NAVAL POSTGRADUATE SCHOOL
Monterey, California

OC 3570 Operational Oceanography

A Comparison of Expendable Bathythermograph and Conductivity Temperature Depth Profiles

by

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INTRODUCTION

A variety of instrumentation and technology is available for sampling and processing oceanic field station data. The sophistication and ability to regularly calibrate many of today's conductivity temperature and depth (CTD) profilers make them the instrument of choice for oceanographic field sampling, particularly in research applications. However, the nature of naval operations and fiscal constraints render the CTD profiler impractical as an expedient tool to obtain temperature versus depth profiles. The expendable bathythermograph (XBT) remains the primary method for low cost quick acquisition of temperature versus depth information in the field for sound velocity profile (SVP) determination by naval forces. Yet, the reduced sophistication of some of today's XBTs presents an inherent risk of lower quality data and potential biases that must be identified.

The Naval Postgraduate School's winter 2003 Operational Oceanography class conducted a two-leg research cruise aboard the R/V Point Sur in California coastal waters between Moss Landing and Port San Luis from 27 January to 3 February 2003 (Figure 1). The first leg

departed Moss Landing, CA on 27 January and completed on 30 January in Port San Luis with a student turnover and leg two concluded on 3 February in Moss Landing, CA.

The purpose of this study is to compare the temperature versus depth profiles obtained in this cruise using the XBT against temperature versus depth profiles obtained using the CTD at the same sampling stations. Due to the increased level of sophistication of the CTD this study will be conducted from the perspective that the CTD is the accepted standard with the XBT compared to that. This paper will include a review of data collection methods, results and a discussion with mention of previous studies and the potential impact on sound velocity profile determination naval operations.

Study Region

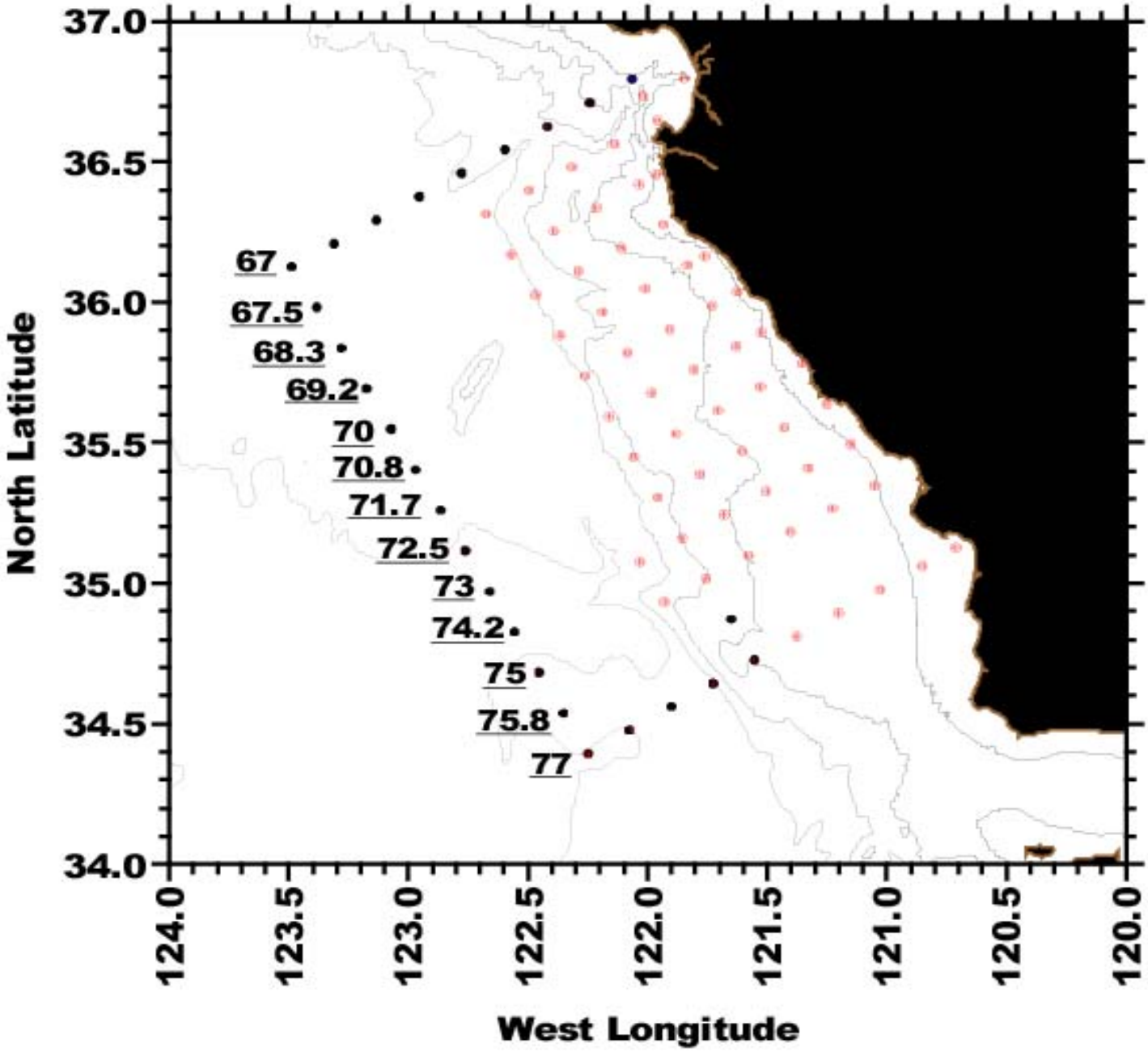

Figure 1 Study region off California coast from Monterey Bay to the north and Port San Luis outside San Luis Obispo to the south. Cruise sampling stations correspond to numbered CalCOFI stations labeled in red and stations where XBT / CTD pairs sampled labeled in black.

METHODS

CTD profiles were obtained using a Sea-Bird SBE911 plus model CTD and all XBT drops were conducted using a Sippican XBT model T-7. Twenty-five CTD and XBT profile pairs were obtained in leg one of the research cruise and one was obtained in leg two (Figure 1 and Appendix A). XBT83 failed during deployment at CalCOFI station 67-70 however, a second XBT was deployed at that station and an XBT/CTD pair for this station is included in the analysis. Raw CTD data was presented for analysis in ASCII data format while XBT data was initially downloaded as European data format for processing. MATLAB 5.3 was used for the extraction of temperature, salinity and depth data from CTD ASCII files and temperature, depth and sound speed data from XBT data as well as for all subsequent processing.

Data processing was initiated with two quality control measures. Temperature versus depth profiles was plotted for all CTD and XBT pairs (Appendix B). The first quality control step was a visual inspection of all profiles to identify bad or erroneous data. The second quality control step used a MATLAB program to compare the measured temperature at each level to the average of the temperature of levels above and below it to identify potentially

erroneous temperature readings. Measured temperatures at a particular level that differed by more than 0.2°C from the average of the surrounding levels were flagged as a possibly bad data point for subsequent investigation. Only one level was available for comparison for the top and bottom levels. The selected temperature criteria of 0.2°C was determined to be less than two standard deviations of the final statistics by Roth (2001) and Schmeiser (2000) and considered acceptable.

The vertical profile for both the CTD and XBT was between 0 and 760 meters(m). Most CTD casts were deeper that 760 m however the maximum limit of the Sippican T-7 XBT is 760 m and therefore the analyses of the CTD profiles were truncated to this same 760 m depth for uniform comparison. The CTD profile is broken into 383 vertical levels between the surface and 760 m by the program software while the XBT software automatically breaks the vertical dimension into 1183 vertical levels. An interpolation program defined by Roth (2001) was used to convert the XBT depth increments from 1183 to 383 levels consistent with the number of CTD levels. The CTD profiler measures temperature against decibars of pressure vice meters of depth, which is the case for XBTs. However,

pressure was automatically converted to depth in meters using this CTD software package and therefore no pressure to depth conversion was necessary for this study unlike previous studies.

The CTD and XBT profiles from twenty-six collocated stations were paired and three plots were produced for analysis. A profile of temperature versus depth for each sensor at each station was produced, followed by a plot of the difference between the CTD and XBT temperature at each depth and third plot of the isotherm depth difference at each level was produced (Appendix B). Mean and standard deviation values were determined for all 383 levels. Sound velocity profiles using XBT and CTD data were produced for qualitative comparison (Figures 5 and 6).

RESULTS

Visual inspection of temperature versus depth profiles indicated erroneous XBT data for XBT 75 (pair 1) and XBT 93 (pair 18) (Appendix B), therefore these pairs were disregarded leaving twenty-four XBT/CTD pairs for analysis. The total number of resulting levels checked was 18384 (9192 XBT + 9192 CTD). Twenty-two XBT levels (0.24%) and fifteen CTD levels (0.16%) were flagged as potentially bad points. Those that were flagged as potentially bad were inspected individually and determined to be part of a logically decreasing sequence of temperature versus depth and therefore retained for analysis.

The mean and standard deviation of the temperature different between the XBTs and CTDs were determined for 383 levels between the surface and 760 meters (Table 1). The XBT temperatures ranged between 0.0677°C to 0.1873°C warmer than corresponding CTD measurements and had an average warm bias of 0.1275°C overall. A maximum average temperature difference of 0.5088°C was observed at 60 m and below 80 m the average temperature difference was less than 0.12°C and generally decreased with depth.

The greatest variability was observed in the upper 80 m. The greatest standard deviations also occur in the upper levels with the standard deviation of the 25-125m levels roughly twice the value of the overall standard deviation, while a maximum standard deviation of 0.6488°C was observed at 56 m. The standard deviation below 80m was 0.0355°C and also generally decreased with depth (Figure 2).

Studies	Depth(m)	Mean(deg C)	Std(deg C)
Schmeiser Aug 2000	25-125	-0.2198	0.3598
	175-375	-0.1212	0.1981
	0-760	-0.1549	0.2151
Roth Feb 2001	25-125	-0.0907	0.1779
	175-375	-0.0851	0.096
	0-760	-0.0783	0.1047
Boedeker Aug 2001	25-125	-0.1530	0.5135
	175-375	-0.0549	0.2157
	0-760	-0.0882	0.2147
Fang Jul 2002	25-125	-0.2453	0.4123
	175-375	-0.0802	0.1172
	0-760	-0.1074	0.1546
Dixon Feb 2003	25-125	-0.2366	0.1009
	175-375	-0.1010	0.0193
	0-760	-0.1275	0.0598
Average	0-760	-0.1113	0.1498

Table 1 Mean and standard deviation of CTD-XBT temperature differences on NPS OC3570 cruises aboard R/V Point Sur.

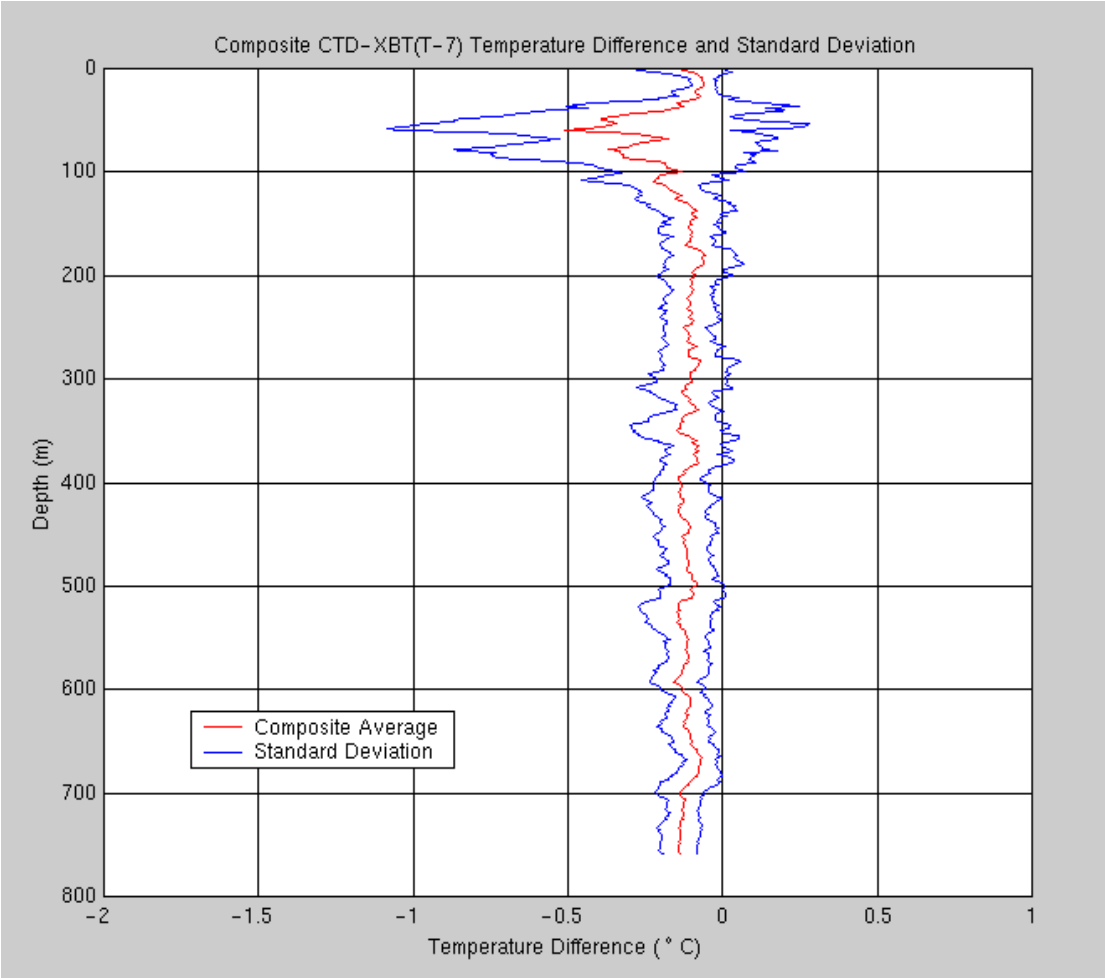

Figure 2 Plot of average CTD - XBT temperature difference versus depth for twenty-four XBT/CTD pairs. Values are subtraction of XBT temperature from CTD temperature, negative values indicate warm bias exhibited by XBT.

The mean XBT isotherm depths were on average greater (deeper) than the CTD measurements. This trend is consistent for all depths with the exception of the deepest 50 m depth. The average isotherm depth measured by XBT was 13.53 m deeper than measured by CTD with a standard deviation of 6.20 m throughout the depth range. The

greatest average depth difference occurs between 600 and 700 m with a maximum depth difference of 24.44 m observed at 693 meters depth. The maximum standard deviation of 16.70m was observed at 695 m (Figure3).

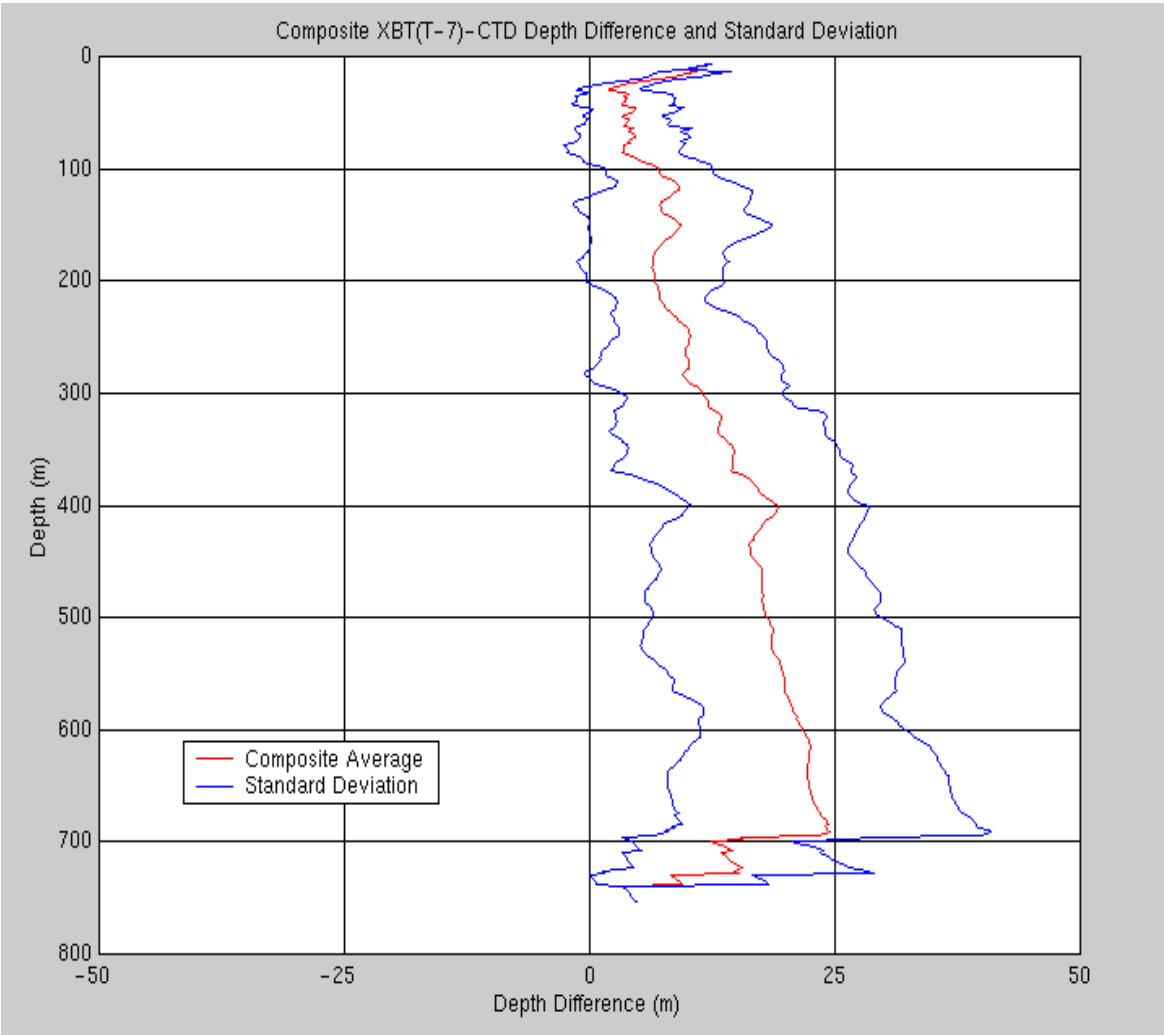

Figure 3 Plot of average CTD - XBT isotherm depth difference versus depth for twenty-four XBT/CTD pairs. Values are subtraction of XBT depth from CTD depth indicating the average isotherm measured by XBT is deeper than the same isotherm measured by the CTD.

DISCUSSION

Four OC3570 student studies comparing CTD and XBT profiles have been performed previously by Fang (2002), Boedeker (2001), Roth (2001) and Schmeiser (2000) which compared twenty-eight, twenty-seven, nine and eighteen CTD/XBT pairs respectively, while this study compared twenty-four pairs. Past studies compared both Sippican T-7 and some T-4 XBTs to a Sea-Bird CTD on board the R/V Point Sur along the central California coast, results are summarized in Table 1, this study utilized only T-7 XBTs.

Quality control and processing methods did vary slightly among the student studies. This study interpolated the XBT data before the data was quality checked consistent with Fang (2002), Boedeker (2001) and Roth (2001), which Schmeiser (2000) did not do. The XBT sampling interval is considered small therefore it is concluded that employment of the quality control measures after interpolation will have little effect on the outcome of the quality control (Roth, 2001).

The results of the previous four student projects are generally consistent and this study is in agreement with the results of these studies (Table 1). The selected depth categories of 25-125 m and 175-375 m were selected first by

Schmeiser (2000) and could be considered somewhat arbitrary. Other depth categories may form a better basis for research such as those correlating commonly to accepted definitions of the mixed layer and thermocline however; these depth categories have been retained to facilitate a consistent method of comparison among studies.

The XBT exhibits a systematic error of higher temperature readings and decreased isotherm depths. The warm bias in the XBT measurements is most pronounced in the upper portion of the water column and generally decreases with depth (Figure 2). Consistent with Fang (2002) and Boedeker (2001) this study has a larger mean temperature difference in the 25-125 m layer than those results obtained by both Boedeker (2001) and Schmeiser (2000) but the difference is less dramatic than in Roth's study. The increased warm bias and variability in this layer is consistent with the greatest change in temperature with depth in the thermocline layer and is to be expected. Heinmiller et al (1983) compared results obtained from both Sippican T-4 and T-7 XBTs to a calibrated Neil Brown CTD in the Sargasso Sea and summarized results of similar previously conducted field studies and came to similar conclusions.

The standard deviation of the temperature difference between XBT and CTD measurements in this study is lower than previous studies. As indicated, quality control steps among studies did differ and decision to eliminate what is assumed as bad data can be subjective. The temperature versus depth profile for XBT/CTD pair eighteen indicates an obvious problem with temperature measurement by the XBT justifying its elimination. The temperature anomaly at depth of XBT 75 in pair one is subtler however; this XBT/CTD pair was disregarded as well. If both XBT/CTD pairs one and eighteen were included in analysis the standard deviation of the XBT - CTD temperature difference would have been -0.1679^{o}C, and in greater agreement with previous studies (Table 1.).

Qualitative comparison of the temperature versus depth profiles of XBTs and CTDs between this study and Fang's (2002) indicates greater difference between XBT and CTD temperature profiles in Fang's (2002) study, particularly in the upper thermocline layer. This study occurred in February under a more winter regime as opposed to Fang's (2002) study that was conducted in a more summertime regime in July. XBT/CTD sampling stations between this study and Fang's (2002) are close spatially indicating that

investigation of patterns of temporal variability may provide greater insight into this observed variability.

Impact on Sound Velocity Profiles

XBTs are the primary instrument for developing sound velocity profiles (SVP) for the Navy for use in antisubmarine warfare (ASW) operations. The results of this study indicates that a warm bias is introduced by the XBT but the question of exactly how this warm bias affects the SVP must be addressed. The average warming bias introduced by the XBT in this study is 0.1275^{o}C (Table 1) and from all the student cruises is 0.1113^{o}C. A 1°C increase in temperature will roughly increase the sound speed by 4 m/s (Urick, 1983). As shown in Schmeiser (2000), a bias of 0.4°C would change the computed sound speed by only 1.6 m/s, about 0.1% of the average 1500 m/s sound speed. The average bias of 0.1275^{o}C presented by the T-7 XBT in this study would increase the average speed of sound by only 0.51 m/s. SVPs produced by XBTs are slightly modified as compared to profiles at the same stations produced by CTDs, a qualitative representation of this is indicated in Figure 4.

Since the XBT bias is almost consistent through out the entire profile, the sound speed will be effected roughly the same amount at each depth. Sound speeds are only nominally increased by the warm bias of the XBTs and the sound speed gradients are not appreciably affected. Therefore it is concluded that the sound speed and sound speed gradient change is not appreciably affected by the warm bias of the XBT and sound velocity measurements obtained by the XBTs are not impacted significantly enough to impose an operational degradation upon the ASW problem.

Figure 5 illustrates a number of SVPs at one example station and how it is affected by the different measured parameters. A consistent sound velocity bias is exhibited by the XBT however it must be considered that a constant salinity value of 33.5 psu is utilized by Sippican T-7 XBTs. Since sound speed is a function of temperature, salinity and pressure (Urick, 1983) the impact of a constant salinity value versus in-situ measurement cannot be disregarded. Figure 5 includes a SVP (in green) that uses the temperature measured by the XBT at that station and an average salinity value of 34.05 psu obtained by the CTD. This SVP is in closer agreement with the SVP produced

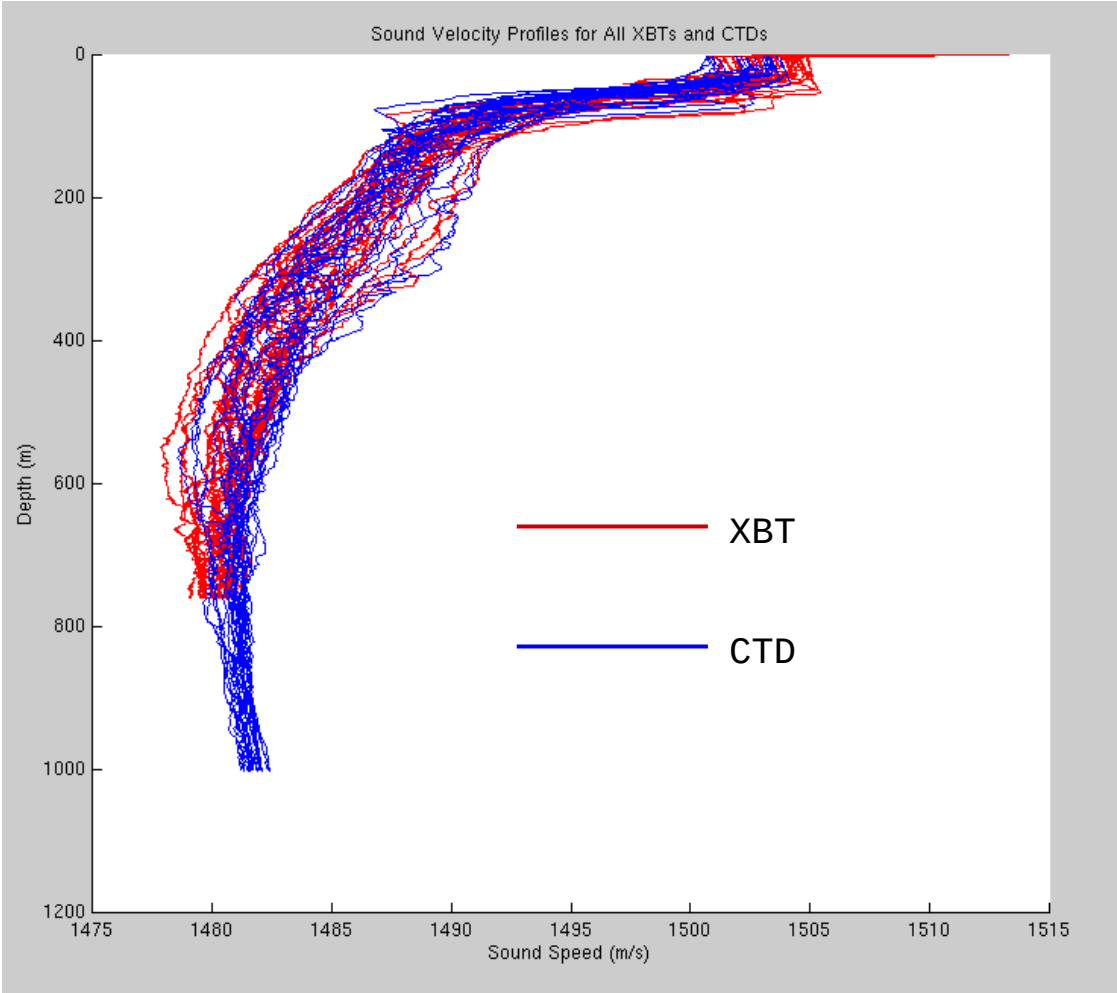

Figure 4 Plot of sound velocity profiles produced by XBT and CTDs for the twenty-four XBT/CTD pairs.

by the CTD (in blue) indicating that use of a constant salinity value can negatively impact the SVP produced by the XBT in addition to temperature measurement bias by the XBT. For comparison an SVP produced using the climotological model Generalized Digital Environmental Model (GDEM) is included.

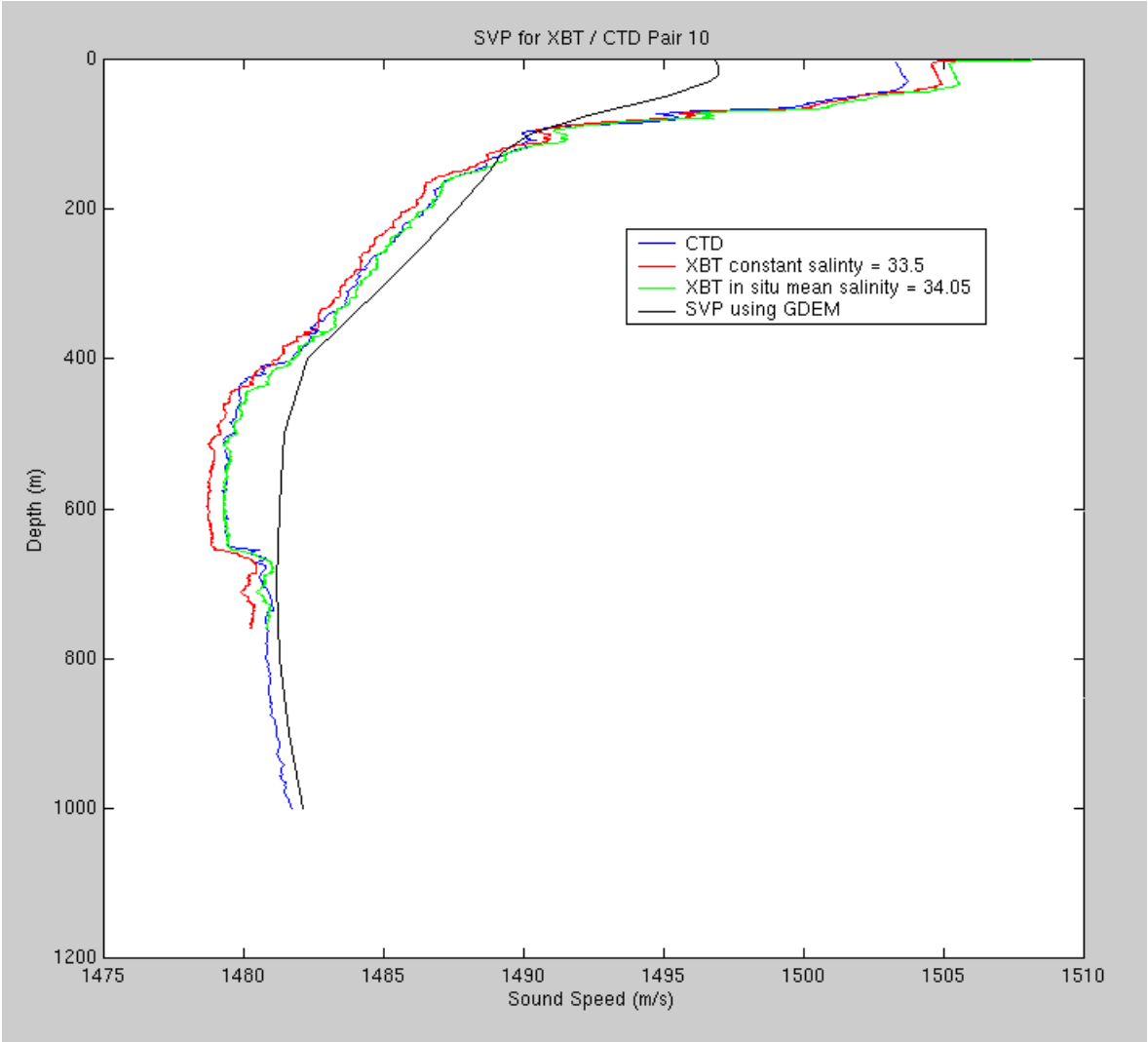

Figure 5 Plot of sound velocity profiles produced by XBT and CTDs using different salinity values and an SVP produced by GDEM at CalCOFI station 67.5 - 70.

In conclusion, four different NPS studies have indicated that XBT's record ocean temperature warmer than actual. A larger sample size will help to validate the statistics. As Roth (2001) suggests, the XBTs should be released before the CTD to reduce temporal variation to a

minimum. The depth differences introduced by the warm bias of the XBT indicate that XBTs should not be used for research purposes. However, the magnitude of the impact of the warm bias and use of a constant salinity value in XBTs for generation of sound velocity profiles is small enough that the sound velocity profile is not negatively impacted and XBTs essentially serve the purpose to develop SVPs in the navy.

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Roth, M.J., “XBT and CTD Temperature Measurement Comparison, Quality of JJYY Data and XBT Data Analysis of the Mixed Layer Depth.” Paper submitted for OC3570, 2001.

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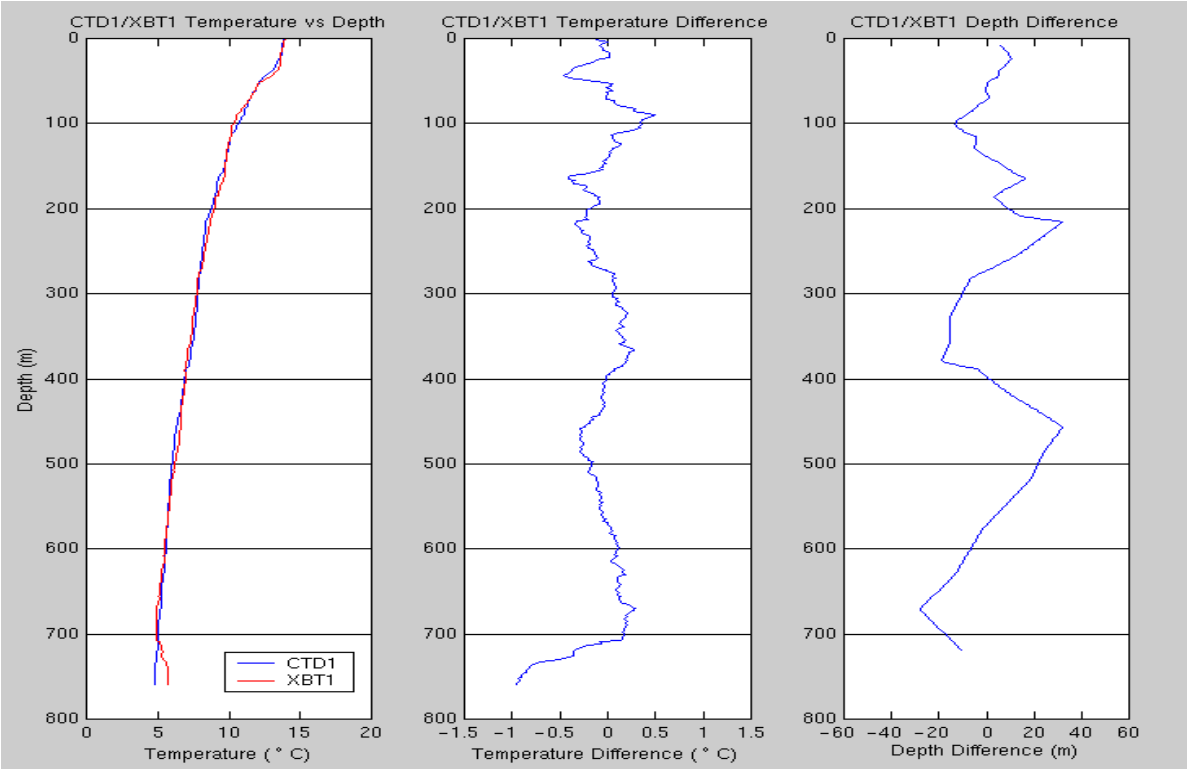
Urick, R.J., 1983: *Principles of Underwater Sound.* 3d ed. McGraw-Hill, 423pp.

APPENDIX A
Location of CTD and XBT Temperature Profiles

Pair No.	XBT No.	POSITION North	POSITION West	CTD No.	POSITION North	POSITION West	DATE
1	75	36-43.93	122-03.17	2	36-44.08	122-01.19	27 Jan 03
2	76	36-42.61	122-14.99	3	36-42.58	122-14.27	28 Jan 03
3	77	36-36.83	122-27.58	4	36-37.53	122-25.22	28 Jan 03
4	78	36-32.23	122-37.46	5	36-32.52	122-36.26	28 Jan 03
5	79	36-28.08	122-47.34	6	36-27.68	122-46.54	28 Jan 03
6	80	36-23.31	122-58.97	7	36-22.71	122-57.39	28 Jan 03
7	81	36-17.55	123-09.35	8	36-17.51	123-08.05	28 Jan 03
8	82	36-12.79	123-20.09	9	36-12.55	123-18.57	28 Jan 03
9	84	36-06.34	123-28.59	10	36-07.62	123-29.43	28 Jan 03
10	85	35-59.30	123-23.40	11	35-58.88	123-23.11	28 Jan 03
11	86	35-50.75	123-17.19	12	35-50.44	123-16.79	28 Jan 03
12	87	35-41.80	123-11.24	13	35-41.79	123-10.54	28 Jan 03
13	88	35-33.19	123-04.55	14	35-32.96	123-04.42	29 Jan 03
14	89	35-23.81	122-58.60	15	35-24.30	122-58.20	29 Jan 03
15	90	35-15.26	122-52.32	16	35-15.51	122-52.00	29 Jan 03
16	91	35-06.60	122-46.00	17	35-06.94	122-45.79	29 Jan 03
17	92	34-59.15	122-41.43	18	34-58.45	122-39.54	29 Jan 03
18	93	34-49.67	122-33.65	19	34-49.57	122-33.37	29 Jan 03
19	94	34-41.27	122-27.60	20	34-40.95	122-27.66	29 Jan 03
20	95	34-32.56	122-21.22	21	34-32.25	122-21.15	29 Jan 03
21	96	34-24.09	122-15.03	22	34-23.61	122-14.99	29 Jan 03
22	97	34-29.17	122-04.82	23	34-28.85	122-04.36	29 Jan 03
23	98	34-33.97	121-53.82	24	34-33.73	121-54.06	29 Jan 03
24	99	34-38.71	121-43.79	25	34-38.58	121-43.54	30 Jan 03
25	100	34-44.40	121-33.30	26	34-43.62	121-33.02	30 Jan 03
26	101	34-53.36	121-40.18	44	34-52.44	121-39.17	31 Jan 03

Appendix A Position and date of CTD and XBT data used in this study. CTD and XBT numbers refer to the number in the cruise report; pair number refers to the pair numbering system used in this study for simplification and in the figures in Appendix B.

APPENDIX B
CTD and XBT Temperature Profiles and Difference Plots Plots



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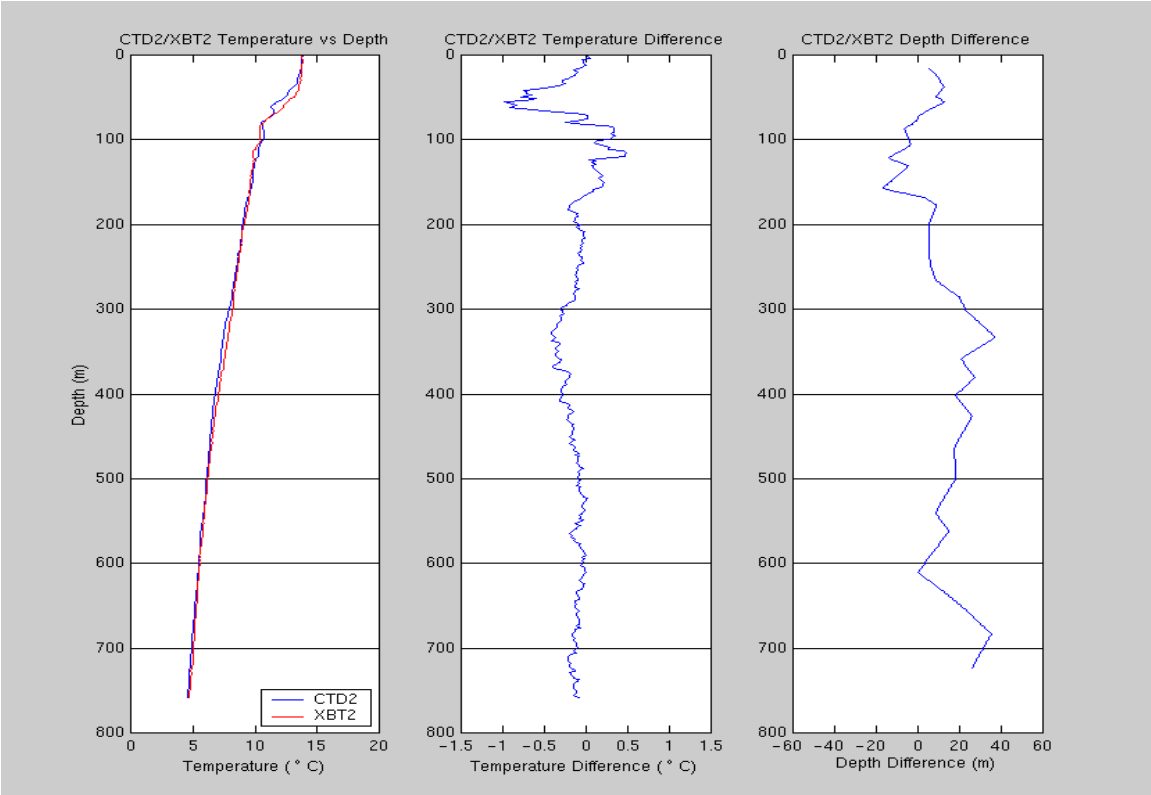

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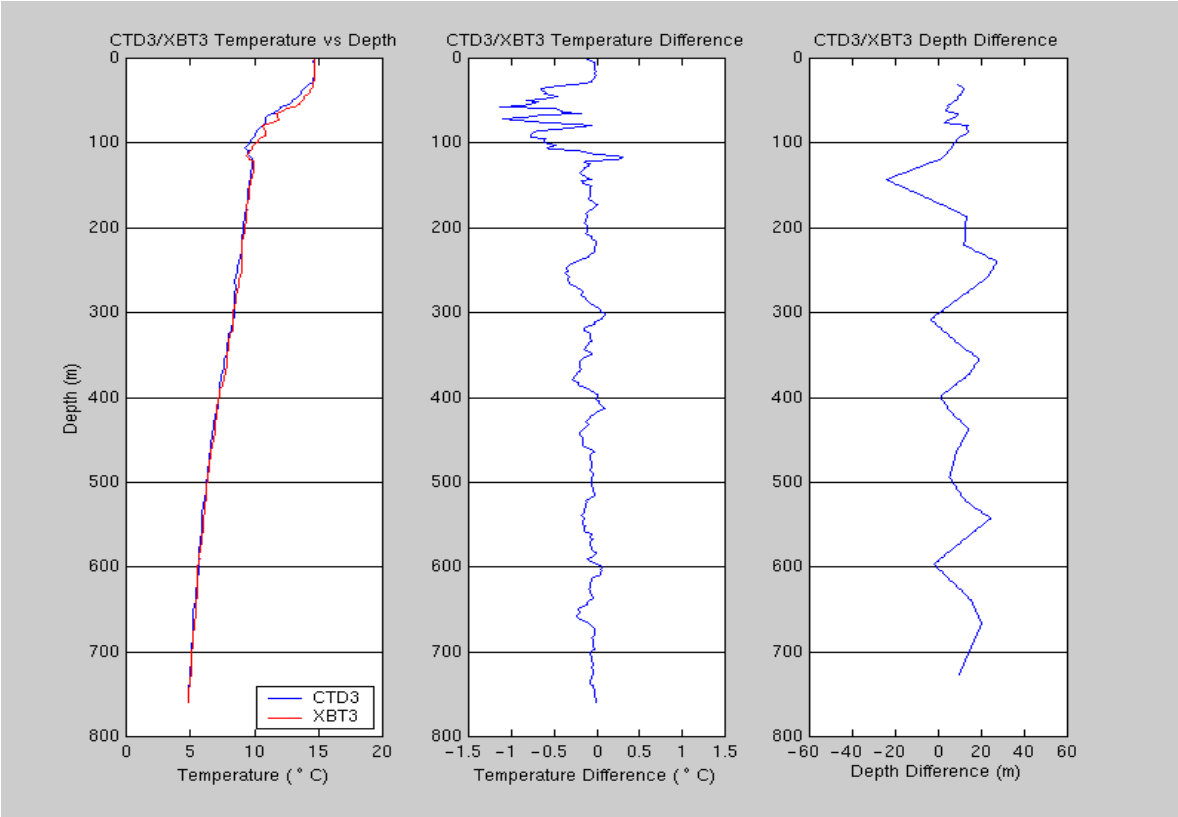

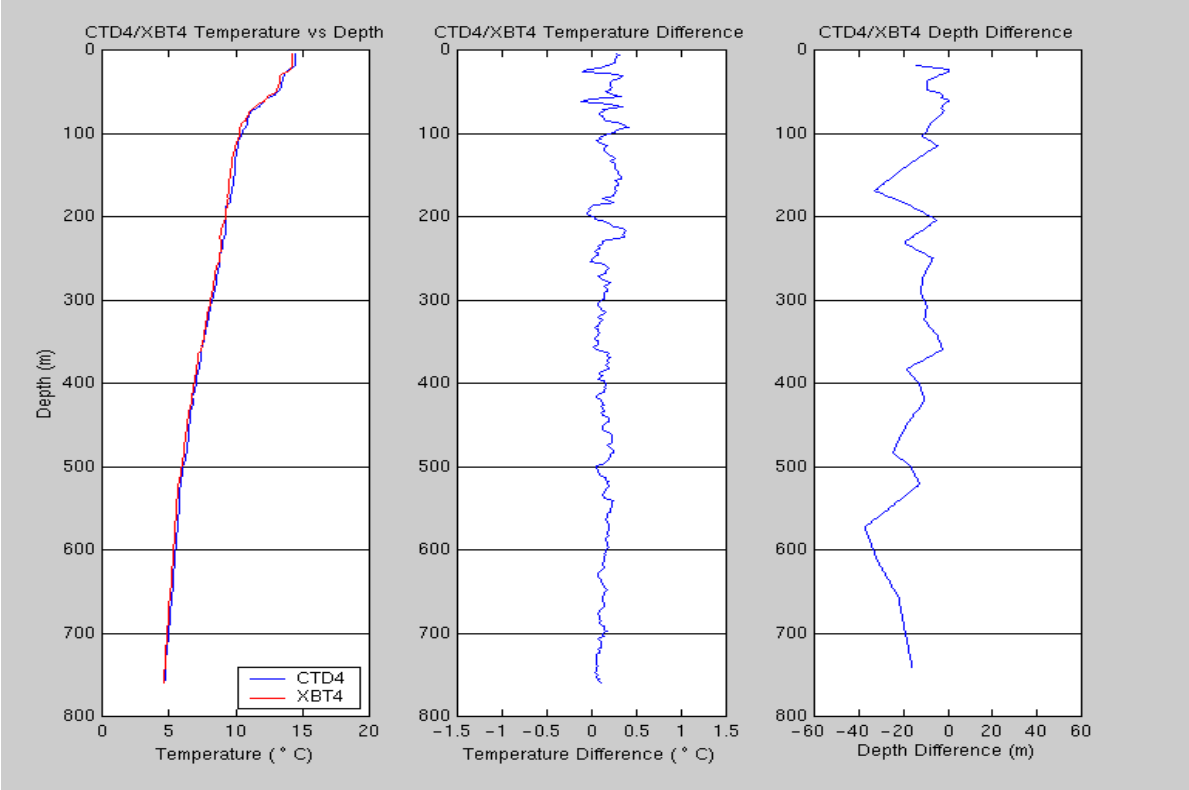

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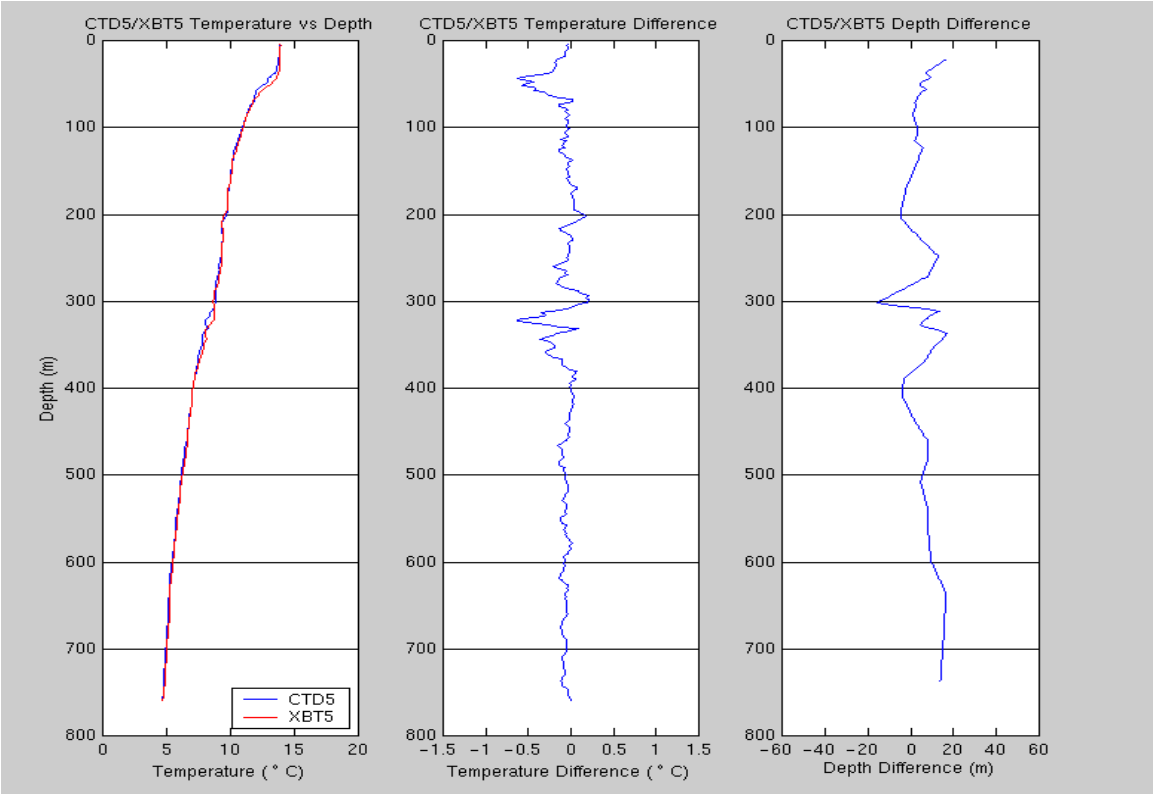

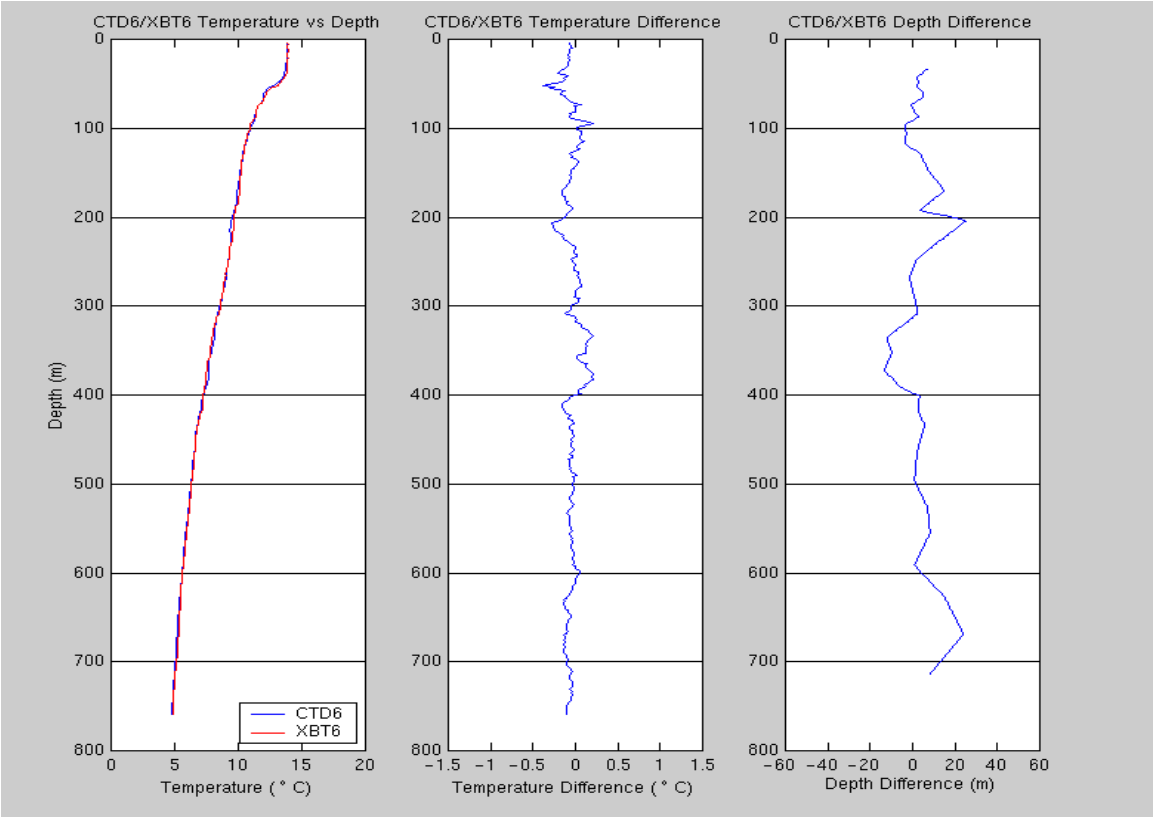

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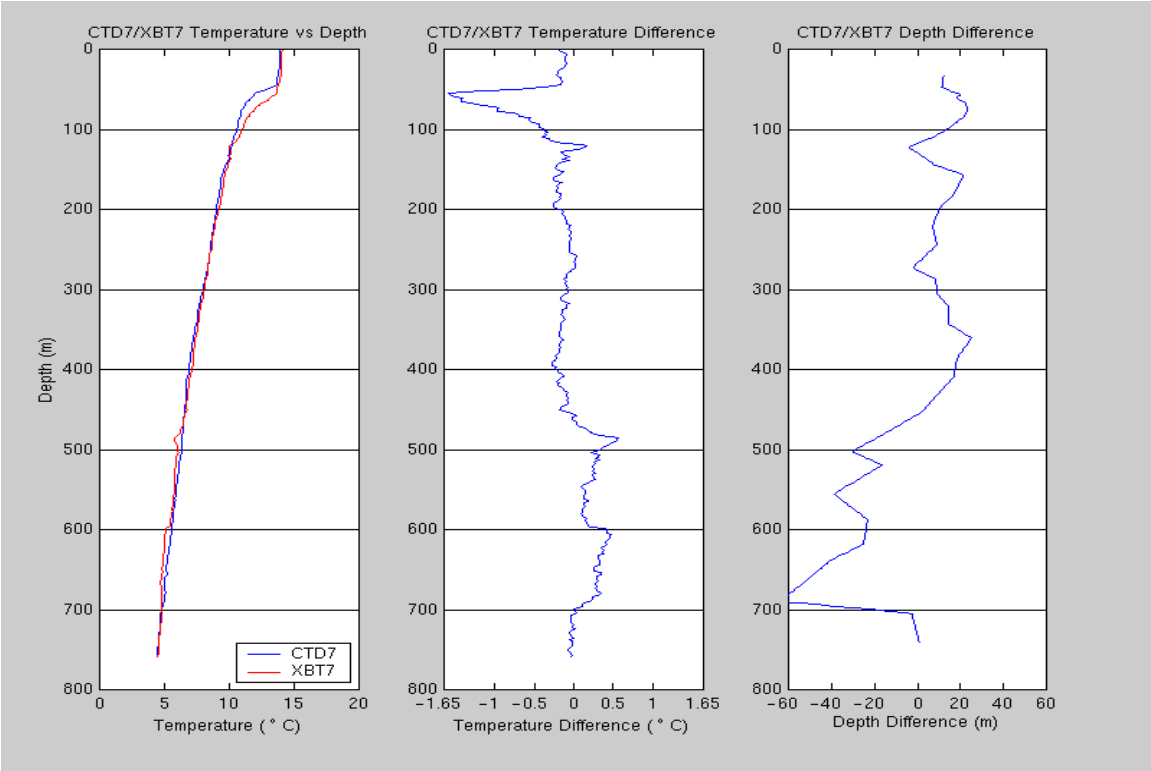

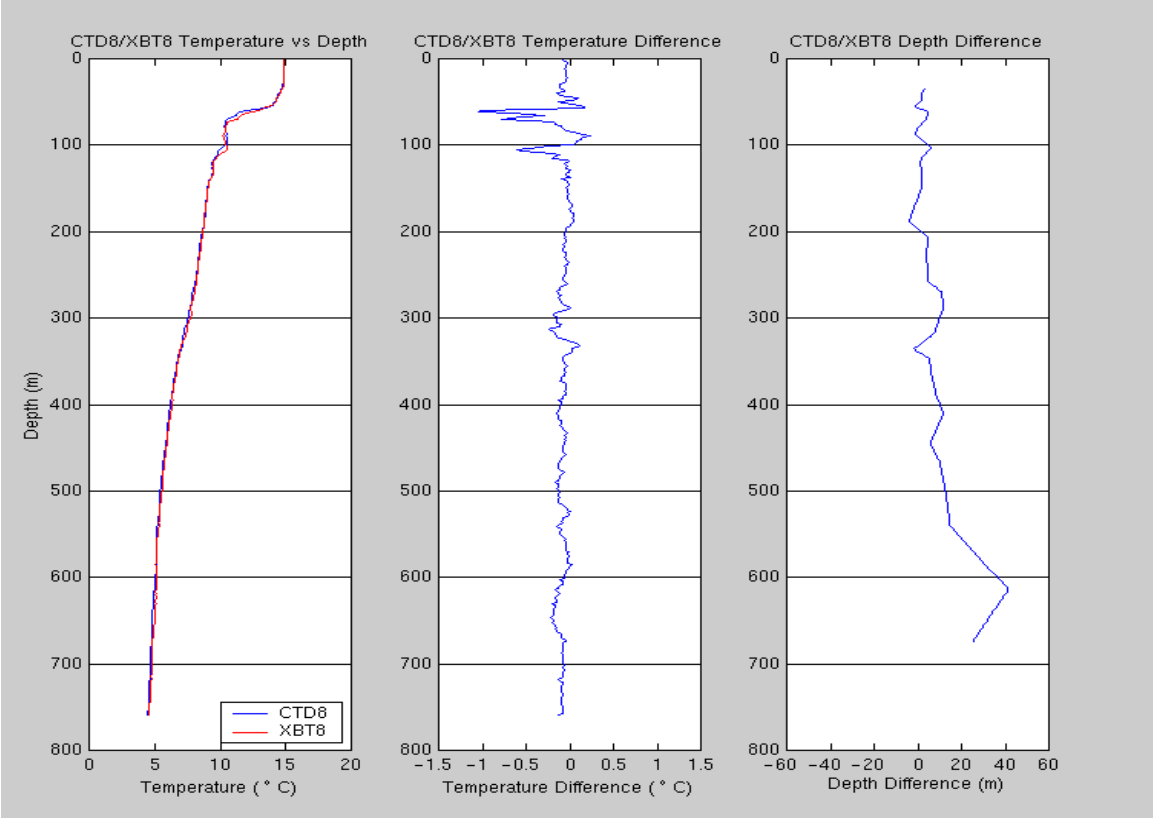

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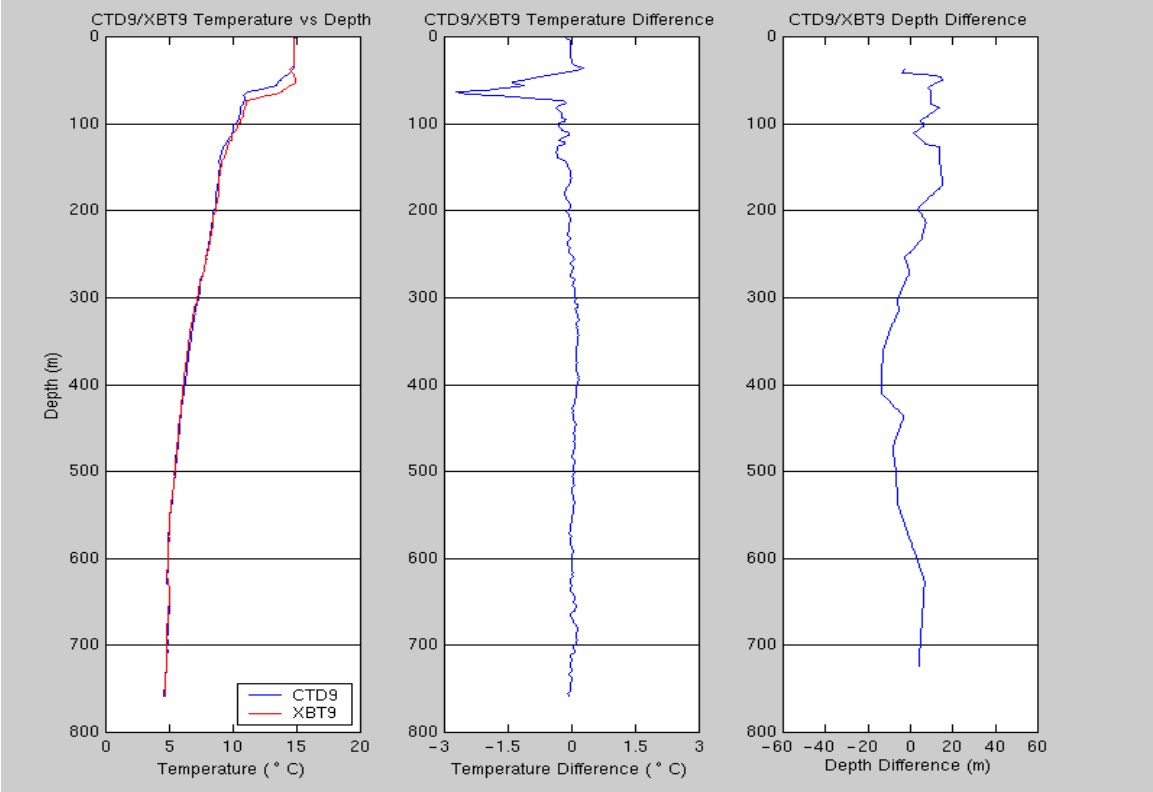

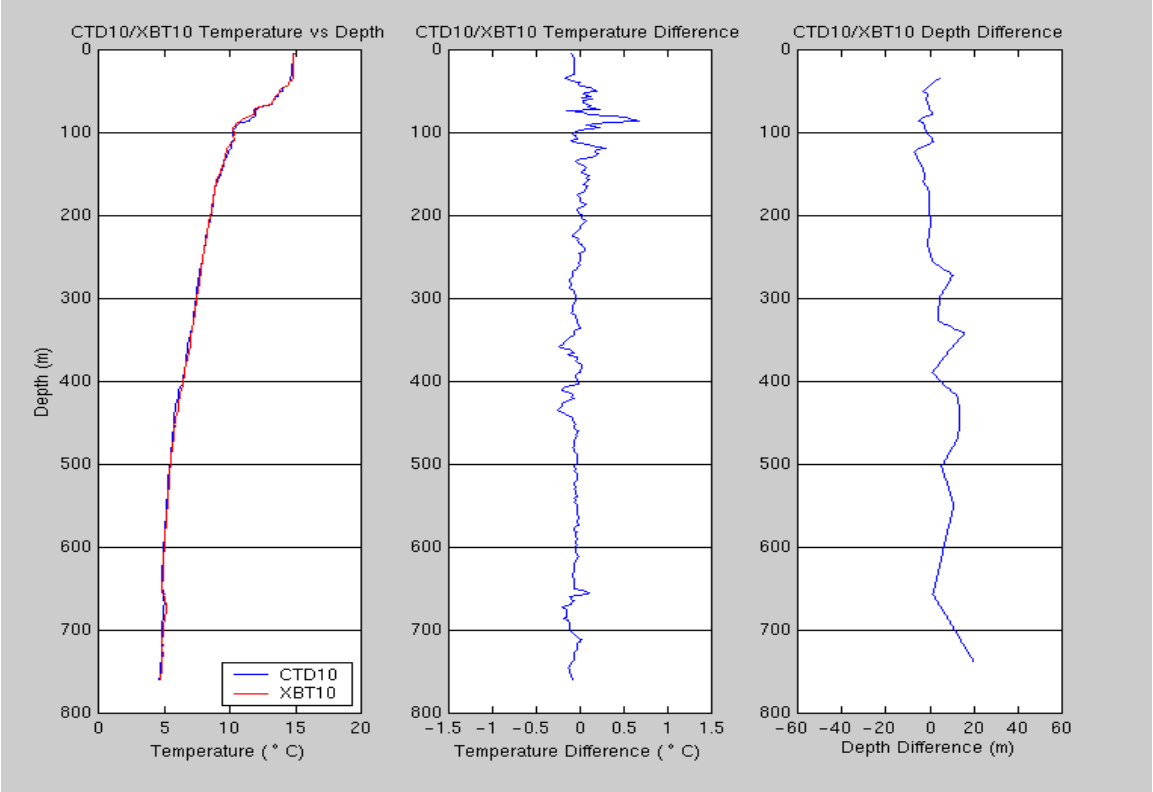

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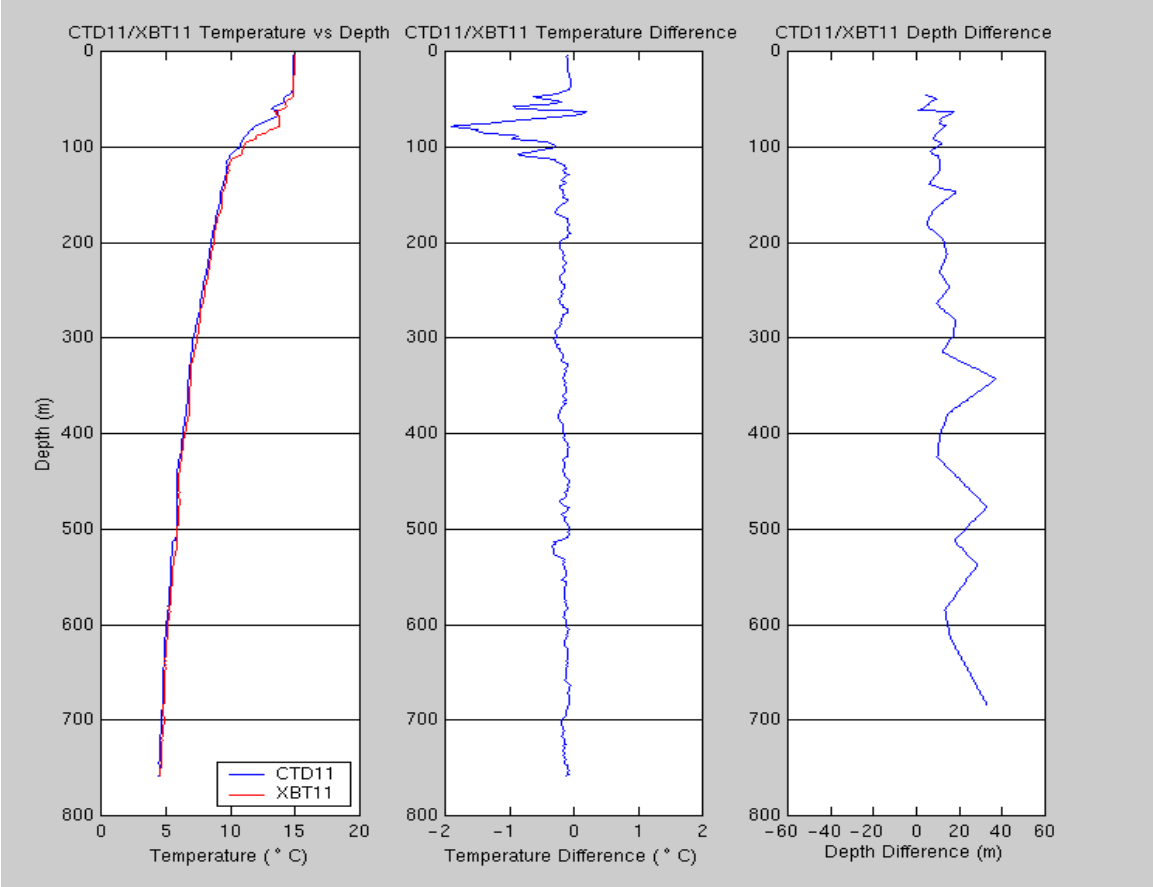

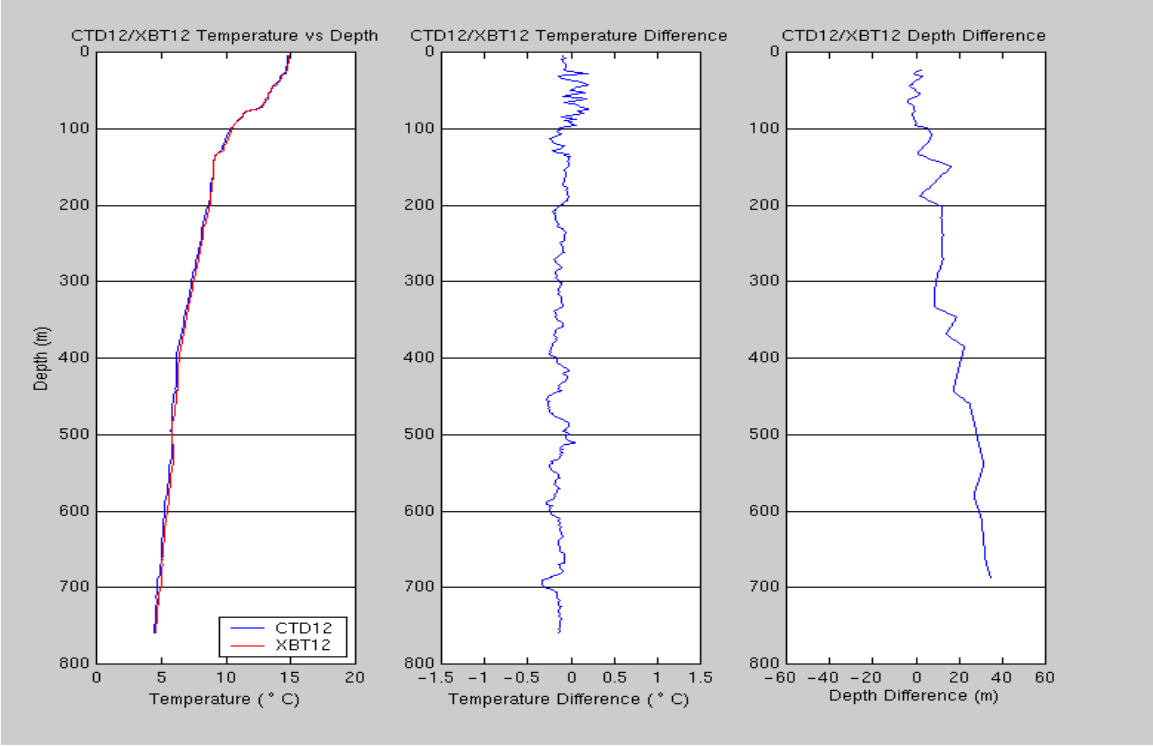

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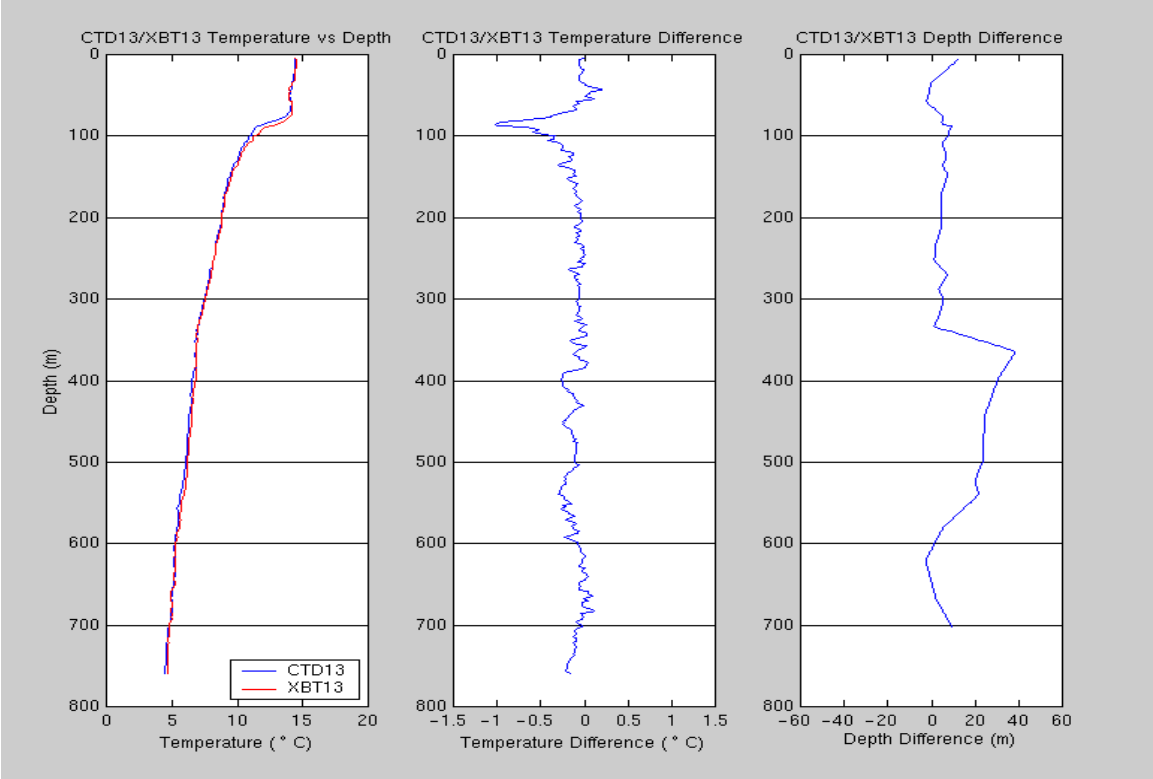

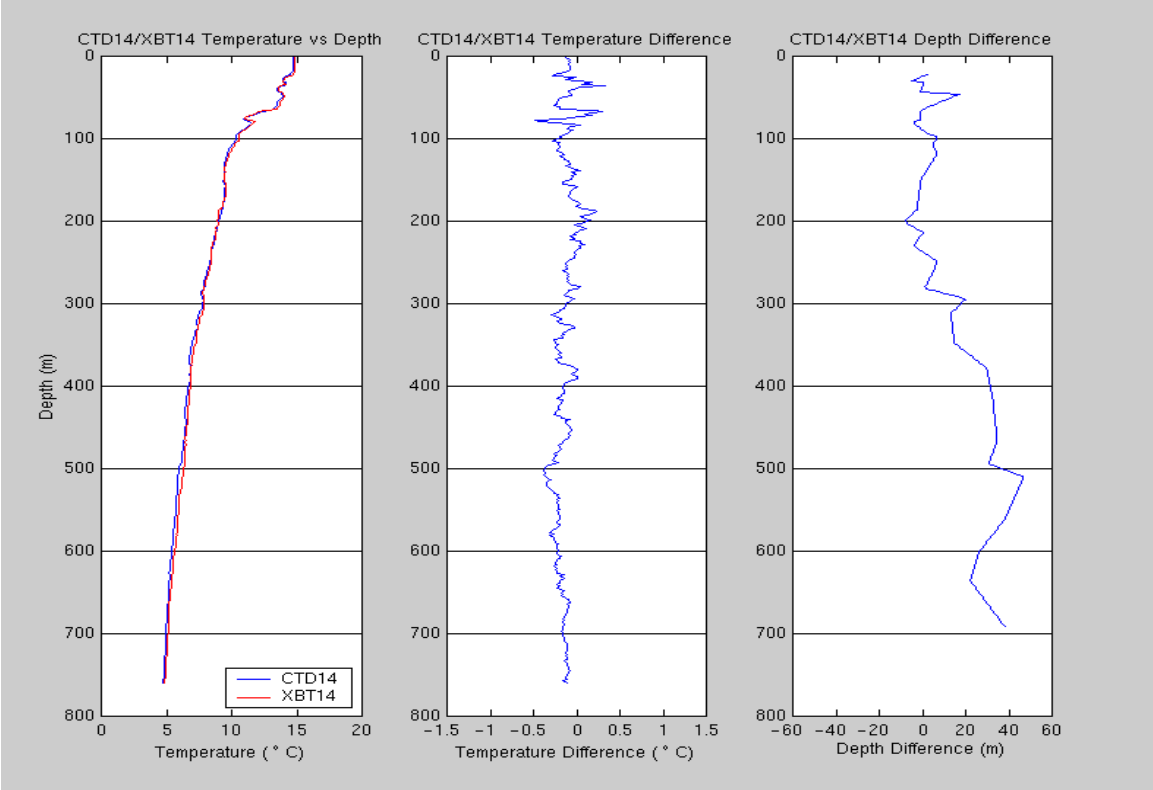

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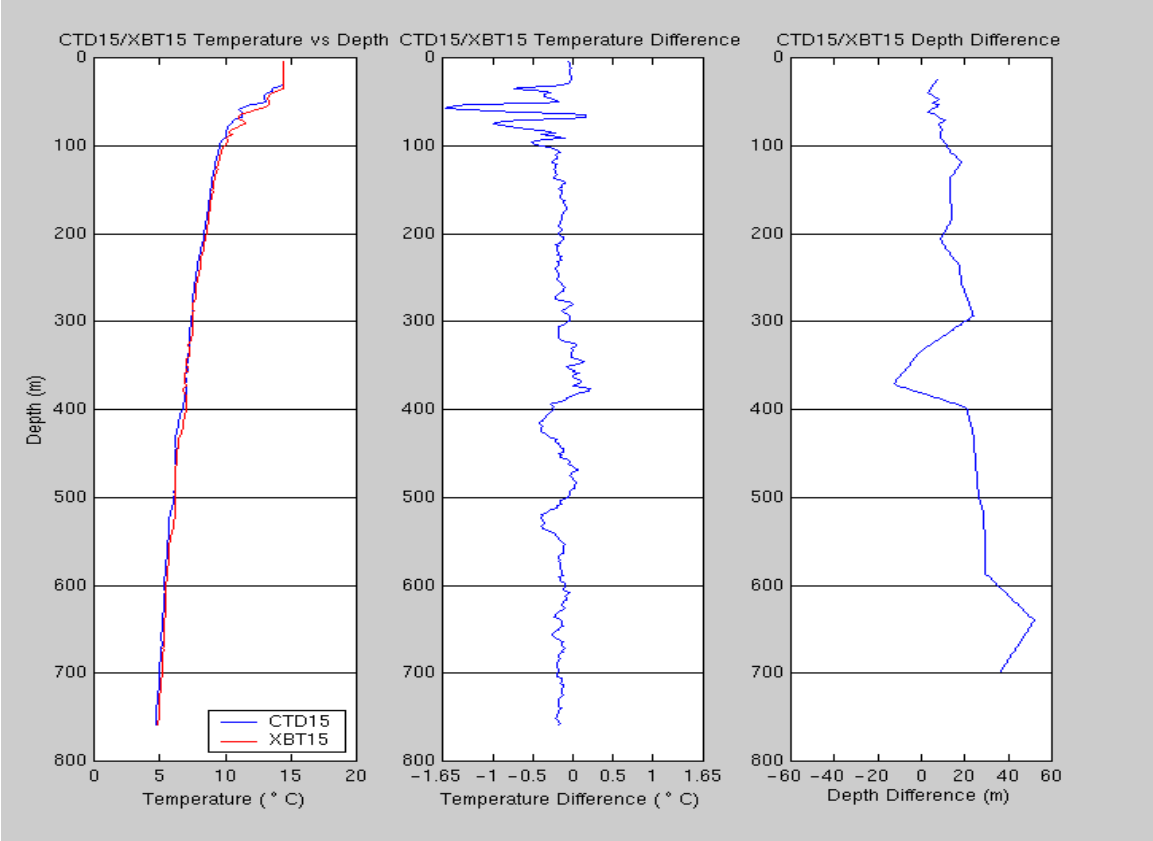

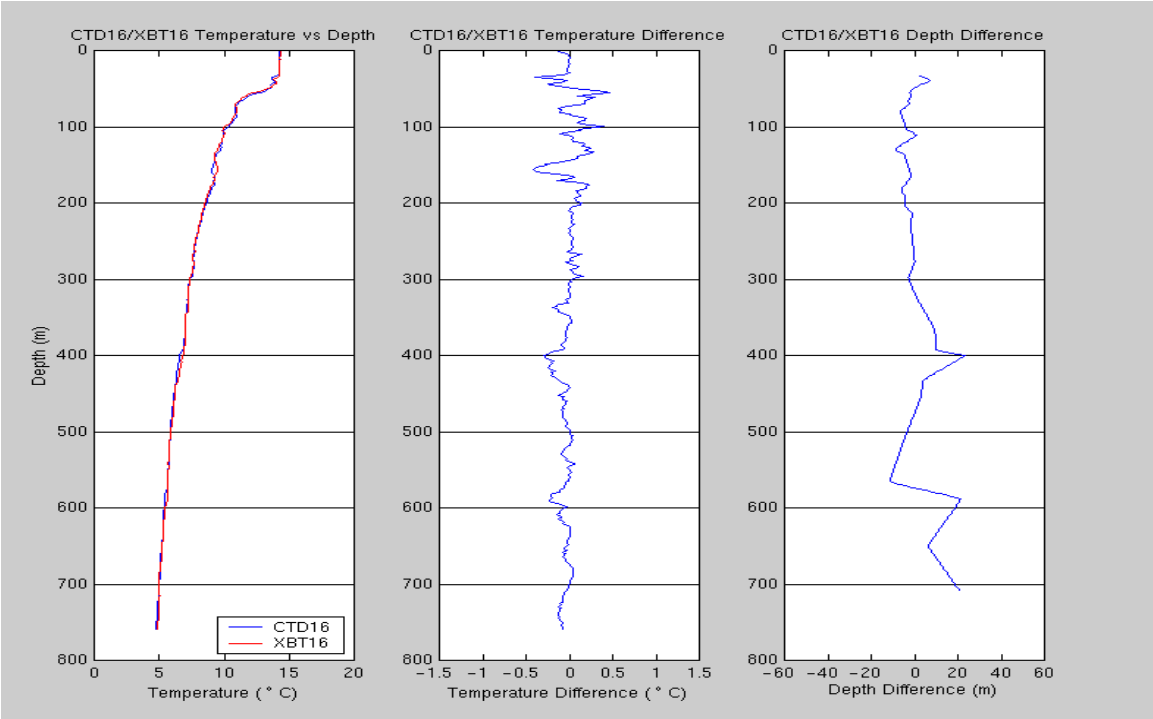

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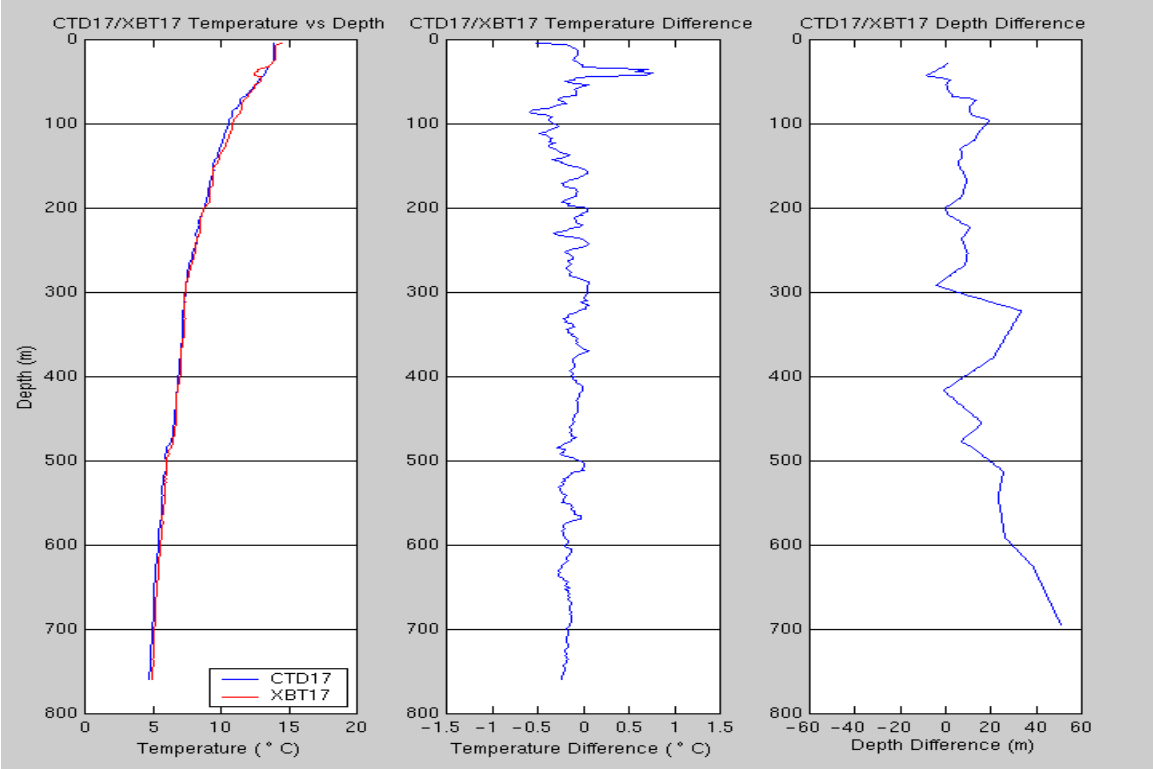

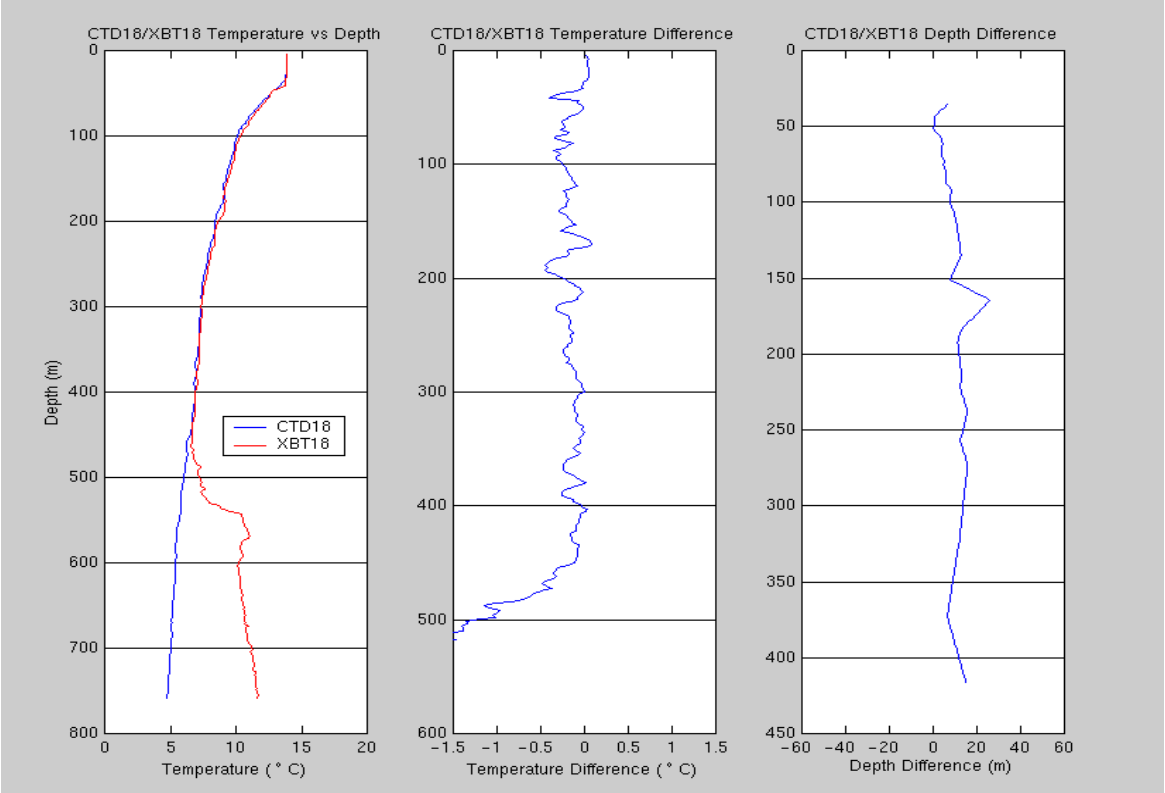

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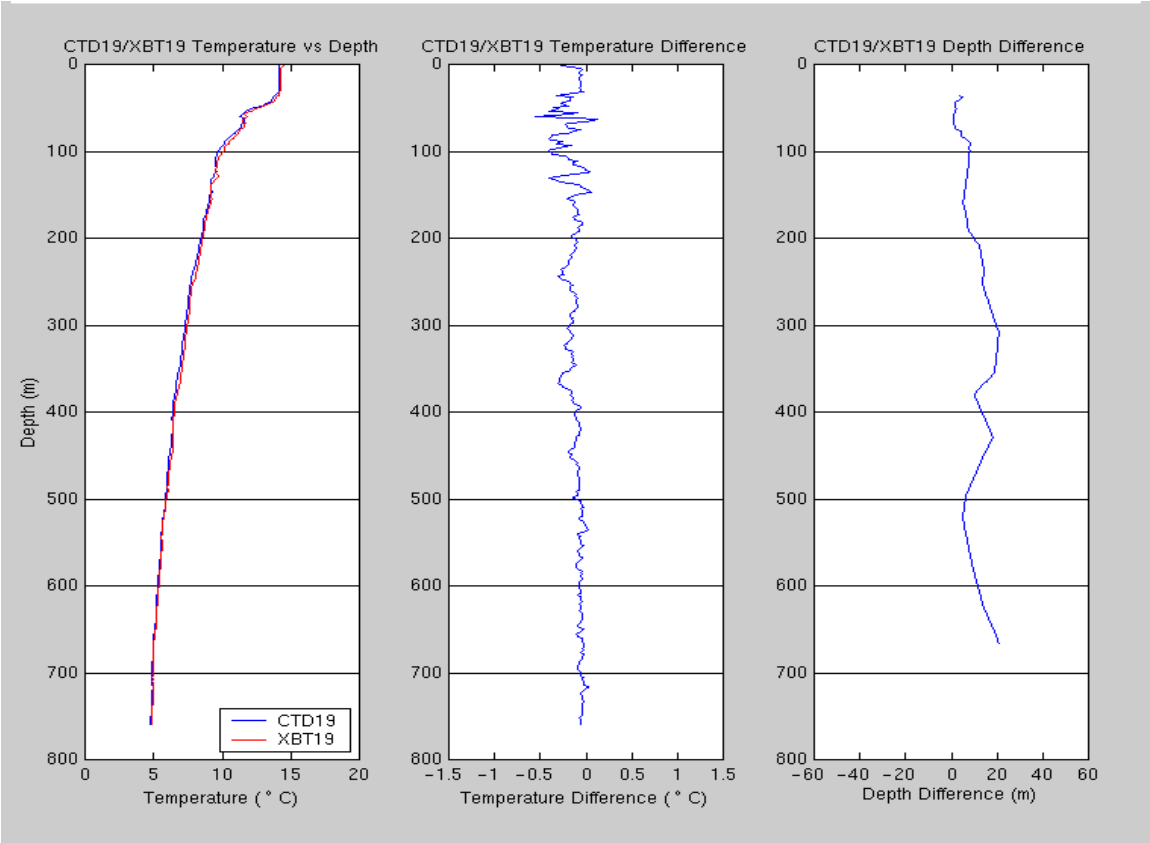
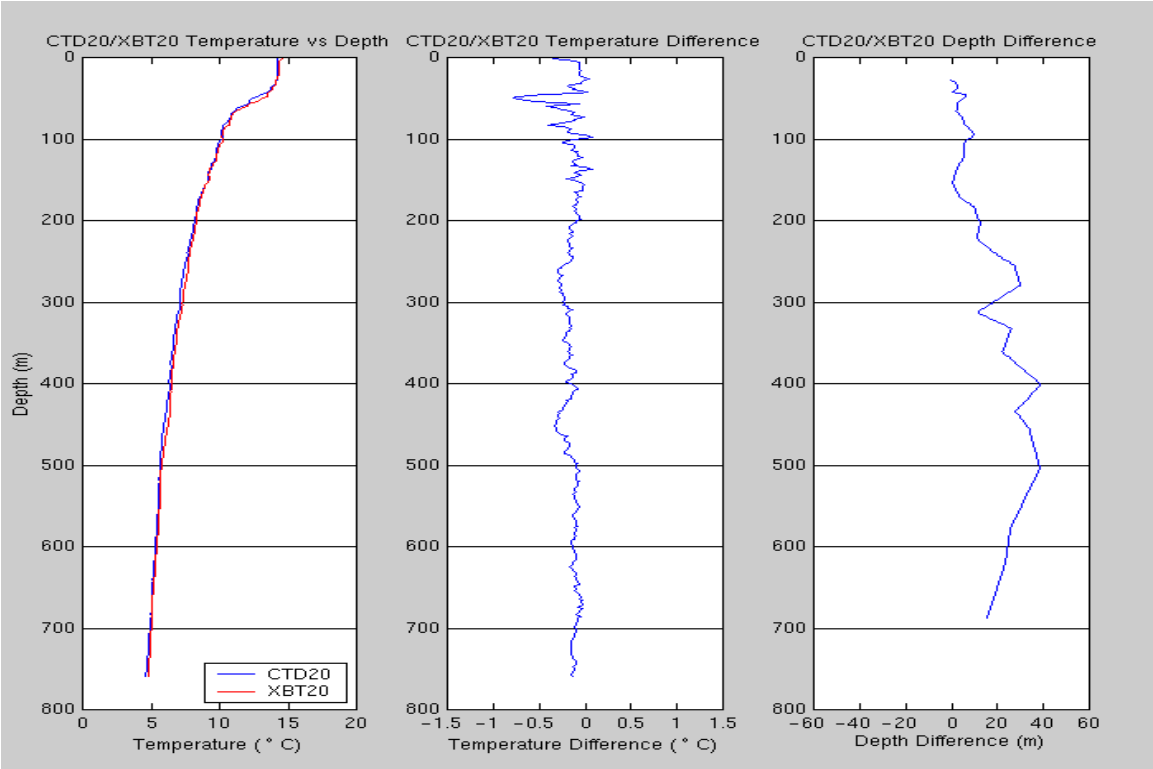
APPENDIX B

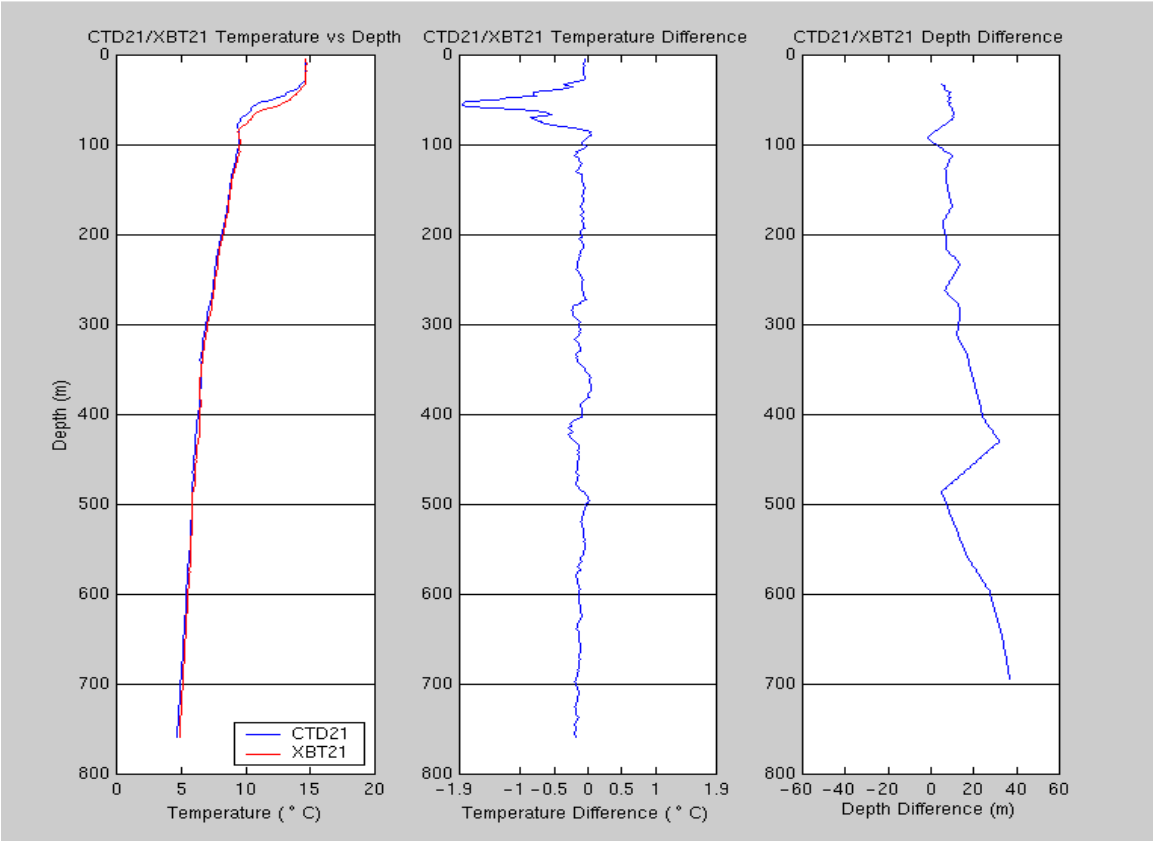
CTD and XBT Temperature Profiles and Difference Plots

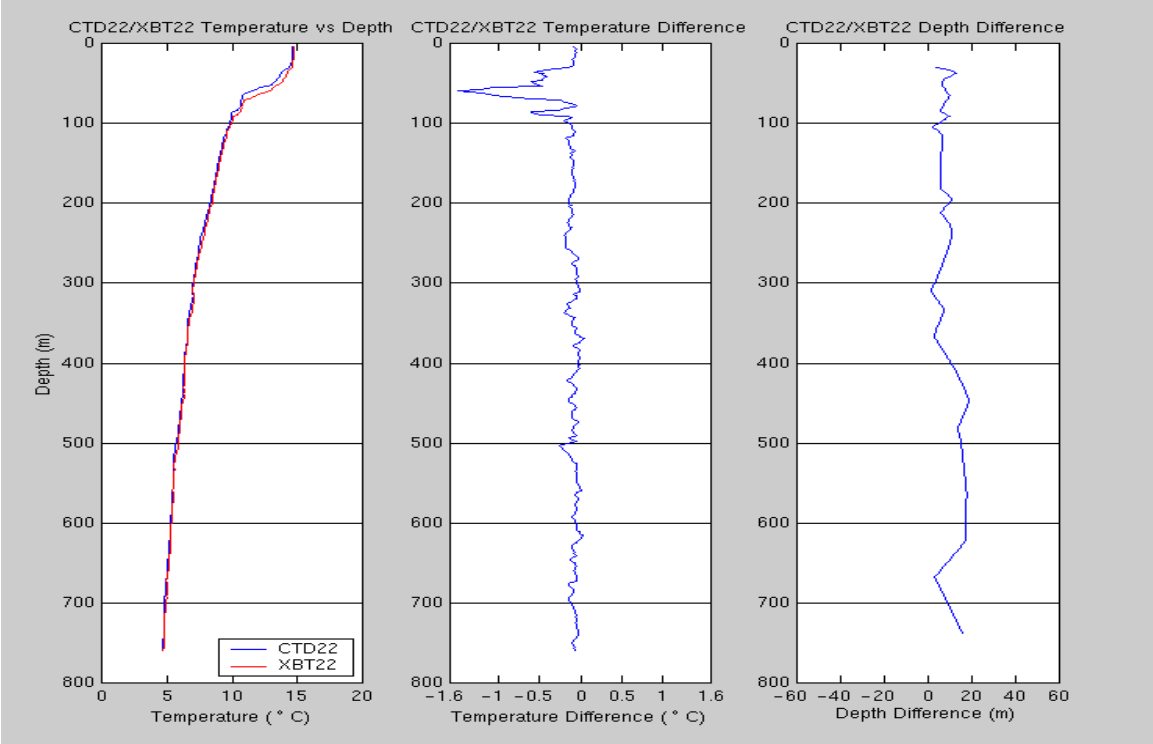




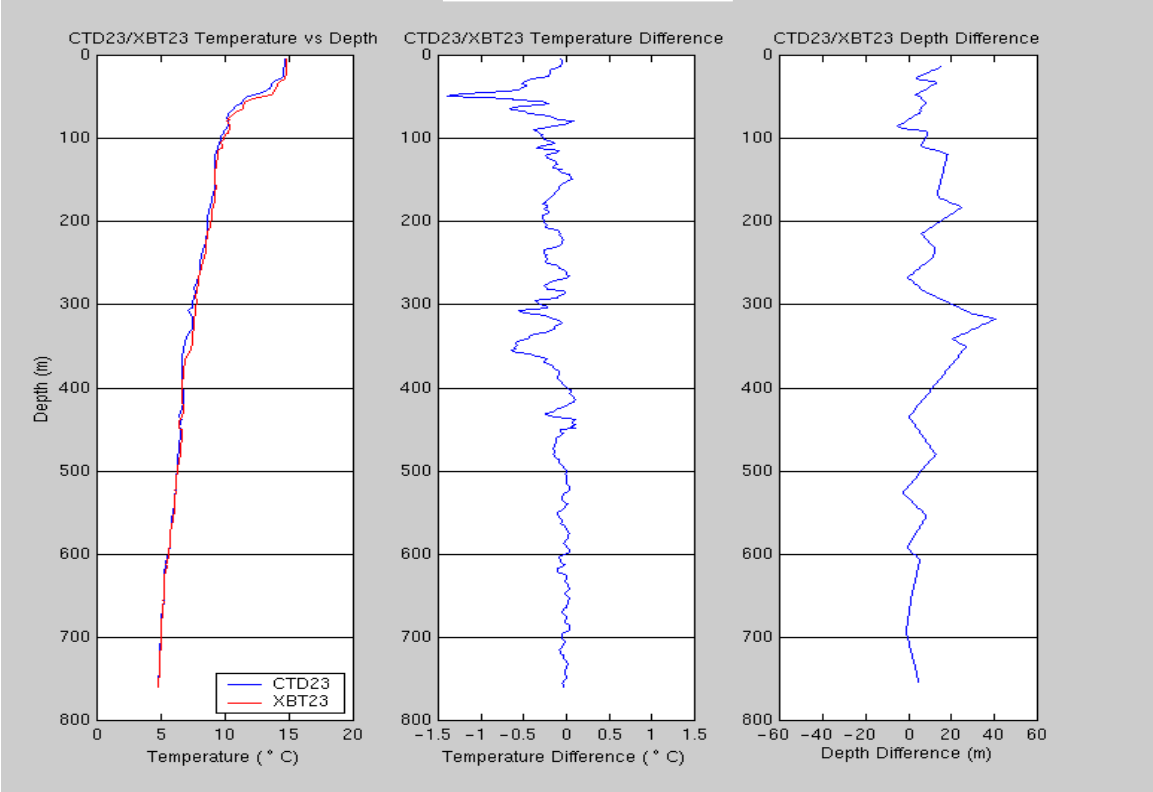
APPENDIX B

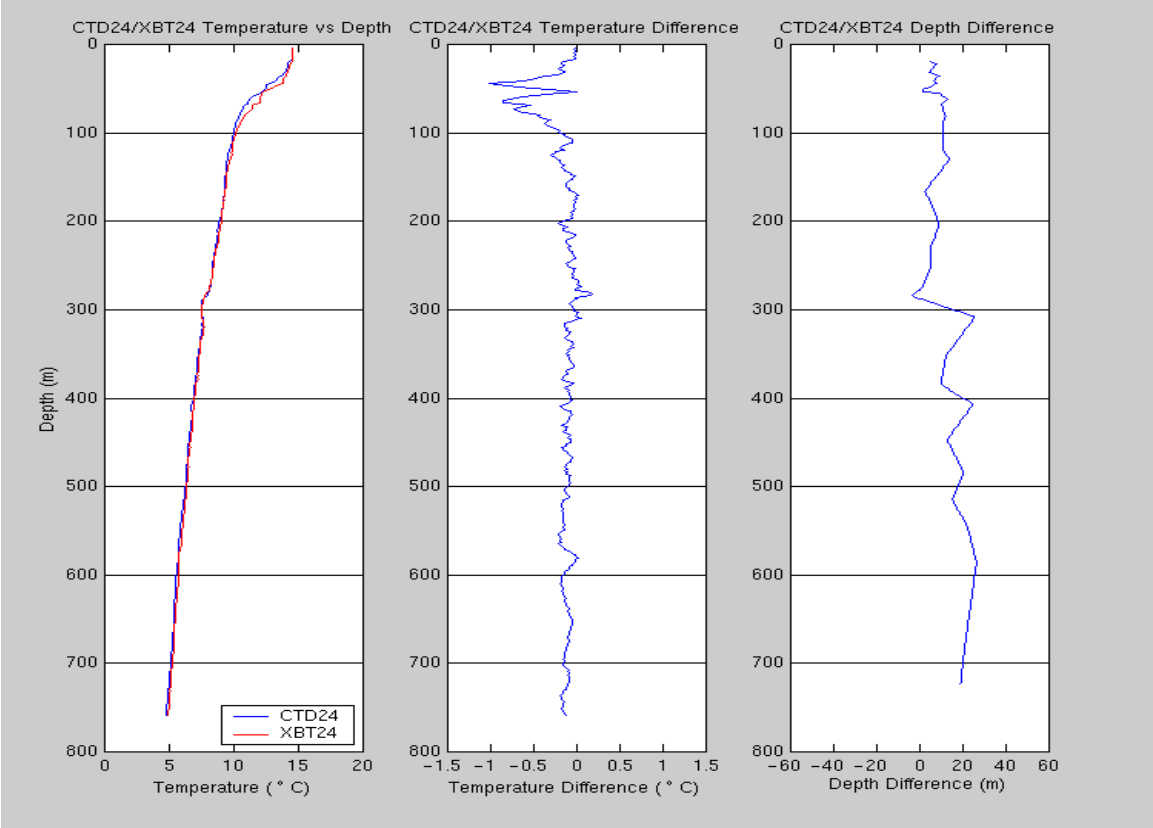
CTD and XBT Temperature Profiles and Difference Plots



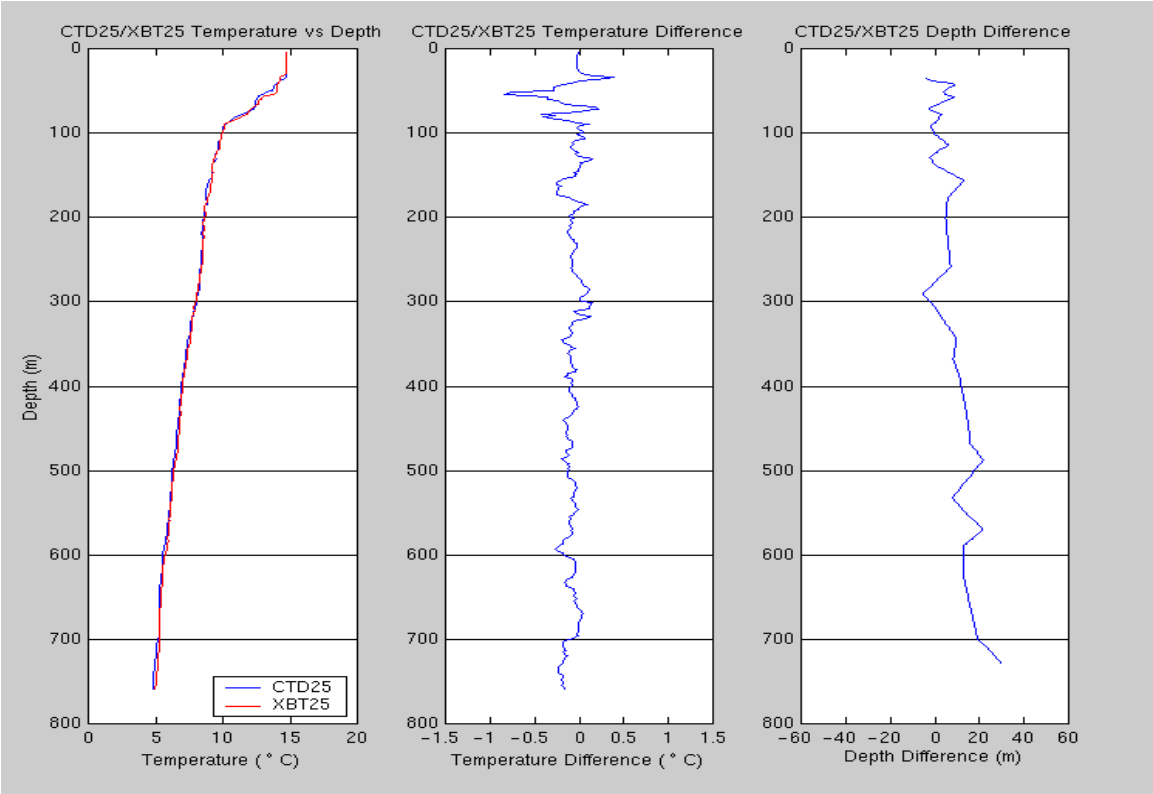


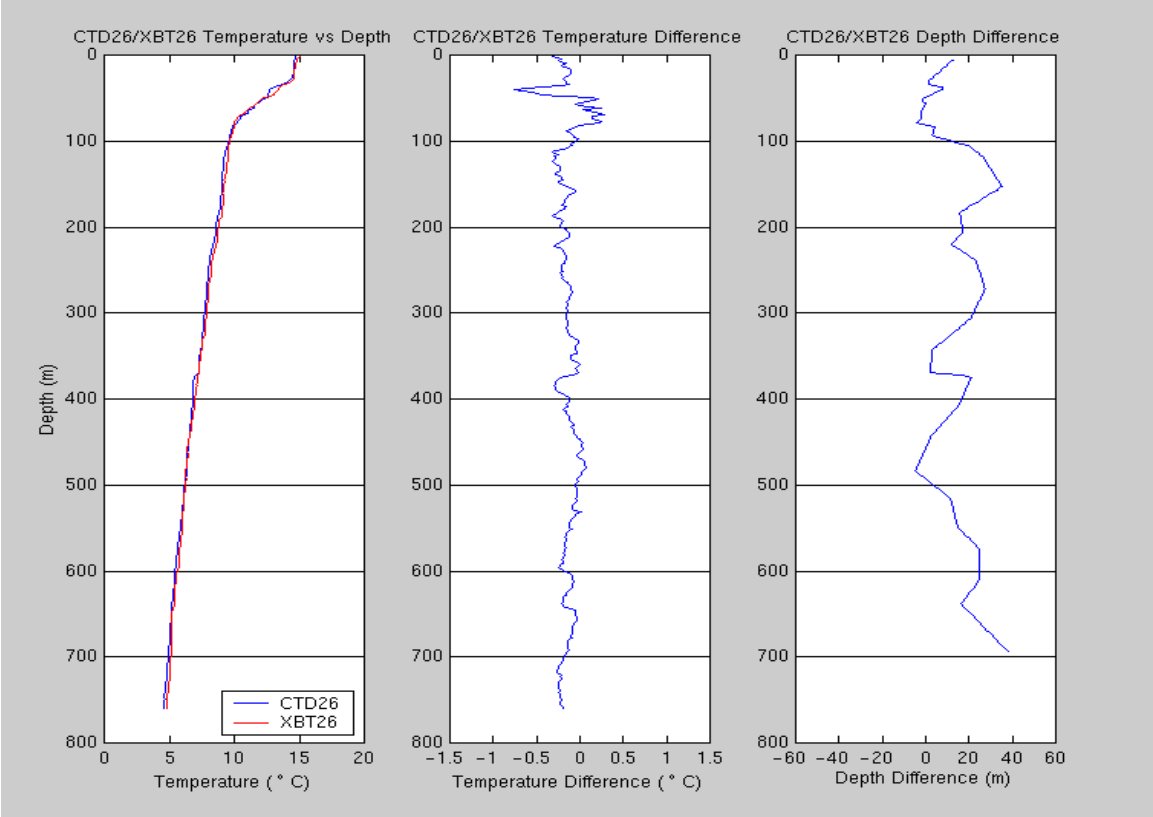
APPENDIX B


CTD23/XBT23 Temperature vs Depth
CTD23/XBT23 Temperature Difference
CTD23/XBT23 Depth Difference
Depth (m)
Temperature (° C)
Temperature Difference (° C)
Depth Difference (m)
CTD23
XBT23


CTD24/XBT24 Temperature vs Depth
CTD24/XBT24 Temperature Difference
CTD24/XBT24 Depth Difference
Depth (m)
Temperature (° C)
Temperature Difference (° C)
Depth Difference (m)
CTD24
XBT24

APPENDIX B


CTD25/XBT25 Temperature vs Depth
CTD25/XBT25 Temperature Difference
CTD25/XBT25 Depth Difference
Depth (m)
Temperature (° C)
Temperature Difference (° C)
Depth Difference (m)
CTD25
XBT25


CTD26/XBT26 Temperature vs Depth
CTD26/XBT26 Temperature Difference
CTD26/XBT26 Depth Difference
Depth (m)
Temperature (° C)
Temperature Difference (° C)
Depth Difference (m)
CTD26
XBT26