COMPARISON OF CTD AND XBT TEMPERATURE PROFILES

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INTRODUCTION

The Naval Postgraduate School OC3570 class participated in a two-leg cruise aboard the R/V Point Sur in the coastal and offshore waters between Moss Landing and Port San Luis, California. The first leg was from 2-5 August 2001; the second leg from 6-9 August. Temperature profile data was recorded from many CTD and XBT drops. Twenty-eight pairs of CTD and XBT data were chosen for comparison based on their proximity to each other. The CTD data was obtained by a Sea-Bird CTD and the XBT's were Sippican T-7's. The data sets were used to compare temperature profiles recorded by the two different instruments. The goal of these comparisons was to identify any biases inherent in the XBT and to discuss the impact of any bias.

Quality control and data editing procedures were performed on each profile. After processing, the temperature profiles were compared, and the mean and standard deviation for all samples was determined for 383 levels between and 760 meters. The results were that XBT temperature readings were 0.0117°C cooler to 0.4398°C warmer than CTD measurements over the whole depth range and averaged an overall 0.0882°C warmer. Only at depth levels 6,8 and 10 meters did the XBT average slightly cooler than the CTD, the other 380 levels were warmer.

These statistics were compared to data obtained and analyzed from similar past cruises by Roth (2001) and Schmeiser (2000). The findings between the three studies show similar mean temperature differences with a wider variation in standard deviations. All three studies show a warm bias to XBT’s.

This report concludes with a discussion of the impacts of the findings from both a Naval operational and a scientific perspective. XBT’s are the primary instrument (T) for developing sound speed profiles in Under Sea Warfare (USW) for the surface Navy. The affect of a slight warm bias is considered. For the scientific community, XBT’s are routinely deployed by ships of opportunity to provide temperature profiles around the world for climate studies. This may affect global warming predictions.

DATA COLLECTION

There were 19 data sets collected from leg one of the cruise. On leg one, XBT’s were deployed between CTD casts so the pairs were not co-located but are close together. The remaining 9 data sets from leg two were co-located. All XBT’s were deployed in water with depth’s greater than the

750 meter operational depth of the XBT. The locations of the CTD and XBT profiles are included in Appendix A.

The XBT records temperature versus depth while the CTD records temperature versus pressure. Temperature versus depth plots were printed at the time of each drop and the data was also saved to ASCII files. This study used the data from the ASCII files.

QUALITY CONTROL PROCEDURES

MATLAB 6.0 was used for all data extraction, computations and plotting. 56 ASCII data files (28 CTD and 28 XBT) were edited and loaded into MATLAB. A program was used to extract the depth and temperature data from each file. Each profile was scanned visually and by computer for bad data points. Erroneous data was rejected and statistics determined on the good data.

The first line of quality control was to visually inspect each temperature profile to identify any bad information. In this manner the XBT-1 profile was seen to corrupt. XBT-1 is shown on page B1 in Appendix B. The data pair of XBT-1/CTD-1 was not used in the statistical analysis. Following visual inspection, a MATLAB program was used to compare the temperature at each level to the average of the temperature of the levels above and below it. If the temperature of a particular level differed by more than

0.2°C from the average of the surrounding levels, it was identified as a possible bad data point and labeled for investigation. For the top and bottom levels, only one level was available for comparison. Roth (2001) and Schmeiser (2000) chose 0.2°C because it was shown to be less than 2 standard deviations of the final statistics. This would also be the case in this study.

Each profile contained 383 levels between the surface and 760m. The total number of levels checked was 20682 (10341 XBT + 10341 CTD). Of these, 40 CTD (0.39%) and 51 XBT (0.49%) were identified as possibly bad points. Those that were identified were individually inspected and all were found to be either within 0.2°C of one of the surrounding levels or were part of a logical sequence decreasing with depth. Therefore all data points (aside from XBT/CTD 1) were included in the statistics.

DATA PROCESSING

Due To the high accuracy and calibration of the Sea-Bird CTD, the CTD temperature measurements were considered to be the true temperature profile against which the XBT profile would be compared. Any differences are assumed to reflect inaccuracies in the XBT measurement.

Because the CTD records temperature versus pressure, it was necessary to convert pressure to depth. A formula described by Saunders (1981) for pressure (P) in decibars and depth (Z) in meters follows:

$$Z=(1-C_1)*P-C_2P^2$$

Where $C_1=(5.92+5.25\sin^2\Phi)*10^{-3}$; Φ is latitude;

$$C_2= 2.21*10^{-6}$$

The CTD measured pressure in 2 dbar increments for all casts; therefore the only variable between casts was latitude, Φ. Because the latitude variation was fairly small, between 36 44.12°N and 34 33.34°N, a constant value of 36°N was used for latitude and applied to all data sets. This was performed in previous studies and deemed appropriate (Schmeiser, 2000). The introduced error is less than 0.005%.

After converting the CTD data sets to temperature versus depth vice pressure, the XBT data sets were matched to the size of the CTD data using the same technique as Roth (2001). The CTD data was over 383 levels while the XBT data was over 1183 levels. A MATLAB program was used to linear interpolate the XBT data sets to the CTD measurement depths. Following linear interpolation, both CTD and XBT profiles contained 383 levels between about 2m and 760m.

Two plots were made for each CTD/XBT pair. The first contained the temperature profile for each sensor. The second showed the XBT temperature subtracted from the CTD temperature at each level. These plots are shown in Appendix B.

The 27 sets of CTD – XBT values were combined, and the mean and standard deviation determined by MATLAB for all 383 levels. These statistics are plotted and shown in Appendix B, page B8.

FINDINGS

As can be seen on Appendix page B8, the mean temperature difference (red line) is negative throughout the range with the exception of three levels near the surface that are slightly greater than zero. This indicates that on average the XBT measured a higher (warmer) temperature than the CTD. The greatest average temperature difference occurs in the upper 80m. The upper 80m also had the greatest standard deviation. However, an analysis of the data shows that in the upper 20m the average temperature difference is only 0.0506°C. The largest temperature differences are between 20 and 40 meters with a maximum of 0.4398°C at 32 meters depth. The standard deviation at 32m was also a maximum, 1.2108°C.

Below 80m, the average temperature difference was less than 0.15°C and was generally decreasing with depth meaning the XBT readings were closer to the CTD readings. The standard deviation below 80m was less than 0.3°C and also generally decreased with depth with a minimum of 0.07°C near 750m.

COMPARISON WITH PREVIOUS STUDIES

Similar comparisons of CTD and XBT profiles have been performed by both Roth (2001) and Schmeiser (2000). Roth's study compared 9 co-located CTD/XBT pairs while Schmeiser compared 18. This study performed statistics on 27 pairs, 9 of which were co-located. All compared Sippican T-7 XBT's to a Sea-Bird CTD on board the R/V Point Sur along the central Californian coast. A similar study published by Heinmiller et al. (1983) is not compared to this study due to different data editing techniques. Comparisons to Heinmiller (1983) can be found in Schmeiser (2000) and Roth (2001).

In this study, as in Roth (2001), the XBT data was interpolated before being quality checked. This was not determined to have a significant effect in comparing against Schmeiser's data which was quality checked before interpolation. (Roth, 2001)

Ship	R/V Point Sur					
Date	08/2001		02/2001		07-08/2000	
			Roth (2001)		Schmeiser (2000)	
Depth (m)	Mean	Std	Mean	Std	Mean	Std

	(°C)	(°C)	(°C)	(°C)	(°C)	(°C)
25-125	-0.1530	0.5135	-0.0907	0.1779	-0.2198	0.3598
175-350	-0.0502	0.2131	-0.0810	0.0951	-0.1171	0.1975
175-375	-0.0549	0.2157	-0.0851	0.0960	-0.1212	0.1981
250-350	-0.0725	0.2372	-0.0731	0.0903	-0.1076	0.2194
Sfc-750	-0.0882	0.2147	-0.0783	0.1047	-0.1549	0.2151

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

As can be seen in Table 1, the results of this study are very similar to results from the two previous studies. All three show a warm bias in the XBT measurements that is most pronounced in the upper portion of the water column and generally decreases with depth. The 25-125m layer has a markedly larger mean temperature difference in this and Schmeiser's study but the difference is less dramatic in Roth's study.

The greatest standard deviations also occur in the upper levels. The standard deviation of the 25-125m level is roughly double the value of the overall standard deviation and the three others compared in the three studies. In this study the 25-125m standard deviation is much larger than Schmeiser and especially Roth.

The larger standard deviation in this study may be a result of including data pairs that were not co-located. All the data pairs in the previous two studies were co-located. Data sets separated in time and space could have larger differences in the more mixed surface levels than in the more quiescent, deeper water. The spike in the mean temperature difference and standard deviation at about 30m could be caused by the depth of the mixed layer varying above and below this level between the locations and/or times of the CTD and XBT casts.

The entry of the XBT into the water could also be responsible for a small amount of error. An abnormal entry could cause the probe to take more time to reach depth than the software allows. A few fractions of a second difference could change the depth at which the bottom of the mixed layer is recorded.

DISCUSSION

Leg one of the NPS OC3570 cruise aboard the R/V Point Sur collected 19 CTD and 19 XBT temperature profiles that were not co-located but were used in this study. One of these pairs was not used in the statistics due to bad XBT data. The second leg of the cruise collected 9 pairs of profiles that were co-located for a total of 27 pairs for statistical analysis.

Temperature differences were calculated between the CTD and XBT for each pair at 383 levels between 2 and 760 meters. A mean temperature difference and standard deviation was then computed for the 27 pairs. The statistics showed a warm bias in the XBT measurements between 0°C and 0.44°C and averaged 0.09°C for the entire range. The greatest variation in both mean and standard deviation occurred in the upper 80 meters. This was also a trend in the two previous studies. It was perhaps made worse in this study by using data pairs that were not co-located as discussed earlier. This is likely the largest source of error in this study.

What impact would a warm bias in XBT's of the magnitude found in this study have on Naval operations? The Navy uses the temperature profile from XBT's to determine the sound speed profile for Under-Sea Warfare (USW) applications. For this purpose, the indicated bias would have a negligible effect. As shown in Schmeiser (2000), even 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 less than 0.1°C would have an even smaller impact. Therefore, the data from this and previous studies suggests that any bias present in the Sippican T-7 XBT will not hinder USW operations.

While not posing a problem in an operational use, the consistent warm bias could negatively impact climate studies. As with all data, biases should be removed before using it to draw conclusions. Scientists relying on these XBT profiles to look for global warming without accounting for the bias would "see" a rise in ocean temperature even if there was no change and a higher rise if there was. A well designed experiment could determine an inherent bias and a correction that could be applied to XBT data collected around the world. The sample size, in addition to the temporal and spatial variation, in this study is not sufficient for such a determination.

Three different NPS studies have indicated that XBT’s record ocean temperature warmer than actual. Future research should attempt to use a larger sample size of co-located profiles from different locations. As Roth (2001) suggests, the XBT should be released before the CTD to reduce temporal variation to a minimum. Different batches of XBT’s should also be used if possible, i.e. do not use 100 XBT’s out of the same box. Using XBT’s with different manufacturing dates will more generalize the results.

REFERENCES

Heinmiller, R.H., et al. “Instruments and Methods: Systematic Errors in Expendable Bathythermograph (XBT) Profiles.” Deep-Sea Research, Vol 30, No. 11A, pp.1185-1197. Great Britain: Pergamon Press Ltd., 1983.

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.

Saunders, P.M., “Practical Conversion of Pressure to Depth.” Journal of Physical Oceanography, Vol 11, April 1981, p.573. American Meteorological Society, 1981.

Schmeiser, G., “XBT and CTD Temperature Measurement Comparison.” Paper submitted for OC3570, 2000.

APPENDIX A

Location of CTD and XBT Temperature Profiles

My #	XBT #	POSITION North	West	CTD #	POSITION North	West	DATE
1	4	36-43.84	122-07.36	10	36-44.12	122-01.27	2 AUG 01
2	5	36-39.86	122-19.75	11	36-42.32	122-14.14	2 AUG 01
3	8	36-29.42	122-41.54	13	36-32.24	122-35.72	3 AUG 01
4	9	36-24.98	122-51.93	14	36-27.17	122-46.51	3 AUG 01
5	10	36-19.46	123-03.82	15	36-22.00	122-57.52	3 AUG 01
6	11	36-15.32	123-13.12	16	36-17.36	123-07.88	3 AUG 01
7	12	36-09.63	123-24.89	18	36-07.26	123-29.13	3 AUG 01
8	13	36-02.59	123-25.88	19	35-58.58	123-22.86	3 AUG 01
9	14	35-54.41	123-19.99	20	35-50.16	123-16.78	3 AUG 01
10	15	35-45.96	123-13.58	21	35-41.49	123-10.56	3 AUG 01
11	16	35-37.38	123-07.63	22	35-33.06	123-04.38	3 AUG 01
12	17	35-28.45	123-01.18	23	35-24.43	122-58.30	3 AUG 01
13	18	35-20.20	122-55.30	24	35-15.90	122-52.14	3 AUG 01
14	19	35-11.73	122-49.34	25	35-07.31	122-46.01	4 AUG 01
15	22	34-45.72	122-30.66	27	35-50.20	122-33.80	4 AUG 01
16	23	34-37.39	122-24.99	28	34-41.61	122-27.67	4 AUG 01
17	27	34-35.33	121-49.68	32	34-33.34	121-53.93	4 AUG 01
18	28	34-40.81	121-38.50	33	34-38.23	121-43.49	5 AUG 01
19	29	34-46.10	121-27.93	34	34-43.39	121-30.01	5 AUG 01
20	30	35-58.47	121-57.33	64	35-57.31	121-57.53	7 AUG 01
21	31	36-02.63	121-52.55	65	36-01.45	121-52.53	7 AUG 01
22	32	36-06.66	121-47.31	66	36-05.61	121-47.64	7 AUG 01
23	33	36-18.00	122-25.95	77	36-19.96	122-25.29	8 AUG 01
24	36	36-00.45	122-09.26	78	35-59.97	122-09.12	8 AUG 01
25	37	36-05.19	122-06.78	79	36-04.61	122-06.79	8 AUG 01
26	38	36-09.87	122-04.67	80	36-09.10	122-04.53	8 AUG 01
27	40	36-30.84	122-04.40	86	36-30.27	122-03.98	9 AUG 01
28	41	36-33.03	122-08.57	87	36-32.46	122-07.53	9 AUG 01

Table A1. *Position and date of CTD and XBT data used in this study. CTD and XBT #'s refer to the number from the cruise report and shown in the following figures. My # refers to the numbering system used in this study for simplification.*

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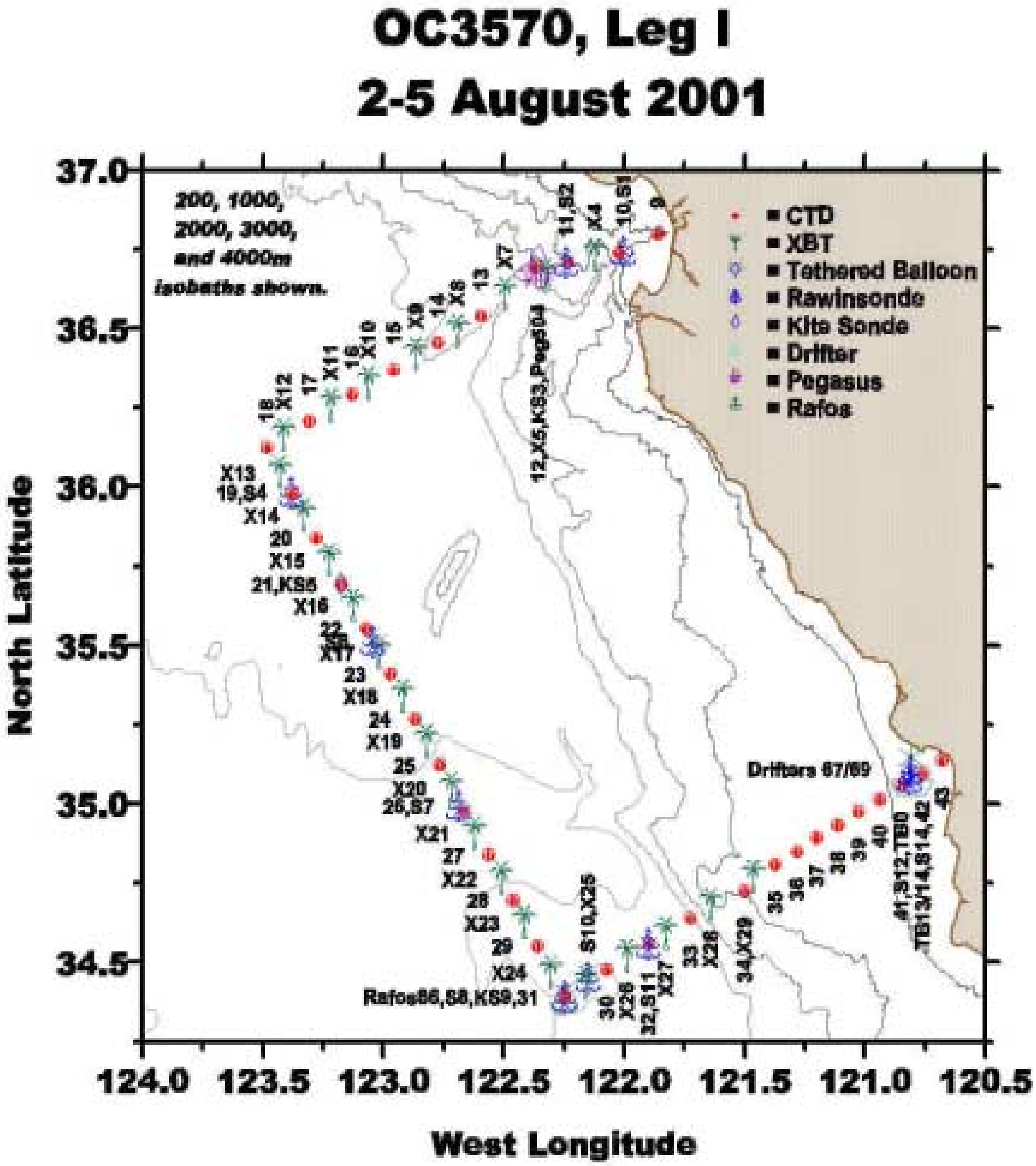
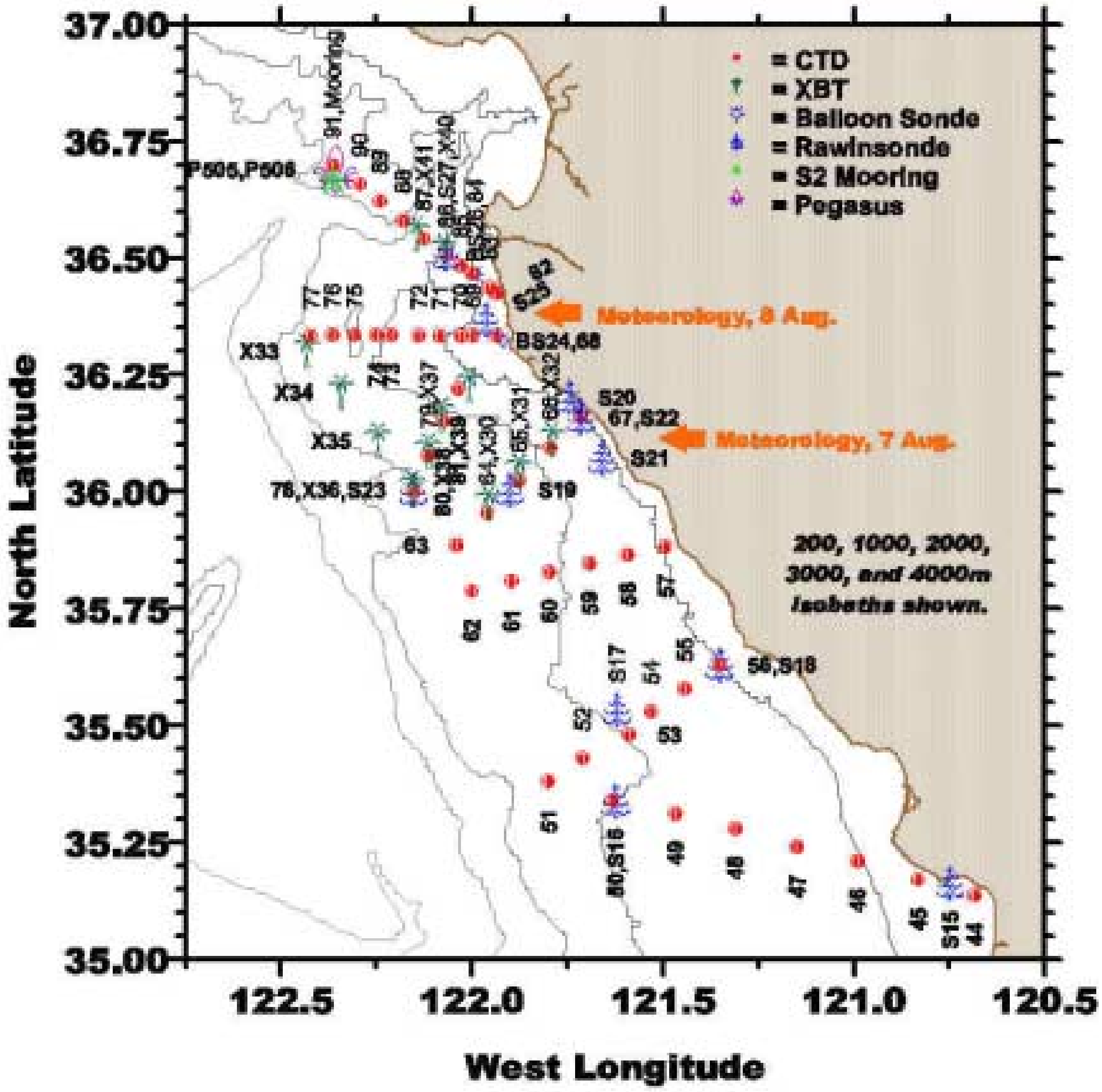
Location of CTD and XBT Temperature Profiles



APPENDIX A

Location of CTD and XBT Temperature Profiles

OC3570, Leg II
6-9 August 2001



Line D: CTDs 82-90

Line R: CTDs 44-50

Line Y: CTDs 63-67

CUC Line: CTDs 68-77

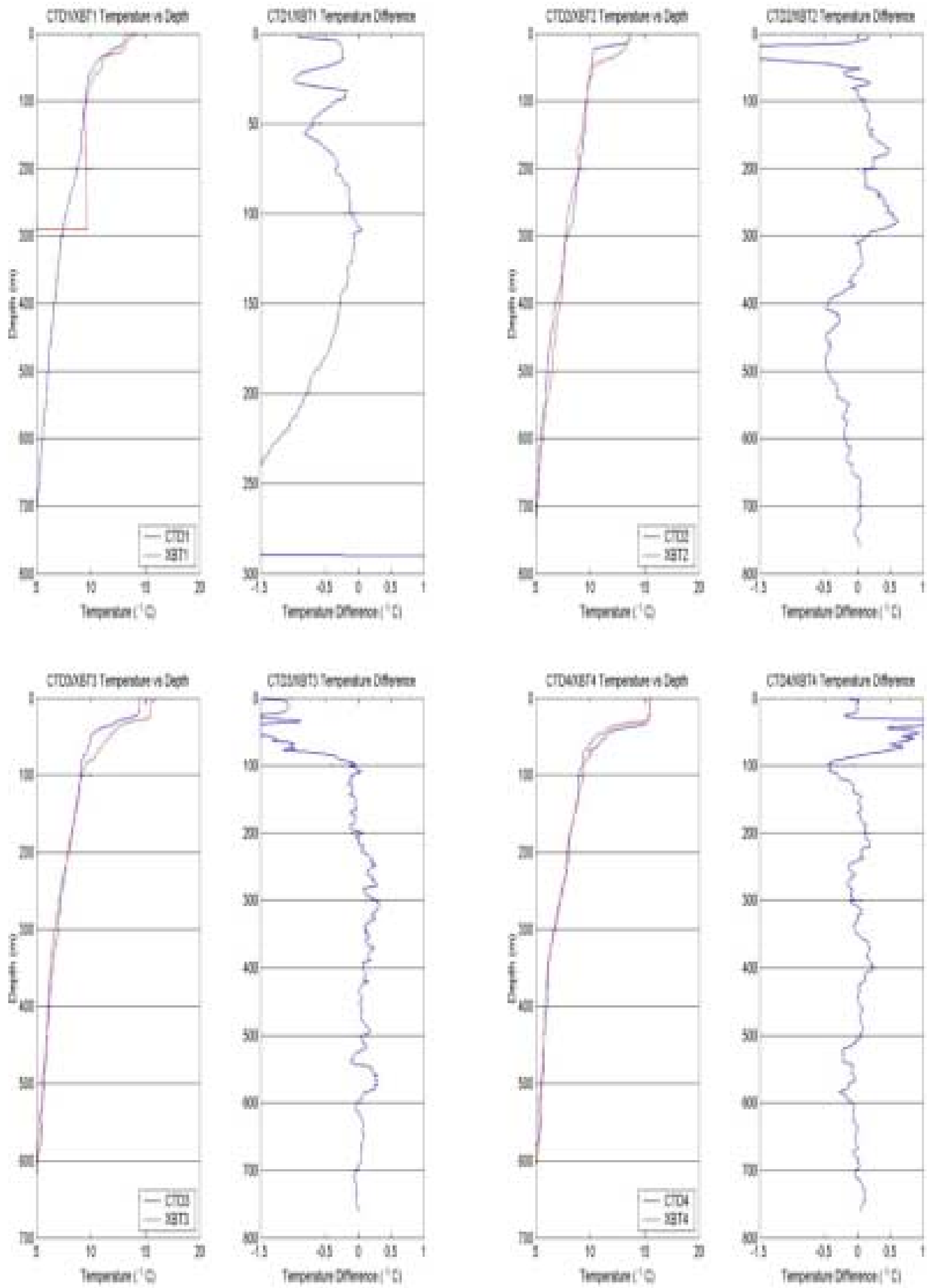
Line Q: CTDs 51-56

Line X: CTDs 78-81

Line Z: CTDs 57-62

APPENDIX B

CTD and XBT Temperature Profiles and difference Plots



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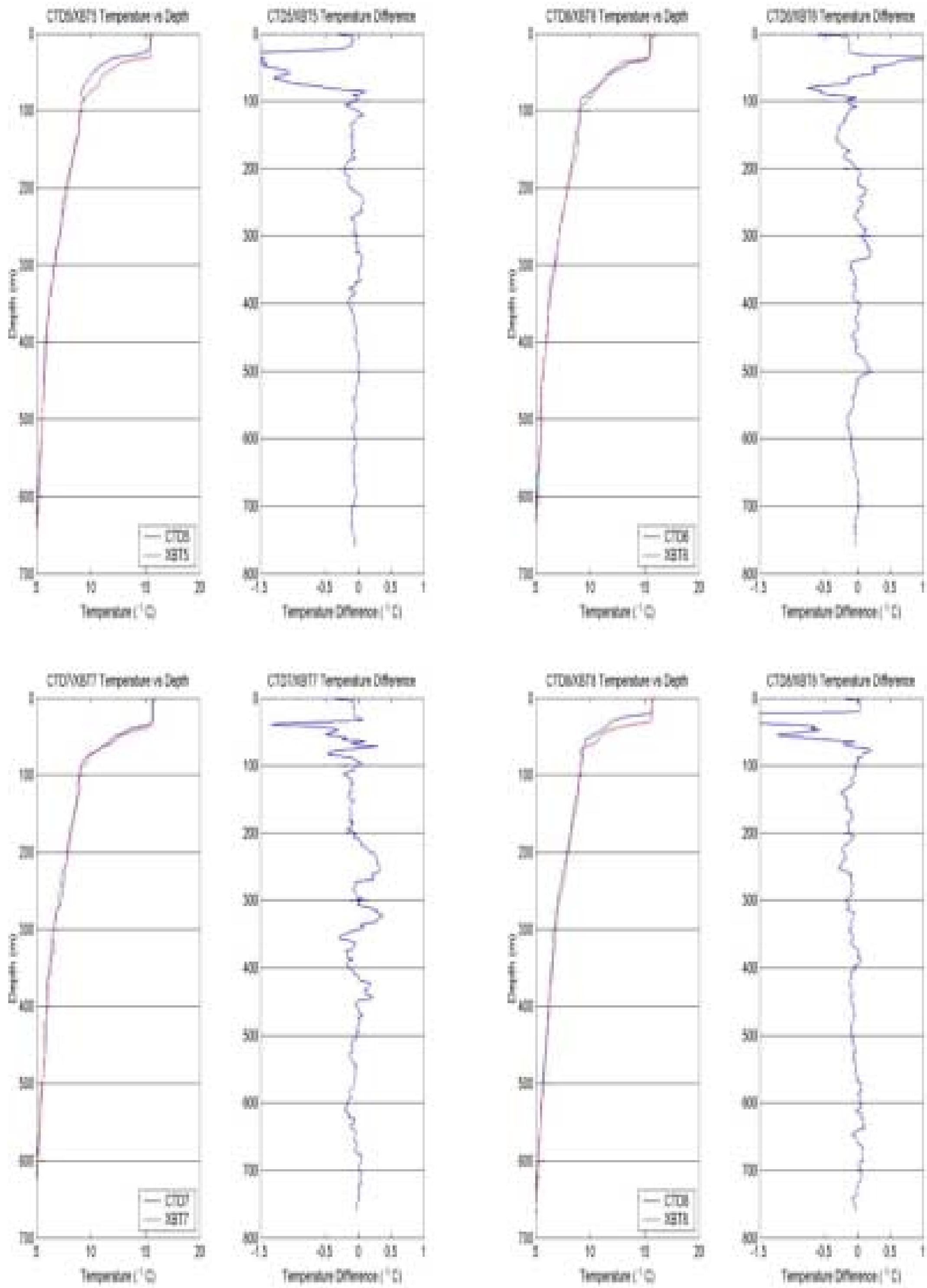

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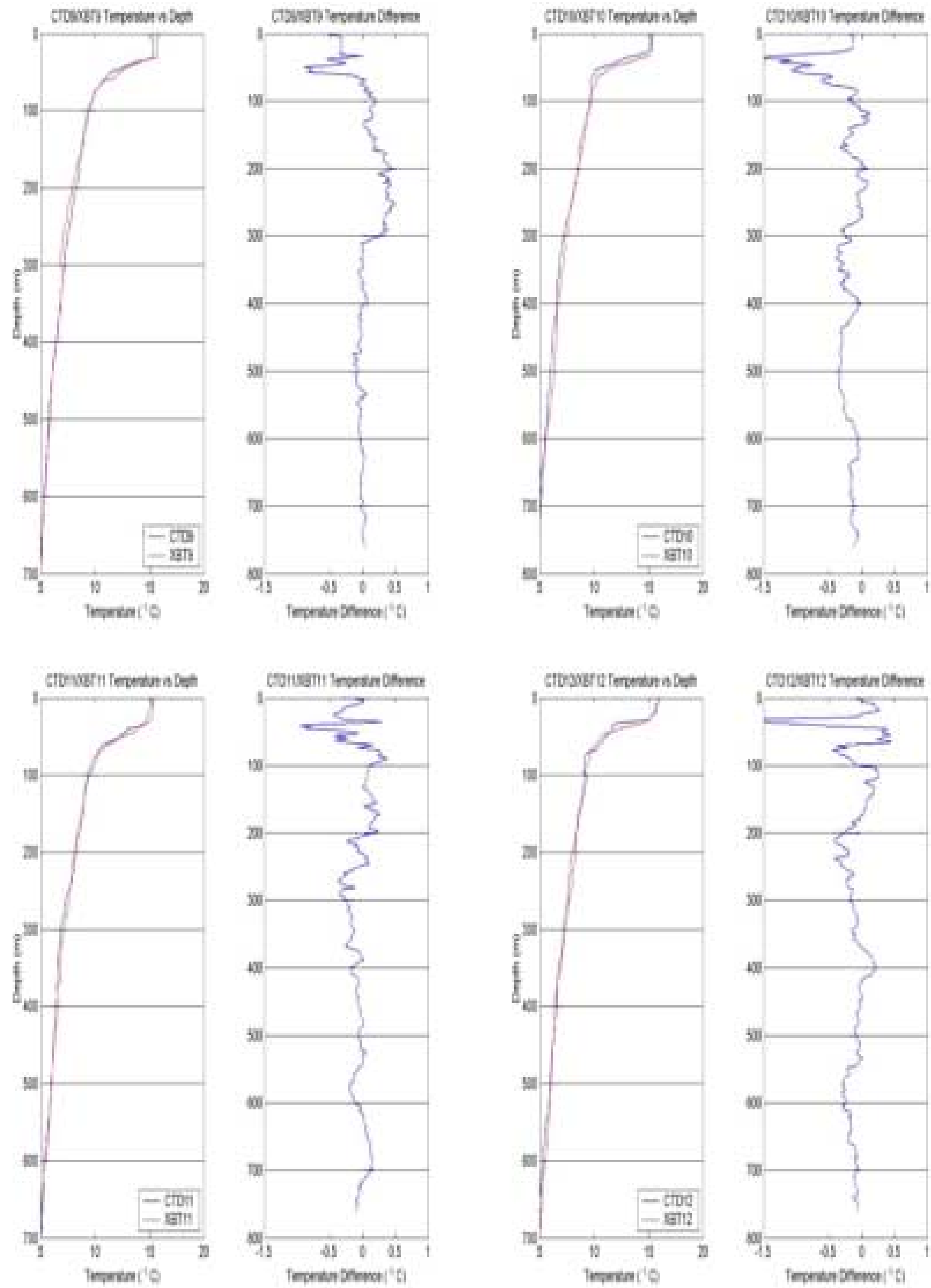

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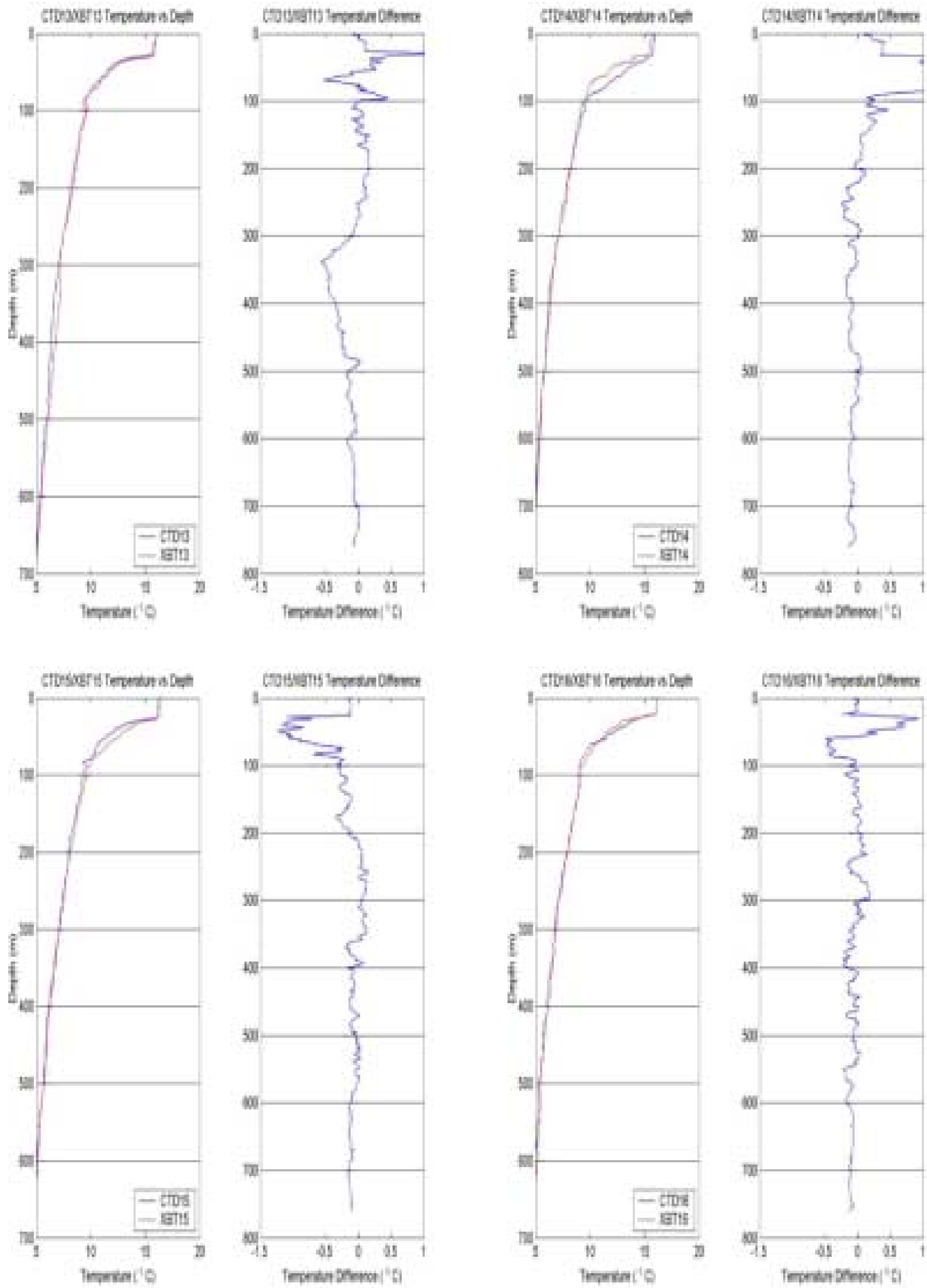

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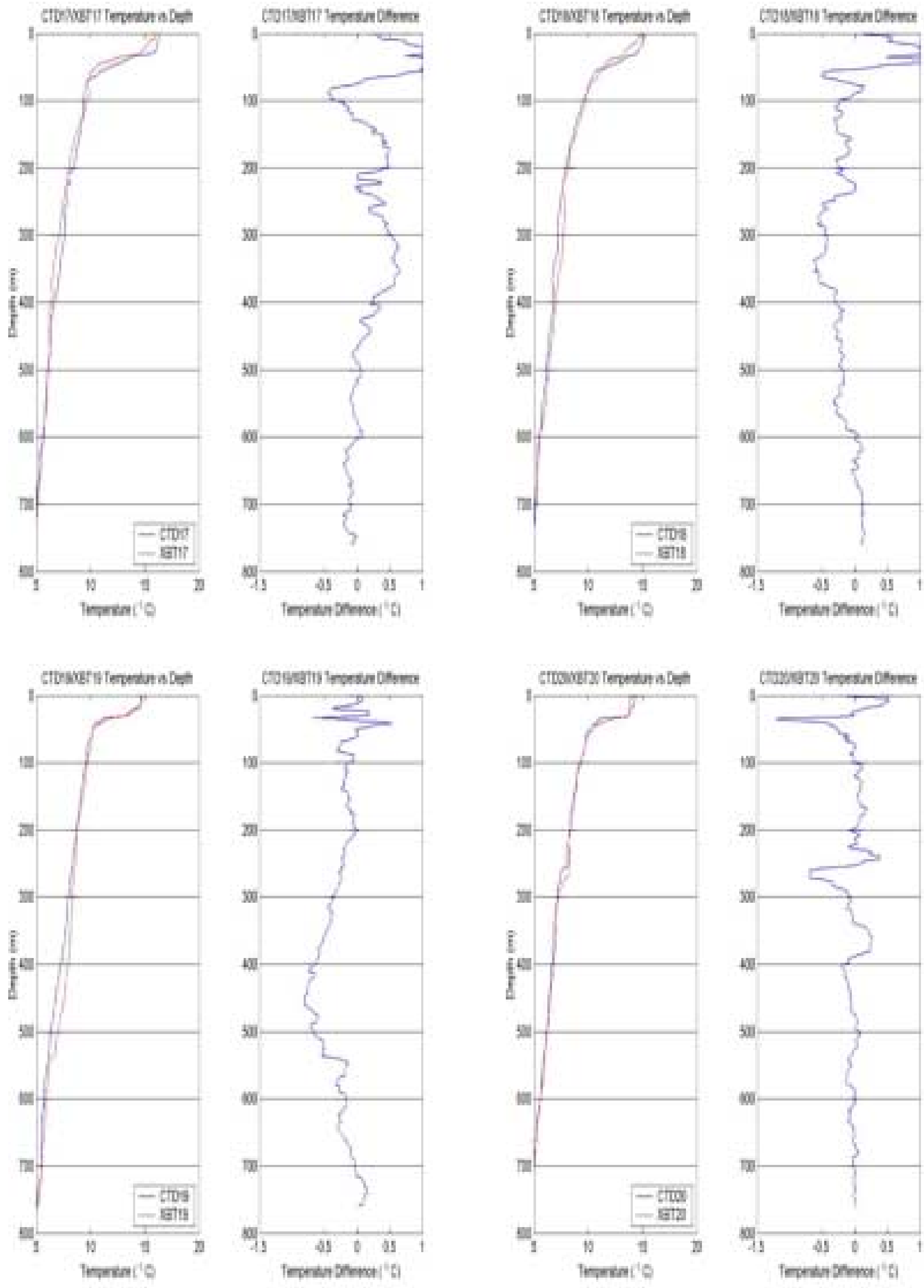

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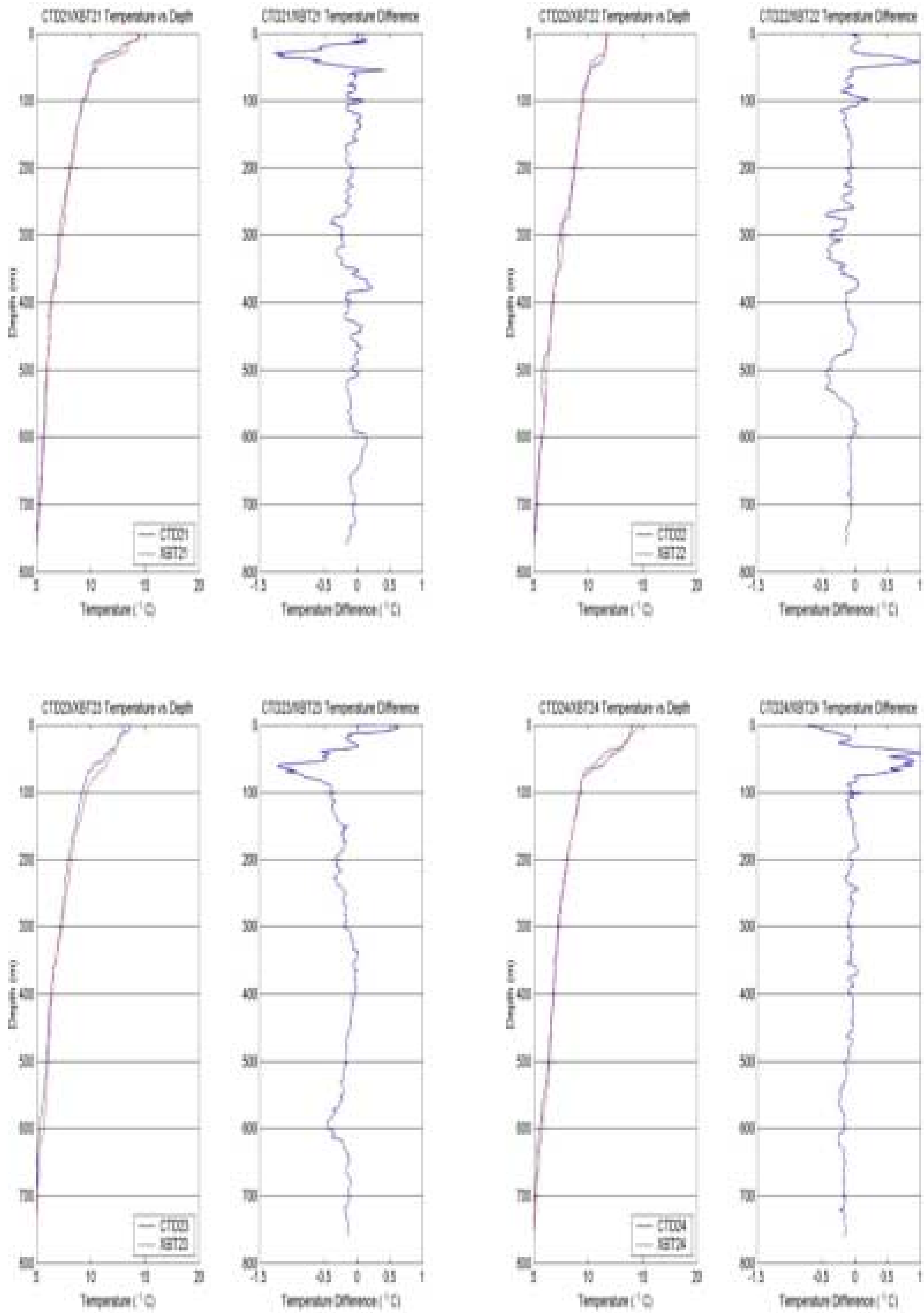

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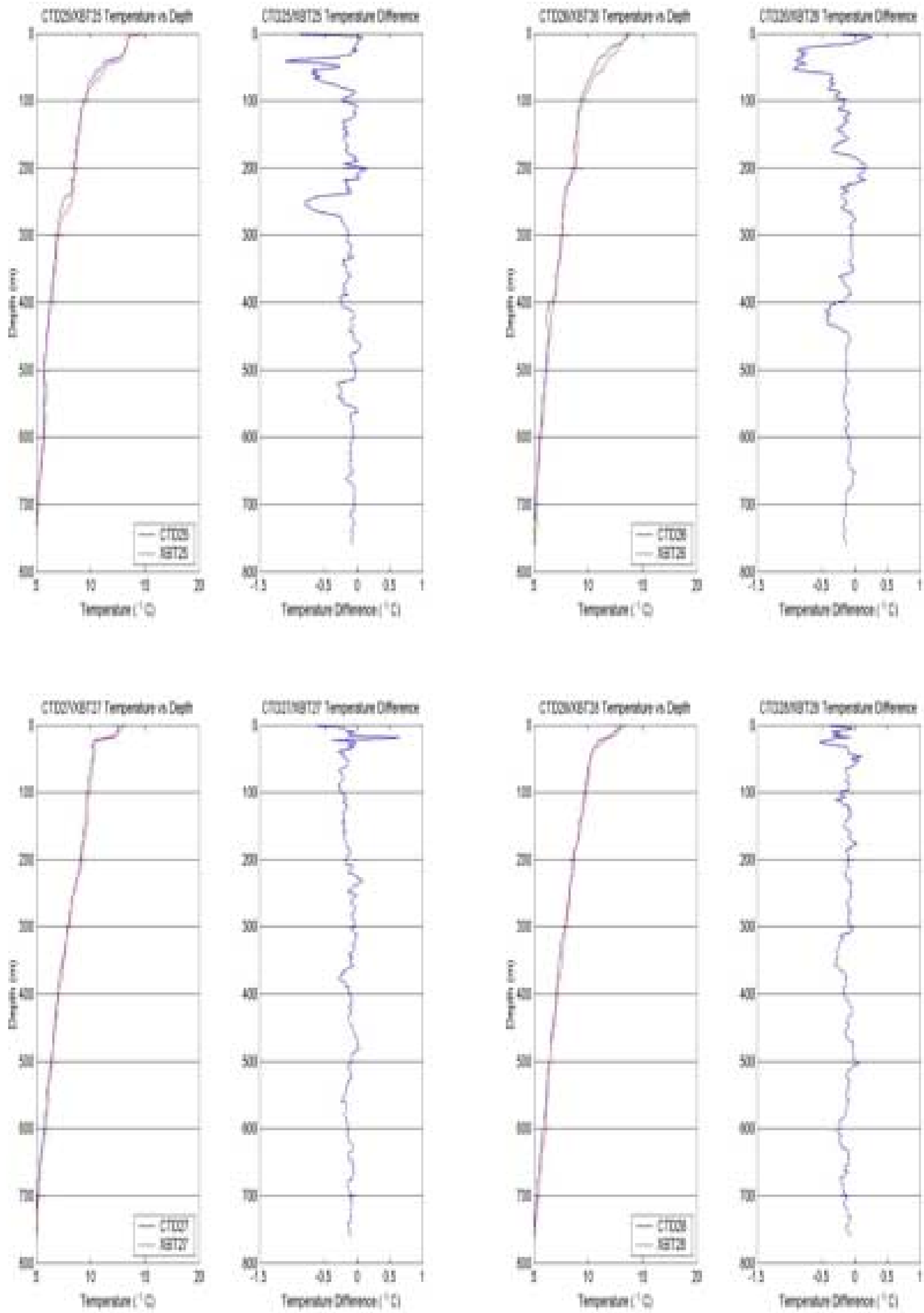

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