XBT/CTD COMPARISONS

LCDR Chin-lung Fang

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INTRODUCTION

The Naval Postgraduate School OC3570 class completed a two-leg cruise aboard the R/V Point Sur from 15 to 22 July 2002. 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. A Sea-bird CTD and Sippican XBTs (T-4 and T-7) were utilized. These data sets were used to compare temperature measurements between the profiles of the XBTs and CTDs. 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 data files, the mean and standard deviation of CTD/XBT temperature and depth differences at 383 levels between surface and 760 meters were calculated. The results were that T-4 and T-7 XBTs temperature readings were overall 0.0252°C and 0.1074°C warmer than CTD measurements over the whole depth range, respectively. Also T-4 and T-7 XBTs depth readings were, on average, 0.2867 m and 7.3911 m deeper than CTD measurements at all levels, respectively.

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

This report is concluded with a discussion of the impacts of the findings, from both a Naval perspective and a scientific view. XBTs are the primary instrument (T) for developing sound speed profiles in Under Sea Warfare (USW) for the Navy. The affect of a slight warm bias is considered. Likewise, the scientific community uses XBT profiles for climate studies. A link between XBT biases and global warming is explored.

DATA COLLECTION

There were 29 data sets collected from leg one of the cruise. On leg one, XBTs were released immediately after each CTD observation so the pairs were co-located. The locations of the CTD and XBT profiles are included in Appendix A.

The XBT records temperature versus depth in meters, while the CTD records its data with reference to pressure in decibars (dbar). Plots of temperature versus depth were made at the time of each drop. The data was also saved to ASCII files. This study was completed with the data from these ASCII files.

QUALITY CONTROL PROCEDURES

MATLAB 6.0 was used for all data extraction, computations and plotting. 58 ASCII data files (29 CTD and 29 XBT) were edited and loaded into MATLAB. A script-m file was written to extract the depth and temperature data from each file. Each profile was scanned visually and by computer for bad data points. Bad data was rejected, and statistics were performed on the good data.

The first quality control check was to plot the temperature profile of each data set. The goal was to visually identify any bad information. In this manner the XBT-33 profile was seen to be corrupt. The XBT-33 plot is included in Appendix B. There was no indication of how this data file was damaged. The copper wire of the XBT possibly may have made contact with the ship and caused these spikes. Whatever the reason, the data pair of XBT-33/CTD-7 was discarded for lack of accurate digitized temperature readings.

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. In particular, the temperature of each level was compared to the average of the temperatures of the surrounding two levels. If the temperature on a 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 final investigation. For the top and bottom levels, only one level was available for comparison. All previous three studies chose 0.2°C because it was shown to be less than 2 standard deviations of the final statistics, and was, therefore, considered a reasonable criterion. 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 21448 (10724 XBT + 10724 CTD). Of these, 39 CTD (0.36%) and 44 XBT (0.41%) were identified as possibly bad points. Those that were identified were individually inspected and compared to the surrounding data points. 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 the data points (aside from XBT-33/CTD-7) were considered reasonable and consistent, and no further data was excluded.

DATA PROCESSING

Due To the high accuracy and calibration of the Sea-Bird CTD, the CTD temperature measurements were considered to be the true representation of the temperature profile. All comparisons were made comparing the XBT data to the CTD data, and any differences are assumed to reflect inaccuracies in the XBT measurement.

For each CTD cast, temperature were recorded every 2 dbar. It was necessary to convert units from dbar to meters. A formula described by Saunders (1981) was used. Using P in decibars, the conversion to Z in meters is as follows:

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

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

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

The CTD measured pressure in 2 dbar increments for all casts; therefore the only variable between casts was latitude, Φ. The latitude of the casts were between 36 44.16°N and 34 58.33°N. Because of the close latitudinal spacing of the casts a value of 36°N was used for latitude and applied to the conversion for all casts. Using 36°N in place of the actual latitude introduces less than 0.005% error for all depth conversions, and is therefore considered an acceptable practice for this study.

After converting the CTD data sets to temperature versus depth vice pressure, each CTD data set had a temperature sample for approximately every 2 meters of depth. The XBT data was already measured with reference to meters, but the data was recorder in 0.6 meter increments. A MATLAB program was used to linear interpolate the XBT data sets to the CTD measurement depths. A linear interpolation was considered appropriate because of the close vertical spacing of XBT temperature measurements. Following linear interpolation, both CTD and XBT profiles contained 383 levels between about 2m and 760m. Besides, another MATLAB script-m file was used to linear interpolate both XBT and CTD data sets to a set of selected isotherms (from 4°C to 16°C in 0.02°C increments) for the depth comparison later.

For each XBT/CTD pair, the XBT temperature at each depth was subtracted from the CTD temperature and the CTD depth at each isotherm was subtracted from the XBT depth. Three plots were made for each pair. The first contained the temperature profile for each sensor. The second showed the temperature difference at each level. The third showed the isotherm depth difference at each CTD isotherm depth. These plots are shown in Appendix C.

For both the 13 sets of T-4 XBT and the 15 sets of T-7 XBT, temperature and depth differences were combined, and the mean and standard deviation determined by MATLAB for all levels. These statistics are plotted in Figure 1 and 2.

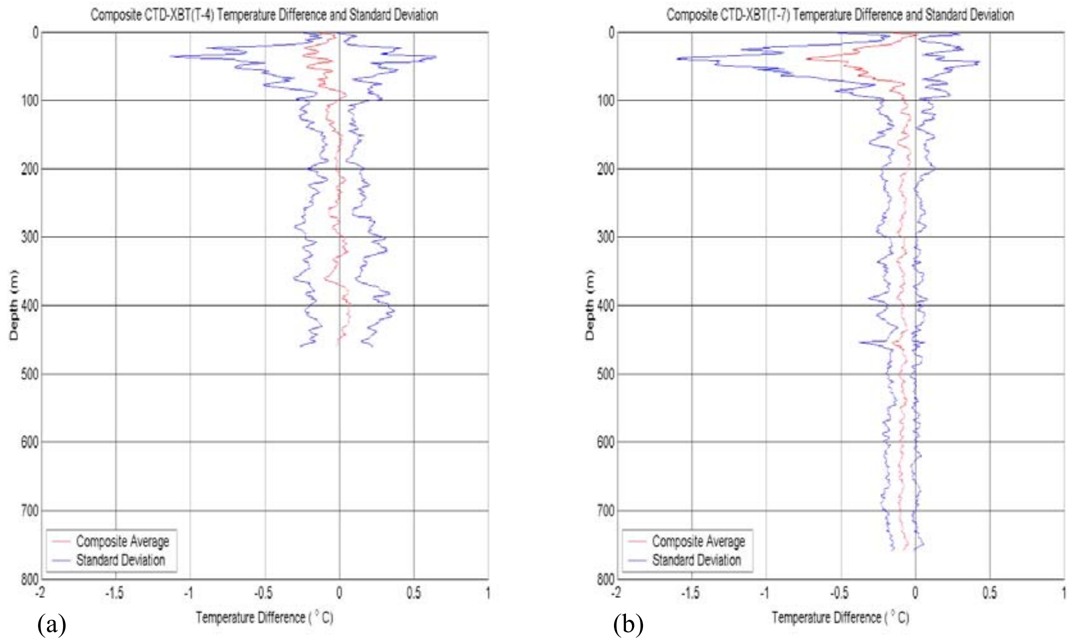

Figure 1*. The mean and standard deviation of (a)CTD-XBT(T-4) (b)CTD-XBT(T-7) temperature differences from the 28 collocated CTD and XBT drops.*

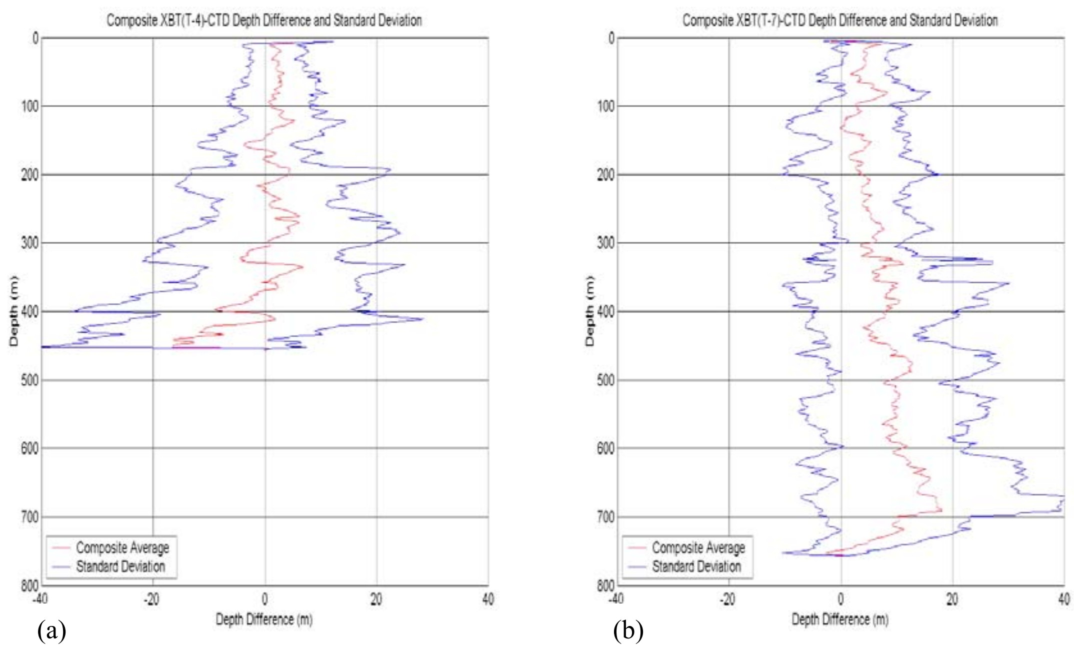

Figure 2*. The mean and standard deviation of (a)XBT(T-4)-CTD (b)XBT(T-7)-CTD depth differences from the 28 collocated CTD and XBT drops.*

FINDINGS

As can be seen from Figure 1, for both types of XBT, the mean temperature difference (red line) is almost negative throughout the range. This indicates that on average, the XBT temperature measurements were higher (warmer) than the CTD measurements for all depths with the exception of several levels of T-4 that are slightly greater than zero.

For T-4 XBT, the greatest average temperature difference occurs in the upper 60 m. The largest temperature differences are between 20 and 50 m with a maximum of 0.2441°C at 34 m depth. The standard deviation at 36 m was a maximum, 0.8919°C. Below 50 m, the average temperature difference was only 0.0131°C warmer than the CTD measurement meaning the XBT readings were very closer to the CTD readings. But the standard deviation below 50m was 0.2050°C, nearly twice the value of T-7 XBT (0.1147°C).

For T-7 XBT, the greatest average temperature difference occurs in the upper 80m. The upper 80m also had the greatest standard deviation. However, a closer analysis of the data shows that the average temperature difference in the upper 20 m was only 0.1114°C with a standard deviation of 0.2516°C. The largest temperature differences are between

20 and 60 m with a maximum of 0.7331°C at 40 m depth. The standard deviation at 44 m was a maximum, 0.8863°C. Below 80 m, the average temperature difference was less than 0.08°C and was generally decreasing with depth meaning the XBT readings were closer to the CTD readings. The standard deviation below 80m was 0.1147°C and also generally decreased with depth with a minimum of 0.07°C near 756 m.

From Figure 2, for T-4 XBT, the mean depth difference (red line) is positive in the upper 150 m and back and forth between positive and negative value below 150 m with the exception of the levels of the last 50 m depth that are decreasing across zero to negative value. This indicates that the XBT depth measurements were slightly higher (deeper) than the CTD measurements in the upper 150 m and almost no difference below 150 m except the last 50 m depth. The average depth difference was only 0.2867 m deeper than the CTD measurement with a standard deviation of 12.9654 m throughout the range.

For T-7 XBT, the mean depth difference is positive throughout the range. This indicates that on average, the XBT depth measurements were higher (deeper) than the CTD measurements for all depths with the exception of the levels of the last 50 m depth that are decreasing across zero. The greatest average depth difference occurs between 600 and 700 m with a maximum of 18.12 m at 690 meters depth. The standard deviation at 672 m was a maximum, 24.2 m. The average depth difference was 7.3911 m deeper than the CTD measurement with a standard deviation of 11.1775 m throughout the range.

It should be noted that the large magnitude of the temperature differences were occurred in the upper levels. Because of the large vertical temperature gradients in the upper levels it demonstrate that many of the apparent temperature differences are, in reality, depth differences. Therefore, if the depth difference exists, the stronger temperature gradients the larger temperature differences.

COMPARISON WITH PREVIOUS STUDIES

A similar study was published in 1983 by Heinmiller et al. Heinmiller et al. studies both Sippican T-4 and T-7 XBTs and used a calibrated Neil Brown CTD. The portion of the Heinmiller et al. study comparing the T-7 XBT to the CTD was conducted in the Sargasso Sea and consisted of 139 casts.

Also, Three previous OC3570 similar studies of CTD and XBT profiles have been performed by Boedeker (2001), Roth (2001) and Schmeiser (2000). Boedeker’s, Roth’s and Schmeiser’s study compared 27, 9 and 18 CTD/XBT pairs respectively. This study performed statistics on 28 pairs. All compared Sippican T-7 (also T-4 in this study) XBT’s to a Sea-Bird CTD on board the R/V Point Sur along the central Californian coast.

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).

In this study, as in Boedeker (2001) and 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. Since the XBT sampling interval is so small, quality control after interpolation will have little effect on the outcome of the quality control (Roth, 2001).

Table 1 is a summary of the significant findings of the four studies. As can be seen in Table 1, the results of this study are very similar to results from the three previous studies. All 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 both Schmeiser’s and Boedeker’s studies but the difference is less dramatic in Roth’s study.

Studies	Depth(m)	Mean(°C)	Std(°C)
Schmeiser 08/2000	25-125	-0.2198	0.3598
	175-375	-0.1212	0.1981
	0-760	-0.1549	0.2151
Roth 02/2001	25-125	-0.0907	0.1779
	175-375	-0.0851	0.0960
	0-760	-0.0783	0.1047
Boedeker 08/2001	25-125	-0.1530	0.5135
	175-375	-0.0549	0.2157
	0-760	-0.0882	0.2147
Fang 07/2002	25-125	-0.2453	0.4123
	175-375	-0.0802	0.1172
	0-760	-0.1074	0.1546

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

The greatest standard deviations also occur in the upper levels. The standard deviation of the 25-125m level is roughly 2-3 times the value of the overall standard deviation.

DISCUSSION

Leg one of the NPS OC3570 cruise aboard the R/V Point Sur collected CTD and XBT temperature profiles at 29 locations. One of these pairs was not used in the statistics due to bad XBT data, and the study was conducted with the remaining 28 pairs.

Both temperature and depth differences were calculated between the CTD and XBT for each pair at 383 levels between 2 and 760 meters. A mean difference and standard deviation was then computed for the 28 pairs. The statistics indicated that the average standard deviation for T-4 XBTs was almost twice the value for T-7 XBTs. Also, the results showed a warm bias in the both types of XBT temperature measurements for the entire range and demonstrated a deep bias in the T-7 XBT for the entire range except the last 50 m depth. No significant depth differences were found for T-4 XBT. The greatest temperature differences were occurred in the upper 80 meters. This was also a trend in the three previous studies.

The following is a simple formularized relation among the effects of the temperature gradient, depth difference and temperature difference. That is :

Effects of ∇T (dominant term) * Effects of Depth diff.

= Effects on Temp diff.

If the temperature gradient (or depth difference) does not exist, we could expect that no temperature difference will occur. But, if the temperature gradient (and depth difference) does exist, even though the value is small, we could still expect that obvious temperature difference will occur.

The Navy uses the temperature profile from XBTs to determine the sound speed profile for Under-Sea Warfare (USW) applications. From a Naval standpoint, these temperature differences are almost insignificant. A general rule of thumb is that a 1°C increase in temperature will increase the sound speed by 4 m/s. 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 0.0252°C and 0.1074°C, for T-4 and T-7 XBT respectively, would have an even smaller impact. Additionally, 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. Although the sound speeds may be slightly higher, the sound speed gradients will not be appreciably affected. Therefore, the XBT measurements should not impose any operational problems to the acoustic, and in turn, the anti-submarine warfare problem.

While not posing a problem in an operational use, the consistent warm bias could negatively impact climate studies. 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.

Finally, 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. In order to generalize the results, different batches of XBTs should also be used if possible.

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