Efforts at NOAA/AOML to estimate and correct biases in XBT observations

Pedro N. DiNezio[1,2] pdinezio@rsmas.miami.edu

Gustavo J. Goni[2] gustavo.goni@noaa.gov

Molly Baringer[2] molly.baringer@noaa.gov

Bob Molinari[3] icpo@noc.soton.ac.uk

[1] University of Miami/CIMAS

[2] NOAA/Atlantic Oceanographic and Meteorological Laboratory

[3] International CLIVAR Project Office

Abstract

Uncertainties in the determination of the XBT depth are the most important source of error in XBT temperature profiles because XBTs determine the depth of the temperature observations indirectly from a time trace converted into depth using a fall-rate equation (FRE). The impact of systematic errors (biases) in XBT profiles was fully recognized in the 1990s when a correction was developed after a study by Hanawa et al. (1995). The XBT bias is sufficiently small not to have an impact in the study of mesoscale or interannual variability (e.g. El Nino), but becomes increasingly influential in studies of decadal variability or long-term trends in ocean heat storage.

A time-varying positive temperature bias was recently found by globally comparing climatologies derived from XBT and CTD/bottle observations. This result was later confirmed and attributed to fall-rate variations due to minor manufacturing changes over time. However, a recent study of the global XBT database shows that the time-dependent XBT bias may be explained as a superposition of a depth (fall-rate) bias and a pure thermal bias. Because the ocean is thermally stratified, depth errors and pure thermal errors cannot be separately identified when comparing climatologies. These studies provide robust evidence of both depth and pure thermal biases in the XBT data, however, the origin of time-dependence of these errors remains unclear.

XBT profiles currently make up about 25% of the current global temperature profile observations, XBTs have provided over 30 years (1970-2000) a large (>25%) fraction of the ocean observing system for upper ocean thermal observations, and, in addition, are currently the most important platform for monitoring ocean heat transport. Thus attributing the origin of the biases is important to understand potential biases that may arise in the future. Additionally, systematic biases between observing systems with disparate quality capabilities, such as Argo and XBTs, need to be assessed to avoid introducing future spurious climatic signals in heat storage when data from the two systems are combined.

The following studies are currently being carried out at NOAA/AOML to advance these questions:

1. Identification of fall-rate and pure temperature biases between XBT and Argo profiles.

2. Detection of time-dependent fall-rate bias using side-by-side XBT and CTD casts with XBTs of different manufacturing dates.

3. Evaluation of different recording systems.

4. Study of the hydrodynamics of the XBT probes.

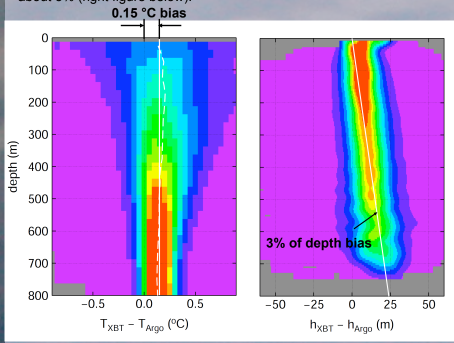
5. Development of an XBT probe capable of measuring pressure at selected depths.

1. Identification of fall-rate and pure temperature biases between XBT and Argo profiles.

Because the ocean is thermally stratified, fall-rate errors and pure thermal errors cannot be separately identified when comparing climatologies.

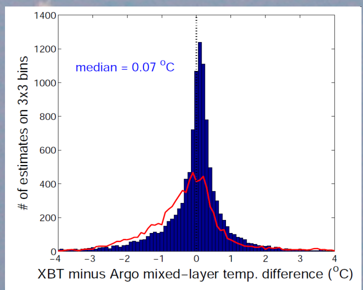
During 2000-2009, the differences in the thermal structure (left figure below) show a systematic and nearly constant-with-depth warm bias of 0.15 °C that can be attributed to a systematic error in the XBT thermistor.

However, these temperature differences between XBT minus Argo profiles can also be interpreted as a bias in the depths of isotherms of about 3% (right figure below).



Frequency distribution of the XBT minus Argo differences in temperature (right) and isotherm depth (left) as a function of depth. Colors indicate the number of 2°x2° bins where the XBT minus Argo climatologies have a given value (x-axis) for each depth (y-axis).

Differences between the temperature of the mixed-layer estimated from XBT and Argo are indicative of *pure* temperature biases because depth errors do not show as temperature differences in the absence of of temperature gradients.

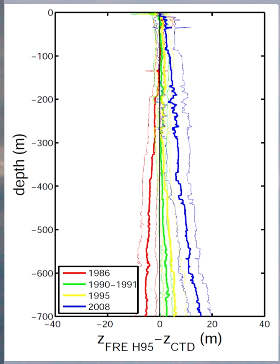


The frequency distribution of the XBT minus Argo temperature differences in the mixed later (figure above, blue bars) shows a rather narrow Gaussian distribution. The median of these differences is not zero, suggesting a 0.07 °C warm temperature bias in XBT observations with respect to Argo.

This 0.07°C warm bias in the mixed-layer explains about 50% of the 0.15°C temperature bias assuming that this temperature bias is systematic, thus present in the full water column.

2. Detection of time-dependent fall-rate bias using side-by-side XBT and CTD profiles

Only collocated XBT and CTD casts can be used to unambiguously separate depth and temperature errors by comparing the vertical gradient in temperature. During a recent research cruise in the tropical Atlantic, NOAA/AOML scientists collected collocated XBT and CTD profiles with XBTs manufactured in 1986,1990-1991,1995 and 2008. Analysis of these profiles shows strong evidence for time-dependent changes in the XBT fall-rate (figure below).



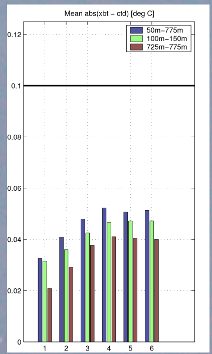
Depth differences between co-located XBT and CTD profiles collected during s research cruise in the tropical Atlantic in 2009. XBTs manufactured on four different years (colors) were dropped in the 2009 cruise.

manufacture date	stretching factor	temperature bias
1986	3.8 ± 0.2	- 0.06 ± 0.15
1990 – 1991	2.8 ± 0.2	- 0.03 ± 0.03
1995	2.4 ± 0.2	- 0.01 ± 0.04
2008	1.2 ± 0.2	- 0.00 ± 0.06

Dates included in the Hanawa et al. (1995) correction which estimated a stretching factor of 3.6%

These results provide strong evidence that the Hanawa et al. (1995) correction was adequate during the 90s, however, the original Sippican FRE coefficients are more adequate for the years after 2008.

3. Evaluation of different recording systems



XBT profiles obtained using six recording systems were compared with co-located CTD profiles in order to determine whether the XBT bias is associated with any of the recording systems currently used operationally.

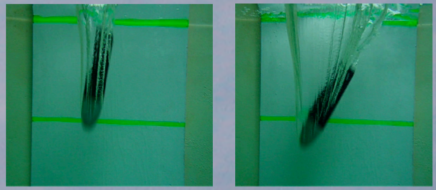
However, all recording systems temperature differences about the same magnitude of 0.05ºC (left figure).

1. aomlauto
2. devilhand
3. seasauto
4. seashand
5. sioauto
6. siok98

Depth-averaged temperature differences between co-located XBT and CTD profiles collected during a research cruises in the tropical Atlantic on 2007. The XBT profiles where collected using six different recording systems.

3. Study of the hydrodynamics of the XBT probe

Hydrodynamical transients during the initial descent of the XBT probe have also been hypothesized to introduce depth errors that can bias an entire XBT profile. AOML engineers and scientists are studying these processes order to better include their effect in the XBT fall-rate equation. Experiments in a tank indicate that these transients last a few tenths of a second, even if the the probe does not enter the ocean in a vertical direction (figure below).



4. Development of an XBT probe with pressure switches

Improving the XBT technology could be an alternative and effective path to reducing future errors and biases. During the 90s, an attempt was made to do include pressure sensors in the XBTs. The prototype included a pressure switch that recorded the pressure (i.e. depth) at fixed depths during the descent of the probe. These "real" depth observations could then be used for calibrating the depth estimated using the FRE. This effort was not successful due to several technological limitations that dramatically reduced the shelf life of the XBT. Recent technological advances in cost and reliability of pressure sensors and digital systems could now make this prototype viable. Moreover, a few pressure switches strategically activated during the descent could substantially reduce the depth errors in both fall-rate and surface offset.

Conclusions

1. The XBT minus Argo differences in the mixed-layer suggest a "pure" temperature bias of about 0.07°C during 2000-2009, potentially linked with systematic errors introduced by the XBT thermistor or the recording system.
2. Co-located XBT and CTD casts in the tropical Pacific suggest that the fall-rate bias in the XBTs has changed with time. These results indicate that the Hanawa et al. (1995) correction was adequate during the 1990s, but is not longer accurate.
3. Comparison of XBT profiles obtained using different recording devices and co-located CTD profiles shows that the XBT biases do not depend on the recording system.

Recommendations

1. XBTs where not designed to measure temperature with the accuracy required to observe the warming of the global ocean due to increasing greenhouse gases. However, a few "real" depth observations obtained with pressure switches could improve the quality of the profiles collected with this versatile instrument.
2. Continue the collection of co-located XBT and CTD profiles for monitoring current and future changes in fall-rate and temperature biases.

Acknowledgements

Claudia Schmid provided the quality controlled XBT and Argo profiles. Rick Lumpkin run the side-by-side XBT - CTD casts. Altimetry data is from AVISO.

Funded by NOAA/OCO through the Ship Of Opportunity Program.