Field Evaluation of Real-Time XBT Systems

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INTRODUCTION

The use of XBT's to measure the ocean's subsurface temperature has significantly increased over the past decade. NOAA is actively participating in an international effort to increase the number of subsurface temperature observations in support of global oceanographic and climate studies. NOAA's XBT program currently supports more than one hundred voluntary observing ships (VOS). These vessels are responsible for more than 12,000 XBT observations each year. Determining the field performance of XBT data systems is an importance step in the quality control of these data. The purpose of this field test was to evaluate the performance of four XBT systems under field conditions. The systems evaluated were a SEAS III (Sippican's MK-9), a Bathy Systems' 810 XBT Controller, an ARGOS XBT system, and Oregon State University's (OSU) XBT Data Box. In addition, the capability of both the ARGOS and GOES satellite systems to transmit XBT data in the JJXX format were evaluated. The SEAS III and ARGOS systems were used to evaluate the satellite transmission process for GOES and ARGOS respectively.

METHODS AND PROCEDURES

All XBT data were evaluated relative to a field standard. The field standard used was a Neil-Brown Instrument Systems Mark III CTD. Each XBT system and the Neil-Brown CTD were calibrated before and after the test. A decade box and XBT test canister were used to evaluate the XBT systems over a range of eleven resistance (temperature) values. The results of the XBT calibration check are presented in Table 1. Initially the OSU system failed the calibration test at temperatures below 5 degrees Celsius. The system was returned to the manufacturer for adjustments. The values from the OSU system in Table 1 were taken from a second calibration check of the OSU system after adjustments were made by the manufacturer.

The XBT Field Evaluation took place on board the NOAA Ship WHITING during July 1988. The WHITING was participating in studies of the current and water mass structure in the Southwestern North Atlantic Ocean in the context of the Subtropical Atlantic Climate Studies (STACS) Program. The evaluation occurred during the Barbados-Barbados leg of the cruise when thirty-three CTD casts were taken. Station locations are shown in Figure 1. During each CTD cast, two XBT's were released from each system. One was released during the descent of the CTD and one was released during the ascent of the CTD. Each XBT system was set up for an XBT drop prior to the descent of the CTD. To minimize the influence of internal waves, XBT's were released from each system at the same time when the CTD was located in the thermocline. Similar procedures were repeated during the ascent of the CTD. XBT's released during the ascent of the CTD were used to help indicate the temporal variability of the thermal structure while on station. Only XBT's released during the descent of the CTD were used for the XBT-CTD comparison. A total of 250 XBT's were released during the evaluation. Of these, 126 were released during the descent of the CTD. Table 2 presents the total number and type of XBT probe released for each system during the descent of the CTD. No T-5 or T-10 probes were used with the OSU and ARGOS system since these systems were not programmed with the corresponding depth coefficients.

Table 1. XBT SYSTEM CALIBRATION CHECK
(Temperature in Degrees Celsius)

		XBT System Temp - Calibration temp			
Resistance	(Calibration Temp)	MK-9	BATHY	OSU	ARGOS
3193	(35.55)	0.00	-0.06	-0.05	**N/A
3350	(34.44)	-0.05	0.08	-0.08	**N/A
4024	(30.00)	0.02	0.13	-0.01	-0.03
5000	(25.00)	-0.01	0.08	-0.04	-0.06
6247	(20.00)	0.00	0.06	-0.05	-0.06
7274	(16.66)	0.01	0.05	-0.05	-0.06
9948	(10.00)	0.02	0.04	-0.05	-0.06
12679	(5.00)	0.03	0.04	-0.02	-0.03
16329	(0.00)	0.01	0.00	-0.05	-0.06
17287	(-1.10)	0.00	0.01	-0.06	-0.07
18094	(-2.00)	0.01	0.00	-0.04	-0.05

** - The ARGOS system does not handle temperatures in these two ranges.

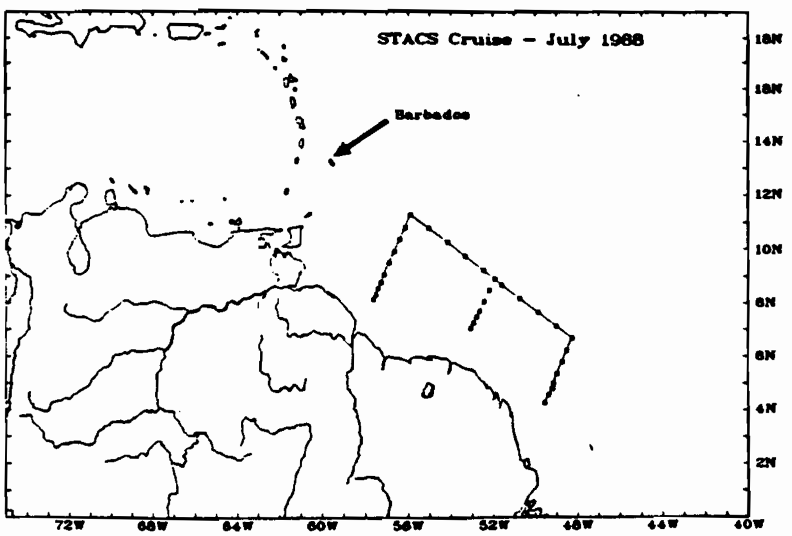

Figure 1. Cruise Track and XBT/CTD Stations

Table 2. PROBE TYPE AND NUMBER RELEASED FOR EACH XBT SYSTEM DURING DESCENT OF CTD

PROBE TYPE	MK-9	BATHY	OSU	ARGOS
T-10	7	7	0	0
T-7	7	7	7	7
T-6	7	7	15	15
T-5	5	5	0	0
T-4	7	7	8	8

Out of the 250 XBT's released, there were a total of five probe failures (2%). A summary of common XBT malfunctions is presented in Kroner and Blumenthal, 1978. The BATHY system had one probe failure, while the OSU and ARGOS systems each had two probe failures. Five software/system crashes occurred with the OSU system. These failures were attributed to incompatibility between the OSU software and the PC clone (televideo XL computer) used. All XBT data collected by the SEAS III and the ARGOS systems were transmitted in real-time contingent on available space in the satellite transmission window.

Before comparing the XBT data to the CTD data, XBT depth-temperature pairs were computed using a linear interpolation scheme so as to have the XBT depth coincide with the CTD depth. Except for the profile plots comparing the XBT and CTD traces, analysis was based on the interpolated XBT data.

RESULTS

Several factors must be considered in the evaluation of XBT - CTD temperature comparisons. Some of the important factors are the methods used to determine the depth of the XBT and the CTD, thermistor errors, and environmental factors such as the stability of the water column. Differences between a temperature measured by the CTD and an XBT can in part be attributed to the computation of the XBT probe depth. The depth of the XBT is determined by using a depth equation based on the fall rate of the probe, while the CTD depth is measured using a pressure transducer. In addition, the XBT descends at a faster rate than the CTD (6.5 m/sec, XBT; 0.5 m/sec, CTD). The XBT and CTD will therefore measure temperature simultaneously at the same depth and time only once. Any changes in the thermal structure of the water column during the descent of the CTD due to internal waves will appear as a temperature difference between the CTD and XBT. Temperature differences between an XBT system and the CTD can also be attributed to the individual thermistor in each XBT probe. While each XBT system and the CTD thermistor were calibrated, the actual thermistor in each XBT probe were not.

The mean of the absolute temperature difference between the CTD and each XBT system over the total XBT profile for each probe type is provided in Table 3. These results show differences greater than the +/- 0.15 degree Celsius specification for XBT probes. To interpret these results it is important to identify the factors which contribute to these differences between the XBT and CTD measurements.

Table 3. MEAN OF THE ABSOLUTE DIFFERENCE BETWEEN THE XBT AND CTD TEMPERATURE (Degrees Celsius)

	Probe Type									
SYSTEM	T-04		T-05		T-06		T-07		T-10	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD	Mean	SD
MK-9	.36	.14	.11	.06	.33	.13	.34	.24	.30	.21
BATHY	.30	.15	.24	.17	.26	.11	.30	.19	.33	.18
OSU	.19	.19			.14	.06	.18	.07		
ARGOS	.38	.22			.39	.11	.42	.33		

To isolate the contributions of the XBT thermistor error to the results shown in Table 3, temperature differences in the isothermal portion of the mixed layers were analyzed. This was done because temperature differences due to depth errors, instrument response, and internal waves would be minimized by these conditions. Thus, as shown in Table 4, when comparing only temperatures in the isothermal portion of the mixed layers, the temperature difference between the CTD and all four systems was reduced by an order of magnitude. The mean departure of the XBT temperature from that of the CTD is well within the XBT specifications. These results also agree well with the XBT system calibration check in Table 1.

Table 4. MEAN TEMPERATURE DIFFERENCES BETWEEN THE XBT AND CTD IN THE MIXED LAYERS (DEGREES CELSIUS)

SYSTEM	MEAN	STANDARD DEVIATION
MK-9	.029	.046
BATHY	.106	.064
OSU	-.074	.083
ARGOS	.016	.055

Errors in XBT depth can also contribute to the differences found between the XBT and CTD temperatures. The temperature profiles in Figure 2 show a depth offset between the XBT and CTD data. To determine the associated XBT temperature error due to an offset in XBT depth, the XBT data was shifted in depth to find a best fit with the CTD data. A best fit of the XBT profile to the CTD was found by shifting the XBT data in 50 meter segments by one-meter increments up and down until the least mean difference between the XBT and CTD temperatures was determined. The depth error was then

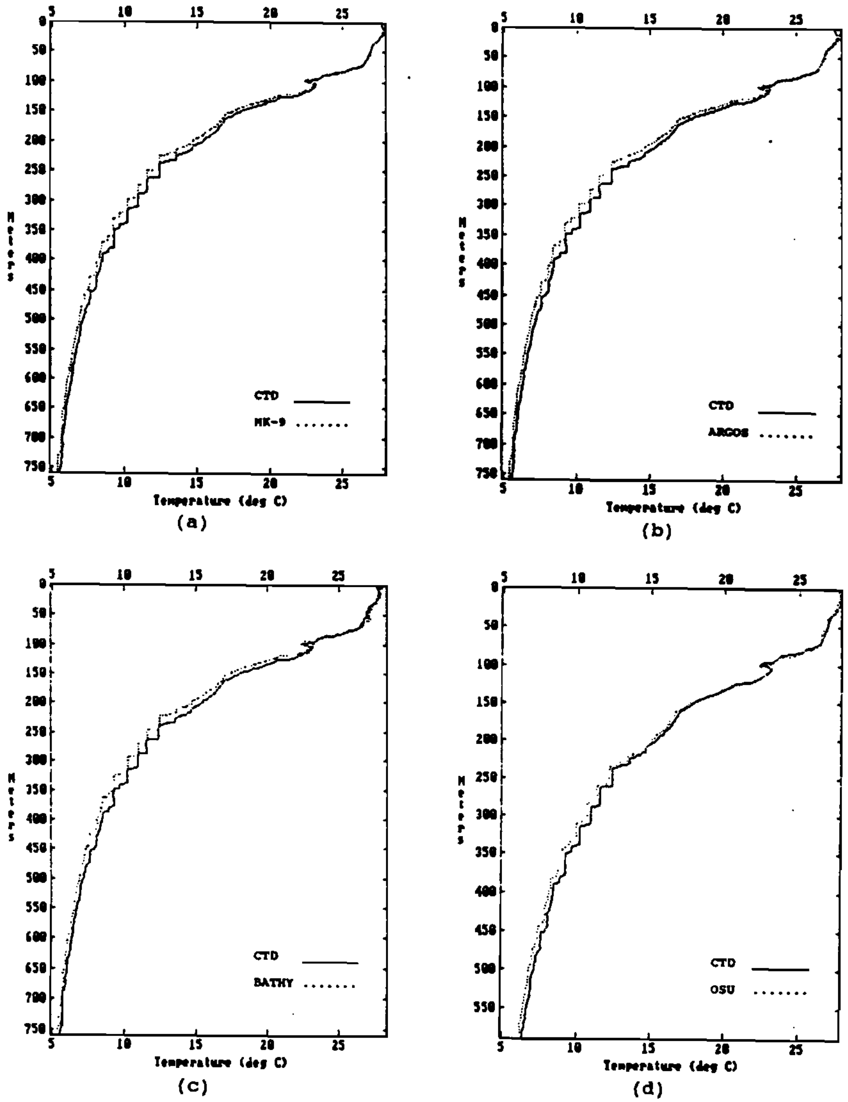

Figure 2. XBT - CTD Temperature Profiles, XBT Drop 25.
(a) MK-9 (b) ARGOS (c) BATHY (d) OSU

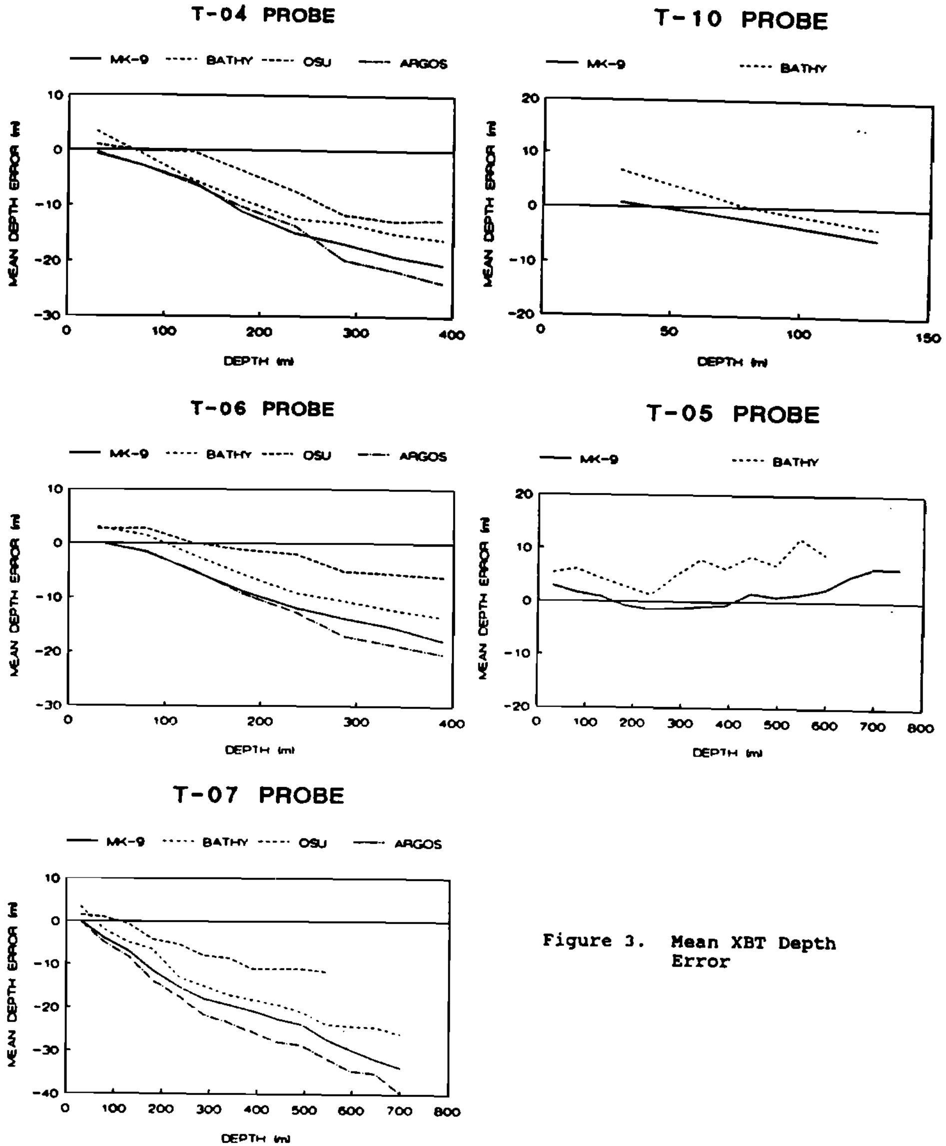

Figure 3. Mean XBT Depth Error

computed from how many meters the original XBT data was moved to best fit the CTD data. Table 5 provides a sample output from this analysis. As is shown in Table 5, by shifting the XBT depth the temperature difference between the XBT and CTD can be reduced by an order of magnitude. The mean temperature difference with a depth correction agrees well with the temperature difference found in the mixed layers and those from the calibration check.

For each of the XBT systems, the mean depth error in 50 meter segments is shown in Figure 3 by probe type. While there appears to be some bias between different XBT systems, it is important to note that for all the XBT systems the depth error for probe types T-4, T-6, and T-7 show a similar trend. This trend indicates that these XBT probe types are falling at a faster rate than calculated by the XBT depth equation, using the standard coefficients. The standard depth equation and coefficients are provided in Table 6 (Sippican, 1973). Similarly, the T-10 probes are falling at a faster rate, while the T-5 probes are falling at the proper rate. The OSU system depth error, as shown in Figure 3, was less than the other systems. This resulted in a smaller temperature difference from the CTD data as was indicated in Table 3.

Table 5. BEST-FIT ANALYSIS

System type: MK-9 Drop Number 27 Probe Type T-07

Depth Range (meters)	Depth Error (meters)	Mean Temp. Error w/ Depth Corrected (C)	Mean Temp. Error w/ Depth Uncorr. (C)
5.0 to 52.7	- 0.99	0.05 +/- 0.03	0.07 +/- 0.04
56.7 to 104.4	- 3.98	0.09 +/- 0.05	0.45 +/- 0.10
108.4 to 156.1	- 6.96	0.11 +/- 0.07	0.63 +/- 0.08
160.0 to 207.7	-10.93	0.05 +/- 0.05	0.62 +/- 0.10
211.7 to 259.4	-17.88	0.04 +/- 0.04	0.68 +/- 0.14
263.4 to 311.0	-19.86	0.02 +/- 0.03	0.49 +/- 0.10
315.0 to 362.7	-21.84	0.03 +/- 0.02	0.37 +/- 0.12
366.6 to 414.3	-24.82	0.03 +/- 0.02	0.48 +/- 0.07
418.2 to 465.9	-27.79	0.04 +/- 0.02	0.32 +/- 0.07
469.8 to 517.5	-30.76	0.04 +/- 0.02	0.32 +/- 0.03
521.4 to 569.0	-33.73	0.04 +/- 0.02	0.35 +/- 0.04
573.0 to 620.6	-41.65	0.03 +/- 0.02	0.35 +/- 0.02
624.6 to 672.2	-48.58	0.01 +/- 0.02	0.31 +/- 0.02
676.1 to 723.7	-49.56	0.03 +/- 0.02	0.22 +/- 0.02

Table 6. STANDARD FORM OF THE DROP EQUATION

Probe type	Coefficients A	Coefficients B
T-4	6.472	.00216
T-5	6.828	.00182
T-6	6.472	.00216
T-7	6.472	.00216
T-10	6.301	.00216

$$\text{Depth} = A*T - B*T^2 \quad \text{(meters)}$$

T= sample rate * sample no.

To determine if the XBT depth for the T-4, T-6, and T-7 probes could be corrected by modifying the coefficient in the depth equation, a regression analysis was employed to revise the coefficients using the MK-9 data. This was accomplished by first calculating what the sample interval would have to be to provide the correct depth as determined by the best fit analysis. This sample interval was found to be 0.105 seconds. The actual MK-9 sample interval is 0.1 seconds. The revised coefficients A' and B' were then determined by the following method:

$$A' = (6.472 * 0.105) / 0.1 = 6.796$$

$$B' = (0.00216 * (0.105)^2) / 0.01 = 0.00238$$

New temperature and depth pairs for the T-4, T-6, and T-7 probes using the revised coefficients were then computed. Scatter plots comparing the XBT and CTD using the standard and revised coefficients are presented in Figure 4. As shown in these plots the revised coefficients improve the agreement between the XBT and CTD temperature data. Using the same revised coefficients, the ARGOS and BATHY data had similar results. The temperature profiles that were shown in Figure 2 are replotted in Figure 5 using the revised coefficients. Most of the temperature errors associated with the depth offset (previously characterized by the temperature profiles in Figure 2) are now reduced or eliminated. The exception is the OSU XBT data which has better agreement with the CTD data using the standard coefficients.

To determine the temporal variability of the water column during the XBT-CTD comparison, XBT's were launched from each system during the ascent of the CTD. This provided a measure of the variability on the scale of one hour. Any variability on this time scale is likely a result of internal waves. While a few stations exhibited variability in the thermocline of about 10 meters, typically the variability was less than 2 meters. To quantitatively determine the influence of internal waves on the CTD - XBT comparison, several more XBT drops are required during the descent of the CTD. Although variability of the water column due to internal waves can influence the comparison between the XBT and CTD, it should be minimal since it takes approximately 16 minutes for the CTD to reach 500 meters.

The real-time transmission of XBT data is crucial to the optimum utilization of these data sets by the oceanographic and climatological communities. The alternative is retrospective data submission to national data archives which historically can take months, years or even worse never. During the field test the ARGOS and GOES satellite systems were evaluated for their XBT data transmission capability using the SEAS III and ARGOS XBT systems, respectively. For both these systems, data received was disseminated to the community on the Global Telecommunication System (GTS).

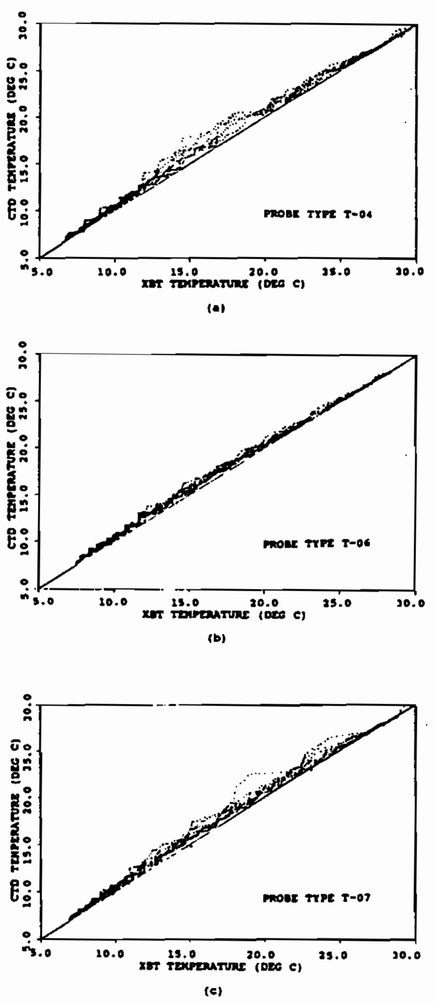

Figure 4. Scatter Plots of MK-9 XBT Data vs. Ctd Data
(a-c) Standard Depth Coefficients
(d-f) Revised Depth Coefficients

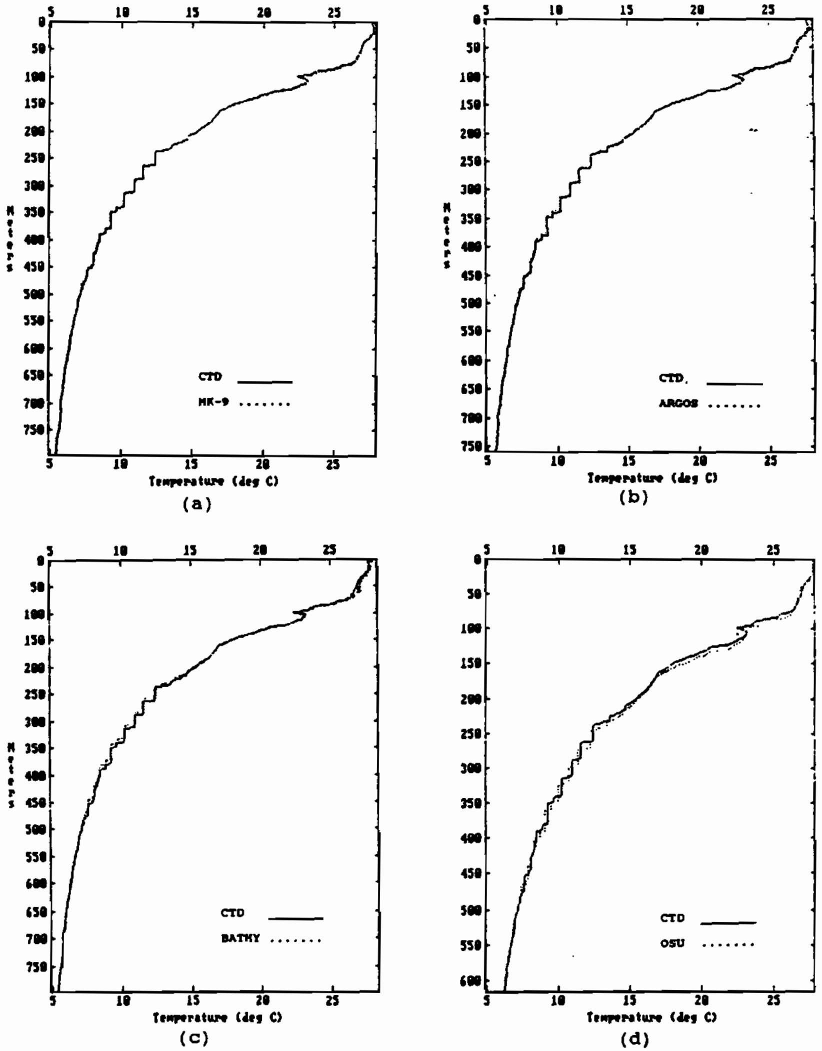

Figure 5. XBT -CTD Temperature Profiles, XBT Drop 25
with Revised Depth Coefficients.
(a) MK-9 (b) ARGOS (c) BATHY (d) OSU

Table 7 summarizes the results from evaluating the real-time data transmissions. Of the 60 XBT's dropped using the ARGOS XBT system, 48 XBT messages were transmitted. Ten were not transmitted because of the 15 iteration limit, imposed by the software in version 1.0, to compute the 15 inflection points. This limitation has been corrected in version 2.0. Two XBT messages were not transmitted because of faulty probes. The high launch frequency, sometimes generating a message every hour, resulted in 11 of the 48 messages not being generated into GTS bulletins. The bulletins were not generated because of the required two transmission receptions not being received. This should not be considered a limitation of the system since most oceanographic surveys do not require the high XBT launch frequency used during this field test. Of the 65 XBT's dropped using the SEAS III system, 58 XBT messages were transmitted and entered onto the GTS. Seven of the XBT drops were not transmitted because of the high frequency of XBT launches. The XBT buffer in the GOES transmitter allows for 3 XBT messages. Since the GOES satellite assignment permitted a transmission every 4 hours, the XBT transmitter rejected seven XBT drops. Again, most oceanographic surveys do not require this high frequency of XBT launches. If necessary, the data can be stored on floppy disk and transmitted at a later time.

TABLE 7 SUMMARY OF REAL-TIME DATA TRANSMISSION

SYSTEM	XBT's DROPPED	TRANSMISSION STATUS	DATA DISSEMINATION STATUS
ARGOS	60	Transmitted - 48	Data Bulletins - 37
		Not Transmitted - 10 (1)	Not Disseminated - 11 (3)
		Not Transmitted - 2 (2)	
SEAS III	65	Transmitted - 58	Data Bulletins - 58
		Not Transmitted - 7 (3)	

(1) Ten XBT messages not generated because criteria for obtaining 15 inflections points were too strict. This limitation is corrected in latest software, Version 2.0.

(2) Two XBT messages not generated because of XBT probe failure.

(3) Eleven from the ARGOS XBT system and 7 from the SEAS III system were neither transmitted or disseminated in real-time because of the high launch frequency during field evaluation.

SUMMARY

This field test evaluated both the performance of XBT systems under field conditions and the capability of the ARGOS and GOES satellite systems to transmit XBT data in the JJXX format. Results show that the mean temperature differences between the CTD and each XBT system over the total XBT profile were greater than the +/- 0.15 degrees Celsius specification for XBT probes. In the isothermal portion of the mixed layer where the temperature differences between the XBT and CTD are minimized due to depth, instrument response, and internal waves, the temperature differences between the XBT's and CTD were reduced by an order of magnitude. From these results, it was determined that temperature error due to the XBT's thermistor is small. The major contributing factor for the differences in temperature is an error in the computation of the XBT probe depth. The error in depth for the T-4, T-6, and T-7 probe types was found to be greater than allowable by the manufacturer's specifications (+/- 5 meters or +/- 2% of depth, whichever is greater). It was determined that these probes are falling at a faster rate than calculated by the standard coefficient of the drop equation. This depth error has been previously identified by Heinmiller et al.(1983) and Seaver and Kuleshov (1982). The depth errors can be reduced by revising the coefficients in the depth equation. While all XBT systems indicated a depth error, there was a system bias among the systems, some showing a greater error than others. This bias among system requires further analysis. Transmission results demonstrated that both ARGOS and GOES satellite based XBT systems provided adequate capability to transmit data in real-time. Together, ARGOS and GOES provide the necessary data communications for a global ocean observation program.

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