the internal clock, and the offset recorded in the engineering log. If the offset becomes excessively large (>30 s), the clock is reset to GPS time. All three APEX experienced a drift in their internal clocks, as can be seen in Figure 6. This offset was

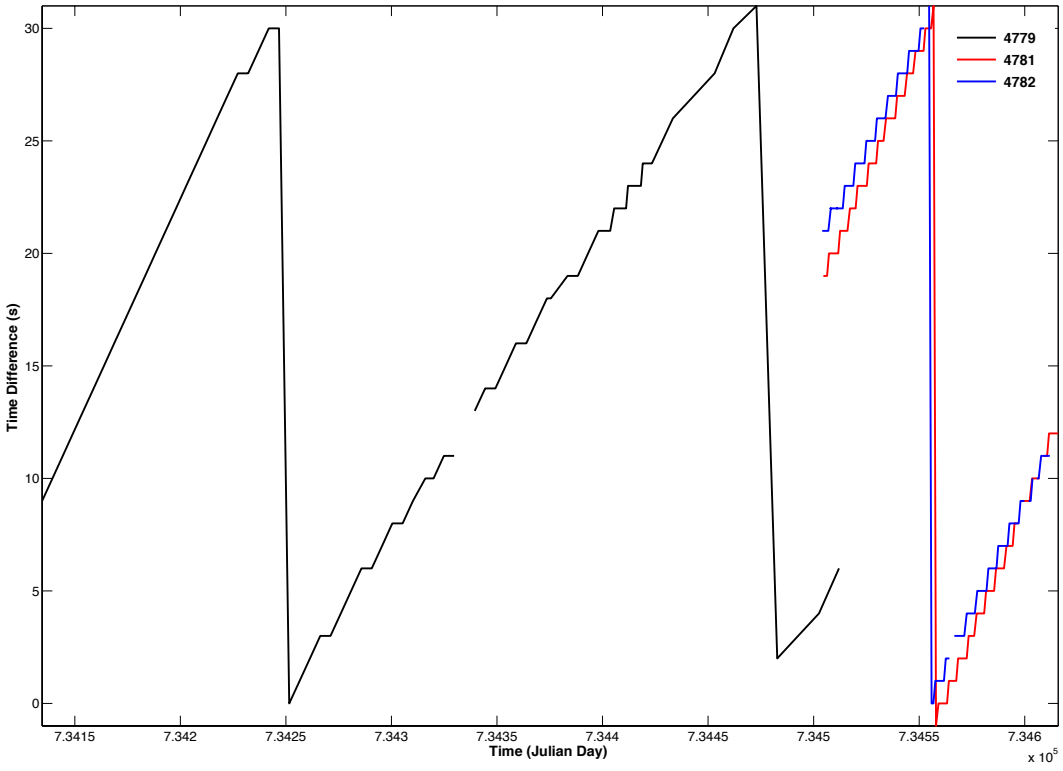

Figure 6. Time difference between internal APEX clock and GPS time, for 4779 (black), 4781 (red) and 4782 (blue). If the time offset is excessive (>30 s), the internal clock is reset to GPS time.

removed from the TOA data, before tracking.

Tracking of all three APEX was straightforward, using sounds sources UK1-1, UK1-2, UK1-3 and UK1-4. Large time offsets were used on all four sounds sources, calculated directly from the first corrected TOA's for each sounds source (see Table 3). As a quality check, longitudinal offsets between the track and GPS position were calculated and compared with the associated speeds at these points (Figure 7). Since the float does not simultaneously record TOA's and acquire a GPS fix, there is a time offset between the two. Median time offsets[1] for APEX 4779, 4781 and 4782 were 10.8, 9.5 and 13.0 hours, respectively. This time offset translates into a distance offset, and since the flow is strongly zonal it appears as an eastward drift. Figure 7 shows an increase in the longitudinal offset for increasing speeds. Both APEX 4779 and 4782 show eastward drift for almost all GPS points. APEX 4781, however, shows an eastward drift for approximately 2/3 of its GPS points. This could be due to ARTOAs large tracking error along the northeastern edge of the Scotia Sea (see Figure 1b in Appendix B).

Table 3. Sound source offset for ARTOA

APEX	*Time Offset (seconds)*			
	UK 1-1	*UK 1-2*	*UK 1-3*	*UK 1-4*
4779	88	70	70	78
4781	70	70	70	78
4782	70	70	70	78

Figure 1.b in Appendix A, B and C contains the float track for APEX 4779, 4781 and 4782, respectively.

8. Sound Source Clock Offset

[1] The time offsets were calculated from 02:00 GMT each day.

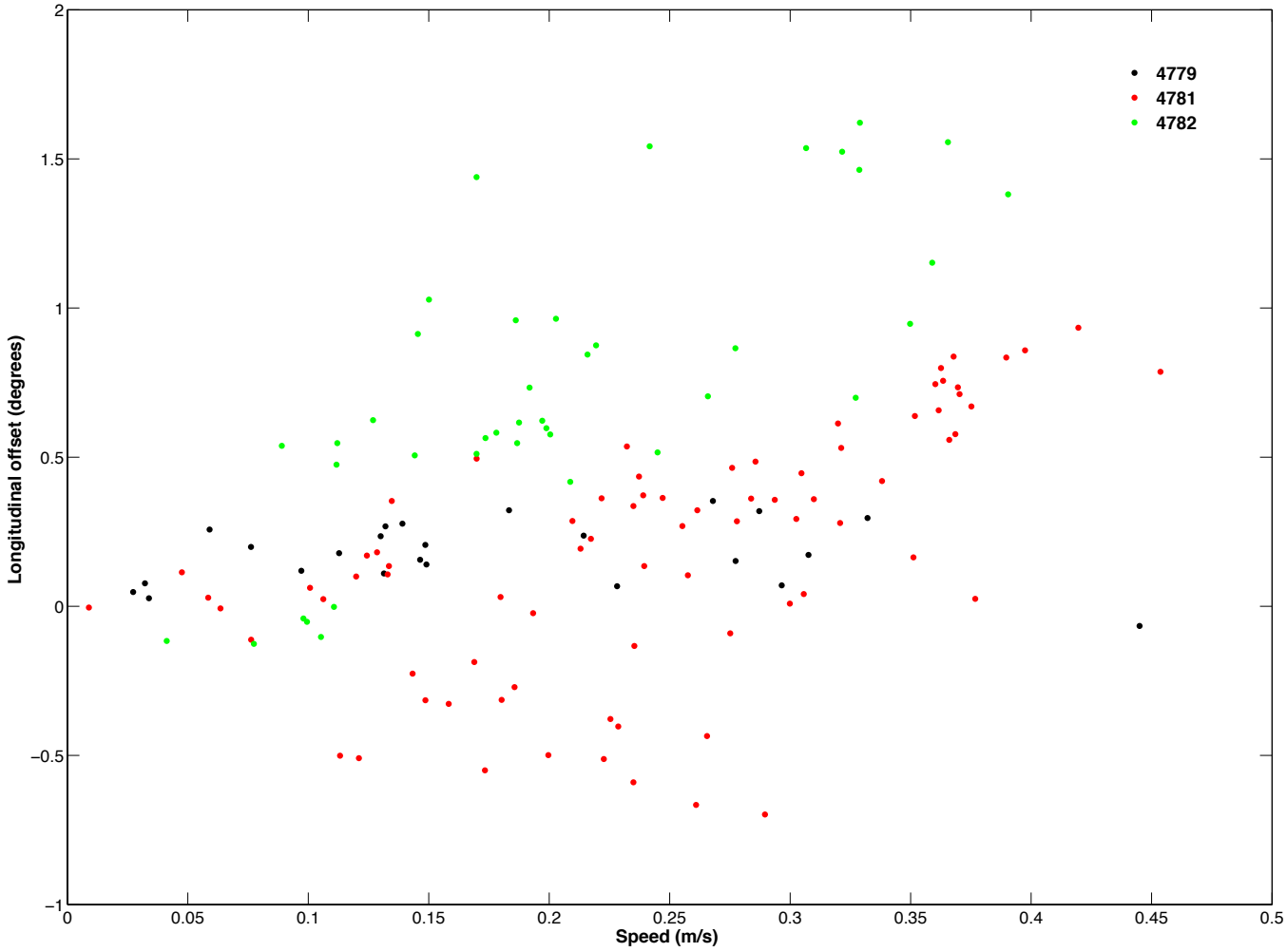

Figure 7. Longitudinal offset (degrees) between ARTOA track and GPS position versus float speed (m/s) for APEX 4779 (black dots), 4781 (red dots) and 4782 (green dots). A positive longitudinal offset indicates GPS position is east of ARTOA track.

9. Acknowledgements

The authors thank the captain and crew of RRS James Cook for their able assistance in carrying out this sea-going experiment. Thanks are given to the Chief Scientists Ablerto Naveira-Garabato (UK1) and Michael Meredith (UK2). Peter Lazarevich is acknowledged for assistance with floats on UK1. Special acknowledgement is given to Stephanie White for preparation and deployment of floats on UK2. DIMES was funded by the National Science Foundation under Grant No. OCE-0622670.

10. References

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Rossby, T., Dorson, D., and Fontaine, J. (1986). The RAFOS system. *J. Atmos. Oceanic Technol.*, **3**, 672-679.

Wooding, C. M., Furey, H. H., and Pacheco, M. A. (2005). RAFOS Float Processing at the Woods Hole Oceanographic Institution. *Woods Hole Oceanog. Inst. Tech. Rept.*, WHOI-2005-02.

Woods Hole Oceanographic Institute (2005). ARTOA: Advanced RAFOS Float Tracking Software, Version 3.0. http://www.whoi.edu.science/PO/rafos/software.html.

Appendix A

The following figures show float track diagram (Figure 1), drift temperature, salinity and pressure (Figure 2), along track sections of potential temperature (Figure 3a), absolute salinity (Figure 3b), potential density (Figure 3c), sigma0 (Figure 3d) and speed of sound (Figure 3e), and T-S diagrams (Figure 4) for APEX 4779.

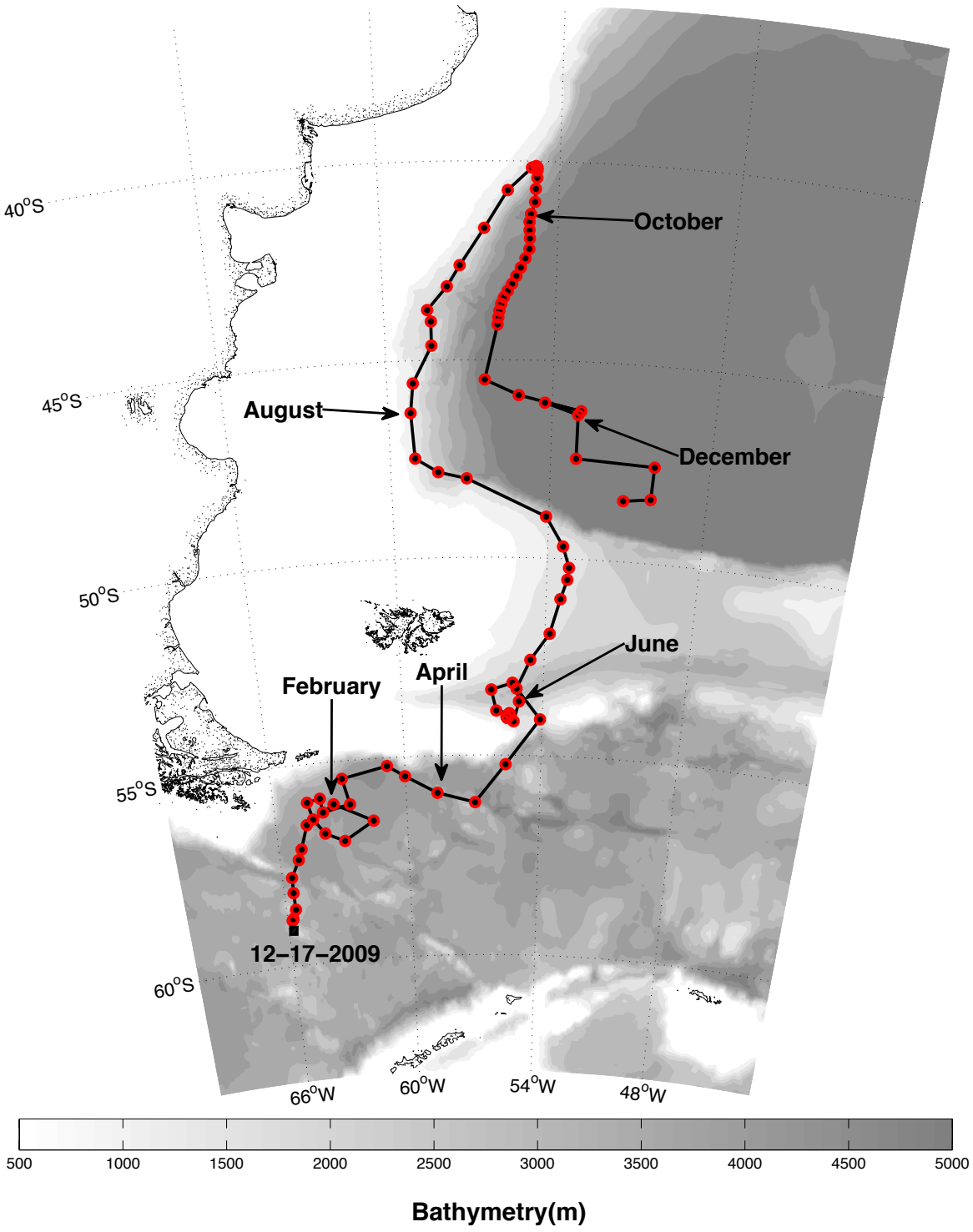


Figure 1a**.** APEX 4779 track diagram from GPS position data. Red dots indicate CTD profiles with GPS positions, whereas the black square is deployment position (with date). Bathymetry is shaded in 500-meter intervals, according to the color bar.

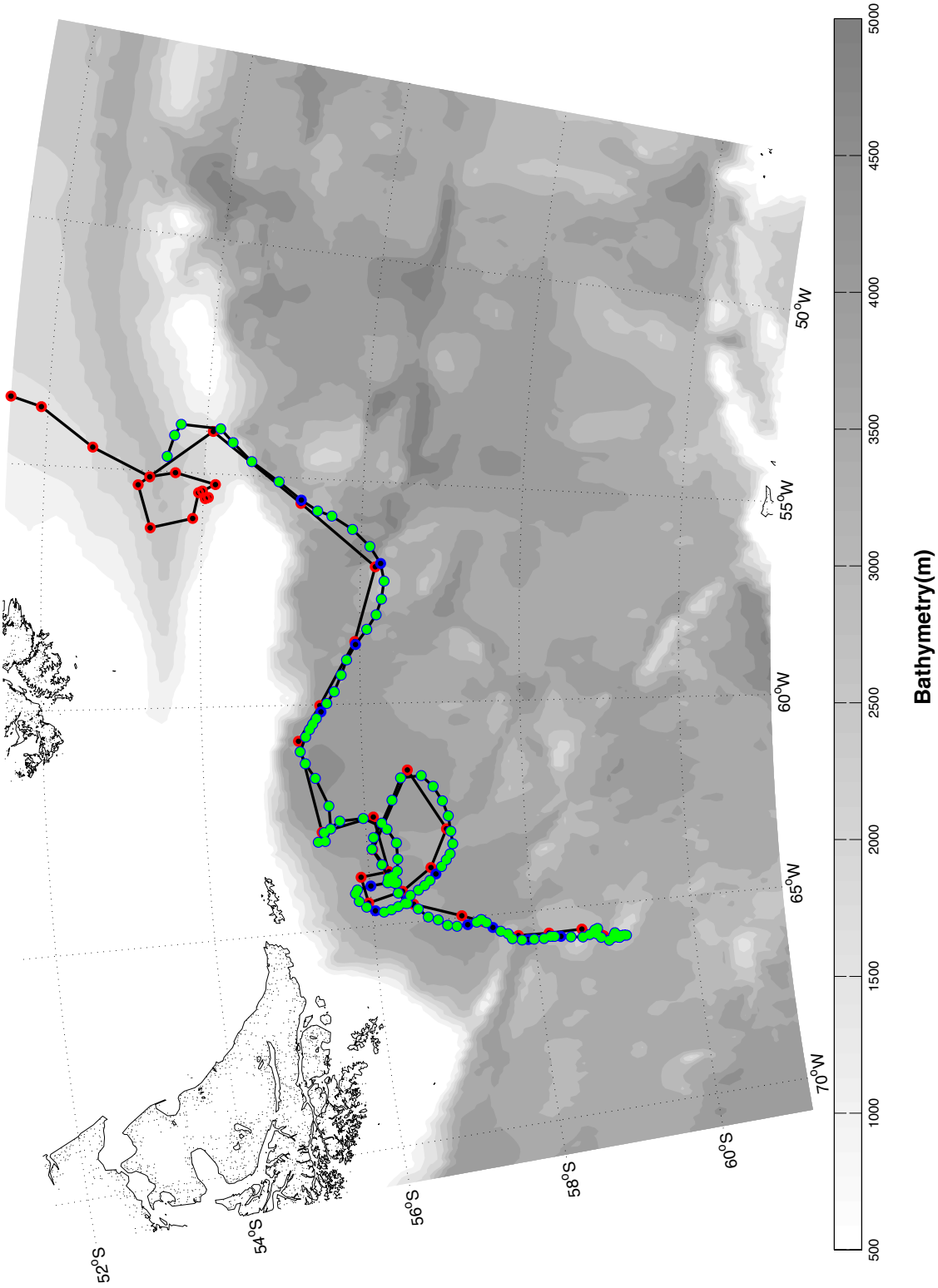


Figure 1b. APEX 4779 track diagram from sound source data (blue dots and line), GPS position (red dots and black line) and points of recorded TOA's (green dots). Bathymetry is shaded in 500-meter intervals, according to the color bar.

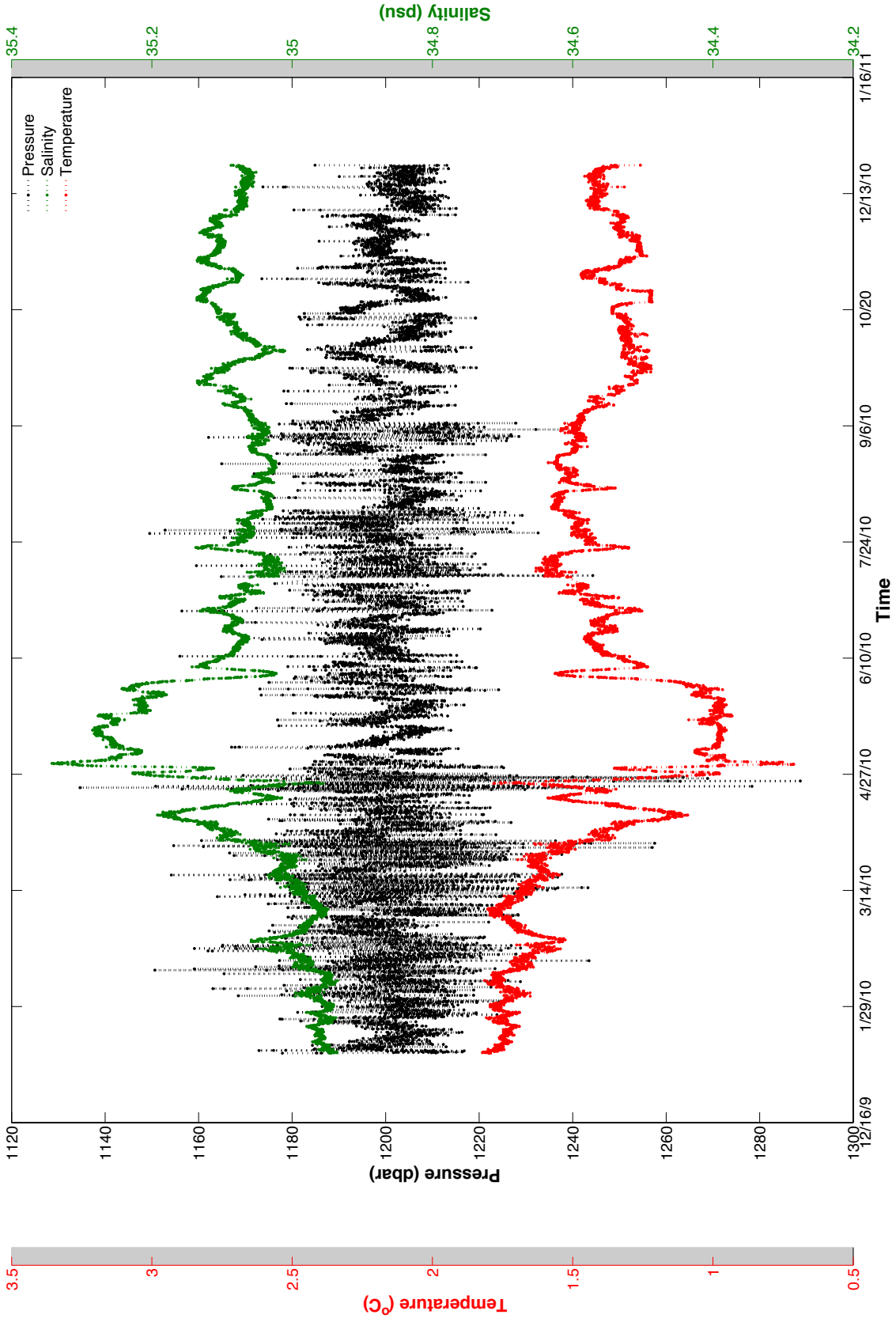


Figure 2. Pressure (black), temperature (red) and salinity (green) during the drift phase of each cycle for APEX 4779.

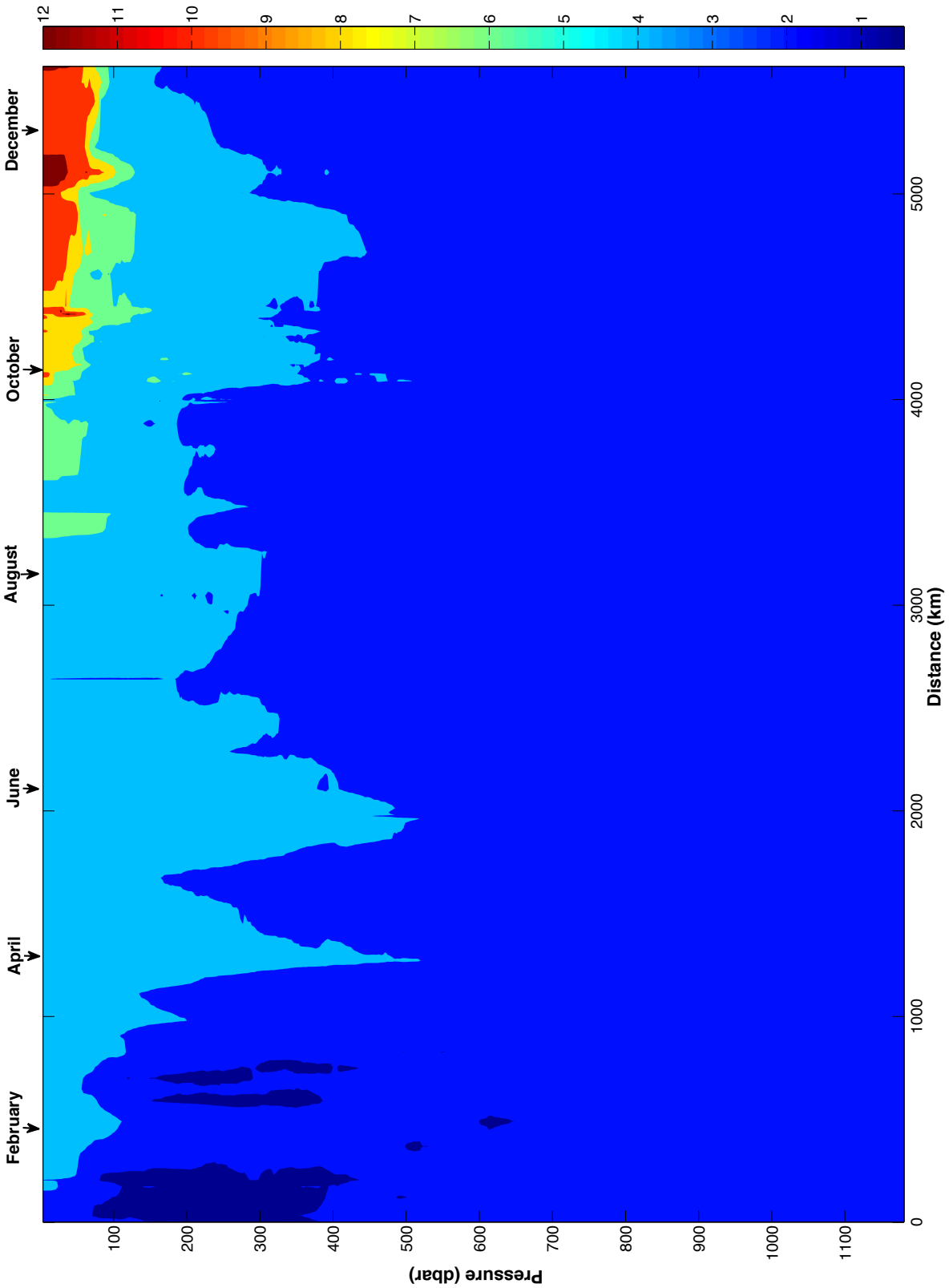


Figure 3a. Along track potential temperature (˚C) for APEX 4779. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

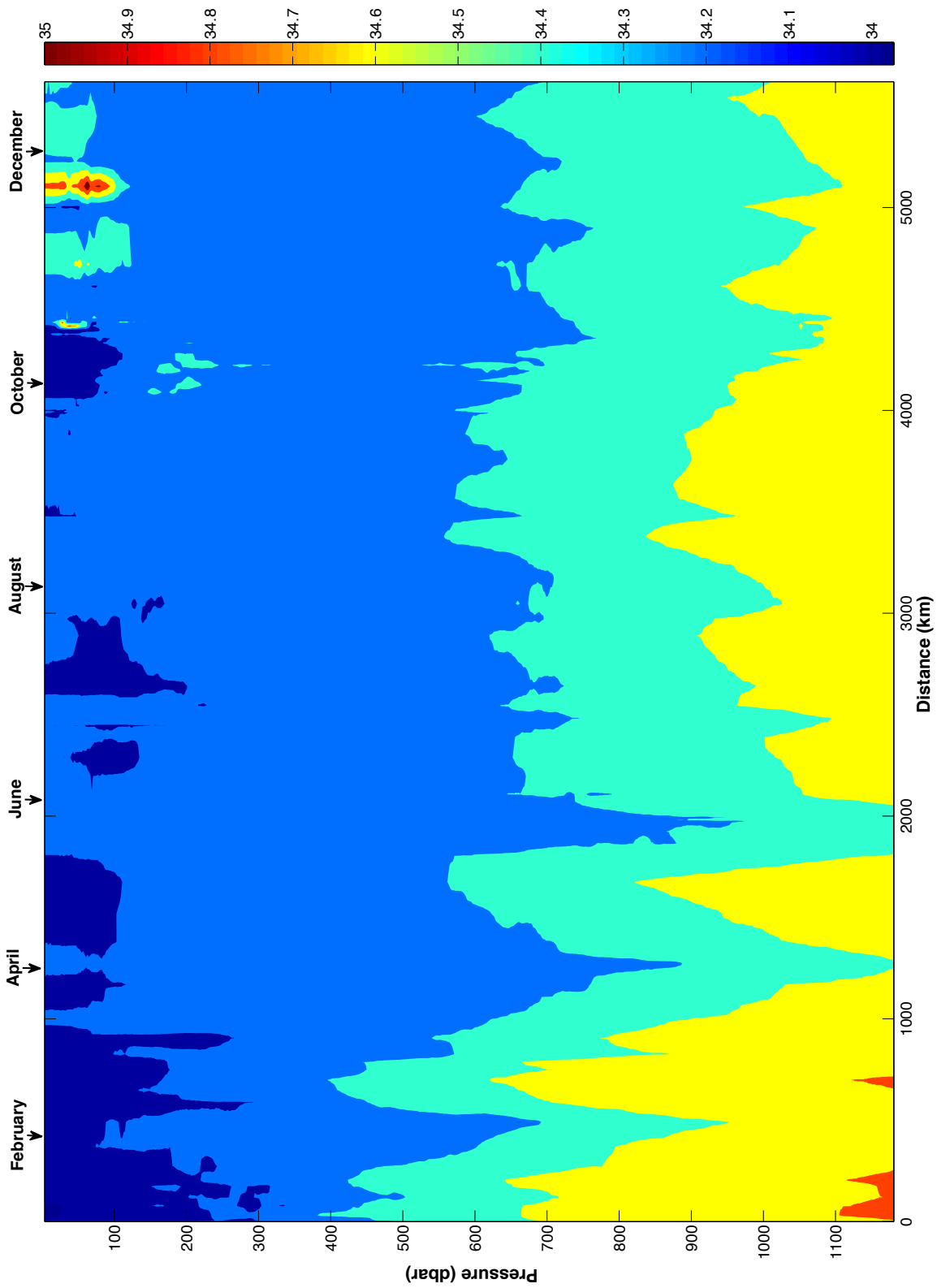


Figure 3b. Along track absolute salinity (g/kg) for APEX 4779. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

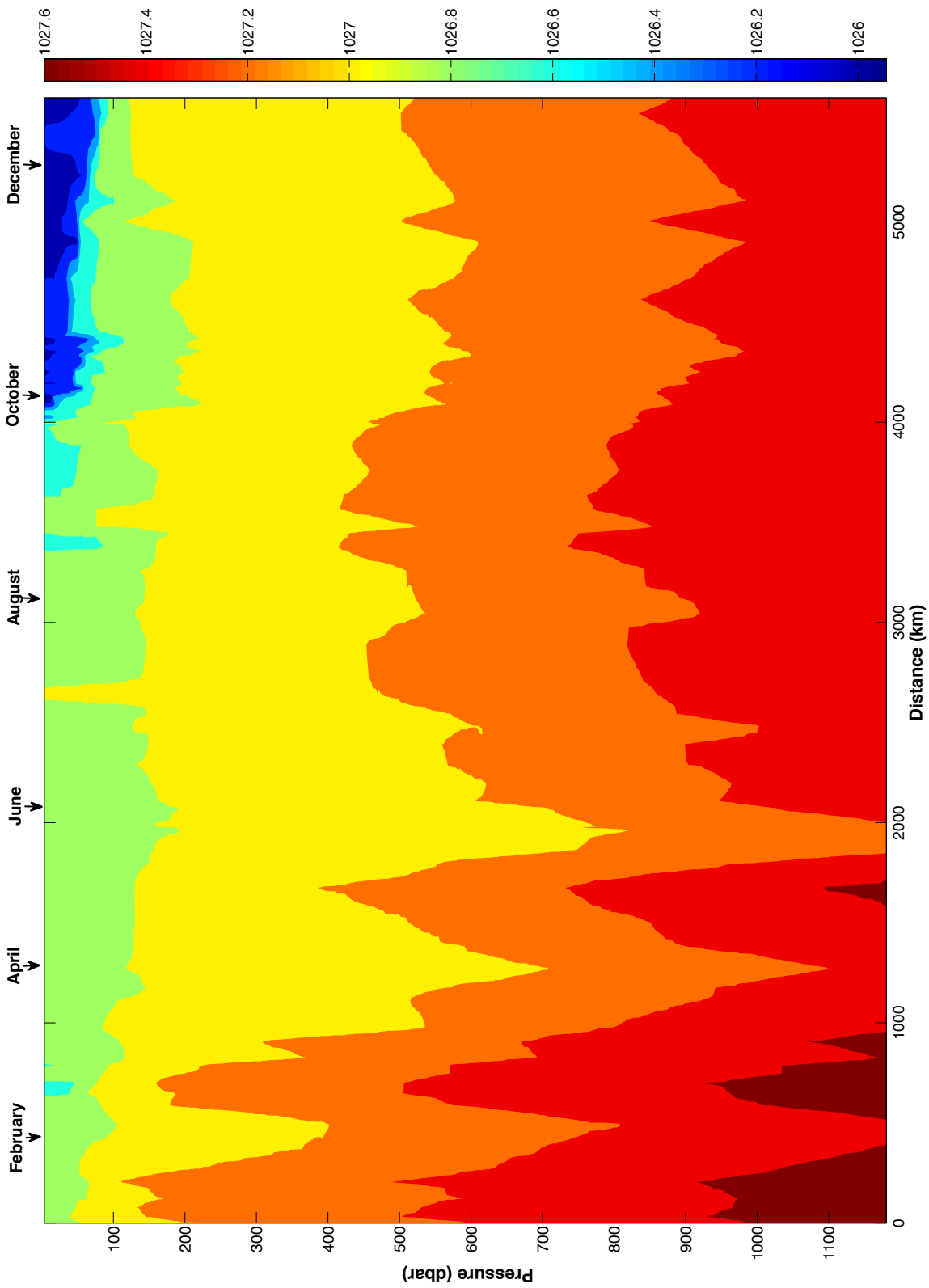


Figure 3c. Along track potential density (kg/m^3) for APEX 4779. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

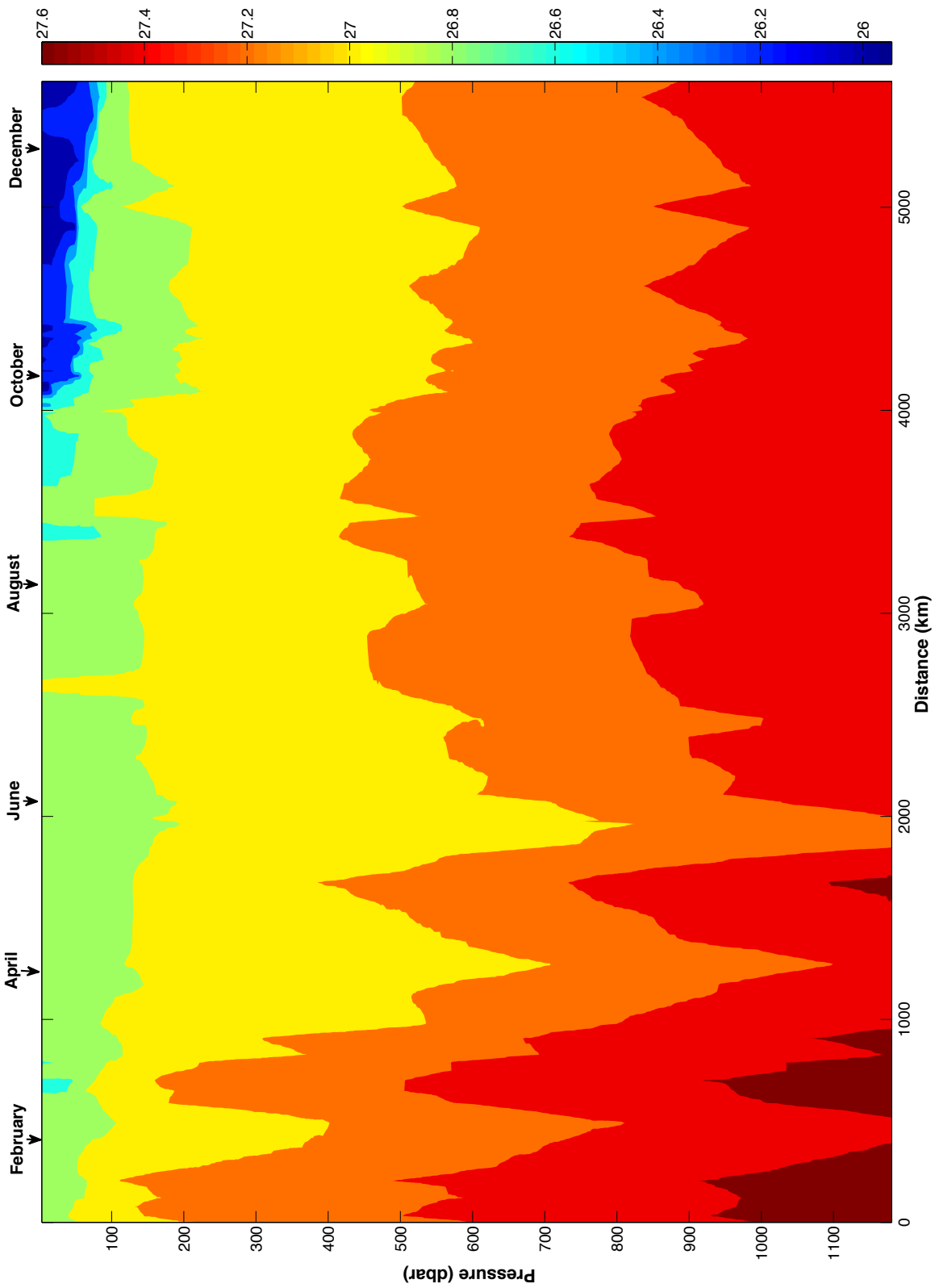


Figure 3d. Along track sigma0 (kg/m^3) for APEX 4779. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

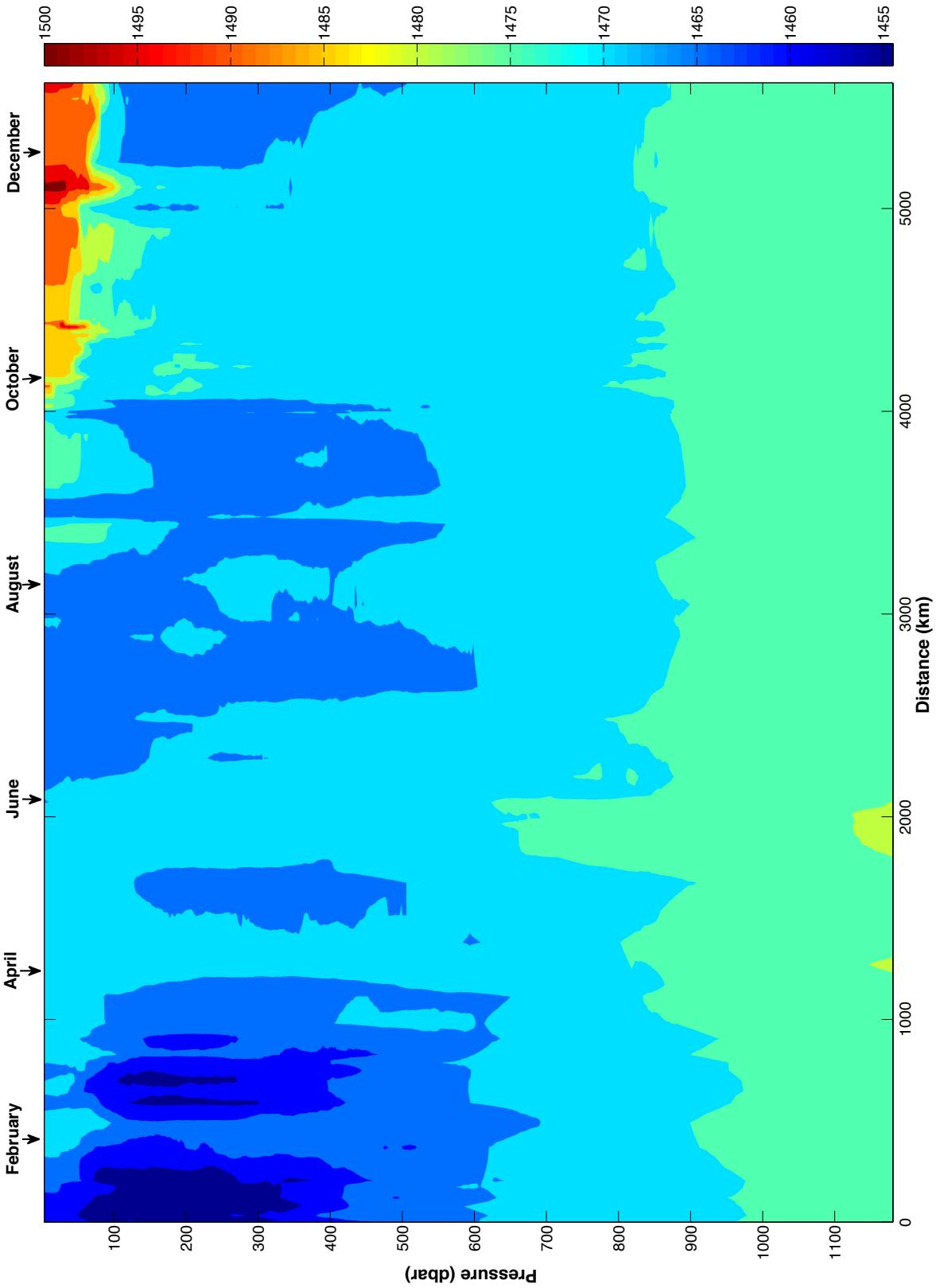


Figure 3e. Along track speed of sound (m/s) for APEX 4779. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

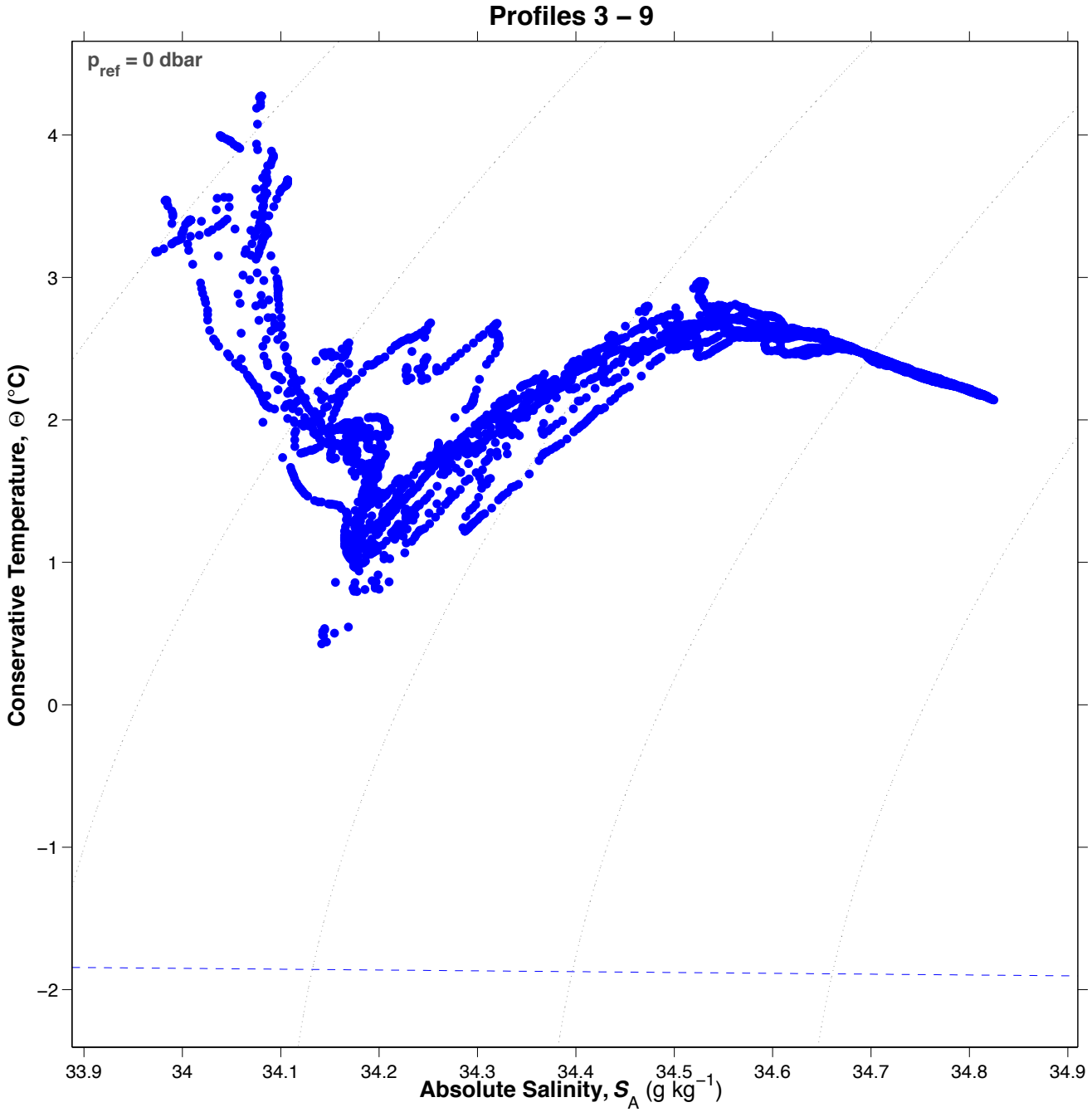
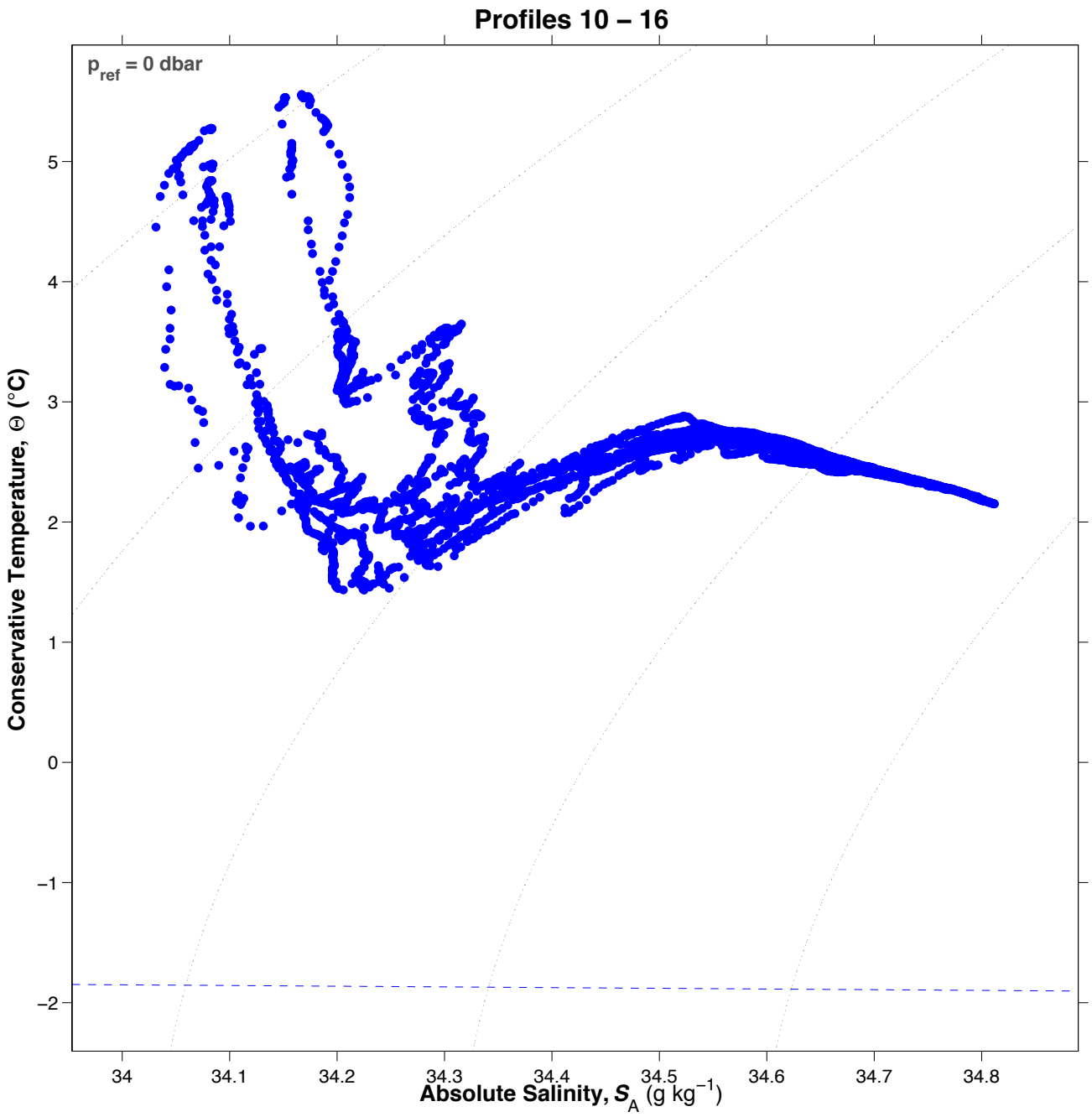


Figure 4: Conservative Temperature (˚C) versus Absolute Salinity (gkg^{-1}) along track, starting with the first profile after deployment, for APEX 4779. Each figure shows seven successive profiles. The freezing line is indicated by the blue dashed line.



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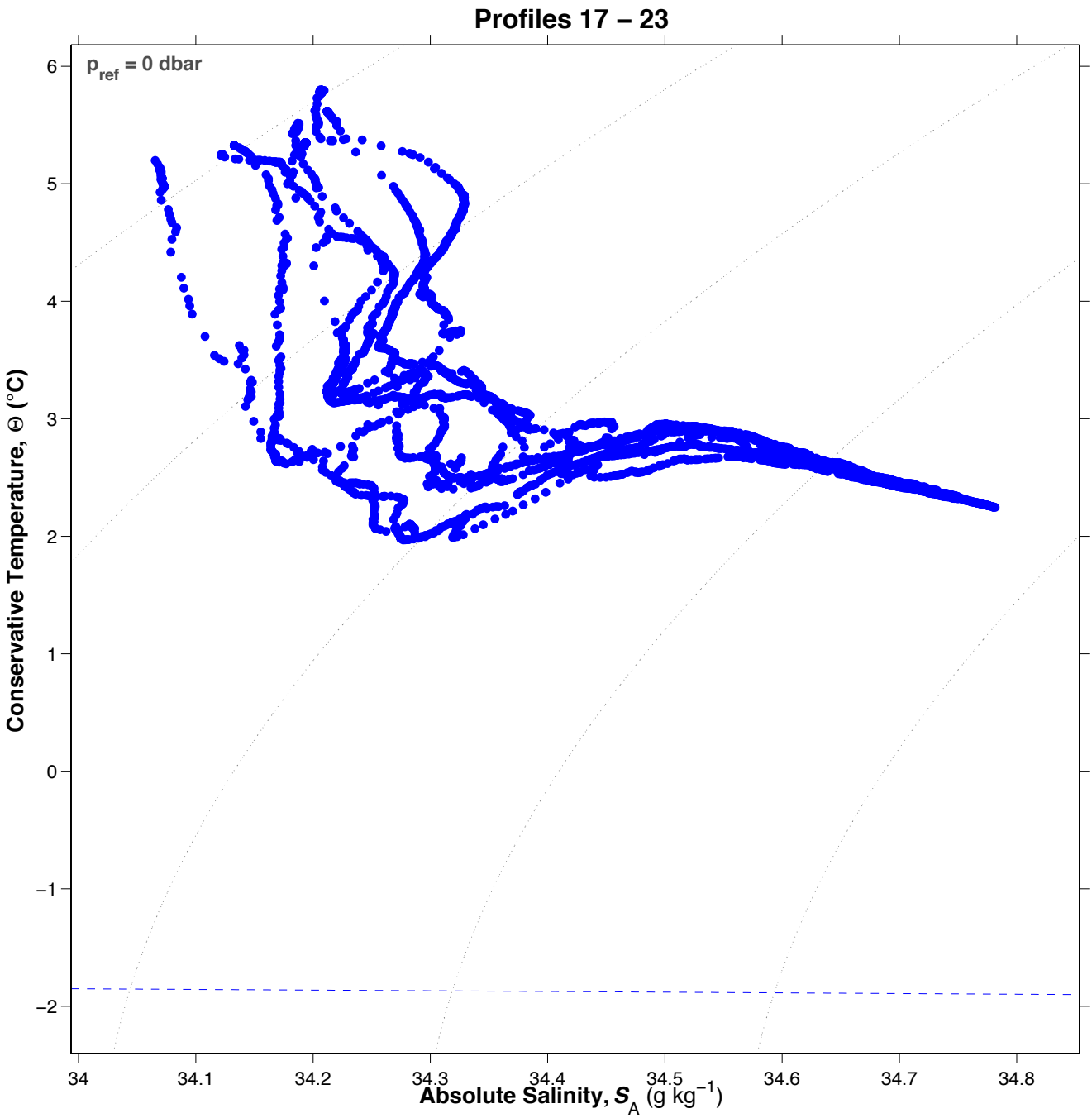

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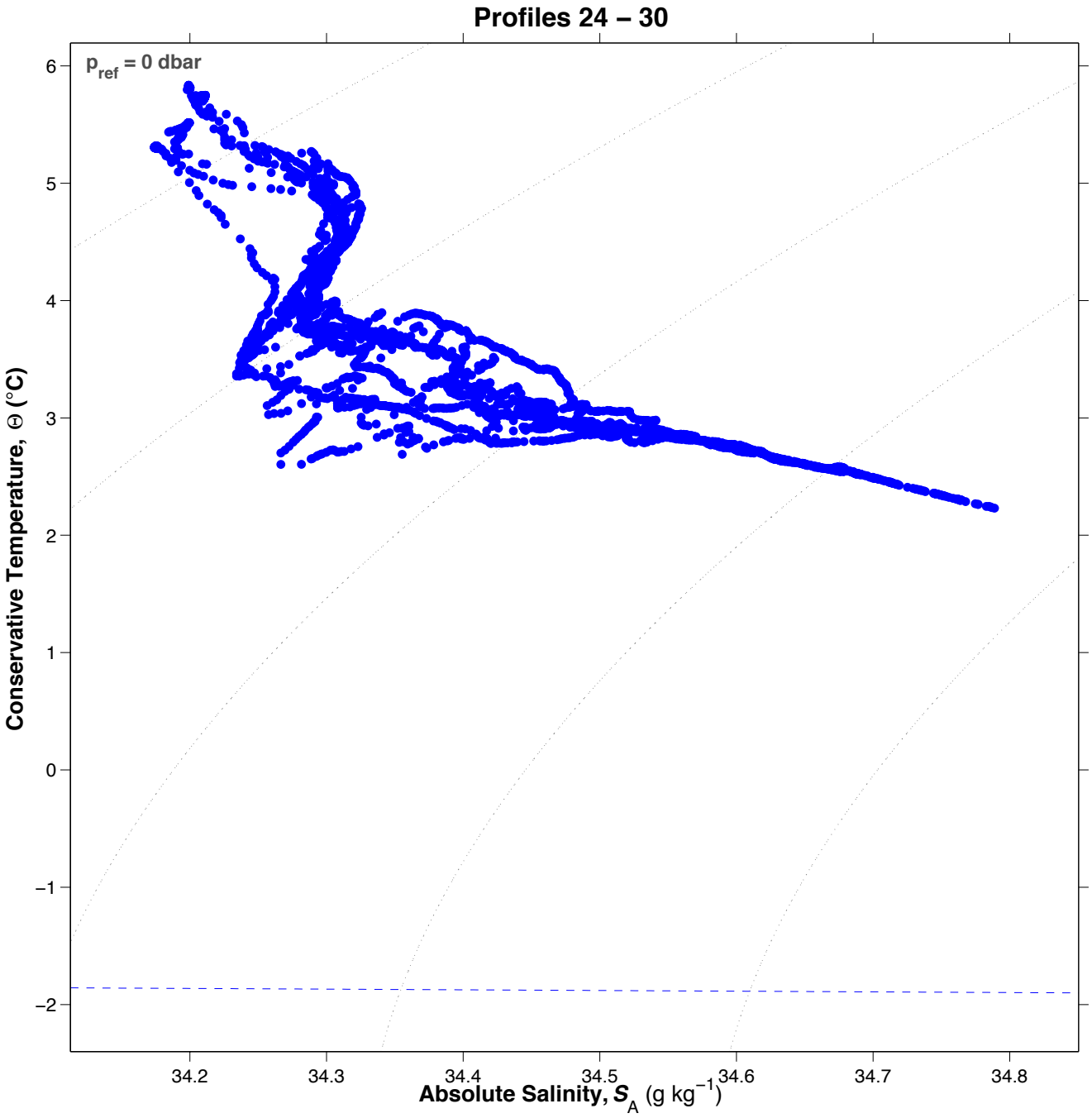

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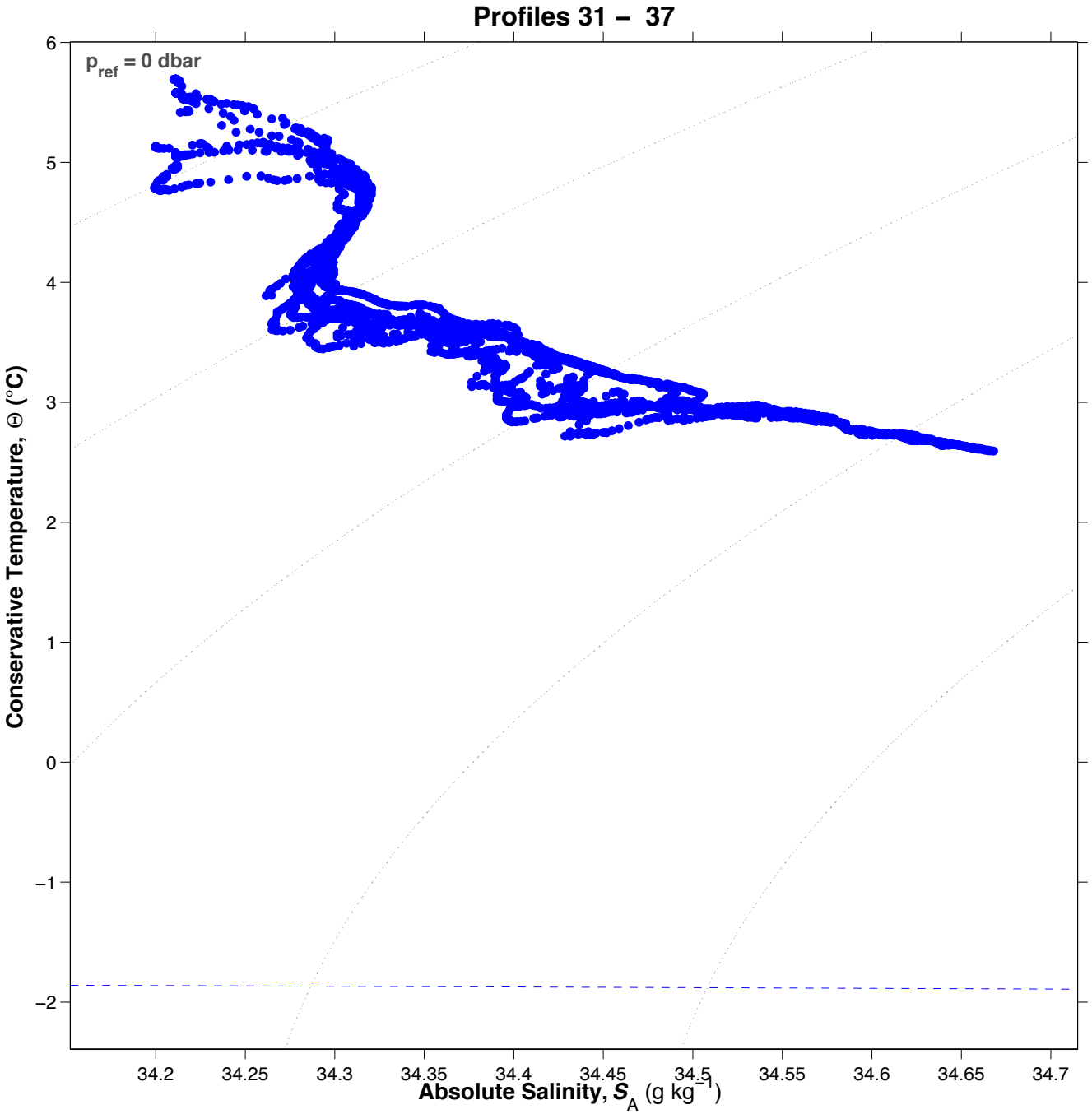

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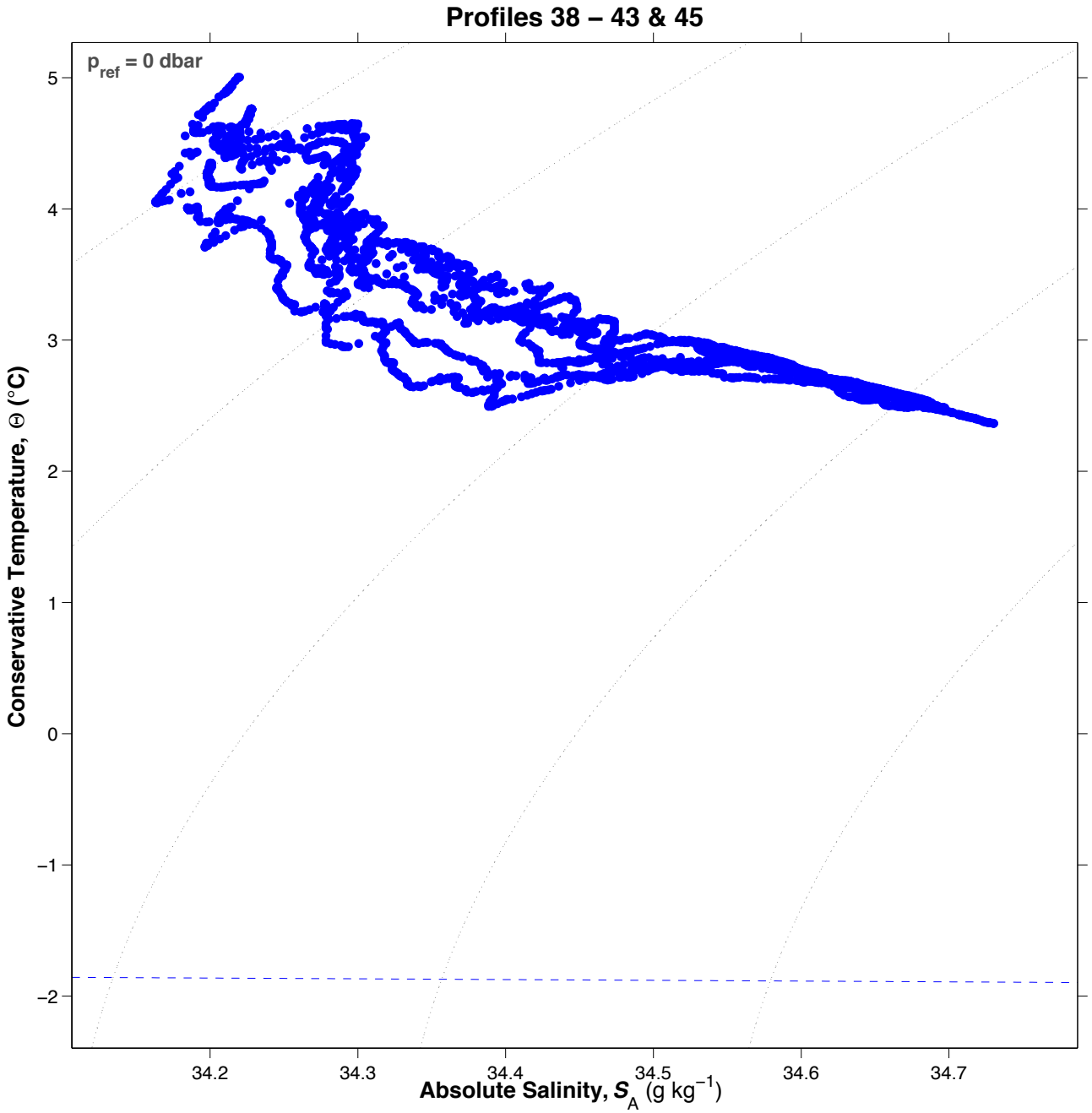

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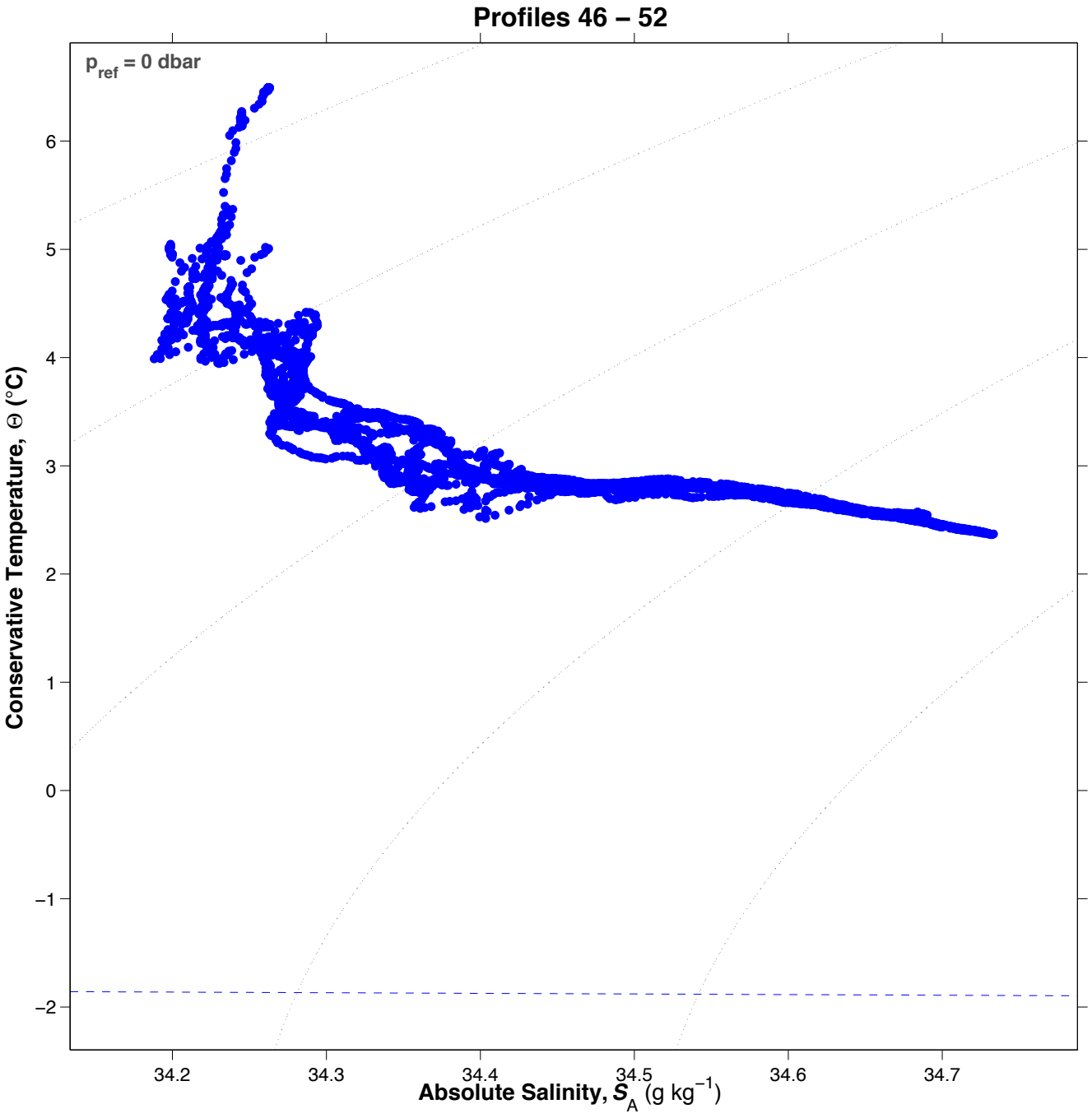

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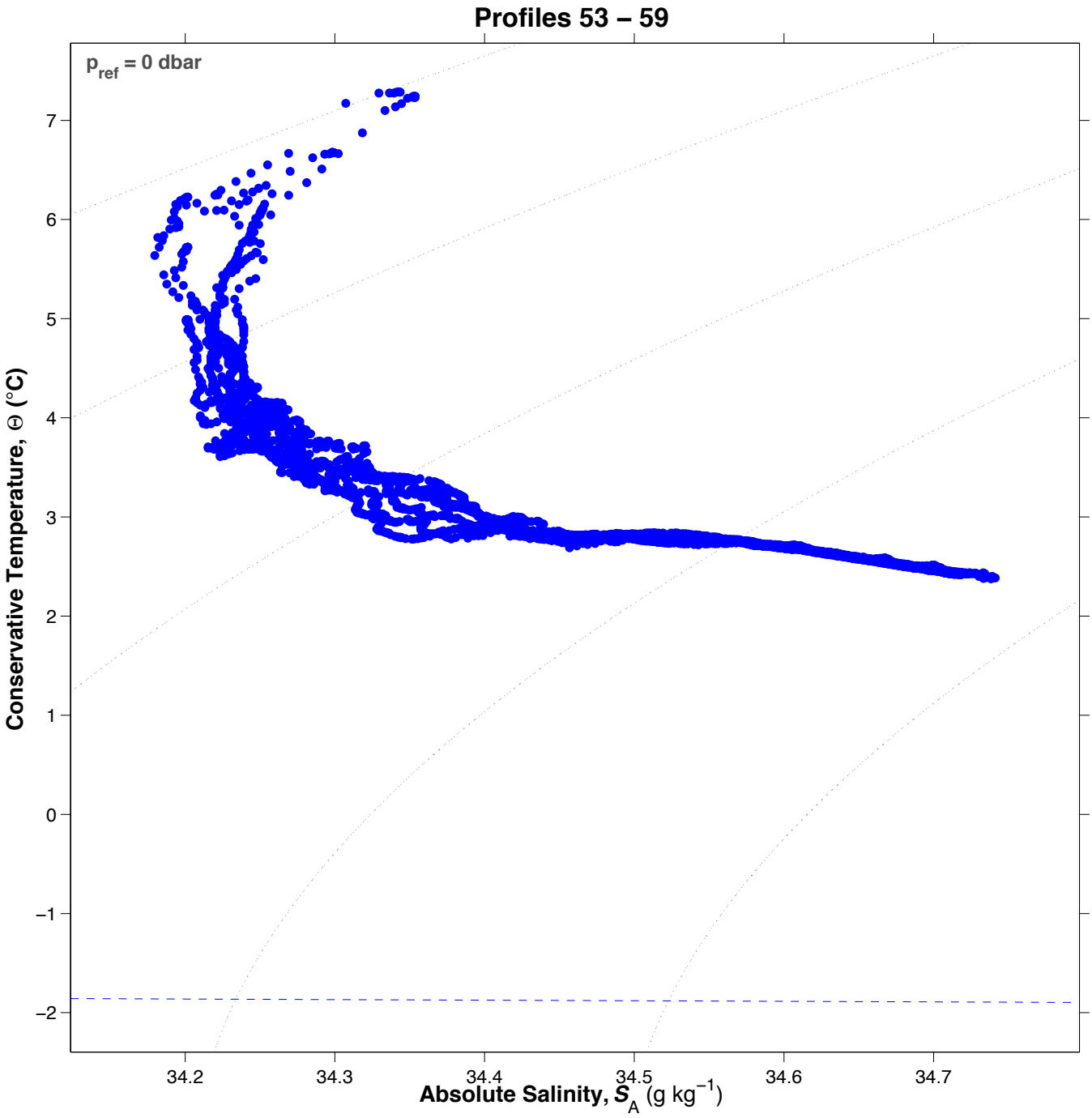

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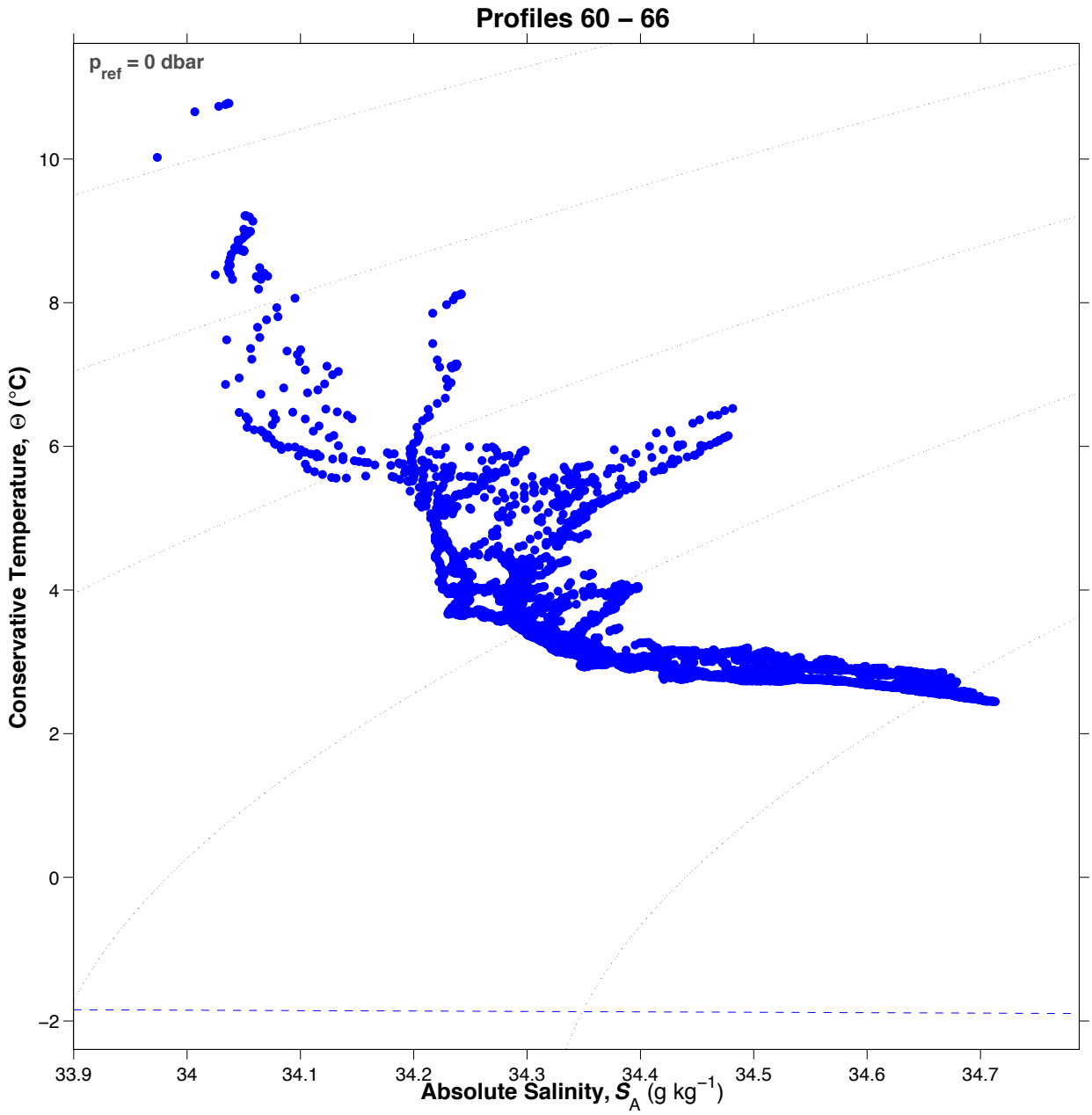

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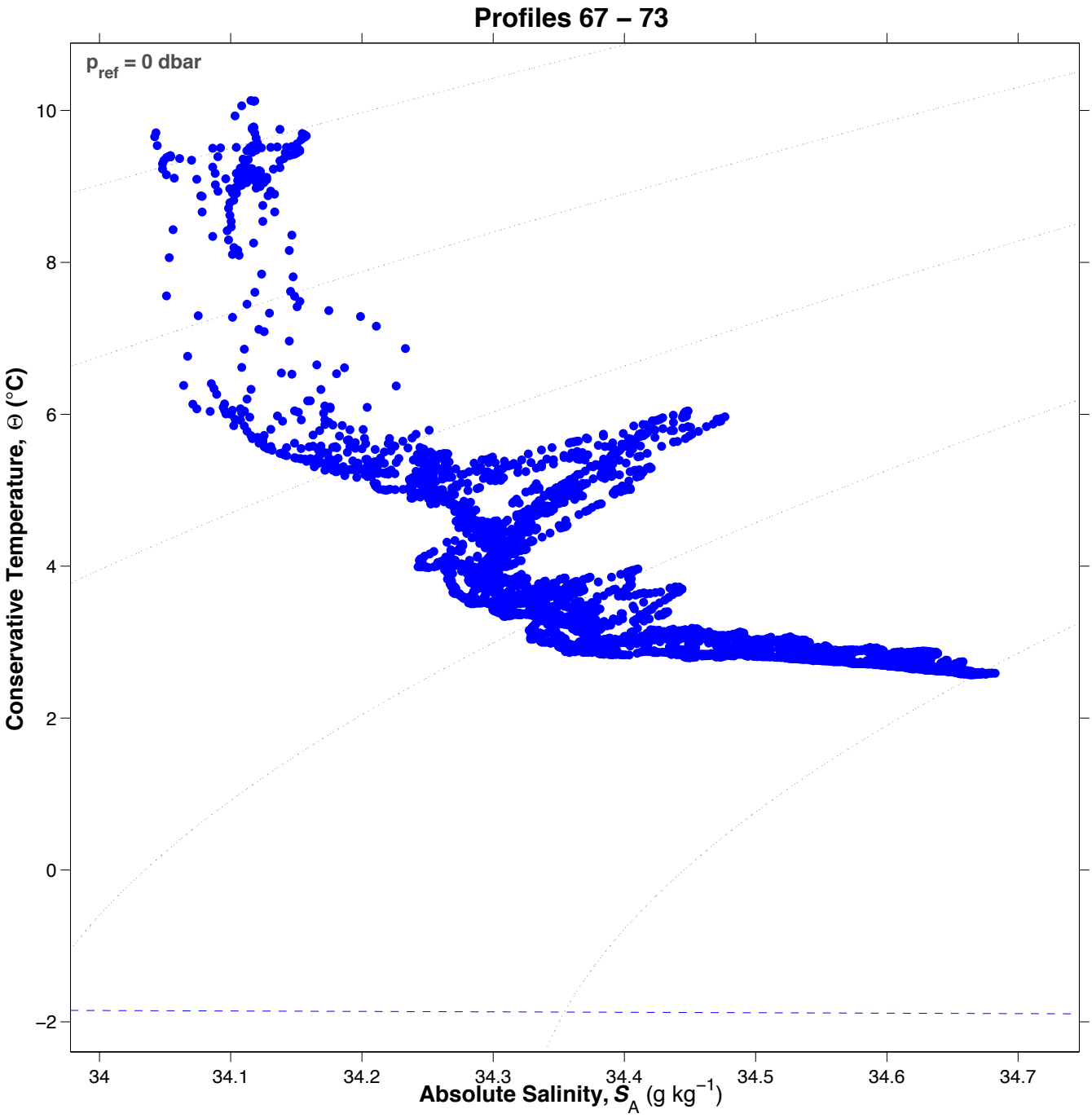

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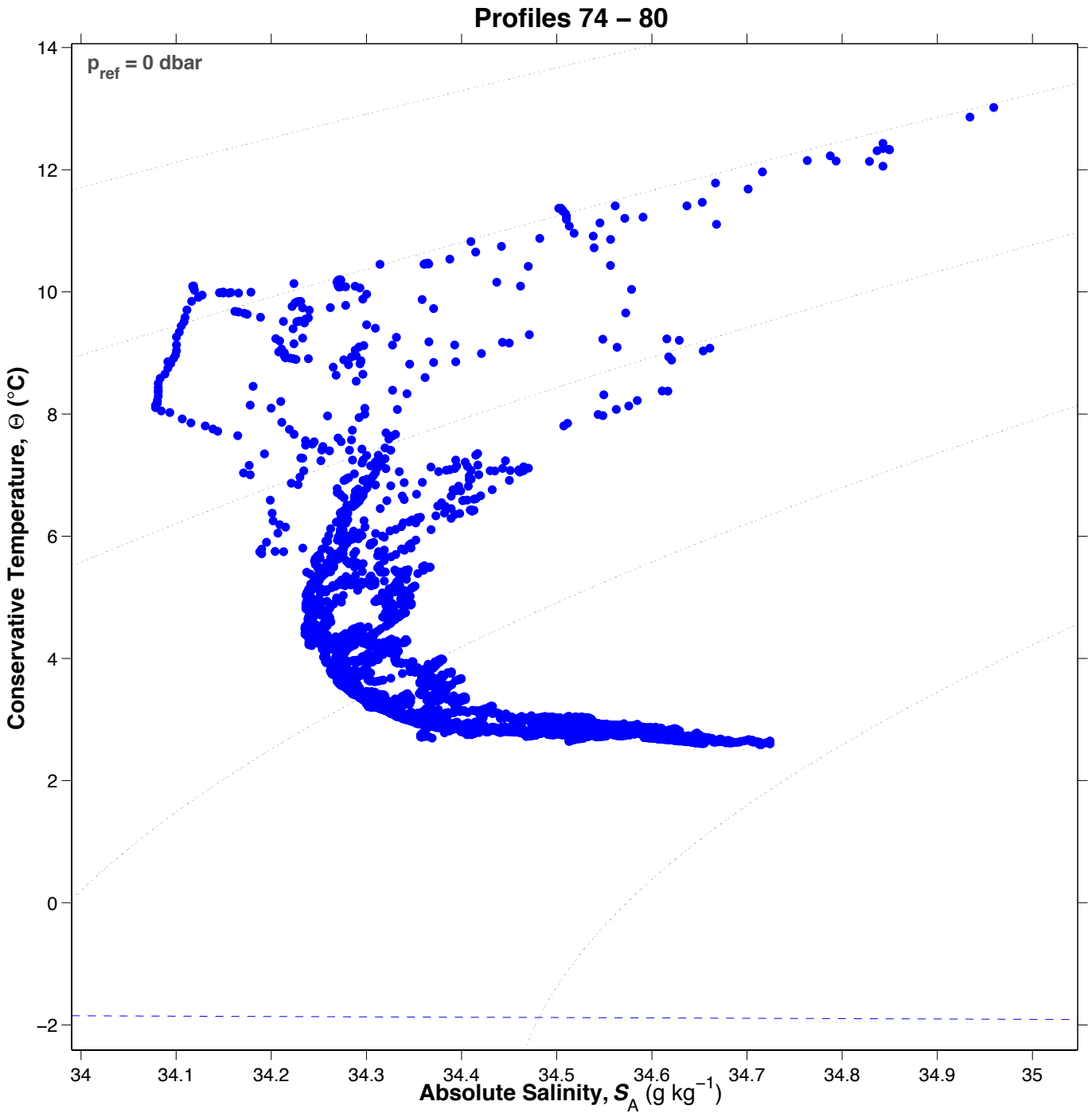

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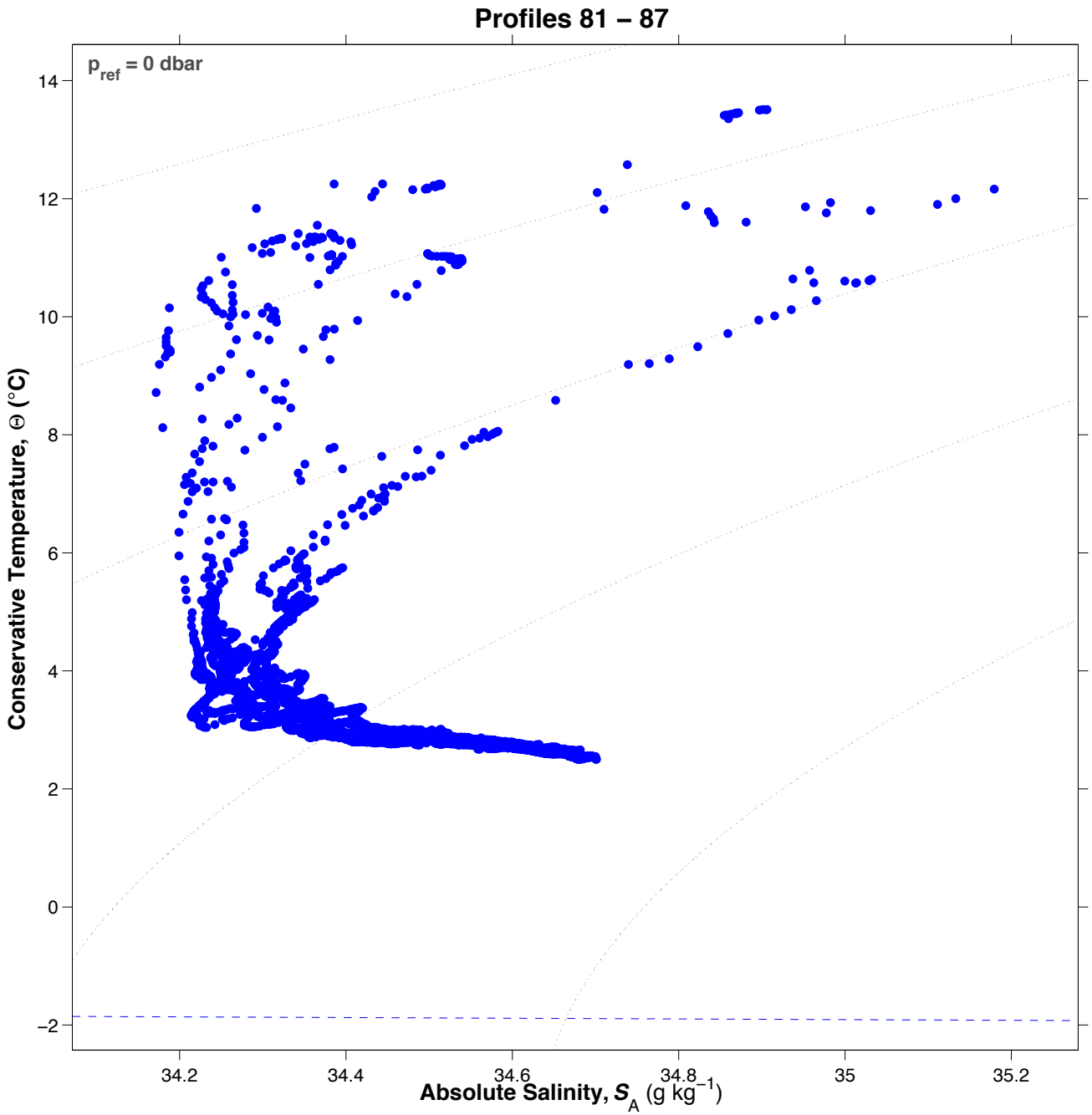


Figure 4, continued.

Appendix B

The following figures show float track diagram (Figure 1), drift temperature (Figure 2a), drift salinity (Figure 2b) and drift pressure Figure 2c)), along track sections of potential temperature (Figure 3a), absolute salinity (Figure 3b), potential density (Figure 3c), sigma0 (Figure 3d) and speed of sound (Figure 3e), and T-S diagrams (Figure 4) for APEX 4781.

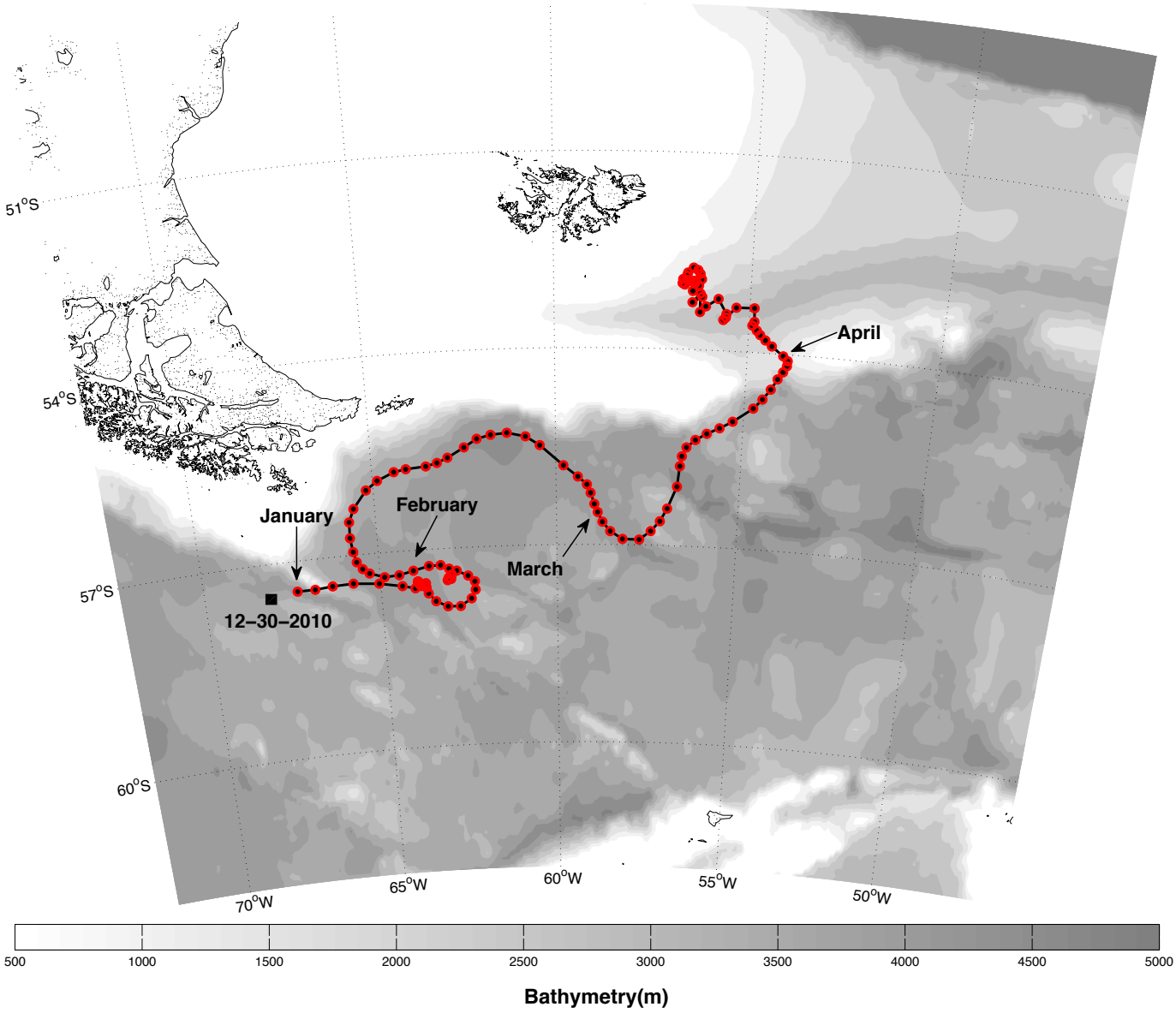


Figure 1. APEX 4781 track diagram from GPS position data. Red dots indicate CTD profiles with GPS positions, whereas the black square is deployment position (with date). Bathymetry is shaded in 500-meter intervals, according to the color bar.

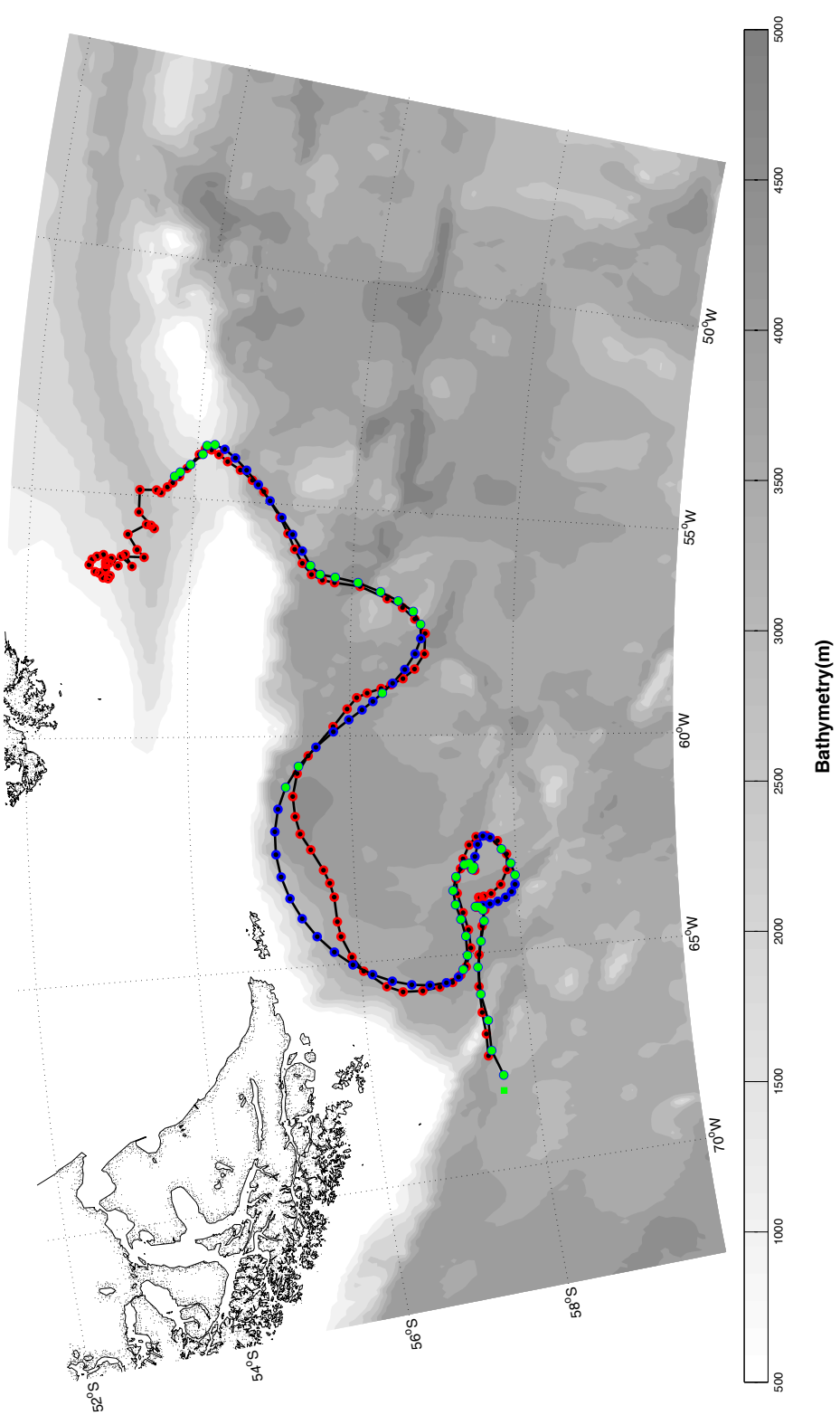


Figure 1b. APEX 4781 track diagram from sound source data (blue dots and line), GPS position (red dots and black line) and points of recorded TOA's (green dots). Bathymetry is shaded in 500-meter intervals, according to the color bar.

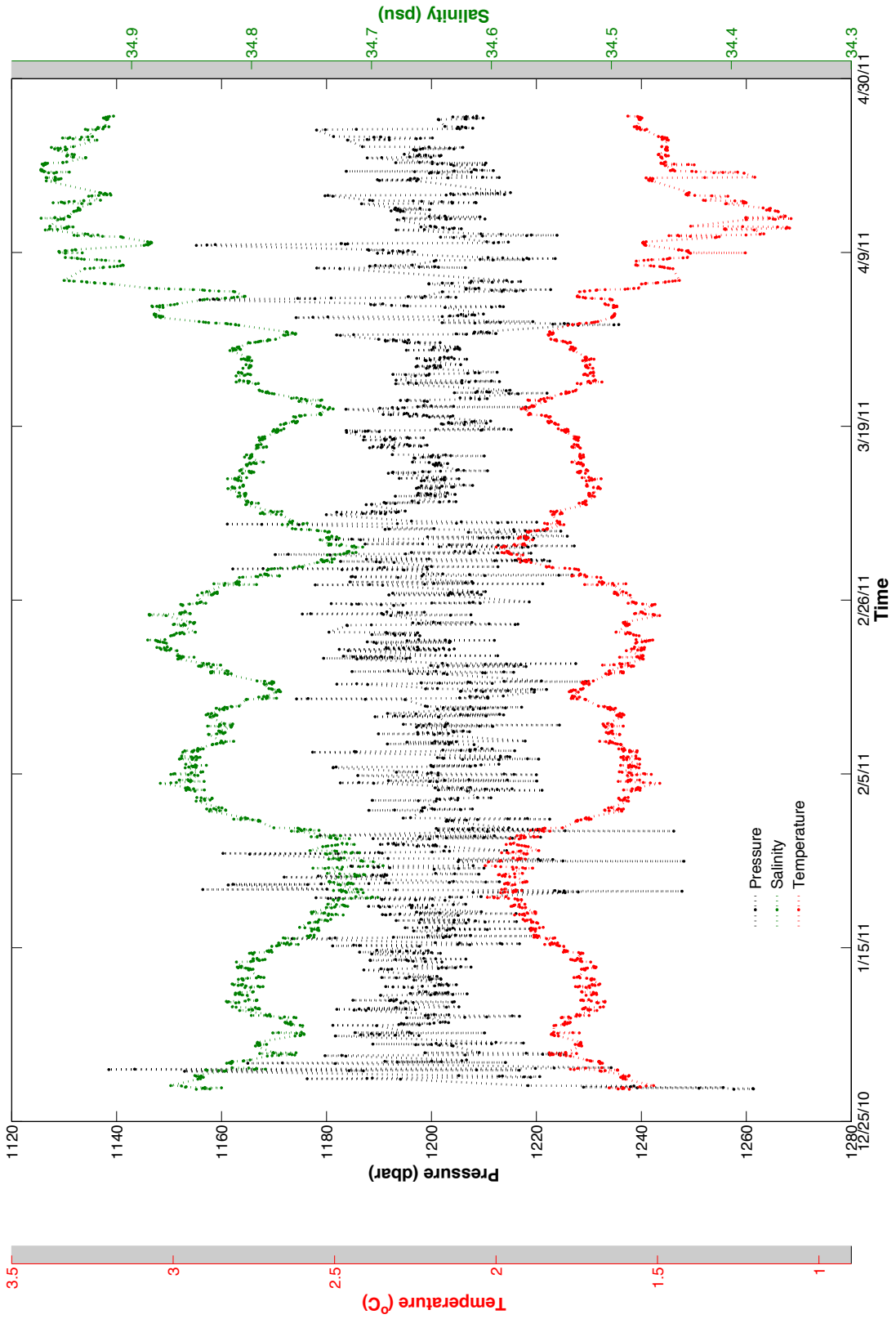


Figure 2. Pressure (black), temperature (red) and salinity (green) during the drift phase (~10-11 hrs) of each day for APEX 4781.

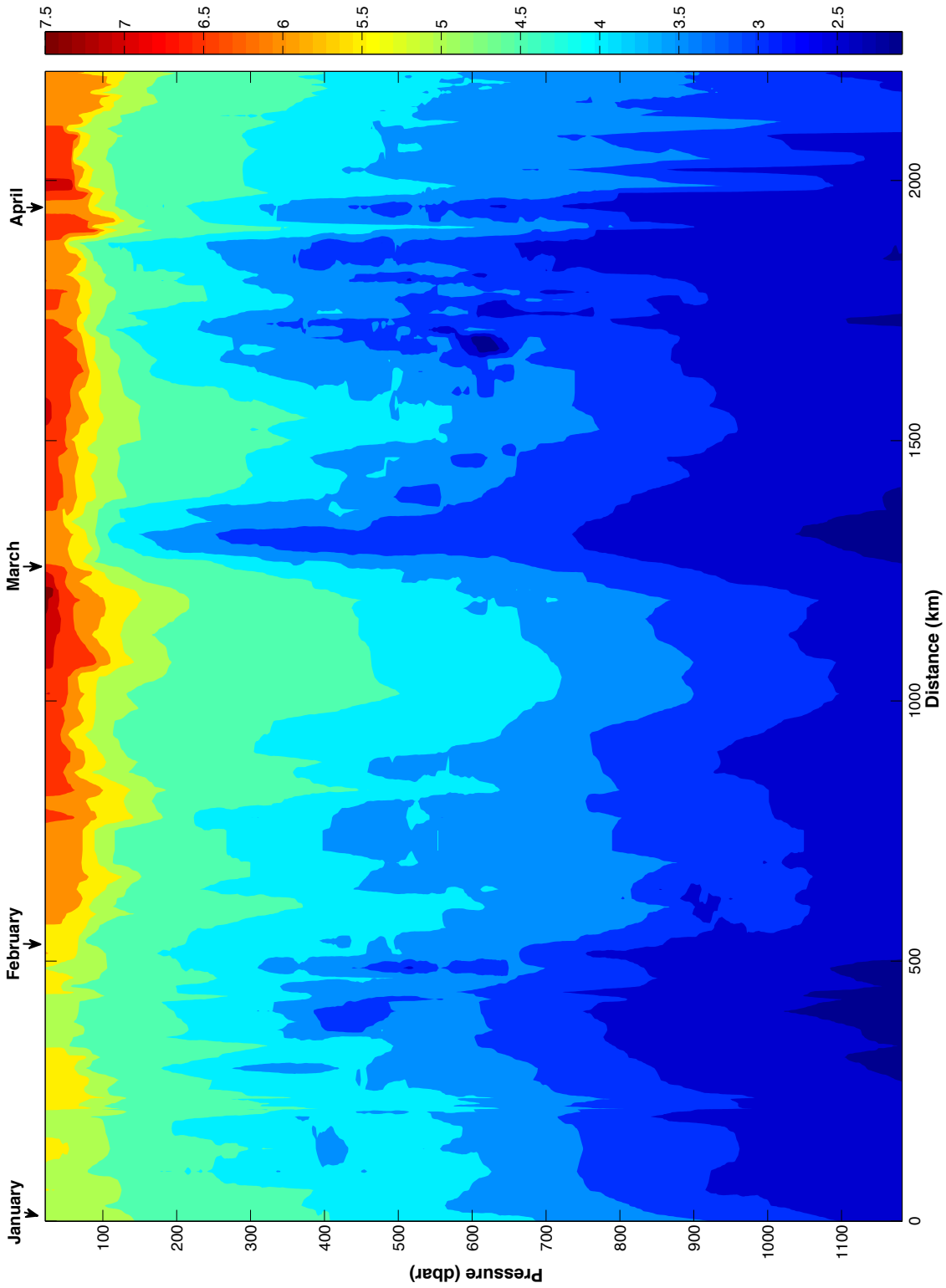


Figure 3a. Along track potential temperature (˚C) for APEX 4781. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

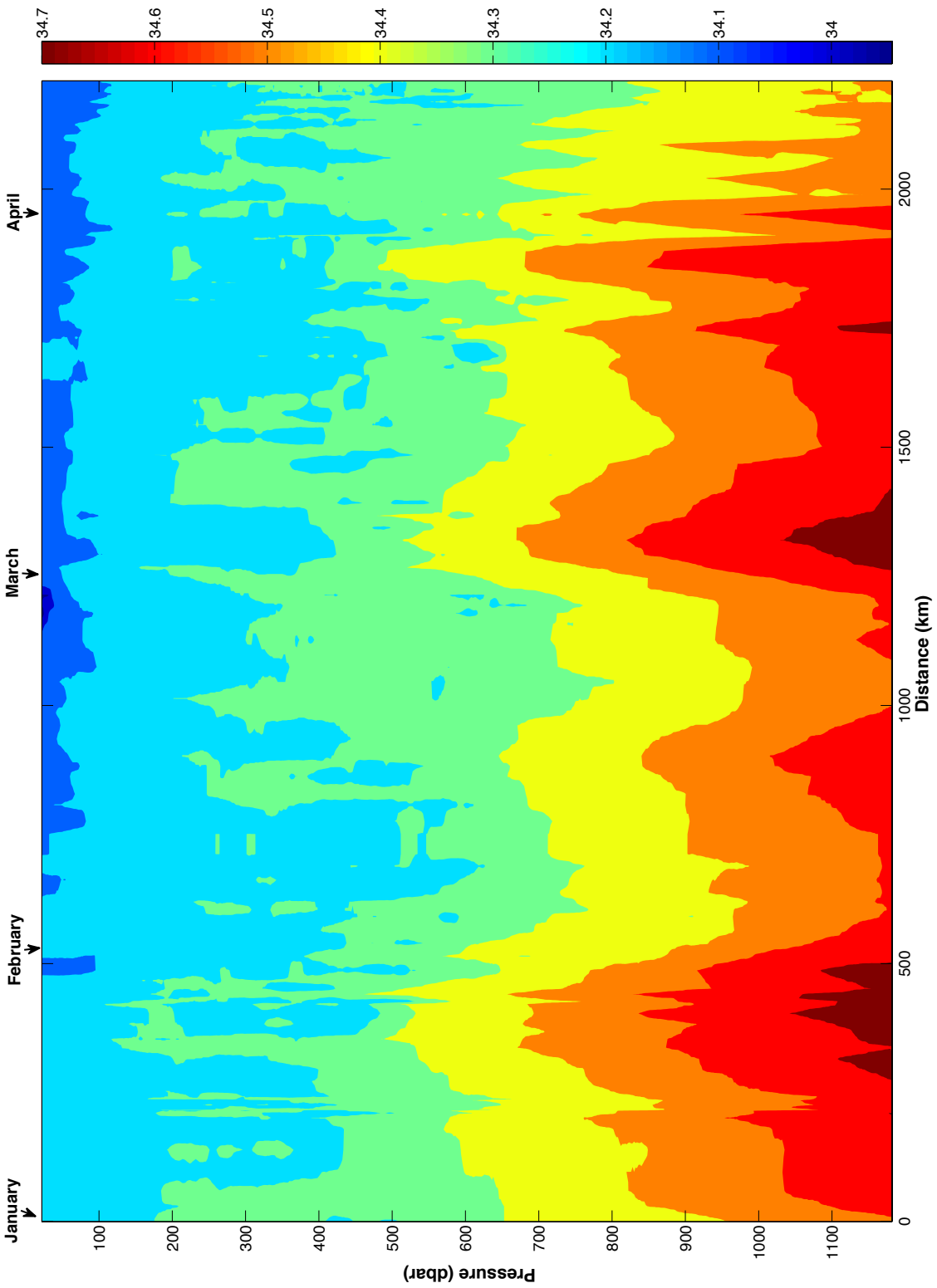


Figure 3b. Along track absolute salinity (g/kg) for APEX 4781. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

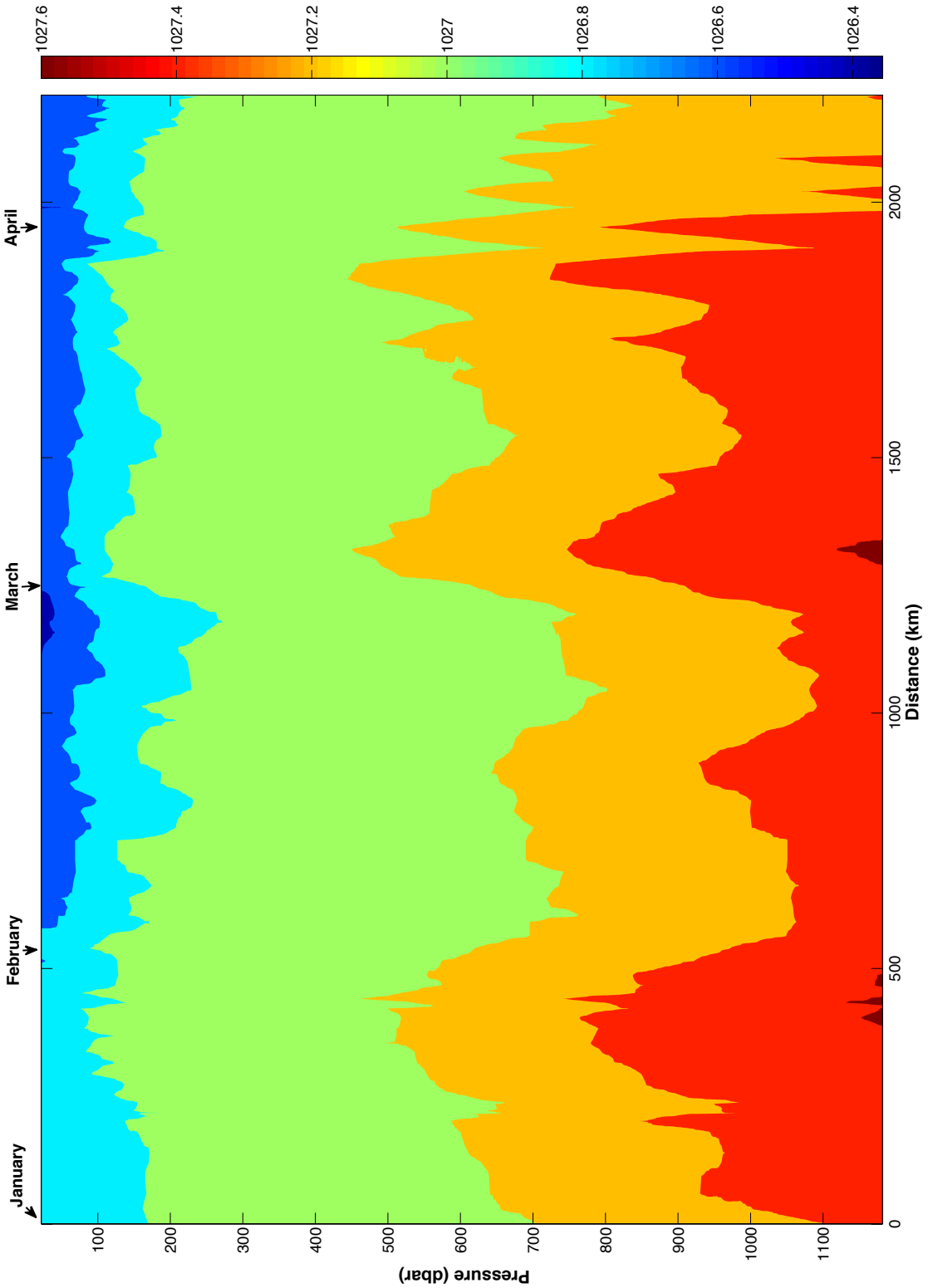


Figure 3c. Along track potential density (kg/m^3) for APEX 4781. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

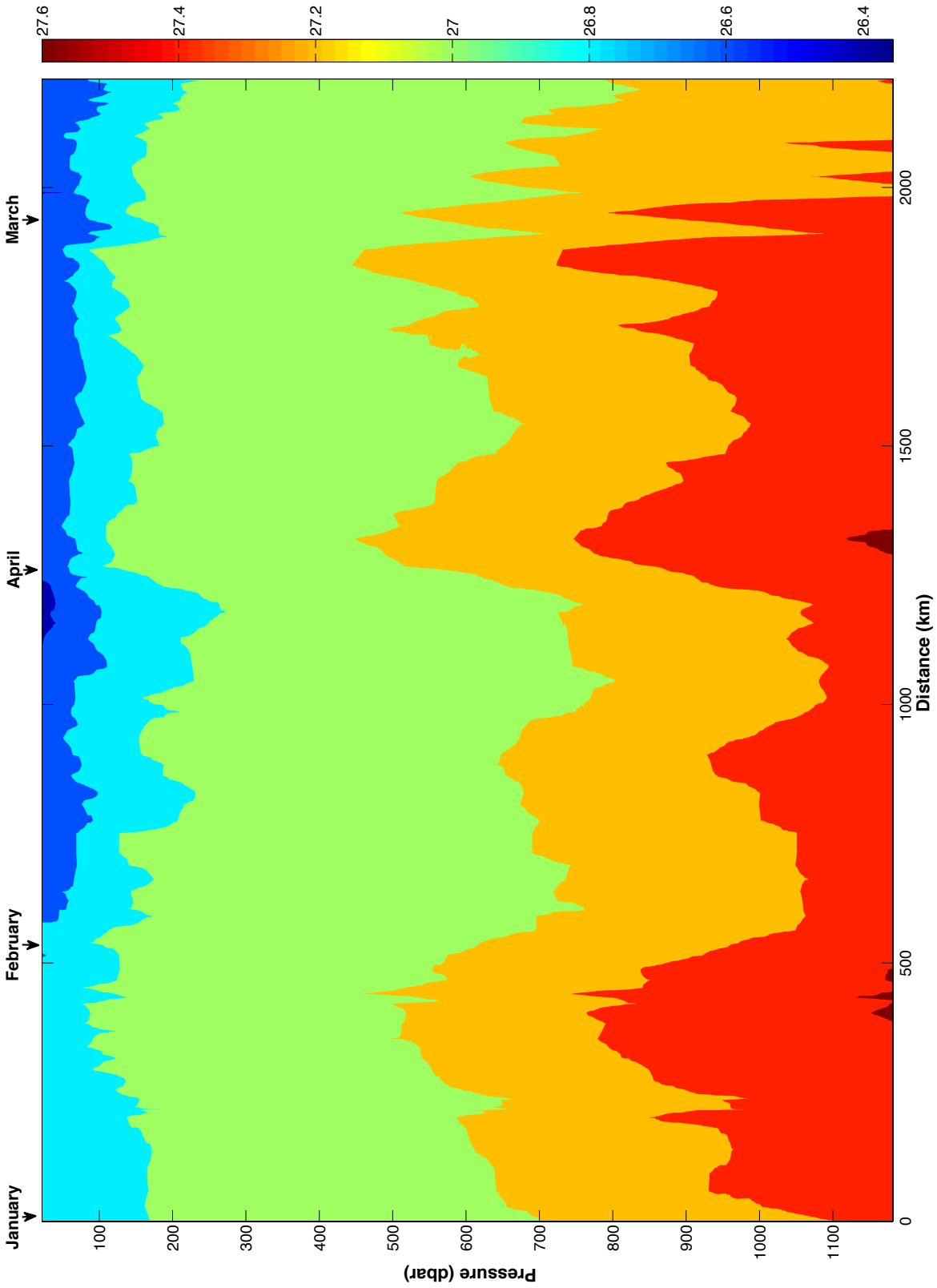


Figure 3d. Along track sigma0 (kg/m^3) for APEX 4781. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

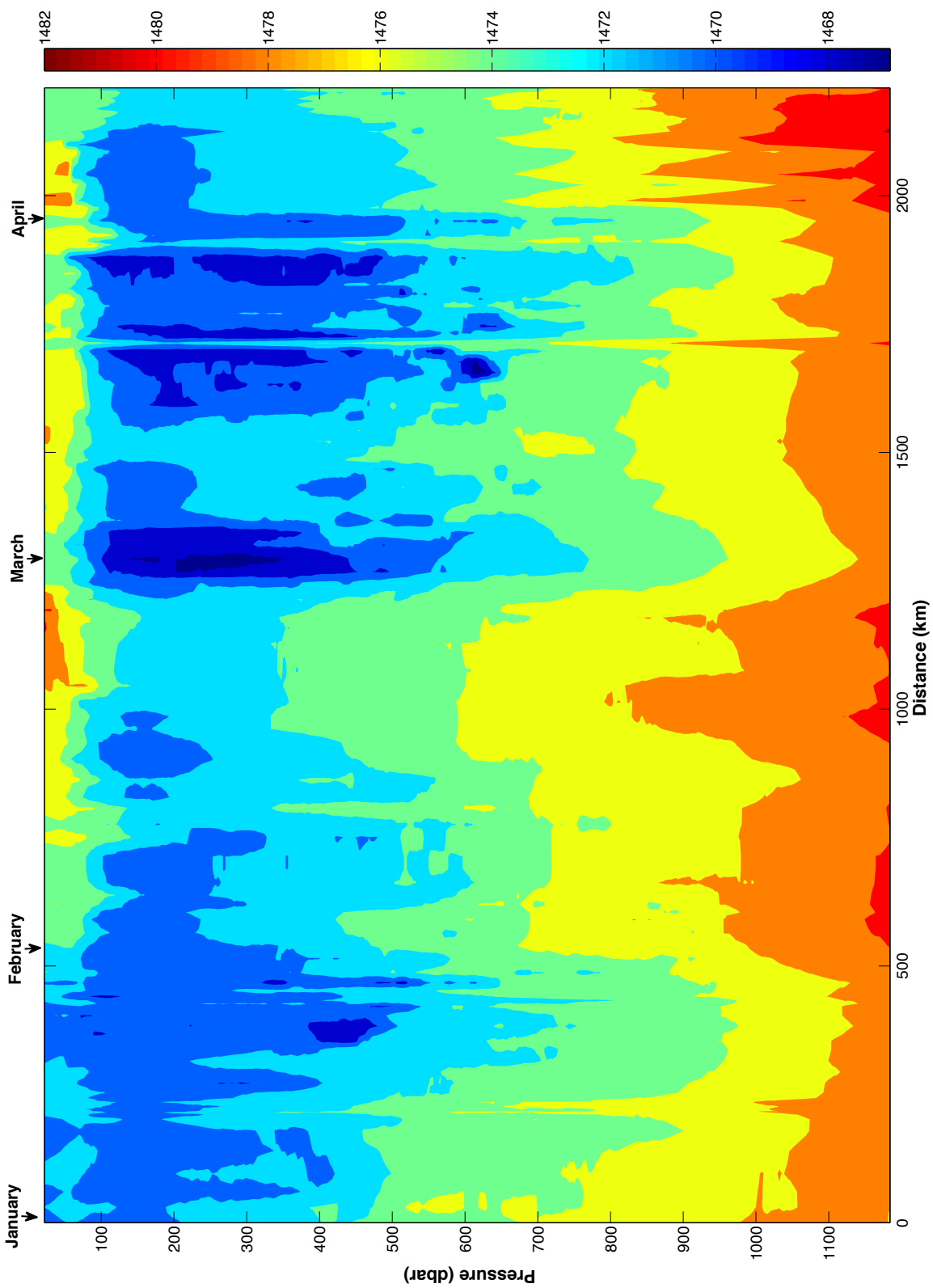


Figure 3e. Along track speed of sound (m/s) for APEX 4781. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

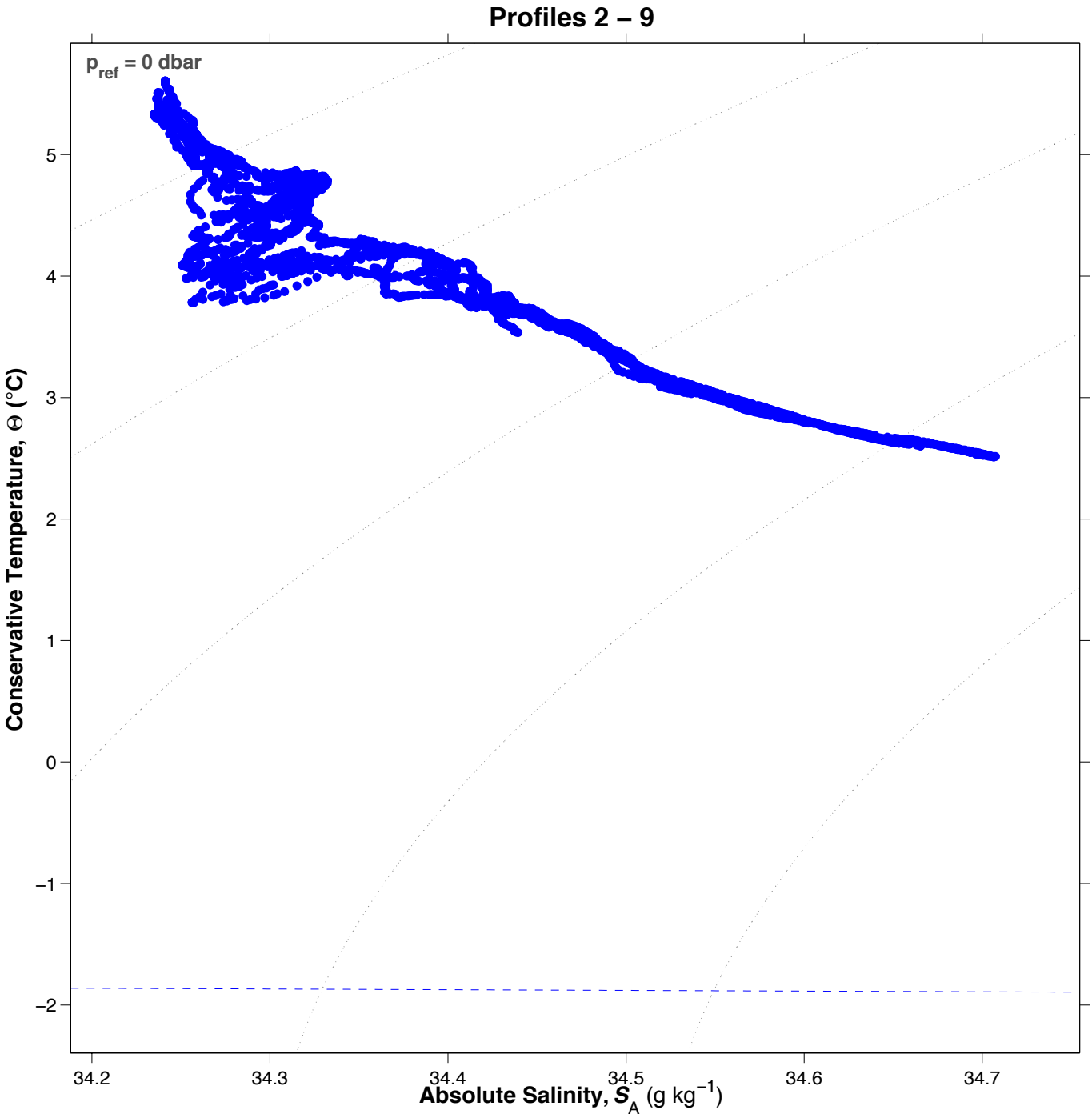


Figure 4: Conservative Temperature (˚C) versus Absolute Salinity (gkg^{-1}) along track, starting with the first profile after deployment, for APEX 4781. Each figure shows eight successive profiles. The freezing line is indicated by the blue dashed line.

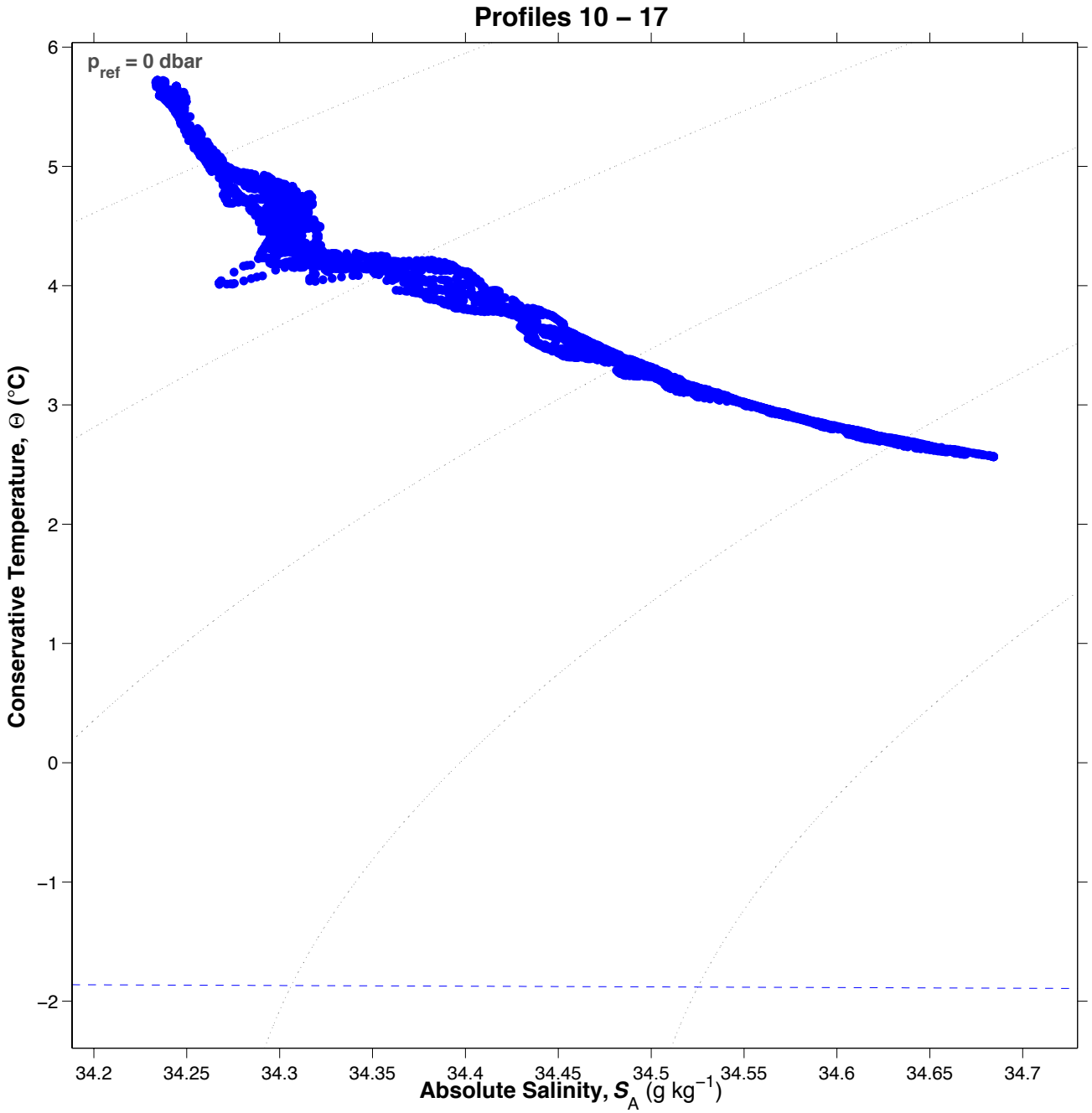


Figure 4, continued.

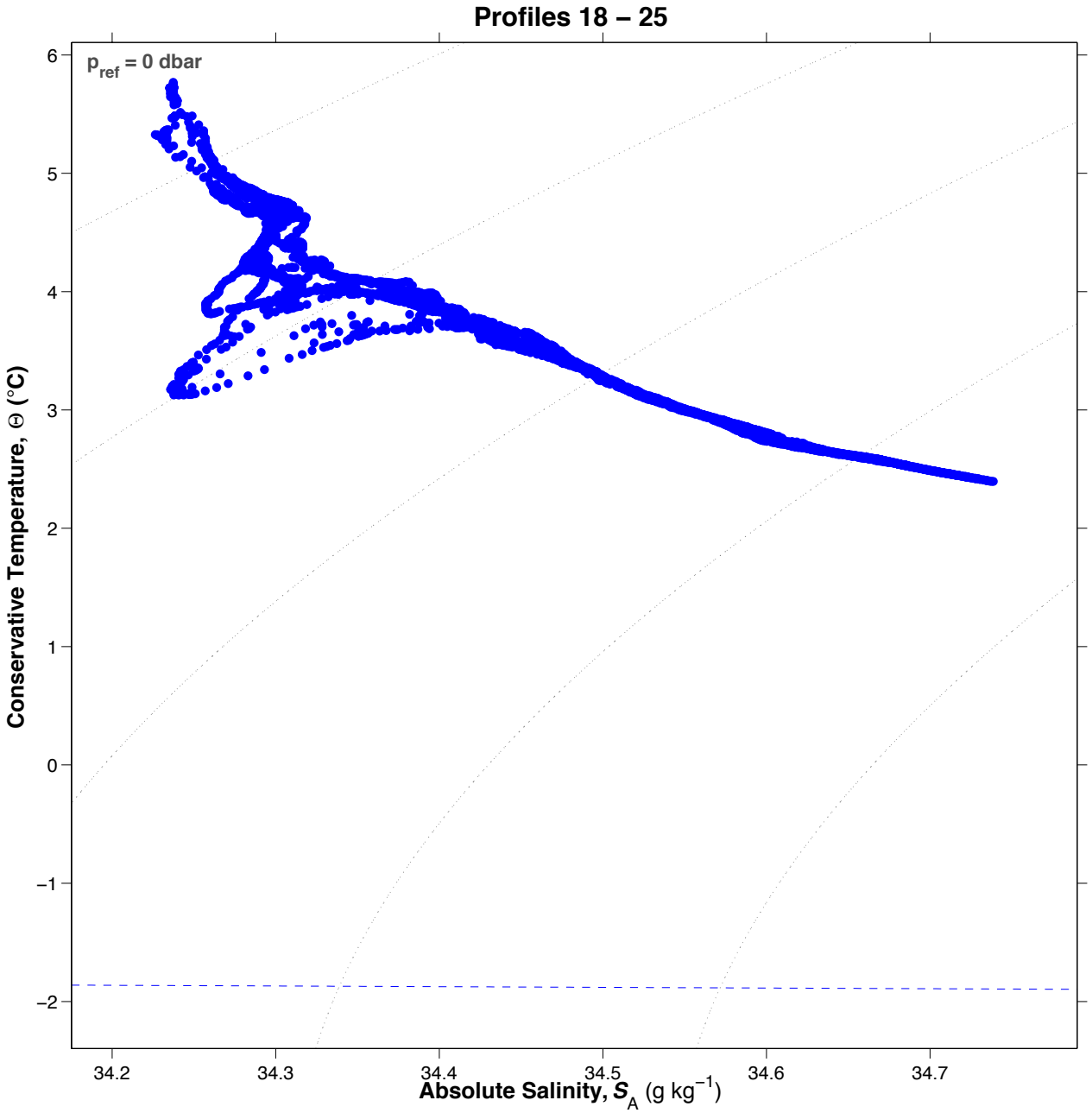
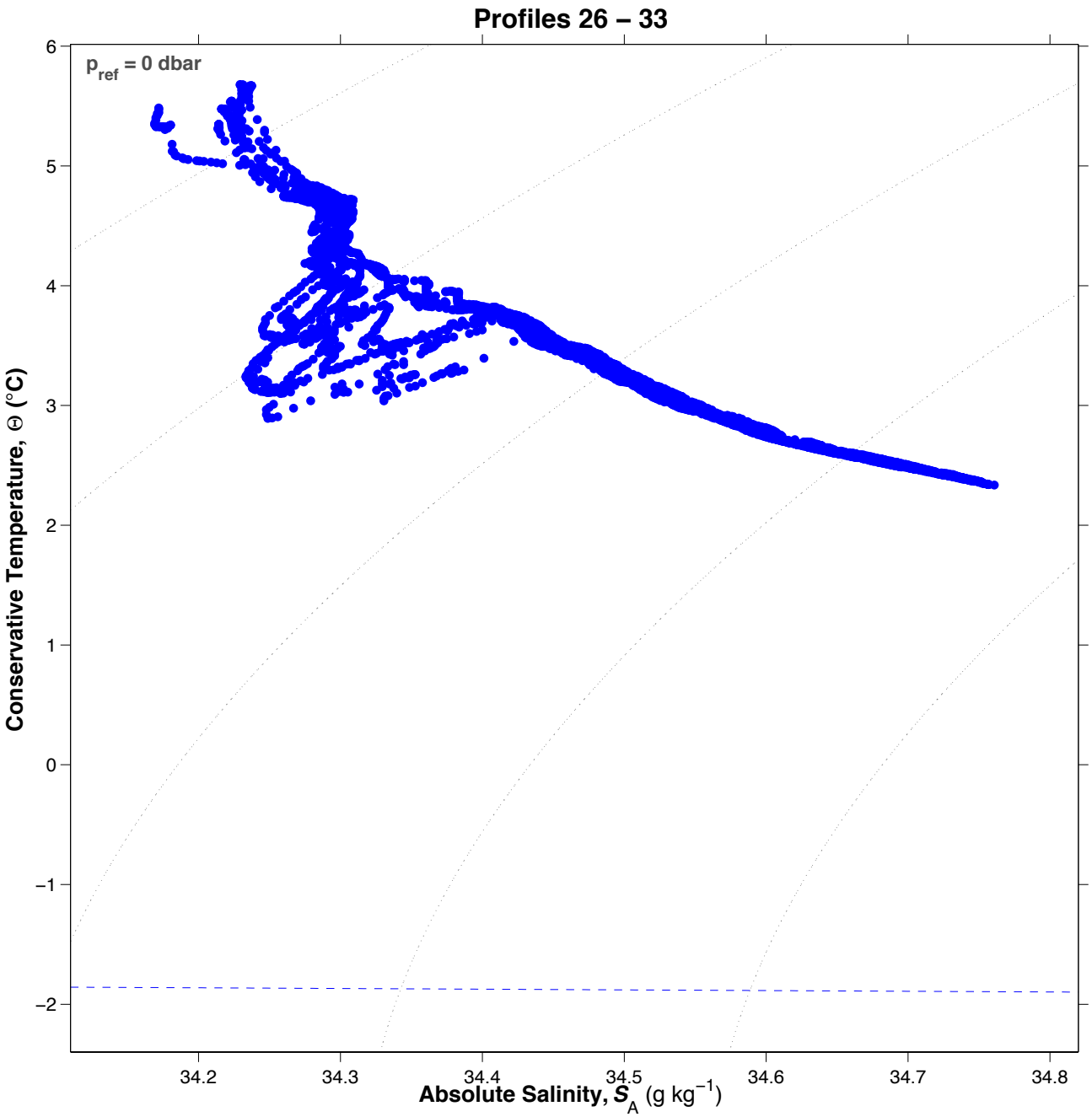


Figure 4, continued.



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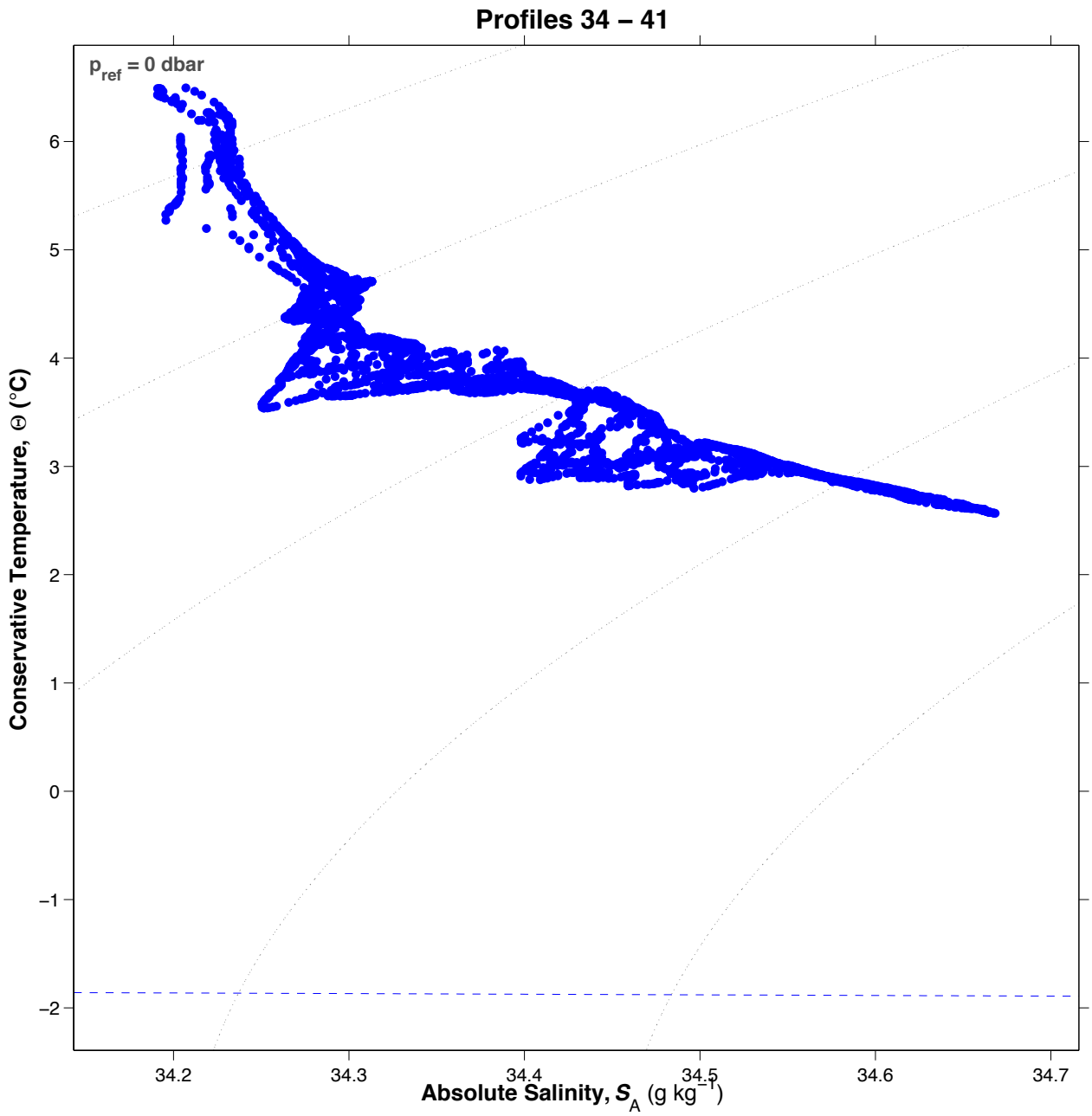


Figure 4, continued.

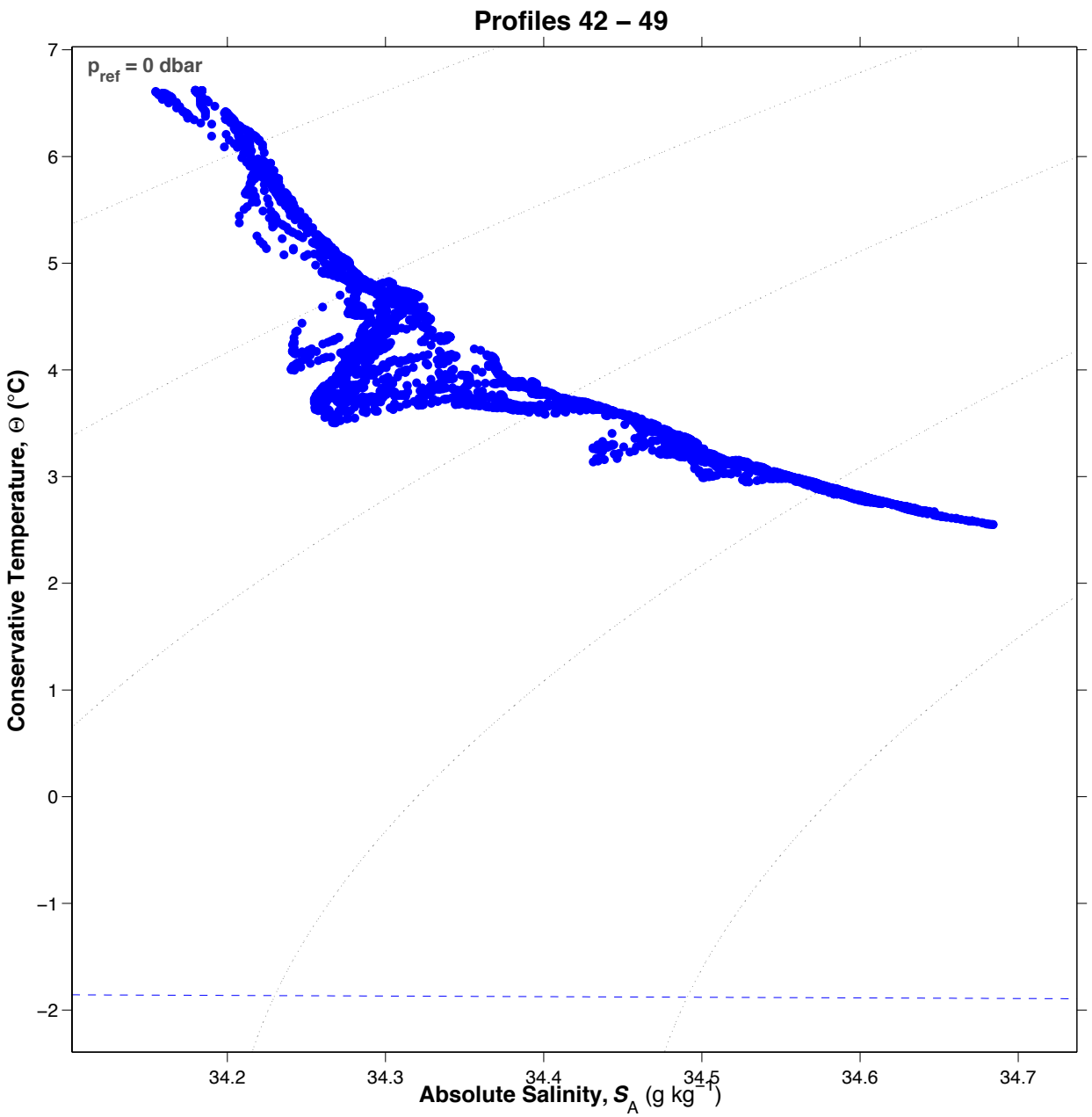


Figure 4, continued.

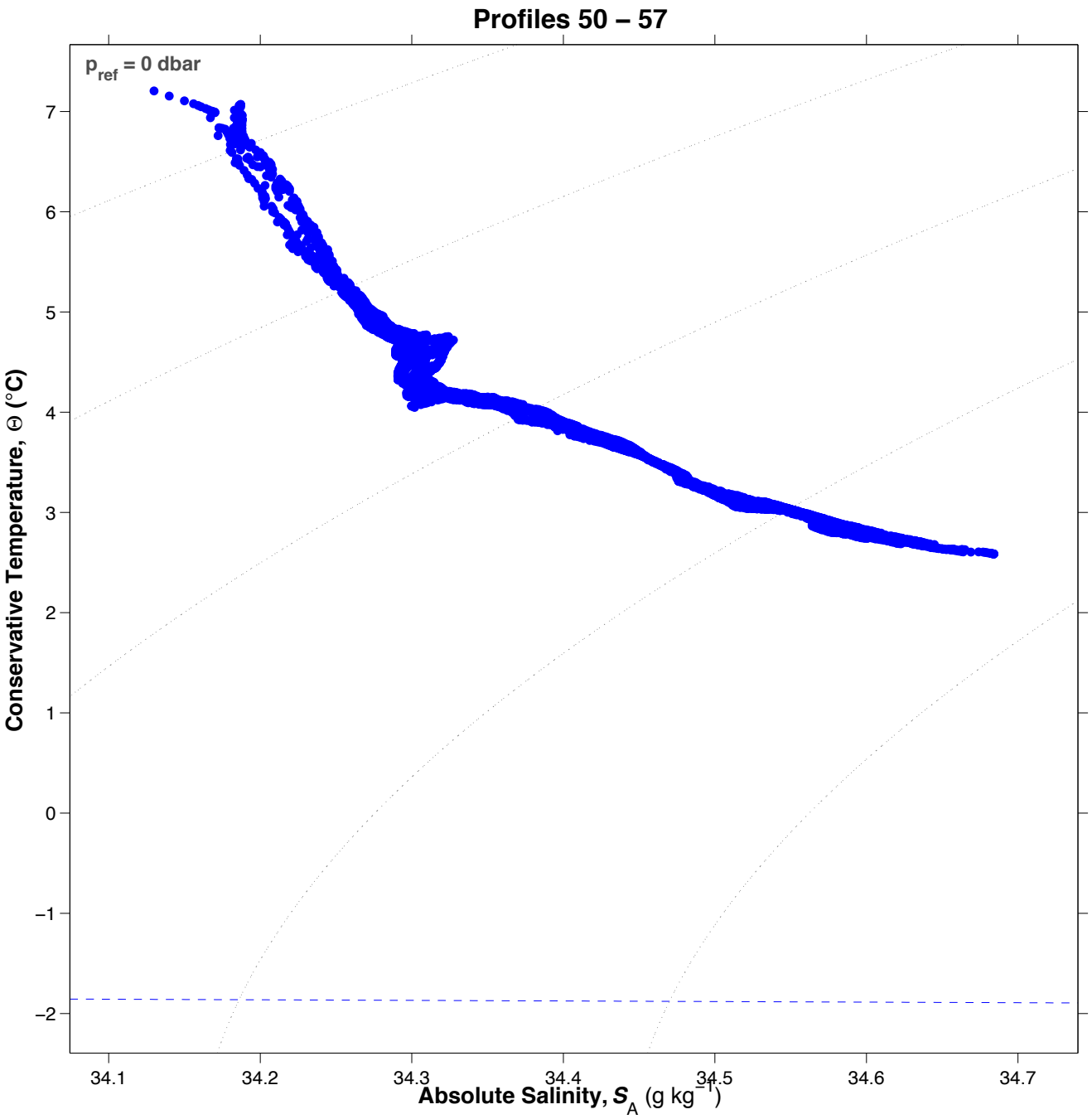


Figure 4, continued.

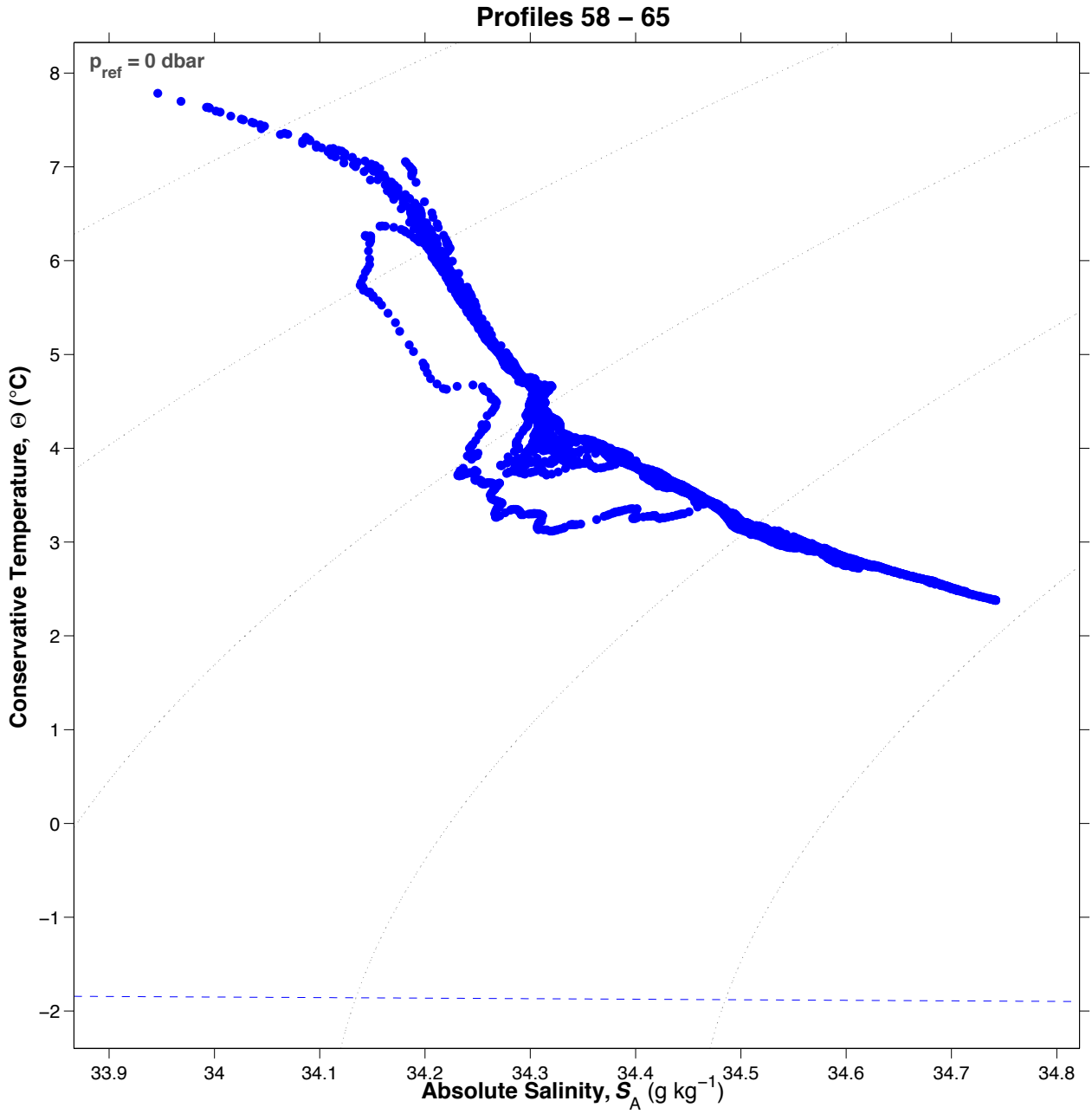


Figure 4, continued.

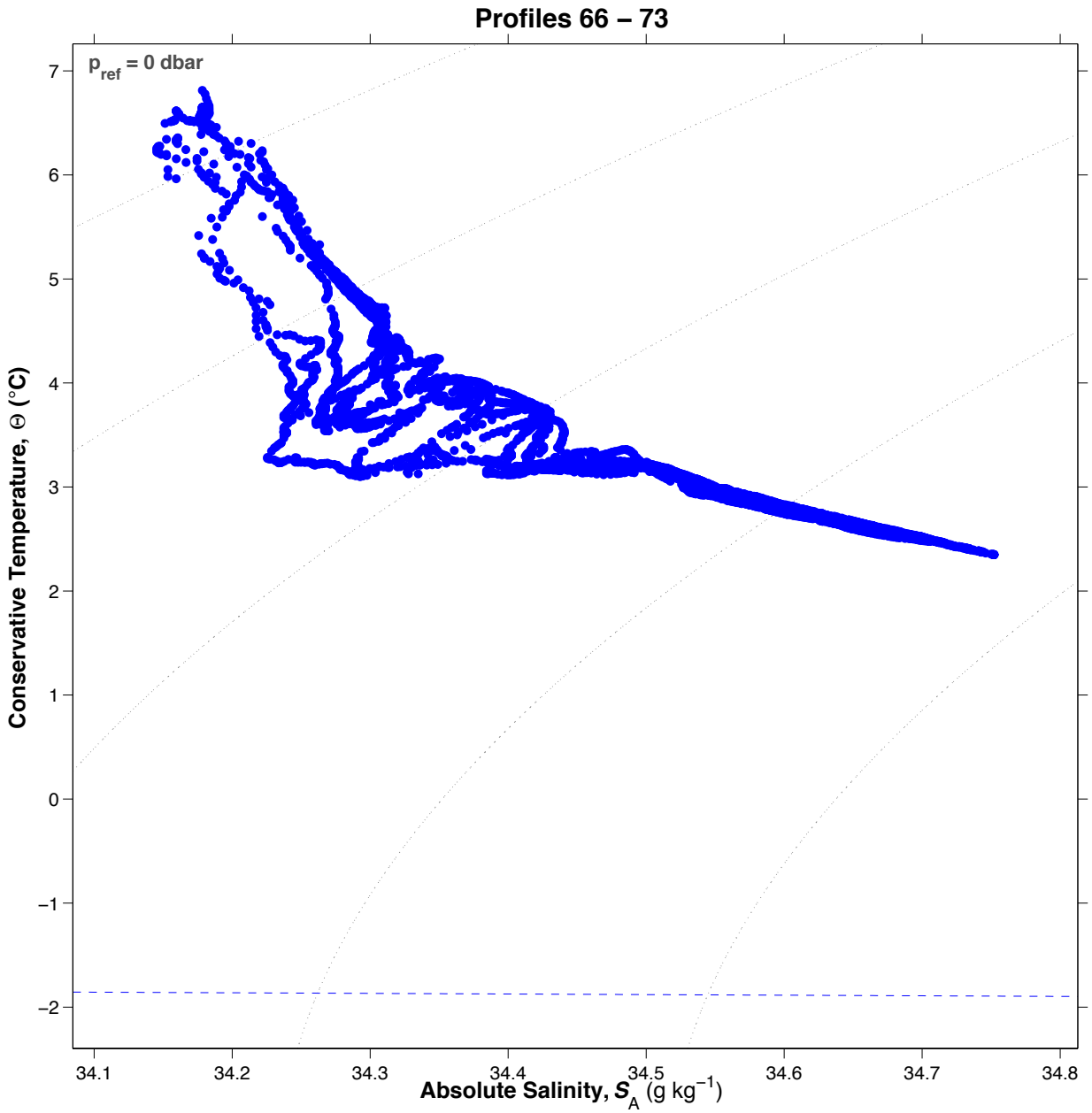


Figure 4, continued.

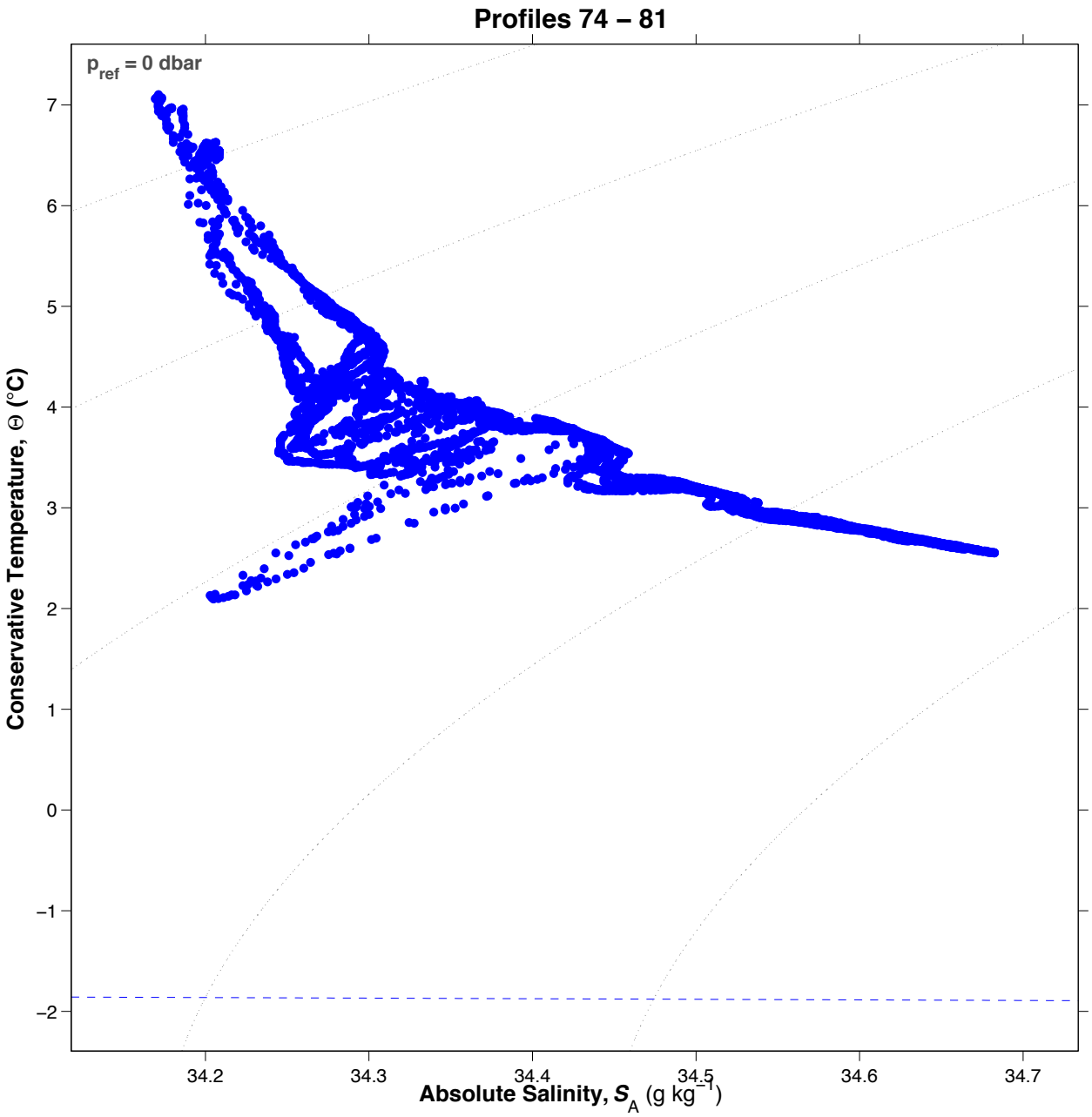


Figure 4, continued.

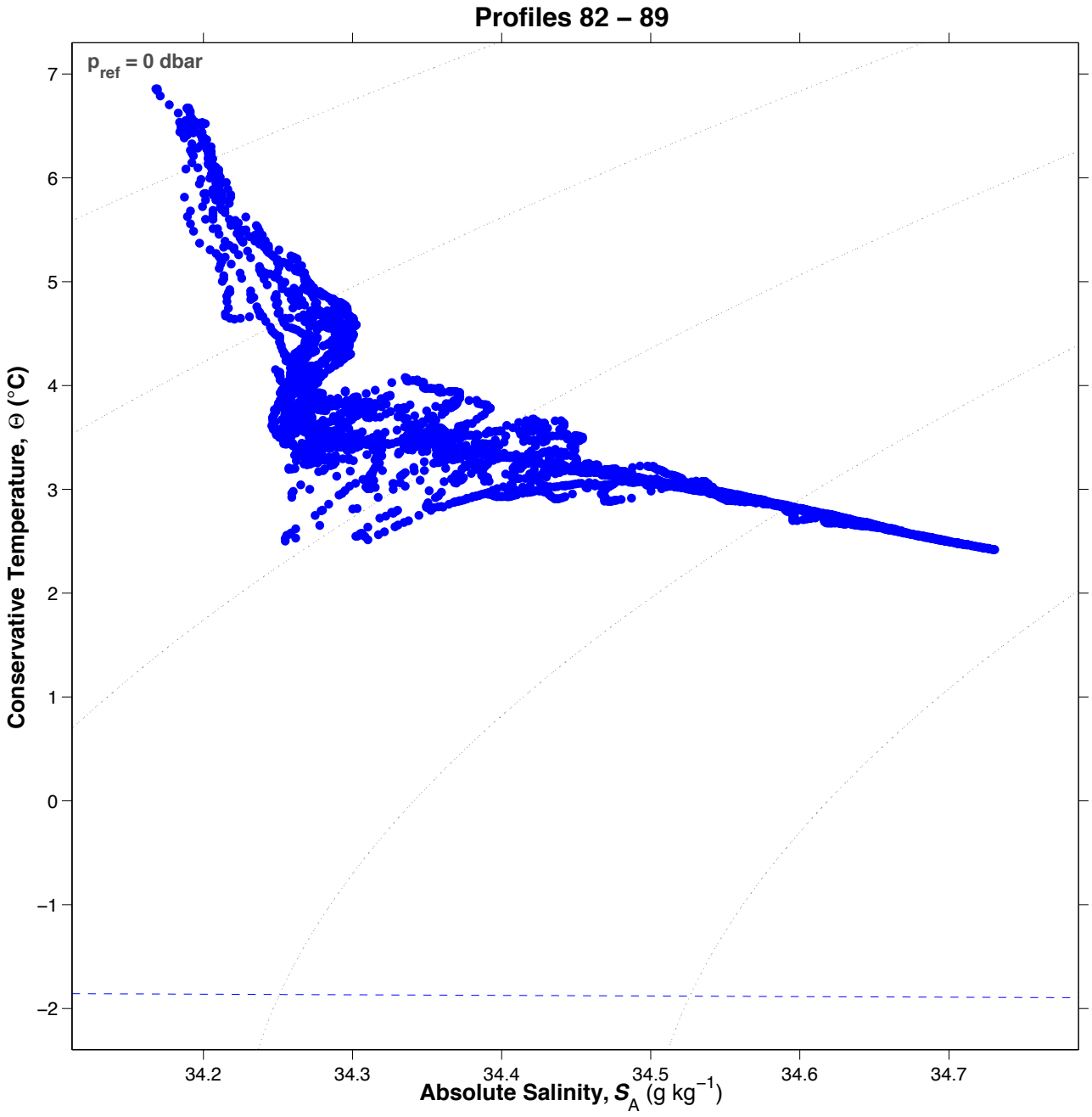
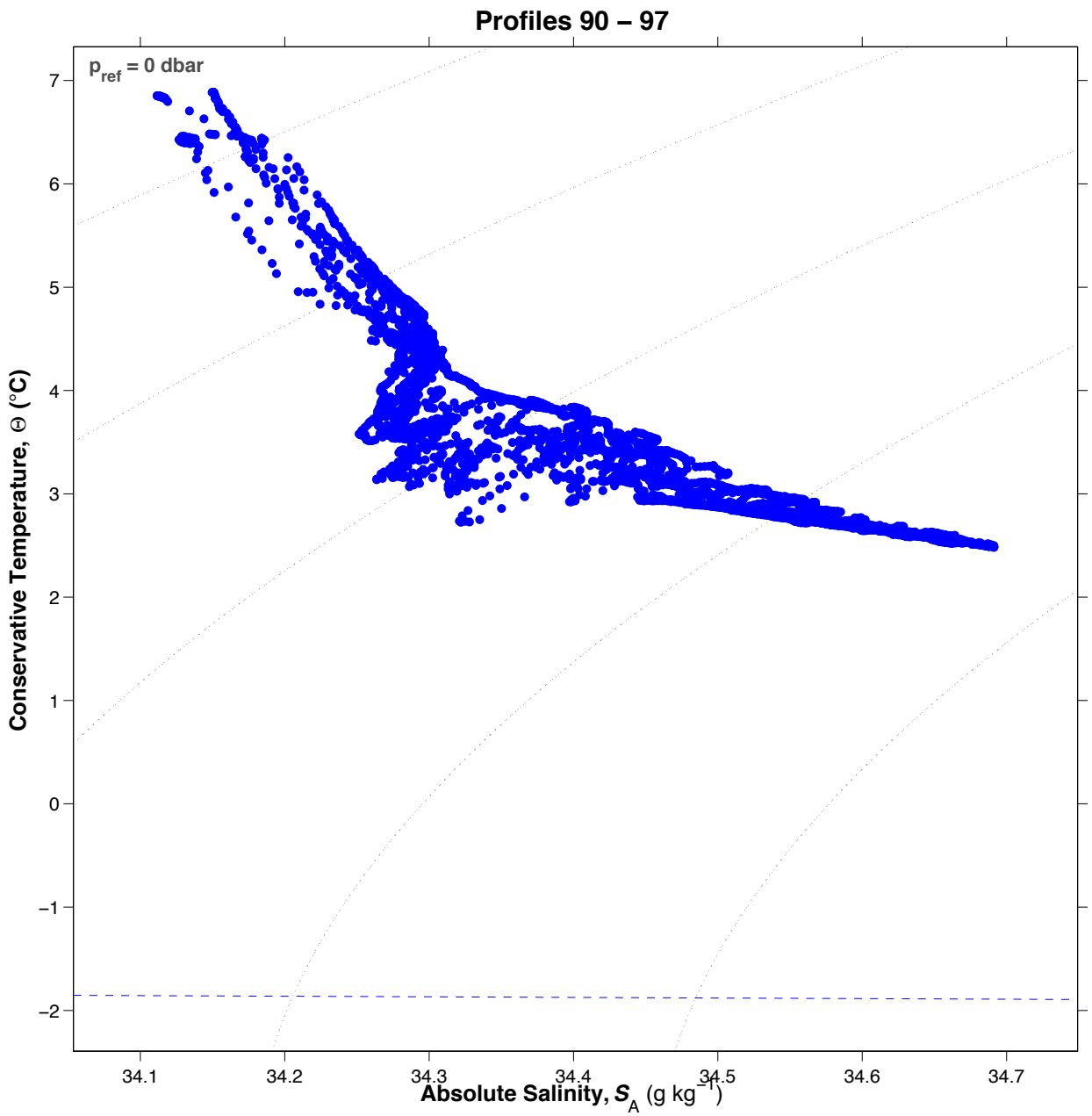


Figure 4, continued.



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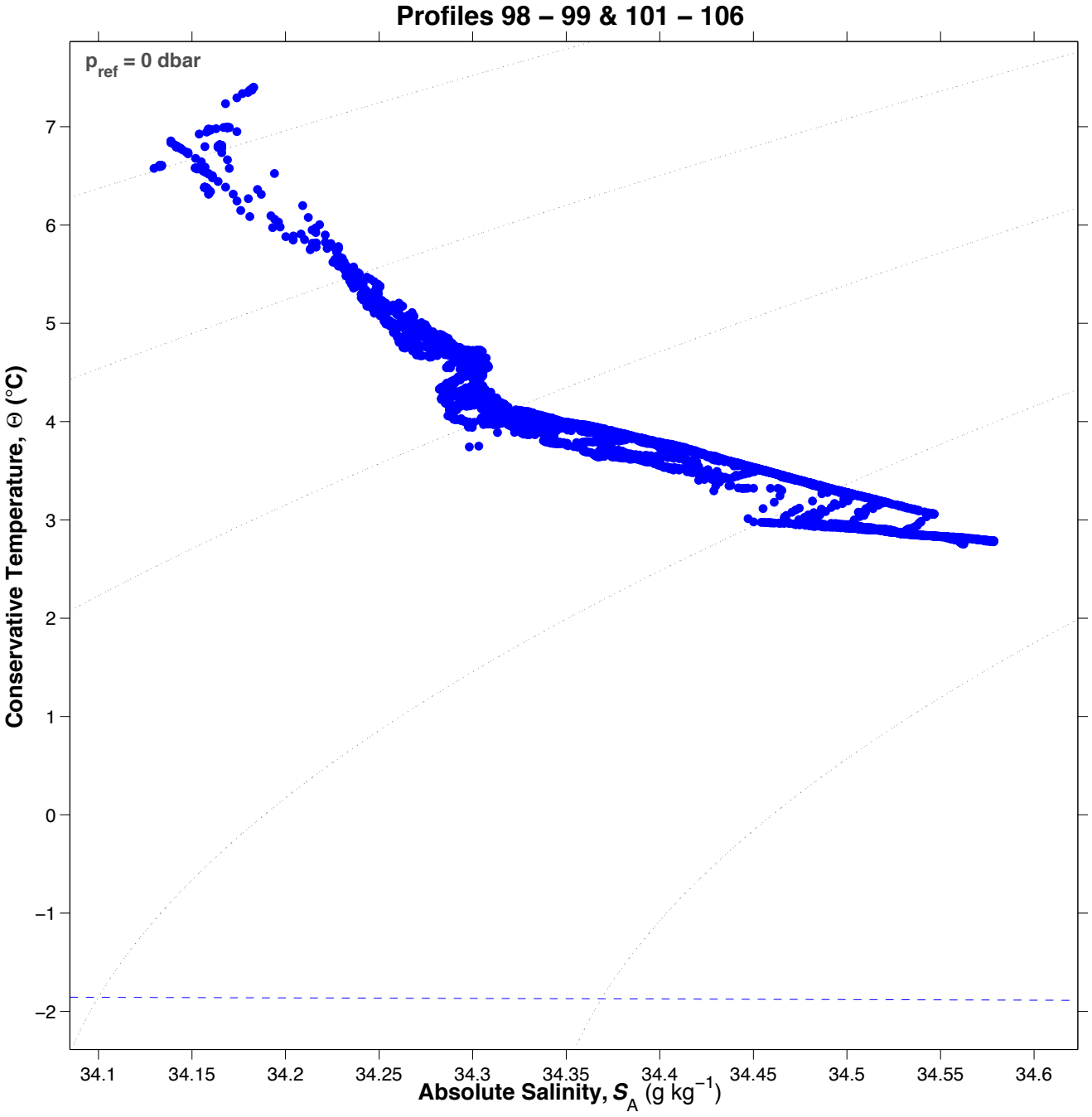

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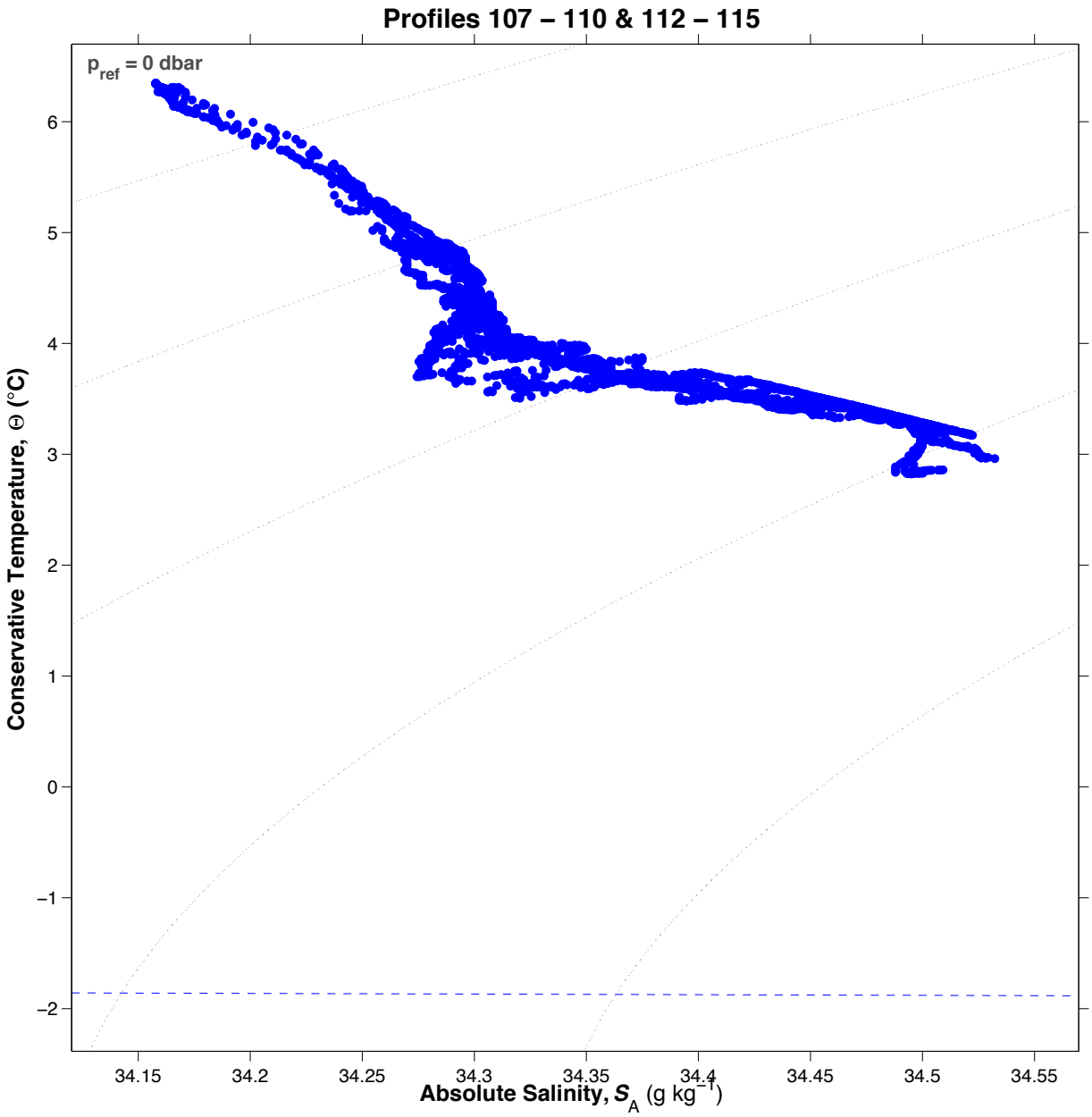


Figure 4, continued.

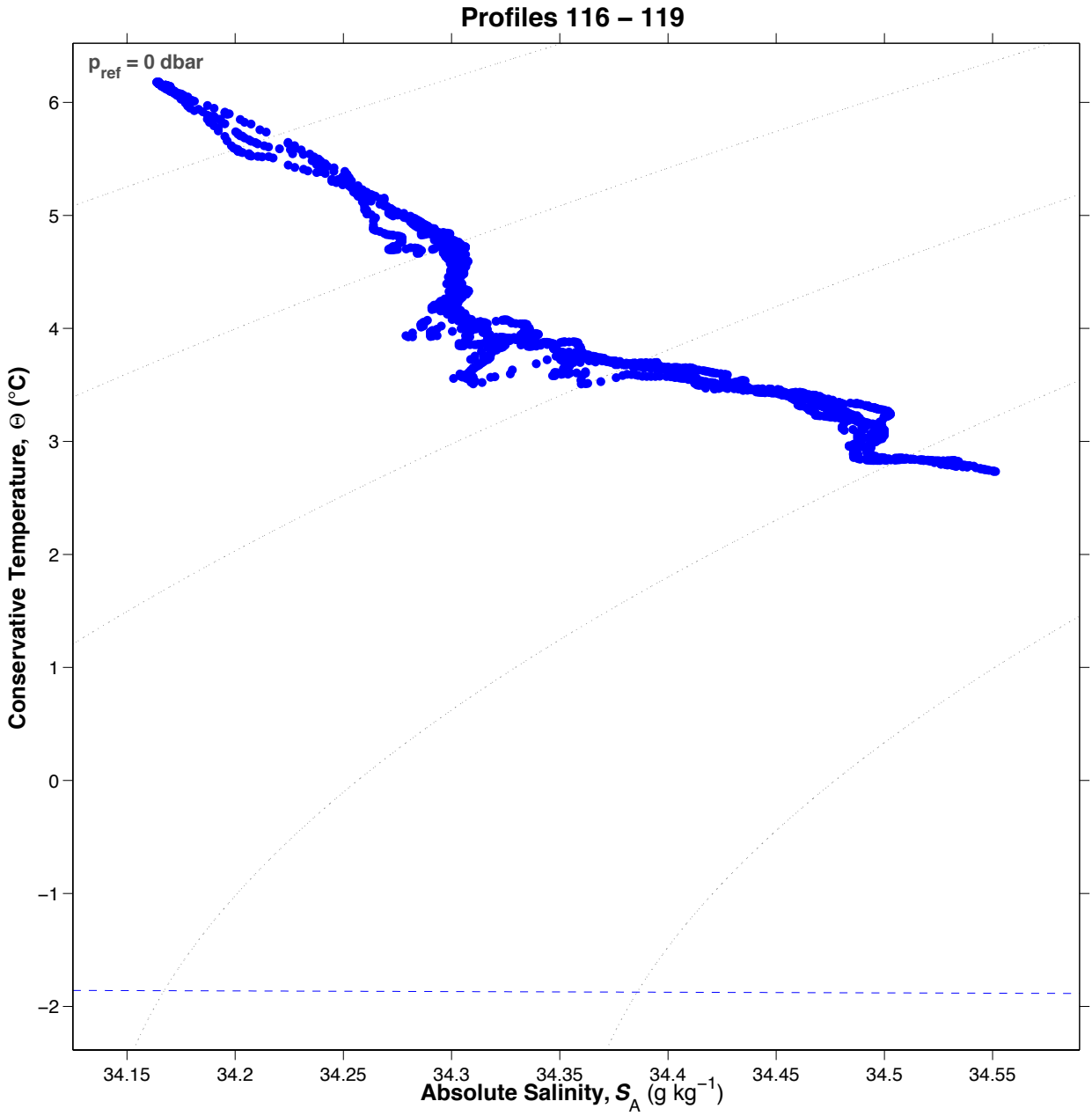


Figure 4, continued.

Appendix C

The following figures show float track diagram (Figure 1), drift temperature (Figure 2a), drift salinity (Figure 2b) and drift pressure Figure 2c)), along track sections of potential temperature (Figure 3a), absolute salinity (Figure 3b), potential density (Figure 3c), sigma0 (Figure 3d) and speed of sound (Figure 3e), and T-S diagrams (Figure 4) for APEX 4782.

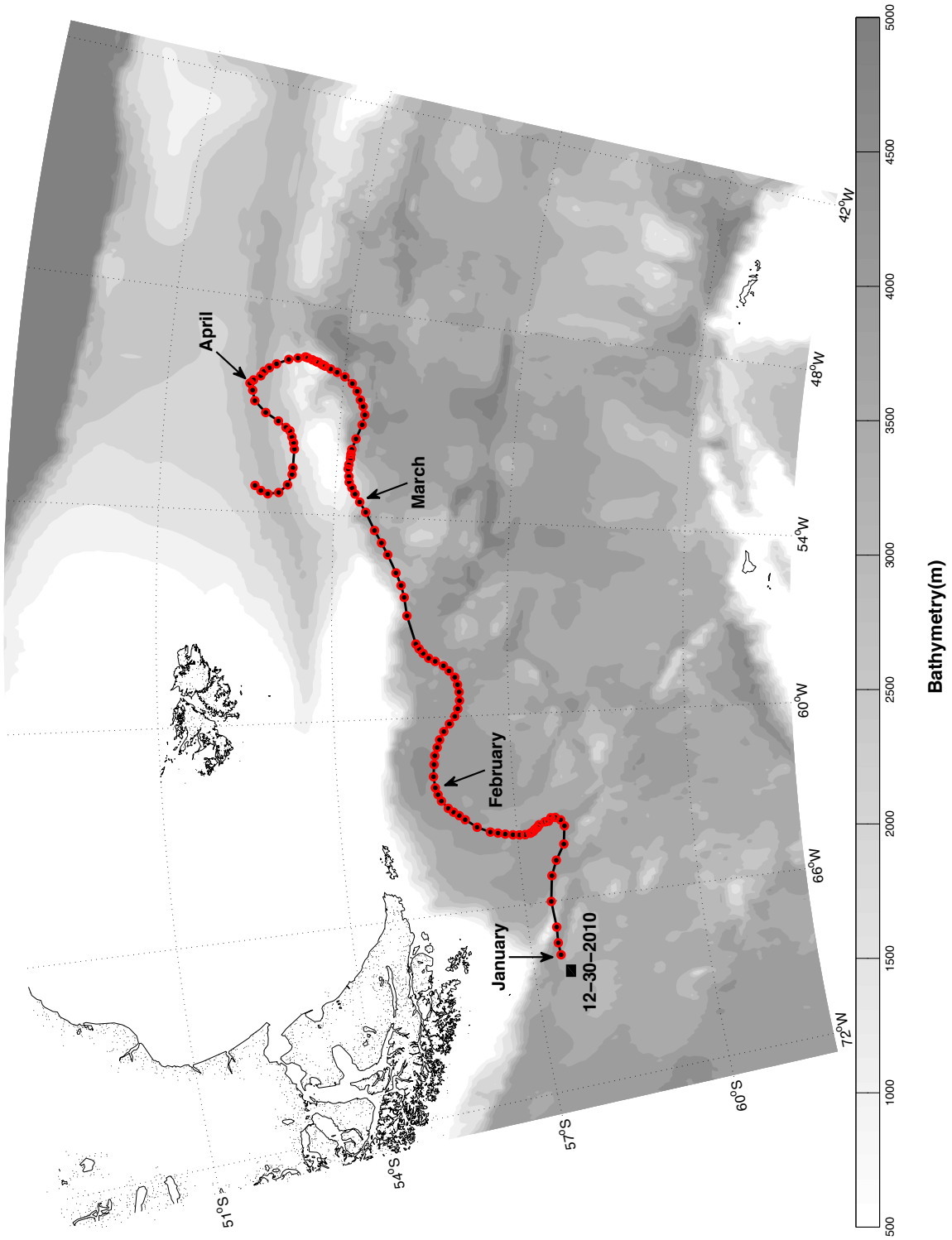


Figure 1. APEX 4782 track diagram from GPS position data. Red dots indicate CTD profiles with GPS positions, whereas the black square is deployment position (with date). Bathymetry is shaded in 500-meter intervals, according to the color bar.

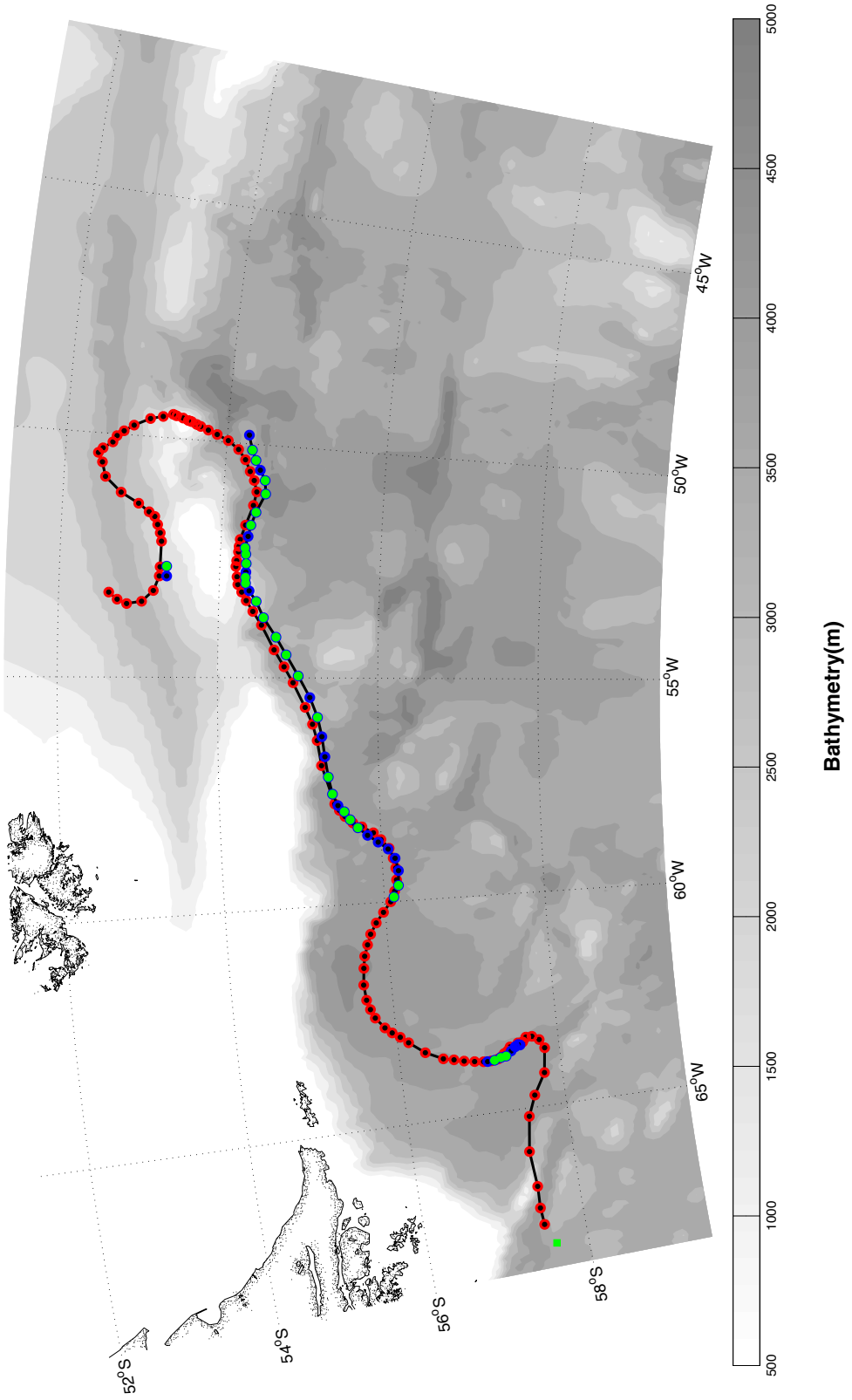


Figure 1b. APEX 4782 track diagram from sound source data (blue dots and line), GPS position (red dots and black line) and points of recorded TOA's (green dots). Bathymetry is shaded in 500-meter intervals, according to the color bar.

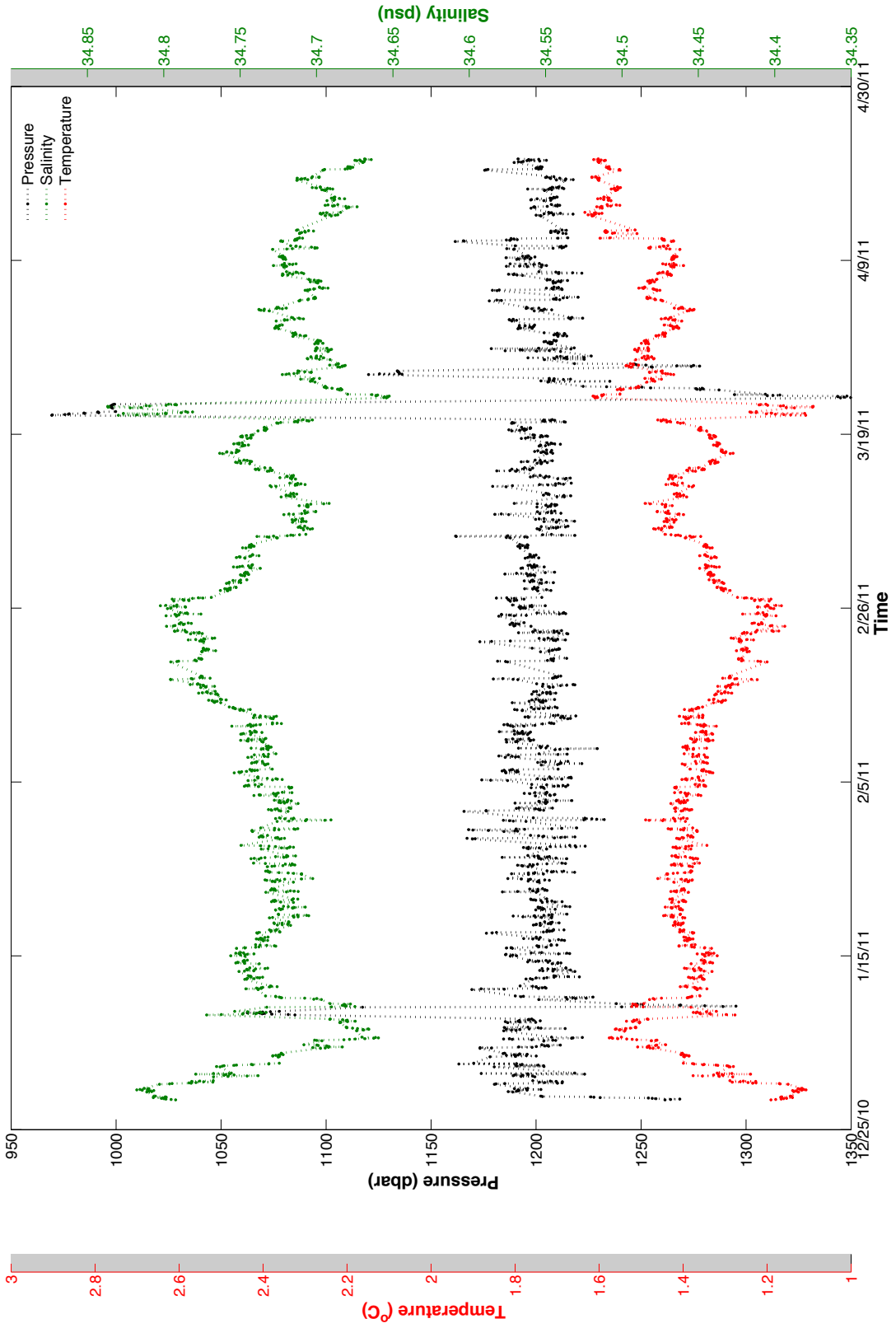


Figure 2. Pressure (black), temperature (red) and salinity (green) during the drift phase (~10-11 hrs) of each day for APEX 4782.

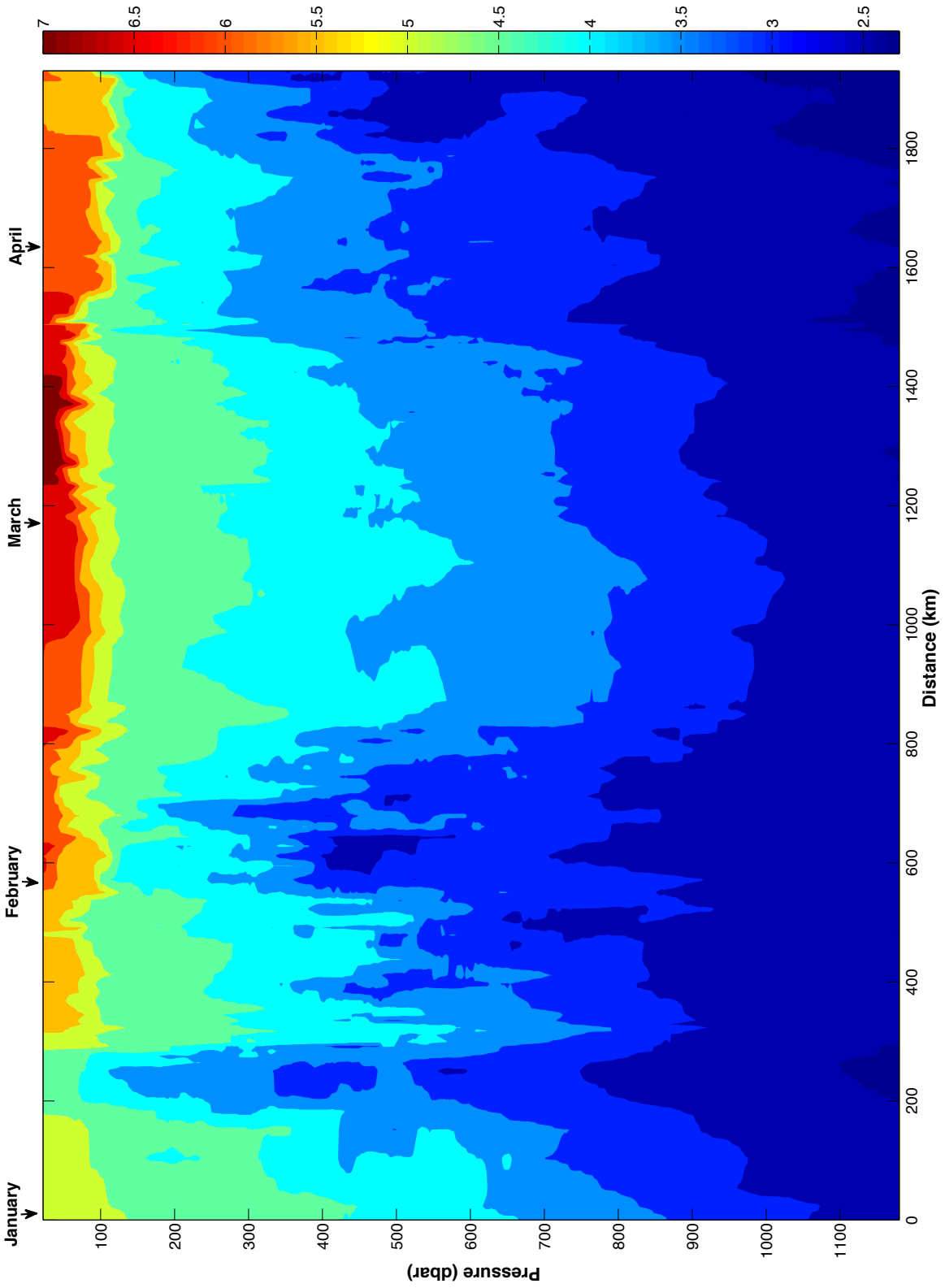


Figure 3a. Along track potential temperature (˚C) for APEX 4782. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

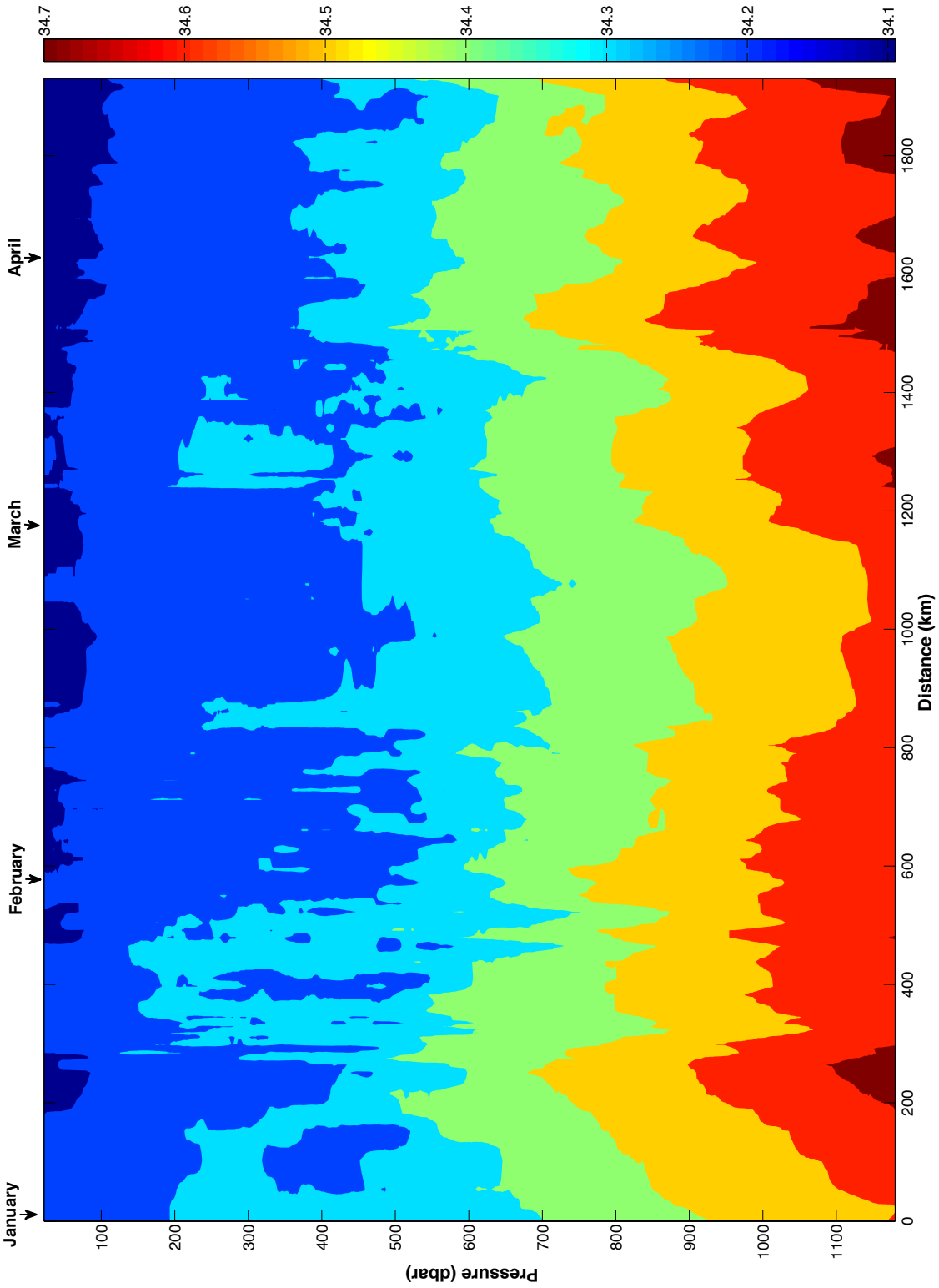


Figure 3b. Along track absolute salinity (g/kg) for APEX 4782. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

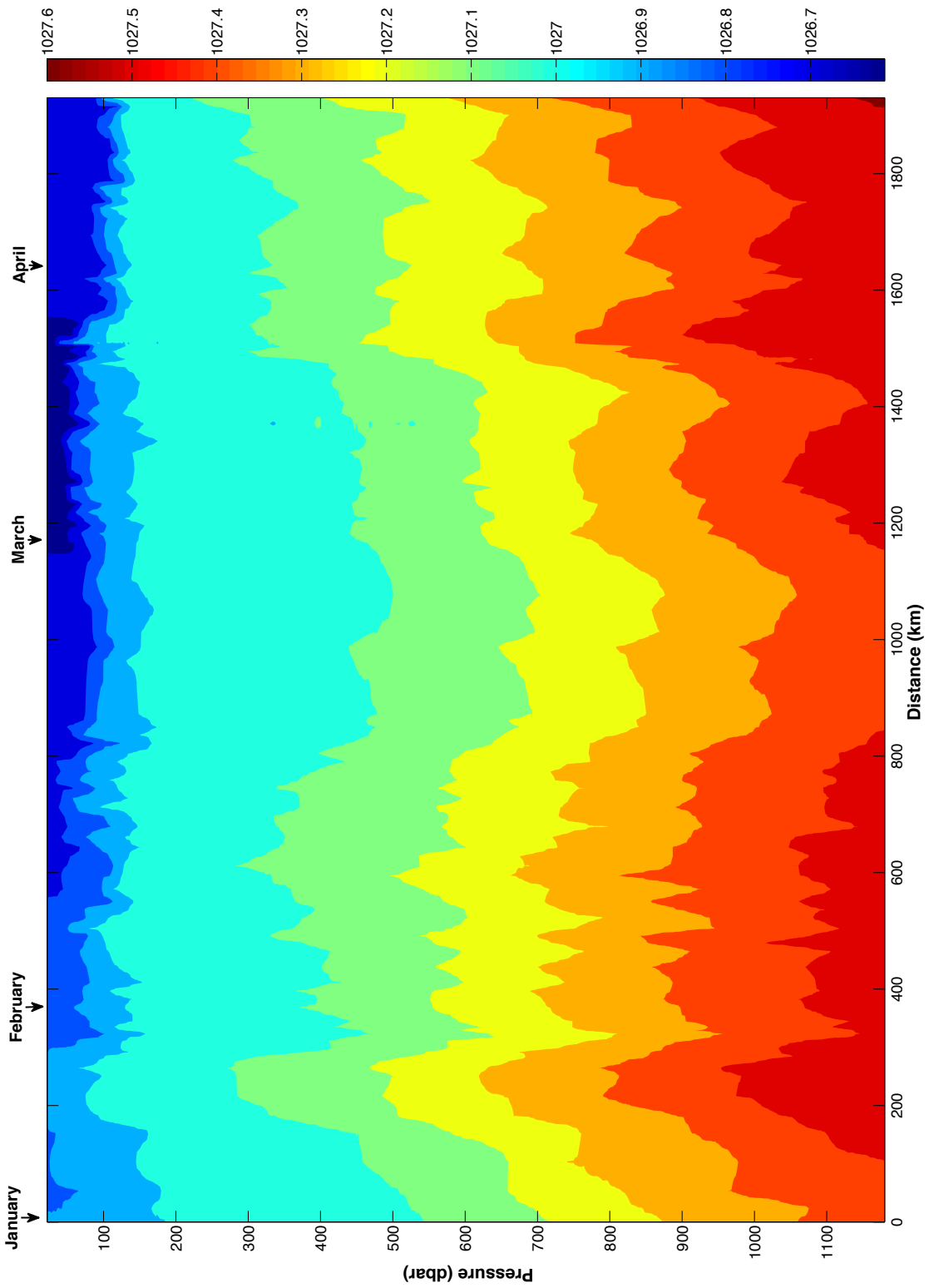


Figure 3c. Along track potential density (kg/m^3) for APEX 4782. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

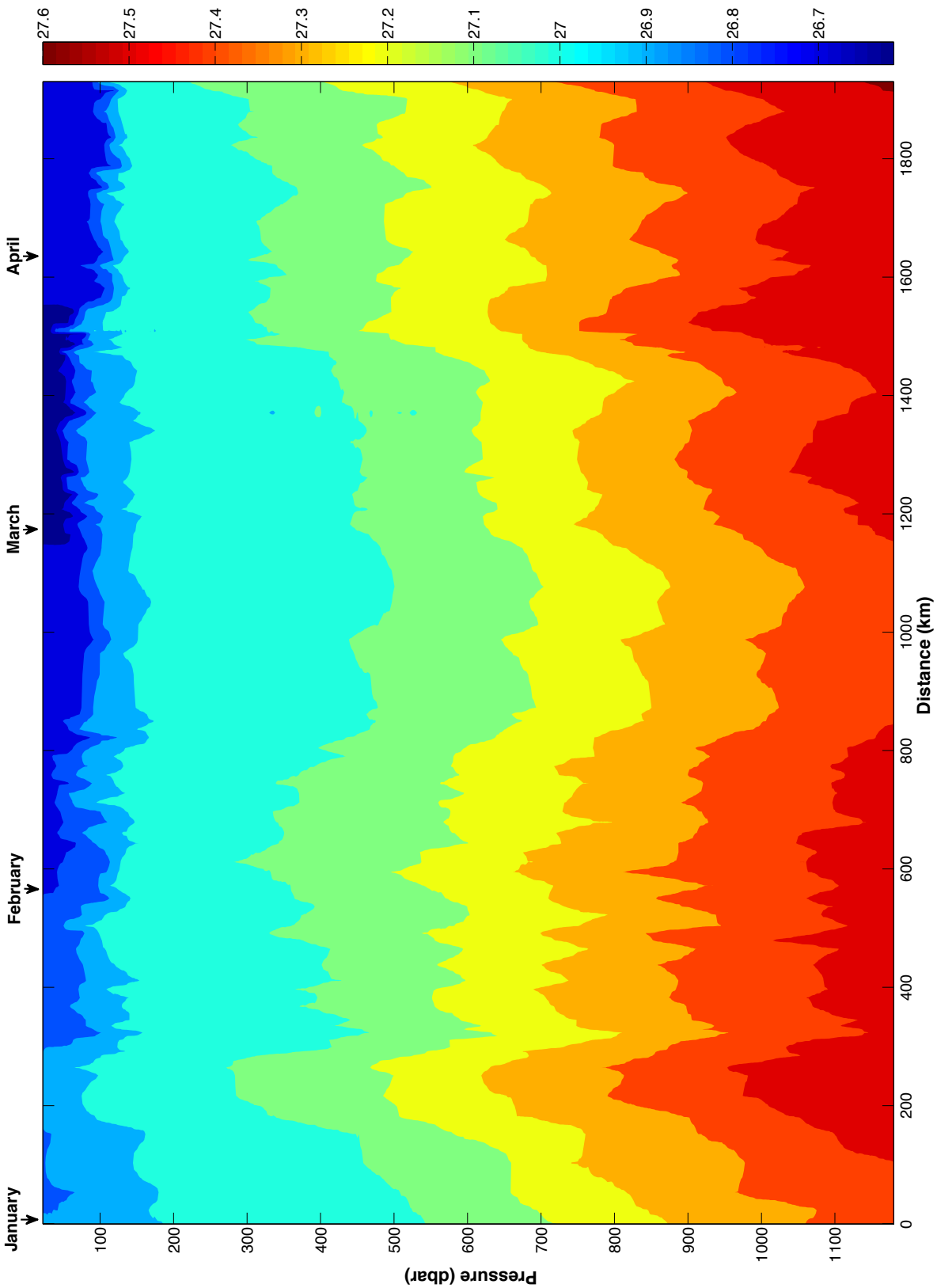


Figure 3d. Along track sigma0 (kg/m^3) for APEX 4782. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

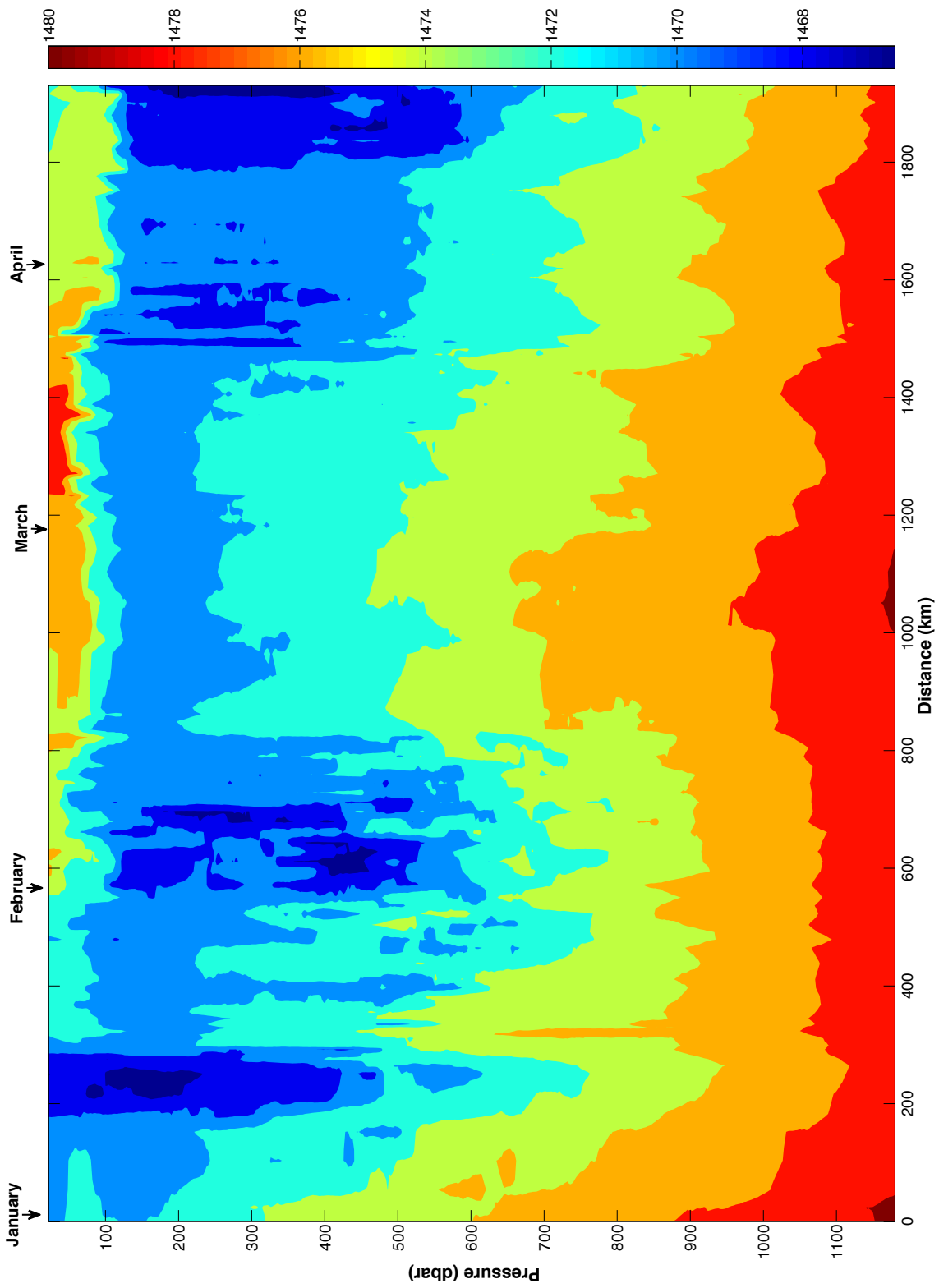


Figure 3e. Along track speed of sound (m/s) APEX 4782. X-axis indicates horizontal distance (km) from the start of the section (i.e. first CTD profile).

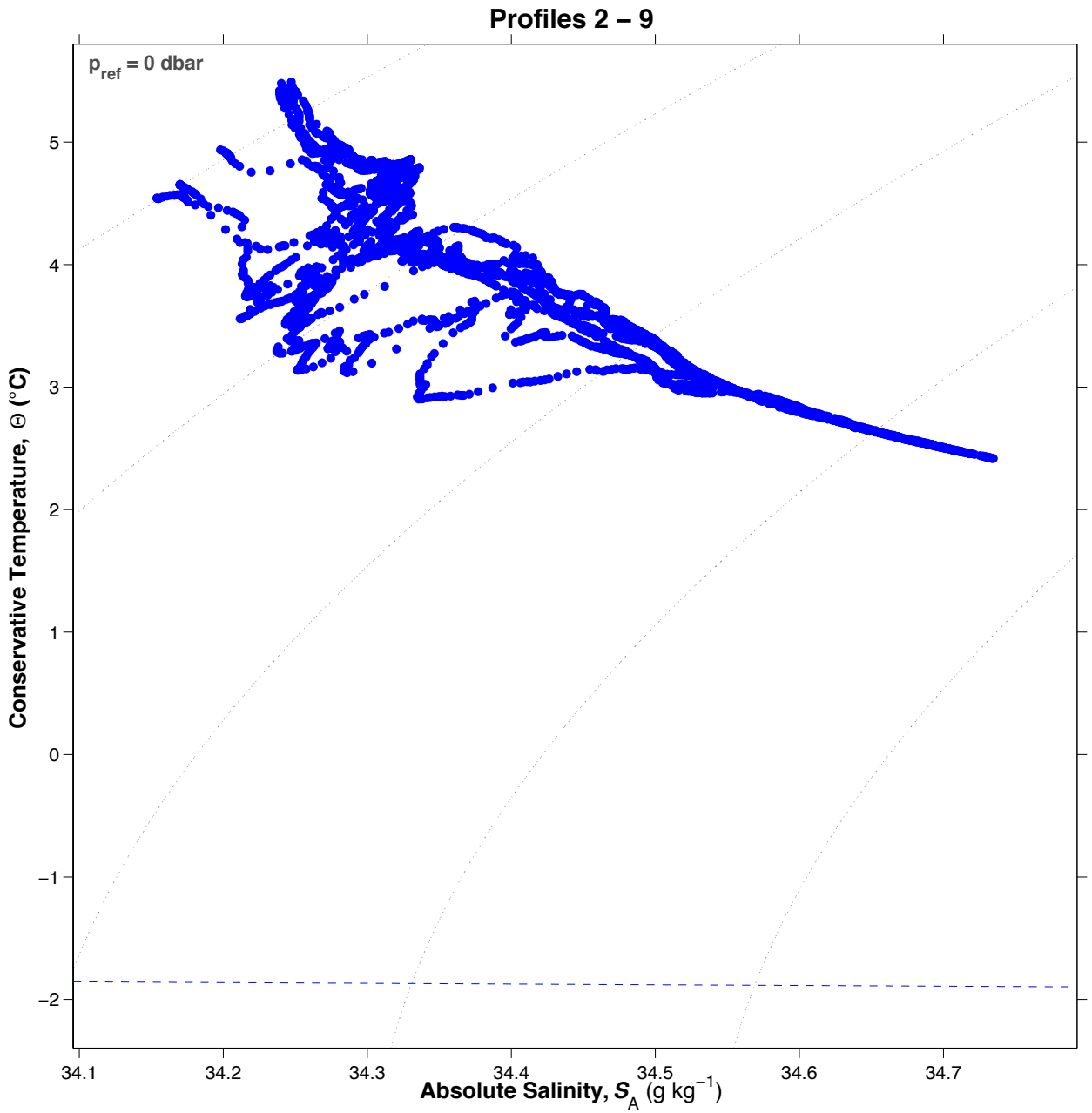


Figure 4: Conservative Temperature (˚C) versus Absolute Salinity (gkg^{-1}) along track, starting with the first profile after deployment, for APEX 4782. Each figure shows eight successive profiles. The freezing line is indicated by the blue dashed line.

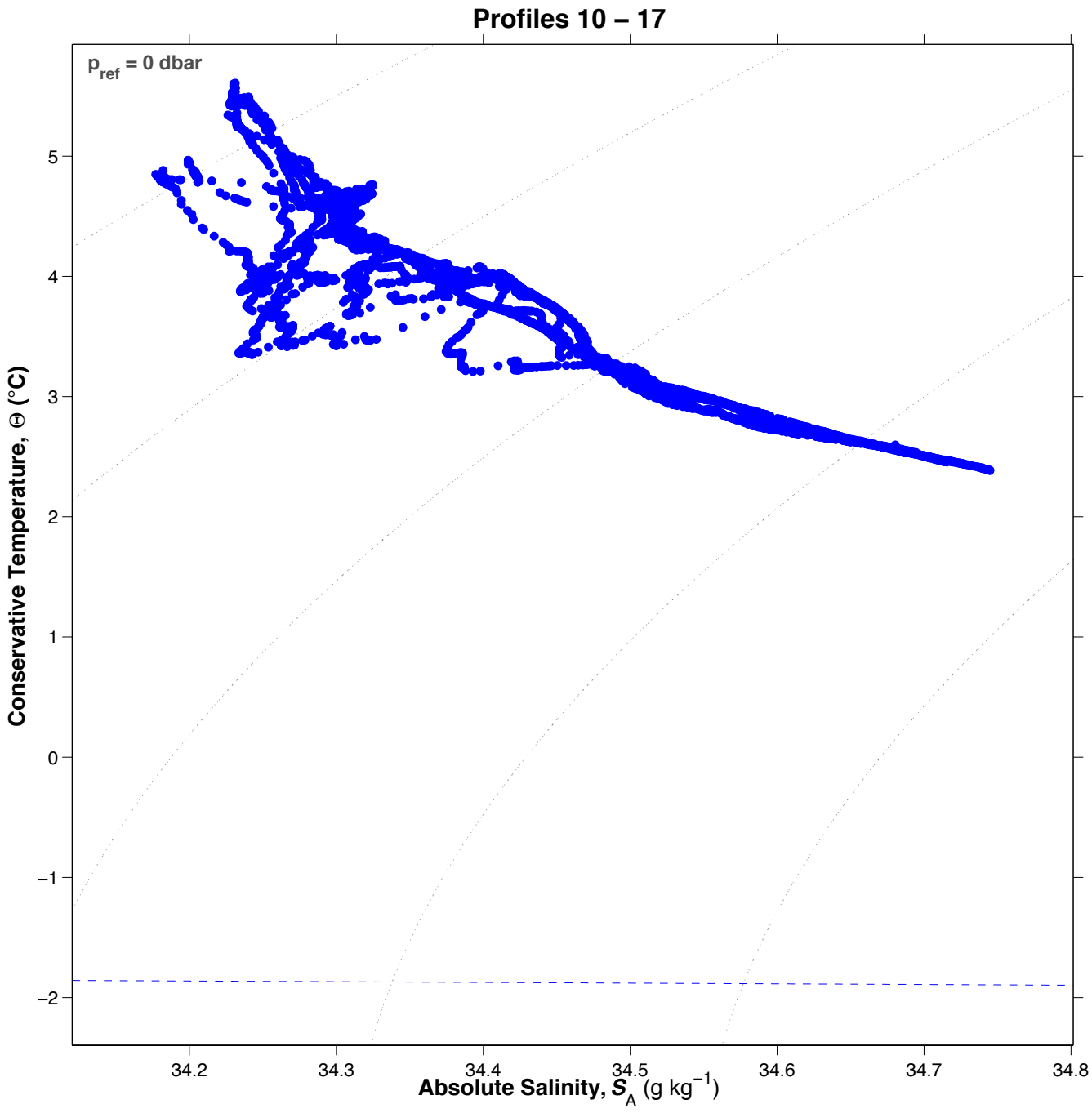


Figure 4, continued.

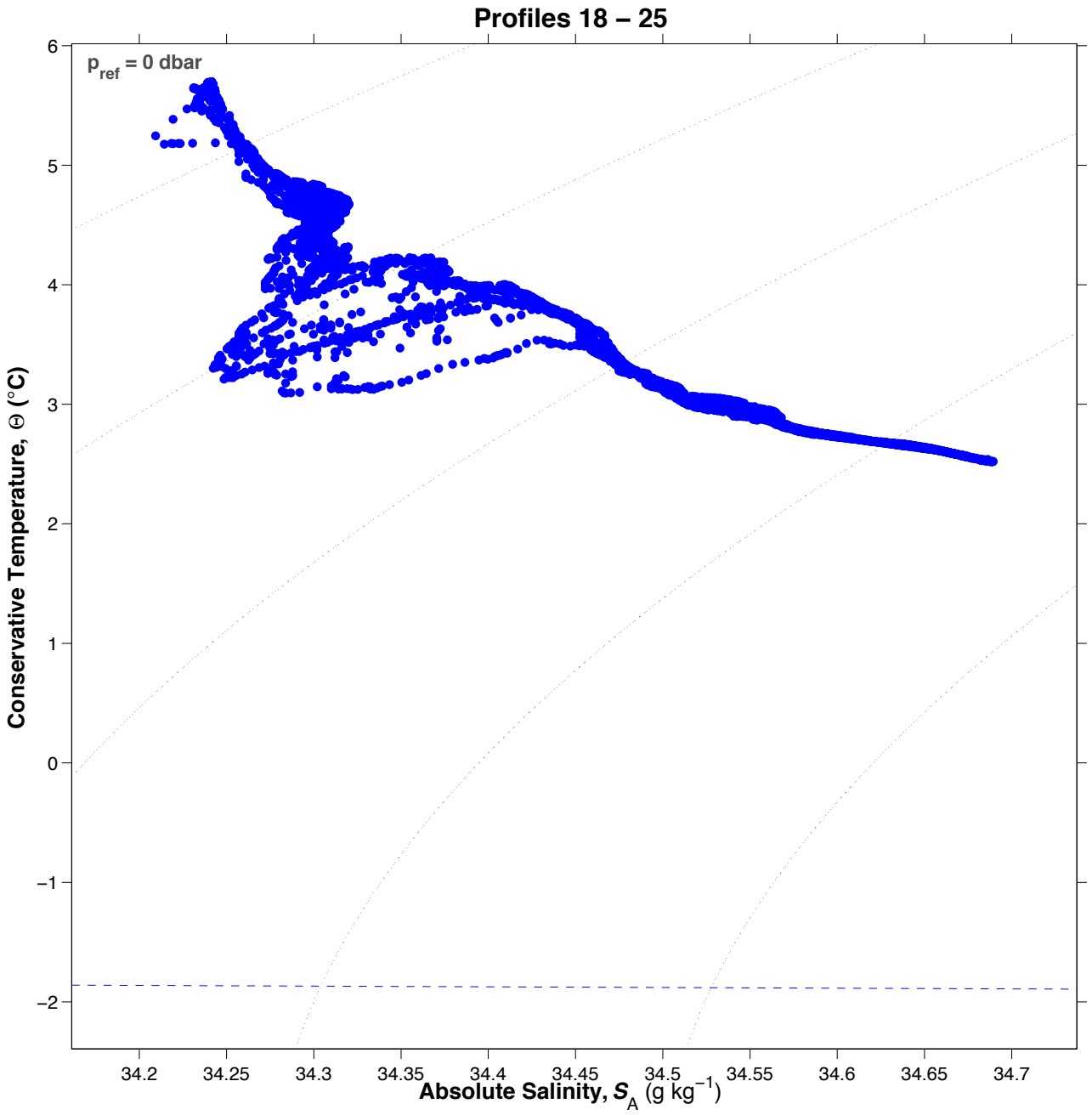


Figure 4, continued.

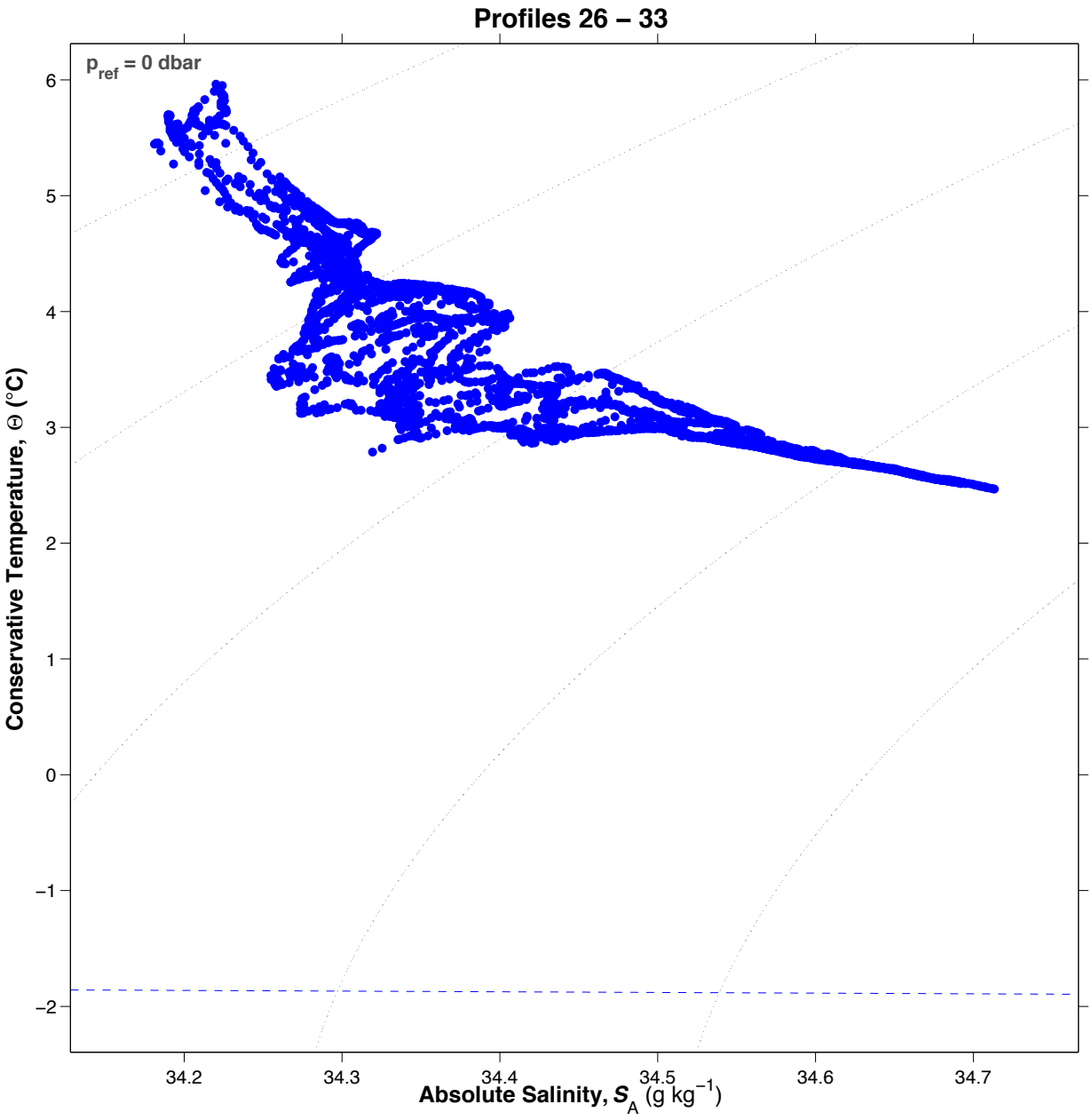


Figure 4, continued.

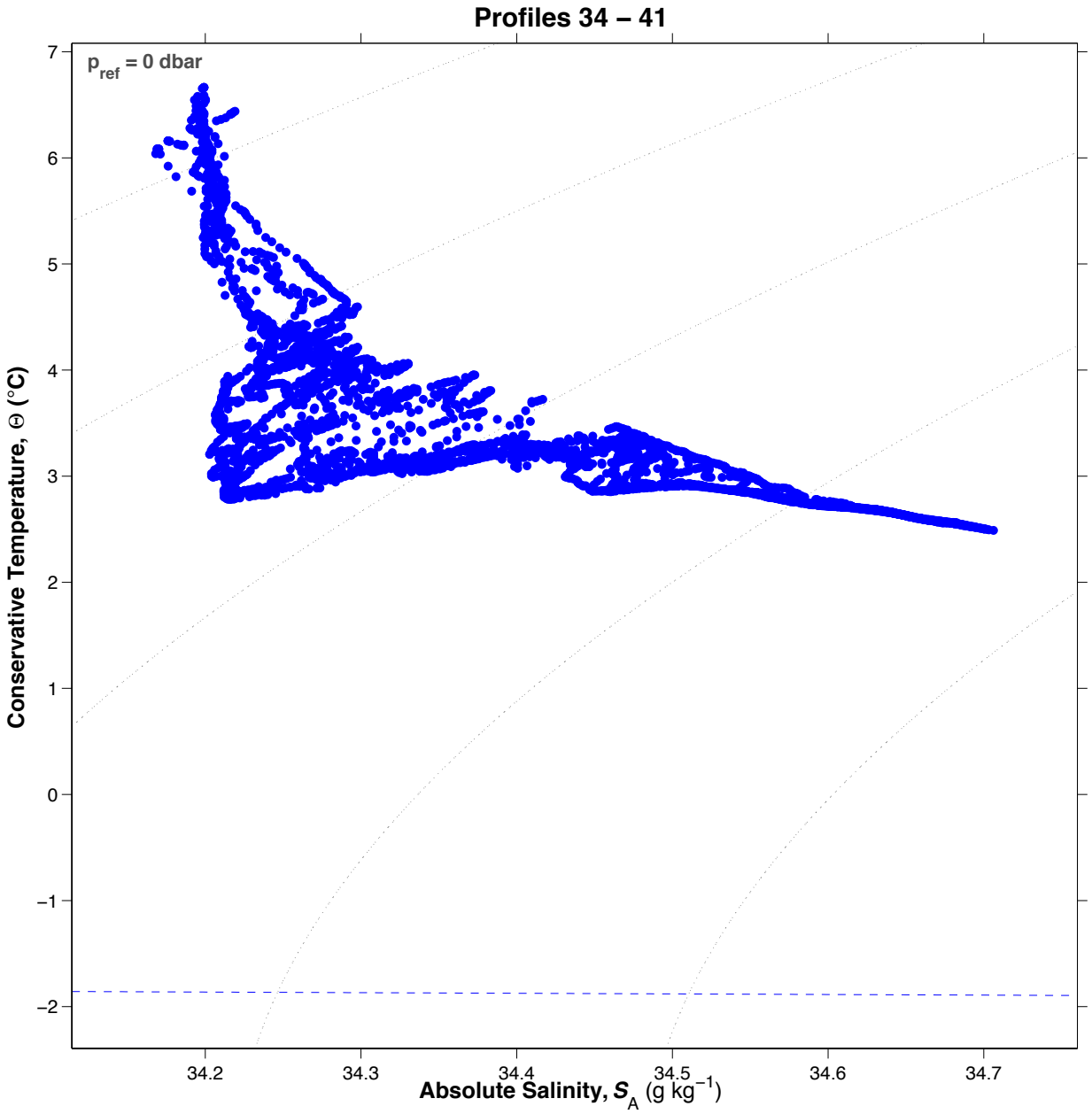


Figure 4, continued.

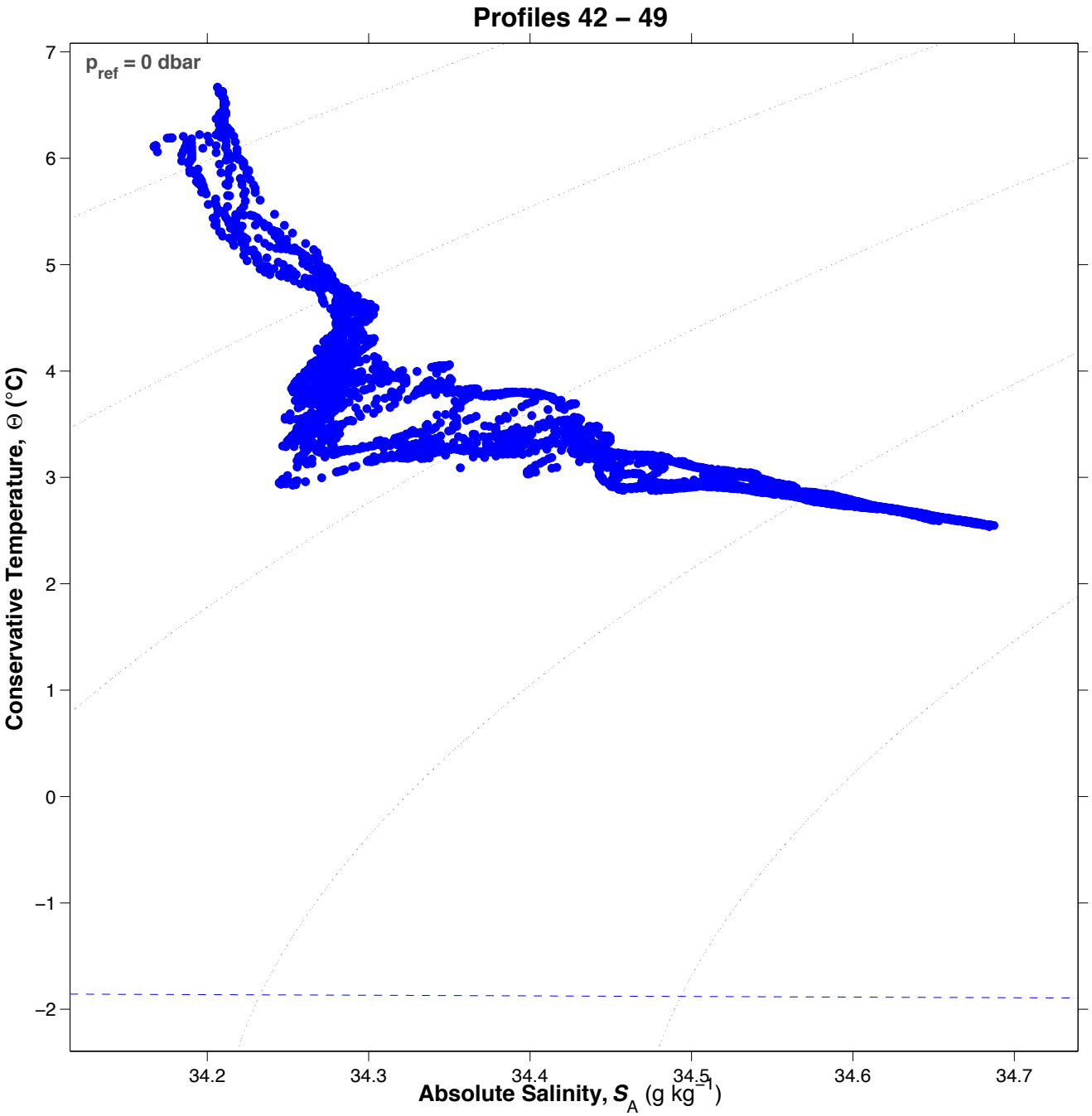


Figure 4, continued.

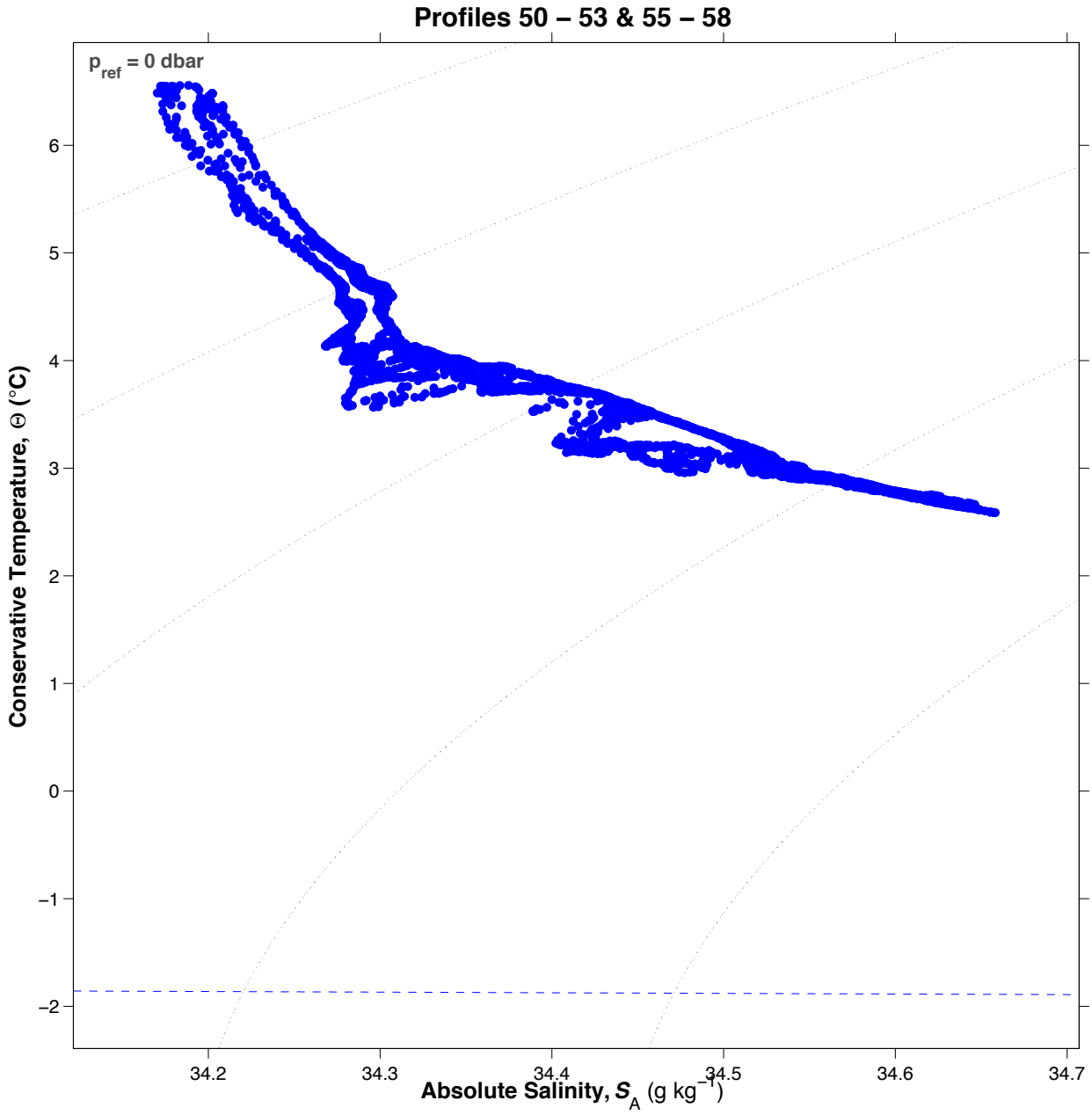


Figure 4, continued.

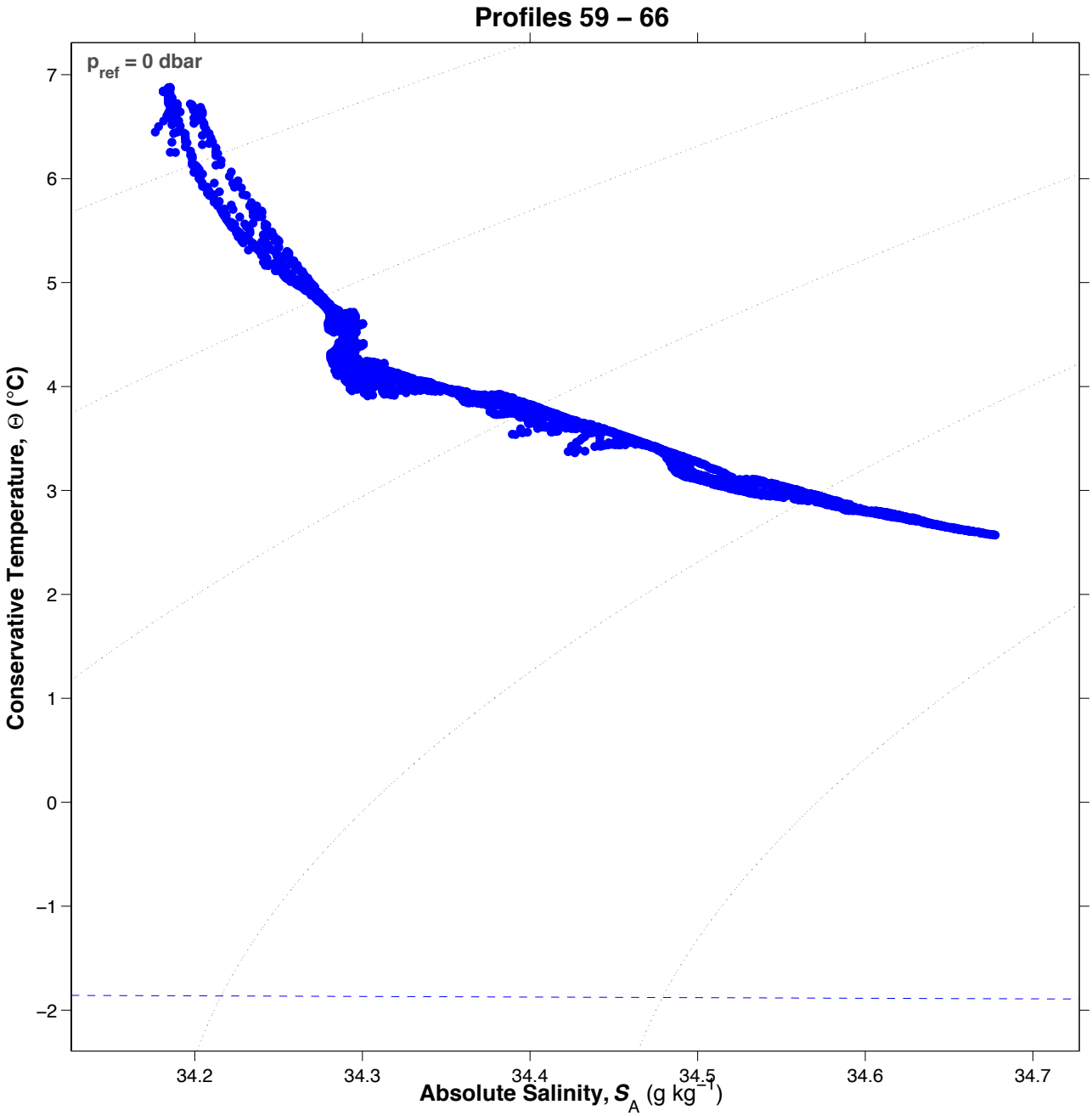
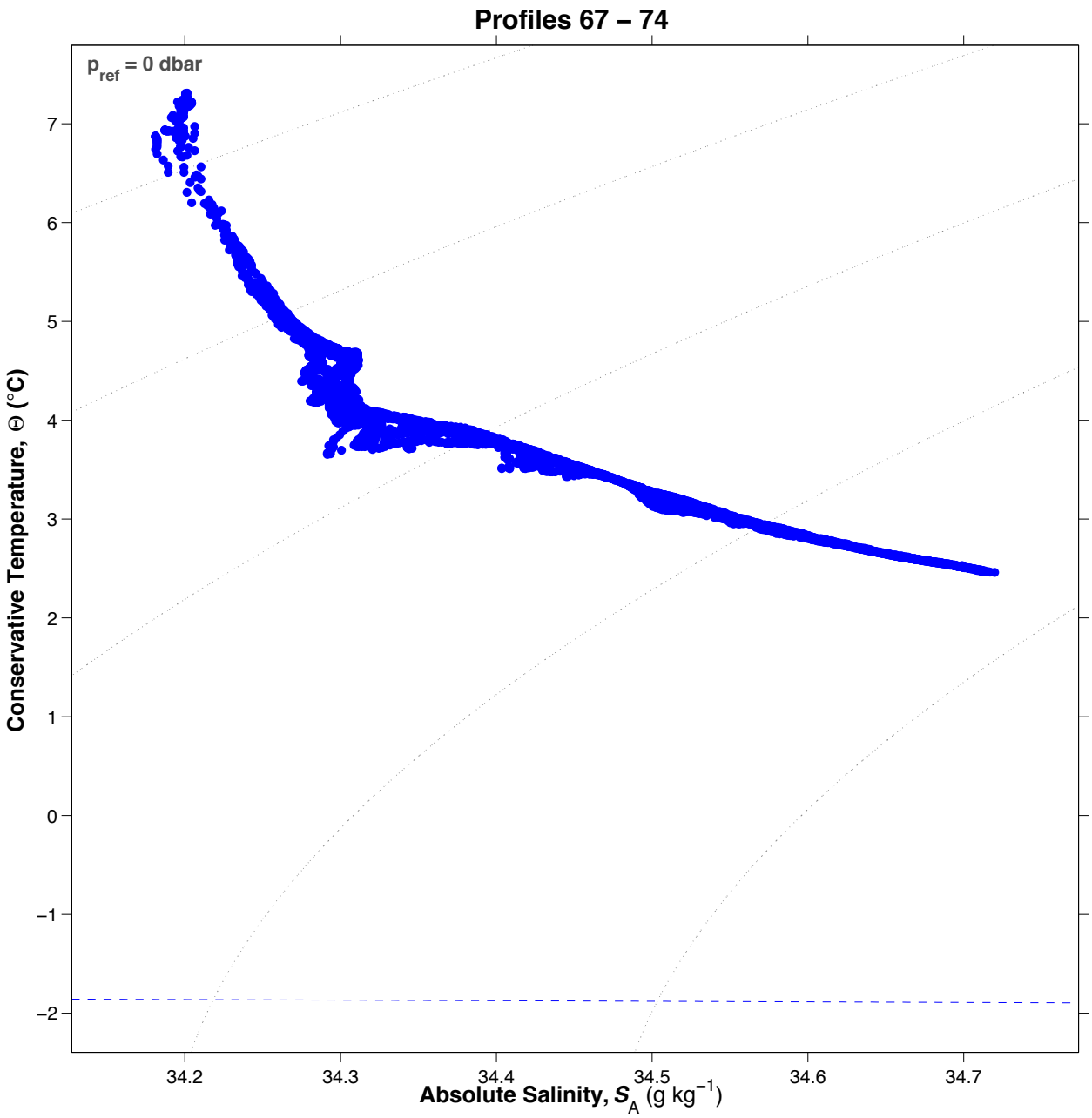


Figure 4, continued.



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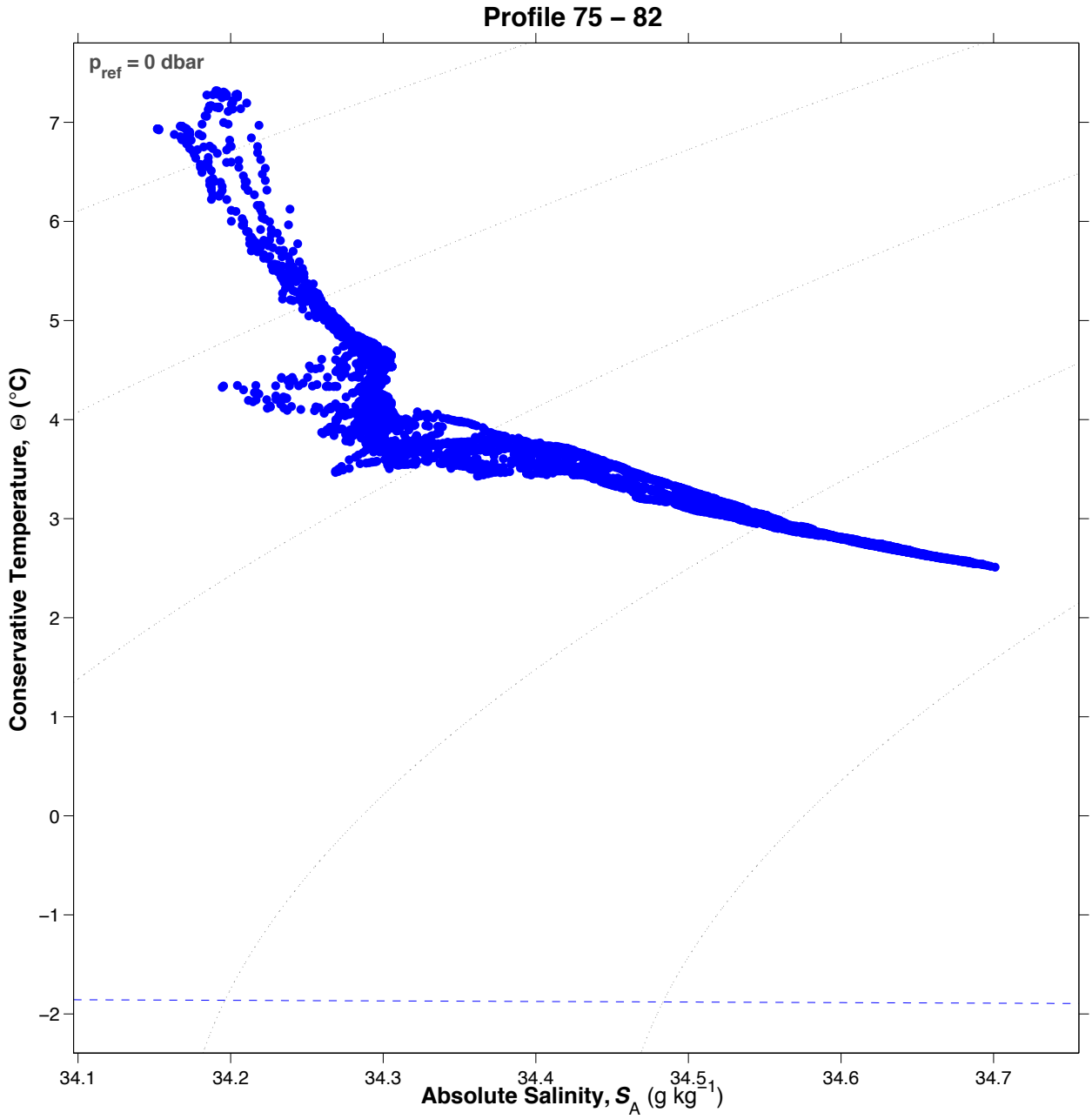

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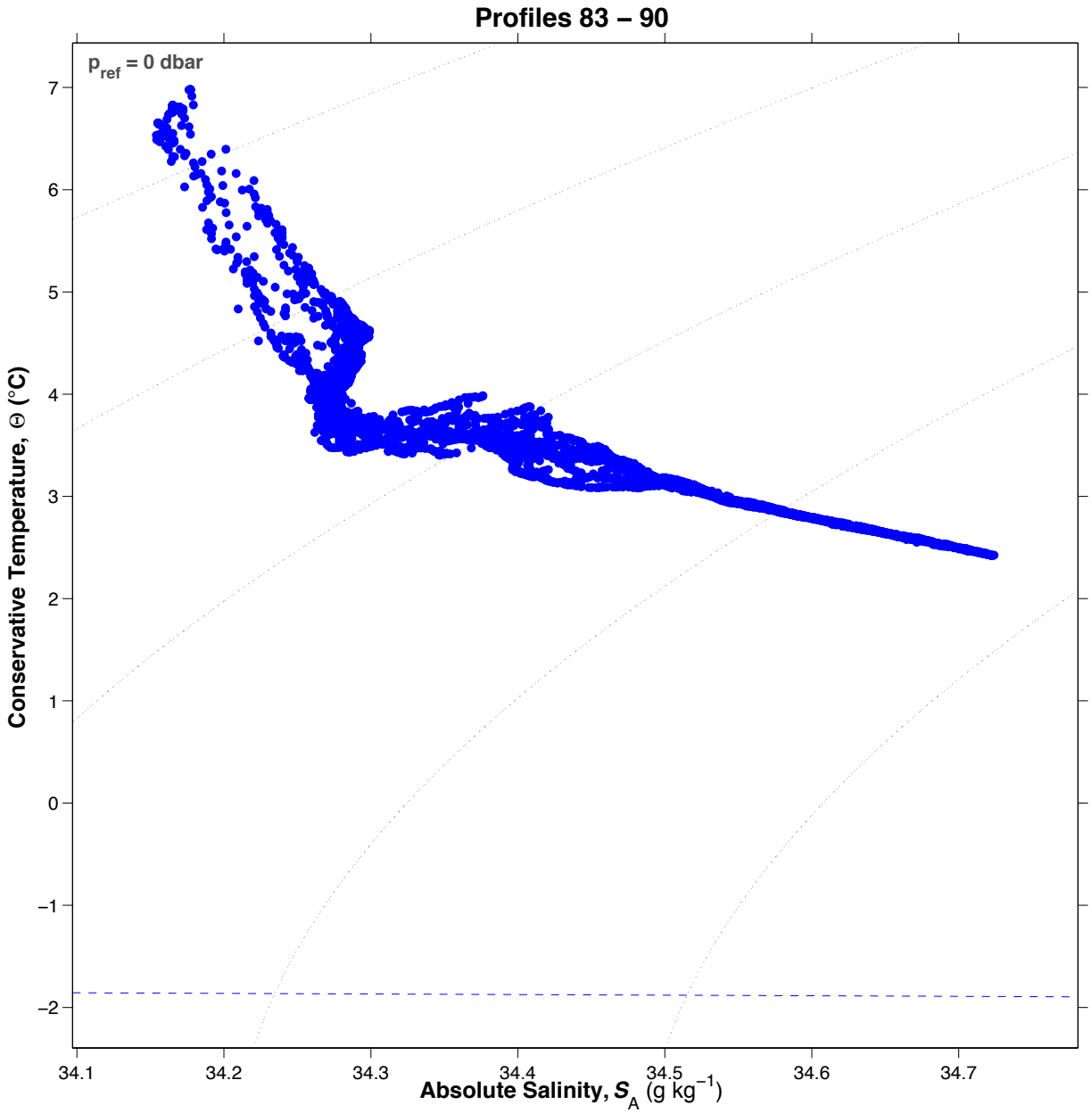

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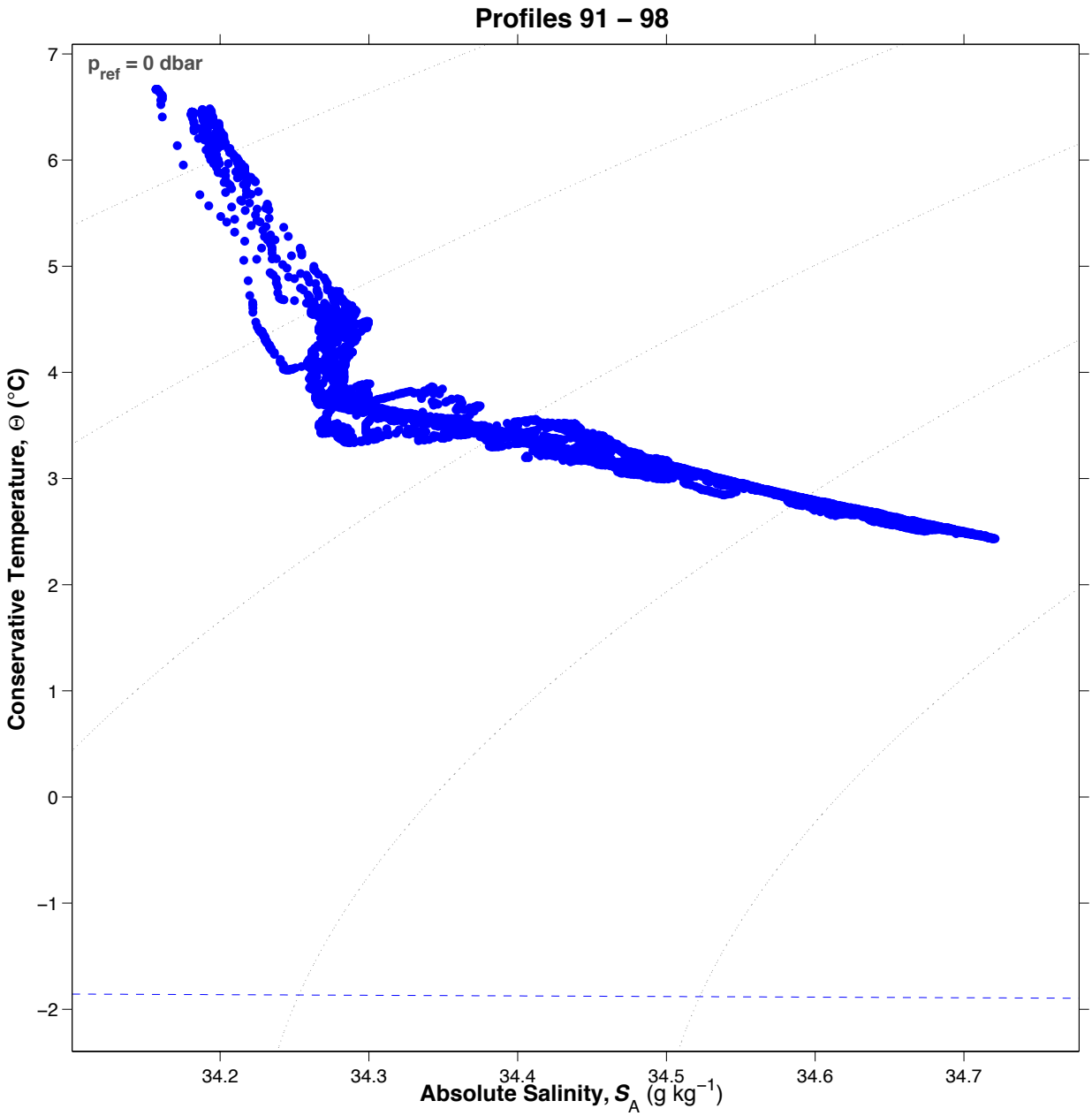

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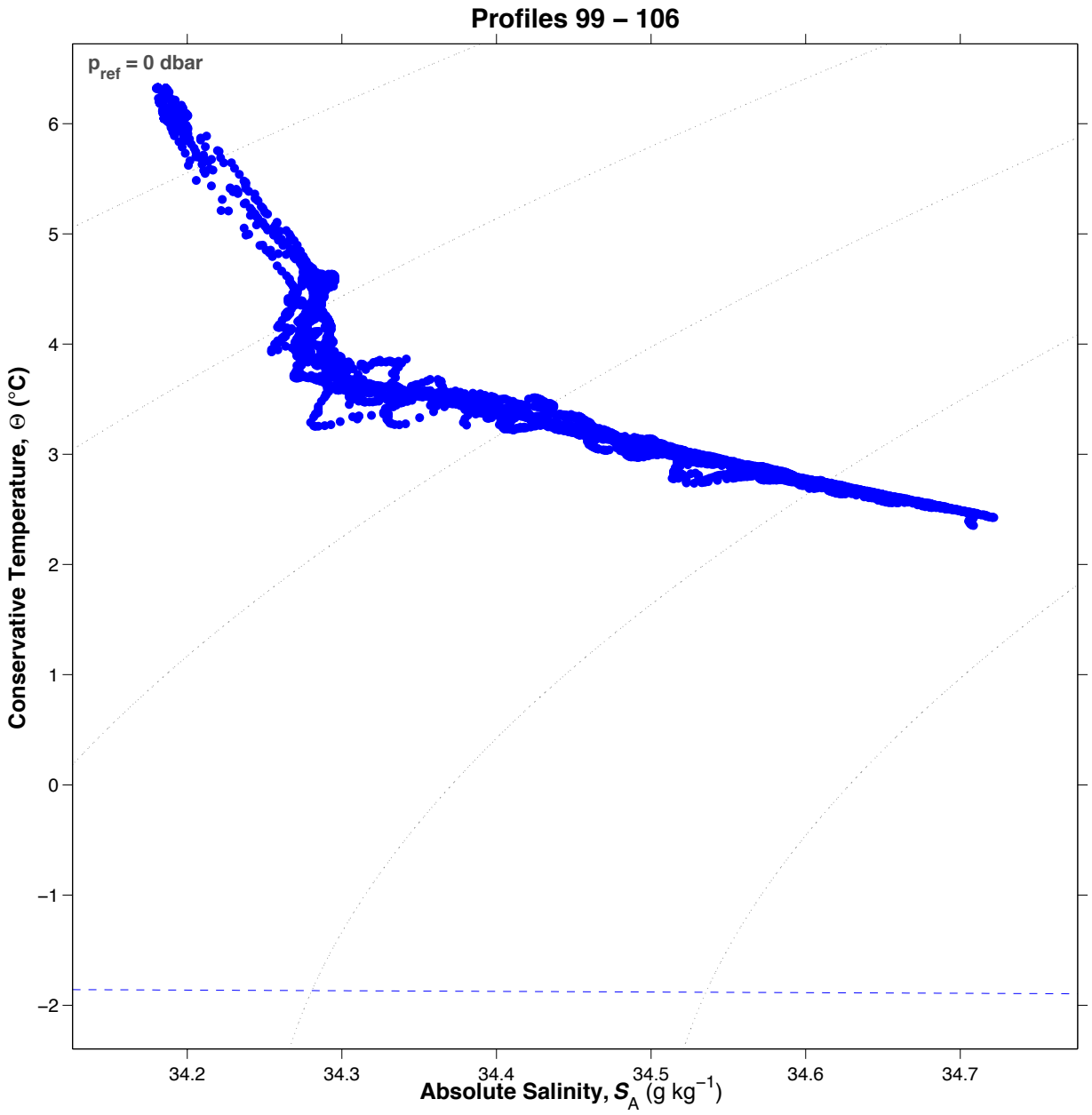

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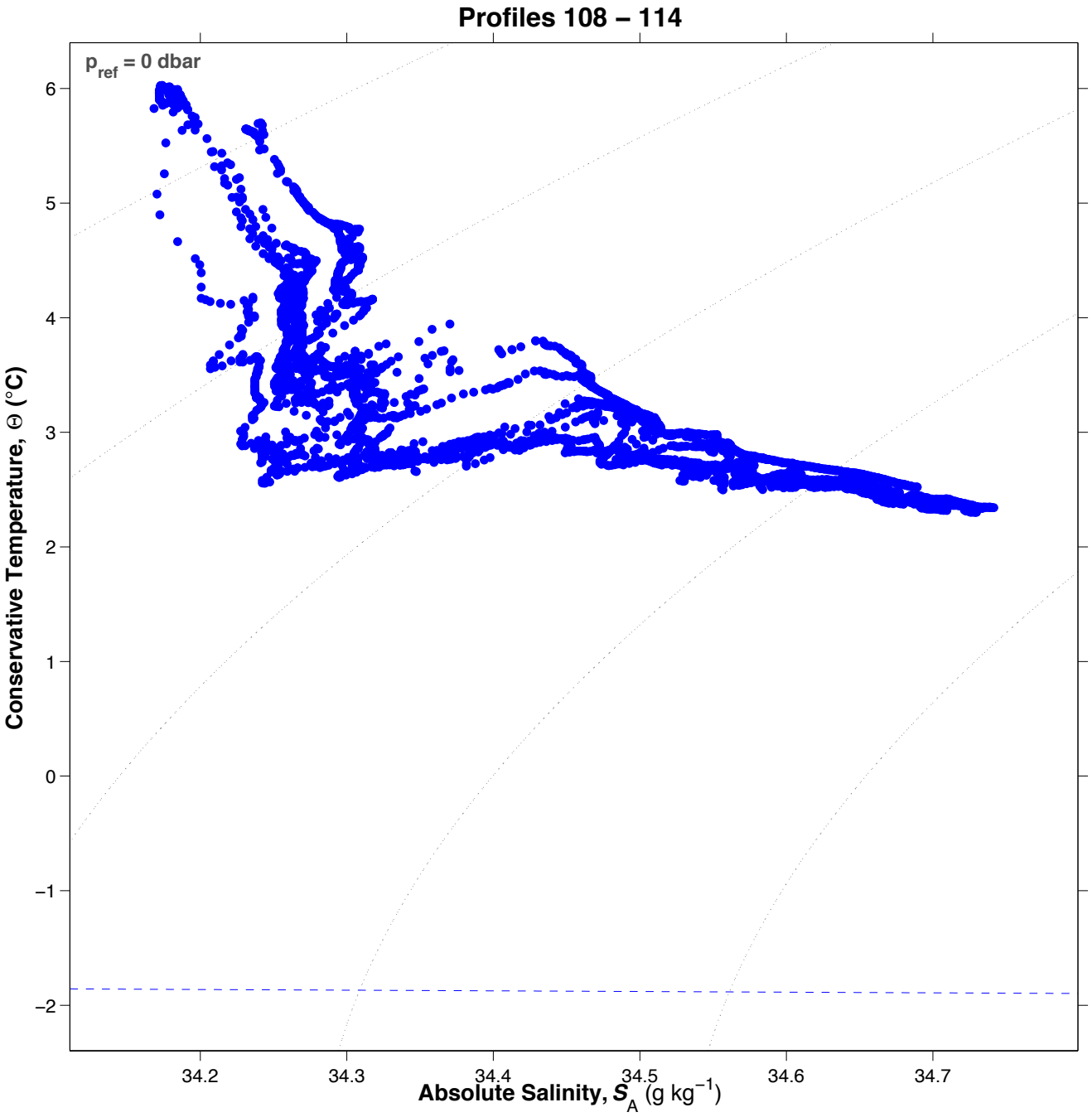

Figure 4, continued.