XBT and CTD Temperature Measurement Comparison,

Quality of JJYY Data and

XBT Data Analysis of the Mixed Layer Depth

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1. Introduction

In support of the Operational Oceanography (OC3570) course objectives a two-leg cruise was conducted aboard the Research Vessel (R/V) Point Sur from February 5 to February 12, 2001. A Descriptive Oceanography (OC3230) one-day cruise was also conducted on February 15, 2001. A portion of the cruises entailed the periodic lowering of a Sea-bird Conductivity, Temperature, Depth (CTD) sensor for retrieval of oceanographic and biological samplings. One of the measurements of the CTD includes temperature with depth. Additionally, Sippican T-7 Expendable Bathythermographs (XBTs) were dropped in order to record temperature versus depth profiles. Ten of the XBT and CTD measurements during the cruises were collocated for minimal temporal and spatial variability. The data sets were used to compare the temperature measurements of the XBT to the temperature measurements of the CTD for each pair of collocated XBT/CTD. The purpose of these comparisons was to identify any XBT biases and compare findings to similar studies.

Quality control of data is a significant factor in the outcome of any experiment. The Naval Oceanographic Office (NAVO) has created a software package, Sound Velocity Profile Generator (SVPG) version 2.5, that together with operator interface facilitates the preparation of Navy JJYY messages that contain select data points that are considered representative of the original XBT temperature versus depth profile. The data included in these messages are fed into the Fleet Numerical Meteorological and Oceanographic Center (FNMOC) database. The results of the software-edited XBT profiles are compared to the collocated CTDs in order to determine if any value is lost through the use of JJYY data points vice the entire XBT profile. Throughout this paper, the term “JJYY-XBT” refers to the temperature versus depth profiles taken from the JJYY messages.

The first OC3570 cruise happened to take place at the backside of a cold front and was dominated by the advection of relatively cool air and fairly constant marginal gale to gale force winds. Nine XBTs were dropped during the outbound leg that took place during the onset of the strong north/northwesterly winds. Nine additional XBTs were dropped during the inbound leg that took place after the winds had been steadily present for a considerable period of time. The XBT temperature versus depth profiles help describe the characteristics and properties of the ocean at the onset of the marginal gale force winds and throughout their duration. These profiles were analyzed in order to determine the impact of the steady north/northwesterly winds of the low pressure system on mechanical mixing of the mixed layer depth and the depth of the thermocline of the ocean.

2. Data collection

a. *XBT-CTD comparison*

The CTD-XBT comparison was comprised of a total of ten collocated XBT/CTDs of which seven were obtained during cruise one and three during cruise three. Inclement weather and a high sea state precluded the second cruise from gathering XBT data since the ship was restricted to shallow water depths for the entire duration. The end result was a fairly small sample size. The T-7 XBT has an operational depth of 760 meters. The CTD can be lowered to a desired depth and was generally lowered to a depth of 1006 to 1014 dbar (995 to 1004 m), however, depth restrictions for the OC3230 cruise limited CTDs 8, 9, and 10 to depths of 244, 644, and 404 dbar (242.0, 638.1, and 400.5 m) respectively. The locations of each collocated XBT drop and CTD cast are plotted in Figure A1 and listed in Table A1 of Appendix A. In order to enhance clarity and ease the data analysis, the XBT launches and CTD casts used in the comparison were renumbered 1 through 10 and therefore the numbers do not coincide with the numbers recorded in the laboratory log/cruise report.

The XBT records depth in meters while the CTD references depth to decibars. The XBT records temperature in degrees celcius as does the CTD. Only the temperature data of the CTD was used in the comparison. All data was saved in ASCII file format for easy ingestion by Unix-based Mathworks Matlab 5.0.

b. *NAVO JJYY XBT-CTD versus XBT-CTD comparison*

The NAVO JJYY software, SVPG, was used immediately following each XBT drop during cruise one. The operator is able to interface with the software and modify the points such as corrupt data that can cause unlikely spikes in the profile. The operator can also select additional points to make the JJYY more representative of significant features in the profile. Unfortunately there were no JJYY files for the OC3230 cruise and the data set for this analysis is reduced to seven collocated CTD/JJYY-XBTs vice the original ten profiles. The software saves the information as a JJYY message in ASCII file format.

c. *XBT profile analysis and impact of mechanical mixing on ocean mixed layer depth*

A total of eighteen XBTs were dropped during the first cruise comprised of nine on the outbound leg (east to west) and nine during the inbound leg (west to east). The locations of each XBT drop are plotted in Figure A2 and listed in Table A2 of Appendix A. In order to enhance clarity and ease the data analysis, the XBT launches used in the comparison were renumbered 1 through 18 and therefore the numbers do not coincide with the numbers recorded in the laboratory log/cruise report or used in the previous section. All data was saved in ASCII file format for easy ingestion by Unix-based Mathworks Matlab 5.0.

Meteorological data recorded from the ship's Serial Data Acquisition System (SDAS) is displayed as a time series for the 4-day period in Figures A3 through A6 of Appendix A. Figure

A7 shows the wind speed and direction along each leg of the first cruise. The surface winds were consistently out of the north/northwest from 10 to 18 m/s during the entire first cruise. The temperature of the air was generally 1 to 3 °C less than the sea surface temperature (SST).

3. Data processing

a. *XBT-CTD comparison*

The depth and temperature data for each of the 10 XBTs and 10 CTDs were extracted by a Matlab script file. For each CTD cast, the depth in dbars was converted to depth in meters using the technique described by Saunders (1981):

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

where Z is the depth in meters and P is the pressure in dbars,

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

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

This technique was useful since the CTD consistently measured depth in 2 dbar increments starting at the same depth of 2 dbar. Upon conversion to depth in meters, each CTD could be used as a reference for standard depth levels for its collocated XBT. Although latitude varied for the various data collection sites (between 36° 22.55' N and 36° 49.33' N) a standard latitude of 36° N was used for the conversions. The minimal variation from the standard latitude leads to an extremely small error of approximately 0.005% during the conversion process as addressed by a study (Schmeiser, 2000) with similar latitudinal variation and was considered acceptable.

Since some of the CTD data sets included data beyond the maximum depth recorded by the XBTs, the data was considered useless for comparison purposes and all data greater than 758.7792 m was removed. Additionally for the three CTDs during the OC3230 leg that contained data that did not reach this depth, the data was represented by Matlab Not a Number (NaN) and therefore enabled statistics to be computed with ease and without affecting the outcome.

Upon conversion of decibars to meters, the standard levels were in increments of roughly 1.98 m from 1.9845 m to 758.7792 m and consisted of 383 levels for each CTD. The converted data sets for the three CTDs (CTD 8, 9 and 10) during the OC3230 cruise consisted of a total of 1,149 (383*3) levels of which 504 levels were represented by NaNs. In comparison to the CTD data sampling interval, the XBT data interval was much smaller (approximately every 0.7 m vice 1.98 m) and slightly varied with each XBT drop. Therefore each XBT data contained 1,183 levels and it was necessary to reduce each data set to the standard interval of its collocated CTD for statistical analysis. A linear interpolation scheme using Matlab was chosen for this process because of the small intervals between the XBT data. For the three OC3230 XBTs, the data that corresponded to a NaN was also interpolated as a NaN for statistical analysis. The result was a set of XBT and CTD data for each location based on the 383 consistent depth levels from 1.9845 m to 758.7792 m. The CTD and XBT data each had a total of 3,326 temperature measurements (7*383 + 122 (CTD 8) + 321 (CTD 9) +202 (CTD 10)) representing a total of 6,652 temperature measurements prior to quality control.

b. *NAVO JJYY XBT-CTD versus XBT-CTD comparison*

The JJYY messages in ASCII format for the seven XBTs were accessed and the temperature and depth data were manually decoded. The data was then ingested into the same Matlab script file used for the XBT-CTD comparison. Each JJYY-XBT varied in depth layers because the NAVO SVPG software was used to select representative points in the original XBT data sets. The same linear interpolation scheme, previously described, was used to determine the values of the JJYY- XBT data at the standard levels of the collocated CTD. In cases where some of the CTD data sets included data beyond the maximum depth that the NAVO software/user selected as a cutoff for the XBTs, the JJYY-XBT data was represented as a NaN during the interpolation. In cases where the operator chose to exclude points in the upper few meters, the interpolation sheme also replaced those levels with NaNs. The CTD and JJYY-XBT data each had a total of 2,247 temperature measurements representing a total of 4,494 temperature measurements prior to quality control.

c. *XBT profile analysis and impact of mechanical mixing on ocean mixed layer depth*

A total of eighteen XBT data sets (9 on the outbound leg and 9 on the inbound leg) were available for the analysis. There was no need for depth conversion or interpolation since the objective did not include comparison with a CTD. All XBTs recorded to the operational depth of 760 m. Each XBT recorded temperature from 0.7 m to 760 m with an interval of approximately 0.7 m. This led to 1,183 temperature measurements for each XBT and provided a total of 21,294 (1,183 *18) available temperature measurements for the MLD analysis. In order to focus on the mixed layer depth and the thermocline, all data deeper than 350.2 m were discarded. This resulted in a total of 9,594 (533*18) available temperature measurements for the analysis prior to quality control.

4. Quality control

a. *XBT-CTD comparison*

In order to perform quality control of the 10 CTD and 10 XBT data, by identifying and removing bad data, a three-stage process was utilized. First, for each CTD and XBT, a Matlab script file was used to compare the temperature at each standard depth level with the temperature one standard level above and below it. More specifically, if the temperature at a level differed by more than 0.2° C from the average of the temperature one level above and one level below it, the temperature data at that level was considered flagged. The top level was only compared to the second level as was the lowest level compared to the level immediately above it with the same 0.2° C criteria since they only have one adjacent level for comparison. The final analysis will show that the 0.2° C threshold is well within two standard deviations of the final statistical data and therefore was considered acceptable.

None of the CTD data was flagged. The XBT data had a total of 43 flagged points. The first run of quality control revealed that a few of the flagged XBT data points (16.28%) occurred in the upper 4 meters. The effect of the XBT first entering the ocean is a probable explanation for this data corruption. Additionally, XBT-6 had a large number of data points flagged (65.12%) and was considered a possible bad XBT.

The second stage of quality control involved a visual inspection of the temperature versus depth plots for each of the XBTs and CTDs with specific emphasis on areas of the plots that corresponded to the flagged data points. Visual inspection confirmed XBT-6 to be a bad XBT and all of its data along with its collocated CTD were discarded from the comparison. A temperature-depth plot for CTD-6/XBT-6 is at the end of Appendix B. Additionally, visual inspection of XBT-4 and XBT-8 profiles revealed larges spikes indicative of the XBT copper wire possibly coming in contact with the hull of the ship and grounding out the XBT. These spikes occurred a depth of 578.7297 m for XBT-4 and at 202.3303 m for XBT-8. All data at and below the spike was removed from the XBT as well as from the collocated CTD. All remaining flagged data points were also removed.

The third stage involved running the quality control with the 0.2° C criteria again and no data points were flagged. Upon completion of the quality control, a total of 501 data points were removed from the XBT data as well as from the CTD data (total of 1,002). The remaining 2,825 XBT temperature measurements and 2,825 CTD temperature measurements (total of 5,650) were used in the statistical analysis. This was 85% of the original data.

b. *NAVO JJYY XBT-CTD versus XBT-CTD comparison*

The same three-stage process describe above was used to perform quality control of the seven collocated CTD/JJYY-XBT data. The JJYY-XBT data only had 2 flagged points after the first stage of quality control. Such a low number was expected since the quality control had already been done on the data though the NAVO software and user interface.

The second stage, visual inspection of the temperature versus depth plots for each of the JJYY-XBTs and CTDs, revealed no additional removal of data was necessary. JJYY-XBT-6 appeared valid from a depth of 7.938 m to 105.1554 m. Therefore, in contrast to the XBT/CTD analysis, the CTD-6/JJYY-XBT-6 data was not discarded. The third stage of quality control, re-running the quality control with the 0.2° C criteria, showed no data points were flagged. Upon completion of the quality control, a total of only 2 temperature measurements were removed from the JJYY-XBT data as well as from the CTD data (total of 4). The remaining 2,245 XBT temperature measurements and 2,245 CTD temperature measurements (total of 4,490) were used in the statistical analysis. This was 99.9% of the original data.

c. *XBT profile analysis and impact of mechanical mixing on ocean mixed layer depth*

The same three-stage process describe above was used to perform quality control of the eighteen XBT data sets. A total of 127 points were flagged. The first run of quality control revealed that a large percentage of the flagged XBT data points (31.5%) occurred in the upper 4 meters. The upper 4 meters of temperature measurements were therefore removed from each XBT. Additionally, XBT-6, XBT-8 and XBT-12 had large numbers of data points flagged and were considered as possible bad XBTs.

The second stage, visual inspection of the temperature versus depth plots for each of the

XBTs, confirmed that XBT-6 and XBT-8 were bad XBTs and all of their data were discarded. Although the spikes were small, XBT-12 was also discarded because the contour plots would become distorted. Figure D1 of Appendix D is a temperature-depth plot for the three bad XBTs. The third stage of quality control, re- running the quality control with the 0.2° C criteria, showed no data points were flagged. Upon completion of the quality control, a total of 1,674 temperature measurements were removed from the XBT data. The remaining 7,920 (528*15) temperature measurements between 4.0 and 350.2 m were used in the temperature contour plots. This was 82.6% of the original data.

5. Data analysis

a. *XBT-CTD comparison*

For each XBT/CTD pair, the XBT temperature at each of the standard depth levels was subtracted from the CTD temperature at the same depth. Appendix B includes a subplot of the CTD and XBT temperature/depth profiles for comparison as well as a subplot of the resulting CTD-XBT temperature difference versus depth for each collocated XBT/CTD. Additionally, all of the CTD-XBT differences for each standard depth layer were analyzed by calculating the mean and standard deviation at each of the 383 standard depth levels. The standard deviation was normalized by N-1 since the sample size was considered small. The results of the composite CTD-XBT difference mean with +/- 1 standard deviation and after quality control are shown in Appendix B. Due to the high accuracy and calibration associated with the Sea-bird CTD coupled with the fact that none of the CTD data was flagged during quality control, an assumption is made that any temperature differences observed between the XBT and CTD data are a reflection of inaccuracies of the XBT.

b. *NAVO JJYY XBT-CTD versus XBT-CTD comparison*

The same statistical analysis described above was completed for each JJYY-XBT/CTD pair. Appendix C includes a subplot of the CTD and JJYY-XBT temperature/depth profiles for comparison as well as a subplot of the resulting CTD/JJYY-XBT temperature difference versus depth. The results of the composite CTD/JJYY-XBT difference mean with +/- 1 standard deviation and after quality control are also shown at the end of Appendix C.

c. *XBT profile analysis and impact of mechanical mixing on ocean mixed layer depth*

In order to examine the mixed layer depth at the onset of the marginal gale force winds, a waterfall plot of the XBT temperature versus depth profiles for the outbound leg is included as Figure D2 in Appendix D. Similarly, Figure D3 of Appendix D is a waterfall plot of the inbound leg of cruise one representing the upper 350 m after the steady north/northwesterly winds had been present for a considerable period of time. Figures D4 and D5 are contour plots of the outbound and inbound legs respectively.

6. Findings

a. *XBT-CTD comparison*

The composite plot on page B3 of Appendix B shows with the exception of a few layers in the vicinity of 100 m, the XBT temperature was greater than the CTD temperature resulting in mean temperature differences with negative values (red line generally lies to the left of the 0° C temperature difference vertical line). The greatest average temperature differences occur in the upper 100 m (mean = -.09° C) as well as the largest standard deviations (mean = .172° C). The upper 35 meters without including the first standard level, however, have average temperature differences less than 0.1° C (mean = -0.058° C) with standard deviations below 0.1° C (mean = 0.052° C), significantly less than the standard deviations observed between 35 and 100 m (mean = 0.229 ° C). The largest average temperature differences in the upper 100 m occur between 60 and 80 m (mean = -0.209° C), with a maximum difference of –0.2915° C at 69.448 m. The maximum standard deviation of 0.5007° C is at 67.464 m. A feature that stands out is the positive CTD-XBT values observed between 87 m and 105 m (mean = 0.0226° C) with standard deviations ranging between 0.08 and 0.1° C. In this band of layers, the XBT actually underestimated the temperatures. The maximum positive XBT-CTD average temperature difference of 0.0538° C occurred at 91.270 m.

At depths greater than 105 m, the average temperature difference varied between approximately –0.134 and –0.005° C (mean = -0.077° C). Below a depth of 400 m, the average temperature differences fluctuated between approximately –0.13 and –0.005 ° C (mean = -0.07° C). The standard deviation below 105 m was between 0.04 and 0.17° C (mean = 0.095° C). In general, there was less deviation and smaller temperature differences with deeper depths.

A comparison of the findings is made with two similar studies. The Heinmiller et al. (1983) study included the use of both Sippican T-4 and T-7 XBTs and a calibrated Neil Brown CTD in the Sagrasso Sea with139 casts. The Schmeiser (2000) study compared T-7 XBTs with a Sea-bird CTD and in a similar location west of Monterey Bay with 18 casts. The sample size for both studies was significantly larger than the available sample size for this study.

Schmeiser (2000) provides a detailed comparison of the data collection and editing techniques of the Heinmiller et al. (1983) study with his study. Since the techniques of this study are very similar to those of Schmeiser (2000), a detailed comparison of Heinmiller et al. (1983) with this study would be redundant and readers are referred to Schmeiser (2000). The only significant difference between the techniques in this study and those of Schmeiser (2000) is in the quality control of the data. Whereas Schmeiser (2000) performed quality control on the XBT data prior to interpolation to the standard levels represented by the CTD data, in this study quality control of XBT data took place after the interpolation. Since the XBT sampling interval is so small, quality control after interpolation will have little effect on the outcome of the quality control. This was confirmed by running quality control on the XBT data prior to interpolation and it was found that data at similar depths were flagged. Additionally, each CTD cast of Schmeiser (2000) was greater than the deepest depth recorded by the collocated XBT, whereas in this study three CTDs were not lowered as far as the deeper depths recorded by their collocated XBTs.

Table E1 of Appendix E is a summary of the significant findings of the three studies. For consistency, the XBT-CTD average temperature differences for Heinmiller et al. (1983) were reversed to reflect the CTD-XBT average temperature difference.

In the Schmeiser (2000) and Heinmiller et al. (1983) studies the XBT average temperature difference consistently was a negative value at all standard depth levels, indicative of the XBT measuring slightly higher temperatures than the collocated CTD. In comparison, this study did contain a small area (87 m to 105 m) of positive CTD-XBT average temperature differences in the composite. A close review of all the XBT/CTD temperature profiles reveals that XBT-10 had measured significantly lower temperatures than its collocated CTD-10 for a portion of its recording that encompasses the small area of positive temperature deviations on the composite. Since the sample size is much smaller in this study, a single XBT had a larger impact on the composite profile. If a larger sample size had been available, the region of positive temperature difference most likely would not have been present in the composite.

Schmeiser (2000) found mean temperature differences to be very similar to those of Heinmiller et al. (1983). As was the case for Schmeiser (2000) the mean temperature differences were also similar in this study, but were generally slightly lower than those observed in the other two studies.

As in the other two studies, a larger temperature difference in the 25 to 125 m is present, but not by much. This is most likely caused by the positive CTD10-XBT10 temperature difference that was measured within this layer. A higher CTD-XBT mean temperature difference (-.09° C) occurring in the upper 100 m and the presence of a maximum difference of –0.2915° C at 69.448 m, however, do support largest temperature differences being observed in the upper layers as found in the other studies.

The results of Schmeiser (2000) showed standard deviations that were considered significantly greater than those of Heinmiller et al. (1983). The results in this study show standard deviations in general agreement with those found by Heinmiller et al. (1983) except for the 25-125 m depth average. In the 25-125 m depth range, the standard deviation is approximately two and a quarter times greater than that of Heinmiller et al. (1983) but less than that of Schmeiser (2000).

b. *NAVO JJYY XBT-CTD versus XBT-CTD comparison*

Quality control of the JJYY-XBTs was much easier. The JJYY-XBT data only had 2 points flagged after quality control upon completion of the interpolation. In comparison the XBT had 43 flagged points after the first stage of quality control of data. The upper 100 m of the JJYY-XBT-6 was actually salvaged whereas the complete XBT-6 profile had been discarded.

Table E2 of Appendix E is a comparison of the outcome of the average mean and average standard deviation of the composite CTD/XBT and CTD/JJYY-XBT temperature differences. Additionally, the temperature/depth profiles and temperature difference subplots of Appendices B (XBT/CTD) and C (JJYY-XBT/CTD) are compared. All results are very similar. The CTD/JJYY-XBT composite was based on only 7 XBTs while the CTD/XBT composite was based on 9 XBTs. Additionally, the CTD/JJYY-XBT composite had 4,490 temperature data points after interpolation and quality control while the CTD/XBT composite had 5,650 temperature data points.

In summary, the NAVO SVPG software with user interface performs a pre-quality control of the data saving a great deal of time. The JJYY-XBT with a linear interpolation of the data points performs well as representing the full XBT profile.

c. *XBT profile analysis and impact of mechanical mixing on ocean mixed layer depth*

Thermal forcing due to an upward heat flux from the ocean to the atmosphere and strong mechanical wind forcing lead to entrainment of deeper, cooler waters from below and a subsequent deepening of the MLD (Chu et al., 1997). The waterfall plot for the inbound leg does show a generally deeper MLD for the XBTs closer inshore as compared to those of the outbound leg. This supports a deepening of the MLD due to the sustained marginal gale force winds that were present for a considerable period of time.

Further support of the deepening of the MLD is shown in the contour plots. The temperatures in the upper 50 m of the outbound leg were generally a degree or so warmer than those of the inbound leg. The mechanical and thermal forcing caused a loss of heat in the upper layers of the inbound leg due to heat lost to the atmosphere and entrainment of cooler water from below. The thermocline gradient for the outbound leg is stronger as expected due to less mixing since the marginal gale force winds had been sustained for a smaller time period.

7. Conclusions

Results of all three objectives show that the use of good quality control of data is absolutely essential. Without the removal of bad data results are significantly flawed and unrealistic. For example, data analysis was performed on the CDT/XBT data sets without any quality control, which included XBT-6 as well as all flagged points. As expected, the standard deviations (mean = 0.2730° C) and average temperature differences (mean = -0.166° C) had significantly larger values. The larger average temperature differences and standard deviations showed up at much deeper depths (583 m) vice in the upper 125 m.

It is highly recommended that research involving the use of XBTs exclude data in the upper 4 m. Objectives one and three for example showed 16.28% and 31.5% respectively of the flagged data occurred in the upper 4 m.

The XBT/CTD comparison did support the results of past studies. The XBT has a general trend of overestimating the true temperature particularly in the upper 125 m. Although this bias exists, it is relatively small and a correction factor can easily be obtained through empirical studies since the bias appears to be consistent and similar in magnitude.

In agreement with Schmeiser (2000), quality controlled XBTs are still useful for naval applications involving acoustic prediction sound velocity profile generation. The temperature differences are minimal and are generally consistent for the entire depth of the profile. This results in a high degree of accuracy for the calculations of the sound speed gradients that are vital to naval acoustic prediction models.

The NAVO SVPG software with user interface proved to be a useful tool for selecting data points that accurately represented the original XBT profile. To my knowledge, the program is not used in the Fleet. Ships and P-3 squadrons could greatly benefit from this software and it may improve the quality of the data going into the FNMOC model database.

In order to reduce possible temporal and spatial variability in future XBT/CTD comparison studies, it is recommended that the XBT be dropped prior to the casting of the CTD, particularly if there is strong mechanical forcing present within the region. In this study, the CTDs were lowered first, often requiring a full 40 minutes of time to complete the cast. The XBTs only require about 5 minutes to obtain the data. The spatial variability caused by drift of the research vessel and the temporal variation that elapsed between the initial lowering of the CTD and the subsequent firing of the XBT most likely had an impact on the final results.

Unfortunately this study was limited to small sample sizes that may have had an impact on final results. For example, the major limitation of the MLD analysis objective was the use of ungridded XBT data. The spacing between the various XBT drops varied between 7.3080 km and 40.2488 km and both legs had a degree of latitudinal variation. Additionally, the easternmost XBT of the outbound leg, XBT-1, was dropped at a distance much closer to the shoreline than its counterpart XBT-18 on the inbound leg. Such a limitation caused by the relatively small sample size does not paint a true picture of the MLD as accurately as gridded data composed of a larger sample size.

References

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APPENDIX A

Location of Data Collection Sites for CTD- XBT Temperature Comparisons

XBT #	POSITION	CTD #	POSITION	DATE
1	36-43.97N 122-01.94W	1	36-43.97N 122-01.54W	5FEB01
2	36-40.79N 122-12.63W	2	36-40.77N 122-11.93W	5FEB01
3	36-36.90N 122-25.21W	3	36-36.97N 122-24.36W	5-6FEB01
4	36-32.68N 122-36.58W	4	36-32.06N 122-35.34W	6FEB01
5	36-29.26N 122-47.25W	5	36-28.35N 122-46.71W	6FEB01
6	36-22.75N 122-58.23W	6	36-22.55N 122-56.92W	6FEB01
7	36-44.27N 122-01.77W	7	36-44.06N 122-01.12W	8FEB01
8	36-48.07N 121-50.93W	8	36-47.93N 121-50.97W	15FEB01
9	36-46.45N 121-58.71W	9	36-46.19N 121-58.51W	15FEB01
10	36-49.68N 121-59.15W	10	36-49.33N 121-59.09W	15FEB01

Table A1. Position and date of each XBT drop and CTD cast. XBT# and CTD#s do not agree with laboratory logs because they have been renumbered as discussed in the text of this report.

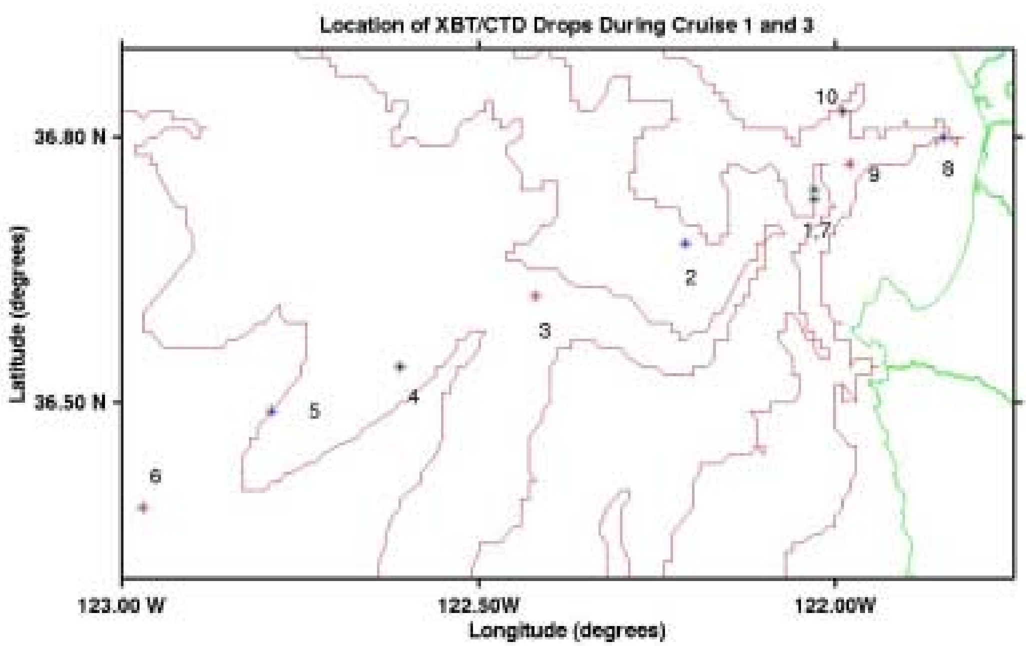


Figure A1. Plotted positions of the 10 collocated XBTdrops/CTD casts from the OC3570 cruise 1 and the OC3230 cruise.

APPENDIX A

Location of Data Collection Sites for Cruise 1 XBT Temperature Profiles

	OUTBOUND LEG			INBOUND LEG	
XBT #	POSITION	DATE	XBT #	POSITION	DATE
1	36-43.97N 122-01.94W	5FEB01	10	36-25.43N 123-05.92W	7FEB01
2	36-40.79N 122-12.63W	6FEB01	11	36-20.52N 122-55.99W	7FEB01
3	36-36.90N 122-25.21W	6FEB01	12	36-14.90N 122-44.01W	7FEB01
4	36-32.68N 122-36.58W	6FEB01	13	36-10.50N 122-35.07W	8FEB01
5	36-29.26N 122-47.25W	6FEB01	14	36-07.12N 122-27.32W	8FEB01
6	36-22.75N 122-58.23W	6FEB01	15	36-02.32N 122-17.59W	8FEB01
7	36-27.40N 123-09.94W	6FEB01	16	35-57.36N 122-06.38W	8FEB01
8	36-20.39N 123-09.96W	7FEB01	17	35-53.33N 121-57.44W	8FEB01
9	36-29.71N 123-14.80W	7FEB01	18	35-54.13N 121-52.75W	8FEB01

Table A2. Position and date of each XBT drop during OC3570 cruise 1. XBT#s do not agree with laboratory logs because they have been renumbered as discussed in the text of this report.

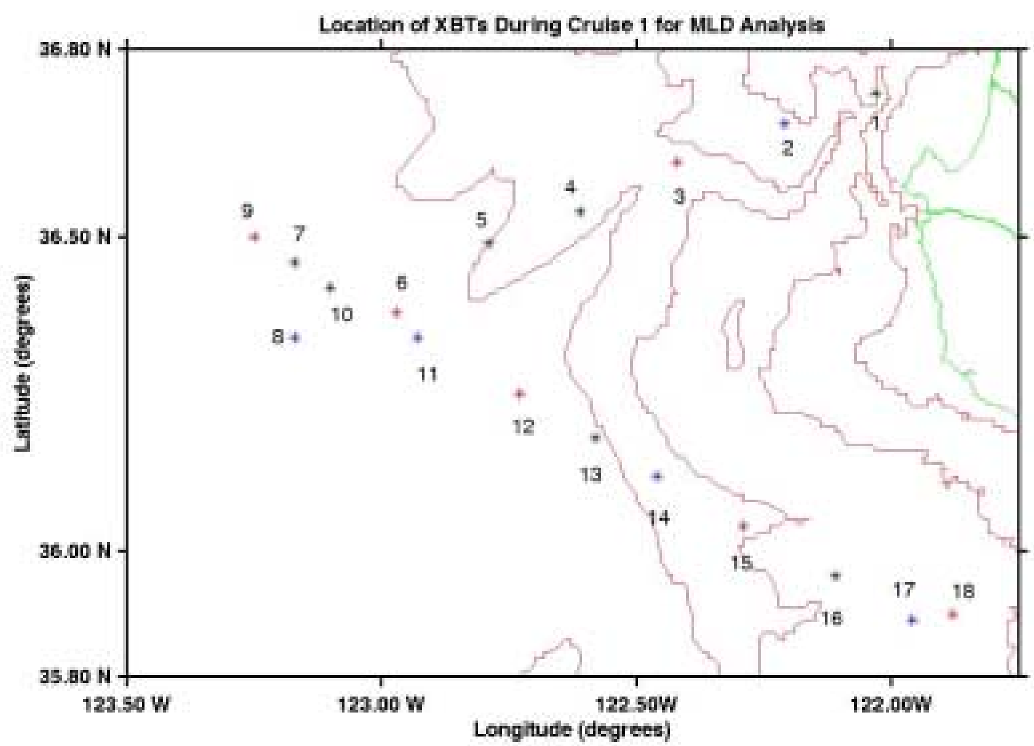


Figure A2. Plotted positions of the 18 XBT drops from the OC3570 cruise 1.

APPENDIX A

SDAS Time Series of Meteorological Data During Cruise 1

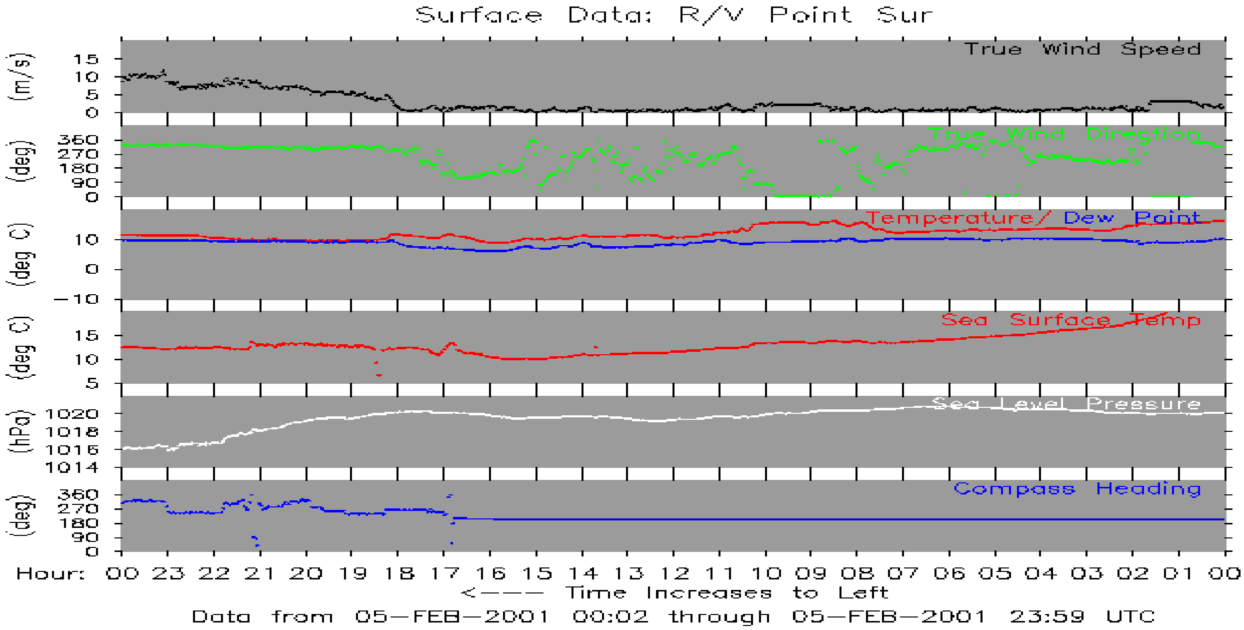


Figure A3. February 5, 2001.

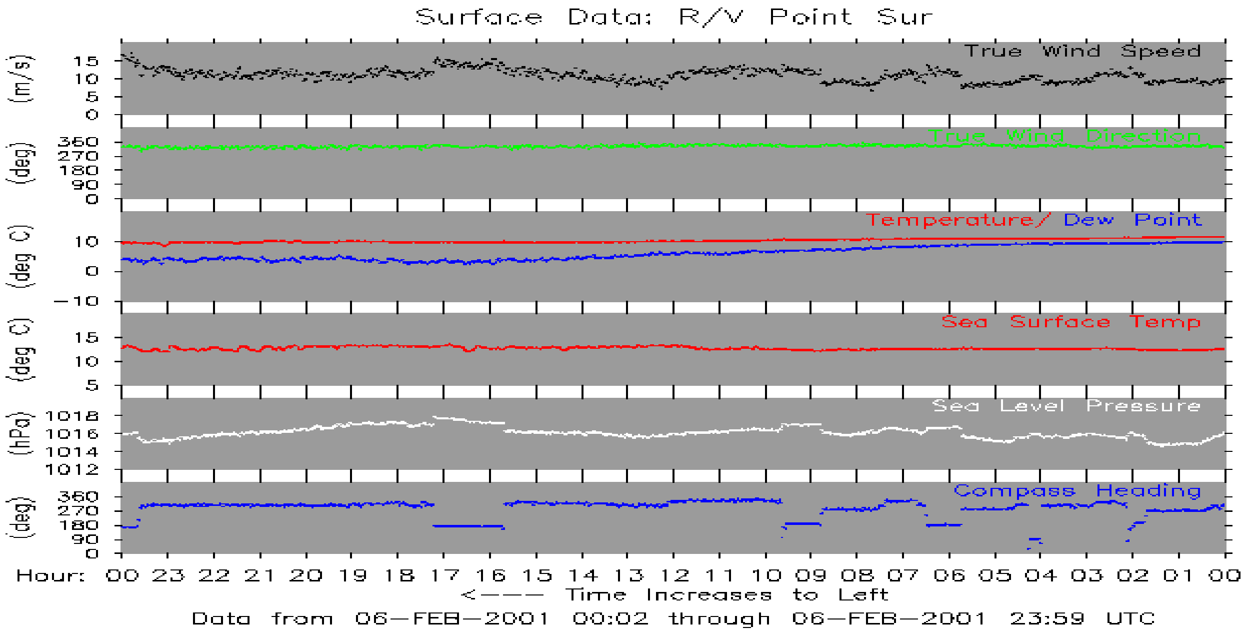


Figure A4. February 6, 2001.

APPENDIX A

SDAS Time Series of Meteorological Data During Cruise 1

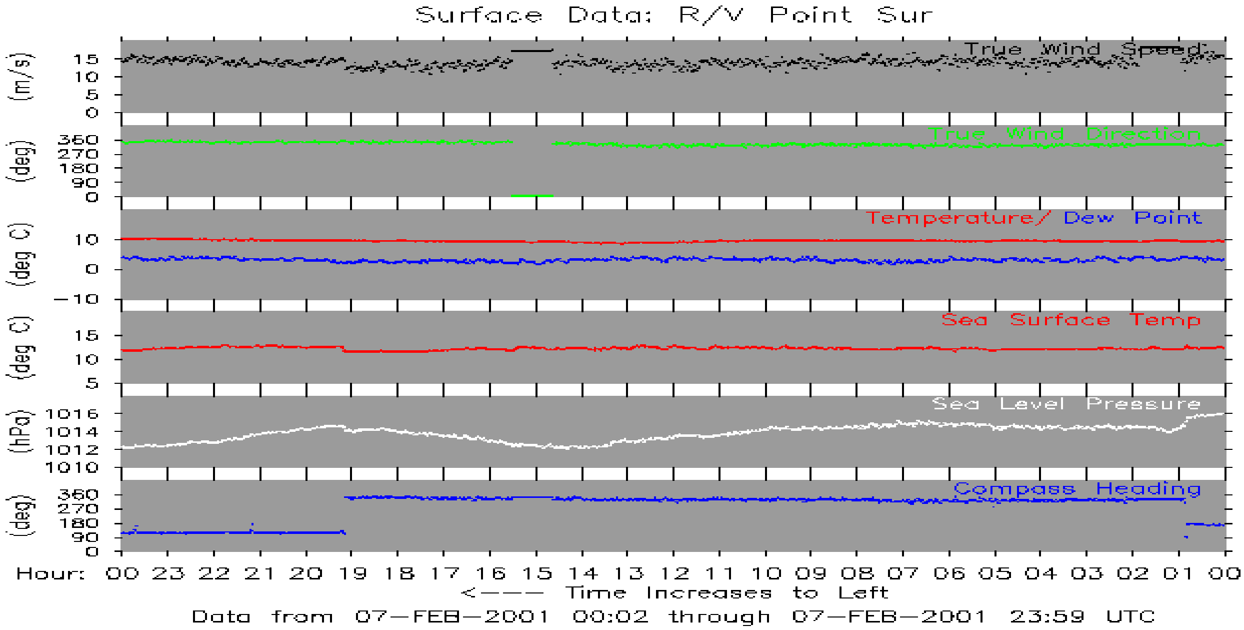


Figure A5. February 7, 2001.

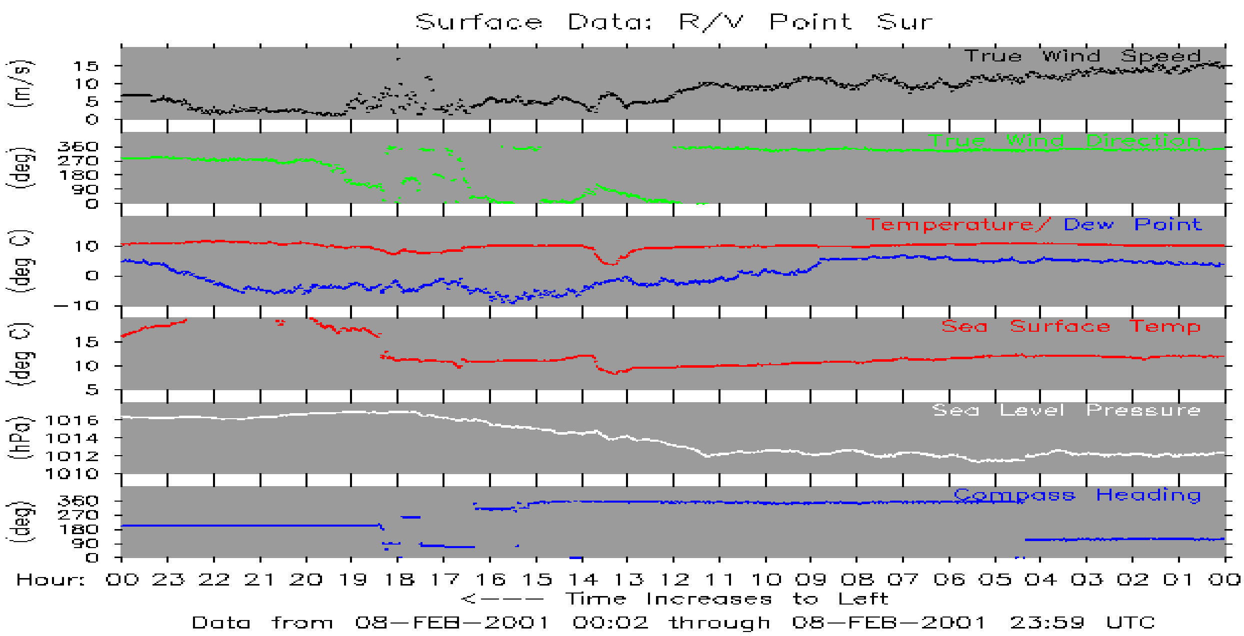


Figure A6. February 8, 2001.

APPENDIX A

Surface Wind Speed and Direction Along Outbound and Inbound Legs of Cruise 1

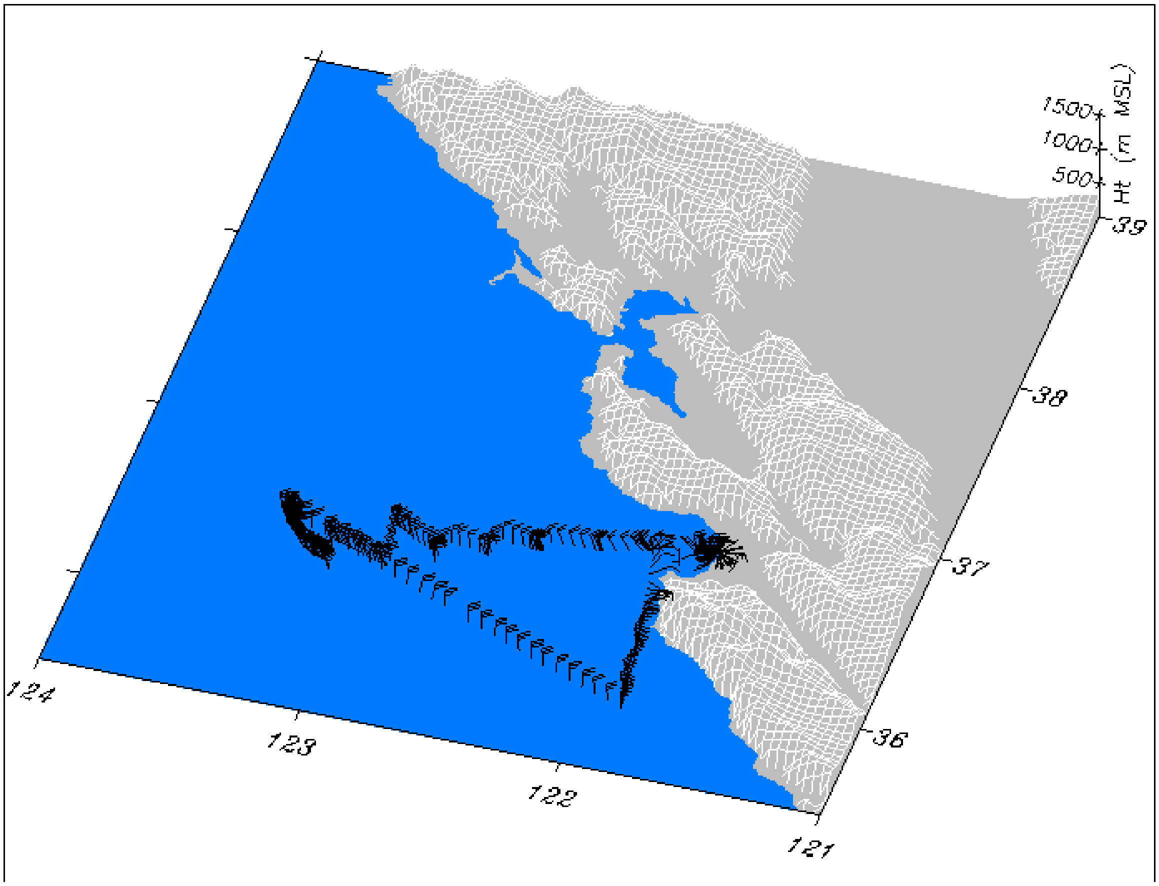
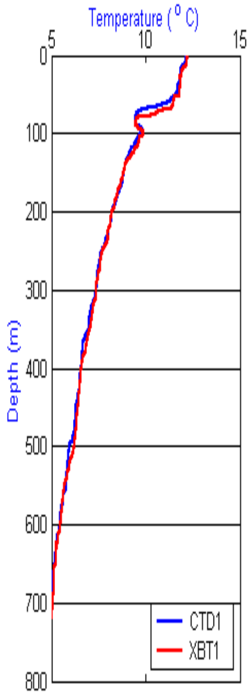


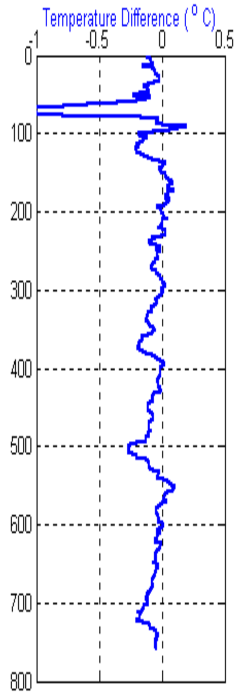
Figure A7. Wind speed and direction from February 5 through February 8, 2001.

APPENDIX B

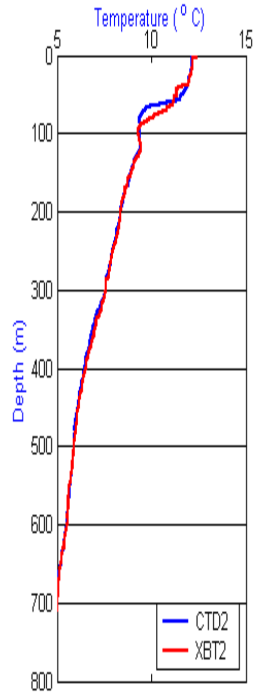
CTD and XBT Temperature Profiles and Temperature Difference Plots



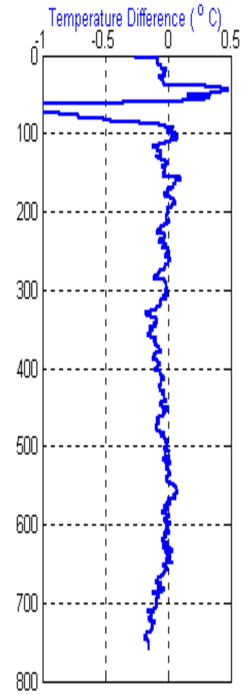
CTD1/XBT1 Temperature vs Depth



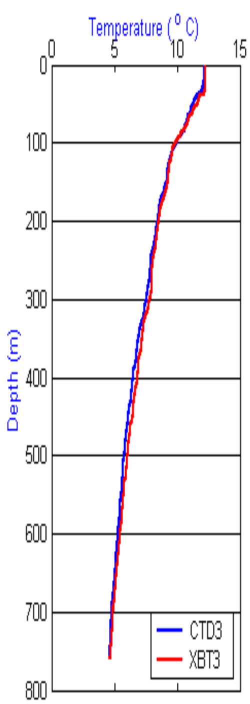
CTD1/XBT1 Temperature Difference



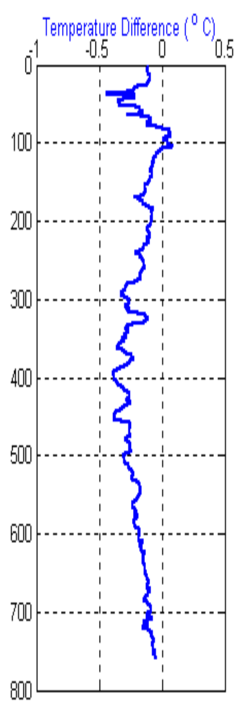
CTD2/XBT2 Temperature vs Depth



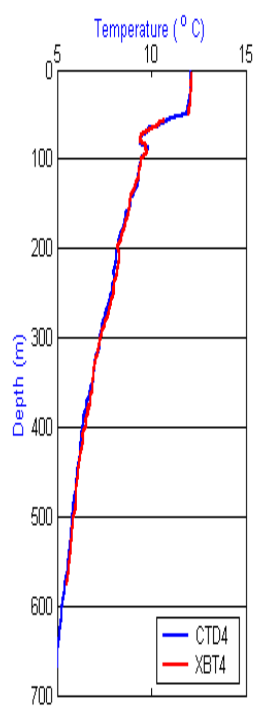
CTD2/XBT2 Temperature Difference



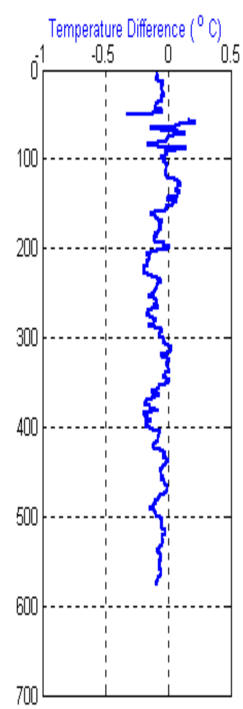
CTD3/XBT3 Temperature vs Depth



CTD3/XBT3 Temperature Difference



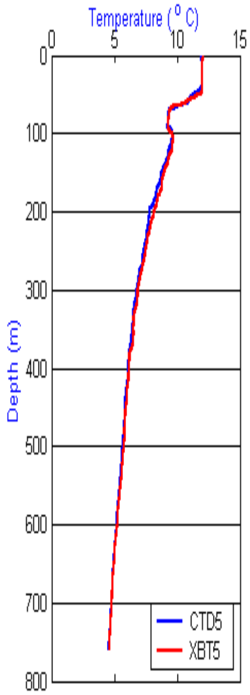
CTD4/XBT4 Temperature vs Depth



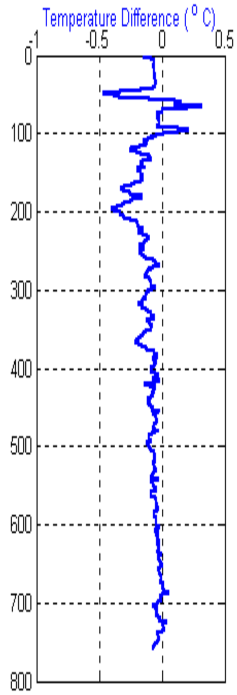
CTD4/XBT4 Temperature Difference

APPENDIX B

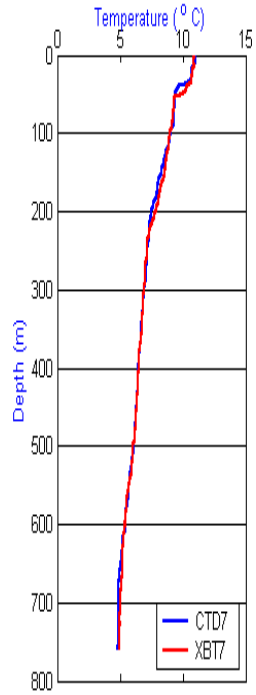
CTD and XBT Temperature Profiles and Temperature Difference Plots



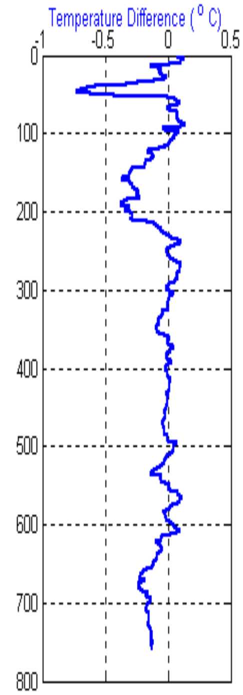
CTD5/XBT5 Temperature vs Depth



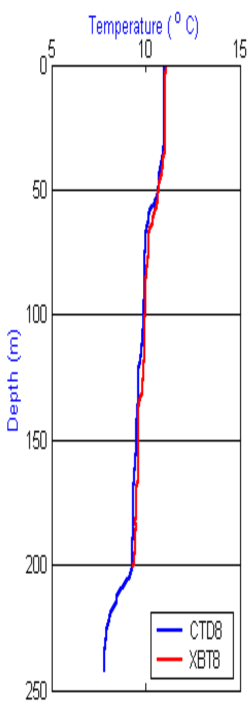
CTD5/XBT5 Temperature Difference



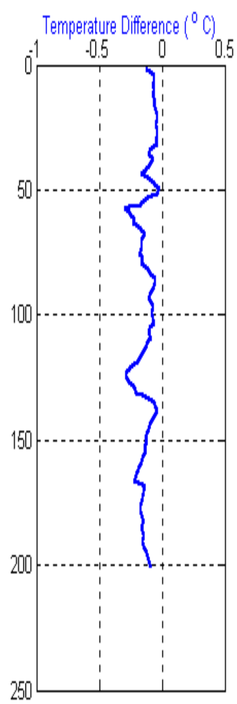
CTD7/XBT7 Temperature vs Depth



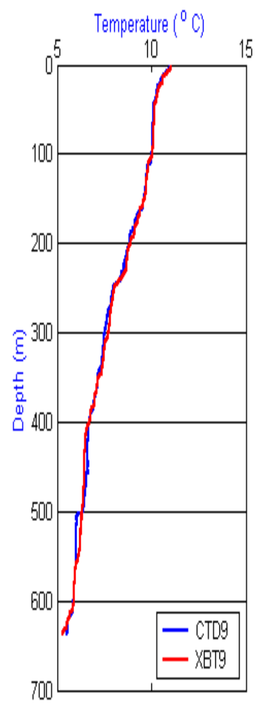
CTD7/XBT7 Temperature Difference



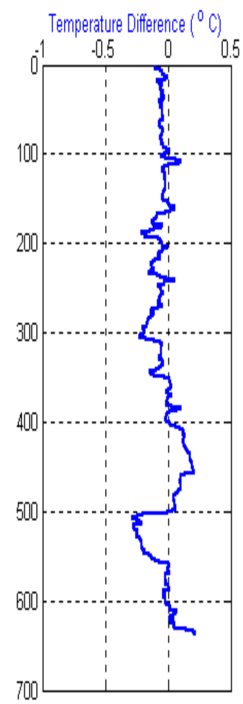
CTD8/XBT8 Temperature vs Depth



CTD8/XBT8 Temperature Difference



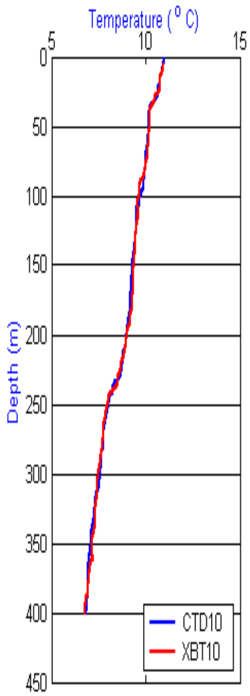
CTD9/XBT9 Temperature vs Depth



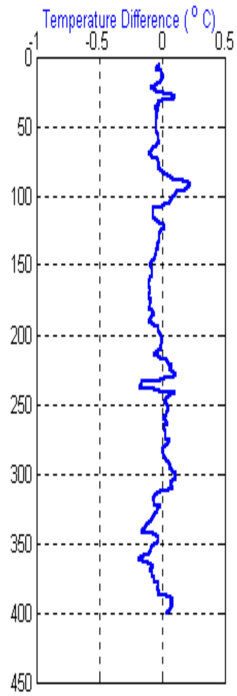
CTD9/XBT9 Temperature Difference

APPENDIX B

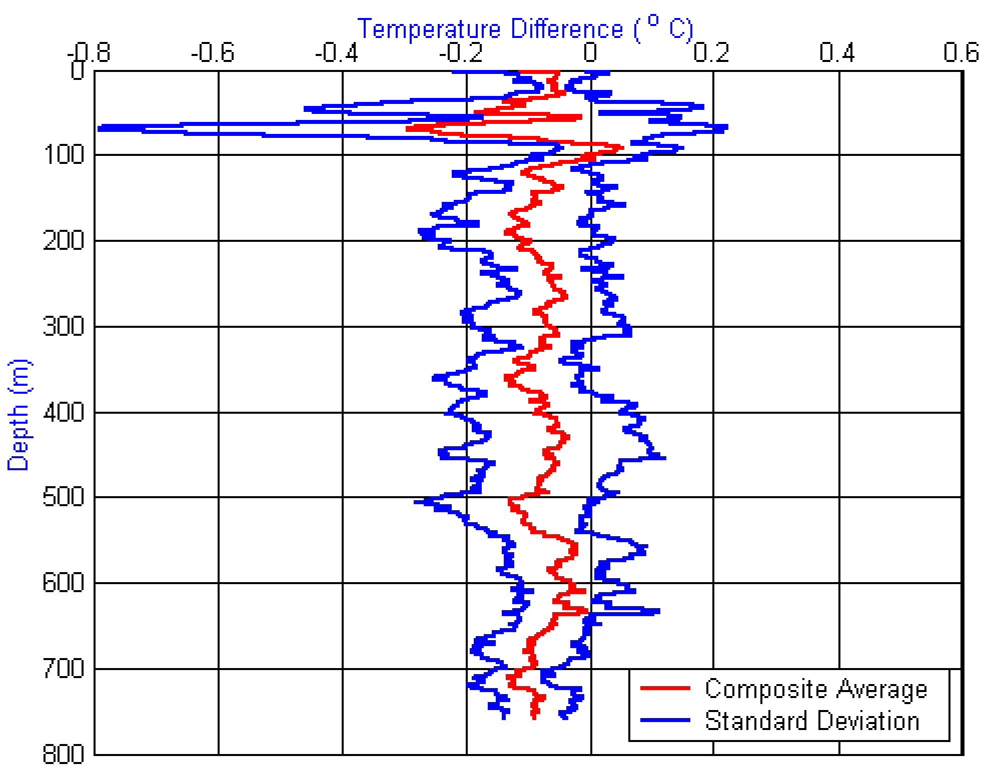
CTD and XBT Temperature Profiles and Temperature Difference Plots



CTD10/XBT10 Temperature vs Depth



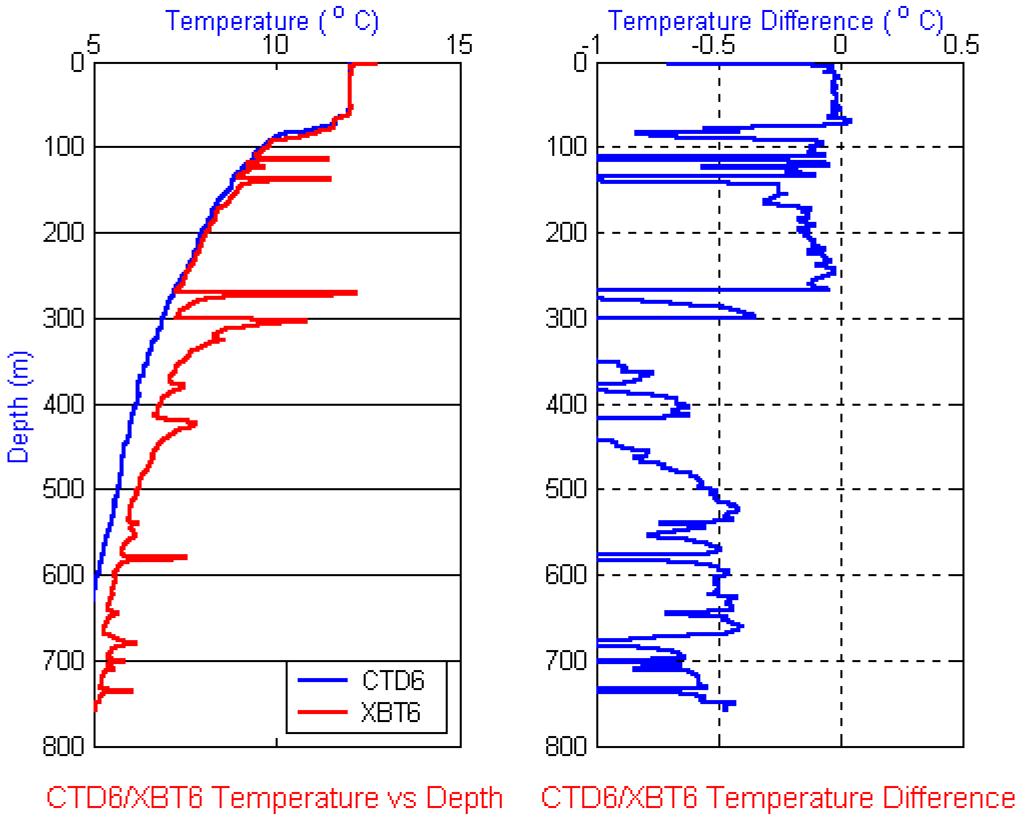
CTD10/XBT10 Temperature Difference



Composite CTD-XBT Temperature Difference and +/- One Standard Deviation

APPENDIX B

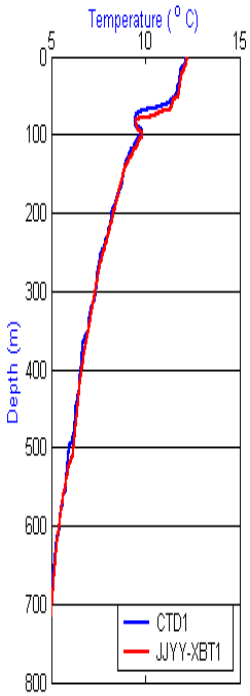
Bad XBT-6 Temperature Profiles and Temperature Difference Plot



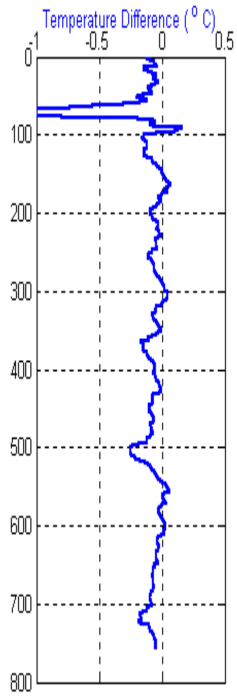
The XBT-6 profile was rejected after quality control revealed numerous flagged points and upon visual inspection. As a result of a bad XBT, all data from XBT-6/CTD-6 was discarded from the data set.

APPENDIX C

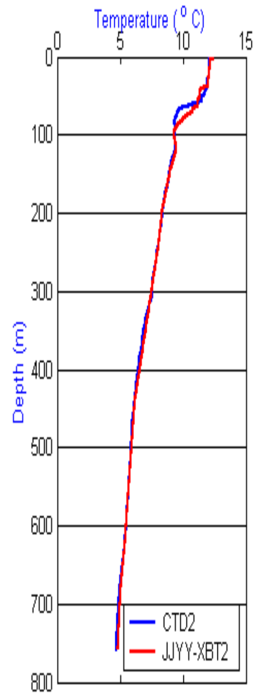
CTD and JJYY-XBT Temperature Profiles and Temperature Difference Plots



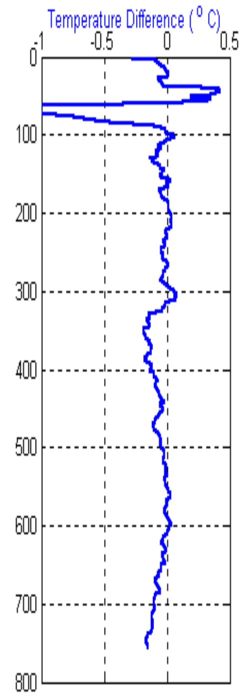
CTD1/JJYY-XBT1 Temperature vs Depth



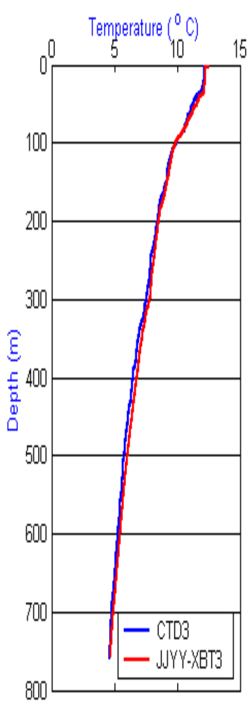
CTD1/JJYY-XBT1 Temperature Difference



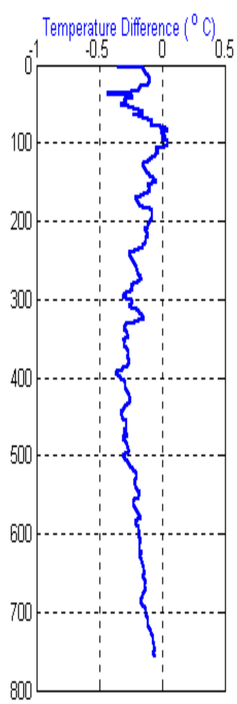
CTD2/JJYY-XBT2 Temperature vs Depth



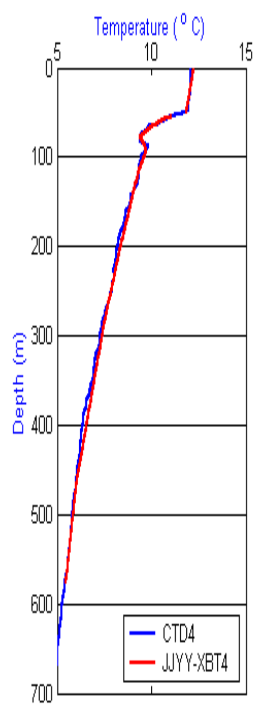
CTD2/JJYY-XBT2 Temperature Difference



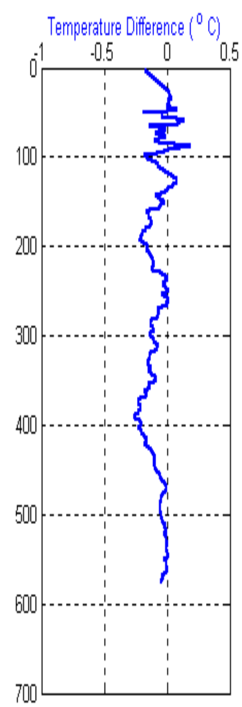
CTD3/JJYY-XBT3 Temperature vs Depth



CTD3/JJYY-XBT3 Temperature Difference



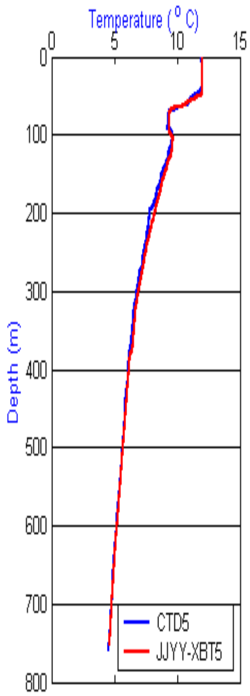
CTD4/JJYY-XBT4 Temperature vs Depth



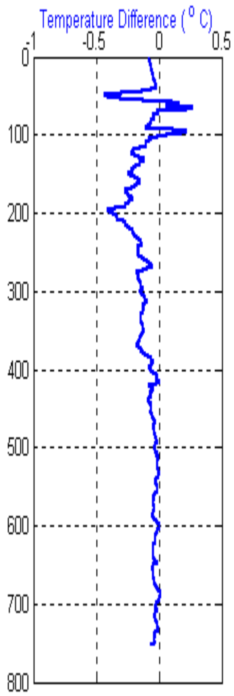
CTD4/JJYY-XBT4 Temperature Difference

APPENDIX C

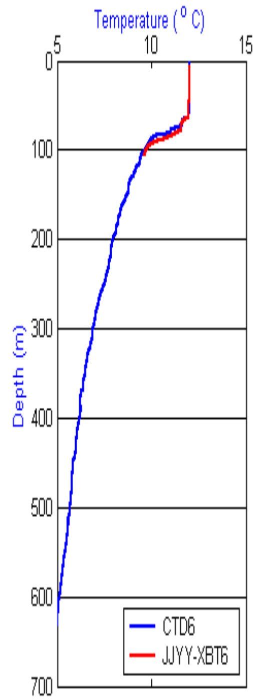
CTD and JJYY-XBT Temperature Profiles and Temperature Difference Plots



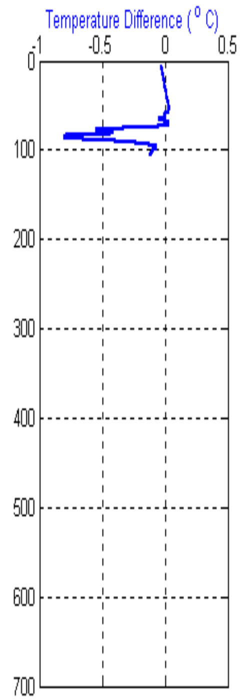
CTD5/JJYY-XBT5 Temperature vs Depth



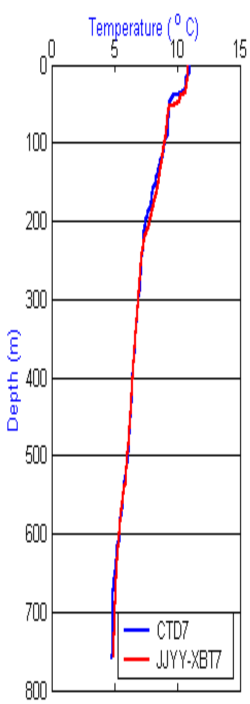
CTD5/JJYY-XBT5 Temperature Difference



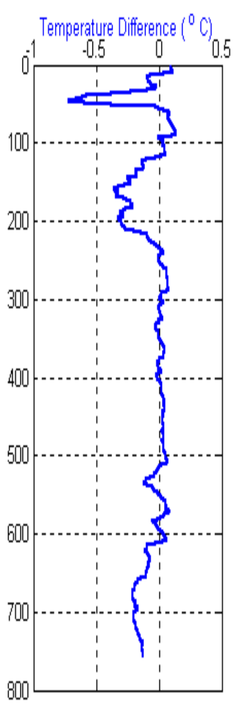
CTD6/JJYY-XBT6 Temperature vs Depth



CTD6/JJYY-XBT6 Temperature Difference



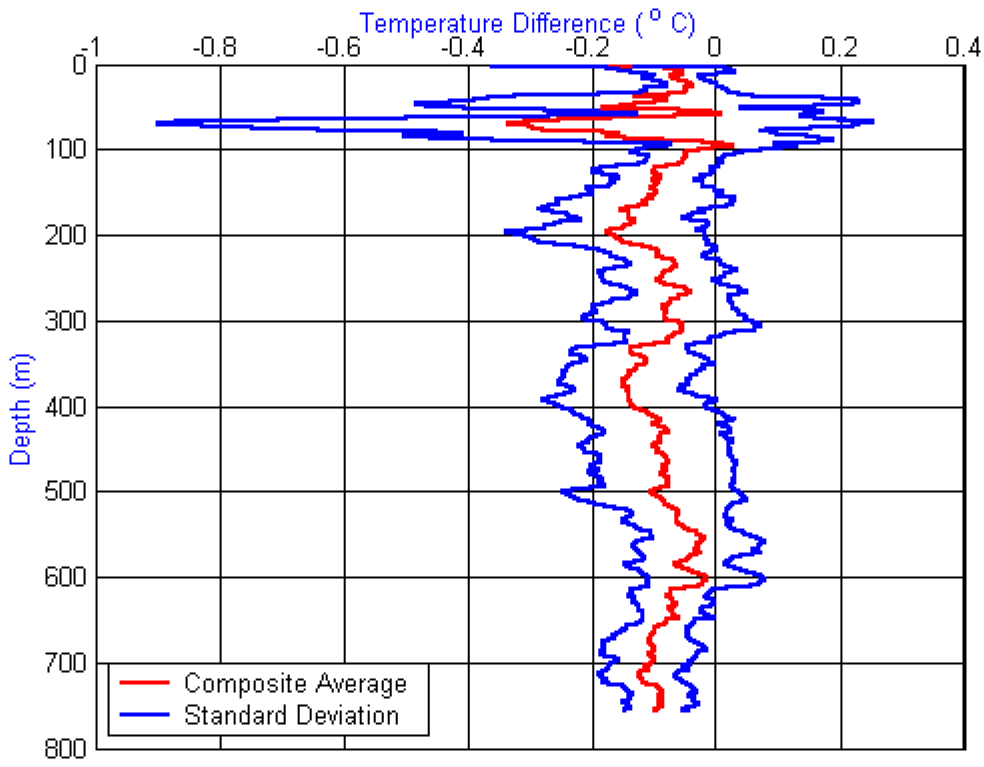
CTD7/JJYY-XBT7 Temperature vs Depth



CTD7/XBT7 Temperature Difference

APPENDIX C

Composite CTD/JJYY-XBT Temperature Difference and Standard Deviation



Composite CTD/JJYY-XBT Temperature Difference and +/- One Standard Deviation

APPENDIX D

Bad XBTs from the from the XBT Profile Analysis of Cruise One

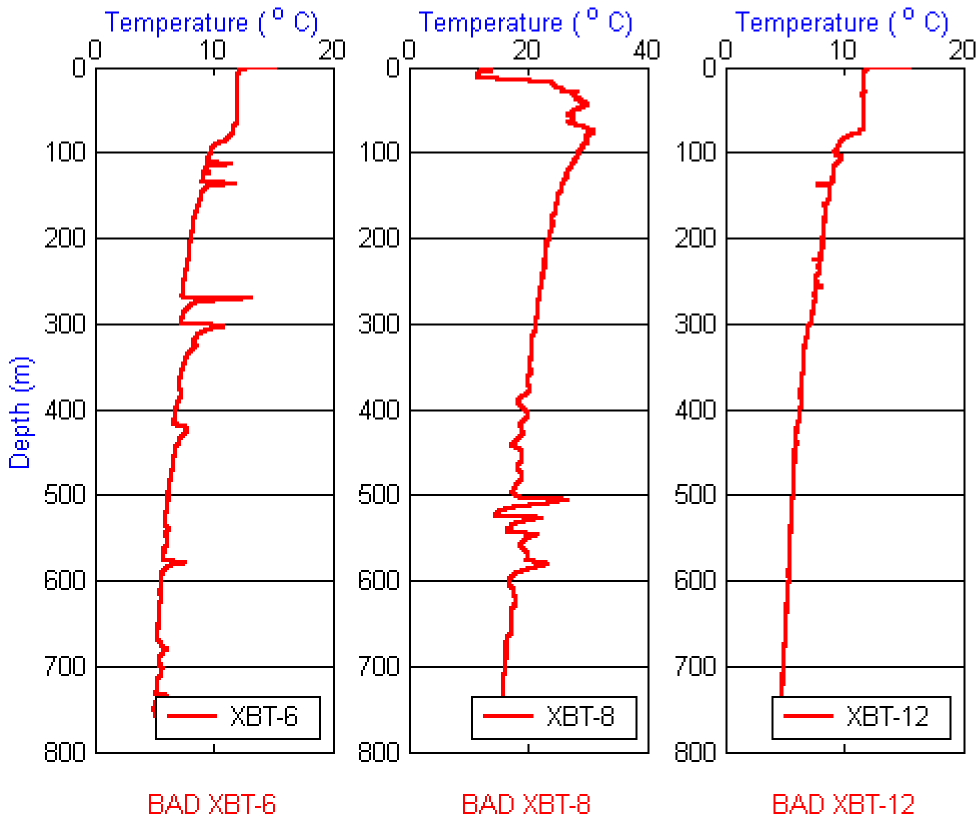


Figure D1. The XBT-6 and XBT-8 profiles were rejected after quality control revealed numerous flagged points and upon visual inspection. As a result of a bad XBT, all data from XBT-6 and XBT-8 were discarded from the data set. XBT-12 was also discarded because the small fluctuations would distort the contour plots.

APPENDIX D

Waterfall plots of the XBTs from Outbound Leg of Cruise One

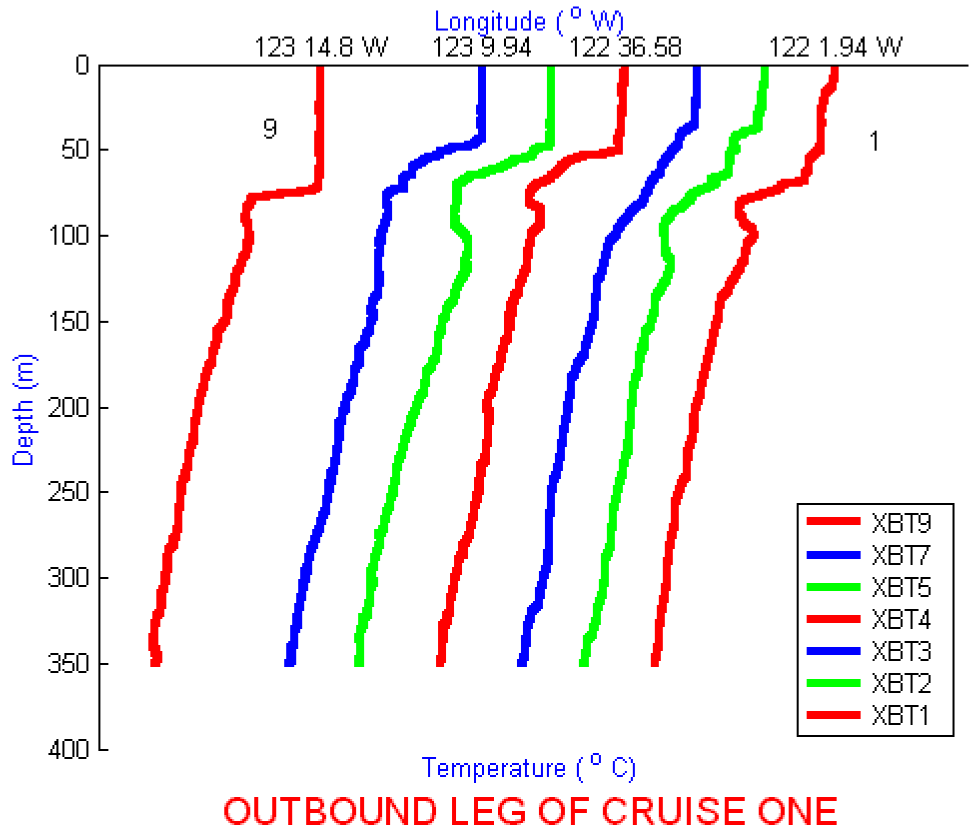


Figure D2. Waterfall plot of the XBT temperature versus depth profiles for the outbound leg of cruise one during the onset of marginal gale force winds. Plot shows easternmost XBTs on the right and western most XBTs on the left.

APPENDIX D

Waterfall plots of the XBTs from Inbound Leg of Cruise One

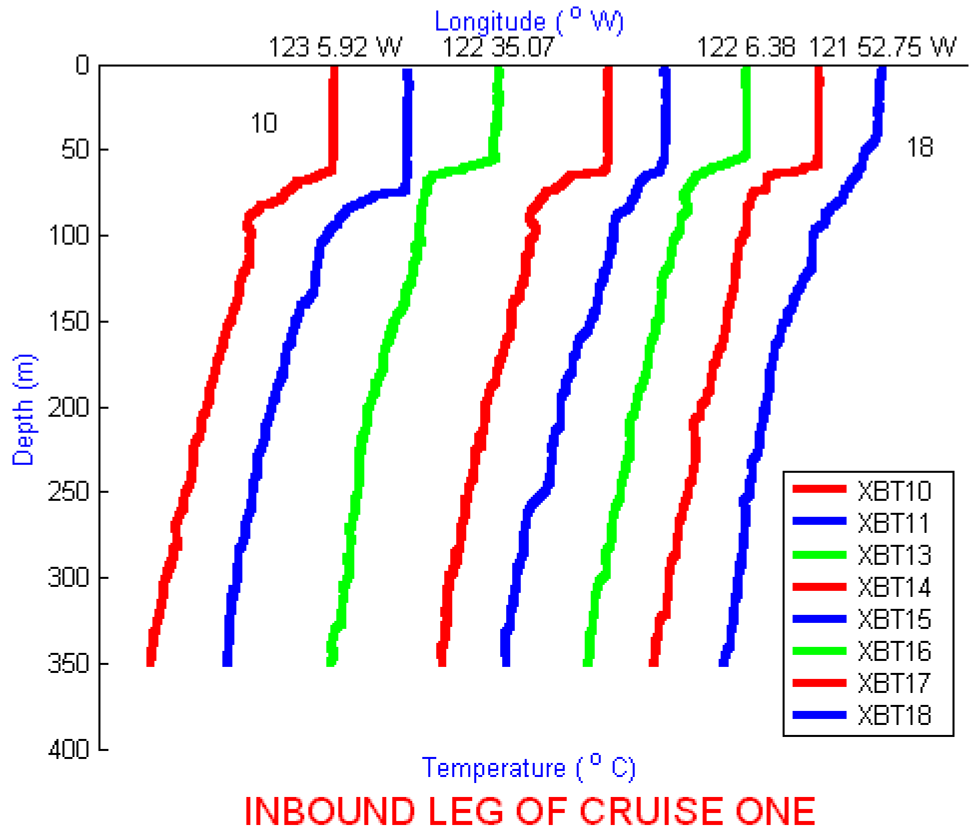


Figure D3. Waterfall plot of the XBT temperature versus depth profiles for the inbound leg of cruise one during the presence of marginal gale force winds which had been sustained for a considerable period of time. Plot shows eastern most XBTs on the right and western most XBTs on the left.

APPENDIX D

Contour plot of the XBTs from Outbound Leg of Cruise One

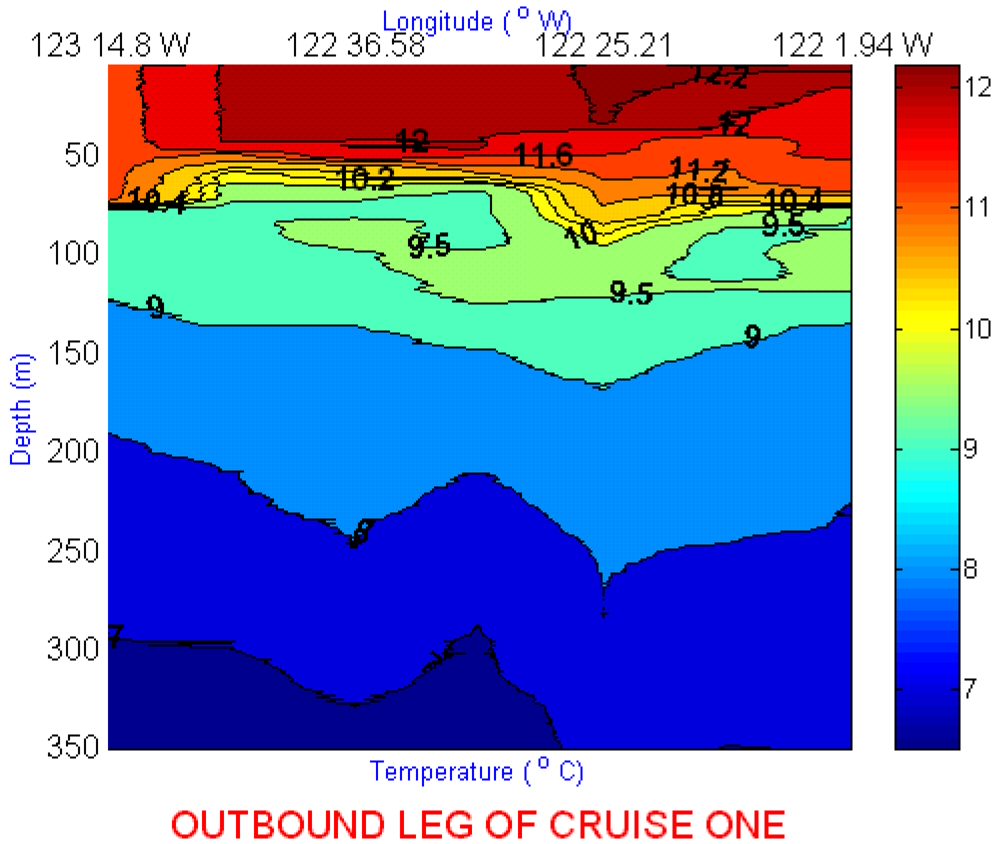


Figure D4. Contour plot of the XBT temperature versus depth profiles for the outbound leg of cruise one during the onset of marginal gale force winds. Plot shows east on the right and west on the left.

APPENDIX D

Contour plot of the XBTs from Inbound Leg of Cruise One

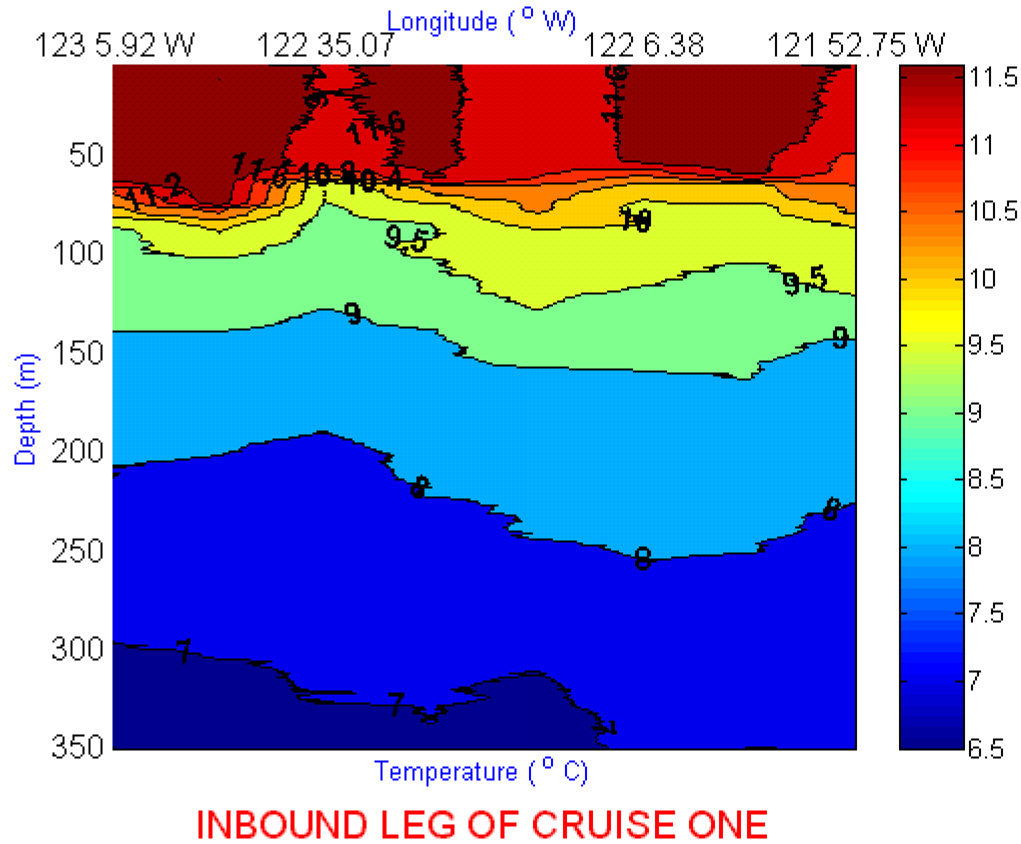


Figure D5. Contour plot of the XBT temperature versus depth profiles for the inbound leg of cruise one during the presence of marginal gale force winds that had been sustained for a considerable period of time. Plot shows east on the right and west on the left.

APPENDIX E

Comparison of Results

	NPS R/V Point Sur February 2001		NPS R/V Point Sur July-August 2000 Schmeiser (2000)		Heinmiller et al. (1983)	
	CTD – XBT Temp. Diff.		CTD – XBT Temp. Diff.		CTD – XBT Temp. Diff.	
Depth (m)	Mean (° C)	Std (° C)	Mean (° C)	Std (° C)	Mean (° C)	Std (° C)
25-125	-0.0907	0.1779	-0.2198	0.3598	-0.17	0.08
250-350	-0.0731	0.0903	-0.1076	0.2194	-0.10	0.10
175-350	-0.0810	0.0951	-0.1171	0.1975	-0.10	0.11
175-375	-0.0851	0.0960	-0.1212	0.1981	-0.13	0.16
Mean	-0.0783	0.1047	-.1549	0.2151	-0.13	0.11

Table E1. Mean and standard deviation of CTD-XBT temperature differences for NPS R/V Point Sur 2001 study, NPS R/V Point Sur 2000 study (Schmeiser 2000), and Heinmiller et al. (1983) study.

	JJYY-XBT/CTD	XBT/CTD
Mean of composite temperature difference (° C)	-0.0924	-0.0783
Mean of composite temperature standard deviation (° C)	0.1073	0.1047
Maximum temperature difference of composite (° C)	0.0258 at 95.2372 m	0.0538 at 91.2698 m
Minimum temperature difference of composite (° C)	-0.3348 at 69.4478 m	-0.2915 at 69.4478 m
Maximum standard deviation of composite (° C)	0.5651 at 69.4478 m	0.5007 at 67.4639 m
Mean of upper 100 m composite temperature difference (° C)	-0.1118	-0.0917
Mean of upper 100 m composite temperature standard deviation (° C)	0.2083	0.1724
Mean of 100 to 758.7792 m composite temperature difference (° C)	-0.0894	-0.0763
Mean of 100 to 758.7792 m composite temperature standard deviation (° C)	0.0921	0.0946

Table E2. Comparison of the outcome of the average mean and average standard deviation of the composite CTD/XBT and CTD/JJYY-XBT temperature differences.