



Mediterranean Forecasting System:
Toward Environmental Predictions

Work Package 1 Voluntary Observing Ships

Comparison between quasi-contemporaneous and co-located CTD
and XBT measurements.

Sono passati diciotto anni da quando cominciai a disegnare La ballata del mare salato, ma ne sono passati molti di più da quando iniziai a leggere Henry de Vere Stackpoole, scrittore poco conosciuto recuperato dalla «romantica» Sanzognò, una collana di letteratura popolare italiana. Figlio di un prete, nacque a Dablon, studiò medicina e fu anche giudice di pace per casi minori. Fece tutto malvolentieri, ma riuscì a scrivere una buona novella nel 1909: La laguna azzurra. È la storia di due ragazzi che non sapevano di dover morire e di un vecchio marinaio ubriaccone che lo sapeva benissimo. Fu questo scrittore, e non Robert Louis Stevenson, non Conrad e neppure Melville, che per primo mi fece amare i mari del Sud. È a lui che dedico questa ballata, dove appare per la prima volta Corto Maltese il marinaio.

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Paragraph	Title	Page
1	Introduction	5
2	Data collection and processes	5
3	Comparison with recent studies	7
4	Conclusions and future applications	10
	Acknowledgements	11

Comparison between quasi-contemporaneous and co-located CTD and XBT measurements.

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Abstract

In this note, a comparison between quasi-coincident in time and in position seawater temperature measurements as collected by different types of XBT probes and CTDs is done. The systematic error is computed and an improved use of XBTs is checked. From the analysis of the data collected for this study, it seems that XBTs exhibit a "systematic" difference of higher temperature readings. Two different hypotheses were analysed looking for a possible solution to this problem:

- 1. intrinsic electronic properties of XBT + card system, and then a necessity to update this part of the Sippican data acquisition system;*
- 2. the remaining one supposes an error in depth-time equation, and then a necessity to modify the IGOSS formula for the Mediterranean.*

1. Introduction

The expendable bathythermograph (XBT) still remains the most effective method for low cost and easy acquisition of temperature profiles, but the quality of these data has to be checked and potential biases must be identified.

Recently, some papers concerning the comparison between CTD and XBT temperature measurements were published, but only Sippican T7, and, sometimes, T4 probes were analysed. The common conclusion indicates a warm bias in T7 temperature profiles with respect to the CTD ones. Sometime, a disagreement between CTD and XBT depth values was proposed as a responsible of temperature differences.

In ADRICOSM and MFS Projects, T4, T6, and Deep Blue XBT probes are used, and more detailed analyses are needed in order to estimate quality and reliability of measurements done with these probes in Mediterranean seawater. Therefore, a comparison between quasi-coincident in position and time XBTs and CTD casts has been done.

The plan of this paper is the following: in sect. 2, data and their processing are reviewed; in sect. 3, the results of data processing are shown; in sect. 4, a comparison with recent papers is done and the results are discussed and checked; in sect. 5 concluding remarks and applications for future applications are exposed.

2. Data collection and processing

Sippican Deep Blue, T4 and T6 XBT probes were launched immediately before and/or later a CTD casts, that were done by using SEABIRD 911Plus automatic probe. This probe was calibrated before and later each cruise at Nato Saclant Centre in La Spezia (Italy). The actual accuracy on temperature value from a CTD dynamical measurement can be estimated at a level of $\sim 0.003\text{-}0.005^\circ\text{C}$. The XBT data were obtained by using a Sippican MK-12 read-out card.

The data were collected during 3 different cruises of opportunity:

- 1) January 2001: Eastern Tyrrhenian Sea + Sicily Channel, 4 XBTs and 4 CTD casts (Tab. 1);
- 2) October 2002: Western Ligurian Sea, 22 XBTs and 12 CTD casts (Tab. 2);
- 3) May 2003: Central Ligurian Sea, 11 XBTs and 9 CTD casts (Tab. 3).

Very different seawater characteristics were found. For instance: vertically homogeneous waters in January 2001 measurements, strongly stratified upper layer in October 2002 data, and a thermocline at intermediate depth in May 2003 data.

The CTD maximum depth was adapted to the different XBT characteristics, namely 760 m for DB, and 460 m for T4 and T6. It was also taken the opportunity to use the entire copper wire of the XBTs, by setting the maximum depth as a free parameter in Sippican's software. Reliable data were obtained down to 506 - 574 m for T4 and T6.

In tables 1, 2 and 3 geographical co-ordinates and dates of the sampling positions are shown for CTDs and XBTs. There are some discrepancies in time and position: unfortunately, only 21 XBT probes over 36 were launched within 1 hour difference and only 18 XBT probes over 36 within 0.5 degrees.

Quality control and data editing procedures were performed on each profile: XBT raw data are processed following the quality control procedures described in (Manzella et al., 2003), while CTDs values were processed by using standard SEABIRD's software and averaged at each meter depth. Successively, the CTD data were controlled by using Medatlas protocols (Maillard et al., 2001 and references therein). For XBT quality check procedures in literature, see for instance Hanawa et al., 1995, Thadathil et al., 1998 and 2001, and Bailey et al., 2003.

The CTD measurements were considered to be the true representation of the temperature profile: the XBT data were compared to the CTD ones, and any differences were assumed to reflect inaccuracies in the XBT measurement.

The mean and standard deviation of the temperature difference between the XBTs and CTDs were determined at each common depth; moreover, the global values on the whole data set were computed. In all the present work, T values are expressed with three decimal figures for both CTD and XBT measurements: for the former, this corresponds to a "detected" value, for the latter it is due to 1-m filtering and averaging process.

It has to be stressed that the difference in time and in geographical position prevents more refined and reliable analysis.

3. Results

The main results are summarised in Table 4. The differences between CTD and XBT temperature data are shown in Figures 1 – 4, as well as mean profiles and standard deviations. In the figures it is supposed that the calculation of depth with IGOSS formula is valid for the Mediterranean. In summary:

- 1) Four T4 XBTs vs. four CTD casts, January 2001 (1 cast Tyrrhenian Sea, 3 casts Sicily Channel), (Figures 1);
- 2) 22 DB XBTs vs. 12 CTD casts, October 2002 (Ligurian Sea), (Figures 2);
- 3) Six T4 XBTs vs. six CTD casts, May 2003 (Ligurian Sea), (Figures 3);
- 4) Five T6 XBTs vs. five CTD casts, May 2003 (Ligurian Sea), (Figures 4).

In Figures 5, the averaged differences with related standard deviations for all the different ships of opportunity are drawn in the same plot.

As quoted in Hanawa et al., 1995, during the May 2003 cruise, an upgraded use of T4 and T6 XBT probes was tried, by setting a practically free maximum depth in data acquisition software. Contrary to Hanawa et al., 1995, the data acquisition continued below the nominal maximum depth: the obtained average depth was 558.5 ± 7.8 m (min. 543 m, max. 570 m) for T4 probes, and 542.1 ± 22.6 m (min. 506 m, max. 574 m) for T6 probes. The comparison with CTD casts has shown a global good reliability of T values below the 'standard' depth of 460 m, without a significant increase in measured difference (Figures 3c, 4c, 5c).

It has to be stressed that also DB probes were launched during a VOS project (ADRICOSM) with a "free" maximum depth, but without comparison with CTD measurements. At the present (August 2003), with a sample of ~ 80 drops, the averaged maximum depth is $\sim 890 \pm 25$ m.

4. Comparison with recent studies and discussion.

Many recent papers, which studied usually T7 XBT measurements, and sometimes T4, have indicated that XBTs record seawater temperature warmer than actual (Heinmiller, 1983; Schmeiser, 2000; Roth, 2001; Boedeker, 2001; Fang, 2002; and Dixon, 2003). The main results are summarised in Table 5 and compared with the values obtained in this work.

In order to better check this difference, it was also suggested the XBTs should be released before the CTD to reduce temporal variation to a minimum (Roth, 2001). 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.

On the other hand, in Hanawa et al., 1995, it was used a delay of ~ 10 minutes of the start of XBT with respect to the CTD cast, in order to have a coincidence at the thermocline. In Thadathil et al., 1998, XBTs were dropped when CTD was at ~ 100 m depth.

From the analysis of the data collected for this study, it seems that XBTs exhibit a "systematic" difference of higher temperature readings. In fact, the anomaly (mean temperature difference between CTD and XBT) is almost negative throughout the depth range with the exception of several intermediate levels of T4 and T6 XBTs where the difference is slightly positive. The anomaly is most pronounced in the upper (above 100 metres) portion of the water column, which is also presenting the highest variability, as expected, and generally decreases with depth.

Probably, due to the winter season vertical homogeneity, January 2001 data do not show large difference between XBT and CTD measurements in the upper layer. On the contrary, the remaining XBT near surface measurements present a significant spread, with a difference up to $\sim 4.0^\circ\text{C}$ in October 2002 and up to $\sim 2.8^\circ\text{C}$ in May 2003. For a comparison see Thadathil et al., 1998, and Kizu et al., 2002 (a).

DB XBTs show a practically constant negative difference, lesser than the nominal accuracy XBTs have. When only temperature values below 100 meters depth are analysed, DB XBTs seem to show the same behaviour T7 XBTs have, see the plots in the previously quoted reference. On the contrary, T4 and T6 have a reduced, more irregular behaviour, but within their standard accuracy.

Therefore, it is worth that XBT data have to be used in a critical way, especially for studies concerning the variability/changes in the upper layers of the sea. Below 100 m depth, the differences are relatively small: if they are a real systematic (a warm bias), it could be possible a correction by a term derived from combined XBT - CTD observations. A more refined check should be necessary in order to better understand the observed data, but presently only a qualitative analysis is possible.

The strongest differences appearing in upper layers seem to be strictly related to strong temperature gradients. In this case, the most part of XBT profiles show temperatures (even much) higher than the corresponding CTD values; the difference slows down and vanishes below the region where gradients occur.

Two different hypotheses were analysed looking for a possible solution to this problem:

3. intrinsic electronic properties of XBT + card system, and then a necessity to update this part of the Sippican data acquisition system;
4. the remaining one supposes an error in depth-time equation, and then a necessity to modify the IGOSS formula for the Mediterranean.

The response time of the XBT thermistor (~ 0.15 s) is much higher than the CTD one (~ 0.02 s). Moreover, from Sippican's logbooks and from XBT Cookbook, the XBT sensor thermal response in order to capture a step change at a level of 98 % is quoted as 0.63 s. During this time, the probe moves ~ 4 m: this is the minimum distance an XBT has to fall down before it can reproduce a significant temperature difference. The comparison at each depth of XBT and CTD available measurements indicates that the differences vanish after ~ 20 m. This means that a time interval of ~ 3 s is needed (and sufficient) to the Sippican system to become closer to a 'true' state in which $\Delta T \sim 0.1^\circ\text{C}$ T with respect to the CTD ones.

Having no further information on combined CTD and XBT data and no theoretical way to include this effect in a procedure modifying the temperature profile from XBTs, an ideal experiment was performed. This experiment could be described as follows: an XBT probe touches seawater, falls down, and has a steady functioning state at a depth deeper than 5 m (start-up effect). When it reaches the region where (strong) T gradients are present, the readout card + thermistor need a time of ~ 0.6 s in order to fully reproduce T variations.

In the present trial, the starting gradient depth was defined as that one where T difference between two consecutive depths is greater than 0.1°C for four times. Practically, dT/dz occurs when $\Delta T > 0.5^\circ\text{C}$ over 4 m. In a similar way, the thermocline base was defined as the depth where the T difference is lower than 0.1°C for four times. Then, the T values at depth ranging from 2 m above the starting point and 2 m below the ending point of the thermocline were substituted with T values at depth 4 m lower: practically, a 4 m cut was applied to the XBT profiles. Finally, the averaged difference at each depth and the related standard deviation were computed, the main results being summarised in Table 6 and in Figures 6. The results are coincident for January 2001 XBTs, due to the absence of temperature gradient.

It is worth this is a completely arbitrary procedure, even if the hardware characteristics influence the value of the cut. As a result, a better agreement is obtained, but an even large discrepancy still remains in upper layer: its origin is presently unknown and many different factors could induce this phenomenon. But the main point arisen here is that, due to the XBT characteristics, some corrections are necessary in the computation of the depth from surface to the thermocline base. The new algorithm should recover about 4 metres in this upper layer.

In a similar way, also the first part of XBT data needs a critical check (see Hanawa et al., 1995, and Kizu et al., 2002(a)). In MFS-PP, as a standard procedure, an initial path of 5 m was rejected in order to allow the XBT thermistor to be in 'true' state.

The data available in the present work, even if only a qualitative point of view is allowed, seem to suggest an extended layer to be eliminated, at a level of ~ 5-8 metres.

Another possible solution to the measured T differences can be a depth error: the differences could be attributed to the approximation of the calculation of the XBT depth, which may introduce apparent temperature disagreement that in reality are depth differences (Hanawa, 1995 and references therein, Thadathil, 1998). Temperature differences and standard deviation may be even more significant as a consequence of the inclusion of data pairs not co-located and/or not coincident in time, which could have larger than actual differences in layered waters, see for instance at the thermo-cline depth.

Presently, the IGOSS depth-time equation (a parabolic equation with experimentally deduced A and B coefficients) was proposed in Hanawa et al., 1995. The IGOSS formula indicates a higher fall speed than manufacturers propose.

In Seaver et al., 1982, it was firstly shown the influence of viscosity on the XBT probes dynamics. As pointed out in Hanawa et al., 1995, it is a very difficult task to find a global relationship among physical seawater properties and the falling speed of XBTs: *"..The expected influence, if any, should be a decrease in the speed of the probes (decrease of A mainly) with increasing viscosity"*.

It has to be stressed that viscosity is inversely proportional to the mean temperature, to the first order; moreover, the density seems to be strongly anti-correlated to the temperature values. Consequently, T should give the main contribution to the falling speed variation, if any. As a final remark, in Thadathil et al., 1998, any dependence of fall rate on temperature seems to be excluded in data concerning Indian Ocean.

Mediterranean seawater has peculiar characteristics: usually, T values are greater than 12.9°C at all depths: only strongly windy conditions occurring in winter period can lower that T value in upper layers (less than 200 m depth). Therefore, Mediterranean seawater never reaches T values that Ocean seawater shows (even ~ 5 °C), moreover, in summer season, density and salinity have even significant differences with respect to the Ocean values, although T values are comparable. Finally, no studies comparing XBT and CTD data in Mediterranean seawater are available in literature nor the depth equation for T4-T6 and DB was checked.

Unfortunately, the amount and the time and geographical dispersion of the available data in this work do not allow a systematic study in order to check the validity of standard A and B coefficients or to evaluate a systematic depth difference.

It has been computed only the depth at which the thermocline starts and ends for XBT and CTD. Then, the absolute difference and the related standard deviation have been deduced:

- 1) January 2001 (T4): no gradient was found;
- 2) October 2002 (DB): starting point = 3.0 ± 2.4 m; ending point = 3.4 ± 2.9 m;
- 3) May 2003 (T4+T6): starting point = 3.2 ± 3.2 m; ending point = 3.7 ± 4.0 m.

See for instance Figure 7, where the averaged T differences for DB case are plotted.

The same analyses have been done on DB XBT data within no more than half hour from the CTD casts (10 XBT profiles). As example, the T differences averaged over the whole profiles are quoted:

Standard = $-0.081 \pm 0.181^{\circ}\text{C}$ (see Figure 2a);

Standard 4 m cut = $-0.057 \pm 0.128^{\circ}\text{C}$ (see Figure 6c);

Thermocline cut = $-0.058 \pm 0.132^{\circ}\text{C}$ (see Figure 7);

Within 30' 4m cut = $-0.069 \pm 0.105^{\circ}\text{C}$ (see Figure 8);

Within 30' + Thermocline cut = $-0.070 \pm 0.115^{\circ}\text{C}$ (see Figure 9).

It is worth a reduction of the T averaged difference at each depth in upper layers for both the procedures even if it is not clear how each factor influences the disagreement.

As a final remark, it has to be further checked the reliability of augmented depth profiles, obtained by setting the Sippican software at a deeper depth, which allows a longer temperature profile, down to ~ 550 m for T4 and T6 and ~ 890 m for DB probes. In the small number of profiles that were analysed for this study, the averaged differences of the CTD - XBT temperatures present a sharp change (see Figure 3c, 4c) followed by a higher variability. In any case, the presently available values are within the nominal accuracy and behaviour of XBT probes.

Therefore, further measurements are needed in order to improve the knowledge on processes affecting the quality of temperature data. A new comparison is foreseen in September 2003: different type "free maximum depth" XBT will be dropped from a steady vessel no more than 2 minutes later the start of a CTD cast, looking for an explication to the temperature discrepancy.

5. Conclusions and future applications.

In this work, a comparison between XBT and CTD quasi-coincident in time and position temperature measurements has been done.

As a main result, a general good agreement between them is worth, mainly below 100 m depth. More in detail, DB profiles show a "systematic" negative bias (warmer seawaters were measured), while T4 and T6 probes have a more variable behaviour. These discrepancies are within the nominal accuracy of XBT probes; they could be attributed to different factors, like intrinsic XBT system properties or error in depth-time equation. If confirmed, these differences could be introduced in model and forecast assimilation.

Finally, an extended data acquisition with T4 and T6 XBTs was tried and checked, even if the available sample is very small. In any case, it seems to be possible and reliable a data acquisition below the standard terminal depth within the nominal accuracy. It should be better to apply and check this procedure to DB XBTs also.

In summary, it should be useful to remind and apply the following conclusions to the incoming projects using XBT technique:

- The application of good quality control procedures to data is definitely essential. Without the removal of bad data, results may be significantly unrealistic.

- It is highly recommended that the use of XBTs excludes data in the upper 5 m, where the temperature sensor is not yet in equilibrium with the environmental temperature. The way an XBT enters 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 second could change the depth at which the thermocline is recorded.
- Data recorded at depths where temperature gradients occurs have to critically analysed because of time response of the thermistor and of the falling speed of XBT probes. Standard procedures have to be searched for.
- The validity (confidence level) of XBT depth-time equation (Hanawa 1995) should be checked in Mediterranean Sea, due to its high salinity, temperature and density.
- The use of XBT at depth deeper than nominal has to be checked and improved. It is necessary to analyse a significant amount of profiles, possibly deriving from batches and different manufacturing date, since a small number of profiles may have an adverse impact on final results.

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Table caption

- 1) Data from January 2001 Ship of Opportunity, XBT model T4, co-ordinates of CTD casts and XBT drops and their differences.
- 2) Data from October 2002 Ship of Opportunity, XBT model DB, co-ordinates of CTD casts and XBT drops and their differences.
- 3) Data from May 2003 Ship of Opportunity, XBT models T4 and T6, co-ordinates of CTD casts and XBT drops and their differences. The symbol * means XBT launched with vessel speed equal to 0.
- 4) Main results of temperature differences for the different SOOPs. The values on the whole profile, in upper and lower part are specified. The greater differences, the standard deviations and the related depths are also detailed.
- 5) Comparison of present results with previously published analyses: averaged differences and standard deviations are quoted.
- 6) As in Table 4, but when a 4 m cut in T profiles is applied.

Figures caption

- 1) T difference for each XBT and the corresponding CTD, its mean value and the standard deviation for January 2001 T4 data (depth in metres, T differences in °C):
 - a) full profile;
 - b) 0 – 100 m depth;
 - c) 100 – max depth.
- 2) T difference for each XBT and the corresponding CTD, its mean value and the standard deviation for October 2002 DB data (depth in metres, T differences in °C):
 - a) full profile;
 - b) 0 – 100 m depth;
 - c) 100 – max depth.
- 3) T difference for each XBT and the corresponding CTD, its mean value and the standard deviation for May 2003 T4 data (depth in metres, T differences in °C):
 - a) full profile;
 - b) 0 – 100 m depth;
 - c) 100 – max depth.
- 4) T difference for each XBT and the corresponding CTD, its mean value and the standard deviation for May 2003 T6 data (depth in metres, T differences in °C):
 - a) full profile;
 - b) 0 – 100 m depth;
 - c) 100 – max depth.
- 5) T averaged difference and its standard deviations for all the available data (depth in metres, T differences in °C):
 - a) full profile;
 - b) 0 – 100 m depth;
 - c) 100 – max depth.
- 6) T averaged difference and its standard deviations when a 4 m. cut is applied to T profiles (depth in metres, T differences in °C):
 - a) May 2003, T4 data;
 - b) May 2003, T6 data;
 - c) October 2002, DB data.
- 7) T averaged difference and its standard deviations for October 2002 DB data when the difference in depth at the top of the thermocline top is included (depth in metres, T differences in °C).
- 8) T averaged difference and its standard deviations for October 2002 DB data when a 4 m cut is applied T profiles from XBT launched within 30 minutes from the CTD cast (depth in metres, T differences in °C).
- 9) T averaged difference and its standard deviations for October 2002 DB data when the difference in depth at the top of the thermocline is applied T profiles from XBT launched within 30 minutes from the CTD cast (depth in metres, T differences in °C).

Table 1

CTD nr	Lat (°)	Lat (')	Lon (°)	Lon (')	Time (h.m)	XBT nr	DLat(')	DLon(')	DTime (h.m)
49	40	20.100	13	29.940	15.58	1	- 00.038	+00.002	- 01.30
432A	37	43.990	12	20.000	08.38	13	+00.118	+00.066	- 00.50
451	37	20.280	11	36.040	21.25	15	+00.064	- 00.134	+01.13
463	37	21.800	11	39.760	20.17	14	- 00.171	- 00.584	+02.11

Table 2

CTD nr	Lat (°)	Lat (')	Lon (°)	Lon (')	Time (h.m)	XBT nr	DLat(')	DLon(')	DTime (h.m)
901	43	41.490	07	42.950	23.55	023	+01.244	- 01.200	+ 02.25
902	43	37.200	07	46.970	20.08	022	- 00.320	+00.265	- 01.03
						021	+00.831	- 00.437	+ 00.20
903	43	33.290	07	50.100	18.05	020	- 00.454	+00.331	- 01.16
						019	+0.555	- 00.458	+ 00.17
904	43	29.310	07	53.990	16.09	018	- 00.209	+00.184	- 01.13
						017	+00.497	- 00.718	+ 00.12
905	43	25.510	07	58.010	13.15	016	- 00.294	+00.080	- 02.19
						015	+00.790	- 00.757	+ 00.16
906	43	17.410	08	06.000	10.34	014	- 00.899	+00.806	- 01.43
						013	+00.717	- 00.677	+ 00.15
907	43	09.040	08	13.970	08.01	012	- 00.814	+00.567	- 01.35
						011	+01.118	- 01.064	+ 00.29
908	43	00.980	08	21.960	05.18	010	- 00.390	+00.309	- 01.25
						009	+0.668	- 00.649	+ 00.19
909	42	51.700	08	30.020	02.33	008	- 00.183	+00.290	- 01.28
						007	+00.701	- 00.827	+ 00.23
910	42	47.810	08	34.010	00.28	006	- 00.802	+00.770	- 01.24
						004	+00.442	- 00.437	+ 00.14
911	42	43.510	08	37.990	22.47	003	- 00.210	+00.195	- 01.00
						002	+00.671	- 00.632	+ 00.19
912	42	40.430	08	40.890	21.07	001	- 00.247	+00.189	- 01.06

Table 3

CTD nr	Lat (°)	Lat (')	Lon (°)	Lon (')	Time (h.m)	XBT nr	DLat(')	DLon(')	Dtime (h.m)
804	43	34.890	08	16.220	10.03	002 T4*	+00.009	+00.008	- 00.05
STA1	43	24.980	08	59.980	23.06	004 T4	+01.332	- 01.940	+ 00.04
STA1	43	24.980	08	59.980	23.06	005 T6*	+00.163	- 00.195	- 00.16
STA5	43	24.990	08	59.990	10.59	006 T6*	+00.046	- 00.148	+ 01.35
STA8	43	24.990	09	00.020	20.16	007 T4*	- 00.008	+00.099	- 00.31
607	43	48.780	08	36.610	08.32	008 T6	+00.586	+00.407	+ 00.04
606	43	53.580	08	38.520	10.19	009 T4	+01.746	+00.767	+ 00.11
605	43	58.190	08	40.610	11.53	010 T4	+00.624	+00.235	+ 00.05
605	43	58.190	08	40.610	11.53	011 T6	- 00.076	- 00.005	- 01.11
604	44	02.750	08	42.540	13.28	012 T4	+00.189	+00.119	+ 00.03
603	44	07.120	08	44.560	14.55	013 T6	- 00.699	+00.438	- 01.49

Table 4

	January 2001	October 2002	May 2003 T4	May 2003 T6
T <CTD-XBT> Full profile	- 0.052 ± 0.087°C 5-453 m	- 0.081 ± 0.181°C 5-753 m	- 0.062 ± 0.160°C 5-550 m	- 0.049 ± 0.178°C 5-540 m
T <CTD-XBT> 100 m-max. dep.	- 0.031 ± 0.030°C 100-453 m	- 0.054 ± 0.043°C 100-753 m	- 0.019 ± 0.086°C 100-550 m	+ 0.011 ± 0.101°C 100-540 m
Max. T aver. diff. < 100 m dep.	- 0.283°C 82 m	- 0.769°C 31 m	+0.991°C 18 m	- 1.337°C 15 m
Max. T aver. diff. > 100 m dep.	- 0.120°C 105 m	- 0.064°C 424 and 646 m	+0.094°C 192 m	- 0.154°C 181 m
Max. Stand. Dev. < 100 m dep.	0.348°C 69 m	1.333°C 31 m	0.932°C 15 m	1.061°C 17 m
Max. Stand. Dev. > 100 m dep.	0.166°C 113 m	0.060°C 384 m	0.188°C 196 m	0.258°C 186 m

Table 5

Author - Year - XBT	Analysed depth (m)	Mean difference (°C)	Stand. Deviation (°C)
Heinmiller 1983 T7	0 – 760	- 0.13	0.11
Schmeiser 2000 T7	0 – 760	- 0.1549	0.2151
Roth 2001 T7	0 – 760	- 0.0783	0.1047
Boedeker 2001 T7	0 – 760	- 0.0882	0.2147
Fang 2002 T7	0 – 760	- 0.1074	0.1546
Dixon 2003 T7	0 – 760	- 0.1275	0.0598
This work : T4-2001	5 – 453	- 0.052	0.087
This work : T4-2001	100 – 453	- 0.031	0.030
This work : DB-2002	5 – 753	- 0.081	0.181
This work : DB-2002	100 – 753	- 0.054	0.043
This work : T4-2003	5 – 558	- 0.062	0.160
This work : T4-2003	100 – 558	- 0.019	0.086
This work : T6-2003	5 – 542	- 0.049	0.178
This work : T6-2003	100 – 542	+0.011	0.101

Table 6

	January 2001	October 2002	May 2003 T4	May 2003 T6
T <CTD-XBT> Full profile	- 0.052 ± 0.087°C 5-453 m	- 0.057 ± 0.128°C 5-753 m	- 0.044 ± 0.166°C 5-550 m	- 0.026 ± 0.188°C 5-540 m
T <CTD-XBT> 100 m-max. dep.	- 0.031 ± 0.030°C 100-453 m	- 0.054 ± 0.043°C 100-753 m	- 0.019 ± 0.086°C 100-550 m	+ 0.012 ± 0.101°C 100-540 m
Max. T aver. diff. < 100 m dep.	- 0.283°C 82 m	- 0.319°C 52 m	- 0.497°C 23 m	- 0.820°C 16 m
Max. T aver. diff. > 100 m dep.	- 0.120°C 105 m	- 0.078°C 112 m	+0.107°C 512 m	- 0.152°C 198 m
Max. Stand. Dev. < 100 m dep.	0.348°C 69 m	0.996°C 32 m	1.419°C 7 m	1.329°C 12 m
Max. Stand. Dev. > 100 m dep.	0.166°C 113 m	0.073°C 105 m	0.188°C 196 m	0.258°C 186 m

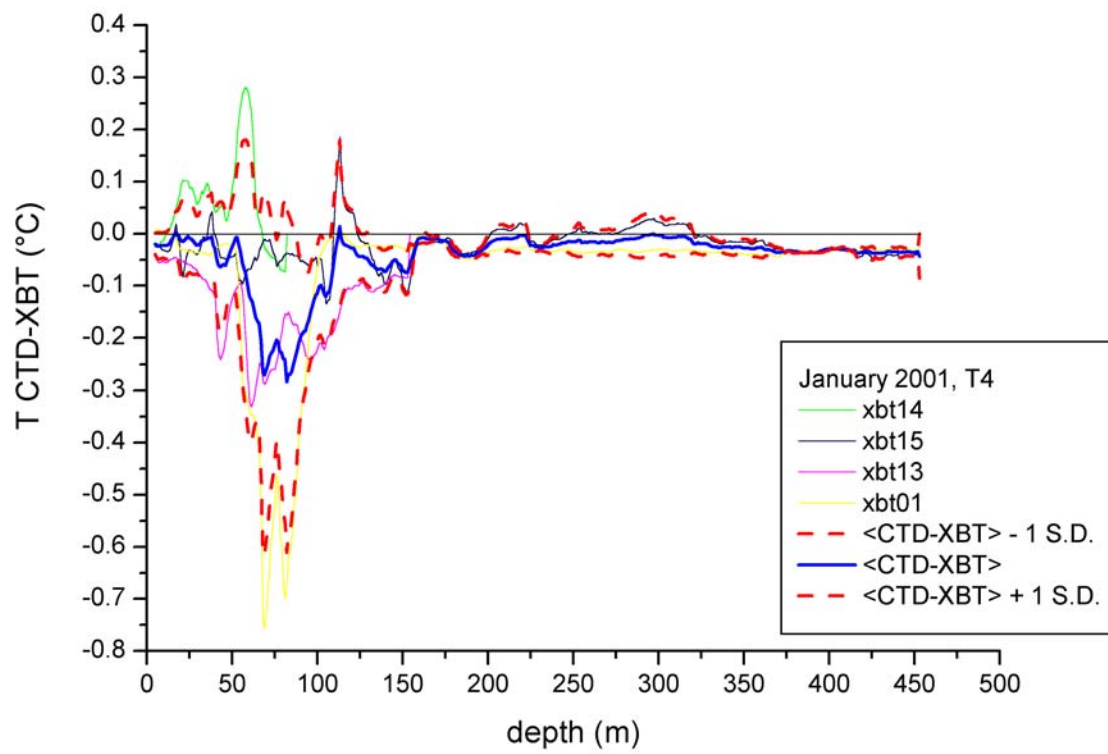


Figure 1a

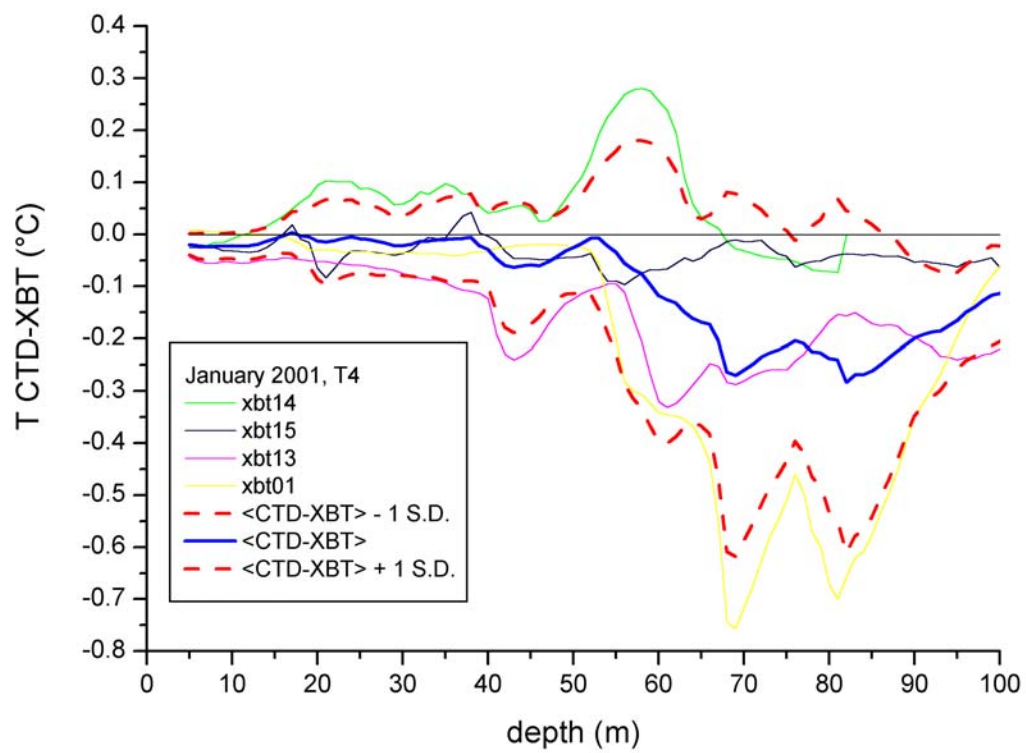


Figure 1b

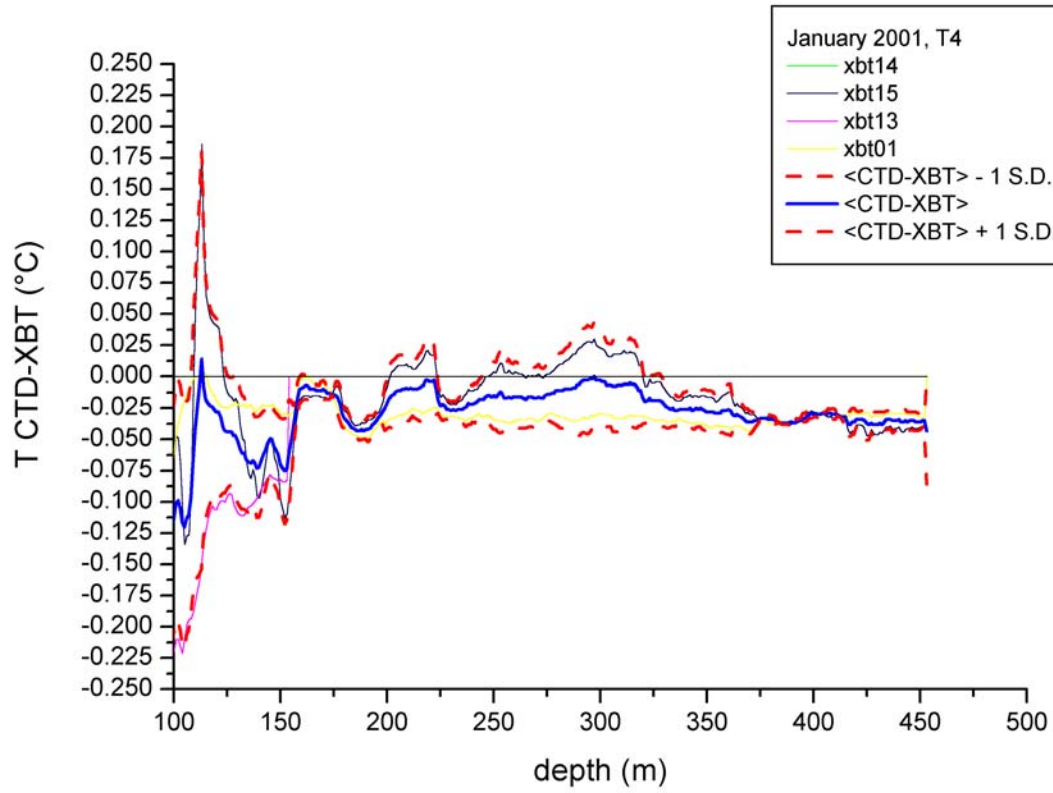


Figure 1c

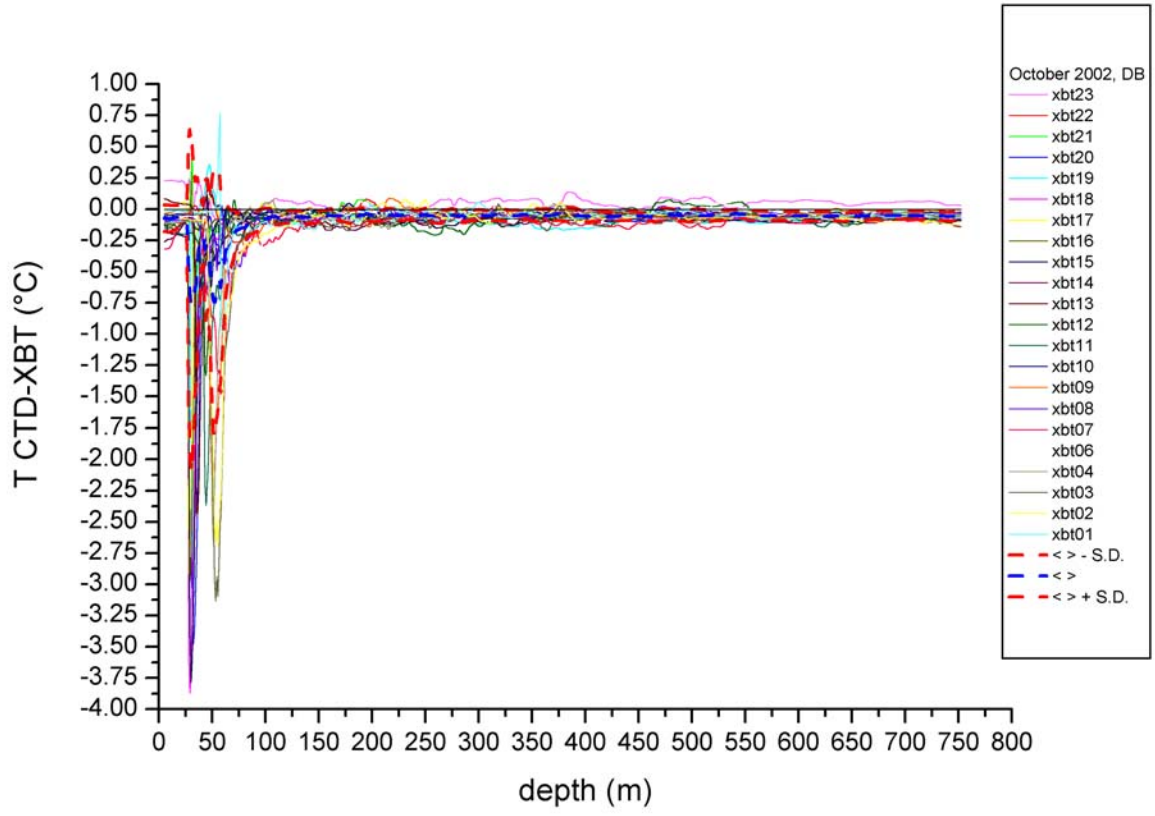


Figure 2a

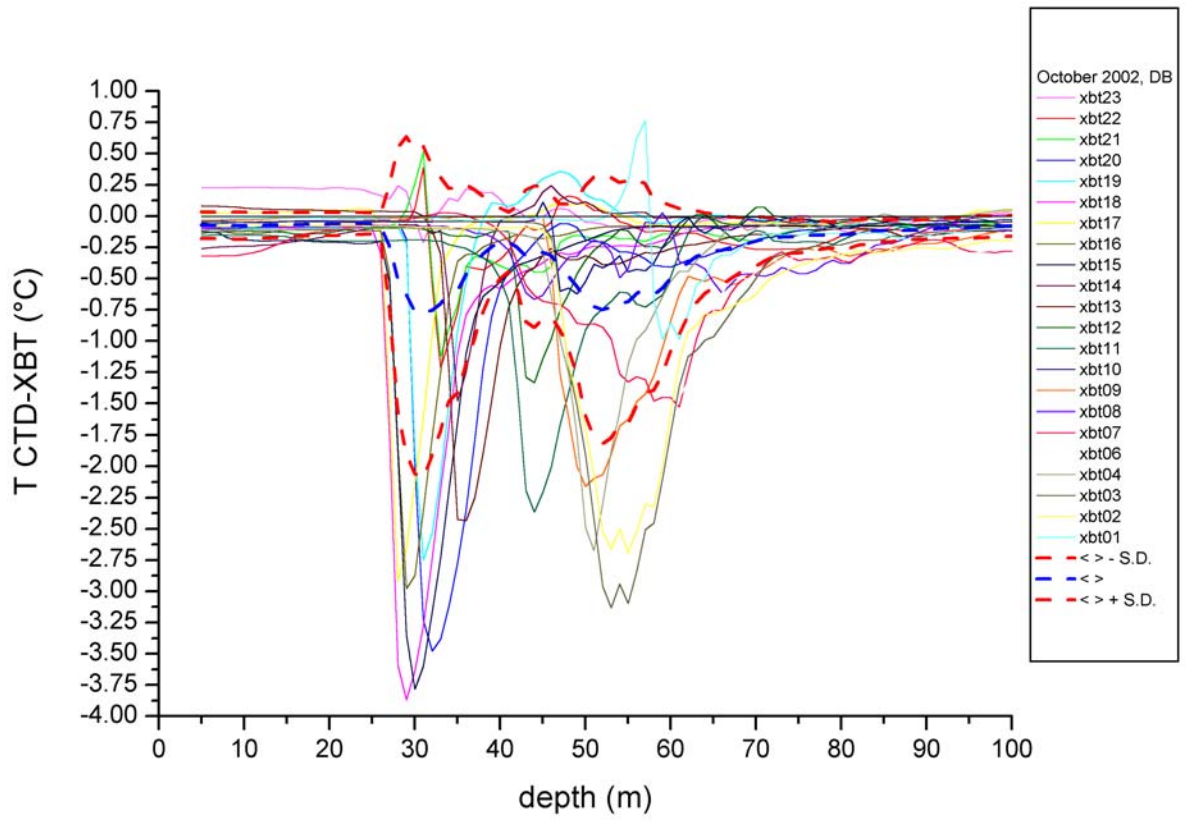


Figure 2b

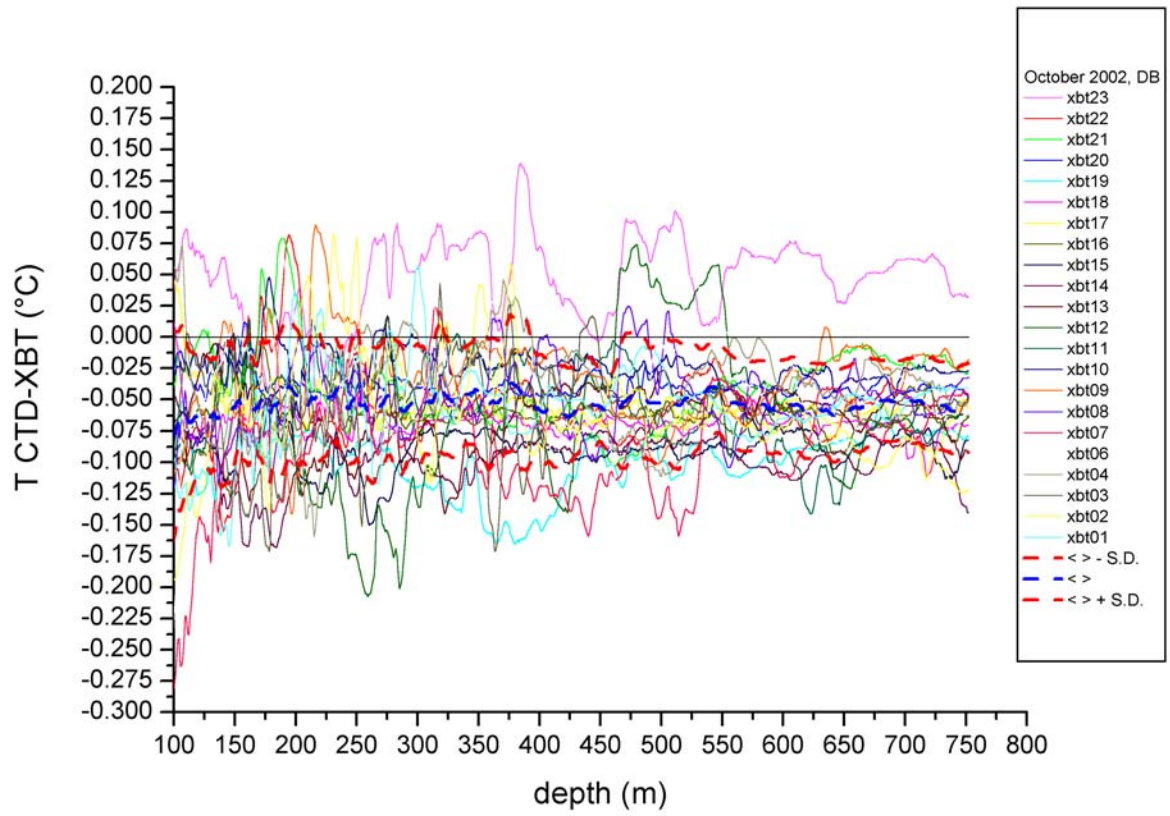


Figure 2c

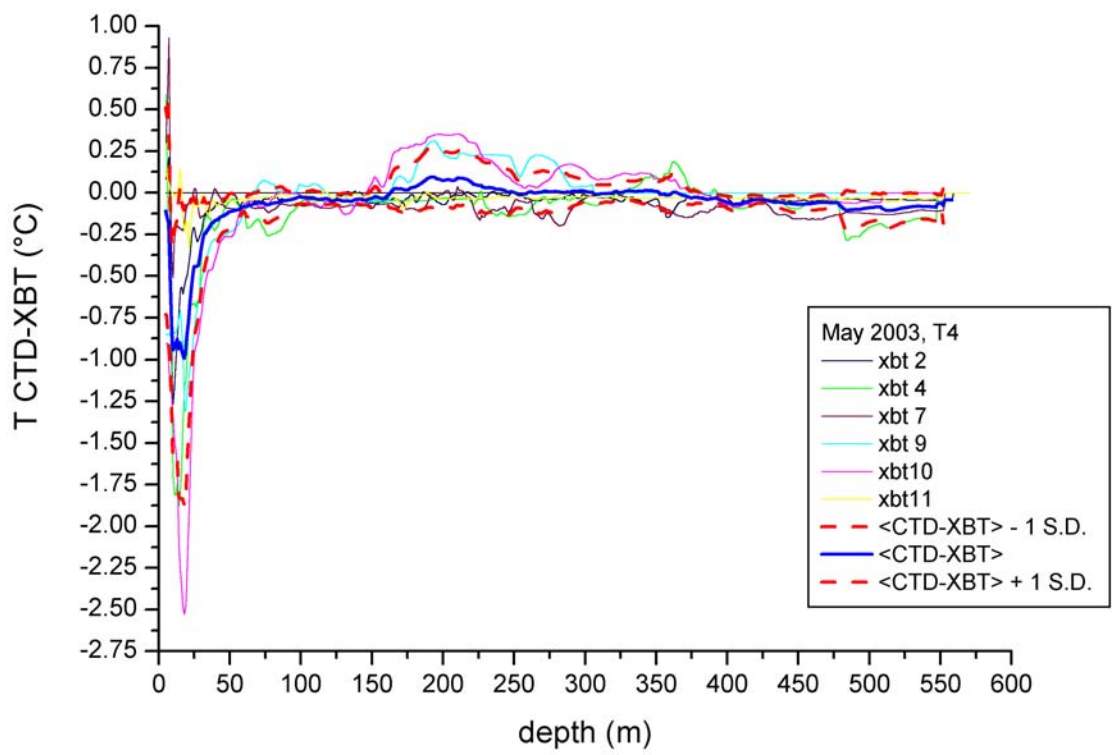


Figure 3a

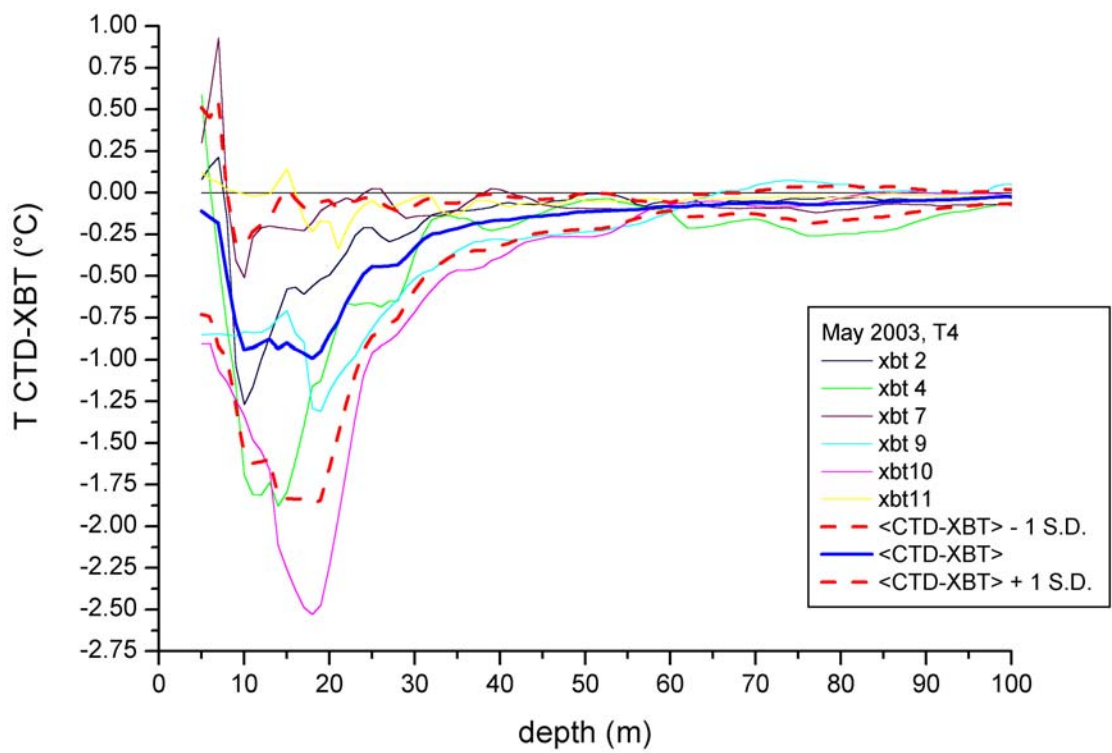


Figure 3b

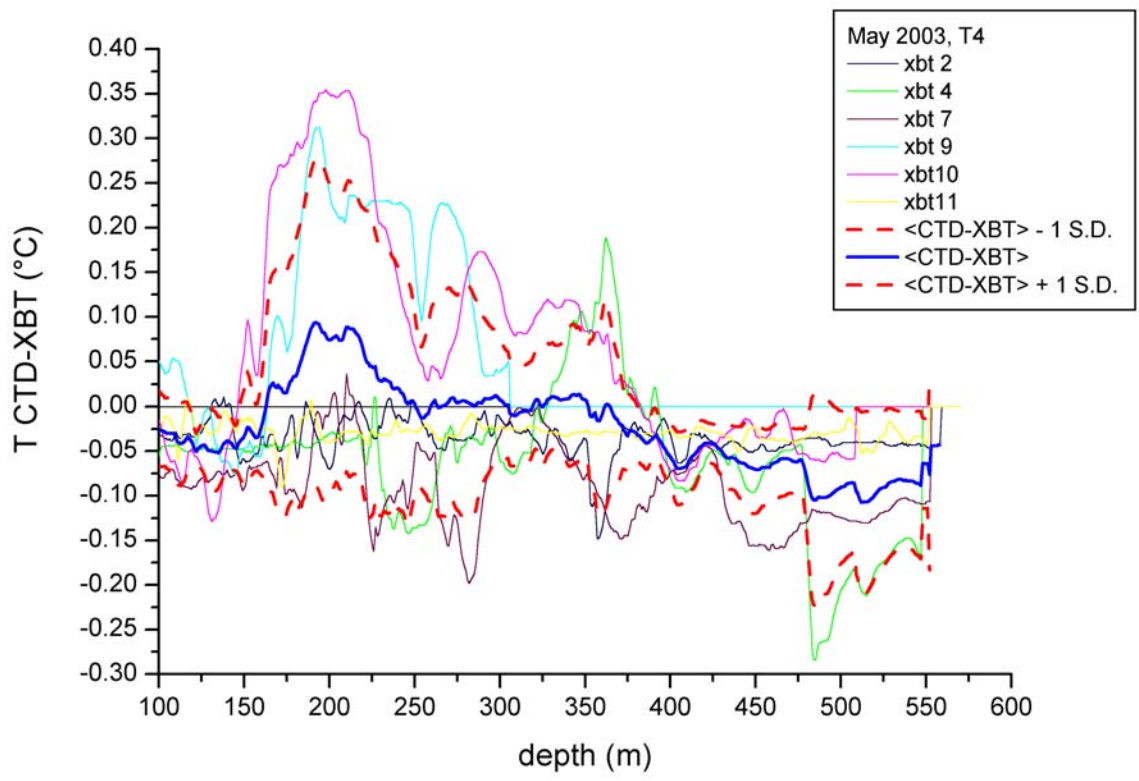


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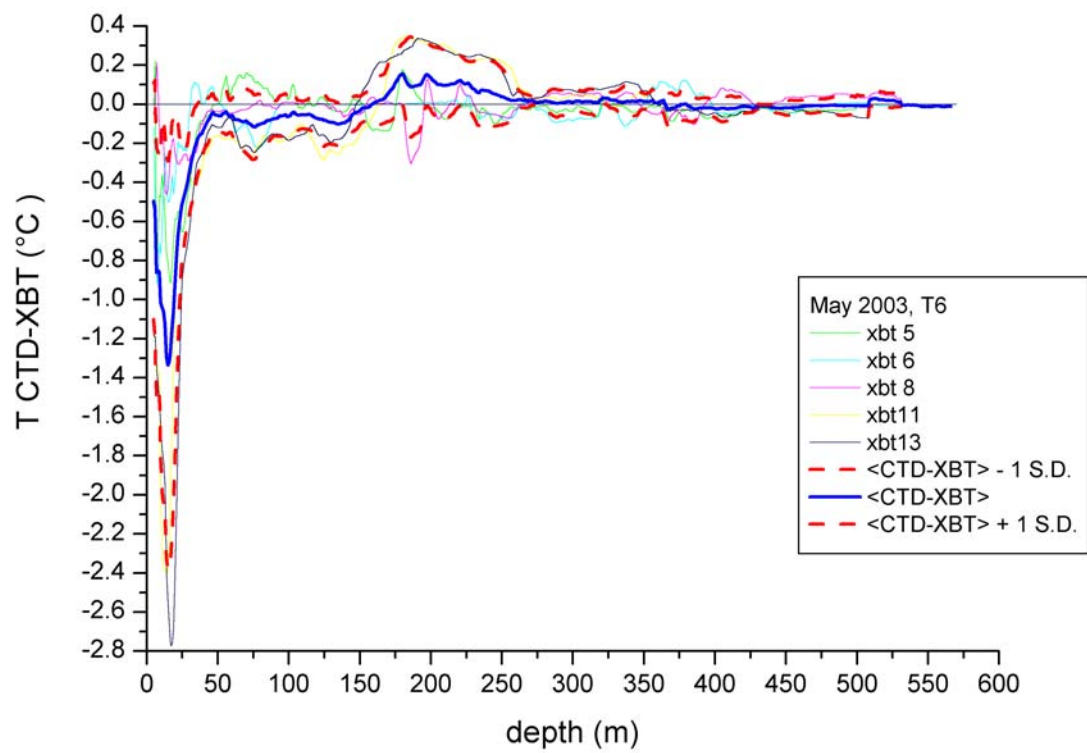


Figure 4a

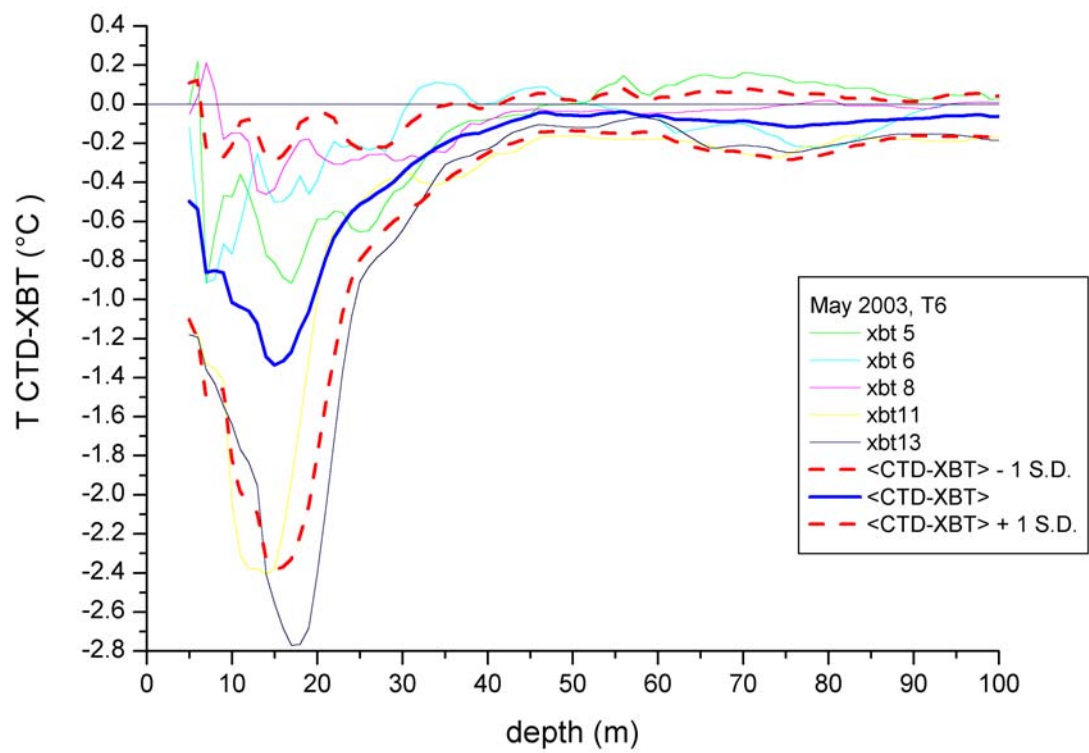


Figure 4b

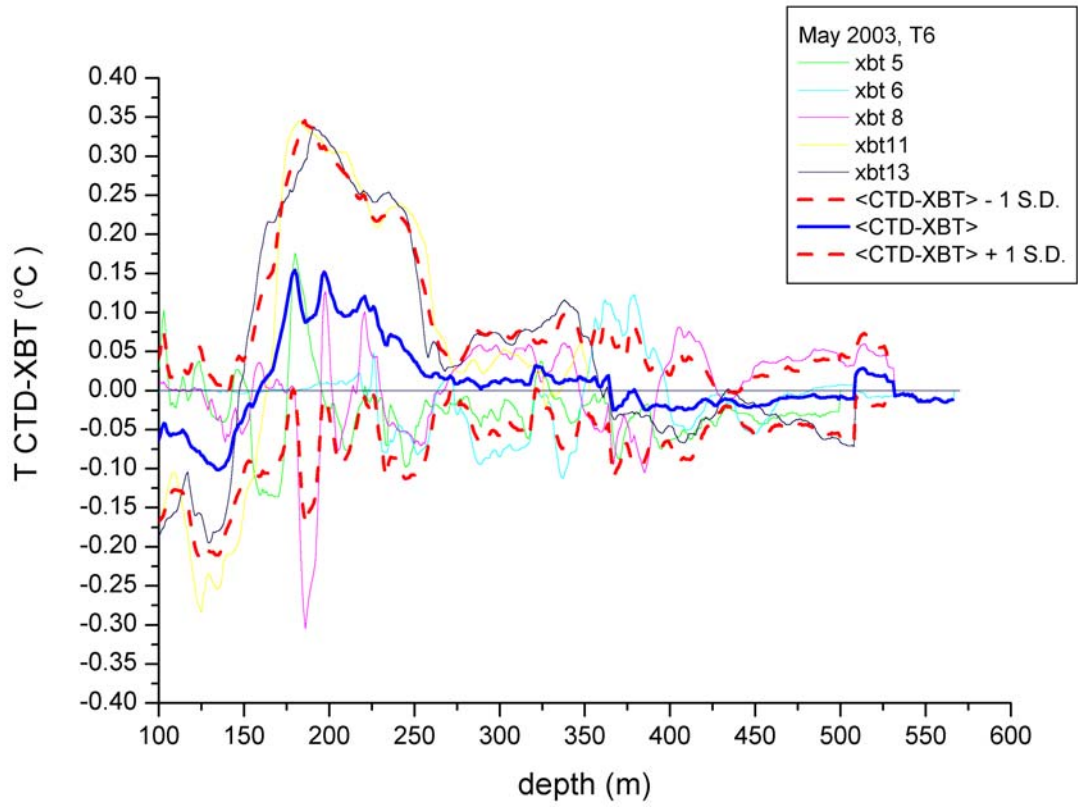


Figure 4c

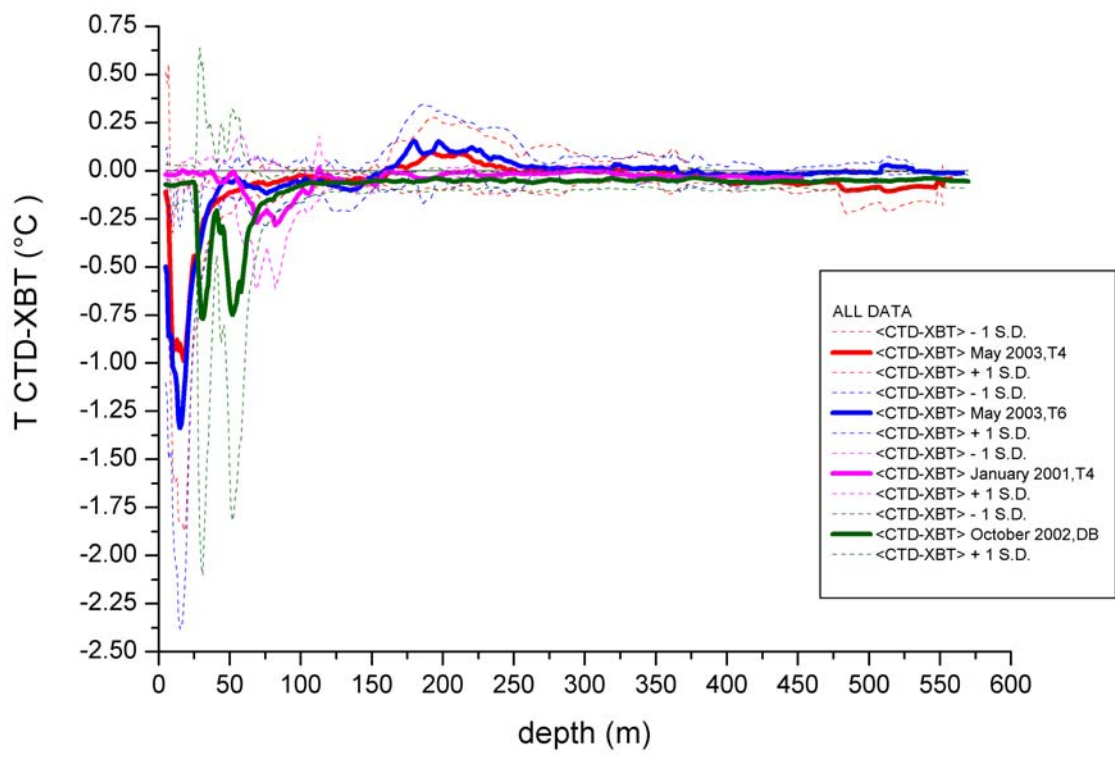


Figure 5a

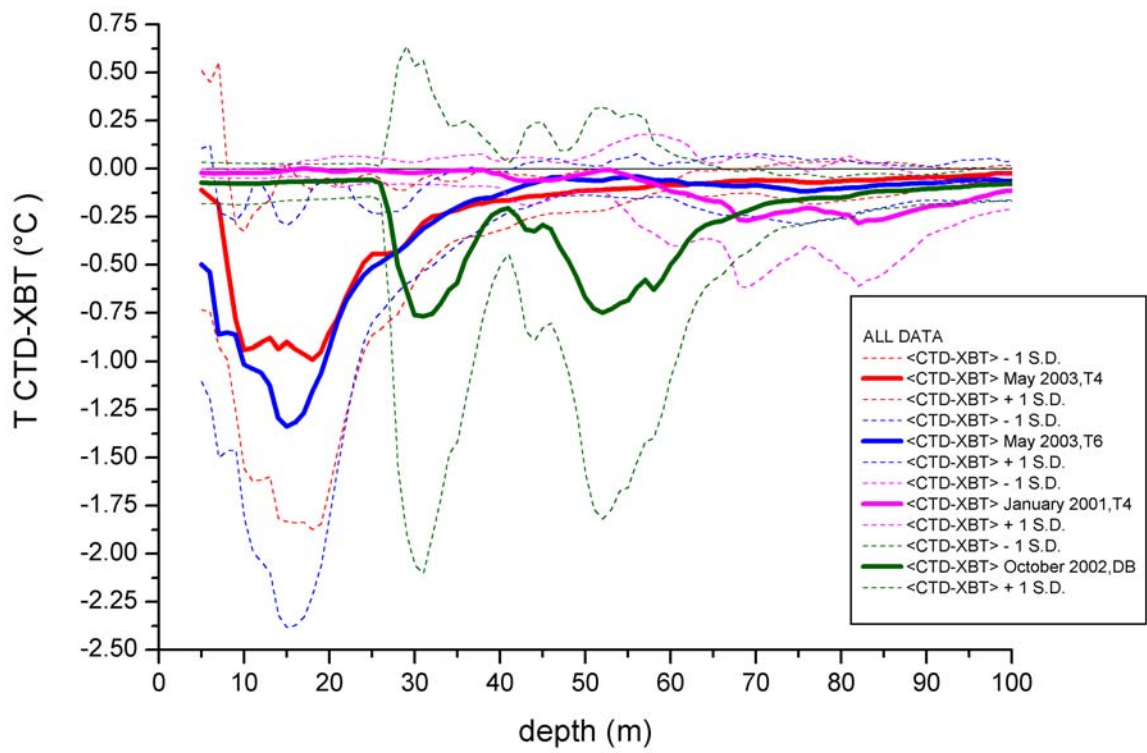


Figure 5b

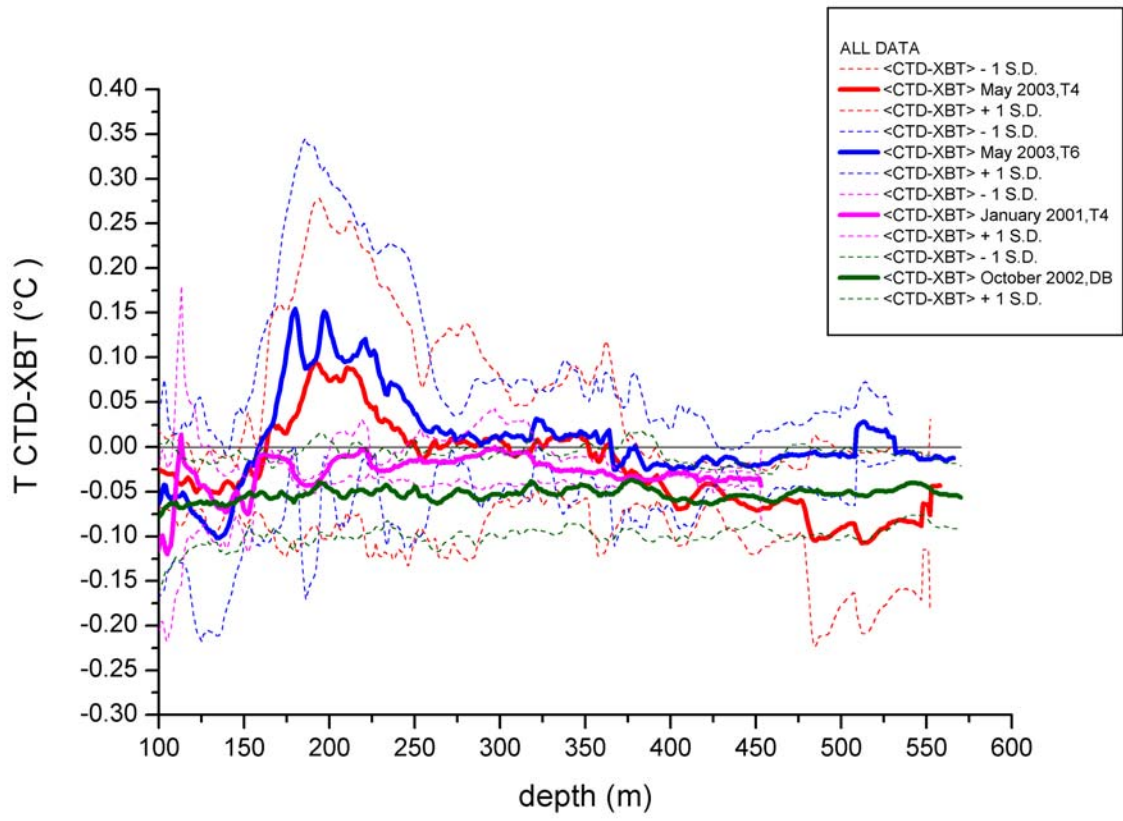


Figure 5c

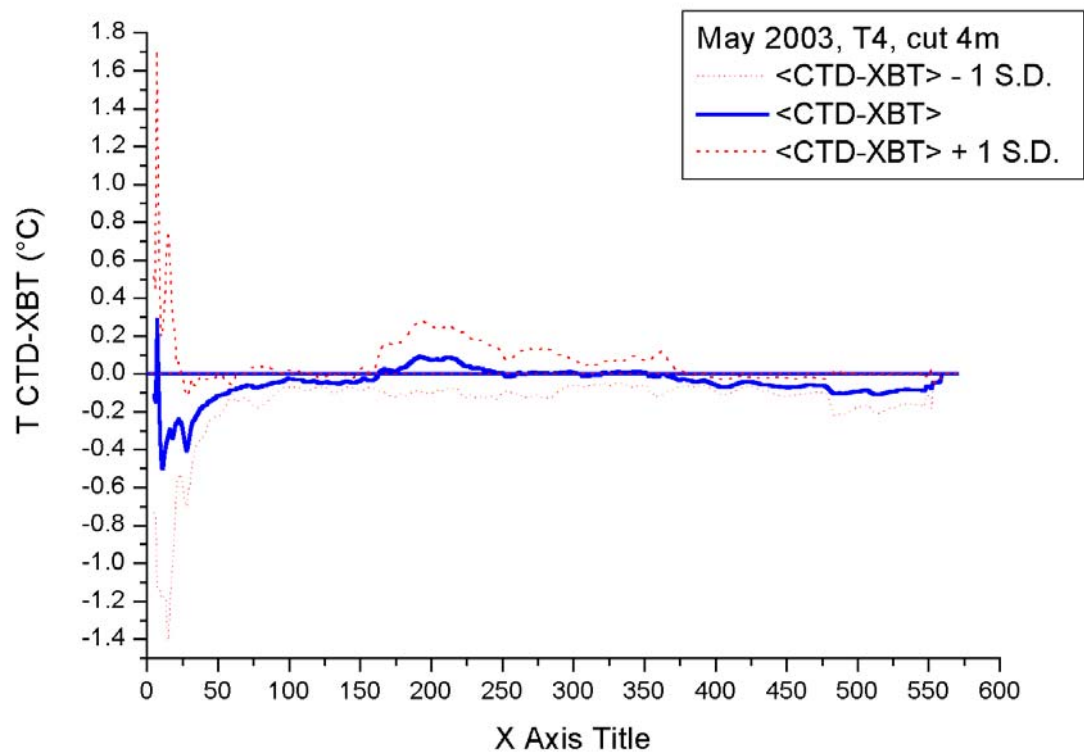


Figure 6a

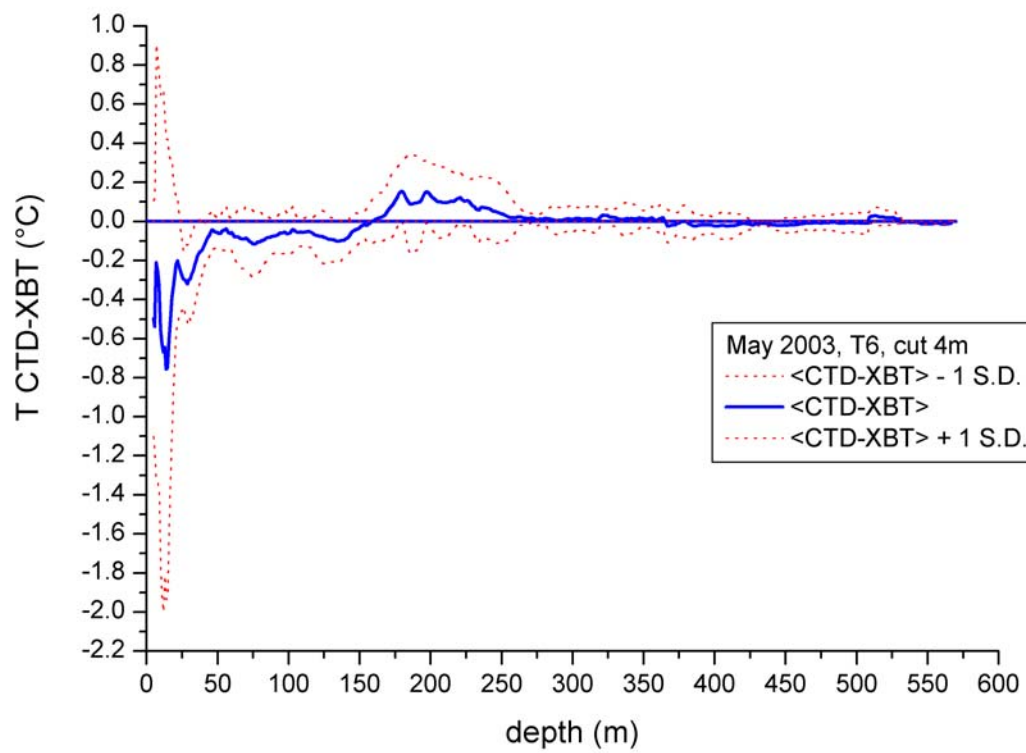


Figure 6b

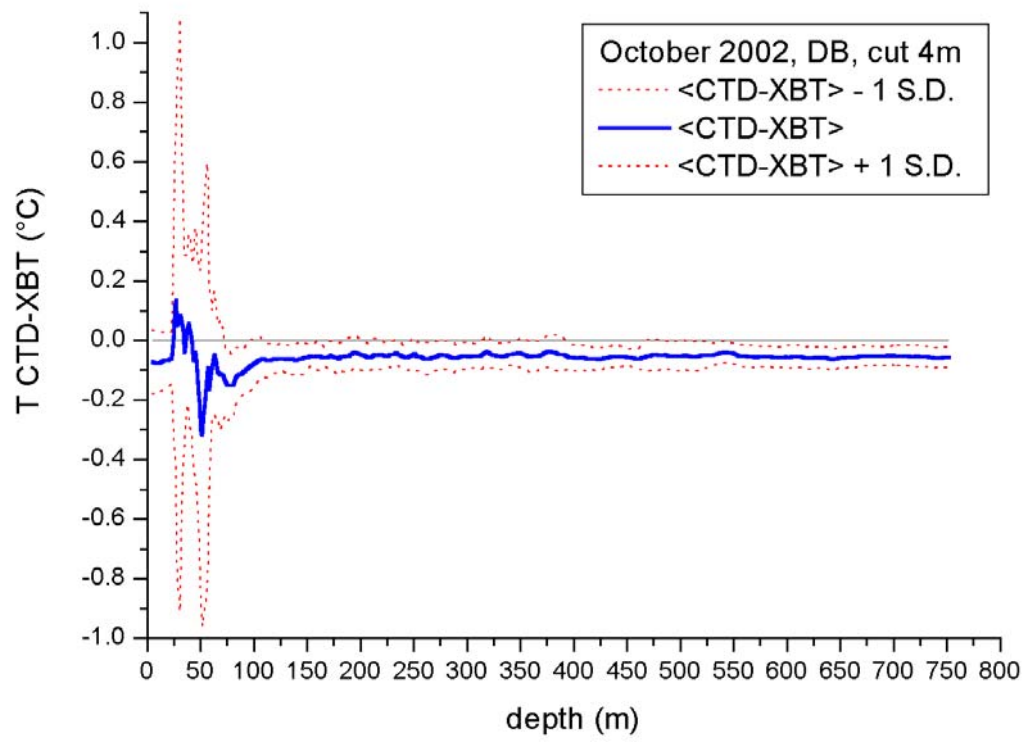


Figure 6c

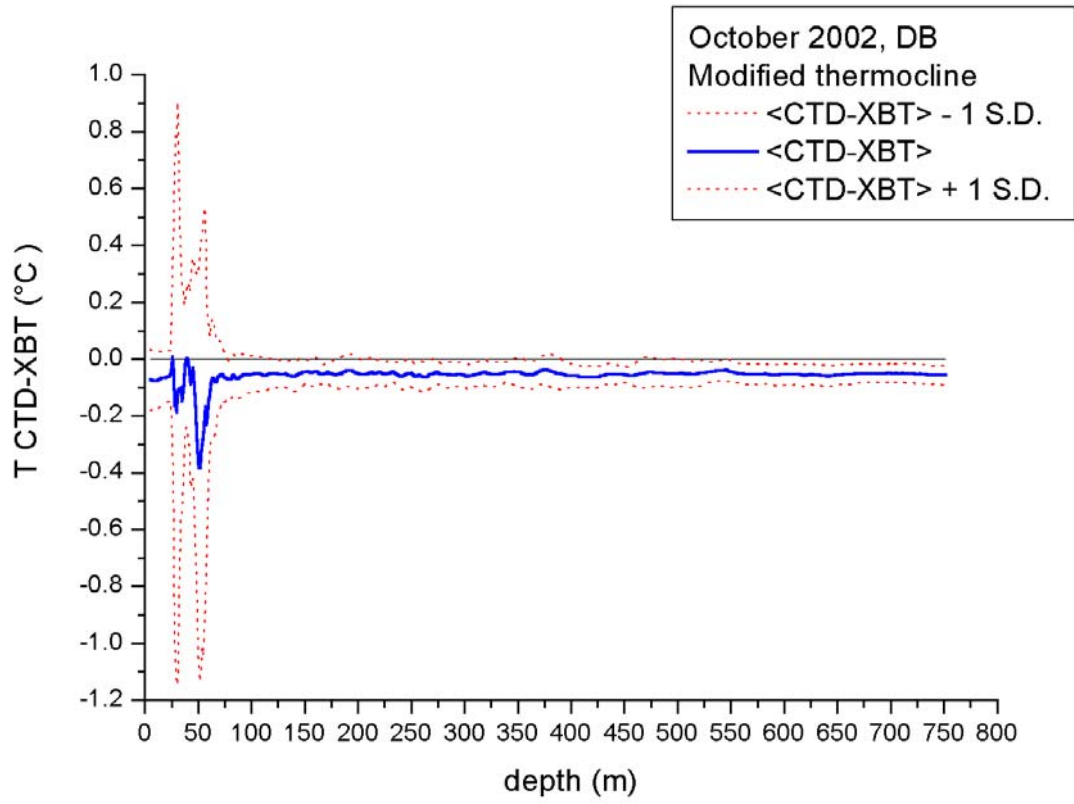


Figure 7

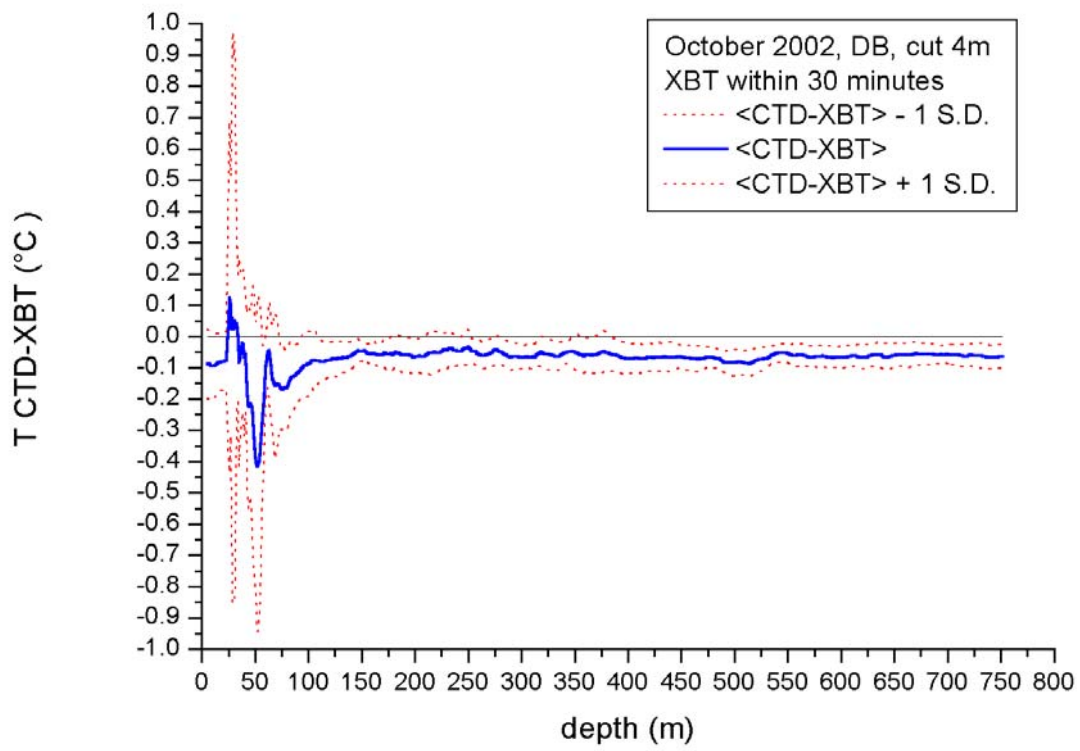


Figure 8

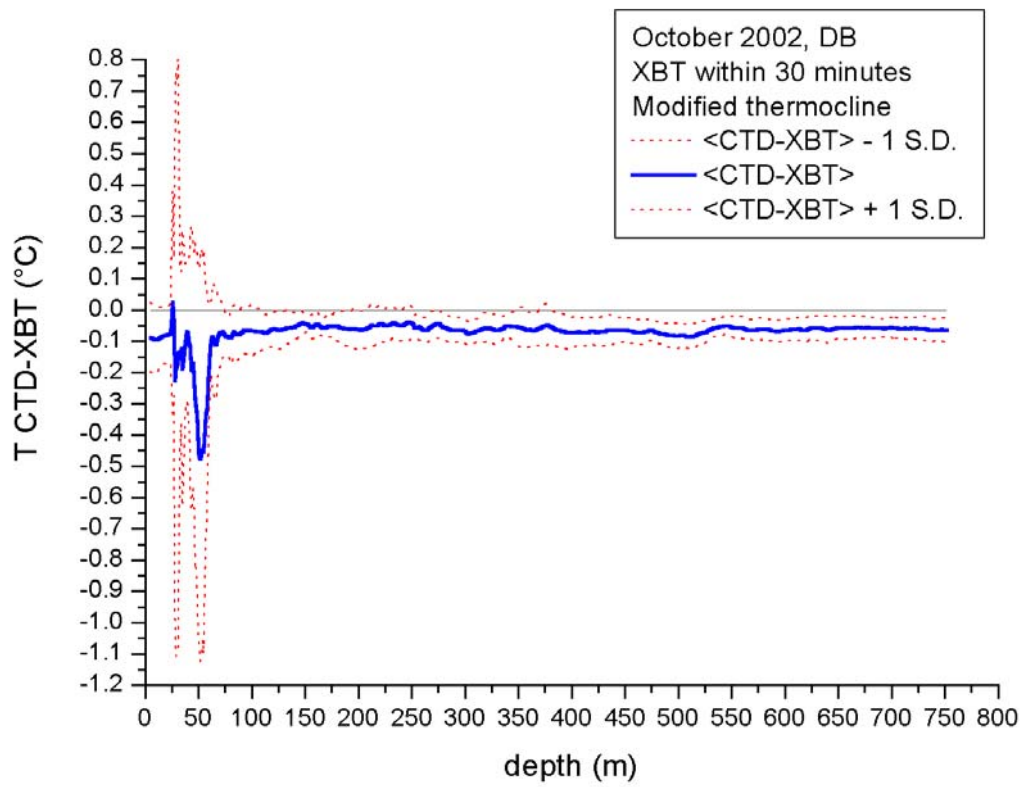


Figure 9