XBT Bias and Fall Rate Workshop

Summary Report

University of Hamburg, KlimaCampus,
Hamburg, Germany
25-27 August 2010

University of Hamburg - KlimaCampus
Hamburg

September 2010

Workshop organization

On August 25-27 2010, a workshop on biases in the XBT data was held at the Hamburg University, Germany. The workshop was hosted by the KlimaCampus of the University (the organizers were Viktor Gouretski and Ingo Harms). Travel support for six workshop participants was provided both by the KlimaCampus and the International CLIVAR Project Office. The venue for the Workshop was the building of the Centre for Marine and Atmospheric Sciences (ZMAW).

The workshop was organized following the recommendations of the CLIVAR Fourth Global Synthesis and Observations Panel Meeting, held on 11-13 November 2009 in Tokyo.

The workshop was attended by 27 participants from the following organizations:

- University of Hamburg, KlimaCampus, Hamburg, Germany
- German Maritime and Hydrographic Agency, Hamburg, Germany
- Atlantic Oceanographic and Meteorological Laboratory, NOAA, Miami, FL, USA
- Pacific Marine Environmental Laboratory, NOAA, Seattle, WA, USA
- NOAA , Office of Oceanic and Atmospheric Research, Silver Spring, MD, USA
- Scripps Institution of Oceanography, University of California, San Diego, CA, USA
- Jet Propulsion Laboratory, California Institute of Technology, Pasadena, CA, USA
- Naval Postgraduate School, Monterey, CA, USA
- National Oceanographic Data Centre,Silver Spring, MD, USA
- TSK-America, Inc., North Bend, WA, USA
- Lockheed Martin Sippican, Marion, MA, USA
- Institute of Atmospheric Physics, Chinese Academy of Sciences, Beijing, China
- National Institute Of Oceanography, Dona Paula – Goa, India
- CSIRO, Hobart, Australia
- Tohoku University, Sendai, Japan
- Meteorological Research Institute, Tsukuba, Ibaraki, Japan
- Oceanographic Institute, Federal University of Rio Grande, Rio Grande, Brazil
- South African Institute for Aquatic Biodiversity, South Africa
- ENEA National agency for new technologies, Energy and sustainable economic development, S.Teresa, Italy
- CLS / Space Oceanography Division, Ramonville Saint-Agne, France

2. Workshop objective

During about a 35-year period since 1967 expendable bathythermographs provided the majority of the subsurface temperature profiles down to about 750 meters depth. Though XBTs were not designed for climate relevant applications, because of their historical abundance, their data were used for the estimation of the global ocean heat content changes. However, subsequent analyses of concurrent XBT and CTD/bottle observations indicated differences in temperature profiles, likely resulting due to errors in the XBT fall rate equation and to a thermal bias. In general, these errors have introduced a time-variable warm bias in the global XBT data base and led to erroneous estimates of the decadal global heat content variability. The recognition of the bias problem stimulated the organization of a first international XBT fall rate workshop which was held in March 2008 in AOML, Miami.

The current Bias and Fall rate Workshop was conceived as a follow-up meeting of international XBT experts to 1) summarize the progress achieved since the Miami workshop, 2) seek consensus on the nature and size of the biases in XBT data, and 3) to make recommendations for future work on reducing these biases (in both historical and future XBT data sets). The workshop program included presentations and discussions on specific topics related to all kind of systematic errors in the XBT data.

3. Scientific Presentations

Viktor Gouretski (KlimaCampus) welcomed the participants on behalf of the organizing committee and introduced the agenda for the meeting. Prof. Detlef Stammer, director of the Institute of Marine Research, welcomed the Workshop participants and noted the importance of this meeting both for the improvement of the available historical database and for the future XBT observations in the Global Ocean. He also briefly outlined scientific activities within the recently established KlimaCampus of the University of Hamburg.

The scientific presentations during the workshop can be crudely subdivided in several groups:

1) Assessment of XBT biases from the co-located side-by-side inter-comparisons.
2) Assessment of XBT biases from inter-comparison of binned reference and XBT data.
3) Effects of different XBT correction schemes on ocean heat content calculations.
4) Numerical studies of the XBT fall rate.
5) Managing the modern XBT data stream

Viktor Gouretski (KlimaCampus, Germany) started scientific presentations by providing a review of the XBT bias studies based both on the peer-reviewed and unpublished publications between 1965 and 2010. He noted that a considerable progress has been achieved since the Miami workshop. Many earlier difficult-to-access studies on XBT behavior have come to light, some of which identified clear biases – commonly a warm thermal bias. Viktor pointed out the dearth of knowledge of biases from the pre-digital era where XBT data were recorded on strip charts. The upper 10-50m presents a particular challenge as it may be affected by the well known transient problem, plus probe acceleration. Another outstanding and unresolved question is whether fall rate is affected by ocean temperature.

Grant Johnson (LM Sippican, USA) presented results on evaluation of the XBT fall rate by comparison with echo-sounder bottom depth measurements (as yet un-calibrated for the temperature effect on sound speed). This method of drop rate evaluation has been utilized since May 2009 off the coast of Florida, USA and will continue to be used in the future as part of the routine quality assurance testing, albeit with some improvements. It has been found that some groups of Deep Blue probes produced before August 2008, while meeting the stated accuracy, drop statistically slower than probes produced after this date. This was speculated to be due to a reduction in the gap between the nose and body of the probe (from 0.5mm to 0.21mm in July 2008). The gap was originally introduced in the late 1999 to accommodate the installation of vexar netting over the wire spool. This discussion underscored our lack of knowledge of which aspects of the shape of the XBT probe are most important in determining its fall rate.

Shoichi Kizu (Tohoku University, Japan) presented evaluation results of the fall rate for the recent T-7 probes manufactured by LM-Sippican and TSK. The two companies' T-7 have been believed to fall at the same rate in the water, but they had never been compared directly at sea. A side-by-side fall rate comparison between TSK T-7 and LMS T-7 in May 2008 in the sea near Japan found that the TSK T-7 falls faster than the LMS T-7 by about 3.5%. Their fall rates were also dependent on water temperature. A detailed inspection of the probes revealed appreciable differences in both their weight and structure. The relative difference in fall rate was greater than that in weights (about 2%), and this points to the effect due to structural differences between the probes. It was clearly shown that recent LMS T-7 and TSK T-7 should be treated as different types, but it is still unknown when and how those differences in weights and structures occurred.

Gustavo Goni (NOAA/AOML) briefly outlined the Ship of Opportunity Program for the deployment of the XBT on selected transoceanic sections and described NOAA/AOML efforts to resolve XBT fall rate equation issues. It was noted that about 19,000 XBT profiles contributed to the global subsurface database in 2009. Gustavo further presented inter-comparison results at stations in the equatorial and tropical Atlantic Ocean where probes manufactured in past years were dropped as well as modern probes. The fall rate was found to change steadily across these year batches such that probes manufactured in 1986 were close to a H95 fall rate, but subsequent batches moved closer to (but not in full agreement with) the original Sippican 1965 fall rate. The inter-comparison results did not find any clear thermal bias.

Pedro DiNezio (NOAA/AOML, USA) presented results of an XBT vs. profiling float data inter-comparison study. Global comparison of the XBT and Argo isotherm depths shows an about 3% depth underestimation by the XBTs before 2000, but confirms the validity of the Sippican fall rate equation for more recent manufacturing dates. The study also reveals a 0.07^{o}C positive thermal bias for the XBT data within the upper mixed layer.

Franco Reseghetti (ENEA, Italy) summarized results on XBT performance mainly based on XBT vs. CTD inter-comparisons in the Mediterranean Sea between 2003 and 2010. The XBT depth range was found to considerably exceed the value specified by the manufacturer without an evident deterioration of the data quality. A dependence on acquisition system (warm bias for an old recorder and cold but time-variable bias for a more recent device), and a depth overestimation by about 1 meter within the upper 130 meters were reported. Tests in the shallow water (less than 30m) with accurately measured bottom depth indicated a slower fall rate compared to the Sippican fall rate equation. The influence of the height of the launching platform has been also verified, but more side-by-side inter-comparisons are needed for statistically robust results. Laboratory tests demonstrate a light temperature-dependence of the thermal bias, with bias increasing with temperature but with a dependence on the probe type. Comparison with Argo float temperatures (mainly in Tyrrhenian Sea) indicate a positive XBT temperature bias of 0.06^{o}C.

Rebecca Cowley (CSIRO, Australia) presented results of a comprehensive side-by-side inter-comparison study, in which all publically available datasets of direct XBT and CTD comparisons have been collated with previously unavailable comparisons from CSIRO Marine and Atmospheric archives in order to ascertain fall rate errors and temperature bias in the XBT T-7 and Deep-Blue probes back to 1987. It has been shown, that a simple weighted linear depth correction reduces the XBT temperature bias. A time-dependent depth error (after applying Hanawa et al. 1995 corrections) is estimated to be within +/-2%. The study also reveals a positive depth error intercept of about 2 meters for all years.

Birgit Klein (German Maritime and Hydrographic Agency (BSH), Hamburg, Germany) gave an overview of the long-term monitoring of the Sub-polar North Atlantic by the BSH XBT program. This program has been initiated in the end of the 1980s and provided an unprecedented coverage of the latitude band centered around 48N between Europe and North America. Parallel to the XBT observations the CTD/Bottle measurements have been conducted on a number of the BSH cruises between the beginning of the 1990s and 2010. Klein noted, that these XBT data are obviously available in the world hydrographic database in a reduced form, whereas original data (more suitable for the XBT quality analysis) may be also made available for the community. Preliminary inter-comparison results characterize the XBT data to be on average warmer than the concurrent CTD data

Glenn Pezzoli (SIO, San Diego, USA) presented an overview of the Shipboard procedures for XBT data quality implemented in the Scripps Institution of Oceanography. He stressed the importance of proper grounding of the system, and the need to use test canisters to confirm proper installation. These procedures return a high percentage of good data (97%). Using the XBT launch location on the stern at a main deck level instead of bridge wings is crucial for obtaining a high percentage of good data from measurements on the ships of opportunity. Immediate detecting and re-dropping questionable XBT profiles further helps to identify erroneous data. Glenn noted that thunderstorms cause noise in XBT systems and data.

Mathias van Caspel (Institute of Oceanography, Rio Grande-RS, Brazil) informed on the monitoring of the Southwest Atlantic upper ocean temperature field with a high resolution XBT line (Listed under NOAA/AOML database as AX97). The mean depth difference between the CTD and XBT (T-5 probes) in the upper 975m was approximately 50m based on 45 XBT/CTD pairs. A new regional fall rate equation was suggested as $z = 6.5728 * t - 0.0028 * t$. Applying this equation, the mean depth mismatch between CTD and XBT measurements dropped to about 5m.

Tammy Morris (Bayworld Centre for Research and Education, Cape Town, South Africa) presented results of the XBT vs. CTD inter-comparison study for the ocean area within the Mozambique Channel in the South West Indian Ocean, which is characterized by a strong mesoscale eddy field. XBTs, launched on four multi-disciplinary research cruises between 2007 and 2010. Only CTD/XBT pairs with a separation less than 20 km were considered. Preliminary results from the December 2008 cruise showed XBT data to have an overall warm bias of 0.26 ˚C for the entire water column and 0.33 ˚C for the top 100 m representative of the thermocline. An XBT data warm bias of 0.22 ˚C persists for the water column below 100 m suggesting greatest instrument inconsistencies to occur within the thermocline region suggestive of a fall rate error.

Joaquin Trinanes (AOML/NOAA, Miami, USA) reported on the status of the migration of XBT GTS data format from traditional alphanumeric codes to BUFR (Binary Universal Format for the Representation of data), which is the WMO standard format for observational data distributed via the GTS/RMDCN. The BUFR template for XBT data under validation should be able to incorporate all necessary fall-rate equation related metadata, as well as the full high resolution profile, which implicitly provides information about the FRE.

Vissa Gopalakrishna (National Institute of Oceanography, Dona Paula, Goa, India) presented XBT/CTD inter-comparison results from the cruises conducted in the Arabian Sea and the Bay of Bengal during 2008-2009 by Indian research ships. He pointed out a significant probe-to-probe variability within a cruise as well as cruise to cruise variability. New FRE coefficients were obtained for each cruise, and a small (~0.01°C) temperature bias was also identified for XBTs. Due to the different values, no new FRE coefficients are proposed for either the Bay of Bengal or Arabian Sea XBTs. Gopalakrishna further presented new FRE coefficients (one for each basin) for XCTDs, which were found to be significantly higher than the manufacturer's coefficients or those from previous tests, probably due to the influence of temperature on XCTD FRE coefficients.

Stephanie Guinehut for Mathieu Hamon (CLS / Space Oceanography Division, France) reported on the empirical correction on XBT fall rate and its impact on heat content EOF reconstruction. A comparison was done between the binned XBT and CTD/Bottle data (bin size 1°*2°*15 days). An analysis of the annual medi an bias on depth suggests that it is necessary to apply a second order correction and a depth offset representing XBT measurement errors during the XBT deployment. The data have been separated in several categories: according to the XBT type (shallow or deep) and with respect to the low (30°N-30°S) or high latitude. An iterative EOF procedure is used for the reconstruction of spatial temperature fields. The analysis confirms earlier results which explain the heat content maximum in the upper 700 meters during the 1970's as caused by the bias in the XBT data. This study suggests existing suggested corrections remain inadequate, and also confirm that separate treatment of deep and shallow probes is necessary.

Kimio Hanawa (Tohoku University, Japan) presented a simple numerical model describing the fall rate of an XBT probe. The model comprises an equation of motion for a body falling in a fluid, and an equation describing the change of the probe weight during the fall. The coefficients of the normal (algebraic) fall rate equation are obtained by a least-square fit of a numerical solution. Numerical experiments allow investigation of the dependence of the fall rate on the unknown drag coefficient and on its change with depth. Numerical experiments suggest that the fall rate difference of 0.24m/s between the Sippican and TSK probes can not be explained by the difference in their weights, and the assumption is made, that it is the difference in shape that results in different effective drag coefficients for the two probe types. Kimio plans to validate the model using XBT/CTD inter-comparison experiments. One key result is that variations in the entry velocity of the probe results in the correlation between the *a* and *b* FRE coefficients found from fits of the class quadratic FRE to field data.

Lijing Cheng (Institute of Atmospheric Physics, Chinese Academy of Sciences, Bejing, China) introduced a new statistical technique to estimate three major biases of XBT probes (fall rate error, start-up transient and pure temperature error). The new method is applied to temperature profiles instead of vertical gradient temperature profiles. A new fall rate equation is proposed, where an additional term is introduced to the standard FRE, which describes transient effects occurring when the probe enters the water and during the fall within the near surface layer. Two sets of profiles from XBT vs. CTD inter-comparisons, collected near Barbados in 1990 and in Western Mediterranean (2003-2004, and 2008-2009), have been used to test the method. The new integral method significantly reduces both the temperature difference between DB and T7 XBT and CTD profiles and their standard deviation (namely, less than 0.1^{o}C for both datasets, being randomly distributes around the null value). The maximum depth error computed with the datasets near Barbados is within 1.1% of its real value. Results also indicate that the method has a good performance both for regions with a very high and very low temperature gradient.

Josh Willis (Jet Propulsion Laboratory, USA) showed results of the comparison between the in situ and satellite observations of the sea surface temperature. His analysis indicates that the agreement between the Argo SST and the GHRSST NCDC SST is better than 0.05℃ for the temperature range between 5 and 27 ^{o}C. However, the XBT-derived SST deviates significantly from the GHRSST NCDC SST, being lower by 0.4 ^{o}C at 5 ^{o}C and higher by 0.2 ^{o}C by 30 ^{o}C. XBT vs. Argo inter-comparison reveals similar discrepancy, with XBT temperatures being colder than Argo temperatures by 0.2 ^{o}C at 0 ^{o}C and being higher by 0.15 ^{o}C by 30 ^{o}C. The cause for the discrepancy is not clear, and is in a clear disagreement with other inter-comparisons of binned data.

Tim Boyer (NODC, USA) demonstrated the effect of different XBT correction methods on the global heat content anomaly estimates. Six correction methods have been compared using the same data set subjected to the same quality control method. The effect of corrections on assimilation model calculations was also estimated. In addition, the US NODC XBT bias web-page was introduced. Most fall rate only corrections do not fix the near-surface biases – all perform poorly there. Tim also introduced the US NODC XBT bias web-page.

Masayoshi Ishii (MRI, Japan) showed the results of his broad-scale ‘buddy’ calculation where probe type was separately analyzed. He finds a depth error that is linear with depth but changes yearly. He underscored the need to pay attention to the statistics – using broad-scale buddies, a linear depth model requires only 10 000 pairs to resolve the bias, but a quadratic model requires over 30 000 buddies. Masayoshi stressed the need to separate out TSK from LM Sippican probes. He also showed the impact of XBT biases on the performance of a new decadal prediction system (MIROC). When biases are removed, there is a clear improvement in system skill (Mochizuki et al, PNAS, 2010; Yasunaka et al (submitted)).

Shoichi Kizu (Tohoku University, Japan) reported on preliminary comparisons of electric leakage in LM Sippican probes compared to TSK. He did some extreme wire stretch tests in three temperature waters (3℃, 10℃ and 20℃) in th e laboratory. He measured the stretch of the wire at time of insulation break. TSK wire is hard to break compared to LM Sippican wire. In cold (3℃) water LM Sippican wire broke more eas ily and frequently due to pure stretch without physical scraping of the wire coating. Using a simplified circuit diagram provided by TSK, Kizu also explained that leakage in wire or thermistor could cause a positive temperature bias

John Lyman (Pacific Marine Environmental Laboratory, USA) reported on the uncertainties in global heat content estimates due to the errors in the XBT data. Global heat content anomaly for the upper 700 meters was estimated for the time period 1993-2009 for seven XBT correction methods. It has been shown that the uncertainty due to the XBT systematic errors dominates among other uncertainty factors, however a robust warming is confirmed.

Rebecca Cowley (on behalf of Ann Thresher, CSIRO) presented proposals for a new GTSPP format, which would accommodate more meta-data and higher resolution data in the real time data stream. The proposed new netcdf format for the GTSPP is based on the Argo netcdf format currently in use. Input and comments were requested from the group.

4. Workshop statements, conclusions and recommendations.

The Workshop emphasized a significant progress in understanding causes for systematic errors in XBT data since the previous XBT Fall rate Workshop in 2008.

4.1 Side by side XBT/ CTD inter-comparisons

In situ side by side XBT/CTD inter-comparisons provide the most reliable way of the XBT bias assessment. However, significant discrepancies exist between different inter-comparison studies. As a consequence, more in situ inter-comparisons are needed to improve our knowledge of XBT bias statistics, especially in the cold regions of the oceans. Thus the workshop encourages agencies to collect more side-by-side data during CTD cruises and to submit these with appropriate meta-data to Tim Boyer at NODC.

A number of new side-by-side XBT vs. CTD inter-comparisons, along with historical XBT/CTD profile pairs, extended considerably the existing database of the in situ tests of the XBT performance.

On average positive *thermal bias* was confirmed during the majority of the inter-comparison studies. A typical magnitude of this bias is about 0.05^{o}C, but may vary from probe to probe and between the inter-comparison experiments. The need to compile adequate pair numbers was underscored. Around ~30 pairs are needed to form useful estimates of these small but important biases. There are suggestions that the thermal bias may be dependent on the acquisition system, but definitive results are not available. The thermal bias appears to depend on temperature, but the strength of this effect is not clear as more data from cold regions is required. Thermal bias seems to be probe-manufacturer independent. The majority of the side-by-side experiments indicate that this temperature errors have remained approximately constant (within few hundredth degrees C) during the 1986-2008 period. Studies comparing binned data suggest a certain time-dependence of the thermal bias for the same time period, however within a typical range of $\pm$0.03^{o}C.

The fall rate below the upper 50-150 m is faster than given by the LM Sippican's original FRE in some studies. A surface depth offset has been diagnosed in most studies, indicating depth overestimation in the near-surface layer.

Side-by-side experiments provide strong evidence for time-dependent changes in the XBT fall-rate during the 1986-2008 period. All studies of this type indicate that the Hanawa correction was adequate during the 90s, but for the years after 2008 the original LM Sippican fall rate equation works better than that derived by Hanawa et al. 1995. Respectively the hypothesis that both thermal and fall rate bias are time-dependent can't be ruled out.

Some evidence suggests the XBT fall rate is dependent on the ambient water temperature, but greater pair numbers are needed in cold waters to reliably confirm and quantify this effect.

LM Sippican T-7 and TSK T-7 should be treated as different types, at least as far as their recent probes are concerned.

Comparisons between the XBT reported bottom depth and the bottom depth measured independently and precisely by an echo-sounder or other instruments provide an effective way to directly estimate the depth bias. Direct measurements of the fall rate similar to those which are conducted by LM Sippican should be continued, but with larger numbers of pairs (~30) to ensure statistically stable results. Such direct measurements should also include tests at shallow bottom sites to better investigate transient behavior of the XBT probes in the near-surface layer (LM Sippican, ENEA,...), and should ensure careful calibration of echosounder speed.

We encourage teams to carry out fall rate tests for XBTs with older manufacturing dates. Before deployment however, we encourage these groups to weigh and note physical characteristics of the old probes compared to new ones.

The group identified a need to produce a manual recommending procedures for conducting side-by-side XBT vs. CTD tests. Shoichi Kizu pointed out an existing document produced by SOOP-IP which forms a clear basis for an update (http://www.jcommops.org/soopip/doc/manuals/soopog/XBT-XCTD%20std%20test%20procedures.pdf) (CSIRO, ENEA, AOML?)

Continue comparison between in situ XBT vs. CTD inter-comparisons and binned-data inter-comparisons(NODC/NOAA, KlimaCampus?)

Further acquisition system inter-comparisons needed (SIO, ENEA?)

The potential impact of the launch height on XBT biases remains essentially unknown. Results from few experiments with varying launch height provided statistically insignificant results. More tests are needed (possibility for such tests at SIO?). Glen Pezzoli suggested the SIO HD network provides an ideal opportunity to compare high (bridge) against low (fantail) drop heights with the ability to drop enough pairs to produce good statistics.

Comparison of XBT lines occupied by VOS (usually a higher than nominal launch position) and by the research vessels (usually close to nominal launch height) can be done using existing data (e.g. 48^{o}N, North Atlantic) (BSH and KlimaCampus?)

The group also recommended to draft a statement (summary) on XBT accuracy, confirming the suitability of the XBT data for many not climate relates applications (AOML, CSIRO, ENEA, Tohoku University?). Emphasize the possibility to significantly reduce systematic biases in XBT data with a subsequent use for climate related applications.

4.2 Global-scale XBT vs. CTD comparisons:

Further investigations are needed on thee causes for of discrepancies between the different global XBT vs. CTD/Argo inter-comparison studies. For example, Goni and DiNezio diagnose a rather constant depth correction multiplicative factor whereas Gouretski-Reseghetti find a highly depth-variable stretching. Willis finds very high XBT T-biases vs. SST data differences which are not confirmed in binned XBT vs. CTD analyses by Boyer and Gouretski&Reseghetti.

Kizu's work clearly suggests the need to separately analyse TSK probes in broad-scale buddy analyses by all groups. This requires a clear way to identify probe source, which is not part of historical meta-data. Shoichi Kizu inquired about the sales territories of the two companies, supplied below:

> ***Sales Territory (as of 26 August 2008; provided by TSK)***
>
> ***LM Sippican:***
> *Europe, North America, South America, Australia, NZ, India, Malaysia, Singapore, South Korea (mil.), Taiwan (mil.), Thailand (mil.)*
>
> ***TSK:***
> *Japan, Myanmar, Estonia, Latvia, Lithuania, Philippines, China, Armenia, Azerbaijan, Belarus, Georgia, Kazakhstan, Kyrgyz, Moldova, Russia, Tajikistan, Turkmenistan, Ukraine, Uzbekistan, South Korea (civil.), Taiwan (civil.), Thailand (civil.)*

While Japan is the largest customer for TSK, the company says that it sporadically received orders from out of Japan, but the quantity for each was not large - typically something like a few (or several) tens of probes per country as an annual total for 2009. The company also commented that the total of probes sold to China (incl. Hong Kong), Philippines, Russia, and Taiwan (Chinese Taipei) during the recent five years is about 1500.

Repeat fall rate bias estimates for TSK and LM Sippican probes separately (NODC/NOAA, KlimaCampus)

The possible dependence of fall rates on ship-speed could also be explored by compiling buddies into groups based on data taken from research vessels (< 12knots) versus SOOP container ships (> 20knots). This may be possible in the Argo era or using altimetric pseudo-profile buddies.

4.3 Correction methods

Reconciling the conclusions from side-by-side experiments and from analyses comparing climatologies remains the main obstacle towards a definitive correction for XBT errors. Side-by-side experiments do not go back to the 70s so it remains unclear whether the 70s "bump" is an artifact of a temperature bias, possibly linked with the strip-chart recorder, or a fall-rate bias. Both type of evaluations have advantages and disadvantages. Side-by-side experiments are the only methods that can separate "pure" temperature errors from depth errors, however this method may lack statistical robustness due the lack of sufficient collocated pairs of XBT and CTD casts. In contrast, larger amounts of data can be used when climatologies are compared, thus providing more robust results. However, separation of temperature and depth errors has to be performed carefully in order to avoid confusing them.

Suggested correction procedures give significantly different results and no currently available scheme appears ideal yet, in the sense the significant residuals remain (e.g. discrepancies between the global heat content anomaly time series). Further comparisons are needed to exclude effect of different methodologies and QC procedures.

The group encourage to repeat bias calculations using the formation of a best identical datasets (NODC/NOAA, KlimaCampus) for comparisons. NODC, by maintaining a nearby buddy data base, can assist teams in evaluating proposed bias corrections schemes.

4.4 XBT fall rate model studies

The numerical model study reported by Hanawa provides an alternative way to investigate the fall rate problem. Besides field studies, the group encourages investigations into probe-fall behavior in special tank facilities (SIO, ENEA, IFREMER) or via detailed computation fluid dynamical studies. Currently, the community has no clear understanding of what aspects of the XBT shape and texture is most important in modulating its fall rate. Work reported at this meeting clearly demonstrates that probe weight is not the dominating factor. It would be extremely useful to understand which aspects of shape determine fall rate, as this could then guide manufacturing tolerances in the future to reduce variability and change.

4.5 Questions to LM Sippican and TSK:

The workshop seeks further assistance from LM Sippican and TSK which addresses the following issues in the following way:

1) Could a search be done for any internal historical “unknown” old technical reports or data to share them with the community? Data on strip-chart recorder performance, in particular, is very important.
2) Search for, and if possible, release of data to NODC from annual Bermuda QA test casts, for comparison with Bermuda Time Series Station hydrographic data. Could current in situ fall rate tests using an echo-sounder measurements be extended to include a shallow water site? Could AOML collaborate by providing a CTD during these tests?
3) Could a summary of manufacturing changes, their implementation dates (and Serial Numbers) be made available? Even qualitative information could be of great use in interpreting observed probe behavior changes. In particular adding date and serial number to, and expanding the following known changes would be very helpful:
   - Change to new wire (more springy) around or before 1997
   - Addition of vexar netting (around 2000?)
   - Move of factory to Juarez, Mexico
   - Change in head from motor oil to paraffin wax

4) Could manufactures notify JCOMM/SOOPIP of any changes in manufacturing?

NOAA/AOML could provide technical and man-power support for the in situ tests

4.6 Challenge for the future: XBTP

Is the development of a pressure-sensor equipped XBT feasible? Accuracy requirements must be specified by the scientific community. The development of the new probe could be undertaken within the frames of the US Small Business Innovation Research (SBIR) Program. AOML will work on a proposal to be submitted to SBIR (Small business Innovation Research) to solicit work to develop a probe similar to and XBT that can also determine pressure at given depths. The call for proposals will be in October 2011. Until this time, AOML will make estimates of how many pressure switches will be needed and at what depths.

Susan Wijffels will draft a statement of requirements for an expendable probe suitable for decadal and longer climate applications for consideration by SOOPIP and GSOP.

A continuous depth-profiling is not needed, only few pressure points would suffice to adjust the sample depth.

Other issues

Do we need to provide acquisition time along with the (calculated) sample depth? Should this field be included in the new BUFR template for XBT data?

Consider the possibility of in situ tests with XBT probe being attached to a CTD rosette. These test could help to diagnose a thermal bias and start-up transients.

Franco Reseghetti deserves special thanks for making available his electronic collection of XBT related publications for the oceanographic community. Most of this literature is represented by not peer-reviewed technical notes and reports which are usually not easily accessible through oceanographic libraries.

Draft a statement (summary) on XBT accuracy, confirming the suitability of the XBT data for many climate and ocean now and forecasting applications (GSOP, AOML,). Emphasize the possibility to significantly reduce systematic biases in XBT data with a subsequent use for climate-change related applications. This information could be in the form of an article for EOS based on this workshop report.

Could the collocated XBT/CTD profiles and associated metadata be part of a unified archive that everybody could access (e.g. through NOAA/NODC)?

Workshop presentations may be downloaded from

http://www.klimacampus.de/996.html

XBT Bias and Fall rate Workshop: Participant and Presentation List			
	Participant	**AFFILIATION**	**Title of presentation**
1	Gustavo Goni	NOAA/AOML,US	*NOAA/AOML hydrographic efforts to assess the FRE and evaluate different acquisition systems*
2	Tim Boyer	NOAA/NODC,US	*Effects of different XBT corrections on historic and recent ocean heat content calculations*
3	Pedro Di Nezio	UM/CIMAS and NOAA/AOML, US	*Some new results and work in progress on determining whether the temperature differences between XBTs and Argo are due to a temp. bias, a fall rate problem, or an offset.*
4	Joaquin Trinanes	Univ Santiago, University of Miami, and NOAA/AOML, US	*Migration of XBT GTS data format from Traditional Alphanumeric Codes to BUFR: FRE-related metadata.*
5	Glenn Pezzoli	SIO, US	*Shipboard procedures to maximize XBT data quality: What things go wrong besides fall rate error?"*
6	John Lyman	NOAA/PMEL, US	*The impact of recent XBT corrections on global upper ocean heat content*
7	Josh Willis	NASA/JPL, US	*Combining Satellite and In Situ Observations to Improve the Historical XBT Dataset*
8	Grant Johnson	LM Sippican, US	*Echo Sounder Evaluation of XBT Drop Rate off the coast of Florida*
9	Wolfgang Schlegel	LM Sippican, US	-
10	Curtis Collins	Naval Postgradual School, Monterey, US	-
11	Steve Piotrowicz	NOAA, US	-
12	Tony Escarcega	TSK - America, Inc., US	-
13	Vissa Gopalakrishna	NIO, India	*Investigation of XBT and XCTD biases in the Seas around India*
14	Viktor Gouretski	University of Hamburg, Germany	*Biases in the XBT data and their corrections: a review*
15	Birgit Klein	BSH, Germany	*Long-term monitoring of the Sub-polar Atlantic with the BSH XBT Program.*
16	Sabine Huettl-Kabus	BSH, Germany	-
17	Detlev Machoczek	BSH, Germany	-
18	Susan Wijffels	CSIRO, Australia	-
19	Rebecca Cowley	CSIRO, Australia	*Investigation of fall rate error and temperature bias in XBTs from global XBT/CTD pairs.*
20	Franco Reseghetti	ENEA, Italy	*Performance of XBT systems in Mediterranean Sea (2003-2010)*."
21	Stephanie	*CLS/Space Oceanogr.*	*Empirical correction on XBT fall rate and its impact on heat*

	Guinehut	*Division, France*	*content EOF reconstruction*
22	Masayoshi Ishii	MRI, Japan	*Reevaluation of Historical Ocean Heat Content Variations with Time-Varying XBT and MBT Depth Bias Corrections*
23	Kimio Hanawa	Tohoku University, Japan	*A numerical model for free-fall type sensor in order to check fall rate of prove*
24	Shoichi Kizu	Tohoku University, Japan	*Evaluation of the fall rate of recent T-7 probes manufactured by Sippican and TSK"*
25	Lijing Cheng	Academy of Sciences, PR China	*A method to estimate systematic errors of XBT including fall rate, start-up transient, pure temperature errors,*
26	Mathias R. van Caspel	Instituto de Oceanografia – FURG, Brazil	*Fall rate equation experiments in the Southwestern Atlantic and the effect on the baroclinic transports across the NOAA/AOML-FURG section AX97*
27	Tammy Morris	South African Institute for Aquatic Biodiversity, South Africa	*Inter-comparison of temperature data collected by XBT and CTD instruments: a Mozambique Channel case study*

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Hamburg, 27 September 2010