Empirical correction on XBT fall rate and its impact on heat content analysis

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Introduction

- The Expendable BathyThermograph (XBT) system does not measure directly the depth of the probe, it uses a fall rate to estimate it.

- Is there a correct depth equation for correcting temperature as a function of depth from XBT that could be applied to the global datasets?

- Gouretski and Koltermann (2007) used a CTD climatology to identify a positive temperature bias of XBT.

- Wijffels et al (2008) proposed a yearly correction which is a linear function of the depth.

- Levitus et al (2009) used a simpler temperature correction to estimate the ocean heat content.
Introduction

- The W08 correction is a reference for the treatment of XBT, but how does this correction vary with the method of comparison of XBT and CTD profiles?

- Correcting individually each type of XBT cannot be envisionned but can we refine the W08 correction including regional correction?

- What is the impact of such a correction on the calculation of the ocean heat content?
Data and method

- We used WOD05 profiles, interpolated to standard levels
  - CTD and OSD are our reference profiles
  - XBT have been processed when identification was possible with the Hanawa correction (Hanawa et al 1995)

- Rather than to use climatologies as W08, we used a collocation method (1°lat*2°lon*15 days)
  - For each individual XBT profile, we calculated the median of all CTD/OSD selected in the collocation area, to obtain a single reference profile
  - Using the median is preferred for this kind of data distribution, it reduces influence of outliers
  - Every XBT profile less deep than 200-m have been removed
  - Large influence to oceanographic cruises where CTD/XBT jointly deployed

- This method allows us to capture about $10^4$ XBT profiles per year between 1967 and 2008, or 10% of XBT profiles associated to a reference profile
Test of the W08 correction

- The W08 is a linear annual correction on depth. It separates XBTS (shallow) and XBTD (deep):
  \[ Z_{true} = Z(1 - r) \]

- The W08 corrections have been applied to our collocated profiles

*Figure: XBT-CTD median bias = original depth eq. (green) and corrected by W08 (red) integrated between 0 and 700m.*

*Figure: Median bias = original depth eq. (green) and corrected by W08 (red) function of depth on average over the study period.*
Test of the W08 correction

- The linear correction is not always performing well (with our collocation method) especially between 1975 and 1985. It provides too strong correction below 500m depth and a too small correction for surface layers.
A new correction

Second order correction

- Annual median depth correction computed using:
  \[ \mathcal{Z} = \left(T_{CTD} - T_{XBT} \right) \frac{\delta Z}{\delta T_{CTD}} \]

- The difference between collocated profiles do not seem to indicate a linear function for depth correction, but rather a second order function with an offset,

- Between the surface and 30m, the bias doesn't follow a parabolic behavior because of high variability noise due to the surface mixed layer.

- Correlation between depth correction term and the deployment latitude.

We can't distinguish XBTS to XBTD comparing depth correction at a given depth.

Median XBT-CTD depth bias at 100m function of absolute latitude for XBTS (red) and XBTD (blue)
A new correction
Second order correction

Separation of XBT into 4 classes:
- XBTS and XBTD
- Low and high latitudes (40°N/S)

Different behaviors between the 4 classes

Linear part function of parabolic part and years in meters, at 400m for XBTS (stars) and XBTD (filled circles).

\[ Corr = A(t,xbt,lat)z + B(t,xbt,lat)z^2 + OFFSET(t,xbt,lat) \]
A new correction

*Offset*

- An offset is necessary and is computed in an empirical fashion.
- An offset could be justified by human mishandling (drop height in board, probe can touch the surface not vertically...) and environmental factors (swell, waves...).
- It's calculated to minimize the temperature bias on the profile between 30m and 200m.

⇒ Maximum of the offset between 1970 and 1985.

*Offset in meters calculated for XBTD deployed in high/low latitudes (blue/black) and XBTS deployed in high/low latitudes (red/green) function of years.*
Results

The correction reduces the median temperature bias.

Contribution of the offset is significant.
A new correction
Specific case

- A strong negative temperature bias is found in the western Pacific (from 0 to 60°N, West of 180°W) after the global correction.
- It is predominantly located at 300m between 1970 and 1985.

Evolution of XBT-CTD median globally corrected bias for XBT deployed in western Pacific, function of depth and years

- A regional correction is available
- These profiles (years 1968 to 1985) have been separated from the global dataset
Heat content analysis

- The calculation of the ocean heat content confirms that on average XBT temperature data are now closer to CTD temperature data.
- Using the same methodology, we corrected MBT (second order correction and an offset, latitude classes).
- We finally found a heat content linear trend of \(0.4 \times 10^{22} \text{J yr}\) between 1970 and 2008.

Evolution of [0-700] m ocean heat content calculated from only WOD05 XBT (black), corrected XBT (green), all data from WOD05 (red) and all corrected data (blue)
Conclusion

- According to W08, XBT are subject to a depth bias varying with the year of deployment.
- However, our collocation method reveals that this bias should be better corrected with a second order function added to an offset.
- Behavior of XBTS and XBTD are quite different and depends on the latitude of deployment.
- We confirm that the maximum of heat content during the 70's in early papers can be explained by the XBT bias.
- In addition, a linear trend of $0.4 \times 10^{22} \text{ J/yr}$ is apparent between 1970 and 2008 (identical to Levitus et al., 2009).
- We have now available a corrected database and we are now working on field reconstruction using a EOF method (DINEOF, Beckers et al., 2003).
- We can provide the correction table (contact: mathieu.hamon@ifremer.fr).